Institute of Chemical and Engineering Sciences

ICES

CCUS CAPABILITIES AND INITIATIVES AT ICES, A*STAR

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Institute of Chemical and Engineering Sciences

A*STAR

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Outline

Introduction

CO_2 Mineralisation

CO_2 to fuels and chemicals

CCU Translational Testbed (CCUTT)

Summary

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CO_2 can be a valuable raw material, not just a climate killer

- **CO_2-based products** (building materials, chemicals, fuels) is a **trillion-dollar market**
- CO_2 can be **reused** instead of pulling carbon from fossil sources
- CCU technology is key to helping us meet climate goals as well as economic goals

[Using CO2 as an industrial feedstock could be a game-changer | World Economic Forum (weforum.org)]

[CO2 can be a valuable raw material, not just a climate killer. Here's how | World Economic Forum (weforum.org)]

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CCUS value chain at ICES

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Capture

- Ammonia-based Low Conc. CO_2 Capture

Storage

- Feasibility study of storage of CO_2 in regional reservoirs (with NUS)

Utilisation

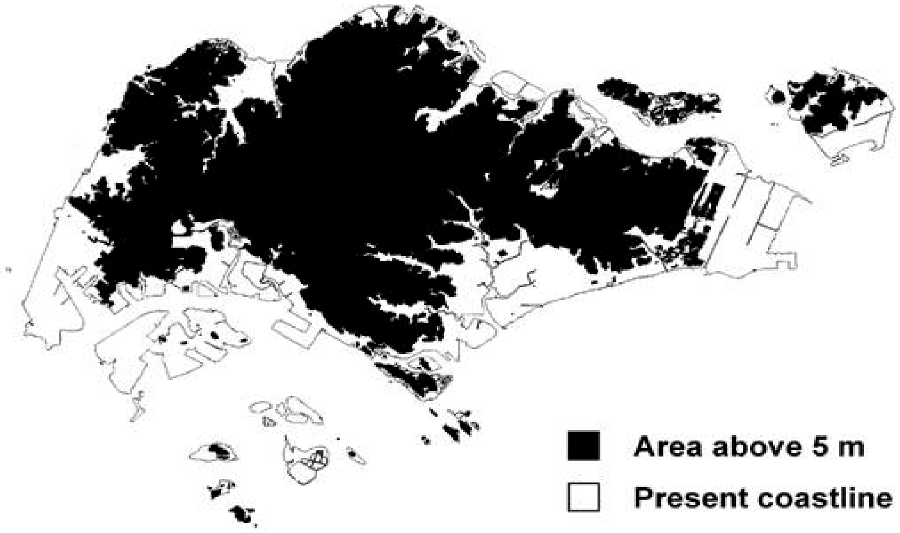
- CO_2 Mineralisation
- CO_2 to Fuels\Chemicals\Materials

- Process Safety
- Process Design
- Techno-Economic Analysis + Life Cycle Assessment
- Carbon Capture and Utilisation Translational Testbed

CO_2 Mineralisation

Global warming has a large impact on Singapore

- Sea levels will rise up to 5 m by 2300 if CO_2 reduction targets are not met
- **30% land area of Singapore is lower than 5 m above sea level, including areas of high economic importance like Jurong Island**
- Large quantities of sand required for coastal protection



https://www.straitstimes.com/singapore/national-day-rally-2019-100-billion-needed-to-protect-singapore-against-rising-sea-levels

CO_2 Mineralisation generates "Alternative Sand"

- CO_2 Mineralisation

  Olivine: $Mg_2SiO_4 + \mathbf{2CO_2} \rightarrow \mathbf{2MgCO_3 + SiO_2}$

  Serpentine: $Mg_3Si_2O_5(OH)_4 + \mathbf{3CO_2} \rightarrow \mathbf{3MgCO_3 + 2SiO_2} + 2H_2O$

- Solid carbonated mineral can be stored **safely and permanently**, 20 – 30 kt CO_2/ha
- Natural minerals, mineral waste from construction & demolition and incineration bottom ash (IBA) can be used as feedstock for mineralisation

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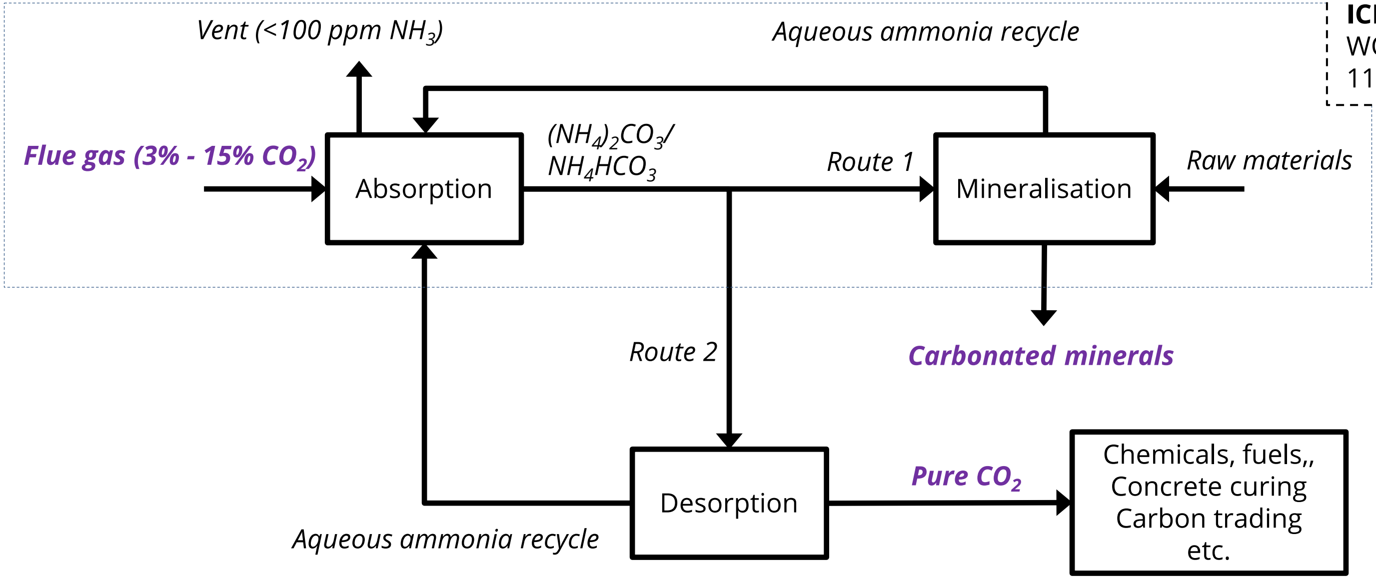
Integration of CO_2 Mineralisation Tech with CO_2 Capture

ICES Patent Filed :
WO 2018/182506 (WO)
11201908958V (SG)



- Flexible in capturing different CO_2 concentrations, including dilute CO_2 in flue gas (typical of Singapore's emissions)
- Comparatively low energy cost – operates at room conditions
- Avoids the use of environmentally unfriendly binders or additives

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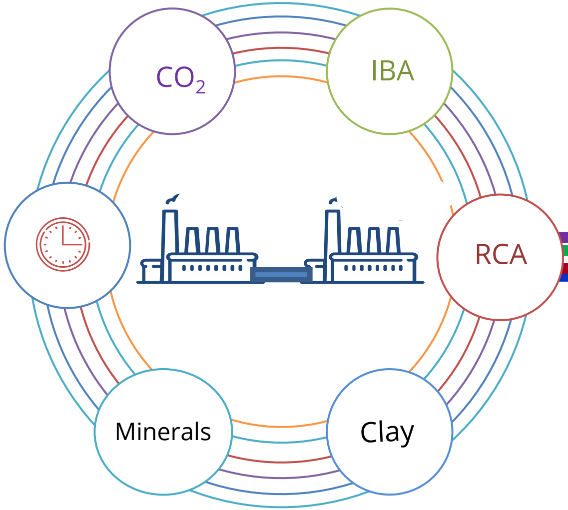
CO_2 Mineralisation brings 3R benefits to Singapore

R educing CO_2 **R** educing landfill **R** educing sand imports



CCUS	CO_2 capture technology for low conc. flue gas
IBA	Efficient utilisation instead of landfill
RCA – Construction by-products	Repurposing concrete based materials
Marine Clay	Readily available material

ICES' CO_2 Mineralisation technology has attracted interest from public agencies and industries

- Produced up to bench scale
- Funding to scale up mineralisation for field testing
- Collaboration opportunities

CO_2 → **CO_2 Mineralisation Package** → Carbonated aggregates

Minerals → **CO_2 Mineralisation Package** → Byproducts

CO_2 abatement substitute for sand or aggregate

Valuable products
Silica, $MgCO_3$

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CO_2 to Fuels and Chemicals

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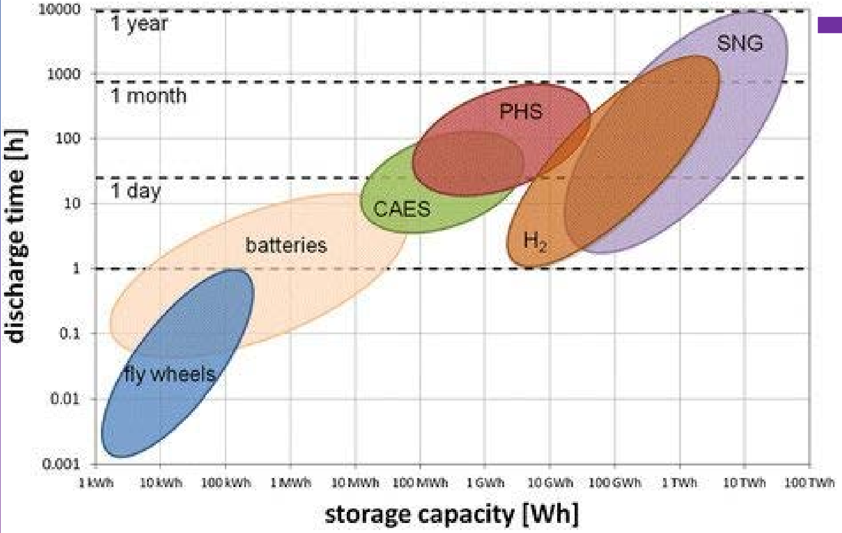
Advantages of Substitute Natural Gas as an energy carrier

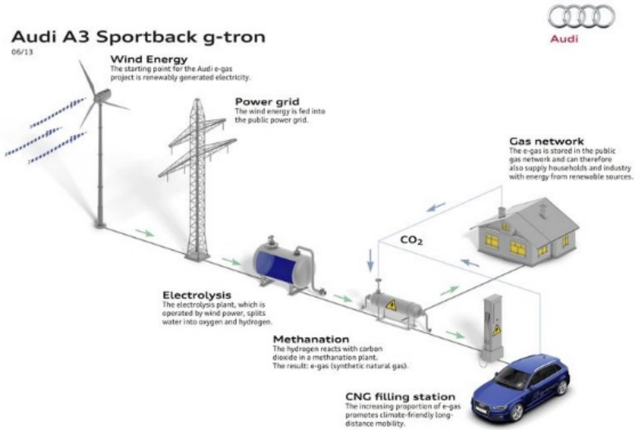
CO_2 methanation using renewable H_2



Schaaf *et al*. Energy, Sustainability and Society
DOI 10.1186/s13705-014-0029-1

1. Simpler to handle / transport
2. Mature gas grid system
3. Can be stored long-term
4. High storage capacity

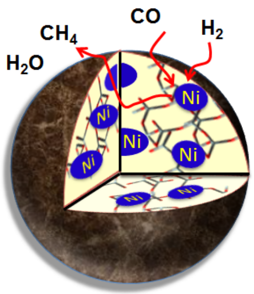
Audi PtG e-Gas project



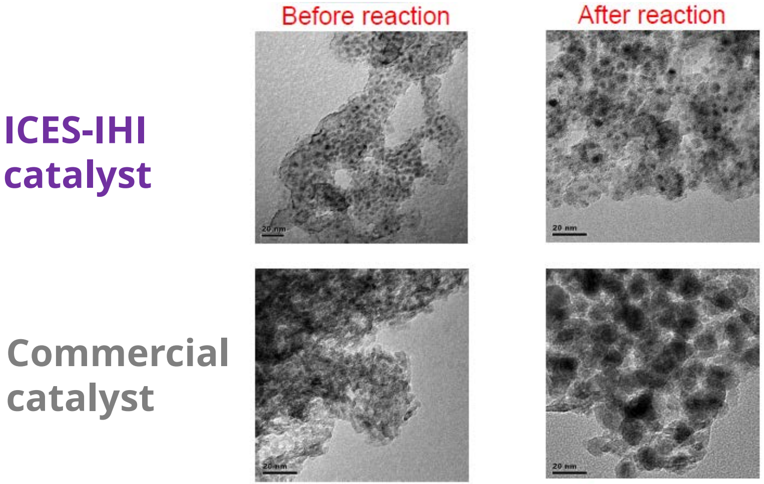
https://www.greencarcongress.com/2015/07/20150715-egas.html

Unique advantages of ICES-IHI Catalyst for methanation reaction

- Well dispersed Ni nanoparticles protected by porous SiO_2
- Flexible for a wide range of Ni loading
- Enhanced resistance to sintering, coking and S poisoning
- Easy to scale up



Ni#mSiO_2
Dispersed Ni NPs in porous SiO_2 matrix



JP Patent No. 6185073, Grant Date: 4 August 2017
SG Patent No. 11201503403Q, Grant Date: 17 April 2017

IHI Realize your dreams

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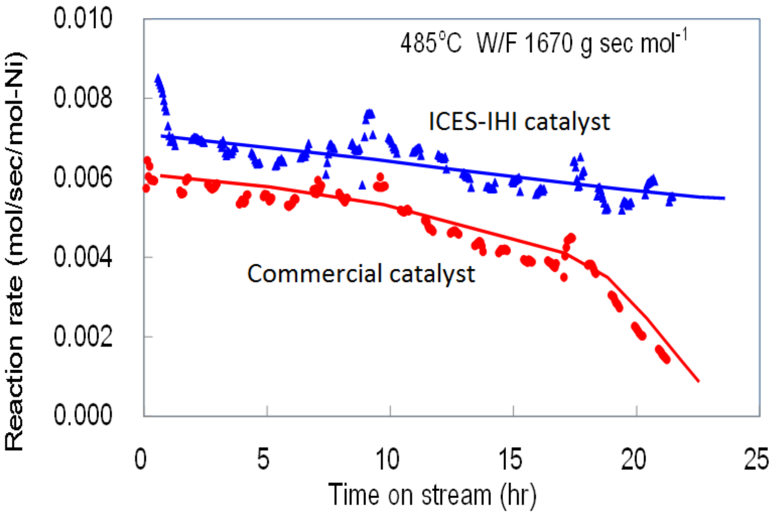
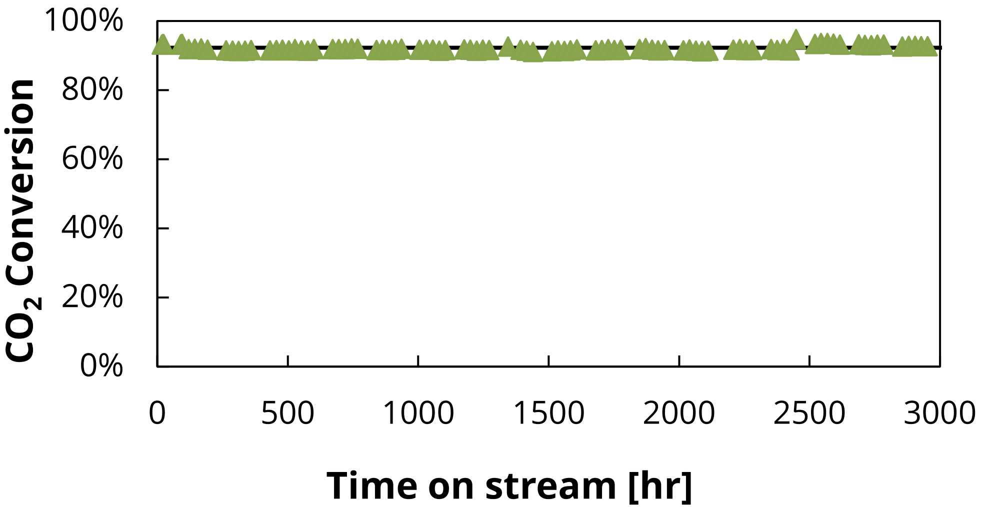
Lab and field test of catalyst stability





IHI Realize your dreams

Institute of Chemical and Engineering Sciences ICES

Translating science to industrial application

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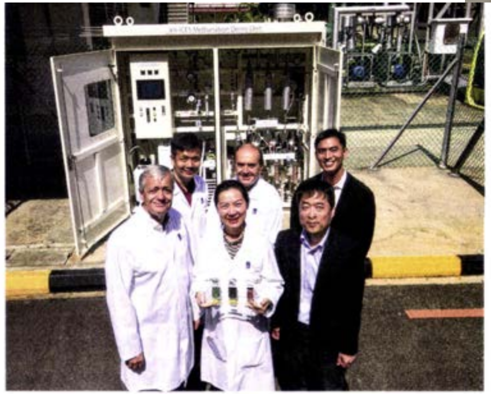
The Business Times report



A demonstration unit of the new technology by IHI and ICES is set for launch on Jurong Island on May 10. The development makes economic and environmental sense for Jurong Island's energy-intensive industries, amid Singapore's new carbon tax that kicks in this year. PHOTO:

CO_2 feed rate

0.2 kg/d
Lab scale

2 kg/d
Demo unit
ICES

50 kg/d
IHI
Yokohama

0.5 tonne/d
Industrial-scale demo at IHI, Soma

IHI Realize your dreams

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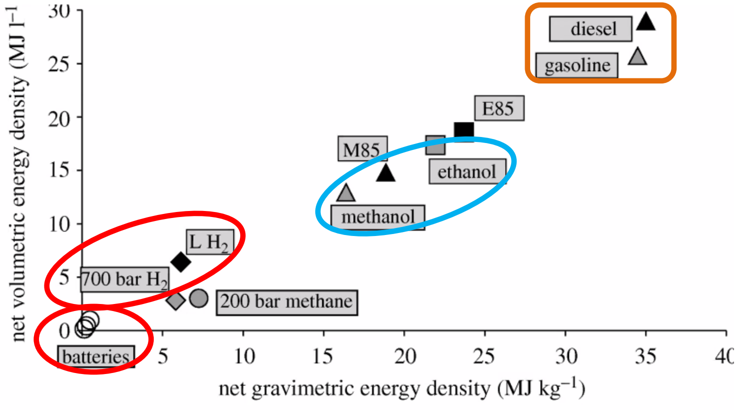
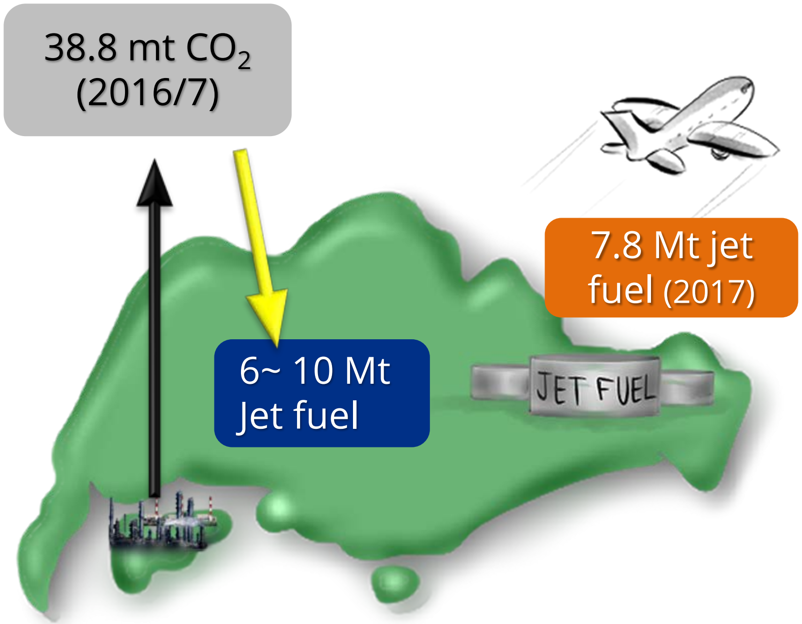
CO_2-based jet fuel offers a potential solution for decarbonisation of aviation industry

Existing alternative technologies have limitations

- Battery and H_2 have low energy densities compared to hydrocarbon fuels
- Biofuel is limited (< 0.1% of total SAF in 2018)



Z. Jiang, P. Edwards*, et al, Phil. Trans. R. Soc. A (2010), **368,3343.**



Direct thermal catalytic conversion of CO_2 to jet fuel

ICES is developing a thermal catalytic process to **directly convert CO_2 into carbon-neutral liquid fuel** which has potential for the decarbonisation of aviation industry as drop in fuel

ICES' approach:

One step mild exothermic reaction
CO_2 +H_2

- Smaller footprint
- Simpler process
- Higher energy efficiency
- Cost reduction

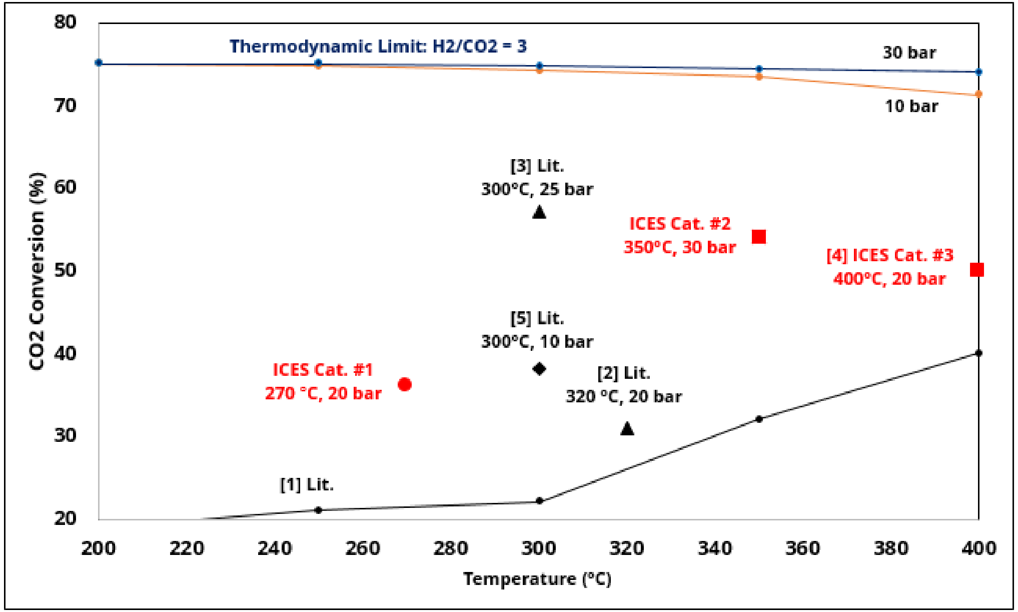
Current **two-step** approach:

High energy required to break CO_2 to CO → Strong Exothermic CO+H_2 reaction

Benchmarking ICES Catalysts with Published Results

Supported by UGT A*STAR seed funding

TRL2~3, 1 TD submitted



[1]. Environmental Progress & Sustainable Energy, 38, 1, 98

[2]. Nature Comm. 2017, 8, 15174

[3]. Catal. Sci. Technol., 2018,8, 4097

[4] J. Mater. Chem. A, 2020, https://doi.org/10.1039/D0TA04608F

[5] Nat Commun. 2020, 11, 6395

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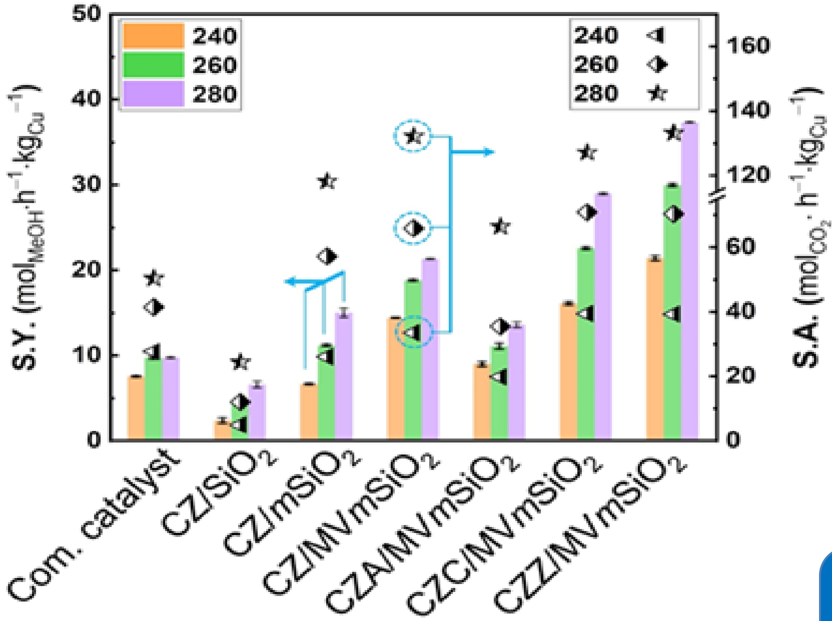
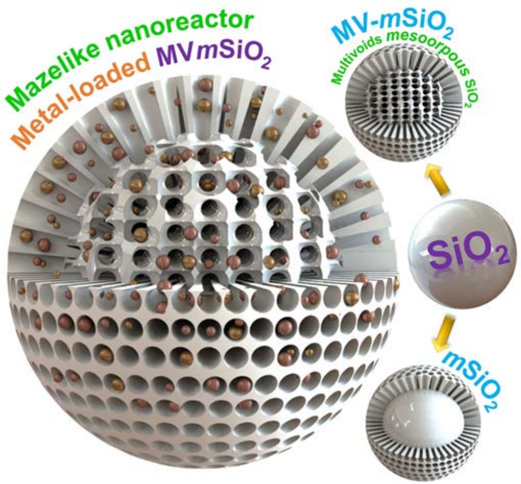
Mazelike nano-reactor for enhanced catalysis in CO_2 to methanol





ICES-NUS Collaboration

- Cu activity and selectivity: 2~5 times higher than commercial catalyst
- High stability and low metal content

Mohammadreza Kosari et al, Advanced Functional Materials
https://doi.org/10.1002/adfm.202102896

Catalytic CO_2 conversion development at ICES

H_2

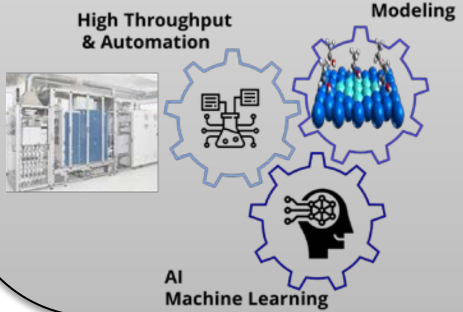
- Kerosene/methanol (CCUS OTR)
- Light olefins (industrial collaboration)
- Methane (industrial collaboration)

Catalyst design/ scale up → Reactor/ process design → System integration

Accelerated catalyst development platform

CCU Translational Testbed (CCUTT)

Pilot plant & Commercialisation



CCU Translational Testbed (CCU-TT)

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State of the Industry: The road to commercialisation

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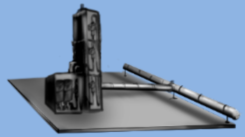
CCU
Translational Testbed

Research

mg - g / d

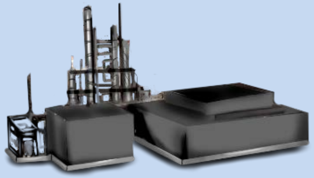
Test bedding of emerging technologies

kg / d



Industrial Pilot

t / d



Industrial Adoption

kt-Mt / d

Invention & Lab Validation (TRL 1-3)

Testbedding & Demonstration (TRL 4-7)

Technology Adoption (TRL 8-9)

Increasing scale, Increasing capital costs, higher cost of failure

Typical Timeline 8 – 10 Years

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How do we transform the speed of technology development for multiple emerging technologies?

Can we move from the conventional way.....

Invention & Lab Validation (TRL 1-3) → Testbedding & Demonstration (TRL 4-7) → Technology Adoption (TRL 8-9)

g / d **kg / d** **t / d** **kt / d**

.....to the future?

- Faster technology development and implementation
- Greater flexibility
- De-risk technology adoption
- Reduced capital costs

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New paradigm of testbedding and production:
A Future-State approach to supporting the Green Economy

Research

A B D
B C A
Flue CO_2
Carbon Capture
Membrane

A B D
B C A
Flue CO_2
Carbon Capture
Solid Adsorbent

Utilisation
→ X
CO_2 to Methanol
Catalysis

Utilisation
→ X
CO_2 to Kerosene
Catalysis

Utilisation
→ X
CO_2 to Olefins
Catalysis

Green H_2
E.g. electrolysis, methane pyrolysis

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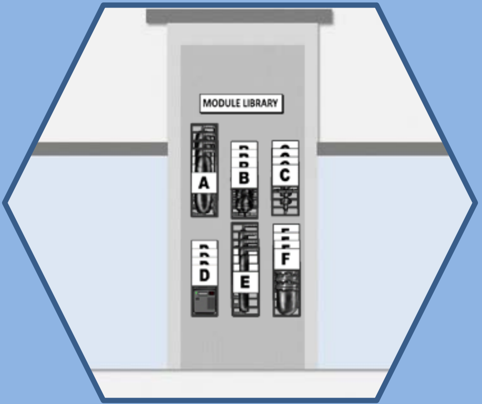
SINGAPORE ENERGY CENTRE
SUTD
NUS
NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE
SIT SINGAPORE INSTITUTE OF TECHNOLOGY

Accelerated CCU Technology Translation

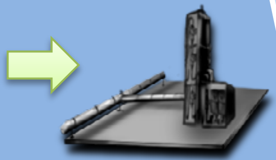


The Future of Chemical Processing

- Modular testbed for multiple technologies
- Data-driven insights
- Land- & cost-effective
- De-risk translation of chemical processes
- Cutting edge workforce

Industrial Pilot

Utilisation
→ X
CO_2 to Kerosene
Catalysis



A B D
B C A
Flue CO_2
Carbon Capture
Membrane

Industrial Adoption

- New, sustainable production paradigms
- Accelerated uptake of CCU technologies

Stakeholders

SURBANA JURONG
sembcorp
PanUnited
Keppel Data Centres
TEMASEK
Shell
ExxonMobil
Chevron

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Key Takeaways

- ICES is active in research areas of CCUS such as CO_2 capture, CO_2 mineralisation and CO_2 to fuels/chemicals with different TRLs
- A unique first-in-its-class flexible modular plug and play tested (CCU-TT) is at the conceptual design phase.
- We are looking for researchers and industrial partners for collaboration in CCUS

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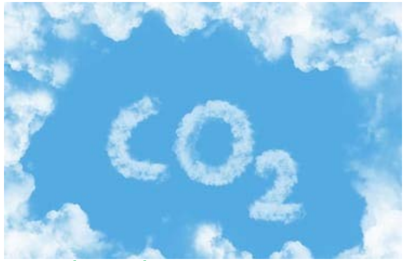
THANK YOU

enquiry@ices.a-star.edu.sg
www.a-star.edu.sg/ices

Other capabilities

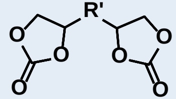
CO2 to polymers at ICES



An abundant, inexpensive, renewable raw material

Bis-Epoxide

Bis-cyclic carbonate

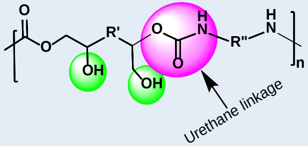


CO_2 content 25-38%

Diamine

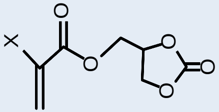
Polymerization

Non-Isocyanate Polyurethane (**NIPU**)



Epoxide (meth)acrylate

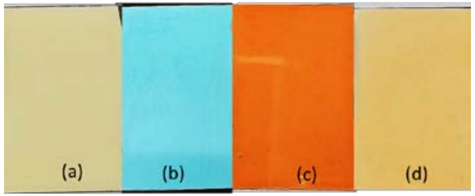
Cyclic carbonate (meth)acrylate



CO_2 content >25%

Radical Polymerization

Poly(meth)acrylates



Polymer coating with different colors on stainless steel substrate

NIPU self standing film

WO2019190408A1
WO2019190409A1
TD 1804-SJ-PEC

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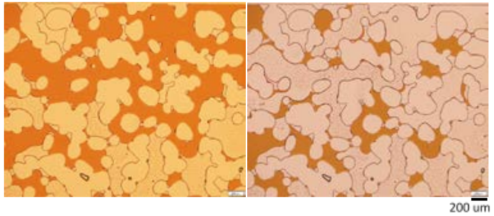
Enhanced oil recovery research at A*STAR and NUS

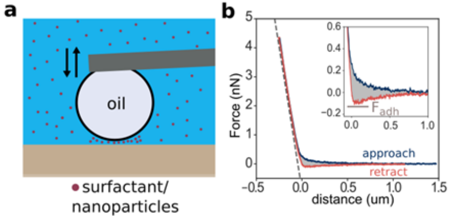
- **ICES** has set up state of the art facilities to test EOR formulations under real life (reservoir) conditions in microfluidic and core flood experiments.
- A strong background in nanoscience, polymer science and formulation to enable development and screening of nanofluids for EOR, including CO_2 based EOR
- Modelling at **IHPC** and AFM studies at **IMRE** complement the experimental findings

- **NUS:** Petroleum Engineering (Prof Lau Hon Chung) – *Mobility control with Pickering emulsions*
- **IHPC:** MSE (Zheng Jianwei) – *Modelling of nanoparticle-rock surface-polymer interaction*
- **ICES:** FMP (Alex van Herk) – *Polymer & nanocolloid synthesis*
- **IMRE:** ACI (Sean O'Shea)- *Colloidal AFM of nanoparticle-rock interactions, ellipsometry*

- **Collaborators:**
- **NTNU (**Norway): Petroleum Engineering (Prof Ole Torsaeter) – *CT imaging of cores*



Micromodel studies



AFM droplet probe

Reservoir condition core flood