ASTRI

AUSTRALIAN SOLAR THERMAL RESEARCH INITIATIVE

ASTRI Solar Fuels
Preliminary Study to set LCOF Benchmark

ASTRI Annual Workshop, 2015

G. Nathan[1], P. Ashman[1], W. Saw[1], P. van Eyk[1], P. Guo[1], G. Metha[1], J. Alvino[1], C. Doonan[1], D. Losic[1], R. Karunagaran[1], A. Bayon[2], J. Hinkley[2], J. Pye[3], W. Lipinskí[3], M. Venkataraman[3], A. Weimer[3,4], T. Nann[5], G. Andersson[6], E. Stechel[7], A. Steinfeld[8]

[1]The University of Adelaide
[2]CSIRO
[3]Australian National University
[4]University of Colorado
[5]Flinders University
[6]University of South Australia
[7]Arizona State University
[8]ETH Zürich

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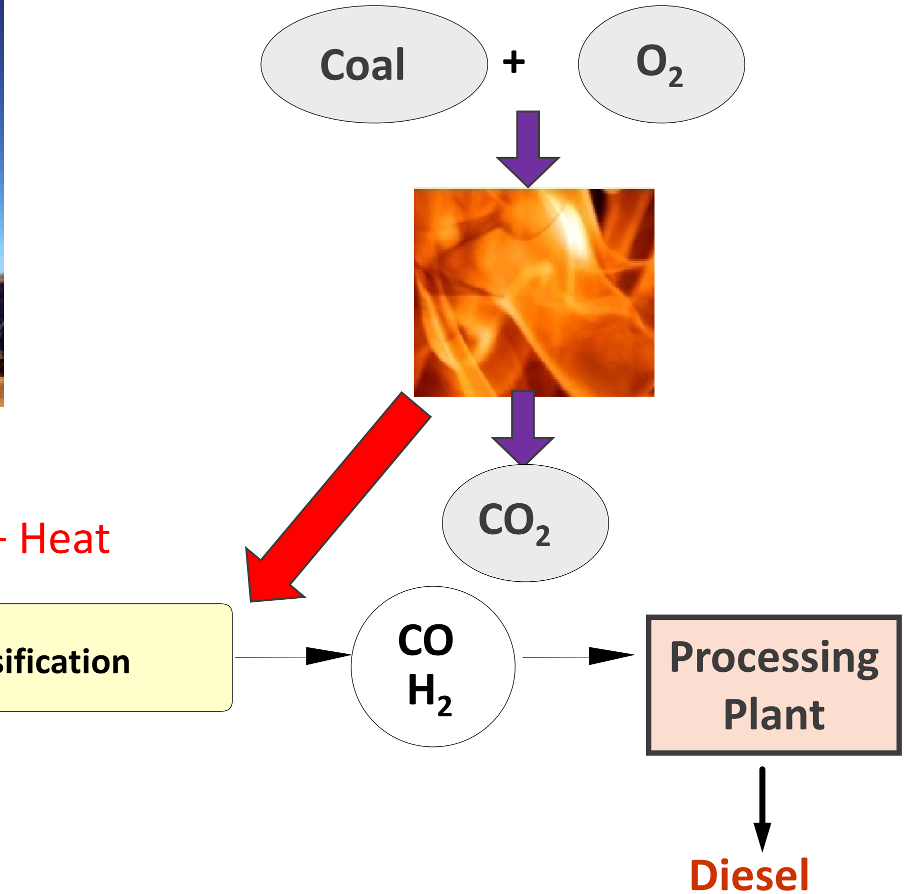
Need for Targets for cost and broad viability

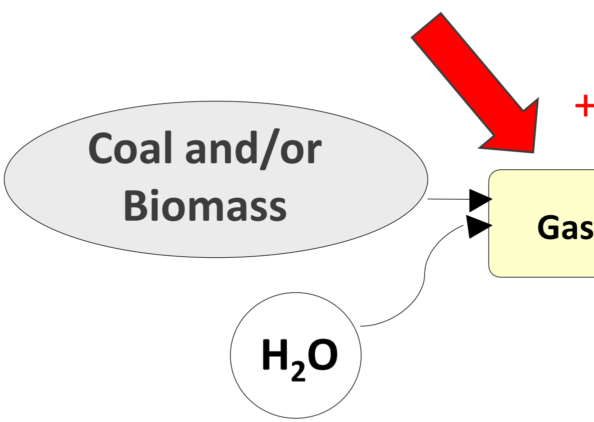
- **IEA's Solar PACES Executive committee identified (at last meeting):**
  - Cost targets are needed to drive development of solar chemistry
    - None are available to our knowledge
- **Setting realistic targets is challenging because**
  - Solar chemistry is at a much earlier stage of development than solar power
    - No commercial plants have been built
    - No pilot-scale plants have been built of the full process
  - Significant differences between commercial and solar chemical process
    - Commercial processes are steady while the solar resource is intermittent
    - Commercial processes are 10 – 1,000 times larger
  - Significant differences between CST power and chemical process
    - Chemical plants operate at higher temperature than current power plants
    - Solar reactors typically differ from solar receivers
    - Solar chemistry are typically more complex, with more downstream processing
  - The diversity of chemical process is greater than for power plants
    - Many types of fuels and mineral processes
    - Many options within each type of chemical process
    - No standardised methodology with which to compare different options

Conventional and Solar Gasification (and reforming)

Solar Gasification

Conventional Gasification

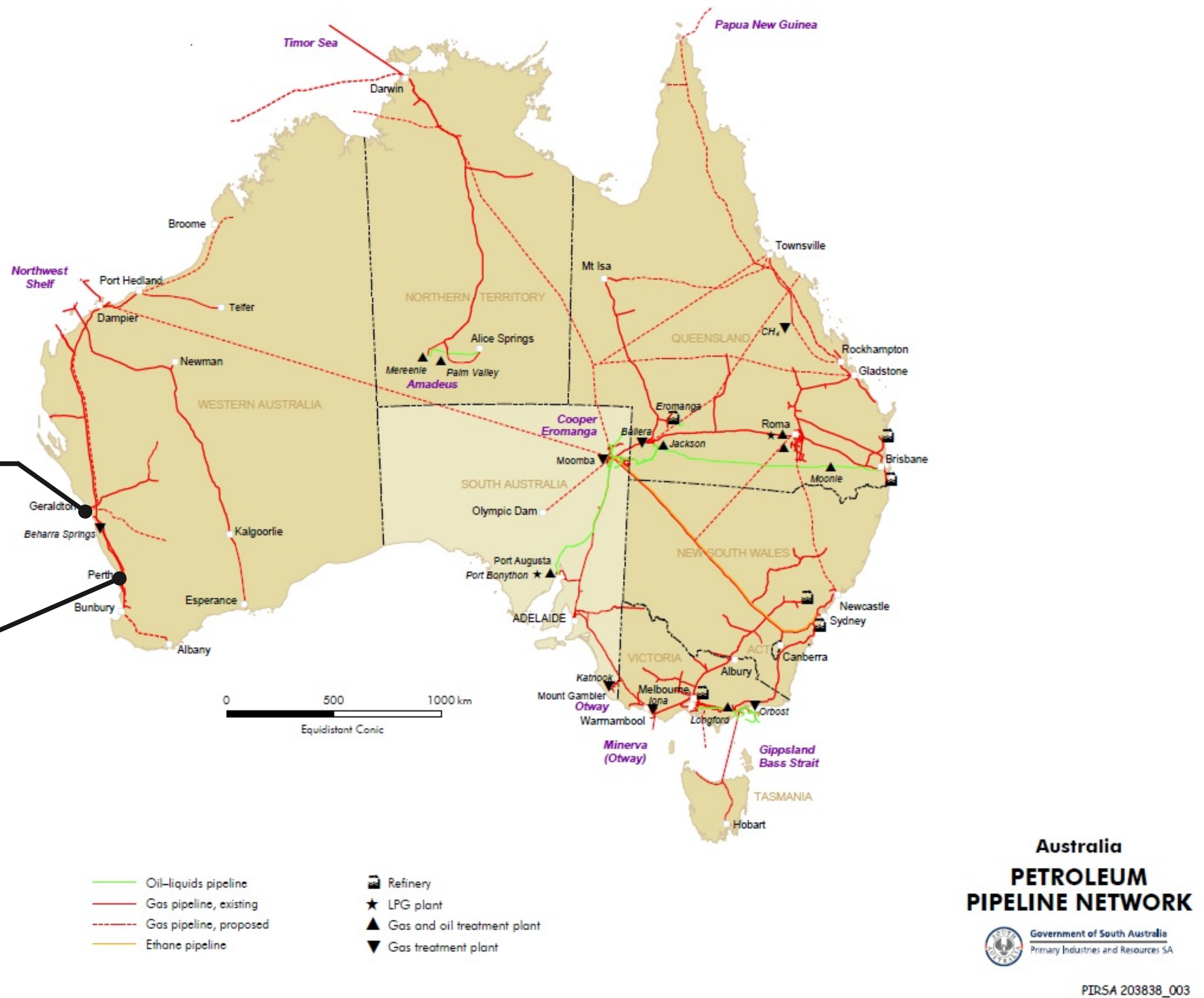




ASTRI Approach

- Selected Solar Fuels as the process closest to commercial
  - 1st Aust. Workshop on Solar Thermal Chemical Processes, Adel. Jan. 2013
  - Syngas production has been demonstrated at 250 kW
  - Long-term commercial drivers for fuels as high value product
- Developed a set of standard conditions by expert opinion
  - Solar Receiver Scale: 50 MW thermal
  - FT (mini) reactor scale: 1500 bbl/day (9.94m^3/h)
- Selected Reference site as Geraldton, WA
  - good solar resource, 6.6 kWh/m^2/day (DNI)
  - Ready access to all feedstocks (natural gas, coal, wood)
  - Access to seawater for growing algae (micro / macro)
- Selected common economic parameters

ASTRI Reference Location



Geraldton

Perth

ASTRI Reference Field Design

PARAMETER	CAVITY RECEIVER	EXTERNAL RECEIVER
Type of field	Sector	Surround
Design thermal incident power, MW_{th}	270.6	270.6
Tower height (100 MW_e), m	133	223
Solar multiple	1.33	1.33
Field size (100 MW_e), m^2	708,933	748,104
Optical efficiency of solar field‡	56.4%	53.5%
Approximate field size, 50 MW_{th}	130,999	138,237

Field Design

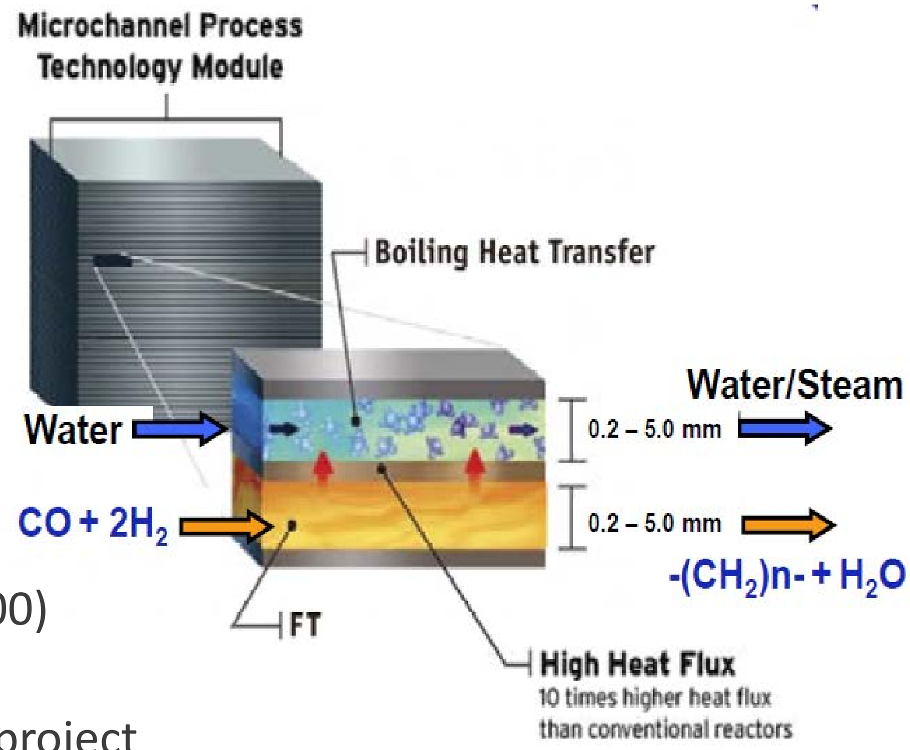
Developed with SAM
Scaled down from:

270 MW_{th} = 100 MW_e

DESIGN POINT RADIATION TO RECEIVER	50,000	KW
Design point DNI	900	W/m^2
Annual energy yield	110.5	MWh
Solar field capacity factor (annual)	28.9%	
Solar field optical efficiency at design point	58.8%	

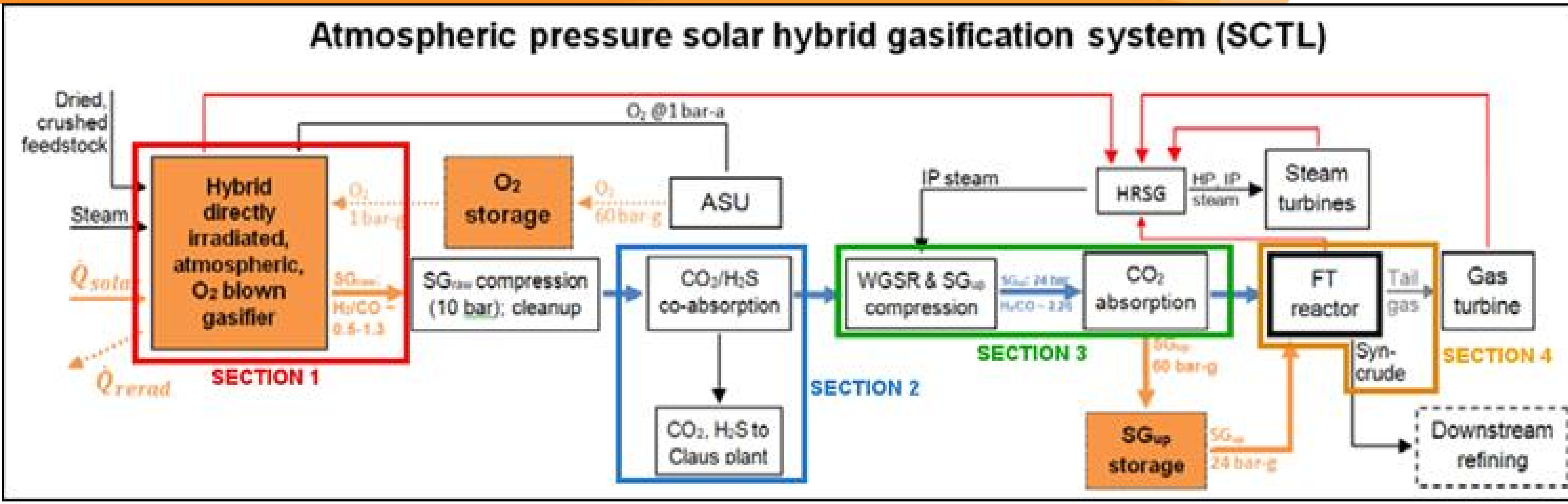
Turn-down of FT-reactor

- Current FT Reactors:
  - Employ large tubes
  - Take > 5 days to stabilise
  - No turn-down capability
- New mini-micro reactors
  - Employ small channels or tubes
  - ~ 10 × higher rates of heat transfer
  - Economic at much smaller scale (< 1/100)
  - Have potential for large turn-down
    - Being assessed within current ASTRI project



- Various approaches adopted in preliminary assessment
  - Three Hybrid processes: all achieve continuous production
  - Methane reforming: Storage 61% average daily output (requires turn-down)
  - Super-critical gasification: 6 hours storage (requires turn-down)

ASTRI Process modelling



- Processes models were developed for each technology option
  - All assumed "pseudo-steady-state" – steady at each time-step
  - Accounted for resource variability, but in different ways
    - Hybrid cases ensured full output was maintained throughout year

ASTRI – Key economic parameters

$$LCOF = \frac{\sum_{t=1}^{n} (I_t + M_t + F_t - S_t)/(1+r)^t}{\sum_{t=1}^{n} (E_t)/(1+r)^t}$$

LCOF = Levelised cost of fuel in $/GJ ($/Litre)

I_t = Investment expenditure or capital cost in the year *t*

M_t = Operations and maintenance cost in the year *t*

F_t = Feedstock cost in the year *t*

S_t = Annual sale price of any electricity in the year *t*, if produced from the process, in AUD

E_t = Quantity of energy produced (GJ), including electricity for sale in year *t*.

r = Discount rate

n = Amortisation period

ASTRI – Key economic parameters

SOLAR COST COMPONENTS	CURRENT COST (2014 AUD)	FUTURE COST 2020 (2014 AUD)	UNITS
Solar Field plus site costs	240	135	$\$/m^2$
Tower	51.0	46.6	$\$/kW_{th}$
Receiver (based on molten salt)	150.8	137.7	$\$/kW_{th}$
BOP solar	35.1	32.1	$\$/kW_{th}$
Solar field O&M	65	55.8	$\$/(kW_{th}.year)$
Power generation	1025	965	$\$/kW_e$
Syngas storage	20,833	19,027	$/GJ

ASTRI – Summary of economic analysis

Process	Technical feasibility (22%)	Solar share (10%)	Economic feasibility	-LCOF ($/L)	Sustainability (20%)	-Feedstock sustainability (50%)	-CO_2 emission (50%)	Stage of development (15%)	Overall	Priority
Solar mixed reforming of methane	**7.8**	**3.0**	**6.8**	$1.0/L	**2.5**	1.0	4.0	**6.5**	**5.7**	1
Solar hybridized coal gasification via vortex flow reactor	**6.3**	**3.0**	**5.3**	$1.2/L	**1.0**	1.0	1.0	**4.5**	**4.3**	2
Solar hybridized coal gasification via dual fluidised bed gasifier	**7.5**	**3.0**	**7.1**	$0.9/L	**1.0**	1.0	1.0	**6.0**	**5.4**	1
Solar hybridized biomass gasification via dual fluidised bed gasifier	**7.0**	**3.0**	**4.5**	$1.4/L	**9.0**	8.0	10.0	**6.0**	**6.0**	1
Supercritical water gasification of Algae	**5.8**	**5.0**	**2.3**	$2.9/L	**9.0**	8.0	10.0	**6.5**	**5.3**	1
Thermochemical cycles	**5.0**	**10.0**	**2.3**	$2.0/L	**7.8**	5.5	10.0	**7.0**	**5.4**	1

Final Comments

- ASTRI Milestones for costs by Dec 2016:
  - $1.20/L for fossil fuel feedstock with a life-cycle emission of CO_2 that is at least 10% lower than conventional diesel, and
  - $2.50/L for future renewable feedstock with a life-cycle emission of CO_2 that is at least 50% lower than conventional diesel.
    - Note: "Targets" could be set lower
- ASTRI milestone for wholistic viability:
  - develop a broad assessment system

Acknowledgements

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CSIRO

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THE UNIVERSITY of ADELAIDE

University of South Australia

QUT

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Thank you