Emerging technologies to lower the cost of renewable gas

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Introduction

Conversion of hydrogen to methane via Sabatier

- "Excess" power lowers power price of 'some' hydrogen production
  - However, hydrogen is more valuable on average
- CH_4 can utilise existing infrastructure as hydrogen carrier

Conversion of methane to hydrogen: SMR or pyrolysis

- Hydrogen is more valuable (if CO_2 neutral)
- SMR generates CO_2
- Pyrolysis avoids CO_2 production
- Can produce a valuable by-product

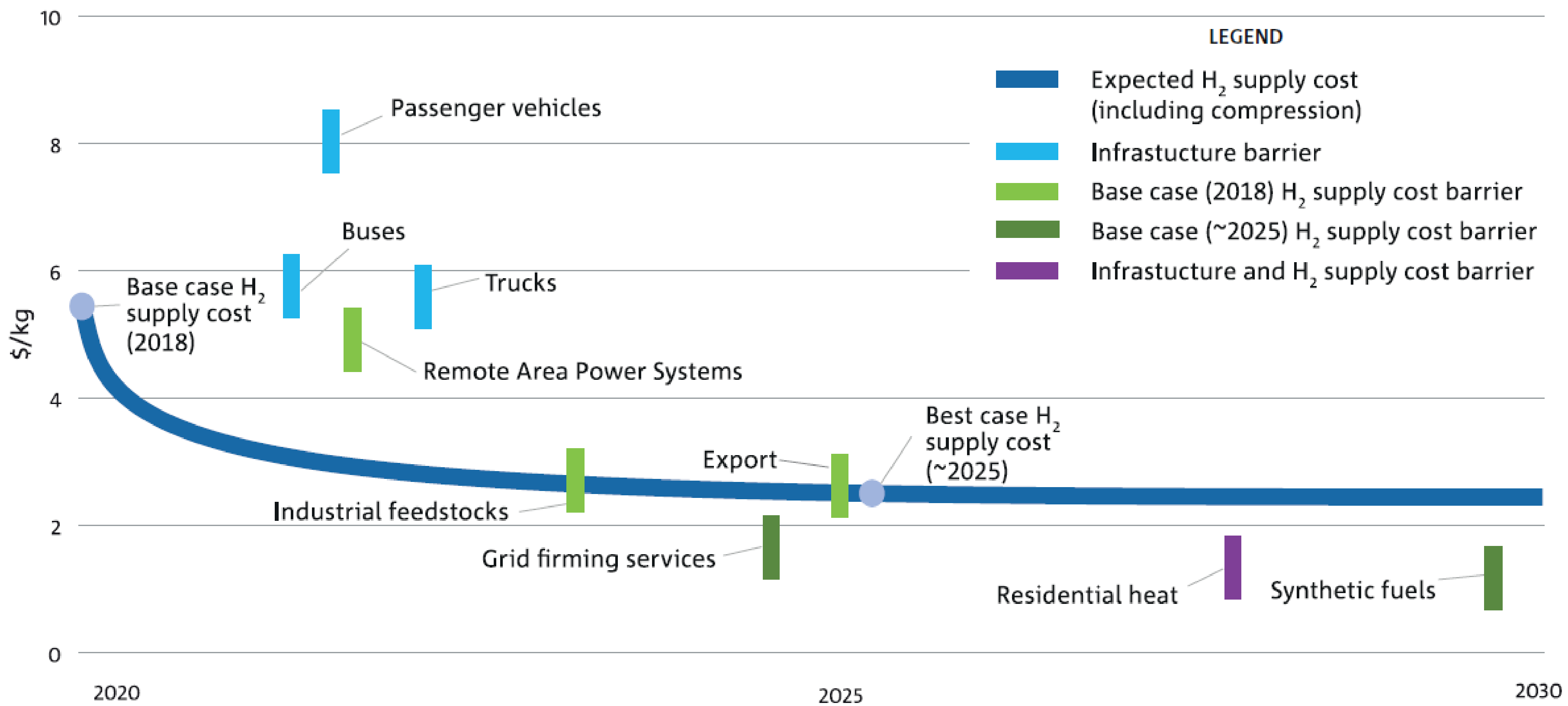
Critical path: The cost curve for production of CO_2 neutral hydrogen

- Costs of commercial electrolysis is continuing to fall rapidly
- Other emerging technologies offer potential for lower prices

Methane to Hydrogen Options

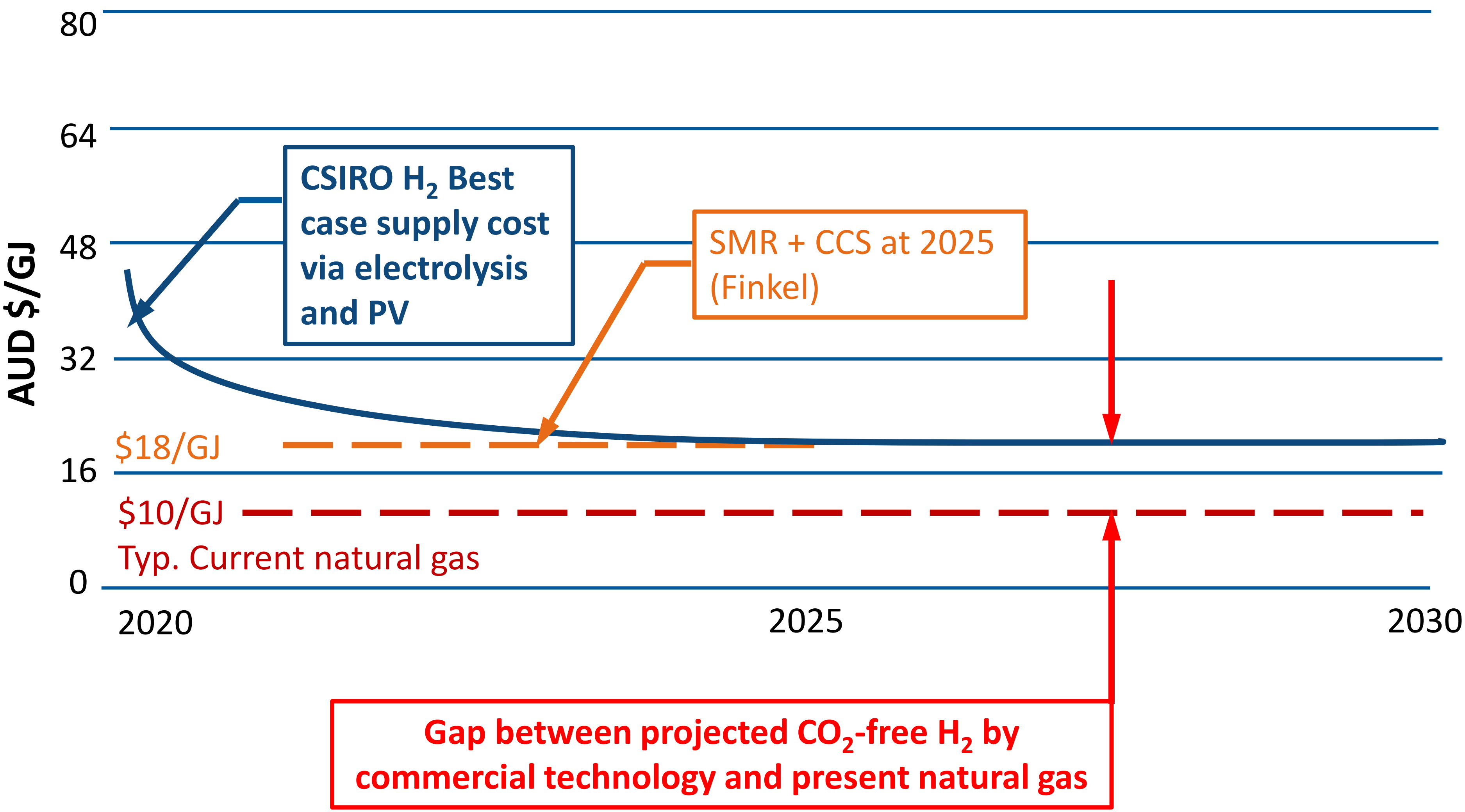
	Steam methane reforming	Methane Pyrolysis (or cracking)
Status	Commercial	Pilot
Overall Reaction	$CH_4 + H_2O \rightarrow CO + 3H_2$ $CO + H_2O \rightarrow CO_2 + H_2$	$CH_4 \rightarrow C + 2H_2$
Energy requirement	~20%	~15%
Carbon by-product	CO_2	C
Process to manage CO_2	CCS / EGR / reuse	Nano-tubes / char / bury
Cost for CO_2-neutral	~\$1:90 - \$2:30 / kg_{H2}	~\$0:50 - \$1:90 / kg_{H2} (estimated)

Anticipated cost trajectory & markets for commercial renewable H_2

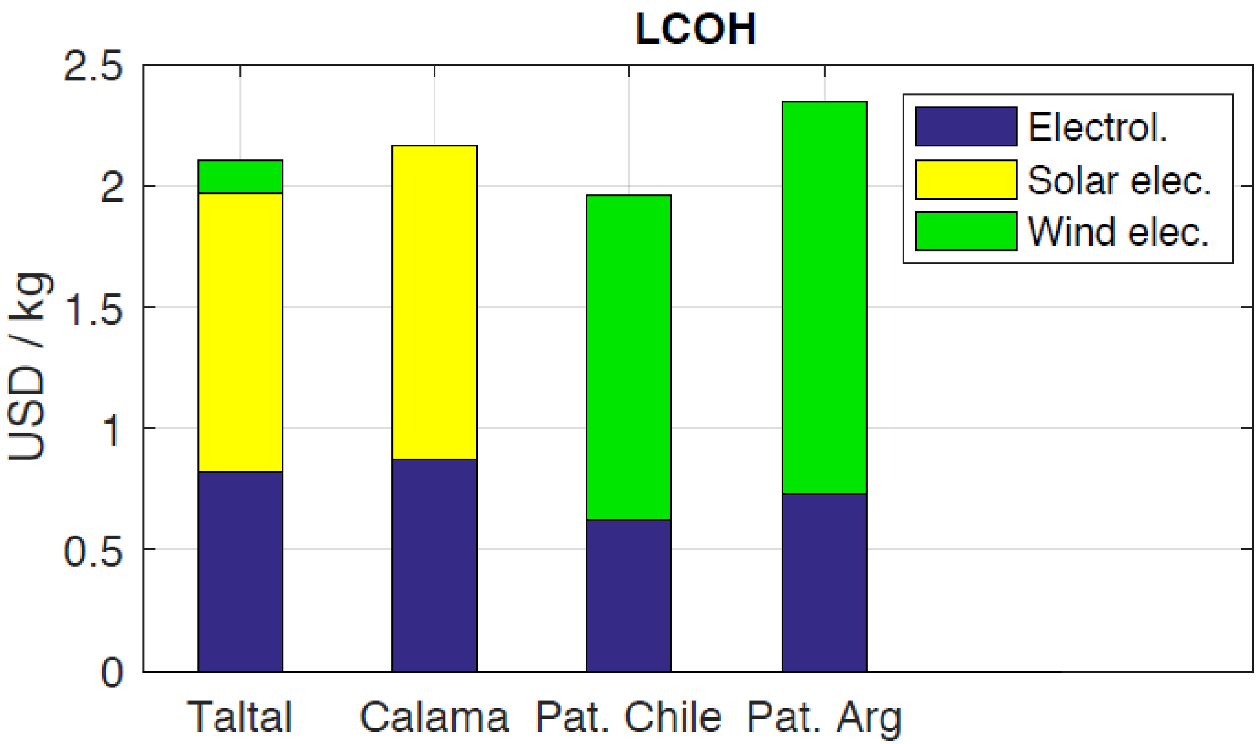


CSIRO Roadmap (2018): Bruce, Temminghoff, Haywood, Schmidt, Munnings, Palfreyman, Hartley

Gap between projected H_2 costs and current fuels / electricity

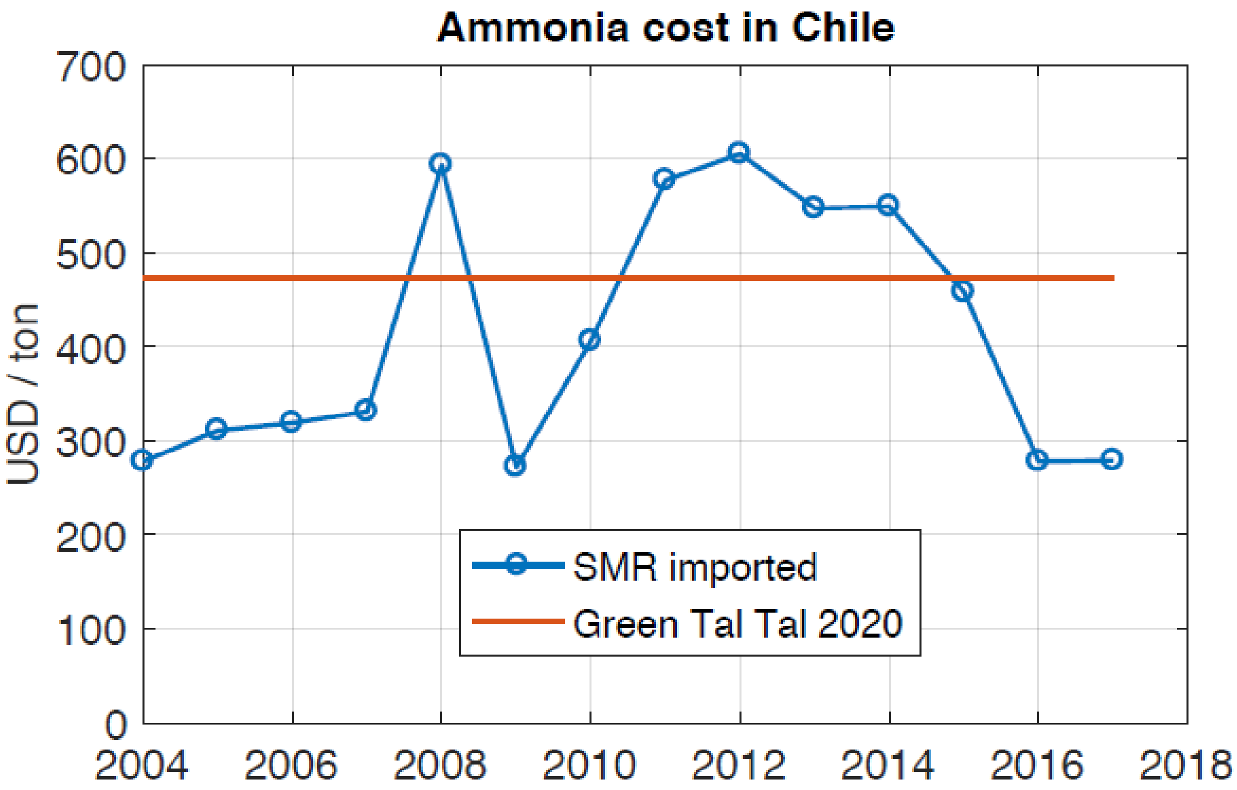


Estimated current costs of renewable H_2 in Chile



CSIRO Roadmap (2018): Bruce, Temminghoff, Haywood, Schmidt, Munnings, Palfreyman, Hartley

Estimated costs of renewable NH_3 in Chile



CSIRO Roadmap (2018): Bruce, Temminghoff, Haywood, Schmidt, Munnings, Palfreyman, Hartley

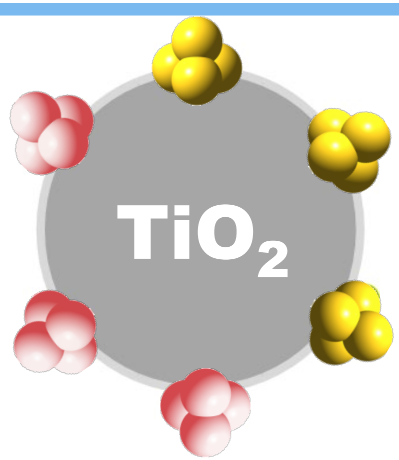
Estimated costs of alternative H2 production options

TABLE 1: COSTS, EFFICIENCIES AND CO_2 EMISSIONS FROM DIFFERENT HYDROGEN PRODUCTION PATHWAYS.

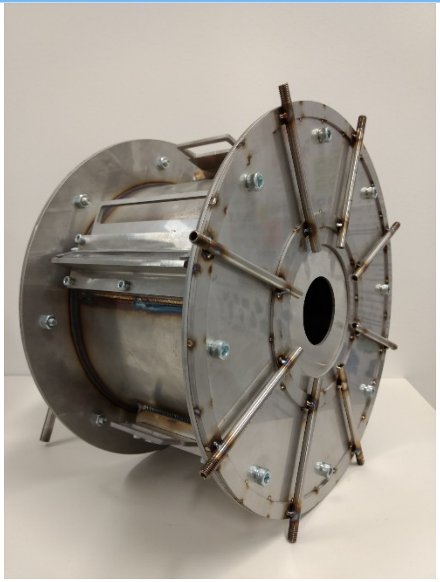
PRODUCTION PROCESS	PRIMARY ENERGY SOURCE	HYDROGEN PRODUCTION ENERGY EFFICIENCY (%, LHV)[33]	HYDROGEN PRODUCTION COST A$/KG[34]		HYDROGEN PRODUCTION COST A$/GJ (LHV)[35]		NET PROCESS CO_2 EMISSIONS IN KG CO_2/GJ OF HYDROGEN[36,37]
			2018 ESTIMATE	2025 BEST CASE MODEL	2018 ESTIMATE	2025 BEST CASE MODEL	
Steam methane reforming with CCS	Natural gas	64	2.30-2.80	1.90-2.30	19.20-23.30	15.80-19.20	6.3
Coal gasification with CCS	Coal	55	2.60-3.10	2.00-2.50	21.70-25.80	16.70-20.80	5.9
Alkaline electrolysis	Renewable electricity	58	4.80-5.80	2.50-3.10	40.00-48.30	20.80-25.80	~ 0
PEM electrolysis	Renewable electricity	62	6.10-7.40	2.30-2.80	50.80-61.70	19.20-23.30	~ 0

Finkel Briefing Note to COAG “Hydrogen for Australia’s Future” (2019)

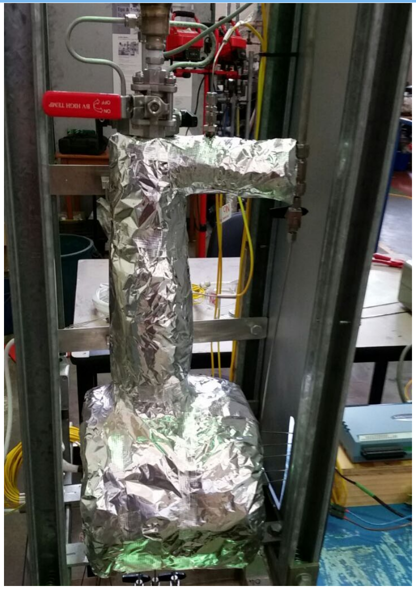
University of Adelaide Novel Technologies for H_2 Production



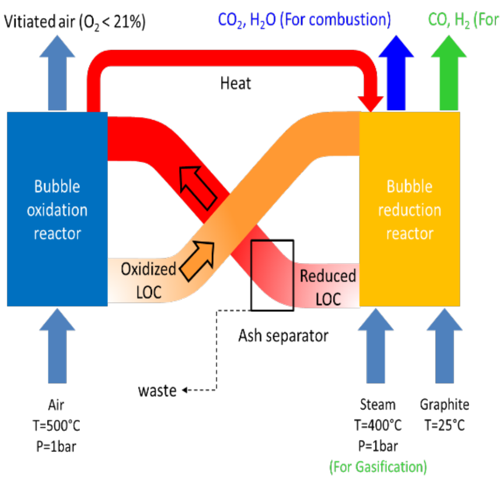
Solar Photo-catalysis



Solar Vortex Receiver



Solar Bubble Receiver



Chemical Looping Bubble Reactor

$CH_4 \rightarrow C + H_2$

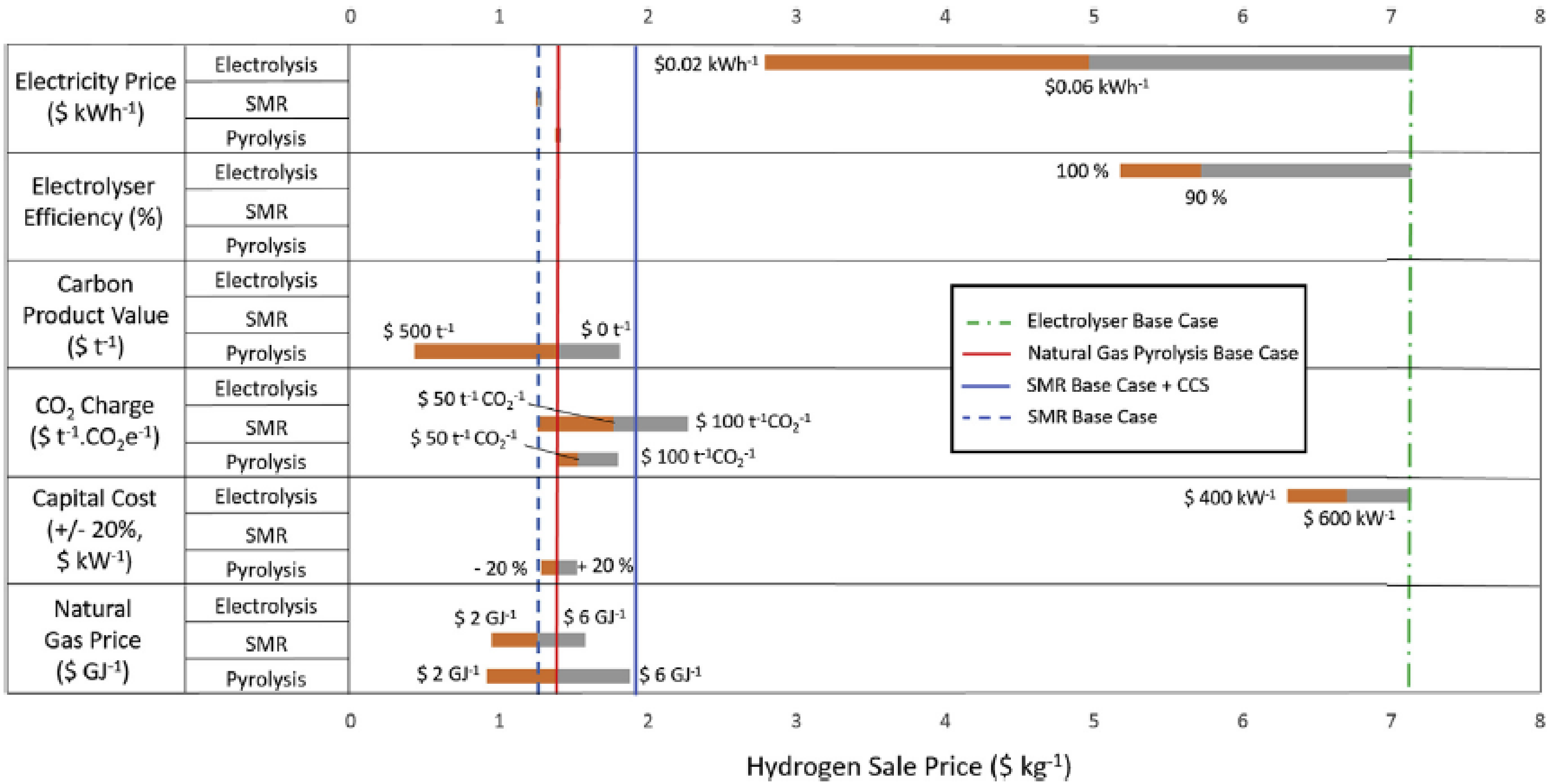
H_2O

Methane Pyrolysis: Blue hydrogen without CCS

$$CH_4 + \text{Heat} \rightarrow 2H_2 + C_{(solid)}$$

- Avoids producing CO2 by not using steam or O2
- 60% of the enthalpy is partitioned in the H2
- Potential to generate a valuable carbon by-product
  - high value carbon nano-tubes, etc
  - bulk commodities such as agricultural char
- Can be solarised:
  - use concentrated solar thermal heat to drive the reaction
  - Increases energy of the fuel by 15%

Estimated opportunity for H2 from methane pyrolysis



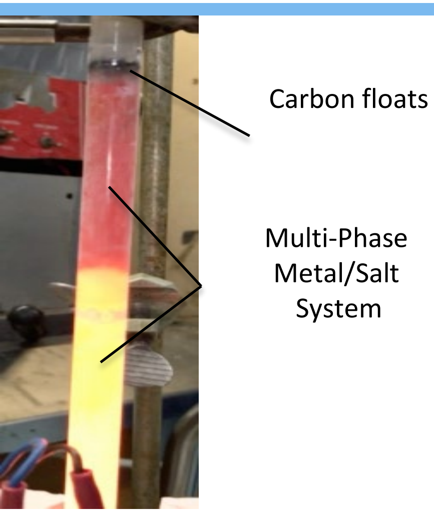
Parkinson, Tabatabaei, Upham, Ballinger, Greig, Smart, McFarland (2018), J. Hydrogen Energy, 2540-2555

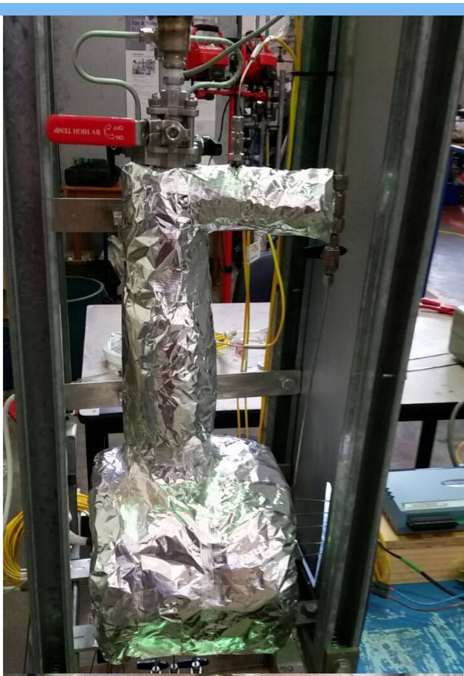
Commercial status of methane pyrolysis

Abanades et al, *I. J. Hydrogen Energy*, **41**, 8159-67, 2016

- **Solid catalytic process (Hazer)**
  - ➢ demonstrated at pilot and above
  - ➢ must address coking of catalyst
- **Molten metal bubbling reactors**
  - ➢ demonstrated at pilot scale
  - ➢ avoids coking of catalyst, since Carbon floats
  - ➢ reaction occurs at ~800 °C (in molten tin)

Uni Adelaide / Uni Queensland collaboration





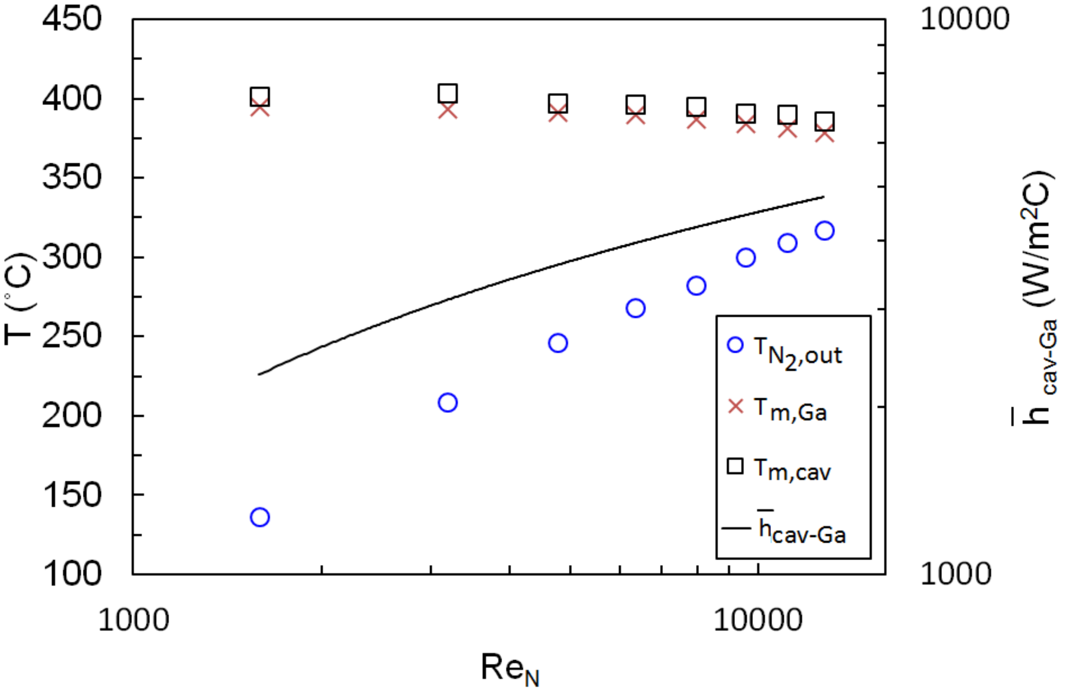
Developing advanced materials & reactors together

- Novel metals and salts (UQ)
- Optimising patent-pending reactors (UA)
- Demonstrating improved system at lab scale
- Techno-economics

Bubbling molten metal reactor technology

Solar bubbling reactor demonstrated

- high rates of heat and mass transport
  - Jafarian & Nathan, (2019) Solar Energy (in press)
- patent-pending interconnected bubbling reactor
  - Jafarian, Abdollahi, Arjomandi, Chinnici, Tian, Nathan (2017) Int. Patent App. No. PCT/AU2018/050034



Emerging options for solar gasification or reforming For liquid fuels

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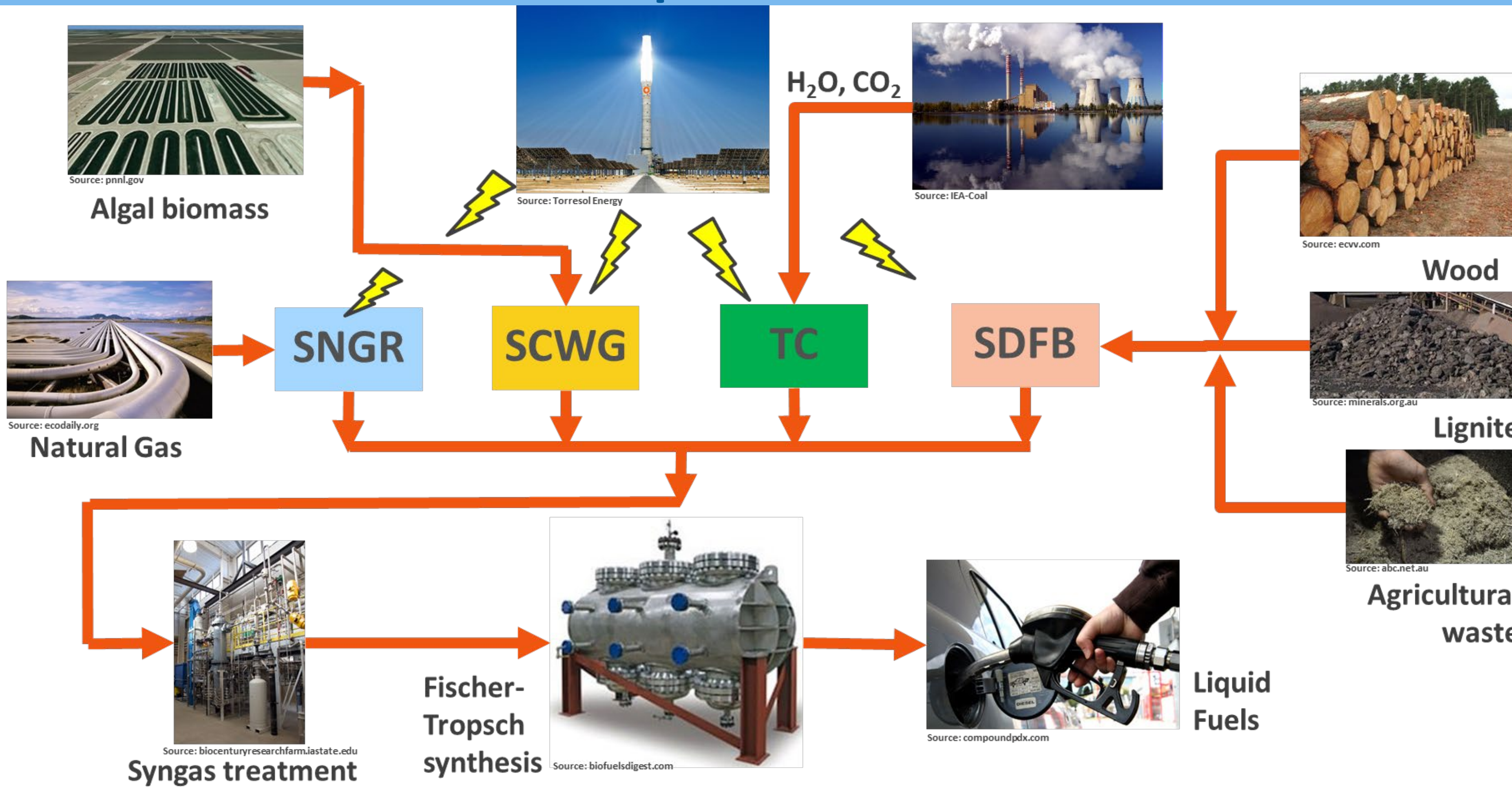
AUSTRALIAN SOLAR THERMAL RESEARCH INITIATIVE



SNGR: Steam natural gas reforming
SCWG: Supercritical water gasification
TC: Thermochemical water splitting
SDFB: Solar dual bed gasification

CSIRO
Australian National University
THE UNIVERSITY of ADELAIDE
QUT
Flinders UNIVERSITY

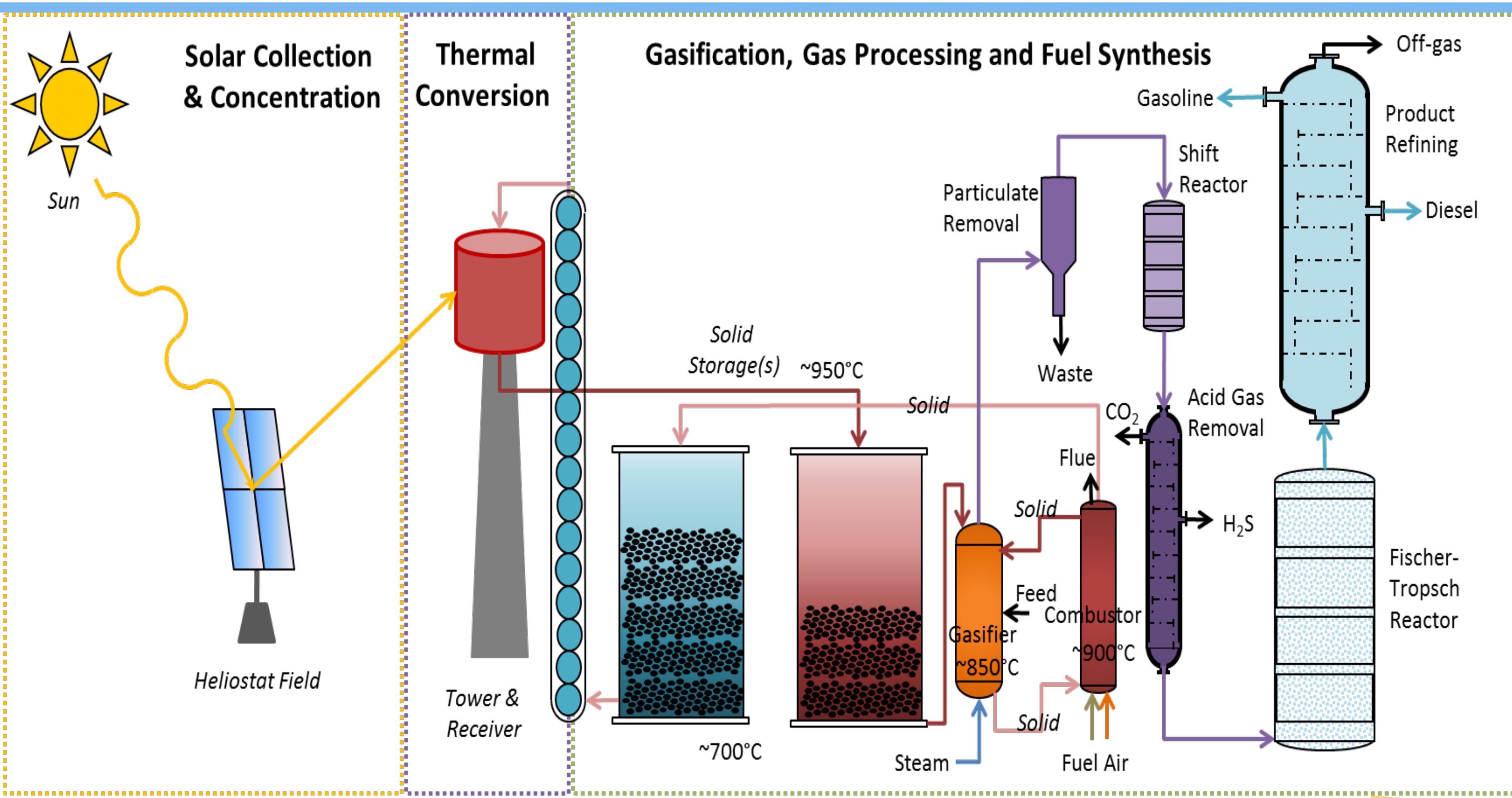
Solar thermal gasification of agriculture residues:



Value drivers for solar gasification:

- Conversion to diesel yields higher value than power or methane
- Liquid fuels are readily stored
- Steps toward a circular economy – re-use in the business
- Avoids the need to connect to a pipeline
- Reduces exposure to potential increases in the cost of diesel
- Market advantage from green products

Solar hybridised dual bed gasification - Typical configuration



$T_{receiver} \approx 950°C; \quad T_{gasifier} \approx 850°C;$

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Levelised Cost of Fuel: re 2020 data

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Term	Process	Conditions	Product / Cost
	Low sulphur diesel (LSD) Australian Institute of Petroleum		LSD $1.1/L (TGP[b])
Short-term	Solar mixed reforming of natural gas (CSIRO) $3 CH_4 + 2 H_2O + CO_2$	< 750˚C (1-15 bar) – Catalyst + FTS	Diesel/Gasoline $1.0/L
Mid-term	Solar hybridised gasification of coal + CCS (UA) $C + H_2O$	SDFB - 850˚C (1 bar) + Syngas upgrading + FTS	Diesel/Gasoline $0.9/L
Mid-term	Solar hybridised gasification of biomass (UA) $C + H_2O$	SDFB - 850˚C (1 bar) + Syngas upgrading + FTS	Diesel/Gasoline $1.4/L
Long-term	Solar SCWG of microalgae (ANU/CU/UA) $C_aH_bO_cN_d \bullet (H_2O)$	400-700˚C (230-250 bar) with catalyst + Syngas upgrading + FTS	Diesel/Gasoline $3.0/L
Long-term	TC cycles to split $H_2O + CO_2$ (ANU/CSIRO) $CO_2 + 2 H_2O$	900-1500˚C (1 bar) - Metal oxides (non-stoic.)	Diesel/Gasoline $2.0/L

SDFB – Solar hybridised dual fluidised bed gasification
SCWG – Supercritical water gasification

TC – Thermochemical
Stoi – Stoichiometric

a- Mui, S., Tonachel, L., McEnaney, B. and Shope, E., GHG Emission Factors for High Carbon Intensity Crude Oils. Natural Resources Defense Council, 2010.
b- http://www.aip.com.au/ October 2015, Terminal Gate Price

Saw et al. (2016), *Internal report to ARENA*.

Final points

Drivers to convert between methane and hydrogen are expected to grow

- methane is an established fuel
- hydrogen is a CO_2 free fuel

Strong drivers to also develop methane to hydrogen via pyrolysis

- Anticipated low cost route to mitigate CO_2 emissions from NG;
  - potential for CO_2 neutrality with solar thermal production or offsets;
- Applicable to bio gas as well as natural gas
- Potential to extend the life of natural gas assets

Many alternative technologies for CO_2-neutral H_2 are under development

- methane pyrolysis / cracking
- solar photo-catalysis
- solar thermo-chemical water splitting
- solar gasification of biomass with water-gas shift
  - Production of liquid fuels is likely to be more attractive;

Thankyou!

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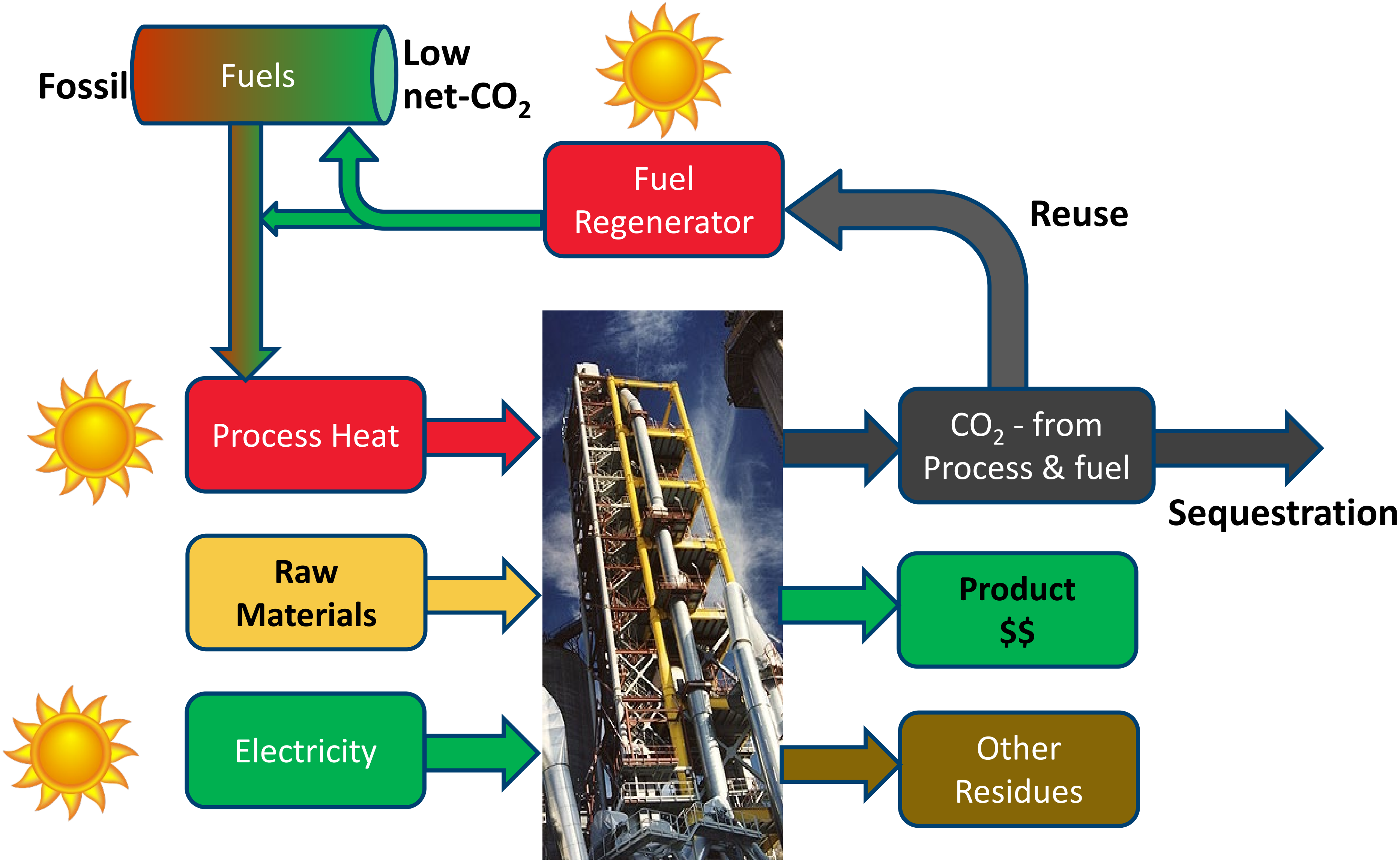
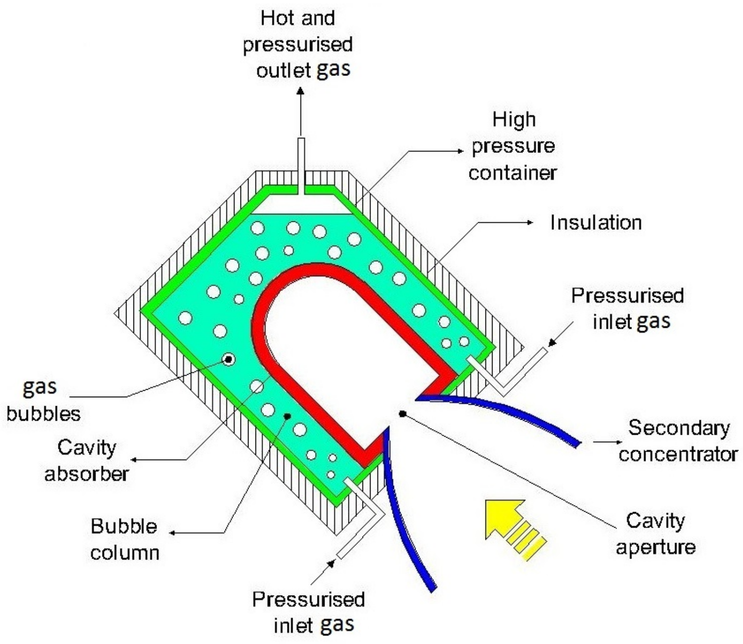
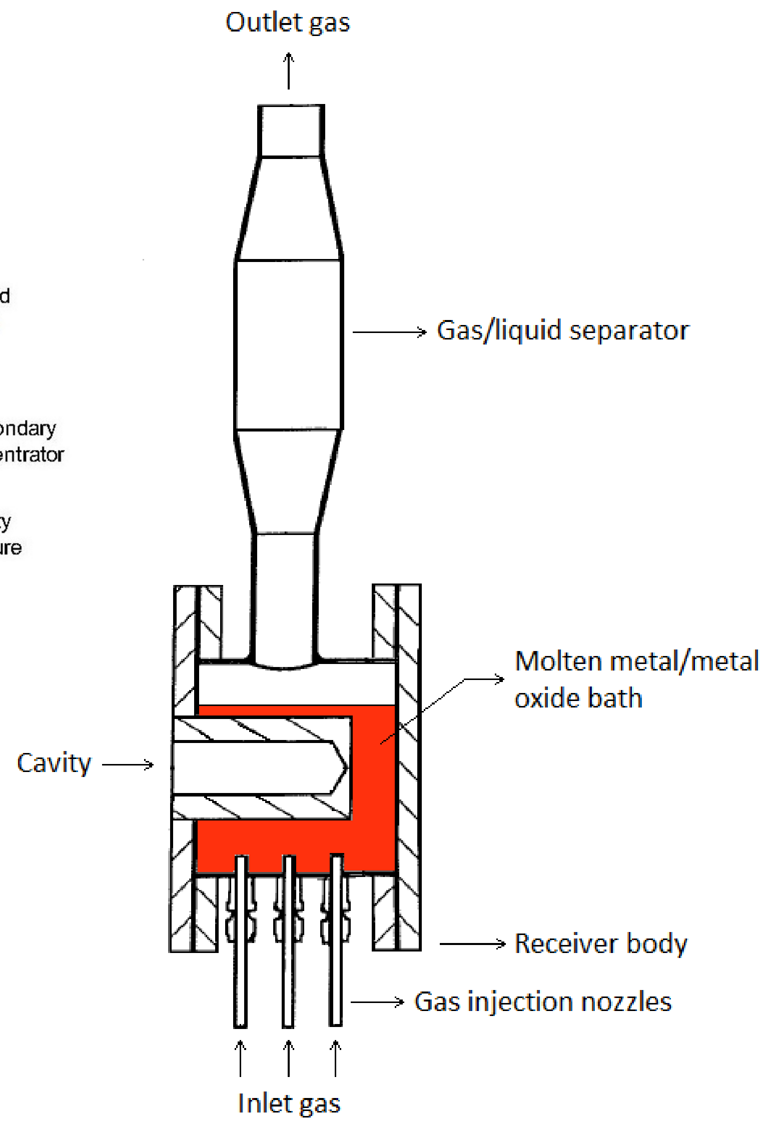
Options for producing valuable, green products

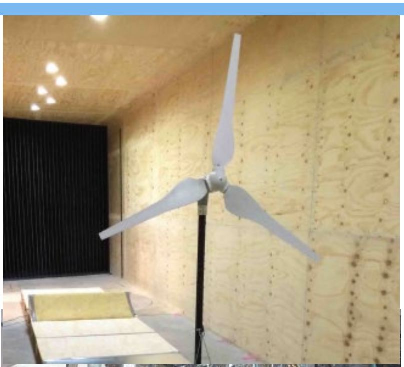


Utilises Patent Pending Bubbling Cavity Receiver



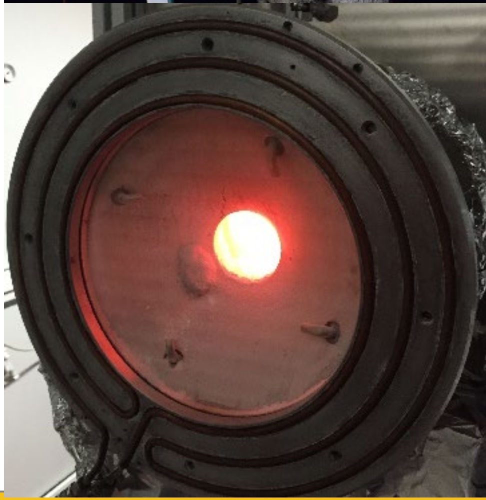


The Centre for Energy Technology



- **Multi-disciplinary team - within the Institute for Mineral & Energy Resources**
  - >25 academic staff
  - 13 RA's & > 60 PhD students
  - Engineering, Sciences, Professions
- **Strong links with industry**
  - 70 recent consultancies
  - $12m in joint R&D programs
  - Industry Advisory Board
- **Strong Research outputs**
  - > 140 Journal papers p.a.
  - 2 patents per year
- **Significant budget**
  - Approx $8m p.a. (external cash)





CET Facilities

Four Laser Laboratories ($5m)

- single and two phase flow
- combustion diagnostics

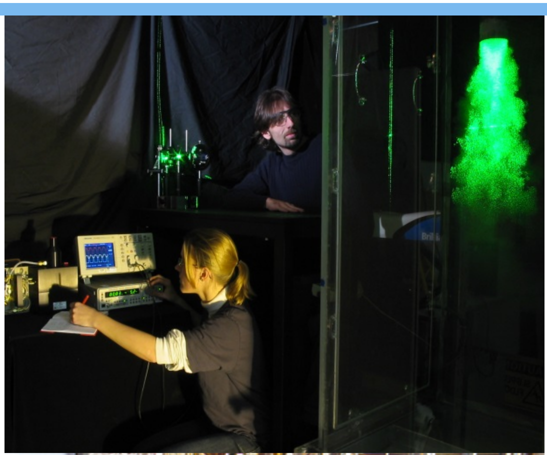
Thermal technology labs ($4m)

- Gasification & Pyrolysis
- Solar thermal simulators (× 3)
- Combustors

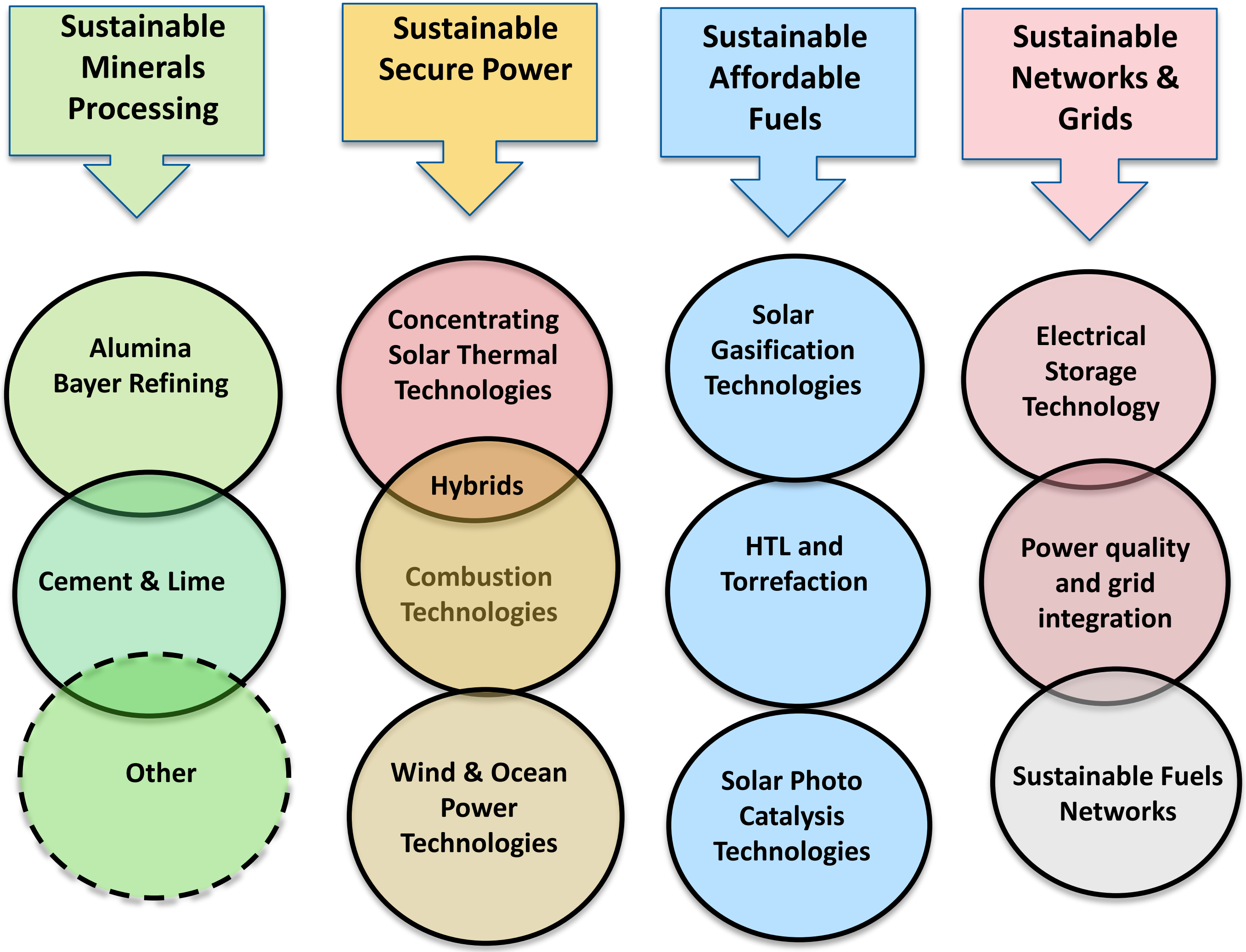
Large Wind Tunnel: ($5m)

- 2.8m ×2m × 50m/s Hi-speed
- 3m ×3m × 33m/s

Other specialist facilities & instruments



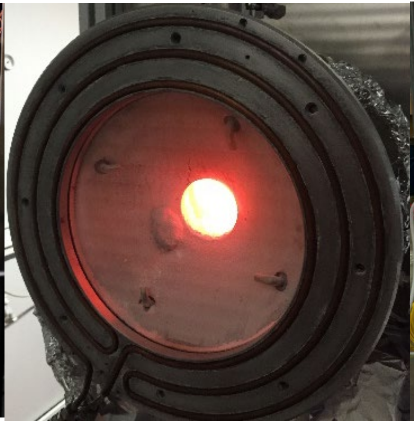
CET Research Programs



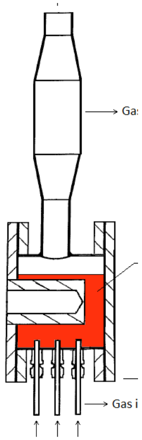
Key CET patented Technologies

CET technologies behind Australia's Exporter of the Year (Optus, 2018)

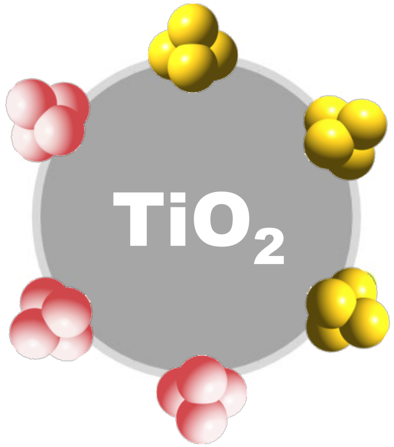
Hybrid Solar Receiver-Combustor



Solar Vortex Receiver



Solar Bubble Receiver



Solar Photo-Catalysis

CET solar technology platforms with strong commercial potential