NANYANG TECHNOLOGICAL UNIVERSITY

Energy Research Institute @ NTU

## Decarbonisation Technical Workshop of Energy Innovation 2021


# H2FC Research @ NTU

23 July 2021

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- H2FC RD&D in Singapore
- H2FC research @ NTU in the last 30 years
- Commercialization efforts
- Proposed projects aligned with national's decarbonization effort

# History of $H_2$ Activities in SG

**2001**
- Gashub Power formed, 1st FC company in SG
- NTU set up Fuel Cell Strategic Research Program

**2002**

**2003**
- Horizon FC Technologies formed, 2nd FC company in SG
- Rolls-Royce FC Systems engaged EDB, Temasek Holdings, NTU, A*STAR
- F-Cell maintenance facility & 1st BP $H_2$ refueling station

**2004**
- EMA represented SG in APEC EWG workshop – interim framework document for $H_2$
- 1st report "Fuel cell RD&D activities in SG" in FC Bulletin
- 6 Daimler Chrysler F-Cell car test bedding

**2005**
- Enertek formed, US$ 100 m investment
- 2nd H2 refueling station launched
- 3 yr SERC FC programme (A*STAR) launched
- 1st World Hydrogen Technologies Convention hosted in SG

**2006**

**2007**
- Launch of FC community by TP
- Update to "Fuel cell RD&D activities in SG"
- The Singapore Business Federation and Temasek Polytechnic launched Clean Energy Test bedding Community
- HES and NASA set a record for FC powered UAV flight of 128 km

**2008**

**2009**
- Review of SG FC program organized by A*STAR
- Launch of ERI@N, FC is one of the key research areas

**2010**
- SBS Transit & NTU trial H2 hybrid bus during YOG
- MPA and TP launched maritime FC research initiative

**2011**
- JTC installed FC system in CTP 1
- SPURc low carbon research between NTU, NUS & Peking University. Electrolysis & $H_2$ technologies are core focus

**2012**
- Horizon FC and ERI@N flew FC powered UAV

**2013**
- Electro Power System SpA opens a strategic base in SG
- Start of Cambridge center for carbon reduction in chemical technology
- Launch of FC science and technology course in NTU
- Intelligent Energy set up Asian supply chain hub in SG
- H2SG formed in SG

**2014**
- Sembcorp Marine & NTU launch research lab for marine applications of FCs
- Bluebird & HES unveil 10 hrs endurance civilian UAV
- Oneberry technologies offers FC powered CCTV systems
- GIC invests US$ 63 m in Intelligent Energy
- NTU and EU institutions collaborated in "Solid Oxide Cell and Stack Testing, Safety and Quality Assurance"
- ERI@N announces REIDS

**2015**
- ERI@N, Gencell & CIF collaborated on converting waste $H_2$ to energy
- Duralite Power spin-off from TP
- Boeing and HES worked on next-gen zero emissions flight platform
- MHA announced plan to power its new Prison HQ with FC power
- IE signs contract with 2 local companies to deliver key FC parts
- EPS demonstrated FC back-up power system in MAE FC lab

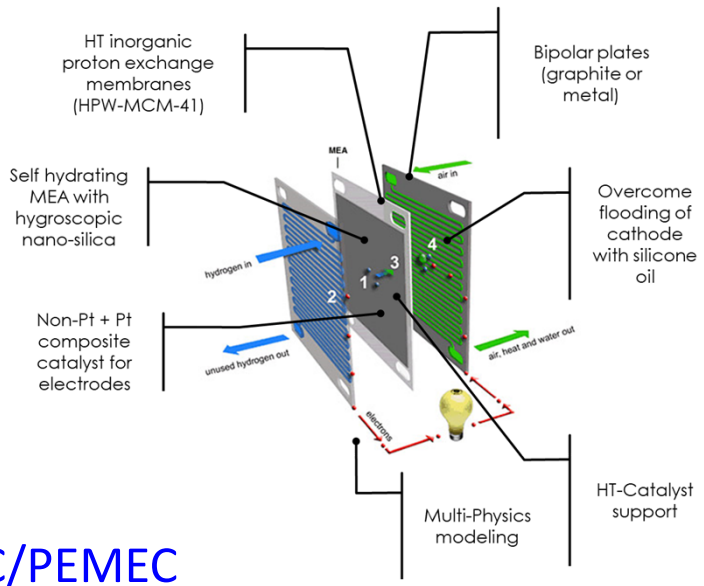
**2016**
- IE, Accenture, Omnetric Group, DNV GL & Grass Energy committed S$150 m in business expenditure on solar, FC, smart grid & testing services in SG
- DNV GL & Horizon Ferry worked on FC powered ferries

**2017**

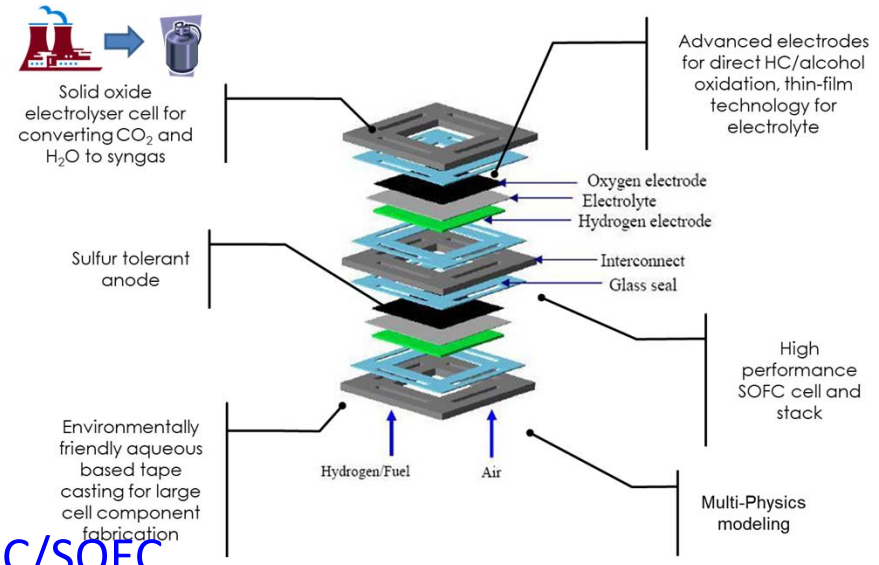
**2018**
- HYPOTHESIS XIII, 1st EU based $H_2$ symposium hosted in SG
- Study of hydrogen imports and downstream applications for SG commissioned by PMO, NCCS
- MOU signed between 4 $H_2$ associations to promote $H_2$ activities

**2019**
- 1st zero-emission building powered by green $H_2$
- NTU & CSIRO hosted $H_2$ hub development workshop

**2020**

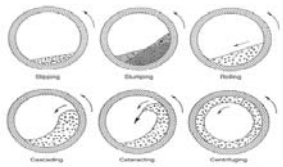


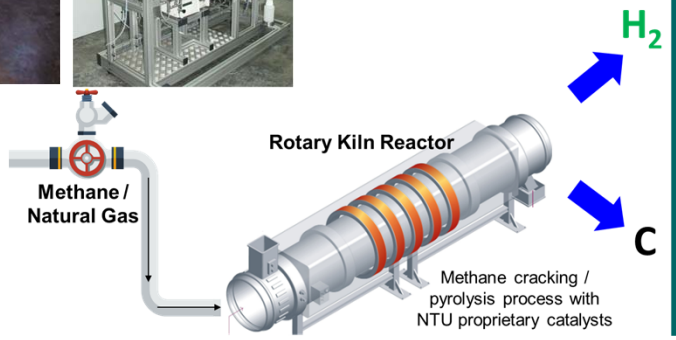

PEMFC/PEMEC



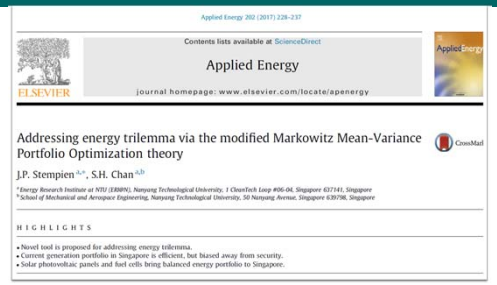

SOFC/SOEC

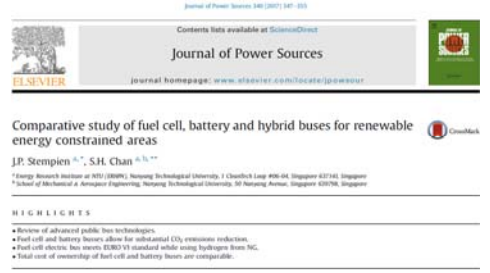
Reforming

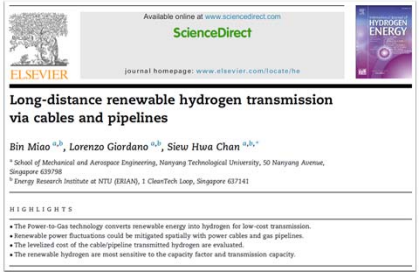





CDM



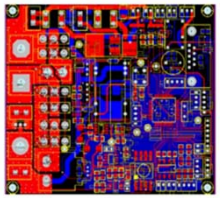



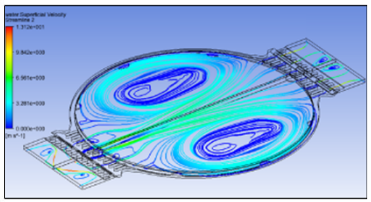




Feasibility study

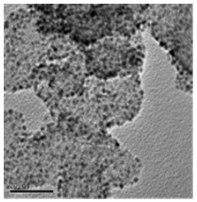
# Snapshot of H2FC Research @ NTU over the last ~30 years

**|PEMFC + EC | SOFC + EC | Hydrogen Technologies|**


*Control circuit board & programming*


*Thermo fluids & thermodynamic analysis*


*Stack development*


*Catalyst development*

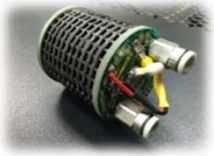

*FC based backup power*


*Distributed Power Generation*

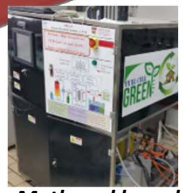

*SOFC/EC*


*H2 based range extender*


*FC charger*

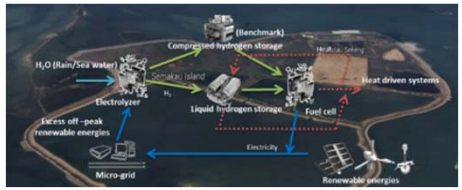

*Mini fuel cell*


*UAVs*


*Methanol based range extender*



*FC hybrid bus for YoG*



*$H_2$ demo @ Semakau Island*

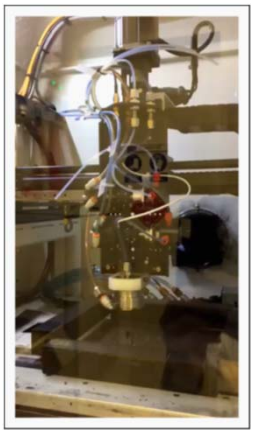

*Remote power generator*


*Micro-power SOFC*


*H2-On-Demand*


*Regenerative fuel cell system*

# Four Major Laboratories *for H2FC Research and Development*

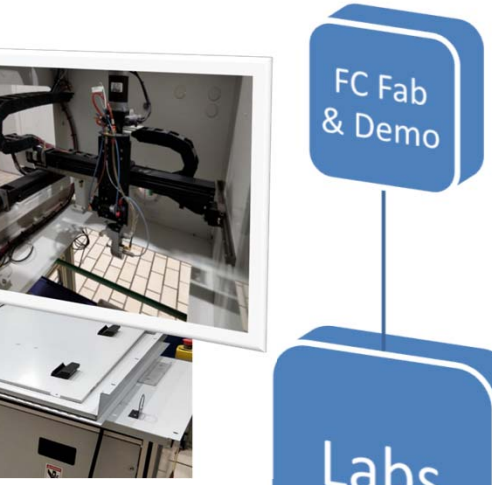


**CSIJRI @ GKC**

(Commercialization)

**ERI@N**

(Novel Catalyst)

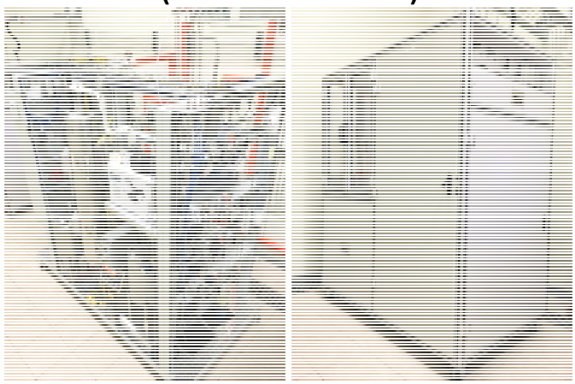



**MAE**

(Fabrication &
Characterization)

**CBE**

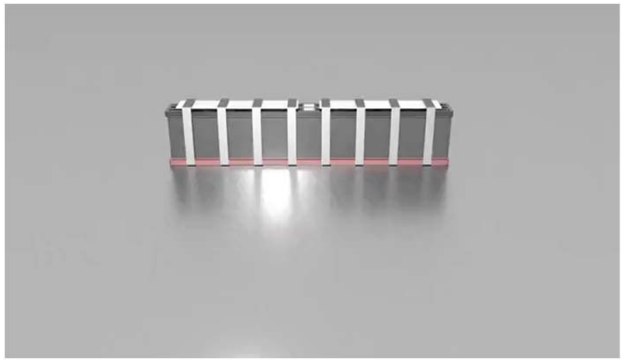
(Power to Gas)

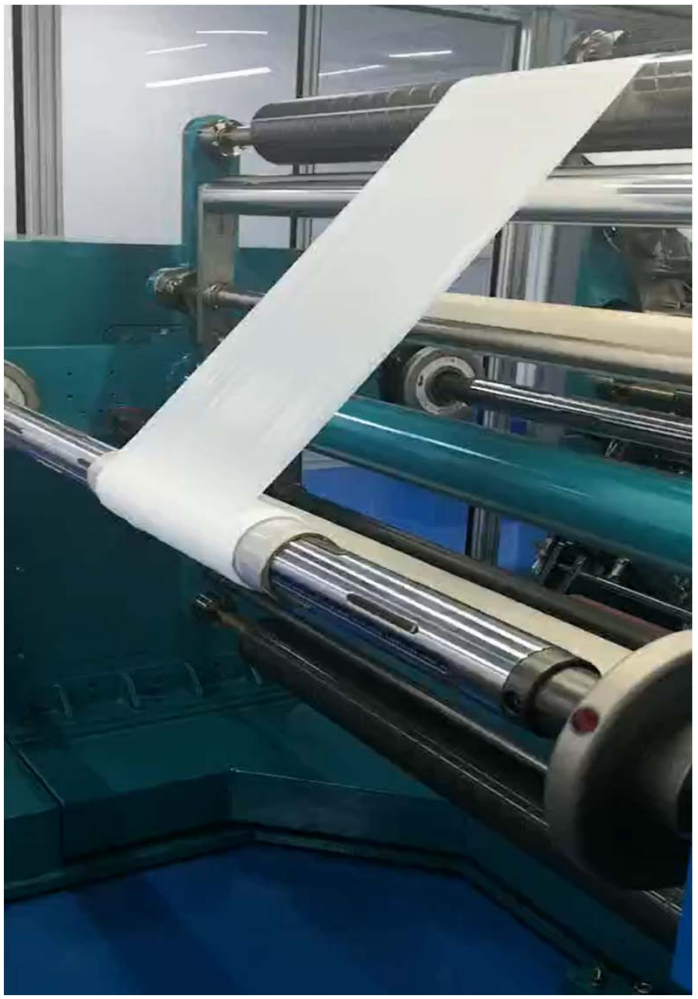


# Xin-Xiang (GZ) Hydrogen Technologies

Commercialization through China-Singapore International Joint Research Institute @ GKC

- Catalyst mass production
- CCM/MEA mass production





Visit of Guangdong Governor Ma Xingrui

Visit of DPM Heng to CSIJRI

Visit of DPM Heng to 新向氢能科技

# NTU-Sydrogen Energy Partnership

- Sydrogen Energy: a JV company of Nanofilm and Temasek
- Sydrogen Energy Core Activity: Manufacture of Fuel Cells
- Scope of collaboration: PEMFC technology, key components design and manufacturing, characterization.

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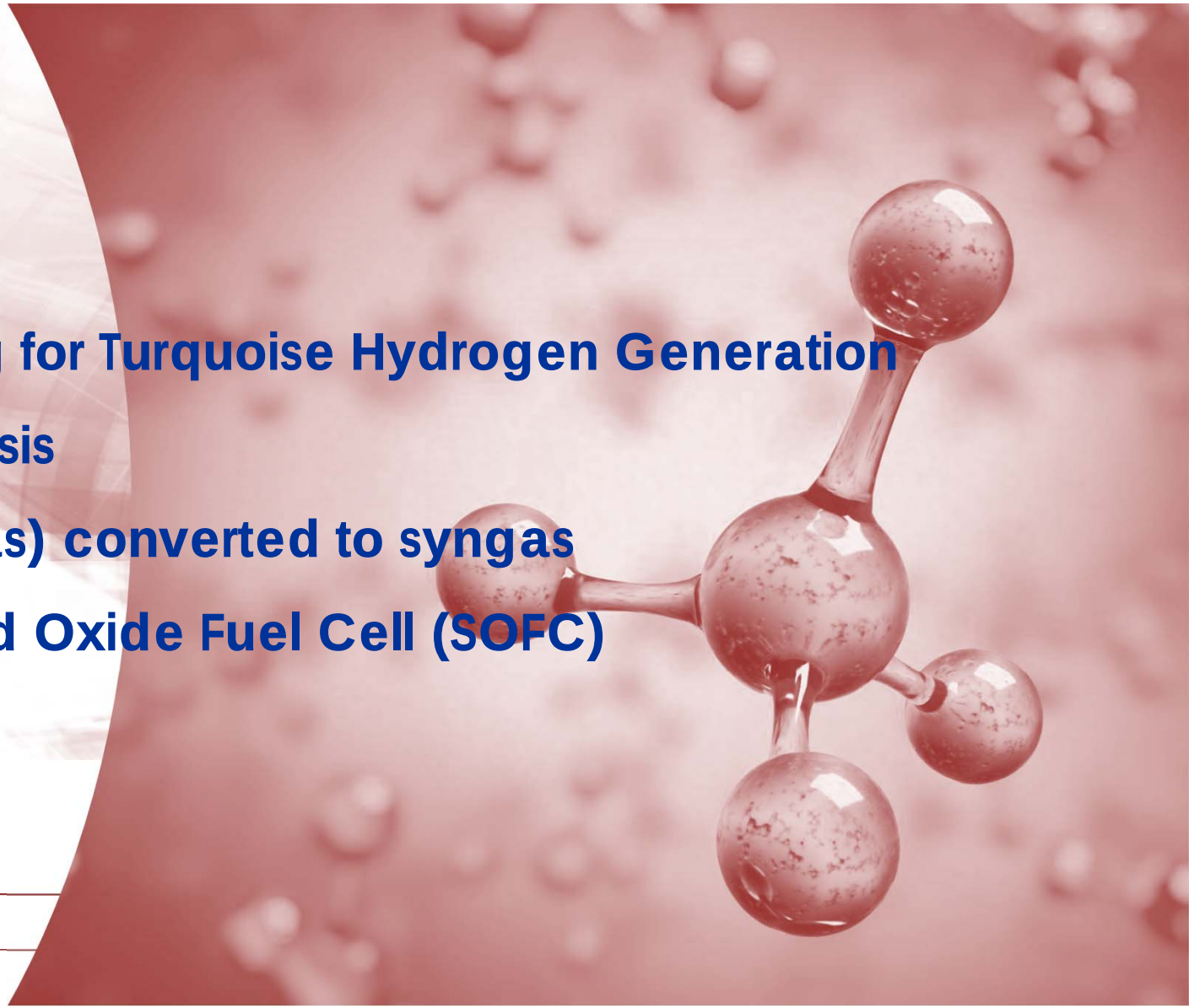
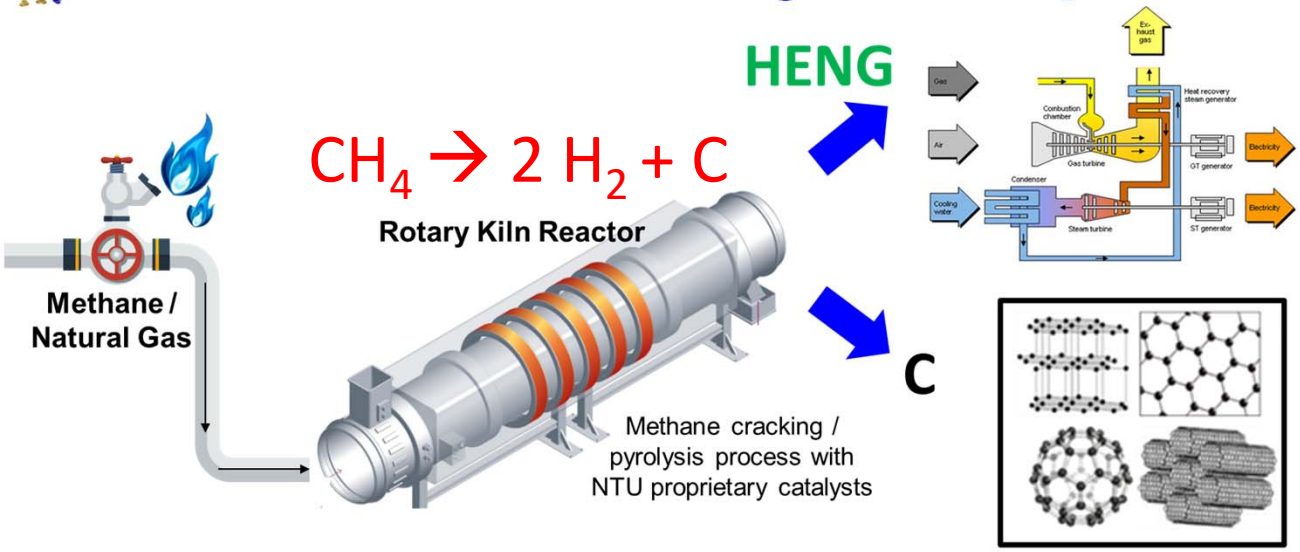
## Research projects:

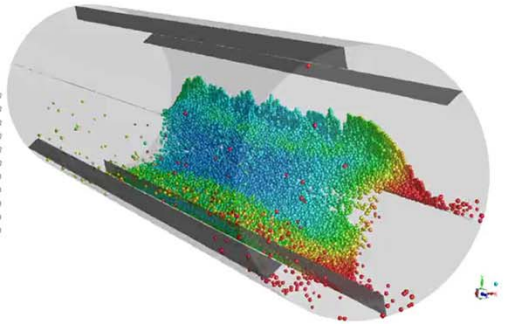
1. Methane Cracking for Turquoise Hydrogen Generation
2. Seawater Electrolysis
3. $CO_2$ + $H_2O$ (flue gas) converted to syngas
4. Ammonia-fed Solid Oxide Fuel Cell (SOFC)



# Methane Cracking for Turquoise Hydrogen Generation

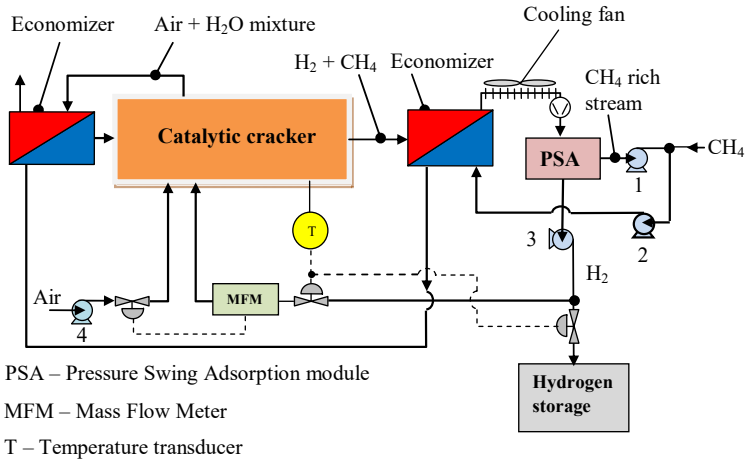



- A technology can potentially produce hydrogen at a cost like SMR but without $CO_2$ emissions.
- By-product graphite powder can be valorized to offset the cost of $H_2$.
- Compared to other reactors, rotary kiln reactor can potentially be scaled up for mass production.
- The challenging issues for research includes (1) catalyst fouling, (2) catalyst regeneration, (3) continuous operation.



Catalyst beads in reactor

| | Ni | Co | Fe |
|---|---|---|---|
| Catalytic activity | Best | Moderate | Relatively poor |
| Temperature range | 500-650°C | 500-900°C | 700-900°C |
| Oxide form | NiO | CoO & $Co_2O_3$ | $Fe_2O_3$ |

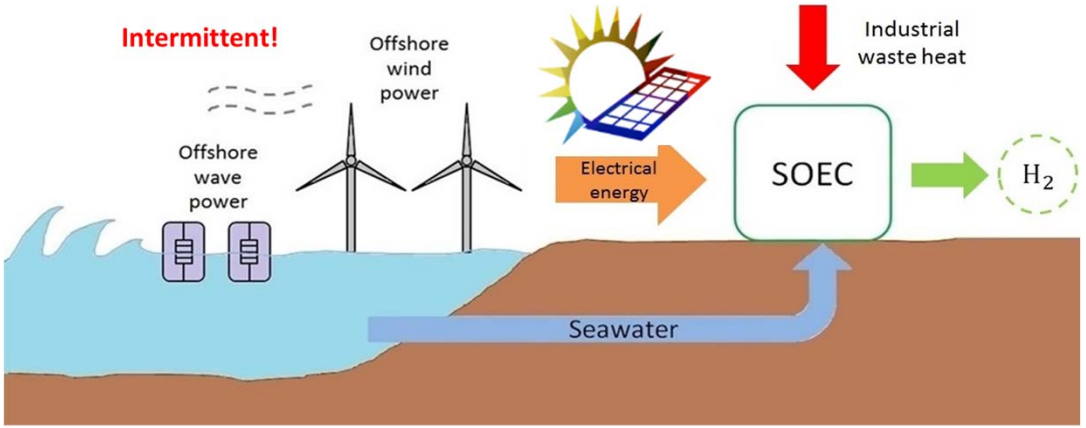



PSA – Pressure Swing Adsorption module

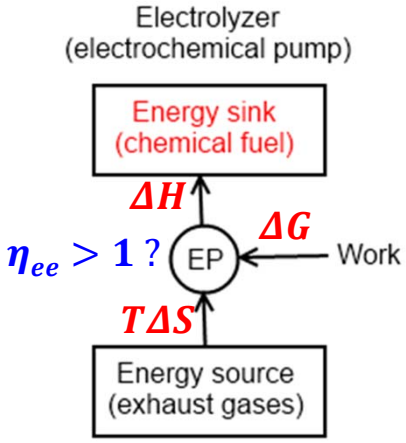
MFM – Mass Flow Meter

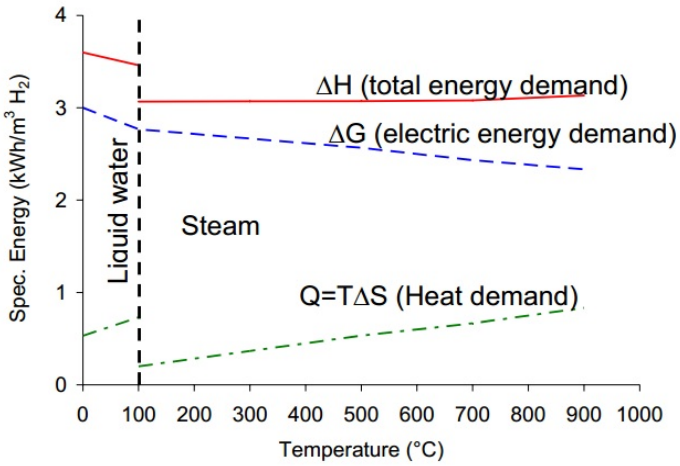
T – Temperature transducer

# Seawater Electrolysis




Overall concept for seawater electrolysis using an SOEC to store offshore renewable energy in the form of $H_2$

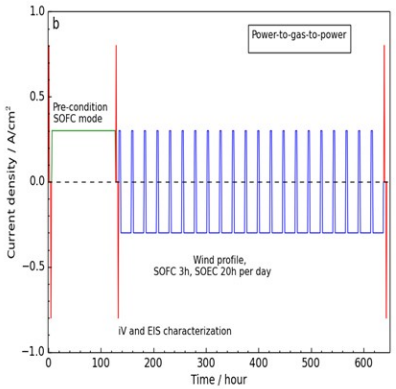


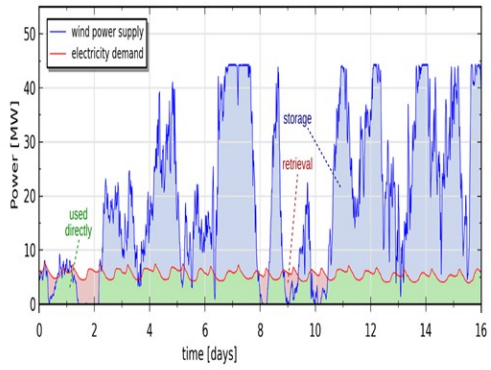




- Solid oxide cell is the ONLY technology that can operate in both fuel cell & electrolyzer modes.
- The electricity to $H_2$ heating value can be more than 100% if waste heat is available.
- SOCTESQA (2014-2017) is a consortium led by DLR. Testing conducted under reversible SOFC/SOEC mode following a wind profile recorded in a Danish island (3 h SOFC, 20 h SOEC per day).
- Challenges: (1) oxidation of fuel electrode, (2) long term effect of impurities ($Na^+$, $Ca^{++}$, etc.) on the fuel electrode.

**SOCTESQA Project Partners**

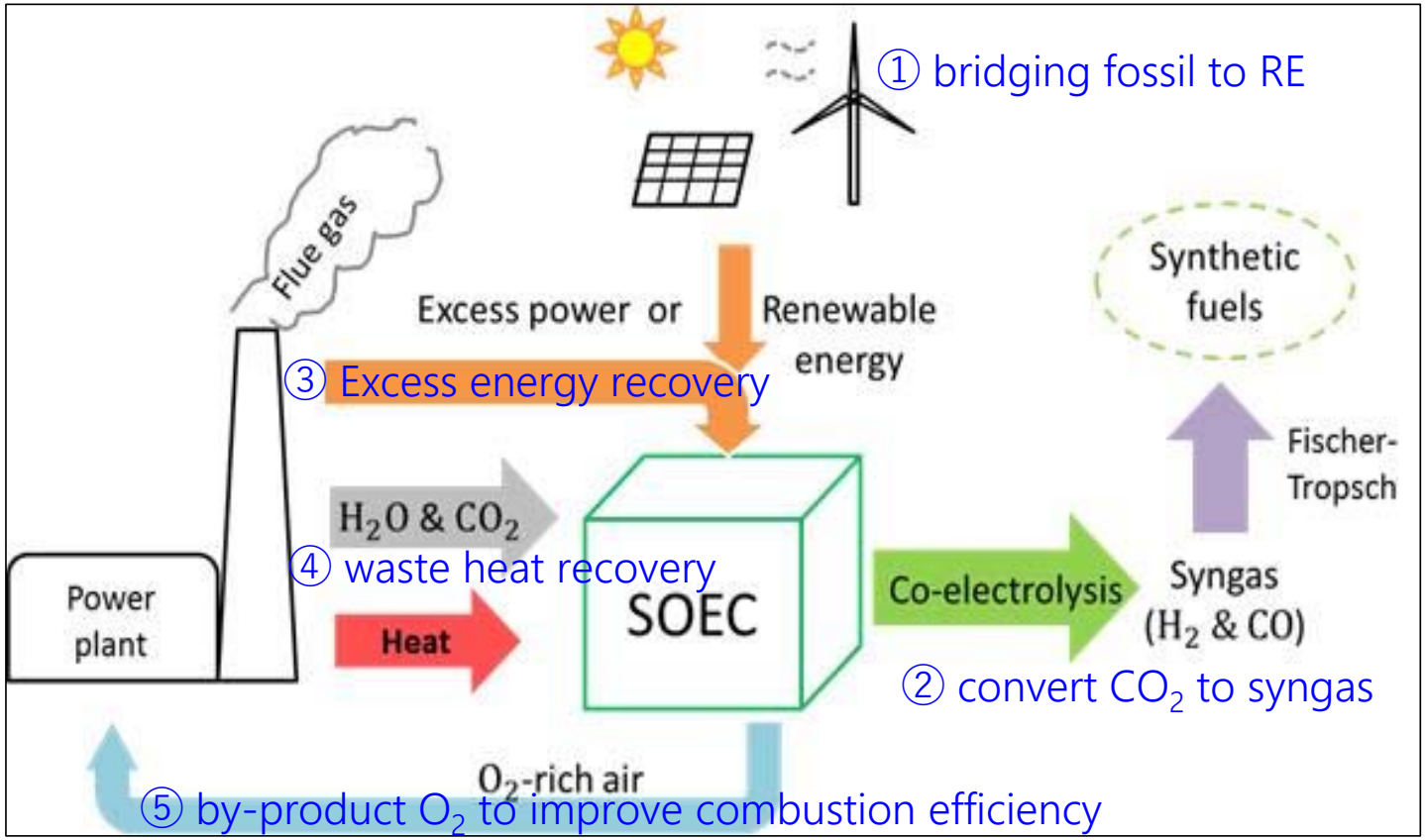
DLR · CEA · DTU · JRC EUROPEAN COMMISSION · ENEA · EIFER · NANYANG TECHNOLOGICAL UNIVERSITY



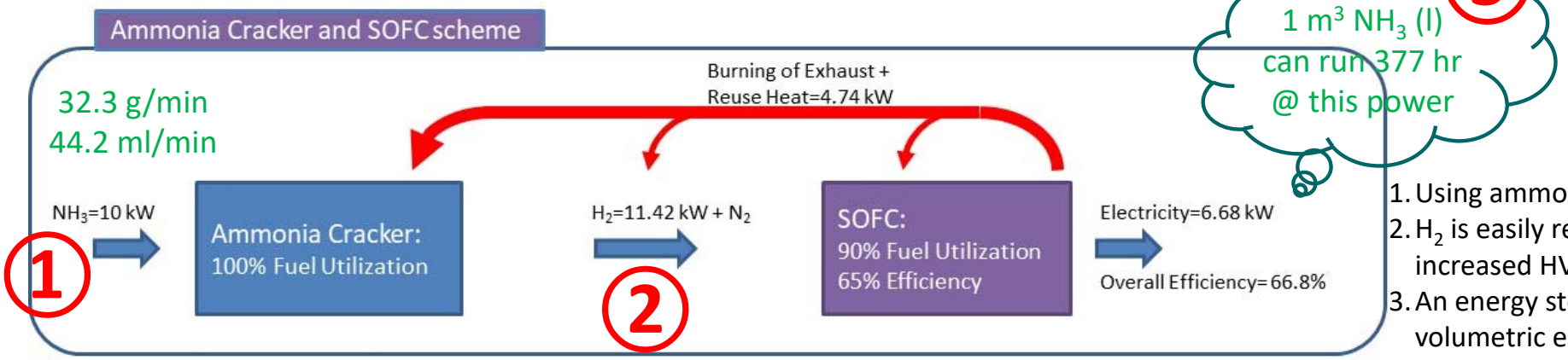



# $CO_2$ Capture from Oxy-Power Plant using SOEC

Flue gas from oxy-combustion plants (metal smelting, glass industries, etc.) contain rich $CO_2$ and $H_2O$.

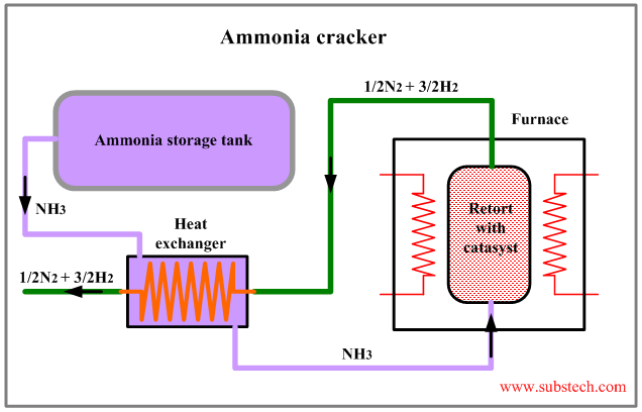


# Ammonia-fed Solid Oxide Fuel Cell (SOFC)




1. Using ammonia as $H_2$ carrier
2. $H_2$ is easily regenerated with increased HV of 14.2%
3. An energy storage with high volumetric energy density
4. NOx issues can be solved.

## Ammonia Cracker




## *NOx can be reduced chemically by either $H_2$ or $NH_3$

4

| | dH [kJ/mol reaction] | dH [kJ/mol NH3] |
|---|---|---|
| 2 NH3 + 3 N2O = 4 N2 + 3 H2O | dH=-1010 | -506 |
| 4 NH3 + 6 NO = 5 N2 + 6 H2O | dH=-2071 | -517 |
| 8 NH3 + 6 NO2 = 7 N2 + 12 H2O | dH=-3259 | -407 |
| H2 + N2O = N2 + H2O | dH=-368.4 | |
| 5 H2 + 2 NO = 2 NH3 + 2 H2O | dH=-844 | |
| 3.5 H2 + NO2 = NH3 + 2 H2O | dH=-651 | |

# Thank you