Teesside University

School of Science, Engineering & Design
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Hydrogen and CCUS – Laboratory Research to Commercial Technology

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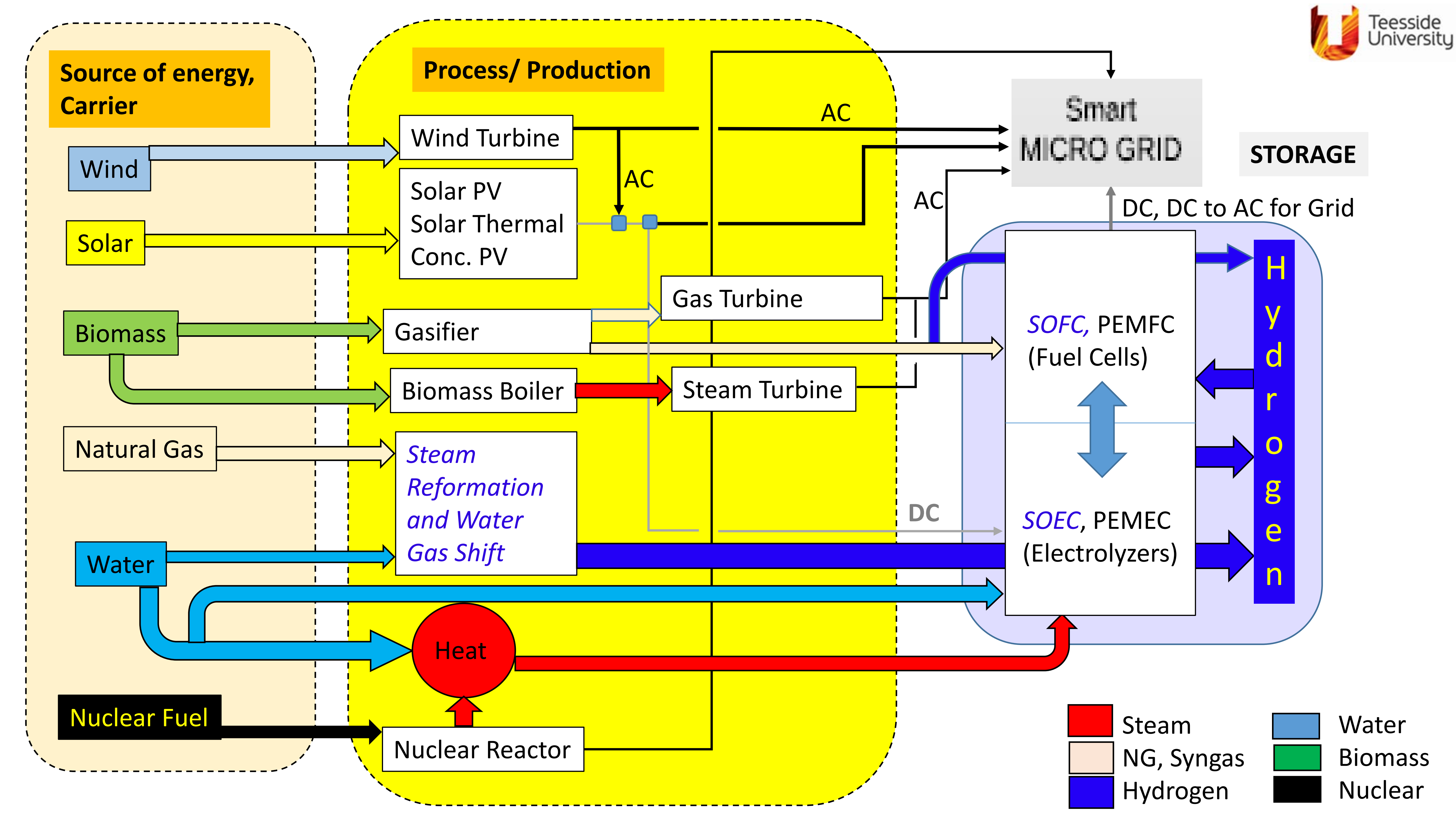

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Source of energy, Carrier
Process/ Production
Wind
Solar
Biomass
Natural Gas
Water
Nuclear Fuel
Wind Turbine
Solar PV
Solar Thermal
Conc. PV
Gasifier
Biomass Boiler
Steam Reformation and Water Gas Shift
Heat
Nuclear Reactor
Gas Turbine
Steam Turbine
AC
AC
AC
DC
Smart MICRO GRID
STORAGE
DC, DC to AC for Grid
SOFC, PEMFC (Fuel Cells)
SOEC, PEMEC (Electrolyzers)
Hydrogen
Steam
NG, Syngas
Hydrogen
Water
Biomass
Nuclear

Tees Valley Hydrogen Innovation Project – Part Of Building A Hydrogen Economy

- ERDF part funded with a duration 1/9/18 – 31/8/21
- 8 TU staff deployed
- Essentially an R & D project TRL 4-5
- Aim of building, commissioning and trialling a laboratory demonstrator unit based on CMR technology for producing H_2 – typical output 150 g/day
- Medium term aim (post project – 2023) of a pilot plant capable of being used as a modular/mobile piece of 'kit'- typical output of 150 Kg/day
- Key project aims:
  - help support the region drive forward a H_2 economy
  - help SMEs develop/build their capability
  - access to demonstrator facility
  - build collaborative networks
  - accelerate innovation
  - seek to improve development and production efficiencies

Collaborative Hydrogen Network – Tees Valley Decarbonisation Agenda

Tees Valley Hydrogen Group

- **Industrial (NEPIC)**
- **Transport (TVCA)**
- **RTOs (Materials Processing Institute, CPI, TWI, TU et al)**

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Promotion

Promote the Project

SMEs registration

Knowledge Exchange

Design, commission and build a demonstrator

Implement new hydrogen technology

Build a scale up hydrogen generator prototype

Access funding support

Development

Support SMEs in new hydrogen technology

Support SMEs to test and develop new materials

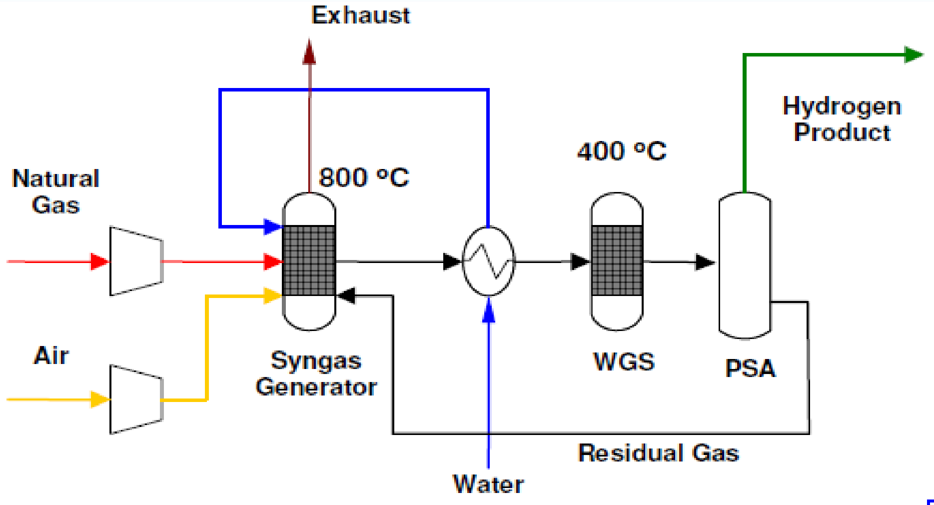
Opportunities for innovation/funding support

Dissemination

Technology/ knowledge exchanges

New training/ academic courses

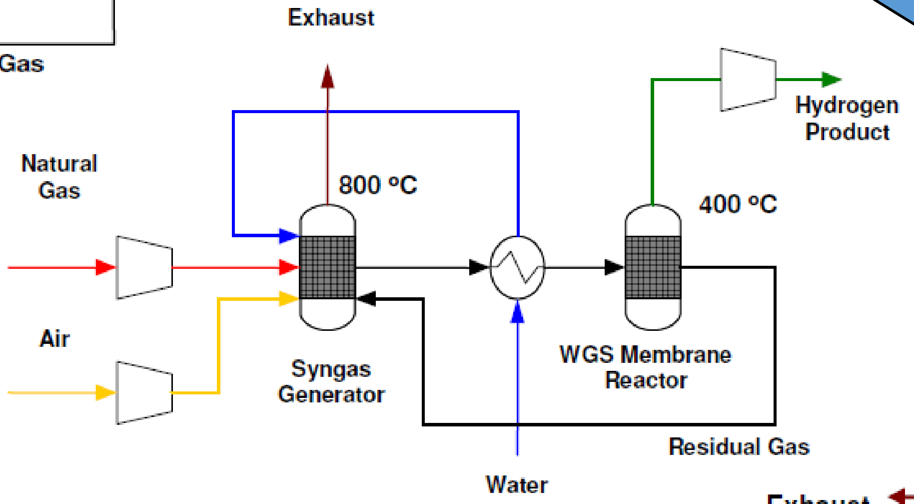
Building a hydrogen economy



Process Intensification

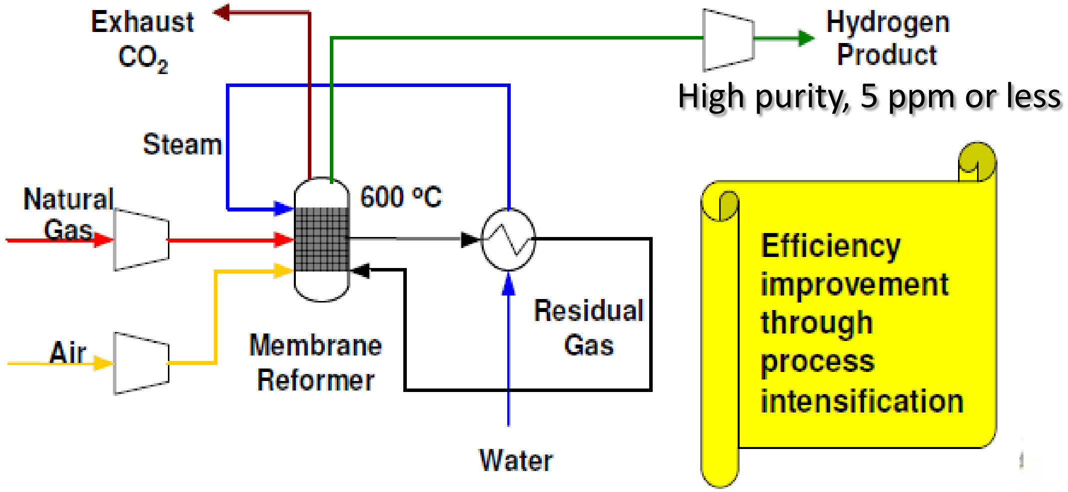
Lowering the Temperature of the Steam Reformation by using membrane assisted Steam Reformation

Towards Lower Greenhouse (CO_2) emissions



Transitioning from a conventional process for producing pure Hydrogen from a fossil fuel source viz. Natural Gas or a NG/ syngas mixture, to a process that progressively incorporates ***membrane technology*** (Source: Pall Corporation)

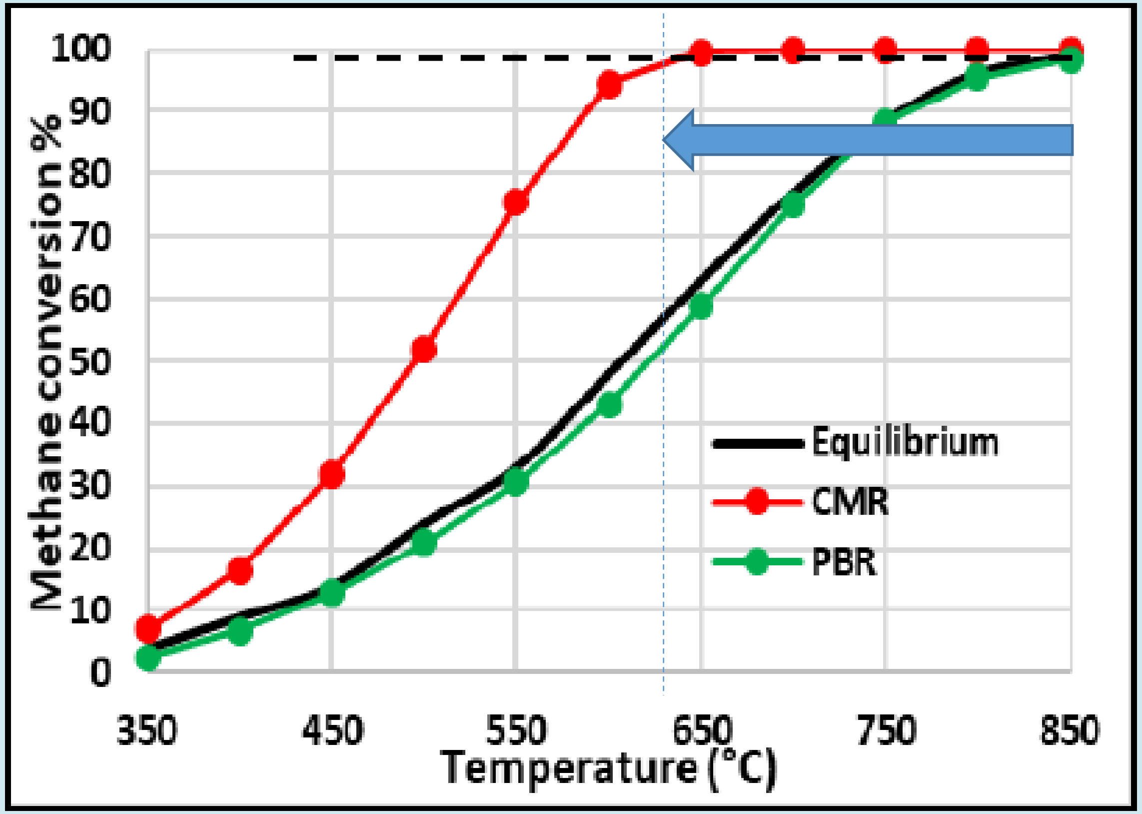
Technology Overview



Lowering Heat requirements by using membrane separations; Lower the endotherm, the lower the fuel requirement in furnace, and lower the CO_2 emissions

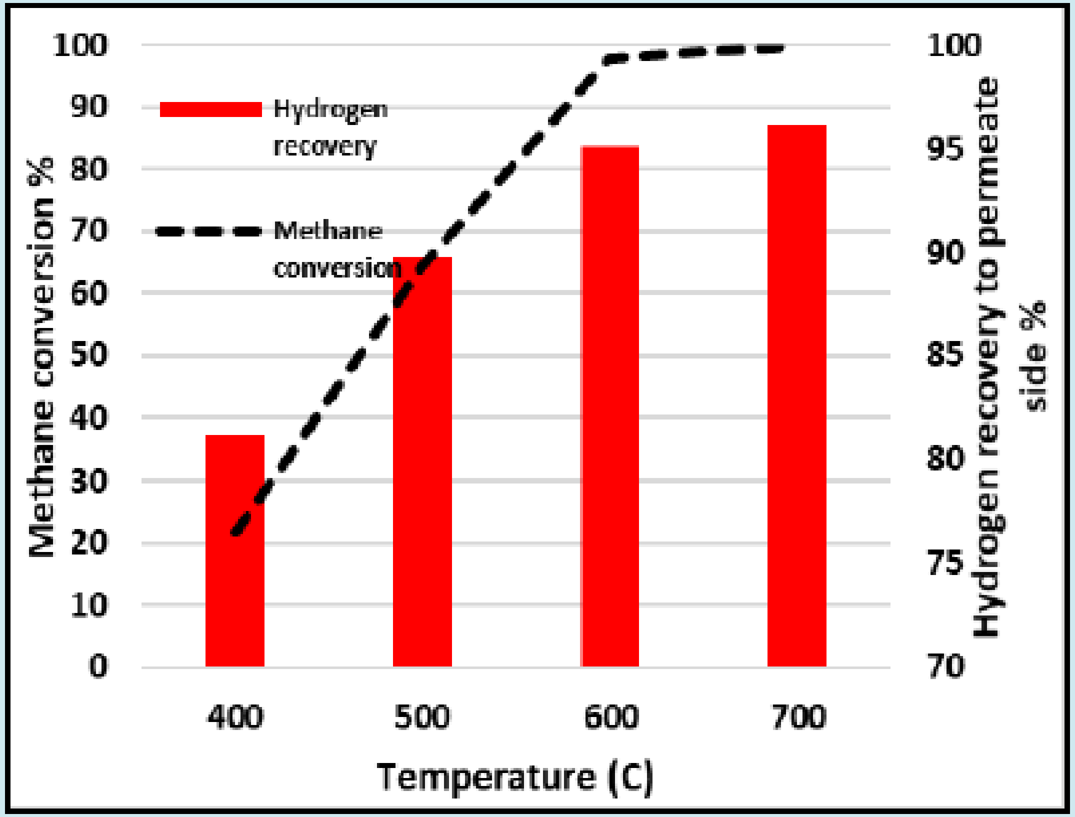
Efficiency improvement through process intensification

Preliminary Calculations with appropriately sized CMR-SMR



CMR's significant increase in methane conversion beyond equilibrium limit.

$$CH_4 + H_2O \rightarrow CO + 3\,H_2$$
$$CO + H_2O \leftrightarrow CO_2 + H_2$$



Amount of hydrogen recovered in permeate side is plotted against temperature along with methane conversion.

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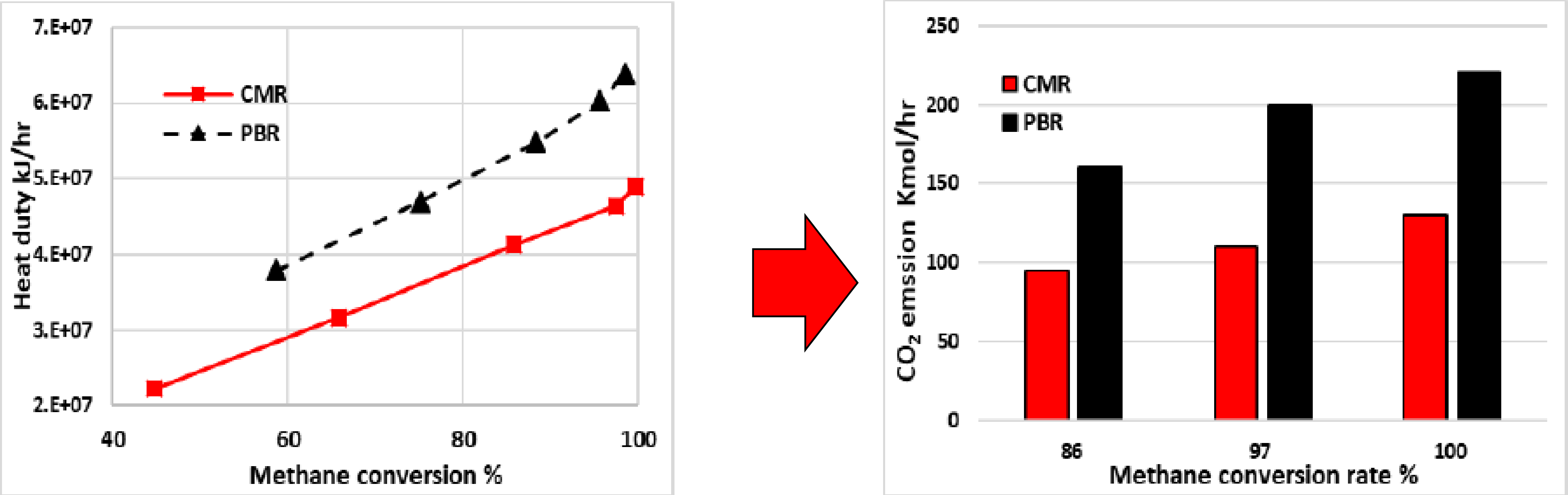
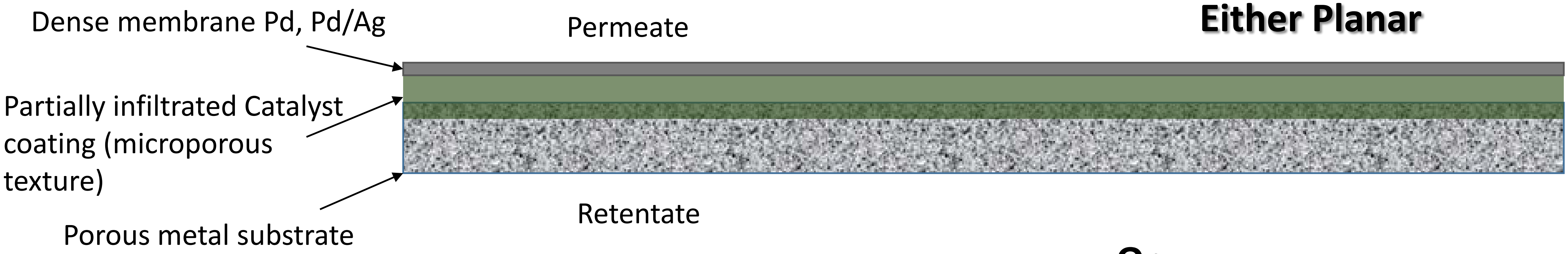


- Potential for lowering the reactor temperature to at least 650º C or less
- Similar Infrastructure (furnaces), Annular-Tubular reactor modifications, at best
- Pd, Pd-Ag sheets/ membranes are expensive, fabrication on industrial scale is a challenge
- Correspondingly lower Heat Duty on Furnace → Much Lower CO_2 emissions in flue gases
- CO_2 emissions from Flue Gases could be reduced by about 40% by membrane-assisted lower temperature reforming system

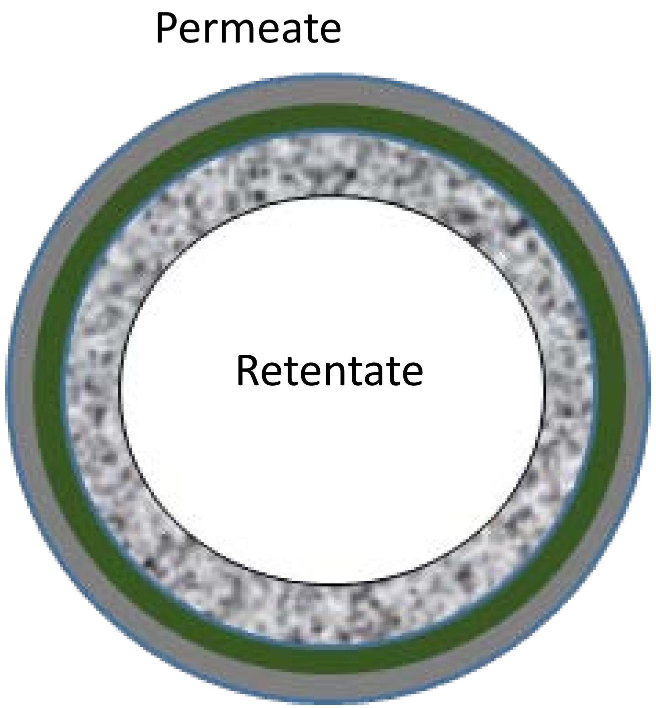
Reactor-separator geometries for SMR w CMR



Either Planar

Or

Tubular



- Take a porous substrate
- Deposit/ partially infiltrate Catalyst coating
- Deposit Dense membrane, Pd, Pd/Ag on top to the required thickness ~10-100 microns

Opportunities for Membrane Manufacture

SINTEF (Norway) – 2 stage Physical Vapor Deposition (PVD)

ECN (Netherlands) – Electroless Deposition of Pd, Pd/Ag

Tecnalia (Spain), AIST (Japan) – 'Pore fill' Pd membrane fabrication of Electroless plating

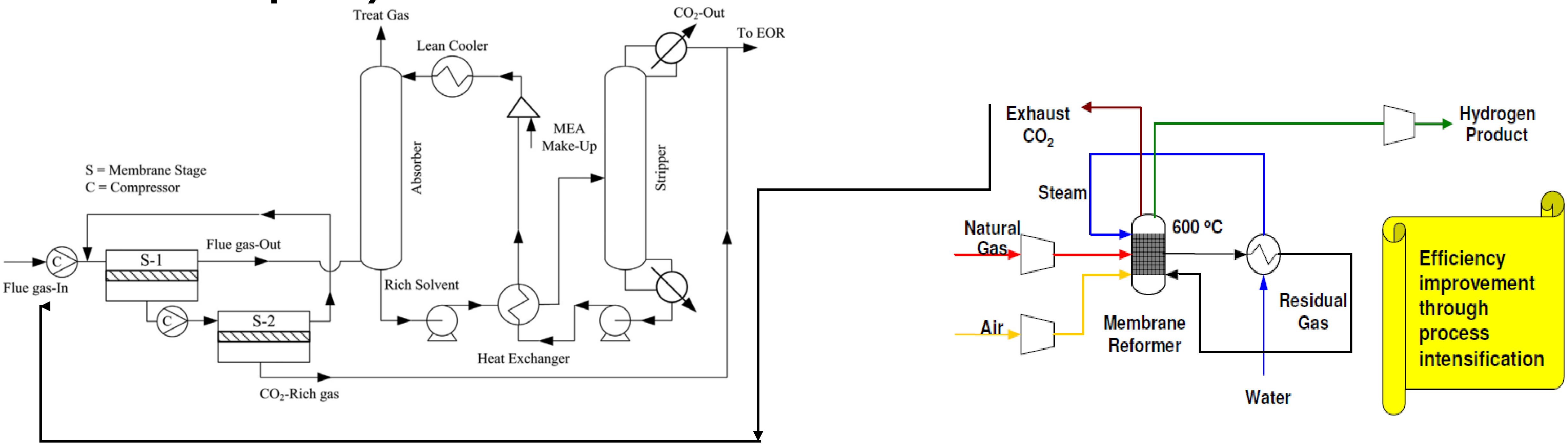
ENEA (Italy) – Cold-rolling, Diffusion Welding, to produce thin walled Pd-Ag membranes for Hydrogen production

Many Membrane manufacture and deposition Techniques available – we are looking to mix these with catalyst coatings to get a composite reactor-separator bi-phase

Impact of the Hydrogen Economy (CMRs) on Local SMEs

Reactor Technology Area	Potential SME Contributions/Beneficiary
Furnace Design, Heating – Hydrogen Usage	Potential market development of bespoke and custom made furnaces for H_2 applications
Membrane manufacture/accessories	Potential for manufacture of specialised membranes for H_2 extraction in CMR-SMR systems and for purification of impure H_2
Fabrication – metal working	Brazing, welding etc.
Software developers, CFD, process simulation	Development of new tools for producers and consumer's. Process modelling, CFD analysis .
Coatings/speciality coatings	Development of new coating technologies for the production of H_2 related to CMR technology.
Instrumentation and Control	Opportunities for SMEs to adapt and grow into the specific requirements associated with process control.
Precision engineering	Hotbox design, CMR design

Integrating CMR-SMR with CO_2 Capture (Hybrid Membrane-Amine Absorption)



Ref:

P.K. Kundu et al. / International Journal of Greenhouse Gas Control 28 (2014) 248–256;

Hydrogen Impacting Initiatives

TVCA successful bid into OLEV for 2 hydrogen refuelling stations (HRS) – additional district heating schemes/energy networks.

H21 Leeds City Gate – implications/benefits for Tees Valley → markets for Hydrogen
https://www.northerngasnetworks.co.uk/event/h21-launches-national/

Potential New Markets – Hydrogen into the UK train network – [10 regional trains = 3 tonnes H_2/day]

Industrial thinking/developments

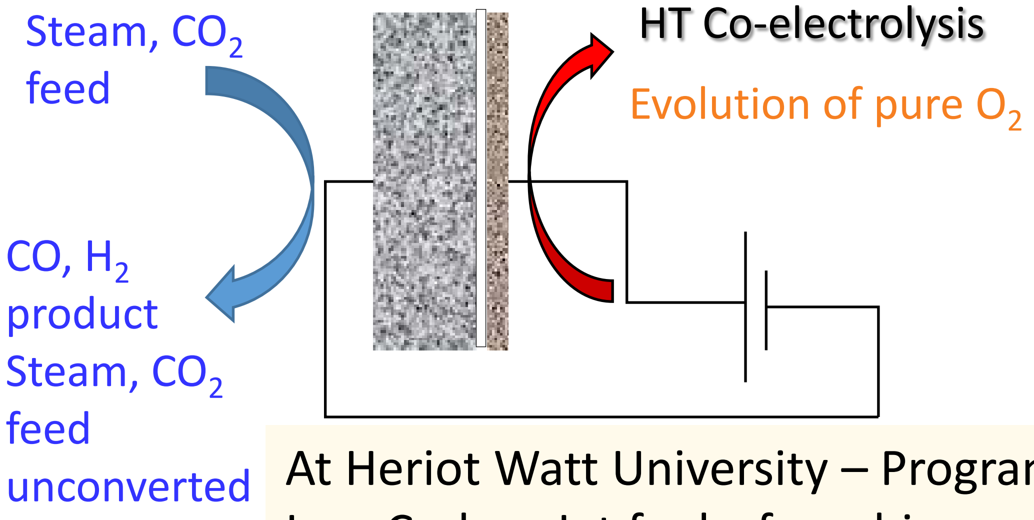
Japan has identified hydrogen as the answer to the energy problem, both for transportation and in power generation (extract from The Chemical Engineer 1/4/2019).

Carbon Utilization

<u>Steam electrolysis/ CO_2-steam co-electrolysis</u> – Steam electrolysis for production of Hydrogen or CO_2-steam electrolysis for co-production of CO, and Hydrogen, at high temperature offers lower electrical consumption compared to low temperature water electrolysis.

$$H_2O\ (\text{steam}) + CO_2 + \text{electricity} \rightarrow H_2 + CO + O_2$$

In the event of available heat sources, viz. waste heat from industry or from nuclear reactors, geothermal sources etc., and high temperature co-electrolysis is a great opportunity to convert CO_2 to CO/H_2, which is a crucial feedstock for a variety of chemicals/ fuels.



At Heriot Watt University – Program on Low Carbon Jet fuels, from biomass

Biomass Gasification → Syngas, steam, CO_2 → Steam and CO_2 co-electrolysis → CO, H_2 in proportions → FT chemistry

Major Challenges to overcome in high temperature Electrolysis – Stability of steam/ CO_2 electrode, prevention of coke formation; electrocatalyst degradation over time; cost of electricity, need for renewable electricity, wind/solar

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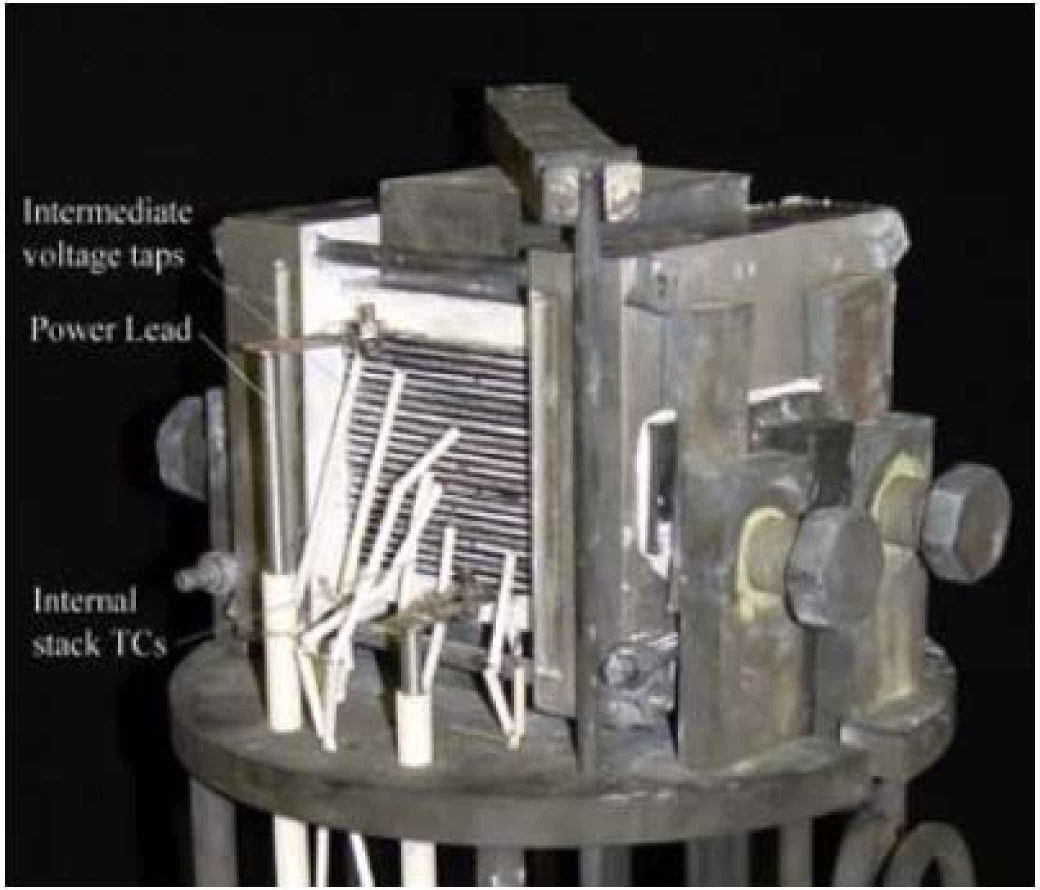
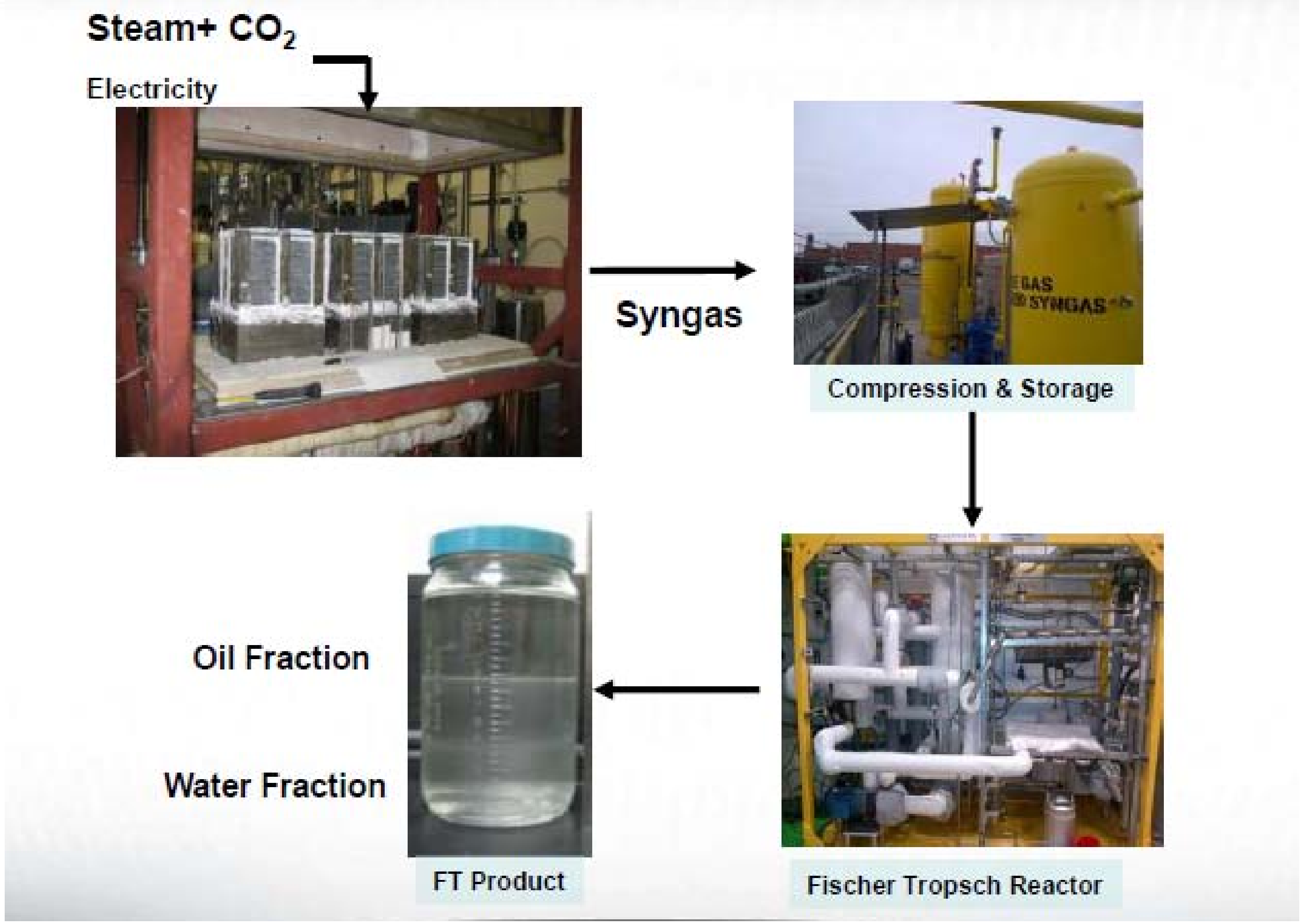
CO_2 Utilization via HT Co-Electrolysis (HTCE), cont'd - Cerametec

From Cerametec (Utah)



10 cm x 10 cm laboratory unit



CO_2 utilization via Hydrogenation

Generating chemicals/ fuels, e.g. (Figure 1). The heart of the process lies in the catalysis of CO_2 Hydrogenation towards any of the pathways shown below. This also fits in well with the usage of renewable energy to produce Hydrogen, viz. electrolysis, it generates additional market for Hydrogen, and decarbonizes the environment.

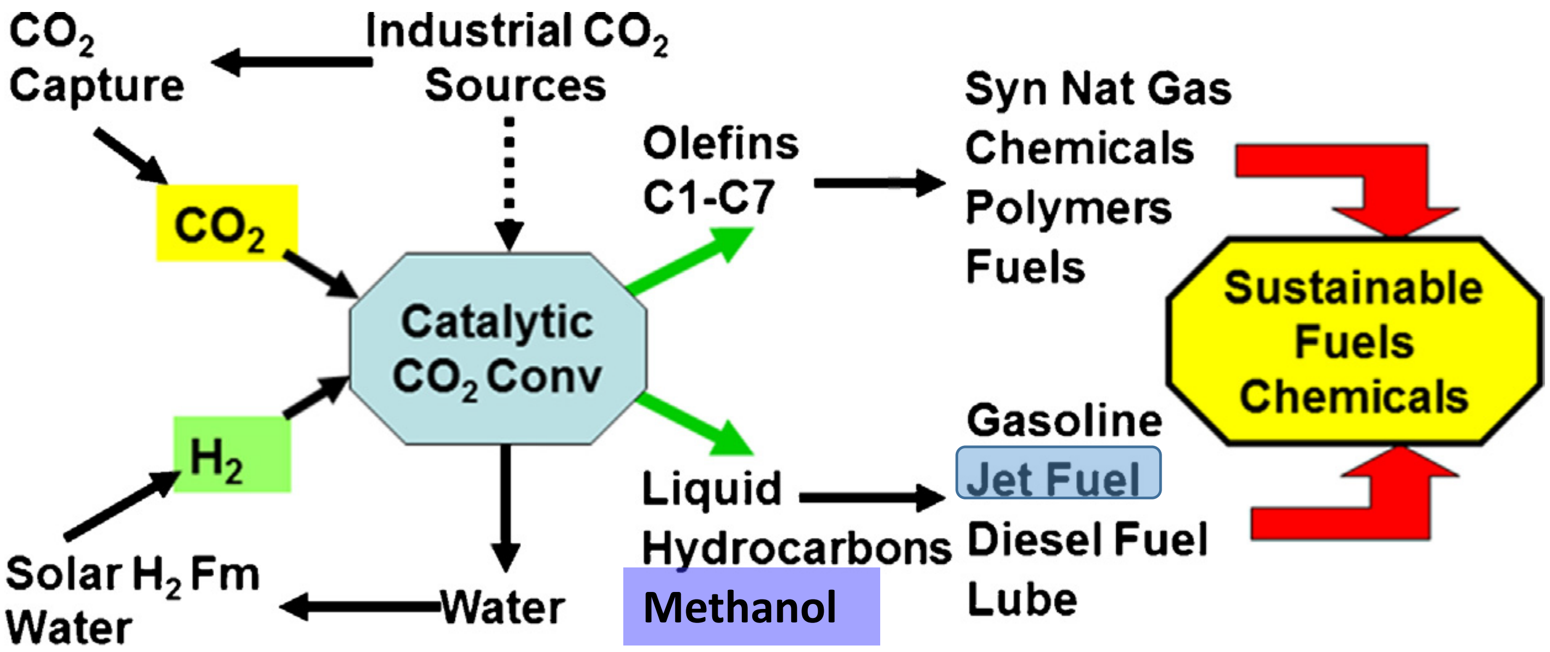


Figure 1: R. Satthawong et al.; Journal of CO_2 Utilization 3–4 (2013) 102–106

SUMMARY – H_2, CCUS

Hydrogen Production, Via

CMR-SMR (High Efficiency, Low T, Low Carbon emissions

Hydrogen Production

Via

Electrolysis (PEMECs, SOECs)

CO_2 Capture
Via
Advanced Amine Absorption (with Membrane usage)

CO_2 Utilization, with Steam

Via

High Temp Co-electrolysis (HTCEs)

CO_2 Utilization with Hydrogen (Hydrogenation

Via

Heterogeneous Catalysis – Reverse WGS and FT

Targeting Sustainable Jet Fuel (Aviation Turbine Fuel)