Yixin Li, Lin Yao, Jinglin Li, Tianqi Yu, Liang Qiu, Muhammad Salman Nasir, Tao Wang, Md Afjalur Rahman, Nirmal Anand, Sharif Md. Sadaf, Baowen Zhou,

GaN nanowire-supported NiOx for low-temperature and durable dry reforming of methane toward syngas,

Applied Catalysis B: Environment and Energy,

Volume 366,

2025,

125051,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2025.125051.

(https://www.sciencedirect.com/science/article/pii/S0926337325000347)

Abstract: Dry reforming of methane toward syngas (CH4 + CO2 = 2CO + 2H2) presents a proper solution for depleting petroleum and climate change yet remains not industrialized. Herein, NiOx nanoparticles are coupled with GaN nanowires for this target. The as-designed hybrid of NiOx/GaN NWs demonstrates a low onset temperature of 280 °C for dry reforming of methane with a syngas activity of 121.7 mmol·gcat−1·h−1 and nearly 100 % selectivity. Together with the outstanding stability, a turnover number of 40372 mol syngas per mole Ni species is achieved over 160 cycles without noticeable activity degradation. The correlative kinetic experiments, isotope experiments, in-situ spectroscopic characterizations, as well as density functional theory calculations reveal that the oxidized nickel species with O vacancies and its unique electronic interaction with GaN significantly reduce the apparent activation energy of the reaction, primarily contributing to the superior activity at low temperature. What is more, the evolution track of CH4 and CO2 to syngas was comprehensively studied at atomic level, disclosing an obvious anti-coking chemical loop with excellent stability. This work presents a strategy for efficient and stable dry reforming of methane toward syngas under mild conditions.

Keywords: Dry reforming of methane; NiOx/GaN NWs; Durable; Electron rearrangement

Huanhuan Xia, Haihong Huang, Jun Zeng, Chengxiong Dang, Weiquan Cai,

Promotion effect of Zr on the dendritic layered Ni/CeO2 catalyst for methane dry reforming,

Chemical Engineering Science,

Volume 302, Part A,

2025,

120890,

ISSN 0009-2509,

https://doi.org/10.1016/j.ces.2024.120890.

(https://www.sciencedirect.com/science/article/pii/S0009250924011904)

Abstract: Ni-based catalysts are considering a promising option for the commercialization of dry reforming of methane (DRM), but catalyst deactivation caused by coking and sintering poses a serious challenge. Here, we reported Zr-modified dendritic layered Ni/CeO2 with high stability. The dendritic layered CeO2 can efficiently stabilize the catalyst structure and Ni nanoparticles due to the surface confinement effect provided by compartmentalization strategy. The Zr doping mainly facilitates the generation of abundant oxygen vacancy and reactive oxygen species by promoting the migration and release of lattice oxygen in CeO2. These oxygen vacancies and reactive oxygen species can not only improve the conversion of CO2 and CH4, but also effectively eliminate carbon deposits, thus enhancing the carbon deposition resistance of the catalyst. 5Ni-Ce0.95Zr0.05O2 catalyst consistently achieves CH4 and CO2 conversion of 81.6 % and 92.6 % for 50 h. Meanwhile, H-assisted CO2 dissociation with HCOO\* as the intermediate species dominates the reaction pathway of DRM.

Keywords: Dry reforming of methane; Carbon deposition; Sintering; Zr doping; Ni-based catalysts

Jiaqi Wang, Ying Zhang, Qingshan Rong, Yan Shi, Zhiwei Yao,

On the catalytic nature of nitrided NiMo/γ-Al2O3 catalysts for dry reforming of methane,

Phosphorus, Sulfur, and Silicon and the Related Elements,

Volume 200, Issue 1,

2025,

Pages 46-53,

ISSN 1042-6507,

https://doi.org/10.1080/10426507.2024.2435943.

(https://www.sciencedirect.com/science/article/pii/S1042650724000765)

Abstract: Nitrogen and phosphorus are one of the most common Group 15 elements. The chemistry of nitrogen and phosphorus is very important in the field of catalysis. Three types of nitride containing NiMo/γ-Al2O3 catalysts were synthesized using different loading-nitriding sequences and oxide precursor types for dry reforming of methane (DRM). The active components (Ni2Mo3N and Ni/Mo2N) firstly reacted with CO2, transforming into NiO and MoO2. They were then carburized with CH4 to produce Ni/Mo2C during the DRM process. From that point on, a redox cycle, viz. NiO/MoO2 ⇆ Ni/Mo2C, occurred during the DRM reaction. The low activity of nitriding-first NiMo nitride catalyst can be attributed to bulk oxidation. The observed gradual decline in performance of loading-first Ni/Mo nitride catalyst was due to coking. Noticeably, the loading-first NiMo nitride catalyst can demonstrate superiority in both activity and resistance to coking, which was due to its strong metal–Al2O3 interaction and high metal dispersion.

Keywords: Nickel molybdenum nitride; molybdenum nitride; molybdenum carbide; catalytic nature; dry reforming of methane

Lavan Maharaj, David Lokhat,

Dry reforming of methane in a direct irradiated solar powered system: Process design and optimisation,

Applied Energy,

Volume 377, Part B,

2025,

124536,

ISSN 0306-2619,

https://doi.org/10.1016/j.apenergy.2024.124536.

(https://www.sciencedirect.com/science/article/pii/S0306261924019196)

Abstract: This study investigates the dry reforming of methane (DRM) using solar energy to produce syngas at a pilot-scale level. A combined waste gas stream from a prominent South African petrochemical complex is considered as the system feed. A cryogenic distillation column operated at 30 bar with ceramic Berl saddle packing is found suitable for the initial removal of hydrogen sulfide from the waste gas stream. A shallow cross-flow fluidised bed reactor is optimised using available literature guidelines and ASPEN Plus simulation software. A nickel alumina catalyst is chosen for its efficiency, availability and affordability. A Langmuir Hinshelwood Houston Watson (LHHW) kinetic model closely matches experimental data for the applicable reaction kinetics. Results show a 93.55 % CH4 conversion, yielding syngas with 7.42 mol% CO and 7.43 mol% H2. An operating temperature of 800 °C is found to be optimal and requires a solar energy supply of 8.37 kW.

Keywords: Dry reforming of methane (DRM); Syngas production; Solar energy utilisation; Cross-flow fluidised bed reactor; Dry reforming of methane catalysis; Sustainable energy conversion

Arisha Sharma, Prakash Biswas,

Methane tri-reforming over Ni, Ru monometallic and Ni-Ru bimetallic catalyst supported on MIL-53 metal-organic framework,

Catalysis Today,

Volume 450,

2025,

115209,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2025.115209.

(https://www.sciencedirect.com/science/article/pii/S0920586125000276)

Abstract: Methane tri-reforming (MTR) is a promising approach for the utilization of anthropogenic greenhouse gases such as CH4 and CO2 to produce syngas. In this work, the activities of monometallic (Ru, Ni) and bimetallic (Ru-Ni) catalysts supported on the alumina derived from metal-organic framework (MOF) precursors were compared for MTR. The catalysts were synthesized by impregnation technique, and their activity was investigated in a packed bed-down flow tubular reactor over a temperature range of 600–800 °C at 1 atm. The catalyst structure-activity relationship was determined with the help of extensive catalyst characterization techniques, including N2 physisorption, X-ray diffraction (XRD), temperature-programmed reduction (TPR), and CO2 temperature-programmed desorption (CO2-TPD). Experimental results demonstrated that the bimetallic catalyst was more active as compared to monometallic one. Among the bimetallic catalysts, 0.65RuNAlM-53 catalyst demonstrated comparatively high CO2 conversion (36.1 %) and an almost complete conversion of CH4 (99.9 %) with an H2/CO ratio of 3.2 at 800 °C. The 0.65RuNAlM-53 catalyst showed consistent activity for a prolonged duration of > 125 h with no carbon deposition. Based on the experimental observation, a probable reaction mechanism is proposed for the MTR. The catalyst structure was intact even after 125 h of reaction, which suggested the MOF-derived Ru-Ni bimetallic catalyst developed is very promising for MTR.

Keywords: Methane tri-reforming; Alumina-MOF; Ru-Ni bimetal; Syngas; Catalyst stability

Kun Liu, Liang Ye, Zhihua Cao, Miao Li, Lizhi Zhang, Wenming Liu, Qingxiang Ma, Honggen Peng,

Synergistic enhancement of coke resistance in methane dry reforming via oxygen vacancies and spatial confinement on Ni-ZrO2/DMS catalysts,

Fuel,

Volume 388,

2025,

134588,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134588.

(https://www.sciencedirect.com/science/article/pii/S0016236125003126)

Abstract: Methane dry reforming (DRM) encounters substantial challenges, notably the demand for elevated temperatures to achieve efficient conversion, catalyst sintering, and carbon deposition, particularly at lower temperatures, impeding its industrial deployment. To address these hurdles, an innovative approach has been taken in crafting dendritic mesoporous silica catalysts (Ni/DMS and Ni-ZrO2/DMS) through surface spatial confinement. These catalysts exhibit exceptional activity, stability, coking resistance, and sintering resistance. Experimental results emphasize that the unique dendritic pore structure of the mesoporous silica layers, coupled with the incorporation of oxygen vacancy-rich ZrO2, notably enhances the catalyst’s reaction rate and minimizes carbon deposition. Notably, minimal coke formation was observed after prolonged exposure at 600 °C for 20 h and at 800 °C for 100 h. An in-depth investigation into the reaction mechanism, leveraging in-situ characterization and theoretical calculations, elucidates a Langmuir-Hinshelwood (L-H) pathway. Within this mechanism, ZrO2 enriched with oxygen vacancies facilitates CO2 adsorption and activation, which promotes the oxidation of carbon species, thus inhibiting coke formation. This study offers profound insights into the design of high-performance, coking-resistant catalysts for methane dry reforming, presenting promising avenues for widespread industrial applications.

Keywords: Dry reforming of methane (DRM); Dendritic mesoporous silica (DMS); Nickel-based catalyst; Particle sintering; Carbon deposition

Parisa Ebrahimi, Anand Kumar, Mohammed J. Al-Marri,

Impact of magnesium substitution on the structural stability and catalytic performance of LaNiO₃ perovskites for methane dry reforming,

Gas Science and Engineering,

Volume 134,

2025,

205530,

ISSN 2949-9089,

https://doi.org/10.1016/j.jgsce.2024.205530.

(https://www.sciencedirect.com/science/article/pii/S2949908924003261)

Abstract: Mg-doped LaNiO3 perovskite nanoparticles, denoted as LaNixMg1-xO3 (0 ≤x ≤ 1), were prepared via the solution combustion technique and evaluated for dry reforming of methane. The results suggest that at 750 °C, a nickel content 0.57 achieved optimal conversion rates of 86% for CO2 and 77% for CH4, as determined by the Design of Experiment (DOE) analysis. These findings were subsequently experimentally confirmed through the synthesis of LaNi0.5Mg0.5O3. The TPR analysis revealed that partially substituting Ni with Mg raised the reduction peak temperatures, indicating a more stable perovskite structure that is harder to reduce compared to LaNiO3. Notably, all catalysts, except LaMgO3, demonstrated high activity for generating syngas in the DRM reaction, the replacement of Ni with Mg did not significantly enhance the catalytic efficiency of LaNi0.5Mg0.5O3; however, the samples showed enhanced stability with the inclusion of Mg. The XRD patterns of the synthesized LaNixMg1-xO3 solids indicated that with higher concentrations of Mg, the development of the perovskite phase was hindered; instead, spinel (La2NiO4) and oxide phases (MgO and NiO) appeared on the surface of the sample.

Keywords: Dry-reforming of methane; Carbon deposition; Perovskites; Cation substitution

Jianan Li, Changlei Qin, Zongze Lv, Chang Gao, Liangyong Chen, Shaojun Xu,

Techno-economic analysis of integrated carbon capture and dry reforming of methane,

Energy,

Volume 316,

2025,

134516,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2025.134516.

(https://www.sciencedirect.com/science/article/pii/S0360544225001586)

Abstract: Integrated carbon capture and utilization (ICCU) with dry reforming of CH4, a derivative by simplifying the process of conventional capture and utilization (CCU), is considered to be a promising pathway in mitigating CO2 and recycling carbon resources. Although significant advances have been made in the development of ICCU with DRM, studies on its techno-economics are still lacking. Herein, four systems of CCU, ICCU, and direct/indirect solar driven ICCU with DRM are established and evaluated in the aspects of mass and energy balance, economics, CO2 emissions and cost sensitivity. Results show that energy efficiency of ICCU reaches 80.98 %, an improvement of 7.29 % comparing to CCU. In terms of economy, ICCU is more advantageous with only 75.5 % total annual cost of CCU, and 26.6 % and 54.2 % cost reduction in producing syngas and avoiding CO2 emissions. With the inclusion of solar energy, there is a significant drop of syngas cost to be 112.92 $·t−1, well below the market price, while CO2 avoiding cost falls by 79.8 %. All these results show that ICCU technology, especially when driven by solar energy has significant advantages in mitigating CO2 and producing syngas.

Keywords: Integrated CO2 capture and utilization; Techno-economic analysis; Dry reforming of methane; Solar driven; System simulation

Yi Herng Chan, Chung Loong Yiin, Mee Mee Huang, Serene Sow Mun Lock, Bridgid Lai Fui Chin, Jia Sheng Wee, Shin Ying Foong, Su Shiung Lam,

Advances in bi-reforming of methane: Syngas production for low-carbon energy solutions,

Chemical Engineering Journal,

Volume 505,

2025,

159660,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159660.

(https://www.sciencedirect.com/science/article/pii/S1385894725004590)

Abstract: Syngas, composed mainly of H2 and CO, is a key intermediate for the synthesis of chemicals and fuels. Traditionally, syngas is produced from steam methane reforming (SMR), a well-established but carbon-intensive process. With increasing global decarbonization efforts and high carbon footprint associated with SMR process, novel syngas production methods such as bi-reforming of methane (BRM) have gained attention. BRM, which utilizes CO2 aside from methane and steam as the feedstocks, offers significant potential for low-carbon syngas production. This review critically examines key process parameters (i.e., temperature, pressure, GHSV, feedstock composition) and their impact on BRM performance. In addition, emerging advanced techniques and reaction kinetic models of BRM are discussed comprehensively. The economic and environmental viability of BRM for syngas production are also scrutinized from various techno-economic analysis (TEA) and environmental impact assessments. This paper provides new perspectives especially on the advanced BRM techniques driven by electric/solar and presents new insights of the economic feasibility of BRM integrated with downstream processes such as chemicals production (e.g., methanol, FT fuels, dimethyl ether). A comprehensive Strengths-Weaknesses-Opportunities-Threats (S.W.O.T.) analysis is then provided, outlining the challenges and opportunities for the commercial deployment of BRM, with a particular focus on its role in achieving sustainable industrial practices. The findings and insights from this review highlight the state-of-the-art and identify the current gaps and outlook which could assist in accelerating the maturation of BRM as a feasible low-carbon syngas production route worldwide. Overall, key factors such as catalyst development, optimization of BRM reaction conditions (e.g., temperature, pressure, GHSV, feedstock composition, reactor design) and process integration (from CO2 capture, conversion to syngas, and downstream chemical synthesis) are critical for the advancement of this technology as a more holistic solution, whereas execution of carbon tax incentives/policies and premium for low-carbon products would greatly expedite the deployment of this technology.

Keywords: Bi-reforming of methane (BRM); Low-carbon syngas; Kinetics of BRM; Economic feasibility

Yuri K.R.O. Silva, Dulce M.A. Melo, Rodolfo L.B.A. Medeiros, Ângelo A.S. Oliveira, Willame G.S. Batista, Amanda L. Azevedo, Tomaz R. Araújo, Renata M. Braga,

One-Pot synthesis of Ni-B2O3/Al2O3 catalysts with high resistance to coke formation for the dry reforming reaction of methane,

Molecular Catalysis,

Volume 574,

2025,

114884,

ISSN 2468-8231,

https://doi.org/10.1016/j.mcat.2025.114884.

(https://www.sciencedirect.com/science/article/pii/S2468823125000707)

Abstract: The production of hydrogen from dry reforming of methane (DRM) is crucial for the energy transition, aiming for a more sustainable energy matrix due to its similarity to biogas reforming, which provides a renewable substrate for large-scale synthesis gas production. In this context, the efficiency of catalysts plays a fundamental role in optimizing this process, considering the extreme operational conditions in terms of temperature and competing reactions. This study investigates the synthesis, characterization, and stability of nickel catalysts supported on alumina, using a one-pot synthetic approach via microwave-assisted combustion, compared to catalysts synthesized by the commonly used wet impregnation method. Structural characterization was performed using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and temperature-programmed reduction (TPR-H2). Textural properties were assessed through nitrogen (N2) adsorption. The results showed that the catalysts synthesized by the one-pot method tend to have a high dispersion of nickel particles and a larger surface area, contributing to superior catalytic activity. Catalytic stability tests revealed that the catalysts promoted with B2O3 exhibited lower deactivation and reduced coke formation compared to unpromoted catalysts; however, an increase in the amount of B2O3 raised deactivation due to sintering, which was mitigated by the one-pot method that enhances metal-support interaction. The one-pot synthetized nickel catalyst with 2.5 wt% stood out, with stability more than ten times greater than that of the conventional Ni/Al2O3 catalyst and four times greater than the promoted catalyst synthesized via impregnation. Among the 3 catalysts mentioned, the final CH4 conversions were 78 %, 72 %, and 75 %, respectively, while the H2 yields were 60 %, 55 %, and 58 % after 12 h of reaction. The findings indicate that promotion with B2O3 and the one-pot synthesis significantly improved the stability and efficiency of the catalysts, offering potential for larger-scale synthesis gas production applications.

Keywords: One-pot synthesis; Dry reforming; Boron; Promoter; Coke

Hongchuan Liu, Meirong Dong, Junchang Xiong, Zehua Huang, Huaming Hou, Youcai Liang, Jidong Lu,

Study on Ce-MOF-derived oxides as morphology-tunable catalyst supports for dry reforming of methane,

Applied Surface Science,

Volume 679,

2025,

161167,

ISSN 0169-4332,

https://doi.org/10.1016/j.apsusc.2024.161167.

(https://www.sciencedirect.com/science/article/pii/S0169433224018816)

Abstract: Dry reforming of methane (DRM) using CH4 and CO2 as feedstocks to catalytically produce high-value synthesis gas products has great application prospects. However, as a high-temperature heterogeneous catalytic reaction, the challenge lies in preparing efficient and stable catalysts for long-term operation. To enhance the catalytic performance by optimizing support, this study proposed regulating the catalyst structure and properties using Ce-based metal-organic framework (MOF) derivatives. Compared with the conventional Ni/CeO2, Ni/CeO2-MOF catalysts performed better in DRM. Especially, Ni/CeO2-UiO-66 demonstrated significant improvement in both catalytic activity and stability. It was also noticed that the Ni/CeO2-MOF catalysts had a potential benefit in limiting the conversion of carbon species to inactive forms given the relatively lower carbon gasification temperatures at their surfaces. The advantage of Ni/CeO2-MOF catalysts was attributed to their better void structure and reduction characteristics, as well as higher oxygen vacancy concentration and improved CO2 adsorption activation capability after pre-activation. This study revealed that MOF-derived supports had distinctive structural characteristics, which were manifested as an important component in high-temperature catalyst systems.

Keywords: CO2 utilization; Dry reforming of methane; Metal-organic frameworks; Catalyst modification

Zhen-Yu Zhang, Ji-Long Yao, Ya-Qing Pan, Dong-Meng Su, Mao-Jiong Cao, Xiang-Jiao Gong, Ting Li, Lei Chen, Tao Xie,

Strong metal-support interaction induced excellent performance for photo-thermal catalysis methane dry reforming over Ru-cluster-ceria catalyst,

Nano Energy,

Volume 133,

2025,

110474,

ISSN 2211-2855,

https://doi.org/10.1016/j.nanoen.2024.110474.

(https://www.sciencedirect.com/science/article/pii/S2211285524012266)

Abstract: The utilization of solar energy in driving methane dry reforming (MDR) reaction through photo-thermal synergetic catalysis could simultaneously realize the reduction of carbon footprint and the fixation of solar energy, which is an environmentally and economically beneficial route. However, the currently developed catalysts still require further optimization in catalytic performance and stability. Here, we prepared RuNC, a Ru nanoclusters catalyst anchored on CeO2 with strong metal-support interaction (SMSI) effect via a facile preparation method. The formation rates of H2 and CO over RuNC catalyst were 1.41 and 2.16 mol·gcat−1·h−1 respectively under photo-thermal catalysis (PTC) at 500 °C, which is up to one order of magnitude higher than existing PTC-MDR catalysts. Moreover, the prepared catalyst did not show significant deactivation under 100 hour test. The in-depth structure-function relationship between catalytic activity/stability and Ru nanocluster sites/induced SMSI effect were determined by systematic structural characterization. The advantages of RuNC catalyst structure under PTC catalytic conditions were demonstrated by optical characterization. Besides, the excitation-migration path of photo-electron under PTC conditions was determined by ISI-XPS experiments. Finally, the mechanism of PTC-MDR reaction and the specific reaction steps enhanced by light irradiation were determined by operando experiments. This work provided theoretical basis and excellent catalyst for the industrial application of PTC-MDR route.

Keywords: Methane dry reforming; Photo-thermal catalysis; Nano-cluster; Strong metal-support interaction; Reaction mechanism

Jin Wang, Jonathan Lucas, Hayato Nakashima, Isao Ogino, Kerry M. Dooley, Oz M. Gazit,

Strong electrostatic adsorption sequence of Ni and Co affects low temperature dry reforming performance over NiCo/MgAlOx/ZrO2,

Applied Catalysis B: Environment and Energy,

Volume 366,

2025,

125004,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.125004.

(https://www.sciencedirect.com/science/article/pii/S0926337324013183)

Abstract: In bimetallic catalysts, the synergistic interactions between the metals and the support are crucial for catalytic performance, especially when supported on low-dimensional materials like metal oxide rafts. This study investigates the effect of the impregnation sequence of Ni and Co on the formation of bimetallic NiCo alloy catalysts and their impact on the dry reforming of methane (DRM) activity. We show that on reducible supports, the process of metal adsorption is governed by the metal-support interactions (MSI) and the synthesis sequence, which in turn affects low-temperature DRM catalysis. Using a MgAlOx/ZrO2 hierarchical support, we observed dramatic changes in DRM activity, achieving a minimum at 534 °C and 240 Lgcat⁻¹h⁻¹ , compared to 696 °C and 48 Lgcat⁻¹h⁻¹ in the control. The study employs XANES/XAFS, XPS, HAADF-STEM-EDS, and H2-TPR to reveal that NiCo alloy nanoparticle formation and Ni/Co molar ratio depend on impregnation order, correlating changes in catalyst properties with performance and MSI levels.

Keywords: Bimetallic; Low-dimensional; Surface phase oxides; Rafts; Metal oxides; Low-temperature dry reforming

Nazli Kesan Celik, Sena Yasyerli, Huseyin Arbag, H.Mehmet Tasdemir, Nail Yasyerli,

Regenerable nickel catalysts strengthened against H2S poisoning in dry reforming of methane,

Fuel,

Volume 383,

2025,

133903,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133903.

(https://www.sciencedirect.com/science/article/pii/S0016236124030539)

Abstract: In this study, alumina-supported bimetallic Ni-Cu and trimetallic Ni-Cu-Ce catalysts were synthesized to improve catalysts resistant to coke formation and sulfur poisoning for dry reforming of methane (DRM). The effects of parameters such as feed composition, synthesis method, and H2S concentration using the catalyst with the best activity were also investigated. To determine the physical and chemical properties of the synthesized catalysts, XRD, N2 adsorption–desorption, TGA-DTA, ICP-OES, SEM-EDX, XPS, and DRIFTS analyses were performed. XRD analysis showed that the fresh Ni-Cu catalysts have elemental nickel and γ-alumina phases in their structures. In addition to these structures, the CeO2 crystal structure was determined for the Ni-Cu-Ce catalyst. Type IV isotherm with H1 hysteresis indicating uniform mesoporous structure was obtained with all the catalysts. The activities of the synthesized catalysts in DRM were performed in the presence of different concentrations of H2S (2 ppm, 50 ppm, and 500 ppm) in a fixed bed reactor at 750 °C using a gas chromatography-equipped system. The alumina-supported 8Ni-3Cu-8Ce catalyst prepared by the impregnation method exhibited a higher and more stable activity comparing the bimetallic Ni-Cu catalyst in the presence of H2S. Adding copper and cerium to the nickel catalyst has a curative effect on resistance to coke formation and sulfur poisoning. Excess CO2 in the feed stream increased the H2S poisoning resistance of the catalyst. To analyze the reactor exit stream in catalytic activity using different feed stream compositions such as H2S+He, H2S+CO2+He, and H2S+CO2+CH4+He, FTIR with a gas cell was used. The formation of carbonyl sulfide (COS) and H2O, which occurs due to the possible reaction between CO2 and H2S, was observed. Regeneration studies showed that the catalyst could undergo regeneration with a low oxygen concentration (0.3 % O2 in He). 8Ni-3Cu-8Ce@SGA, which gave 71 % CH4 conversion in the first minute of the reaction test in the presence of 50 ppm H2S, was regenerated after completely losing its activity at the end of 5 h. 66 % CH4 conversion was achieved when tested again in the absence of H2S (CH4/CO2/Ar:1/1/1). The 8Ni-3Cu-8Ce@SGA catalyst was deemed worthy of investigation for industrial applications.

Keywords: Dry reforming; H2S; Copper; Cerium; Biogas; H2S poisoning

Mumtaj Shah,

Development of versatile Ni–Ce-based catalyst for syngas production through dry reforming and catalytic partial oxidation of methane,

International Journal of Hydrogen Energy,

Volume 105,

2025,

Pages 505-520,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.309.

(https://www.sciencedirect.com/science/article/pii/S0360319925003465)

Abstract: The study explored the development of a versatile Ni–Ce/TiO2–ZrO2 (TiZr) catalytic system for the partial oxidation and CO2 reforming of methane in which the ZrO2 content was varied from 5 wt% to 15 wt%. The effect of support composition on catalytic activity, stability, CO selectivity, and water formation rates was examined under various operating conditions for partial oxidation and dry reforming of methane. The catalysts showed excellent stability during methane partial oxidation, but only TiZr with 15 wt% of ZrO2 catalyst demonstrated stable activity for CO2 reforming of methane. The synergistic catalytic composition, strong metal support contacts, and oxygen storage capacity of Ti15Zr catalysts confirm the study's results. Increasing space velocity from 10 to 40 L g−1 h−1 led to a significant drop-in activity (∼50%) due to active metal oxidation during partial methane oxidation. However, catalysts containing 5 and 15 wt% ZrO2 regain the activity within 30 h. Again, switching from partial oxidation to dry reforming boosted methane conversion by 10% for the catalyst with 15 wt% ZrO2. The highest syngas productivity was for the Ti15Zr catalyst for both the reactions, and it showed a stable activity for 100 h of time on stream study without any deactivation.

Keywords: Dry reforming of methane; Partial oxidation of methane; Nano catalysts; Synthesis gas production; Industrial catalyst

Dinmukhamed Shoganbek, Mark Martinez-Klimov, Olha Yevdokimova, Anssi Peuronen, Mika Lastusaari, Atte Aho, Svetlana A. Tungatarova, Tolkyn S. Baizhumanova, Daulet A. Zhumadullaev, Manapkhan Zhumabek, Yermek A. Aubakirov, Alua Manabayeva, Päivi Mäki-Arvela, Dmitry Yu. Murzin,

Dry methane reforming over lanthanide-doped Co–Al catalysts prepared via a solution combustion method††Electronic supplementary information (ESI) available. See DOI: https://doi.org/10.1039/d4ma00991f,

Materials Advances,

Volume 6, Issue 3,

2025,

Pages 1173-1190,

ISSN 2633-5409,

https://doi.org/10.1039/d4ma00991f.

(https://www.sciencedirect.com/science/article/pii/S2633540924008314)

Abstract: Cobalt-based catalysts containing Ce, La and Al were prepared via solution combustion synthesis (SCS) and used in dry reforming of methane (DRM). Combustion temperature for the highest active 20Co–10La–20Al catalyst measured during the combustion process was 861 °C, explaining the formation of CoAl2O4, which was active for DRM in the present work. No graphite structure was defined from the XRD pattern and TPO profiles of the spent Co–La–Al catalyst, while other catalysts contained this phase. In addition, only 10 wt% of carbon was identified in Co–La–Al, according to CHNS results. All catalysts were well dispersed, and the metal particle size varied between 19 and 28 nm. TPR analyses showed that doping of rare-earth metals leads to easier reduction due to oxygen vacancies, which suppress coking. The highest CH4 transformation rate and space-time yield of hydrogen were observed for CoLaAl, which exhibited a metal particle size of 23 nm, giving the lowest carbon content in the spent catalysts after temperature cycling experiments in DRM. This catalyst containing metallic cobalt and an active CoAl2O4 spinel demonstrated stable formation of hydrogen and CO during 50 h time-on-stream. The spinel phase was, however, decomposed during the DRM. The best catalyst also contained a perovskite-type mixed oxide, LaCoxAl1−xO3, which was already formed during synthesis through an SCS method. This phase was not, however, stable in long-term experiments.

Zhen-Yu Zhang, Tao Xie,

In situ DRIFTs-based comprehensive reaction mechanism of photo-thermal synergetic catalysis for dry reforming of methane over Ru-CeO2 catalyst,

Journal of Colloid and Interface Science,

Volume 677, Part A,

2025,

Pages 863-872,

ISSN 0021-9797,

https://doi.org/10.1016/j.jcis.2024.08.019.

(https://www.sciencedirect.com/science/article/pii/S0021979724018009)

Abstract: Solar-driven photo-thermal dry reforming of methane (DRM) is an environmentally friendly production route for high-value-added chemicals. However, the lack of thorough understanding of the mechanism for photo-thermal reaction has limited its further development. Here, we systematically investigated the mechanism of photo-thermal DRM reaction with the representative of Ru/CeO2 catalyst. Through in situ DRIFTs and transient experiments, comprehensive investigation into the reaction steps and their reactive sites in the process of DRM reaction were conducted. Besides, the excitation and migration direction of photo-electron was determined by ISI-XPS experiments, and the change of surface defect structure induced by light was characterized by ISI-EPR experiments. Based on the above results, the photo-enhancement effect on each micro-reaction step was determined. This study provides a theoretical basis for the industrialization of photo-thermal DRM reaction and its development of catalysts.

Keywords: Dry reforming of methane; Photo-thermal catalysis; Operando experiment; Comprehensive reaction mechanism

Mojtaba Mokhtari, Jaber Shabanian, Jamal Chaouki,

Methane dry reforming in a microwave heating-assisted dense fluidized bed,

Powder Technology,

Volume 449,

2025,

120444,

ISSN 0032-5910,

https://doi.org/10.1016/j.powtec.2024.120444.

(https://www.sciencedirect.com/science/article/pii/S003259102401088X)

Abstract: Dry reforming of methane helps mitigate greenhouse gas emissions as a global issue. This technology produces syngas, which can be converted into valuable chemicals, e.g., synthetic fuels. Electrification of this technology by adopting a microwave heating-assisted dense fluidized bed dry reformer can enhance its sustainability. In the present study, we developed a model to assess the performance of this reactor. This first-of-its-kind model employed an Eulerian-Granular multiphase model in conjunction with Maxwell's equation to simulate catalyst particles' hydrodynamics and microwave-induced heating while combined with the corresponding reactions to predict the overall performance of the dense fluidized bed reactor. We validated the model with experimental data from literature and performed a set of parametric studies with the validated model. This model holds promise for identifying the optimal operating conditions of the selected reformer, i.e., a crucial step toward commercialization of microwave heating-assisted dry reforming of methane.

Keywords: Methane dry reforming; Fluidized bed; Process electrification; Microwave heating; Multiphase model

Kexin Zheng, Xiaochun Gao, Yuhan Xie, Ziyang He, Yujiao Ma, Shaoqi Hou, Dawei Su, Xiaoguang Ma,

Free-standing bimetallic Co/Ni-MOF foams toward enhanced methane dry reforming under non-thermal plasma catalysis,

Journal of Colloid and Interface Science,

Volume 683, Part 1,

2025,

Pages 564-573,

ISSN 0021-9797,

https://doi.org/10.1016/j.jcis.2024.12.106.

(https://www.sciencedirect.com/science/article/pii/S0021979724029606)

Abstract: Understanding of the structure and interfacial merits that reactive metal–organic frameworks (MOFs) undergo is critical for constructing efficient catalysts for non-thermal plasma-assisted conversion of greenhouse gases. Herein, we proposed a free-standing bimetallic (Co/Ni) MOFs supported on bacterial cellulose (BC) foams (Co/Ni-MOF@BC) toward the coaxial dielectric barrier discharge (DBD) plasma-catalytic system, of which the Co/Ni ions coordination demonstrated an intriguing textual uplifting of the malleable BC nanofiber network with abundant pores up to micrometer-scale, which could impart a more intensive predominant filamentary microdischarge current to 180 mA with stronger plasma-catalytic interaction. Remarkably, compared to the monometallic MOF@BC foams, this bimetallic Co/Ni-MOF@BC also delivered a substantially improved alkaline absorption ability as further confirmed by the CO2- temperature-programmed desorption (TPD) result. Benefiting from its 3D superiority and synergy of Co/Ni dual-regulation, the Co/Ni-MOF@BC, therefore, displayed the highest CO2 and CH4 conversion rates to 52.31 % and 71.50 %, which was above 1.5 and 1.3 times higher than those of monometallic counterparts and Co/Ni-MOF powder. Additionally, its robust cycling performance has also been evidenced by the excellent long-time DRM performance, unchanged crystallinity, morphology, and surface chemical states. By taking both the catalyst existing form and interfacial optimization of MOFs into consideration for designing a unique DRM catalyst, we believed this free-standing 3D Co/Ni-MOF@BC foams could inspire more research outputs on the design of functional catalysts with abundant pores and alkaline absorption sites to accelerate the redox kinetics of CO2/CH4 conversion.

Keywords: Dry methane reforming; Metal–organic frameworks; Free-standing; Filamentary microdischarge; Alkaline absorption

Lei Zheng, Di Wang, Yunfeng Jiang, Yingyu Ren, Yihai Wu, Yu Fu, Jun Zhang,

Volumetric internal Joule heating of a catalyst packed SiSiC foam for efficient dry reforming of methane,

Chemical Engineering Journal,

Volume 503,

2025,

158291,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2024.158291.

(https://www.sciencedirect.com/science/article/pii/S1385894724097821)

Abstract: The strong endothermic dry reforming of methane (DRM) is a reaction of interest to convert greenhouse gases into syngas for downstream chemical synthesis. However, conventional external combustion heating not only generates unwanted CO2 emissions but also suffers from heat transfer limitations. With the rising trend of renewable electricity, process electrification with Joule heating emerges as a promising alternative to combustion, facilitating decarbonization and process intensification. In this study, we systematically assessed the catalytic performance in direct Joule heating of an internal SiSiC open-cell foam packed with Ni-based pellet catalysts for DRM reaction. The interconnected porous structure of SiSiC foam enables selective and volumetric heating of pellet catalysts in a packed bed configuration. The direct selective heating of internal structure requires extremely low input power, i.e., only 65 W to reach 800 °C compared to 143 W for external oven heating, and results in a reactor wall temperature approx. 300 °C lower than from the foam centerline, with the potential to significantly reduce reactor material requirements and cost. Additionally, volumetric Joule heating provides more uniform heating profiles and approx. 30 °C higher average temperatures over the catalytic bed with no cold spots observed, leading to enhanced methane and CO2 conversions reaching 94 % and 64 % at 800 °C, respectively, which are approx. 5–10 % higher than external heating at the same foam outlet temperatures. The Joule-heated DRM ensures a significantly low specific energy demand of approx. 0.71 kWh/Nm3 for syngas production. The insights gained from this work are in principle transferable to direct Joule heating of internal structured catalysts for other endothermic reactions.

Keywords: Joule heating; Dry reforming of methane; Internal structures; Selective heating; Volumetric heating

Xirui Yan, Haixia Liang, Ruicong Wang, Da Li, Jun Li, Wencai Peng, Jinli Zhang,

Preparation of high stability hierarchical bimetallic Ni-Mo catalysts for CO2 reforming with methane,

Molecular Catalysis,

Volume 573,

2025,

114835,

ISSN 2468-8231,

https://doi.org/10.1016/j.mcat.2025.114835.

(https://www.sciencedirect.com/science/article/pii/S2468823125000215)

Abstract: CO2 reforming with methane (DRM) is a potential effective carbon neutralization strategy to convert greenhouse gases into syngas. The key to the DRM process is to design active and coking resistant catalysts. Herein, hollow hierarchical bimetallic NiMo-HMgO catalysts were prepared via hydrothermal-impregnation method. The prepared NiMo-HMgO catalysts exhibited higher catalytic performance during the DRM process than commercial NiMo-CMgO catalysts, due to the formation of Ni-Mo-MgO composite on hierarchical MgO (HMgO), which is promoted by exposed (111) polar surface of HMgO with alternate arrangement of anion and cation layers. The deposited carbon and stability can be effectively regulated by adjusting the amount of Ni and the molar ratio of Mo/(Ni+Mo). The synergistic effect of metal and HMgO can provide reference for the research in other related fields.

Keywords: CO2 reforming with methane; Hierarchical MgO; Ni-Mo-MgO; Deposited carbon

Hossein Rouhandeh, Alireza Behroozsarand,

Simulation and optimization of methanol production process via bi-reforming of methane: A novel genetic algorithm-based approach in Python,

International Journal of Hydrogen Energy,

Volume 101,

2025,

Pages 1161-1171,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.003.

(https://www.sciencedirect.com/science/article/pii/S0360319925000084)

Abstract: Bi-reforming of methane (BRM) is a promising method for syngas production in Methanol synthesis that consumes CH4 and CO2 while allowing feed ratio tuning. In this study as main novelty, an innovative optimization approach(integratrd genetic algorithm, Python programming language, and Aspen Plus software) for Methanol synthesis using a bi-reforming process to increase productivity and reduce CO2 emissions is proposed. Furthermore, By using a genetic algorithm, Python programming language, and integrated Aspen Plus software, the optimal temperature and pressure feed conditions were determined for a BRM reactor. The molar feed ratio of CH4: CO2:H2O = 1:0.36:0.9 at a temperature of 901 °C and a pressure of 5 bar, instead of 3:1:2 and 1:1:2, was recognized as the optimal ratio in the bi-reforming process. The optimal conditions resulted in 93% CH4 conversion, 76% CO2 conversion, and an H2/CO ratio of 2.08, achieving the ideal stoichiometric number (M = 2) for Methanol synthesis. Comparative analysis with a referenced method showed that the proposed process produces an additional 11.8 tonne/h of methanol, consumes 7.63 tonne/h more CO2, and reduces steam consumption by 54.11 tonne/h. Moreover, the process exhibits improved environmental performance, consuming over 20% more CO2.These results indicate that the BRM process can be a suitable alternative to the SMR process in methanol synthesis.

Keywords: Methanol production; Bi-reforming of methane; Python programming; Genetic algorithm; Carbon dioxide utilization

G. Sorbino, O. Tammaro, A. Padua, A. Basco, S. Scognamiglio, M. Sisti, R. Arletti, A. Marocco, M. Pansini, G. Landi, S. Esposito,

Unveiling the role of Ni nanometric particles in ultra-stable hierarchically porous Y zeolite to drive methane steam reforming and CO2 hydrogenation,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 887-900,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.244.

(https://www.sciencedirect.com/science/article/pii/S0360319925002666)

Abstract: Three catalysts containing 5, 10 and 20 % wt. Ni trapped in the porous zeolite framework (Ni5, Ni10 and Ni20, respectively), were prepared. An ultra-stable zeolite Y, with a Si/Al molar ratio of 385, selected for its high thermal stability, was impregnated under vacuum with an aqueous solution of Ni2+ ions and thermally treated at 600 °C in a reducing atmosphere. The Ni nominal contents were compliant with the nominal value as confirmed by X-ray fluorescence spectroscopy. The catalysts were tested in the steam reforming of methane and in the hydrogenation of carbon dioxide. Catalytic activity is significantly structure-dependant. Several physical-chemical characterizations were carried out. X-ray powder diffraction with synchrotron source, followed by Rietveld analysis, and H2-TPR analysis indicate that all the loaded nickel is in the metallic form. High-resolution transmission electron microscopy showed that the particle size distribution is centred around 30 nm for Ni5 and Ni 10, while particles of around 150 nm are obtained with Ni20. A thorough NLDFT analysis of the pore size distribution shows a certain fraction of large mesoporosity in addition to the microporosity typical of zeolites. This hierarchical structure, also evidenced by the TEM micrographs, has a profound impact on the catalytic response since the nickel particles are located in the mesoporosity, whereas the reaction appears limited by Knudsen diffusion through zeolite micropores. O2-TPOs carried out on used samples showed no coke deposition suggesting a good resistance to fouling, that can be related to a very low acidity, as measured by NH3-TPD measurements.

Keywords: Ultrastable Y zeolites; Nickel-reduced species; Hierarchical porosity; Methane steam reforming; CO2 hydrogenation

Quanqi Zhang, Zhonghua Jiang, Yimin Zhang, Xinyu Xu, Ye Yang, Yucai Qin, Lijuan Song, Yi Mei, Yun Zu,

Deciphering transient carbon footprint for methane dry reforming over Ni@S-1 nanosheet zeolite catalyst,

Applied Catalysis B: Environment and Energy,

Volume 362,

2025,

124722,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124722.

(https://www.sciencedirect.com/science/article/pii/S0926337324010361)

Abstract: Carbon deposition, an inevitable product operated at high temperatures, is a headache-inducing obstacle to enhance catalyst stability for methane dry reforming (MDR). Herein, we have ingeniously designed sintering-resistant Ni@S-1 nanosheet zeolites to purposefully induce common linear and non-linear deactivation of catalysts during MDR reaction for deciphering carbon footprint. Multiple evidences unveiled that "transient carbon", composed of multi-phenyl-rings via rapidly rearrangement of CHx\* fragments, was a crucial vane for catalyst deactivation. Accordingly, we proposed a dynamic equilibrium theory for the generation and elimination of "transient carbon". Achieving this balance was dependent of the matching degree between Ni0 nanoparticles and NiOx(OH)y, which both separately originated from the evolutions of 1:1 and 2:1 Ni phyllosilicates controlled by nanosheet thickness. Delightfully, synthetic Ni@S-1–60nm catalyst with an optimal ratio of Ni0/NiOx(OH)y contributed higher MDR activity and durability. These findings derived a new MDR reaction pathway and afforded value-filled information for developing high carbon-resistant MDR catalysts.

Keywords: Methane dry reforming; Ni@S-1 nanosheet zeolite; Nickel phyllosilicate; Transient carbon footprint, Reforming mechanism

Shabnam Yousefi, Mina Tavakolian, Mohammad Reza Rahimpour,

Bio-templated Ni/MgO-Al2O3 as an efficient catalyst toward methane dry reforming,

Inorganic Chemistry Communications,

Volume 171,

2025,

113557,

ISSN 1387-7003,

https://doi.org/10.1016/j.inoche.2024.113557.

(https://www.sciencedirect.com/science/article/pii/S1387700324015478)

Abstract: Following the principles of green chemistry and recognizing the significant role of catalysts in chemical transformations, this study explores the impact of walnut and almond shells as bio-templates on the physical properties and catalytic performance of mesoporous Ni/MgO-Al2O3 in methane dry reforming. At the same time, by incorporating magnesium as a promoter and employing walnut and almond shells as bio-templates, we achieved a uniform distribution of Ni particles and a more porous structure with a larger surface area for the synthesized catalysts. These findings were validated through X-ray diffraction (XRD), Brunauer-Emmett-Teller (BET), Scanning Electron Microscopy (SEM), Temperature-programmed reduction (TPR), Raman, and Thermogravimetric analysis (TGA) analyses. Based on findings, bio-templates, particularly the walnut shell, can enhance the catalyst’s physical properties. This includes structural and catalytic properties modifications, leading to higher surface areas, improved nickel dispersion, and increased carbon deposition and sintering resistance, resulting in superior catalytic performance in methane dry reforming. Surprisingly, the synthesized catalyst using walnut bio-template could effectively improve the catalyst performance of the Ni/MgO-Al2O3 closer to equilibrium values, which is highly desirable.

Keywords: Green chemistry; Bio-templates; Natural waste; Methane dry reforming; Hydrogen production

Xinglong Chen, Shuqing Li, Zhenchao Xu, Hongyu Li, Jiong Li, Yu Fu, Jun Zhang,

Interface engineering of Ni and CeO2 catalysts for ethane dry reforming,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 501-512,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.288.

(https://www.sciencedirect.com/science/article/pii/S0360319925003234)

Abstract: The dry reforming of ethane (DRE) provides an efficient route for converting CO2 into syngas. Ni-based catalysts are highly regarded for their activity and cost-effectiveness; however, issues such as metal sintering and carbon deposition remain significant challenges. In this study, we developed a shell-structured Ni–Si@Ce catalyst for DRE, aimed at enhancing catalytic activity and stability by optimizing Ni–O–Ce interfaces. Comprehensive characterization using XRD, XPS, EXAFS, and H2-TPR revealed the geometric and electronic structures of the catalyst, while TEM confirmed the confinement of ∼4 nm Ni particles between the SiO2 core and CeO2 shell. Performance evaluation demonstrated C2H6 and CO2 conversion rates of 70% and 71% at 650 °C and 24,000 mL·h−1gcat −1, with minimal carbon deposition and excellent stability over 24 h of reaction. The activation energies for C2H6 and CO2 activation were determined to be 120.9 and 105.5 kJ/mol, respectively. A dual active site mechanism is proposed, where the CeO2 shell provides spatial confinement of Ni particles, suppresses carbon deposition, and facilitates the activation of C2H6 and CO2 via the Mars-van Krevelen mechanism, thereby enhancing catalytic performance and addressing competitive adsorption challenges.

Keywords: Dry reforming of ethane; Ni–O–Ce interface; Dual active site; Mars-van krevelen mechanism; Ni–Si@Ce

Cheng Li, Guangyu Li, Yongtao Zhan, Chenzhao Liu, Yujie Tang, Dong Yan, Jian Li, Lichao Jia,

An engineering approach for active and stable dry methane reforming within solid oxide fuel cell stacks using La0.6Sr0.2Cr0.85Ni0.15O3-δ as a catalyst,

International Journal of Hydrogen Energy,

Volume 98,

2025,

Pages 1079-1086,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.193.

(https://www.sciencedirect.com/science/article/pii/S0360319924053965)

Abstract: A strategy of in-stack dry reforming of methane (DRM) is proposed by using La0.6Sr0.2Cr0.85Ni0.15O3-δ-loaded Ni foam (LSCrN@NF) as a CH4–CO2 reformer, fuel gas distributor, and anode current collector in a SOFC stack. The prepared LSCrN exists as a single phase in a perovskite structure; its reduced form contains exsolved Ni nanoparticles embedded on the surface of the LSCrN substrate. Introduced into an NF, the reduced LSCrN@NF demonstrates high DRM activity that increases with the increase of LSCrN amount to an optimum of about 42%. With the LSCrN@NF in-stack DRM, the conversions of CH4 and CO2 into CO and H2 increase. Thus, the electrode polarization resistance, including the cathode and anode, decreases to 0.62, 1.07, and 3.93 Ω cm2 at 800 °C, 750 °C, and 700 °C, respectively. Consequently, the peak power density (PPD) of the cell using 45% CH4-45% CO2–10% N2 as fuel is 1.17, 0.94, and 0.47 W cm−2, significantly higher than that of the cell without LSCrN@NF in-stack DRM. In addition, the voltage of the cell with LSCrN@NF in-stack DRM is stable on a level between 0.81 and 0.82 V at 400 mA cm−2 and 750 °C for 270 h without detected carbon deposition in the Ni–Y2O3 stabilized ZrO2 anode. This LSCrN@NF in-stack DRM strategy is also adopted with a large-scale (13 × 13 cm2) single cell, which shows an extrapolated PPD of 428.3 mW cm−2 at 750 °C and is operated for 40 h at 400 mA cm−2 without noticeable performance degradation.

Keywords: Olid oxide fuel cell; Dry reforming of methane; In-stack reforming; Carbon deposition

Xiaoyan Tian, Yu Shi, Weidong Shi, Fagen Wang,

CeO2/ZrO2 ratio optimization in (Ni/CexZr1−xO2)@SiO2 catalysts for high performance of photothermal dry reforming of methane reaction,

Fuel,

Volume 389,

2025,

134594,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134594.

(https://www.sciencedirect.com/science/article/pii/S0016236125003187)

Abstract: Photothermal catalytic dry reforming of methane (PTC-DRM) is a potential technique to convert greenhouse gases (CH4 and CO2) for syngas (CO + H2) with sustainable solar energy. However, Ni sintering and carbon deposition are challenges for stabilizing performance. This study examined core–shell catalysts consisting of SiO2 shell and Ni/CexZr1−xO2 core for PTC-DRM, intending to resolve the challenges. Thermal and optical properties of the (Ni/CexZr1−xO2)@SiO2 catalysts were found to be dependent on CeO2/ZrO2 ratio. The (Ni/Ce0.8Zr0.2O2)@SiO2 catalyst exhibited the highest conversions of 67.8 % CH4 and 78.5 % CO2 in PTC-DRM at 1023 K and high space velocity of 120 L/(gcat·h), compared to the respective conversions of 58.5 % and 69.7 % by the (Ni/Ce0.9Zr0.1O2)@SiO2 and the respective conversions of 48.2 % and 60.1 % by the (Ni/Ce0.7Zr0.3O2)@SiO2. The characterization results show that the (Ni/Ce0.8Zr0.2O2)@SiO2 catalyst displayed the greatest redox with the most active surface lattice oxygen, the narrowest band gap energy and the best charge separation efficiency. The active lattice oxygen and light irradiation reduced carbon deposition to 0.1 wt% on the used (Ni/Ce0.8Zr0.2O2)@SiO2. Ni sintering was prevented through silica encapsulation and Ni-Ce0.8Zr0.2O2 interaction, contributing to performance stable for 50 h. This study optimized CeO2/ZrO2 ratio in the (Ni/CexZr1−xO2)@SiO2 catalysts to maximize PTC-DRM performance, providing advice to additional catalysts containing CexZr1−xO2 for performance enhancement.

Keywords: Photothermal; Dry reforming of methane; (Ni/CexZr1−xO2)@SiO2 catalysts; CeO2/ZrO2 ratio; Carbon deposition

Yuwen Shi, Xiaoyuan Wang, Naisong Wu, Haijun Chen, Yuezhao Zhu, Yixing Li, Jinqiang Zhang, Gang Wang, Lei Wang, Xiaotao Bi,

Experimental investigation on the feasibility of integrating heat pipe in fixed-bed reactor for dry reforming of methane,

Energy,

Volume 319,

2025,

135125,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2025.135125.

(https://www.sciencedirect.com/science/article/pii/S0360544225007674)

Abstract: Dry reforming of methane (DRM) is of great significance for alleviating the pressure of global warming. However, since DRM is a highly endothermic process, its industrial applications are hindered due to the problems of inefficiencies and large temperature gradients in conventional reactors. To address these limitations, this work explores the integration of a high-temperature heat pipe into a fixed-bed reactor (HP-FBR) for DRM. An HP-FBR was experimentally investigated and compared with a traditional FBR based on bench-scale tests. The results show that the heat pipe can enhance the heat transfer in the fixed catalyst bed to substantially reduce the axial temperature gradient. Under the conditions of relatively low operational temperatures (570–700 °C) and high feed ratios of CH4/CO2, HP-FBR demonstrates higher conversion efficiency than the conventional FBR. In addition, a longevity test with 100 h for the HP-FBR was conducted to evaluate its stability. Challenges such as the hydrogen inactivation and surface corrosion of the heat pipe, and the carbon deposition of catalysts were also discussed. This work provides a comprehensive insight for the industrialization of DRM reactors based on high-temperature heat pipes.

Keywords: Dry reforming; High-temperature heat pipe; Fixed-bed reactor; Temperature gradients; Hydrogen inactivation

Victória Gonçalves F Pereira, Ana Serrano-Lotina, Raquel Portela, Miguel A. Bañares, Clarissa Perdomo Rodrigues, Fabio Souza Toniolo,

Ni/Al2O3 promoted by CeO2, CeO2-La2O3, and CeO2-ZrO2 supported on cordierite monoliths for methane steam reforming,

Catalysis Today,

Volume 445,

2025,

115107,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2024.115107.

(https://www.sciencedirect.com/science/article/pii/S0920586124006011)

Abstract: Promotion of Ni-based catalysts supported on cordierite monoliths was investigated for methane steam reforming. First, cordierite was coated by ɣ-Al2O3, and then the catalyst components were deposited by successive wet impregnation, obtaining: NiAl/cordierite; NiCeAl/cordierite; NiCeLaAl/cordierite and NiCeZrAl/cordierite. The monolithic catalysts were characterized by adherence test, Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy (SEM-EDX), N2 physisorption, Temperature-Programmed Reduction (TPR), CO chemisorption, as well as by in situ and operando Raman spectroscopy. The catalyst layer showed very good adherence and distribution of the components over the cordierite surface. The catalysts presented high activity between 600 and 800 °C at a H2O/CH4 molar ratio=1.5, except for NiCeAl/cordierite, which obtained lower methane conversion, associated with its lower nickel dispersion. The catalysts showed high stability under extreme conditions for carbon deposition (600 °C and H2O/CH4=1), over 90 h on stream. Raman spectroscopy revealed the presence of oxygen vacancies, which may be increased during ceria reduction, highlighting the potential of these catalysts to enhance the resistance to deactivation by carbon deposition in long-term tests.

Keywords: Nickel; Ceria; Honeycomb; Catalysis; operando Raman

Chao Zhang, Yongsheng Gao, Haipeng Wang, Lulu Jiang, Delu Zhang, Shujun Ming, Guangying Fu, Chao Wang, Zhiguo Lv,

Hydrophobic driving fabrication of highly dispersed PtNi in Zr-doped 3D hollow flower-like MgAl2O4 spheres with abundant O vacancies for enhanced dry reforming of methane,

Journal of Colloid and Interface Science,

Volume 685,

2025,

Pages 244-254,

ISSN 0021-9797,

https://doi.org/10.1016/j.jcis.2025.01.101.

(https://www.sciencedirect.com/science/article/pii/S0021979725001158)

Abstract: The dry reforming of methane (DRM) could convert CH4 and CO2 into syngas, offering potential for greenhouse gas mitigation. However, DRM catalyst sintering and carbon deposition remain major obstacles. In this study, a highly dispersed PtNi alloy@Zr-doped 3D hollow flower-like MgAl2O4 (AMO) spheres was prepared through a hydrophobic driving strategy. During a 50-hour test at 550 °C, the catalyst exhibited no significant decline in CH4 and CO2 conversion rates, demonstrating its excellent anti-sintering and anti-coking performance. The unique anti-coking performance can be attributed to Zr-induced oxygen vacancies, which enhance oxygen mobility and reduce carbon deposition. Besides, doped Zr increases basic active sites, enhancing CO2 adsorption and activation, thus accelerating carbon species conversion. At 700 °C, the unique synergy between highly dispersed Pt and Ni enabled CH4 and CO2 conversion rates to reach 67.5 % and 73.8 %, respectively. The incorporation of Pt or Zr extends the Ni–Ni bond and partially coordinates with Ni, enhancing the stability of the Ni lattice. The reaction of CH4 and CO2 follows the Langmuir-Hinshelwood (L-H) mechanism, where both reactant molecules are adsorbed and activated on the metallic sites. Moreover, the effective energy barrier for the CH oxidation pathway is lower by 0.16 eV than that for the C oxidation pathway, which helps suppress the formation of carbon deposits.

Keywords: PtNi alloy; Carbon deposition resistance; Oxygen vacancies; Methane dry reforming

Amanda C.P. Guimarães, Lícia R.F. Coelho, Andressa A.A. Silva, Yutao Xing, Rita C. Colman, Lisiane V. Mattos, Cristiane A. Henriques,

Dry reforming of methane over Ni catalysts supported on hierarchical ZSM-5 and USY zeolites,

Catalysis Today,

Volume 447,

2025,

115159,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2024.115159.

(https://www.sciencedirect.com/science/article/pii/S0920586124006539)

Abstract: In this study, 3 wt% of Ni supported on hierarchical ZSM-5 and USY zeolites were prepared using desilication and dealumination/desilication methods, respectively. These catalysts were used to produce syngas via dry reforming of methane. Mesoporosity was introduced in both zeolites, leading to increased initial values of CH4 and CO2 conversions, possibly attributable to higher Ni dispersion. The catalyst supported on hierarchical ZSM-5 exhibited a good NiO/Ni2 + species distribution, an improved metal-support interface, and strong basicity. These aspects of the catalyst increased the number of accessible Ni active sites, resulting in higher stability, lower carbon formation, and reduced metal sintering. The inferior performance of the hierarchical USY-based catalyst could be ascribed to a greater quantity of trapped Ni2+ species within smaller pores, thus reducing their reducibility and hindering the accessibility of reagents to metal and basic sites.

Keywords: Syngas; DRM; Hierarchical zeolites; Nickel; ZS M-5; USY

Jiayin Li, Jing Xu, Evgeny Rebrov, Annemie Bogaerts,

Machine learning-based prediction and optimization of plasma-catalytic dry reforming of methane in a dielectric barrier discharge reactor,

Chemical Engineering Journal,

Volume 507,

2025,

159897,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159897.

(https://www.sciencedirect.com/science/article/pii/S1385894725006965)

Abstract: We developed an innovative machine learning (ML) model, including a supervised learning (SL) and reinforcement learning (RL) model, to predict and optimize the plasma-catalytic dry reformation of methane (DRM) over Ni/Al2O3 catalysts in a dielectric barrier discharge (DBD) reactor based upon experimental data. To tackle its intricate and non-linear characteristics, the SL model uses artificial neural networks (ANN) to accurately predict the performance, achieving excellent consistency with the experimental results. The RL model subsequently investigates the optimal optimization policy, namely starting with a coarse tuning of the more influential parameters, followed by fine-tuning of the less important parameters, to obtain the best performance. The optimal results show that a discharge power at lowest bond (i.e., 20 W) but CO2/CH4 ratio at highest bond (i.e., 1.5) result in the minimum energy cost (21 eV/molec), validated by our SL model and experimental data. Furthermore, we also investigated the simultaneous optimization of total conversion and energy cost, resulting in a maximum total conversion of 36 %, combined with a minimum energy cost of 34 eV/molec, at a Ni loading of 9.5 wt%, discharge power of 60 W, and total flow rate of 74 mL/min. Our ML model showcases an impressive capacity to derive advantageous insights from existing datasets, thereby advancing and optimizing plasma-catalytic chemical processes.

Keywords: Plasma catalysis; Dry reforming of methane; Machine learning; Process optimization; Syngas production

Beom-Jun Kim, Ho-Ryong Park, Su-Jin Ryu, Byong-Hun Jeon, Hyun-Seog Roh,

CO2-intensified dry reforming of methane over oxygen-defective Ni-CeO2 catalysts: Synergistic coupling with reverse water-gas shift reaction,

Chemical Engineering Journal,

Volume 505,

2025,

159299,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159299.

(https://www.sciencedirect.com/science/article/pii/S1385894725000981)

Abstract: This study investigates the performance of Ni-CeO2 catalysts synthesized via a cellulose-assisted combustion method (CACS) for the synergistic coupling of dry reforming of methane (DRM) and the reverse water–gas shift reaction (RWGS), referred to as SCDR. Among the catalysts with varying Ni loadings, the 15 wt% Ni-CeO2 catalyst exhibited an optimal balance of Ni dispersion and oxygen vacancy formation, achieving superior CH4 and CO2 conversions. In DRM reaction, catalytic activity was primarily determined by the number of Ni active sites, with higher Ni dispersion enhancing CH4 conversion. In contrast, under SCDR conditions, catalytic performance was significantly influenced by the oxygen storage capacity (OSC), which facilitated CO2 activation and intermediate formation. The well-dispersed Ni and strong metal-support interaction at the Ni-O-Ce interface further promoted CO2 activation, improving sintering resistance and enabling the formation of key intermediates such as bidentate carbonates and formates. These intermediates were essential for sustaining reaction turnover, with the Ni-O-Ce interface contributing to the rapid regeneration of active sites and maintaining catalytic activity under CO2-rich conditions. Additionally, the high CO2 partial pressure in SCDR suppressed carbon deposition, enhancing stability and reaction rates compared to DRM.

Keywords: Dry reforming of methane; Reverse water–gas shift reaction; Synergistic coupling; Cellulose-assisted combustion method; Oxygen storage capacity

Jie Luo, Mei Zhong, Zhenghua Dai, Yang Liu, Lijun Jin,

The integrated process of CO2 reforming of methane with co-pyrolysis of Naomaohu coal and elm to improve tar yield,

Fuel,

Volume 388,

2025,

134502,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134502.

(https://www.sciencedirect.com/science/article/pii/S0016236125002261)

Abstract: Co-pyrolysis of coal and biomass is an effective route to replace coal utilization with alternative biomass resource. However, it is crucial to acquire high tar yield during co-pyrolysis. To improve tar yield during co-pyrolysis of Naomaohu coal and elm, in this work, a new process was constructed by integrating co-pyrolysis with CO2 reforming of methane over 10Ni/γ-Al2O3 catalyst (CP-CRM) on an infrared-heated fixed-bed reactor, and the effect of pyrolysis temperatures on the integrated process was investigated. The comparison of co-pyrolysis behaviors under N2 (CP-N2) or CH4/CO2 (CP-CH4/CO2) atmosphere was conducted to reveal the reaction mechanism during CP-CRM. Result revealed that the CP-CRM showed higher tar yield than co-pyrolysis under CP-N2, and the maximum tar yield of 21.68 wt% was achieved at 500 °C during the integrated process, which was 1.13 times as that under CP-N2. In comparison, tar yield in co-pyrolysis under CH4/CO2 mixture gas was between those of CP-N2 and CP-CRM, indicating that CH4 and CO2 themselves could facilitate the formation of tar, which could further be strengthened under the action of 10Ni/γ-Al2O3 catalyst. The analyses of co-pyrolysis tar by simulated distillation, GC/MS, 1H-NMR and 13C-NMR showed that the pitch content in co-pyrolysis tar from CP-CRM was higher than those in CH4/CO2 and N2 atmospheres, and high phenols content up to 60.05 % was obtained, higher than 51.61 % in tar from CP-N2. Additionally, the tar from CP-CRM possessed more aromatics with short side chains compared than those from pyrolysis under N2 and CH4/CO2, which was mainly ascribed to the participation of active free radicals from CO2 reforming of CH4. This work provides a simple route to improve tar yield and phenols content in tar during co-pyrolysis.

Keywords: Coal; Biomass; Co-pyrolysis; CO2 reforming of methane; Tar

Rubina Khatun, Rohan Singh Pal, Kapil Bhati, Anil Chandra Kothari, Shivani Singh, Nazia Siddiqui, Swati Rana, Rajaram Bal,

Ni/Ce0.8Zr0.2O2−x solid solution catalyst: a pathway to coke-resistant CO2 reforming of methane††Electronic supplementary information (ESI) available. See DOI: https://doi.org/10.1039/d4su00481g,

RSC Sustainability,

Volume 3, Issue 2,

2025,

Pages 844-855,

ISSN 2753-8125,

https://doi.org/10.1039/d4su00481g.

(https://www.sciencedirect.com/science/article/pii/S2753812524003513)

Abstract: The CO2 reforming of methane effectively produces syngas using two prevalent greenhouse gases: CO2 and CH4. This study investigates the performance of three nickel-based catalysts, Ni/ZrO2, Ni/CeO2 and Ni/Ce0.8Zr0.2O2−x, in the DRM reaction. Each catalyst was thoroughly examined using a range of techniques, including XRD, TPR, BET, TPD, HR-TEM, Raman, O2-TPD, XPS, TGA and CO2-TPD to assess its structural and catalytic properties. The Ni/Ce0.8Zr0.2O2−x catalyst, combining the advantages of both supports to form a solid solution, achieved the best overall performance with enhanced activity and stability. Meanwhile, Ni/ZrO2 and Ni/CeO2 catalysts showed a tendency towards deactivation over extended reaction times. Characterization showed that incorporating zirconia into the CeO2 lattice led to the solid solution synthesis with a solely defective cubic fluorite phase, as confirmed by XRD and Raman analysis. The TPR and CO2-TPD revealed that the resulting Ni/Ce0.8Zr0.2O2−x catalyst possesses strong metal–support interaction and higher CO2 adsorption compared to pure CeO2 and ZrO2 samples. This composite support facilitated the generation of oxygen vacancies/active oxygen species, which are beneficial for reducing coke deposition. The Ni/Ce0.8Zr0.2O2−x catalyst demonstrated exceptional performance, achieving around 90.8% methane conversion and 91.0% CO2 conversion at 700 °C, with the resulting H2/CO ratio precisely equal to one. The stability test revealed remarkable stability against coke deposition for Ni/Ce0.8Zr0.2O2−x; meanwhile, Ni/ZrO2 and Ni/CeO2 are more susceptible to coke deposition, with the Ni/ZrO2 sample showing a greater tendency towards graphitic coke deposition. This study highlights the importance of catalyst supports in optimizing the performance of nickel-based catalysts for CO2 reforming applications.

Qikai Ren, Shuaishuai Wang, Haoyu Liu, Xing Zhang, Yanran Cui, Gui-Rong Zhang, Lei Nie, Donghai Mei,

Synergistic Ni-Ce-SSZ-13 catalysts for enhanced dry reforming of methane,

International Journal of Hydrogen Energy,

Volume 104,

2025,

Pages 202-211,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.08.304.

(https://www.sciencedirect.com/science/article/pii/S0360319924034657)

Abstract: The dry reforming of methane (DRM) serves as a pivotal reaction for hydrogen generation and the simultaneous conversion of methane and carbon dioxide, two major greenhouse gases, into syngas that can further be converted into high-value fuels and chemicals. However, catalyst deactivation imposes a major challenge that prohibits the market penetration of DRM. Here we reported a series of bifunctional Ni-Ce catalysts supported on SSZ-13 (Ni-Ce-SSZ-13) and discovered that a small amount of Ce could significantly enhance the activity, selectivity, and stability for DRM. Optimal ratio of Ni to Ce has been identified to yield peak catalytic performance. The optimal performance is correlated with the maximum Ce3+/Ce4+ ratio as revealed by XPS analysis, which implies an increased presence of oxygen vacancies in the catalysts. It played a crucial role in facilitating the oxidation of activated CH4 species at Ni sites, thereby enhancing DRM activity and diminishing the detrimental coke formation. It is also disclosed that integrating proper amount of Ce fosters its interactions with Ni, effectively preventing the agglomeration of Ni sites. This work presents great implications for the rational design and catalytic synergy of bi-/multi-functional zeolite catalysts for other technological applications.

Keywords: Dry reforming of methane; Zeolite; Oxygen vacancies; Bifunctional catalysts; Carbon deposition

Zheng Zhang, Yang Zhang, Mingzhong Shen, Xiaolong Wang, Kailiang Wang, Junhua Su, Siu Fai Au, Yingying Han, Wanbing Guan,

Achieving high stability in nickel-based solid oxide fuel cell stacks with direct internal reforming of methane,

International Journal of Hydrogen Energy,

Volume 106,

2025,

Pages 1285-1295,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.02.045.

(https://www.sciencedirect.com/science/article/pii/S036031992500610X)

Abstract: Solid oxide fuel cells (SOFCs) are acclaimed for their exceptional fuel flexibility, particularly their capability to directly utilize methane. However, traditional nickel-based anodes typically require external reforming processes, which complicate the overall system architecture by necessitating additional integration components. In this study, we present an innovative SOFCs with a flat-tube configuration, specifically designed for the direct internal reforming of methane. This design functions effectively as a reactor for the internal reforming process, exhibiting remarkable methane conversion rates, particularly at elevated steam-to-carbon (S/C) ratios. For instance, a conversion rate of 96.76% was achieved at an S/C ratio of 3. In-situ infrared spectroscopy has elucidated the critical roles of OH∗ and CH3∗ intermediates in facilitating the production of H2 and CO from water vapor and methane. A flat-tube stack, consisting of three single cells, reached a maximum power output of 52.82 W with an S/C ratio of 1 at 750 °C. Furthermore, the SOFC stack demonstrated exceptional stability during operation with methane reforming gas, maintaining continuous operation for over 437 h without significant performance degradation, even under challenging conditions with an S/C ratio of 1. These findings highlight the superior performance of the flat-tube SOFC, offering a more simplified, direct, and efficient solution, particularly under conditions of low S/C ratios.

Keywords: Methane; Direct internal reforming; Flat tube; Stack; Solid oxide fuel cell

Xirui Yan, Rui Wang, Fen Yue, Ruicong Wang, Huigang Zhang, Jun Li, Wencai Peng, Jinli Zhang,

High performance Ni-MgO (111) nanosheet catalysts for CO2 reforming with methane,

Fuel,

Volume 385,

2025,

134176,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134176.

(https://www.sciencedirect.com/science/article/pii/S0016236124033271)

Abstract: Synthesizing active and coking resistant catalysts is a challenge for CO2 reforming with methane (DRM), which is a potential effective strategy to convert greenhouse gases into syngas. In this work, Ni-MgO (111) nanosheet (Ni-MgO-NS) catalysts were prepared via a simple and effective coprecipitation-hydrolysis method and employed in DRM. The Ni-MgO nanoparticles (NPs) hydrolysis formed Ni-Mg(OH)2 nanosheets precursors, and the precursors decomposed into the Ni-MgO nanosheets exposed (111) polar planes. The prepared Ni-MgO-NS1 catalyst exhibited the best catalytic activity and carbon deposition resistance during DRM, due to the formation of Ni-O-Mg structure. The density functional theory (DFT) further unveiled that Ni4-MgO (111) can better activate CO2 to generate O\* species and has better intrinsic carbon deposition resistance than Ni4-MgO (100). Combined with experiments, the reaction mechanism for DRM on Ni-MgO-NS1 was explored. The synergistic effect of metal and MgO-NS can provide reference for the research in other related fields.

Keywords: CO2 reforming with methane; Hydrolysis; Ni-O-Mg; Carbon deposition resistance; DFT

Gema Gil-Muñoz, Juan Alcañiz-Monge,

Unusual redox dynamics of Nb in the perovskite LaNbxNi1-XO3 and its impact on the dry catalytic reforming of methane,

Fuel,

Volume 390,

2025,

134720,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134720.

(https://www.sciencedirect.com/science/article/pii/S0016236125004442)

Abstract: This study investigates the potential of Nb doping in Ni-based perovskites as a precursor for dry reforming of methane (DRM) applications. X-ray diffraction results indicate that Nb solubility in the LaNiO3 perovskite structure can be up to 25 % of B-sites. Furthermore, X-ray photoelectron spectroscopy (XPS) analysis suggests that the Nb incorporated into the perovskite adopts an unusual oxidation state (+4). The reducibility of Ni on this catalyst is influenced by both factors, which, in turn, affect its activity and catalytic stability during the DRM reaction. The duration of the reduction stage plays a crucial role, with an optimal reduction time identified: shorter reduction times result in lower catalytic activity but higher stability, while longer reduction times lead to higher catalytic activity but reduced stability. Carbon deposition on the surface of Ni nanoparticles is more pronounced in Nb-doped samples.

Keywords: Perovskites; Catalyst deactivation; Dry reforming; Charge redistribution

Xiaoyan Tian, Fagen Wang,

A review on catalyst advances for photothermal dry reforming of methane reaction,

Separation and Purification Technology,

Volume 354, Part 2,

2025,

128799,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.128799.

(https://www.sciencedirect.com/science/article/pii/S1383586624025383)

Abstract: Dry reforming of methane (DRM) converts the greenhouse gases of methane and carbon dioxide to useful chemical intermediates of syngas, contributing to both environment and energy. However, the high bond energies of C–H in methane and C=O in carbon dioxide result in the endothermicity of DRM, requiring high temperature for considerable conversions of carbon dioxide and methane in conventional thermal DRM. This causes problems of carbon deposition and catalyst sintering. Recently, the photothermal DRM are demonstrated needing lower temperature than thermal DRM, significantly enhancing performance, reducing carbon deposition and minimizing sintering. These are owned to the synergistic contribution from both photo and temperature, which reduces activation energies of methane and carbon dioxide, increases surface temperature of catalyst and adjusts reaction path ways etc. in photothermal DRM. To have an overview achievement of photothermal DRM in recent years, this paper reviews catalyst developments and mechanism investigations for photothermal DRM. We firstly introduce the active sites and principles in photothermal DRM, then the latest development of catalysts including TiO2-, CeO2- C3N4-, SiO2-based catalysts, layered double hydroxide catalysts and single atom catalyst are summarized. After illustrating the reaction mechanism, the outlook of possible investigation is suggested in future. It is hoped that this paper could provide pioneers useful guidance developing catalyst for photothermal DRM, as well as other photo-sensitive reactions.

Keywords: Methane dry reforming; Photothermal; Catalyst advances; Mechanism; Carbon deposition; Sintering

Obed Yeboah Boakye, Seyed Mojtaba Hashemi, Nader Mahinpey,

Investigation of Al2O3, ZrO2, SiO2, and CeO2 supported nickel catalysts for tri-reforming of methane,

International Journal of Hydrogen Energy,

Volume 109,

2025,

Pages 802-812,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.02.098.

(https://www.sciencedirect.com/science/article/pii/S0360319925006639)

Abstract: Tri-reforming of methane (TRM) combines steam reforming, dry reforming, and partial oxidation to produce syngas while utilizing CO2, offering a sustainable approach for energy applications. The development of cost-effective, stable catalysts remains a critical challenge for industrial deployment of TRM. This study hypothesizes that different oxide supports synthesized using a novel solution-combustion synthesis method significantly affect the performance of Ni-catalysts in TRM. The Ni-catalysts supported on Al2O3, SiO2, CeO2, and ZrO2 were characterized using XRD, N2-physisorption, SEM, TEM, H2-TPR, and TGA. Catalytic activity tests at 1 atm and 800 °C, revealed superior performance of Ni/Al2O3 and Ni/SiO2, with CH4 conversion >99%, CO2 conversion ∼42%, and H2/CO ratio ≈2.0. The enhanced performance is attributed to higher surface areas, smaller nickel particle sizes, strong metal-support interactions, and improved reducibility. These findings highlight the potential of solution-combustion synthesis for scalable design of efficient TRM catalysts.

Keywords: Tri-reforming; Solution combustion; Methane; Support; Syngas

Intan Clarissa Sophiana, Soen Steven, Arnetta Revieri, Anisa Permatasari, Riezqa Andika, Norikazu Nishiyama, Bambang Heru Susanto,

Simultaneous utilization of CO2 and CH4 through dry reforming of methane with Ni–Ce@SiO2 catalyst: Parametric and simulation studies,

Case Studies in Chemical and Environmental Engineering,

Volume 11,

2025,

101078,

ISSN 2666-0164,

https://doi.org/10.1016/j.cscee.2024.101078.

(https://www.sciencedirect.com/science/article/pii/S2666016424004729)

Abstract: The dry reforming of methane (DRM) can reduce CO2 and CH4 simultaneously. This study utilized East Natuna gas fields, composed of 70 % CO2 and 30 % CH4, for syngas production via DRM using a Ni–Ce@SiO2 catalyst. The kinetic parameters employed the Langmuir-Hinshelwood mechanism on the surface reaction as the rate-determining step. The simulation results provided an error margin below 5 %. A CO2:CH4 feed ratio of 70:30 at 700oC achieves higher CH4 conversion than a 50:50 ratio (97.10 % vs. 79.01 %), yet with lower H2/CO ratio (0.68 vs. 0.92). Also, higher temperatures impact shorter reactor lengths and swifter times to reach stable conversion.

Keywords: Langmuir-hinshelwood; Syngas; Nickel; Kinetic parameter; Greenhouse gas

Yan Zhao, Yuchao Cui, Na Sun, Hongda Wu, Zhiwei Yao,

First comparison of the catalytic stability of cobalt metal, nitride and phosphide catalysts for dry reforming of methane,

Phosphorus, Sulfur, and Silicon and the Related Elements,

Volume 200, Issue 1,

2025,

Pages 54-62,

ISSN 1042-6507,

https://doi.org/10.1080/10426507.2025.2450402.

(https://www.sciencedirect.com/science/article/pii/S1042650725000012)

Abstract: For the first time, the catalytic stability of cobalt metal, nitride, and phosphide phases supported on MgO was compared for dry reforming of methane. The initial CH4 conversions for Co/MgO, Co4N/MgO, and Co2P/MgO catalysts were 88.1, 87.7 and 86.0%, respectively. However, after 15 h of testing, these values gradually decreased to 69.9, 75.0 and 79.4%, respectively. The Co2P catalyst demonstrated superior stability compared to the Co and Co4N catalysts. The enhanced stability of the Co2P/MgO catalyst was attributed to its smaller particle size and a lower ratio of CH4 and CO2 dissociation rates.

Keywords: Co4N; Co2P; dry reforming of methane; particle size; CH4 and CO2 dissociation rates

Joshua O. Ighalo, Michael Paddock, Haider Almkhelfe, Arjun Nepal, Brice Lacroix, Xiaoqing He, Jennifer L. Anthony, Placidus B. Amama,

Dry reforming of methane at high space velocities on CeO2-supported Ni catalysts,

Chemical Engineering Journal,

2025,

160707,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.160707.

(https://www.sciencedirect.com/science/article/pii/S1385894725015281)

Abstract: High space velocities help to overcome diffusion limitations and achieve high throughput, features critical for scale-up. The performance of CeO2-supported Ni catalysts was evaluated for DRM at high space velocity (180,000 ml/gcat.hr) and extended time on stream (45 h) and compared with γ-Al2O3-supported Ni as a reference. Ni nanoparticles exhibited stronger metal-support interaction with CeO2 than γ-Al2O3. The catalysts were tested at 700 °C, 1:1 feed ratio, and atmospheric pressure. The average apparent CO2 reaction rate was higher for Ni/CeO2 catalysts than Ni/γ-Al2O3. Ni/CeO2 catalysts had lower H2/CO ratios of 0.4 – 0.55, while Ni/γ-Al2O3 was 0.6. The high CO2 reaction rate and low H2/CO ratio were due to the severe reverse water gas shift side reaction in Ni/CeO2 catalysts at high space velocities, which correlates with the oxygen vacancies in the support. DRM side reactions decreased the apparent CH4 reaction rate, an observation verified by thermodynamic calculations. The increased CO2 dissociative adsorption and oxygen radical migration in Ni/CeO2 catalysts lowered the carbon deposition rate (12 – 27 µg/gcat.min) compared to Ni/γ-Al2O3 (116.6 µg/gcat.min). Thiele-modulus (ϕ), effectiveness factor (η), and Weisz–Prater criterion (CWP) were used to confirm the absence of internal diffusion limitations in the catalysts under the reaction conditions. Ni/CeO2 catalyst is promising for scalable production of CO-rich syngas.

Keywords: Dry reforming; Cerium oxide; Catalyst synthesis; Renewable energy; Syngas

Feiyang Yu, Xuyingnan Tao, Haoran Yu, Tingting Zhao, Ming Li, Lvdan Liu, Haiqian Wang,

Enhancing the sintering stability of NiCo/CeO2-Al2O3 catalyst in dry reforming of methane by shaping the Ostwald ripening diffusion path,

Chemical Engineering Journal,

Volume 504,

2025,

158725,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2024.158725.

(https://www.sciencedirect.com/science/article/pii/S1385894724102161)

Abstract: Dry reforming of methane (DRM) is attractive for producing value-added syngas by consuming the CH4 and CO2 greenhouse gases, but the catalysts are challenged by sintering and coking. A series of NiCo/CeO2-Al2O3 catalysts with the nominal composition of (Ni0.5Co0.5)AlxCe10-xOy (x = 0–10) were prepared by sol–gel method. This work demonstrates that the formation of (NiCo)AlxOy spinel (or spinel-like) phase enhanced the metal-support interaction (MSI) and plays a crucial role in the catalyst’s performance. Small (NiCo)AlxOy grains reside in the holes and along the grain boundaries of the CeO2 matrix in the fresh catalysts. (NiCo)AlxOy becomes amorphous under DRM conditions and exhibits a high affinity to both NiCo NPs and the CeO2 grains, keeping the MSI strong enough to direct the sintering of metal NPs to the Ostwald ripening pathway. We proposed that the sintering of NiCo NPs in the x  ≥ 2 catalysts follows the Ostwald ripening pathway: (NiCo)AlxOy serves as the diffusion path for the metal atoms while CeO2 serves as the spacer shaping the length and cross-section of the diffusion path. A proper Al2O3/CeO2 ratio makes the inter-grain diffusion path long and narrow, which effectively hinders the sintering of NiCo NPs. The NiCo/CAO-2 catalyst with the stoichiometric Ni0.5Co0.5Al2O4 spinel composition exhibits the best DRM performance. The CH4 and CO2 conversions at 700 ℃ achieved 76 % and 84 %, respectively. The catalyst was stable during the 100-hour DRM test, and the carbon deposition rate was small. The present work provides a new strategy for developing anti-sintering catalysts for high-temperature reactions.

Keywords: Dry reforming of methane; Spinel; Sintering; Ostwald ripening; Diffusion path

H.J. Muñoz, S.A. Korili, A. Gil,

Surface tuning of a highly crystalline Ni/LaAlO3 perovskite catalyst obtained from aluminum saline slags using various synthesis methods for the dry reforming of methane,

Catalysis Today,

Volume 447,

2025,

115158,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2024.115158.

(https://www.sciencedirect.com/science/article/pii/S0920586124006527)

Abstract: This research presents the first synthesis of nickel-modified lanthanum aluminate (Ni/LaAlO3) perovskite from aluminum (Al) saline slag waste involving acid extraction. Two methods were employed to extract Al: a 2 M HCl aqueous solution (AH) and various citric acid (CA) aqueous solutions (0.5, 1.0, or 2.0 M). Three preparation methods (Pechini, modified citrate, and metal–organic gel) were evaluated to obtain the pure lanthanum aluminate (LaAlO3) phase. This study also investigated the effects of several factors, with some variations being observed depending on the methodology used. The factors analyzed were: (i) preparation method; (ii) type of Al precursor solution (either extracted using HCl or CA); (iii) ligand/cations molar ratio (La3 + + Al3+), ranging from 0.3 to 3.0; (iv) CA concentration; (v) molar ratio (La/Al), between 0.5 and 1.0; (vi) calcination temperature; and (vii) acid etching of the final materials with aqueous dilute nitric acid (HNO3). The results indicated that it is possible to obtain LaAlO3 perovskite using all three methodologies and the Al extracted from saline slags. For the Pechini and metal–organic gel methods, ligand/cations molar ratios (La3+ + Al3+) of 3.0 and between 0.3 (with CA) and 1.5 (with AH), respectively, were obtained, while a CA concentration of 1.0 M was used for the modified citrate method. The optimal molar ratio (La/Al) for obtaining the perovskite was 1.0 in all three methods. The perovskite was synthesized at low temperatures, starting from 650 °C, and was obtained in a completely pure form at between 950 and 1050 °C. Treatment with aqueous dilute acid had a marked effect, especially on the materials obtained when using the initial solution extracted with 2.0 M HCl. This treatment was particularly beneficial for the material prepared using the Pechini method, which induced a 2.5-fold increase in the specific surface area and total pore volume without affecting the crystalline structure, and allowed the specificity of the nickel (Ni) active sites incorporated to be directed, particularly towards a higher proportion of β1 reducible species. This result improved the catalytic performance in the dry reforming of methane (DRM) reaction, achieving conversions of up to 73 % in CO2 and up to 70 % in CH4, with average selectivity of 0.93 after 20 h of reaction. These outcomes even surpassed the reference catalyst, which was entirely prepared using commercial-grade reagents. Factors such as the presence of other metals in the slag and the versatility of cationic substitution contributed to enhancing the physicochemical properties of the catalysts. Ultimately, all of this led to suppression of the formation of double-walled filamentous carbon deposits, which tend to deactivate the catalyst due to sintering and deformation of the active phase.

Keywords: Nickel lanthanum aluminate; Aluminum saline slags; Pechini method; Carbon dioxide; Methane

Yixiong Lin, Minkai Yu, Qinglian Wang, Wei Zhang, Wang Yin, Chen Yang, Ting Qiu,

Unraveling the structure-performance relationship of foam reactor with hierarchical pore structure for dry reforming of methane reaction,

Fuel,

Volume 389,

2025,

134596,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134596.

(https://www.sciencedirect.com/science/article/pii/S0016236125003205)

Abstract: Dry reforming of methane (DRM), which is a viable approach for carbon capture and utilization, is notably inclined towards carbon deposition due to the formation of cold spots, causing catalyst rapid deactivation, thereby limiting its industrial application. In order to prevent catalyst coking, it is imperative to improve the heat and mass transfer processes in DRM reactors. A foam reactor with hierarchical pore structure was proposed in this work, which is composed of fine and coarse pores and avoids contact thermal resistance due to the contact of foam structures with different pore sizes. Based on lattice Boltzmann model, this work investigated the impact of hierarchical pore structure on the heat and mass transfer, as well as DRM reaction in Ni/Al2O3 based foam reactors. The findings suggest an optimal overall heat transfer coefficient with the variation of dcoarse/dfine under equal pumping power. Furthermore, it reveals a synergistic mechanism between the heat and mass transfer processes, identifying an optimal hierarchical pore structure which, compared to uniform fine and coarse pore structures, facilitates an enhancement in reaction performance by 14.1 % and 13.0 %, respectively. This work provides a theoretical foundation and technical direction for the design of foam reactors.

Keywords: Foam reactor; Hierarchical pore structure; Heat and mass transfer; Dry reforming of methane; Lattice Boltzmann method

Lukasz Szablowski, Malgorzata Wojcik, Olaf Dybinski,

Review of steam methane reforming as a method of hydrogen production,

Energy,

Volume 316,

2025,

134540,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2025.134540.

(https://www.sciencedirect.com/science/article/pii/S0360544225001823)

Abstract: The article presents a comparison of the performance of the steam methane reforming process in various conditions and scales. First, a bibliometric analysis of articles related to steam reforming of methane was performed. On the basis of this analysis, a literature review was created in terms of the most popular issues (those with the highest number of reads and the highest number of citations). An important aspect of the selection of topics discussed in the review was that their interest must be new and not historical. Based on the criteria formulated in this way, the review is divided into non-catalytic and catalytic reforming. As part of the discussion of catalytic reforming, there was also a review of catalysts and their range of applicability (in terms of temperature, fuel composition, pressure, etc.) A further division is made by the scale of the reforming process: laboratory, technical and industrial scale. The article describes methods of meeting the energy needs of the steam reforming process and methods of purifying the hydrogen obtained. The installations for the reforming process presented in the article are summarized in terms of the conditions under which the reaction takes place, type of catalyst used (or none), steam-to-carbon ratio (s/c), installation size, percentage of methane conversion and installation location. As the steam methane reforming is a very broad topic, the article summarizes all the most important issues and shows the forthcoming opportunities of new technologies.

Keywords: Steam methane reforming; Hydrogen production; Non-catalytic reforming; Catalytic reforming; Laboratory scale reforming; Industrial reforming; Energy management of steam methane reforming processes

Xu Ma, Wei-Wei Yang, Jia-Rui Zhang, Xin-Yuan Tang,

Structural evolution of Ni-Ce bimetallic alloy on Al2O3 support in methane dry reforming: Achieving sustainability and high-efficiency reaction through cerium modulation strategy,

Fuel,

Volume 384,

2025,

134084,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134084.

(https://www.sciencedirect.com/science/article/pii/S0016236124032356)

Abstract: This research delves into the methane dry reforming, meticulously exploring the structural-evolution of Ni-Ce bimetallic alloy on Al2O3 support during the reaction-process and its impact on catalytic performance. By delicately tuning the cerium content to an optimal proportion of 10 wt%, we achieved a remarkable optimization of the catalyst structure, fostering the low-temperature reduction of nickel-species and an increase in oxygen-vacancies. At 800 °C, this optimized catalyst exhibited a methane conversion as high as 98.34 % (maintained for 50 h), significantly outperforming the Ni@Al2O3. Our findings revealed that the synergistic-interaction between the Ni-Ce bimetallic properties and the hydrogen-reduction-process enhanced the crystallinity and accessibility of active-sites within the catalytic. In-situ DRIFT spectroscopy and thermogravimetric analysis demonstrated that the adoption of a cerium modulation strategy markedly enhances the adsorption and dissociation efficiency of reactants, while effectively mitigating the formation of carbon deposition during extended reaction periods. Consequently, this ensures that the catalyst maintains exceptional activity throughout a continuous 50-hours operation. This study expands the new adsorption and carbon-accumulation mechanism in the methane dry reforming and lays a solid-foundation for its industrial application.

Keywords: Sustainability; Dry reforming of methane; Regulation strategy; Oxygen vacancy; Carbon deposition combustion

Osarieme Uyi Osazuwa, Kim Hoong Ng,

An overview on the carbon deposited during dry reforming of methane (DRM): Its formation, deposition, identification, and quantification,

Results in Engineering,

Volume 25,

2025,

104328,

ISSN 2590-1230,

https://doi.org/10.1016/j.rineng.2025.104328.

(https://www.sciencedirect.com/science/article/pii/S2590123025004098)

Abstract: Carbon deposition in dry reforming of methane (DRM) is associated with two side reactions: CH4 decomposition and Boudouard reaction. Effective management of DRM technology necessitates a thorough comprehension of associated side reactions. In view of this, the current review systematically provides insights into carbon in DRM, with its formation, deposition, identification, qualitative and quantitative determinations highlighted herein. Under most occasions, the carbon formed and deposited can be broadly categorized into graphitic, amorphous and filamentous forms, each with varied resilience under regenerative conditions. Therefore, correctly identifying the genre of deposited carbon serves the first vital step to effective carbon gasification and formulating appropriate catalytic regeneration strategies. While presenting the main characteristic of each carbon species, the reliance of their formation kinetics on different factors, namely temperature, pressure, inlet feed (reactants composition and CH4-to-CO2 ratio), catalyst genre, etc., were highlighted in this review too. In brief, elevated temperatures and pressures, catalyst formulation and CH4/CO2 ratio impact graphitic build-up, decarbonization, and carbon reactivity, crystallinity, and quantity. Meanwhile, characterization techniques that provide valuable insights into the deposited carbon species were identified too, with emphasis placed on those unveiling crystallinity, morphological, structural, thermal stability, reactivity and quantity of deposited carbon. Understanding the features of deposited carbon is crucial, particularly for DRM reaction that suffers severely from this hindrance. Despite advances in understanding carbon species in DRM, strategies to control carbon species formation mechanisms towards reactive carbon formation remain underdeveloped, emphasizing the need for continued research by experienced and new researchers in the DRM community.

Keywords: Carbon deposition; Methane; Carbon dioxide; Greenhouse gases; Catalysis; Hydrogen

Javier Jurado, Fernando Trejo, Jorge Ancheyta, Andrey Elyshev, Andrey Zagoruiko,

A comprehensive analysis of kinetic models for methane autothermal reforming reactions,

Fuel,

Volume 386,

2025,

134136,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134136.

(https://www.sciencedirect.com/science/article/pii/S0016236124032873)

Abstract: An analysis of the autothermal reforming (ATR) kinetic models reported in the literature was performed. The ATR model equations, kinetic parameters, experimental setup, and comparisons of experimental and simulated results were analyzed and discussed. The greatest part of the kinetic models accurately predicted the experimental data. The effect of the main operating variables on methane conversion and product selectivity are discussed. However, it is recognized that there is a need for a robust kinetic model of methane ATR, being the main challenge the accurate prediction of product yields and the temperature profile along the catalyst bed. The development of a new kinetic model needs to consider a balance between the number of kinetic parameters and the amount of experimental data, this latter is one of the main activities for further optimization of the methane ATR reactor technology.

Keywords: Hydrogen production; Methane autothermal reforming; Kinetic modeling; Methane steam reforming; Methane partial oxidation; Methane dry reforming

Ehsan Akbari, Mehran Rezaei, Zahra Montazeri, Roya Monjazi, Gholamali Mansourian,

Synergistic catalytic effects of nickel-based catalysts on calcium aluminate supports in methane dry and combined reforming processes,

Process Safety and Environmental Protection,

Volume 196,

2025,

106903,

ISSN 0957-5820,

https://doi.org/10.1016/j.psep.2025.106903.

(https://www.sciencedirect.com/science/article/pii/S0957582025001703)

Abstract: The significance of converting natural gas, particularly methane, into valuable chemical components is crucial across various industries. In this investigation, calcium aluminate powders (CA) with various CaO/Al2O3 molar ratios were synthesized and the resulting calcined samples were employed as support for the preparation of nickel-based catalysts. The research indicated a significant impact of the calcium aluminate content on the physical and chemical structures as well as the catalytic efficiency of the samples. Among the evaluated samples, 12 wt%Ni/CA with a cement percentage of 30.55 % and a BET area of 8.56 m2.g−1 demonstrated superior catalytic activity, stability, and carbon deposition suppression in methane dry reforming. The results indicated that increasing the nickel loading from 6 to 15 wt% enhanced the conversion of CH4 and CO2. However, the maximum conversion values for CH4 and CO2 were achieved at 92.9 % and 98.4 %, respectively, at 800 ℃ over the sample containing 15 wt% Ni. Additionally, the selected catalyst, 12 wt%Ni/CA, was utilized in the direct reduced iron (DRI) process to assess its potential in DRI process. The study revealed an improvement in CH4 conversion from 20 % to 91.6 %, and the H2/CO ratio decreased from 2.55 to 1.9 with an increase in temperature from 600 to 800 ℃. The results also demonstrated satisfactory performance of the studied sample under real feed conditions containing 5 vol% propane.

Keywords: Methane dry reforming; Directed reduced iron; Ni/CaAl2O4; Propane

Chenlong Liu, Wenqiang Tang, Yuxin Zhong, Siddig Abuelgasim, Chenghua Xu, Atif Abdalazeez,

Dry reforming of methane by LaNiO3 perovskite oxide: Cu-substituted improving reactivity and stability,

International Journal of Hydrogen Energy,

Volume 101,

2025,

Pages 617-626,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.487.

(https://www.sciencedirect.com/science/article/pii/S0360319924057069)

Abstract: The conversion of greenhouse gases is pivotal for mitigating environmental pollution. Dry reforming of methane is an attractive technological process as it facilitates the conversion of both CO2 and CH4 into a suitable syngas. However, the coke deposition inhabits the development of Ni-based catalyst. In this study, the effects of Cu-substituted in LaNi1-xCuxO3 (x = 0, 0.2, 0.4 and 0.6) perovskites were investigated. In comparison with the LaNiO3 sample, the Cu-substituted samples exhibit enhanced stability and resistance to coke deposition; However, a marginal decrease is observed in the conversion of CH4. In the case of Cu-substituted samples, the weight loss rates due to coke deposition are below than 3.9%, with LaNi0.4Cu0.6O3 showing a particularly low rate during the 3h reaction. This improvement in coke resistance is more than 22 times greater compared to the LaNiO3 sample. LaNi0.8Cu0.2O3 demonstrated the highest conversion rates for both CO2 and CH4 among all Cu-substituted samples. Characterization results have demonstrated that the Cu-substituted sample promotes the formation of Ni–Cu alloy particles. Notably, there is a pronounced tendency for Ni–Cu particle to aggregate when x equals 0.4 and 0.6. The LaNi0.8Cu0.2O3 sample has been subjected to further investigation across a range of temperatures from 600 to 750 °C. It has been observed that the conversion of CH4 and CO2 is notably enhanced at temperatures exceeding 700 °C. The results indicate that the optimal reaction temperature is 700 °C, yielding a favorable H2/CO ratio of approximately 1, which is suitable for syngas production. Characterization results indicate a tendency for the Ni–Cu alloy to segregate into Ni and CuO phases. Furthermore, the activity of La2O2CO3 is enhanced, which contributes to a reduction in coke deposition. In an 8h stability test, the LaNi0.8Cu0.2O3 sample demonstrated a relatively stable performance in terms of CH4 conversion, CO2 conversion, and H2/CO ratio.

Keywords: Dry reforming methane; Cu-substituted; LaNiO3; Perovskite

Yang Zhang, Jun Shen, Yubin Zeng, Xin Tian, Mingyue Ding,

Direct reduction of calcium carbonate by coupling with methane dry reforming using NiO/S-1 as catalyst,

Separation and Purification Technology,

Volume 354, Part 4,

2025,

128816,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.128816.

(https://www.sciencedirect.com/science/article/pii/S1383586624025553)

Abstract: Thermal decomposition of carbonate is an important process in the production of cement, refractory materials, and steel. Nevertheless, this process requires high temperature and is always accompanied with large amounts of CO2 emission. To reduce the decomposition temperature and simultaneously mitigate CO2 emissions, direct reduction of carbonate under a reducing atmosphere has been proposed as a novel strategy. This work mainly investigated the feasibility of direct reduction of CaCO3 by CH4 in the presence of a highly dispersed NiO/S-1 catalyst. It was found that the introduction of a CH4 atmosphere without a catalyst had little promotion effect on CaCO3 decomposition (as compared to air atmosphere), and no notable conversion of CO2 was observed. However, the presence of a highly dispersed NiO/S-1 catalyst significantly decreased the decomposition temperature of CaCO3 in a CH4 atmosphere, and most of the carbon species in CaCO3 can be converted to CO. To gain a comprehensive understanding of CaCO3 reduction in CH4, the effects of reaction temperature, CH4 concentration, and NiO loading in the NiO/S-1 catalyst were systematically explored. With the best-performing catalyst, i.e., 7NiO/S-1, complete CaCO3 decomposition and approximate 90 % CH4/CO2 conversion can be achieved under the condition of 750 °C and 25 vol% CH4. Characterization results indicated that the CaO particles obtained in the CH4 reducing atmosphere exhibited a more porous structure compared to that attained in air, due to the more intensive CaCO3 decomposition in CH4. Further data analysis revealed that reverse water-gas shift reaction also contributed to CO2 conversion during the reduction of CaCO3 in CH4. The findings obtained in this research can provide new perspectives for CO2 emission control and energy saving in traditional heavy-emission and high energy consumption industries.

Keywords: CaCO3 reduction; CH4 dry reforming; In-situ CO2 conversion; NiO/S-1 catalyst

Baitao Li, Jing He, Xiaoqing Yuan,

Effect of lanthanum modification on core–shell structured nitrogen-doped carbon coated nickel catalysts for dry reforming of methane,

Fuel,

Volume 388,

2025,

134495,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134495.

(https://www.sciencedirect.com/science/article/pii/S0016236125002194)

Abstract: This work directly faced and challenged carbon deposition for nickel-based catalyst when they are applied in the dry reforming of methane (DRM). The influence of lanthanum amount on the catalytic behavior of nickel based catalyst (Ni@NC-La) with Nickel as core and Nitrogen doped Carbon derived from glucose as shell, was investigated. Extensive characterization results confirmed this core–shell structure and successful incorporation of lanthanum and nitrogen into the catalyst. The modification of lanthanum strongly modulated the microstructural and physicochemical features of Ni@NC-La, including pore structure, graphitization of pristine carbon, oxygen vacancy and distribution of doped nitrogen functionality. These features positively impacted the CO2 adsorption ability of Ni@NC-La and induced the formation of the La2O2CO3. Meanwhile, the mobile oxygen vacancy triggered by lanthanum provided extra active sites for the activation of CO2, which facilitated the gasification of carbon. The deactivation of carbonaceous catalysts caused by carbon deposition could be delayed and effectively improved when the catalyst possessed more mobile oxygen vacancy and alkaline sites. These results delicately uncovered the crucial role played by Lanthanum in catalyst activity and stability enhancement for DRM. This is the first report showcasing the effectiveness of Lanthanum on nickel-based carbon material with core–shell structure suitable for DRM.

Keywords: Dry reforming of methane; Ni-based catalyst; Glucose-derived carbon; Core-shell; Lanthanum content; Carbon deposition

Sanli Tang, Zhongrui Gai, Yang Li, Yunlian Liu, Mingkai Liu, Ying Pan, Hongguang Jin,

From lab to industry: Scaling-up Fe-Ni bimetallic nano oxygen carrier for mid-temperature methane chemical looping reforming,

Applied Energy,

Volume 377, Part C,

2025,

124588,

ISSN 0306-2619,

https://doi.org/10.1016/j.apenergy.2024.124588.

(https://www.sciencedirect.com/science/article/pii/S0306261924019718)

Abstract: Chemical looping methane reforming has emerged as a promising avenue to produce blue hydrogen. Currently, satisfactory CH4 conversion and H2 productivity typically requires reaction temperature above 800 °C, bringing challenges for industrial reactor design and energy conservation. To realize high chemical looping methane reforming performance at low temperature, a Fe-Ni bimetallic nano oxygen carrier was presented, along with the workflow and platform for scaled-up synthesis of the oxygen carrier. On account of the synergy of nanoscale Fe-Ni species, the operating temperature could be lowered to 500–600 °C. The lab-scale oxygen carrier converted >90 % CH4 and produced 3.5 H2 per CH4 molecule with 80–82 % outlet H2 purity at 575–600 °C. The 10-kg scale synthesized oxygen carrier powder exhibited >90 % CH4 conversion, >78 % H2 purity and produced 2.8–3.5 H2 per CH4, with performance penalty from scaling up controlled within 5 %. After shaping and calcination, the 10-kg oxygen carrier beads still produced 2.8 H2 from per CH4 molecule with >70 % H2 purity. Longevity test revealed the 10-kg powder and beads as stable in phase, morphology, and redox activity over 110 cycles. Experiments of variable operating conditions found that the 10-kg oxygen carriers can meet industrial requirements of H2 production at >550 °C, with low steam/carbon ratio favored by 10-kg beads. Further analysis attributed the performance distinction of 10-kg beads to its lower surface area, reduction extent and steam affinity, compared to those of the lab-scale and 10-kg powders. These findings contributed to the mid-temperature chemical looping methane reforming by bridging laboratory practices and industrial application.

Keywords: Mid-temperature chemical looping reforming; Nanoscale bimetallic oxygen carrier; Industrial-scale hydrothermal synthesis; Blue hydrogen production

Amir Hassan, Yaroslavl Utkin,

Dry reforming of methane and interaction between NiO and CeZrPrOx oxide in different crystallographic plane,

Next Energy,

Volume 6,

2025,

100199,

ISSN 2949-821X,

https://doi.org/10.1016/j.nxener.2024.100199.

(https://www.sciencedirect.com/science/article/pii/S2949821X24001042)

Abstract: Methane dry reforming (DRM) holds promise as a pathway for converting methane into valuable synthesis gas (syngas) and high-value chemicals. In this study, we investigate the crystallographic plane interactions between nickel oxide (NiO) and a modified ceria-zirconia-praseodymium oxide support (CeZrPrOx) to elucidate their influence on catalytic activity in methane dry reforming. X-ray diffraction (XRD) patterns and transmission electron microscopy (TEM) techniques were employed to characterize the catalyst. Our findings reveal that specific crystallographic planes significantly impact the catalytic performance of NiO/CeZrPrOx catalyst. The (111), (110), and (100) facets of the support material are examined for their interactions with NiO. We observe that the (110) plane of the support exhibits strong interaction with NiO, leading to enhanced catalytic activity. This interaction facilitates superior anchoring of Ni nanoparticles, lowering sintering and promoting a strong metal-support interaction effect (SMSI). Additionally, our analysis suggests that the (110) interface is particularly favorable for methane dry reforming. Overall, this study highlights the importance of crystallographic plane interactions in NiO/CeZrPrOx catalysts and offers valuable insights for optimizing catalyst design for methane conversion processes.

Keywords: Methane dry reforming; Crystallographic planes; Metal-support interaction effect (MSI) and catalyst optimization

Miaomiao Zhang, Yibo Gao, Yang Jin, Wenlong Wang, Zhanlong Song, Yanpeng Mao,

New insights into microwave-mediated dry reforming of methane over Al2O3-stabilized activated carbon-based catalysts: Experimental and DFT study,

International Journal of Hydrogen Energy,

Volume 109,

2025,

Pages 344-356,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.379.

(https://www.sciencedirect.com/science/article/pii/S0360319925004227)

Abstract: The rapid deactivation of activated carbon (AC)-based catalysts limits the development of microwave-mediated dry reforming of methane (MW-DRM) technology. Here, Al2O3-stabilized Ni/AC (Ni–Al2O3/AC) catalysts obtain excellent reactant conversion (XCH4 > 97%, XCO2 > 98%) due to the mitigation of metal sintering and excessive gasification of AC support in the MW-DRM process, which is unattainable by conventional heating (CH). Compared with the severe carbon loss of 94% in Ni/AC after CH-DRM test, the carbon content change in Ni–Al2O3/AC after MW-DRM test is negligible, demonstrating the synergistic effect between MW and Al2O3 on the maintenance of AC support. The localized high-temperature hotspot and micro-plasma generated under MW can enhance the graphitization degree of carbon in Ni–Al2O3/AC catalyst, contributing to the stability of AC support. Moreover, activation energy and DFT calculations indicate that microwave can facilitate the adsorption of CH4 and CO2 on the catalyst surface, leading to the enhancement of reactivity.

Keywords: CO2; Methane; Microwave; Activated carbon; Alumina; Carbon loss

Jintao Song, Yaping Fan, Fuqiang Wang, Xuhang Shi, Chunzhe Li, Jiaxin Du, Hongliang Yi,

Thermodynamic analysis of a novel compressed carbon dioxide energy storage coupled dry methane reforming system with integrated carbon capture,

Applied Energy,

Volume 377, Part D,

2025,

124769,

ISSN 0306-2619,

https://doi.org/10.1016/j.apenergy.2024.124769.

(https://www.sciencedirect.com/science/article/pii/S0306261924021524)

Abstract: Chemical absorption CO2 capture, compressed carbon dioxide energy storage (CCES) and dry reforming of methane (DRM) can be used for continuous carbon capture, storage and utilization. However, CO2 capture is often accompanied by significant energy consumption. Considering the waste high-grade thermal energy at the exit of solar methane reforming, the article proposes a coupled system in which the thermal energy at the exit of the DRM system is used in CCES to improve the system's work capacity, and the remaining heat and the compression heat of the CCES are used for CO2 capture. The study established mathematical models of the three subsystems, performed thermodynamic analyses, and completed experiments on dry reforming of methane. The results show that the coupled system can increase the electro-electric conversion efficiency by 150.49 % reaching 220.33 % and the energy efficiency by 7.25 % reaching 77.09 %. The coupled system can save up to 43.33 % of CO2 capture heat. The DRM subsystem can utilize the higher temperature CO2 in the tail end of the CCES system, and its methane conversion efficiency and solar-fuel efficiency can be increased by 3.54 % and 3.20 % respectively to reach 58.22 % and 61.02 %. And the economic analysis found that the coupled system has better economics.

Keywords: Carbon emission reduction; Compressed carbon dioxide energy storage; Dry methane reform; Solar energy; Thermal gradient utilization

O. Bazta, F.J. Botana, J.J. Calvino, M.A. Cauqui, J.M. Gatica, H. Vidal, L. González-Rovira, J. López-Castro, M.P. Yeste, G. Blanco, J.C. Hernández-Garrido,

Novel combination of 3D-printing and electrochemical deposition to design and prepare metallic honeycomb supported catalysts for dry reforming of methane,

Chemical Engineering Journal,

Volume 506,

2025,

159939,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159939.

(https://www.sciencedirect.com/science/article/pii/S1385894725007387)

Abstract: A multidisciplinary approach has been followed for the development of structured catalysts based on 3D-printed metallic honeycomb monoliths, which allows overcoming some of the barriers that limit the industrial application of significant catalytic processes such as those related to CO2 valorization. In particular, nickel and/or cerium-containing catalysts have been incorporated into stainless steel honeycombs and evaluated in the Dry Reforming of Methane (DRM) reaction. Moreover, taking advantage of the conductive nature of the metallic substrate, a methodology that allows the incorporation of the active phase by electrochemical deposition has been implemented. The prepared catalysts were characterized by SEM coupled EDX compositional analysis, X-ray fluorescence, X-ray diffraction, X-ray Photoelectron Spectroscopy and Temperature-Programmed Reduction. In contrast to the catalyst where cerium and nickel were co-deposited, the catalyst obtained by sequential electrodeposition of Ce (first) and Ni (second) proved to be highly active and stable in the DRM process, with conversions of both CH4 and CO2 above 90 % and H2/CO ratio of ca. 0.8 at 750 °C for more than 40 h. Moreover, the catalyst kept its good performance after doubling the flow proving its great potential for a real application at higher scale.

Keywords: Dry reforming of methane; Electrodeposition; 3D printing, nickel/ceria catalysts; Stainless steel honeycomb

Alfred Bekoe Appiagyei, Sasha Yang, Jinxing Gu, Alan Chaffee, Jefferson Zhe Liu, Qinfen Gu, Lian Zhang,

Phase Segregation-Dictated superior Fe-rich ferrite composite for intensified methane dry reforming with CO2 splitting,

Chemical Engineering Journal,

Volume 507,

2025,

160684,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.160684.

(https://www.sciencedirect.com/science/article/pii/S1385894725015050)

Abstract: Earth-abundant iron oxide serves as a promising oxygen carrier for the chemical looping dry reforming of methane, addressing the emission of both CH4 and CO2. However, its development faces a challenge with a trade-off between high activity and stability. We successfully resolved this issue by advancing an Fe-rich (61 wt% Fe) oxygen carrier derived from a global waste, fly ash. This oxygen carrier incorporates six cations (Fe, Mg, Al, Ca, Ti and Mn) in a composite consisting of distorted spinel ferrites (MgFeAlO4 and Fe3O4) and discrete oxides (MgO and Fe2O3), recording a superior oxygen transfer capacity of ∼ 19.8 mmol/gOC during the 900 °C CH4/CO2 cycles. This is attributed to a promoted deep reduction of Fe3+, a high phase segregation of the structure due to oxygen migration, and a strong metal-support interaction between inert MgO and the deeply reduced metallic Fe0. Additionally, the oxygen carrier is capable of catalysing both CH4 reforming and cracking reactions, yielding a high H2/CO molar ratio of 5.3 and a large H2 production (∼70.6 mmol/gOC) in the CH4 reduction stage. In the subsequent CO2 oxidation stage, the lattice oxygen is fully restored, and the Boudouard reaction is also catalysed by the trace cations (Ca, Ti and Mn) to eliminate the coke deposit effectively, which resulted in a total CO production of ∼ 82 mmol/gOC. Meanwhile, the segregated phases are re-integrated together, enabling a successful reversion of the structure for the oxygen carrier and its constantly high and stable activity over cyclic use.

Keywords: Intensified Methane Dry Reforming; CO2 Splitting; Fly ash Waste; Fe-rich Ferrite Composite; Oxygen Transport Capacity

Xuyingnan Tao, Feiyang Yu, Pengcheng Yu, Haoran Yu, Tingting Zhao, Ming Li, Haiqian Wang,

Local coordination configuration of Ni and Co in MgAl2O4 spinel structure and the performance of NiCo/MgO-Al2O3 catalyst for dry reforming of methane,

Chemical Engineering Journal,

Volume 507,

2025,

160708,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.160708.

(https://www.sciencedirect.com/science/article/pii/S1385894725015293)

Abstract: MgAl2O4 spinel exhibits high flexibility in accommodating doped metal atoms and other solid defects, providing a powerful tool for tailoring the metal-support interaction (MSI) and developing high-performance catalysts for dry reforming of methane (DRM). We prepared a series of Ni and/or Co catalysts supported on MgO-Al2O3 (MAO) with different MgO/Al2O3 ratios (x = 0–4). We found that the coordination configuration of Ni and Co in the MgAl2O4 spinel structure depends on the Mg content: Ni atoms are pushed from the tetrahedral (Td) site to the octahedral (Oh) site as the Mg content increases (x ≥ 1.2), while Co tends to occupy both the Td and Oh sites. A proper MSI strength achieved by tuning the metal coordination configuration not only increases the thermal stability of the catalysts but also reduces the crystallinity of the deposited carbon species, making them more amorphous and prone to be removed during DRM. We proposed that driven by high temperature and the fluctuations in the local chemical environment, Ni and Co atoms may undergo reversible redox cycles and shuttle between the metal and support across the metal-support interface. This self-regeneration process helps retards the sintering of metal nanoparticles and suppresses the formation and crystallization of filamentous carbon. The CH4 conversion over bimetallic NiCo/MAO-2 achieves 84.4 % at 750 °C, remaining stable over a 110-h long-term test. This study provides an atomic-scale understanding of the catalysts, enabling the full utilization of the MgAl2O4 spinel structure for the rational design of high-performance DRM catalysts.

Keywords: Dry reforming of methane; NiCo bimetallic catalyst; Coordination; Spinel; Metal-support interaction

Abdulrahman bin Jumah, Marie-Nour Kaydouh, Ahmed S. Al-Fatesh, Mohammed O. Bayazed, Anis H. Fakeeha, Ahmed A. Ibrahim, Ahmed E. Abasaeed, Kirankumar J. Chaudhary, Nissrine El Hassan,

Cerium-induced modification of acid-base sites in Ni-zeolite catalysts for improved dry reforming of methane,

Journal of the Energy Institute,

Volume 118,

2025,

101901,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2024.101901.

(https://www.sciencedirect.com/science/article/pii/S1743967124003799)

Abstract: Dry reforming of methane (DRM) is a promising route to mitigate greenhouse gas emissions by converting CH4 and CO2 into valuable syngas. The present work explores the effect of Ce addition to Ni-based catalysts supported on CBV3020E (ZSM-5) for DRM. The use of Ce as a promoter to tune the acid-base properties of zeolites for DRM is addressed for the first time in detail. While Ce has traditionally been used to improve oxygen storage capacity, this work explores its novel use as a means to enhance surface basicity and promote CO2 adsorption. The samples were prepared by wet impregnation, characterized using N2-sorption, X-ray diffraction, H2-temperature-programmed reduction, temperature-programmed desorption of CO2 and ammonia, and Fourier transforms infrared spectroscopy, and tested for DRM at 800 °C and 42,000 mL/g.h GHSV. Results show that ZSM-5 zeolite can be beneficial in achieving high metal dispersion. The introduction of 2 wt% Ce to Ni5/ZSM-5 increases the concentration of strong basic sites, resulting in improved catalytic performance from 37 % CH4 conversion and 48 % CO2 conversion for Ni5/ZSM-5 to 55 % and 65 % on promoted Ni5Ce2/ZSM-5, respectively. Thus, the best results are observed on Ni5Ce2/ZSM-5 and an optimal H2/CO ratio of 0.84 is achieved in this case. Upon decreasing GHSV to 15,000 mL/g.h, CH4 and CO2 conversions jump to 83 % and 88 %, respectively on Ni5Ce2/ZSM-5. Cerium doping produces more desirable strong basic sites and enhances NiO reducibility. This promotes CO2 adsorption and drives the catalytic reaction towards syngas formation, which eventually results in increased efficiency and improved performance.

Keywords: Dry reforming of methane; Cerium; ZSM-5; Basic sites; Syngas

Hongyu Liu, Yuting Tang, Xiaoqian Ma, Jiehong Tang, Jingmin Deng, Wenchang Yue,

Calcium looping-enhanced biomass gasification for methanol production: Integrating methane dry reforming and carbon utilization,

Separation and Purification Technology,

Volume 354, Part 7,

2025,

129377,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.129377.

(https://www.sciencedirect.com/science/article/pii/S1383586624031162)

Abstract: Developing integrated CO2 capture and utilization (ICCU) is an attractive strategy that aims to reduce CO2 emissions while realizing the potential benefits of CO2. This paper investigates the techno-environmental-economic performance of biomass gasification to methanol (BtM) based on calcium looping (CaL) coupled with dry reforming of methane (DRM) and CaL coupled with reverse Boudouard reaction (RB). The results indicate that BtM systems based on CaL-DRM (BtM:CaL-DRM) and CaL-RB (BtM:CaL-RB) achieve CO2 capture and utilization, and enable efficient methanol synthesis. Compared to BtM:CaL-DRM, BtM:CaL-RB demonstrates higher exergy efficiency and lower global warming potential (GWP). The exergy efficiency of BtM:CaL-RB reaches 71.60 %. In terms of economic viability, BtM:CaL-DRM demonstrates more promising economic feasibility. The BtM systems reaches breakeven when the methanol selling price ranges from 440.8 $/ton to 529 $/ton. This study provides valuable insights into exploring novel ICCU systems.

Keywords: Biomass; Integrated CO2 capture and utilization; Natural gas; Biochar; Solid oxide electrolysis cell

Zhiyou Lian, Zhourong Xiao, Junjie Zhang, Xiangwen Zhang, Li Wang, Ji-Jun Zou, Guozhu Li,

Controllable adjustment of nickel accessibility on CeO2 by hard template for efficient hydrogen production via steam reforming of methane,

International Journal of Hydrogen Energy,

Volume 99,

2025,

Pages 716-728,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.255.

(https://www.sciencedirect.com/science/article/pii/S0360319924054624)

Abstract: The sol-gel method produces supported nickel catalysts possessing good stability. However, the catalysts are plagued by the issue of severe nickel embedment, which limits the accessibility and utilization efficiency of active sites. To address this issue, hard template (e.g., CNTs and SBA-15) was added during the sol-gel synthesis of Ni/CeO2, and subsequently removed to optimize the accessibility and stability of Ni nanoparticles on ceria. This approach effectively adjusts the embedment, exposure, deficiency and dispersion of Ni nanoparticles on ceria, thus endows Ni/CeO2 with high activity, high H2 selectivity and good stability. As regulated by SBA-15, the Ni/CeO2 catalyst possesses high specific surface area (128.9 m2/g), abundant oxygen defects, large surface nickel content (5.39%), and small nickel particle size (4.58 nm). The optimized Ni/CeO2 catalyst achieved a methane conversion of 82% at 650 °C, under a methane GHSV of 10000 mL h−1·gcat−1 and a water/methane ratio of 2. Moreover, this activity is well maintained for 100 h without any deactivation.

Keywords: Steam reforming; Hydrogen production; Nickel-based catalyst; SBA-15; Template; Active site accessibility

Da Hae Lee, Yun Ha Song, Sejin Jang, Jaekyoung Lee,

Modulating surface properties of Al2O3 based on AACH for stable Ni-based dry reforming of methane catalysts,

Journal of Environmental Chemical Engineering,

Volume 13, Issue 2,

2025,

115407,

ISSN 2213-3437,

https://doi.org/10.1016/j.jece.2025.115407.

(https://www.sciencedirect.com/science/article/pii/S2213343725001022)

Abstract: Dry reforming of methane (DRM) is gaining attention as an effective means of reducing greenhouse gases (CH4 and CO2). While Ni/Al2O3 catalysts are typically used for DRM, catalyst deactivation due to Ni sintering and coke deposition remains a challenge. In this work, we studied how tailoring the surface properties of Al2O3 based on ammonium aluminum carbonate hydroxide (AACH) affects its interaction with the active Ni phase and enhances the DRM catalytic performance. We prepared two δ-Al2O3 by calcination at 900 °C from different Al2O3 precursors of AACH and boehmite (AlOOH). Ethanol-temperature programmed desorption, NH3-TPD, pyridine-infrared spectroscopy, and CO2-TPD revealed that AACH-based Al2O3 (A900) possessed fewer Lewis acid sites and basic sites than boehmite-based Al2O3 (P900). Surface properties of A900 led to smaller Ni particles, as confirmed by X-ray diffraction and transmission electron microscopy, and higher reducibility of Ni, as evidenced by H2-temperature programmed reduction, compared to P900. DRM reaction was performed at 700 °C. Interestingly, Ni/A900 exhibited significantly improved catalytic activity and stability, along with H2/CO ratios closer to theoretical value of 1 than Ni/P900. Specifically, 20Ni/A900 achieved CH4 and CO2 conversions of 78 % and 85 %, respectively, outperforming the 20Ni/P900 (69 % CH4 and 78 % CO2 conversion) after 24 h. The superior catalytic performance of Ni/A900 originates from a higher number of available Ni sites with less Ni sintering, and lower coke deposition (∼28 wt% less at 20Ni/Al2O3) compared to Ni/P900 due to fewer residual Lewis acid sites. Overall, modulating the surface properties of Al2O3 supports based on AACH without additives suggests a novel approach for designing stable DRM catalysts.

Keywords: Dry reforming of methane; Ni catalysts; AACH; Acidity; Coke deposition

Xinyu Huang, Weiting Lin, Pengyin Lu, Zhichao Zhao, Jiawei Zhong, Jun Xie, Yong Chen,

Catalytic upgrading of biogas exclusively to metgas (CO-2H2) through the combined steam and dry reforming over Sm2O3 promoted robust Ni nano-catalysts supported on boron nitride nanosheets,

Fuel,

Volume 388,

2025,

134476,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134476.

(https://www.sciencedirect.com/science/article/pii/S0016236125002005)

Abstract: Robust Ni-based nanocatalysts supported on boron nitride nanosheets (BNNS), modified by Sm2O3, were synthesized via the co-impregnation and freeze-drying methods. The optimized 8Ni-8Sm2O3/BNNS catalysts demonstrated remarkable initial catalytic activity during the combined steam and dry reforming of biogas, achieving CH4 and CO2 conversions of 95 % and 46 %, respectively, and maintaining stable performance for 200 h. The introduction of Sm2O3 improved the amount of moderately basic sites and enhanced the activation of oxygen-containing molecules including CO2 and H2O, thereby promoting the formation of reactive oxygen species (e.g., O\*, OH\*) and effectively removing the coke precursors, significantly enhancing the carbon resistance. Moreover, the strong interaction between the small-sized Ni nanoparticles (NPs) and the BNNS support endowed the catalysts with excellent anti-sintering performance. The satisfactory catalytic performance of the 8Ni-8Sm2O3/BNNS catalysts can be attributed to the surface oxygen vacancies generated by Sm2O3, the moderately basic sites, and interaction between the highly dispersed Ni NPs and the BNNS support.

Keywords: Combined steam and dry reforming; Biogas; Metgas; BNNS; Sm2O3

Francesca Zaio, Matteo Ambrosetti, Carlo Tregambe, Alessandra Beretta, Gianpiero Groppi, Enrico Tronconi,

Intensification of methane steam reforming by Cu-foams packed with Rh-Al2O3 catalyst: A pilot-scale assessment,

Chemical Engineering Research and Design,

Volume 215,

2025,

Pages 98-107,

ISSN 0263-8762,

https://doi.org/10.1016/j.cherd.2025.01.022.

(https://www.sciencedirect.com/science/article/pii/S026387622500022X)

Abstract: Efficient heat transfer is a crucial factor in the design of compact methane steam reformers for distributed hydrogen networks. The adoption of copper packed foams was proposed and demonstrated at lab-scale by our group to strongly intensify heat transfer in these systems. Moreover, a 2D heterogeneous model of the packed-foam reformer was developed and validated against experimental data. In this work, an existing pilot-scale annular methane steam reformer (with maximum inlet methane flow rate equal to 3 Nm3/h) was successfully loaded to work with the innovative concept: comparative runs with conventional packed bed layout were performed on the same reactor keeping the same catalyst formulation and load. The advantage of packed foam configuration was demonstrated by lower radial temperature gradients and considerably higher methane conversions. Upon increasing by three times the feed methane flow rate with respect to the packed bed, the copper internals still enabled almost full methane conversion due to the enhanced heat transfer. Adapting the mathematical model to the reactor configuration, a good correspondence between radial temperature difference and methane conversion from experimental and simulation results was observed. The scalability of the packed foam concept to the industrial scale is here demonstrated, including simple procedures for loading and unloading of the reactor tubes.

Keywords: Hydrogen production; Structured catalysts; Process intensification; Scale up

Wentao Du, Patchanee Chammingkwan, Keisuke Takahashi, Toshiaki Taniike,

Unbiased dataset for methane dry reforming and catalyst design guidelines obtained by high-throughput experimentation and machine learning,

Journal of Catalysis,

Volume 442,

2025,

115930,

ISSN 0021-9517,

https://doi.org/10.1016/j.jcat.2024.115930.

(https://www.sciencedirect.com/science/article/pii/S0021951724006432)

Abstract: Traditional solid catalyst design is a highly labor-intensive and post hoc process, involving repeated experimental trials and errors based on hypotheses derived from prior knowledge. Recently, integrating high-throughput experimentation (HTE) with machine learning (ML) aims to achieve a more systematic catalyst design without relying on specific knowledge or assumptions about the target catalysis. As a first step, this study constructs an unbiased HTE dataset for dry reforming of methane (DRM) at 500 °C on 256 γ-Al2O3-supported multi-element catalysts, prepared by randomly combining 17 elements selected from the periodic table without any preconceptions. The obtained data and selected catalysts are analyzed in various ways to gain insights into catalyst design and catalysis. It is found that the inclusion of Ni or platinum group elements does not necessarily lead to DRM activity; rather, careful combinations of elements are crucial. Specifically, catalysts that exhibit the highest activities are not only based on Ni as the main active element but also frequently contain Li, Al, and Nb, with Al and Nb being elements that are seldom recognized as promoters in literature. Experimental validation of predictive ML models demonstrated that these frequent patterns were practically applicable for designing other high-performance catalysts. Studying the best-found Ni-based catalyst elucidates individual elements’ roles in improving activity and suppressing carbon deposition. In particular, the ternary combination of Al, Nb, and Hf reduces carbon deposition while enhancing activity. Overall, this study demonstrates the validity of unbiased exploration in providing a foundational dataset for ML and in discovering catalyst design guidelines.

Keywords: Dry reforming of methane; High-throughput experimentation; Machine learning; Multi-element catalyst design

Mohammed Mosaad Awad, Ijaz Hussain, Saheed A. Ganiyu, Khalid Alhooshani,

Highly active nickel-based fibrous silica ZnO (NSZF) catalyst for efficient syngas production through dry reforming of methane,

Fuel,

Volume 380,

2025,

133261,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133261.

(https://www.sciencedirect.com/science/article/pii/S0016236124024104)

Abstract: In this study, a highly active catalyst was synthesized using microemulsion and impregnation methods for dry reforming of methane (DRM). The catalyst was developed by incorporating ZnO as a co-support inside the silica fibrous framework, acting as a core in the fibrous shell of the silica structure (SZF). The catalysts were analyzed using XRD, FESEM, EDX, XPS, TEM, FTIR, and BET techniques. The spent catalysts were also examined by XRD, TEM, Raman spectroscopy, and TGA to examine alterations in morphology and carbon deposition. It was found that the incorporation of ZnO improved the selectivity of hydrogen during the DRM reaction. Among the tested catalysts, NSZF-10 (10 wt% Ni) exhibited remarkable efficiency in the DRM reaction, achieving methane (CH4) and carbon dioxide (CO2) conversions of 82 % and 74 %, respectively, over a 40-h reaction period at 750 °C. The amount of Ni over the SZF support played a significant role in boosting overall catalytic performance. Additionally, the improved textural and morphological properties of the SZF, and the strong metal support interaction in which ZnO bonded the optimum loading amount of Ni nanoparticles in the SZF framework. Furthermore, the fibrous shell of silica acted as a protective barrier for the Ni nanoparticles, impeding their migration to the catalyst’s surface. The long-term stability of the NSZF-10 catalyst confirmed their coke resistance with minimal carbon deposition and without changes in morphological structure.

Keywords: Dry reforming of methane; Heterogeneous catalysts; Syngas production; Silica zinc-based nickel catalysts; Hydrogen production

Keqing Zheng, Yangtian Yan, Xue-Mei Lin, Hui Sun, Li Li, Meng Ni,

A new type of methane steam reformer with a self-regulating structure,

International Journal of Hydrogen Energy,

Volume 100,

2025,

Pages 668-677,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.314.

(https://www.sciencedirect.com/science/article/pii/S0360319924055277)

Abstract: Methane steam reforming is a key technology for large-scale hydrogen production; however, its performance and lifetime are significantly influenced by carbon deposition. In this study, a new type of methane steam reformer with a self-regulating structure is proposed to inhibit carbon deposition and improve the lifetime of the reformer. By incorporating a main gas channel and branch gas channels within the reformer, the gas flow direction can be automatically adjusted, allowing the primary location of the reforming reaction to shift when partial blockages occur due to carbon deposition. To evaluate the feasibility of the proposed new structure, numerical models are developed to simulate and compare a conventional reformer with the newly designed reformer. The simulation results show that the lifetime of the proposed novel structure reformer is increased by approximately 56.0% compared to that of the conventional reformer with a packed bed structure when β = 2 and L/R = 5. The hydrogen molar fraction at the outlet of the novel structure reformer (β = 2) is on average 5.41% higher than that of the conventional packed bed reformer (β = 3) when their lifetimes are similar. Additionally, the proposed novel structure reformer can achieve superior performance when applied to large L/R conditions. These findings suggest that the proposed design offers a promising strategy for developing a durable and high-performance methane steam reformer.

Keywords: Methane steam reformer; Carbon deposition; Self-regulating structure; Hydrogen production

Fangshu He, Jiaomei Ma, Qiang Hu, Jiashuo Wang, Yingquan Chen, Haiping Yang, Yang Yang,

Enhancing energy efficiency and decarbonization of cement production through integrated calcium-looping and methane dry reforming (CaL-DRM) for in-situ CO2 conversion to syngas,

Carbon Capture Science & Technology,

Volume 14,

2025,

100359,

ISSN 2772-6568,

https://doi.org/10.1016/j.ccst.2024.100359.

(https://www.sciencedirect.com/science/article/pii/S2772656824001702)

Abstract: The cement industry is exceptionally energy-intensive and a major global carbon emitter, with CO2 primarily arising from the calcination of carbonate raw meal and the combustion of fossil fuels. This study proposes a novel process integrating calcium looping and dry reforming of methane (CaL-DRM) based on an “in-situ carbon capture and conversion” strategy to enhance the energy efficiency and decarbonization in the cement production process. Models for both conventional cement production process model and the CaL-DRM processes were developed using Aspen Plus to compare the mass flow and process energy balances of conventional cement production with the CaL-DRM process. The modelling results were validated by the cement plant operating data and published results. Sensitivity analyses were performed to optimize key production parameters, including CH4/O2 = 1.37 and CaCO3/CH4 = 0.5, which resulted in the highest conversion efficiencies of CO₂ and CH₄. Subsequently, the optimization of the tertiary air volume and the proportion of hot raw meal entering the carbonator was carried out. The optimal tertiary air volume was found to be less than 28529 Nm³/h, and 13% of the hot raw meal was directed to the carbonator. With these conditions, the process thermal efficiency can be increased from 58 % to 86 %. CO2 emissions were analyzed at key stages of cement production process, focusing on fuel combustion and carbonate decomposition at the calciner and rotary kiln, with a comparison of the conventional method and the CaL-DRM process to quantify emissions at each stage. The results indicate that 852.3 kg CO₂ per ton of cement clinker can be converted to produce 1680 kg of syngas per ton of cement clinker along with cement clinker. Additionally, up to 62.5 kg CO₂ per ton of cement clinker can be captured by the carbonator, reducing the CO₂ volume fraction in flue gas from 23.29 % to 0.24 %, thus eliminating the need for subsequent CO₂ purification and transport. These findings demonstrate the significant potential of this novel method for sustainable development in the cement industry.

Keywords: Industrial energy efficiency; Industrial decarbonization; Cement production; Dry reforming of methane; Calcium looping

Yujun Cheng, Yanhua Li, Xinjun Li, Fang Cheng, Shiwei Ma, Tao Song,

Synergetic promotional roles of CeO2 and Ni on red mud oxygen carrier for chemical looping steam methane reforming,

International Journal of Hydrogen Energy,

Volume 106,

2025,

Pages 1332-1343,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.02.061.

(https://www.sciencedirect.com/science/article/pii/S0360319925006263)

Abstract: Red mud, an iron-containing industrial waste, has been explored as a potential oxygen carrier for chemical looping steam methane reforming (CL-SMR). However, its low reactivity requires enhancement. While Ni can improve the reactivity of red mud, the CH4 conversion remains limited, which was less than 30% for red mud modified with 5 wt % NiO (5Ni-RM). In this work, the CeO2–Ni co-doping red mud was developed for CL-SMR, and the synergetic effects of CeO2 and Ni were investigated. Among the tested samples, red mud with 10 wt % CeO2 and 5 wt % NiO loading (10Ce–5Ni-RM) exhibited the best performance. For 10Ce–5Ni-RM in 50 cycles, the average CH4 conversion during steady-state operation was 67.6%, significantly higher than that of 5Ni-RM at 24.4%, and its CO selectivity was 83.6% with a H2/CO ratio of 1.97. Furthermore, the syngas yield of 10Ce–5Ni-RM was 0.274 mmol g−1·min−1, 71.3% higher than that of 5Ni-RM, and its H2 yield was 0.114 mmol g−1·min−1. The superior performance of 10Ce–5Ni-RM can be ascribed to the synergistic promotional roles of CeO2 and Ni dopants. The interaction between these dopants and red mud generated CeO2-based Ce–Ni–O and Ce–Fe–O solid solutions, as well as perovskite CeFeO3, significantly promoting the generation of oxygen vacancies for lattice oxygen transfer. Besides, the metallic Ni activated CH4 molecules, and the substitution of Ni2+ into Fe3O4 generated high-activity Ni–Fe–O spinel. Overall, the synergistic promotional roles of CeO2 and Ni improved the reactivity and thus high gas yields for red mud oxygen carrier in CL-SMR.

Keywords: Red mud; Chemical looping; Steam methane reforming; Ni; CeO2

Gema Gil-Muñoz, Juan Alcañiz-Monge,

Examining the effect of zirconium doping in lanthanum nickelate perovskites on their performance as catalysts for dry methane reforming,

Journal of Environmental Chemical Engineering,

Volume 13, Issue 2,

2025,

115387,

ISSN 2213-3437,

https://doi.org/10.1016/j.jece.2025.115387.

(https://www.sciencedirect.com/science/article/pii/S221334372500082X)

Abstract: This study evaluates the viability of Zr doping in Ni-based perovskites as a precursor for dry reforming of methane (DRM) applications. X-ray diffraction results indicate that the solubility of Zr in the LaNiO₃ perovskite structure can reach up to 25 % on B-sites; however, the formation of new crystalline phases is observed when the Zr content increases to 50 %. The presence of Zr has been found to significantly enhance the catalytic activity of these samples, which exhibit the highest conversions rates despite their reduced Ni content. Furthermore, they demonstrate high temporal stability and an absence of carbonaceous deposit formation. These properties are attributed to a strong interaction between Ni and Zr species. However, excessive SMSI, as observed in Ti-bearing perovskite, may lead to a reduction in catalytic activity. Additionally, it has been observed that the presence of Zr influences the growth mechanism of the carbon nanotubes on Ni, shifting from tip-growth to a pulse-growth mechanism.

Keywords: Perovskites; Catalyst deactivation; Dry reforming; Carbon nanotubes

Collins D. Don-Pedro, Ram R. Ratnakar, Sumana Chenna, Vemuri Balakotaiah,

Comprehensive thermodynamic analysis and simulation of electrified modular reactors for bi-reforming of methane,

Chemical Engineering Science,

Volume 306,

2025,

121229,

ISSN 0009-2509,

https://doi.org/10.1016/j.ces.2025.121229.

(https://www.sciencedirect.com/science/article/pii/S0009250925000521)

Abstract: The simultaneous conversion of two major greenhouse gases, methane and carbon dioxide, into higher-value products is of significant interest towards mitigation of global warming. It offers advantages over other methane reforming processes by achieving a favorable H2 to CO product ratio for Fisher-Tropsch and methanol synthesis processes. This work examines the optimum conditions for no carbon deposition based on thermodynamic equilibrium analysis, and presents modelling results for methane bi-reforming in electrified modular reactors. The results show that use of excess reforments (steam/CO2, and/or inert) reduces the operating temperature requirement for no carbon deposition. In addition, higher conversion of CH4 and CO2 can be achieved with programmed/multi-staged heating without overheating the catalyst. Further, Joule heating is shown to have higher thermal efficiency compared to other heating methods. These results can serve as a guide to experimental validation, catalyst testing, and reactor scale-up of the bi-reforming process.

Keywords: Carbon deposition; Methane reforming; Net Carbon zero; Process electrification; Modeling and analysis

Dian H. Wahyudi, Aishah A. Jalil, Muhammad A. Aziz, Abdul H. Hatta, Mohd H.M. Sofi, Nadiatus Silmi, Hermania E. Wogo, Nurul S. Hassan, Veinardi Suendo, Rino R. Mukti, Ismunandar,

Tailoring catalyst support with bicontinuous concentric lamellar morphology for dry reforming of methane,

Microporous and Mesoporous Materials,

Volume 387,

2025,

113511,

ISSN 1387-1811,

https://doi.org/10.1016/j.micromeso.2025.113511.

(https://www.sciencedirect.com/science/article/pii/S1387181125000253)

Abstract: Since the utilization of greenhouse gases has been an important topic for the last decade, a great effort has been made to find a way to ameliorate this utilization. Dry reforming of methane (DRM) has gained much attention due to its ability to decrease greenhouse gas emissions and generate valuable syngas. In this study, unique material with bicontinuous concentric lamellar (bcl) morphology has been synthesized and employed as catalyst support for DRM reaction. Ni/bcl-Silica and Ni/bcl-AAs catalysts with bcl morphology were successfully synthesized and characterized using XRD, SEM, TEM, FTIR, N2 adsorption, and CO2-TPD analysis. In the DRM reaction, the Ni/bcl-AAs catalyst demonstrated significantly better performance, achieving 90 % CH4 selectivity and 77 % CO2 conversion, compared to Ni/bcl-Silica. This superior performance is attributed to the bcl morphology, which provides a high surface area and improved accessibility of reactants to the active metal sites, thereby enhancing catalytic efficiency. Moreover, the presence of Al content in Ni/bcl-AAs composition can enhance the basicity of the Ni/bcl-AAs catalyst. The synergistic effect between the high surface area and basic sites resulted in a good performance in DRM reaction.

Keywords: CO2; Syngas; Dry reforming of methane; Catalyst support; bcl morphology

Ruth D. Alli, Nima Ghafarvand, Mohammad H. Sedghkerdar, Nader Mahinpey,

Kinetics, response surface methodology, and regeneration studies of MOF-derived Ni-Ce catalyst for dry reforming of methane,

Journal of the Energy Institute,

Volume 118,

2025,

101898,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2024.101898.

(https://www.sciencedirect.com/science/article/pii/S1743967124003763)

Abstract: The MOF-derived bimetallic Ni-Ce catalyst was studied under three major headings: kinetics, stability and regeneration, and response surface methodology (RSM). The impact of reaction temperature and inlet gas flowrate on H2/CO, CO2 and CH4 conversions in DRM were determined by using RSM and design of experiment (DOE). Optimal values, determined through RSM evaluation, revealed CO2 and CH4 conversions and H2/CO ratio of 99 %, 96 %, and 0.98, respectively, achieved at a reaction temperature of 793 °C and an inlet flowrate of 0.03 mol/h. Furthermore, the kinetic assessment was evaluated using six kinetic models, with reversible Langmuir Hinshelwood and Power law models identified as the best fits. Also, the stability and 2-cycle regeneration analysis at 700 °C, 0.033 mol/h inlet gas flowrate, and a 1:1 CH4:CO2 ratio, showed the MOF-derived Ni-Ce catalyst stability and better regeneration was observed under CO₂ compared to air, as air regeneration caused a higher degree of sintering on the catalyst than CO₂ regeneration.

Keywords: Reaction kinetics; Response surface methodology; Catalyst regeneration; Nickel; Cerium; Metal organic framework

Siqi Wang, Ziqi Shen, Amin Osatiashtiani, Seyed Ali Nabavi, Peter T. Clough,

Experimental and DFT study of (sorption-enhanced) steam methane reforming over bimetallic Ni-Cu catalysts,

Fuel,

Volume 381, Part D,

2025,

133654,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133654.

(https://www.sciencedirect.com/science/article/pii/S0016236124028035)

Abstract: The catalytic performance of a monometallic Ni/Al2O3 and three bimetallic Ni-Cu catalysts (with Cu loading of 2.5, 5, and 7.5 mol%, respectively) for the (sorption-enhanced) steam methane reforming reaction was evaluated. Physico-chemical characterization of the materials confirmed the formation of Ni-Cu alloy and the even distribution of active metals within the porous high-surface area support. All three bimetallic catalysts showed enhanced methane conversion compared to the conventional Ni/Al2O3 catalyst at higher temperatures (800 °C), which was attributed to the promotion of the water–gas shift reaction by the addition of Cu. The experimental observations were supported by the Density Functional Theory calculations of carbon and oxygen adsorption on the mono and bimetallic surfaces. Ni3Cu1 and Ni1Cu1 were calculated to have a similar level of catalytic activity as Ni, based on results from a microkinetic model of the steam methane reforming reaction. Ni1Cu3 showed slightly lower activity, potentially due to its low carbon adsorption ability which impedes the rate-determining methane decomposition process. The SMR reaction was further improved by adding calcium oxide as the CO2 sorbent, which increased both methane conversion and hydrogen yield. Ni3Cu1/Al2O3 and Ni1Cu1/Al2O3 were identified as promising SMR catalysts with a high methane conversion of approximately 90 % at 800 °C and 97 % at 700 °C, without and with the sorbent, respectively.

Keywords: Bimetallic Ni-Cu catalyst; Steam methane reforming; Sorption-enhanced steam methane reforming;; Hydrogen production; Density Functional Theory; Microkinetic modelling

Daniela De Cata, Leone Mazzeo, Vincenzo Piemonte, Alberto Giaconia,

Electrified steam methane reforming as efficient pathway for sustainable hydrogen production and industrial decarbonization: A critical review,

International Journal of Hydrogen Energy,

Volume 105,

2025,

Pages 31-44,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.202.

(https://www.sciencedirect.com/science/article/pii/S0360319925002228)

Abstract: Hydrogen (H2) is a promising candidate for decarbonizing energy systems due to its high energy density and zero CO2 emissions upon combustion. However, the current paradox is that primary H2 synthesis relies on fossil fuels, accounting for 96% of global production, primarily through Steam Methane Reforming (SMR). The conventional SMR process is energy-intensive and contributes significantly to global CO2 emissions. Electrified steam methane reforming (eSMR) emerges as an effective alternative, as conventional furnaces are replaced with electric heating systems. The process electrification contributes to the decarbonization of energy-intensive industrial sector by leveraging renewable energy integration into the electric grid. Furthermore, eSMR overcomes limitations present in traditional SMR, such as inefficient heat transfer and the impact of the economy of scale. This review critically analyses the potential of eSMR for decarbonization and process intensification, providing insights into the most reported electrification techniques, technological advancements, limitations, and considerations for industrial scale-up perspectives.

Keywords: Green hydrogen; Joule heating; Induction heating; Renewable energy; Electrification; Biomethane

Bruno Agún, Alberto Abánades,

Comprehensive review on dry reforming of methane: Challenges and potential for greenhouse gas mitigation,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 395-414,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.160.

(https://www.sciencedirect.com/science/article/pii/S0360319925001818)

Abstract: The need of reducing the inventory of greenhouse gases, as CO2 and CH4 in the atmosphere is attracting the research of processes as dry reforming of methane (DRM). DRM has not yet industrially implemented for some reasons, among them coke formation, energy demand and cost-performance of the catalyst balance. Most of the information regarding DRM available is relying on specific catalyst development and analysis. In this paper, a broad overview of the DRM process is analysed. The reduction of CO2 and CH4 into syngas (CO and H2) is of great interest for the decarbonization of the industrial sector. Integration of this process with renewable energy sources for heat delivery, as well as the use of biogas/biomethane can contribute to the circularity of the process. The implementation of DRM at industrial scale might be viable with the optimization of the performance and stability of current catalysts, including new materials as perovskites, spinel, pyrochlore, to improve their cost-benefit balance and their coke deposition resistance. Additional research on new innovative heating systems and reactor concepts, as microwaves, molten material columns, and others like liquid metals may contribute as well to improve process economics.

Keywords: Dry reforming; Syngas; Catalyst; Hydrogen; DRM

Vanessa S.S. Favacho, Dulce M.A. Melo, Jennifer E.L. Costa, Lalyson M.L.R. Souza, Yuri K.R.O. Silva, Amanda L. Azevedo, Ângelo A.S. Oliveira, Renata M. Braga, Rodolfo L.B.A. Medeiros,

Influence of pH and soft templates on the hydrothermal synthesis of rod-shaped LaNiO3 catalytic precursors applied to dry reforming of methane for hydrogen production,

Catalysis Today,

Volume 448,

2025,

115167,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2024.115167.

(https://www.sciencedirect.com/science/article/pii/S0920586124006618)

Abstract: LaNiO₃ perovskite catalytic precursors synthesized via the hydrothermal method can exhibit different structures and morphologies depending on the synthesis factors, such as soft templates and pH. Depending on the structures and morphologies of the catalytic precursors, their catalytic performance (field, conversion, stability, etc.) in dry reforming of methane (DRM) may change. Thus, this study aimed to synthesize LaNiO3 catalytic precursors with rod-like morphology by the hydrothermal method without and with soft templates (CTAB and citric acid), varying pH values (9 and 13), to evaluate the best catalytic precursors in DRM. The samples were characterized by energy-dispersive X-ray spectroscopy (EDXRF), X-ray diffraction (XRD), scanning electron microscopy (SEM), N2 adsorption-desorption analysis, H2 temperature-programmed reduction (H2-TPR), and thermogravimetric analyses (TGA/DTG/DTA). After activation, the catalysts' performance was evaluated based on a stability test in DRM for 15 h at 600 °C and with 96 L h−1 g−1 GHSV (gas hourly space velocity). Thus, the results showed that the LaNiO3 catalytic precursors synthesized without soft template at pH 9 and 13 presented rod-like morphology and were chosen for DRM application. The reducibility test showed that the catalysts synthesized at pH 9 and 13 had a degree of reduction of 69.89 % and 77.18 %, respectively. The stability test showed that the catalyst synthesized at pH 13 had a greater CH4 and CO2 conversion and stability than the catalyst synthesized at pH 9, as well as the H2 and CO yield, and H2/CO ratio. Its greater stability was assigned to its nanorod-like morphology, which favored a more homogeneous Ni0 dispersion after activation stage. Furthermore, the spent catalysts showed whisker-like carbon deposition, in which the catalyst synthesized at pH 13 (90.36 wt%) had a greater amount than the catalyst synthesized at pH 9 (47.67 wt%). Its greater whisker-like carbon deposition was assigned to the lower amount of La2O2CO3 phase formed after DRM.

Keywords: Soft template; Hydrothermal synthesis; LaNiO3; Dry reforming of methane; H2 production

Lianghuan Wei, Ning Lin, Jixiang Cai, Fang Huang, Zejun Liu, Hengli Qian, Chao Xie, Weizun Li, Meiting Ju, Qidong Hou,

Hydroxyapatite supported Ni and La2O3 boost methane-enriched gas production from pyrolysis-steam reforming of corn stalk,

Catalysis Today,

Volume 446,

2025,

115112,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2024.115112.

(https://www.sciencedirect.com/science/article/pii/S0920586124006060)

Abstract: The production of methane-enriched gas via thermo-chemical process is an important approach for biomass valorization. However, current pyrolysis processes generally give low yield of value-added gas product. Herein, a series of Ni-based materials with hydroxyapatite (HAP) and titanium silicate (TS) as supports were prepared and investigated as catalysts to boost CH4 production from pyrolysis-steam reforming of corn stalk. The surface element composition, chemical state and crystal structure of materials were characterized by transmission electron microscope (TEM), N2 adsorption-desorption, X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) analysis. The expected loading of Ni, La and Ce were successfully loaded onto HAP via simple impregnation method, while the loading of active metals on TS is finite. Ni-5La2O3/HAP exhibited the best catalytic activity for pyrolysis-steam reforming of corn stalk, attaining CH4 yield (19.41 mmol/g) that is 89.9 % and 46.2 % higher than control experiment and Ni-5CeO2/MCM-41, indicating that loading high-density Ni and La species onto HAP supports can greatly boost the CH4 formation. However, the catalysts lost activity obviously during recycling experiment probably due to carbon accumulation.

Keywords: Hydroxyapatite; Methane; Pyrolysis; Biomass; Lanthanum

Jakub Mokrzycki, Piotr Legutko, Olga Kaczmarczyk, Monika Fedyna,

Investigating the carbon deposit formation, hysteresis phenomenon and stability of Ni-AlSBA-15 catalysts in dry reforming of methane,

Journal of Environmental Chemical Engineering,

Volume 13, Issue 1,

2025,

115040,

ISSN 2213-3437,

https://doi.org/10.1016/j.jece.2024.115040.

(https://www.sciencedirect.com/science/article/pii/S2213343724031725)

Abstract: The catalytic activity of Ni-AlSBA-15 with different metal doses i.e. 3, 5, or 10 wt%., prepared by impregnation method, were evaluated for dry reforming of methane at a total flow of 100 and 200 mL min−1. Regardless of the reaction mixture flow rate, all catalysts were active in the entire temperature range tested and exhibited high H2 and CO yields. Changes in the H2/CO ratio was observed and resulted from parallel side reactions pathways accompanying the dry reforming of methane, controlled primarily by nickel crystallite size and the reaction temperature. With an increase in nickel content on the surface of the tested catalysts, the formation of NiAl2O4 spinel was observed. The results of time-on-stream test revealed the carbon deposit formation resistance of the investigated catalysts (only <5.2 % drop in the conversion after 20 h). Formation of carbonaceous deposits over the catalysts surface was rising along with an increase in the loading of active phase. The phenomenon of hysteresis formation at the catalysts cooling stage in the DRM atmosphere was confirmed. The conversions of CH4 and CO2 were maintained even at temperatures < 450 °C and depended upon the content of active phase and the amount of carbon deposit formed during the catalyst heating stage in the DRM atmosphere.

Keywords: AlSBA-15; Dry reforming of methane; Hysteresis phenomenon; Carbon deposit formation; CO2 utilization

Yuqi Zhang, Ziyan Yang, Di Zhang, Pengwei Lei, Lina Liu, Jiao Ma, Zhikun Zhang,

Synthesis and catalytic activity of municipal solid waste incineration bottom ash derived catalyst for dry reforming of methane,

Fuel,

Volume 379,

2025,

132993,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.132993.

(https://www.sciencedirect.com/science/article/pii/S0016236124021422)

Abstract: Ni-based catalysts are currently the most studied catalysts in dry reforming of methane (DRM) due to their high activity and cheapness. However, carbon deposition and low durability greatly limit their application in DRM. Municipal solid waste incineration bottom ash (MSWI BA) contains a large amount of CaO, which improves the carbon resistance of the catalyst. It also contains a large amount of SiO2, which can be used as a catalyst support and is a promising candidate for DRM catalysts. Therefore, in this study, calcium acetate and molten ash (MA) were extracted from MSWI BA using acid extraction method, and MA was modified by NaOH to prepare MA(M) support. The Ni/MA(M)-xCa were prepared by sol–gel method for DRM. The effect of different Ca additions on the catalyst and DRM was investigated. The results showed that the active sites of the catalysts were NiFe alloys after reduction because of the Fe element in the MSWI BA. The metal particle size of the reduced catalyst decreased and then increased with the addition of Ca. Ni/MA(M)-20Ca had the smallest NiFe alloy particle size with the highest CH4 and CO2 conversions of 91.55 % and 95.56 %, respectively. The addition of Ca increased the basic sites and oxygen vacancies on the catalyst surface, which is favorable for CO2 adsorption and activation. In addition, there was the enhanced metal-support interaction and no obvious carbon accumulation after the addition of Ca, so the CH4 and CO2 conversions of Ni/MA(M)-20Ca was not significantly decrease in 100 h. Therefore, the catalysts prepared from calcium acetate extracted from MSWI BA and MA showed high activity and stability in DRM, which demonstrated the possibility of using MSWI BA for the preparation of DRM catalysts.

Keywords: Dry reforming of methane; NiFe alloy; Carbon resistance; Waste recycling

Yuhua Zhang, Qian Zhang, Yizhan Luo, Shaowen Wu,

Silicalite-1 confined ultrafine nickel nanocrystals for efficient photothermal catalytic methane dry reforming,

Molecular Catalysis,

Volume 573,

2025,

114844,

ISSN 2468-8231,

https://doi.org/10.1016/j.mcat.2025.114844.

(https://www.sciencedirect.com/science/article/pii/S2468823125000306)

Abstract: Full spectrum driven photothermal catalytic methane dry reforming is an effective strategy to realize the conversion of two greenhouse gases into fuels. In the meantime, metal sintering as well as carbon deposition affect the catalytic stability at high temperatures. Herein, sample of silicalite-1 molecular sieve confined ultrafine Ni nanoparticles (Ni@S-1) was prepared by one-step hydrothermal method for photothermal catalytic methane dry reforming. Only upon focused light irradiation, extremely high production of H2 and CO (28.3 and 40.9 mmol g−1 min−1) was achieved. The high photothermal catalytic activity is due to the photothermal conversion caused by strong plasma absorption and the activation of molecules by light irradiation. Compared with Ni loaded amorphous silicon oxide (Ni/SiO2), the strong confinement effect of S-1 enables Ni nanoparticles to maintain high dispersion and strong CO2 adsorption at high temperatures, thereby improving catalytic stability. This research achievement provides an effective way to achieve efficient and stable dry reforming of methane.

Keywords: Photothermal catalysis; Methane dry reforming; CO2 reduction; Confinement; Stability; Molecular activation

M.B. Bahari, C.R. Mamat, A.A. Jalil, N.S. Hassan, A.H. Hatta, M. Alhassan, M.A. Aziz, V.G. Le, T.J. Siang, S.N. Timmiati,

Mitigating deactivation in dry methane reforming by lanthanum catalysts for enhanced hydrogen production: A review,

International Journal of Hydrogen Energy,

Volume 104,

2025,

Pages 426-443,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.06.122.

(https://www.sciencedirect.com/science/article/pii/S0360319924023218)

Abstract: Catalyst deactivation in dry methane reforming, resulting from coke accumulation and sintering, has long captivated academic interest due to its negative impact on catalytic performance and hindrance to industrial scalability. Thus, developing efficient catalysts capable of sustaining high reforming activity and stability is crucial. Lately, lanthanum (La) has gained popularity in catalysis for its ability to enhance performance and resist coking, owing to its great basicity, redox capabilities, and high oxygen storage capacity. As a result, diverse strategies for incorporating La into catalysts, including support, promoter, bimetallic combinations, and perovskite formation, have been extensively explored. Herein, this review delves into various advancements in lanthanum-based catalysts and their effectiveness in dry methane reforming while addressing catalyst deactivation and regeneration. Finally, the prospect of La-based catalysts in dry methane reforming is also emphasized in this review.

Keywords: Hydrogen; Dry methane reforming; Catalyst deactivation; Lanthanum; Coke accumulation

Yocelin B. González-González, Fernando Plascencia-Hernández, Rubén Mendoza-Cruz, Heriberto Pfeiffer,

Hydrogen production from dry reforming of methane, using CO2 previously chemisorbed in the Li6Zn1-xNixO4 solid solution,

Journal of Environmental Sciences,

Volume 149,

2025,

Pages 535-550,

ISSN 1001-0742,

https://doi.org/10.1016/j.jes.2023.12.015.

(https://www.sciencedirect.com/science/article/pii/S1001074223005806)

Abstract: Li6ZnO4 was chemically modified by nickel addition, in order to develop different compositions of the solid solution Li6Zn1-xNixO4. These materials were evaluated bifunctionally; analyzing their CO2 capture performances, as well as on their catalytic properties for H2 production via dry reforming of methane (DRM). The crystal structures of Li6Zn1-xNixO4 solid solution samples were determined through X-ray diffraction, which confirmed the integration of nickel ions up to a concentration around 20 mol%, meanwhile beyond this value, a secondary phase was detected. These results were supported by XPS and TEM analyses. Then, dynamic and isothermal thermogravimetric analyses of CO2 capture revealed that Li6Zn1-xNixO4 solid solution samples exhibited good CO2 chemisorption efficiencies, similarly to the pristine Li6ZnO4 chemisorption trends observed. Moreover, a kinetic analysis of CO2 isothermal chemisorptions, using the Avrami-Erofeev model, evidenced an increment of the constant rates as a function of the Ni content. Since Ni2+ ions incorporation did not reduce the CO2 capture efficiency and kinetics, the catalytic properties of these materials were evaluated in the DRM process. Results demonstrated that nickel ions favored hydrogen (H2) production over the pristine Li6ZnO4 phase, despite a second H2 production reaction was determined, methane decomposition. Thereby, Li6Zn1-xNixO4 ceramics can be employed as bifunctional materials.

Keywords: Dry reforming of methane (DRM); CO2 chemisorption; H2 production; Solid solution; Li6ZnO4

Ran Ji, Weiguang Su, Xiaoyong Men, Jiadi Yang, Xudong Song, Yonghui Bai, Jiaofei Wang, Peng Lv, Guangsuo Yu,

Ultra-low amount of Ag substantially improves the stability for dry reforming of methane on Ni/Ag/MgAlO bimetallic catalyst,

Applied Surface Science,

Volume 688,

2025,

162320,

ISSN 0169-4332,

https://doi.org/10.1016/j.apsusc.2025.162320.

(https://www.sciencedirect.com/science/article/pii/S0169433225000339)

Abstract: Ni, Ag bimetallic catalysts with different impregnation sequence were applied to dry reforming of methane (DRM) reaction. When the molar ratio of Ag/Ni was only 1/19, ultra-low amount of Ag not only greatly improved the stability of Ni catalyst, but also did not reduce the methane and CO2 conversions. The impregnation sequence of Ag had an important effect on the activity and stability of DRM reaction as well as the physical and chemical properties of Ni, Ag bimetallic catalysts. Ni/Ag/MgAlO synthesized by first impregnating Ag and then Ni had the highest activity and stability in DRM reaction. CH4 conversion only decreased slightly from 94.5 % to 90.2 % and CO2 conversion from 96.3 % to 92.7 % after reacting for 26 h at 800 ℃. Ag effectively mitigated the amount of carbon deposition by inhibiting the nucleation and growth of whisker carbon. Ag also enhanced the interaction between Ni and MgAlO, preventing the aggregation of Ni species. Ni/Ag/MgAlO first impregnated Ag and then Ni had the strongest interaction among Ni, Ag and MgAlO, the smallest Ni0 particle size, and produced the least amount of carbon deposition, finally immensely improved the stability of DRM reaction without decreasing the DRM reaction activity.

Keywords: Dry reforming of methane reaction; Ni/MgAlO; Ag; Stability; Carbon deposition

Andrea Osti, Simone Costa, Lorenzo Rizzato, Beatrice Senoner, Antonella Glisenti,

Photothermal activation of methane dry reforming on perovskite-supported Ni-catalysts: Impact of support composition and Ni loading method,

Catalysis Today,

Volume 449,

2025,

115200,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2025.115200.

(https://www.sciencedirect.com/science/article/pii/S0920586125000185)

Abstract: The Dry Reforming of Methane (DRM) is an intriguing process to convert two greenhouse gases, CH4 and CO2, into syngas (CO+H2) and to upgrade biogas into biosyngas. However, the challenges of high operating temperatures and catalyst deactivation have hindered its large-scale implementation so far. Recently, photothermal catalysis has emerged as a sustainable alternative to conventional thermocatalysis, enabling a reduction of the required temperature and improvement of catalyst stability. This approach necessitates the development of a suitable photocatalyst. Herein, we proposed the use of active Ni nanoparticles (NPs) with plasmonic features, supported over semiconductive perovskites LaFeO3 or LaMnO3 with La-deficiency. The incorporation of Ni was achieved through either B-site substitution within the perovskite lattice or surface loading via Ammonia Deposition Precipitation (ADP), followed by a reductive treatment under H2 to yield Ni0 NPs. The prepared samples were extensively characterized by XRD, N2 physisorption, H2-TPR, SEM-EDX, HAADF STEM-EDX, XPS, UV-Vis DRS. The pre-reduced catalysts were then tested for thermal and photothermal DRM under visible light illumination (3 suns) at 600 °C. The Fe-based samples were poorly active because of Ni0 reoxidation, whereas a good activity and stability were ensured by Mn-perovskites, preserving the Ni0 active species. Among the Ni loading procedures, only ADP ensured improved activity in photothermal conditions thanks to high Ni NPs concentration, while the B-site doped catalyst showed better thermal than photo-activity because of low surface Ni concentration. Interestingly, light illumination was found to reduce perovskite decomposition and coke deposition. A Ni/Al2O3 reference catalyst demonstrated slightly higher activity than Ni/LaMnO3 but suffered from much faster deactivation due to coking and reoxidation.

Keywords: Photothermal catalysis; Dry reforming of methane; Perovskite semiconductors; Ni plasmonic; Exsolution; Ammonia deposition precipitation

Leonardo Duranti, Umberto Pasqual Laverdura, Elisabetta Di Bartolomeo, Maria Luisa Grilli, Rosa Chierchia, Claudio Larosa, Alessio Varotto, Simonetta Tuti, Silvia Licoccia, Igor Luisetto,

Coking resistant Ru supported on Sm-substituted CaZrO3 catalyst for dry reforming of methane: The effect of Ru loading on catalytic activity,

International Journal of Hydrogen Energy,

Volume 106,

2025,

Pages 1403-1416,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.366.

(https://www.sciencedirect.com/science/article/pii/S0360319925004094)

Abstract: Dry reforming of methane has industrially appealing advantages over other routes towards syngas production: CH4 and CO2 DRM conversion simultaneously tackles two main greenhouse gases to obtain a H2/CO ratio close to unity, ideal for long-chain hydrocarbons production via Fischer-Tropsch method. Designing high-performing and stable catalysts is pivotal for long-lasting operation. Ni-supported systems are by far the most used, owing to their outstanding activity and cost-effectiveness. Nevertheless, Ni promotes carbon deposition which results in severe deactivation. Supported noble metals combine high performance to coking resistance but this comes at a high cost. Here, the effects on DRM activity of low (≤3.0 wt%) ruthenium strategical loading onto a calcium zirconate perovskite oxide were investigated. In the CaZrO3, Zr substrate was partially substituted with samarium (CaZr0.85Sm0.15O3-δ, CZSm) to increase the extent of oxygen vacancies, favoring reactants adsorption on a highly basic surface. Ru was added during the perovskite synthesis to obtain RxCZSm (x = 0.5, 1.5, 3.0 wt% Ru). Structural and textural analyses revealed partial Ru inclusion in the oxide lattice leading to a net surface area increase (>50%). Different DRM activity depending on Ru oxidation state, substrate NPs coverage and reaction temperature was observed. R0.5CZSm displayed higher CH4 conversion (97.6 %) at 850 °C, while R3.0CZSm outperformed the lower Ru-loaded compounds at 550 °C, showing an H2/CO ratio of 0.77. Durability tests revealed high stability of all RxCZSm catalysts, with no carbon deposition. Low Ru loading on a tailored oxide substrate is an effective alternative for active and durable DRM catalysts.

Yu Shi, Xiaoyan Tian, Zhiyong Deng, Fagen Wang,

Microwave catalytic dry reforming of methane over Ni/SiC catalysts for efficient syngas production,

Fuel,

Volume 388,

2025,

134574,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134574.

(https://www.sciencedirect.com/science/article/pii/S0016236125002984)

Abstract: Syngas is a crucial industrial feedstock in the F-T process to produce energy compounds. Dry reforming of methane (DRM) provides a green approach for syngas production by consuming greenhouse gases CH4 and CO2. Here, we investigated syngas production by microwave catalytic DRM over Ni/SiC catalysts. The Ni/SiC catalysts exhibited robust metal-support interaction and a high ability to absorb microwave energy. The 3Ni/SiC-423K catalyst outperformed the 3Ni/SiC-363K and 3Ni/SiC-473K catalysts in adsorbing microwave energy. This resulted in the highest rates of CH4 (8.98 mmol/(gNi·s)) and CO2 (10.88 mmol/(gNi·s)) at 923 K. The Ni-SiC support interaction retarded Ni nanoparticle sintering and the high surface temperature reduced carbon deposition on the used 3Ni/SiC-423K catalyst. The work reported efficient syngas production by microwave catalytic DRM, and the microwave technique can be extended to other reactions for performance enhancement.

Keywords: DRM; Syngas; Ni/SiC; Microwave; Carbon deposition

Yahia H. Ahmad, Assem T. Mohamed, Anand Kumar, Atef Zekri, Ahmed Abotaleb, Alessandro Sinopoli, Siham Y. Al-Qaradawi,

Impact of trace noble metals on the catalytic performance of LaNiMgO towards methane dry reforming,

Gas Science and Engineering,

Volume 134,

2025,

205533,

ISSN 2949-9089,

https://doi.org/10.1016/j.jgsce.2024.205533.

(https://www.sciencedirect.com/science/article/pii/S2949908924003297)

Abstract: CO2 reforming of methane was investigated using trace noble metal anchored MgO-promoted Ni/La2O3 catalyst (LaNiMgO-X), where X = Ir, Pt, Ru, Pd, and Rh. The incorporation of noble metals enhanced Ni dispersion on the support and facilitated the Ni reducibility due to the H2 spillover effect. At 650 °C and in the early stages of the reaction, all catalysts exhibited enhancement in the catalytic activity. However, at longer times, the control and Pd-embedded catalysts revealed sharp decay in the catalytic activity compared to counterparts, which was assigned to the extensive coke deposition originated by methane cracking methane and Boudouard reactions. Whereas, other noble metals embedded catalysts, in particular, Rh- and Ir-anchored catalysts exhibited high chemical durability with minor decay in the catalytic activity. For instance, after 25h, LaNiMgO-Pd exhibited 22.7 % and 33.2 % decay of its maximum CO2 and CH4 conversion, respectively, while LaNiMgO lost 19.7 % and 27.2 % of its maximum CO2 and CH4 conversion, respectively. On the other hand, at the same time-on-stream LaNiMgO-Rh lost 0.3 and 0.7 % of its maximum CO2 and CH4 conversions, respectively. In durability measurements, and after 140h LaNiMgO-Rh exhibited slight decay in the CO2 conversion from 77.6 % to 70.5%, the CH4 conversion decreased from 72.3% to 64.2%. On the other hand, LaNiMgO-Pd depicted rapid decay in the CO2 conversion from 68.3 % to 49.3 % and the CH4 conversion felled from 66.5 % to 41.5 % after 50h. In addition, the reactor was blocked in case of LaNiMgO-Pd after about 54h. Excluding Pd, the enhancement of noble metals was assigned to the formation of noble metal-rich Ni surfaces, which suppressed the oxidation of nickel and enhanced the gasification of deposited coke. In addition, the presence of noble metals at the Ni surface afforded a high density of adsorbed oxygen species, which enhanced coke gasification and consequently decreased the extent of deactivation of the catalysts by coke formation. While Pd-anchored sample showed extensive carbon deposition, in particular, recalcitrant γ-carbon, which is hardly gasified, encapsulating the active Ni catalyst, which causes catalyst deactivation.

Keywords: Trace noble metals; Methane dry reforming; Nickel; Lanthanum oxide; Magnesium oxide promoter

Ahmed S. Al-Fatesh, Naitik Patel, Vijay Kumar Srivastava, Ahmed I. Osman, David W. Rooney, Anis H. Fakeeha, Ahmed E. Abasaeed, Mohammed F. Alotibi, Rawesh Kumar,

Iron-promoted zirconia-alumina supported Ni catalyst for highly efficient and cost-effective hydrogen production via dry reforming of methane,

Journal of Environmental Sciences,

Volume 148,

2025,

Pages 274-282,

ISSN 1001-0742,

https://doi.org/10.1016/j.jes.2023.06.024.

(https://www.sciencedirect.com/science/article/pii/S1001074223002784)

Abstract: Developing cost-effective and high-performance catalyst systems for dry reforming of methane (DRM) is crucial for producing hydrogen (H2) sustainably. Herein, we investigate using iron (Fe) as a promoter and major alumina support in Ni-based catalysts to improve their DRM performance. The addition of iron as a promotor was found to add reducible iron species along with reducible NiO species, enhance the basicity and induce the deposition of oxidizable carbon. By incorporating 1 wt.% Fe into a 5Ni/10ZrAl catalyst, a higher CO2 interaction and formation of reducible "NiO-species having strong interaction with support" was observed, which led to an ∼80% H2 yield in 420 min of Time on Stream (TOS). Further increasing the Fe content to 2wt% led to the formation of additional reducible iron oxide species and a noticeable rise in H2 yield up to 84%. Despite the severe weight loss on Fe-promoted catalysts, high H2 yield was maintained due to the proper balance between the rate of CH4 decomposition and the rate of carbon deposit diffusion. Finally, incorporating 3 wt.% Fe into the 5Ni/10ZrAl catalyst resulted in the highest CO2 interaction, wide presence of reducible NiO-species, minimum graphitic deposit and an 87% H2 yield. Our findings suggest that iron-promoted zirconia-alumina-supported Ni catalysts can be a cheap and excellent catalytic system for H2 production via DRM.

Keywords: Dry reforming of methane; Coke resistant; Hydrogen production; Cheap catalyst; Fe-promoted catalyst

Siti Nurqurratulainie Miskan, Bashir Abubakar Abdulkadir, Nurul Ainirazali, Aishah Abd Jalil, Jun Wei Lim, Herma Dina Setiabudi,

Unveiling the effects of nickel loading on methane dry reforming: Perspectives from ni/fibrous Zeolite-Y catalysts,

International Journal of Hydrogen Energy,

Volume 104,

2025,

Pages 302-312,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.05.058.

(https://www.sciencedirect.com/science/article/pii/S0360319924017452)

Abstract: The development of new technologies that employ greenhouse gases, such as CO2 and CH4, is becoming more important in the fight against global warming. Catalytic methane dry reforming (MDR) is one straightforward way to reduce CO2 and CH4. In this study, the influence of nickel (Ni) loading on the catalytic performance of fibrous zeolite-Y catalysts (Ni/FHY) for MDR was explored. The study involved the synthesis and testing of Ni/FHY with varying Ni loadings (1 wt% to 10 wt%). The results demonstrate that the metal loading significantly affects the catalysts' performance through metal-support interaction. The catalytic activity showed that the performance of FHY increased with optimum metal loading of 5 wt% where the CO2 conversion increased to 90.3% from 82.2%, and CH4 conversion to 94.2% from 79.6%. The findings suggest that the 5 wt% optimal Ni loading showed the critical role of the metal-support interaction in shaping catalytic properties. Hence, this work provides insights into catalyst optimization for sustainable industrial processes, highlights the importance of the synergistic metal-support interaction, and provides insights into the relationship between Ni content and catalytic behavior. Thus, it offers a basis for optimizing catalysts in MDR and contributes to the advancement of sustainable industrial processes.

Keywords: Methane dry reforming; Syngas; Hydrogen; Fibrous zeolite-Y; Nickel

Saeed Moarrefi, Mohan Jacob, Nilay Shah, Stephen Skinner, Weiwei Cai, Liyuan Fan,

Comparison of steam and dry reforming adsorption kinetics in solid oxide fuel cells,

Fuel,

Volume 388,

2025,

134413,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134413.

(https://www.sciencedirect.com/science/article/pii/S0016236125001371)

Abstract: Internal steam reforming (SRM) and dry reforming of methane (DRM) within solid oxide fuel cells offer significant potential for zero-carbon energy production. This study explores how electrochemical reactions influence reforming kinetics, which is crucial for designing fuel cell materials under various conditions. The research examines how gas composition, process temperature, and current draw from the fuel cell impact methane reforming adsorption kinetics. Both processes inside solid oxide fuel cells have been studied individually under varying conditions and anode materials, leaving a significant research gap in understanding electrochemical interactions’ impact on catalytic behavior within a unified fuel cell framework. Findings indicate that increasing methane-to- H2O and CO2 ratio decreases methane conversion. Both processes show higher methane conversion with increased current density drawn from the fuel cell. In comparison, SRM achieves greater methane conversion than DRM under equal methane concentration in the feed stream. SRM also produces more hydrogen than DRM inside the fuel cell. Reforming reaction rates increase with fuel cell temperature, and DRM consumes methane slower than SRM. Higher methane concentration in the feed and current density boost reaction rates. The reaction order for H2O is generally higher than CO2 in Langmuir–Hinshelwood model but lower than CH4. Both processes show reduced activation energy when current is drawn, with current density affecting H2O adsorption enthalpy more than CO2. The SRM model estimates activation energy more accurately, while the DRM model has an R2 value close to 0.95, indicating acceptable accuracy.

Keywords: Dry Reforming Kinetics; Langmuir–Hinshelwood SOFC; Steam Reforming Kinetics; Power-Law

Yufeng Li, Zhenwei Li, Nan Wang, Yajun Zha, Ke Zheng, Yuebing Xu, Bing Liu, Xiaohao Liu,

Strong activity-based volcano-type relationship for dry reforming of methane through modulating Ni-CeO2 interaction over Ni/CeO2-SiO2 catalysts,

Chem Catalysis,

Volume 5, Issue 2,

2025,

101189,

ISSN 2667-1093,

https://doi.org/10.1016/j.checat.2024.101189.

(https://www.sciencedirect.com/science/article/pii/S2667109324003981)

Abstract: Summary

The dry reforming of methane (DRM) reaction holds significance for efficient conversion of CH4 and CO2 into syngas for the subsequent production of premium fuels and high-value chemicals. However, catalyst deactivation is easily caused by carbon deposition over Ni-based catalysts. Here, we investigated the effects of ultrasmall CeO2 nano-islands on the DRM reaction and found a strong volcano-type relationship between CeO2 content and reaction activity over Ni/CeO2-SiO2 catalysts. A suitable CeO2 amount can only slightly suppress CH4 dissociation but largely promote carbon species elimination. More importantly, the presence of these CeO2 nano-islands positively affected the types and location of coke species by “carbon-phobic effect” and thus alleviated coverage of Ni active sites. As a result, a higher TOFCH4 was obtained by an increase of about 82% and a continuous 2,000-h run almost without any side reaction, and deactivation was achieved along with CO2 and CH4 conversions at about 96% and 92%, respectively.

Keywords: dry reforming of methane; Ni-CeO2 interaction; carbon deposition; carbon elimination; carbon-phobic effect; heterogeneous catalysis

Isabele Giordani Wenzel, Oscar W. Perez-Lopez,

CO2 reforming of methane over Ni-Al-LDH catalysts prepared with different precipitants,

Materials Chemistry and Physics,

Volume 329,

2025,

130115,

ISSN 0254-0584,

https://doi.org/10.1016/j.matchemphys.2024.130115.

(https://www.sciencedirect.com/science/article/pii/S0254058424012434)

Abstract: NiAl-LDH catalysts were synthesized using the co-precipitation method with different precipitant. One of the samples (NiAl\_C) was prepared with a Na2CO3 solution, while the other sample (NiAl\_M) was prepared with a mixture of Na2CO3 and NaOH. These catalysts were evaluated in the dry reforming of biogas, utilizing a synthetic biogas consisting of 60 % (v/v) CH4 and 40 % CO2. Characterization techniques including X-ray diffractometry (XRD), N2 adsorption-desorption, thermogravimetric analysis (TGA), and temperature-programmed reduction and oxidation (H2-TPR and TPO, respectively), NH3, CO2, and H2 desorption (NH3-TPD, CO2-TPD, and H2-TPD, respectively) where used in different stages of catalysts. Both samples resulted in LDH with small differences in cell parameter c and specific surface area. The precipitant containing NaOH led to an increase in the NiAl2O4 spinel phase and in the metallic dispersion of NiAl\_M, enhancing thermal stability and resistance to sintering. However, this elevated metallic area facilitated the presence of acid sites, promoting CH4 decomposition and carbon deposition. The reduction step proved unnecessary for this catalyst, as the reduced catalyst led to an increase in structured carbon formation. The delicate balance between thermal stability and carbon deposition favors the NiAl\_M sample under reaction conditions without the reduction step.

Keywords: LDH-Derived catalyst; Ni catalyst; Biogas conversion; Dry reforming of methane; Hydrogen production

Ao Zhu, Dongfang Li, Tao Zhu, Xing Zhu,

Tailored SrFeO3-δ for chemical looping dry reforming of methane,

Green Chemical Engineering,

Volume 6, Issue 1,

2025,

Pages 102-115,

ISSN 2666-9528,

https://doi.org/10.1016/j.gce.2024.04.003.

(https://www.sciencedirect.com/science/article/pii/S2666952824000335)

Abstract: Chemical looping dry reforming of methane (CL-DRM) is a highly efficient process that converts two major greenhouse gases (CH4 and CO2) into syngas ready for the feedstock of liquid fuel production. One of the major obstacles facing this technology now is creating oxygen carriers that are stable and reactive. We fabricated high-performance Sr0.98Fe0.7Co0.3O3-δ perovskite-structured oxygen carrier by combining A-site defects and B-site doping of SrFeO3-δ. During isothermal CL-DRM tests at 850 °C, Sr0.98Fe0.7Co0.3O3-δ achieved 87% CH4 conversion and 94% CO selectivity in the CH4 partial oxidation reaction, followed by a syngas yield of 8.5 mmol/g, and CO yield of 4.2 mmol/g in CO2 decomposition. A-site defect engineering of the perovskite creates abundant oxygen vacancies and enhances oxygen storage capacity (OSC). Co-doping of the B-site of Sr0.98FeO3-δ increases oxygen mobility and CH4/CO2 activation, resulting in high activity in the CL-DRM process. This methodology resulted in high ionic mobility and facilitated the rapid diffusion of oxygen in the bulk phase, thereby increasing the redox properties of SrFeO3-δ. The oxygen carrier exhibits excellent structural stability and regeneration ability in successive redox cycles. This strategy offers a simple but very effective pathway to tailor OSC, oxygen mobility, and oxygen vacancies of perovskite-structured materials for chemical looping or redox-involved processes.

Keywords: Chemical looping; Reforming; Methane; Carbon dioxide; Oxygen carrier

Jinghao Li, Xin Cui, Yihong Yu, Liu Qu, Yinglei Liu, Yujuan Wen, Gaowu Qin, Song Li,

Electrified reforming of methane and carbon dioxide over structured Ni/MgO-CeO2/FeCrAl wire catalyst,

Renewable Energy,

Volume 242,

2025,

122453,

ISSN 0960-1481,

https://doi.org/10.1016/j.renene.2025.122453.

(https://www.sciencedirect.com/science/article/pii/S0960148125001156)

Abstract: The valorization of greenhouse gases, such as CO2 and CH4, through renewable energy is a pressing imperative. Dry reforming of methane (DRM) offers a promising route to convert these gases into valuable syngas, but its endothermic nature poses significant challenges. This study develops a novel Ni/MgO-CeO2/FeCrAl wire catalyst that enables electrification and in situ heating of the reactive center for the DRM reaction. The synergistic interaction between MgO and CeO2 was utilized to enhance DRM performance by promoting CO2 adsorption and oxygen transfer. Under an applied power input of 50 W (∼820 °C), a 2-m-long Ni/MgO-CeO2/FeCrAl wire catalyst achieves exceptional conversions of both CO2 (97.5 %) and CH4 (96.5 %), with H2/CO ratio approaching unity (0.99), outperforming its counterparts operating under conventional heating conditions. The electrified “in situ heating” approach employed in this work enables a rapid temperature response. Furthermore, the Ni/MgO-CeO2/FeCrAl catalyst exhibits superior coking resistance, reducing carbon deposition by over 70 % compared to conventional external heating modes. This research offers a promising avenue for the electrification of chemical processes, contributing to decarbonization in critical industries such as metallurgy and chemical engineering.

Keywords: Dry reforming of methane; Electrothermal catalysis; Chemical electrification

Mohadeseh Golestani Kashani, Yalda Ramezani, Fereshteh Meshkani,

Enhancing glycerol dry reforming performance through metal promoters: A study on 10Ni/La.Al catalyst with Mo, Sn, and Cd additions,

Materials Research Bulletin,

Volume 182,

2025,

113135,

ISSN 0025-5408,

https://doi.org/10.1016/j.materresbull.2024.113135.

(https://www.sciencedirect.com/science/article/pii/S0025540824004653)

Abstract: The effect of metal promoters (Mo, Sn, and Cd) on the performance of the 10Ni/La.Al nanocrystalline catalyst in Glycerol Dry Reforming (GDR) was investigated. 2x.10Ni/La.Al (x = Mo, Sn, and Cd) catalysts were prepared using the solid-state method and 10 wt.% Ni and 2 wt.% Mo, Sn, and Cd were added to the catalyst using the impregnation method. The catalysts were characterized by BET, X-ray diffraction, temperature-programmed reduction (TPR), oxidation (TPO), Raman, and scanning electron microscopies (SEM) techniques. It was found that adding Mo caused an increase in glycerol conversion and improved the long-term stability of the 10Ni/La.Al. Furthermore, catalysts with different amounts of promoter loading (2, 4, and 6 wt%) were synthesized to evaluate the optimum amount of Mo. 4Mo.10Ni/La.Al was selected to achieve 58 % glycerol conversion and the best stability.

Keywords: Dry reforming of glycerol; Effect of promoters; Ni-based catalysts; Syngas production

Zeyu Jiang, Bernardo Jordão Moreira Sarruf, Ahmad El-kharouf, Wenfeng Zhan, Zhenxing Liang, Robert Steinberger-Wilckens,

Evaluation of electrochemical performance and carbon deposition behaviour of Sn, Ag, Cu, Fe-doped Ni/ScCeSZ anode solid oxide fuel cells operated with simulated biogas,

Chemical Engineering Journal,

Volume 505,

2025,

159392,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159392.

(https://www.sciencedirect.com/science/article/pii/S1385894725001913)

Abstract: The infiltration of Sn, Ag, Cu, and Fe dopants into a Ni/ScCeSZ anode was investigated to enhance its catalytic activity towards methane dry reforming and improve the carbon resistance of Ni-based anode solid oxide fuel cells (SOFCs). The electrochemical performance of the modified SOFCs was evaluated under hydrogen and simulated biogas at 750 °C. Among all the tested cells, the Sn-doped cell exhibited the highest power output, with peak power densities of 0.997 W•cm−2 and 0.963 W•cm−2, respectively. The undoped Ni/ScCeSZ anode ceased operation after 11 h of exposure to biogas at 750 °C due to severe carbon deposition. In contrast, all doped cells operated successfully for over 120 h under simulated biogas. SEM and Raman spectroscopy characterisation confirmed that no carbon deposition occurred on the surfaces of the Sn, Ag, and Cu-doped anodes during biogas operation. Despite carbon deposition being detected on both undoped and Fe-doped anodes after biogas operation, the infiltration of the Fe dopant resulted in a reduced degree of graphitisation of the carbon deposited on the biogas-tested anode surface.

Keywords: Solid oxide fuel cells; Dry methane reforming operation; Anode carbon resistance; Carbon deposition; Degradation

Babusi Balopi, Joshua Gorimbo, Mahluli Moyo,

7 - Reforming as a green technology for the utilization of biogas,

Editor(s): Tonderayi S. Matambo, Riann Christian,

In Woodhead Series in Bioenergy,

Innovations in the Global Biogas industry,

Woodhead Publishing,

2025,

Pages 181-209,

ISBN 9780443223723,

https://doi.org/10.1016/B978-0-443-22372-3.00007-8.

(https://www.sciencedirect.com/science/article/pii/B9780443223723000078)

Abstract: Reforming reactions have emerged as pivotal processes for extracting hydrogen and hydrogen-rich synthesis gas (syngas) from light hydrogen-bearing compounds, including methane and light alcohols such as methanol and ethanol. This methodology has garnered significant attention within the green technology sector, particularly for generating green hydrogen and syngas from renewable sources. Biogas, derived economically from organic waste in the agricultural, household, and industrial sectors, stands out as a promising renewable resource. The motivation to exploit biogas stems from the imperative to curtail greenhouse gas emissions, achieve independence from nonrenewable fossil fuels, and harness locally available resources. While various reforming reactions exist, the dry reforming of biogas is notable for its capability to convert both methane and carbon dioxide into syngas at high conversions exceeding 90%. However, challenges such as coke formation on the catalyst and the substantial endothermic nature necessitating external heat addition are encountered. Autothermal reforming of biogas offers a compelling alternative, utilizing both methane and carbon dioxide to produce syngas with nearly energy-neutral characteristics. Despite its advantages, this method yields less hydrogen and incurs minimal coke formation on catalysts. Conversely, other reforming reactions, such as biogas steam reforming and partial oxidation reforming, neglect the carbon dioxide component, resulting in notable carbon dioxide emissions. This exploration of biogas reforming processes contributes crucial insights for the development of sustainable and efficient hydrogen production technologies.

Keywords: Reforming reactions; hydrogen production; synthesis gas (syngas); renewable sources; organic waste

Dun Li, Heming Dong, Ziqi Zhao, Hong Liu, Hailiang Luo, Qian Du, Jianmin Gao,

Characterizations and performances of Ni/diatomite catalysts for methane decomposition to obtain carbon nanotubes and high-purity H2,

International Journal of Hydrogen Energy,

Volume 109,

2025,

Pages 732-741,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.386.

(https://www.sciencedirect.com/science/article/pii/S036031992405599X)

Abstract: Catalytic decomposition of methane (CDM) to produce COx-free H2 along with high-value-added carbon nanomaterials is a unique potential route. However, the cost of catalysts and applications of carbon products are necessary issues that need to be addressed. Directly using natural materials as supporting material catalysts is significant along with the research of green and energy savings. The low-cost natural diatomite was selected as a catalyst support for CDM for the first time. Herein, diatomite support Ni catalysts were synthesized by a facile wet impregnation route, characterized for their structural and chemical properties, and were successfully used for the CDM at low temperatures. The 20 wt% Ni-loaded catalyst had a maximum methane conversion of 33% at a reaction temperature of 500 °C, which was maintained for 120 min. Both low and high Ni loading will affect the reaction activity of the catalyst. The MWCNTs obtained from the reaction were uniformly loaded on the surface of the diatomite support, and this MWCNTs/diatomite composite product could theoretically be used for natural rubber reinforcement, which avoids cleverly the process of separating the carbon product and catalyst. In addition, DRIFTS and CH4 TPSR spectra demonstrated that the reaction process does not produce COx. Our findings provide valuable insight into catalyst and process design for CDM. Meanwhile, it proposes a new approach to solve the utilization of carbon by-products in CDM reactions.

Keywords: Carbon nanotubes; H2 production; Nickel; Diatomites; Methane decompositon

Dinghao Xue, Pingyang Zhang, Yuanyuan Lin, Wenshuo Wang, Jiachang Shi, Qiang Hu, Gartzen Lopez, Cristina Moliner, Jin Sun, Tao Wang, Xinyan Zhang, Yingping Pang, Xiqiang Zhao, Yanpeng Mao, Zhanlong Song, Ziliang Wang, Wenlong Wang,

Parametric study of the decomposition of methane for COx-free H2 and high valued carbon using Ni-based catalyst via machine-learning simulation,

Green Energy and Resources,

Volume 3, Issue 1,

2025,

100114,

ISSN 2949-7205,

https://doi.org/10.1016/j.gerr.2025.100114.

(https://www.sciencedirect.com/science/article/pii/S2949720525000013)

Abstract: With industrial informatization, abundant data provides solutions for the digital design of methane-based hydrogen production. Catalytic methane decomposition (CMD) is a promising strategy for COx-free hydrogen production, with high-value carbon products generated. However, affected by various factors, the proper process parameters are challenge to be ascertained by the time-consuming experimental method. In this study, five machine learning methods were utilized for the precise prediction of methane conversion using Ni-based catalysts. Combined with SHAP method and univariate analysis method, XGBoost model with the best accuracy (with R2 = 0.894, RSME = 7.724) was selected for the exploration of the reaction impact of active phase loading, support loading, and reaction conditions in methane convention, hydrogen production, carbon yield, and carbon quality. The result shows that methane conversion rate is mainly influenced by space velocity, reaction temperature, nickel loading, and methane percentage. Copper doping significantly affects carbon yield and its quality, and there is a strong bond between Ni and Al2O3, contributing the most to the reaction. This work would provide a guidance for the efficient catalyst design and effective hydrogen production.

Keywords: Catalytic methane decomposition; Machine learning simulation; Catalyst; Carbon; Hydrogen

Mingming Wang, Zhifei Hu, Kai Xue, Ziyu Ding, Jaka Sunarso, Purnami Purnami, Femiana Gapsari, Xiaoyao Tan, Zhigang Wang, Shaomin Liu,

Enhanced H2 production via catalytic steam reforming of acetic acid as bio-oil model compound using asymmetric-structured nickel hollow fiber membrane,

Journal of Membrane Science,

Volume 717,

2025,

123637,

ISSN 0376-7388,

https://doi.org/10.1016/j.memsci.2024.123637.

(https://www.sciencedirect.com/science/article/pii/S0376738824012316)

Abstract: An intensified membrane reactor offers promising near future solution for converting ‘carbon-neutral’ bio-oil to hydrogen (H2). This work reports the development of two membrane reactor configurations made from asymmetric-structured nickel (Ni) hollow fiber membranes (ANHFMs), i.e., catalytic membrane reactor (CMR) and catalytic membrane micro-reactor (CMMR) for steam reforming of bio-oil, represented by acetic acid as bio-oil model compound. In CMR and CMMR, the dense Ni thin film in ANHFM serves as an H2-selective permeation membrane, which allows H2 permeation out of the reaction chamber while added Ni/Al2O3 functions as an efficient catalyst bed. CMMR is a new configuration developed here, that relies on the presence of fine catalyst particles on the microchannels within the porous substrate inside hollow fiber, deposited using special coating process. CMR, in contrast, adopts conventional membrane reactor configuration, with catalyst particles packed outside hollow fiber. Although both CMMR and CMR demonstrated higher carbon gasification efficiency and H2 yield due to in situ H2 removal, the former showed higher H2 separation efficiency relative to the latter, especially at higher liquid hourly space velocity (LHSV). Notably, CMMR displayed performance that is close to the target required for industrial H2 separation, i.e., H2 recovery of ∼72 % at 1000 °C and an LHSV of 59.84 h−1. The performance of CMMR for steam reforming of bio-oil model compound consisting of acetic acid, acetone, and ethanol was also tested, which was comparable to the performance of acetic acid alone. CMMR may thus play significant role for enabling hydrogen economy via biomass conversion pathway.

Keywords: H2-selective; In situ removal; Intensified process; Membrane reactor; Ni/Al2O3 catalyst

Weisong Li, Rongrong Nie, Yang Song, Lijun Ni, Di Wu, Guoguang Wu, Ruizhi Chu, Xianliang Meng,

Microwave-driven ethanol steam reforming for low-temperature H2 production over the carbon nanotubes supported NiFe-based catalysts,

International Journal of Hydrogen Energy,

Volume 101,

2025,

Pages 490-503,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.414.

(https://www.sciencedirect.com/science/article/pii/S0360319924056337)

Abstract: To overcome difficulties in lowering the ethanol steam reforming (ESR) temperature for H2 production and inhibiting CH4 and CO by-products, this work developed series of carbon nanotubes (CNTs) supported NiFe-based catalysts and achieved efficient microwave-initiated ethanol steam reforming in a relatively low temperature range. The effects of the La dopant and CNTs supports on the dispersion of active components, the interaction between active components and supports, and the coking-resistance under microwave irradiation are comprehensively studied. It is revealed that the La doping promotes the Ni–Fe alloy formation and the dispersion of NiFe active species. The formation of the NiFe2O4 complex metal oxide which can be regarded as the solid-state solution of γ-Fe2O3 and NiO was maximized with 5 wt% La doping, which helps to suppress CH4 generation and coke deposition. The carbon nanotube support with a larger specific surface area (designated as CNTs-2 in this work) disperses active species more effectively and exhibits stronger interactions with these components. Though all the CNTs supported catalysts are effective for ESR reactions, CNTs-2 exhibit lower electrical conductivity compared to other CNT supports due to its lower graphitization degree. While the heating rate of the NiFeLa5/CNTs-2 is significantly higher than that of NiFeLa5/CNTs-1, and exhibiting higher H2 yield and stronger resistance to carbon deposition. NiFeLa5/CNTs-2 demonstrates excellent and stable catalytic performance, achieving ethanol conversions exceeding 97% at 470 °C. Within the investigated temperature range, hydrogen product concentration for the NiFeLa5/CNTs-2 remain around 65 vol%, while simultaneously reducing CH4 and CO content to just approximately 5 vol%.

Keywords: Microwave; Ethanol steam reforming; Low-temperature reforming; Hydrogen production; La doping; CNTs supports

Martina Fracchia, Thantip Roongcharoen, Mauro Coduri, Luca Sementa, Soroosh Saeedi, Xuan Trung Nguyen, Dragos Constantin Stoian, Emanuela Pitzalis, Beatrice Campanella, Claudio Evangelisti, Alessandro Fortunelli, Vladimiro Dal Santo, Filippo Bossola,

Enhancing and understanding the stability of Ni catalysts via In-promotion for the steam reforming of oxygenates: An in-depth operando XRD-XAS and modeling investigation,

Applied Catalysis B: Environment and Energy,

Volume 366,

2025,

125074,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2025.125074.

(https://www.sciencedirect.com/science/article/pii/S0926337325000578)

Abstract: Indium is a well-known stability promoter for high-temperature dry reforming reactions but has not yet been applied to other reforming reactions for hydrogen production, such as those of oxygenated compounds which suffer from rapid deactivation. In addition, little is known about the stabilization mechanism and the limited insights mostly come from ex-situ characterizations. Here, we developed an In-modified Ni-based catalyst by synthesizing a Mg-Al-In mixed oxide support and by depositing Ni via a urea-assisted deposition procedure. The catalyst was evaluated in the steam reforming reaction of acetic acid showing stable activity for more than 24 h at 700 °C and S/C = 3 corresponding to double the hydrogen productivity than the unpromoted catalyst which, on the contrary, was not stable. Superior stability was achieved also with glycerol. We then investigated the catalysts under operando conditions performing a quasi-simultaneous XAS and XRD experiment using synchrotron light, assisted by computational modeling. After reduction, the surface of the Ni nanoparticles is enriched with In, as confirmed by TEM-EDS, in the form of a shell consisting of a Ni3In-like phase. The presence of In in the surface layers competes with C insertion thus protecting the Ni particles from coke deposition. As the reaction proceeds, the intermetallic phase is consumed resulting in Ni nanoparticles that are more stable, although less active, than those of the unpromoted catalyst. This may be due to a different faceting caused by the dealloying of the Ni-In phase, which once again disfavors the coke formation.

Keywords: Hydrogen; Steam reforming; Nickel-indium; Quasi-simultaneous XRD/XAS; Modeling; Operando

Hengyu Wei, Min Lin, Juping Zhang, Di Gao, Yuhao Chen, Liang Zhang, Xing Zhu,

Carbon-resistant bifunctional catalyst composed of LaFeO3 enhanced Ni-CaO for integrated CO2 capture and conversion,

Carbon Capture Science & Technology,

Volume 14,

2025,

100358,

ISSN 2772-6568,

https://doi.org/10.1016/j.ccst.2024.100358.

(https://www.sciencedirect.com/science/article/pii/S2772656824001696)

Abstract: Coupled calcium cycling and dry reforming of methane (CaL-DRM) process has garnered significant attention in recent years as a promising technique for the CO2 capture and in-situ conversion. However, traditional Ni-CaO catalysts with substantial CaL-DRM activity are susceptible to severe carbon deposition, which greatly hinders their industrial application. A combination of sol-gel and impregnation methods to include LaFeO3 into Ni-CaO to enhance CO2 capture and conversion is utilized. The characterization results indicate that the incorporation of LaFeO3 significantly improves the dispersion of Ni and CaO, increases the concentration of oxygen vacancies, effectively suppresses the sintering and carbon deposition, and improves the cycling stability of Ni-CaO. In addition, LaFeO3 promotes the outward diffusion of lattice oxygen, thereby facilitating CO2 capture and CH4 conversion to syngas. At 700 ℃, up to 86.5 % CO2 conversion, 87.6 % CO selectivity, and syngas yield close to the theoretical value of 1.0 were achieved over 5Ni-30CaO-LFO (30 wt% CaO). More importantly, the activity of catalyst remains almost unchanged after 30 cycles. This study introduces an innovative approach for CaL-DRM, showing significant potential for effective and stable CO2 capture and in-situ conversion.

Keywords: CaL-DRM; CO2 capture; Carbon deposition; Methane; Hydrogen production

Omid Jazani, Moses Adejumo, Simona Liguori,

Chapter 3 - Alcohol reforming processes in membrane reactors,

Editor(s): Angelo Basile, Kamran Ghasemzadeh,

Current Trends and Future Developments on (Bio-) Membranes,

Elsevier,

2025,

Pages 51-79,

ISBN 9780443138768,

https://doi.org/10.1016/B978-0-443-13876-8.00008-2.

(https://www.sciencedirect.com/science/article/pii/B9780443138768000082)

Abstract: Hydrogen is considered the energy carrier of the future since it produces only water when it is fed to polymer electrolyte membrane fuel cells. Currently, hydrogen is mainly produced by methane steam reforming, which is an energy-intensive process emitting approximately 9kg-CO2/kg-H2-produced. However, using alcohols from biofeedstock could reduce the CO2 emission. In addition, green hydrogen could be produced if a membrane reactor (MR) is used. The MR has the main benefit to intensify the process in terms of energy and efficiency since hydrogen is produced and simultaneously separated from the CO2 by a membrane. In this chapter, the relevant progress in topics of alcohol reforming via MR technology and the effect of operating conditions on the reforming reaction in MRs are reviewed and discussed. Moreover, mathematical models used for modeling reforming processes in MRs are discussed.

Keywords: Hydrogen; steam reforming; alcohols; biofeedstock; membrane reactors; palladium-based membrane

Zongze Lv, Junqiang Han, Tao Deng, Chang Gao, Jianan Li, Changlei Qin,

Study on the arrangement of CO2 sorbent and catalyst for integrated CO2 capture and methanation,

Separation and Purification Technology,

Volume 355, Part A,

2025,

129679,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.129679.

(https://www.sciencedirect.com/science/article/pii/S138358662403418X)

Abstract: Integrated CO2 capture and utilization (ICCU) is an emerging technology to reduce CO2 emissions by greatly simplifying the processes of conventional CO2 capture and utilization. In particular, ICCU-methanation could directly convert the low-concentration CO2 into CH4 using hydrogen from new energy electricity, representing an efficient Power-to-Gas route. CO2 adsorption/catalytic materials play a crucial role for the operation of ICCU-methanation, and it is more feasible to scale up material production and avoid components interference by directly combining the sorbent and catalyst. However, it is necessary to reveal the effect of different arrangements of sorbent and catalyst on reaction characteristics of ICCU-methanation. In the work, the matching of K2CO3-doped Li4SiO4 sorbent with various supported Ni-based catalyst was tested and four arrangements of sorbent and catalyst particles in a fixed-bed were investigated to understand the influences on ICCU-methanation. Results show that the presence of catalyst accelerates CO2 supply by sorbent and achieves quicker methanation, and the promotion effect becomes more obvious with a closer contact between the sorbent and catalyst. Under optimized conditions, ICCU-methanation of uniformly mixed K-Li4SiO4 and Ni/Al2O3 shows an excellent performance with very stable CO2 conversion of 95.58% and CH4 selectivity of 93.29% during cyclic reactions.

Keywords: Integrated CO2 capture and utilization; ICCU-methanation; High-temperature CO2 sorbent

Su Li, Jinkai Qiu, Zijun Bian, Bin Shao, Zhicheng Liu, Cheng Lian, Honglai Liu, Jun Hu,

Breaking trade-off between catalytic activity and carbon deposit by tailoring d-band center of NiFe alloy for dry reforming of carbonate,

Applied Catalysis B: Environment and Energy,

Volume 368,

2025,

125114,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2025.125114.

(https://www.sciencedirect.com/science/article/pii/S0926337325000979)

Abstract: The dry reforming of carbonate with methane (CaDRM) can be one of the breakthrough technologies to address the challenge of mitigating inevitable CO2 emissions into value-added chemicals but remains great challenges for efficient catalysts design. In this study, we break the trade-off between the catalytic activity and the carbon deposit by tailoring the d-band center of Ni through Fe doping, which matches the energy level of CH4\* dehydrogenation but is far away from that of the over cleavage of CH\* . In this light, the porous spherical FexNi/Al2O3 catalysts with Ni3Fe alloy nanoaggregates are obtained through a one-step spray drying method. The optimized Fe0.6Ni/Al2O3 catalyst shows an excellent catalytic activity with a superior CO selectivity of 91.75 % at a complete CaCO3 conversion at 700°C, and successfully prevents the carbon deposit to maintain its excellent stability. Moreover, the extremely low activation energy of 45.2 kJ/mol and the good porosity of FexNi/Al2O3 ensure its fast dynamics. Therefore, this tailoring d-band center approach through the formation of alloy catalysts supplied a novel strategy for effectively cracking hydrogen species while avoiding over cleavage of CHx\* in the thermal catalysis, which promoted the CaDRM technology to be a promising solution for carbon neutrality in industrial sectors in near future.

Keywords: Dry reforming of carbonate with methane (CaDRM); Ni3Fe alloy; Tailoring d-band center; CH4\* dehydrogenation; Carbon deposit

Kian Hoong Chai, Loong Kong Leong, Sumathi Sethupathi, Steven Lim, Yean Ling Pang, Yeow Hong Yap,

Overcoming oxidation-induced deactivation of Ni-based dual-function materials in integrated sequential carbon capture and methanation with Ni/CeO2 catalyst and “Na2O”/Al2O3 sorbent in adjacent beds,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 23-33,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.188.

(https://www.sciencedirect.com/science/article/pii/S0360319925002095)

Abstract: Researchers developed dual-function materials (DFMs) that combine CO2-capturing and methanation catalyst components to reduce carbon dioxide emissions and generate valuable methane in integrated sequential carbon capture and methanation. However, severe oxidation-induced deactivation (high reduction temperature requirements) limits the use of Ni-"Na2O"/Al2O3 DFM in O2-containing applications. Therefore, Ni-"Na2O"/CeO2 DFM is synthesized, as CeO2 lowers the reduction temperature. Nevertheless, it fails to produce CH4 due to the inability to desorb CO2 at methanation temperatures. A two-bed system, with Ni/CeO2 catalyst and “Na2O”/Al2O3 sorbent in a catalyst-to-sorbent ratio of 2:8, captures an average of 0.1187 mmol CO2/gsorbent-catalyst and produces an average of 0.0727 mmol CH4/gsorbent-catalyst over ten cycles at 300 °C. This system shows that a separate catalyst-sorbent system is more suitable than a DFM for O2-containing applications. However, validation of the materials and reactor design requires the presence of high levels of steam in the CO2 capture feed gas for real-world applicability.

Keywords: CO2 capture and utilization; CO2 methanation; CO2 capture; Power to gas; Dual function material

Salma A. Al-Zahrani, Rawesh Kumar, Mohammed F. Alotibi, Sahar Y. Rajeh, Najat Masood, Hessah Difallah A Al-Enazy, Ahmed S. Al-Fatesh,

Hydrogen-rich syngas production through partial oxidation of methane over Ni-promoted molecular sieves: Impact of reducibility and surface area,

Results in Engineering,

Volume 25,

2025,

103847,

ISSN 2590-1230,

https://doi.org/10.1016/j.rineng.2024.103847.

(https://www.sciencedirect.com/science/article/pii/S2590123024020905)

Abstract: CH4 is a potential greenhouse gas, and its fast-catalytic transformation into hydrogen-rich syngas by molecular oxygen escalates both environmental and industrial benefits. Herein, Mordenite-based molecular sieve (SiO2/Al2O3 = 13) is investigated for supporting Ni and various promoters like In, Cs, and Ga for the partial oxidation of methane reaction (POM). Catalysts are characterized by X-ray diffraction, surface area-porosity, temperature programmed studies, thermogravimetry analysis, transmission electron microscopy and X-ray photo electron spectroscopy. The stability of major active sites (metallic Ni) under oxidizing gas (O2 and CO2) is checked by Cyclic H2TPR-CO2TPD-H2TPR and Cyclic H2TPR-O2TPOH2TPR experiment where metallic Ni was found more susceptible to oxidize under oxygen. So, active sites should be deactivated but the current catalysts are found promising for achieving hydrogen rich syngas (H2/CO > 2) with high H2 yield through direct pathways and indirect pathways of POM. The co-presence of hydrogen (from hydrogen rich syngas) must stabilize the metallic state of Ni during POM. 1 wt.% Ga promotional addition over 5Ni-MOR13 brings the least crystallinity, highest surface area, and adequate population of active sites derived from NiO which is interacted with support with moderate to strong interaction. 5Ni+1Ga-MOR13 becomes coke resistance and outperforms than others. It attains 70 % CH4 conversion, a 69 % H2 yield, and a 2.5 H2/CO ratio up to 240 min time on stream.

Keywords: Partial oxidation of methane; Molecular sieve; Mordenite; Ni active sites; Ga promoter; Caesium promoter

Raziye Salehi, Fereshteh Meshkani,

Evaluation of catalytic performance of the Ni/M-MgO (M=Cu, W, and Ti) catalysts for dry reforming of glycerol,

Biomass and Bioenergy,

Volume 192,

2025,

107524,

ISSN 0961-9534,

https://doi.org/10.1016/j.biombioe.2024.107524.

(https://www.sciencedirect.com/science/article/pii/S096195342400477X)

Abstract: TiO2.MgO supports with different TiO2/MgO molar ratios (1, 1/3, 1/6, and 1/9) were prepared via the hydrothermal method and chosen as support for the 20 wt% Ni active phase. The MgO support was also modified with WO₃ and CuO for comparison. XRD, BET, SEM, H₂-TPR, and O₂-TPO analyses were conducted to estimate the structural properties of the catalysts. Examination of the BET of the catalysts showed a decreased surface area in the 18.4–63.6 m2/g range with an increasing TiO2/MgO ratio. The TiO2/MgO = 1/6 ratio exhibited the best performance and lifetime even after reaction for 20 h at 750 °C and GHSV = 54000 mL/g.h and was selected as the optimal ratio. The catalytic results also demonstrated that the TiO2, WO3, and CuO-doped Ni/MgO catalysts positively affect catalyst performance. However, due to the higher surface area and strong metal-support interaction, the Ni/TiO2.6MgO catalyst seems to be a better choice for the glycerol dry reforming process.

Keywords: Glycerol dry reforming; Syngas generation; Promoters; TiO2.MgO-Supported Ni catalyst; Coke reduction

Wenwu Liu, Mouxiao Song, Xiuping Wang, Shuqi Liu, Changyong Wang,

Investigation into the effect of reduction treatment on the in-situ catalytic pyrolysis of distillers dried grains with solubles (DDGS) over nano-nickel-based catalyst Ni-Me/HZSM-5 (Me = La, Pd),

Fuel,

Volume 381, Part C,

2025,

133483,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133483.

(https://www.sciencedirect.com/science/article/pii/S0016236124026322)

Abstract: The work was to investigate the effect of reduction treatment on in-situ pyrolysis of DDGS over nano-nickel-based catalyst Ni-Me/HZSM-5 (Me = La, Pd) at 550 °C in N2. The fresh and reduced catalysts were characterized by XRD, SBET, NH3-TPD, H2-TPR, CO2-STD, (HR)TEM. The results showed that the reduced and fresh catalysts exhibited many differences in metal particle size, acidic/basic properties and the catalytic performances, etc., resulting in the increasing sequence of H2 (vol. %) in corresponding pyrolytic gas: Ni-Pd/HZSM-5(f) (50.14) < Ni-Pd/HZSM-5(r) (61.87) < Ni-La/HZSM-5(r) (73.04) < Ni-La/HZSM-5(f) (78.29). Overall, for the catalysts employed, the strong ability to produce H2 resulted from the dispersion of Ni/Me species, the reactions forming alkoxy-organosilicon-compounds, the reforming reactions of CH4 with CO2 or steam, or the formation of Ni0-Pd0-alloy, etc. Specifically, the outstanding ability of Ni-La/HZSM-5(f) was attributed principally to not only the highest dispersion of Ni/La species, the intramolecular cooperativity of producing H2 in NiLa2O4, but also the most-deeply-promoted reforming reactions by NiLa2O4, accompanied with the less carbon deposition as a result of the reaction of some carbon deposited with CO2. The main reason for the ability of Ni-La/HZSM-5(f, r) was obviously stronger than that of Ni-Pd/HZSM-5(f, r) was because the Ni-La/HZSM-5 catalysts had promoted further the reforming reactions, resulting from La plus Ni species and higher dispersion of Ni/La in Ni-La/HZSM-5(f, r), than the Ni-Pd/HZSM-5 catalysts did. As for Ni-La/HZSM-5(r), though its Ni species reuniting to a certain degree, the strong ability owed chiefly to the deeply-promoted reforming reactions of CH4 with CO2 or steam by La2O3 plus Ni, simultaneously companied by the intermolecular cooperativity of producing H2 between Ni and La2O3 clusters. The strong ability of Ni-Pd/HZSM-5(r) was owing to the maximum ratio of Alkoxy-organosilicon-compounds to Cyclo-organosilicon-compound in bio-oil and intramolecular-cooperativity of producing H2 on Ni0-Pd0 alloy.

Keywords: Distillers dried grains with solubles; Nano-nickel-based catalyst; Reduction treatment; In-situ catalytic pyrolysis; Ni-La composite oxide; Ni0-Pd0 alloy

Husain Hassan Al Naji, Osamah Siddiqui, Stephen N. Paglieri, Ammar Alahmed,

Multi-physics open-source computational modeling of a protonic membrane reformer for lower-carbon compressed hydrogen production,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 951-963,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.147.

(https://www.sciencedirect.com/science/article/pii/S0360319925001685)

Abstract: The hydrogen economy has emerged recently as the pathway toward reducing our carbon emissions by utilizing hydrogen as a clean fuel and energy carrier. Among the numerous methods for hydrogen production, the protonic membrane reformer (PMR) has recently been developed to produce hydrogen very efficiently with near-zero energy loss, surpassing the conventional methods for hydrogen generation. In this paper, a comprehensive 2D model of the PMR is developed using the OpenFOAM platform to more thoroughly understand and optimize its operation. A sensitivity analysis is conducted to find the optimum current density for thermal-balanced operation. The results show that full methane conversion and nearly full hydrogen recovery (99.7%) can be obtained from the PMR with a current density of 0.375A/cm2. Overall, the PMR is a promising technology for future hydrogen production, and with cheap renewable electricity, it could become a highly effective method for hydrogen production globally.

Keywords: Protonic membrane reformer; Low-carbon hydrogen; Multi-physics modelling

Weiting Lin, Xinyu Huang, Zhifeng Qin, Bingying Han, Jianjun Chen, Kai Yan, Xinwen Guo, Jiawei Zhong,

Bi-reforming of biogas to metgas (CO-2H2) over β-cyclodextrin modified hydrotalcite derived oxides supported robust Ni nanocatalysts,

Separation and Purification Technology,

Volume 360, Part 2,

2025,

130848,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.130848.

(https://www.sciencedirect.com/science/article/pii/S1383586624045878)

Abstract: The valorization of renewable biogas to high quality metgas (CO-2H2) via bi-reforming meet the demands of green carbon science as well as methanol economy. Herein, β-CD modified hydrotalcite derived Mg3AlO oxides (MAO) supported Ni nanocatalysts (Ni/MAO-CD) were prepared with the β-CD assisted mechanochemical method, and employed in the bi-reforming of biogas. The optimized 9Ni/MAO-CD(1/10) catalysts exhibit satisfying initial CH4/CO2 conversion of 94 %/60 % and excellent long-termed stability up to 400 h at 800 ℃. Comprehensive characterizations (HRTEM-EDS, CH4-TPSR/CO2-TPO, in situ DRIFTS, H2-TPH, etc.) were carried out to clarify the structure–property-performance relationship. 9Ni/MAO-CD(1/10) catalysts exhibit relatively small Ni sites and strong basic sites, which facilitate balanced coke formation-coke elimination steps, lead to improved anti-coking behavior. The pathway via monodentate carbonate and formate intermediates is followed. Meanwhile, the interaction between Ni sites and Mg3AlO oxides result into high anti-sintering behavior. The synergistic effect of small-sized Ni sites for CH4 activation, strong basic sites of MAO support for CO2 activation, and the strong Ni-MAO interaction contributed to the satisfying catalytic performance, and the catalysts in kilogram-scale synthesis via β-CD-assisted mechanochemical method still maintained satisfying catalytic performance.

Keywords: Bi-reforming; Methane; Metgas; Hydrotalcite; β-cyclodextrin

Yuchen Deng, Min Hye Jeong, Kyung Soo Park, Jong Wook Bae,

Chemical-looping-based syngas production by separate CH4 decomposition and CO2 activation over mesoporous Ni-Co/MgAl2O4,

Chemical Engineering Journal,

Volume 507,

2025,

160351,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.160351.

(https://www.sciencedirect.com/science/article/pii/S1385894725011568)

Abstract: Methane can be catalytically decomposed to generate H2 fuel and surface carbons on NiCo-MgAl2O4 catalysts, where the surface carbons can be successively reacted to form CO through reverse Boudouard reaction as a potential alternative way for dry reforming of methane (DRM) reaction through chemical looping-based catalytic DRM reaction (denoted as CL-DRM). The active Ni-Co bimetal oxides nanoparticles were impregnated on the ordered mesoporous MgAl2O4 support, where MgAl2O4 support was previously prepared by using an evaporation induced self-assembly (EISA) method. The well-distributed active Ni-Co metal oxides on the MgAl2O4 support revealed a higher CH4 decomposition activity and successive CO2 activation to separately form H2 and CO product. The Ni nanoparticles were active and stable for CH4 decomposition and oxophilic Co promoter enhanced CO2 activation reaction through reverse Boudouard reaction at an optimal Ni/Co ratio of ∼6 for 20 successive CL-DRM cycles, which were mainly attributed to the presence of abundant surface oxygen vacant sites.

Keywords: Chemical-looping (CL); CH4 decomposition; Reverse Boudouard reaction; Ni-Co metal (oxides); Mesoporous MgAl2O4; Dry reforming of methane (DRM)

Mohammed A. Albuali, Hend Omar Mohamed, Enrique V. Ramos-Fernandez, Natalia Morlanes, Alejandra Rendon-Patino, Arwa Alahmadi, Xueqin Bai, Pedro Castaño, Jorge Gascon,

NiFeMnBaPr perovskite Pre-Catalysts for stable steam reforming of heavy crude oil,

Fuel,

Volume 388,

2025,

134560,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134560.

(https://www.sciencedirect.com/science/article/pii/S0016236125002844)

Abstract: This study evaluates the stability and activity of Pr0.5Ba0.5Mn0.8Ni0.15Fe0.05O3 perovskite pre-catalyst, demonstrating its capability to resist deactivation and produce hydrogen under the challenging conditions required for reforming heavy crude oil. Operating at 800 °C, the catalyst achieved an 88 % conversion, yielding a hydrogen-rich gas stream (54 mol% H2) with minimal pressure buildup, outperforming the “traditional” NiCoCeMgAl catalysts (stable for 3 h) by maintaining stability for 30 h. The catalyst resistance against carbon deposition and sulfur is enhanced through a unique composition, which enables efficient coke gasification and the formation of phases that keep the activity. These phases formed during the reaction (NiSx, NiC, Fe2O3, FeC, and MnOx) contribute to prolonged activity by releasing oxygen to react with carbonaceous deposits. Our work highlights the potential for hydrogen production from heavy crude oil and establishes a pathway for developing highly durable catalysts for industrial applications

Huaming Dai, Yi Yang, Hongting Wang,

Synergistic enhancement of methane partial oxidation in heat-recirculating reactor with the composite catalytic effect of Co-based double perovskite and CeO2,

Process Safety and Environmental Protection,

Volume 193,

2025,

Pages 533-549,

ISSN 0957-5820,

https://doi.org/10.1016/j.psep.2024.11.034.

(https://www.sciencedirect.com/science/article/pii/S0957582024014472)

Abstract: The emission of low-concentration coal mine methane (LCM) resulted in serious greenhouse effect. In order to utilize the LCM efficiently, a heat-recirculating porous reactor was built to realize the catalytic partial oxidation of the methane and air mixture. The effects of composite double-perovskite catalysts on the reaction temperature and gas production were investigated at different operating parameters. The results demonstrated that the B-site of Mn obviously enhanced the low-temperature catalytic activity of Co-based double-perovskite, which improved the methane reaction rate and hydrogen yield. The highest H2 yield (YH2 = 50.3 %) was obtained by La2CoMnO6 (D-CoMn). And the A-site partial doping of Ce promoted the production of syngas (ηe−s = 50.2 %). The addition of 25 % CeO2 enhanced the methane reaction rate and syngas production efficiency of D-CoMn. However, excessive CeO2 inhibited the generation of syngas. Meanwhile, the anti-supported catalyst CoMn/25Ce-S, synthesized by the sol-gel impregnation, performed good crystal morphology and the largest concentration of oxygen vacancies ((OIII+OII)/OI = 0.9). This enhanced the partial oxidation of methane and lowered the reaction temperature. The maximum H2 selectivity (SH2 = 44.2 %) and CH4 conversion efficiency (ηCH4 = 92.7 %) were attained at T4=998 K. Moreover, the increased flow velocity and equivalency ratio led to enhanced syngas production.

Keywords: Composite catalyst; Double perovskites; Porous media; Heat recirculation; Oxygen vacancy

Xin Ru Wang, Xiang Jun Liu, Jun Cheng Wang,

Effects of typical components of blast furnace slag on methane reforming with carbon dioxide: ReaxFF–MD and DFT studies,

International Journal of Hydrogen Energy,

Volume 97,

2025,

Pages 1411-1423,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.016.

(https://www.sciencedirect.com/science/article/pii/S036031992405211X)

Abstract: Methane reforming with carbon dioxide by utilizing the high temperature blast furnace slag is an effective way for waste heat recovery and energy conservation. Three typical oxides, CaO, MgO, and Fe2O3, are selected to present the active components of blast furnace slag, and the effects on CH4/CO2 reforming process are investigated by using ReaxFF-MD and DFT simulation methods. The reaction behaviors of different systems under different conditions are revealed and discussed. The participation of CaO, MgO and Fe2O3 induces new reaction pathways for the CH4/CO2 reforming system, reduces the energy barrier of various reaction steps, and decreases the overall activation energy of CH4/CO2 reforming process remarkably. The energy barrier of the additional reaction caused by CaO is as low as 49.3 kJ/mol. The overall activation energy of the reforming reaction under the addition of Fe2O3 is reduced to 110.41 kJ/mol. However, the presence of blast furnace slag components may provide excess oxygen into the system, induces more types and amounts of by‒products, and may decrease the yields of CO and H2 in the system. The ratios of CH4/CO2 and gas/slag should be adjusted and optimized for the practical CH4 reforming process by using the waste heat of blast furnace slag to achieve a high reaction rate as well as high yields of CO and H2.

Keywords: Blast furnace slag; CH4/CO2 reforming; Waste heat recovery; ReaxFF–MD simulation; DFT simulation

M.Salomé Macedo, Elka Kraleva, Heike Ehrich, N.Acha Uriarte, R. Sanz, D. Alique, M.A. Soria, Luis M. Madeira,

High-purity H2 production through glycerol steam reforming in multifunctional reactors,

Chemical Engineering Journal,

Volume 505,

2025,

159230,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159230.

(https://www.sciencedirect.com/science/article/pii/S1385894725000282)

Abstract: Different hybrid intensified reactor configurations (sorption-enhanced reactor -SER-, membrane reactor -MR- and sorption-enhanced membrane reactor -SEMR-) were studied aiming to assess their benefits comparatively to a traditional reactor (TR) for high-purity H2 production through glycerol steam reforming (GSR). In the different reactor configurations, home-prepared materials have been employed: a NiAlLaOx reforming catalyst, an hydrotalcite-based sorbent for CO2 capture, and a composite-membrane with a Pd-thickness of ca. 9 μm to selectively separate H2 from the reaction medium. An enhancement of 5.5 % in the H2 production was observed in the SER during the pre-breakthrough stage in comparison to the conventional TR. Further enhancement of the H2 yield was observed using the SEMR during pre-breakthrough, being attained an H2 yield of 6.6 molH2·molG,in-1 at 475 °C and retentate pressure of 4.0 bar (1.0 bar in the permeate side), which represents an average enhancement of 80 % in comparison to the TR configuration, evidencing also the positive effect of the membrane upon being coupled with the CO2-selective sorbent. The simultaneous removal of both H2 and CO2 clearly improves the overall GSR performance, allowing to obtain highly-pure H2 in both retentate and permeate sides during pre-breakthrough. It was also demonstrated that the use of a real crude glycerol effluent in the SEMR allows to obtain highly-pure renewable H2 through steam reforming in both reactor sides, thus evidencing a possible viable path for biomass-based H2 production, while also allowing to promote the economics of the biodiesel manufacturing process.

Keywords: Glycerol steam reforming; Biomass-based hydrogen; Multifunctional reactors; Membrane reactor; Sorption-enhanced reactor; Sorption-enhanced membrane reactor

Yingying Yu, Yincheng Wang, Yongjie Hu, Xiaopeng Jia, Qingguo Bu, Beibei Yan, Chen Chen, Junyu Tao, Guanyi Chen,

Treatment and hydrogen generation of bisphenol a by aqueous phase reforming over Ni-based catalysts with different supports,

International Journal of Hydrogen Energy,

Volume 98,

2025,

Pages 127-138,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.11.430.

(https://www.sciencedirect.com/science/article/pii/S0360319924051279)

Abstract: Bisphenol A (BPA) is a hazardous pollutant in industrial wastewater, whose safe disposal remains a worldwide problem. This paper explored the potential of aqueous phase reforming (APR) towards the treatment and H2 generation of concentrated BPA wastewater over Pt/C and Ni-based catalysts supported by Al2O3, C, and ZSM-5. It was demonstrated that Ni/Al2O3 outperformed Ni/C and Ni/ZSM-5 in chemical oxygen demand (COD) removal and H2 production, which could be attributed to its high medium basic sites and large pore volume. In addition, the H2 yield over Ni/Al2O3 (21.93 mmol H2/g COD) was even higher than that over Pt/C (3.51 mmol H2/g COD). The optimal COD removal and H2 yield over Ni/Al2O3 reached 88.09% and 250.97 mmol/g COD H2 was obtained at 340 °C for 4 h. According to the identified reactants and previous research, the reaction pathway for APR of BPA over Ni/Al2O3 involved the cleavage of the C–C bond of BPA to generate phenol and p-isopropylphenol, with Bis-(4-hydroxyphenyl)-methane formed concurrently through the demethylation of BPA.

Keywords: Bisphenol a; Aqueous phase reforming; H2 production; Ni-based catalysts; Reaction pathway

Luís Alves, Vítor Pereira, Paula Dias, Tiago Lagarteira, Simone Meloni, Gonzalo Prieto, Adélio Mendes,

Effect of macro-structure of Ni-based catalysts on methane splitting systems,

Fuel,

Volume 379,

2025,

133115,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133115.

(https://www.sciencedirect.com/science/article/pii/S0016236124022646)

Abstract: Methane splitting, also known as methane decomposition or cracking, is an emergent technology to allow swift energy decarbonization since it produces hydrogen without emitting CO2. This work aims at improving hydrogen production from low temperature methane splitting process catalyzed on Ni surfaces. Six different systems were evaluated for their productivity: Ni-foil (pristine and acid treated), Ni particles deposited on α–Al2O3 and on carbon felt, and SiO2-Al2O3-supported Ni catalyst deposited on α–Al2O3 and on carbon felt. Ni-foil displayed negligible hydrogen production even after chemical abrasion treatments were used to increase the surface area. For α–Al2O3 substrates, the coating of Ni/SiO2-Al2O3 vastly outperformed the bulk Ni system (ca. 40 vs 0.011 gH2·gNi–1 total hydrogen production). Depositing bulk Ni on carbon felt improved total hydrogen production to ca. 0.095 gH2·gNi–1. Ni/SiO2-Al2O3 deposited over carbon felt was particularly stable (40 gH2·gNi–1 total hydrogen production), presenting an activity loss rate of ca. 0.011·gH2·gNi–1·h−2, compared to ca. 0.020 gH2·gNi–1·h−2 for the Ni/SiO2-Al2O3 deposited over α–Al2O3. Furthermore, the mechanical integrity of the carbon felt-deposited film was shown to be maintained, while the α–Al2O3-deposited film structure collapsed, due to carbon formation.

Keywords: Methane splitting; Methane decomposition; Hydrogen; Catalytic films; COx-free; Carbon

Irati Garcia, Gartzen Lopez, Laura Santamaria, Enara Fernandez, Martin Olazar, Maite Artetxe, Maider Amutio,

Kinetic effect of oxygen incorporation into the catalytic steam reforming of biomass fast pyrolysis volatiles,

Chemical Engineering Journal,

Volume 505,

2025,

159262,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159262.

(https://www.sciencedirect.com/science/article/pii/S1385894725000609)

Abstract: Continuous steam reforming of biomass pyrolysis volatiles has been approached under oxidative conditions in a bench scale lab unit, and a kinetic model has been proposed for the assessment of the results obtained and prediction of process performance. The pyrolysis and in-line oxidative steam reforming (P-OSR) has been performed in a two-step system consisting of a conical spouted bed reactor (CSBR) for the pyrolysis process and a fluidized bed (FBR) for the reforming one. The OSR process was carried out on a commercial Ni based catalyst, in the 600–700 °C temperature range, with space time values between 2.5 and 20 gcat min gvolatiles-1, a steam/biomass ratio of 3 and an equivalence ratio (defined based on the volatiles fed into the reforming step) of 0.12. The reaction scheme considered for the kinetic modeling accounted for five reactions, which are the steam reforming of bio-oil oxygenate compounds, C2-C4 hydrocarbons and methane, the WGS reaction and the oxidation of hydrogen. A comparison of the kinetic results obtained in this study with those in a previous one dealing with the steam reforming of biomass pyrolysis volatiles (P-SR) under non-oxidative conditions shows substantial differences. Thus, the kinetic constant determined for bio-oil steam reforming is from 2.6 and 4.1 times higher when the process is conducted with oxygen. By contrasting the experimental conversion and H2 production values obtained in P-SR with those obtained in P-OSR, a synergistic effect of O2 addition on the reforming process is evident when operation is conducted under partial conversion conditions.

Keywords: Hydrogen; Pyrolysis; Oxidative steam reforming; Biomass; Kinetic model; Autothermal

Wang Liu, Lemei Song, Yuanhui Su, Yu Huan, Tao Wei,

In-situ exsolution super-excess Ni metal anchoring on Ba2V0.4Fe0.9Mo0.7O6−δ using as high catalytic activity solid oxide fuel cell composite anode,

Materials Science and Engineering: B,

Volume 311,

2025,

117809,

ISSN 0921-5107,

https://doi.org/10.1016/j.mseb.2024.117809.

(https://www.sciencedirect.com/science/article/pii/S092151072400638X)

Abstract: Perovskite materials, such as Ba2FeMoO6−δ using as Solid oxide fuel cells (SOFCs) anodes have shown excellent anti-carbon deposition to catalyze hydrocarbon fuel gases. However, the perovskite-based anodes still show insufficient catalytic activity and conductivity, which restricted for achieving highest SOFC power output. In this work, a Ni super-excess Ba2V0.4Fe0.9Mo0.7O6−δ-Nix (BVFMO-Nix, x = 0, 0.2, 0.4, 0.6) composite anode was first synthesized by in-situ exsolving FeNi3 alloy nanoparticles and firmly anchoring on the surface of parent BVFMO, which shows obvious improvement in conductivity and catalytic activity for methane fuel gas. When BVFMO-Ni0.4 is subjected to methane reforming for hydrogen production, the conversion rate reaches 56 % at 750 °C and remains above 50 % for more than 640 h continue test. Using BVFMO-Ni0.4 as a single-cell composite anode and testing at 850 °C, the maximum power outputs reach 991 mW cm−2 and 578 mW cm−2 with hydrogen and methane as fuel gas, respectively.

Keywords: SOFCs; In-situ super-excess exsolution; FeNi3 alloy nanoparticles; Anti-carbon deposition perovskite anode; Hydrocarbon fuel gas

Cui Quan, Shaoxuan Feng, Ningbo Gao,

Production of hydrogen-rich syngas from catalytic reforming of biomass gasification tar model compounds coupled with in-situ CO2 capture,

Biomass and Bioenergy,

Volume 193,

2025,

107569,

ISSN 0961-9534,

https://doi.org/10.1016/j.biombioe.2024.107569.

(https://www.sciencedirect.com/science/article/pii/S0961953424005221)

Abstract: Biomass gasification for hydrogen production has received widespread attention in recent years as a sustainable energy technology. However, the biomass gasification process produces tar. This can seriously affect subsequent gas cleaning and utilization. In this study, toluene was used as a tar model compound. The effects of different catalyst carriers, reforming temperatures, S/C ratio, and in-situ CO2 capture on the yield of toluene steam reforming were investigated. The results showed that under the same working conditions, the hydrogen yield of the SiC carrier catalyst was much higher than that of the SiO2 and Al2O3 carriers. This is due to the excellent thermal conductivity and suitable acid-base properties of the SiC carrier. CaO could effectively adsorb CO₂ and increase the hydrogen yield. The hydrogen yield reached 90.63 % with the addition of 0.3 g of CaO, which was 13.7 % higher than that without the addition of CaO. In addition, to investigate the structural changes and chemical state of the catalysts, the differences between the catalysts before and after use were analyzed using a variety of characterization methods. This study provides critical insights into the design of efficient catalysts and processes for overcoming the challenges associated with biomass-derived tar.

Keywords: Toluene; Hydrogen; CO2 capture and conversion; Catalytic reforming

Feng Lin, Zezhi Chen, Huijuan Gong, Xiaoshu Wang, Yong Qin,

A synergistic catalyst of Ni-β-Mo2C/γ-Al2O3 for robust syngas production via catalytic steam reforming of chlorinated volatile organic wastes,

Applied Catalysis B: Environment and Energy,

Volume 370,

2025,

125181,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2025.125181.

(https://www.sciencedirect.com/science/article/pii/S092633732500164X)

Abstract: Catalytic steam reforming offers a groundbreaking solution capable of converting chlorinated volatile organic compounds (CVOCs) into syngas (H2 and CO), achieving energy recovery while addressing environmental concerns. The implementation of this process, however, is hampered by the low activity and durability of conventional transition metal catalysts. The present study demonstrated a ternary catalyst, Ni-β-Mo2C/γ-Al2O3, with molybdenum carbide (β-Mo2C) as the main active component. The catalyst achieved a durable and highly efficient (> 90.6 %) conversion efficiency for the steam reforming of various CVOCs at 600 °C. The microstructure and working mechanism of the Ni-β-Mo2C/γ-Al2O3 catalyst have been thoroughly studied by characterizations and theoretical calculations, revealing that the γ-Al2O3 support enables close contact between Ni and β-Mo2C nanoparticles, resulting in a synergistic catalytic effect through their interfacial structure. This facilitates the rapid generation and coupling of carbon and oxygen intermediates, thereby enhancing catalytic performance and resistance to carbon deposition and oxidation.

Keywords: CVOCs; Steam reforming; Ni-β-Mo2C/γ-Al2O3; Interface; Synergistic catalysis

Aamir Baig, Sagar Dhanuskar, Sonal,

Coke-resistant lanthana promoted Ni/CeO2-ZrO2 catalysts for hydrogen generation via ethanol steam reforming,

Gas Science and Engineering,

Volume 134,

2025,

205537,

ISSN 2949-9089,

https://doi.org/10.1016/j.jgsce.2025.205537.

(https://www.sciencedirect.com/science/article/pii/S2949908925000019)

Abstract: Ethanol steam reforming (ESR) has been a reliable and efficient process of renewable hydrogen generation. A highly stable and coke-resistant reforming catalyst was developed using La2O3 modified Ni catalyst supported on CeO2-ZrO2. A range of promoted (Ni-La/CeO2-ZrO2) and unpromoted (Ni/CeO2-ZrO2) catalysts were prepared in a laboratory and tested in a tubular fixed-bed reactor. Detailed characterizations of the fresh and spent catalyst revealed that the La2O3 promotion helped to tune the Ni dispersion, catalyst reducibility, and oxygen storage capacity of the catalyst. These properties account for the reforming activity of the catalysts and are reflected in enhanced ethanol (EtOH) conversion, H2 yield, and catalyst stability. The coke-resistance property of La2O3 enhanced the catalyst stability and activity. 7.5Ni-7.5La/CeO2-ZrO2 catalyst showed an optimum H2 selectivity (65 %) and EtOH conversion (97 %) at 600 °C, 1atm, S/C molar ratio 4.5:1 and WHSVEtOH- 2.48 g/h-gcat.

Keywords: Ethanol reforming; Ni-based catalyst; Hydrogen production; Coke-resistant; La promoter

Xiong He, Ziyi Hu, Mingyue Liao, Tingwei An, Weiwei Kuang, Keliang Wang, Ziwei Li, Fei Liu, Min Li,

Bifunctional carbon elimination mechanism of CeO2 nanorod@Ni3Co7Phy core shell catalyst for CO2 reforming of methane,

Separation and Purification Technology,

Volume 360, Part 2,

2025,

130952,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.130952.

(https://www.sciencedirect.com/science/article/pii/S1383586624046914)

Abstract: CO2 capture and utilization via reforming of methane (DRM) is an efficient route to promote the achievement of the carbon neutralization goal. Whereas, the carbon deposition problem on cheap Ni-based catalysts slows down its industrial progress. Although Co doping to form NiCo bimetallic catalysts is effective to enhance the carbon resistance, the bifunctional carbon elimination mechanism has not been unveiled. Here, core shell structured CeO2@Ni7Co3Phy catalyst with high sintering and carbon resistance has been designed, exhibiting the stable CH4 and CO2 conversion of 72 % and 78 % respectively at 973 K for 120 h. The outstanding performance is due to the formation of Ni7Co3 bimetal, enhanced metal support interaction, and the highest surface Ni0 concentration, increasing sintering resistance and boosting the DRM activity. In situ diffuse infrared Fourier transform spectroscopy analysis and density functional theory calculations further confirm the bifunctional carbon elimination mechanism that both the oxygen vacancies in CeO2 and the electron deficient oxidative Co sites adsorb and activate CO2, providing oxygen species to eliminate carbon. By comparison, either serious Ni sintering and carbon accumulation or oxidation of Co0 phase due to excessive CO2 activation occurred for CeO2@NiPhy and CeO2@CoPhy catalyst respectively, leading to their worse DRM performance. The bifunctional carbon elimination mechanism illuminates the design of other carbon resistant catalysts.

Keywords: Bifunctional mechanism; Carbon elimination; CeO2 nanorod; NiCo phyllosilicate; Oxidative Co site

Rakesh Saini, Danda Srinivas Rao, Ramanuj Narayan, Suryakanta Behera, Sanjay M. Mahajani,

Industrial coal gasification ash as a support substrate for the thermocatalytic decomposition of methane into hydrogen and carbon nanotubes,

Fuel,

Volume 388,

2025,

134432,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134432.

(https://www.sciencedirect.com/science/article/pii/S0016236125001565)

Abstract: This novel study has demonstrated an economical and sustainable solution to utilize the industrial waste of coal gasification ash (CGA) for the preparation of co-precipitated Ni and Co-based catalysts to generate COx-free hydrogen and high-end carbonaceous products in the form of carbon nanotubes (CNTs). Catalysts with different transition metal loadings were investigated at a reaction temperature of 700 °C and atmospheric pressure conditions in a gas-chromatograph coupled fixed-bed reactor system to decipher the impact on methane conversion and hydrogen yield performance parameters. The catalysts and the product samples were characterized using a series of complementary bulk and surface-sensitive analytical techniques consisting of X-ray fluorescence (XRF), Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), thermogravimetric analysis (TGA), Raman, and energy dispersive X-ray spectroscopy (EDX) coupled scanning electron microscopy (SEM) & field emission scanning electron microscopy (FESEM) instruments. The morphology and texture properties of the product CNTs were analyzed using high-resolution transmission electron microscopy (HRTEM) and the methods mentioned above. The thermocatalytic decomposition of methane (TDM) reaction conducted at the earlier mentioned process parameters demonstrated the Ni-CGA catalyst as the most active catalyst among the investigated Co-CGA and Ni-Co-CGA catalysts over testing on stream for almost 4 h with the highest methane conversion and hydrogen yield performance. The Brunauer-Emmett-Teller (BET) and Barrett-Joyner-Halenda (BJH) analysis results showed a remarkable rise in the specific surface area (SBET) and total pore volumes (Vt) for the prepared Ni–CGA catalyst, compared to the support CGA substrates. The EDX-assisted FESEM and HRTEM showed the formation of CNTs with external diameters of 40 nm to 125 nm and lengths from 600 nm to 1,500 nm, originating from the active Ni-Fe alloy metal sites with equivalent spherical diameters of few 100 nm.

Keywords: Carbon nanotubes (CNTs); Coal gasification ash (CGA); Hydrogen production; Methane decomposition; Nickel and Cobalt catalyst

Song He, Lifan Gao, Yawen Zheng, Junyao Wang, Shenghui Lin, Zhi Yang, Xuelan Zeng,

Carbonation heat recovery via dry reforming to improve the techno-economic performance of the Ca-Cu looping post-combustion CO2 capture,

Journal of CO2 Utilization,

Volume 92,

2025,

103014,

ISSN 2212-9820,

https://doi.org/10.1016/j.jcou.2024.103014.

(https://www.sciencedirect.com/science/article/pii/S2212982024003494)

Abstract: Calcium looping process has presented great potential realizing low-energy-consumption CO2 capture since high-grade thermal energy can be recovered. However, in current calcium looping configurations, the carbonation heat is recovered for steam generation, resulting in the significant exergy destruction. This study presents a novel Ca-Cu looping process with thermochemical recuperation to address the significant exergy destruction during carbonation heat recovery. System integration is carried out for the typical flue gas decarbonization. Results indicate that the proposed system present superior performance than that in the reference system without thermochemical recuperation. The specific primary energy consumption for CO2 avoided decreases from 2.29 MJLHV/kg CO2 in the reference system to 1.68 MJLHV/kg CO2 in the proposed system. Energy analysis and exergy analysis reveal that carbonation heat recovery via thermochemical recuperation and efficient utilization of the increased chemical energy contribute to reduction of energy consumption. The research also examines how operating conditions impact the thermodynamic efficiency. An optimized primary energy consumption for CO2 avoidance of 1.58 MJLHV/kg CO2 can be achieved through the response surface method. Besides, the cost of CO2 avoided can achieved at 37.52 €/t CO2, which is more economically feasible with that of the conventional calcium looping technology.

Keywords: Ca-Cu looping; Dry reforming; Thermochemical recuperation; CO2 recycling; Post-combustion CO2 capture

Mohammadreza Kosari, Samuel B. Portillo, Shibo Xi, Andrew Pedersen, Abhijit Talpade, Fanxing Li,

Zr-promoted Ni nanoparticles in mesoporous silica spheres (NiZr/mSiO2) for catalytic decomposition of methane,

Chemical Engineering Journal,

Volume 507,

2025,

160328,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.160328.

(https://www.sciencedirect.com/science/article/pii/S1385894725011337)

Abstract: Catalytic decomposition of methane (CDM) is a promising method for producing carbon nanotubes (CNTs) and H2 at-scale, with net-zero CO2 emission. Herein, a highly active CDM catalyst is presented comprised of inert mesoporous silica spheres (mSiO2) as a support loaded with Ni nanoparticles (NPs) and dopants, resulting in high CH4 conversion and potential inhibition of tip-growth CNTs. Specifically, uniformly dispersed Ni NPs onto mSiO2 promoted by scant Zr deposition (rendering NiZr/mSiO2) exhibited decent reducibility and an excellent H2 production rate (4.52 molH2·gNi–1·h−1 at T = 600 °C and GHSV = 24 L·gcat–1·h−1). As the best-performing catalyst, 10Ni0.2Zr/mSiO2 exhibited satisfactory long-term stability with a low deactivation rate and cyclability performance with marginal activity loss over 10 cycles. Besides, the CNTs growth mode from tip-growth to base-growth could be switched by altering the synthetic chemistry of inert mSiO2 but at the expense of catalytic activity.

Keywords: Catalytic decomposition of methane (CDM); Hydrogen; Supported nanoparticles; Bimetallic Ni NPs; Zr Promoter

José Valecillos, Sergio Iglesias-Vázquez, Aingeru Remiro, Javier Bilbao, Ana G. Gayubo,

Formation and properties of carbon/coke as nanostructured materials and deactivating agent in the ethanol steam reforming over a catalyst derived from Ni-Al spinel,

Fuel,

Volume 385,

2025,

134082,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134082.

(https://www.sciencedirect.com/science/article/pii/S0016236124032332)

Abstract: The ethanol steam reforming (ESR) on a Ni/Al2O3 catalyst derived from the complete reduction of NiAl2O4 spinel provides high H2 yield with low greenhouse gas emissions due to a significant co-production of solid carbon under certain conditions. The impact of temperature and steam/ethanol (S/E) ratio on the carbon formation has been studied both theoretically and experimentally (by ESR tests in a fluidized bed reactor, in the 450–650 °C range and with S/E ratios in the 0–9 range), identifying the main precursors and formation routes. The carbon has been characterized by scanning electron and transmission electron microscopies (SEM and TEM), Raman spectroscopy, X-ray diffraction (XRD) and temperature programmed oxidation (TPO) to define its dual role as nanostructured material (with commercial interest) or as catalyst deactivation agent (coke), depending on operating conditions. The amorphous carbon covering the active sites has a deactivating role and prevails at 650 °C (< 0.9 g/(g catalyst)), whereas nanostructured carbon (nanotubes with no significant effect on deactivation) prevails below 600 °C and a stable production of 34 g/(g catalyst)) is obtained at 500 °C and S/E ratio of 3. The carbon crystallinity and structural purity are enhanced as the temperature increases and the S/E ratio decreases. The analysis by temperature programmed gasification (TPG) has emphasized the potential of the gasification above 650 °C to valorize the carbon/coke into syngas (without the CO2 emissions obtained by combustion). The results are interesting for the scale-up of a versatile combined process (ESR + carbon/coke gasification) that integrates carbon valorization into syngas, while minimizing the CO2 emissions.

Keywords: hydrogen (H2); Ethanol steam reforming; Ni/Al2O3 catalyst; NiAl2O4 spinel; Nanostructured carbon; Carbon gasification

Weishan Yao, Xiaoyan Wu, Yan Lin, Xixian Yang, Guoqiang Wei, Zhen Huang, Liangyong Chen, Shengsen Zhang, Yongqi Zhang, Jun Xie,

A novel cascade high purity hydrogen production via chemical looping reforming of landfill gas with LaFe1-xNixO3 perovskite oxygen carrier,

Separation and Purification Technology,

Volume 361, Part 3,

2025,

131223,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.131223.

(https://www.sciencedirect.com/science/article/pii/S1383586624049621)

Abstract: Landfill gas is an essential renewable energy, which can lead to greenhouse gas emissions if not appropriately handled. A novel cascade high-purity hydrogen production via chemical looping reforming of landfill gas coupled H2O splitting (CLR-HS) was proposed in this work, which revealed advantages in CH4 dry reforming conversion and hydrogen purity. LaFe1-xNixO3 (x = 0, 0.2, 0.4, 0.6, 0.8) perovskite oxygen carriers with different Ni contents on the B-site were investigated in a fixed bed reactor combined with multivariate analysis. The results indicated that Ni provided the active site and formed a metal synergistic effect for strengthening the CLR-HS process. This resulted in a large amount of active lattice oxygen generation with moderate Ni element. Meanwhile, excessive nickel depressed the active site generation of oxygen carriers, reducing the conversion efficiency of CLR-HS. During the CLR stage, 87.2 % and 94.9 % conversion for CH4 and CO2 in chemical looping reforming of landfill gas and syngas selectivity approaching 99 % by the LaFe0.8Ni0.2O3 oxygen carrier. Correspondingly, 98.9 % purity was obtained in the HS stage by splitting H2O in oxygen vacancies. The abundant lattice oxygen and CO2 contributed synergistically to activating and oxidizing CH4 via dry reforming and the CLR process. The carbon deposition on the surface of LaFe0.8Ni0.2O3 played a crucial role in inhibiting the purity of H2 production in the HS stage, which was the key to improving H2 production purity. For the 20 cycles redox tests of oxygen carrier performance stability, the conversion of CH4 and CO2 was not less than 84.6 % and 92.4 % with LaFe0.8Ni0.2O3, the syngas selectivity was close to 95.1 %, and the purity of hydrogen prepared by H2O splitting was stable near 95 %. Overall, LaFe0.8Ni0.2O3 showed higher reactivity than other types of oxygen carriers constructed in this study.

Keywords: Landfill gas; Chemical looping reforming; Hydrogen; Perovskite; Oxygen carriers

Byung Sun Yoon, Jae-Rang Youn, Wan-Gil Jung, Gwan-Joong Park, Da-Bin Kang, Sung-Bin Choi, Su-Ji Kim, Woohyun Kim, Chang Hyun Ko,

Catalytic methane decomposition using Ni supported on mesoporous SiO2 catalyst: Ni position-dependent carbon yield change,

Applied Surface Science,

2025,

162731,

ISSN 0169-4332,

https://doi.org/10.1016/j.apsusc.2025.162731.

(https://www.sciencedirect.com/science/article/pii/S0169433225004453)

Abstract: Catalytic methane decomposition (CMD) is a promising reaction for hydrogen production without direct CO2 emissions. During CMD, gas-phase hydrogen and solid-phase carbon are produced, necessitating strategic catalyst design to manage carbon yield. In this study, we investigated the influence of narrow mesopores in catalysts for CMD. Using Ni supported on mesoporous silica (5.5 nm pore diameter) as a model catalyst, we prepared two types of catalysts: one with Ni0 particles located outside the pores and the other with Ni0 particles situated within the pores, and applied them to CMD. The catalysts with Ni0 particles within the pores exhibited lower carbon yield and produced carbon materials with lower graphitic quality compared to catalysts with Ni0 particles located outside the pores. Ni0 particles within the pores generated defect-rich carbon materials due to spatial limitations, resulting in decreased accessibility for CMD.

Keywords: Metallic Ni; SBA-15; Ni location; Mesopore; Hydrogen production; Turquoise hydrogen

Mengjie Cao, Shuangde Li, Shikun Wang, Weichen Xu, Xin Zhou, Guangxin Ma, Xiaoze Wang, Linfeng Nie, Yunfa Chen,

Highly stable hydrotalcite-derived NiCrAl catalyst for methane cracking and directly application for electromagnetic wave absorption,

Fuel,

Volume 379,

2025,

133128,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133128.

(https://www.sciencedirect.com/science/article/pii/S0016236124022774)

Abstract: Catalytic cracking of methane is considered a promising route to hydrogen production because no carbon oxides are produced during the reaction. Designing well-stable Ni-based catalysts with long durability and high activity for methane cracking to H2 and carbon nanomaterials has been a long enormous challenge. Here, high performance NiCr/Al2O3 methane cracking catalyst was prepared by reducing NiCrAl hydrotalcite precursor. The impact on reaction temperature and Cr/Ni ratio on catalytic performance were systematically analyzed. The catalyst with a Cr/Ni ratio of 1:9 showed the best catalytic performance. The catalyst activity decreased while the stability increased with decreasing reaction temperature, and the Ni2.7Cr0.3Al catalyst was able to stabilize 70 % hydrogen yield at 620 °C for 360 min. Furthermore, it was found that Cr doping reduced the metal grain size, increased the specific surface area of the catalyst, and promoted the reduction of Ni due to the NiCr alloying. In addition, the electromagnetic parameters of the methane cracking spent catalysts with the carbon nanotubes embedding were tested to be shown outstanding impedance matching characteristics at 620 °C, with a minimum reflection loss of −44.5 dB at 15.3 GHz at a thickness of 1.6 mm, and the effective absorption bandwidth reached 4.7 GHz. This paper provides valuable ideas for the design of highly stable methane cracking catalysts and opens a new application direction for spent catalysts as the electromagnetic absorption.

Keywords: Methane cracking; NiCrAl catalyst; Hydrogen; Carbon nanomaterials; Electromagnetic absorption

Notsawan Swadchaipong, Vut Tongnan, Panupan Maneesard, Matthew Hartley, Kang Li, Rossarin Ampairojanawong, Ammarika Makdee, Unalome Wetwatana Hartley, Issara Sereewatthanawut,

Study of nitrous oxide utilization for syngas production via partial oxidation of methane using Ni-doped perovskite catalysts,

RSC Advances,

Volume 15, Issue 5,

2025,

Pages 3080-3088,

ISSN 2046-2069,

https://doi.org/10.1039/d4ra06805j.

(https://www.sciencedirect.com/science/article/pii/S2046206925003316)

Abstract: Four different materials—pure NiO, pure LSCF (La0.3Sr0.7Co0.7Fe0.3O3−δ), 10% Ni/LSCF, and 20% Ni/LSCF—were studied. The Ni/LSCF catalysts demonstrated superior catalytic performance for both N2O decomposition and the partial oxidation of methane (POM) compared to pure NiO and pure LSCF. This enhancement is attributed to an increase in oxygen vacancies and improved oxygen mobility within the catalyst, as evidenced by O2-TPD analysis. During N2O decomposition, both LSCF and 10% Ni/LSCF achieved complete N2O conversion at 800 °C, whereas pure NiO provided 81.7% at the same temperature. However, 10% Ni/LSCF is more active at lower temperatures, as evidenced by its T50 value of 536 °C, compared to 546 °C for the unmodified LSCF. For the POM reaction using N2O as an oxidant, 10% Ni/LSCF achieved 70.9% CH4 conversion, 96.6% CO selectivity, and 97.4% H2 selectivity at 600 °C. In contrast, both pure LSCF and 20% Ni/LSCF catalysts exhibited significantly lower efficiency, with approximately 20% CH4 conversion and less than 5% syngas selectivity. The enhanced performance of the 10% Ni/LSCF compared to the 20% Ni/LSCF is likely attributed to its smaller Ni crystallite size (23.7 nm vs. 32.3 nm) and the lower temperature required for reducing Ni2+ to the active Ni0 species (480 °C vs. 500 °C). Kinetic analysis of the POM reaction using N2O over the 10% Ni/LSCF catalyst revealed a second-order reaction with respect to CH4 and a zero-order reaction with respect to N2O, with an apparent activation energy of 71.8 kJ mol−1.

Wei Man Liew, N. Ainirazali,

Cutting-edge innovations in bio-alcohol reforming: Pioneering pathways to high-purity hydrogen: A review,

Energy Conversion and Management,

Volume 326,

2025,

119463,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119463.

(https://www.sciencedirect.com/science/article/pii/S0196890424014043)

Abstract: The current review article discusses contemporary developments in the generation of hydrogen from bio-alcohols which include ethanol and glycerol, emphasizing the following primary processes: dry reforming (DR), sorption-enhanced steam reforming (SESR), and aqueous phase reforming (APR). These approaches give long-term paths to hydrogen by utilizing sustainable bio-alcohols. DR converts bio-alcohols and CO2 into syngas for carbon capture. However, it confronts problems such as elevated temperatures during operation and deactivation of the catalyst owing to coking. SESR combines CO2 capture with steam reforming for enhanced hydrogen purity and efficiency. However, this requires rigorous catalyst optimization. APR works at lower temperatures in water-based solutions, lowering energy consumption while generating hydrogen. The study discusses advances in catalyst design, process optimization, and the impact of nanostructured compounds for enhancing the production of hydrogen and lowering greenhouse gas emissions. The study emphasises the aforementioned technologies potential for long-lasting, high-purity hydrogen generation while simultaneously addressing the remaining technological challenges.

Keywords: Ethanol; Glycerol; Catalyst; Dry Reforming (DR); Aqueous Phase reforming (APR); Sorption-Enhanced Steam Reforming (SESR)

Chao Gai, Yijing Tao, Nana Peng, Xiaomin Dou, Zhengang Liu,

Sustainable regeneration of deactivated hydrochar-supported Ni catalyst for enhancing low-temperature tar reforming performance,

Journal of Analytical and Applied Pyrolysis,

Volume 186,

2025,

106918,

ISSN 0165-2370,

https://doi.org/10.1016/j.jaap.2024.106918.

(https://www.sciencedirect.com/science/article/pii/S0165237024005734)

Abstract: Catalytic tar reforming using biochar-supported nanoparticle catalyst has emerged as a prominent approach for efficient biomass gasification. However, the widespread issue of catalyst deactivation significantly impedes their industrial application. Recent studies have successfully elucidated the deactivation and regeneration behaviors of pyrochar-based catalysts during high temperature (700–900 °C) tar reforming. In contrast, the deactivation and regeneration mechanisms of hydrochar-based catalysts for low temperature (e.g., 600 °C) biomass tar reforming remain unclear. In this study, we report a simple and cost-effective approach for the regeneration deactivated hydrochar-supported nickel catalyst (Ni0.1/HC). A straightforward N2 regeneration treatment (800 °C, 30 mL/min for 30 min) restored the Ni0.1/HC catalyst to its highest tar reforming efficiency (71 %), H2 selectivity (38 %), H2 yield (758 mL/g) and highest LHVg (8.59 MJ/Nm3). We attribute this promising regeneration performance, which significantly outperforms previously reported regeneration atmospheres (such as CO2, O2, and air), to the suppression of Ni sintering that achieved by limiting oxidation of the coke/hydrochar support. This work advances our understanding of the deactivation and regeneration mechanisms of the hydrochar-based tar reforming catalysts and could facilitate the practical application of biochar-supported catalysts in biomass conversion.

Keywords: Biomass; Solid waste; Hydrothermal carbonization; Hydrogen; Catalyst

Ju Ho Son, Gyungah Park, Dong-Hyeon Lee, Yunjo Lee, Yang Sik Yun, Jong Hyeok Park, Jeong-Cheol Seo, Seung Ju Han,

Selenium-promoted molten metal catalysts for methane pyrolysis: Modulating surface tension and catalytic activity,

Applied Catalysis B: Environment and Energy,

Volume 366,

2025,

125009,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.125009.

(https://www.sciencedirect.com/science/article/pii/S0926337324013237)

Abstract: Compared with the commercial hydrogen production methods, molten metal–catalyzed methane pyrolysis has a smaller carbon footprint but is less mature, particularly regarding catalyst optimization. To bridge this gap, we herein examine the effects of Se content on the surface activity and physical properties of Se-promoted benchmark molten metal (NiBi and CuBi) catalysts for methane pyrolysis. At appropriate Se contents, methane conversion increases by 36.3 % (Ni27Bi72Se1) and 20.5 % (Cu45Bi47Se8), while the surface energy decreases (from 389 mN∙m−1 for Ni27Bi73 to 317 mN∙m−1 for Ni27Bi72Se1), and the volume-specific surface area of bubbles increases. Among the Se-doped NiBi catalysts, Ni27Bi72Se1 shows the lowest apparent methane C–H activation energy (201.2 kJ mol−1), whereas increased values are observed at overly high Se contents (>1 at%). Theoretical calculations reveal that the introduction of an optimal amount of Se (1 at%) increases the surface activity of the NiBi catalyst by reducing the activation energy and promoting the surface exposure of the Ni sites. Whereas the excess Se decreases surface activity by suppressing the surface exposure of Ni sites. Similarly, the addition of Se to CuBi enhances its methane pyrolysis performance by modifying surface activity. The experimental and theoretical data demonstrate that Se addition not only increases surface activity and solute exposure but also reduces surface tension, offering hydrodynamics-related advantages. Thus, this study provides a new perspective on the development of promoters for molten metal–catalyzed methane pyrolysis.

Keywords: Methane pyrolysis; Molten metal catalyst; Selenium; Promoter; Turquoise hydrogen production; Surface activity

Letícia Forrer Sosa, Marco Aurélio Suller Garcia, Augusto César Azevedo Silva, Braulio Soares Archanjo, Adriano Friedrich Feil, Dario Eberhardt, Santiago José Alejandro Figueroa, João Monnerat Araújo Ribeiro de Almeida, Pedro Nothaft Romano,

Highly efficient low metal content Ni/CeO2 catalysts prepared by magnetron sputtering deposition for ethanol steam reforming reaction,

Applied Catalysis B: Environment and Energy,

Volume 365,

2025,

124940,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124940.

(https://www.sciencedirect.com/science/article/pii/S0926337324012542)

Abstract: We explored the impact of synthesis methods on the physicochemical properties and catalytic performance of Ni/CeO2 catalysts for ethanol steam reforming (ESR). Sputtering (SP) deposition and incipient wetness impregnation (IWI) were employed to prepare the catalysts; detailed characterizations, including HRTEM, XPS, Raman spectroscopy, and TPR analyses, revealed that the Ni/CeO2-SP catalyst exhibits a more uniform Ni nanoparticle distribution, stronger metal-support interactions, and more oxygen vacancies. The Ni/CeO2-SP catalyst demonstrated superior catalytic performance, with a hydrogen production rate of 8.1 L.h−1.gcat−1 (672 L.h−1.gmetal−1). Such results are superior to the observed in the literature, which can be related to the highly uniform Ni dispersion and low metal loading (1.0 wt%). Additionally, the synthesis method affected the type of coke deposition, which was also attested by theoretical calculation insights regarding their mechanism formation. Finally, we also observed differences in oxygen vacancy creation, indicating that the SP deposition method provides a more effective strategy.

Keywords: Ethanol steam reforming; Sputtering deposition; Incipient wetness impregnation; Oxygen vacancies; Metal-support interaction

Hakim S. Sultan Aljibori, Murtadha M. Al-Zahiwat, Abdul Amir H． Kadhum, Dheyaa J. Jasim, Heba A. El-Sabban, Young Gun Ko, Mumtaj Shah, Khursheed B． Ansari,

High-yield hydrogen and methane production via supercritical water gasification of glucose using Ni/Cu-doped CeO2 catalyst: Synthesis process optimization utilizing RSM,

Chemical Engineering and Processing - Process Intensification,

Volume 208,

2025,

110144,

ISSN 0255-2701,

https://doi.org/10.1016/j.cep.2024.110144.

(https://www.sciencedirect.com/science/article/pii/S0255270124004823)

Abstract: This study investigates the synthesis and performance of a nickel/copper-doped cerium oxide catalyst for hydrogen and methane production during the supercritical water gasification of glucose, which is important for producing clean fuel. The effects of key synthesis parameters—cerium molar concentration, nickel salt to cerium salt, and copper salt to cerium salt weight ratios—on catalyst activity were optimized using Response Surface Methodology. The catalyst demonstrated significant improvements in hydrogen and methane yields compared to supercritical water gasification without a catalyst, achieving increases of 181 % and 226 %, respectively. The optimal synthesis conditions yielded 5.46 mmol.g-feed-1 hydrogen and 2.45 mmol.g-feed-1 methane with minimal error between experimental and predicted results. Characterization techniques, including XRD, TEM, and EDS-Mapping, confirmed the catalyst's uniform dopant dispersion. Reusability studies revealed deactivation due to coke deposition, but performance was partially restored via regeneration. This work highlights the potential of aforementioned effective catalyst for clean fuel production.

Keywords: Catalytic supercritical water gasification; Hydrogen; Methane; Glucose; Response surface methodology

Hengyu He, Zhen Zhou, Hong Tian, Chenyang Sun, Yanni Xuan,

Study on the effect of Ni-modified biochar-based catalysts on the steam reforming process of biomass and plastics for hydrogen production,

Journal of the Energy Institute,

Volume 119,

2025,

101960,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2024.101960.

(https://www.sciencedirect.com/science/article/pii/S1743967124004380)

Abstract: As traditional fossil fuels are gradually depleting, finding green and renewable alternative energy sources has become increasingly important. The steam reforming of waste plastics and biomass mixtures for hydrogen production is regarded as a promising solution. Biomass (wheat straw) and Plastic (low-density polyethylene) were picked as the study's basic materials, water (H2O) was employed as the gasification agent, and biochar (Wheat straw charcoal)-loaded nickel (Ni) was utilized as the catalyst. BET, XRD, FTIR, SEM, and ICP-OMS have been employed to examine the modified biochar's catalyst chemical makeup and structural characteristics. The impact of varying Ni loadings catalyst, catalytic reforming temperature, steam flow rate, and feedstock blending ratio on the process of steam reforming of biomass/plastics to hydrogen were investigated. The outcomes showed that the catalyst Ni/WB-C had functional groups that contained oxygen and a rich pore structure. The optimal experimental conditions for steam reforming of biomass/plastics to hydrogen were achieved at a Ni loading of 15 wt%, pyrolysis temperature of 600 °C, catalytic reforming temperature of 800 °C, steam flow rate of 0.2 g/min, and biomass/plastic ratio of 5:5. In accordance with the aforementioned condition, the total gas yield, the H2 yield, and its percentage, and the H2/CO ratio, were found to be 109.4 mmol/g, 77.5 mmol/g, 70.8 %, and 3.97. Therefore, this study provides an effective new approach to enhance H2 production from steam reforming of waste plastics/biomass.

Keywords: Hydrogen; Steam reforming; Biomass/plastics; Ni-modified biochar

Alyaa K. Mageed, May Ali Alsaffar, Mohamed Abdel Rahman Abdel Ghany, Khalid A. Sukkar, Bamidele Victor Ayodele,

Advances in synthesis and application of cobalt and nickel-based nanomaterials for catalytic reforming of hydrocarbons and oxygenates to hydrogen-rich syngas,

Journal of Industrial and Engineering Chemistry,

Volume 144,

2025,

Pages 1-17,

ISSN 1226-086X,

https://doi.org/10.1016/j.jiec.2024.09.022.

(https://www.sciencedirect.com/science/article/pii/S1226086X24006130)

Abstract: Catalytic reforming of hydrocarbons and oxygenates produces synthetic gas (syngas), a mixture of carbon monoxide (CO) and hydrogen (H2). The syngas produced is an important intermediate for clean energy and chemical synthesis. A key research question guiding this review is: How do different synthesis techniques and modifications of Co and Ni-based nanomaterials influence their catalytic efficiency in reforming hydrocarbons and oxygenates to hydrogen-rich syngas? By synthesizing recent advancements and identifying key challenges, this review aims to inform researchers and industry professionals about the current state of knowledge and suggest directions for future research and development. The review revealed that Co and Ni catalysts used for hydrocarbon and oxygenates reforming have high surface area, catalytic activity, and precise catalytic properties. Due to their increased surface area, the catalysts activate and reform hydrocarbons and oxygenates more efficiently. Future research might focus on commercial processes, catalyst enhancement, and using innovative approach to examine and improve catalyst design and performance in real-world operating conditions. Catalytic reforming technique with Co and Ni nanoparticles can boost sustainable energy production and chemical synthesis.

Keywords: Cobalt; Nickel; Hydrogen; Syngas; Hydrocarbon reforming

Nailma J. Martins, Oscar W. Perez-Lopez,

Tuning the composition of Ni-Al-LDH catalysts for low-temperature CO2 methanation,

Fuel,

Volume 381, Part C,

2025,

133594,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133594.

(https://www.sciencedirect.com/science/article/pii/S0016236124027431)

Abstract: CO2 methanation has attracted attention because of its potential ability to decrease carbon emissions and generate methane, a fuel, and a precursor for manufacturing organic products. Methanation of carbon dioxide was carried out in a continuous flow reactor (CO2:H2 = 1:4, GHSV = 12000 h−1) over a series of Ni-Al-LDH catalysts with Ni/Al ratio between 1.5 and 3. Characterization of catalysts was performed by N2 adsorption–desorption isotherms (BET), X-ray fluorescence (XRF), X-ray powder diffraction (XRD), temperature programmed reduction (TPR), temperature programmed desorption of H2 (H2-TPD), and CO2 (CO2-TPD). The Ni/Al ratio influences the specific surface area, crystallinity, phases present, reducibility and metallic dispersion, and total basicity. Higher Ni amount led to lower specific surface area, larger crystallite sizes, and significantly increased total basicity. The increase in the Ni/Al ratio increased the amount of H2 consumed but the metallic surface and dispersion decreased. The Ni70Al30 catalyst presented the best compromise between crystallite size and metallic dispersion and a higher proportion of spinel phase, which should result in greater thermal stability for this catalyst. The activity on the Ni70Al30 catalyst was higher than that of the other catalysts over the entire temperature range attaining 85 % CO2 conversion with 100 % CH4 selectivity at 250 °C. This sample maintained its activity with the time on stream without noticeable deactivation, due to the high resistance to sintering associated with the small size of the metal crystallites.

Keywords: Methanation of CO2; CO2 conversion; Nickel catalysts; Layered-double hydroxides; Ni/Al ratio

H.B.Trujillo Ruales, C. Italiano, A. Vita, A. Iulianelli,

Low impact emissions H2 production via biogas steam reforming in a foam structured membrane reactor: Energy efficiency and exergy analyses, and H2 production cost assessment,

Energy Conversion and Management,

Volume 326,

2025,

119504,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2025.119504.

(https://www.sciencedirect.com/science/article/pii/S0196890425000275)

Abstract: This work focuses on the utilization of a novel Ru-Ni foam structured catalysts housed in a Pd-Ag membrane reactor to generate decarbonized H2 by steam reforming of synthetic biogas, analysing from energy/exergy point of views the whole MR based plant, including also the ancillary devices (condenser, boiler, pump etc.). The influence of the wall temperature in the reforming process has been studied to determine the temperature profile along the foam structured membrane reactor. In addition, the overall process efficiency as well as an economic study to determine the cost of the decarbonised hydrogen production have been analysed with the further objective of contributing to meet the European Green Deal policies in the framework of renewable energy carriers production respecting the net zero gas emissions by 2050. The experimental campaign has been realized between 673 and 773 K and varying the pressure between 100 and 200 kPa, reaching 74 % CH4 conversion, 95 % hydrogen recovery and 55 % yield at 773 K and 200 kPa, S/C = 2/1 and WHSV = 0.6 h−1, and a total exergy efficiency of 85 %. The purity of the hydrogen stream recovered in the foam structured membrane reactor was superior to 99.999 % in the whole range of operating conditions analyzed in this work, meeting the expected values of the European Clean Hydrogen Agency (Targets-2030: hydrogen recovery = 95 %, hydrogen purity = 99.99 %)

Keywords: Foam structured membrane reactor; Decarbonized hydrogen; Biogas steam reforming; Energy/exergy analyses; Hydrogen production cost

José Juan Bolívar Caballero, Ilman Nuran Zaini, Anissa Nurdiawati, Irina Fedorova, Pengcheng Cao, Thomas Lewin, Pär G. Jönsson, Weihong Yang,

Electrified catalytic steam reforming for renewable syngas production: Experimental demonstration, process development and techno-economic analysis,

Applied Energy,

Volume 377, Part B,

2025,

124556,

ISSN 0306-2619,

https://doi.org/10.1016/j.apenergy.2024.124556.

(https://www.sciencedirect.com/science/article/pii/S0306261924019391)

Abstract: Biomass is a key renewable feedstock for producing green fuels; however, renewable feedstock presents a high risk for catalyst deactivation and poor stability. In addition, the heat source of industrial reforming processes comes from fuel combustion and most heat is lost in the flue gas. In this study, a Ni/Al2O3/FeCrAl-based monolithic catalyst with a periodic open cellular structure (POCS) was designed and 3D-printed. A reforming process was then conducted by directly heating the catalyst using electricity instead of fuel combustion. This e-reformer technology was demonstrated in continuous catalytic steam reforming of biomass pyrolysis volatiles. A high H2 yield of ≈7.1 wt % of biomass has been obtained at a steam-to-biomass (S/B) ratio of 4.5, reforming temperature of 800 °C and weight hourly space velocity (WHSV) of 310 h−1, resulting in an energy consumption of 8 kWhel kg−1 biomass (66% energy efficiency). The results show a successful demonstration of the electrified technology with improvement potential; in addition, a process was designed and assessed economically for synthetic natural gas (SNG) production of 80 MWHHV, comparing electrification and partial oxidation in different scenarios.

Keywords: 3D-printed catalyst; Pyrolysis; Steam reforming; Hydrogen; Pyrolysis volatiles; Electrified reforming

Jie Luo, Mei Zhong, Zhenghua Dai, Yang Liu, Lijun Jin,

The integrated process of CO2 reforming of methane with co-pyrolysis of Naomaohu coal and elm to improve tar yield,

Fuel,

Volume 388,

2025,

134502,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134502.

(https://www.sciencedirect.com/science/article/pii/S0016236125002261)

Abstract: Co-pyrolysis of coal and biomass is an effective route to replace coal utilization with alternative biomass resource. However, it is crucial to acquire high tar yield during co-pyrolysis. To improve tar yield during co-pyrolysis of Naomaohu coal and elm, in this work, a new process was constructed by integrating co-pyrolysis with CO2 reforming of methane over 10Ni/γ-Al2O3 catalyst (CP-CRM) on an infrared-heated fixed-bed reactor, and the effect of pyrolysis temperatures on the integrated process was investigated. The comparison of co-pyrolysis behaviors under N2 (CP-N2) or CH4/CO2 (CP-CH4/CO2) atmosphere was conducted to reveal the reaction mechanism during CP-CRM. Result revealed that the CP-CRM showed higher tar yield than co-pyrolysis under CP-N2, and the maximum tar yield of 21.68 wt% was achieved at 500 °C during the integrated process, which was 1.13 times as that under CP-N2. In comparison, tar yield in co-pyrolysis under CH4/CO2 mixture gas was between those of CP-N2 and CP-CRM, indicating that CH4 and CO2 themselves could facilitate the formation of tar, which could further be strengthened under the action of 10Ni/γ-Al2O3 catalyst. The analyses of co-pyrolysis tar by simulated distillation, GC/MS, 1H-NMR and 13C-NMR showed that the pitch content in co-pyrolysis tar from CP-CRM was higher than those in CH4/CO2 and N2 atmospheres, and high phenols content up to 60.05 % was obtained, higher than 51.61 % in tar from CP-N2. Additionally, the tar from CP-CRM possessed more aromatics with short side chains compared than those from pyrolysis under N2 and CH4/CO2, which was mainly ascribed to the participation of active free radicals from CO2 reforming of CH4. This work provides a simple route to improve tar yield and phenols content in tar during co-pyrolysis.

Keywords: Coal; Biomass; Co-pyrolysis; CO2 reforming of methane; Tar

Zhihui Wang, Nan He, Qicheng Chen, Yingjin Zhang, Liang Yao,

Co-generation of methanol and electricity using integrated concentrated solar power, calcium looping, and methane bi-reforming: Energy, exergy and economic analyses,

Energy Conversion and Management,

Volume 327,

2025,

119585,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2025.119585.

(https://www.sciencedirect.com/science/article/pii/S0196890425001086)

Abstract: Concentrated solar power integrated with the calcium looping process enables dispatchable power generation. However, from an equipment perspective, various challenges such as high energy demand of CO2 compressors and the immaturity of solid–solid heat exchangers impede the application of such a system. In the present work, an integrated system incorporating concentrated solar power and methane bi-reforming was proposed for the co-generation of methanol and electricity. Energy analysis examined the impact of eliminating the CO2 compressor, designing thermal integration without solid–solid heat exchangers and adopting solar reforming receivers on the system. Results showed that removing CO2 compressors led to a power generation efficiency of 19.51 %, indicating an increase of 11.68 %. Thermal integration further improved the power generation efficiency to 21.00 %, indicating an increase of 7.64 %. The thermal efficiency for the synthesis of methanol exhibited no decline and achieved a value of 50.27 %. In addition, solar-driven methane bi-reforming reduced the CO2 emissions by 76.60 % to 0.11 t CO2/t CH3OH for the synthesis of methanol. Exergy analysis showed that the total exergy efficiency of the proposed system reached the value of 58.42 %. Techno-economic analysis showed that levelized costs of electricity and product for the proposed system were as low as 148.92 $/MWh and 348.37 $/t, respectively. Therefore, the proposed system has considerable potential for the co-generation of electricity and methanol.

Keywords: Concentrated solar power; Calcium looping; Methane bi-reforming; Methanol synthesis; Exergy analysis; Economic analysis

Ke Li, Yifan Zhang, Weixin Shen, Zhihao Liu, Qinxiang Ma, Jianli Zhang, Faliang Luo,

Design and catalytic performance of Ni catalyst for CO2 methanation based on DIW-3D printing,

Fuel,

Volume 380,

2025,

133129,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133129.

(https://www.sciencedirect.com/science/article/pii/S0016236124022786)

Abstract: Direct ink writing (DIW/Robocasting), a form of 3D printing, also known as additive manufacturing(AM), providing a convenient way to build 3D structures layer-by-layer, which extrudes ink through a nozzle.The three-dimensional catalyst structure of wooden pile was printed by ink direct writing technology and applied to the fixed bed, which effectively reduced the pressure drop and reaction temperature of the reactor, and improved the conversion rate of the reaction target and catalytic efficiency. In this work, CO2 methanation was studied on monolithic structures fabricated by robocasting technique by extruding PDMS loaded nickel catalyst. After characterization, the catalytic performance of monolithic catalysts were evaluated in the reactor in CO2 methanation reaction at temperatures between 250 and 400 °C. In particular, the CO2 conversion rate of 20 %Ni/SiOC monolithic catalyst reached 96.48 % at 300℃. The catalytic performance remained high after 240 h test, and the selectivity of CH4 in all catalytic evaluations was 100 %.

Keywords: 3D printing; DIW; Catalyst; Methanation; PDMS

Jakob Müller, Alexander Feldner, Simon Markthaler, Peter Treiber, Jürgen Karl,

Adaptation of an additively manufactured reactor concept for catalytic methanation with in-situ tar co-reforming of biogenic syngas,

Chemical Engineering Journal Advances,

Volume 21,

2025,

100692,

ISSN 2666-8211,

https://doi.org/10.1016/j.ceja.2024.100692.

(https://www.sciencedirect.com/science/article/pii/S2666821124001091)

Abstract: The methanation of biogenic syngas for GreenLNG production is a promising alternative for fossil gas. The market price of renewable methane is currently still too high to compete with fossil LNG. One of the reasons for that is the extensive gas cleaning that is necessary for the methanation of syngas from the thermochemical gasification of biomass. A main cost factor is the removal of tar components. As part of the Horizon Europe project CarbonNeutralLNG, we propose a 3D-printed methanation reactor, which makes use of the freedom in design gained by the additive manufacturing process in order to adapt the reactor design for the in-situ co-reforming of tars. The reactor uses heat pipes and a conically widened reaction channel to effectively control local temperatures, suiting the needs of the methanation reaction. A temperature hot spot near the inlet provides the necessary conditions (high temperature, a suitable catalyst and sufficient residence time) for the reforming of tar species, that are present in the syngas. Two reactor concepts are proposed. ADDmeth3.1 uses a dedicated internal channel structure that serves as a counter-current heat exchanger for the feed gas, whereas ADDmeth3.2 is optimized to fill the triangular footprint of a scalable reactor module as best as possible. Both designs were subject to a preliminary feasibility study, to ensure sufficient heat removal and a finite element analysis regarding structural stability was performed. Minimum safety factors against yielding of 3.53 and higher were achieved even without the internal diamond lattice support structure. The triangular modular reactor cell can easily be scaled up by connecting multiple cells in parallel, since the triangular shape can be extended efficiently into a honeycomb pattern.

Keywords: Reactor design; Additive manufacturing; 3D-printing; Catalytic methanation; Tar removal; Heat pipes; Finite element analysis

G.U. Ingale, D.H. Park, C.W. Yang, H.M. Kwon, T.G. Wi, Y.J. Park, S. Kim, Y.B. Kang, Y.I. Lim, S.W. Kim, U.D. Lee,

Low-carbon hydrogen production by molten metal–catalyzed methane pyrolysis: Catalysts, reactor design, and process development,

Renewable and Sustainable Energy Reviews,

Volume 208,

2025,

114999,

ISSN 1364-0321,

https://doi.org/10.1016/j.rser.2024.114999.

(https://www.sciencedirect.com/science/article/pii/S1364032124007251)

Abstract: This review focuses on low-carbon H2 production via the non-oxidative decomposition of CH4. The plasma-based methane decomposition, water splitting, nuclear thermochemical cycles, and steam methane reforming were compared with those of molten metal (MM)-based CH4 pyrolysis based on thermodynamic, techno-economic, and environmental aspects. The selection of MM catalysts and reactor materials was described for CH4 pyrolysis, followed by sustainable heat sources and reactor configurations. An electromagnetic levitation method was presented to elucidate the intrinsic reaction rates based on the bubble surface area, regardless of the reactor type and residence time. Models including the physical properties of the gas and liquid phases, reaction kinetics, and mass transfer of carbon were then discussed for the effective design of MM-based bubble column reactors (MMBCRs). Moreover, a process flow diagram integrating natural gas pre-treatment, CH4 pyrolysis reaction, H2 and carbon separations, and H2 storage was introduced for commercial-scale H2 production. As carbon byproduct is three times the H2 weight, the applications of carbon products were investigated to improve the economic feasibility of MM-based CH4 pyrolysis. Metal impurities in the carbon byproduct should be removed to increase the purity and convert carbon into a high-value-added material. This review culminates with conclusions and future perspectives on low-carbon H2 production using MMBCRs.

Keywords: Low-carbon hydrogen production; Methane pyrolysis; Molten metal; Bubble column reactor; Reactor design; Carbon separation

Junqiang Zhang, Peng Dong, Haifeng Lei, Ruonan Liu, Junwen Wang, Zhitong Zhao, Wei Zhang,

Coal-to-aromatics process integrated with dry/steam-mixed reforming: Techno-economic analysis and environmental evaluation,

Chemical Engineering Science,

Volume 304,

2025,

120934,

ISSN 0009-2509,

https://doi.org/10.1016/j.ces.2024.120934.

(https://www.sciencedirect.com/science/article/pii/S000925092401234X)

Abstract: Two alternative coal-to-aromatics processes, the methane steam reforming-assisted process (NG-CTA-S) and methane dry/steam reforming-integrated process (NG-CTA-DS), are proposed to mitigate carbon dioxide (CO2) emissions associated with conventional coal-to-aromatics (CTA) processes. This study conducted a detailed process simulation and optimization of key parameters to determine the aromatic production route with the lowest carbon emission. A comprehensive technical and economic analysis, along with an environmental assessment, was carried out to compare the proposed processes with existing ones. The results indicate that the NG-CTA-DS process has demonstrated superior techno-economic performance and environmental evaluation. It achieved an elemental carbon utilization of 85.95 %, an energy efficiency of 78.80 %, a reduced CO2 emission of 3.65 kg/kg-aromatics, and a production cost of only 1018.87 M$. Therefore, it is evident that the proposed NG-CTA-DS process holds significant potential to enhance the technical, economic, and environmental performance compared to the conventional process, making it a promising candidate for industrialization.

Keywords: Coal-to-aromatics; CO2 utilization; Natural gas; Techno-economic analysis; Cleaner production

Hamza Asmat, Puja Paul, Fergus McLaren, Lee Djumas, James Bott, Matthew R. Hill, Akshat Tanksale,

Electrified reformer for syngas production – Additive manufacturing of coated microchannel monolithic reactor,

Applied Catalysis B: Environment and Energy,

Volume 361,

2025,

124640,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124640.

(https://www.sciencedirect.com/science/article/pii/S0926337324009548)

Abstract: Here, an electrified reformer with a bespoke design of catalyst-coated and additively manufactured monoliths with 3-D pore architecture is presented. The 2D-pore architecture of the hexagonal honeycomb monolith was compared against the 3D-pore architecture of three broad classifications - triply periodic minimal surface (Gyroid), strut-based (Octet) and stochastic lattice (Voronoi). Gyroid structured reactor, coated with NiO/Ce0.8Gd0.2O2-δ catalyst and heated to 900 °C achieved >99 % conversion of CO2 and CH4 at WHSV = 11,000 L.h−1.kgcat−1, while remaining active for >42 h with no evidence of coke deposition. Whereas Octet and Voronoi reactors showed slightly lower conversions, with 6-fold and 4-fold higher pressure drops, respectively. This study combines Computational Fluid Dynamics and experimental evidence to reveal that the Gyroid lattice provides high catalyst deposition and catalytic activity at low pressure drops. This study demonstrates the feasibility of renewable energy-powered structured reactors to provide a pathway for low carbon footprint chemical production.

Keywords: Structured Monolith Catalyst; Electric Dry Reforming of Methane; Gyroid Lattice; Octet Lattice; Induction Heating

M.A. Zavyalov, A.A. Markov, M.V. Patrakeev, O.V. Merkulov,

Thermal control and process optimization in methane partial oxidation with CO2 addition in catalytic membrane reactor,

Journal of Membrane Science,

Volume 720,

2025,

123748,

ISSN 0376-7388,

https://doi.org/10.1016/j.memsci.2025.123748.

(https://www.sciencedirect.com/science/article/pii/S0376738825000614)

Abstract: This work examines the influence of carbon dioxide on the partial oxidation of methane (POM) in a catalytic reactor equipped with a La0.5Sr0.5Fe0.9Mo0.1O3–δ membrane. A combined modeling approach using Gibbs energy minimization and the Wagner equation was employed to predict the thermal behavior and oxygen flux under varying flows of methane and CO2. The experimental results confirmed that adding CO2 reduces heat release in the reaction zone, improves thermal stability control, and helps maintain membrane integrity. The use of CO2 as a carrier gas in the reactor start-up mode was shown to improve the controllability of a targeted increase in the oxygen partial pressure gradient across the membrane, thereby reducing mechanical stress in it. Under operating conditions, although CO2 addition reduces CO selectivity slightly, it was shown that optimizing methane flow restores high selectivity levels (>90 %) while ensuring more stable thermal conditions. These findings suggest that CO2 addition, along with methane flow regulation, offers an efficient solution to improving both the thermal management and operational reliability of mixed ionic-electronic conducting membrane reactors.

Keywords: Oxygen membrane; Ferrite; Partial oxidation of methane; Carbon dioxide reforming; Syngas production; Thermodynamic modeling

Ahmad Salam Farooqi, Abdelwahab N. Allam, Muhammad Zubair Shahid, Anas Aqil, Kevin Fajri, Sunhwa Park, Omar Y. Abdelaziz, Mahmoud M. Abdelnaby, Mohammad M. Hossain, Mohamed A. Habib, Syed Muhammad Wajahat ul Hasnain, Ali Nabavi, Mingming Zhu, Vasilije Manovic, Medhat A. Nemitallah,

Advancements in sorption-enhanced steam reforming for clean hydrogen production: A comprehensive review,

Carbon Capture Science & Technology,

Volume 14,

2025,

100336,

ISSN 2772-6568,

https://doi.org/10.1016/j.ccst.2024.100336.

(https://www.sciencedirect.com/science/article/pii/S2772656824001489)

Abstract: The sorption-enhanced steam methane reforming (SE-SMR) process, which integrates methane steam reforming with in situ CO2 capture, represents a breakthrough technology for clean hydrogen production. This comprehensive review thoroughly explores the SE-SMR process, highlighting its ability to efficiently combine carbon capture with hydrogen generation. The review evaluates the mechanisms of SE-SMR and evaluates a range of innovative sorbent materials, such as CaO-based, alkali-ceramic, hydrotalcite, and waste-derived sorbents. The role of catalysts in enhancing hydrogen production within SE-SMR processes is also discussed, with a focus on bi-functional materials. In addition to examining reaction kinetics and advanced process configurations, this review touches on the techno-economic aspects of SE-SMR. While the analysis does not provide an in-depth economic evaluation, key factors such as potential capital costs (CAPEX), operational expenses (OPEX), and scalability are considered. The review outlines the potential of SE-SMR to offer more efficient hydrogen production, with the added benefit of in situ carbon capture simplifying the process design. Although a detailed economic comparison with other hydrogen production technologies was not the focus, this review emphasizes SE-SMR's promise as a scalable and flexible solution for clean energy. With its integrated design, SE-SMR offers pathways to industrial-scale hydrogen production. This review serves as a valuable resource for researchers, policymakers, and industry experts committed to advancing sustainable and efficient hydrogen production technologies.

Keywords: Clean hydrogen; Carbon capture and storage (CCS); Sorption-enhanced steam methane reforming (SE-SMR); Sustainable energy production; Solid sorbents

Jicheng Wang, Haimiao Yu, Hao Liang,

Activity and stability of Ni/magnesium slag catalysts enhanced by plasma pretreatment for toluene steam reforming,

Journal of Analytical and Applied Pyrolysis,

Volume 187,

2025,

106996,

ISSN 0165-2370,

https://doi.org/10.1016/j.jaap.2025.106996.

(https://www.sciencedirect.com/science/article/pii/S016523702500049X)

Abstract: This study investigated the influence of plasma pretreatment on the catalytic performance of a nickel-based catalyst supported by magnesium slag (MS) in the catalytic steam reforming of toluene. The catalyst obtained after plasma pretreatment achieved the highest toluene conversion rate of 99.11 % and the substantial hydrogen yield of 3165.02 mL/g after 6 h of reaction. Additionally, at the end of the reaction, the toluene conversion rate of the plasma-pretreated catalyst was 92.56 %, which was 38.19 % higher than that of the calcined catalyst. Plasma pretreatment significantly enhanced the activity and stability of Ni-based catalyst in toluene steam reforming. Characterization results indicated that plasma treatment promoted the migration of metal species from pores to the external surface of the support and facilitated the formation of smaller Ni particles with higher dispersion. Therefore, plasma treatment exposed more active sites and enhanced the catalytic activity. Furthermore, plasma pretreatment improved the interaction between Ni and the support, generated more Ni(111) crystal planes, reduced the formation of filamentous carbon, accelerated the removal of carbon deposits, and thus enhanced the catalyst stability.

Keywords: Toluene; Tar; Plasma treatment; Nickel-based catalyst; Magnesium slag

Seyyed Mohammad Jokar, Payam Parvasi,

Chapter 2 - Natural gas reforming processes in membrane reactors,

Editor(s): Angelo Basile, Kamran Ghasemzadeh,

Current Trends and Future Developments on (Bio-) Membranes,

Elsevier,

2025,

Pages 25-50,

ISBN 9780443138768,

https://doi.org/10.1016/B978-0-443-13876-8.00003-3.

(https://www.sciencedirect.com/science/article/pii/B9780443138768000033)

Abstract: Many nations are looking for alternative renewable energy in light of the devastating effects of climate change. The most prevalent element on earth, hydrogen, can be used as a clean, nontoxic alternative energy source. The inorganic metallic and nonmetallic membranes with the highest selectivity and permeation rate for producing hydrogen are those made of silica, zeolite, palladium, and its alloys. Meanwhile, Pd-based membranes have a lot of potential for addressing environmental issues and harmful greenhouse gas side effects brought on by industrial processes. This chapter focuses on natural gas as a nonrenewable feedstock for reforming processes. Membrane reactors are commonly used in various chemical processes for the production of hydrogen, syngas, and other valuable chemicals. The processes that can occur in a Pd-based membrane reactor include the following: wet, dry, and tri-reforming; partial oxidation, autothermal reforming; and the Fischer–Tropsch process.

Keywords: Hydrogen generation; Pd-based membrane; natural gas reforming

Pedro E. González Vargas, Javier E. Morales-Mendoza, Jorge L. Domínguez-Arvizu, Blanca C. Hernández-Majalca, José L. Bueno-Escobedo, Alma B. Jasso Salcedo, Luz I. Ibarra-Rodríguez, Virginia H. Collins-Martínez, Alejandro López-Ortiz,

NiWO4 self supported oxygen carrier for the chemical looping steam methane reforming,

International Journal of Hydrogen Energy,

2025,

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ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.477.

(https://www.sciencedirect.com/science/article/pii/S0360319925005270)

Abstract: This study presents the Chemical Looping Steam Methane Reforming (CL-SMR) using NiWO₄ mixed metal-oxide as a self-supported oxygen carrier (OC) to produce syngas during its reduction, while reduced metals are reoxidized with steam to generate hydrogen. The aim of this research is, through a comprehensive material characterization, to evaluate the performance of NiWO₄ as a stable and efficient OC for hydrogen-rich syngas production in the CL-SMR process. NiWO₄ synthesis involved the co-precipitation technique and characterization through XRD, SEM-EDS, and XPS. A thermodynamic analysis and detailed kinetic study were performed on NiWO4 to find suitable reaction conditions to produce syngas and to determine the reaction parameters for both stages. The reduction step employed a CH₄/Ar mixture (5–9%), while the oxidation step used H₂O/Ar (0.8–2.2%). Kinetic analysis revealed the global reaction orders for both reduction and oxidation steps were approximately one, with activation energies indicating that each reaction is controlled by surface chemical reactions. Redox cycle stability tests demonstrated that NiWO₄ remains stable after 10 consecutive redox cycles at 950 °C, with no observed decrease of its average OC capacity of 17.4%. The extent of NiWO₄ reduction increased with each redox cycle, while full oxidation of the reduced species was consistently achieved. XPS results indicate that this enhancement in reduction is attributed to the generation of oxygen vacancies which promote oxygen mobility and improve material reactivity. Overall, the CL-SMR using thermally-stable and unsupported NiWO₄ as an OC, offers a viable pathway for the continuous, efficient, and sustainable production of syngas-hydrogen.

Keywords: NiWO4; Kinetics; Syngas; Chemical looping; Steam methane reforming

Jiaxuan Wu, Xi He, Liujie Xu, Qingbin Song, Zhipeng Tian, Chao Wang, Ming Zhao, Guopeng Zhou, Yajing Gao,

Efficient production of hydrogen-rich syngas by pyrolysis coupled with catalytic steam reforming of degradable polylactic acid waste plastics over high-entropy oxide catalyst,

International Journal of Hydrogen Energy,

2025,

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ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.350.

(https://www.sciencedirect.com/science/article/pii/S0360319925003933)

Abstract: To mitigate the solid waste crisis, converting waste plastics into valuable products through thermochemical processes, such as through pyrolysis, is emerging. Polylactic acid (PLA) plastics are difficult to separate from other plastics in solid waste, and mixed waste is usually directly landfilled or incinerated. Moreover, studies focused solely on the pyrolysis of PLA plastic remain relatively scarce. The large amount of tar produced during plastic pyrolysis can reduce the high-value production of hydrogen, and high-entropy oxide (HEO) catalyst exhibit excellent performance in tar conversion and anti-carbon deposition. In this research, HEO catalyst was synthesized by the sol-gel method for the pyrolysis of waste PLA plastic volatiles, aiming to generate H2-rich syngas in a two-stage integrated reactor system. During catalytic reforming, the highest hydrogen production was 124.1 mmol∙gPLA−1, and the gas yield based on plastic mass reached 259.8 wt%. The superiority of HEO catalyst stems from the synergistic interaction of various elements, enhancing the structural stability of the high-entropy system and increasing oxygen vacancies, resulting in strong C–C and C–H bond-breaking capabilities in the Ce, Mg, Fe, Co, and Ni HEO catalyst. In addition, this study investigated the mechanism of PLA’s simple pyrolysis and the role of the HEO catalyst in the catalytic steam reforming of PLA. This study developed a novel high-entropy aluminate catalyst demonstrating efficient hydrogen-rich syngas production, providing an innovative approach for generating hydrogen-rich syngas from high-molecular-weight polymer plastics through pyrolysis coupled with catalytic steam reforming.

Keywords: Polylactic acid; Pyrolysis; High-entropy oxide catalysts; Catalytic steam reforming; Hydrogen production

Cholila Tamzysi, Tatsuya Takahashi, Yuji Kunisada, Ade Kurniawan, Takahiro Nomura,

Optimizing Ni MEPCM catalysts for thermal regulation in CO2 methanation: ZrO2-CaO surface doping,

Chemical Engineering Journal,

Volume 506,

2025,

159753,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159753.

(https://www.sciencedirect.com/science/article/pii/S1385894725005522)

Abstract: CO2 methanation has become a crucial part of the carbon recycling process owing to its potential to reduce greenhouse gas emissions from renewable hydrogen sources. The reaction is highly exothermic and, under inadequate control, may cause thermal runaway and lead to catalyst deactivation. Therefore, thermal regulation is crucial for ensuring optimum productivity. Microencapsulated phase change materials (MEPCM) were introduced as a promising thermal regulation approach because of their superior capability in controlling the system temperature using the latent heat storage (LHS) concept. This study aims to improve the effectiveness of MEPCM as catalysts support by incorporating mass transfer agent for CO2 methanation process, building upon prior research which focuses on direct impregnation on MEPCM support. To accomplish this goal, a novel MEPCM catalyst structure was developed by loading a Ni metal active site onto the ZrO2-CaO surface-enhanced MEPCM. Novel MEPCM catalysts were prepared using three sequential methods: MEPCM synthesis, surface modification, and catalyst impregnation. Characterization analysis revealed that the modification improved the surface area by 45%. ZrO2-CaO doping successfully enhanced the catalytic performance by increasing the CO2 conversion and CH4 selectivity by 8 and 6%, respectively. In addition, the LHS function of the catalyst-loaded MEPCM suppressed the rapid increase in temperature during the initiation of CO2 methanation. Further development of this concept is expected to enhance the efficiency of runway reaction control across numerous chemical industries.

Keywords: CO2 methanation; Exothermic; Thermal runaway; MEPCM; Surface modification

Oscar E. Medina, Andrés A. Amell, Diana López, Alexander Santamaría,

Comprehensive review of nickel-based catalysts advancements for CO2 methanation,

Renewable and Sustainable Energy Reviews,

Volume 207,

2025,

114926,

ISSN 1364-0321,

https://doi.org/10.1016/j.rser.2024.114926.

(https://www.sciencedirect.com/science/article/pii/S136403212400652X)

Abstract: This study reviews the advancements in nickel-based catalysts for carbon dioxide methanation, a key process for reducing greenhouse gas emissions and supporting renewable energy. It explores the development of Ni-based catalysts, focusing on innovations in catalyst composition, structure, and operating conditions that address challenges like deactivation and low efficiency. This review presents a comprehensive analysis of the factors influencing catalytic performance, including the effects of supports, promoters, and structured catalysts, as well as environmental impacts such as energy use and greenhouse gas emissions. By comparing different catalysts and highlighting the benefits of structured catalysts like foams and monoliths, this work provides a new perspective on enhancing methane production efficiency. Key factors influencing catalyst activity are discussed, including basicity, bimetallic structures, particle size, feed gas composition (O2, H2O, SOx and NOx), and the impact of contaminants (siloxanes, NH3, and halogenated compounds). The study addresses deactivation mechanisms, such as carbon deposition and sulfur poisoning, and proposes mitigation strategies. The review also discusses the Life Cycle Assessment (LCA) of Ni-based catalysts, demonstrating their potential to minimize environmental impacts. This comprehensive approach offers valuable insights for advancing CO2 methanation technology, contributing to sustainable energy production and aligning with global emissions targets and sustainable development goals.

Keywords: CO2 conversion; Catalyst poisoning; Lyfe cycle assessment; Methanation; Nickel-based catalysts

Jingxun Zhou, Wenwen Zhang, Chengxiong Dang, Weiquan Cai,

Effect of porous structure on Ni-CaO bifunctional catalysts for the integrated CO2 capture and methanation process,

Separation and Purification Technology,

Volume 359, Part 3,

2025,

130833,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.130833.

(https://www.sciencedirect.com/science/article/pii/S1383586624045726)

Abstract: Integrated CO2 capture and in-situ methanation technology (ICCU-M) is a promising approach for directly capturing and simultaneously converting CO2 into CH4 in a single process. The bifunctional catalyst that combines CO2 adsorption and catalytic properties into one particle is an ideal choice for ICCU-M process. In this work, we demonstrate that pore structure of bifunctional catalysts plays a pivotal role in their ICCU-M performance. The characterization results indicate that the presence of porosity weakens the encapsulation of Ni nanoparticles by the formed CaCO3 layer due to the volume expansion caused by the larger molar volume of CaCO3 compared to CaO (36.1 cm3/mol vs 16.9 cm3/mol). The ICCU-M performance shows that 5Ni-CaO-C1:1 has a lower CH4 formation temperature of 325 °C than 425 °C of 5Ni-CaO-w due to its abundant pores retaining more Ni sites, thus providing higher methanation activity. Meanwhile, 5Ni-CaO-C1:1 also exhibits higher CH4 selectivity than 5Ni-CaO-w (93.5 % vs 40 %) at 525 °C. Our results show that the volume expansion process of bifunctional catalysts has a significant impact on ICCU-M performance, which needs to be considered when designing efficient bifunctional catalysts for ICCU processes.

Keywords: Integrated CO2 capture and methanation; Bifunctional catalyst; Porous structure; Volume change

Zahra Memarian, Fereshteh Meshkani,

CO2 reforming of glycerol on Ni/Al2O3 catalyst: Influence of doping of alkaline earth metals (Mg, Ca, Sr, and Ba) to support,

Biomass and Bioenergy,

Volume 193,

2025,

107578,

ISSN 0961-9534,

https://doi.org/10.1016/j.biombioe.2024.107578.

(https://www.sciencedirect.com/science/article/pii/S0961953424005312)

Abstract: The catalytic performance of nickel catalysts affixed on MeO.Al2O3 (Me = Mg, Ca, Sr, Ba) was studied to reform glycerol with CO2. The catalyst carriers were fabricated via a solid-state method, and the Ni-prepared catalyst characterization was carried out using XRD, BET, H2-TPR, CO2-TPD, TPO, and SEM techniques. The results indicated that adding alkaline earth metal oxides to the Al2O3 carrier improved the catalytic performance. Among the catalysts studied, the 10%Ni/BaO.Al2O3 exhibited higher glycerol conversion equal to 51 % at 750 °C and GHSV of 54000 ml (g h)−1. This is due to the increase in carriers' basic sites. Also, Ni/BaO.Al2O3 catalysts with various BaO/Al2O3 molar ratios were studied. The 10%Ni/1BaO.Al2O3 catalyst with BaO/Al2O3 ratio of 1 demonstrated a stable conversion at about 50 % during 25h at 750 °C without any decline in glycerol conversion. The CO2-TPD also confirmed the increased basic strong sites of the samples with increasing BaO/Al2O3 molar ratios. The outcomes also illustrated that the product yield peaked at approximately 49 % for H2 and 71 % for CO when the BaO/Al2O3 ratio was set to 1.

Keywords: Glycerol; Dry reforming; Ni/Al2O3; Alkaline earth metals; Hydrogen

Owen Khosashi, Yoondo Kim, Seoyeon Cho, Hyangsoo Jeong, Yongmin Kim, Sung Pil Yoon, Kwang Ho Song, Suk Woo Nam, Sun Hee Choi, Hyuntae Sohn,

Enhanced hydrogen production over Ni-M alloys (M = Co, Zn) formed from hydrotalcite-derived structures for aqueous-phase reforming of xylose,

Applied Surface Science,

Volume 687,

2025,

162229,

ISSN 0169-4332,

https://doi.org/10.1016/j.apsusc.2024.162229.

(https://www.sciencedirect.com/science/article/pii/S0169433224029490)

Abstract: Non-noble metal-based catalysts derived from Ni-hydrotalcite, incorporating various metal promoters (Cu, Co, Ca, Mg, and Zn) were studied for Aqueous-phase reforming (APR) of xylose. The formation of a hydrotalcite structure in the as-prepared samples and their transition into mixed-metal oxides upon calcination was confirmed. During subsequent reduction, more reducible promoters (Cu, Co, and Zn) formed alloys with Ni, while less reducible promoters (Ca and Mg) remained in their oxide form within the catalyst. NiZnAl and NiCoAl catalysts outperformed NiAl, achieving higher hydrogen yields and production rates per gram of Ni for APR of xylose. NiZnAl exhibited the highest catalytic activity, owing to the formation of a NiZn alloy with increased electron density, leading to a lower surface acidity and enhanced adsorbate–metal interactions, thereby improving the reforming activity. The proposed Ni-hydrotalcite-derived catalyst offers a simple and cost-effective solution for scalable xylose reforming with high catalytic performance and stability.

Keywords: Hydrogen; Aqueous phase reforming; Xylose; Nickel; Promoter; Hydrotalcite

D.M.T. Dinh, P.H. Tu, M. Baba, Y. Iijima, Y. Shiratori,

Performance of a liquor-fueled direct internal reforming solid oxide fuel cell with a paper-structured catalyst,

International Journal of Hydrogen Energy,

Volume 99,

2025,

Pages 909-925,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.097.

(https://www.sciencedirect.com/science/article/pii/S0360319924052959)

Abstract: Liquors can serve as an emergency fuel if they can be directly converted to electricity using a highly efficient solid oxide fuel cell (SOFC). To realize this concept, integrating a paper-structured catalyst (PSC) onto the SOFC anode is an effective solution. Shochu is a most popular distilled liquor in Japan with nominal composition of 25 vol% ethanol and 75 vol% water. In this study, the catalytic performance of a Ni-loaded hydrotalcite (HT) dispersed-PSC (Ni/HT-PSC) toward the steam reforming of ethanol (SRE) was evaluated in 500–800 °C when shochu was supplied. The H2 production rate for a shochu produced by a continuous distillation (Shochu-25°-A) was comparable to that of a mixture of 25 vol% ethanol–75 vol% water (simulated-Shochu). However, that for a shochu produced by a single-type distillation (Shochu-25°-B) containing various types of volatile organic compounds (VOCs), including sulfur compounds, was lower in the whole investigated temperature range. The results thus indicate that Shochu-25°-A is suitable as an emergency fuel, whereas a refinement process is necessary for Shochu-25°-B. Electrochemical evaluations of electrolyte-supported cells (ESCs) with the Ni/HT-PSC applied on the anode revealed that the PSC effectively avoids coking on the anode when shochu is supplied for power generation at 750 °C.

Keywords: Liquor; Volatile organic compound; Paper-structured catalyst; Steam reforming of ethanol; Solid oxide fuel cell

Huaming Dai, Chun Liu, Wei Wang, Ziwei Song, Yi Yang, Xiaojie Gao, Yasen Wang,

Optimization of hexaaluminate catalytic activity in hydrogen production from methane through bimetallic synergy effects,

Journal of the Energy Institute,

Volume 119,

2025,

101958,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2024.101958.

(https://www.sciencedirect.com/science/article/pii/S1743967124004367)

Abstract: Hydrogen plays an important role in developing low-carbon economy and solving environmental pollution. To promote hydrogen production, LaFexCo3-xAl9O19 (x = 0.5, 1.5 and 2.5) catalyst was prepared and loaded on SiC ceramic foams to realize the efficient partial oxidation of methane. The effect of Fe and Co ratio on catalytic performance was investigated at different operating conditions and the samples before and after the reactions were characterized for the catalytic activity analysis. Results indicated that the catalytic performance increased with the increasing of Fe content, and the LaFe2.5Co0.5Al9O19 showed the best catalytic activity. The highest H2 concentration of 14.9% was obtained, which was 16% higher than that of the inert group. The appropriate addition of Co increased the reducibility of Fe and enhancing the synergy effects of Fe and Co. However, the sintering and carbon deposition phenomenon after reaction was more obvious for the excess Co of LaFe0.5Co2.5Al9O19 so that the catalytic performance was reduced due to the occupation of the surface active site. The increasing of equivalence ratio and inlet velocity was beneficial to the improvement of hydrogen concentration and reforming efficiency. And the peak temperature was nearly proportional to the inlet velocity.

Keywords: Hexaaluminate catalyst; Catalytic activity; Porous media; Efficient combustion; Partial oxidation

Merve Doğan Özcan, Orhan Özcan, Ayşe Nilgün Akın,

Effect of H2S on oxidative steam reforming of biogas for syngas production over MgAl-supported Ni–Ce-based catalysts,

International Journal of Hydrogen Energy,

2025,

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ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.156.

(https://www.sciencedirect.com/science/article/pii/S0360319925001764)

Abstract: This study investigates the effect of hydrogen sulfide (H2S) on the oxidative steam reforming (OSR) of biogas over particulate and monolithic NiCe/MgAl catalysts synthesized via the sol-gel method followed by the incipient wetness impregnation. Catalytic performance was evaluated in a flow reactor at 600 °C, 700 °C, and 800 °C under a constant space velocity of 45,000 mL gcat-1 h-1 and a CH4/CO2/O2/H2O molar feed ratio of 1/0.67/0.1/0.3, under H2S concentrations of 0, 12, and 50 ppm. Characterization was conducted using N2 physisorption, XRD, SEM, TGA, XPS and ICP-OES. Monolithic NiCe/MgAl (NCMA) exhibited reduced carbon deposition across all temperatures, whereas particulate NCMA achieved the highest CH4 (94%) and CO2 (80%) conversions at 800 °C. With 12 ppm H2S, particulate NCMA showed only a 10% decrease in CH4 conversion after 270 min. At 50 ppm H2S, both catalysts experienced significant deactivation, with CH4 conversion declining by approximately 50% after 270 min.

Keywords: Biogas; H2S; Oxidative steam reforming; Syngas; Ni–Ce-based catalysts

Mina Karaminejad, Reza Golhosseini, Fereshteh Meshkani, Patrick Da Costa,

Insight into the moderate interaction between the metal and support and reinforcing of Ni/SiO2-based catalysts efficiency with the manganese integration in thermal catalytic methane decomposition,

Energy Conversion and Management,

Volume 323, Part A,

2025,

119229,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119229.

(https://www.sciencedirect.com/science/article/pii/S0196890424011701)

Abstract: Developing an environmentally friendly and highly efficient catalyst is crucial for generating clean hydrogen without COx and structured carbon. The catalytic decomposition of methane encourages technology to convert natural gas into these valuable products. For this purpose, surface defects in activating CH4 have garnered much interest in developing silica-supported nickel catalysts by maintaining active sites and modulating metal-support interaction (MSI). Thus, It is shown here that the presence of Mn improved the reducibility of superficial NiO and created a moderate interaction between Ni and the support, decreasing the electron density around the Ni atom and elevating surface oxygen species’ presence by introducing lattice defects, thus facilitating the reduction, promoting the dissociation of methane on the nickel surface and enhancing the reactivity of the reaction Consequently, this MSI modulate stabilized the active sites, preventing quick sintering under reaction conditions. Based on TEM analysis, the surface morphology revealed well-dispersed metallic Ni and the restriction of Ni crystal growth. The strong metal-support interaction resulted in a high carbon diffusion driving force, providing more sites for growth in carbon nanofiber (CNFs). Maintaining the balance between the infiltration of dissolved carbon and the expansion of CNFs while also preventing the deactivation of the catalyst due to the covering of active sites by channeling carbon deposits towards the edges of the active sites and oxidation of coke produced by active oxygen species, all showed the effective presence of manganese in the catalyst’s configuration.

Keywords: H2 Production; Metal-Support Interactions; Superior Stability; CNF Growth; Mn Doping

Changchang Yang, Fukang Guo, Chunhuan Luo, Qingquan Su,

A novel two-step Ru/Al2O3 catalyst impregnation method for CO selective methanation,

International Journal of Hydrogen Energy,

Volume 97,

2025,

Pages 845-855,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.11.411.

(https://www.sciencedirect.com/science/article/pii/S0360319924051073)

Abstract: CO selective methanation (CO-SMET) is an important method for removing CO from reforming gases. Ru/Al2O3 catalyst prepared by the conventional impregnation method is the most commonly used CO-SMET catalyst and exhibits a spontaneous eggshell-type distribution due to the strong interaction between Ru and Al2O3. The eggshell-type Ru/Al2O3 catalysts exhibited reduced catalytic activity at a high Ru loading due to the agglomeration of Ru at the thin eggshell layer, making it difficult to meet practical CO removal requirements. To address this, four types of acids were individually introduced into the impregnation solutions to weaken the strong interaction between Ru and Al2O3. The prepared catalyst introduced with HNO3 exhibited a near-uniform distribution and relatively high catalytic activity, but low CO selectivity. Subsequently, a two-step impregnation method was proposed to form a unique distribution. The prepared Ru/Al2O3 catalyst with a Ru loading of 1.5% demonstrated an excellent CO-SMET performance by removing CO to below 10 ppm with a wide temperature range of 213 °C–257 °C, corresponding to CO selectivity ranging from 87.5% to 64.4%.

Keywords: CO selective methanation; Ru/Al2O3; Eggshell-type catalysts; Catalytic activity

Peng Cheng, Mao Gan, Chenghong Shu, Chenyu Ding, Qi Chen, Yingchun Xu, Lihong Huang, Ning Wang,

Layered perovskite-derived Ni/La2-2xPr2xO3 catalysts for hydrogen production via auto-thermal reforming of acetic acid,

International Journal of Hydrogen Energy,

Volume 104,

2025,

Pages 13-22,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.07.382.

(https://www.sciencedirect.com/science/article/pii/S0360319924030714)

Abstract: Auto-thermal reforming (ATR) is an effective route to extract hydrogen from acetic acid (HAc) from bio-oil. Nickel-based catalysts were found active for conversion of HAc via the ATR process. However, the main concerns, such as carbon deposition and sintering, led to deactivation of catalysts. Herein, to address these issues, a series of (La,Pr)2NiO4 layered perovskites and the derived catalysts of Ni/La2-2xPrxO3 were prepared, and evaluated by ATR. It was found that with Pr entering the La2O3 lattice, the reduction temperature of Ni oxide was decreased with improved dispersion of Ni0; meanwhile, lattice defects were found within La2-2xPr2xO3, and oxygen vacancies were formed with more reactive oxygen species, promoting gasification of coking precursors. The lower formation energy of oxygen vacancy over Pr-doped La2O3 support was further proved by DFT, confirming the improved oxygen vacancies. Therefore, the Ni0·8La1.35Pr0.73O3.92±δ catalyst exhibited excellent catalytic performance along with a stable HAc conversion near 100% and a hydrogen yield around 2.49 mol-H2/mol-HAc, while no coking was detected.

Keywords: Acetic acid; Oxygen vacancy; Auto-thermal reforming; Layered perovskite-Derived catalyst; Hydrogen production

Muhammed Arslan, Ceyhun Yilmaz,

Evaluation of multi–hydrogen production for Afyon biogas plant from excess methane and by–product hydrogen sulfide through desulfurization process,

Process Safety and Environmental Protection,

Volume 193,

2025,

Pages 1139-1156,

ISSN 0957-5820,

https://doi.org/10.1016/j.psep.2024.11.088.

(https://www.sciencedirect.com/science/article/pii/S0957582024015088)

Abstract: This study presents a detailed computational simulation of a hybrid hydrogen production system that integrates steam methane reforming (SMR) and hydrogen sulfide (H₂S) electrolysis, coupled with waste heat recovery, at the Afyon Biogas Power Plant (ABP). The plant operates with a capacity of 4000 kW and an exhaust gas temperature of approximately 767 K, converting 55 % of the biogas to energy, constrained by the limitations of both the turbine and biogas plant operations. Despite these constraints, a methane yield of up to 75 % from biomass is achievable. The surplus methane is converted into blue hydrogen via SMR, while H₂S, a byproduct of biogas production, undergoes electrolysis to generate green hydrogen. Additionally, gray hydrogen is separated and stored during the biogas production process. The system achieves a hydrogen production rate of 0.061 kg/s through optimization, comprising 91.4 % blue hydrogen, 8.18 % gray hydrogen, and 0.41 % green hydrogen. The energy and exergy efficiencies of the primary system are calculated to be 26.23 % and 22.99 %, respectively. The integration of waste heat recovery enhances these efficiencies to 76.21 % and 42.96 %. A techno-economic analysis indicates that the cost of electricity is 0.04644 $/kWh, while the average hydrogen production cost is 2.05 $/kg. The total investment cost (TIC) amounts to 21,177,230 $, with an estimated annual revenue of 4,702,000 $, yielding a payback period of 4.405 years. This study demonstrates the efficiency and economic feasibility of hydrogen production from waste products at the biogas plant, underscoring the viability of the proposed investment.

Keywords: Biogas energy; Hydrogen energy; Thermodynamic analysis; Techno-economic analysis

Talita Nimmas, Suwimol Wongsakulphasatch, Merika Chanthanumataporn, Sakhon Ratchahat, Worapon Kiatkittipong, Sumittra Charojrochkul, Sibudjing Kawi, Suttichai Assabumrungrat,

Enhanced NiO-CaO-based multifunctional material pellets with Ce and La oxides on aluminosilicate support for sorption-enhanced chemical looping steam reforming of glycerol,

Chemical Engineering Journal,

Volume 503,

2025,

158237,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2024.158237.

(https://www.sciencedirect.com/science/article/pii/S1385894724097286)

Abstract: Multifunctional materials in pellet form composed of NiO-CaO-based aluminosilicate support have been developed for hydrogen (H2) production via sorption-enhanced chemical looping steam glycerol reforming (SE-CL-SGR). The effect of CaO content (50–70 wt%) and an addition of promoter (CeO2 and La2O3) on material properties and H2 production performances were investigated. A good H2 production of 90 %v/v purity for 75 mins has been achieved from 15 wt% NiO, 70 wt% CaO, and 30 wt% aluminosilicate support (15Ni(70Ca.30S)) pellets. However, it totally showed a loss of CO2 adsorption ability by the 5th cycle as a formation of carbon caused the pellet cracking. Rare-earth oxides such as CeO2 and La2O3 have been incorporated into the structure to improve the mechanical properties. An addition of 5 wt% La2O3 (5La-15Ni(70Ca.30S)) provides superior H2 production performance to that with CeO2 and without rare-earth as 95 %v/v H2 purity can be constantly produced for 60 mins throughout five testing cycles. These enhancements indicate that the CeO2 and La2O3 modifications effectively improve the multifunctional material pellet performance and stability, making it suitable for large-scale hydrogen production applications.

Keywords: Sorption-enhanced chemical looping steam reforming; Glycerol; NiO-CaO-based multifunctional material pellets; Hydrogen; CO2 capture

Shafqat Ullah, Yongqi Pan, Qiangqiang Xue, Tianyi Huang, Yizhi Hu, Runping Ye, Yujun Wang, Guangsheng Luo,

The structure activity relationship of promoted La doped Ni-CeO2 catalysts prepared by continuous-flow microreactor for low temperature CO2 methanation,

Fuel,

Volume 379,

2025,

133034,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133034.

(https://www.sciencedirect.com/science/article/pii/S0016236124021835)

Abstract: CO2 methanation has emerged as a key strategy for its potential uses and ability to alleviate climate change by reducing CO2 emissions. Herein, we present a controllable and continuous improved coprecipitation catalyst preparation method employing a T-junction microreactor to investigate La doped Ni-CeO2 catalysts. A series of catalysts was systematically synthesized, with Ni/CeLa (5:5) emerging as the most promising candidate, exhibiting 76 % CO2 conversion at 250 °C and 60.5 mmol/gcat.h space–time yield of methane. Different structural characterization techniques, including in-situ Raman, Quasi in-situ XPS, in-situ DRIFTS, and DFT calculations were employed to unravel the structure activity mechanisms contributing to the enhanced catalytic performance. The findings indicate that the introduction of La as a dopant reduces particle size, promotes Ni dispersion, and increases interfacial sites. These enriched interfacial sites contribute a pivotal role in facilitating the adsorption and hydrogenation of bicarbonate species, ultimately leading to improved methanation performance. This study not only highlights the efficiency of the La doped Ni-CeO2 catalyst, but it also gives valuable insights for chemical strategy to improve structure activity relationships and mechanism studies for efficient CO2 methanation performance.

Keywords: Microreactor; La doped Ni-CeO2 catalysts; CO2 methanation; Low temperature hydrogenation; Bicarbonate species; Interfacial sites

Thitiporn Suttikul, Chantaraporn Phalakornkule,

Chapter 2 - Plasma-assisted CO2 reforming of methane,

Editor(s): Ghulam Yasin, Duc Ba Nguyen, Ram K. Gupta, Saira Ajmal, Tuan Anh Nguyen,

Energy From Plasma,

Woodhead Publishing,

2025,

Pages 37-68,

ISBN 9780443265846,

https://doi.org/10.1016/B978-0-443-26584-6.00002-6.

(https://www.sciencedirect.com/science/article/pii/B9780443265846000026)

Abstract: Global climate change is primarily caused by two primary greenhouse gases: carbon dioxide (CO2) and methane (CH4). The process of simultaneously converting CO2 and CH4 into syngas and higher hydrocarbons, known as dry reforming of CH4 (DRM) or CO2 reforming of CH4 has drawn the interest of researchers. Dielectric barrier discharge (DBD), a form of nonthermal plasma, has emerged as a potentially effective method for initiating DRM reactions under ambient conditions. This technique offers the advantages of decreased energy consumption and diminished catalyst deactivation. Moreover, the catalyst and plasma contribute to a synergistic effect that enhances the efficiency of the reaction and decreases coke formation. This chapter provides a summary of the plasma-assisted CO2 reformation of CH4 in a parallel plate DBD system. It includes details on process performance parameters and examination of the DBD for DRM with and without Ni-based catalysts. In conclusion, future work prospects that emphasise reducing coke formation and increasing DRM efficiency are discussed.

Keywords: Dry reforming of methane; dielectric barrier discharge; plasma catalysis; Ni catalyst/ promoters

Shu-nan Yin, Jinxian Zhao, Shiping Wu, Xiaoxia Han, Jun Ren,

Fabrication of highly efficient Ni/Al2O3 catalysts for the CO2 methanation reaction using atomic layer deposition technology,

Chemical Engineering Journal,

Volume 504,

2025,

158723,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2024.158723.

(https://www.sciencedirect.com/science/article/pii/S1385894724102148)

Abstract: Ni/Al2O3 catalysts with lower Ni loading have been fabricated using atomic layer deposition (ALD) technology and applied toward CO2 methanation reaction. The Ni250/Al2O3-ALD catalyst exhibits a remarkably high CH4 selectivity of 93.7 % and comparable CO2 conversion of 90.2 % at 360 °C and 0.5 MPa when compared to Ni/Al2O3-IMP with an identical Ni loading prepared via the impregnation method. The abundant Ni-Al2O3 interface caused by the ultrahigh uniform dispersion of Ni provided an adequate number of adsorption sites for CO2. More importantly, the single Ni atoms and small Ni nano-clusters (ca. 1.7 nm) strongly adsorbed the key CO\* intermediates, which resulted in the highly selective production of CH4 on the Ni250/Al2O3-ALD catalyst. Moreover, the higher concentration of oxygen vacancies and moderate basic sites also played pivotal roles toward enhancing the hydrogenation activity during the CO2 methanation reaction. Our results provided a convenient strategy for the construction of promising Ni-based catalysts for CO2 abatement.

Keywords: Atomic layer deposition (ALD); CO2 methanation; Ni catalyst; Ni-Al2O3 interface; Oxygen vacancies

J. Palo, M. Reinikainen, S. Rautiainen, A.T. Pasanen, D. Baudouin, H. Grénman, J. Lehtonen,

Aqueous-phase reforming of methanol, acetic acid, 4-methylcatechol, and phenol over supported nickel and platinum catalysts,

Applied Catalysis A: General,

2025,

120172,

ISSN 0926-860X,

https://doi.org/10.1016/j.apcata.2025.120172.

(https://www.sciencedirect.com/science/article/pii/S0926860X25000730)

Abstract: The aqueous phase reforming of methanol, acetic acid, phenol, and 4-methylcatechol was studied to evaluate the potential of using process water from hydrothermal liquefaction of black liquor for hydrogen production. Various catalysts, including Cu- or Co-doped nickel and commercial Pt/AC, were tested under plug-flow conditions (230 °C, 32 bars). The platinum catalyst showed superior stability, maintaining high conversion with methanol and acetic acid. However, it showed no activity with phenol and deactivated rapidly when exposed to 4-methylcatechol. Doped nickel catalysts experienced severe deactivation, particularly with acetic acid and phenolic compounds. While nickel catalyst deactivated in the presence of acetic acid, Pt showed stable conversion but favored decarboxylation reaction. APR of methanol primarily produced H2 and CO2, with NiCu/γ-Al2O3 being the most selective for H2. Co-doped nickel favored hydrogenation, forming CH4 and thus reducing H2 yield. APR of phenol and 4-methylcatechol produced H2, CO2, and hydrodeoxygenated or hydrogenated liquid products.

Keywords: APR; black liquor; hydrogen; copper; cobalt; deactivation

Zezhong John Li, Jong In Jeon, Arian Ebneyamini, C. Jim Lim, Naoko Ellis, John R. Grace, Jun Young Kim,

Kinetic-embedded CFD modeling of integrated steam methane reforming and limestone calcination in a fluidized bed reactor,

Chemical Engineering and Processing - Process Intensification,

Volume 209,

2025,

110190,

ISSN 0255-2701,

https://doi.org/10.1016/j.cep.2025.110190.

(https://www.sciencedirect.com/science/article/pii/S0255270125000406)

Abstract: The combination of limestone calcination, catalytic methane reforming, and combustion in one reactor (MRCCAL) was previously proposed to achieve autothermal and hydrogen-producing sorbent regeneration for calcium-looping technology. However, this technology was only assessed using kinetic-only simulations. To further evaluate its viability, the present study developed an Eulerian-Eulerian CFD model with full reaction kinetics in a bubbling fluidized bed reactor. Three different operating parameters were studied: the inlet gas velocity, the sorbent to catalyst ratio, and the sorbent calcination extent. CFD simulations demonstrated that increasing the inlet gas velocity increased the H2 production by altering the particle distribution through the bed. Decreasing the catalyst-to-sorbent ratio improved local mixing whereas the catalyst tended to locate at the bottom of the bed where an increased total solid holdup was also found. Sorbents with higher calcination extent led to a decreased CO2 composition in the off-gas whilst increasing the H2 composition. When compared with kinetic-only simulations of a continuous reactor, the CFD results showed a noticeable discrepancy in the gas compositions mainly due to the free gas expansion and the more rigorous calculation of the particle mixing patterns, which were not included in the kinetic simulations. The sharp differences emphasized the importance of hydrodynamics in developing novel processes.

Keywords: Computational fluid dynamics; Steam methane reforming; CO2 capture; Modeling

Jamna Prasad Gujar, Aniket verma, Bharat Modhera,

Optimizing glycerol conversion to hydrogen: A critical review of catalytic reforming processes and catalyst design strategies,

International Journal of Hydrogen Energy,

Volume 109,

2025,

Pages 823-850,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.02.077.

(https://www.sciencedirect.com/science/article/pii/S0360319925006421)

Abstract: The global energy transition highlights the importance of sustainable hydrogen production methods in combating environmental challenges. This paper is a critical review of the catalytic reforming of glycerol-an abundant cheap by-product of biodiesel-as a promising clean hydrogen production route. These are: several reforming techniques such as steam reforming (SR), partial oxidation reforming (POR), auto-thermal reforming (ATR), aqueous phase reforming (APR) and supercritical water reforming (SCWR), which are evaluated in detail and compared for the purpose of high hydrogen yield and maximum glycerol conversion: In efficiency, selectivity, and stability, the function of the catalyst plays the greatest part in the successful accomplishment of these processes. The paper addresses innovations with nickel-based catalysts, 15 wt%Ni/Al2O3 and 15 wt%Ni/γ-Al2O3. It has shown successful performances above positive conditions. Besides, it also identifies the ways towards overcoming obstacles in this sense. It also puts greater emphasis on modern catalyst designing methods such as addition of a promoter, utilization of porous supports, and doping for improvement. This study also shows a high transformative potential of AI/ML in the research and development processes. Moreover, AI/ML tools open new possibilities in optimizing the glycerol reforming process through high-throughput material screening, accurate control of reaction parameters, and predictive modeling of catalytic behaviour. This research highlights the importance of glycerol reforming in addressing waste management issues inherent in the biodiesel industry and becoming a foundational technology toward an economy of hydrogen.

Keywords: Catalytic conversion; Glycerol (C3H8O3); Hydrogen (H2); Reforming processes (RP); Catalyst (ni/Al2O3), environmental sustainability

M.A. Aziz, A.A. Jalil, N.S. Hassan, M.B. Bahari, T.A.T. Abdullah, N.W.C. Jusoh, Y. Nagao, K. Aoki, S. Nishimura, Rajendran Saravanan,

Isomorphously substituted cerium induced oxygen vacancy and medium basicity in Ni/fibrous silica catalyst for superior low-temperature CO2 methanation,

Applied Catalysis A: General,

Volume 689,

2025,

120019,

ISSN 0926-860X,

https://doi.org/10.1016/j.apcata.2024.120019.

(https://www.sciencedirect.com/science/article/pii/S0926860X24004642)

Abstract: A series of promoters (Ce, La, Mo, and Zr) was introduced into the Ni/CHE-SM catalyst by using the impregnation method and tested for CO2 methanation. Among these, Ni-Ce/CHE-SM possessed a high CO2 conversion of 80 % at 250 °C, signifying its potential at low temperature. The superior performance of Ni-Ce/CHE-SM was attributed to the formation of Si-O-Ni and Si-O-Ce species, as confirmed by FTIR-KBr analysis. XPS and CO2-TPD analyses revealed an abundance of oxygen vacancies existed within Ni-Ce/CHE-SM, resulting in enhancement of basicity amount and strength. In addition, Raman analysis showed the existence of three and four silica member rings which was believed that the Si atom be substituted with the Ce atom, thus contributing to create more oxygen vacancies. Hence, additional active sites were provided which enhance the adsorption of reactant molecules and improve the production of CH4, thus emphasizing the greater potential of Ni-Ce/CHE-SM in CO2 methanation application.

Keywords: Isomorphous substitution; Cerium; Basicity; CO2 methanation; Oxygen vacancy

Nikita V. Makolkin, Alexey P. Suknev, Ekaterina M. Sadovskaya, Dmitriy A. Yatsenko, Pavel S. Ruvinskiy, Maxim A. Panafidin, Vladimir S. Derevschikov,

CO2 methanation on Ni/Y2O3 Catalysts: The effects of preparation procedure and cerium oxide promotion,

Chemical Engineering Science,

Volume 301,

2025,

120672,

ISSN 0009-2509,

https://doi.org/10.1016/j.ces.2024.120672.

(https://www.sciencedirect.com/science/article/pii/S0009250924009722)

Abstract: Present paper reports on the CO2 methanation (CME) performance of novel Ni catalysts supported on yttria, ceria, and ceria-doped yttria carriers. Catalysts were synthesized using incipient wetness impregnation and precursor nitrate co-decomposition. These systems outperformed on a mass-specific basis an industrial Ni/alumina benchmark catalyst. In addition, this work examines in details the impact of both the preparation procedure and the Ni-content on the CME activity both in terms of the reaction rate and the apparent activation energy. Our research demonstrates that Y2O3 is an effective catalytic support promoting stability and activity of the catalysts. CeO2–doping further improves activity, remarkably with little to no penalty to the thermal stability of the catalysts. Comparison of the performance of a conventional IWI-synthesized Ni-catalyst with a counterpart obtained via a co-decomposition route, demonstrated an advantage of the latter. Our findings suggest Ni-CeO2/Y2O3 prepared via co-decomposition may be advised as the active and stable catalysts for CME applications.

Daniela De Cata, Leone Mazzeo, Vincenzo Piemonte, Alberto Giaconia,

Electrified steam methane reforming as efficient pathway for sustainable hydrogen production and industrial decarbonization: A critical review,

International Journal of Hydrogen Energy,

Volume 105,

2025,

Pages 31-44,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.202.

(https://www.sciencedirect.com/science/article/pii/S0360319925002228)

Abstract: Hydrogen (H2) is a promising candidate for decarbonizing energy systems due to its high energy density and zero CO2 emissions upon combustion. However, the current paradox is that primary H2 synthesis relies on fossil fuels, accounting for 96% of global production, primarily through Steam Methane Reforming (SMR). The conventional SMR process is energy-intensive and contributes significantly to global CO2 emissions. Electrified steam methane reforming (eSMR) emerges as an effective alternative, as conventional furnaces are replaced with electric heating systems. The process electrification contributes to the decarbonization of energy-intensive industrial sector by leveraging renewable energy integration into the electric grid. Furthermore, eSMR overcomes limitations present in traditional SMR, such as inefficient heat transfer and the impact of the economy of scale. This review critically analyses the potential of eSMR for decarbonization and process intensification, providing insights into the most reported electrification techniques, technological advancements, limitations, and considerations for industrial scale-up perspectives.

Keywords: Green hydrogen; Joule heating; Induction heating; Renewable energy; Electrification; Biomethane

Syed Muhammad Wajahat ul Hasnain, Ahmad Salam Farooqi, Bamidele Victor Ayodele, Herma Dina Setiabudi, Abid Salam Farooqi, Rayed S. Alshareef, Bawadi Abdullah,

Synthesis, characterization, and catalytic performance of Ni supported on sustainable POFA-derived SBA-15 for hydrogen-rich syngas from CO2 reforming of methane,

Journal of Industrial and Engineering Chemistry,

Volume 141,

2025,

Pages 104-120,

ISSN 1226-086X,

https://doi.org/10.1016/j.jiec.2024.06.021.

(https://www.sciencedirect.com/science/article/pii/S1226086X2400409X)

Abstract: Palm Oil Fuel Ash (POFA) is massively produced by numerous palm oil mills worldwide, creating an environmental waste disposal problem. Notably, POFA serves as a cost-effective alternative silica source instead of the expensive tetraethyl orthosilicate (TEOS). This research focused on synthesizing SBA-15 from POFA waste and examining the effect of promoters on POFA-derived SBA-15-supported Ni-based catalysts. The 10 wt% Ni/SBA-15-POFA catalyst was sequentially impregnated with promoters having 1 wt% loading of Zr, Ce, La, and Cr. The catalysts were tested for CO2 methane reforming (CMR) at 800 °C for 8 hours while maintaining a stoichiometric feed ratio. Various characterization techniques, including XRD, FESEM, XPS, H2-TPR, CO2-TPD, and BET analysis were employed to assess the catalyst physicochemical properties. The addition of promoter changed the properties of catalyst. Except for Cr-promoted catalyst, the addition of promoters positively impacted catalytic performance, activity, and stability. XRD analysis showed that Cr addition had detrimental effects on the crystallite structure of the Ni/SBA-15-POFA catalyst. In contrast, Zr, Ce, and La additions significantly reduced the crystallite size and improved active metal dispersion. Overall, the Zr-promoted catalyst exhibited the best performance in terms of activity and stability, with a CH4 conversion of 90 % and CO2 conversion of 94.4 %. The spent catalyst characterization, including XRD, FESEM, O2-TPO, and RAMAN, showed that promoter addition significantly reduced carbon deposition. The stable and superior perfromance of Zr-promoted catalyst was attributed to the production of MWCNTs. Conversely, the rapid deactivation of the unpromoted catalyst may be due to the formation of amorphous carbon, which tends to quickly block active sites and reduce the catalytic activity.

Keywords: CMR; Reforming; Promoter; POFA; Syngas; Waste utilization

Faisal Khan, Osama Khan, Mohd Parvez, Hamad Almujibah, Praveen Pachauri, Zeinebou Yahya, Taufique Ahamad, Ashok Kumar Yadav, Ümit Ağbulut,

Innovative hydrogen production from waste bio-oil via steam methane reforming: An advanced ANN-AHP-k-means modelling approach using extreme machine learning weighted clustering,

International Journal of Hydrogen Energy,

Volume 105,

2025,

Pages 1080-1091,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.269.

(https://www.sciencedirect.com/science/article/pii/S0360319925003039)

Abstract: Steam Methane Reforming (SMR) is an established, cost-effective technique where methane or hydrocarbons react with steam, producing mostly hydrogen and carbon monoxide. This research explores hydrogen production through SMR applied to bio-oil, particularly from pyrolysis of various biomass sources. The methodology employs similarity analysis to select suitable bio-oils, which are then tested for hydrogen production using SMR. The results are analyzed through Pearson's R correlation plot to establish relationships, while the Analytic Hierarchy Process (AHP) prioritizes different outcomes. This prioritization is applied in k-means clustering to categorize bio-oils, enabling comparative performance assessments. Correlation analysis shows a strong positive correlation between CH₄ conversion and energy efficiency (r = 0.97219), indicating that optimizing methane conversion improves the overall process efficiency. AHP analysis ranks CO yield (0.5) as the most significant performance factor, followed by hydrogen yield (0.35), CH₄ conversion (0.25), and energy efficiency (0.15). k-Means clustering identified Jatropha Press Cake, Hemp Residue, and Eucalyptus Leaves as efficient bio-oils for hydrogen production. In the Artificial Neural Network (ANN) prediction model, Jatropha Press Cake is recognized as the most effective biomass for hydrogen production through SMR, achieving an RMSE of 0.48, an R2 value of 0.93, and a MAPE of 2.40%. Following closely is Hemp Residue, which has an RMSE of 0.52, an R2 of 0.91, and a MAPE of 2.80%. The study identifies Jatropha Press as the leading choice for hydrogen production from bio-oil, yielding 3.6 mol H₂/mole of biomass with a methane (CH₄) conversion rate of 82% and an energy efficiency of 66%. In comparison, Rice Bran demonstrates the least effective performance, achieving only 2.8 mol H₂/mole of biomass.

Keywords: Steam methane reforming; Biomass; ANN; Hydrogen yield; Energy efficiency; Machine learning

Hao Zheng, Atta Ullah, Xubin Zhang, Liang Zeng,

Ni-modified La2Ce2O7 oxygen carriers for chemical looping partial oxidation of methane,

International Journal of Hydrogen Energy,

Volume 104,

2025,

Pages 193-201,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.05.213.

(https://www.sciencedirect.com/science/article/pii/S0360319924019001)

Abstract: Chemical looping partial oxidation of methane (CLPOM) is an attractive approach for efficient production of syngas with a suitable H2/CO ratio. In this paper, the surface and bulk properties of La2Ce2O7 oxygen carrier were modified by NiO to promote its ability of methane activation and increase the availability of lattice oxygen. With the introduction of NiO, methane conversion increased by about three times compared to La2Ce2O7, with the H2/CO ratio remaining around 2. The doping effect on the structural characteristics was investigated by experimental characterization. The characterization results indicated that the surface Ni species promoted the activation of methane and its reaction with lattice oxygen while the bulk Ni species could weaken the strength of the Ce–O bond. This work illustrates that regulating the surface catalytic sites and bulk lattice oxygen availability of the oxygen carriers through doping is an effective strategy for modulating the CLPOM performance of oxygen carriers.

Keywords: Chemical looping; Partial oxidation; Oxygen carrier

Haowei Zhang, Marcos Millan, Ziyin Chen, Tiantian Li, Zhengwei Cui, Guanming Yuan,

Steam reforming of glycerol for co-producing hydrogen and carbon nanotubes over nanoscale Ni-based catalysts: Insights into support effect and carbon deposition,

International Journal of Hydrogen Energy,

Volume 105,

2025,

Pages 896-909,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.352.

(https://www.sciencedirect.com/science/article/pii/S0360319925003957)

Abstract: Glycerol, a major byproduct of biodiesel production, is commonly used as an inexpensive feedstock for hydrogen (H2) production through catalytic reforming. Developing efficient Ni-based catalysts with appropriate supports remains a challenge. In this study, three Ni-based catalysts, each containing 10 wt% Ni with different supports: carbon nanofibers (Ni@CNF), activated carbon (Ni/AC), and alumina (Ni/γ-Al2O3), were comparatively evaluated for their effectiveness in the catalytic steam reforming of glycerol. The results show that both the catalyst support and the reforming temperature influence the co-production of H2 and carbon nanotubes. All three catalysts exhibit good catalytic performance of H2 production at 700 °C for 1 h. The corresponding H2 yields, based on a steam-glycerol molar ratio of 11.9 and a flow rate of 0.2 mL/min, are 86.5%, 81.3%, and 69.2% for Ni@CNF, Ni/AC, and Ni/Al2O3, respectively. Ni@CNF demonstrates high H2 production and good catalytic stability, whereas Ni/Al2O3 generates high-yield carbon nanotubes.

Keywords: Glycerol steam reforming; Ni-based catalyst; Support effect; Porous carbon nanofibers; Hydrogen production; Carbon nanotubes

Md Jahiruddin Gazi, Anushka Bahuguna, Satyajit Panda, Bharat Singh Rana, Desavath Viswanatha Naik, Sahil Bhandari, Ankur Bordoloi,

Synthesis of Ni-Fe particle embedded CNx matrix for efficient catalytic methane decomposition,

International Journal of Hydrogen Energy,

Volume 101,

2025,

Pages 1518-1531,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.015.

(https://www.sciencedirect.com/science/article/pii/S0360319925000205)

Abstract: A series of three catalysts consisting of Ni and Fe nanoparticles with different compositions varied from 5 to 10% have been synthesized in situ on mesoporous CNx by using Si-Al2O3 as a hard template followed by a template-assisted modified solvothermal method. The nanomaterial-embedded mesoporous CNx catalysts are tested for H2 production from natural gas methane (CH4) via pyrolysis. The influence of the composition of active metals, weight hour space velocity, conversions, and catalytic stability was evaluated in the temperature range 700–850 °C with different weight hourly space velocities (WHSV) varying from 1200 to 2400 g−1 h−1. It was found that among the three catalysts, the catalyst having a composition of 7.5Fe-7.5Ni-CNx/Si-Al2O3 outperforms other catalyst formulations in terms of catalytic conversion (which was found to be around 75%) and stability. To understand the structure-activity correlation catalysts were exposed to various characterization techniques like ICP-AES, BET, XRD, SEM, Raman, XPS, and HRTEM after and before reaction studies. It is observed that the nano-sized active metal with the combination of carbon nitride matrix is responsible for the extended stability of the catalyst system.

Keywords: Ni-Fe nanoparticle; Mesoporous CNx; Methane pyrolysis; Hydrogen production; Solid carbon

Mingke Peng, Rui Han, Lifei Wei, Yang Wang, Zhiyong Li, Han Yan, Gaoqi Han, Qingling Liu,

Cu promoted Ni-Ca dual functional materials for integrated CO2 capture and utilization in O2-containing flue gas: Eliminating the delay in the utilization stage,

Separation and Purification Technology,

Volume 354, Part 8,

2025,

129516,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.129516.

(https://www.sciencedirect.com/science/article/pii/S1383586624032556)

Abstract: Integrating CO2 capture and utilization by dry reforming methane (ICCU-DRM) technology is promising in concentrating and utilizing diluted CO2 from flue gas, which depends on developing Dual Functional Materials (DFMs) with adsorption and catalytic sites. Ni-Ca materials are widely applied in ICCU-DRM due to their excellent catalytic and CO2 adsorption properties. Nevertheless, the challenge remains that oxygen in the actual flue gas would oxidize the active Ni, leading to a delay in the DRM stage. In this work, Cu-promoted, ZrO2-stabilized Ni-Ca based DFMs were developed, which suppressed the delay and enhanced the performance of the DRM reaction. Attribute to the excellent reducing properties, Cu could be rapidly reduced in the CH4 atmosphere and further promote the reduction of NiO to the catalytically active Ni monomers by activating methane to generate reactive hydrogen (H\*). What’s more, attributed to the disappearance of delay times, it is accompanied by a satisfying yield distribution with a 0.11 decrease in H2/CO ratio and an improvement in conversion, especially CH4 conversion with an increase of more than 10%. In addition, the bifunctional material also exhibits favorable cycling stability due to the stabilizers.

Keywords: Integrated CO2 capture and utilization; Dual functional materials; Methane activation; Cu; O2-containing flue gas

Shaoqin Chen, Yun Hang Hu,

Progress in the development of NiO/MgO solid solution catalysts: a review,

Surface Innovations,

2025,

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ISSN 2050-6260,

https://doi.org/10.1680/jsuin.24.00103.

(https://www.sciencedirect.com/science/article/pii/S2050626025000036)

Abstract: NiO/MgO solid solution materials have emerged as highly effective catalysts for various catalytic processes, including dry methane reforming, CO2 hydrogenation, methane partial oxidation, and steam reforming of hydrocarbons. The similar lattice parameters of NiO and MgO allow the formation of homogeneous solid solutions, where metallic Ni particles can be generated through the NiO reduction that is controlled by MgO isolation effect on NiO in the solid solution. The small size of these particles plays a crucial role in preventing carbon deposition and sintering in catalytic reactions. In this review, the basic principles of the formation of NiO/MgO solid solution, the reduction properties of the catalysts, and the insight into its high catalytic activity are elucidated. The synthesis methods of NiO/MgO solid solutions are presented. In addition, the recent progress of catalytic applications of NiO/MgO solid solutions is provided. By offering deep insights into solid solution catalysts, this review aims to facilitate their further development for diverse catalytic processes.

Keywords: carbon dioxide; catalysis; CO2 hydrogenation; dry methane reforming; materials science; nickel oxide; solid solution; steam reforming

Mingqiang Chen, Jinlong Wang, Yishuang Wang, Defang Liang, Peng Wang, Zhuowu Men, Xiaoxiao Sun, Chang Li, Haosheng Xin,

Effect of Pt content in Pt–Ni/sepiolite on hydrogen production from aqueous phase reforming of methanol,

International Journal of Hydrogen Energy,

Volume 109,

2025,

Pages 1-16,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.02.074.

(https://www.sciencedirect.com/science/article/pii/S0360319925006391)

Abstract: Exploring high-efficiency catalysts was the important problem in aqueous phase reforming of methanol (APRM). A series of sepiolite supported Pt–Ni (xPtNi/SEP, x = 0, 0.5, 1.0,1.5, 2.0, 2.5 wt%) catalysts were synthesized to research the effects of Pt content on catalyst microstructures. It demonstrated that the appropriate Pt content could optimize surface acidity/basicity, metal-support interaction and distributions of Ni0/Pt0 sites and oxygen vacancies. Amongst, 1.5PtNi/SEP exhibited the abundant active Ni0/Pt0 metal sites and oxygen vacancies and then presented the highest cumulative hydrogen production (97 mmol H2/gcat), methanol conversion (26.68 %) and the lowest CO concentration (0.52 %) during APRM at the optimized reaction conditions. Additionally, the Pt additive enhanced the catalytic dehydrogenation performance and promoted the WGS reaction, and the possible reaction mechanisms of APRM over 1.5PtNi/SEP were proposed.

Keywords: Aqueous phase reforming; Hydrogen production; Methanol; Ni-based catalysts; Sepiolite; Pt

Santiago Veiga, Mariano Romero, Darío Segobia, Carlos Apesteguía, Juan Bussi,

The promoting effect of magnesium on NiMgLaZr catalysts for biogas upgrading to syngas via a tri-reforming process,

Biomass and Bioenergy,

Volume 193,

2025,

107588,

ISSN 0961-9534,

https://doi.org/10.1016/j.biombioe.2024.107588.

(https://www.sciencedirect.com/science/article/pii/S0961953424005415)

Abstract: The effect of partial substitution of lanthanum by magnesium on the catalytic activity of the Ni-La2Zr2O7 catalyst in the biogas tri-reforming reaction was studied. Four catalysts, Ni-La2-xMgxZr2O7-δ (x = 0.25, 0.5, 0.75, and 1), were prepared using a modified polymeric precursor method, characterized using several techniques, and evaluated at 800 °C with a sub-stoichiometric molar feed composition of CH4/CO2/H2O/O2 = 1/0.33/0.33/0.08. The catalyst with x = 0.5 showed the best performance, which is attributed to its optimum properties of nickel particle size, metal-support interactions, and basicity. A stability test was performed with this catalyst using a molar feed composition of CH4/CO2/H2O/O2 = 1/0.33/0.67/0.08, previously optimized to obtain a synthesis gas with a H2/CO ≈ 2 molar ratio for 100 h, and compared with a commercial steam reforming catalyst. The catalyst with x = 0.5 exhibited higher CH4 and CO2 conversions, a lower amount of carbon deposited, and a lower degree of nickel particle sintering.

Keywords: Biogas; Syngas; Nickel catalysts; Tri-reforming

Yu Guan, Guoqiang Song, Claudia Li, Kang Hui Lim, Sonali Das, Poulomi Sarkar, Lina Liu, Huchao Song, Yixing Ma, Qiang Lyu, Yinhe Liu, Sibudjing Kawi,

Recent progress in single-atom catalysts for thermal and plasma-assisted conversion of methane,

Energy Conversion and Management,

Volume 325,

2025,

119390,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119390.

(https://www.sciencedirect.com/science/article/pii/S0196890424013311)

Abstract: Methane (CH4), a major component of natural gas and a potent greenhouse gas, poses significant environmental and industrial challenges. Catalytic conversion of CH4 emerges as a crucial strategy, contributing to the production of cleaner energy carriers and the synthesis of valuable product. In this context, single-atom catalysts (SACs) have gained prominence with their superior catalytic properties. This comprehensive review provides an in-depth exploration of SACs for thermal and plasma-assisted conversion of CH4. The review commences with the distinctive catalytic features exhibited by SACs. Subsequently, detailed discussions are presented on the design strategies and synthesis methods for developing SACs. Furthermore, a comprehensive examination is conducted on physicochemical characterization techniques specific to SACs. Importantly, this review comprehensively outlines the application of SACs for thermal and plasma-assisted conversion of CH4, encompassing their advantages in facilitating the conversion of CH4 into high value chemicals, as well as their utilization in various indirect (dry reforming of methane (DRM), steam reforming of methane (SRM) and partial oxidation of methane (POM)), and direct (oxidative routes and non-oxidative routes) CH4 conversion processes. Additionally, this review delves into the experimental techniques and theoretical research of density functional theory (DFT) to reveal the reaction mechanism of CH4 conversion on SACs. The synthesis of knowledge culminates in a summary of key findings and forward-looking perspectives. This comprehensive review aspires to provide guidance for the efficient conversion of methane through thermal/plasma catalysis using SACs.

Keywords: Single-atom catalysts (SACs); Thermal/plasma catalysis; Methane; Indirect conversion; Direct conversion

Ching Wei Low, Andrei Veksha, Rupendra Aryal, Wei Ping Chan, Grzegorz Lisak,

Catalytic reforming of biomass pyrolysis gas over Ni catalysts: Alumina, spent fluid catalytic cracking catalyst and char as supports,

Applied Catalysis A: General,

Volume 691,

2025,

120074,

ISSN 0926-860X,

https://doi.org/10.1016/j.apcata.2024.120074.

(https://www.sciencedirect.com/science/article/pii/S0926860X24005192)

Abstract: The potential replaceability of a Ni catalyst supported on commercial α-Al2O3 (Ni/Al2O3) by Ni on biomass-derived char (Ni/Char), and Ni on spent fluid catalytic cracking catalyst (Ni/FCC) for steam reforming of biomass pyrolysis gas was investigated (14 h at 850°C, steam/carbon ratio = 5). The catalysts reformed 60–80 % of C2-C5 hydrocarbons, producing 2.7–4.1 mg min−1 of H2. The reforming activity of Ni/Al2O3 and Ni/FCC was higher compared to Ni/Char, indicating the beneficial role of metal oxide supports. The use of Al2O3 and FCC resulted in a lower thermo-oxidative stability of coke formed on Ni/Al2O3 and Ni/FCC compared to Ni/Char. Furthermore, the deposited Ni showed higher stability towards oxidation by steam into NiO in case of Al2O3 and FCC compared to char. According to reforming activity, H2 production rate, coking, and Ni oxidation of the catalysts, FCC has better prospects as an alternative support in a reforming catalyst than char.

Keywords: Alumina; Catalytic steam reforming; Biomass pyrolysis gas; Char; Spent FCC catalyst

Snigdha Senapati, Koustuv Ray, Narayan C. Pradhan,

An energy-efficient aspen plus model for H2-rich syngas production via dry reforming of ethanol: A thermodynamic analysis,

International Journal of Hydrogen Energy,

Volume 98,

2025,

Pages 1107-1118,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.071.

(https://www.sciencedirect.com/science/article/pii/S0360319924052704)

Abstract: A sensitivity analysis on the dry reforming of ethanol is performed by examining the suitability of oxygen and steam as co-feed reactants. A desirable H2/CO molar ratio of 1 is obtained in the carbon-free zone by operating at 800 °C, 1 atm and oxygen/CO2/ethanol molar ratio of 0.20/1/1. On the other hand, a favorable H2/CO molar ratio of 2 is achieved by adding 2 moles of steam to an equimolar mixture of CO2-ethanol at 650 °C, and 1 atm pressure. This study aims to produce a tunable H2/CO molar ratio suitable for desired end-use industrial applications. Furthermore, the waste heat from the product stream utilized by the heat exchanger led to a net reduction in energy demand by 35% and 33%, when 0.20 mole of oxygen and 2 moles of steam were added respectively, at a reformer temperature of 800 °C, pressure of 1 atm and inlet CO2/ethanol molar ratio of 1. Therefore, DRE with co-feeding oxygen or steam could offer an economical alternative for syngas production compared to the traditional, energy-intensive dry reforming of methane.

Keywords: Dry reforming of ethanol; H2-rich syngas; Parametric sensitivity; Oxygen and steam; Carbon formation

Zhongqian Ling, Peng Yang, Ling Bo, Xinlu Han, Maosheng Liu, Guangxue Zhang, Jiangrong Xu,

Enhanced combustion of lean methane by La-based perovskite catalysts in a porous media burner,

Separation and Purification Technology,

Volume 360, Part 2,

2025,

131105,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.131105.

(https://www.sciencedirect.com/science/article/pii/S1383586624048445)

Abstract: Methane emissions from coal mining not only result in significant energy loss but also contribute substantially to the greenhouse effect. This study investigates the application of porous media combustion (PMC) technology for lean methane combustion, with a particular focus on La-based perovskite catalysts. The catalysts (LaFeO3, LaNiO3, and LaMnO3) were synthesized by impregnating them onto alumina spheres using a citric acid complexation impregnation method. Scanning electron microscopy (SEM) analysis revealed that these catalysts significantly enhanced the specific surface area of the porous media, thereby increasing the number of catalytically active sites and reaction interfaces, which in turn improved catalytic activity. Experimental results demonstrated that catalytic combustion improves cold-start response, flame stability, and temperature distribution compared to inert PMC. The catalytic system achieved faster stabilization, attributed to enhanced heat transfer and fuel oxidation. The catalytic burner exhibited a wider range of gas flow rates for flame stabilization (equivalence ratio: 0.325–0.45, gas flow rate: 22.5–75 cm/s) compared to the inert burner (equivalence ratio: 0.35–0.45, gas flow rate: 30–70 cm/s). Notably, the LaMnO3-loaded porous spheres demonstrated superior performance, reaching the highest combustion temperature of 1473 K and a methane conversion efficiency of 92.2 % at an equivalence ratio of 0.45 and a gas flow rate of 75 cm/s. This study highlights the potential of PMC catalyzed by La-based perovskite in treating low-concentration methane emissions, thereby contributing to cleaner combustion processes and environmental sustainability.

Keywords: Porous media combustion; Flame stabilization; Perovskite catalysts

César Rodríguez, Phillippe Bazin, Marco Daturi, Sonia Moreno, Rafael Molina,

Effect of CePr and CeZr promoters on NiCo oxycarbonates and growth of carbon structures in oxidative steam reforming of ethanol (OSRE),

Surfaces and Interfaces,

Volume 56,

2025,

105729,

ISSN 2468-0230,

https://doi.org/10.1016/j.surfin.2024.105729.

(https://www.sciencedirect.com/science/article/pii/S2468023024018844)

Abstract: The effects of incorporating CePr and CeZr promoters into a NiCo catalyst were studied for the oxidative steam reforming of ethanol (OSRE), as well as the growth of carbon structures during the reaction (in real time). Although the promoters do not alter the size of the metal (NiCo) particles, they significantly improve key catalytic properties such as reducibility and the density of strong basic sites. This directly influences the catalytic activity. The XPS analysis indicated the presence of Zr4+, Ce3+, Ce4+, Pr3+, and Pr4+, highlighting that the promoters favored a high proportion of oxygen vacancies, with CePr generating a redox couple for both species and CeZr only for Ce. The OSRE catalytic tests showed that the promoters increased in stability with a greater production of H2 (Selectivity of 59 %), CO2 (32 %), and CH4 (8 %) and with low amounts of CO (<2 %). A decreasing trend and subsequent stabilization were observed in the conversion and selectivity, which were attributed to the type of interaction of metallic particles where the low-interaction is deactivated, and the high-interaction prevails. The use of an infrared-thermogravimetric (AGIR) platform to monitor the growth of carbon structures in real time is an innovative approach. Clear evidence is provided regarding how this growth follows a logarithmic function and affects the stability of the catalyst, which is similar to the trend observed after 150 h of reaction in conventional TGA. This innovative approach not only optimizes ethanol conversion, but also provides a tool for designing more stable and efficient catalysts, with a direct impact on sustainable hydrogen production.

Keywords: Oxygen vacancies; Surface carbon; OSRE; NiCo-CeZr; NiCo-CePr

Mahendra Tiwari, Ravikrishnan Vinu,

In situ and Ex situ Catalytic Microwave Pyrolysis of Biomass Pellets using Ni/Al2O3 for Hydrogen and Bio-oil Production,

Journal of Analytical and Applied Pyrolysis,

2025,

107044,

ISSN 0165-2370,

https://doi.org/10.1016/j.jaap.2025.107044.

(https://www.sciencedirect.com/science/article/pii/S016523702500097X)

Abstract: Four different biomass feedstocks, viz., rice straw (RS), sugarcane bagasse (BG), pine wood (PW), and Prosopis juliflora (PJ), were pyrolyzed in a microwave reactor at 800 W- 800 °C, and the hydrogen generation potential was assessed under different conditions using Ni/α-Al2O3 catalyst. Uniquely, four different configurations were evaluated in this study, which include non-catalytic pyrolysis of biomass in powder and pellet forms, and catalytic pyrolysis of biomass pellets in in-situ and ex-situ modes. The hydrogen yield was high in the case of biomass pellets and in the presence of catalyst. The general trend was: (biomass pellets) In-situ > (biomass pellets) Ex-situ > biomass pellets > powder biomass. The heating rates also followed the above trend for all biomass feedstocks. Gas yield increased by 2-10% with pelletization of biomass, and 18-32% by the use of catalyst due to efficient cracking of the pyrolysis vapours. The H2:CO (mol/mol) ratio was higher in the case of in-situ pyrolysis mode, and the trend was: BG (1.60) > PW (1.52) > RS (1.32) ≈ PJ (1.31). In-situ catalytic pyrolysis of PW pellets yielded high amount of hydrogen (39 vol.%, 27.7g/kgbiomass). In-situ catalytic pyrolysis mode was effective for higher hydrogen yield due to better contact of the pyrolysates with the Ni catalyst that effectively promoted water gas shift reaction. Ex-situ catalytic pyrolysis of biomass pellets produced high yields of CO+CO2. Detailed bio-oil composition analysis revealed that the selectivity to phenolics in the bio-oil obtained from biomass pellets (64-71%) was more than that from biomass in powder form (51-61%). Notably, in-situ catalytic pyrolysis of pellets resulted in a sharp decline in phenolic selectivity (22-45%) accompanied by increased production of aliphatic oxygenates (38-52%), and mild increase in aliphatic hydrocarbons. This study proves that microwave-assisted pyrolysis of biomass pellets is a promising strategy for hydrogen generation at high yields with potential to reform the gases for further enhancement of hydrogen.

Keywords: Biomass; Catalytic pyrolysis; Microwave; Hydrogen; Ni/α-Al2O3; Bio-oil

Hao-Yu Lian, Shuo Geng, Yi-Zhi Wang, Yuan Lv, Hao-Chen Yang, He Zhang, Xiao-Qing Deng,

Plasma-enhanced methanol steam reforming over Pt/In2O3-ZnO/Al2O3 catalyst with ultralow Pt-loading for in-situ H2 production,

Chemical Engineering Journal,

Volume 503,

2025,

158479,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2024.158479.

(https://www.sciencedirect.com/science/article/pii/S1385894724099704)

Abstract: Methanol steam reforming (MSR) by plasma-catalysis is a promising route of in-situ hydrogen production that enables the safe storage and transportation of hydrogen. Pt-based catalysts have been considered suitable for MSR due to their excellent activation ability towards methanol, but they suffer from high costs. Non-thermal plasma has the ability to activate reactants which may allow efficient conversion of methanol with less Pt. Here we report a plasma-catalytic MSR process combining a Pt/In2O3-ZnO/Al2O3 catalyst which has an ultralow Pt-loading of ∼0.1 wt% with dielectric barrier discharge plasma. A comparative study of thermal- and plasma-catalysis shows that MSR is significantly enhanced by strong plasma-catalyst synergy. The product selectivity results reveal that MSR in plasma-catalysis is largely through the surface reaction on the catalyst rather than through the gas-phase reaction in plasma. The calculation of apparent activation energy (Ea) demonstrates that the plasma-catalytic condition obtains lower Ea of 33.8 kJ/mol than that in thermal-catalytic condition (93.3 kJ/mol), confirming a favorable MSR process under the action of plasma. The in-situ DRIFT spectra results confirm that plasma can substitute for Pt to activate methanol thus enables MSR on In2O3-ZnO/Al2O3 catalyst. Moreover, plasma can also activate water and help to form hydroxyl groups which is important for MSR. This might be one of the plausible explanations for the plasma-catalyst synergy in this work.

Keywords: Methanol steam reforming; Plasma-catalysis; Hydrogen production; Synergy effect

Zewen An, Jialu Li, Kun Wang, Xiaoying Yuan, Cuiping Wang, Qingjie Guo,

Effect of calcination temperature of red mud POC and hydrothermal pretreatment of wet sludge on syngas quality,

Journal of Analytical and Applied Pyrolysis,

Volume 187,

2025,

106993,

ISSN 0165-2370,

https://doi.org/10.1016/j.jaap.2025.106993.

(https://www.sciencedirect.com/science/article/pii/S0165237025000464)

Abstract: CaMn0.5Fe0.5O3-δ-type perovskite oxygen carriers (POCs) were prepared using red mud as the main raw material and configuring certain ratios of calcium and manganese elements followed by calcination under different temperatures. A series of experiments were conducted in a fixed bed reactor to prepare hydrogen-rich syngas from municipal wet sludge chemical looping gasification (CLG). The results showed that the calcination temperature has an important influence on the oxygen storage capacity of the modified red mud perovskite oxygen carrier. With the increase of calcination temperature, the oxygen decoupling capacity of the oxygen carrier continues to improve, but the catalytic performance continues to weaken. Compared with the POCs calcined at 1050 ℃ and 950 ℃, the quality of hydrogen-rich gas prepared by the POC calcined at 850 ℃ was better, with a hydrogen gas volume fraction of 44.7 %, exceeding the theoretical value of converting hydrogen elements contained in dry sludge into hydrogen gas. The lower calcination temperature makes POC have larger specific surface area and better catalytic performance, which is conducive to the catalytic reforming of gas components such as CH4 and CO. The hydrothermal pretreatment of sludge is beneficial to improve the specific surface area of sludge and thus to improve the quality of syngas. The syngas hydrogen gas volume fraction reached 59.9 % using the POC calcined at 850 ℃ with sludge hydrothermal pretreatment at 250 ℃, and the syngas calorific value reached 13.47 MJ/Nm³ . By balancing the carbon and hydrogen elements transferring after the wet sludge gasification, part of sludge moisture participated in the carbon gasification and methane reforming reactions, thereby increasing the hydrogen content in syngas. The study is of guiding significance for the selection of oxygen carriers and fuel pretreatment in CLG of wet sludge.

Keywords: Municipal wet sludge; Perovskite oxygen carrier; CLG; Hydrogen-rich synthesis gas

Dhok Ameya, Kumar Praveen,

Chapter 8 - Hydrogen production from biogas derived from waste biomass anaerobic digestion,

Editor(s): Sreedevi Upadhyayula, Amita Chaudhary,

In Advances in Green and Sustainable Chemistry,

Sustainable and Green Catalytic Processes for Renewable Fuel Production with Net-Zero Emissions,

Elsevier,

2025,

Pages 209-240,

ISBN 9780443218996,

https://doi.org/10.1016/B978-0-443-21899-6.00009-4.

(https://www.sciencedirect.com/science/article/pii/B9780443218996000094)

Abstract: Methane is more potent greenhouse gas (GHG) than CO2 and contributes around 90% of total GHG emissions around the world, and most of them are generated from landfills. Thus, utilization of methane-rich biogas could be a panacea especially for the energy industry to migrate from gray hydrogen primarily derived through steam methane reforming to green hydrogen, thereby reducing their share of Scope-1 emissions. This chapter explores the production of hydrogen from biogas through anaerobic digestion and potential pathways for conversion of methane to hydrogen. It also touches upon mechanistic pathways for catalytic reduction of methane to hydrogen based on the computational works published in the literature. In addition, the chapter provides holistic insights on the technology readiness level of the technologies for production of hydrogen from natural gas for large-scale deployment across the process industry.

Keywords: Biomass; energy sustainability; energy resource; biofuel; circular economy

Chunsheng Wang, Xueyu Ren, Hongxia Cao,

Metal redispersion strategy for regeneration of sepiolite derived Co-phyllosilicate catalyst during glycerol steam reforming,

Journal of Industrial and Engineering Chemistry,

Volume 144,

2025,

Pages 323-336,

ISSN 1226-086X,

https://doi.org/10.1016/j.jiec.2024.09.026.

(https://www.sciencedirect.com/science/article/pii/S1226086X24006178)

Abstract: Metal sintering and coke deposition have become main and irreversible obstacles for catalyst deactivation during H2 production from glycerol steam reforming (GSR). The regenerability of 15Co/SEP catalyst with a phyllosilicate derived strong metal-support interaction (SMSI) was probed by five successive GSR/regeneration cycles in order to evaluate the deactivation process and initial reactivity recovery. Two different regeneration methods were selected for the cycles: redox regeneration and combined regeneration. After the combined regeneration, reproducible GSR behaviors were obtained among the whole cycles. An almost recovery of initial activity (∼94 % of conversion and ∼ 73 % of H2 yield) and 50 h stability was noticed at 15Co/SEP-5 catalyst. By various characterizations analysis of fresh and spent catalysts, it was observed that irreversible metal sintering was aggravated by the redox regeneration, thus provoked initial activity loss and accelerated coking deactivation tendency. The combined regeneration achieved phyllosilicate recrystallization and metal exsolution/redispersion by a combination of NH4F-HNO3 assisted recrystallization and redox treatments, which ensured a small increase in Co0 nanoparticle size (13.2 nm vs. 15.3 nm) and coke deposition (23.9 wt% vs. 27.3 wt%) and inconspicuous change in the C1 species selectivity. The results suggested that 15Co/SEP catalyst is a promising candidate for commercialized GSR due to the favorable regenerability.

Keywords: Glycerol steam reforming; Catalyst regeneration; Phyllosilicate; Metal redispersion; Hydrogen production

Massamba Sow, Mohamed. M. Ibrahim, Abdelghafour Zaabout,

Integration of sorbent enhanced in hydrothermal waste transformation for negative CO2 emission fuel production: Techno-economic assessments,

Energy Conversion and Management,

Volume 326,

2025,

119519,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2025.119519.

(https://www.sciencedirect.com/science/article/pii/S0196890425000421)

Abstract: All major scenarios highlight the need for significant CO2 removal from the atmosphere to achieve the 2050 carbon neutrality targets, with key contribution of Biogenic Energy with CO2 Capture and Storage (BECCS) in the Carbon Negative mix. However, the largest biogenic waste feedstocks are highly moisturized, making it challenging to valorize due to the associated energy-intensive drying process required by conventional thermochemical methods. This study introduces the techno-economic of novel process configurations integrating hydrothermal carbonization (HTC) and sorption-enhanced gasification/reforming (SEG/SER). The goal is to convert Wet Biogenic Waste into carbon-negative hydrogen, hydrogen-rich syngas, or hydrochar with integrated CO2 capture using calcium looping technology. The exothermic CO2 capture by CaO provides the needed thermal energy to the endothermic gasification and reforming processes, thus maximizing energy efficiency and hydrogen yield. Atmospheric gasification/reforming was found to favor hydrogen production at the highest energy efficiency (up to 80.4%) and cost-effectiveness (levelized cost of hydrogen LCOH, 1.65 €/kg-H2). This is facilitated by the high carbon capture rates (up to 100%) that generate carbon credits with a substantial contribution in offsetting a considerable portion of the produced hydrogen costs. High-pressure gasification/reforming resulted in poor hydrogen yields in favor of substantial CH4-rich syngas. This triggered investigating configurations targeting the production of partly decarbonized superior syngas, resulting in heating values exceeding natural gas and anaerobic digestion biogas, achieving global efficiencies of up to 84% and production costs of 38.47 and 57.9 €/MWh.

Keywords: Carbon-negative fuel; CCS; Hydrothermal biomass conversion; Sorption enhanced gasification & reforming; Techno-economic analysis

Ke-Wei Lin,

Thermodynamic analysis and experimental study of autothermal diesel reforming for hydrogen-rich syngas production with a 10 kW heat recovery reformer,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 598-608,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.191.

(https://www.sciencedirect.com/science/article/pii/S0360319925002125)

Abstract: Hydrogen has emerged as a highly prioritized technology for achieving the 2050 goal of achieving net-zero emissions. This study evaluates the process of autothermal reforming diesel fuel to produce hydrogen-rich syngas. The evaluation is performed through thermodynamic analysis and experimental research methodologies. Using the Gibbs free energy approach, the thermodynamic analysis evaluates the consequences of hydrogen-rich syngas production at various O2/Diesel and H2O/Diesel molar ratios. The results demonstrate that it is possible to obtain five sets of parameters for SOFC applications that can operate at thermally neutral temperatures, produce hydrogen-rich syngas optimally, and prevent carbon deposition. The maximum steam and oxygen flow rate was taken as S12O7 (H2O = 12 mol, O2 = 7 mol), at which the reforming efficiency was about 91.37%, the hydrogen concentration was 34.29%, the CO concentration was 17.84%, and the overall hydrogen-rich concentration was 52.63%. A 10 kW heat recovery reformer with thermal energy storage capability has been created for the experiment in this study. The Ru/CeO2–Al2O3-γ catalysts achieved the highest hydrogen concentration of 31.4% when the O2/Fuel molar ratio was 8, the H2O/Fuel molar ratio was approximately 12, and the reforming efficiency reached 75.4%, the carbon conversion rate reached 89.4%, and the maximum power reached 10.26 kW.

Keywords: Autothermal reforming; Hydrogen-rich syngas; 10 kW reformer

Xiaolong Li, Yahui Zhang, Jundi Wan, Manni Sun, Yongning Ma, Junli Zhu, Mingyuan Guo, Yuhao Yang,

Ultra-low CO selectivity in aqueous-phase reforming of methanol using Pt/Fe5C2@C catalyst with strong metal-support interaction,

International Journal of Hydrogen Energy,

Volume 98,

2025,

Pages 563-575,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.115.

(https://www.sciencedirect.com/science/article/pii/S0360319924053187)

Abstract: Aqueous-phase reforming of methanol (APRM) is essential for the application of polymer electrolyte membrane fuel cells (PEMFCs) that utilize hydrogen as fuel. The development of highly active catalysts with low CO selectivity is crucial to addressing this challenge. This paper presents a novel high-activity APRM catalyst, Pt/Fe5C2@C, composed of Fe5C2 nanoparticles encapsulated in graphite carbon layers (Fe5C2@C) along with loaded Pt. Both XPS and TEM confirm the presence of strong metal-support interaction (SMSI) between Pt and Fe5C2@C. This SMSI not only enhances the dispersion of Pt on the Fe5C2@C surface but also changed the electron density of the loaded Pt, thereby maximizing the active sites. Consequently, the Pt–Fe5C2 interface in Pt/Fe5C2@C effectively activates methanol molecules, promoting the water-gas shift reaction on the catalyst surface, resulting in excellent hydrogen production activity and extremely low CO selectivity. Specifically, the hydrogen production rate of the 11%Pt/Fe5C2@C catalyst reached 139.9 mmol g−1 h−1, which is significantly higher than that of other common Mo-based oxides and Mo-based carbide catalysts, with a CO selectivity as low as 0.01%, achieving almost CO-free hydrogen production. This finding offers a promising pathway for CO-free hydrogen production via the APRM reaction.

Keywords: APRM; Pt/Fe5C2@C; SMSI; Ultra-low CO selectivity

G.M. Korableva, D.A. Agarkov, D.S. Katrich, A.V. Samoilov, A.U. Sharafutdinov, S.I. Bredikhin,

The investigation of the influence of the addition of cerium dioxide to the anode composition on the internal carbon dioxide conversion of methane on second-generation SOFCs,

Fuel,

Volume 385,

2025,

134104,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134104.

(https://www.sciencedirect.com/science/article/pii/S0016236124032551)

Abstract: The effect of the addition of cerium dioxide in different forms – GDC (gadolinia-doped ceria, CeO2 doped with 10 mol% Gd2O3) layer on the surface, CeO2 nanoparticles – on the results of internal carbon dioxide conversion of methane at the anode of solid oxide fuel cells was studied in the present work. The studies were carried out mainly using a technique that combined electrochemical techniques, Raman spectroscopy, and flow gas analysis. It was shown that the long-term operation of the fuel cell under conditions of carbon dioxide conversion led to the formation of carbon deposits throughout the thickness of the model samples. The presence of carbon was confirmed by the micrographs of a scanning electron microscope, as well as the results of energy-dispersive analysis and Raman spectroscopy. It was found that carbon had a form of graphite inside the fuel electrode. Polymerization of carbon clusters into carbon nanotubes was observed closer to the free surface of the anode. Raman spectroscopy studies showed the presence of D- and G-graphite bands in the spectrum, which also indicated the presence of disordered and filamentary carbon. At the same time, longer exposure to carbon-containing fuel led to an increase in the proportion of carbon polymerized into nanotubes. Cerium dioxide was shown to have a positive effect on the electrochemical characteristics of the cells: the time of stable operation increased, and the amount of carbon deposits decreased even after adding a small amount of CeO2.

Keywords: Solid oxide fuel cell; Anode-supported SOFC; Methane internal conversion; Doped ceria; Impregnation; Carbon deposition

Adrian Chun Minh Loy, Wei Lin Ng, Jisheng Ma, Md Hemayet Uddin, Jitraporn Vongsvivut, Mark J. Tobin, Shanthi Priya Samudrala, Sankar Bhattacharya,

Deciphering the role of Cu0 and Cuσ+ in engendering the hydrogen production from glycerol reforming over Cu/CeO2: The effect of different Cu precursors,

Applied Catalysis B: Environment and Energy,

Volume 365,

2025,

124865,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124865.

(https://www.sciencedirect.com/science/article/pii/S0926337324011792)

Abstract: Copper-based catalysts have been widely reported as remarkable candidates in reforming processes; however, they often suffer from poor stability, sintering, and deactivation over extended periods under high-temperature conditions. Hitherto, the information of the mechanism of the Cu precursor that induces the strong metal-support interaction over the Cu-based catalysts, the role of Cu0 and Cuσ+ that engendered the reforming, and the stabilization of Cu facets remain limited in the literature. Here, we demonstrate that copper-acetate-based catalyst supported on CeO2 (Cu/CeO2(A)) is a promising candidate for glycerol reforming in terms of stability and reforming efficiency compared to sulphate and nitrate-based Cu/CeO2 catalysts. Through a series of characterization analyses (H2-TPR, H2-TPD, XPS, N2O, HRTEM, Raman spectroscopy, in-situ DRIFTS, and variable-temperature PXRD), the presence of Cuδ+ species in the Cu/CeO2 were found to be the main active sites for promoting the reforming and CO activation. Whereas the Cu0 and oxygen vacancies of CeO2 were to aid in facilitating the glycerol decomposition. Moreover, the in-situ synchrotron-FTIR microspectroscopy further shows that the ratio of Brönsted: Lewis acidic active sites ratio of Cu/CeO2(A) (in high spatial-resolution mode) remained stable between 0.17 and 0.18, for both physisorbed and chemisorbed, indicating that the main acidic sites promoting the glycerol dissociative and adsorption were on the LS sites. Notably, a remarkable performance of 95.1 % of glycerol conversion and 80.8 vol.% H2 production were obtained under the reaction condition of Cu species loading = 10 wt.%, reaction temperature 600 °C, glycerol concentration = 10 wt.%, and WHSV =1.953 h−1.

Keywords: Glycerol reforming; Hydrogen; Cu/CeO2; Heterogeneous catalyst; Copper precursors; In-situ analysis

Xulong Qin, Zhiwei Xue, Kang Hui Lim, Jiaheng Han, Claudia Li, Xinyu Wang, Xiuxia Meng, Xiaobin Wang, Yuesong Shen, Naitao Yang, Sibudjing Kawi,

Highly selective production of green syngas by methanol decomposition over steam activated Ni/NaX zeolite catalyst,

Energy,

Volume 319,

2025,

135009,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2025.135009.

(https://www.sciencedirect.com/science/article/pii/S0360544225006516)

Abstract: Production of syngas from green energy carrier methanol is of great significance to reform the traditional industry of synthetic chemistry. In this paper, we propose the strategy to tune the catalytic behavior of Ni-based catalyst for highly selective methanol decomposition into green syngas by combining the nano-confined effect of zeolite and the regulatory effect of steam on the structure of Ni/NaX zeolite catalyst. The optimal Ni/NaX zeolite catalyst achieves the H2 selectivity of 98.8 %, the H2/CO molar ratio of 2, high coking resistance and superior stability at 340 °C. The coexistence of mesopores and micropores in NaX zeolite and the strong metal-support interaction are considered as factors for the elevated catalytic performance. An optimal fraction of Ni0, Ni2+ and Ni3+ in Ni/NaX zeolite catalyst is found to significantly contribute to the catalyst's high selectivity and activity. Steam acts as promoter that tunes catalytic behavior of Ni/NaX zeolite catalyst. With the presence of steam, the amount of both Lewis and Brønsted acids decreases, and the coke deposition reduces. This also accelerates the desorption of CO, enhances activity and inhibits both the methanation and Boudouard reaction. The current work provides a new idea for developing effective catalysts and optimizing reaction processes.

Keywords: Green syngas; Methanol decomposition; Steam activated catalyst; Nano-confined effect; High selectivity

Aliakbar M. Vora, Arun G. Basrur, Ran Bahadur Yadav,

Effect of composition of multicomponent supports on properties of supported nickel catalysts,

Journal of the Indian Chemical Society,

Volume 102, Issue 1,

2025,

101506,

ISSN 0019-4522,

https://doi.org/10.1016/j.jics.2024.101506.

(https://www.sciencedirect.com/science/article/pii/S0019452224003868)

Abstract: Ni catalysts supported on combinations of alumina, magnesia, zirconia with rare earth supports are studied for the steam reforming of ethanol (ESR). The composition of the supports is systematically varied to identify the role of individual components and their contribution when they are combined. Supports containing magnesia or zirconia show contrasting behavior of acidity, XRD crystallite size of NiO, reducibility, dispersion of Ni(0), OSC, coking and metals sintering characteristics. Catalyst activity and deactivation are strongly influenced due to these differences. HRTEM indicates the redispersion of Ni(0) during reduction of NiO on catalysts containing magnesia. Magnesia and alumina-magnesia based catalysts show hindered reduction of nickel and highest intrinsic activity (H2 yields). But sintering of Ni is their nemesis. Moderate interaction of Ni with zirconia-based supports (H2-TPR) lends sintering stability in ESR. Quaternary Alumina-Magnesia-Zirconia catalysts imbibe advantages of individual components and are overall best with fair H2 yield, good stability and regenerability. Long duration (80 h) performance tests give holistic results because they encompass multiple factors influencing deactivation. Intrinsic chemical reactivity (as opposed to) active metal dispersion is important while comparing the activity of catalysts with different compositions. Degree of reducibility of nickel is an important consideration while measuring metal dispersion by chemisorption. Metal reducibility by H2-TPR, dispersion measurement by chemisorption and particle size determination by HRTEM are used as complementary techniques for rationalizing results of metal dispersion measurement.

Jishuo Li, Tie Wang, Tengteng Hao, Xiwen Yao, Kaili Xu, Jia Liu,

Application of biochar catalysts in tar catalytic reforming: A review on preparation, modification, deactivation, and regeneration,

Energy,

Volume 317,

2025,

134734,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2025.134734.

(https://www.sciencedirect.com/science/article/pii/S0360544225003767)

Abstract: The presence of tar significantly hinders the development of biomass pyrolysis and gasification technologies, making efficient tar removal methods critically important. Catalytic tar removal has attracted significant attention for its high efficiency and simplicity. Biochar, with its abundant pore structure, high surface area, and unique chemical properties, shows great potential as a catalyst in tar reforming, enhancing resource utilization and system efficiency. This paper provides a systematic review of biochar's preparation methods, modification and activation techniques, catalytic performance in tar reforming, deactivation mechanisms, and regeneration strategies. It also analyzes the challenges in biochar's practical applications and proposes future research directions. By addressing key issues in biochar-based tar reforming, this review aims to advance biomass pyrolysis technologies and promote the sustainable utilization of biomass energy, offering both theoretical insights and practical guidance for the field.

Keywords: Biomass pyrolysis; Biochar catalyst; Biomass tar; Catalytic reforming; Tar removal

M.G. Zimicz, L.M. Toscani, A. Prado, I.O. Costilla, A.L. Soldati, M.E. Aristizábal, S.A. Larrondo, F.D. Prado,

Catalytic oxidation of methane over Zr and La-doped ceria nanocatalysts,

Molecular Catalysis,

Volume 573,

2025,

114834,

ISSN 2468-8231,

https://doi.org/10.1016/j.mcat.2025.114834.

(https://www.sciencedirect.com/science/article/pii/S2468823125000203)

Abstract: Ce1-x-yZrxLayO2-δ mixed oxides were synthesized by a cation complexation method with citric acid. The obtained solids were analyzed by X-ray diffraction (XRD), linear dilatometry, transmission (TEM) and scanning (SEM) electron microscopy, temperature programmed reduction (TPR), nitrogen physisorption and Raman spectroscopy. Finally, the solids were tested as catalysts for methane total oxidation in different CH4/O2 ratios. Morphologic properties and defect concentration for each sample was found to be different, leading to variations in the oxygen mobility and catalytic behavior. The mixed oxide Ce0.9Zr0.05La0.05O2-δ evidenced smallest crystallite size, highest pore volume and specific surface area after calcination at 600 °C, but evidenced the more pronounced collapse of the pore structure and coalescence of particles after catalytic test at 750 °C. The solid with composition Ce0.9La0.1O2-δ showed the highest concentration of defects, retained a mesoporous structure, and showed the better resistance to coalescence and agglomeration of crystallites, resulting in an improved catalytic performance for methane total oxidation. For the catalytic test performed in excess of oxygen, methane conversion is improved, shifting the light-off curves to lower temperatures compared to the stoichiometric CH4/O2 ratio. Also, it was observed that in an oxygen deficient atmosphere, sample CL maintains its catalytic activity providing oxygen from its lattice to oxidize the methane molecule, more efficiently than Ce0.9Zr0.05La0.05O2-δ and Ce0.9Zr0.1O2. This sample also demonstrated good resistance to water vapor deactivation.

Keywords: La-doped ceria; Zr-doped ceria; Methane total oxidation; Oxygen vacancies

Lizbeth Moreno Bravo, Frederic C. Meunier, Jan Kopyscinski,

Rare earth oxide promoted Ru/Al2O3 dual function materials for CO2 capture and methanation: An operando DRIFTS and TGA study,

Applied Catalysis B: Environment and Energy,

Volume 361,

2025,

124591,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124591.

(https://www.sciencedirect.com/science/article/pii/S0926337324009056)

Abstract: Dual-function materials (DFMs) combine sorbent and catalytic components to perform selective CO2 capture and subsequent hydrogenation. This study explores the performance of rare-earth oxides (REOs) as CO2 adsorption sites on Ru/Al2O3. REOs increase CO2 uptake by upwards of +60 % by enhancing the overall catalyst surface basicity and favoring metal–support interactions. Thermogravimetric analysis during CO2 adsorption-hydrogenation cycles exhibited significant catalytic activity and enhanced stability of Ru-REO/Al2O3 at temperatures as low as 200 °C. This leads to methane production of 50–85 µmol g−1, surpassing recently reported values obtained for alkali and alkali-earth promoted Ru-based materials operated at 250 °C. The highest performing studied DFM, RuNd2O3/Al2O3, achieved 85 % CO2 capture efficiency and steadily produced methane in cyclic operation (+120 % CO2 uptake relative to Ru/Al2O3). Operando DRIFTS revealed that the dominant mechanism for methane formation is the hydrogenation of ruthenium carbonyls, which are stabilized by REOs. Upon CO2 exposure, surface carbonates and bicarbonate species form more abundantly on DFMs than on Ru/Al2O3. This confirms that REOs enhance the adsorption and retention of carbonates, which generate additional promoter-related reaction pathways during low-temperature hydrogenation. These findings are crucial in the advancement of sustainable, wider operation range carbon capture and utilization technologies.

Keywords: CO2 capture; CO2 methanation; Operando DRIFTS; DFMs; Rare earth oxides

Yan Zheng, Qing Ma, Yaxin Zhang, Zejiang Li, Yao Xu, Yongjun Gao,

Photothermal reforming of cellulose to syngas over ZSM-5-supported heterojunction cobalt catalyst,

Molecular Catalysis,

Volume 572,

2025,

114788,

ISSN 2468-8231,

https://doi.org/10.1016/j.mcat.2024.114788.

(https://www.sciencedirect.com/science/article/pii/S2468823124009702)

Abstract: The sustainable utilization of abundant biomass plays a crucial role in mitigating energy crises and protecting the environment. By using Co/ZSM-5 as a photothermal catalyst, natural cellulose can be reformed into H2 and CO under focused light irradiation. The heterojunction involving CoO and Co promotes the hydrogen production through photocatalytic hydrogen evolution, while ZSM-5 enhances the cleavage of C-C bond under photothermal conditions. Light irradiation, which provides both high frequencies to excite electrons and long wavelength to generate heat, accelerates the photothermocatalytic reforming of cellulose efficiently. Under optimal conditions, natural corn straws, waste paper and other cellulose-rich wastes can be reformed into syngas. This research clarifies the functions of various components within the catalytic system and their mechanism, providing valuable insights for the design of sustainable photothermocatalytic systems.

Keywords: Biomass; Cellulose; Photothermal catalysis; Syngas; Cobalt

Yongfan Zhu, Meng Wu, Wanglin Zhou, Jinkun Tan, Zhicheng Zhang, Guangru Zhang, Zhengkun Liu, Gongping Liu, Wanqin Jin,

Low chemical-expansion and self-catalytic nickel-substituted strontium cobaltite perovskite four-channel hollow fibre membrane for partial oxidation of methane,

Journal of Membrane Science,

Volume 715,

2025,

123454,

ISSN 0376-7388,

https://doi.org/10.1016/j.memsci.2024.123454.

(https://www.sciencedirect.com/science/article/pii/S0376738824010482)

Abstract: In membrane reactors, the thermo-mechanical stability of the membrane determines the operability of the reaction, while the permeability and catalytic performance dictate the reaction process. A high chemical expansion coefficient can exacerbate the mismatch in the thermal expansion behaviour between the two sides of the membrane, potentially resulting in fracture. The low permeability and slow catalytic activity can slow the reaction process and result in an unsatisfactory product composition. Here, a Ba0.5Sr0.5Co0.7Fe0.2Ni0.1O3-δ (BSCFN) four-channel hollow fibre membrane with a low chemical-expansion and high oxygen permeation flux has been successfully fabricated by phase inversion and a one-step thermal process (OSTP). Reaction sintering during the OSTP forms an NiO in-situ exsolution phase on the membrane surface, and A-site stoichiometry excess occurs, improves the oxygen permeation flux, and provides the membrane with self-catalytic ability during the partial oxidation of methane (POM) reactions. Consequently, the BSCFN membrane shows excellent performance; exhibiting an oxygen flux of 11.75 mL cm−2·min−1 at 900 °C. Furthermore, the self-catalytic BSCFN membrane has a good hydrogen production of 10.1 mL cm−2·min−1 during the POM process, which is 7.5 times higher than that of Ba0.5Sr0.5Co0.8Fe0.2O3-δ membranes (1.87 mL cm−2·min−1). This offers a viable strategy for the development of membrane reactor applications.

Keywords: Multi-channel hollow fibre; Low chemical-expansion; Self-catalytic ability; Partial oxidation of methane; Hydrogen production

Tian Heng Qin, Guozhao Ji, Boyu Qu, Alan J McCue, Shaoliang Guan, Jos Derksen, Ye Shui Zhang,

Pyrolysis-catalytic gasification of plastic waste for hydrogen-rich syngas production with hybrid-functional Ni-CaOCa2SiO4 catalyst,

Carbon Capture Science & Technology,

Volume 14,

2025,

100382,

ISSN 2772-6568,

https://doi.org/10.1016/j.ccst.2025.100382.

(https://www.sciencedirect.com/science/article/pii/S2772656825000223)

Abstract: The production of H2-rich syngas from pyrolysis-catalytic gasification of plastic waste bottles has been investigated. The hybrid-functional materials consisting of Ni as catalyst, CaO as CO2 sorbent and Ca2SiO4 as a polymorphic active spacer were synthesized. The different parameters (Ni loading, temperature, N2 flow rate and feedstock-to-catalyst ratio) have been investigated to optimise the H2 production. The catalysts were analysed by N2 physisorption, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), Temperature-programmed reduction (TPR) and in-situ Transmission Electron Microscopy (TEM). Temperature-programmed oxidation (TPO) was used to analyse the carbon formation on the used catalysts. The highest H2 production of 59.15 mmol g-1of plastic was obtained in the presence of a catalyst with 20 wt.% Ni loading, which amounts to H2 purity as high as 54.2 vol% in gas production. Furthermore, 90.63 mmol g-1of plastic of syngas was produced by increasing the feedstock-to-catalyst ratio to 4:1, yielding 84.4 vol.% of total gas product (53.1 vol.% of H2 and 31.3 vol.% of CO, respectively). The Ni-CaOCa2SiO4 hybrid-functional material is a very promising catalyst in the pyrolysis-catalytic gasification process by capturing CO2 as it is produced, therefore shifting the water gas shift (WGS) reaction to enhance H2 production from plastic waste. Detailed elucidation of the roles of each component at the microscale during the catalytic process was also provided through in-situ TEM analysis. The finding could guide the industry for future large-scale application to convert abundant plastic waste into H2-rich syngas, therefore contributing to the global ‘net zero’ ambition.

Keywords: Pyrolysis-catalytic gasification; Hydrogen; Plastic waste; Hybrid-functional catalyst

Yuming Wen, Bella, Guoqiang Song, Jie Chang, Sibudjing Kawi, Chi-Hwa Wang,

Machine learning insights into the production and characteristics of carbon nanotubes from methane catalytic decomposition,

Journal of Energy Chemistry,

Volume 104,

2025,

Pages 726-739,

ISSN 2095-4956,

https://doi.org/10.1016/j.jechem.2025.01.023.

(https://www.sciencedirect.com/science/article/pii/S2095495625000646)

Abstract: The sustainability of methane catalytic decomposition is significantly enhanced by the production of high-quality value-added carbon products such as carbon nanotubes (CNTs). Understanding the production yields and properties of CNTs is crucial for improving process feasibility and sustainability. This study employs machine learning technique to develop and analyze predictive models for the carbon yield and mean diameter of CNTs produced through methane catalytic decomposition. Utilizing comprehensive datasets from various experimental studies, the models incorporate variables related to catalyst composition, catalyst preparation, and operational parameters. Both models achieved high predictive accuracy, with R2 values exceeding 0.90. Notably, the reduction time during catalyst preparation was found to critically influence carbon yield, evidenced by a permutation importance value of 39.62%. Additionally, the use of Mo as a catalytic metal was observed to significantly reduce the diameter of produced CNTs. These findings highlight the need for future machine learning and simulation studies to include catalyst reduction parameters, thereby enhancing predictive accuracy and deepening process insights. This research provides strategic guidance for optimizing methane catalytic decomposition to produce enhanced CNTs, aligning with sustainability goals.

Keywords: Methane catalytic decomposition; Machine learning; Carbon yield; Carbon nanotubes; Catalyst synthesis; CH4 conversion

Wei-Jyun Wang, Chong Wei Ong, Denny K.S. Ng, Cheng-Liang Chen,

Conceptual design and economic analysis of biomethanol production process from palm oil mill effluent for sustainable biodiesel production,

Sustainable Energy Technologies and Assessments,

Volume 75,

2025,

104207,

ISSN 2213-1388,

https://doi.org/10.1016/j.seta.2025.104207.

(https://www.sciencedirect.com/science/article/pii/S2213138825000384)

Abstract: Biodiesel is one of the most potential sustainable alternatives to fossil fuels in transportation sector. However, methanol used in biodiesel production is usually synthesized from natural gas. In this work, a feasibility study of biomethanol (bio-MeOH) production from palm oil mill effluent is conducted. Biogas produced from palm oil mill effluent (POME) via anaerobic digestor is used to synthesize bio-MeOH to support sustainable biodiesel production. The treated biogas is converted into syngas via methane steam reforming (MSR) and water gas shift (WGS) processes. Raw syngas from WGS reactor is dehumidified and mixed with an additional amount of carbon dioxide (CO2) to achieve desired 2:1 H2/CO2 molar ratio before being fed into a CO2 hydrogenation reactor to produce bio-MeOH. The raw bio-MeOH is then purified to 99.9 mol% via distillation columns. To reduce utility consumption and CO2 emissions, the bio-MeOH production process is further enhanced via heat integration. The optimized results show that the levelized production cost and carbon emission of the intensified design are 1,101.56 USD and 3.42 tonne-CO2 per tonne-MeOH. For the internal rate of return (IRR) to attain the profitable threshold of 5 %, the selling price of bio-MeOH must be higher than $1,600 USD per tonne-MeOH.

Keywords: Biomethanol; Palm oil mill effluent; Methane steam reforming; CO2 hydrogenation; Aspen Plus

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Shude Zhang, Jason Yi Juang Yeo, Jian Song, Basil T. Wong, Jaka Sunarso, Tao Li, Shaomin Liu,

Co-free La0.9Ca0.1Fe1-xCuxO3-δ (x = 0.05, 0.1) hollow fiber membranes for H2/N2 and H2/CO co-production by coupling water splitting and partial oxidation of methane,

Journal of Membrane Science,

Volume 714,

2025,

123401,

ISSN 0376-7388,

https://doi.org/10.1016/j.memsci.2024.123401.

(https://www.sciencedirect.com/science/article/pii/S0376738824009955)

Abstract: Mixed ionic-electronic conducting oxygen transport membranes have demonstrated high oxygen permeability, which can be coupled with other oxidation reactions. The membrane reactor coupling water splitting with partial oxidation of methane reaction has great practical potential as it produces valuable feedstocks such as ammonia syngas and liquid fuel syngas. However, the existing membrane materials often exhibit structural stability issue and/or unsatisfactory oxygen permeability. In this work, copper-doped LCF1-xCuxO3-δ (x = 0.05–0.1) hollow fiber membranes were used for hydrogen production by coupling the oxygen separation with water splitting and partial oxidation of methane. A small amount of copper doping could effectively reduce the sintering temperature of the membrane and increase the conductivity of the material, where a maximum oxygen flux of 0.55 mL min−1 cm−2 was achieved on LCFCu0.05 membrane under the experimental conditions. In the water splitting test, a maximum hydrogen production rate of 3.7 mL min−1 cm−2 was achieved by using steam as the raw gas (driven by nitrogen) at the shell side and hydrogen/helium mixture as the sweep gas at the lumen side of the LCFCu0.05 hollow fiber membrane with 10 wt.% Ni/SDC catalyst coated on the shell side. As pure methane gas was introduced at the lumen side coated with Ni/LaNiO3/γ-Al2O3 catalyst, the H2 production rate was further increased to its highest of 4.4 mL min−1 cm−2. In addition, the membrane reactor could be stably operated for 300 h under three different flow conditions without performance degradation. These results paves the development of robust membrane reactor for integrated water splitting and partial oxidation of methane.

Keywords: Copper doping; Hydrogen production; Oxygen separation; Membrane reactor; Syngas

Atieh Ranjbar, Abdullah Irankhah, Amir Mosayebi, Mohammad Hosein Eghbal Ahmadi,

Reverse water gas shift reaction over Ni/MgAl2O4 catalyst: Study about kinetic and type-2 fuzzy model approaches,

Journal of the Taiwan Institute of Chemical Engineers,

Volume 168,

2025,

105930,

ISSN 1876-1070,

https://doi.org/10.1016/j.jtice.2024.105930.

(https://www.sciencedirect.com/science/article/pii/S1876107024005881)

Abstract: Background

Mitigation of CO2 via catalytic reverse water gas shift reaction has received great deal of interest in recent years. The formed CO is usedfor methanol and higher hydrocarbons production.

Methods

Reverse water gas shift (RWGS) experiments were analyzed over a Ni/MgAl2O4 catalyst in a fixed bed reactor. The MgAl2O4 support and Ni-based catalyst were prepared through CTAB assisted co-precipitation and impregnation technique, respectively. The activity was tested at different conditions including: temperature as400-600 °C, H2/CO2 ratio as 0.44-1.33 and W/F as 12-14 gcat.h/mol. The reaction kinetic model was constructed via the Langmuir–Freundlich (LF) adsorption model and Levenberg-Marquardt method was used to fit the kinetic model parameters based on the experimental data. A type-2 fuzzy model was also developed tocompare with the mechanistic results purposes.

Findings

The TEM images of catalyst displayed Ni particles with average of 5.6 nm. The prediction error of the kinetic and type-2 fuzzy model approaches determined 11.86 % and 13.1 %, respectively. According to calculated statistical indices including root mean square error (RMSE), coefficient of determination (R2) and relative residual (RR), the ability of kinetic and fuzzy models in fitting the experimental CO2 conversion was better compared to CO selectivity and CH4 selectivity.

Keywords: Reverse water gas shift; Conversion; Selectivity; Kinetic; Fuzzy model; Langmuir–Freundlich

Aysylu Askarova, Tatiana Alekhina, Evgeny Popov, Pavel Afanasev, Aliya Mukhametdinova, Alexey Smirnov, Alexey Cheremisin, Elena Mukhina,

Innovative technology for underground clean in situ hydrogen generation: Experimental and numerical insights for sustainable energy transition,

Renewable Energy,

Volume 240,

2025,

122259,

ISSN 0960-1481,

https://doi.org/10.1016/j.renene.2024.122259.

(https://www.sciencedirect.com/science/article/pii/S0960148124023279)

Abstract: Hydrogen production in subsurface reservoirs attracts global research interest for its potential in sustainable energy generation and climate change mitigation. However, limited experimental data make optimizing in situ hydrogen generation (ISHG) processes under reservoir conditions challenging. ISHG combines reverse methane combustion with steam methane reforming (SMR), leveraging existing reservoir infrastructure to generate hydrogen efficiently while minimizing surface emissions. The primary objective is to enhance hydrogen yield by investigating key variables, such as catalyst type, water saturation, and cyclic operational modes. Results indicate that cyclic combustion followed by SMR can boost hydrogen yield by up to 68 % in controlled reservoir settings, utilizing combustion heat to drive reactions efficiently. Additionally, the in situ catalyst delivery system developed here achieved a sustained hydrogen production rate of 49 %, significantly improving process stability and scalability. Numerical simulations demonstrated that adjustments in methane combustion kinetics, validated through history matching, lead to improved alignment with observed temperature profiles and hydrogen production rates. By integrating experimental data with numerical modeling, this research provides foundational insights for environmentally sustainable ISHG applications, offering substantial greenhouse gas reductions compared to conventional hydrogen production methods. These findings underscore ISHG's promise as a transformative, low-emission technology for clean energy generation.

Keywords: Hydrogen production; Sustainable energy; Steam methane reforming; In situ combustion; Catalysts; Numerical simulation

Alessandro Blasi, Antonella Dimotta, Alessandra Verardi, Giuseppe Fiorenza,

Chapter 4 - Biomass reforming processes in membrane reactors,

Editor(s): Angelo Basile, Kamran Ghasemzadeh,

Current Trends and Future Developments on (Bio-) Membranes,

Elsevier,

2025,

Pages 81-123,

ISBN 9780443138768,

https://doi.org/10.1016/B978-0-443-13876-8.00009-4.

(https://www.sciencedirect.com/science/article/pii/B9780443138768000094)

Abstract: Decarbonization of transport and mobility sector constitutes a challenging issue since the utilization only of power from renewables appears to be lacking to achieve an ambitious target in the short-to-medium term. The production of usable fuels, specifically hydrogen, from sustainable biomass can provide an essential contribution to reduce harmful emissions from transportation. In this chapter, reforming processes for fuel production from biomass are analyzed. The study is especially focused on innovative technologies based on membrane reactors to efficiently carry out the conversion of biomass into hydrogen. A technoeconomic assessment of membrane technologies is also included as well as an analysis of the main barriers still to be overcome for the effective diffusion of these advanced processes.

Keywords: Biomass; hydrogen; thermochemical conversion; biological conversion; thermal gasification; pyrolysis; anaerobic digestion; membrane; membrane technology; membrane material; membrane reforming reactors; steam reforming

Ali Mojtahed, Gianluigi Lo Basso, Lorenzo Mario Pastore, Antonio Sgaramella, Livio de Santoli,

Application of machine learning to model waste energy recovery for green hydrogen production: A techno-economic analysis,

Energy,

Volume 315,

2025,

134337,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2024.134337.

(https://www.sciencedirect.com/science/article/pii/S036054422404115X)

Abstract: This paper presents an innovative energy recovery approach for hydrogen production in landfill waste disposal plants. The proposed scenario integrates water electrolysis with direct methane reforming into hydrogen at a moderate temperature (500 °C) and incorporates a supercritical CO₂ heat pump. This design achieves reforming without relying on external heat sources, enhancing the system's efficiency. Additionally, the study applies machine learning to model landfill gas with a focus on energy recovery potential. Various machine learning algorithms are assessed for accuracy, and the highest-performing models—achieving R-squared values between 92 % and 99%—are benchmarked against existing landfill models, demonstrating improved precision. The landfill model developed in the initial phase serves as input for the energy model. Results suggest that the levelized cost of hydrogen production could be below 2 €/kg H₂ at stack level, aided by internal energy recovery mechanisms that increase production rates. At 500 °C, the methane conversion efficiency aligns closely with that of conventional systems, making this approach a viable and cost-effective alternative.

James G. Highfield, Agnieszka M. Ruppert, Nicolas Keller,

Sustainable energy cycles based on liquid oxygenates as carbon-neutral hydrogen carriers: A holistic vision,

Catalysis Today,

Volume 451,

2025,

115207,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2025.115207.

(https://www.sciencedirect.com/science/article/pii/S0920586125000252)

Abstract: Simple energy-dense liquid oxygenates obtained directly from biomass e.g., fermentation ethanol, or “solar methanol”, synthesised from renewable hydrogen (via PV-driven water electrolysis) and recycled carbon dioxide, could provide the basis of an energy cycle that is climate-neutral and promotes long-term sustainability in industrial chemical processing. The development of new earth-abundant heterogeneous (photo-)catalysts and associated reaction engineering promoting hydrogen release (by steam-reforming) and insertion (by CO2 hydro-deoxygenation) under mild conditions will be pivotal to its success. This review anticipates the key methodologies involved in future bio-refineries and forecasts the increasing role therein of modular and portable low-power solar concentrators as renewable (photonic and thermal) resources. The techno-economic prospects for oxygenates like acetaldehyde, ethylene glycol, and glycerol, are also considered based on their reactivity (C2) and/or a pre-existent supply glut in need of valorisation (C3). Many examples highlighting the growing importance of computational (DFT and microkinetic) modelling in catalyst development are presented.

Keywords: Oxygenates reforming; Catalytic upgrading; CO2 valorisation; Solar hydrogen; Renewable fuels; Sustainable energy cycles; Carbon-neutral hydrogen carriers

Ye Tian, Wenze Liu, Chongzhe Zeng, Xiong Zhou, Shihan Du, Yihao Wang, Heng Li,

Experimental study on steam co-gasification of biomass/municipal solid waste (MSW) for H2-rich gas production,

Journal of the Energy Institute,

Volume 118,

2025,

101931,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2024.101931.

(https://www.sciencedirect.com/science/article/pii/S1743967124004094)

Abstract: Co-gasification of biomass and MSW represents an effective approach for the waste recovery and carbon emission reduction. The optimal conditions for biomass/MSW gasification is important in planning large–scale setups. Here, an experimental study was conducted in a lab-scale fluidized bed gasification system at various temperatures (700–850 °C), steam/feedstock ratio (S/F: 0.25–1.0), MSW mixing ratio (MMR: 0–100 %) and Ni contents (0–20 %) for H2-rich gas production. Ni/dolomite was selected as an in-bed material for tar reformer and solid absorption. The motivation of this work is to find out the suitable conditions for obtaining high-quality and low-tar syngas appropriate to use in engineering applications. Compared with calcined dolomite, Ni/dolomite revealed better catalytic activity in terms of tar modification. The results showed that there is an optimal value for Ni content. Increasing Ni content from 0 to 15 % resulted in more H2 production, higher gas yield (Yg) and lower tar yield (YT). However, a slight reduction in the catalytic activity of Ni/dolomite with a further increase of Ni content from 15 % to 20 % was observed, probably due to a slight coke deposition on Ni/dolomite catalyst for Ni content> 15 %. With the growth of MSW content, YG showed a slight variation due to a slight change in carbon content of biomass-MSW mixtures at high MMRs.

Keywords: Biomass; MSW; Co-gasification; Ni/dolomite; Tar

Yin Fong Yeong, Naveen Sunder, Zheng Fu Chan,

CO2 and CH4 conversion to syngas via membrane and plasma routes: Challenges and future directions,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 327-340,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.193.

(https://www.sciencedirect.com/science/article/pii/S0360319925002149)

Abstract: The increase in emissions of greenhouse gases (GHGs) such as CO2 is the main reason for global warming which has attracted considerable attention over the year. Dry reforming is one of the attractive processes among the CO2 conversion and utilization approaches due to its ability to convert both CO2 and CH4 into syngas. Catalytic membrane and non-thermal plasma catalytic reactors are promising technologies for CO2 and CH4 conversion. Non-thermal plasma-catalytic in particular benefits from its low energy consumption and ease of operation. In this review, the mitigation techniques for CO2 capture along with their advantages and disadvantages are initially presented. Then, catalytic membrane reactors for dry reforming are introduced, followed by an analysis on the effect of operating parameters as well as the presence of catalysts toward gas conversion. Non-thermal dielectric barrier discharge (DBD) plasma method for dry reforming is subsequently introduced and discussed. Furthermore, the challenges and problems of both technologies to form syngas are highlighted. Lastly, examples of integrated DBD plasma-membrane systems utilized in other processes are explored which leads to a discussion on the future directions of these technologies for CO2 and CH4 conversion.

Keywords: Carbon dioxide; Membrane; Catalytic conversion; Dielectric barrier discharge; Syngas

Yongsu Park, Debabrata Chakraborty, Eun-Bum Cho,

Highly stable mesoporous Ni-phyllosilicate particle under high temperature hydrothermal and base conditions towards industrial catalytic applications,

Journal of Industrial and Engineering Chemistry,

Volume 141,

2025,

Pages 521-539,

ISSN 1226-086X,

https://doi.org/10.1016/j.jiec.2024.07.013.

(https://www.sciencedirect.com/science/article/pii/S1226086X24004581)

Abstract: Two mesoporous nickel phyllosilicate (Ni-PS) samples with Ni/Si ratios of 0.3 and 1 were used to compare high-temperature hydrothermal stability. The Ni-PS structures have well-developed porosity and pore size distributions mainly ranging from 2 to 20 nm. To assess their hydrothermal resistance as a reusable heterogeneous catalyst in high-temperature reactions, the samples were exposed to 800 °C for 7 days using steam-supplied muffle furnaces. Three types of mesoporous silica samples (i.e. MCM-41, SBA-15, and mesoporous benzene-silica) and two zeolites (i.e. ZSM-5 and zeolite-Y) were compared under the same conditions. The hydrothermal resistance was primarily confirmed based on changes in pore size distribution and surface area through nitrogen-sorption isotherm analysis. The crystal structure and the binding energy of each sample were investigated by X-ray diffraction and X-ray photoelectron spectroscopy measurements. The Ni-PS structures displayed excellent stability (i.e. BET surface area retained over 77 % and 65 % after 1-d and 7-d treatment, respectively.) compared with other mesoporous samples, and even higher stability than zeolite Y. In addition, structural stability at pH = 10 is much higher than that of ZSM-5. This suggests that it could be used for various catalytic chemical reactions including hydrogenation and cracking processes because NiO and Ni nanoparticles are uniformly distributed on the surface, maintaining their particle shape even after a reduction process.

Keywords: Nickel-phyllosilicate; Mesoporous metal–silica; Hydrothermal stability; Heterogeneous catalyst; Support material

Kuerbangnisha Kadeer, Yufei Jiang, Yushen Huang, Youyu Lin, Rumei Jin, Chenghao Yin, Fangqin Guo, Takayuki Ichikawa, Xingguo Li, Jie Zheng,

Hydrogen generation from coupled methanol steam reforming with metal hydride hydrolysis: Effects of metal catalysts and hydrides,

International Journal of Hydrogen Energy,

Volume 102,

2025,

Pages 29-36,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.053.

(https://www.sciencedirect.com/science/article/pii/S036031992500059X)

Abstract: On a transition metal-metal hydride (TM-MH) composite, methanol steam reforming (MSR) can be coupled with metal hydride hydrolysis to provide higher hydrogen density compared to metal hydride hydrolysis and higher hydrogen purity and more balanced thermal effect compared to MSR, which is attractive for onsite H2 generation for fuel cells. In this work, the effects of the metal catalysts and hydrides on the coupled reaction are studied. The results showed that different TMs primarily affect the selectivity of the reaction. Cu and Pd showed good activity for the coupled reaction with CaH2 and generated high purity H2, while Ni and Co generated a high fraction of CH4. Different MHs determines the effects of CO2 capture during the coupling reaction. With Cu catalyst, CO2 can be completely eliminated by LiH, NaH and CaH2 while incompletely captured by MgH2 and YH3. On Cu/NaBH4, only hydrolysis reaction occurs without MSR. Considering the overall performance in terms of hydrogen storage density, hydrogen purity, and cost of the materials, Cu/CaH2 is the best combination for the coupled reaction, which holds promising potential for hydrogen production in portable devices.

Keywords: Hydrogen; Methanol steam reforming; Metal hydrides; Hydrolysis; Coupling

Jie Wang, Chen Yuan, Claudia Li, Guanlong Geng, Jian Song, Naitao Yang, Sibudjing Kawi, Jaka Sunarso, Xiaoyao Tan, Shaomin Liu,

Nickel-based metallic membranes for hydrogen production in membrane reactor: A brief overview,

Separation and Purification Technology,

Volume 358, Part B,

2025,

130435,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.130435.

(https://www.sciencedirect.com/science/article/pii/S1383586624041741)

Abstract: Hydrogen (H2) displays great potential as an alternative fuel in the future, whereby its production and separation have become an intensive research subject. In addition to the traditional separation techniques such as pressure swing adsorption (PSA) and cryogenic separation, membrane separation technology has been favored by researchers given the advantages of simple operation, low cost, high separation efficiency, and ease of integration with catalytic reactions and other processes. This review overviews the preparation and structural regulation of high-efficiency and stable H2 separation membranes. Among the H2 separation membranes, nickel (Ni)-based metallic membranes have received extensive attention for their low cost and good stability. In this review, the classification, H2 permeation mechanisms, and fabrication methods of Ni-based metallic membranes as well as Ni-based metallic membrane reactors and their applications are discussed. Emphasis is put on the phase inversion-sintering method in the fabrication of Ni-based metallic membranes and the application of Ni-based metallic membrane reactors for reforming and H2 production. H2 production from reforming normally provides high H2 yield and is expected to provide one of the most practical pathways for future H2 energy industry.

Keywords: Ni-based metallic membrane; Hollow fiber; H2 separation; Membrane reactor; H2 production from reforming

Tatiana Alekhina, Aliya Mukhametdinova, Alina Khayrullina, Pavel Afanasev, Aysylu Askarova, Evgeny Popov, Alexey Cheremisin, Elena Mukhina,

Influence of catalyst variation on underground hydrogen generation in gas reservoirs: Impact on hydrogen yield and alteration of catalyst structure and rock properties,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 740-754,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.257.

(https://www.sciencedirect.com/science/article/pii/S0360319925002782)

Abstract: Experimental and numerical studies highlight the potential of subsurface hydrogen production to generate substantial quantities of hydrogen, however certain aspects remain unclear. One such aspect involves the application of catalysts, including their delivery and efficiency in reservoir porous media. This study explores in situ hydrogen generation in a natural gas reservoir using Ni/Al2O3, Nb-doped Ni/Al2O3, and in situ synthesized Ni-based catalysts. Laboratory experiments tested two catalyst delivery methods in flow reactors and a combustion tube under conditions of up to 800 °C and 8 MPa. Results indicate in situ synthesized catalysts provide superior distribution and stable hydrogen synthesis, reaching up to 48.4 vol%, while industrial catalysts met some benchmarks but proved less effective for in situ use. The findings confirm the feasibility and safety of this approach, highlighting critical factors affecting hydrogen generation efficiency and its practical potential.

Keywords: Hydrogen; In situ hydrogen generation; Steam methane reforming; Gas reservoir; Rock properties; Catalysts; Catalyst properties; Nickel catalyst; In situ catalyst

Haocheng Sun, Zhiwei Ge, Zhihan Yao, Liang Wang, Xipeng Lin, Yakai Bai, Shuang Zhang, Haisheng Chen,

Coupling system of calcium looping thermal energy storage and adsorption-enhanced hydrogen production,

Energy Conversion and Management,

Volume 325,

2025,

119254,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119254.

(https://www.sciencedirect.com/science/article/pii/S0196890424011956)

Abstract: CaL(Calcium Looping)-based Sorption-Enhanced Steam Methane Reforming (SE-SMR) is an essential method for achieving low-carbon hydrogen production. However, existing in-situ reactors struggle to produce H2 continuously over long periods. This study proposes an innovative quasi-in-situ SE-SMR reactor based on CaL and develops a multi-physical field model with multiple reaction couplings. The study elucidates the mechanisms of heat and mass transfer, as well as reaction enhancement, and identifies the key parameters influencing the hydrogen production process in this reactor. During the pre-breakthrough phase, stored heat drives the reforming reaction, sustaining an average H2 purity of 95.62% and a high carbon capture rate. A hydrogen yield of 3.61 demonstrates efficient methane reforming and conversion. Under the pre-breakthrough replacement strategy, the reactor performance stabilizes after the second replacement and generally maintains the high-performance level of the pre-breakthrough phase. Additionally, the heat storage properties of CaL help to reduce the heat demand of the reactor, enhancing system stability under fluctuating heat source conditions. These findings highlight the crucial role of the heat-mass coupling relationship in CaL in enhancing the hydrogen production process, offering valuable insights for developing long-term, high-performance hydrogen production solutions in solar-powered systems.

Keywords: Hydrogen; Reactive sorption-enhanced; Methane reforming; Long-term continuous hydrogen production

Xuelin Chen, Jinxia Quan, Hailing Yang, Yiyun Chen, Jingwen Zhuang, Guocai Li, Juan Lv, Zhifeng Hu,

The quenching-based enhancement on the strong metal-support interaction and pore structure of Ni-CaO for efficient CO2 capture and in-situ conversion,

Chemical Engineering Journal,

Volume 505,

2025,

159690,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159690.

(https://www.sciencedirect.com/science/article/pii/S1385894725004899)

Abstract: Integrated CO2 capture and utilization (ICCU) technology with Ni-CaO dual-functional materials (DFMs) is promising. However, DFMs suffer from carbon deposition and sintering after continuous cyclic reaction, resulting in the decrease of capture capacity, activity, and even pore collapse. Herein, the effects of synthesis modes such as mechanical mixing, sol–gel, and impregnation on the reactivity and stability of DFMs are investigated. Furthermore, a quenching process is proposed to be applied to the preparation of Ni-CaO DFMs in order to improve the performance. The results show that synthesis mode significantly affects the properties of Ni-CaO DFMs. Specifically, the quenching process not only contributes to the strong metal-support interaction (SMSI) in the material, but also results in a richer pore structure and smaller, more dispersed metal particles. Consequently, its CO2 capture and conversion capabilities are enhanced by at least 70.67 % and 73.73 % respectively, compared to the conventional sol–gel synthesis modes. After 10 cycles, the CO2 capture still reaches 11.912 mmol/g, and the conversion rate maintains above 80 %. Finally, a kinetic model is used to reveal the carbonation-decarbonation mechanism of DFMs, providing new insights into the potential application of the quenching process in ICCU.

Keywords: Dual-functional materials; Quenching; CO2 capture; In-situ conversion; Carbonation-decarbonation mechanism

Rujira Jitrwung, Kuntima Krekkeitsakul, Nattawee Teerananont, Parinya Thongyindee, Weerawat Patthaveekongka, Chinnathan Areeprasert,

Utilization of CO2 and recycling of methanol Residue from the refining process for production of Bio-Methanol,

Carbon Resources Conversion,

Volume 8, Issue 1,

2025,

100302,

ISSN 2588-9133,

https://doi.org/10.1016/j.crcon.2024.100302.

(https://www.sciencedirect.com/science/article/pii/S2588913324000917)

Abstract: This study explores the synthesis of bio-methanol from biogas, focusing on the optimization of carbon dioxide (CO2) separation via alternating pressure adsorption and subsequent methanol production using varying methane (CH4) ratios. Methanol synthesis was conducted under CH4/CO2 ratios of 30/70, 50/50, and 70/30, utilizing both pure water and methanol solutions at concentrations of 10 %, 20 %, 30 %, and 40 %. The results demonstrated that increasing the CH4 ratio led to enhanced CO2 conversion, with maximum values of 42.59 % and methanol production reaching 3,850 g/day. The study further investigated the refining process of crude methanol, achieving a purity exceeding 99 % through a three-column distillation approach. Notably, the recycling of waste methanol significantly improved both methanol yield and CO2 consumption, indicating a promising pathway for sustainable bio-methanol production. Overall, this research highlights the potential of integrating biogas utilization with efficient methanol synthesis and refining processes.

Keywords: CO2 utilization; Methanol refining; Waste methanol recycling; Bio-methanol production; Syngas generation; Biogas

Jingxun Zhou, Chengxiong Dang, Guiping Zheng, Weiquan Cai,

The capture and in-situ hydrogenation of CO2 over Ni-CaO-Ca12Al14O33 bifunctional catalyst,

Separation and Purification Technology,

Volume 354, Part 7,

2025,

129375,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.129375.

(https://www.sciencedirect.com/science/article/pii/S1383586624031149)

Abstract: The integrated CO2 capture and hydrogenation conversion (ICCH) can realize CO2 adsorption and conversion in a single process, which provides the possibility of large-scale CO2 treatment. The arrangement of adsorption and catalyst is crucial for the ICCH process. In this work, we have studied four different adsorbent (CaO)/catalyst (Ni/Al2O3) packing methods and found that the bifunctional catalyst is the best arrangement for ICCH. 10Ni-CA2.8 bifunctional catalyst provides the intimate contact between the catalytic sites and adsorption sites, offering 97.8 % conversion of CO2 and 97.5 % selectivity of CH4 in ICCH reaction. Additionally, the superior performance of 10Ni-CA2.8 lowers the temperature of ICCH and weakens the sintering of the sample, thus guaranteeing the high stability of ICCH reaction. A nearly 100 % CO2 conversion with 98 % selectivity of CH4 is achieved at the same temperature of 525 °C for 50 cycles. Meanwhile, only 3 % recession of CO2 sorption capacity is shown in the whole stability test. In-situ DRIFTS shows that direct methanation of CaCO3 rather than CaCO3 dissociation followed by hydrogenation dominates the reaction pathway of ICCH.

Keywords: CO2 capture and conversion; In-situ hydrogenation; Methanation; Bifunctional catalyst

Bohan Li, Chaoyang Wang, Chang Liu, Ming Liu, Junjie Yan,

Three-dimensional dynamic multi-physics modeling and long-term degradation performance analysis of solid oxide fuel cell considering carbon deposition,

Journal of Power Sources,

Volume 631,

2025,

236195,

ISSN 0378-7753,

https://doi.org/10.1016/j.jpowsour.2025.236195.

(https://www.sciencedirect.com/science/article/pii/S037877532500031X)

Abstract: Carbon deposition is a critical issue in solid oxide fuel cell (SOFC) operations. In this study, a 3D dynamic model of SOFC considering carbon deposition is established and validated to investigate the effects of key operating conditions (i.e., output voltage, operating temperature, and fuel composition) on the long-term power degradation of the cell. Additionally, the total working lifecycle power generation (Ptot) of the cell is calculated for methane molar fractions in the feeding fuel (XCH4) ranging from 0.1 to 0.4, output voltages (U) from 0.6 V to 0.8 V, and operating temperatures (T) from 1003 K to 1043 K. The results indicate that the long-term SOFC operating voltage should exceed the voltage for maximum steady-state power output to achieve higher Ptot. When the power degradation threshold (PDT) equals 0.75, Ptot reaches 2880 kW h/m2 at U = 0.75V, approximately twice that at U = 0.55V. The power degradation process of the cell can be divided into two stages: a rapid degradation stage and a slow degradation stage. Decreasing the operating temperature or reducing XCH4 to regulate PDT to the slow degradation stage can significantly enhance the cell's total working lifecycle power generation. A distinct boundary in XCH4 is observed between high and low Ptot. When XCH4 exceeds the boundary value (0.25), the cell's Ptot decreases by over 70 %.

Keywords: Solid oxide fuel cell; 3D dynamic model; Direct internal reforming; Carbon deposition

Guang Miao, Leizhao Zheng, Cuiting Yang, Guoqing Li, Jing Xiao,

Performance analysis of a novel SMR process integrated with the oxy-combustion power cycle for clean hydrogen production,

Chemical Engineering Science,

Volume 302, Part B,

2025,

120861,

ISSN 0009-2509,

https://doi.org/10.1016/j.ces.2024.120861.

(https://www.sciencedirect.com/science/article/pii/S0009250924011618)

Abstract: The steam methane reforming (SMR) process has been instrumental in industrial hydrogen production, despite its high carbon footprint. The direct capture of CO2 from its flue gas remains a challenge. In this study, we propose a hybrid SMR process integrated with the NET Power Cycle (NPC) to repurpose exhausted CO2 and produce supercritical CO2 directly. To simulate the conventional SMR process, we developed mathematical and machine-learning models to predict hydrogen production. The integration of heat between the SMR and NPC units led to 40 % reduction in natural gas consumption, while the energy required for CO2 capture was reduced by 54 %. The optimization of the SMR-NPC process was conducted using the genetic algorithm (GA), resulting in low direct CO2 emissions of 0.6 kg-CO2/kg-H2 and levelized cost of hydrogen (LCOH) of $3.39/kg-H2. The novel process proposed in this study offers an efficient means to enhance both the economic and environmental performance of industrial hydrogen production.

Keywords: Mathematical modeling; Machine learning; CO2 reduction; Hydrogen production; Process simulation

Ju Ho Son, Gyungah Park, Dong-Hyeon Lee, Yunjo Lee, Yang Sik Yun, Jong Hyeok Park, Jeong-Cheol Seo, Seung Ju Han,

Selenium-promoted molten metal catalysts for methane pyrolysis: Modulating surface tension and catalytic activity,

Applied Catalysis B: Environment and Energy,

Volume 366,

2025,

125009,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.125009.

(https://www.sciencedirect.com/science/article/pii/S0926337324013237)

Abstract: Compared with the commercial hydrogen production methods, molten metal–catalyzed methane pyrolysis has a smaller carbon footprint but is less mature, particularly regarding catalyst optimization. To bridge this gap, we herein examine the effects of Se content on the surface activity and physical properties of Se-promoted benchmark molten metal (NiBi and CuBi) catalysts for methane pyrolysis. At appropriate Se contents, methane conversion increases by 36.3 % (Ni27Bi72Se1) and 20.5 % (Cu45Bi47Se8), while the surface energy decreases (from 389 mN∙m−1 for Ni27Bi73 to 317 mN∙m−1 for Ni27Bi72Se1), and the volume-specific surface area of bubbles increases. Among the Se-doped NiBi catalysts, Ni27Bi72Se1 shows the lowest apparent methane C–H activation energy (201.2 kJ mol−1), whereas increased values are observed at overly high Se contents (>1 at%). Theoretical calculations reveal that the introduction of an optimal amount of Se (1 at%) increases the surface activity of the NiBi catalyst by reducing the activation energy and promoting the surface exposure of the Ni sites. Whereas the excess Se decreases surface activity by suppressing the surface exposure of Ni sites. Similarly, the addition of Se to CuBi enhances its methane pyrolysis performance by modifying surface activity. The experimental and theoretical data demonstrate that Se addition not only increases surface activity and solute exposure but also reduces surface tension, offering hydrodynamics-related advantages. Thus, this study provides a new perspective on the development of promoters for molten metal–catalyzed methane pyrolysis.

Keywords: Methane pyrolysis; Molten metal catalyst; Selenium; Promoter; Turquoise hydrogen production; Surface activity

Xi Zhang, Xiaodi Zhang, Lingling Ren, Mingjuan Han, Nengjie Feng, Hui Wan, Guofeng Guan,

Progress and challenges of spinel materials for catalytic combustion of methane,

Fuel,

Volume 379,

2025,

133090,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133090.

(https://www.sciencedirect.com/science/article/pii/S0016236124022397)

Abstract: Methane (CH4) serves as both a valuable fuel and a crucial raw material for chemicals, while also playing a pivotal role in coal mine safety and various industries. CH4, as the world’s second-largest greenhouse gas, is considered the “holy grail” of catalytic reactions for its activation and conversion. Catalytic combustion (2C) technology offers a rapid and continuous mean to mitigate CH4 emissions and enhance both global warming and air quality. Effective catalyst selection plays a crucial role in this process. Spinel metal oxides (SMO) are as promising candidates due to their adaptable structure, composition, phase, valence state, morphology and defects. This paper reviews the progress made in the past decade in synthesizing and applying SMO catalysts for catalytic combustion of CH4 (CCM) and highlights advancements in the catalytic removal of various pollutants beyond CH4, achieved through modifications to SMO catalysts over the past five years. Finally, the challenges associated with designing and preparing efficient SMO catalysts for CH4 removal and the future theoretical and applied research of SMO catalysts in CH4 catalytic purification is prospected. This provides systematic guidance for the design and preparation of efficient spinel catalysts for catalytic removal of atmospheric pollutants.

Keywords: Methane; Catalytic combustion; Spinel metal oxides; Modification strategies; Catalysts

Yuxin Li, Hongkai Di, Tao Zhang, Juanmin Hou, Jingsi Yang, Kunjie Li, Jiangze Han, Ruihong Zhao,

Catalytic cracking of tar model compounds over char-based catalysts,

Journal of the Energy Institute,

Volume 119,

2025,

102017,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2025.102017.

(https://www.sciencedirect.com/science/article/pii/S1743967125000455)

Abstract: Catalytic cracking of biomass pyrolysis tar model compounds was conducted in a fixed bed reactor using char and metal-impregnated char (Ni-char, Zn-char) as the catalyst. The catalytic effect of the catalysts on the model compounds (n-heptane, cyclohexane, toluene, thiophene and pyridine) was investigated. The catalytic cracking caused the higher non-condensable gas yield and the lower total tar yield, especially for the Ni-char catalyst. The supported nickel on the Ni-char catalyst was existed in the form of Ni, and the Zn was existed in the form of ZnO on the Zn-char catalyst. NH3-TPD desorption results revealed that the catalyst acidity decreased in the order of Ni-char > Zn-char > Char, which is in accordance with the catalytic activity. The final catalytic effect of the Ni-char catalyst on different tar model compounds is mainly determined by the structure of the compounds. The FT-IR analysis results of the products obtained from catalytic cracking the model compounds over Ni-char catalyst showed that the hydrogenation reaction usually occurred when n-heptane was cracked, the ring-opening and reforming reactions mainly occurred when cyclohexane and toluene were cracked, while the thiophene and pyridine were changed little.

Keywords: Biomass; Pyrolysis; Tar; Char-based catalysts; Catalytic cracking

Roberto Fiorenza, Luca Calantropo, Eleonora La Greca, Leonarda Francesca Liotta, Antonino Gulino, Angelo Ferlazzo, Maria Grazia Musumeci, Giuseppe Proietto Salanitri, Sabrina Carola Carroccio, Giusy Dativo, Maria Teresa Armeli Iapichino, Salvatore Scirè, Giuliana Impellizzeri,

Solar-promoted photo-thermal CO2 methanation on SiC/hydrotalcites-derived catalysts,

Catalysis Today,

Volume 449,

2025,

115182,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2024.115182.

(https://www.sciencedirect.com/science/article/pii/S092058612400676X)

Abstract: The photothermo-catalysis is a combined multicatalytic approach that allows to overcome some drawbacks of the respective single catalytic processes as the thermocatalysis and the photocatalysis. In this work, to efficiently exploit the potentiality of the solar photothermo-catalysis, SiC/hydrotalcites-derived catalysts were prepared with a simple hydrothermal method to exploit both the thermocatalytic properties of the formed multifunctional mixed oxides and the photo(thermo)-catalytic features of the silicon carbide. Two different hydrotalcite-derived catalysts were prepared, one with Mg-Co ions and another with Zn-Co ions. This latter sample, after the addition of SiC, showed the best performance in the CO2 methanation reaction, with a CH4 selectivity maximum of 71 % in the photothermal conditions at 250 °C, strongly improving the performance of the thermocatalysis (36 % at 350 °C). The presence of SiC permitted to increase the harvesting of the solar light, to modify the basic sites of the hydrotalcite-derived catalysts, allowing an efficient CO2 activation, and to generate self-heating effects that enhanced the photo-driven thermocatalysis. Moreover, the formation of photocatalytic active species as the ZnO and the ZnAl2O4 after the calcination of the corresponding hydrotalcite precursor, led to exploit additional photocatalytic contributions to further increase the catalytic activity in the photo-promoted thermocatalytic CO2 conversion into methane. The high versatility and the several synergisms generated by the application of this hybrid catalysis with these peculiar SiC/hydrotalcite-derived catalysts can be a sustainable strategy to efficiently valorise the carbon dioxide.

Keywords: Methane; Photothermo-catalysis; Hydrotalcite; CO2; SiC

Sohrab Zendehboudi, Bahram Ghorbani,

Chapter 2 - Common hydrogen feedstock and production pathways,

Editor(s): Sohrab Zendehboudi, Bahram Ghorbani,

Hydrogen Production, Transportation, Storage, and Utilization,

Elsevier,

2025,

Pages 43-161,

ISBN 9780443240423,

https://doi.org/10.1016/B978-0-443-24042-3.00002-3.

(https://www.sciencedirect.com/science/article/pii/B9780443240423000023)

Abstract: This chapter reviews various methods for hydrogen (H2) production, exploring cutting-edge technologies and traditional processes. It begins by emphasizing the importance of H2 as a clean and versatile energy carrier, highlighting its potential role in the transition to a sustainable energy future. This chapter categorizes H2 production methods into several categories, including fuel processing, electrolysis, thermochemical cycles, renewable methodologies, and innovative strategies. Among these methods, plasma reforming emerges as a promising approach, utilizing plasma to decompose organic materials and produce syngas containing H2. Ammonia reforming offers another pathway for H2 generation, utilizing the catalytic dehydrogenation of NH3 at lower temperatures compared to conventional methods. Aluminum-based methods present intriguing possibilities, utilizing reactions with water or hydrocarbons to yield H2 gas. However, challenges such as reactant corrosiveness and catalyst activation need to be addressed for practical implementation. Additionally, the chapter explores chlor-alkali processes, which utilize electrolysis of water and sodium chloride to produce H2, Cl2, and NaOH. This versatile industrial process finds applications across various industries, contributing to the production of essential materials such as textiles and paper. The chapter emphasizes balancing technological innovation with practical factors such as cost-effectiveness, scalability, and environmental impact. While each method offers unique advantages, they also present challenges that should be overcome to realize their full potential in sustainable H2 production. Overall, this chapter provides a comprehensive overview of different pathways for H2 production, highlighting the importance of continued research and development in advancing clean energy technologies. By exploring a range of methods, from plasma reforming to chlor-alkali processes, the chapter further highlights the multidimensional nature of the H2 economy and the need for integrated approaches to address global energy challenges.

Keywords: Energy resource; energy sustainability; H2 production methods; feedstock diversity; chemical reaction; thermochemical cycles; fuel processing; green chemistry; biomass; H2 feedstock; electrolysis units; catalysts; practical considerations; H2 economy

Fanmeng Zeng, Andreas Goldbach,

Methanol steam reforming over copper supported on apatites,

Applied Catalysis B: Environment and Energy,

Volume 362,

2025,

124710,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124710.

(https://www.sciencedirect.com/science/article/pii/S0926337324010245)

Abstract: Low-temperature methanol steam reforming (MSR) over Cu is an efficient process for releasing H2 from this promising liquid hydrogen carrier but the Cu contents of commercial catalysts are often exceedingly high. Here we show that Sr-exchanged fluoro and hydroxyapatites with 1 wt% Cu exhibit very high methanol turnover frequencies up to 386 h−1 and H2 production rates up to 6569 mol H2 kgCu−1 h−1 with CO selectivity as low as ∼0.25 % at 250 °C. Formaldehyde and methyl formate are the only other byproducts which are especially observed over catalysts with low Sr/P ratio in the hydroxyapatite. The reforming proceeds through methoxy, formaldehyde and formate species according to in situ FTIR and mass spectrometric measurements. The spectroscopic analyses further reveal the involvement of apatitic HPO42- ions in the catalytic sequence. Thus, the catalytic synergy between Cu and apatites provides a basis for highly efficient, bifunctional MSR catalysts with low copper content.

Keywords: Methanol steam reforming; Copper; Hydroxyapatite; Fluoroapatite; FTIR spectroscopy; Methyl formate

Ankit Nema, Arvind Kumar, Vilas Warudkar,

An in-depth critical review of different carbon capture techniques: Assessing their effectiveness and role in reducing climate change emissions,

Energy Conversion and Management,

Volume 323, Part A,

2025,

119244,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119244.

(https://www.sciencedirect.com/science/article/pii/S0196890424011853)

Abstract: Capturing, utilizing, and storing CO2 is recognized as a vital strategy to combat climate change driven by fossil fuel use. This approach helps reduce greenhouse gas emissions and promotes sustainability by managing CO2 emissions through innovative capture technologies, exploring its conversion into valuable products, and ensuring safe storage to prevent atmospheric re-entry. Several strategies for CO2 capture have been developed, including pre-combustion, post-combustion, and oxyfuel combustion. Pre-combustion methods can be further categorized into chemical looping, gas-liquid absorption, autothermal reforming, and steam methane reforming. Post-combustion capture is divided into techniques such as absorption, adsorption, membrane separation, cryogenic distillation, calcium looping, and direct air capture. Each of these approaches plays a critical role in reducing CO2 emissions and addressing climate change. This study aims to enhance CO2 capture technologies by providing a comprehensive overview of the current state of carbon capture methods. To achieve this, the major strategies and technologies for capturing CO2 from coal gasification processes have been thoroughly reviewed. The review article is structured into three main sections, covering pre-combustion, post-combustion, and oxyfuel combustion techniques. Each of these methods is further divided into various sub-techniques. The article thoroughly examines the impact of these carbon capture methods, comparing them with other available techniques. It provides readers with a clear understanding of the current status of carbon capture technologies and their effectiveness.

Keywords: Coal Gasification; Carbon Capture; Syngas; Pre-combustion; Emissions; Oxy-fuel combustion; Post-combustion

Jun Lu, Mutao Xu, Mengfei Yang, Qijie Jin, Ranran Zhou, Liguo Chen, Yaping Zhang, Jing Song, Changcheng Zhou, Haitao Xu,

Methanol steam reforming for hydrogen production over NiO/NaOH catalyst: Relationship between crystal facet and sodium ions,

International Journal of Hydrogen Energy,

Volume 101,

2025,

Pages 403-418,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.475.

(https://www.sciencedirect.com/science/article/pii/S0360319924056945)

Abstract: Hydrogen is one of the clean fuels with wide prospects due to its high energy density and zero carbon emission. The effects of Na+-doped CeO2 carriers and Ce4+-doped NaOH carriers on nickel-based methanol reforming catalysts for hydrogen production were investigated. When the carrier was mainly composed of NaOH, it would not only cause the main exposed crystal facet of NiO to become strongly polarized (111), but also cause the main exposed crystal facet of CeO2 to become high energy (002). When the carrier was mainly composed of CeO2, the doping of Na + would cause the main exposed crystal facet of CeO2 to become (200), and the co-doping of Na+ and elemental nitrogen will turn the exposed crystal surface of CeO2 into a mixture of (111) and (110). Furthermore, the use of NaOH as the main component of the carrier enhanced both the hydrogen consumption and the basic sites of catalyst. These advantages safeguarded NiO/C–NaOH excellent hydrogen production performance for methanol reforming. In addition, there were two reaction paths for methanol reforming on the NiO/C–NaOH surface: (1) Methanol decomposed into methoxy intermediates, and then continued to decompose; (2) Methanol was oxidized to formic acid, and then reacted with the hydroxyl groups.

Keywords: Methanol steam reforming; Hydrogen production; Crystal facet; NaOH carrier; Cerium oxide

Yongxing Zhang, Jafar Zanganeh, Behdad Moghtaderi,

Advancement in neutral and negative emissions production of ammonia from carbonaceous sources: A review,

International Journal of Hydrogen Energy,

Volume 109,

2025,

Pages 40-62,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.417.

(https://www.sciencedirect.com/science/article/pii/S0360319925004616)

Abstract: The demand for sustainable ammonia has been increasing substantially since ammonia has been recognised as a promising energy carrier over hydrogen. The carbon-neutral and/or negative ammonia production via carbonaceous feedstocks could be achieved by efficient system design, such as integrating advanced carbon-to-hydrogen technologies and integrating chemical looping with Harber-Bosch process (ICLHB). This review is to provide an overview on technologies towards net-zero emissions and theoretical BAT energy performance for ammonia production via carbonaceous feedstocks (coal, methane, and biomass) through thermochemical methods, which is the most carbon- and energy-intensive pathways. It highlighted that the viable path to achieving carbon-neutral ammonia production via carbonaceous feedstocks requires a multi-faceted approach. Coal-based ammonia production, the most carbon-intensive method, relies on coal gasification to produce synthesis gas, resulting in high CO₂ emissions and energy consumption. The integration of co-gasification with biomass results in negative emissions of −0.656 t CO2/t NH3, making the coal to ammonia process a carbon-negative industrial method. ICLHB represents the most promising pathway to synthesis clean ammonia from coal. Methane-based production, currently the most widely used method, offers higher energy efficiency and lower CO₂ emissions compared to coal. Gas switching reforming (GSR) and membrane assisted autothermal reforming (MA-ATR) exhibit superior performance and are the most promising approaches for clean ammonia production via natural gas. Biomass-based ammonia production presents a potentially carbon-neutral alternative, contingent on sustainable feedstock sourcing and efficient gasification technologies. Techno-economic analysis indicates that biomass fed ICLHB could be the best option for clean ammonia from biomass. The selection of technology for biomass-to-ammonia production must consider the influence of feedstock variability. Different feedstocks exhibit varying characteristics that can impact the overall process efficiency and economic viability. In this context, the implementation of a carbon tax is essential, as it incentivizes the transition to carbon-neutral and economically sustainable ammonia production pathways across diverse feedstock types.

Keywords: Ammonia synthesis; Carbonaceous feedstocks; Carbon neutrality; CCS

Zhulian Li, Junnan Zhan, Yu Fang, Peiying Chen, Taixiu Liu, Qibin Liu,

Development of a new CO2-rich natural gas to high-purity CO zero carbon emission system employing chemical looping process: Thermodynamic and environmental investigation,

Energy Conversion and Management,

Volume 328,

2025,

119617,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2025.119617.

(https://www.sciencedirect.com/science/article/pii/S0196890425001402)

Abstract: Offshore natural gas (NG), as an important energy resource, has high CO2 concentrations widely distributed from 20% to 80%. The effective conversion and utilization of these NG hold substantial environmental value. However, traditional NG conversion technologies, such as dry reforming of methane (DRM), cannot fully convert NG with such high CO2 concentrations, often requiring decarbonization processes which causes significant energy loss and carbon emissions. In this work, a novel zero-carbon emission system for the efficient and environmentally friendly conversion of CO2-rich NG is developed. Different from the traditional DRM route to produce syngas, the CO2-rich NG is converted directly into high-purity CO through metal oxide oxygen carrier chemical looping reactions with CO2 adsorption enhancement. Through the proposed method, a higher amount of CO2 can be reduced per unit of methane, showing the capable advantage for higher CO2 concentration NG. Based on the system configuration, key process experiments were conducted to validate the feasibility and advancement of the proposed system. Furthermore, system integration and parameter analysis were conducted to investigate the thermodynamic and environmental performance of the developed system, verifying its adaptability and conversion capability to various types of NG. The promising results show that, the novel system can convert NG with up to 63.50% CO2 to CO with 99.10% purity. Compared to the DRM, the amount of CO2 reduced per unit of CH4 raises from 0.76 to 1.71, representing 1.25 times increase, with a 17.00% improvement in system energy efficiency. This research significantly improves the utilization efficiency and environmental sustainability of CO2-rich fuels, such as CO2-rich NG and biogas, providing a new pathway for reducing greenhouse gas emissions and high valorization utilization of CO2.

Keywords: CO2-rich fuel valorization; Zero-carbon system; System analysis; CO2 reduction; Chemical looping conversion

M.Yu. Lopatin, E.M. Sadovskaya, A.S. Ksenz, A.A. Vorobyova, A.I. Boltalin, A.V. Knotko, N.M. Sorokina, T.B. Shatalova, D.I. Petukhov, Yu.E. Fedorova, N.F. Eremeev, V.A. Sadykov, I.V. Morozov, A.A. Fedorova,

A new approach to lanthanum silicates with apatite structure synthesis using β-cyclodextrin,

Colloids and Surfaces A: Physicochemical and Engineering Aspects,

Volume 708,

2025,

135979,

ISSN 0927-7757,

https://doi.org/10.1016/j.colsurfa.2024.135979.

(https://www.sciencedirect.com/science/article/pii/S0927775724028437)

Abstract: Apatite-type lanthanum silicates attract the attention of scientists due to their high oxygen mobility and, therefore, the opportunity for different applications. The samples of undoped and iron-doped lanthanum silicates with apatite structure were obtained by the modified sol-gel method using β-cyclodextrin as a template. The precursor decomposition was investigated by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) methods with mass-spectrometry registration of evolved gaseous products. Obtained lanthanum silicates were studied by X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDX) and low-temperature nitrogen adsorption (BET and BJH). Oxygen mobility in samples was examined with a temperature-programmed isotopic exchange using 18O2 and C18O2, which complement each other. The catalytic activity of samples with supported nickel was investigated in the ethanol steam reforming reaction. It was shown that the described synthesis method allows obtaining lanthanum silicates at relatively low temperatures. Synthesized samples have a high oxygen mobility, which increases with iron doping. Also, it was shown that catalyst based on iron-doped lanthanum silicate possesses higher oxygen mobility and catalytic activity than catalysts based on undoped apatites.

Keywords: Lanthanum silicates; Iron doping; Sol-gel method; Cyclodextrin; Isotopic exchange; Ethanol steam reforming

Kaisar Ahmad, Maguy Abi Jaoude, Anifat Adenike Bankole, Kyriaki Polychronopoulou,

Hydrogen production towards carbon-free economy: A comprehensive thermodynamic analysis,

Energy Conversion and Management,

Volume 326,

2025,

119492,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2025.119492.

(https://www.sciencedirect.com/science/article/pii/S0196890425000159)

Abstract: Sustainable hydrogen production is key to achieving zero-emission targets and a hydrogen-based economy. Hydrogen production methods vary in terms of resource, technology, and system efficiency. This work analyzes the thermodynamics of fourteen hydrogen production pathways using Gibbs free energy minimization to examine the effects of pressure (1–60 bar), temperature (100–1000 °C), and feed composition, using reactant conversion and product selectivityas key indicators of reaction performance. The impact of simultaneous reactions on hydrogen production is also discussed. From the results, full conversion (100 %), independent of parameter variations at 1 bar pressure, was observed for biomass gasification and steam reforming of glycerol, methanol, ethanol, and bio-oil reactions. However, H2 selectivity in all tested reactions, except for NH3 dissociation and the splitting of water and H2S, is greatly affected by side reactions. Finally, the thermodynamic results of all reactions are compared and validated with published experiments, followed by an evaluation of the challenges and opportunities in hydrogen production. The study provides optimal reaction parameters and a comprehensive comparison of H2 production processes, aiding in designing and developing processes based on regional resource availability. Additionally, it highlights the potential for both local and remote hydrogen production pathways from various renewable energy sources.

Keywords: Clean energy; CO2 utilization; Green hydrogen; Hydrogen production pathways; Thermodynamic analysis; Zero carbon emission

Mingfei Li, Xiaoyu Li, Zhengpeng Chen, Xiuyang Qian, Hongmin Liu, Jiangbo Dong, Kai Xiong, Mumin Rao, Chuangting Chen, Yihan Ling,

Hydrogen enriched natural gas-fueled solid oxide fuel cells supported by Ni-Cu co-doping CeO2-δ catalyst-modified finger-like pore anode,

Fuel,

Volume 381, Part B,

2025,

133428,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133428.

(https://www.sciencedirect.com/science/article/pii/S0016236124025778)

Abstract: Hydrogen blending in natural gas pipelines is one of the key technologies to realize the long-distance hydrogen transmission, which facilitates the large-scale hydrogen utilization. Solid oxide fuel cells can directly use hydrogen enriched natural gas (HENG, with 20 % H2) to generate electricity without separating and purifying the hydrogen, which enables the efficient conversion of hydrogen energy. In this work, finger-like pore anodes and Ni0.05Cu0.05Ce0.9O2-δ (NCCO) catalyst are prepared to address the need for anode performance and stability with hydrogen-doped natural gas fuels. The results show that NiCu@CeO2 precipitates NiCu nano-alloys on the surface after reduction treatment, which is beneficial for the anode activity. With NCCO catalyst, the maximum power densities of the single cells are 970 mW cm−2 and 700 mW cm−2 at 750 °C under wet H2 and HENG fuel atmospheres, respectively. At 750 °C, the methane conversion is as high as 46 %. More importantly, the single cell can run smoothly for 150 h, with the constant voltage (0.8 V) discharge and HENG as fuel gas. Our results confirm that the synthesized NCCO catalysts have excellent ability to catalyze CH4 and carbon resistance.

Keywords: Solid oxide fuel cells; Hydrogen enriched natural gas; Catalyst; Finger-like pore anodes; Carbon deposition

Baoyu Huang, Xiaomei Zhao, Yang Ma, Zhengjun Fang,

Proper NCoordination improves catalytic activity of graphene edge anchored Pt single atom for conversion of methane and carbon dioxide to acetic acid,

Molecular Catalysis,

Volume 570,

2025,

114688,

ISSN 2468-8231,

https://doi.org/10.1016/j.mcat.2024.114688.

(https://www.sciencedirect.com/science/article/pii/S2468823124008708)

Abstract: The reaction of directly converting CH4 and CO2 into acetic acid has a wide and important application in the chemical industry. In this work, we carried out systematically computational chemistry study on the catalytic performance of the single Pt atom catalyst anchored at the edge of N-doped graphene for the direct co-conversion of CH4 and CO2 to acetic acid based on density functional theory (DFT) calculations. The DFT calculation results show the catalytic activity of single Pt atom is significantly tuned by the local N-atom coordination. The Pt-N1C exhibits the best catalytic performance of CH4 and CO2 conversion with a low rate-determining free energy barrier of 0.69 eV The microkinetic modeling shows that the TOF of CH3COOH on Pt-N1C catalyst reaches 7.63×102 s−1 at 600 K and 2 bar Further analysis shows that the adsorption strength of reactant CH4 and CO2 is linearly correlated with the energy level of dxy orbital center of Pt atom. A moderate adsorption strength of CH4 and CO2 over the Pt-N1C leads to easier activation of methane and migration of H and CH3 during the conversion reaction.

Keywords: Pt-N1C catalyst; Co-conversion; Acetic acid; DFT; Microkinetic Modeling

Wei-Hsin Chen, Meng-Hong Zhong, Thanh-Binh Nguyen, Amit Kumar Sharma, Chung-Gang Li,

Hydrogen production in reverse tesla valve reactor combining ethanol steam reforming and water gas shift reaction,

Energy,

Volume 318,

2025,

134783,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2025.134783.

(https://www.sciencedirect.com/science/article/pii/S0360544225004256)

Abstract: This study uses a reverse Tesla valve (RTVR) as a reactor for ethanol steam reforming (ESR) and water gas shift reaction (WGSR) to produce hydrogen. By combining ESR with WGSR to produce hydrogen, the dual objectives of enhancing hydrogen production and mitigating the negative impacts of carbon monoxide on the reactor can be implemented. This application of the RTVR reactor in thermochemical hydrogen production represents a novel advancement in this field. Three different reactors, including RTVR, bridge-type, and rectangular-type reactors, are adopted for comparison. The results reveal that the RTVR outperforms the other reactor types, achieving higher ethanol conversion rates and greater hydrogen yield, stemming from its special flow field design. However, a drawback accompanied by the RTVR is its higher pressure drop. The study identifies optimal operating conditions, including a temperature of 600 °C, a steam-to-ethanol (S/E) ratio of 3, outlet pressure of 1.5 atm, and a Reynolds number of 10, under which the RTVR reaches an ethanol conversion rate of 96.76 % and a hydrogen yield of 4.7 mol (mol C2H5OH)−1, showing its high performance. This advancement in reactor design offers the potential for more efficient hydrogen production technologies.

Keywords: Tesla valve; Hydrogen production; Steam reforming; Water gas shift reaction; Ethanol; Ethanol conversion

Ziyu Zengcai, Shuting Liu, Yating Han, Baofang Zhang, Wenting Lin, Jingyao Yang, Yunhong Pi, Tiejun Wang,

Insights into photothermal methanol reforming into hydrogen: The role of tailored dual-active-centered defective amino-MOFs for hydroxyl activation,

Applied Catalysis B: Environment and Energy,

Volume 362,

2025,

124767,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124767.

(https://www.sciencedirect.com/science/article/pii/S0926337324010816)

Abstract: This work highlights a dual-active-centered defective amino-MOFs (metal-organic frameworks) heterojunction catalyst tailored to offer distinct active sites for the separate adsorption and activation of CH3OH and H2O during the photothermal-driven reforming process of methanol solutions (PTRM). The catalyst, Cu@HPNM(Ti), integrates defect-rich HPNM(Ti) (hierarchically porous NH2-MIL-125(Ti)) and with abundant oxygen vacancies and Ti3+ centers as carrier for H2O adsorption and activation, and concurrently incorporates Cu centers to be actively responsible for promoting CH3OH decomposition. The synergistic dual-active-center of Cu@HPNM(Ti) afforded a H2 evolution rate of 51.2 mmolgcat−1h−1 within 80 min at 210 ℃, surpassing that of the thermocatalytic condition by approximately 9 times. Moreover, at 100 ℃, it exhibited a H2 production rate of 313.24 μmolgcat−1h−1. This dual-active-center enables promoted O-H and C-H bond activation, remarkably lowers the energy barriers of the rate-determining step during PTRM and water-gas shift (WGS) process, enabling highly efficient synergistic H2 production from PTRM at low temperatures.

Keywords: Hydrogen energy; Photothermal reforming; Metal-organic frameworks (MOFs); Dual-active-center; Hydroxyl activation

Zilong Huang, Yongheng Lu, Riyang Shu, Jianping Liu, Libin Lei, Zhipeng Tian, Chao Wang, Ying Chen,

Study on the methanol aqueous phase reforming performances over Pt/CeO2 catalysts: The effect of CeO2 morphologies and oxygen vacancies,

Journal of Alloys and Compounds,

Volume 1010,

2025,

177532,

ISSN 0925-8388,

https://doi.org/10.1016/j.jallcom.2024.177532.

(https://www.sciencedirect.com/science/article/pii/S0925838824041203)

Abstract: CeO2-supported catalysts have been extensively studied for hydrogen production via aqueous phase reforming of methanol (APRM) although several issues remain unclear, such as the influence of different morphologies on catalytic performance and the role of their oxygen vacancies in enhancing hydrogen yield. In this study, CeO2 with three distinct morphologies were synthesized, and platinum was loaded onto these supports via a photoreduction method to produce highly-dispersed catalysts designated as Pt/CeO2-R (rod-shaped), Pt/CeO2-C (cubic) and Pt/CeO2-O (octahedral) respectively. A series of APRM experiments suggested that Pt/CeO2-R exhibited the highest hydrogen production capacity (146.2 mmol-H2/gcat.). This superior performance is likely to attribute to the highly-dispersed Pt on the rod-shaped CeO2 support, which provides a substantial number of active metal sites, promoting the efficient adsorption and activation of methanol throughout the process. The anchoring effect of platinum on support surface and redox properties of Pt species were also thoroughly investigated with various characterization techniques. Further analysis revealed a strong correlation between turnover frequency (TOF) and the presence of oxygen vacancies on Pt/CeO2. Notably, abundant oxygen vacancies on catalyst enhanced substrate adsorption and the rapid conversion of CO\* intermediates adsorbed on platinum, which accelerated the water-gas shift (WGS) reaction through a faster redox pathway, leading to higher hydrogen production with low CO selectivity.

Keywords: Aqueous phase reforming; Hydrogen production; Catalyst morphology; Oxygen vacancy

Ismael Fuentes-Pereira, Robert E. Hayes, Adriana Blanco, Ignacio Poblete-Castro, Pablo Donoso-García, Francisco Gracia,

CO hydrogenation in a microreactor under non-differential regime: Kinetics, and impact of reactor design and operational variables,

Fuel,

Volume 386,

2025,

134134,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134134.

(https://www.sciencedirect.com/science/article/pii/S001623612403285X)

Abstract: A kinetic model for CO methanation and the water gas shift reaction, using a commercial catalyst 12 % Ni/γ-Al2O3 powder catalyst, is developed for a wall-coated microreactor to assess the impact of reactor design and operational parameters on catalytic performance. This model incorporates the simultaneous resolution of multidimensional balances of momentum, energy, and species continuity both in the catalytic and the hollow zones within the microchannels. The microreactor consists of 80 microchannels, each with dimensions of 0.45 × 0.15 × 50 mm3 and coated with a catalytic layer with an average thickness of 0.04 mm. Ninety-five experimental assays are carried out in triplicate under various conditions, including temperature (250 – 350 °C), H2/CO molar ratio at the inlet (2 – 11) and volumetric flow rates (110 – 140 mL/min). The corrected Akaike Information Criterion (AICc) indicated that a variation of the Champon model accurately described the experimental data of CO conversion and methane selectivity up to the non-differential regime, which generally occurs at an industrial scale. An apparent activation energy of 92.3 and 156 kJ/mol for the CO methanation and water gas shift reactions are calculated, respectively. The impact of operational variables on the methane mass flow, such as reaction temperature, feed composition, and flow rate, is quantified. Considering a mixture close to stoichiometric (H2/CO = 3.2), a boundary temperature of 325 °C and GHSV of 88 L/h/gcat, a maximum velocity of 1.26 m/s, complete isothermicity in the microchannel and a pressure drop of less than 0.5 kPa were achieved. Experimentally, a 47 % conversion and 93 % selectivity to methane were achieved, which closely approximated the value reported by the selected model. It is determined that the smaller dimensions of the microchannels favored CO conversion and methane formation, and it is verified that the microchannels operate isothermally throughout their entire domain, with pressure losses being negligible (<1%). Additionally, catalyst thickness has a greater impact on methane mass flow rate than the length and number of microchannels. This research contributes to the design of more efficient catalytic and thermal processes for the production of clean synthetic fuels, which is essential for the sustainable development of processes.

Keywords: CO hydrogenation; Microreactor; Kinetics; Model; Conversion

Masih Hosseinzadeh, Norollah Kasiri, Mehran Rezaei,

A comprehensive multiscale review of shaft furnace and reformer in direct reduction of iron oxide,

Minerals Engineering,

Volume 222,

2025,

109123,

ISSN 0892-6875,

https://doi.org/10.1016/j.mineng.2024.109123.

(https://www.sciencedirect.com/science/article/pii/S0892687524005521)

Abstract: The direct reduction of iron (DRI) process plays a pivotal role in the ironmaking and steelmaking industry and has emerged as a promising solution for reducing CO2 emissions. This intricate process spans metallurgy and chemical engineering, encompassing multiple scales (macroscale, mesoscale, microscale, nanoscale) and various reaction systems, including catalytic gas–solid (reformer) and non-catalytic gas–solid (shaft furnace) processes. The shaft furnace operated as a multiscale moving bed reactor including iron oxide pellets where a complex interplay of 17 non-catalytic gas–solid reactions and several gas reactions is observed. This review covers all relevant fields of gaseous-based DRI and introduces essential mathematical models for shaft furnaces and reformers. Key non-catalytic gas–solid and shaft furnace models developed over the last century are compared and analyzed. The effects of crucial parameters such as solid structure, gas phase conditions, clustering, carbon formation, and lattice defects are discussed. In addition, the reformer in the DRI unit functions as a bottom-fired furnace, comprising a combustion chamber and tubes that carry three types of heterogeneous catalysts, operating as a fixed bed reactor. Diverse radiative and kinetic models have been discussed to characterize the combustion chamber and reactions in detail. Finally, the review discusses potential artificial intelligence (AI) applications in this context and identifies research gaps for future investigations.

Keywords: Ironmaking; Direct reduction; Non-catalytic gas–solid reactions; Shaft furnace; Reformer; Radiative models; Heterogeneous catalysts

Yuhao Peng, Yuefeng Song, Ihar Razanau, Juanxiu Xiao, Wei Xiao, Di Hu, Guoxiong Wang,

Electrochemical conversion of methane to bridge the gap in the artificial carbon cycle,

Journal of Energy Chemistry,

Volume 100,

2025,

Pages 286-308,

ISSN 2095-4956,

https://doi.org/10.1016/j.jechem.2024.08.050.

(https://www.sciencedirect.com/science/article/pii/S2095495624006065)

Abstract: Methane, an abundant one-carbon (C1) resource, is extensively used in the industrial production of vital fuels and value-added chemicals. However, current industrial methane conversion technologies are energy- and carbon-intensive, mainly due to the high activation energy required to break the inert C–H bond, low selectivity, and problematic side reactions, including CO2 emissions and coke deposition. Electrochemical conversion of methane (ECM) using intermittent renewable energy offers an attractive solution, due to its modular reactor design and operational flexibility across a broad spectrum of temperatures and pressures. This review emphasizes conversion pathways of methane in various reaction systems, highlighting the significance and advantages of ECM in facilitating a sustainable artificial carbon cycle. This work provides a comprehensive overview of conventional methane activation mechanisms and delineates the complete pathways of methane conversion in electrolysis contexts. Based on surface/interface chemistry, this work systematically analyzes proposed reaction pathways and corresponding strategies to enhance ECM efficiency towards various target products, including syngas, hydrocarbons, oxygenates, and advanced carbon materials. The discussion also encompasses opportunities and challenges for the ECM process, including insights into ECM pathways, rational electrocatalyst design, establishment of benchmarking protocols, electrolyte engineering, enhancement of CH4 conversion rates, and minimization of CO2 emission.

Keywords: Methane; Electrochemical conversion; Reaction mechanism; Catalyst design; Electrode; Electrocatalysis

Weiqi Li, Enguang Ji, Chaoquan Hu, Xuebing Xu, Junfeng Hui, Tao Yang,

DFT studies on the catalytic hydrogenation of carbon dioxide on Ni (111) in a liquid-phase environment,

Chemical Physics,

2025,

112662,

ISSN 0301-0104,

https://doi.org/10.1016/j.chemphys.2025.112662.

(https://www.sciencedirect.com/science/article/pii/S0301010425000631)

Abstract: CO2 catalytic hydrogenation attracts interest in converting CO2 into useful chemicals and mitigating the greenhouse effect. In this study, CO2 hydrogenation in a liquid-phase environment on the Ni (111) surface was investigated using density functional theory calculations. Based on the analysis of hydrogenation in the gas phase, the water H migration model was introduced to examine the kinetic processes in the liquid phase. The results reveal that water plays a key role in this reaction. During the hydrogenation of CO2\* to COOH\* or HCOO\*, the adsorbed H atom is first transferred to the water molecule, which subsequently donates another H atom to COOH\* or HCOO\*. During this process, water directly participates in the reaction as a medium, enabling H\* to hydrogenate the adsorbed reactant over a limited distance. According to the proposed mechanism, the HCOO pathway is the optimal route for the reaction, exhibiting an energy barrier of 1.08 eV.

Keywords: Density functional theory; Formic acid; Hydrogenation; Carbon dioxide reduction

Ba Long Do, Thi Phuong Vy Bui, Hong Phuong Phan, Tri Nguyen, Cam Anh Ha, Luu Cam Loc,

Fe-promoted Ni catalyst supported on KCC-1 for enhancing synthetic natural gas (SNG) production,

Fuel,

Volume 385,

2025,

134193,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134193.

(https://www.sciencedirect.com/science/article/pii/S0016236124033441)

Abstract: To further improve the performance of the Ni/KCC-1 catalyst, herein, a series of Ni-Fe catalysts supported on KCC-1 (with Ni/Fe theoretical weight ratios of 25/1, 20/1, and 15/1) were facilely prepared by simultaneous impregnation method for application in CO2 methanation reaction. The characterizations of as-prepared catalysts were investigated by several techniques: X-ray diffraction (XRD), scanning electronic microscopy (SEM), high resolution-transmission electronic microscopy (HR-TEM), energy dispersive spectroscopy (EDS) analysis, N2 physisorption, hydrogen temperature-programmed reduction (H2-TPR), carbon dioxide temperature-programmed desorption (CO2-TPD), temperature-programmed oxidation (TPO). The unique structure of KCC-1 facilitates the observation of improved metallic dispersion which can even be seen on SEM images when Fe was added. Due to the Fe addition, the metallic distribution, oxygen vacancies and reducibility were improved due to formation of Ni-Fe alloy and ratio of weak basic sites was raised, although the specific surface area and basicity of the Ni-Fe/KCC-1 dropped compared to the monometallic 25Ni/KCC-1. Correlatively, the catalytic activity at low temperature range was enhanced, and the best performance was found on 25Ni1.25Fe/KCC-1 catalyst with 80 % CO2 conversion and 98 % CH4 selectivity were achieved at 375 °C. The catalyst activity was stable, and no coke formed during the 100 h test. 25Ni1.25Fe/KCC-1 sample seems to be the best anti-coke catalyst compared to the reference others.

Keywords: Synergistic effect; Ni-Fe catalyst; KCC-1; Synthetic natural gas

Bingzhang Li, Kai Liu, Jianjun Chen, Aijiao Xu, Han Zhao, Xueqian Wang, Fangxian Cao, Ping Ning,

Regulation of electronic metal-support interaction for the enhanced Ni-catalyzed water-gas shift reaction,

Molecular Catalysis,

Volume 572,

2025,

114777,

ISSN 2468-8231,

https://doi.org/10.1016/j.mcat.2024.114777.

(https://www.sciencedirect.com/science/article/pii/S2468823124009593)

Abstract: The water-gas shift (WGS) reaction is an important chemical process for hydrogen production and purification. The Ni-based catalyst is considered as a potential substitute for Fe and Cu-based catalysts. However, the origin of support-dependent catalytic behavior of WGS reaction over supported Ni catalysts was not well understood. Herein, a series of Ni-based catalysts with the reducible and irreducible oxides as supports were synthesized and evaluated in the WGS reaction. The catalytic activity followed the sequence: Ni/CeO2 >Ni/ZrO2 >Ni/Al2O3 >Ni/TiO2 >Ni/SiO2. WGS reaction over Ni-based catalysts proceeded via redox mechanism with the CO adsorption/activation as the rate-determining step. Combined with the ex/in-situ characterizations, it was concluded that the strength of support-dependent electronic metal-support interaction (EMSI) was identified as the performance descriptor for WGS reaction. The stronger EMSI for Ni/CeO2 accelerated the surface electron enrichment of Ni nanoparticles which strengthened CO adsorption and promoted CO oxidation with the interfacial oxygen species.

Keywords: Water-gas shift reaction; Support; Redox mechanism; Electronic metal-support interaction; Co adsorption

E. Pachatouridou, E. Zeza, A. Lappas, E. Iliopoulou,

Study of Co/γ-Al2O3 and Fe/γ-Al2O3 materials for catalytic methane pyrolysis to CO2-free hydrogen,

International Journal of Hydrogen Energy,

Volume 101,

2025,

Pages 785-796,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.383.

(https://www.sciencedirect.com/science/article/pii/S0360319924055964)

Abstract: Cobalt and iron (5 wt%) supported on γ-alumina catalysts are evaluated for CH4 pyrolysis reaction. The effect of synthesis method (Wet Impregnation, WI vs. Spray Impregnation, SI) and of catalyst promotion with 0.5 wt% Pd are investigated. All catalysts are pre-reduced and fully characterized. Undoped Co/γ-Al2O3 catalysts present poorer performance (∼6% CH4 conversion at 700 °C) than Fe/γ-Al2O3(∼20% conversion at 850 °C) after 30min of reaction. In all cases SI method enhances catalyst activity. Although Pd addition affects inconsiderably the Fe catalysts, presenting similar activity to the unpromoted catalyst, it significantly enhances Co catalysts performance increasing and stabilizing CH4 conversion at 70% for 30 min. Spray Impregnated Pd–Co catalyst is tested for 8 h of reaction and a gradually diminishing, but still encouraging methane conversion to 29% is observed. Besides the importance of CH4 pyrolysis as a suggested method for clean H2 production, the co-produced carbon structures are also worth studying. Thus, the results obtained from XRD, SEM and TEM indicated formation of carbon nanofibers (CNFs) of various dimensions.

Keywords: (Max. 6): methane pyrolysis; Hydrogen production; Spray impregnation; Cobalt–palladium; Iron–palladium; Carbon nanofibers

Kaisar Ahmad, Anifat Adenike Bankole, Maguy Abi Jaoude,

Chapter 9 - Methanol production from biogas,

Editor(s): Sreedevi Upadhyayula, Amita Chaudhary,

In Advances in Green and Sustainable Chemistry,

Sustainable and Green Catalytic Processes for Renewable Fuel Production with Net-Zero Emissions,

Elsevier,

2025,

Pages 241-260,

ISBN 9780443218996,

https://doi.org/10.1016/B978-0-443-21899-6.00010-0.

(https://www.sciencedirect.com/science/article/pii/B9780443218996000100)

Abstract: The increase in atmospheric greenhouse gas CO2 and the depletion of crude oil reserves demand a carbon-neutral and sustainable energy source. At present, green methanol production from biomass-derived biogas offers a viable alternative to phase down conventional fossil fuels for energy and chemical production. Biogas, primarily methane, is produced from the anaerobic digestion of various compostable organic waste sources. When treated under anaerobic conditions, organic materials such as municipal waste, wood waste, food waste, and animal waste can yield a 50%–70% methane-rich mixture of gases. Biogas also contains CO2 in the range of 30%–50%, impurity gases, namely H2S, H2, N2, O2, NH3, H2O, and siloxanes. The impurities are removed by cleaning, whereas the CO2 removal is done by biogas upgradation through different processes, raising its calorific value from ~18 to 55.5 MJ/m3. The upgraded biogas (biomethane) is converted to methanol through steam reforming followed by syngas conversion. In addition to the catalytic thermochemical process, biomethane is converted to methanol through the biological route. Improving feed quality, optimizing conversion efficiencies, selectivity, economic viability, and environmental footprint are key challenges in methanol synthesis from biogas. Recovering heat throughout the process, raising methanol prices, maintaining consistent feedstock availability, and implementing supportive government policies can boost production and profits in biogas-based methanol production.

Keywords: Biomass; biofuel; biological waste treatment; catalysis; energy resource; environmental pollution; biocatalysis; energy sustainability

Huaming Dai, Xinyu Wei, Qingyuan Cui,

Development of a co-catalytic combustion system with the integration of non-stoichiometric hexaaluminate and NiO to improve methane partial oxidation,

Separation and Purification Technology,

Volume 362, Part 1,

2025,

131616,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2025.131616.

(https://www.sciencedirect.com/science/article/pii/S1383586625002138)

Abstract: The appropriate combination of different functional catalysts effectively improved the methane conversion and syngas production in the porous media burner. In this paper, the hexaaluminates of LaxCo3Al9O19-δ (x = 0.8, 1, 1.2) and La0.8Co3-yAl9O19-δ + yCo (y = 1, 2, 3) with non-stoichiometric A-site and B-site were prepared by co-precipitation. And the composite catalysts of hexaaluminate and NiO were designed to investigate the combustion characteristics and gas production at different operating conditions. The results indicated that the La0.8Co3Al9O19-δ exhibited excellent catalytic activity and the dynamic average methane conversion of 97.64 % was achieved with an increase of 3.83 % compared to the blank group. Due to the lattice distortion and collapse of B-site elements extraction, the catalytic activity and syngas yield were reduced to some extent. In addition, the excellent C–H bond breaking ability of NiO promoted the methane conversion to reach 98.11 %. Compared with single La0.8Co3Al9O19-δ, the layered composite catalysts of NiO and La0.8Co3Al9O19-δ performed obviously higher catalytic performance. And among them, the La0.8Co3/NiO structure achieved the maximum hydrogen yield. The corresponding results provided important optimization strategies for the design of hexaaluminate.

Keywords: Hexaaluminate; Metal oxides; Non-stoichiometric ratio; Composite catalyst; Catalytic activity

Paratee Komen, Suwit Suthirakun, Aunyamanee Plucksacholatarn, Sanchai Kuboon, Kajornsak Faungnawakij, Anchalee Junkaew,

Theoretical screening of single-atom catalysts (SACs) on Mo2TiC2O2 MXene for methane activation,

Journal of Colloid and Interface Science,

Volume 679, Part A,

2025,

Pages 1026-1035,

ISSN 0021-9797,

https://doi.org/10.1016/j.jcis.2024.10.045.

(https://www.sciencedirect.com/science/article/pii/S0021979724023750)

Abstract: Producing value-added chemicals and fuels from methane (CH4) under mild conditions efficiently utilizes this cheap and abundant feedstock, promoting economic growth, energy security, and environmental sustainability. However, the first CH bond activation is a significant challenge and requires high energy. Efficient catalysts have been sought for utilizing CH4 at low temperatures including emerging single-atom catalysts (SACs). In this work, we screened fourteen transition metals (TM = Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ru, Rh, Pd, Pt) doped at a single oxygen vacancy in Mo2TiC2O2 (TMSA-Mo2TiC2O2 SACs) for methane activation using density functional theory (DFT) calculations. Our results reveal that methane adsorption is thermodynamically stable on all simulated TMSA-Mo2TiC2O2 SACs, with the adsorption energies (Eads) ranging from −0.92 to −0.40 eV. For the CH activation process, Ru-SAC exhibits the lowest activation barrier (Ea) of 0.22 eV. In summary, Ru-, Rh-, Co-, V-, Cr-, Ti-, and Pt-SACs demonstrate promising catalytic properties for methane activation, with Ea values below 1.0 eV and an exothermic nature. Our findings pave the way for the design and development of novel single-atom catalysts in MXene materials, applicable not only for methane activation but also for other alkane dehydrogenation processes.

Keywords: Methane; DFT; Dehydrogenation; SAC; MXenes

Manzoore Elahi M. Soudagar, Vinayagam Mohanavel, Aman Sharma, Nagarajan Nagabhooshanam, R. Srinivasan, K. Karthik, Manikandan Ayyar, Manickam Ravichandran, A.H. Seikh,

Recover waste greywater to algae biomass for catalytic conversion of higher hydrogen production via supercritical water gasification reaction,

Biomass and Bioenergy,

Volume 194,

2025,

107642,

ISSN 0961-9534,

https://doi.org/10.1016/j.biombioe.2025.107642.

(https://www.sciencedirect.com/science/article/pii/S0961953425000534)

Abstract: The algae biomass from waste greywater is activated with 0, 2, 4, and 6 % of cerium oxide nanoparticle (CeO2), which favours specific growth algae, and optimum biomass concentration is used for hydrogen energy production. The supercritical water gasification reaction is implemented for hydrogen production from algae under the processing temperatures of 600 °C with 30 min residence time. During the process, the feedstock is varied from 5 to 20 wt%, and the potassium hydroxide (KOH), potassium carbonate (K2CO3), aluminium chloride (AlCl3), and nickel (Ni) catalyst are utilized to enrich the reforming reaction of organic material and enhance the hydrogen yield. Influences of catalytic conversion on molar fraction, hydrogen gas yield, hydrogen selectivity, gasification efficiency, and Low heating value of the present system are evaluated. An algae biomass concentration activated with 6 % CeO₂ exhibited an improved growth rate of 0.98 μ/day. This biomass was utilized in a supercritical water gasification process with a KOH catalyst, resulting in enhanced output properties, including a high hydrogen molar fraction of 66.8 %, a hydrogen yield of 64.5 mol/kg, improved hydrogen selectivity of 18, optimum gasification efficiency of 67.4 %, and improved lower heating value of 21.4 MJ/Nm3.

Keywords: Catalyst; Cerium oxide; Gasification; Hydrogen; Efficiency

Kamalimeera Nakkeeran, Kirubakaran Victor,

Grey and blue hydrogen: Insights into production technologies and outlook on CO2-free alternatives,

Sustainable Energy Technologies and Assessments,

Volume 75,

2025,

104222,

ISSN 2213-1388,

https://doi.org/10.1016/j.seta.2025.104222.

(https://www.sciencedirect.com/science/article/pii/S2213138825000530)

Abstract: Hydrogen is anticipated to accelerate the mitigation of climatic challenges in the upcoming future. Globally, for every kg of H2 produced, around 11–12 kg of CO2 is emitted. While adding CCS to existing systems increase the cost and complexity and leads to both CO2e and fugitive emissions. It is important to develop low-carbon approaches for the existing technologies to address the environmental concerns and to meet the global energy goals on decarbonization. This paper presents various existing hydrogen production methods using hydrocarbon feedstock concerning operating principles, technical barriers, advancements and prevailing challenges and economic and environmental aspects. Additionally, the paper highlights the present status of the real-time blue hydrogen plants globally. It discusses the CO2-free alternative methods such as solar-SMR and methane pyrolysis covering their status quo in becoming the sustainable energy choice. It also identifies and addresses the key difficulties in the production of low-carbon H2. Carbon-pricing is trying to hasten the adoption of green energy and carbon abatement by increasing the cost of hydrogen production. However, detailed investigations in the techno-economic aspects incorporating the ecological benefits are required for developing H2 as an alternative fuel for sustainable development.

Keywords: Hydrogen production; Carbon capture and storage; Grey hydrogen; Turquoise hydrogen; Low-carbon hydrogen

Jinxiong Tao, Hongxia Lin, Jiguang Deng, Yuxi Liu, Lin Jing, Zhiquan Hou, Lu Wei, Zhiwei Wang, Hongxing Dai,

Enhanced low-temperature catalytic activity and stability in methane combustion of Pd−CeO2 nanowires@SiO2 by Pt dispersion,

Applied Catalysis B: Environment and Energy,

Volume 360,

2025,

124554,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124554.

(https://www.sciencedirect.com/science/article/pii/S0926337324008683)

Abstract: The long-standing contradiction between low-temperature activity and high-temperature stability is one of the difficulties in catalytic combustion of low-concentration methane. The traditional Pd−CeO2 catalyst system has been applied to the oxidation of methane with low concentrations. However, the problem of sintering at high temperatures still exists. In this work, we prepared the Pt-modified Pd−CeO2 nanowires (NW) sample (in which the actual Pt, Pd, and Ce contents were 0.12, 0.86, and 9.8 wt%, respectively) using the one-pot reverse-micelle emulsion method. It was found that Pt-Pd−CeO2NW@SiO2 showed the highest low-temperature catalytic activity at a space velocity of 20,000 mL/(g h) and the best water resistance and high-temperature stability in the combustion of methane. The T50 % and T90 % (the temperatures for achieving methane conversions of 50 and 90 %) were 298 and 342 ℃, respectively, methane reaction rate at 270 ℃ was 0.49 μmol/(gcat s), and turnover frequency (TOF) at 270 °C was 0.198 s−1 over Pt-Pd−CeO2NW@SiO2; whereas over Pd−CeO2NW@SiO2 (in which the actual Pd and Ce contents were 0.82 and 10.6 wt%, respectively), the T50 % and T90 % were 360 and 420 ℃, respectively, methane reaction rate at 270 ℃ was 0.074 μmol/(gcat s), and TOF at 270 °C was 0.032 s−1. The introduction of the highly dispersed Pt to Pd−CeO2NW@SiO2 could effectively increase the PdOx sites of unsaturated coordination through the electron-donating interaction of the Pt with PdO, which played an important role in activating the C−H bonds in methane. In addition, the unique structure of encapsulation also rendered the Pt-Pd−CeO2NW@SiO2 sample to possess good water resistance and thermal stability in methane combustion. We are sure that the present work provides a possibility for developing the catalysts with stable catalytic and water-resistant performance at low and high temperatures in the combustion of methane.

Keywords: Methane combustion; Supported palladium catalyst; Platinum doping; Ceria nanowire; Water resistance

Li Wang, Qingxi Yin, Xiaohan Zhai, Yanhui Yi,

Recent progresses of plasma-catalytic CH4/CO2 conversion to oxygenates: A short review,

Current Opinion in Green and Sustainable Chemistry,

Volume 51,

2025,

100989,

ISSN 2452-2236,

https://doi.org/10.1016/j.cogsc.2024.100989.

(https://www.sciencedirect.com/science/article/pii/S245222362400110X)

Abstract: Plasma catalysis is a promising alternative for the direct conversion of CO2 and CH4 to high-value oxygenates at mild conditions. However, this direct process suffers from low selectivity and high diversity of the liquid oxygenates, generally consisting of C1-4 alcohols, C1-2 acids, C1-2 aldehydes and acetone, and little is known yet about how to selectively produce one target oxygenate. The trial-and-error approach still dominates the current researches, especially in screening effective catalysts. This short review highlights researches in the last two years, revealing the crucial factors that affect oxygenates formation, and then proposing some feasible strategies to improve oxygenates formation in plasma-catalytic CO2/CH4 conversion.

Keywords: Plasma catalysis; Dry reforming; Oxygenates; Catalyst; Micro-discharge

Yan Cao, Yu Bai, Jiang Du,

Hydrogen production from catalytic steam-gasification of biomass using char and char-supported iron catalysts,

Journal of the Energy Institute,

Volume 120,

2025,

102031,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2025.102031.

(https://www.sciencedirect.com/science/article/pii/S1743967125000595)

Abstract: Char derived from the pyrolysis of carbon-based fuels, such as biomass and coal, has been widely used as a support material. In this study, biochar, coalchar, biochar-supported Fe (Fe/B) and coalchar-supported Fe (Fe/C) were prepared for tar cracking and H2 enhancement during wood chips gasification. All experiments were conducted in a fluidized bed gasification system using steam as the gasification agent. The results revealed that the effectiveness of each catalyst in removing tar is ranked as follows: biochar < coalchar < Fe/B < Fe/C. The highest H2 content (49.2 vol%) was also obtained at 800 °C and in the presence of 6 wt% Fe/C as catalyst. Tar cracking improved significantly with increasing Fe content from 0 to 6.0 wt%, but showed little further improvement beyond 6.0 wt% Fe content. The results indicated that adding steam had minimal effect on the tar content in the gas produced from the gasification of wood chips using the Fe/C catalyst. However, raising the gasifier temperature from 700 to 850 °C led to a significant reduction in tar yield. This reduction is attributed to the promotion of cracking and reforming reactions during the gasification process. This work showed that the char composition significantly influences its catalytic performance regarding tar reduction and H2 enhancement.

Keywords: Gasification; Biomass char; Coal char; Tar reduction; H2 enhancement

Ruiqiang Huo, Xiaojun Miao, Huiyun Cheng, Derui Chen, Yu Liu, Hu Zhang, Huaiyu Wang, Nan Xue, Hui Zhu, Jiao Yin,

A highly stable leaf-like Ni/Ca3AlO catalyst for hydrogen production from biomass gasification,

Energy,

Volume 316,

2025,

134638,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2025.134638.

(https://www.sciencedirect.com/science/article/pii/S0360544225002804)

Abstract: The stability of the nickel-based catalyst is a crucial factor in the catalytic gasification of biomass. In this study, a series of Ni/CaxAlO catalysts, synthesized by the hydrothermal method, were applied to the catalytic gasification of pear wood for hydrogen production. The results demonstrated that the Ni/Ca3AlO catalyst exhibited excellent catalytic transformation performance and favorable cycle stability. The hydrogen yield and concentration were 30.08 mmol/gbiomass and 60.61 vol% for the reduced Ni/Ca3AlO catalyst and were still 16.75 mmol/gbiomass and 45.31 vol% after 10 cycles. Material characterization analysis revealed that the leaf-like morphology and the strong metal support interaction enable Ni/Ca3AlO catalyst to display a robust anti-sintering performance, resulting in the average particle size of Ni particles increased by only 3.24 nm after 10 cycles. Moreover, reduced encapsulating coke precursors caused by Ca doping together with the oxidizing capacity of Ca12Al14O33 to filamentous coke qualify Ni/Ca3AlO catalyst to show a powerful resistance to coke deposits. Compared with Ni/AlO catalyst, the coke accumulation of Ni/Ca3AlO catalyst was reduced by 65.02 % after 10 cycles. The results provide a basis for the design of a new nickel-based catalyst and its application in biomass catalytic gasification for hydrogen production.

Keywords: Biomass gasification; Hydrogen-rich syngas; Calcium doping; Morphology regulation; Sintering and coke resistance

Fábio C. Antunes, João P.J. de Oliveira, Ricardo S. de Abreu, Thiago Dias, Bruno B.N.S. Brandão, Josué M. Gonçalves, Josimar Ribeiro, Julian Hunt, Hudson Zanin, Gustavo Doubek,

Reviewing metal supported solid oxide fuel cells for efficient electricity generation with biofuels for mobility,

Journal of Energy Chemistry,

Volume 103,

2025,

Pages 106-153,

ISSN 2095-4956,

https://doi.org/10.1016/j.jechem.2024.10.056.

(https://www.sciencedirect.com/science/article/pii/S2095495624007848)

Abstract: Metal-Supported Solid Oxide Fuel Cells (MS-SOFCs) hold significant potential for driving the energy transition. These electrochemical devices represent the most advanced generation of Solid Oxide Fuel Cell (SOFCs) and can pave the way for mass production and wider adoption than Proton Exchange Membrane Fuel Cells (PEMFCs) due to their fuel flexibility, higher power density and the absence of noble metals in the fabrication processes. This review examines the state-of-the-art of SOFCs and MS-SOFCs, presenting perspectives and research directions for these key technological devices, highlighting novel materials, techniques, architectures, devices, and degradation mechanisms to address current challenges and future opportunities. Techniques such as infiltration/impregnation, ex-solution catalyst synthesis, and the use of a pre-catalytic reformer layer are discussed as their impact on efficiency and prolonged activity. These concepts are also described and connected with well-dispersed nanoparticles, hindrance of coarsening, and an increased number of Triple Phase Boundaries (TPBs). This review also describes the synergistic use of reformers with MS-SOFCs to compose solutions in energy generation from readily available fuels. Lastly, the End-of-Life (EoL), recycling, and life-cycle assessments (LCAs) of the Fuel Cell Hybrid Electric Vehicles (FCHEVs) were discussed. LCAs comparing Fuel Cell Electric Vehicles (FCEVs) equipped with (PEMFCs) and FCHEVs equipped with MS-SOFCs, both powered with hydrogen (H2) generated by different routes were compared. This review aims to provide valuable insights into these key technological devices, emphasizing the importance of robust research and development to enhance performance and lifespan while reducing costs and environmental impact.

Keywords: Reform; Metal-supported solid oxide fuel cell; Powertrain systems; Fuel cell; Hybrid electric vehicle; Biofuel

Wenwen Guo, Huangjie Bao, Han Chen, Guoneng Li, Youqu Zheng, Mengjie Zhang,

Photothermal coupling-driven low-temperature steam reforming of acetic acid for hydrogen production,

Fuel,

Volume 379,

2025,

132705,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.132705.

(https://www.sciencedirect.com/science/article/pii/S0016236124018544)

Abstract: Low-temperature and high-efficiency acetic acid (AcOH) steam reforming was realized based on photo-thermal coupled catalysis. Four semiconductor materials (ZnO, TiO2, CeO2, CeO2-TiO2) were used as the supports and Co was selected as the active metal. The physical phases, crystal structures and specific surface areas of the different catalysts were analyzed by various characterization methods. From the XPS spectra, it can be seen that CeO2 loaded with TiO2 to make a composite support produced a higher proportion of Ce3+ ions and formed more oxygen vacancies on the catalyst surface. The catalytic activity of all four catalysts was low at temperatures less than 400 °C, and the carbon conversion and hydrogen yield gradually increased with increasing temperature. Co/CeO2-TiO2 had the best catalytic activity among the four catalysts and the carbon conversion of Co/CeO2-TiO2 could reach 97.9 % at 500 °C. When photothermal co-catalysis was introduced, the four catalysts activity was enhanced with different degree. The carbon conversion enhancements of Co/CeO2-TiO2 photocatalytic reaction reached an impressive 714.9 % and 78.7 % at 300 and 350 °C respectively. The experimental results indicated that photo-thermal synergy had a more dramatic effect on the catalyst activity than single thermal drive at low temperatures. It might be due to the fact that the oxygen vacancies generated in the composite support CeO2-TiO2 acted as electron supports to provide more favorable channels for the transport and migration of photogenerated electrons, which could effectively separate the photogenerated electrons and holes, thus improving the catalytic performance of the catalyst.

Keywords: Photothermal coupling; Composite support; Low temperature; High enhancement; Oxygen vacancy

Sebin Oh, Dohee Kim, Taehyun Kim, Jinwoo Park,

Design of a hydrogen-water nexus by integrating autothermal reforming, electrolysis, and desalination,

Energy Conversion and Management,

Volume 325,

2025,

119356,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119356.

(https://www.sciencedirect.com/science/article/pii/S0196890424012974)

Abstract: A novel system for producing clean hydrogen and pure water is proposed, integrating an autothermal reforming (ATR), a proton exchange membrane electrolysis cell (PEMEC), and a multi-stage flash (MSF) desalination. This system maximizes energy and material utilization, leading to significant energy and cost savings. The ATR-PEMEC-MSF system can produce both blue and green hydrogen, as well as freshwater, using only natural gas, seawater, and renewable electricity. Waste heat from the ATR process satisfies the substantial thermal energy demand of MSF desalination, thereby enhancing overall energy efficiency. Furthermore, the ATR process utilizes oxygen generated as a by-product of the PEMEC process, eliminating the need for a separate energy-intensive air separation unit. Co-locating the desalination and hydrogen production facilities ensures that the PEMEC process is optimized for seawater as its primary water source. As a result, the components of this system are interdependent, with the production rates of green hydrogen and freshwater directly linked to the production capacity of blue hydrogen. Techno-economic analysis reveals that the system can produce 96.5 ton/d of blue hydrogen and 48.1 ton/d of green hydrogen, with competitive levelized costs of hydrogen at $0.825/kg and $6.467/kg, respectively. The net present value of $348.2 million and payback period of 4.12 years underscore the system’s economic feasibility, presenting it as a superior alternative to existing systems. This novel integration offers a promising solution for the future hydrogen energy and water nexus.

Keywords: Process design; Blue hydrogen; Green hydrogen; Desalinated water; Process integration; Techno-economic analysis

Guanying Liu, Jiabao Lv, Jinlong Zou, Feng Li, Hui Fu, Youhe Wang, Hongman Sun, Zifeng Yan,

Crystal facet regulation of Ru/CeO2 catalysts towards boosted low-temperature CO2 methanation,

Journal of Environmental Chemical Engineering,

Volume 13, Issue 2,

2025,

115700,

ISSN 2213-3437,

https://doi.org/10.1016/j.jece.2025.115700.

(https://www.sciencedirect.com/science/article/pii/S2213343725003951)

Abstract: Crystal facets significantly impact the performance of CO2 methanation at low temperatures. This study systematically investigates CO2 methanation of Ru/CeO2 catalysts with various shapes-rod, cube, sheet, and sphere-exposing predominantly (110) and (100), (100), (111), and (111) facets, respectively. It was observed that the rod- and cube-shaped Ru/CeO2 catalysts with (100) facets demonstrated markedly better performance in CO2 methanation compared to the sheet- and sphere-shaped catalysts with (111) facets at temperatures below 300 °C. For instance, at 250 °C, Ru/CeO2-R and Ru/CeO2-C achieved CO2 conversions of around 70 %, which is significantly higher than that of Ru/CeO2-SH and Ru/CeO2-SP which were below 10 %. This performance disparity is attributed to the lower energy required to form oxygen vacancies on the (100) and (110) facets, which leads to a higher concentration of these vacancies compared to the (111) facets. Both experimental results and DFT calculations reveal that the formate pathway is the primary pathway, and (100) and (110) facets are more effective in CO2 adsorption and HCOO\* formation than the (111) facet. This research underscores the importance of facet-specific surface modification in Ru/CeO2 for enhancing CO2 methanation. Selecting the appropriate CeO2 crystal facet can significantly boost the activity and selectivity of catalysts, offering valuable guidance for designing low-temperature methanation catalysts.

Keywords: Ru-based catalysts; Crystal facet regulation; Oxygen vacancies; CO2 methanation; Low-temperature

Lei Shi, Yinhai Su, Liren Yang, Yuanquan Xiong, Shuping Zhang,

Enhancing the tar removal efficiency and gas production for the pyrolysis of biomass through the nickel-based hollow zeolite,

Journal of the Energy Institute,

Volume 118,

2025,

101914,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2024.101914.

(https://www.sciencedirect.com/science/article/pii/S1743967124003921)

Abstract: Using metal-zeolite catalysts to improve the catalytic efficiency for tar cracking during biomass pyrolysis has attracted a lot of attention of scholars. Herein, the Ni@ZSM-5 catalyst with a hollow structure encapsulating Ni metal was synthesized by hydrothermal-recrystallization. The properties of the catalysts were evaluated by a series of characterization and compared with the solid ZSM-5 as well as nickel loaded ZSM-5. Through TEM observation, it was found that a regular cavity was constructed inside ZSM-5 with Ni particles encapsulated in it successfully. The unique hollow structure facilitated Ni@ZSM-5 owning greater Brønsted acidity and coke resistance, presenting a great activity and stability in tar catalytic cracking. The microporous shell prevented the sintering and loss of Ni significantly. Tar removal efficiency reached 92.2 %, and remained around 90 % after 10 cycles. Pyrolysis gas yield increased by 27.2 %, simultaneously. The reasons for excellent catalyst performance was analyzed as well as the potential evolutionary mechanism for tar molecule over Ni@ZSM-5. The utilization of this unique catalyst provides a reference in the field of biomass utilization.

Keywords: Biomass; Hollow structure; ZSM-5; Catalytic tar cracking; Reaction mechanism

Luke Roebuck, Min Hu, Helen Daly, Hubertus Warsahartana, Louise S. Natrajan, Arthur Garforth, Carmine D’Agostino, Marta Falkowska, Christopher Hardacre,

H2 production from photocatalytic reforming of PET over Pt/TiO2: The role of terephthalic acid,

Catalysis Today,

Volume 452,

2025,

115242,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2025.115242.

(https://www.sciencedirect.com/science/article/pii/S0920586125000604)

Abstract: Photoreforming is a promising method for the conversion of waste materials with simultaneous production of H2. The use of waste polyethylene terephthalate (PET) as a photoreforming substrate has been previously investigated, however its insolubility in aqueous media and the resistance of the aromatic terephthalate towards conversion are major obstacles. Commonly an alkaline pretreatment step is used to initiate hydrolysis to ethylene glycol and terephthalic acid which promotes H2 evolution. However, in this work we have found that TPA has both promotional and inhibitory effects by modification of the catalyst surface that depend on the relative concentration of ethylene glycol. Terephthalic acid inhibits the oxidation reactions by scavenging hydroxyl radicals and blocking complexation sites. This leads to lower H2 evolution compared to the photoreforming of an equivalent concentration of ethylene glycol. Even in trace amounts, terephthalic acid would still inhibit the reaction unless the concentration of ethylene glycol was high enough. Surprisingly, at ethylene glycol concentrations of > 1.2 M, residual terephthalic acid promoted the reaction which is thought to be due to increasing the interaction between ethylene glycol and the catalyst surface but also an increased role of water. On the basis of these results, we suggest that, if PET is to be used as a feedstock for H2 generation by photoreforming, an initial hydrolysis should be performed after which terephthalic acid is separated for re-use. The remaining hydrolysate may then be used for photoreforming. Furthermore, the ethylene glycol concentration should be maximized in order to overcome the inhibitory effects of residual terephthalic acid.

Keywords: PET; Plastics valorisation; Depolymerization; Photoreforming; Hydrogen production; TiO2; Waste-to-energy

Heng Chen, Junguang Meng, Jiaming Tang, Xinye Wang, Yiqiang Liu, Changsheng Bu, Jubing Zhang, Changqi Liu, Hao Xie, Guilin Piao,

Overcoming carbon deposition in non-thermal plasma catalyzed biomass tar reforming: Innovative strategies employed by GPPC systems,

Fuel,

Volume 381, Part D,

2025,

133649,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133649.

(https://www.sciencedirect.com/science/article/pii/S0016236124027984)

Abstract: Tar is a key issue hindering the commercial application of biomass gasification. Graded post-plasma catalysis (GPPC) provides a new idea for tar treatment. The system solves the paradox of plasma discharge intensity and catalyst activity for temperature setting. The effects of GPPC system operating parameters (graded temperature, discharge power and S/C), catalyst configurations (metal ratio and intervention) on the catalytic activity and stability were investigated in conjunction with multiscale characterization of the catalyst. The results show that the benzene conversion of the system can be improved by adding appropriate amount of steam, loading Fe first and then Ni, and shortening the distance between the two reaction intervals. In the GPPC system, there was no significant change in activity after the catalyst oxidation regeneration cycle, and the H2 yield was consistently exceeded 70 %. Compared with in-plasma catalysis (IPC) and thermal catalysis (TC), GPPC has excellent performance with an effective gas yield of 3757.25 mL/g at 48th hour and a H2 yield of 72.1 %, especially with minimal carbon deposition. IPC system at 10 h, the effective gas yield and H2 yield have been reduced to 1261.52 mL/g and 27.2 % respectively. The results of the study further confirmed that GPPC is more capable of utilizing the advantages of non-thermal plasma (NTP) and catalysts than conventional IPC.

Keywords: Biomass tar; Tar reforming; Graded post-plasma catalysis; Synergistic effect

Zhuoyu Zheng, Yuxin Ge, Weiwei Lu, Yiyuan Zhou, Haiping Zhu, Pengxiang Gao, Caimei Li, Wenzheng Lei, Pengcheng Zhao, Jiajin Li, Minglei Lu, Tiejun Wang,

Ce-modified Cu nanoparticles with N-doped carbon encapsulation for efficient H2 production from aqueous phase reforming of methanol at low temperatures,

Fuel,

Volume 382, Part A,

2025,

133775,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133775.

(https://www.sciencedirect.com/science/article/pii/S0016236124029247)

Abstract: Aqueous-phase reforming of methanol (APRM) for both hydrogen (H2) production and high pressure storage shows promising potential in mobile/distributed fuel cell stations or vehicles. Currently, achieving efficient H2 production with low CO selectivity (S-CO) at lower temperatures remains a challenge for its application in these fields (rapid start and running in cycles). Herein, the catalyst of Ce-modified Cu nanoparticles with N-doped carbon encapsulation (Cu-CeO2@PVP catalyst) is developed to give excellent H2 production rate at low temperatures ranging from 110 °C to 180 °C, ensuring excellent hydrothermal stability. The H2 production rate of 32.56 μmol·gcat-1·s−1 at 180 °C is 6.1 times to 10.2 times higher than those of commercial catalysts, which demonstrates its superior performance. The combined effect of Cu+/Cu0 and CeO2 promotes the H2 production from CH3OH/H2O. It also suppresses the CO formation by enhancing the H2O dissociation, CO conversion and HCOOH decomposition in APRM. The stable high purified H2 flow from the integrated slurry bed APRM device can start immediately the fuel cell vehicle without any delay.

Keywords: Cu-based catalyst; Low temperature; Aqueous-phase reforming of methanol; H2 production and storage; Fuel cell vehicle

Maya Chatterjee, Takashi Fukuda, Naoki Mimura,

Rationally designed ruthenium impregnated water-soluble Ti- complex anchored SiO2 sphere as a structured catalyst for CO methanation,

Fuel,

Volume 384,

2025,

133815,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133815.

(https://www.sciencedirect.com/science/article/pii/S0016236124029648)

Abstract: Selective methanation of CO (CO + 3H2 ⇆ CH4 + H2O) in the presence of a large volume of CO2 is a promising, energy-efficient, and cost-effective approach towards the purification of hydrogen rich stream required for proton exchange membrane fuel cell; a viable solution to tackle the climate crisis through zero emission. However, this reaction faces the difficulties of undesired side reactions originating from the simultaneous methanation of CO2 (high consumption of hydrogen) and reverse water gas shift reaction producing CO. Thus, achieving high conversion and concomitant selectivity is highly challenging. Here, we design a promising structured catalyst applicable for large-scale selective CO methanation using a water-soluble Ti-complex anchored on commercial SiO2 sphere. Utilization of various analytical techniques confirmed the presence of Si-O-Ti cross-linking bonds. Thermal degradation of the organic motif of the Ti-complex produces only anatase phase of TiO2 and improves the catalytic stability against hydrolysis of common titanium compound. Promisingly, impregnation of 1 wt% of Ru enables complete conversion (CO detection limit is <6 ppm) and selectivity at the temperature of 200 °C with the feed gas and water flow rate of 200 ml min−1 and 60 μl min−1, respectively. Different process variables such as types of SiO2 sphere, Ru precursor, amount of Ti-complex, amount of water and reactant gas flow rate, were optimized to achieve highest catalytic efficiency. The consequences of this “green” technology developed here, pave the way of designing highly efficient structured catalysts upgradeable to large-scale applications of many catalytic processes.

Keywords: Ru/TiO2-SiO2; Structured catalyst; Water soluble Ti-complex; SiO2-sphere; Selective CO methanation

Mónica Calero, Gabriel Blázquez, Rafael R. Solís, María Ángeles Martín-Lara, Mario J. Muñoz-Batista,

Exploring pyrolysis-based alternatives for the valorization of used diapers through a comprehensive understanding of all generated products,

Chemical Engineering Journal,

Volume 503,

2025,

158244,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2024.158244.

(https://www.sciencedirect.com/science/article/pii/S1385894724097353)

Abstract: This study provides an in-depth evaluation of a pyrolysis process designed for the valorization of baby diaper waste from the rejected fraction of municipal solid waste treatment facilities. The diapers were separated, identified, and classified into distinct fractions/layers, each subjected to Thermogravimetric Analysis to determine the optimal temperature range for operation. This study identified that hydrogen and methane production is maximized at 575 °C. At this temperature, yields reach up to 7.4 mmol of hydrogen and 6.3 mmol of methane, with a total of 23 mmol of non-condensable gases per gram of diaper waste. The temperature of 525 °C optimized the production of lighter liquid fractions. This temperature yielded compounds with boiling points similar to heavy naphtha and comprised over 63 % of the liquid products. The solid residue resulting from pyrolysis was a partially amorphous carbonaceous material, with a maximum surface area of 9.7 m2/g achieved at 575 °C, which is considered low. The analysis is completed with a study of the degradation of the used diapers by TGA/MS-FTIR and the determination of the effective activation energy as a function of conversion. This study highlights the significant potential of pyrolysis technology for treating diaper waste, which generates several potentially usable or valuable products, including hydrogen, methane, light liquid compounds, and carbonaceous material.

Keywords: Pyrolysis; Diapers; Superabsorbent polymer; Hydrogen; Char; Characterization of products

Wenhan Zhao, Yingjie Li, Zhiwei Chu, Duo Xu, Kuihua Han, Zirui He,

Spinel-supported Fe-based catalysts for H2 production via catalytic methane decomposition: Experimental and theoretical studies,

Chemical Engineering Journal,

Volume 505,

2025,

159051,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2024.159051.

(https://www.sciencedirect.com/science/article/pii/S1385894724105426)

Abstract: Catalytic methane decomposition (CMD) process has garnered significant attention for CO2-free hydrogen production. Fe catalyst has been widely investigated due to its low-cost and environmentally friendly features, but is prone to rapid deactivation due to elevated temperatures and coke deposition. To address these limitations, we synthesized a series of spinel-supported Fe catalysts with varying Fe/Mg/Al ratios via the sol–gel method. These catalysts were evaluated in a fixed-bed reactor, revealing that CMD performance depends significantly on Fe positioning within the spinel lattice in the as-prepared catalysts. Methane conversion was optimal and stable when Fe occupied octahedral sites, achieving 86.7 % CH4 conversion and 92.9 % H2 concentration in the outlet gas at 850 °C and 2 L gcat−1 h−1. The mesoporous spinel structure enhances high-temperature stability and improves coke tolerance, which also contributed to additional layers of multi-walled carbon nanotubes. Density functional theory (DFT) calculations further identified the spinel-supported Fe catalysts as top performers. The energy barriers for the CMD process on Fe/MgAl2O4(111) and Fe/MgAl2O4(100) were lower than those on Fe(110). The difference charge density and Bader charge results of CH adsorption and dissociation on the structures, which was the rate-limiting step, demonstrated that the spinel support facilitated the efficient transportation and placement of electrons to the Fe cluster, thereby promoting C–H bond breaking. These findings offer novel insights into the design of cost-effective CMD catalysts with stable catalytic performance and high coke tolerance.

Keywords: Catalytic methane decomposition; Hydrogen production; Fe-based catalyst; Spinel support; Density functional theory

Shenghua Zhang, Guannan Gong, Huan Wang, Sen Chen, Jiangyan Wang, Jian Qi,

Advances and challenges of the spray drying technology: Towards accurately constructing inorganic multi-functional materials and related applications,

Sustainable Materials and Technologies,

Volume 43,

2025,

e01250,

ISSN 2214-9937,

https://doi.org/10.1016/j.susmat.2025.e01250.

(https://www.sciencedirect.com/science/article/pii/S2214993725000181)

Abstract: As an efficient, continuous and controllable particle preparation method, spray drying technology has shown unique advantages and broad application prospects in the synthesis and application of inorganic multi-functional materials. Through spray drying method, one can not only accurately regulate the composition and structure of material, but also can easily assemble nano-subunits into superstructures. This review first introduces the equipment composition and principle of spray drying technology. Subsequently, this review focused on the structure regulation and composition adjustment of inorganic multi-functional materials through spray drying technology. Finally, this review discusses the challenges and future development directions of spray drying in the preparation of inorganic multi-functional materials. Spray drying technology provides an efficient, flexible and controllable path for the synthesis of inorganic multi-functional materials. Its continuous technological innovation and application expansion will continue to promote the rapid development of related fields.

Keywords: Spray drying technology; Inorganic multi-functional materials; Atomizers; Microstructure regulation; Composition adjustment

Jinzeng Cao, Yuncai Song, Yecheng Yao, Guoqiang Wei, Haoran Yuan, Zhen Huang, Fang He, Shengsen Zhang,

Thermodynamic and experimental investigation on chemical looping hydrogen of alkali lignin pyrolysis gas with NiFe2O4 oxygen carrier,

Fuel,

Volume 386,

2025,

134199,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134199.

(https://www.sciencedirect.com/science/article/pii/S0016236124033507)

Abstract: Alkali lignin (AL) is a by-product of papermaking industry, which faces low resource utilization and environmental challenges through traditional disposal methods. Chemical looping hydrogen (CLH) of alkaline lignin with NiFe2O4 oxygen carriers (OCs) is proposed to achieve high purity H2 and realize the resource utilization of alkaline lignin, which exhibits advantages in enhancing heat/mass transfer and improving lattice oxygen reactivity. The reaction equilibrium was analyzed based on the Gibbs energy minimization principle in thermodynamic theory. The batch experiments were carried out by using alkaline lignin-derived pyrolysis gas and NiFe2O4 OCs with a fixed-bed reactor to evaluate the reaction performance and further improve the purity of hydrogen production. The results indicated that the CLH process consisted of chemical looping reforming (CLR) and hydrogen production. The CH4 and CO2 was eliminated in CLR process based on the lattice oxygen and metallic catalytic effect of OCs, where 98.7 % CH4 conversion rate and 85.4 % CO2 conversion rate were achieved. Also, the purity of 97.07 % H2 was obtained in hydrogen production stage via the splitting reaction of H2O with Fe reinforced by Ni. The reaction path of NiFe2O4 OCs was summarized as: NiFe2O4 → Fe0.64/Ni0.36 → Fe3O4/FeNi3 → Fe2O3/NiFe2O4. Although the agglomeration appeared in the regenerated sample, the main crystal phases of OCs was recovered after air calcination, providing that CLH of alkaline lignin is an effective way to achieve high purity H2 and realize resource utilization.

Keywords: Alkali lignin pyrolysis gas; Oxygen carriers; NiFe2O4; Hydrogen; Chemical looping hydrogen; CLH

Suwimol Wongsakulphasatch, Sakhon Ratchahat, Pattaraporn Kim-Lohsoontorn, Worapon Kiatkittipong, Nopphon Weeranoppanant, Merika Chanthanumataporn, Sumittra Charojrochkul, Navadol Laosiripojana, Suttichai Assabumrungrat,

Fuels – Hydrogen – Hydrogen Production | Fossil Fuels Based,

Editor(s): Jürgen Garche,

Encyclopedia of Electrochemical Power Sources (Second Edition),

Elsevier,

2025,

Pages 232-245,

ISBN 9780323958226,

https://doi.org/10.1016/B978-0-323-96022-9.00018-9.

(https://www.sciencedirect.com/science/article/pii/B9780323960229000189)

Abstract: Hydrogen emerges as a technology for achieving carbon neutrality. The challenges of hydrogen implementation lie in its production technology with minimizing carbon dioxide emission and economic feasibility. There are several established technologies for producing hydrogen from fossil sources. Although conventional methods, including steam reforming of natural gas, are considered as economical, most of them are not environmentally friendly with a high global warming potential value. New technologies such as multifunctional reactors are developed to enable a low-carbon production. For example, the sorption-enhanced steam reforming incorporates CO2 capture into gasifier or reforming reactors. The process shows many advantages including lower energy consumption, higher hydrogen purity and yield, lower carbon emission, fewer operational unit, and lower capital and operational costs, as compared to the current method without a sorption unit. At present, such technology is at a technology readiness level (TRL) of 4, indicating its promising potential in the industrial context. Also, a multifunctional reactor can be designed with a membrane unit to provide an in situ product separation, allowing the operation at milder condition. A key challenge of designing these technologies is to reduce GHG emission while maintaining economic feasibility of the overall production. It is also essential for policy makers to facilitate the implementation of new hydrogen production technologies and promote the replacement of fossil fuels with hydrogen.

Keywords: Autothermal reforming; CCUS technology; Dry reforming; Fossil sources; Gasification; Hydrogen; Hydrogen colors; Hydrogen production technology; Membrane reactor; Multi-functional reactor; Partial oxidation; Pyrolysis; Sorption-enhanced steam reforming; Steam reforming

C. Yuh, A. Hilmi, R. Venkataraman,

Fuel Cells – Molten Carbonate Fuel Cell | Cells and Stacks,

Editor(s): Jürgen Garche,

Encyclopedia of Electrochemical Power Sources (Second Edition),

Elsevier,

2025,

Pages 589-599,

ISBN 9780323958226,

https://doi.org/10.1016/B978-0-323-96022-9.00167-5.

(https://www.sciencedirect.com/science/article/pii/B9780323960229001675)

Abstract: The molten carbonate fuel cell (MCFC) operates at temperatures around 600–650°C and uses an electrolyte of molten alkali metal carbonate mixture retained in a porous ceramic support matrix layer. Porous sheets of Ni-based materials are used as electrodes. Stacks of various configurations had been evaluated at hundreds of kilowatt scale. The current commercial MCFC stack is based on internal reforming external manifold design. Systems of multi-MW scale have been being deployed. This article discusses status for MCFC cells and stack designs (electrodes, electrolyte, matrix, catalyst, cell hardware, and stack configuration).

Keywords: Fuel cell; High temperature fuel cell; Internal reforming; Molten carbonate fuel cell; Stack configuration

Chengdong Yuan, Pavel Afanasev, Aysylu Askarova, Evgeny Popov, Alexey Cheremisin,

In situ hydrogen generation in subsurface reservoirs of fossil fuels by thermal methods: Reaction mechanisms, kinetics, and catalysis,

Applied Energy,

Volume 381,

2025,

125219,

ISSN 0306-2619,

https://doi.org/10.1016/j.apenergy.2024.125219.

(https://www.sciencedirect.com/science/article/pii/S0306261924026035)

Abstract: In situ hydrogen generation (ISHG) from fossil fuels in subsurface reservoirs has emerged as a promising way to lower greenhouse gas emissions. This process can be realized within reservoirs through various methods, typically under high-temperature and high-pressure conditions. Multiple reaction pathways, including steam reforming, partial oxidation, pyrolysis, autothermal reforming, dehydrogenation, and gasification, can simultaneously occur inside reservoirs depending on the applied thermal technologies. Achieving the desired reaction pathways, reaction rates, and product yields requires careful selection and control of suitable processes. This review thoroughly discusses the methods and technologies employed in ISHG, along with associated reaction pathways and kinetics. Special emphasis is given to catalyst design and the strategic use of catalysts to optimize specific reactions. The potential of ISHG technology is finally discussed, highlighting the technical challenges that must be addressed to verify the feasibility of ISHG as a viable and competitive process. By enhancing the understanding of the science behind ISHG, this comprehensive review aims to pave the way for the development of innovative technologies that can revolutionize the energy landscape while mitigating the impacts of climate change.

Keywords: Hydrogen; In situ hydrogen generation; Hydrocarbons; Coal; Natural gas; Subsurface reservoir

Michal M. Czachor, Christian J. Laycock, Alan J. Guwy,

Utilisation of steelmaking waste gases in solid oxide cell technology: Opportunities, challenges and future directions,

Fuel,

Volume 389,

2025,

134619,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134619.

(https://www.sciencedirect.com/science/article/pii/S0016236125003436)

Abstract: This review investigates the potential of utilising steelmaking waste gases, specifically coke oven gas (COG) and blast furnace gas (BFG), in solid oxide cell (SOC) technology. It is shown that SOCs, which operate in fuel cell or electrolysis modes, offer promising pathways for energy recovery and chemical production from these underutilised byproducts. COG, with its high methane and hydrogen content, presents significant opportunities for power generation and hydrogen production, while the high CO2 and CO concentrations of BFG make it more suitable for electrolysis applications. Key challenges, such as carbon deposition, sulfur poisoning and tar contamination, are discussed alongside strategies for mitigation. This review highlights the opportunities and challenges of integrating SOC technology with steelmaking processes, offering insights into future research directions to optimise the reuse of COG and BFG for sustainable steel production.

Keywords: Coke oven gas; Blast furnace gas; Solid oxide fuel cells; Solid oxide electrolysis cells; Carbon deposition; Industrial waste gas utilisation

Yingao Zhang, Zidi Yan, Min Xiao, Chunlei Zhang, Luna Ruan, Yanshuang Zhang, Yun Zhong, Yong Yan, Yunbo Yu, Hong He,

Catalytic performance of Pd catalyst supported on CeO2 or ZrO2 modified beta zeolite for methane oxidation,

Journal of Environmental Sciences,

Volume 152,

2025,

Pages 248-261,

ISSN 1001-0742,

https://doi.org/10.1016/j.jes.2024.05.005.

(https://www.sciencedirect.com/science/article/pii/S1001074224002377)

Abstract: Two kinds of oxide-zeolite composite support, Ce-beta and Zr-beta were prepared by a simple wet impregnation method and adopted for the preparation of palladium-based catalysts for catalytic oxidation of methane. The Pd/6.8Zr-beta catalyst showed superior methane oxidation performance, achieving T50 and T90 of 417 °C and 451 °C, respectively, together with robust hydrothermal stability. Kinetic analysis has shown that incorporating Zr into the catalyst significantly enhanced its efficiency, nearly tripling the turnover frequency (TOF) for methane combustion compared to the Pd/beta catalyst. This enhanced performance was attributed to the dispersion of Zr on the zeolite surface, which not only promoted the formation of active PdO sites but also helped maintain the high Pd2+ content via facilitating the oxygen migration during the reaction, thus improving both the catalyst's activity and stability. In the Pd/8.6Ce-beta catalyst, doped CeO2 tended to aggregate in the zeolite's pores, adversely affecting the catalyst's efficiency. This aggregation promoted the formation of inactive Pd4+ species, a result of the enhanced metal-support interaction. This finding is critical for understanding the implications of dopant selection in the design of high-activity methane oxidation catalysts.

Keywords: Methane combustion; Palladium catalyst; Oxide-zeolite; Metal-support interaction; Cerium doping; Zirconium doping

Xingyu Gong, Houfang Lu, Guojie Liu, Kejing Wu, Bin Liang,

High-purity H2 production from biomass through cascade processes based on alkaline thermal treatment,

International Journal of Hydrogen Energy,

Volume 98,

2025,

Pages 148-158,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.019.

(https://www.sciencedirect.com/science/article/pii/S0360319924052145)

Abstract: A cascade process consisting of three techniques of alkaline thermal treatment, catalytic steam reforming, and alkali absorption is introduced to produce high-purity H2. The effect of NaOH and biomass molar ratio is investigated for H2 production, and the interactions between the three components was carried out specially to investigate the effect on H2 and CH4 production for the alkaline thermal treatment of real biomass. Synthesized mesoporous 10 wt% Ni/Al2O3 catalyst is applied in steam reforming of CH4. The NaOH supported on CaO was used for the absorption of CO and CO2 during the alkali absorption process. The results show that the high H2 production of 68.04 mmol g−1 cellulose with a purity of 99.93 vol% is achieved under optimized conditions. The cascade process for sawdust results in a 103% increase in H2 production compared with one-step alkaline thermal treatment, and the H2 purity is greater than 99.9 vol%.

Keywords: High-purity hydrogen; Biomass; Alkaline thermal treatment; Catalytic steam reforming; Alkali absorption

Pranay Rajendra Chandewar, Debaprasad Shee,

Role of copper and cerium species in Cu/CeZSM catalysts for direct methane to methanol reaction: Insights of structure–activity relationship,

Journal of Catalysis,

Volume 442,

2025,

115916,

ISSN 0021-9517,

https://doi.org/10.1016/j.jcat.2024.115916.

(https://www.sciencedirect.com/science/article/pii/S0021951724006298)

Abstract: The direct methane to methanol (DMTM) conversion was studied in a fixed bed reactor under varying reaction parameters including temperature, weight hourly space velocity (WHSV) and CH4:O2 over several CeO2-ZSM5, CeO2-SiO2 and CeO2-Al2O3 supported CuO catalysts prepared by wetness impregnation method and characterized by several techniques including N2 adsorption desorption, X-ray diffraction (XRD), Fourier transformed infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), ultraviolet visible spectroscopy (UV–vis), temperature programmed reduction (H2-TPR), temperature programmed desorption (CO2-TPD) and CO-diffuse reflectance infrared Fourier transform spectroscopy (CO-DRIFT) studies. The characterization results confirm the formation of bis(µ-oxo) dicopper or mono-(µ-oxo) dicopper species considered as the active sites for the DMTM reaction. Moreover, various copper (Cu2+, Cu+ and Cu0) and cerium (Ce3+ and Ce4+) species are coexisted in a redox cycle equilibrium (Cu+ + Ce4+ ⇌ Cu2+ + Ce3+) depending on CeO2 loading. XPS studies indicates the generation of lattice and adsorbed oxygen species on deposition of CeO2 and their ratio varied with the CeO2 loading. Moreover, the different cerium species induces charge unbalance, oxygen vacancies, and formation of unsaturated chemical bonds on the catalyst’s surface. The deposition of CeO2 and CuO incorporates more Lewis’s acid sites in xCu/yCe-ZSM5 composite catalysts and even formation of additional Lewis’s acid sites originated from exchanged copper species. The various copper and cerium species formed in the composite catalysts strongly influenced the methane molecule activation, and selectivity and yield of methanol. The surface Cu2+ species promotes the formation of methanol and prevents the methanol overoxidation forming oxygenates and carbon dioxide. In addition to the Cu2+ species, the lattice and adsorbed oxygen generated on deposition of CeO2 also influence the formation and oxidation of methanol. Thus, optimum surface concentration of Cu2+ and lattice to adsorbed oxygen maximizes the yield of methanol. The process parameters also the affect the methane conversion and methanol selectivity and yield. The methanol selectivity of 6.34 % with methane conversion of 37.89 % was achieved over 20Cu/15CeZ catalysts at 873 K, 1030 ml hr-1 gcat−1 and CH4:O2 = 2:1. A plausible reaction mechanism of oxidation of methane to methanol based on the activity results and in-situ DRFIT studies of methanol oxidation.

Keywords: Methane; Methanol; Copper oxide; Cerium oxide; HZSM-5; XPS; CO-DRIFT; Lattice to adsorbed oxygen ratio

Rendra Hakim Hafyan, Jhuma Sadhukhan, Vinod Kumar, Sunil K. Maity, Siddharth Gadkari,

A comparative techno-economic feasibility of hydrogen production from sugarcane bagasse and bread waste,

Fuel,

Volume 388,

2025,

134469,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134469.

(https://www.sciencedirect.com/science/article/pii/S0016236125001930)

Abstract: An increase in the emphasis on sustainable energy solutions underscores a vital need for hydrogen as a clean, decarbonizing, and efficient energy carrier. This necessity is driving extensive research into alternative feedstocks for hydrogen production. Promising resources like sugarcane bagasse and bread waste, valued for their abundance and high sugar content, can be a promising feedstock for hydrogen. Processes, such as steam reforming of ethanol and aqueous-phase reforming of xylitol, effectively utilize sugarcane bagasse and bread waste to produce hydrogen, supporting a circular bioeconomy and reducing dependence on fossil fuels. This study aims to investigate the process design and techno-economic feasibility of hydrogen production from sugarcane bagasse and bread waste. Results show that sugarcane bagasse-based feedstock requires higher capital investment and annual operational costs, at 68.3 M$ and 24.3 M$ per year compared to bread waste-based feedstock, which involves 49.8 M$ and 18.74 M$ per year, respectively. Profitability analysis indicated that bread waste-based hydrogen production was more economically viable, with a higher net present value of 36.45 M$ and a higher internal rate of return of 17 %, along with a payback period of 11 years. A sensitivity analysis revealed that the selling price of hydrogen and fixed capital investment were the most influential parameters affecting the net present value. These findings highlight the economic advantages of utilizing bread waste over sugarcane bagasse, suggesting that bread waste is a more cost-effective and sustainable option for hydrogen production. By prioritizing bread waste as a feedstock, it is possible to achieve significant economic benefits, making it a strategic choice for future hydrogen production initiatives and advancing renewable energy technologies.

Keywords: Techno-economic analysis; Sugarcane bagasse; Bread waste; Aqueous-phase reforming; Steam reforming of ethanol

Yanyu Yang, Kun Zhou, Boran Wu, Mingqian Cheng, Ming Xie, Ruihao Yang, Jinzhong Yang, Tingting Liu, Youcai Zhao, Qihong Cen, Zewei Liu, Bin Li,

Waste to resource: Developing red mud as low-cost catalysts to enhance catalytic co-pyrolysis of tobacco waste and low-density polyethylene,

Separation and Purification Technology,

Volume 360, Part 1,

2025,

130938,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.130938.

(https://www.sciencedirect.com/science/article/pii/S138358662404677X)

Abstract: Solid waste co-utilization technology is an effective way to improve the resourceful use of solid waste. In this study, Ni- CRM600 catalysts were prepared from industrial solid waste red mud (RM) and used to catalyze the co-pyrolysis of tobacco waste (TW) and low-density polyethylene (LDPE) for H2-rich combustible gas (H2, CO and CH4) production. The results showed that the Ni-CRM600 catalyst was able to significantly promote the reforming reaction of volatile matter, compared to the original RM, the modified Ni-CRM600 catalyst improved the H2 yield by more than 8 times and the CO yield by more than 6 times in the co-pyrolysis of TW with LDPE. The highest yield of H2 reached 572.02 mL/g, and the low heating value (LHV) of the combustible gas was 143.54 J/g. In the regeneration experiments of the catalyst, the regenerated catalyst showed excellent stability and remained catalytic activity after 10 cycles. The characterization of the Ni-CRM600 catalyst showed that the large number of oxygen vacancies (Ov) in RM provided an active site for NiO, resulting in the excellent catalytic activity of Ni-CRM600. The investigation of the main active components of Ni-CRM600 showed that Fe2O3 significantly promotes the yield of CO, CO2 and light hydrocarbons (CH4, C2H4, C2H6) in the gas, while NiO has a high selectivity for H2. This study provided a novel solution for co-disposal of multi-source bulk solid waste with implications on high-quality combustible gas production and synergistic resource utilization.

Keywords: Tobacco waste; Low-density polyethylene; Co-pyrolysis; Combustible gas; Solid waste utilization

Chopendra G. Wasnik, Maki Nakamura, Taiki Shimada, Hiroshi Machida, Koyo Norinaga,

CO2 methanation over low-loaded Ni-M, Ru-M (M = Co, Mn) catalysts supported on CeO2 and SiC,

Carbon Resources Conversion,

Volume 8, Issue 1,

2025,

100241,

ISSN 2588-9133,

https://doi.org/10.1016/j.crcon.2024.100241.

(https://www.sciencedirect.com/science/article/pii/S2588913324000309)

Abstract: The concentration of the major greenhouse gas CO2 is rapidly increasing in the atmosphere, leading to global warming and a range of environmental issues. An efficient circulation and utilization of CO2 is critical in the current environmental context. Methanation, an exothermic process, emerges as a critical strategy for effective CO2 utilization. On this front, there is a significant demand for rational design of catalysts that maintain high activity and methane selectivity over a wide temperature range (250–550 °C). The catalyst that can promise a consistent reaction even at 500 °C under an atmospheric pressure is thus obliged. The present study investigated bimetallic catalysts with SiC, which is known for its exceptional thermal conductivity, and CeO2, which is characterized by its CO₂ affinity, as base materials. We incorporated Ni-M and Ru-M (M = Co and Mn) as the active metals, each loaded at 2 %. Impressively, with merely 20 mg, the Ni-Co/SiC catalyst achieved a CO2 conversion rate of 77 % and CH₄ selectivity of 88 % at 500 °C, in a fixed-bed tubular reactor system with conditions of H2/CO2 = 4, a total flow rate of 70 ml min−1, and a steady GHSV of 12,000 h−1. Moreover, 2Ni-2Co/CeO2 catalyst demonstrated exceptional performance with a 76 % conversion of CO2 and a 83 % selectivity for CH4, all under identical conditions. The catalyst's durability was confirmed by a subsequent 40-hour stability test, which showed only a 3–5 % degradation. The developed catalysts were comprehensively characterized by BET/BJH, CO pulse chemisorption, H2-TPR, HAADF-STEM-EDS, SEM-EDS and XRD etc. to unveil their physicochemical and surface traits. It was found that Co and Mn, when integrated, effectively restrained the agglomeration of Ni and Ru particles, ensuring optimal metal dispersion on the support. In conclusion, our synthesized bimetallic catalysts shown a sustained catalytic capability, even in the high-temperature environment.

Keywords: Greenhouse gas; CO2 methanation; Catalyst activity; Methane selectivity; Ni- and Ru- catalysts; GHSV; Catalyst's durability

Yungpil Yoo, Sang-Yup Lee, Seok-Ho Seo, Si-Doek Oh, Ho-Young Kwak,

Simultaneous production of pink and grey hydrogen using high-temperature (HT) gas-cooled nuclear reactors coupled with HT-electrolyzer and gas reforming unit,

International Journal of Hydrogen Energy,

Volume 102,

2025,

Pages 467-481,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.056.

(https://www.sciencedirect.com/science/article/pii/S0360319925000618)

Abstract: This study reports a novel system that utilizes a high-temperature gas-cooled reactor (HTGR) coupled with a high-temperature (HT)-electrolyzer system and a natural gas (NG) reforming unit to simultaneously produce two types of hydrogen: pink and grey. The 600 MW (heat) HTGR/HT-electrolyzer system produced pink hydrogen and oxygen as by-products. Meanwhile, grey hydrogen can be produced by reforming NG using electricity, water vapor and/or oxygen produced in the HTGR system. Detailed and rigorous energy, exergy and thermoeconomic analyses show that the HTGR/HT-electrolyzer with reformer produces more than 3.04 kg/s of pink and grey hydrogen. The proposed system produces pink and grey hydrogen at a unit cost 40% lower compared to producing pink hydrogen alone, as it produces more than twice as much hydrogen as the HTGR/HT-electrolyzer system. This study demonstrates that the proposed system offers a cost-effective solution for hydrogen production with a reduced carbon footprint.

Keywords: High-temperature gas-cooled reactor; Partial oxidation reforming; Autothermal reforming; Water electrolysis; Unit cost of hydrogen

Tawaf Ali Shah, Zhihe Li, Zhiyu Li, Andong Zhang,

Energy status, anaerobic digestion and role of genetic and metabolic engineering for hydrogen and methane,

Journal of Water Process Engineering,

Volume 69,

2025,

106725,

ISSN 2214-7144,

https://doi.org/10.1016/j.jwpe.2024.106725.

(https://www.sciencedirect.com/science/article/pii/S2214714424019573)

Abstract: The global demand for energy is rapidly escalating, driven by increasing consumption rates, population growth, and expanding human activities. Currently, more than 80–82 % of energy consumption comes from fossil fuels, while only 8–10 % is derived from renewable energy sources. The demand for energy and the consumption of fossil fuels are projected to increase by 2 % annually. The extensive use of fossil fuels leads to the emission of harmful gases, contributing to environmental pollution and ecosystem degradation. This situation underscores the need for cleaner, renewable energy alternatives. Among these, anaerobic digestion (AD) presents a promising method for producing biogases, particularly hydrogen and methane. This literature review provides an overview of the current energy landscape, with a specific focus on anaerobic digestion, the microbial processes involved, and the potential of AD technology in sustainable biogas production. It critically evaluates the advantages, limitations, and future potential of AD while highlighting recent technological advancements in the field. Furthermore, the review explores the application of metabolic and genetic engineering to enhance bacterial efficiency with the goal of increasing methane and hydrogen yields. Additionally, it proposes various strategies for future research in genetic engineering and modification of metabolic pathways with the goal of enhancing the technical efficiency of biogas production. Ultimately, this paper provides a comprehensive understanding of the chemistry between anaerobic digestion, genetic and metabolic engineering, and the yield of methane and hydrogen. It also identifies future prospects and challenges in this promising field.

Keywords: Bioenergy; Anaerobic digestion; Methane; Hydrogen; Biomass; Dark fermentation

Xinyu Huang, Weiting Lin, Jiawei Zhong, Jun Xie, Yong Chen,

Bi-reforming of model biogas to syngas over ultrasmall Ru/MgO nano-catalysts prepared via soft template-assisted mechanochemical method,

Separation and Purification Technology,

Volume 354, Part 7,

2025,

129301,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.129301.

(https://www.sciencedirect.com/science/article/pii/S1383586624030405)

Abstract: The upgrading of renewable biogas into value-added fuel and chemicals via syngas is of great significance. Ru/MgO nano-catalysts were prepared via novel soft template-assisted mechanochemical method. Comprehensive characterizations (XRD, N2 physisorption, ICP-OES, CO-chemisorption, CO2-TPD, XPS, HAADF-STEM, HRTEM, CH4-TPSR/CO2-TPO, TGA and Raman spectroscopy, etc.) were conducted to deeply analyze the fresh/spent catalysts. The 0.2Ru/MgO-0.2CTAB catalyst showed high initial activity in terms of CH4/CO2 conversion (∼94 %/61 %) and maintained catalytic stability over 120 h in bi-reforming of model biogas, at 800 °C under CH4/CO2/N2/H2O molar ratio of 3:2:1:2.6 and weight hourly space velocity of 30960 mL g-1h−1. CTAB and other soft templates were effective in enhancing the dispersion of Ru nanoparticles (NPs), which contribute to the inhibition of the deep cracking of CH4 and coke accumulation. Alkaline MgO oxide was crucial in the activation of CO2 and the production of active O\* species, thus promoting the removal of carbonaceous precursor and inhibiting the coke accumulation. Additionally, the strong interaction between ultrafine Ru NPs and the MgO support significantly contributed to its anti-sintering performance. The combined advantages of narrow size distribution of ultra-small Ru NPs, suitable basicity of MgO as well as the interaction between ultrafine Ru NPs and MgO over 0.2Ru/MgO-0.2CTAB catalyst led to satisfying catalytic performance in bi-reforming of model biogas.

Keywords: Bi-reforming; Biogas; Ultrafine Ru NPs; Soft-template assisted mechanochemical method; MgO

Nguyen Tri, Nguyen Phung Anh, Do Ba Long, Ho Gia Thien Thanh, Bui Thi Hong Nhung, Nguyen Thi Thuy Van, Cam Anh Ha, Hoang Tien Cuong, Luu Cam Loc,

Advanced Zr-CeO2 supported Ni catalysts for production of synthetic natural gas (SNG) from CO2,

Fuel,

Volume 380,

2025,

133137,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133137.

(https://www.sciencedirect.com/science/article/pii/S0016236124022865)

Abstract: A series of ZrO2-modified CeO2 support were synthesized by co-precipitation and hydrothermal methods to support Ni-based catalysts used in CO2 methanation reaction. The physicochemical characteristics of these catalysts were comprehensively investigated using various techniques, including XRD, SEM, HR-TEM, EDS, isotherm N2 adsorption, H2-TPR, CO2-TPD, and Raman spectroscopy. The catalysts were then evaluated for their performance in the methanation of CO2 to synthetic natural gas (SNG) under atmospheric pressure within a temperature range of 250–350 °C. The findings revealed that the catalyst with an optimal ZrO2 modification content of 10 wt% exhibited superior properties, including an increased specific surface area of up to 49.0 m2/g, a pore volume of 0.09 cm3/g, and a pore diameter of 2.52 nm. The introduction of ZrO2 induced changes in the physicochemical properties, enhancing the dispersion and reducibility of NiO, improving the basicity and oxygen vacancy concentration of the support, thereby mitigating coke formation, improving CO2 conversion and CH4 selectivity in the CO2 methanation process. Under atmospheric pressure and a H2:CO2 molar ratio of 4:1, the modified catalysts demonstrated exceptional CO2 conversion in the lower temperature range of 250–325 °C. Notably, the best-performing catalyst, Ni/0.1Zr-CeO2, achieved a CO2 conversion of 92.7 % and a CH4 selectivity of 100 % at a reaction temperature of 300 °C. Both Ni/CeO2 and Ni/0.1Zr-CeO2 catalysts exhibited excellent stability due to excellent structural stability, high Ni sintering resistance, and high coke-resistance, with negligible coke deposition (0.066 and 0.06 mgC/g) after 100 h on stream, much lower than the reference catalysts.

Keywords: Zr-modified CeO2 support; Nickel catalyst; CO2 methanation; Catalytic performance; Coke-resistance

Hailong Zhang, Xinyi Zhang, Xueke Shi, Xiaoxiong Liu, Juan Liang, Shanshan Li, Shenggui Ma, Xin Xiao, Jiaxiu Guo, Lili Zhang, Mingwu Tan,

Single-step conversion of methane-steam to methanol on single-atom Cu1/γ-Al2O3 catalyst prepared via electrostatic anchoring,

Applied Catalysis B: Environment and Energy,

Volume 361,

2025,

124648,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124648.

(https://www.sciencedirect.com/science/article/pii/S0926337324009627)

Abstract: Direct conversion of methane to methanol in heterogeneous catalysis is of paramount importance but remains a challenging issue in improving catalytic activity and selectivity. Here, we report that Cu single-atom sites anchored on γ-Al2O3 oxides (Cu1/γ-Al2O3) using surface electrostatic adsorption, are highly active (methanol yield of ∼47 mmol/molCu/h) and stable in continuous conversion of methane-steam to methanol at 200 °C, comparable to most of the state-of-the-art Cu-zeolite catalysts. The combined DFT calculation and isotope labeling experiments reveal the methane-to-methanol reaction pathway on Cu single-atom sites and methanol formation is the rate limiting step. The further theoretical study indicates that single Cu atom as active site can preferentially activate methane C-H bond instead of methanol and has larger advantage for highly-selective methanol yield compared with [Cu(II)-OH]+ and [CuOCu]2+ active sites. Our molecular-level findings on Cu1/γ-Al2O3 single-atom catalyst pave the way to prepare better non-zeolite catalysts for methane to methanol.

Keywords: Methane to methanol; Single Cu atoms; γ-Al2O3; Electrostatic anchoring; Overoxidation

Yldeney Domingos, Alberto Abad, Margarita De Las Obras Loscertales, María Teresa Izquierdo, Arturo Cabello,

Chemical looping combustion and gasification of swine manure with a Cu-Based oxygen carrier,

Chemical Engineering Journal,

Volume 503,

2025,

158503,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2024.158503.

(https://www.sciencedirect.com/science/article/pii/S1385894724099947)

Abstract: The thermochemical conversion of swine manure by using Chemical Looping Combustion (CLC) and Chemical Looping Gasification (CLG) is an interesting option to obtain bioenergy and solve some environmental issues related to this waste. In this work, experimental tests using swine manure as fuel and a Cu-based oxygen carrier (14 wt% CuO) in a 0.5kWth continuous unit have been performed. For CLC conditions, the effects of the temperature (800–900 °C) and the fluidization agent (CO2 or steam) on the combustion and CO2 capture efficiencies were evaluated. In general, high combustion (97–99 %) and CO2 capture (87–99 %) efficiencies were achieved, which improved by increasing the operating temperature. For CLG conditions, the effect of the oxygen-to-fuel ratio (λ = 0.2, 0.3 and 0.4) on the gas product distribution, CO2 capture efficiency and tar composition was studied using steam and CO2 as fluidizing agents at 900 °C. The CO2 capture potential improved by increasing the oxygen-to-fuel ratio. Regarding the tar distribution, naphthalene was the main product followed by benzene, acenaphthylene, indene and phenanthrene. Additionally, for both processes, CLC and CLG, the distribution of nitrogenous compound emissions (N2, NH3, N2O, NO2 and NO) was analyzed. It was observed that the N-swine manure was mainly converted into inert N2.

Keywords: Swine manure; Chemical Looping Combustion; Chemical Looping Gasification

Divya Bisen, Ashish Pratap Singh Chouhan, Manish Pant, Sankar Chakma,

Advancement of thermochemical conversion and the potential of biomasses for production of clean energy: A review,

Renewable and Sustainable Energy Reviews,

Volume 208,

2025,

115016,

ISSN 1364-0321,

https://doi.org/10.1016/j.rser.2024.115016.

(https://www.sciencedirect.com/science/article/pii/S1364032124007421)

Abstract: This study delves into the promising realm of clean energy production through thermochemical conversion and chemical advancements. As the global demand for sustainable energy intensifies, exploring innovative technologies becomes imperative. The focus here is on harnessing the potential of thermochemical conversion, coupled with advancements in chemical processes. This dual approach holds significant promises for generating clean energy. The abstract underscores the critical role of these technologies in meeting escalating energy needs while shedding light on the advancements, challenges, and opportunities that pave the way for their successful implementation. Waste biomass represents an excellent bioresource that can be harnessed to produce numerous types of energy carriers, including bio-oil, bio-crude oil, biodiesel, syngas, biochar, and hydrogen. This article reviews the potential of various types of biomasses, including food waste, agricultural and forestry biomass, energy crops & oilseed crops, municipal solid waste, and animal manure, and also discusses the different types of reactors. In this review, comprehensively discusses all thermochemical methods for bio-oil production, including pyrolysis, gasification, and liquefaction. Each method is examined in detail, highlighting their respective processes, advantages, and challenges. Additionally, various types of reactors used in these methods are analyzed, emphasizing their roles and efficiencies in optimizing bio-oil yield and quality. Therefore, this review article will help in understanding the potentiality of waste biomasses for the production of clean energy via thermochemical techniques.

Keywords: Biomass; Waste management; Thermochemical conversion; Reactor; Value-added products; Catalytic pyrolysis; Clean energy

Chenlong Liu, Wenqiang Tang, Xuechen zhang, Siddig Abuelgasim, Chenghua Xu, Rui Liu, Hengyi Xie, Fan Jiang,

Biochar chemical-looping gasification for hydrogen-rich syngas production in solid-solid reaction: O, H and CaO of carbide slag effect NiFe2O4 oxygen carrier,

Journal of Environmental Management,

Volume 376,

2025,

124560,

ISSN 0301-4797,

https://doi.org/10.1016/j.jenvman.2025.124560.

(https://www.sciencedirect.com/science/article/pii/S0301479725005365)

Abstract: Biomass chemical-looping gasification represents a promising technology for the production of hydrogen-rich syngas, wherein the yield of gas is contingent upon the rate of solid-solid reactions. In this study, the incorporation of carbide slag as an oxygen carrier, hydrogen carrier, and in-situ carbon capture agent, as well as the modification of the synthesis method for the NiFe2O4 oxygen carrier, were specifically targeted to enhance the solid-solid reaction activity. The results indicate that the reactivity can be significantly improved by synthesizing NiFe2O4 using the sol-gel method with varying ratios of citric acid. Specifically, a citric acid ratio of 1:3 demonstrated a substantial hydrogen gas yield of 0.032 Nm3/kg, although CO remained the predominant product. The addition of carbide slag markedly enhanced the H2 gas yield. Notably, the incorporation of 4g of carbide slag exhibited a pronounced synergistic effect with the NiFe2O4 oxygen carrier, resulting in a H2 gas yield improvement that exceeded fivefold compared to the NiFe2O4 sample alone. The formation of the Ca2Fe2O5 phase was identified as one of the key factors contributing to the enhanced activity of hydrogen production. Regarding the reaction temperature, an optimal H2 gas yield of 0.169 Nm3/kg was achieved at 800 °C. According to Pearson correlation coefficient analysis, both reaction temperature and the amount of carbide slag were identified as the primary parameters influencing hydrogen-rich syngas production. Additionally, the production of H2 was attributed to reforming reactions, while the production of CO was attributed to gasification processes. Ultimately, the possible reaction mechanism involving the interaction between carbide slag and NiFe2O4 was elucidated.

Keywords: Chemical looping gasification; Carbide slag; NiFe2O4 oxygen carrier; Hydrogen; Solid-solid reaction

Kaiyou Shu, Bin Guan, Zhongqi Zhuang, Junyan Chen, Lei Zhu, Zeren Ma, Xuehan Hu, Chenyu Zhu, Sikai Zhao, Hongtao Dang, Tiankui Zhu, Zhen Huang,

Reshaping the energy landscape: Explorations and strategic perspectives on hydrogen energy preparation, efficient storage, safe transportation and wide applications,

International Journal of Hydrogen Energy,

Volume 97,

2025,

Pages 160-213,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.11.110.

(https://www.sciencedirect.com/science/article/pii/S0360319924047852)

Abstract: As the global demand for clean energy continues to rise, hydrogen, as a promising clean energy carrier, is increasingly becoming the focus of international attention. This paper aims to present a comprehensive overview of hydrogen preparation strategies, recent advances in storage and transportation technologies, and the extensive application of hydrogen in many fields. First, we explored the current mainstream hydrogen preparation paths, including but not limited to hydroelectrolysis (decomposition of water molecules using renewable energy power); gas steam reforming (traditional but efficient hydrogen production methods requiring carbon emission management); biomass gasification and coal gasification (based on innovative utilisation of renewable and fossil resources); and hydrolysis hydrogen production (advanced cutting-edge technology directly using solar energy). Each method shows its unique advantages and potential application scenarios. Subsequently, we have focused on hydrogen storage technology, a key area that is undergoing rapid technological innovation and widespread application. Hydrogen storage technology, with its energy storage and release characteristics without carbon dioxide emissions, is regarded as an important bridge to promote the transformation of energy structure and achieve the sustainable development goals. This paper not only expounds the basic principle of hydrogen storage technology and historical evolution, also analyzed in detail in the compressed hydrogen, liquid hydrogen and solid hydrogen storage form of concrete application examples, at the same time, the selection of hydrogen storage materials, cost efficiency, safety performance and deeply analyzes the core challenges, and the future development trend and potential solutions. In terms of hydrogen transport, this paper will introduce three common transport modes: gas transport, liquid transport and hydrogen carrier transport. Further, we turned to the diversified utilisation technology of hydrogen, focusing on the breakthroughs of fuel cell technology in energy conversion efficiency, Hydrogen combustionand, thow hydrogen energy can help to achieve low-carbon travel in the transportation field. The integration and application of these technologies not only broaden the use of hydrogen energy, but also lay a solid foundation for them to occupy a core position in the clean energy system. To sum up, through a detailed review, this paper draws a panorama of hydrogen production, storage, transportation and use, revealing the key role and huge potential of hydrogen energy in the clean energy transition. We look forward to that this paper will provide valuable reference and inspiration for researchers, engineers and policy makers, jointly promote the continuous progress and wide application of hydrogen technology, and contribute to the construction of a green and low-carbon future.

Keywords: Hydrogen production; Hydrogen storage; Hydrogen transport; Hydrogen use

Jiwen Wu, Naiyan Liu, Fengshi Li, Binbin Jia, Jinlong Zheng,

Iron group elements (Fe, Co, Ni) in Electrocatalytic applications: Evaluation, characterization and prospects,

Coordination Chemistry Reviews,

Volume 525,

2025,

216343,

ISSN 0010-8545,

https://doi.org/10.1016/j.ccr.2024.216343.

(https://www.sciencedirect.com/science/article/pii/S0010854524006891)

Abstract: Electrocatalysis represents a promising approach for addressing energy shortages and environmental concerns. The quest for electrocatalysts characterized by high activity, low cost, and excellent stability is pivotal to advancing the field of electrocatalysis. Notably, the extraordinary electronic structure of iron group elements (Fe, Co, Ni) has garnered significant attention. This work introduces the evaluation indexes of electrocatalytic reactions, and also analyzes in-suit/operando characterization techniques commonly used in the study of electrocatalytic processes. The review encompasses the application of iron group electrocatalysts in various reactions including hydrogen evolution reaction (HER), oxygen evolution reaction (OER), overall water splitting (OWS), oxygen reduction reaction (ORR), nitrogen reduction reaction (NRR) and carbon dioxide reduction reaction (CO2RR). Furthermore, the paper presents a summary of the reaction mechanisms underlying each electrocatalytic process. It also delves into the research progress of iron group elements in diverse electrocatalytic reactions, aimed at advancing the advancement of electrocatalysts which are more available and stable. Lastly, the paper examines the situation status, challenges, and future prospects of iron group electrocatalysts, offering insights into the evolving landscape of iron group materials and the design of commercially viable electrocatalysts.

Keywords: Electrocatalysis; Iron group elements; Operando characterization; Reaction mechanisms

Jintao Xu, Ziyang Guo, Xiefei Zhu, Xiao Chen, Zejun Luo, Chunbao Charles Xu, Weihong Li,

Sequential catalysis enables efficient pyrolysis of food waste for syngas production,

Bioresource Technology,

Volume 419,

2025,

132042,

ISSN 0960-8524,

https://doi.org/10.1016/j.biortech.2025.132042.

(https://www.sciencedirect.com/science/article/pii/S0960852425000082)

Abstract: Thermochemical conversion technologies are emerging as one of the most promising approaches to tackle food waste crisis. However, the existing techniques confront significant challenges in terms of syngas selectivity and catalyst stability. This study introduced a cost-effective Joule heating approach utilizing sequential catalysts composed of treated stainless steel (SS) and biochar to optimize syngas production from food waste. This system achieved a syngas yield of 17.64 mmol⋅grice−1, marking a 76.40 % improvement over conventional thermal pyrolysis. The molar ratio of hydrogen (H2) to carbon monoxide (CO) was adjustable from 0.36 to 0.94, offering flexibility for different applications. Over five cycles, the system maintained robust catalytic stability, with only a 9.70 % decrease in syngas yield. Furthermore, the sequential catalysts proved versatile across diverse food wastes, achieving a maximum selectivity of 87.99 vol%. This approach enhanced catalyst activity and stability by promoting the sequential cracking of large oxygenates and reforming small molecules.

Keywords: Food waste; Pyrolysis-sequential catalysis; Syngas production; Cyclic stability

Minghao Wang, Xinyu Zhang, Ai Liu, Wenbiao Xu, Xixin Duan, Junyou Shi, Xueqin Li, Xiangyu Li,

Influence of Ni-loaded red brick powder catalyst on the distribution of pyrolysis products of waste biomass,

Journal of Analytical and Applied Pyrolysis,

Volume 186,

2025,

106938,

ISSN 0165-2370,

https://doi.org/10.1016/j.jaap.2024.106938.

(https://www.sciencedirect.com/science/article/pii/S016523702400593X)

Abstract: Red brick powder, as a construction material, exists in large quantities in construction waste, which has the advantage of developing cheap catalysts due to its rich pore structure and metal composition. In the present study, acid, hydrothermally activated red brick powder and doped ZSM-5 molecular sieves were used as the co-carriers to prepare nickel metal-modified red brick powder-based catalysts by the impregnation method and catalyze the pyrolysis of biomass in a fixed-bed, and the optimal conditions for the preparation of the catalysts were investigated through the analysis of the product distribution pattern and the distribution pattern of the products of the pyrolysis of biomass.Research has shown that catalysts prepared by doping red brick powder with molecular sieves have better pyrolysis effects. When the red brick powder was compounded with ZSM-5 molecular sieves at a mass ratio of 3:1 to load nickel metal, the dispersion of nickel metal was improved. The prepared catalyst not only had a large specific surface area (45.8 m2/g) but exhibits suitable weak acid characteristics. In addition, K, Ca, Na, and Mg in the red brick powder effectively improved the selectivity of the catalyst for H2. These characteristics not only promoted the primary and secondary cracking reactions of biomass, but also effectively reduced the risk of carbon deposition blocking the catalyst pores, prolong the service life of the catalyst, and reduce the possibility of deactivation. The catalyst achieved a gas production rate of up to 63.73 % during the pyrolysis of corn stover, with a hydrogen production rate of 63.73 mL/g. Compared to the pyrolysis process without a catalyst, the gas production rate was significantly increased by 27.82 %. The research results have opened up a new way for the environmental reuse of waste red brick powder, and provided technical support for the efficient conversion of biomass energy.

Keywords: Ni-bearing red brick powder; Waste biomass; Catalytic pyrolysis; Product distribution; Hydrogen-rich gas

Weiying Su, Zhibin Liu, Simin Huang, Daoliang Wang, Xiaoxiao Feng, Yuan Liu, Li Ni,

Insight into aroma dynamic changes during the whole manufacturing process of smoked Lapsang Souchong tea,

Food Chemistry,

Volume 463, Part 4,

2025,

141498,

ISSN 0308-8146,

https://doi.org/10.1016/j.foodchem.2024.141498.

(https://www.sciencedirect.com/science/article/pii/S0308814624031480)

Abstract: Smoked Lapsang Souchong tea (SLST) is a distinctive black tea known for its smokey, fruity, and pine flavor. This study analyzed the aroma dynamic changes during the whole manufacturing process of SLST utilizing E-nose, HS-SPME-GC–MS, and HS-SPME-GC-O-MS. Fresh tea leaves primarily contain green and floral volatiles, such as (E)-2-hexenal (OAV 33.41) and linalool (OAV 313.88). Withering and drying processes introduce pinewood smoke-derived phenolic and terpenoid compounds, such as guaiacols (OAV 77.05) and α-terpineol (OAV 1.08), crucial for the tea's smoky and woody aroma. The study further highlights glycoside hydrolysis and lipid oxidation pathways in generating key tea-derived volatiles during fermentation, contributing to the fruity and floral notes in SLST. Pinewood smoke was identified as a major source of smoky volatiles, with longifolene and α-terpineol being unique to pinewood. These findings elucidate the formation pathways of the key volatile compounds and the impact of traditional processing on SLST's aroma profile.

Keywords: Smoked Lapsang Souchong tea; Volatile compounds; Aroma dynamics; Manufacturing process; GC-O-MS; Pinewood

Ali Salehabadi, Jonathan Perry, Jafar Zanganeh, Behdad Moghtaderi,

Emerging perovskite-based catalysts for sustainable and green ammonia production: A promising hydrogen energy carrier,

International Journal of Hydrogen Energy,

Volume 106,

2025,

Pages 243-260,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.283.

(https://www.sciencedirect.com/science/article/pii/S0360319925003179)

Abstract: Ammonia (NH₃) presents a comprehensive energy storage solution for future energy demands. Its synthesis plays a pivotal role in the chemical industry, acting as a fundamental precursor for fertilizers, explosives, and a wide range of industrial applications. In recent years, there has been a growing interest in exploring novel catalyst materials to enhance the efficiency, selectivity, and sustainability of NH3 production technologies. Among these materials, perovskite-based catalysts have emerged as promising candidates due to their unique properties. This review article aims to provide a sharp and short understanding of the role of perovskite-based catalysts in emerging NH3 production technologies and to stimulate further research and innovation in this rapidly evolving field. It provides an overview of recent advances in the synthesis and characterisation of perovskite-based catalysts for NH3 production in terms of structural properties, and catalytic performance of perovskite catalysts in NH3 synthesis. The review also discusses the underlying mechanisms involved in NH3 production on perovskite surfaces, highlighting the role of surface chemistry, and electronic structure. Furthermore, the review examines the potential applications and prospects of perovskite-based catalysts in NH3 production technologies. It explores opportunities for integrating perovskite catalysts into existing NH3 synthesis processes, as well as the development of process configurations to maximise the efficiency and sustainability of NH3 production.

Keywords: Perovskites; Catalysts; Ammonia synthesis; Energy storage; Electrochemical

Bernardo Jordão Moreira Sarruf, Ulfi Anisya Binti Rastu, Mohammad Ammar,

Improving the degradation behaviour and coking resistance of solid oxide fuel cells via surface modification using wet impregnation of metallic solutions,

International Journal of Hydrogen Energy,

Volume 105,

2025,

Pages 481-491,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.332.

(https://www.sciencedirect.com/science/article/pii/S0360319925003696)

Abstract: Solid oxide fuel cells have reached a market-ready stage, with numerous industrial companies offering a diverse range of products. However, the significant challenge of fully leveraging the fuel flexibility of these devices remains unresolved. One promising approach is the introduction of small but meaningful modifications to commercially available materials, aimed at enhancing performance while minimising costs. In this context, surface engineering through wet impregnation of metallic solutions has demonstrated the potential for enabling complex modifications to electrode materials. This study investigates the wet impregnation of Ce–Co–Mn and Ce–Co–La cation solutions onto the surfaces of commercially procured anodes, with the aim of improving power density, resistance to carbon deposition, and long-term operational stability. The solutions were prepared, applied, and sintered, followed by surface characterisation using X-ray diffraction and scanning electron microscopy. The cells were subsequently tested using hydrogen and simulated biogas as fuels, with the oxidant alternated between air and pure oxygen. After prolonged electrochemical testing under both potentiostatic and galvanostatic conditions, Raman spectroscopy was employed to evaluate potential carbon deposition. Polarisation tests demonstrated the superior performance of the modified cells, achieving maximum power densities exceeding 435 mW cm−2 with O₂ and 401 mW cm−2 with air, compared to 301 mW cm−2 and 401 mW cm−2, respectively, for the benchmark. Additionally, sustained improvements in power densities were observed during extended static testing. Surface modifications were further shown to effectively inhibit carbon deposition, as verified through Raman spectroscopy. The transition between testing regimes offered valuable insights into the predominant degradation mechanisms under varying operational conditions.

Keywords: Surface engineering; Solid oxide cells; Biogas; Hydrogen; Degradation

Pubudi Perera, Rahil Changotra, James Forren, Jennifer Green, Yulin Hu, Quan Sophia He,

Comprehensive review on flax shives–Physicochemical properties and application potential,

Industrial Crops and Products,

Volume 225,

2025,

120585,

ISSN 0926-6690,

https://doi.org/10.1016/j.indcrop.2025.120585.

(https://www.sciencedirect.com/science/article/pii/S0926669025001311)

Abstract: Flax fiber has been used extensively in the production of textiles (e.g., clothing, household linens, and upholstery); however flax shives, as a by-product of the fiber extraction process, lacks advanced utilization or appropriate management strategies and typically ends up as a waste stream material. Recently, the upcycling of flax shives has received a great deal of attention owing to their superior morphological, chemical, and mechanical properties. In this review article, the physiochemical properties of flax shives have been discussed, followed by an in-depth description of the potential applications of flax shives as bio-based materials, energy carriers, and a source of bioactive compounds. Finally, the technical challenges, future directions, and main conclusions drawn from this article are provided. Overall, this review offers a comprehensive overview of the fundamentals and recent advancements in flax shives valorization, providing valuable knowledge for fostering the development of flax shives-derived bioproducts.

Keywords: Flax shives; Physiochemical properties; Downstream applications; Sustainability

Noradiba Nordin, Wei Shi Ng, Nurulfasihah Azhar, Siti Nur Amira Shaffee, Nur Azimah Abd Samad, Rozan Mohamad Yunus,

Evaluation of anion exchange membrane water electrolysis performance using synthesised NiMoO4/Ni cathode via solution combustion synthesis in applied thermal reduction approach,

International Journal of Hydrogen Energy,

Volume 104,

2025,

Pages 416-425,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.07.050.

(https://www.sciencedirect.com/science/article/pii/S0360319924027162)

Abstract: The development of sustainable electrocatalysts is essential for the advancement of anion exchange membrane water electrolysis (AEMWE) technologies. Nickel molybdate-based catalysts may improve the efficiency of hydrogen evolution reaction (HER) during alkaline water electrolysis. This study investigated the influence of thermal reduction temperature on the synthesised NiMoO4-based catalyst via solution combustion synthesis (SCS) and its performance in HER and single-cell AEMWE. The optimal conditions for stable and active HER electrocatalysts were determined by investigating synthesised NiMoO4 catalysts at 450 °C, 550 °C and 750 °C. A NiMoO4 catalyst was characterised at different reduction temperatures through X-ray diffractometer (XRD), field emission scanning electron microscopy (FESEM), energy-dispersive spectroscopy (EDS) and Brunauer–Emmett–Teller (BET) analysis. Results revealed that the NiMoO4-450/Ni cathode became the highest performance 1 A/cm2 current density at 2.2 V and the NiMoO4-550/Ni cathode became the most stable performance among the catalysts, attaining. The average current density of NiMoO4-550/Ni fluctuated by only 22% from 24 h to 100 h.

Keywords: Anion exchange membrane water electrolysis; Nickel molybdate; Solution combustion synthesis; Hydrogen evolution reaction; Thermal reduction; Water splitting

Fupeng Huang, Ross Baird, Weiming Yi, Aimaro Sanna,

Hydrogen production by sorption enhanced catalytic pyrolysis of lignin waste in presence of novel potassium stannate,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 255-267,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.161.

(https://www.sciencedirect.com/science/article/pii/S036031992500182X)

Abstract: Lignocellulosic waste stands out as an abundant and environmentally friendly feedstock to produce biofuels including renewable hydrogen. For the first time, potassium stannate dual functional material (DFM) was synthesised and assessed in the sorption enhanced pyrolysis of lignin waste and compared to zirconates DFMs by thermogravimetric analysis and in a packed bed reactor with online gas analysis. The results indicate that K2SnO3 presents a superior capacity in selectively producing hydrogen at 700 °C with 51 vol% of the gas produced being H2 (45 g H2/kg Etek lignin) with and only 9 vol% CO2, when a lignin: K2SnO3 ratio of 0.5:3 was used. The same DFM with a lignin: K2SnO3 ratio of 1:0.5 promoted the RWGS and Boudouard reactions converting the absorbed CO2 and formed H2 and char into CO at 900 °C. In summary, K2SnO3 is a promising catalyst to produce hydrogen from biomass pyrolysis-reforming.

Keywords: Sorption enhanced pyrolysis; Stannates; Dual functional material; Hydrogen; Biofuel

Wei Zhang, Yingtong Fang, Sheng Qian, Yubao Chen, Xingyong Li, Na Liu,

Biomass gasification to syngas of phosphogypsum as gasification agent: Thermogravimetric analysis and gasification performance,

Fuel,

Volume 385,

2025,

134065,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134065.

(https://www.sciencedirect.com/science/article/pii/S0016236124032150)

Abstract: Biomass utilization in energy production is often regarded as almost carbon neutral, and biomass gasification has significant potential for obtaining products with more value and potential applications for utilizing agricultural and forestry waste. Meanwhile, Phosphogypsum (PG) is a hazardous solid waste generated as a by-product of the wet process of phosphoric acid production, resulting in significant environmental issues. Based on the above, this work proposed that solid waste be utilized effectively by producing syngas through biomass gasification using PG as a gasification agent. The thermal characteristics of biomass with PG and the distribution of gaseous products were discussed, and the effects of the ratio of PG to biomass (O/B values) and temperature were investigated. The mechanism function and activation energy (Ea) were determined by the model-free (Kissinger-Akahira-Sunose method), model-fitting (Coats and Redfern method), and Malek methods. The results indicate that the solid-phase product of the process is calcium sulfide. The experiment obtained the highest peak mass loss Rp2 and comprehensive devolatilization parameter D when the O/B value of 0.5, leading to better devolatilization behavior during the devolatilization stage. The kinetics observed during the devolatilization stage show a decreased activation energy as the reaction progresses. Conversely, it gradually increases during the biochar gasification stage. The primary gaseous product emissions exhibited observable peaks in the devolatilization and biochar gasification stages. A significant amount of methane is released during the biochar gasification phase. Alkali metals and their oxides in PG are believed to serve as catalysts or facilitate the process of tar cracking during gasification.

Keywords: Biomass gasification; Phosphogypsum; Thermochemical conversion; Product distribution; Kinetic analysis

Wei-Wei Yang, Xin-Yuan Tang, Xu Ma, Xiangkun Elvis Cao, Ya-Ling He,

Synergistic intensification of palladium-based membrane reactors for hydrogen production: A review,

Energy Conversion and Management,

Volume 325,

2025,

119424,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119424.

(https://www.sciencedirect.com/science/article/pii/S0196890424013657)

Abstract: Hydrogen is a clean, zero-carbon energy carrier that is critical in the transition to a renewable energy system. Hydrogen production membrane reactors are based on membrane technology for process intensification, allowing simultaneous reaction enhancement and hydrogen purification. However, concentration polarization creates mismatch between reaction and separation processes, limiting the performance. To further develop and increase the hydrogen production efficiency in membrane reactors, this review first provides advances in membrane reactor research from several perspectives, including membrane materials, performance metrics, and evaluation tools. Subsequently, the effects of operating conditions and structural design on the performance enhancement of membrane reactors are organized and analyzed. The review focuses on summarizing the mechanisms for improving membrane reactor design performance, proposing four methods: shortening distance, increasing routes, smoothing paths, and multi-product removal. Additionally, it is suggested to draw on membrane surface pattern designs to guide the disruption of concentration boundary layers. The review finds that enhancement ways primarily revolve around mitigating concentration polarization. Various ways have the potential to achieve low-cost and higher performance by complementing each other’s strengths, such as minimizing the use of precious metals and employing low-cost multi-product separation. Moreover, there is a lack of corresponding evaluation standards for membrane reactors, which hinders the subsequent commercialization development. Finally, this review combines existing challenges and research progress to provide perspectives for the future development of membrane reactors. The major goal is to introduce new research methods to further promote the application of membrane reactors in greater depth.

Keywords: Concentration polarization; Evaluation tools; Hydrogen separation; Membrane materials; Membrane reactor; Performance enhancement method

Fan Yin, Liyan Sun, Rui Xiao,

Hydrogen generation via chemical looping water splitting over modified pyrite cinder as oxygen carrier fueled by biomass pyrolysis gas,

Chemical Engineering Journal,

Volume 507,

2025,

159850,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159850.

(https://www.sciencedirect.com/science/article/pii/S1385894725006497)

Abstract: Chemical looping water splitting is considered as a clean and efficient technology for the generation of high-purity hydrogen with zero/negative carbon emissions. However, the large-scale preparation of cost-effective oxygen carriers (OCs) with high activity remains a pivotal challenge for chemical looping technology. Utilization of industrial solid waste for OCs preparation saves costs, but it results in low reactivity. To address this issue, pyrite cinder is utilized as a precursor for OCs preparation and NiO is doped for the enhancement of reactivity. Results show that oxygen carrier with 10% NiO doping exhibits a 95.9% conversion of biomass pyrolysis gas during the reduction stage, accompanied by a 95.8% outlet CO2 concentration. CH4 conversion is promoted to 74.4%, which is much higher than that without NiO dopped OCs. In addition, the oxygen carrier with NiO doping demonstrates excellent stability of fuel conversion and H2 yield after 10 successive redox cycles. Simultaneously, density functional theory are utilized and the results reveal that the low reactivity of CH4 attributes to the energy barrier. The reaction pathways of OCs are changed with NiO doped and both the reducibility and methane activation are promoted. Finally, the efficiency of inherent CO2 separation and H2 yield are improved.

Keywords: Chemical looping; Oxygen carrier; Hydrogen; Industrial solid waste

T.A. Zepeda,

Insights into active iron phosphide as Fischer-Tropsch synthesis catalyst for sustainable light olefins production,

Molecular Catalysis,

Volume 574,

2025,

114870,

ISSN 2468-8231,

https://doi.org/10.1016/j.mcat.2025.114870.

(https://www.sciencedirect.com/science/article/pii/S2468823125000562)

Abstract: Here reports preliminary results on the performance of iron phosphide-based catalysts supported on SiO2-Al2O3 (denoted as SA) for sustainable light olefin production via Fischer-Tropsch synthesis, compared to conventional iron-based catalysts. Characterization results confirmed the presence of a well-defined FeP phase in the iron phosphide-based catalysts (FeP/SA), whereas the iron-based catalysts (Fe/SA) displayed a mixture of metallic iron (Fe0), oxidized iron (Fe+2/Fe+3), and Hägg iron carbide phase (χ-Fe5C2). The FeP/SA catalyst exhibited significantly higher CO conversion and stability over long reaction times, attributed to its resistance to surface iron species reoxidation, lower loss of exposed surface Fe species, and lower coke formation during the FTS reaction. The FeP/SA catalyst exhibited higher selectivity toward light olefins formation (C2 ⁻- C4 ⁻), while reducing selectivity for methane (CH4) and heavier hydrocarbon formation compared to the Fe/SA catalyst. Furthermore, FeP/SA exhibited lower selectivity to CO2 formation, which may indicate reduced water-gas shift (WGS) activity or the oxidation of adsorbed CO by surface-bound oxygen, resulting from the direct dissociation of CO on the surface, compared to Fe/SA catalyst. These results suggest that iron phosphide-based catalysts provide an efficient alternative for hydrocarbon production in FTS, particularly in the selective formation of light olefins.

Keywords: Metal phosphides; Iron phosphide; Fischer-Tropsch synthesis; Carbon monoxide; Removable fuels; Syngas conversion; Light olefins

Langqi Shi, Jinzhi Zhang, Lin Li, Jinhu Wu, Heyi Huang, Qirong Yang, Zhaoying Li,

Research on reaction mechanisms on chemical looping gasification of naphthalene over NiFe2O4 for syngas production: An experimental and theoretical study,

Fuel,

Volume 381, Part B,

2025,

133511,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133511.

(https://www.sciencedirect.com/science/article/pii/S0016236124026607)

Abstract: The effective removal of tar during biomass gasification is a significant challenge that can be addressed by chemical looping gasification (CLG), which offers a promising alternative for converting biomass into syngas with reduced tar generation. In this study, we investigated the mechanism of CLG of naphthalene as a model biomass tar compound over NiFe2O4 to produce syngas. Both experimental and simulation results indicate the optimal operating conditions for syngas production are 1000℃ and an O/C ratio of 1:1. Under the optimal reaction conditions, the experimental and simulated CO yields were 67 vol% and 73 vol%, respectively, while H2 yields were 22 vol% and 24 vol%. Additionally, carbon conversion rates reached 78% and 76%. Thermodynamic calculations and molecular dynamics simulations revealed that the reactions proceed spontaneously, with increasing temperature favoring naphthalene conversion and syngas production. Density functional theory results indicate that the reaction pathway centered on the carbon at the α-position is the key to naphthalene and NiFe2O4 conversion. The optimal reaction pathways for H2 and CO formation were explored. This study on the CLG of naphthalene over NiFe2O4 provides a theoretical basis for the development of more efficient CLG processes with reduced tar formation.

Keywords: Naphthalene; NiFe2O4; Chemical looping gasification; Syngas; Reaction mechanism

João C.B. Costa, Isabela M. Dias, Lucas C. Mourão, Guilherme B.M. de Souza, Mariana B. Pereira, Fernanda F. Freitas, Christian G. Alonso,

Supercritical water gasification of food waste for hydrogen production,

Renewable and Sustainable Energy Reviews,

Volume 208,

2025,

115091,

ISSN 1364-0321,

https://doi.org/10.1016/j.rser.2024.115091.

(https://www.sciencedirect.com/science/article/pii/S1364032124008177)

Abstract: The conversion of renewable biomass, particularly from food waste, into valuable energy sources via supercritical water (SCW) gasification is a promising approach for addressing environmental concerns related to sustainable energy generation, food waste, and socio-economic issues. In this sense, this review study covers the fundamental principles, process performance, and challenges of the gasification of biomass sourced from food waste by the SCW process. Additionally, it sheds light on advancements in SCW technologies (reactor design, operational conditions, catalysts utilization, etc.). The review explores the availability of food waste biomass, screens its chemical characteristics, and underscores the state-of-the-art methodologies focusing on the conversion of food waste into hydrogen-rich syngas. Thus, it outlines future research and development directions in this field, underscoring the importance of advancing SCW gasification technology for biomass valorization and waste management.

Keywords: Food waste; Hydrothermal process; Gasification; Hydrogen; Supercritical water

Xin Jin, Bo Chen, Tao Pan, Lin Liu, Haonan Chen, Changyi Chen, Caiwei Wang, Yuanyuan Ge, Zhili Li,

Enhanced hydrodeoxygenation of biomass-derived polyols to light alkanes over boron oxide modified nickel silicate catalysts,

Journal of Analytical and Applied Pyrolysis,

Volume 188,

2025,

107043,

ISSN 0165-2370,

https://doi.org/10.1016/j.jaap.2025.107043.

(https://www.sciencedirect.com/science/article/pii/S0165237025000968)

Abstract: Thermal-catalytic hydrodeoxygenation (HDO) of biomass-derived polyols is a potential route for producing renewable light alkanes, but developing efficient and economical non-precious metal catalysts is still challenging. In this study, a boron oxide moderated layered nickel silicate catalyst Ni-xB2O3/NiSi-PS was designed, and its performance and mechanism in the HDO reaction of C3–C6 polyols were systematically investigated. The characterization results showed that the introduction of B2O3 inhibited the agglomeration of active Ni0, reducing its particle size from 13.8 nm to 7.3 nm and significantly enhancing the Lewis acidity of the catalyst. Under the optimized reaction conditions (300 °C, 5 MPa H2), high light alkane selectivity ranging from 70.1 % to 94.1 % were achieved for various C3–C6 polyols. Through detailed product analysis, the reaction network of polyol HDO was proposed, and the regulatory mechanism of B2O3 was revealed. The catalyst exhibited good stability and reductive regeneration ability, and the activity decreased only slightly after five cycles. This study provides insights into catalyst design for thermal-catalytic conversion processes, which is significant in promoting the sustainable development of the biomass refining industry.

Keywords: B2O3 modified nickel silicate; HDO; Polyol; Light alkane; Acid-metal synergy

Karchiyappan Thirugnanasambandham, Ettiyagounder Parameswari, Selvaraj Paul Sebastian, Ramanujam Krishnan,

Advancements in green hydrogen (GH2) recovery from industrial wastewater: A comprehensive review,

Desalination and Water Treatment,

Volume 321,

2025,

100966,

ISSN 1944-3986,

https://doi.org/10.1016/j.dwt.2024.100966.

(https://www.sciencedirect.com/science/article/pii/S1944398624204768)

Abstract: Green hydrogen (GH2), a sustainable and clean energy carrier, is increasingly regarded as a solution to energy challenges and environmental issues. Industrial wastewater possesses a significant potential for hydrogen generation using biological, chemical, and electrochemical methods. This review analysis evaluates progress in GH2 production from industrial wastewater, highlighting its environmental and cost benefits. Process optimization, technological improvements, and enhancements in catalysts for chemical and electrochemical hydrogen generation are also provided. It also considers the integration of GH2 production methods with wastewater treatment procedures to achieve synergistic benefits, including enhanced pollutant removal and energy recovery. Challenges associated with GH2 production include substrate variability, economic viability, reactor scalability, and environmental sustainability are also discussed. Also, this review provides a future outlook to promote sustainable energy solutions and tackle global environmental issues related to GH2 from industrial wastewater.

Keywords: Industrial wastewater; Green hydrogen; Renewable energy; Sustainable technology; Environmental management

Shengxiong Huang, Wenyao Duan, Ziheng Jin, Shouliang Yi, Quanwei Lv, Xia Jiang,

Progress in carbon capture and impurities removal for high purity hydrogen production from biomass thermochemical conversion,

Carbon Capture Science & Technology,

Volume 14,

2025,

100345,

ISSN 2772-6568,

https://doi.org/10.1016/j.ccst.2024.100345.

(https://www.sciencedirect.com/science/article/pii/S277265682400157X)

Abstract: Renewable hydrogen production from biomass thermochemical conversion is an emerging technology to reduce fossil fuel consumptions and carbon emissions. Biomass-derived hydrogen can be produced by pyrolysis, gasification, alkaline thermal treatment, etc. However, the removal of impurities from biomass thermochemical conversion products to improve hydrogen purity is currently technical bottleneck. It is important to assess and investigate the types and properties of impurities, the difficulty of separation, and the impact on downstream utilization of hydrogen in the biomass-derived hydrogen production process. The key objectives of this comprehensive review are: (1) to reveal the current status and necessity of developing biomass-derived hydrogen production; (2) to evaluate the types, devices and impurities distribution of biomass thermochemical conversion; (3) to explore the formation pathways and removal technologies of typical impurities of tar, CO2, sulfides, and nitrides in hydrogen production process; and (4) to propose future insights on the separation technologies of typical impurities to promote the gradual substitution of biomass-derived hydrogen for fossil-derived energy.

Keywords: Hydrogen production; Biomass thermochemical conversion; Tar; Carbon capture; Sulfides

A. Yagmur Goren, Mert Temiz, Dogan Erdemir, Ibrahim Dincer,

The role of effective catalysts for hydrogen production: A performance evaluation,

Energy,

Volume 315,

2025,

134257,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2024.134257.

(https://www.sciencedirect.com/science/article/pii/S0360544224040350)

Abstract: In recent years, research on hydrogen (H2) production for alternative and environmentally-benign energy solution as fuel, storage medium and feedstock has been one of the most highly demanded subjects. It aims to reduce the pressures set by carbon dioxide emissions and the depletion of fossil fuel supplies. Nevertheless, large-scale H2 production is limited by its high cost and low yield. The distinct photo-electrochemical characteristics of catalysts have shown them to have great promise for enhancing the production of H2. This article presents an updated and comprehensive review of enhanced H2 production using various catalysts in biological, thermochemical, and water-based processes. Various operational parameters (reactor configuration, catalyst dosage, catalyst type, catalyst modification methods, temperature, pH, and inoculum type) are summarized to improve the H2 production performance and reduce the environmental impacts and costs of these processes. For instance, in dark fermentation, biological H2 production is enhanced by 3.2–38 % with certain metal catalysts. Overall, results revealed that catalysts, specifically inorganic catalysts such as iron, nickel, titanium oxide, and silver, have improved the production rate of H2. This review has provided the application fields and working principles of catalysts in different H2 production processes. Finally, we suggested the main concerns that need to be prioritized in the long-term advancement of H2 production using catalysts.

Keywords: Catalyst; Hydrogen production; Biological processes; Electrolysis; Sustainable production; Nanomaterials; Energy; Efficiency

Babak Jaleh, Atefeh Nasri, Mahtab Eslamipanah, Mahmoud Nasrollahzadeh, Milad Daneshnazar, Jacky H. Advani, Paolo Fornasiero, Radek Zbořil, Markus Antonietti, Manoj B. Gawande,

State-of-the-art and perspectives of nickel-based single-atom catalysts,

Applied Catalysis B: Environment and Energy,

Volume 361,

2025,

124590,

ISSN 0926-3373,

https://doi.org/10.1016/j.apcatb.2024.124590.

(https://www.sciencedirect.com/science/article/pii/S0926337324009044)

Abstract: Nickel (Ni) plays a key role in many industrially important catalytic applications owing to its unique inherent features and high catalytic activity. In recent years, nickel single-atom catalysts (Ni-SACs) with well-defined structures have received enormous research attention. Taking into consideration the fact that the catalytic reaction happens on the catalyst's surface, the atom utilization efficiency of SACs can ideally reach 100 %, leading to high catalytic efficiency. Due to the high catalytic activity and selectivity, Ni-SACs have been used in numerous significant electrocatalytic, photocatalytic, and thermocatalytic applications. This review provides a critical analysis of the relevant recent progress in Ni-SACs for catalytic applications, and the remaining challenges are discussed for researchers interested in this emerging research area, leading the way to logically design the advanced Ni-SACs for different catalytic processes in the field of energy conversion and storage, and chemical transformations.

Keywords: Single-atom catalysts; Nickel; Photocatalysis; Electrocatalysis; Thermocatalysis

Amarnath Pasupathi, Ragunath Madhu, Subrata Kundu, Yugeswaran Subramaniam,

Plasma induced oxygen vacancies on high entropy oxide surfaces for efficient overall water splitting,

Journal of Power Sources,

Volume 630,

2025,

236144,

ISSN 0378-7753,

https://doi.org/10.1016/j.jpowsour.2024.236144.

(https://www.sciencedirect.com/science/article/pii/S0378775324020974)

Abstract: Oxygen vacancy engineering emerges as a pioneering and effective approach for accelerating electrocatalytic activity in conventional metal oxide electrocatalysts and is recognized as a viable alternative to noble materials. In this study, a DC non-transferred arc thermal plasma torch is used to synthesize high entropy oxides (HEOs) (Ni, Co, Cr, Mn, Mo)3O4 nanoparticles under optimal operating conditions, and oxygen vacancies are created on the surface of the as-synthesized nanoparticles by treating them with Ar-glow discharge plasma. The oxygen vacancy-induced HEOs nanoparticles are characterized using various microscopic and spectroscopic techniques. The results reveal that increasing the Ar-plasma treatment time (0, 5, 10, 15 min) increases the surface oxygen vacancy. The electrochemical water-splitting performance of oxygen vacancy-induced HEOs nanoparticles is examined in 1 M KOH electrolyte solution employing them as an electrocatalyst. Oxygen vacancy rich HEOs nanoparticles demonstrate exceptional performance in both the oxygen evolution reaction (OER) and the hydrogen evolution reaction (HER), achieving an overpotential of 246 and 197 mV to achieve a current density of 50 mA cm−2. Eventually, a two-electrode device is fabricated, which requires a cell voltage of 1.58 V to achieve a current density of 10 mA cm−2. This work pioneers a revolutionary technique for surface engineering in metal oxides nanoparticles using plasma technology, achieving exceptional performance in water splitting.

Keywords: Oxygen vacancy; High entropy oxides; Thermal plasma technology; Electrocatalyst; Water splitting

Muhammad Faizan, Humaira Bibi, Erum Aamir, Roheen Saeed, Tiong Sieh Kiong, Hua Song,

Efficient chromium-based transition metal nitrides catalysts for oxygen and hydrogen evolution reactions,

Renewable and Sustainable Energy Reviews,

Volume 212,

2025,

115385,

ISSN 1364-0321,

https://doi.org/10.1016/j.rser.2025.115385.

(https://www.sciencedirect.com/science/article/pii/S1364032125000589)

Abstract: The abundance of hydrogen resources on Earth, their high gravimetric energy density, and their environmental benefits have collectively encouraged the adoption of hydrogen fuel as a clean alternative to fossil fuels. Due to these qualities, hydrogen fuel is emerging as a potential substitute for conventional fossil fuels in the global search for clean and sustainable energy alternatives. However, the creation of reliable, affordable, and effective electrocatalysts is necessary to achieve a sustainable hydrogen economy. This study methodically investigates recent developments and potential future directions in chromium-based transition metal nitrides (Cr-TMN), addressing the urgent need for durable electrocatalysts amidst the global energy crisis and environmental concerns. It carefully examines the production, properties, and electrochemical performance of these materials, particularly focusing on their potential to revolutionize energy storage and conversion technology. This review critically evaluates the global adoption of Cr-TMN, emphasizing their potential to mitigate environmental deterioration and play a crucial role in sustainable energy solutions. This research offer a solid foundation for further studies and policy decisions, underscoring the transformative potential of Cr-TMN in advancing cleaner and more sustainable energy solutions.

Keywords: Chromium; Cr-nitrides; Electrocatalysis; Water splitting; Green technology; Energy

Yu Wang, Yijun Jiang, Yangyang Yuan, Li Xu, Wanting Sun, Si Wu, Qingmiao Wang, Ning Hu, Li Wang,

Enhanced catalytic combustion of complex VOCs over Ru/Ni-HAP catalyst: Insights into the synergic effects of Ru and Ni species,

Journal of Alloys and Compounds,

Volume 1010,

2025,

177610,

ISSN 0925-8388,

https://doi.org/10.1016/j.jallcom.2024.177610.

(https://www.sciencedirect.com/science/article/pii/S0925838824041987)

Abstract: In this study, Ni was severed as a promoter and impregnated on hydroxyapatite (HAP) to prepare a Ni-doped HAP support, and then Ru was highly dispersed onto the Ni-HAP through urea precipitation method. The synergistic effects between Ru and Ni caused a reduction in the particle size of Ru nanoparticles and an increased Ru4+/Ru0 ratios, which was primarily attributed to the strong interaction between the active components and functional groups of OH- and PO43-. Meanwhile, Ru/Ni-HAP possessed the highest amount of medium-strength acid sites and relatively low reduction temperatures, indicating the critical balance between acidity and redox capability. Ru/Ni-HAP exhibited superior activity with complete conversion of toluene at 280 °C and DCM at 400 °C, respectively, and such high activity can be maintained throughout the stability tests. Besides, optimal catalytic performance was observed under 600 ppm concentrations of toluene and DCM with a space velocity of 40,000 ml(g·h)−1. These findings can provide valuable insights for the development of chlorine-resistant catalysts with promising application prospects.

Keywords: Hydroxyapatite; Ruthenium; Toluene; Dichloromethane; Catalytic oxidation

Evan Terrell, Farid Chejne-Janna, Raúl Pérez-Mena, Manuel Garcia-Perez,

Chapter 3 - Introduction to thermochemical reactors,

Editor(s): Manuel Garcia-Perez, Farid Chejne-Janna,

Thermochemical Conversion of Lignocellulosic Materials,

Elsevier,

2025,

Pages 73-123,

ISBN 9780323955515,

https://doi.org/10.1016/B978-0-323-95551-5.00003-4.

(https://www.sciencedirect.com/science/article/pii/B9780323955515000034)

Abstract: The history of humankind is interlinked with the use of fire. The myth of Prometheus documents the importance of fire mastering in human evolution. Prometheus stole fire from the Olympian Gods and gave it to humanity. Fire is the origin of technology, knowledge, and civilization. The charcoal produced from biomass carbonization was the first synthetic material produced by man. More than 38,000years ago, it was used to make magnificent drawings in the Grotte Chauvet a cave in southeastern France. Charcoal production was also an important ingredient in tin melting to manufacture bronze tools. Thermochemical processing uses heat to promote transformations into energy, fuels, and chemicals. Thermochemical reactors are designed in many different shapes and sizes, across various processing conditions, and they can handle different particle sizes to maximize targeted products. These reaction products include biochar, activated carbon, bio-oils and targeted liquid-phase products, synthetic natural gas or syngas, and heat for power production. Some dry thermochemical conversion technologies include combustion, gasification, pyrolysis, carbonization, and torrefaction. Wet thermochemical technologies include hydrothermal liquefaction, supercritical water gasification, and wet oxidation. Some of these technologies are also conducted in the presence of catalysts. In this chapter, we will discuss general concepts that can be used to analyze any thermochemical reactor.

Keywords: Thermochemical conversion technologies; Torrefaction; Fast and slow pyrolysis; Gasification; Combustion; Hydrothermal liquefaction; Solvolysis; Supercritical water gasification; Wet oxidation

N. Ch Ramgopal, Nipa Roy, Adel El-marghany, Salh Alhammadi, Gedi Sreedevi, Sai Kumar Arla, Dhananjaya Merum, Sang Woo Joo,

Enhancing photo electrocatalytic water splitting efficiency using Bi2O2CO3@Ni(OH)2 composite with flower-like morphology,

Ceramics International,

Volume 51, Issue 4,

2025,

Pages 4388-4399,

ISSN 0272-8842,

https://doi.org/10.1016/j.ceramint.2024.11.415.

(https://www.sciencedirect.com/science/article/pii/S0272884224055147)

Abstract: The rational design of semiconductor heterojunctions is pivotal in enhancing photoelectrochemical (PEC) water-splitting performance. In this study, we synthesized Bi2O2CO3 (BOC) nanosheets, Ni(OH)2 (NH) nanosheets, and their composite Bi2O2CO3@Ni(OH)2 (BOC-NH) separately using a hydrothermal process. The BOC-NH composite displays a distinct 3D flower-like structure with cross-linked petals of 21.82 nm, substantially enhancing the surface area and facilitating effective heterojunction formation between BOC and NH. This synergistic effect enhances charge separation and transport, leading to superior PEC water oxidation performance. The BOC-NH photoanode achieved a remarkable photocurrent density of 5.87 mA/cm2, 4.48 times higher than pure BOC and 1.75 times that of NH, along with a reduced onset potential of 0.464 V. Transient photocurrent measurements demonstrated excellent stability, while electrochemical impedance spectroscopy (EIS) revealed a significantly lower solution resistance (11.06 Ω), and charge transfer resistance (5.27 Ω) compared to the individual BOC and NH photoanodes. The applied bias photon-to-current efficiency (ABPE) of BOC, NH, and BOC-NH was 0.21 %, 0.36 %, and 0.58 %, respectively, with the composite showing the highest efficiency under light illumination. Long-term stability tests over 7200 s showed sustained photoactivity, with the photocurrent density rising from 0.26 to 0.53 mA/cm2, highlighting the durability of the composite. This work presents a robust strategy for improving PEC water splitting through heterojunction engineering and morphological optimization.

Keywords: Bi2O2CO3; Ni (OH)2; Flower-like; PEC water splitting; H2 production

Abdelhakim Elmhamdi, Maryam Khaleel,

Recent innovations in spinel oxide-based catalysts for CO2 hydrogenation to olefins,

Carbon Capture Science & Technology,

Volume 14,

2025,

100367,

ISSN 2772-6568,

https://doi.org/10.1016/j.ccst.2025.100367.

(https://www.sciencedirect.com/science/article/pii/S2772656825000077)

Abstract: With the increased urgency for reducing CO2 emissions, CO2 capture and hydrogenation into hydrocarbons stands out as a promising approach. This review highlights recent advancements in the evaluation of spinel oxide-based catalysts for CO2 hydrogenation into olefins, covering un-doped, doped, and bi-functional spinel oxide-based catalysts. The effect of catalyst composition and promotion on catalytic performance is thoroughly discussed. Among the various spinel oxides, Fe3O4 and K-ZnFe2O4 have shown promising performance, exhibiting 43 % and 46.7 % CO2 conversion, respectively, and 41.5 % and 68.9 % selectivity towards olefins, respectively. Bi-functional catalysts combining spinel oxides with SAPO-34 have shown enhanced olefins selectivity up to 87 % and low methane formation. Bi-functional zinc-based spinel catalysts were shown to outperform bi-functional magnesium-based spinel catalysts, due to their better ability to activate hydrogen and the balance between basicity and reducibility. However, despite improved olefins selectivity, CO2 conversion remains low (13–14 %), highlighting the need for further optimization. This review also provides a comprehensive analysis of the active sites responsible for catalysis, and the proposed mechanisms for CO2 hydrogenation. The mechanism of CO2 hydrogenation over spinel oxide catalysts is strongly influenced by the catalyst composition. The two main proposed pathways are: i) the redox mechanism (such as on ZnFe2O4), and ii) the formate mechanism (such as on ZnAl2O4/SAPO-34). In this review, challenges such as achieving higher CO2 conversion and olefins selectivity, enhancing catalyst stability, and understanding the underlying reaction mechanisms are discussed. Finally, future research opportunities, including enhanced catalyst design, exploring multi-component systems, developing underutilized promoters like cesium, and utilizing advanced in-situ characterization techniques and computational modeling, are proposed to advance the field of CO2 hydrogenation.

Keywords: CO2 conversion; Olefins; Spinel oxide-based catalysts; Bi-functional catalysts; Zeolite

Yunhao Zang, Xuetan Lin, Jiangying Qu, Feng Gao, Jianfeng Gu, Taipeng Wei, Rongrong Wang,

Modulation of CO2 hydrogenation selectivity through microstructural phase evolution-induced electronic transfer on Ni/TiO2,

Fuel,

Volume 385,

2025,

134151,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134151.

(https://www.sciencedirect.com/science/article/pii/S0016236124033027)

Abstract: Regulating the selectivity between CO and CH4 during CO2 hydrogenation is a challenging research topic. However, there is controversy surrounding whether anatase-phase TiO2-supported catalysts favor CO or CH4 production. The fundamental reason for the discrepancies in reported results, according to the authors of this study, lies in the varying purity of anatase-phase TiO2. Based on this, we constructed a catalyst consisting of anatase-phase TiO2 nanotubes loaded with Ni and subjected it to calcination/reduction treatments at different temperatures to induce surface phase evolution. The research findings revealed that Ni/TNTs-450, featuring pure anatase-phase TiO2, exhibited 100 % selectivity towards CO. In contrast, Ni/TNTs-600, which contained trace amounts of rutile phase, showed a decreased CO selectivity of 57.2 %. This can be attributed to the high-temperature calcination/reduction causing partial transformation of anatase surface microdomains into rutile, which in turn weakens the electron transfer between key intermediates m-HCOO\*/H3CO\* and Ni/TNTs-600, consequently reducing their strong affinity. This shift favors the reaction pathway from m-HCOO\*→H3CO\*→CH4, leading to the production of a significant amount of CH4.

Keywords: CO2 hydrogenation; Selective regulation mechanism; Ni/TiO2; Anatase; Rutile

Shashi Kant Bhatia, Anil Kumar Patel, Balasubramani Ravindran, Yung-Hun Yang,

Renewable bioenergy from palm oil mill effluent (POME): A sustainable solution for net-zero emissions in palm oil production,

Journal of Water Process Engineering,

Volume 70,

2025,

107136,

ISSN 2214-7144,

https://doi.org/10.1016/j.jwpe.2025.107136.

(https://www.sciencedirect.com/science/article/pii/S2214714425002089)

Abstract: Palm oil industries have an important role in economic development. The palm oil industry's wastewater known as palm oil mill effluent (POME), is high in organic content and poses a hazard to the environment. Valorisation of POME into bioenergy (methane, hythane, biohydrogen, biodiesel, and electricity) using microbial systems is an eco-friendly approach for its management and reduces greenhouse gas emissions. From the bibliometric analysis of highly cited articles, it can be concluded that POME to hythane conversion seems a more promising approach with >90 % chemical oxygen demand (COD) reduction and high energy yield. Despite the implementation of strategies like co-substrate utilisation, mixed culture, two-stage fermentation (to improve biohydrogen production), self-flocculating microbes (for biodiesel) to improve POME to bioenergy conversion, still, there is a research gap that limits the application of these technologies at industrial scale. POME to energy valorisation techniques are restricted to biogas production and there is not much research done on areas like biohydrogen and microbial fuel cells (MFC). Further with a lack of scale-up studies and technoeconomic analysis (TEA), currently it is not feasible to adopt POME to energy strategies. Future research should focus on improving the yield, integrating the palm oil industry with renewable energy, developing cost-effective scale-up technologies, and studying TEA and life cycle assessment (LCA) of the process. This POME to bioenergy approach is crucial for reducing the environmental footprint while contributing to global energy security and sustainability goals.

Keywords: Bioenergy; Biohydrogen; Hythane; Methane; Biodiesel; Electricity; Palm oil mill effluent; Valorisation

Mingqiang Hu, Yaling Mu, Hui Jin,

A bibliometric analysis of advances in CO2 reduction technology based on patents,

Applied Energy,

Volume 382,

2025,

125193,

ISSN 0306-2619,

https://doi.org/10.1016/j.apenergy.2024.125193.

(https://www.sciencedirect.com/science/article/pii/S0306261924025777)

Abstract: The conversion of CO2 into useful chemicals or fuels has the potential to reduce its concentration in the atmosphere, thereby mitigating the effects of climate change. On the other hand, CO2 represents a plentiful carbon resource that can be employed for the synthesis of chemicals, fuels, and other materials. In recent years, scholars in related fields have devoted considerable attention to CO2 reduction as an effective resource utilisation technology. Following an investigation into the relevant patents, it was determined that the majority of patents related to this field of study fall under the following categories: photocatalytic CO2 reduction technology, electrochemical CO2 reduction technology, thermochemical CO2 reduction technology, biological CO2 reduction technology, and the technology that combines various methods. The increasing number of patent publications reflects the advancement of CO₂ reduction methods in recent years. This paper analyses and summarises CO₂ reduction technologies through representative examples, and the results indicate that the preparation and research of catalytic materials represents the future mainstream trend of the aforementioned four reduction technology patents.

Keywords: Patent search; CO2 reduction technology; Catalytic materials; CO2 reduction method and device innovations

Sembinova Aigul, Enkhtuvshin Enkhbayar, Ashish Gaur, HyukSu Han,

Cr-doped tri-metallic nano prism catalyst for efficient alkaline and seawater splitting,

Journal of Crystal Growth,

Volume 649,

2025,

127928,

ISSN 0022-0248,

https://doi.org/10.1016/j.jcrysgro.2024.127928.

(https://www.sciencedirect.com/science/article/pii/S002202482400366X)

Abstract: Electrochemical water splitting is one of the most promising methods for sustainable production of green hydrogen. The oxygen evolution reaction (OER) is a crucial step in the process of water splitting. However, it exhibits sluggish kinetics and requires a significant overpotential for functioning at reasonable reactionrates. The efficiency of the reaction can be enhanced by reducing the overpotential, lowering the energy barrier, and using an effective electrocatalyst. Transition metal-basedcatalysts are well studied for this purpose. Specially, nickel–cobalt (Ni-Co) based catalysts have been regarded as the best OER electrocatalysts. Therefore, several studies have been carried out to enhance the electrocatalytic efficiency of Ni-Co catalysts. While mixing other transition metals with Ni-Co is a straightforward and reliable method to improve the OER activity of Ni-Co catalysts, there is still a need for a thorough examination of the design of Ni-Co catalysts with various additional elements. Seawater electrolysis, which utilizes abundant water resources that constitute over 97% of the world’s water, is highly appealing for sustainable energy production. To achieve commercial feasibility, scientists are striving to solve challenges, such as corrosion resistance, highoverpotential, and the need for efficient and durable electrocatalysts. In this study, we fabricated a transition metal-based trimetallic catalyst (CNF), consisting of cobalt (Co), nickel (Ni), and iron (Fe). Furthermore, CNF was doped with chromium (Cr-doped CNF) and tested for the OER in alkaline freshwater and alkaline seawater. Our Cr-doped trimetallic CNF catalyst demonstrates exceptional performance in both seawater and freshwater, with overpotential of 320 mV and 280 mV at 10 mA cm−2 current density, making it a promising candidate for large-scale, sustainable hydrogen production.

Keywords: Water splitting; Seawater oxidation; Electrocatalyst; Nano prism

Thanh Tuan Le, Akshay Jain, Ahmed Shabana El-Shafay, Bhaskor Jyoti Bora, Prabhakar Sharma, Xuan Phuong Nguyen, Xuan Quang Duong, Pedro Maireles Torres, Anh Tuan Hoang,

Comprehensive analysis of waste-to-hydrogen technologies integrated with circular economy principles: Potential and challenges,

International Journal of Hydrogen Energy,

2025,

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ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.048.

(https://www.sciencedirect.com/science/article/pii/S0360319925000527)

Abstract: The evolution to a sustainable and circular economy needs the development of innovative waste management and clean energy production technologies. This work looks into the concept of “waste-to-hydrogen (H2)” as a feasible solution to these challenges. It discusses how to use thermochemical, biochemical, and electrochemical technologies to convert various types of waste, like plastics waste, waste tires, biomass, municipal solid waste, metal waste, and wastewater into renewable H2, in which the advantages and drawbacks of waste-to-H2 technologies have been highlighted. In addition to the synergistic benefits that enhance the overall sustainability of the energy system, the study examines the challenges of H2 technology applications in waste, such as feedstock diversity, process efficiency, scalability, and economic development. It reviews existing waste-derived research and demonstration systems aiming to offer the current status of technology to H2 production and determines possible research and development prospects. The policy frameworks, market dynamics, and socioeconomic challenges are analyzed to establish potential advantages and barriers to widespread waste-to-H2 adoption. It is concluded that waste-to-H2 is a sustainable solution to build a circular economy by converting waste into clean and friendly H2 fuel. The promises and limitations outlined in this paper provide an inclusive assessment of the potential of dissipative H2 technologies and serve as a roadmap for further research and policy development in this area.

Keywords: Waste-to-energy concept; Clean energy; Hydrogen production; Greenhouse gas; Circular economy; Sustainable energy

Zhaoguang Chen, Yu Xie, Cheng Yi, Lingling Yao, Bo Li, Zhi Zhou, Wei Luo,

N-doped carbon carriers loaded with NiX (X = Fe, Co, Cu): Catalytic synergistic pyrolysis of herbal residues and polypropylene to generate three-phase products and carbon nanotubes,

Fuel,

Volume 381, Part C,

2025,

133548,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133548.

(https://www.sciencedirect.com/science/article/pii/S0016236124026978)

Abstract: Catalytic pyrolysis can transform organic solid waste into high-quality pyrolysis products, in which N-doped biochar is an efficient and economical catalyst. Herein, N-doped activated carbon (NAC) and modified biochar (NZC) loaded with bimetal NiX (X = Fe, Co, Cu) were used to catalyze the pyrolysis of Chinese medicinal drug residue and polypropylene in a two-stage reaction system to prepare three-phase products and carbon nanotubes. This indicates that the metal/NAC group catalysts possess a larger SBET, whereas the metal/NZC group has better thermal stability. Under NiCo/NZC catalysis, the abundant yield of short-chain carbon C6-C11(49 %) and aromatic hydrocarbons (39.5 %) suggests strong arylation and secondary cracking capabilities. N-doping improved the surface functional group richness of the catalyst, while the bimetal provided more active electrons, which promoted the generation of carbon nanotubes in the late stage of the pyrolysis process. N-doped carbon-based catalysts loaded with metals exhibit an improved catalytic effect, which is conducive to the promotion and application of N-doped catalysts.

Keywords: Catalytic co-pyrolysis; N-doped biochar; Pyrolysis products; Carbon nanotube

Fu Wei, Shuxun Sang, Shiqi Liu, Jing-Ping Zhao, Xiao-Yan Zhao, Jing-Pei Cao,

BECCS carbon-negative technologies based on biomass thermochemical conversion: A review of critical pathways and research advances,

Fuel,

Volume 390,

2025,

134743,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134743.

(https://www.sciencedirect.com/science/article/pii/S0016236125004673)

Abstract: Bioenergy with Carbon Capture and Storage/Utilization (BECCS/U) represents a promising carbon-negative technology critical for addressing global climate challenges and achieving carbon neutrality. Optimized biomass thermochemical conversion technologies integrated with Carbon Capture and Storage (CCS) can efficiently convert biomass into bio-based chemicals, liquid/gas fuels, and electricity, facilitating net negative carbon emissions. The review herein focused on four primary biomass thermochemical conversion processes, namely torrefaction, liquefaction, pyrolysis, and gasification, providing a systematic overview of their process reaction mechanisms, the distribution of reaction derivatives, the upgrading and conversion of primary volatiles. Emphasizing BECCS pathways, the review discussed technological options for integrating torrefaction, liquefaction, pyrolysis, and gasification with CCS, highlighting their process mechanisms, conversion targets, and technical potentials. It also surveyed the progress of thermochemical conversion coupled with CCS as a viable carbon-negative technology. Critical analyses examined the advantages and challenges of each approach, offering insights into future research directions and prospects. Overall, this comprehensive overview presented a technical roadmap and critical insights into biomass thermochemical conversion-based BECCS carbon-negative technologies, fostering advancements in sustainable energy solutions.

Keywords: BECCS; Thermochemical conversion; Torrefaction; Liquefaction; Pyrolysis; Gasification

Mohamed I. Fadlalla, Thulani M. Nyathi, Majid D. Farahani, Ying Zheng, Peter P. Wells, Holger B. Friedrich, Michael Claeys,

Performance of supported Co3O4 catalysts in the preferential oxidation of carbon monoxide: Effect of support type and synthesis method,

Journal of Catalysis,

Volume 442,

2025,

115777,

ISSN 0021-9517,

https://doi.org/10.1016/j.jcat.2024.115777.

(https://www.sciencedirect.com/science/article/pii/S0021951724004901)

Abstract: This study investigated the performance of supported Co3O4 catalysts during the preferential oxidation of carbon monoxide (CO-PrOx) in a H2-rich environment, focusing on the effects of different catalyst synthesis methods, namely, wetness impregnation (WI) and solution combustion synthesis (SCS), and different support materials, namely, Al2O3 and SiC. During CO-PrOx, the SiC-supported Co3O4 catalysts attained higher CO2 yields when compared with the Al2O3-supported Co3O4 catalysts possibly because of the existence of weaker interactions between Co3O4 and SiC. Moreover, the catalysts prepared via SCS achieved higher CO2 yields than the catalysts prepared via WI likely due to the presence of smaller and well-dispersed Co3O4 particles in the SCS-prepared catalysts. Significantly high amounts of unwanted CH4 were produced over the SiC-supported catalysts between 225 and 250 °C. The high CO methanation activity was also attributed to the weaker Co3O4-SiC interactions, which enabled the easier reduction of Co3O4 to methanation active metallic Co.

Keywords: CO-PrOx; Co3O4; Catalyst synthesis methods; Support type; CO2 and CH4 yields; Catalyst reduction

Nan Zheng, Jing Zhu, Haitao Zhu, Jin Xuan, Haoran Xu, Meng Ni,

Toward a circular carbon economy: Production of green C1 compounds through high-temperature CO2 electrolysis,

Nexus,

Volume 2, Issue 1,

2025,

100053,

ISSN 2950-1601,

https://doi.org/10.1016/j.ynexs.2024.100053.

(https://www.sciencedirect.com/science/article/pii/S2950160124000512)

Abstract: Summary

The electrochemical reduction of CO2 to value-added carbon-containing chemicals using solid oxide electrolysis cells presents a significant opportunity for mitigating carbon emissions and enabling a circular carbon economy. Within this context, single-carbon compounds are of particular interest due to their extensive applications as both chemical precursors and fuels. This review summarizes recent advancements in the conversion of CO2 to green methane and methanol through high-temperature electrolysis pathways. To enhance the efficiency and economic viability of this process, comprehensive system-level analysis has been conducted, focusing on system architecture, operational strategy refinement, and techno-economic assessment. The findings indicate that the integration of fluctuating renewable energy inputs can be effectively managed through strategic capacity allocation and energy management protocols. Additionally, modulating operational temperatures and the H2/CO ratio emerges as a promising, albeit challenging, approach to enhance product yields, given the complex kinetics of CO2 reduction. Furthermore, reducing the costs associated with electrolyzer fabrication and electricity consumption is identified as a pivotal factor for the commercial viability of this technology. There is a recognized need for further investigation into hydrogen-proton-conducting solid oxide electrolysis cells systems, particularly regarding the design of component assemblies and a more detailed techno-economic evaluation. Ultimately, this paper proposes a circular economy framework as an innovative solution to the resource challenges inherent in developing a sustainable, green infrastructure for the chemicals and energy sectors.

Keywords: CO2 electrolysis; methane synthesis; methanol synthesis; renewable energy storage; techno-economic evaluation

Mingxuan Zhong, Chenxuanzi Wang, Yongcheng Cai, Shuting Min, Yibo Guo, Bo Xiao, Tingting Xu, Xun Wang,

A novel photo-thermal chemical looping water splitting technology to achieve efficient and stable hydrogen production under mild condition,

Applied Energy,

Volume 381,

2025,

125186,

ISSN 0306-2619,

https://doi.org/10.1016/j.apenergy.2024.125186.

(https://www.sciencedirect.com/science/article/pii/S0306261924025704)

Abstract: The high operational temperatures constrain the practical application of chemical looping steam reforming coupled with water splitting (CLSR-WS) technology. Herein, we first propose a novel photo-thermal CLSR-WS technology to lower the temperature by introducing photothermal coupling catalysis. Under light irradiation, abundant oxygen vacancy (VO) generates on the surface of oxygen carriers (OCs), facilitating the migration of lattice oxygen and the adsorption of gaseous reactants during CLSR. This innovation results in an impressive H2 yield of 8.26 mmol/g OC with 98.14 % purity at 550 °C, comprehensively surpassing the traditional benchmark performance at 800 °C. The reduction of temperature leads to the enhancement in syngas yield and H2 purity, together with a cyclic stability. Co-Fe oxides are found as the suitable OCs for this new technology. Benefitting from the reduced energy of VO formation and bandgap, Co-Fe OCs could utilize the longer-wavelength light to generate VO. Our findings offer a pathway for overcoming the high-temperature bottleneck in CLSR-WS and achieving efficient and stable H2 production under moderate conditions.

Keywords: Photothermal coupling catalysis; Hydrogen production; Chemical looping process; Cyclic stability

Nevzat Yigit, Karin Föttinger, Johannes Bernardi, Günther Rupprechter,

Preferential CO oxidation (PROX) on LaCoO3–based catalysts: Effect of cobalt oxidation state on selectivity,

Journal of Catalysis,

Volume 443,

2025,

115973,

ISSN 0021-9517,

https://doi.org/10.1016/j.jcat.2025.115973.

(https://www.sciencedirect.com/science/article/pii/S0021951725000387)

Abstract: The perovskite LaCoO3 (LCO) was used as catalyst for preferential oxidation of CO (PROX). LCO was synthesized via the modified Pechini method and characterized by X-ray diffraction (XRD), high resolution transmission electron microscopy (HRTEM), and CO– and H2– temperature programmed reduction (TPR). Different reductive and oxidative pretreatments were applied to systematically vary the Co oxidation state in order to examine its effect on catalytic performance and to single out active site requirements. Upon reduction at increasing temperature, LaCoO3 transformed to brownmillerite-type La2Co2O5, exsolved Co0 nanoparticles supported on La2O3 and, upon reoxidation, to Co3O4/La2O3. The Co oxidation state of the various catalysts correlated with their CO2 selectivity: LCO containing only Co3+ exhibited 100 % CO2 selectivity in a wide temperature window, whereas La2Co2O5, Co/La2O3 and Co3O4/La2O3 had markedly lower selectivity. It is suggested that Co3+ is crucial and that the strong resistivity of LaCoO3 towards reduction is responsible for the high and stable CO2 selectivity over a temperature range of 100 °C–220 °C. Higher oxygen concentration further broadens the PROX window.

Keywords: Perovskite; Preferential Oxidation of CO; Brownmillerite; Exsolution; Co Oxidation State

Peter Kurzweil,

Electrochemical Devices | Fuel Cells,

Editor(s): Jürgen Garche,

Encyclopedia of Electrochemical Power Sources (Second Edition),

Elsevier,

2025,

Pages 301-321,

ISBN 9780323958226,

https://doi.org/10.1016/B978-0-323-96022-9.00026-8.

(https://www.sciencedirect.com/science/article/pii/B9780323960229000268)

Abstract: This overview article describes the basics of fuel cell technology. Designs, materials, thermodynamics, redox processes, reaction kinetics, performance data, efficiency, advantages, shortcomings, and operation modes of common and less familiar types are explained.

Keywords: AFC; DMFC; Fuel cells; MCFC; MEA; PAFC; PEFC; PEM; SOFC

Hanzi Liu, Ling Cen, Xinlin Xie, Lei Liu, Zhao Sun, Zhiqiang Sun,

Engineering nanoparticle structure at synergistic Ru-Na interface for integrated CO2 capture and hydrogenation,

Journal of Energy Chemistry,

Volume 100,

2025,

Pages 779-791,

ISSN 2095-4956,

https://doi.org/10.1016/j.jechem.2024.09.025.

(https://www.sciencedirect.com/science/article/pii/S209549562400648X)

Abstract: The development of dual functional material for cyclic CO2 capture and hydrogenation is of great significance for converting diluted CO2 into valuable fuels, but suffers from kinetic limitation and deactivation of adsorbent and catalyst. Herein, we engineered a series of RuNa/γ-Al2O3 materials, varying the size of ruthenium from single atoms to clusters/nanoparticles. The coordination environment and structure sensitivity of ruthenium were quantitatively investigated at atomic scale. Our findings reveal that the reduced Ru nanoparticles, approximately 7.1 nm in diameter with a Ru-Ru coordination number of 5.9, exhibit high methane formation activity and selectivity at 340 °C. The Ru-Na interfacial sites facilitate CO2 migration through a deoxygenation pathway, involving carbonate dissociation, carbonyl formation, and hydrogenation. In-situ experiments and theoretical calculations show that stable carbonyl intermediates on metallic Ru nanoparticles facilitate heterolytic C–O scission and C–H bonding, significantly lowering the energy barrier for activating stored CO2.

Keywords: CO2 capture; Hydrogenation; Ru-Na interface; Dual functional material; Reaction mechanism

Godknows Dziva, Jonas Weitzel, Pengjun Cui, Maxine Yew, Guangchao Ding, Liang Zeng, Songgeng Li,

Low-carbon, hydrogen-rich syngas from sorption-enhanced gasification: A review,

Carbon Capture Science & Technology,

Volume 14,

2025,

100372,

ISSN 2772-6568,

https://doi.org/10.1016/j.ccst.2025.100372.

(https://www.sciencedirect.com/science/article/pii/S2772656825000120)

Abstract: This review aims to provide a comprehensive overview of sorption-enhanced gasification (SEG) with CaO, highlighting its potential as an efficient and sustainable energy conversion technology. SEG integrates dual bed steam gasification with in situ CO2 removal using CaO, efficiently converting solid carbonaceous fuels such as biomass and low-rank coal into hydrogen-rich (up to 80 vol% H2), low-carbon and tar, medium calorific value and nitrogen-free syngas that can be adapted for various downstream applications. The review details the working principle, operating conditions and reaction mechanisms of SEG, emphasizing how these factors influence product distribution. Calcium sorbents are central to the SEG process, so their reactions, catalytic activity and limitations are discussed in this review. Pilot-scale tests are examined to underscore process engineering advancements as well as to highlight scale-up challenges that currently limit the technology to TRL 5–6. Unsustainable long-term sorbent performance and energy penalties from sorbent regeneration and CO2 capture still need to be addressed through scalable and cost-effective material development and process engineering. This review discusses various process intensification concepts as potential solutions to the inherent shortcomings of SEG. Process systems analyses examined indicate the potential of SEG in hydrogen, synthetic fuel and electricity production, positioning it as a promising technology for decentralized sustainable energy conversion. Furthermore, the review explores the sustainable repurposing and disposal of spent solids to foster circular economies. Overall, this comprehensive review provides crucial insights to further leverage and advance the SEG process, offering a platform for future research and development.

Keywords: Dual fluidized bed; Calcium looping; Carbon capture; Hydrogen; Gasification

Henrique Gasparetto, Patricia Concepción, Nina Paula Gonçalves Salau,

A Gibbs free energy minimization thermodynamic analysis for decoding diverse carbon deposits and in-situ water removal in CO2 hydrogenation,

International Journal of Hydrogen Energy,

Volume 105,

2025,

Pages 719-734,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.334.

(https://www.sciencedirect.com/science/article/pii/S0360319925003763)

Abstract: CO2 hydrogenation is an innovative approach to mitigate climate change by converting this greenhouse gas into synthetic methane. Thermodynamic analysis facilitates the establishment of operational parameters before experimental studies. Some investigations have erroneously characterized coke deposits solely as graphite carbon, resulting in inaccurate assessments of reaction conditions. This study provides a detailed thermodynamic analysis of CO2 hydrogenation through Gibbs free energy minimization, employing representations of the solid phase encompassing amorphous, graphite, and nanotube carbon structures. The findings underscore the propensity for carbon deposition at atmospheric pressure, particularly evident at H2/CO2 ratios below 4 and temperatures below 700 °C. This is characterized by a distinct progression from amorphous structures (∼100–300 °C) to graphite forms (250–450 °C), culminating in the emergence of carbon nanotube species (400–700 °C). Elevating the pressure prompts a shift in carbon nanotube production towards higher temperatures (until 900 °C for 20 bar). Under conditions where the H2/CO2 ratio is set at 4 and the pressure is maintained at 20 bar, the attainment of both coke and CO-free CO2 hydrogenation is feasible at operational temperatures below 400 °C. At the CO2 hydrogenation stoichiometric ratio, the in-situ water sorption-enhanced systems can reach up to 100% conversion, although it increases coke formation. An accompanying open-source and extensible MATLAB code for calculating conversion and selectivity is also provided.

Keywords: CO2 methanation; Graphite; Amorphous; Nanotubes

Gang Li, Yongpeng Jin, Qunyan Tan, Zhenwei Yan, Mingqi Tang, Zaiqiang Feng,

In-situ development of highly active Ni-Cu-P@Co-Se as active and stable electrode for energy-saving hydrogen production and urea oxidation reaction,

Materials Science and Engineering: B,

Volume 313,

2025,

117883,

ISSN 0921-5107,

https://doi.org/10.1016/j.mseb.2024.117883.

(https://www.sciencedirect.com/science/article/pii/S0921510724007128)

Abstract: Here, a simple two-step method for synthesizing of unique, active and stable Ni-Cu-P@Co-Se electrocatalyst is introduced. The fabricated electrode demonstrated favorable performance in application as electrocatalyst for hydrogen evolution reaction (HER) processes. When the current density increased from 5 to 10 mA.cm−2, the η10 decreased from 157 to 94 mV which indicated 40 % improvement in catalytic activity. In addition, the deposited electrode at 10 mA.cm−2 demonstrated best UOR performance which needed only 1.323 V vs RHE at 10 mA.cm−2, due to having high electrochemical active area, interfacial engineering, and the optimized interaction between the electrode and the electrolyte. When the Ni-Cu-P@Co-Se electrode was used as a bi-functional electrode in the urea electrolysis process, the cell potential value was 1.413 V. The synthesized electrode presented slight changes in overpotential during stability test. This work introduces an economical and effective method for the synthesis of active electrodes in energy-saving hydrogen production systems.

Keywords: Hydrogen evolution reaction; Urea oxidation reaction; Renewable energy; Phosphide-based nano coatings

Suniti Shrestha, Samvid Parajuli, Shiva Gorjian, Susana Rodriguez-Couto, Michael J. Angove, Bandita Mainali, Shukra Raj Paudel,

Scenario based techno-economic study of surplus hydropower-based urea production from cement plant flue-gas captured using piperazine-absorption,

Energy,

Volume 315,

2025,

134463,

ISSN 0360-5442,

https://doi.org/10.1016/j.energy.2025.134463.

(https://www.sciencedirect.com/science/article/pii/S0360544225001057)

Abstract: This study seeks to assess the viability of a surplus hydropower-driven urea production plant incorporating a novel piperazine-absorption-based carbon capture system from cement plant flue gas in Nepal. It includes a formally unexplored comprehensive technological review, economic analysis, and sensitivity analysis, proposing an optimized pathway to alleviate the government's annual liability of 65.68 million USD from urea subsidies. The capital cost for the 500-ton capacity plant is 155.77 million USD, with hydrogen and urea units contributing 34.00 % and 32.22 %, respectively, and an annual operating cost of 78.90 million USD. The calculated levelized cost of urea is 513.74 USD per ton, demonstrating sensitivity to electricity costs, breaking even below 0.04 USD per kilowatt-hour energy. This allows for annual urea production up to 12,725.93 kilotons while achieving a significant 81.14 % reduction in global warming potential compared to conventional synthesis (0.46 kg CO2 equivalent per kg of urea produced). This approach, presenting a competitive and streamlined alternative, addresses gaps in previous literature. Additionally, the study, for the first time, explores urea production potential in four energy-demand scenarios, offering insights to shape government frameworks for optimizing the food-energy nexus, supporting global energy transition goals, promoting circular economy in Nepal, and guiding similar resource settings in developing economies.

Keywords: Techno-economic analysis; Circular economy; Surplus hydropower & green hydrogen; Carbon capture; Levelized cost; Urea

Xiaolong Bao, Xinyu Wei, Yi Zhang, Liang Chen, Boyan Dai, Xiaoyu Zhou, Qin Zhong, Hongxia Qu,

Regulation of V for the phase transition of NiO to Ni0 to effectively boost hydrogen evolution reaction activity in electrocatalytic water splitting,

International Journal of Hydrogen Energy,

Volume 109,

2025,

Pages 1412-1420,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.02.206.

(https://www.sciencedirect.com/science/article/pii/S0360319925007724)

Abstract: Electrolysis of water to produce hydrogen is a key step in the preparation of green hydrogen. However, the low activity of electrocatalysts and the aggregation and dissolution of active substances limit industrial applications. Here, we report that a self-supporting core-shell structed V–NiO@C for HER was constructed by pyrolysis of NiV- MOF. Compared to non-V-doped, the Vanadium (V) could regulate the electrochemical environment of Ni, forming a new phase transition from NiO to Ni0 during the electrochemical reaction process. The in situ generated Ni0 from NiO improves the adsorption of H∗ intermediate, improving the intrinsic activity, showing excellent performance with a small overpotential of 17 mV at 10 mA cm−2. Meanwhile, thin oxygen-containing carbon layer could effectively reduce resistance, improve stability and limit the formation of high levels of Ni0. Particularly, the carbon layer working together with V could inhibit the dissolution of Ni during the HER process. And the catalyst has bright future for industrial applications due to the overpotential of 204 mV at 400 mA cm−2. In addition, the coupled HER and UOR electrolyzer using this catalyst could drive a current density of 10 mA cm−2 at 1.5 V. This work provides new ideas for the electrocatalysts based on transition metal oxides in industrial catalysis applications.

Keywords: V-doped; Carbon layer; Hydrogen evolution reaction; Phase transition; TMOx

Peeyush Phogat, Bhawana Chand, Shreya, Ranjana Jha, Sukhvir Singh,

Hydrogen and methanol fuel cells: A comprehensive analysis of challenges, advances, and future prospects in clean energy,

International Journal of Hydrogen Energy,

Volume 109,

2025,

Pages 465-485,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.02.133.

(https://www.sciencedirect.com/science/article/pii/S0360319925006998)

Abstract: Fuel cells are potential electrochemical devices capable of directly converting chemical energy into electrical power, providing a clean and efficient alternative to fossil fuel-based systems. Among these, hydrogen and methanol fuel cells represent two significant approaches to address global energy challenges, each with unique advantages and limitations. This study offers an extensive analysis of the operational principles, technological advancements, and applications of hydrogen and methanol fuel cells, emphasizing their relevance in the transition to sustainable energy systems. Hydrogen fuel cells, known for their high efficiency and zero-emission operation, are ideal for automotive and stationary power applications. In contrast, methanol fuel cells, despite producing carbon dioxide (CO₂) as a by-product, are valued for their ease of fuel handling, storage, and portability, making them suitable for niche applications such as portable power and remote operations. By comparing a cell that produces CO₂ with one that does not, this study highlights the trade-offs between environmental impact and practical utility, providing a nuanced perspective on their respective roles in diverse sectors. Key challenges, including the high cost of catalysts, issues related to methanol crossover, hydrogen storage limitations, and the lack of widespread refueling infrastructure, are critically examined. In the present study, relevance of ongoing research in addressing these challenges is discussed, focusing on advancements such as non-precious metal catalysts, novel membrane materials, and the production of green hydrogen through renewable energy sources. The potential of hybrid systems and alternative fuels like ammonia is also explored to expand the versatility of fuel cell technologies. This review justifies the comparative analysis by demonstrating how each fuel cell type fulfils distinct energy needs while identifying areas where their performance and sustainability can be enhanced. The insights presented in this study aim to inform researchers, policymakers, and industry stakeholders, positioning fuel cells as a cornerstone of the renewable energy transition. As hydrogen and methanol fuel cell technologies evolve, they are poised to play complementary roles in reducing carbon emissions and meeting the world's growing energy demands sustainably.

Keywords: Hydrogen fuel cells; Methanol fuel cells; Electrochemical devices; Renewable energy; Fuel crossover; Hybrid systems

Md. Ariful Islam, Aditta Chowdhury, Israt Jahan, Omar Farrok,

Mitigation of environmental impacts and challenges during hydrogen production,

Bioresource Technology,

Volume 415,

2025,

131666,

ISSN 0960-8524,

https://doi.org/10.1016/j.biortech.2024.131666.

(https://www.sciencedirect.com/science/article/pii/S0960852424013701)

Abstract: This paper presents hydrogen production methodologies, their impacts on the environment, and mitigation. Three different types of production procedures, namely fossil fuel-based, renewable energy-based, and biological, are presented along with their key technological characteristics and environmental feasibility. The effects of greenhouse gas emissions from its production on different natural cycles are carried out to show the environmental impact. Different production methods, problem identification, and mitigation of environmental impacts are separately pointed out. Analyses are shown for available methods in terms of their production cost, efficiency, maturity level, advantages, problems, and solutions. A comparative analysis is carried out along with different existing methods to find a suitable H2 production method. Finally, the transition pathway from fossil fuel to biohydrogen production is intended to promote biohydrogen for transportation and industrial applications. It demonstrates the possibility and potentiality of biohydrogen production for a sustainable future.

Keywords: Biohydrogen; Biological hydrogen production; Fossil fuel-based hydrogen production; Hydrogen production; Natural cycle; Renewable energy-based hydrogen production

Z. Qi,

Fuel Cells – Polymer-Electrolyte Membrane Fuel Cell | Systems,

Editor(s): Jürgen Garche,

Encyclopedia of Electrochemical Power Sources (Second Edition),

Elsevier,

2025,

Pages 339-351,

ISBN 9780323958226,

https://doi.org/10.1016/B978-0-323-96022-9.00013-X.

(https://www.sciencedirect.com/science/article/pii/B978032396022900013X)

Abstract: The unique features of a proton-exchange membrane fuel cell system are described. The architecture of a system that involves hydrocarbon fuel reforming is outlined. Key modules and their functions in the system are explained. Cautions and suggestions for designing and operating a fuel cell system are presented. Major challenges are discussed.

Keywords: Fuel cell; PEMFC system; Proton-exchange membrane; Reformer; Stack

Tenzin Dawa, Maria Paula Silva Martinez, Baharak Sajjadi,

Enhanced Production of Hydrogen through Modified Brownmillerite Ca2Fe2-xMxO5 (M: Co, Cu, Ni) for Chemical Looping Gasification,

Fuel,

Volume 390,

2025,

134490,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2025.134490.

(https://www.sciencedirect.com/science/article/pii/S0016236125002145)

Abstract: Chemical looping (CL) technology presents a potential avenue for producing high-purity hydrogen while inherently separating CO2. A critical challenge lies in identifying oxygen carriers with high performance and sustained activity across multiple redox cycles. This study investigates the influence of metal doping (Co, Cu, Ni) on the performance of brownmillerite-structured Ca2Fe2-xMxO5 for biomass conversion to high purity hydrogen in absence (pyrolysis) and presence of steam injection (gasification). Catalytic oxygen carriers, including Ca2Fe2O5, Ca2Fe1.9Cu0.1O5, Ca2Fe1.9Ni0.1O5 and Ca2Fe1.9Co0.1O5 were synthesized via a citric acid-assisted sol–gel method and tested in a fixed-bed reactor. The study systematically examined the effects of temperature, steam injection rate (steam/biomass ratio), and catalysts on biomass conversion. An optimal steam injection rate of 0.1 mL/min with Ca2Fe1.9Ni0.1O5 significantly enhanced hydrogen yield by 82.4 % compared to the undoped carrier. Increasing temperature consistently improved H2 yield throughout the conversion. Notably, doping with Ni and Co significantly increased H2 yield from 27.82 g/mol biomass (undoped) to 33.15 g/mol biomass (Ni) and 32.05 g/mol biomass (Co), respectively. Although Ca2Fe2O5 perfmormed better in absence of steam, the activity of the synthsised catalyst in terms of H2 prodction in presence of steam were as follows; Ca2Fe1.9Ni0.1O5 > Ca2Fe1.9Co0.1O5 > Ca2Fe2O5 > Ca2Fe1.9Cu0.1O5. Moreover, Ca2Fe1.9Ni0.1O5 reached a maximum hydrogen purity of 76 % at 750 °C.

Keywords: Chemical looping gasification; Hydrogen; Ca2Fe2O5; Doping; Co, Cu, Ni

Ahmad Naquash, Zeeshan Hameed, Muhammad Abdul Qyyum, Zakir Khan, Ala’a H. Al-Muhtaseb, Amjad Riaz, Moonyong Lee,

Biohydrogen and biomethane production from biomass gasification: Compositional analysis, recent advancements, challenges, and prospects,

Process Safety and Environmental Protection,

Volume 194,

2025,

Pages 1526-1537,

ISSN 0957-5820,

https://doi.org/10.1016/j.psep.2024.12.029.

(https://www.sciencedirect.com/science/article/pii/S0957582024015866)

Abstract: Renewable fuels such as biohydrogen and biomethane are vital in reducing greenhouse gas emissions and fulfilling energy demands. These biofuels are the main products of the biomass gasification process. Review studies have shown a large number of experimental works performed in recent years to enhance biohydrogen and biomethane production process performance. A few process systems engineering-based reviews have also been published, mainly focusing on production technologies. However, detailed literature review assessments of biohydrogen and biomethane production from biomass gasification, considering both experimental and process systems engineering studies, are not available in the open literature. Here, we investigated biohydrogen and biomethane-focused experimental works and process systems engineering studies considering feed and product specifications, process parameters, and process performances. Additionally, the factors influencing the composition of biohydrogen and biomethane, including pressure, temperature, and gasifying agents, are also discussed. The results show that biomass gasification using water at super-critical conditions improves the biohydrogen and biomethane composition in the product gas. Experimental studies indicate that wood-based biomass sources produce biohydrogen (∼82 vol%) and biomethane (∼10 vol%) rich syngas. The process systems engineering studies indicate energy efficiency (∼67 %) in gasification processes, suggesting further improvement potentials. Integrating other processes and employing a feedstock mix can improve gasification process efficiency. This study can help develop a sustainable, cost-effective, environmentally benign, and energy-efficient biomass gasification process.

Keywords: Biomass gasification; Biohydrogen production; Biomethane production; Compositional analysis; Techno-economic challenges; Process systems engineering assessment

Fanrui Meng, Chenxi Gu, Hui Jin, Liejin Guo,

Hydrogen production for the synergistic catalytic of modified-titanium dioxide supported nickel catalyst with potassium carbonate catalyst by supercritical water gasification of coal,

International Journal of Hydrogen Energy,

Volume 97,

2025,

Pages 1025-1040,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.11.398.

(https://www.sciencedirect.com/science/article/pii/S0360319924050948)

Abstract: Supercritical water gasification (SCWG) is a novel energy utilization technology for converting coal into hydrogen (H2)-rich gas products. Constructing a synergistic catalytic system is crucial for the enhanced production of H2 in the SCWG of coal. This work constructed a novel synergistic catalytic system, Mo, Co, and Cu were employed to modify titanium dioxide-supported nickel (Ni/TiO2) catalysts which were added to separate reaction zones independent with potassium carbonate (K2CO3) to exhibit synergistic effects, thereby enhancing H2 yield. The modification of Ni/TiO2 can improve the stability of the catalyst by causing lattice shrinkage of TiO2, and the synergistic catalytic system exerted much higher carbon gasification efficiency (CGE) and H2 yield than the non-catalytic condition in this way. Among all the Ni/TiO2 catalysts, synergistic Ni–Cu/TiO2 with K2CO3, which has the smallest Ni particle size, maximized the CGE and H2 yield from 30.82% to 15.48 mol kg−1 to 95.43% and 81.42 mol kg−1, respectively. The synergistic catalytic mechanism was further revealed, providing theoretical support for the regulation of hydrogen production from SCWG of coal.

Keywords: Supercritical water gasification; Coal; Hydrogen; Synergistic catalytic; Modified titanium dioxide supported nickel catalysts

Dan Ping, Yapeng Li, Shide Wu, Zhiqiang Zhang, Weitao Liu, Dingsheng Wang, Shuqing Liu, Shiwen Wang, Xuzhao Yang, Guanglu Han, Junfeng Tian, Dongjie Guo, Huajun Qiu, Shaoming Fang,

Designing cobalt–nickel dual-atoms on boron, nitrogen-codoped carbon nanotubes for carbon dioxide electroreduction to syngas,

Journal of Colloid and Interface Science,

Volume 683, Part 1,

2025,

Pages 446-456,

ISSN 0021-9797,

https://doi.org/10.1016/j.jcis.2024.12.096.

(https://www.sciencedirect.com/science/article/pii/S0021979724029503)

Abstract: Developing highly efficient electrocatalysts to produce syngas with a stable hydrogen/carbon monoxide (H2/CO) ratio in a wide potential window via electrochemical carbon dioxide (CO2) reduction is desperately required but still challenging. Herein, a dual-atomic site on boron, nitrogen-codoped carbon nanotubes (BCN) has been designed, containing both cobalt (CoN5) and nickel (NiN3B2) sites. Benefiting from the structure advantage and the bifunctional Co/Ni sites, such designed catalyst (CoNi-BCN) demonstrates remarkable performance for syngas production, achieving a stable H2/CO ratio of 1.5 over a broad potential window from −0.47 to −0.87 V vs. RHE. By tuning the Co/Ni molar ratio in CoNi-BCN, the H2/CO ratio can be adjusted from 0.5 to 2. In addition, this electrocatalyst exhibits outstanding stability within a long-term 20 h electrolyzing. Both experimental and theoretical calculation results confirm the primary role of the Co sites in H2 production and the Ni sites in CO production, as well as the preferred process for H2 evolution. This work provides a strategy in the construction of dual-site catalysts for efficient syngas production, which is significant for practical applications.

Keywords: Dual-atomic site; Electrocatalysts; CO2 reduction; Syngas; Stable H2/CO ratio

Jiacheng Bao, Xin Sun, Ping Ning, Kai Li, Jie Yang, Fei Wang, Lei Shi, Maohong Fan,

Industrial solid wastes to environmental protection materials for removal of gaseous pollutants: A review,

Green Energy & Environment,

Volume 10, Issue 1,

2025,

Pages 34-83,

ISSN 2468-0257,

https://doi.org/10.1016/j.gee.2024.01.006.

(https://www.sciencedirect.com/science/article/pii/S2468025724000177)

Abstract: The application of industrial solid wastes as environmentally functional materials for air pollutants control has gained much attention in recent years due to its potential to reduce air pollution in a cost-effective manner. In this review, we investigate the development of industrial-waste-based functional materials for various gas pollutant removal and consider the relevant reaction mechanism according to different types of industrial solid waste. We see a recent effort towards achieving high-performance environmental functional materials via chemical or physical modification, in which the active components, pore size, and phase structure can be altered. The review will discuss the potential of using industrial solid wastes, these modified materials, or synthesized materials from raw waste precursors for the removal of air pollutants, including SO2, NOx, Hg0, H2S, VOCs, and CO2. The challenges still need to be addressed to realize this potential and the prospects for future research fully. The suggestions for future directions include determining the optimal composition of these materials, calculating the real reaction rate and turnover frequency, developing effective treatment methods, and establishing chemical component databases of raw industrial solid waste for catalysts/adsorbent preparation.

Keywords: Industrial solid waste; Reaction mechanism; Modification method; Air pollutants

Muhammad Zubair Shahid, Ahmad Salam Farooqi, Kevin Fajri, Mohammed El-Adawy, Mohamed Hamdy, Abid Salam Farooqi, Omar Y. Abdelaziz, Mohammad Mozahar Hossain, Medhat A. Nemitallah,

Clean hydrogen production via sorption enhanced water gas shift reaction: A comprehensive review,

International Journal of Hydrogen Energy,

Volume 100,

2025,

Pages 1483-1512,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.400.

(https://www.sciencedirect.com/science/article/pii/S0360319924056131)

Abstract: The development of efficient and economical technology for clean hydrogen production is a significant research challenge to secure future clean energy demands. In this context, the sorption-enhanced water gas shift (SEWGS) process, identified as a potential approach to in-situ CO2 capture and enhancing CO conversion to increase H2 yield. However, the commercial development of the SEWGS process faces technical challenges, primarliy in ensuring the stability and efficiency of sorbent-catalyst systems and optimizing reactor and process design for economic feasibility. This comprehensive review thoroughly explores the fundamental concepts of WGS and SEWGS systems, recent advancements in the development of sorbents, sorbent-catalyst bifunctional materials and advanced reactor designs critical to the SEWGS process. The review also discusses the kinetics and thermodynamics of WGS and SEWGS systems, the development of magnesium and hydrotalcite-based sorbents and bifunctional materials tailored for SEWGS system. Additionally, the review explores modelling aspects including density functional theory (DFT), computational fluid dynamics (CFD) and the design and modelling of advanced reactors. A brief economic assessment of the sorption enhanced processes (SEP) is also presented, emphasizing its potential and technical challenges that must be addressed for commercialization.

Keywords: Clean hydrogen production; Sorption enhanced water gas shift (SEWGS); Carbon capture and storage (CCS); Sorbent–catalyst systems; Magnesium-based sorbents; Hydrotalcite-based sorbents

Farooq Sher, Saman Hameed, Narcisa Smječanin Omerbegović, Alexander Chupin, Irfan Ul Hai, Bohong Wang, Yew Heng Teoh, Magdalena Joka Yildiz,

Cutting-edge biomass gasification technologies for renewable energy generation and achieving net zero emissions,

Energy Conversion and Management,

Volume 323, Part A,

2025,

119213,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119213.

(https://www.sciencedirect.com/science/article/pii/S0196890424011543)

Abstract: Biomass gasification is a significant technology for the production of bioenergy. A deeper understanding of biomass gasification is crucial, especially regarding its role in bioenergy carbon capture and storage and its contribution to achieving net-zero emissions. This novel review encompasses gasification processes, novel design technologies, advanced syngas cleaning strategies, scalability challenges, techno-economic analysis, societal and environmental aspects of biomass gasification for achieving net-zero emissions. Biomass gasification typically occurs within temperatures (500 to 1000 °C), pressures (0.98 to 2.94 atm), S/B (0.3–1), residence time (few minutes), moisture content (below 35%) and with or without the presence of a catalyst. It is found that optimizing the gasification key parameters significantly reduces impurities content. Gasifier design affects tar content significantly: updraft gasifiers produce the most tar (about 100 g/Nm3), downdraft gasifiers the least (around 1 g/Nm3) and fluidized-bed gasifiers have intermediate levels (around 10 g/Nm3). Physical-mechanical methods achieve 99% efficiency but reduce energy conversion and generate hazardous waste. Thermal and catalytic cracking methods offer up to 98–100% efficiency, with nickel-based catalysts being highly effective. Biomass gasification has attained a Technology Readiness Level (TRL) of 8–9, demonstrating its feasibility for large-scale implementation. However, it incurs a 15% cost increase and requires additional advancements to address technical and economic challenges. Furthermore, converting syngas into valuable products is vital for achieving negative GHG emissions. Continued research is essential to enhance the overall efficacy of the gasification process. Developing innovative approaches that efficiently valorize all gasification by-products is crucial for enabling widespread adoption in the global market.

Keywords: Renewable energy; Syngas cleaning strategies; Emissions; Sustainable; Biomass gasification; Syngas and Net Zero

Zhiheng Ye, Jijing Zhao, Jiayi Zheng, Ziyi Xu, Hongyu Hu, Wenhan Li, Zhong-Ting Hu, Junliang Wang, Zhiyan Pan, Mian Hu,

Surface oxygen vacancy regulation and active metal doping for Cu-Al based spinel catalysts synthesis toward high-efficiency reverse water-gas shift reaction,

Catalysis Today,

Volume 443,

2025,

114968,

ISSN 0920-5861,

https://doi.org/10.1016/j.cattod.2024.114968.

(https://www.sciencedirect.com/science/article/pii/S0920586124004620)

Abstract: The reverse water-gas shift (RWGS) reaction is of great significance to convert CO2 to valuable feedstocks. Reasonable design and preparation of catalysts is necessary to achieve high CO2 conversion and CO selectivity. In this study, a series of Cu-Al based spinel catalysts were synthesized by coprecipitation-calcination method or A-site doped with active metal (Co, Zn, Mg, and Fe) for the RWGS reaction. The results indicated that the surface oxygen vacancies and crystal structure of CuAl2O4 can be regulated by calcination temperature. Remarkably, the CuAl-800 catalyst exhibits the highest CO2 conversion rate (62.7 %) with 100 % CO selectivity at 500 °C. Excessive calcination temperatures (> 800 °C) resulted in a well-defined spinel structure, but decreased surface oxygen vacancies and CO2 conversion rate. At calcination temperatures < 800 °C, surface oxygen vacancies increased, but the formation of CuO impurities which irreversibly converted to Cu2O during reduction, decreased catalytic activity. Compared with Zn, Mg and Fe, Co doping can significantly improved the reactivity of CuAl2O4 catalyst in RWGS reaction at 500 °C, increasing the CO2 conversion rate by 8 % while maintaining 100 % CO selectivity. The main reason is that Co doping not only effectively improves the integrity and stability of spinel structure of CuAl2O4, but also enhances its ability to dissociate and activate H species through interfacial sites of CuO-OV-CuXCo1-XAl2O4, thus further enhancing its catalytic conversion ability of CO2 to CO. These results enrich the understanding of surface chemistry of CuAl2O4 spinel and lay an important theory foundation for design of spinel-based catalysts for RWGS reaction.

Keywords: Surface oxygen vacancy regulation; Active metal doping; Cu-Al based spinel catalyst; Reverse water-gas shift reaction; CO selectivity

Ngoc N. Nguyen, Anh V. Nguyen, Muxina Konarova,

Converting rice husk biomass into value-added materials for low-carbon economies: Current progress and prospect toward more sustainable practices,

Journal of Environmental Chemical Engineering,

Volume 13, Issue 2,

2025,

115499,

ISSN 2213-3437,

https://doi.org/10.1016/j.jece.2025.115499.

(https://www.sciencedirect.com/science/article/pii/S2213343725001940)

Abstract: The abundant rice husk agrowaste possesses a silicon-rich composition in the form of natural biogenic silicon/carbon blend. This unique property of rice husk (RH) enables the preparation of nanohybrid materials with particular properties which are otherwise difficult to achieve via synthetic means. RH-derived nanostructured materials show promising applications in low-carbon economies such as heterogeneous catalysts for hydrogen generation and decarbonisation, battery anodes, supercapacitors, drug carriers, quantum dots, solar grade silicon, and adsorbents. Here, we discuss the latest advances in converting RH into such value-added materials and highlight the drawbacks of the current methods which are unsustainable due to high consumptions of energy and harsh chemicals. We elaborate a distinctive forward-looking perspective on the transition toward more sustainable practices via enzymatic processing, microwave- or ultrasound-assisted conversion, and the use of eco-friendly chemicals, for more energy- and cost-efficient productions of RH-derived products. Insights provided by this paper promote the progress in agrowaste recycling toward a circular decarbonised world.

Keywords: Biomass conversion; Circular economy; Waste recycling; Energy materials; Rice husk; Agrowaste; Hydrogen generation

Orlando Palone, Luca Cedola, Franco Rispoli, Domenico Borello,

Municipal solid waste thermochemical conversion to substitute natural gas: Comparative techno-economic analysis between updraft gasification and chemical looping,

Energy Conversion and Management,

Volume 324,

2025,

119294,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119294.

(https://www.sciencedirect.com/science/article/pii/S0196890424012354)

Abstract: A comparative techno-economic analysis has been performed on two innovative pathways for municipal solid waste (100 t/h) thermochemical processing to substitute natural gas. The first pathway is based on updraft gasification with bottom hydrogen oxy-combustion and ashes melting, the second on autothermal chemical looping hydrogen production with Fe2O3/SiC oxygen carrier. Catalytic methanation in a series of adiabatic fixed bed reactors has been implemented and substitute natural gas quality has been evaluated based on the Italian legislation. Although the updraft gasification process shows higher substitute natural gas productivity (16.3 t/h vs 13.7 t/h), better system energy efficiency (42 % vs 35 %) and energy intensity (125 vs 141 GJ/t), the levelized cost of substitute natural gas is more competitive in the chemical looping configuration due to the lower capital expenditure. Product prices of 2.26 €/kg and 1.76 €/kg have been calculated for updraft gasification and chemical looping, respectively, assuming 8 % discount rate, 80 % capacity factor, and 90 €/MWh electricity cost. Sensitivity analyses indicate that, among other parameters, the plant capacity factor and the electric power cost have a relevant impact on the final product cost. Additionally, both pathways are shown to be economically competitive with substitute natural gas production from H2O electrolysis and CO2 capture/purchase. Finally, actions to reach competitivity with fossil natural gas for industrial uses are qualitatively discussed.

Keywords: Chemical looping hydrogen production; Municipal solid waste; Substitute natural gas (SNG); Techno-economic analysis; Updraft gasification; Waste-to-fuel

Mingxuan Dai, Xinyue Tong, Yongcheng Tong, Wei Zhou, Chusheng Chen, Zhongliang Zhan,

A La1.85Mg0.15Ce2O7-δ-based ceramic hydrogen pump for stable hydrogen separation out of the H2-CO2 mixtures,

Separation and Purification Technology,

Volume 359, Part 1,

2025,

130466,

ISSN 1383-5866,

https://doi.org/10.1016/j.seppur.2024.130466.

(https://www.sciencedirect.com/science/article/pii/S1383586624042059)

Abstract: Currently, hydrogen is largely produced from steam methane reforming with the H2-and CO2-containing stream as the process gas. It is highly relevant to explore new pathways to efficiently separate hydrogen out of the H2-CO2 mixed gases. In the present work, a novel ceramic hydrogen pump for H2 purification is designed with thin La1.85Mg0.15Ce2O7-δ (LMCO) electrolytes supported by symmetrical Ni-LMCO electrodes, and is fabricated by using the tape casting, tape lamination and co-sintering techniques. Chemical stability and proton conductivities are evaluated for fluorite LMCO oxides in humidified 10 % H2-90 % CO2. Superior stability of LMCO in CO2 allows for stable and selective hydrogen separation out of humidified 10 % H2–90 % CO2. The Faraday’s efficiency decreases pronouncedly with an increase in the operation temperature, e.g., ≈ 30 % at 700 ℃ vs. ≈ 76 % at 500 ℃, due to increasingly high reduction susceptibility of Ce4+ to Ce3+ and the resultant electronic conductivities. A reasonable H2 flux of 0.57 mL·min−1·cm−2 is achieved at 500 °C and 0.25 V with electricity consumption of 0.72 kWh·Nm−3 H2. Operation at a higher pumping voltage of 0.49 V yields a larger H2 flux of 1.16 mL·min−1·cm−2, but simultaneously results in higher electricity consumption of 1.42 kWh·Nm−3 H2. Impedance analysis reveals that the H2 fluxes for the present ceramic hydrogen pump are predominantly limited by high resistances against bulk transport of protons through the LMCO electrolytes as well as sluggish hydrogen oxidation kinetics in humidified 10 % H2–90 % CO2.

Keywords: Electrochemical hydrogen pumps; Protonic ceramic cells; Symmetrical fuel cells; Doped La2Ce2O7 oxides; Hydrogen separation

C.Y. Yuh,

Fuel Cells – Molten Carbonate Fuel Cell | Systems - Performance and Life-Limiting Considerations,

Editor(s): Jürgen Garche,

Encyclopedia of Electrochemical Power Sources (Second Edition),

Elsevier,

2025,

Pages 600-621,

ISBN 9780323958226,

https://doi.org/10.1016/B978-0-323-96022-9.00174-2.

(https://www.sciencedirect.com/science/article/pii/B9780323960229001742)

Abstract: High temperature carbonate or molten carbonate fuel cell (MCFC) is recognized as one of the cleanest and most efficient power generation option for commercial and industrial customers. Its operating temperature of ∼600–650°C is ideal to facilitate fast reaction kinetics and allows use of commercial commodity materials and well-established manufacturing processes. High-quality waste heat can be utilized for poly-generation for further efficiency increase. It is fuel flexible, capable of utilizing a variety of hydrocarbon fuels. Internal reforming MCFC has unique capabilities to generate clean power, produce distributed hydrogen, and capture CO2 from other point sources. The CO2-rich but contaminant-free anode exhaust can be easily captured for further utilization or sequestration. Therefore, MCFC systems are well suited for not only clean power generation, but also hydrogen production and decarbonization. Significant progress has been made in technology and system developments, manufacturing, product engineering, and commercial field operation over the past several decades. Commercial distributed-generation MCFC systems have already been deployed worldwide. The desired commercial fuel cell stack durability has been confirmed. Material life considerations are well understood, and solutions are available to extend stack life further beyond 10years.

Keywords: Biogas; Carbon capture; Combined cycle; Distributed hydrogen production; Fuel cell; Fuel processing; High temperature fuel cell; Hot corrosion; Hybrid system; Internal reforming; Life considerations; Material stability; Molten carbonate fuel cell

Mostafa Zarandi, Mehdi Panahi, Ahmad Rafiee, Sajad Namazi Rad, Ángel Galán-Martín, Josep M. Mateo-Sanz, Laureano Jiménez,

Exploring the environmental and economic benefits of hybrid natural gas and biomass conversion to liquid fuels,

International Journal of Hydrogen Energy,

Volume 105,

2025,

Pages 1309-1319,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.290.

(https://www.sciencedirect.com/science/article/pii/S0360319925003258)

Abstract: Liquid fuels as the primary global energy source will experience a demand peak in the near future. Fischer-Tropsch technology provides liquid fuels to fulfill part of this demand from a variety of carbon-rich materials. Biomass is a renewable source of carbon that complements conventional liquid fuels. The low efficiency of Biomass to Liquid (BtL) processes which roots to a deficiency of hydrogen in produced syngas makes this process less competitive. This work investigates the enhancement of the BtL process by the integration of rich hydrogen syngas from the Gas to Liquid (GtL) process. The rigorous techno-economic analysis demonstrates that the optimal mass blending ratio between the two feedstocks, biomass and natural gas, is 4.27 in the integrated process of natural gas-biomass to liquid fuels (GBtL). The life cycle assessment of the hybrid system highlights the impact of biomass feed on global warming by considering the biogenic carbon in the feedstock. The analysis reveals that a 30% alteration in biomass feedstock leads to approximately 30% variation in the global warming emission impact of the hybrid plant. Utilizing the different types of biomass feedstock is also evaluated and compared as a potential solution for the difficulties in the supply chain and defining the best type of biomass for the feedstock.

Keywords: Fischer-tropsch; Techno-economic; Biomass to liquid; Natural gas to liquid; Life cycle assessment; Integration process

Meng Liu, Caixia Miao, Zhijie Wu,

Confinement and synergy effect of bimetallic Cu-Ni clusters encapsulated in Beta zeolite for methyl acetate formation from methanol alone,

Applied Catalysis A: General,

Volume 690,

2025,

120045,

ISSN 0926-860X,

https://doi.org/10.1016/j.apcata.2024.120045.

(https://www.sciencedirect.com/science/article/pii/S0926860X24004903)

Abstract: The direct synthesis of methyl acetate (MA) from methanol is an appealing and green approach, but an efficient catalyst is urgently needed. Herein, Cu-Ni bimetallic clusters, with a diameter of ∼1.2 nm, have been successfully encapsulated within BEA zeolite by an in-situ two-step encapsulation method (Cu-Ni@Beta), which significantly favors the dispersion of metals compared to the ion-exchanging (Cu/Ni@Beta) and wet impregnation approach (Cu-Ni/Beta). The as-synthesized Cu-Ni@Beta catalyst shows a MA formation rate of 1.46 mmol s−1 g(Cu+Ni)−1, which is much higher than Cu/Ni@Beta of 0.02 mmol s−1 g(Cu+Ni)−1 and Cu-Ni/Beta of 0.12 mmol s−1 g(Cu+Ni)−1. Characterization studies reveal that zeolite constraints could not only provide the spatial confinement for metal clusters but also induce an electronic interaction between confined Cu and Ni species in Cu-Ni@Beta. This interaction can increase and stabilize Cu+ sites as well as Lewis acid sites, which are crucial for improving catalytic performance. In-situ FTIR experiments indicate that the formation of formaldehyde (CH2O\*) is the critical step for methanol to MA, and the CH2O\* further couples with methoxy (CH3O\*) to form acetate species (CH3CHO\*), which subsequently couples with CH3O\* to produce MA.

Keywords: Bimetallic Cu-Ni clusters; Confinement; Beta zeolite; Methanol; Methyl acetate

Sachin Kajla, Ritu Kumari, Priya Kumari, Vikas Kumar Patel,

Emerging trends and strategies involved in microbial biohydrogen production,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 797-819,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.077.

(https://www.sciencedirect.com/science/article/pii/S0360319925000825)

Abstract: Large-scale sectors relying on burning fossil fuels are exhausting them, triggering climate change and escalating the discharge of greenhouse gases. Significant projects are being established to shift focus from traditional fossil fuels and towards cleaner energy sources. Microbial biohydrogen has received widespread interest as a zero-carbon, long-term protracted alternative source. Because of its elevated energy demand and carbon-neutral emission properties, biohydrogen is a potentially viable fuel for the existing challenges of global warming and escalating greenhouse gas emissions. As hydrogen doesn't occur in its natural form, present ways to generate it (such as water-splitting and steam methane reforming) seem to be energy-intensive with a massive carbon impact. An environmentally friendly, long-lasting, and emission-free approach for manufacturing hydrogen is dark fermentation facilitated by anaerobic hydrogen-producing bacteria. Because of its ability to accumulate carbon, microbial biomass is now being investigated in both academic and industrial sectors as a third-generation biofuel feedstock. Biohydrogen generation from microbes is a plausible alternative source of potentially renewable and self-sufficient energy, despite its preliminary stages of development. The main objective of this article is to address contemporary approaches to novel molecular genetics engineering and metabolic pathway innovations, pre-treatment approaches, economic evaluation, restraints, and research gaps in bio-hydrogen generation from microorganisms.

Keywords: Biohydrogen; Microorganisms; Biomass; Genetic manipulation; Metabolic engineering

Adel Balali, Mahdi Moghimi,

Energy system design based on municipal solid waste gasification and SOFC for multi-demand applications through multi-heat recovery approach: 4E assessment and machine learning optimization,

Process Safety and Environmental Protection,

Volume 195,

2025,

106763,

ISSN 0957-5820,

https://doi.org/10.1016/j.psep.2025.01.017.

(https://www.sciencedirect.com/science/article/pii/S0957582025000175)

Abstract: Municipal solid waste gasification, an environmentally friendly method that complies with the legal limits of greenhouse gas emissions, has been used in this research to supply fuel for solid oxide fuel cell (SOFC). Using the multi-heat recovery approach, the proposed system can satisfy various demands, including electricity, cooling load, hydrogen, and freshwater for domestic and commercial sectors. This study addresses critical gaps in the existing literature by demonstrating the effectiveness of using a cascaded ORC with LNG for waste heat recovery and evaluating techno-economic and environmental impacts through a comprehensive parametric and sensitivity analysis. The simulation of the proposed system has been implemented in MATLAB software, and the influence of design parameters on system outputs and performance indicators has been discussed through a parametric and sensitivity analysis. Investigations reveal that the fuel utilization factor is the most influential parameter on system outputs, affecting the total exergy efficiency and cost rate by 44.7 % and 46.7 %, respectively. Also, the gasification unit has the largest contribution to the total exergy destruction of the proposed system, accounting for 39.98 % (379.61 kW) due to incomplete combustion and thermodynamically unfavorable chemical reactions. Finally, a new optimization method based on data science and machine learning has been used by incorporating the artificial neural network with the genetic algorithm. According to the tri-objective optimization results, the system’s optimal state exhibits a 12.07 % enhancement in exergy efficiency, a 7.35 % reduction in the cost rate, and a 3.9 % rise in CO2 emission index compared to the design conditions.

Keywords: Multi-generation system; Gasification; SOFC; Desalination; Machine learning optimization

Liang Cheng, Yucun Zhou, Linghong Luo, Leying Wang, Xu Xu, Daqin Guan, Wei-Hsiang Huang, Chih-Wen Pao, Zhiwei Hu, Jing Zhou, Shaorong Wang, Zongping Shao,

Mutual dissolution and exsolution enables superior coking resistance of cermet fuel electrode,

Chemical Engineering Journal,

Volume 505,

2025,

159587,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.159587.

(https://www.sciencedirect.com/science/article/pii/S1385894725003869)

Abstract: The matured infrastructures for hydrocarbons storage and transportation makes the reversible conversion between carbon-contained fuels and electricity a highly promising way for the utilization of renewable energy towards a sustainable carbon–neutral society. Reversible solid oxide cells may play a significant role considering their high efficiency, fast reaction kinetics, and easy scale up. However, the nickel-based electrodes face a big challenge in practical use due to easy coking. Here, we report conventional nickel-based cermet can be transferred into an efficient fuel electrode with superior coking resistance and improved activity by simply introducing a mutual dissolution-exsolution strategy. The key is the application of ultrafine nickel oxide as raw material, and their mutual dissolution is realized during calcination and sintering, forming a composite with nickel nanoparticles modified yttrium-stabilized zirconia (YSZ) and zirconia nanoparticles/thin films decorated bulk nickel during the subsequent reduction process. The exsolved nickel nanoparticles provide excellent electrocatalytic activity while the bulk nickel is protected from coke formation by the exsolved nano zirconia nanoparticles/film. As a result, favorable activity and excellent stability for the direct utilization of hydrocarbon fuels for power generation and carbon dioxide electrolysis is realized, making it highly promising for practical application.

Keywords: Mutual dissolution and exsolution; Coking resistance; Carbon dioxide electrolysis; Reversible solid oxide cells

Index,

Editor(s): Angelo Basile, Kamran Ghasemzadeh,

Current Trends and Future Developments on (Bio-) Membranes,

Elsevier,

2025,

Pages 277-284,

ISBN 9780443138768,

https://doi.org/10.1016/B978-0-443-13876-8.00016-1.

(https://www.sciencedirect.com/science/article/pii/B9780443138768000161)

Sayed Abu Sufyan, Kevin J. Whitty, Michael M. Nigra,

CO2 sorption capacity and cyclic performance of quicklime (CaO) under gasification conditions,

Chemical Engineering Journal,

Volume 507,

2025,

160534,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.160534.

(https://www.sciencedirect.com/science/article/pii/S1385894725013555)

Abstract: Calcium looping (CaL), based on the cyclic CaCO3/CaO calcination/carbonation process, is one of the crucial features of sorption enhanced gasification (SEG). CaO sorbent has been validated for in-situ CO2 capture in the gasification unit where gasifying agent steam (H2O) and syngas products CO and H2 co-exist. Even though steam is hypothesized to enhance sorbent reactivity, its behavior in practical conditions is debatable. Additionally, carbonation performance of CaO-based sorbents in the presence of CO and H2 is not well understood. This contribution investigates CO2 sorption performance of CaO under relevant gasification conditions (in the presence of steam and syngas) using a laboratory-scale fluidized bed reactor over a range of representative carbonation temperatures. CO2 sorption increases with increasing carbonation temperature, but is limited by the reaction equilibrium of the CaCO3/CaO system. CO2 sorption performance of CaO sorbent increases notably when steam is introduced into the carbonation atmosphere or followed by ex-situ hydration of CaO sorbent. Steam promotes formation of a microporous structure, thereby facilitating CO2 diffusion through the CaCO3 layer. On the contrary, CO and H2 in the carbonation atmosphere hinder CO2 sorption performance, whereas the combined influence of steam and syngas is insignificant. We hypothesize that CO and H2 limit CO2 sorption performance of CaO through competitive sorption at CaO active sites and by carbon formation that blocks the pores. This work demonstrates that practical gasification conditions for in-situ CO2 sorption change the sorption behavior of CaO significantly, which provides insights for the use of CaO-based sorbents to capture CO2.

Keywords: CO2 sorption; CaO sorbent; Steam; Syngas; Calcium looping; Sorption-enhanced gasification

Ping Jin, Yuhao Wang, Kongzhai Li, Hua Wang, Yane Zheng,

Ni@S-1 facilitated efficient reduction of CO2-containing CO via chemical looping,

Fuel,

Volume 381, Part C,

2025,

133475,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.133475.

(https://www.sciencedirect.com/science/article/pii/S0016236124026243)

Abstract: Gases produced in the steel industry, such as Blast Furnace Gas, mainly contains CO and CO2, which can be converted by a two-step reaction of chemical looping. CH4 is oxidized by the oxygen carriers, and the Blast Furnace Gas can be used to recover the oxygen carriers. However, large amounts of CO existed in Blast Furnace Gas impact the reaction equilibrium of CO2 reduction, resulting in a decrease of CO2 conversion. the composite oxygen carrier LFCC/Ni@S-1 is synthesized by physically mixed method. An appropriate reaction temperature range is selected to minimize the impact of side reactions by the results of HSC calculations and CH4-TPR&CO2-TPO. The LFCC/Ni@S-1 exhibits high activity and durability, with a high syngas yield (9.52 mmol/g) in the CH4 step and a high CO2 conversion (95 %) under the CO2/CO mixed atmosphere at 700°C. This performance is attributed to the activation of CH4 and CO2 facilitated by Ni species and Lewis acid sites provided by silicalite-1. CO2 is converted efficiently under the CO2/CO mixed atmosphere through the selection of a suitable temperature and the efficient LFCC/Ni@S-1 oxygen carrier in chemical looping.

Keywords: Chemical looping; LFCC/Ni@S-1; CH4 activation; Lewis acid sites; CO/ CO2 mixed atmosphere

Yagmur Nalbant Atak, Alper Can Ince, C.Ozgur Colpan, Adolfo Iulianelli, Mustafa Fazil Serincan, Ugur Pasaogullari,

Thermoeconomic analysis of an integrated membrane reactor and carbon dioxide capture system producing decarbonized hydrogen,

Energy Conversion and Management,

Volume 326,

2025,

119506,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2025.119506.

(https://www.sciencedirect.com/science/article/pii/S0196890425000299)

Abstract: In this study, a novel thermo-economic analysis on a membrane reactor adopted to generate hydrogen, coupled to a carbon-dioxide capture system, is proposed. Exergy destruction, fuel, and environmental as well as purchased equipment costs have been accounted to estimate the cost of hydrogen production in the aforementioned integrated plant. It has been found that the integration of the CO2 capture system with the membrane reactor is responsible for the reduction of the hydrogen production cost by 12 % due to the decrease in environmental penalty cost. In addition, the effects of operating parameters (steam-to-carbo ratio and biogas temperature) on the hydrogen production cost are investigated. Hence, this work demonstrates that the latter can be decreased by approximately 2 $/kgH2 when steam to carbon ratio increases from 1.5 to 4. The analyses reveal that steam-to-carbo ratio increases exergy destruction cost, affecting consequently also the hydrogen production cost. However, from a thermodynamic point of view, it enhances the hydrogen production in the membrane reactor, mutually lowering the hydrogen production cost. It has been also estimated that a decrease in the biogas inlet temperature from 450 to 400°C can reduce the hydrogen production cost by 7 %. This study demonstrates that the fuel cost is a major economic parameter affecting commercialization of hydrogen production, while exergy destruction and environmental costs are also significant factors in determining the hydrogen production cost.

Keywords: Membrane reactor; Hydrogen production; CO2 capture; Exergy; Techno-economic analysis

Oxana V. Kharissova, Yolanda Peña Méndez, Boris I. Kharisov, Lucy T. González, Sergei V. Dorozhkin,

Hydroxyapatite-based materials as catalysts: A review,

Particuology,

Volume 96,

2025,

Pages 203-217,

ISSN 1674-2001,

https://doi.org/10.1016/j.partic.2024.11.007.

(https://www.sciencedirect.com/science/article/pii/S1674200124002323)

Abstract: Hydroxyapatite, a bioceramic material, possesses sufficient stability in aqueous and organic medium and it is mainly known for its role in tooth and bone structure. However, it is less-known that, in certain conditions, the HA can be used as a catalyst in its free, metal-doped and composite forms. HA as a catalyst is generally prepared by i mpregnation or co-precipitation methods, sometimes from natural P-containing wastes. HA can be doped with mono- or polymetallic ions or nanoparticles and can contain other admixtures or supports (i.e., carbon). Different Ca/P ratios (ideal 1.67; the ranges are 1.5–1.7 in synthetic and 1.5–1.8 in biologic forms) can be revealed for the HA. Nanosized HA forms are frequent in several applications. A variety of distinct processes can be HA-catalyzed, such as oxidation of alcohols, dehydrogenation, hydrogenation and hydrogenolysis, C-C bond formation, among other important existing low- and large-scale organic processes. The HA can be also used for catalytic environmental remediation, CO2 fixation, and N2O decomposition. In this review, we emphasize most recent advances (mainly last decade) on the catalytic HA applications, except for biomedical ones.

Keywords: Hydroxyapatite; Catalysis; Alcohol oxidation; Biofuel production; Environmental remediation

María del Carmen Recio-Ruiz, Ramiro Ruiz-Rosas, Francisco José García-Mateos, María José Valero-Romero, Juana María Rosas, José Rodríguez-Mirasol, Tomás Cordero,

An integrated approach to the valorization of pyrolysis products from lignocellulosic residues and by-products,

Biomass and Bioenergy,

Volume 196,

2025,

107676,

ISSN 0961-9534,

https://doi.org/10.1016/j.biombioe.2025.107676.

(https://www.sciencedirect.com/science/article/pii/S096195342500087X)

Abstract: Pyrolysis of biomass waste enables the generation of energy and products, although the sustainability of this process requires an integral valorization of all produced fractions. This paper presents a study on the valorization of all pyrolysis products from selected biomass wastes, such as hemp hurd (HH), olive stone (OS) and almond shell (AS), and two technical lignins, focusing on the effect of the biopolymeric composition on the potential applications of the different pyrolysis streams. The stablished correlation between the lignocellulosic biomass composition and the properties of each of the pyrolysis products obtained (bio-oil, biochar and gases) in relation to their potential applications (in addition to the distribution of pyrolysis products and yields) represents the main novelties of this work. The results obtained demonstrate that it is possible to obtain energy to sustain an autothermal pyrolysis process from these residues at operation temperatures above 500 °C. Residual biomass materials with high lignin content deliver gases with higher heating values (up to 23 MJ/m3), higher yields of solids (ca. 58 %), and bio-oil with lower acid and higher phenolic content (up to 19.9%m/m.). Agricultural residues, especially hemp hurd, which contains lower lignin amount, produce chars with narrow microporosity, matching the requirements to selectively adsorb CO2 from biogas and steam reforming streams, achieving CO2/CH4 selectivity values as high as 53.

Keywords: Slow pyrolysis; Lignocellulosic biomass; Syngas; Bio-oil; Biochar; CO2 adsorption

Yanhong Zhang, Ruiqing Song, Jie Zou, Jiaming Chu, Haiyang Lan, Juan Zhou,

Research on CO2 reduction reaction in the proton conducting solid oxide electrolysis reactor with Fe catalyst layer coverage,

International Journal of Hydrogen Energy,

Volume 98,

2025,

Pages 86-95,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.11.483.

(https://www.sciencedirect.com/science/article/pii/S0360319924051875)

Abstract: The multi-layer reactor, prepared by coating a catalyst functional layer onto the fuel electrode surface of the proton conducting solid oxide electrolysis reactor, can accelerate the rate of CO2 reduction reaction while slowing down the rate of carbon deposition on the electrolyte surface. This helps extend the service life of the reactor. In this study, an Fe2O3 catalyst is combined with a single cell to create a proton-conducting solid oxide cell reactor with the structure of La0.6Sr0.4Co0.2Fe0.8O3-δ(LSCF) ǀBaZr0.1Ce0.7Y0.1Yb0.1O3-δ(BZCYYb) ǀNiO-BZCYYb (active layer) ǀNiO-BZCYYb (support layer). An oxidizing atmosphere of 10%H2O+90%Air is utilized, along with fuel gas composition of 30%CO2+70%H2. The reactor achieves an electrolysis current density of 1698 mA·cm−2 under 1.3 V at 700 °C, and it operates continuously for 630 h at 650 °C under both constant-potential electrolysis and constant current electrolysis modes. Moreover, the CH4 selectivity in the carbon-containing fuel generated on the fuel electrode side reaches 19.4% at 550 °C.

Keywords: Proton conducting solid oxide electrolysis reactor; CO2 reduction reaction; Fuel electrode; Fe catalyst layer

Okezie Emmanuel, Rozina, Thaddeus C. Ezeji,

Advances in carbon dioxide capture and conversion technologies: Industrial integration for sustainable chemical production,

Next Sustainability,

Volume 6,

2025,

100108,

ISSN 2949-8236,

https://doi.org/10.1016/j.nxsust.2025.100108.

(https://www.sciencedirect.com/science/article/pii/S294982362500011X)

Abstract: Developing efficient strategies to capture carbon dioxide (CO2) is essential to addressing the escalating challenges of global warming. Despite being a major greenhouse gas, CO2 holds significant potential as a sustainable feedstock for chemical production. It can serve as a solvent, a preservative, a raw material for producing fuels, carbonates, polymers, and chemicals, and as a recovery agent for processes such as enhanced coal bed methane and oil recovery. This review highlights significant progress made in CO2 capture and its integration into various industrial applications. While technologies such as adsorption, absorption, membrane separation, and cryogenics have shown promise, challenges related to cost, scalability, and the efficiency of capture and utilization continue to pose significant barriers to widespread adoption. Innovative strategies, including integrated carbon capture and conversion (ICCC) and integrated carbon capture and utilization (ICCU), present promising pathways to reduce costs by combining capture and utilization processes within a single facility. Additionally, catalytic processes and biological systems, such as microalgae and microbial strains (e.g., acetogens), are paving the way for sustainable CO2 conversion into high-value products. Successful large-scale deployment of these technologies will require sustained interdisciplinary collaboration, robust policy frameworks, and increased investment in research and development. Prioritizing sustainable energy development and management offers the potential to significantly reduce anthropogenic CO2 emissions while creating useful products. Advancing these technologies will not only help in mitigating climate change but also promote the transition to a circular carbon economy, which aligns with global sustainability goals.

Keywords: CO2 capture; Environmental impact; Technologies; Utilization

E.V. Tsipis, A.V. Samoilov, D.V. Matveev, Yu.S. Fedotov, M.S. Dyakina, D.V. Zhigacheva, D.A. Agarkov, S.I. Bredikhin, V.V. Kharton,

Performance of industrial-scale solid oxide electrolysis cells: An assessment of leakage effects,

International Journal of Hydrogen Energy,

Volume 97,

2025,

Pages 614-621,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.11.480.

(https://www.sciencedirect.com/science/article/pii/S036031992405184X)

Abstract: Performance of one short-stack of the electrolyte-supported solid oxide electrolysis cells (SOECs) with multilayered anodes based on (Pr0.6Sr0.4)0.97MnO3-δ and cathodes made of Ni-based cermets was evaluated under the partial unhermetization conditions. Four industrial-scale 10×10 cm2 membrane-electrode assemblies were produced, mounted in the stack, and tested for water vapor electrolysis at 1123 K in conditions when the sealant was partly cracked due to thermal cycling. The hydrogen production rate, faradaic efficiency and specific energy consumption determined as functions of the applied electrical current were compared with the same parameters for a hermetically sealed SOEC stack. The energy consumption for hydrogen generation was approximately 3 kWh/Nm3. Appropriate operation regimes in the presence of sealant leakages may be achieved at maximum possible currents which are still lower than the current limit corresponding to the start of rapid SOEC degradation. The life tests performed at the current densities of ≥370 mA/cm2 and subsequent microscopic studies showed that this degradation is associated with microstructural changes in the solid electrolyte ceramics. The air electrodes exhibited a high electrochemical activity both in the fuel-cell and electrolysis modes, without any indication of possible delamination from the solid electrolyte membranes.

Keywords: Solid oxide electrolysis cell; Steam electrolysis; Hydrogen production; Life tests; Electrolyte degradation

Chiagoziem C. Ukwuoma, Dongsheng Cai, Chibueze D. Ukwuoma, Mmesoma P. Chukwuemeka, Blessing O. Ayeni, Chidera O. Ukwuoma, Odeh Victor Adeyi, Qi Huang,

Sequential gated recurrent and self attention explainable deep learning model for predicting hydrogen production: Implications and applicability,

Applied Energy,

Volume 378, Part A,

2025,

124851,

ISSN 0306-2619,

https://doi.org/10.1016/j.apenergy.2024.124851.

(https://www.sciencedirect.com/science/article/pii/S0306261924022347)

Abstract: To meet the difficulties of the current energy environment, hydrogen has enormous potential as a clean and sustainable energy source. Utilizing hydrogen's potential requires accurate hydrogen production prediction. Due to its capacity to identify intricate patterns in data, Machine learning alongside deep learning models has attracted considerable interest from a variety of industries, including the energy industry. Although these models yield an acceptable performance, there is still a need to improve their prediction results. Also, they are inherently black boxes, which makes it difficult to comprehend and interpret their predictions, particularly in important sectors like hydrogen generation. Sequel to the above, a sequential gated recurrent and self-attention network is proposed in this study to enhance hydrogen production prediction. The framework captures both sequential dependencies and contextual information enabling the model to effectively learn and represent temporal patterns in hydrogen production prediction. The biomass gasification dataset is used for the experiment including the Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Coefficient of Determination (R2), Mean Squared Logarithmic Error (MSLE) and Root Mean Squared Logarithmic Error (RMSLE) evaluation metrics. The proposed model recorded an optimal performance with an MAE of 0.102, MSE of 0.027, RMSE of 0.160, R2 of 0.999, MSLE of 0.001, and RMSLE of 0.030 based on K-cross validation. Among the input features, the percentage of plastics in the mixture(wt%) and RSS Particle Size(mm) are identified to be the most influential features in the proposed model prediction as identified by Shapley Additive Explanation (SHAP), Local Interpretable Model-Agnostic Explanations (LIME) and Feature importance plot. With 99.99 % of the data points for H2 production found within the range of reliability, the model demonstrates robust predictive capability with the majority of observations exerting minimal leverage (0 ≤ u ≤ [leverage threshold]) and limited influence (0 ≤ H ≤ [cooks' threshold]) on the predictive outcome using the modified William plot. Furthermore, various visualization approaches like Matthews correlation coefficient and Tarloy charts were adapted for the result explanations. The proposed model results were compared with state-of-the-art models exploring the significance of the proposed model in providing insights into the underlying mechanisms and factors influencing hydrogen production processes hence improving human understanding of the relationships between input factors and hydrogen production outputs as well as bridging the gap between predicted accuracy and interpretability.

Keywords: Hydrogen production prediction; Deep learning; Gated recurrent neural network; Attention mechanism; Explainable artificial intelligence; Co-gasification

S.S. Salisu, A. Aliyu, A.Y. Atta, B.J. El-Yakubu,

Bimetallic HZSM-5 catalysts: A review on the aromatisation of light alkanes (C1-C5) and liquefied petroleum gas (LPG) for benzene, toluene, and xylene (BTX) production,

Next Research,

Volume 2, Issue 1,

2025,

100181,

ISSN 3050-4759,

https://doi.org/10.1016/j.nexres.2025.100181.

(https://www.sciencedirect.com/science/article/pii/S3050475925000521)

Abstract: The aromatisation of light aliphatic hydrocarbons is essential for converting hydrocarbons into valuable products, particularly benzene, toluene, and xylene (BTX). There is an increasing demand for BTX, which has led to a growing interest in the catalytic conversion of light alkanes. Bimetallic metal species doped on HZSM-5 zeolites demonstrate superior selectivity towards aromatics and reduce undesirable side reactions compared to HZSM-5 or mono-metallic HZSM-5. This review focuses on the aromatisation of light alkanes (C1-C5) and liquefied petroleum gas (LPG) using bimetallic HZSM-5. It provides an overview of light hydrocarbon transformation processes, aromatisation mechanisms, zeolite porosity, mesoporous zeolites, metal doping on ZSM-5, and the impact of the Si/Al ratio on BTX yield. The review discusses the potential of bimetallic ZSM-5 catalysts, highlighting feasible alternatives to naphtha, such as ethane, propane, and butane. Promising developments include adjusting the Si/Al ratio, hydrogen treatment, metal component addition, reaction time optimisation, and external magnetic fields.

Keywords: Alkanes; LPG; Hierarchical HZMS-5; Bi-metallic HZSM-5; Aromatisation; BTX

Huan Xiang, Chenglian Wang, Zhao Yan, Yuanyuan Zhang, Po Zhang, Fangli Jing, Shizhong Luo,

Catalytic production of hydrogen and carbon nanotubes from glycerol via Ni2⁺/Zr⁴⁺-doped double-hydroxide layers,

Materials Chemistry and Physics,

Volume 333,

2025,

130360,

ISSN 0254-0584,

https://doi.org/10.1016/j.matchemphys.2025.130360.

(https://www.sciencedirect.com/science/article/pii/S0254058425000069)

Abstract: Well-dispersed NiZrAl catalysts were prepared by thermally decomposing the NiZrAl-layered double hydroxides (LDH) precursor which was in situ assembled on Al2O3 (Al source) surface through a urea homogeneous precipitation-deposition strategy, characterized by XRD, TG, TEM, N2 adsorption/desorption isotherms, TPR, XPS, H2-chemisorption and Raman techniques. The findings indicated that nickel species were well-dispersed on the support surface. Variation in nickel loading had a more significant influence on the surface chemical state and dispersion. Nickel oxide was only partially reduced to metallic Ni, and larger number and smaller metal particle size of which were more favorable for glycerol cracking. The product distribution was markedly affected by the content of oxygen vacancies, and hydrogen production was enhanced by promoting the water gas shift reaction. The optimal catalytic performance was achieved over the sample 15NiZr@Al2O3 with a glycerol conversion of 92.4 % and a H2 selectivity of 76.7 %. All the catalysts demonstrated good resistance to sintering, and carbon nanotubes were generated as a by-product.

Keywords: Hydrogen; Ni-based catalyst; Layered-double hydroxides; Glycerol; Biomass

Thi Thu Thuy Nguyen, Thi Tieu Ny Nguyen, Phung Anh Nguyen, Ba Long Do, Thi Be Ta Truong, Hong Phuong Phan, Thanh Gia-Thien Ho, Tri Nguyen,

Nickel-ceria-chitosan composite aerogel for the catalytic reduction of various organic compounds in water,

Ceramics International,

2025,

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ISSN 0272-8842,

https://doi.org/10.1016/j.ceramint.2025.01.219.

(https://www.sciencedirect.com/science/article/pii/S0272884225002469)

Abstract: In this study, the Ni/CeO2 (CN) catalyst was favourably synthesized through the CeNiO3 perovskite reduction with a H2 flow, and mixed with chitosan (CS) with various weight ratios (x/y) to fabricate three-dimensional composite aerogel (xCNyCSA) for the catalytic reduction of methyl orange (MO) in the presence of sodium borohydride (SB). The xCNyCSA catalysts were rigorously characterized using analytical techniques including X-Ray diffractometer (XRD), energy dispersive X-ray spectrum (EDS), Brunauer–Emmett–Teller adsorption isotherm (BET), Fourier-transform infrared spectroscopy (FT-IR), Thermogravimetric analysis (TGA), vibrating sample magnetometer analysis (VSM), Raman scattering, scanning electron microscopy (SEM), high-resolution transmission electron microscopy (HR-TEM), and selected-area electron diffraction (SAED). The results showed that the 1CN10CSA composite with a CN/CS weight ratio of 1/10 is the best one having an average CN particle size of 22.3 nm, a specific surface area of 2.3 m2/g, a pore diameter of 25.6 Å, and a pore volume of 0.003 cm3/g. Strikingly, under the optimal conditions, including a catalyst dosage of 0.6 g/L and the MO/SB molar ratio of 1/200, the 1CN10CSA composite exhibited remarkable catalytic activity, boosting the reduction rapidly within 15 min with MO conversion of 94.9 % and a rate constant of 0.144 min−1. Moreover, the 1CN10CSA sample was employed to reduce other organic pollutants, such as p-nitrophenol (PNP) and congo red (CR), with 98.9 % and 85.7 % conversion efficiencies within 15 min, respectively. Therefore, with these superior performances, the novel CN-CSA composite aerogel could be a promising candidate for reducing various organic compounds.

Keywords: Catalytic reduction; Organic compounds; Nickel-ceria-chitosan; Composite; Aerogel

Sivagowri Shanmugaratnam, Swathi Srinivasan, Rathinam Yuvakkumar, Velaug Myrseth Oltedal, Punniamoorthi Ravirajan, Yohi Shivatharsiny, Dhayalan Velauthapillai,

MS2/TiO2 (M = Co, Sn and Ni) electrodes for electrocatalytic and photocatalytic water splitting,

Fuel,

Volume 385,

2025,

134101,

ISSN 0016-2361,

https://doi.org/10.1016/j.fuel.2024.134101.

(https://www.sciencedirect.com/science/article/pii/S0016236124032526)

Abstract: Exploring an efficient and stable nanocatalyst for water splitting is a highly desirable, but still a challenging goal. Herein, we synthesized different metalchalcogenides (MS2: M = Co, Ni, Sn) embedded with TiO2 that form nanocomposites by the facile hydrothermal method for water splitting. The crystallinity and phases of the prepared materials were confirmed by X-Ray diffractive spectra; the morphology of the particles was studied by Scanning Electron Microscopy; and their superior catalytic performance in electrochemical and photocatalytic activity were examined using electrochemical characterization and photocatalytic experiments, respectively. In electrochemical processes, compared with bare TiO2, 10 wt% CoS2/TiO2, SnS2/TiO2, and NiS2/TiO2 nanocomposites exhibited high current densities with low Tafel slope values in hydrogen evolution reaction (HER) and oxygen evolution reaction (OER). In addition, the amounts of hydrogen evolution in electrocatalysis and photocatalysis reactions were examined. These results show that metalchalcogenide (MS2) embedded with TiO2 nanocomposites electrodes are highly promising candidates to be used as efficient electro and photocatalysts for the water splitting process.

Keywords: Metal chalcogenides; Hydrothermal; Hydrogen; Electrocatalytic; Photocatalysis

Jie Chu, Jialin Guo, Yafei Guo, Benshuai Guo, Pu Huang, Zhouzhou Zhang, Chuanwen Zhao,

Solid-state synthesis of alkaline lithium ceramics for integrated CO2 capture and conversion to syngas,

Journal of Environmental Chemical Engineering,

Volume 13, Issue 1,

2025,

115105,

ISSN 2213-3437,

https://doi.org/10.1016/j.jece.2024.115105.

(https://www.sciencedirect.com/science/article/pii/S2213343724032378)

Abstract: Integrating CO2 capture and utilization (ICCU) in the production of syngas for the C1 chemical industry through ICCU-RWGS (reverse water–gas shift reaction) is a vital strategy for achieving carbon reduction, and designing highly active dual-functional materials (DFMs) capable of CO2 adsorption and in-situ conversion is crucial. Alkaline lithium ceramics with high availability, featuring high CO2 capture and catalytic performance, are promising DFMs candidates for ICCU-RWGS. Herein, lithium ceramics of Li5FeO4, Li6CoO4 and Li6ZnO4 were prepared via solid state synthesis as potential DFMs for ICCU-RWGS applications, and structure-property-activity relationships of the lithium ceramics DFMs in ICCU were discussed. The Li-Zn sample with high surface basicity and high density and uniform dispersion of active sites demonstrated a high CO2 uptake (7.71 mmol CO2/g), CO yield (6.52 mmol CO/g), CO2 conversion (84.9 %) and CO selectivity (∼100 %) as well as moderate CO2 adsorption and hydrogenation kinetics at 650 °C, 10 %CO2 and 40 %H2, making it a promising candidate for ICCU-RWGS. However, the Li-Zn DFMs exhibited poor cyclic ICCU-RWGS working stability due to lithium sublimation and crystal sintering at high temperatures, which deserves more future efforts to solve the dilemma. Our findings provide valuable insights into designing cost-effective DFMs for ICCU applications.

Keywords: Lithium ceramics dual function materials; Reversed water gas shift reaction; Kinetics modeling; Structure-property-activity relationships; Catalyst deactivation

Runqiu Dong, Zhigang Liu, Le Wang, Lei Yi, Jialing Xu, Zhiyong Peng, Hui Jin, Bin Chen, Liejin Guo,

Thermodynamic analysis of an integrated hydrogen and power production system by food waste supercritical water gasification,

Journal of Environmental Chemical Engineering,

Volume 13, Issue 1,

2025,

115092,

ISSN 2213-3437,

https://doi.org/10.1016/j.jece.2024.115092.

(https://www.sciencedirect.com/science/article/pii/S221334372403224X)

Abstract: Supercritical water gasification (SCWG) technology has high hopes in the resource treatment of food waste. Current work focuses on the SCWG characterization of food waste at the mechanism level or the design of single-function SCWG systems such as hydrogen production, power generation, and heating. Therefore, this paper developed an integrated hydrogen and power production system by food waste supercritical water gasification to enrich the study of multi-energy fusion systems. Based on exergy flow analysis, significant exergy loss was found in the heat exchanger and cooler of the base case. Integrating the Organic Rankine Cycle (ORC) for waste heat recovery can produce an extra 2615.88 kW of electricity, increasing system energy efficiency by 8.66 % and exergy efficiency by 7.66 %. Sensitivity analysis showed that a lower ratio of preheated water to food waste slurry, higher feedstock concentration, lower oxidation temperature, and system pressure can improve the system efficiency. Because low ratio of preheated water to food waste slurry, high feedstock concentrations. and low oxidation temperature reduced the consumption of hydrogen-rich gas in the oxidation reactor. Higher pressure inhibited the steam reforming reaction, reducing H₂ production. The high energy input at elevated pressure combined with a decreased gas calorific value, resulted in lower system efficiency. Compared to other SCWG systems, this hydrogen-power polygeneration system is competitive due to the significant improvement of system performance by waste heat recovery. This work would be of great value for the optimal design of the food waste SCWG system.

Keywords: Food waste; Supercritical water gasification; Organic rankine cycle; Hydrogen; Thermodynamic analysis

Mohammadreza Mohammadpour, Amirreza Mohammadpour, Mehdi Ashjaee, Ehsan Houshfar,

Efficient utilization of high CO2 landfill-gas for syngas generation: Ultra-rich combustion pathways study in porous media reactor via CFD simulation,

Journal of CO2 Utilization,

Volume 93,

2025,

103044,

ISSN 2212-9820,

https://doi.org/10.1016/j.jcou.2025.103044.

(https://www.sciencedirect.com/science/article/pii/S2212982025000289)

Abstract: The current investigation explores the possibility of extracting syngas from low-calorific value landfill-gas rich-combustion with pure O2, which contains a considerable amount of CO2 in its composition as an effective strategy in CO2 utilization. The results illustrate that enhancement in mixture velocity leads to a notable increment in syngas energy conversion efficiency from 36.9 % to 44.14 %. Furthermore, it was observed that the maximum rate of H2 production occurs at an equivalence ratio of 2.2, followed by a subsequent decrease until the end of the studied interval. At a mixture velocity of 25 cm/s, CH4 and CO2 conversion ratios reach a maximum of 89.02 % and 42.85 %, respectively, alongside the highest syngas production efficiency. Moreover, with an equivalence ratio of 1.6 and a fuel mixture containing 70 % CH4, the highest achievable syngas composition was found to be 0.3277 for CO, 0.2841 for H2, 0.0676 for CH4, and 0.2534 for CO2, indicating useful conditions for syngas production. Eventually, reaction pathways analyses revealed that the hydrogen abstraction reactions of hydrocarbon species by H radical which majorly progress through direct CH4 to H2 conversion route, and hydrocarbon recombination routes have a key role in H2 production from landfill gas. Moreover, for landfill gas with high CO2 content, direct CO2 to the CO reduction route is determinative. Conversely, when the CH4 content of landfill gas is high, hydrocarbon recombination followed by ketenyl radical formation and decomposition to CO is the primary pathway in different mixture equivalence ratios.

Keywords: Sustainable syngas; Ultra-rich combustion; Porous media reactor; Reaction pathways analyses; CO2 utilization

Aravind Ganesan, Olivier Rezazgui, Jimmy Barco Burgos, Patrice J. Mangin, Simon Barnabé,

Valorization of lignocellulosic biomass forest residues in quebec via the integrated hydropyrolysis and hydroconversion (IH2) technology: A review,

Biomass and Bioenergy,

Volume 193,

2025,

107516,

ISSN 0961-9534,

https://doi.org/10.1016/j.biombioe.2024.107516.

(https://www.sciencedirect.com/science/article/pii/S0961953424004690)

Abstract: Lignocellulosic biomass residues from Quebec's forests, such as branches and logging residues, can be thermochemically converted into hydrocarbons-rich renewable fuels, offering a sustainable alternative to fossil oil in transportation. Integrated Hydropyrolysis and Hydroconversion (IH2) has emerged as a promising biorefinery technology for transforming diverse biomass feedstocks into bio-oil with properties akin to petroleum, achieving approximately 45 % carbon conversion and 27 wt% bio-oil yield. Optimal conditions for catalytic fast hydropyrolysis (CFHP) include temperatures of 400–450 °C, hydrogen pressures of 20–30 bar, and biomass heating rates of 100–500 °C/min. For the catalytic hydroconversion (CHC) stage, lower temperatures of 250–400 °C with similar hydrogen pressures are beneficial. To enhance bio-oil quality and yield, feed particle sizes below 1 mm are recommended for enhanced heat transfer. While clean hydrogen for IH2 could be produced from electrolysis and biomass, an alternative co-CFHP process using hydrogen-rich bio-based solvents, UEO, and waste plastics can mitigate the need for external hydrogen, high pressures, and complex setups. This can be operated with or without an optional hydrotreatment stage based on required product specifications. The results highlight some potential catalyst alternatives to TMS like TMO, TMP, TMN, and TMC that could improve deoxygenation efficiency and reduce associated challenges. Carbonaceous supports like biochars can replace conventional Al2O3 and achieve better performance w.r.t coking, surface functionalities, metal dispersibility, and sensitivity to deoxygenation by-products. Additionally, fluidized bed reactors are suggested for their scalability and effectiveness in facilitating consistent reactions. Overall, this study underscores the viability of IH2 and identifies critical areas for further research to achieve demonstration-scale feasibility.

Keywords: Lignocellulose; Catalyst; Hydrogen; Bio-oil; Biorefinery; Pyrolysis

D. Gallego-García, U. Iriarte-Velasco, M.A. Gutiérrez-Ortiz, J.L. Ayastuy,

One-pot synthesized niobium-doped nickel catalysts for efficient hydrogen-free glycerol hydrogenolysis,

Chemical Engineering Journal,

2025,

160860,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.160860.

(https://www.sciencedirect.com/science/article/pii/S138589472501681X)

Abstract: Hydrogenolysis with in situ produced hydrogen is a promising route to the fabrication of bio-based chemicals such as propylene glycol from biomass-derived glycerol. This study examines the effect of doping a nickel aluminate-derived catalyst with Nb on the physicochemical properties and product distribution during the hydrogenolysis of glycerol. The catalysts were synthesized from stoichiometric nickel aluminate spinel doped with different Nb contents using the citrate sol–gel method in a one-pot synthesis approach. Catalytic runs were performed in a continuous plug flow reactor at 235 °C/45 bar for 4 h time-on-stream. Catalysts were thoroughly characterized by XRD, HRTEM, XPS, NH3-TPD, Py-IR, and H2-TPD. Results indicated that Nb doping produced Ni0 crystallites of smaller size, increased the density of both metal and acid sites, and generated more oxygen vacancies when compared to the undoped catalyst. The nanoscale proximity of Nb to metallic nickel particles was also confirmed. The addition of Nb had a noticeable effect on the product distribution, with a marked increase in selectivity for C–O bond hydrogenolysis compared to C–C bond cleavage. The catalyst doped with 1 wt% Nb achieved a glycerol conversion of 58.1 % and a 1,2-propylene glycol yield of 37.5 %. Post-reaction characterization revealed that oxidation and leaching of surface metal species was minimum. In conclusion, the 1 wt% Nb-doped nickel aluminate-derived catalyst showed potential to facilitate the selective production of 1,2-propylene glycol in an environmentally friendly one-pot process coupling both the H2 generation and the hydrogenolysis reactions

Keywords: Glycerol; Hydrogenolysis; Nickel aluminate; Niobium; 1,2-Propylene glycol

Guoqiang Wei, Yecheng Yao, Jinzeng Cao, Weishan Yao, Xiaoyan Wu, Xixian Yang, Haoran Yuan, Lu Wang, Yuncai Song, Jun Xie,

Kinetics and experimental evaluation of hydrogen-rich synthesis gas from alkali lignin by chemical looping gasification with NiFe2O4 oxygen carrier,

Renewable Energy,

Volume 243,

2025,

122557,

ISSN 0960-1481,

https://doi.org/10.1016/j.renene.2025.122557.

(https://www.sciencedirect.com/science/article/pii/S0960148125002198)

Abstract: Chemical looping gasification (CLG) of alkali lignin with NiFe2O4 oxygen carrier was proposed to achieve hydrogen-rich syngas and realize the resource utilization of papermaking by-product, which exhibits advantages of cheaper oxygen source, lower reaction exergy loss, less tar content, and avoiding inert gas dilution in gas products. The kinetic behavior and reaction performance was evaluated by TG and fixed bed reactor coupled with thermal analysis kinetic of non-isothermal and heterogeneous systems. The results exhibited that the exogenous potassium alkali metal significantly reduced the average reaction activation energy from 182.62 kJ/mol to 142.16 kJ/mol and the CLG process conformed to the model of random nucleation and nuclear growth (n = 4). The presence of alkali metal and water molecules with the increasing temperature played a positive role in enhancing the CLG reaction process, adjusting the H2/CO ratio and improving the syngas yield and carbon conversion efficiency. Hydrogen-rich synthesis gas with H2 composition 57.67 %, LHV 13.28 MJ/m3, syngas yields 1.99 m3/kg, H2/CO 3.92 and carbon conversion 82.20 % was achieved in CLG of K-AAL with H2O molecular participation. The carbon conversion of K-AAL in CLG process is 28.78 % higher than that of AAL without alkali metal. The reaction path of NiFe2O4 oxygen carrier in CLG process was summarized as: NiFe2O4 → Fe0.5/Ni0.5 → Fe2O3/NiFe2O4. The CLG process is an effective way to prepare the synthesis gas for Fischer-Tropsch synthesis and realize the resource utilization of alkali lignin.

Keywords: Alkali lignin; Chemical looping gasification; Oxygen carrier; NiFe2O4; CLG; Synthesis gas

Yuge Yan, Xiaofeng Gu, Mingyang Zhou, Zhijie Wang, Xifen Gong, Yu Chen, Qingyu Li, Jiang Liu,

Hydrogen separation from peanut shell pyrolysis gas by using an electrochemical protonic ceramic cell hydrogen pump,

International Journal of Hydrogen Energy,

Volume 98,

2025,

Pages 898-907,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2024.12.085.

(https://www.sciencedirect.com/science/article/pii/S0360319924052832)

Abstract: Here we use the electrochemical hydrogen pump derived from a protonic ceramic cell (PCC) to realize the first demonstration of separating hydrogen from simulated peanut shell pyrolysis gas (64% H2, 26% CO, 4% CO2, and 6% CH4). The single PCC is configured with a thick Ni–BaCe0.7Zr0·1Y0·2O3-δ cathode, a thin BaCe0·7Zr0·1Y0·18Fe0·02O3-δ electrolyte, and an Ag–Ce0.8Gd0.2O1.9 anode with an effective area of 1.5 cm2. At 650 °C and a feeding current density of −500 mA cm−2, a hydrogen flux of 2.34 ml min−1 cm−2, a Faradaic efficiency of 62%, and a hydrogen recovery rate of 29% are achieved. In addition, 20 wt% Ni is mixed into the Ag-GDC electrode to achieve a hydrogen flux of 3.68 ml min−1 cm−2 and a Faradaic efficiency of 97%. Additionally, a 20-h measurement for PCCs with the Ni-mixed electrode shows the hydrogen fluxes and Faradaic efficiencies of above 1.49 ml min−1 cm−2 and 98%, respectively.

Keywords: Electrochemical hydrogen pump; Protonic ceramic cells; Biomass pyrolysis gas; Hydrogen separation

Zhouzhou Zhang, Yafei Guo, Jie Chu, Pu Huang, Pengjie Kong, Jian Sun, Ruilin Wang, Weiling Li, Chuanwen Zhao,

Integrated CO2 capture and conversion performance of Ni-CaO dual functional materials pellets in O2-containing flue gas stream,

Chemical Engineering Science,

Volume 306,

2025,

121241,

ISSN 0009-2509,

https://doi.org/10.1016/j.ces.2025.121241.

(https://www.sciencedirect.com/science/article/pii/S0009250925000648)

Abstract: Efficient Ni-CaO dual function materials (DFMs) pellets show potential in integrated CO2 capture with reversed water gas shift reaction (ICCU-RWGS) for syngas production. However, the presence of O2 in industrial flue gas might affect their ICCU-RWGS performance. In this work, Ni-CaO DFMs pellets were synthesized via the extrusion-spherization method, and the ICCU-RWGS performance of the pellets in O2-containing stream was investigated. The surface basicity of the pellets decreased, and CO2 capture capacity decreased from 10.32 to 8.40 and 6.53 mmol CO2/g when the pellets were exposed to 2 % O2 and 15 % O2, respectively. The presence of 2 %O2 in flue gas resulted in the decay in catalytic activity, and CO yield declined from 6.0 to 5.08 mmol CO/g. Interestingly, the oxidative deactivation of Ni in O2 and the decrease of catalytic activity had avoided the unexpected release of CO in the CO2 capture stage, making the CO2 separation process more efficient.

Keywords: Integrated CO2 capture and conversion; Ni-CaO dual function materials pellets; Oxidative deactivation; CO2 dissociation; O2-containing CO2 capture feed

Kehinde Temitope Alao, Syed Ihtsham ul Haq Gilani, Taiwo Onaopemipo Alao, Abiola Usman Adebanjo, Oluwaseun Ruth Alara,

Potential uses of perovskite-based photovoltaics for hydrogen production: A pathway to sustainable energy solutions,

Next Energy,

Volume 7,

2025,

100215,

ISSN 2949-821X,

https://doi.org/10.1016/j.nxener.2024.100215.

(https://www.sciencedirect.com/science/article/pii/S2949821X24001200)

Abstract: This review examines the potential of perovskite photovoltaic (PV) cells for clean hydrogen production, a vital component of the global shift toward sustainable energy. Utilizing a systematic review of literature from the Scopus and Web of Science databases, this study provides recent advancements and identifies persistent challenges in the application of perovskite PVs for hydrogen generation. Despite their market dominance, traditional silicon PV cells have limitations that perovskite PVs may overcome. While silicon PV cells achieve efficiencies between 23.3% and 26.7%, lababoratory-scale tandem perovskite PV devices have surpassed this, with efficiencies exceeding 29.8% and a greater potential for future improvement. This efficiency leap positions them as promising candidates for hydrogen production via electrolysis. However, the scalability, stability, and environmental impacts of perovskite PVs necessitate further research in materials science. The review highlights the critical need for advancements in material properties and system integration, as well as supportive policies to foster the adoption of perovskite PVs. Ultimately, the review proposes a strategic framework for optimizing hydrogen production with perovskite-based PV technology, making a significant contribution to the discourse on sustainable hydrogen solutions.

Keywords: Clean energy; Electrolysis; Hydrogen production; Perovskite solar cells; Renewable energy

Tomohiro Nozaki, Xiaozhong Chen, Dae-Yeong Kim, Hyun-Ha Kim,

Plasma fluidized beds and their scalability,

Current Opinion in Green and Sustainable Chemistry,

Volume 51,

2025,

100984,

ISSN 2452-2236,

https://doi.org/10.1016/j.cogsc.2024.100984.

(https://www.sciencedirect.com/science/article/pii/S2452223624001056)

Abstract: Over the last decade, plasma catalysis has attracted considerable research attention as an emerging low-carbon technology. In plasma catalysis, stable molecules such as CO2, CH4, and N2 are activated by electron impact or electrical energy, thereby ushering in a low-temperature chemistry domain that departs from energy-intensive, heat-dependent systems. Moreover, renewable-energy-driven plasma technologies are expected to help realize power-to-X schemes. In this short review, fluidized bed (FB) reactors incorporated with dielectric barrier discharge (DBD) are explored as potential candidates for upscaling plasma catalysis systems without employing a numbering-up approach. To that end, a scaled-up FB-DBD reactor is conceptualized using CO2 methanation as a model reaction, followed by the validation of laboratory-scale FB-DBD reactors, which exhibit remarkably high feed gas conversion rates at temperatures lower than those of thermal catalysis units. Finally, certain salient conclusions and perspectives are presented.

Keywords: Plasma catalysis; Scaling up; Dielectric barrier discharge; Fluidized beds; Gas conversion; Renewable energy

Seoyeon Cho, Haneul Mun, Jinwoo Park, Inkyu Lee,

Enhancing the Cost-Competitiveness of Green Ammonia-Based Power Systems: Hybrid Solid Oxide Fuel Cells and Gas Turbines,

Energy Conversion and Management,

Volume 325,

2025,

119430,

ISSN 0196-8904,

https://doi.org/10.1016/j.enconman.2024.119430.

(https://www.sciencedirect.com/science/article/pii/S0196890424013712)

Abstract: Ammonia (NH3) is considered one of the most compelling energy carriers for sustainable power systems. The solid oxide fuel cell (SOFC)–gas turbine (GT) hybrid system, fueled by green NH3-based hydrogen, is regarded as a promising sustainable power generation technology because of its high energy efficiency and low carbon emission. However, despite its significant potential, there have been limited discussions about (i) process configurations that consider the power generation characteristics of SOFC and GT and (ii) the economic performance. To address these limitations, this study proposes three economically optimized SOFC–GT hybrid systems and conducts comprehensive economic analyses. Notably, the heat-integrated parallel system, in which SOFC and GT are configured in parallel, and steam cycle is integrated into the SOFC off-gas stream, demonstrated the highest economic competitiveness among the suggested systems. The system reduces the cost of operating the SOFC, improves the cost-efficiency of the GT, and decreases power consumption for air compression, consequently representing a 6.9% reduction in the levelized cost of electricity and a 22.8%p increase in economic profitability under market uncertainties when compared to the base case with a typical hybrid system.

Keywords: Process design; Power generation; Ammonia decomposition; Solid oxide fuel cell; Gas turbine; Techno-economic optimization

Yan Zhang, Yuyue Zhou, Dalin Sun, Yingxia Nie, Deyu Wu, Lin Ban, Bing Tang, Song Yang, Hui Li, Tianyi Ma, Heng Zhang,

CeO2-based functional materials: Advancing photo and electro-driven catalysis for environmental remediation and energy conversion,

Coordination Chemistry Reviews,

Volume 527,

2025,

216395,

ISSN 0010-8545,

https://doi.org/10.1016/j.ccr.2024.216395.

(https://www.sciencedirect.com/science/article/pii/S0010854524007410)

Abstract: Transition metal oxides have drawn considerable interest due to their distinctive structure, multiple notable oxidation states, non-toxicity, and environmental sustainability. In the field of catalysis research, a particularly promising and urgent area of focus is the creation of stable and highly effective catalysts based on transition metal oxides. The twin global issues of environmental degradation and energy scarcity demand the creation of novel eco-friendly solutions. These challenges underscore the urgent need for advancing cutting-edge sustainable technologies. Currently, significant attention is focused on photocatalysis, electrocatalysis, and photoelectrocatalysis as viable strategies for addressing energy conversion and environmental remediation challenges. CeO2 has emerged as a catalyst of great promise, primarily due to its unique surface characteristics and distinctive 4f electron configuration. Especially, the coordination of Ce4+ with O2− in CeO2, involving Ce(IV) to O(II) charge transfer, yields a critical defect and a highly active surface. Nevertheless, the limited light-absorbing capacity and electrical conductivity of traditional CeO2 hinder its practical application. Consequently, developing diverse strategies to introduce abundant defects and active sites is pivotal for expanding the catalytic applications of CeO2. This review offers an in-depth overview of recent progress in CeO2-based catalytic systems for photocatalytic, electrocatalytic, and photoelectrocatalytic applications, with a focus on sustainable energy production and environmental pollution mitigation. This review emphasizes the synthesis methods of diverse tailored microstructures (including microspheres, hollows, core-shells, and polytopes) of CeO2, as well as strategies to enhance its catalytic activity via elemental doping, atomic loading, and coupling with oxides, MOFs, and carbonaceous materials to modulate the electronic coordination structure. Additionally, the discussion focuses on the catalytic activities, stabilities, and reaction mechanisms of CeO2-based catalysts, including oxygen vacancy defects, interfacial effects, bonding of reaction product intermediates to catalyst metal active sites, and metal-carrier interactions. Furthermore, this review presents a detailed description of quantitative characterization methods for evaluating oxidation states and oxygen vacancies in CeO2-based materials. Furthermore, the review highlights the current challenges and potential prospects in this research area. By providing a comprehensive update on the latest advances, this review aims to facilitate the informed design of high-performance CeO2-based composite catalysts, serving as a valuable resource for the pursuit of sustainable development goals.

Keywords: CeO2 composites; Photocatalysis; Electrocatalysis; Photoelectrocatalysis; Synthesis strategies; Modification

Xiaobiao Ma, Jing Liu, Yingju Yang, Xue Lv, Xin Wang,

Theoretical screening method of oxygen carriers with high lattice oxygen activity towards CO oxidation,

Journal of the Energy Institute,

Volume 119,

2025,

102021,

ISSN 1743-9671,

https://doi.org/10.1016/j.joei.2025.102021.

(https://www.sciencedirect.com/science/article/pii/S1743967125000492)

Abstract: The development of oxygen carriers with superior performance is crucial for chemical looping combustion. Here, the theoretical screening method based on two reactivity descriptors was proposed via the density functional theory calculations in order to screen the transition-metal-doped perovskite-type oxygen carriers. Experiments were conducted to comprehensively investigate the effects of transition-metal doping on the reaction characteristic of LaMnO3 oxygen carrier with CO. The theoretical results indicate that the doping of Fe, Co, Ni and Cu can reduce the formation energy of oxygen vacancy on the LaMnO3 surface. The substitution of Co and Cu can improve the reaction rate of CO oxidation, while CO oxidation is inhibited after the doping of Fe and Ni. Among them, Co-doped LaMnO3 has the lowest activation barrier of 51.06 kJ/mol during CO oxidation. Experimental results demonstrate that Co- and Cu-doped LaMnO3 show better activity than undoped LaMnO3 at the lower temperatures, which is consistent with the theoretical screening results. Co doping can still improve the reaction rate of oxygen carrier at the higher temperatures. Moreover, the doping of Co can further enhance the oxygen release property of LaMnO3. The weight loss of LaMnO3 increases from 8.67 % to 9.09 % after Co doping. Co-LaMnO3 also exhibits good sintering resistance and can be used as a promising oxygen carrier during chemical looping combustion. This work paves a new way to design and screen highly efficient oxygen carriers for chemical looping combustion.

Keywords: Chemical looping combustion; Reactivity descriptor; Screening method; LaMnO3 perovskite; Density functional theory

Bo Jin, Mengtian Xu, Ruiyue Wang, Yihan Fan, Xiaoju Xiang, Haibo Zhao, Zhiwu Liang,

Steel slag derived oxygen carriers and solid sorbents for chemical looping CO2 capture: A mini review,

Results in Engineering,

2025,

104438,

ISSN 2590-1230,

https://doi.org/10.1016/j.rineng.2025.104438.

(https://www.sciencedirect.com/science/article/pii/S259012302500516X)

Abstract: Steel slag is a solid waste in iron and steel industry, which shows a harmful effect on the environment as its high valuable reutilization ratio is quite low. Since it possesses high calcium and iron concentrations, it can be potentially used as oxygen carrier and solid sorbent for chemical looping CO2 capture processes to reduce the material manufacturing cost. To promote the understanding of how to derive oxygen carriers and solid sorbents from steel slags efficiently, this review gives a state-of-the-art on this research area. Two chemical looping CO2 capture process configurations is firstly introduced to address the application scenarios of steel slags and their derivatives. By clarifying the effect of synthesis parameters, reaction conditions and component interactions on the redox reactivity and CO2 sorption performance, the oxygen transport capacity and CO2 sorption capacity of steel slag derived oxygen carrier and solid sorbent can achieve to 10.63% and 370 mgCO2·g-1 with a low material manufacturing cost, respectively. Several integrations of chemical looping CO2 capture and steel slag reutilization are proposed to realize green and low-carbon iron and steel industry. Challenges and perspectives focus on reaction mechanism, impurity effect and large-scale application for steel slag derived oxygen carriers and solid sorbents.

Keywords: Steel slag; Oxygen carrier; Solid sorbent; CO2 capture; Chemical looping

Leila Dehimi, Oualid Alioui, Yacine Benguerba, Krishna Kumar Yadav, Javed Khan Bhutto, Ahmed M. Fallatah, Tanuj Shukla, Maha Awjan Alreshidi, Marco Balsamo, Michael Badawi, Alessandro Erto,

Hydrogen production by the water-gas shift reaction: A comprehensive review on catalysts, kinetics, and reaction mechanism,

Fuel Processing Technology,

Volume 267,

2025,

108163,

ISSN 0378-3820,

https://doi.org/10.1016/j.fuproc.2024.108163.

(https://www.sciencedirect.com/science/article/pii/S0378382024001334)

Abstract: The global push towards a hydrogen economy fuels hydrogen production from various sources. A crucial step in enriching hydrogen and reducing CO in syngas derived from carbon-based hydrogen production is the water-gas shift reaction (WGSR). Given the equilibrium-limited nature of WGSR, low temperatures are necessary to reduce carbon monoxide concentrations to the desired level. Traditionally, iron‑chromium (Fe/Cr) and copper‑zinc (Cu/Zn) catalysts have been widely used at high and low temperatures, respectively. Numerous studies have focused on developing optimal WGS catalysts with the desired characteristics and efficiency. This review extensively discusses various catalysts for different stages of WGSR, including low, medium, high-temperature, and sour WGS catalysts. However, understanding the contrast between the redox and associative mechanisms and the nature of intermediates in the WGS pathway remains unclear. A detailed study of the WGSR pathway is imperative to develop highly active and stable catalysts. Various experimental kinetic values and models have also been reported to elucidate the WGSR mechanism at different temperatures. The primary deactivation sources of WGS catalysts have been discussed to highlight recent advances to improve catalyst performance. The contribution of computational methods such as Density Functional Theory (DFT) to developing WGS catalysts is also explored. Furthermore, the review addresses the challenges encountered in the WGSR, and recommendations and conclusions are drawn to guide future research efforts.

Keywords: WGSR; Hydrogen production; WGS catalysts; Kinetics; Reaction mechanism; Computational Methods (DFT)

Jiajun Chen, Xiaojia Wang, Didi Gai, Jinlong Wang,

B-site semi-doped LaFeO3 perovskite oxygen carrier for biomass chemical looping steam gasification to produce hydrogen-rich syngas,

International Journal of Hydrogen Energy,

Volume 103,

2025,

Pages 446-455,

ISSN 0360-3199,

https://doi.org/10.1016/j.ijhydene.2025.01.190.

(https://www.sciencedirect.com/science/article/pii/S0360319925002113)

Abstract: Chemical looping steam gasification (CLSG) of biomass can produce hydrogen-rich syngas, which is an environmentally friendly and efficient technology. LaFeO3 (LF)-based perovskite is synthesized by sol-gel method as oxygen carrier, and the impact of B-site metal (Ni, Mn) semi-doped on gasification is investigated. The experimental results show that an oxygen carrier LaNi0.5Fe0.5O3 (LNF) doped by Ni doping has a good promotion effect on CLSG performance. Compared with iron ore, the total gas production and hydrogen selectivity of LNF increase by 46.7% and 45.7%, reaching 1.213 Nm3/kg and 0.622 Nm3/kg, respectively. Further, through characterization analysis, the performance improvement of CLSG is mainly attributed to the fact that the loading of Ni can effectively improve the lattice oxygen mobility. In addition, LNF has excellent carbon resistance performance, which ensures catalytic activity during multiple oxidation-reduction processes, and achieves satisfactory cycle stability.

Keywords: Chemical looping steam gasification; Oxygen carrier; Perovskite; Hydrogen-rich syngas

Jun-Xi Wu, Yu Mao, Yongfang Zhou, Zihe Wang, Shanghai Wei, Bruce C.C. Cowie, Aaron T. Marshall, Ziyun Wang, Geoffrey I.N. Waterhouse,

Divalent site doping of NiFe-layered double hydroxide anode catalysts for enhanced anion-exchange membrane water electrolysis,

Chemical Engineering Journal,

2025,

160753,

ISSN 1385-8947,

https://doi.org/10.1016/j.cej.2025.160753.

(https://www.sciencedirect.com/science/article/pii/S1385894725015748)

Abstract: Nickel-iron layered double hydroxide (NiFe-LDH) catalysts exhibit excellent activity for the oxygen evolution reaction (OER) in alkaline media. Doping different metal cations in the divalent (Ni2+) sites of NiFe-LDH catalysts has been shown to enhance OER activity, though the enhancement mechanism remains unclear. Herein, we synthesized a series of MNiFe-LDH catalysts on Ni foams by partial substitution of Ni2+ for various divalent transition metals (M = Mn2+, Co2+, Cu2+, or Zn2+). A CoNiFe-LDH electrocatalyst outperformed both NiFe-LDH and the other MNiFe-LDH catalysts during OER in 1.0 M KOH, delivering a very low overpotential of 191 mV at a current density of 10 mA cm−2 and achieving a high current density of 1 A cm−2 at 1.90 V as the anode catalyst in an anion-exchange membrane water electrolyser (AEMWE) single cell. Density functional theory (DFT) calculations indicate that the introduction of Co2+ can significantly reduce the adsorption strength of the \*OH intermediate on (015) facets of “working NiFe-LDH-based catalysts”, thereby reducing the theoretical overpotential for enhanced OER activity. Furthermore, the CoNiFe-LDH electrocatalyst showed excellent stability during OER at high current densities. Divalent-site doping therefore offers a simple and efficient strategy for enhancing the performance of NiFe-LDH-based catalysts for OER and AEMWEs.

Keywords: Nickel-iron layered double hydroxides; Oxygen evolution reaction; Divalent-site doping; Anion-exchange membrane water electrolysers; Synergetic electronic interactions

Shuo Zhai, Junyu Cai, Idris Temitope Bello, Xi Chen, Na Yu, Rubao Zhao, Xingke Cai, Yunhong Jiang, Meng Ni, Heping Xie,

Boosting direct-ethane solid oxide fuel cell efficiency with anchored palladium nanoparticles on perovskite-based anode,

Advances in Applied Energy,

Volume 17,

2025,

100206,

ISSN 2666-7924,

https://doi.org/10.1016/j.adapen.2025.100206.

(https://www.sciencedirect.com/science/article/pii/S2666792425000010)

Abstract: An efficient anode catalyst for hydrocarbon fuel in Solid Oxide Fuel Cells (SOFC) should possess a stable phase structure, high catalytic efficiency, and excellent coke resistance. However, traditional nickel-based anodes necessitate high steam-to-carbon ratios to prevent coking, complicating system design and reducing the overall performance. In this work, we report a nickel-free PrBaFe1.9Pd0.1O5+δ perovskite as anode material for direct ethane SOFC, which demonstrates superior electroactivity and chemical stability. Under a reducing atmosphere, Pd nano-catalysts exsolved in-situ are uniformly anchored to the perovskite surface. Density functional theory analyses reveal that the Pd exsolution significantly improve ethane adsorption capacity, thereby reducing activation resistance and boosting catalytic performance. When used as an anode for an SDC electrolyte-supported SOFC, superior performance is achieved with the peak power densities (PPDs) of 702 and 377 mW cm-2 at 800 °C when using hydrogen and almost dry ethane (3% H2O) as fuel, respectively. Moreover, the cell exhibits a stable continuous operation over 90 h under almost dry ethane atmosphere at 178 mA cm−2, presenting a promising pathway for developing high-performance, nickel-free SOFC anodes that simplify system design and improves efficiency when operating with hydrocarbon fuels, thus holding significant potential for practical SOFC applications.

Keywords: Solid oxide fuel cell; Anode; Ethane fuel; Pd nanoparticles; Adsorption energy