

Hydrogen generation, storage and utilisation in Australia: Transition to a low emissions energy sector

Cryogenic Engineering Conference
and
International Cryogenic Materials Conference

Honolulu, Hawaii USA
July 2023

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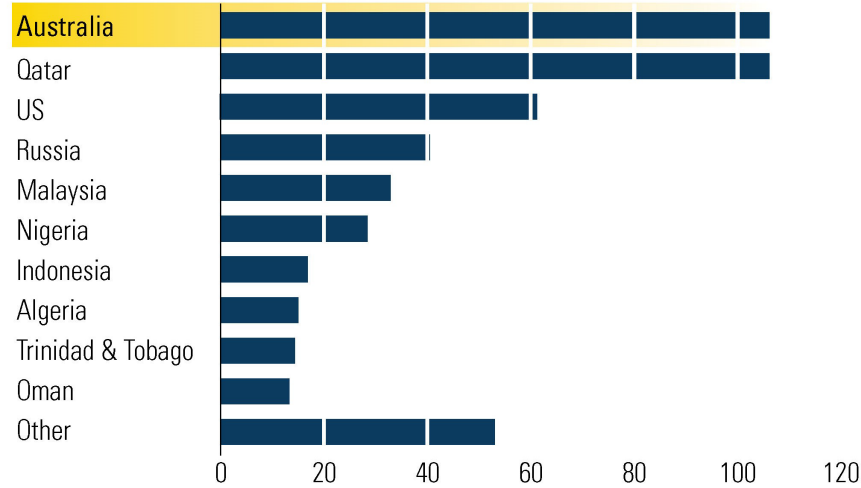


**Centre for Clean Energy
Technologies and Practices**

Australian Resources

Natural Gas

Top 10 LNG exporting countries 2020 (billion cubic metres)**



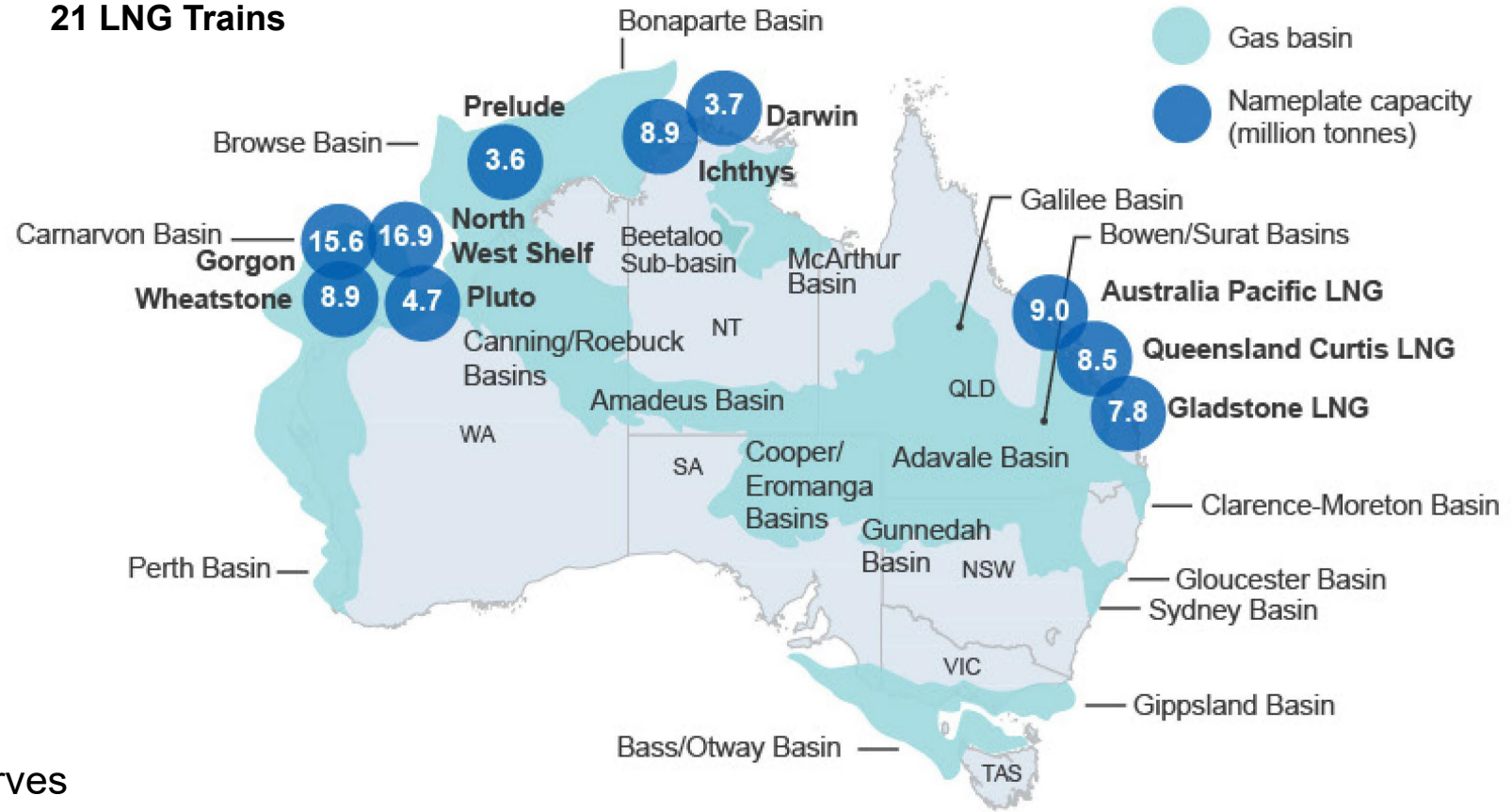
SOURCE: BP STATISTICAL REVIEW OF WORLD ENERGY 2021

Australian LNG Reserves**:

- Ranked 13th in world
- Other countries: 30x to 100x greater reserves
- Russia, Iran, Qatar, Turkmenistan, USA, China

Australia's LNG projects and gas basins

21 LNG Trains



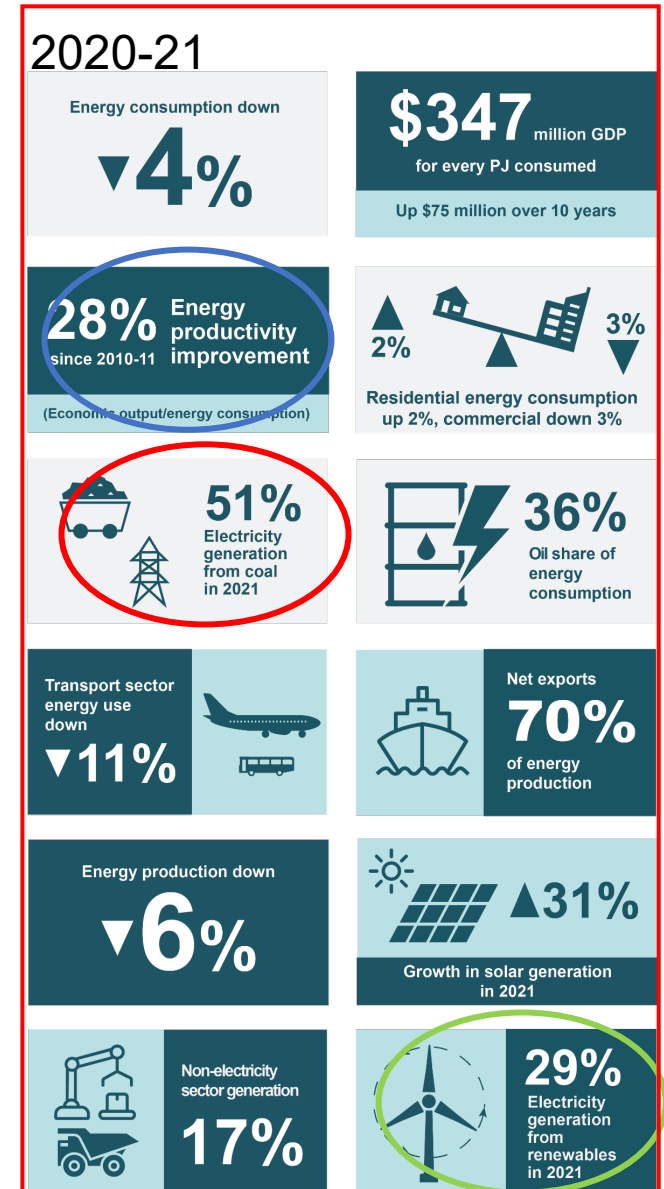
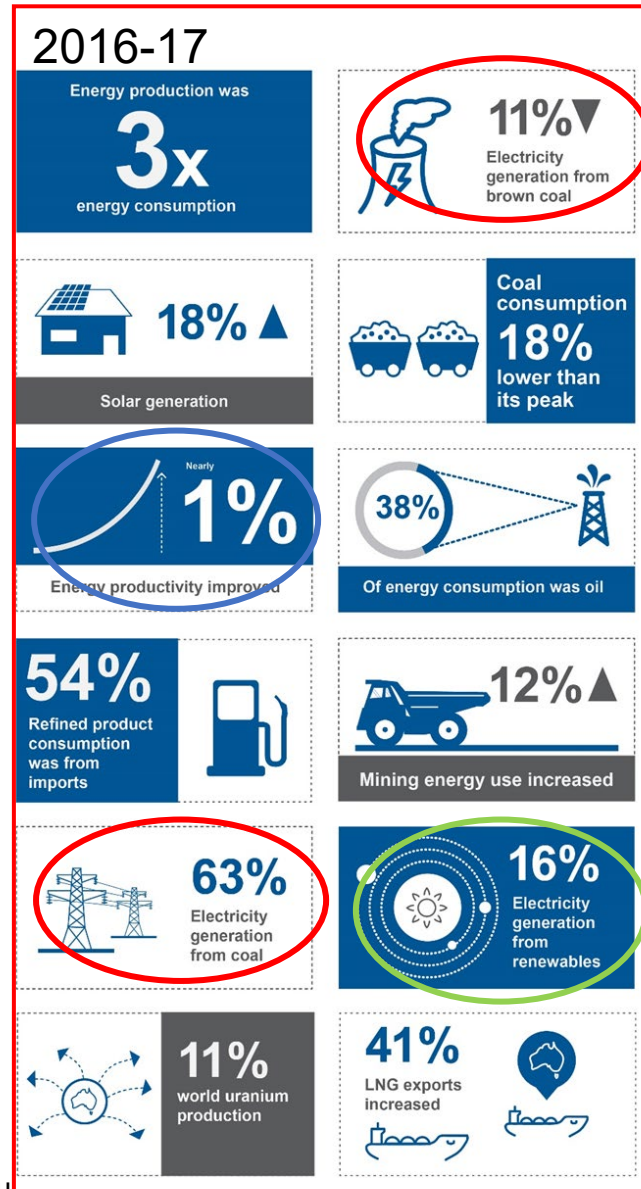
**"Key Statistics 2022", APPEA www.appea.com.au

Australian Energy

Statistics: 2016-17 and 2020-21

Key Trends

- Notable reduction in coal-fired electricity
 - from > 70% to ~50%
 - trend to continue to 2030-35
- Doubling of electricity using renewable energy
 - from ~16% to ~29%
 - in 2022 up to ~36%
 - rate of growth for solar >30%
- Reduced energy production and consumption
- Energy productivity increase by 28%
 - since 2010-11 (10 year trend)
- Net exports remain ~70% of total production
 - Scope 3 emissions challenge



Source: Australian Government, "Australian Energy Update 2018; 2021"; energy.gov.au

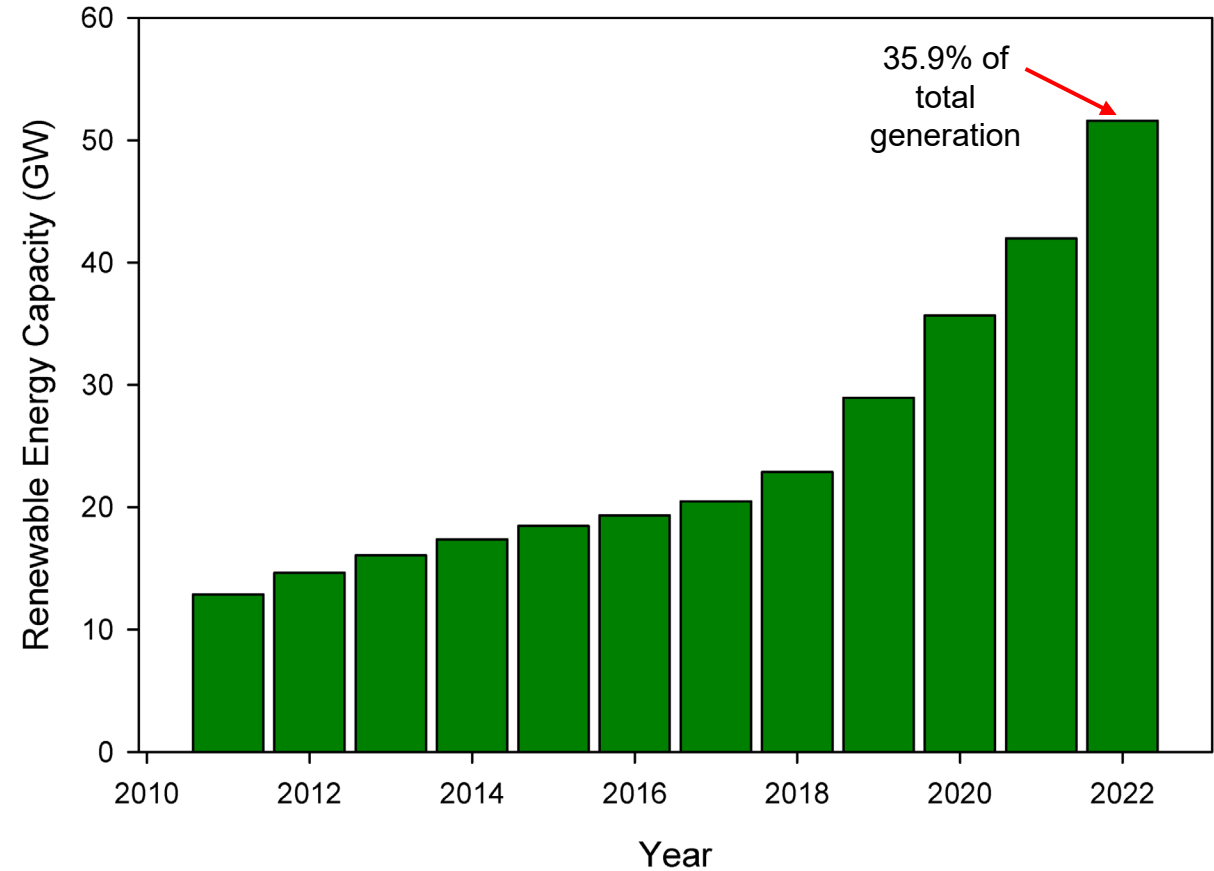
Australia's Transition

Renewable Energy

Renewable Energy Penetration 2022*

State	Total (GWh)	Fossil Fuel (GWh)	Renew (GWh)	% of Total Prod'n	% of Total Used
NSW	70,868	49,103	21,765	30.70%	28.70%
QLD	63,833	49,406	14,427	22.60%	23.30%
VIC	53,794	33,973	19,820	36.80%	40.00%
WA	20,790	13,467	7324	35.20%	35.20%
SA	13,826	3942	9884	71.50%	68.40%
TAS	10,931	95	10,836	99.10%	93.30%
National	234,042	149,986	84,056	35.90%	35.90%

Renewable Energy Change**



Top Clean Energy Producers+
 Norway (98%), Brazil (84%), New Zealand (80%)

*Source: Australian Clean Energy Council Report, April 2023

+<https://earth.org/renewable-energy-facts/>

**Source: Australian Clean Energy Council Reports

Population Distribution

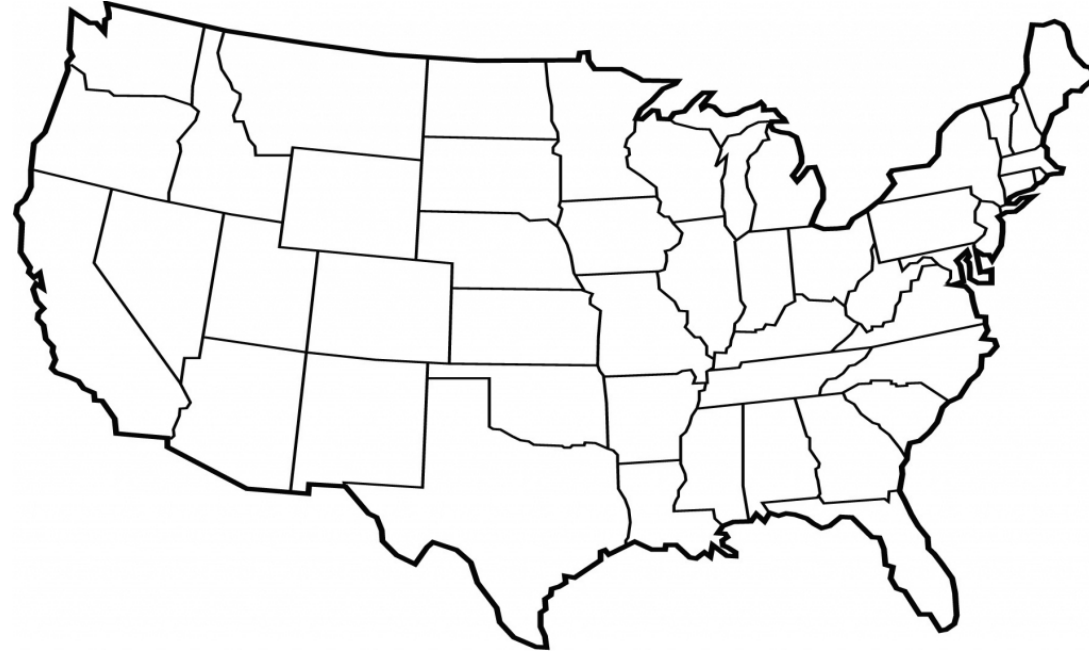
Cities, Regional, Remote

Continental Australia

8.56 million km²
~26 million people

Continental USA

8.08 million km²
~335 million people



Population Distribution

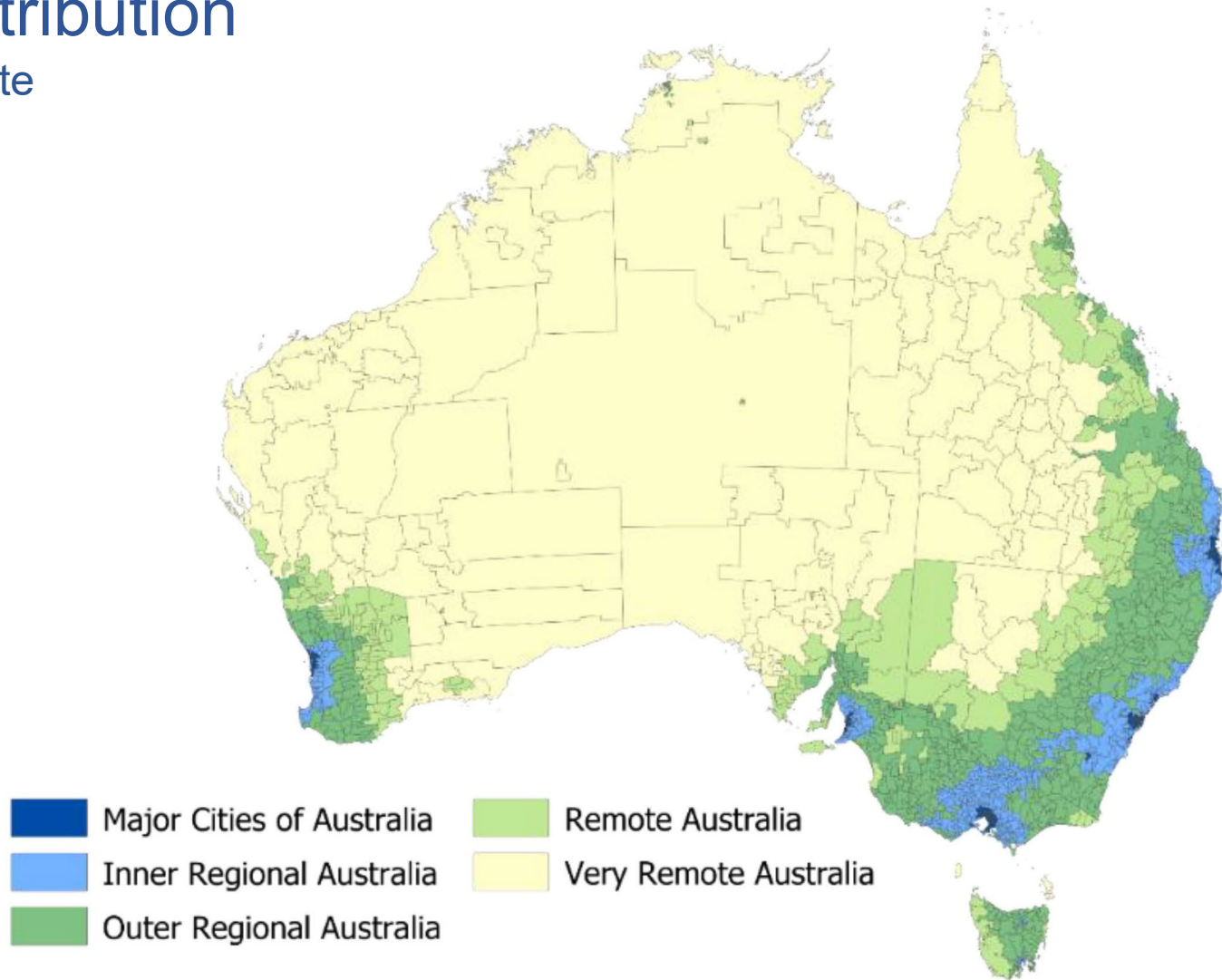
Cities, Regional, Remote

Continental Australia

8.56 million km²
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Continental USA

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Electricity Transmission

“National Electricity Market”

“NEM” Details

- Approx. 40,000 km of lines & cables
- ~A\$11 billion traded in 2021-22

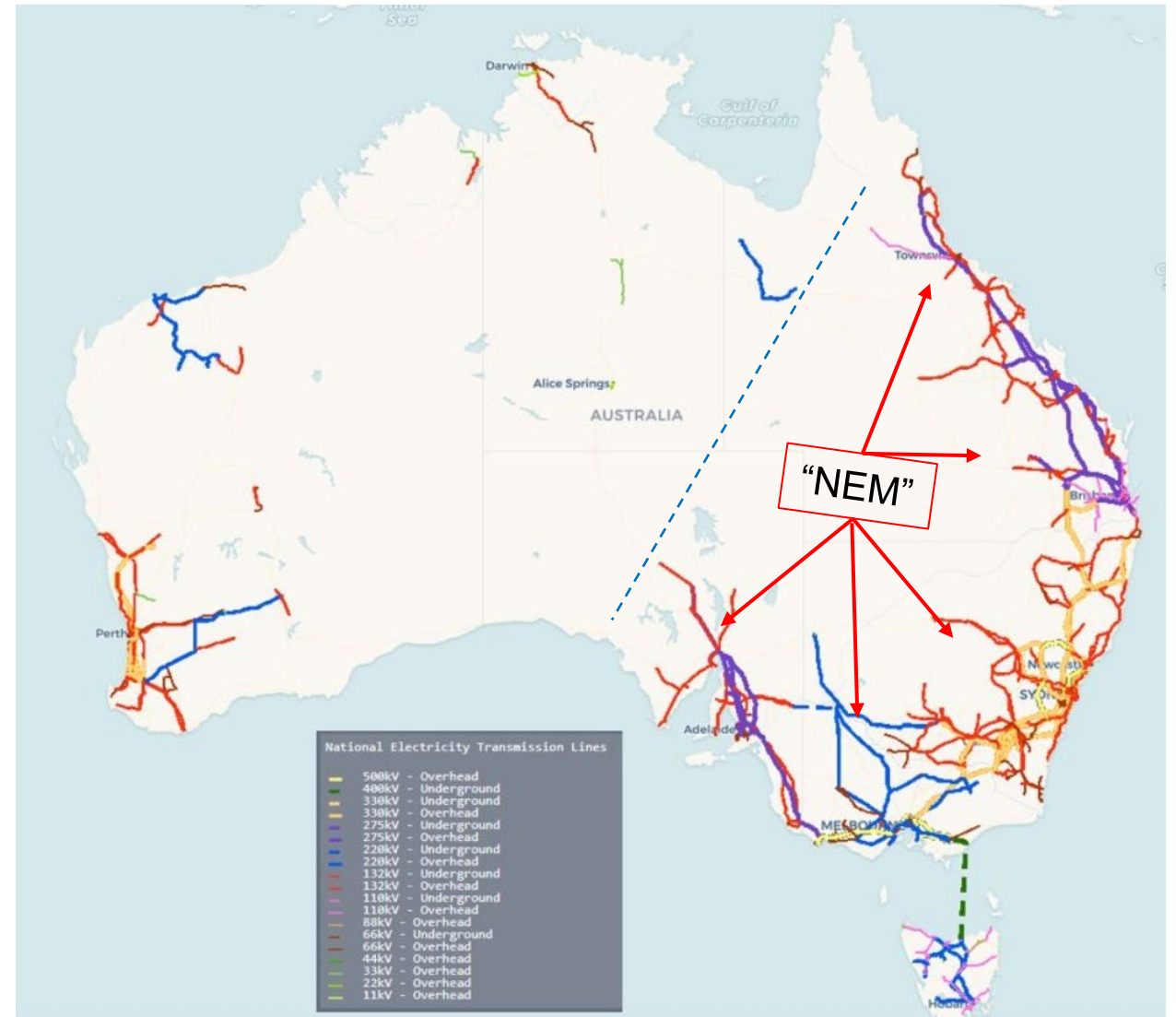
Recent Developments

- Policy link – energy and emissions
- Policies on energy transition align
- Major re-build of electricity grid (NEM)
 - ✓ AU\$20 billion allocated to NEM upgrade*
- Additional funds: clean energy/emissions targets
 - ✓ ~AU\$260 billion by states/territories to infrastructure**
 - ✓ QLD commits >AU\$19billion to 2030 for Energy Plan†

*Source: <https://www.energy.gov.au/government-priorities/australias-energy-strategies-and-frameworks/powering-australia>

†Source: <https://budget.qld.gov.au/overview/the-big-build/>

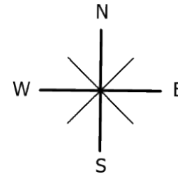
**“The Australian”, July 4th, 2023.



Net Zero Australia

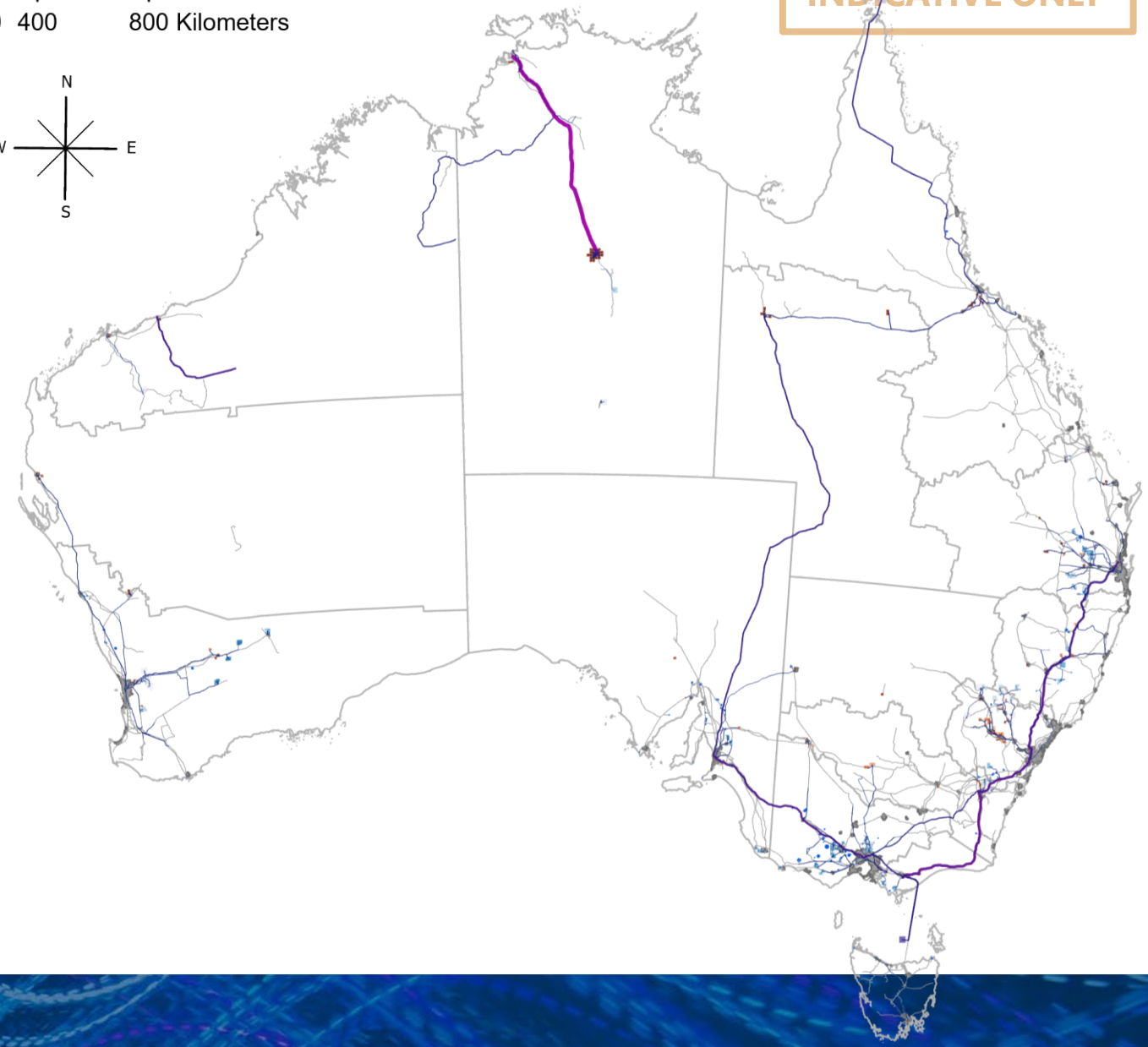
(UMelbourne, UQLD, Princeton, NOUS)

0 200 400 800 Kilometers



INDICATIVE ONLY

2030 Scenario



Renewable Energy

In 2022

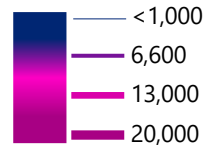
~36% of Total Capacity

By 2060

>90% of Total Capacity
(includes CCS/CCUS)

Powerlines carrying renewable energy

Transmission (MW)



Source: <https://www.netzeroaustralia.net.au/publications/>

Net Zero Australia

(UMelbourne, UQLD, Princeton, NOUS)

Value-add Production
at/near RE site

2060 Scenario
with
onshoring

Renewable Energy

In 2022

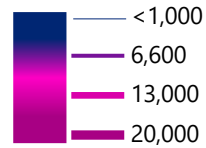
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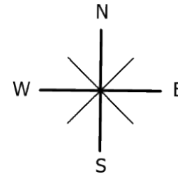
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Powerlines carrying
renewable energy

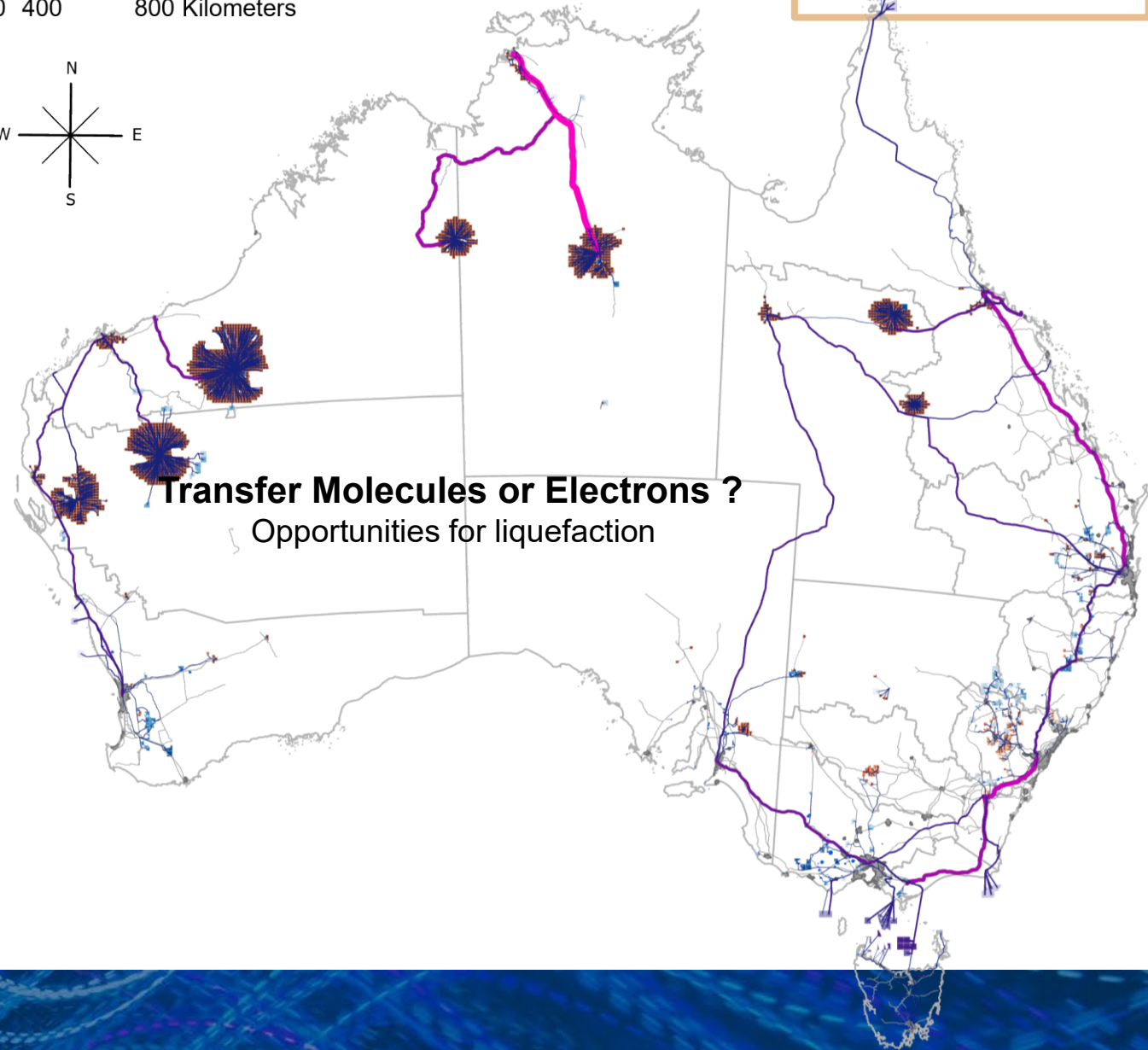
Transmission (MW)



0 200 400 800 Kilometers



INDICATIVE ONLY



Source: <https://www.netzeroaustralia.net.au/publications/>

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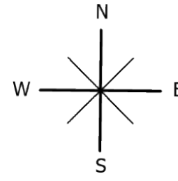
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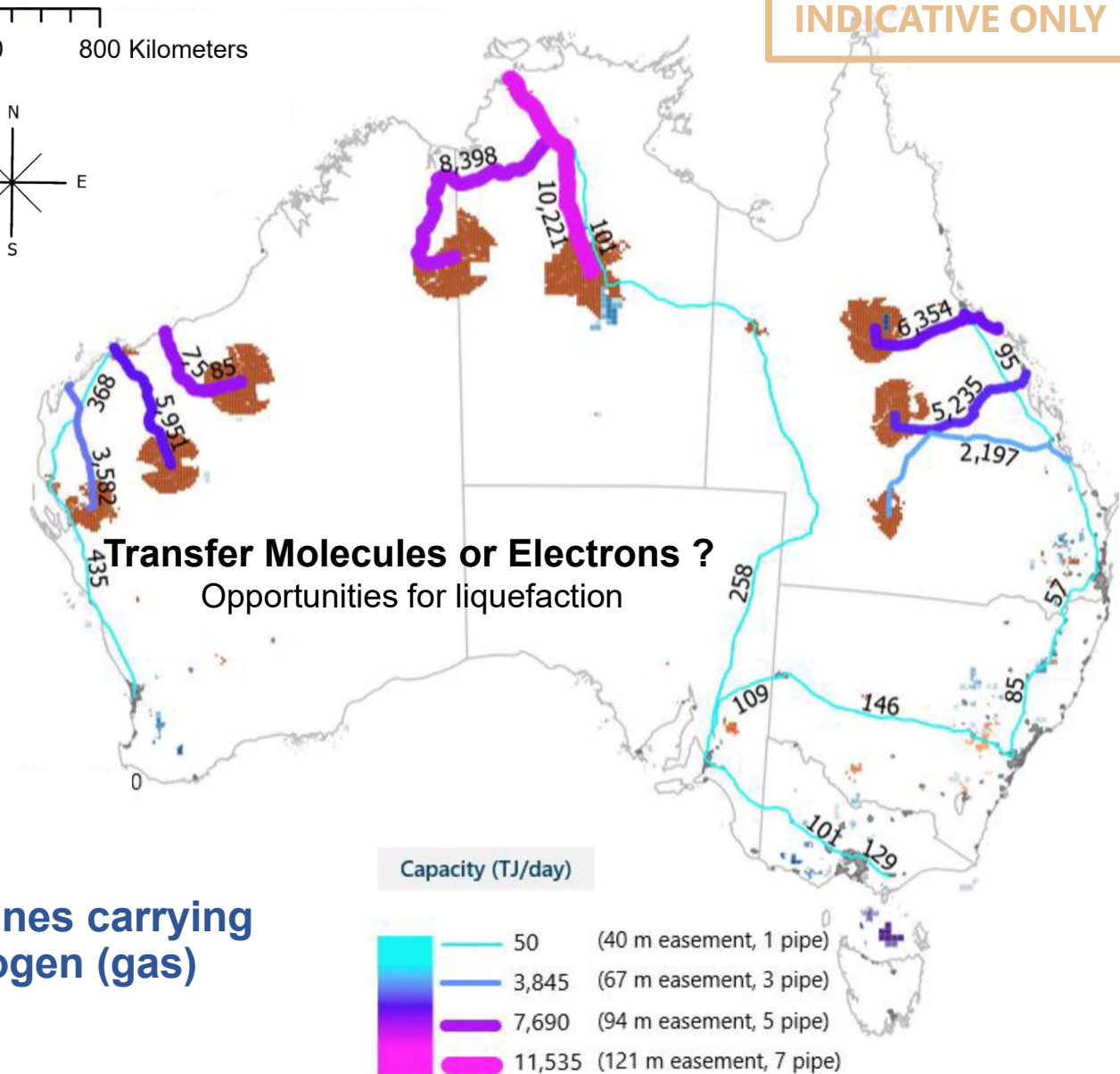
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(includes CCS/CCUS)

Source: <https://www.netzeroaustralia.net.au/publications/>

0 200 400 800 Kilometers



INDICATIVE ONLY



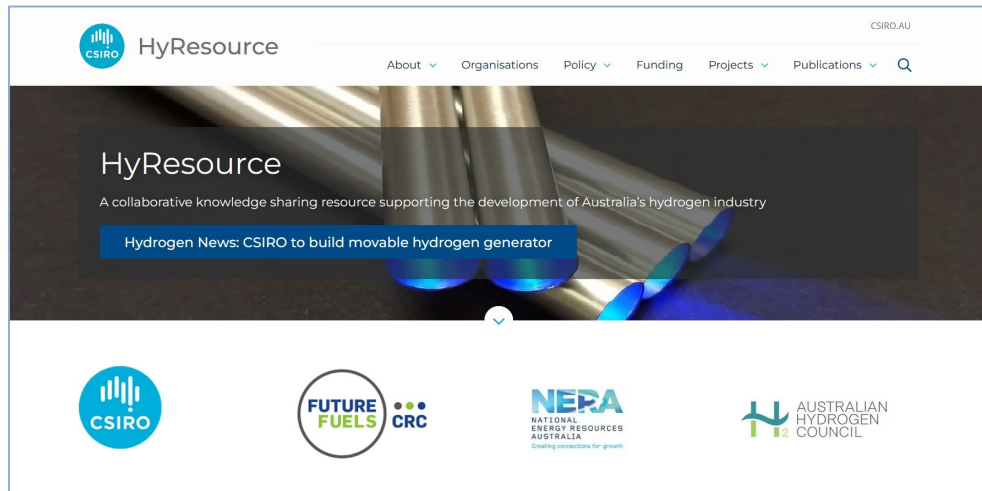
Pipelines carrying
hydrogen (gas)

Hydrogen Projects

Industry scale – June 2023

Status	Number
Operating	11
Under Construction	13
Planning/Development	89
Completed	1
Total Projects	114

Inactive: 15



WebSite: <https://research.csiro.au/hyresource/>

Distribution



Hydrogen Liquefaction

Industry scale – nascent

Latrobe Valley/Port Hastings – HESC Project

- Japan+Australia Govts; Kawasaki, Sumitomo, J-Power
 - Demo shipment; Delivered Kobe Jan, 2022
- JSPC JV: Sumitomo and J-Power ~\$2.4b GIF funding
 - Brown coal + CCS in local depleted basin
 - Target: 30-40 kT/yr up to 225 kT/yr of H₂(g)

Gladstone Port

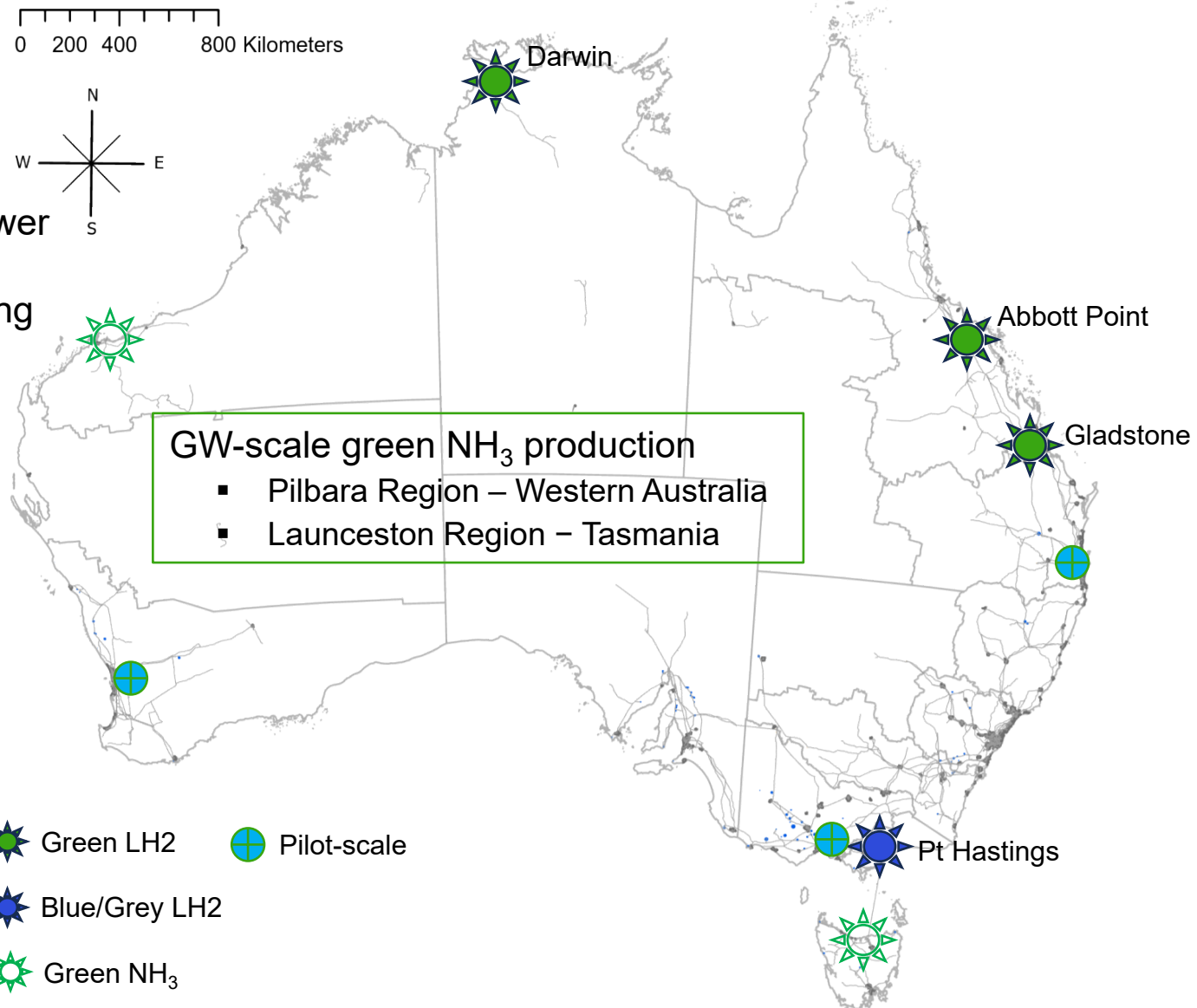
- CQ-H2: Japan, Singapore, Australia
 - FEED in 2023; 2030's Target: 290 kT/yr H₂
- Sumitomo + Rio Tinto (local use ~300 T/yr H₂)
 - FID approved 2023; Stage 2 targets LH2 export

Abbott Point Port

- Energy Estate HyNQ – domestic (30 T/day LH2)

Darwin Port

- Lattice Technology, Sun Cable (42 kT/yr LH2)



Hydrogen Energy Supply Chain Project

HESC – Stage 1



January, 2022

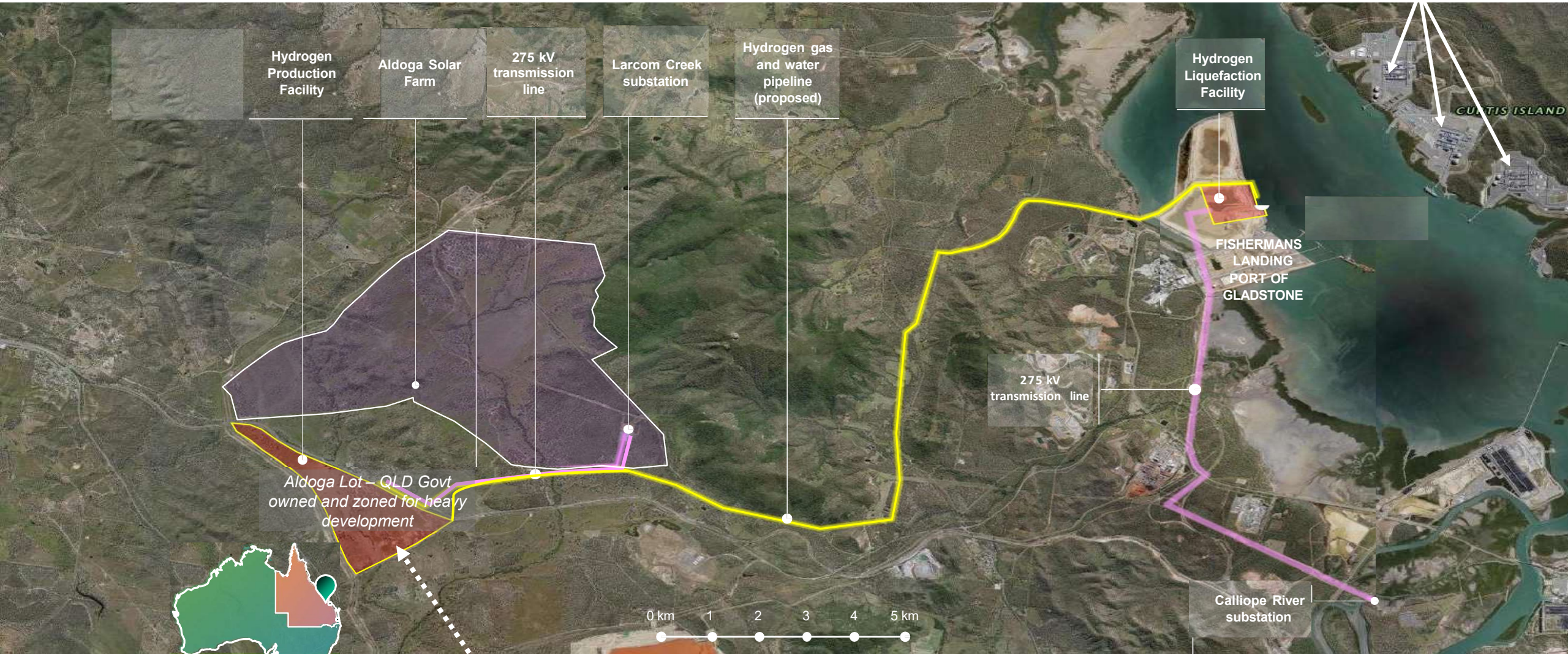


Stage 1
Plant capacity: 0.25 tonne per day
Storage: 41 m³ LH2 container.
Ship capacity: Suiso Frontier 1,250 m³

Supply Chain: <https://www.hydrogenenergysupplychain.com/>
Port Detail: <https://www.hydrogenenergysupplychain.com/supply-chain/port-of-hastings/>

CQ-H2 Project Gladstone Region

LNG Trains
(approx. 26m T/yr)



Target: 520,000 T/yr H₂ production

Hydrogen R&D Projects

Australia – June 2023

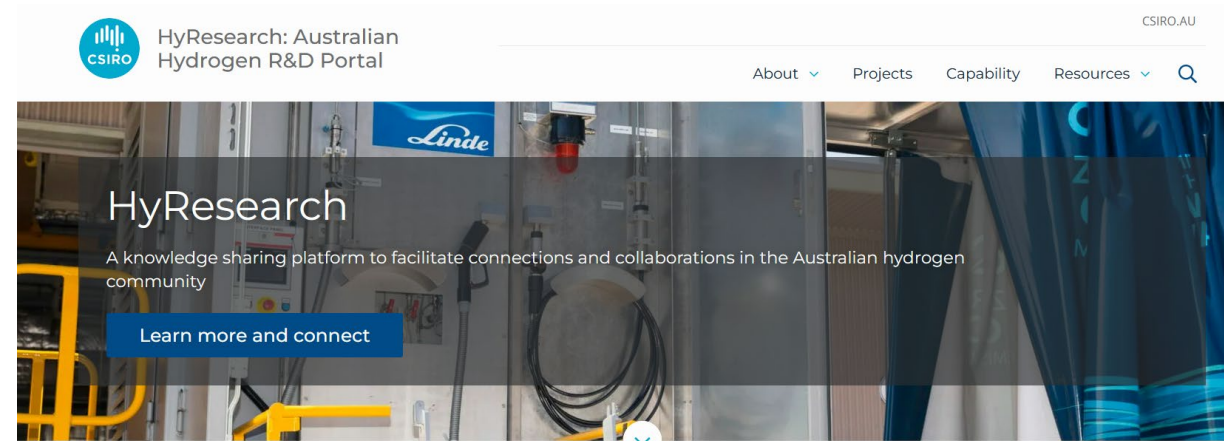
All R&D Projects

- Total of 280 current R&D projects in Australia
 - Website updated every 6 months
- Value-chain mapping
 - ~ 60 Research Focus Areas; project limit up to 3 Focus Areas

Hydrogen Storage

- Predominantly focused on gaseous or metal hydride
- ~9 projects with liquefaction included

- LH2 ortho-para conversion (OPC)
 - Methods: Raman, thermal conductivity, sound velocity
- Small scale testing rigs
 - OPC “catalyst”; H₂ catalyst liquefier
- Model development/modification
 - Ortho-para simulation; mixed cryogenes
- Materials for magnetic refrigeration
 - Compounds with high MCE



Website: <https://research.csiro.au/hyresearch/>

International Collaboration Program

CSIRO Programs

Website: <https://www.csiro.au/en/about/challenges-missions/Hydrogen>

International Collaboration Program

Hydrogen RD&D



Australian Government

Department of Climate Change, Energy, the Environment and Water

Overview

Goal: To build domestic hydrogen RD&D capability by stimulating international research connectivity and knowledge sharing in support of Australia's hydrogen industry development.

- Initial Funding: July 2021-Sept 2023
- CSIRO led program working with AHRN
- Governance: Steering Committee, AHRN, Industry Advisory Group

Update:

- ✓ Seven delegations completed
 - Germany, France, UK, Japan, USA, Canada, Singapore
 - South Korea in September 2023
- ✓ Fellowships awarded
 - 15 fellows in progress

Website: <https://ahrn.org.au/>

Website: <https://events.csiro.au/Newsletters/AHRN/IHRCPR-EOI-Aug-2022>

Program elements

International RD&D scans

Identifying international hydrogen RD&D collaboration opportunities

Hydrogen Knowledge Centre

Australian Hydrogen RD&D+industry promotion, development, knowledge sharing

RD&D delegations

Enabling international connections for the Australian research community

Two-way Research Exchanges

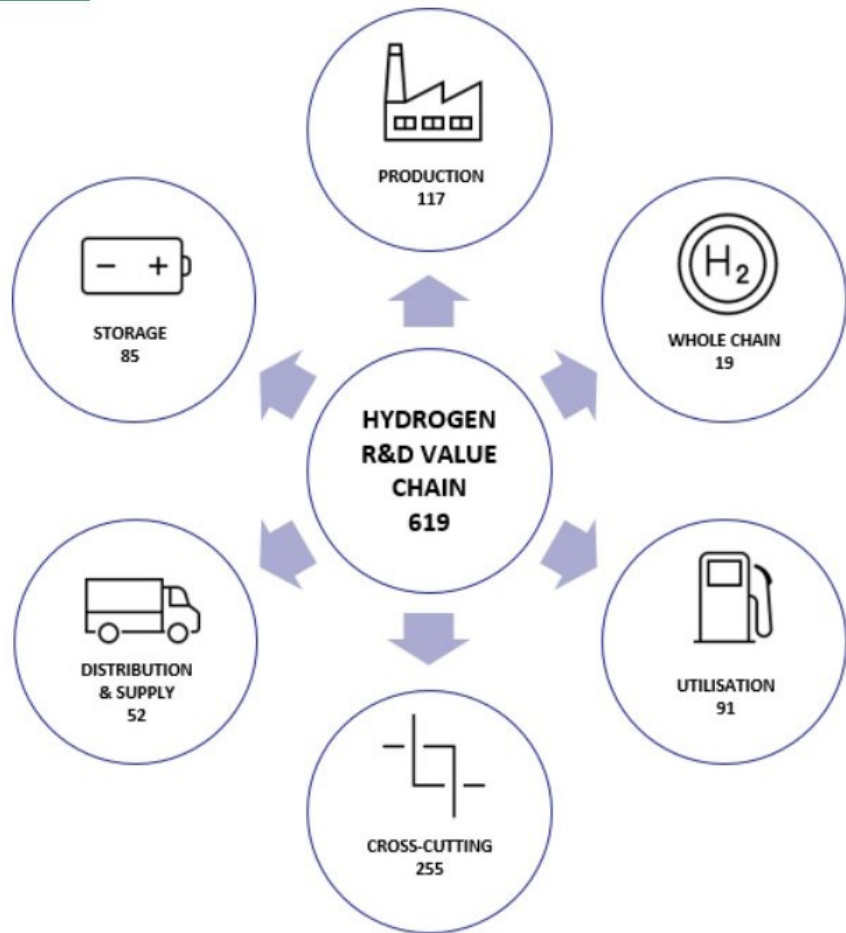
Placing our 'best and brightest' in leading international hydrogen research labs

Hydrogen RD&D Conference

Local & international networking and collaboration development

Hydrogen R&D

Overall value-chain – heat maps



	PRODUCTION	STORAGE	DISTRIBUTION & SUPPLY	CROSS-CUTTING	UTILISATION	WHOLE CHAIN	Grand Total
AUSTRALIAN NATIONAL UNIVERSITY	5	1		19	2		27
CURTIN UNIVERSITY	3	7	3	5	6		24
DEAKIN UNIVERSITY	1		9	12	3		25
EDITH COWAN UNIVERSITY	3	1					4
GRIFFITH UNIVERSITY	5	2		4	2	2	15
MACQUARIE UNIVERSITY	1						1
MONASH UNIVERSITY	6	6		8	2	2	24
MURDOCH UNIVERSITY	1		1	2	1		5
QUEENSLAND UNIVERSITY OF TECHNOLOGY	4		1	9	3	3	20
RMIT UNIVERSITY	3	3		23	1		30
SWINBURNE UNIVERSITY OF TECHNOLOGY	1	1		10	4		16
UNIVERSITY OF ADELAIDE	7	2		30	19		58
UNIVERSITY OF MELBOURNE	6	6	4	25	7		48
UNIVERSITY OF NEW SOUTH WALES	27	6		20	7	2	62
UNIVERSITY OF NEWCASTLE	3	3	2	2	8		18
UNIVERSITY OF QUEENSLAND	9	2	6	21	1		39
UNIVERSITY OF SYDNEY	5	3	4	8	3		23
UNIVERSITY OF TASMANIA				3	2	1	6
UNIVERSITY OF TECHNOLOGY SYDNEY	2	7		4		1	14
UNIVERSITY OF WESTERN AUSTRALIA	2	8	1	4	5		20
UNIVERSITY OF WOLLONGONG	4	1	16	7	4		32
CSIRO	14	19	2	21	6	5	67
GEOSCIENCE AUSTRALIA	1	2		4		1	8
INDUSTRY	4	5	3	14	5	2	33
Grand Total	117	85	52	255	91	19	619

<https://research.csiro.au/hyresearch/c/>

Hydrogen R&D

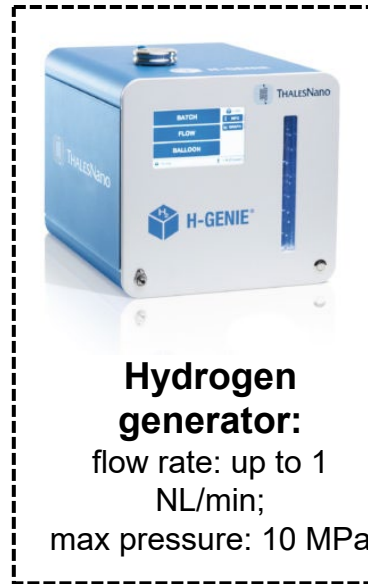
Bench to Pilot Trials – Liquefaction



CSIRO Clayton VIC

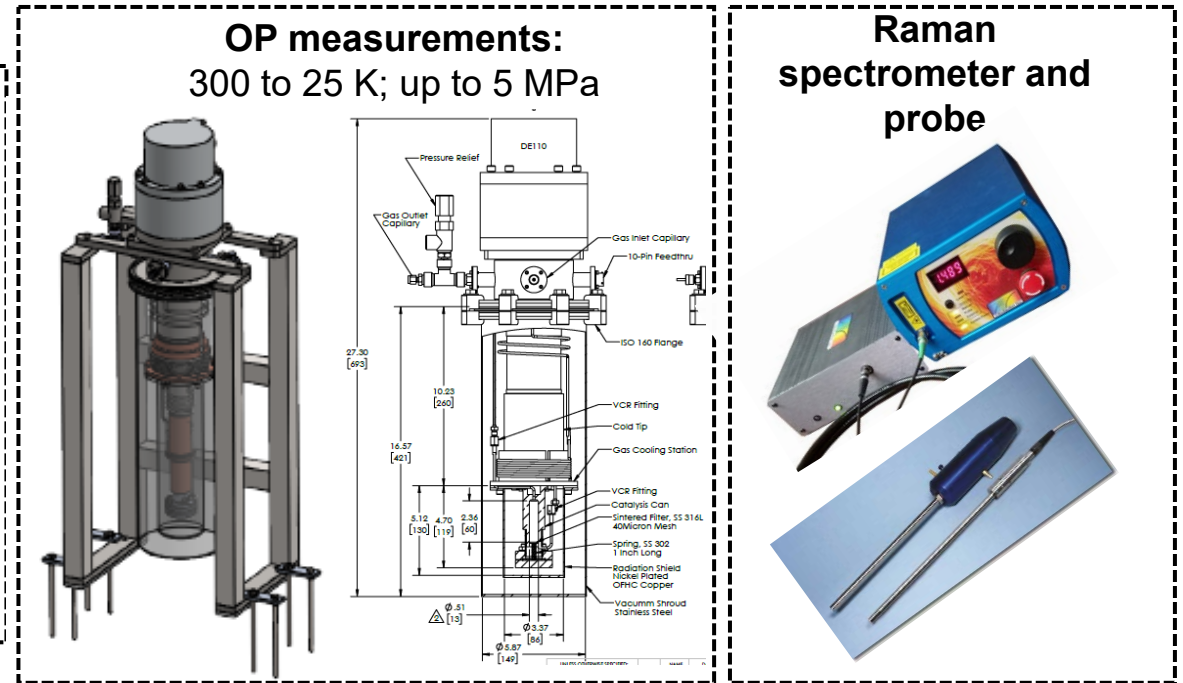


For OPC catalyst trials
(in development)



Hydrogen generator:
flow rate: up to 1 NL/min;
max pressure: 10 MPa

University of Western Australia WA



Future Energy Exports CRC

Translational R&D – Liquefaction Projects

Ongoing

- 21.RP2.0065-P Paths to a sustainable hydrogen supply chain
- 22.RP2.0125-P Simulation and testing of cryogenic ortho-para conversion in hydrogen liquefaction processes

Board Approved

- 23.RP2.0161 Thermophysical properties and simulation of mixed refrigerants used for hydrogen liquefaction process
- 23.RP2.0159-P Natural gas and hydrogen liquefaction by magnetic refrigeration

Other Hydrogen-Related CRC's

Future Fuels <https://www.futurefuelscrc.com/>

Blue Economy <https://blueeconomycrc.com.au/>

Heavy Industry Low-carbon Transition <https://hiltcrc.com.au/>

Review Article: Al Ghafri, S.Z.S., *et al.*, “Hydrogen liquefaction: a review of the fundamental physics, engineering practice and future opportunities”, **Energy Environ.Sci.**, 15, 2690, 2022.

At a glance



\$40m
Commonwealth contributions



\$166m
Cash and in-kind contributions



10
Years of funding



26
PhD students



50
Projects



251
Project team members



7
Commonwealth milestones achieved



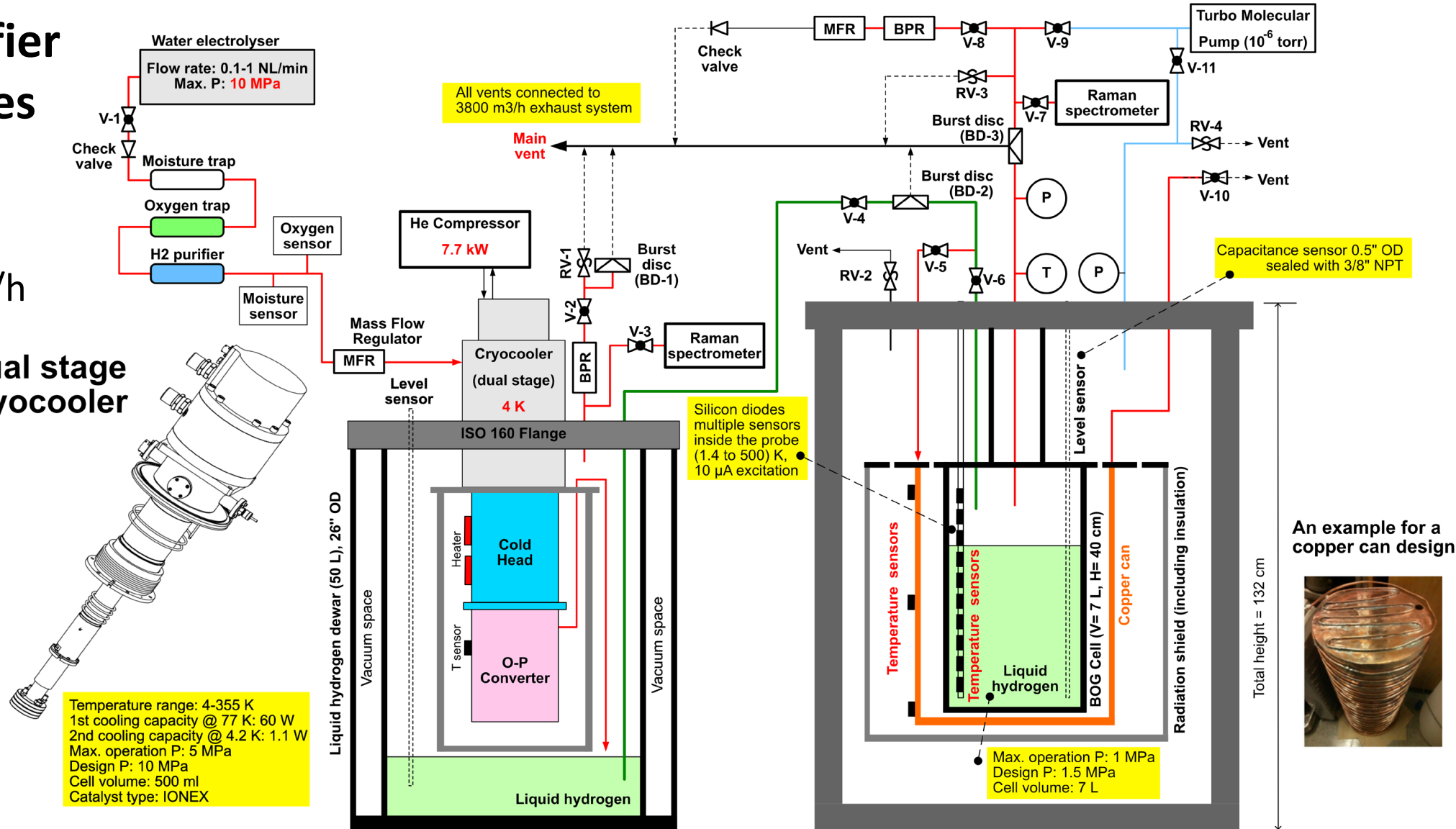
508
Conference, monthly colloquium and workshop attendees

Website: <https://www.fenex.org.au/>

Hydrogen Liquefier and Boil-off Gas

Hydrogen Liquefier and BOG Studies

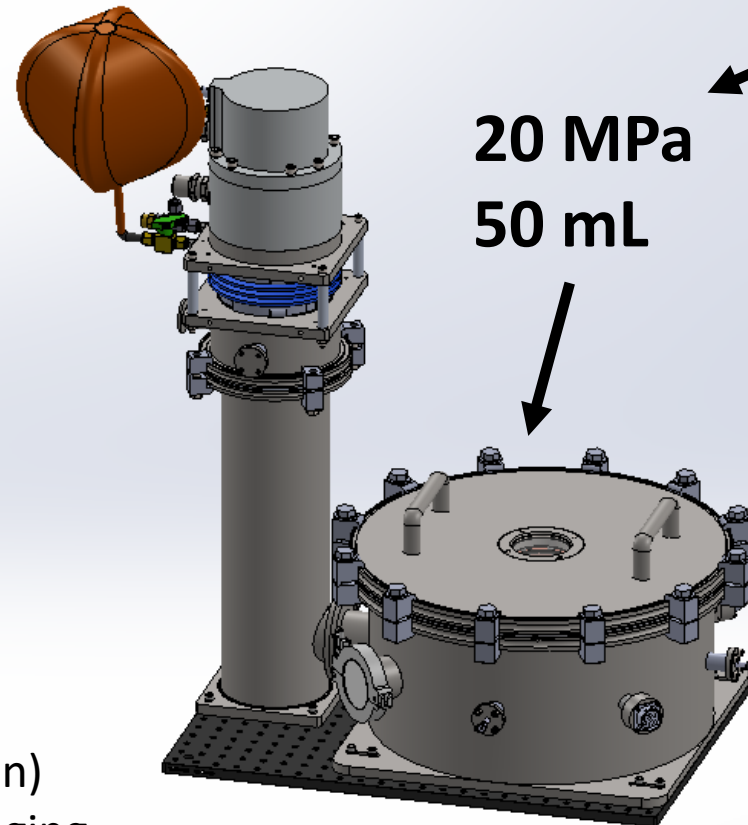
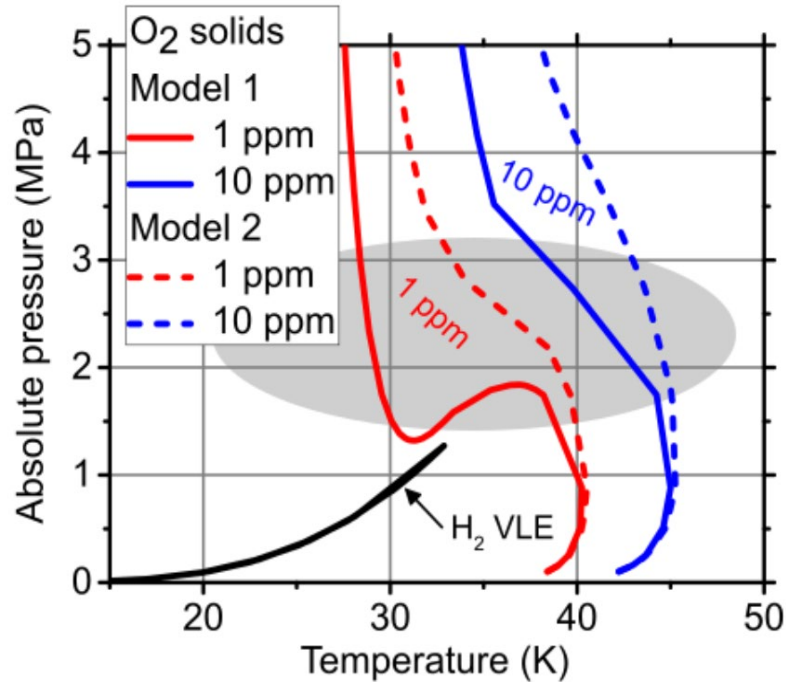
- 7L LH2 storage
- Liquefaction rate: 1L/h
- Max p : 1.5 MPa
- LH2 level sensors
- LH2 stratification
- BOG measurements
- OP conversion



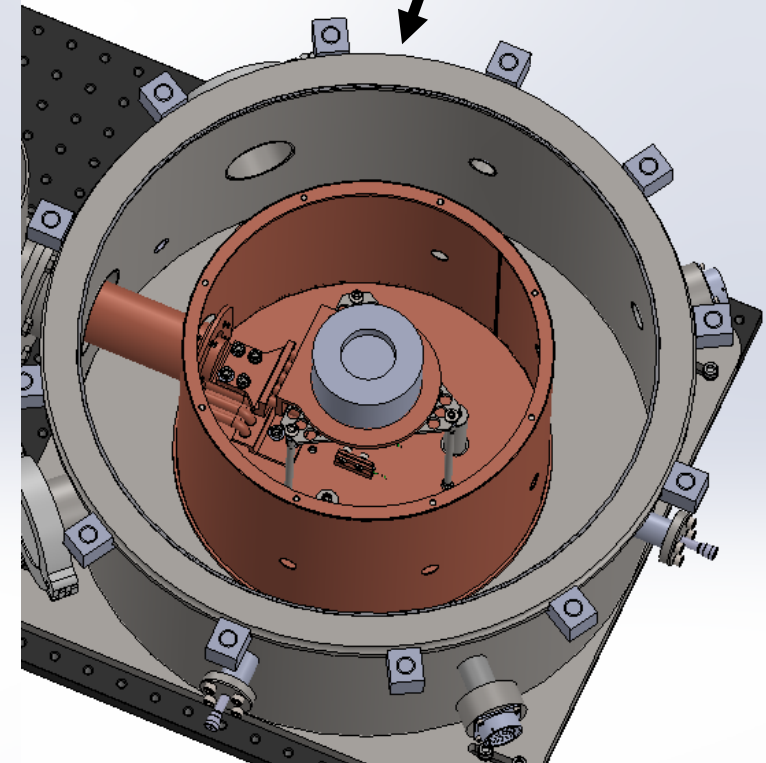
Impurity Freeze-out during Hydrogen Liquefaction

Lack of reliable data characterising solid freeze-out during H₂ liquefaction

May lead to blockages and plant shutdowns and pose significant safety and financial risks



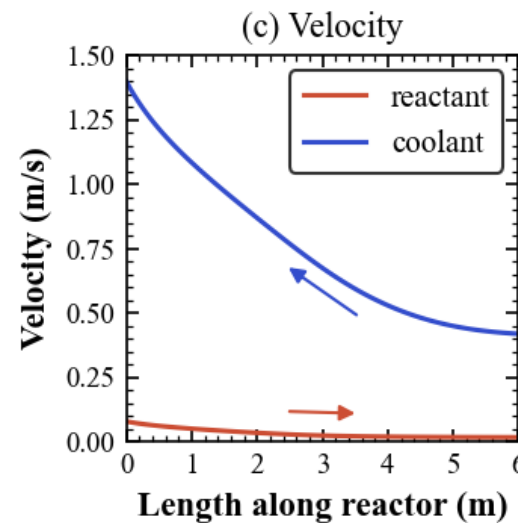
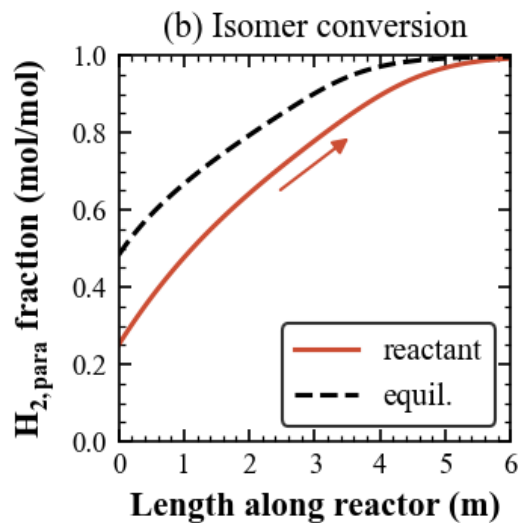
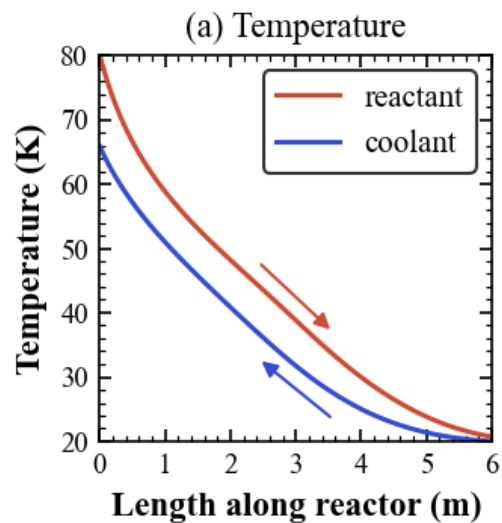
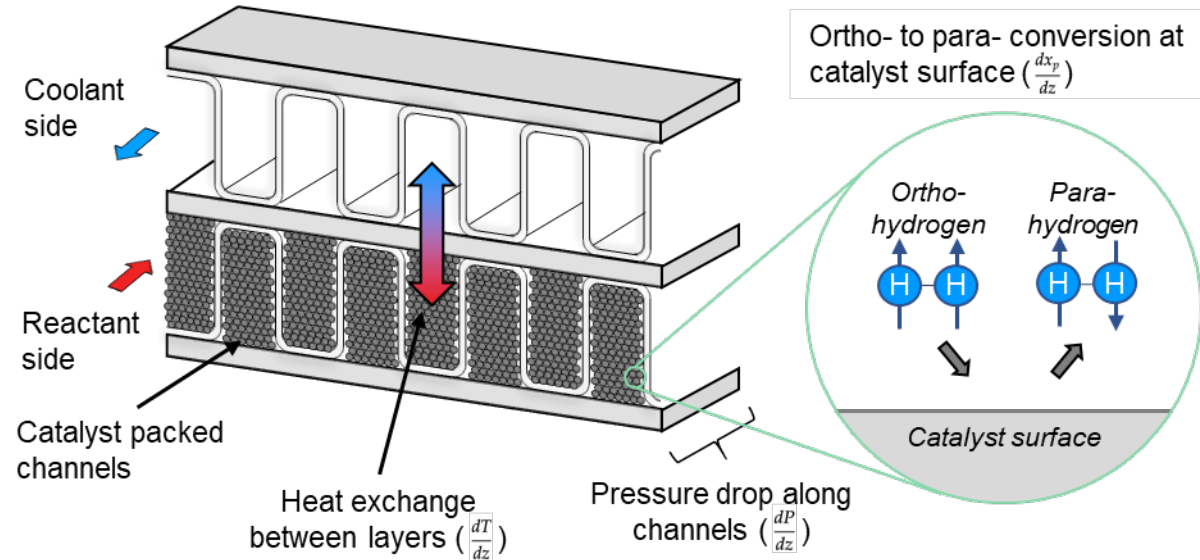
Visual pressure cell



- Minimum sample $T \approx 5$ K
- Closed-cycle cryo-cooler (Gifford-McMahon)
- Helium exchange gas for low-vibration imaging

H₂ Ortho/Para Simulation

- Modelling H₂ liquefaction in Plate-Fin HX:
 - Refrigeration
 - Ortho/Para conversion

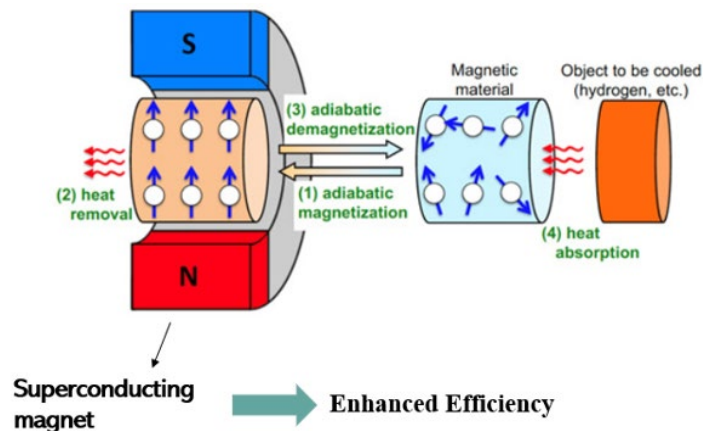
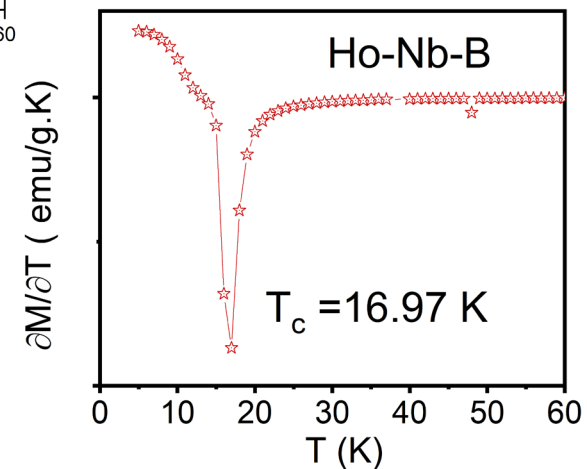
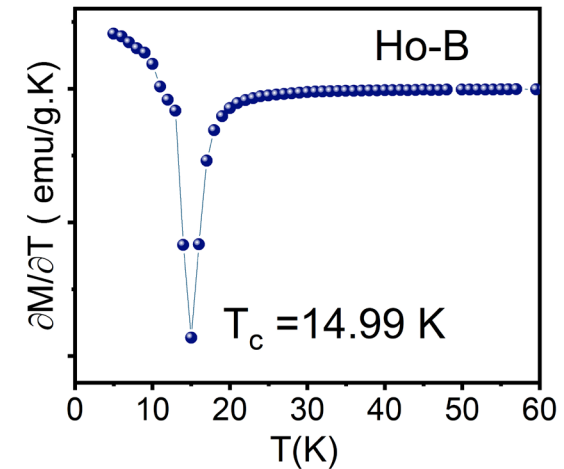
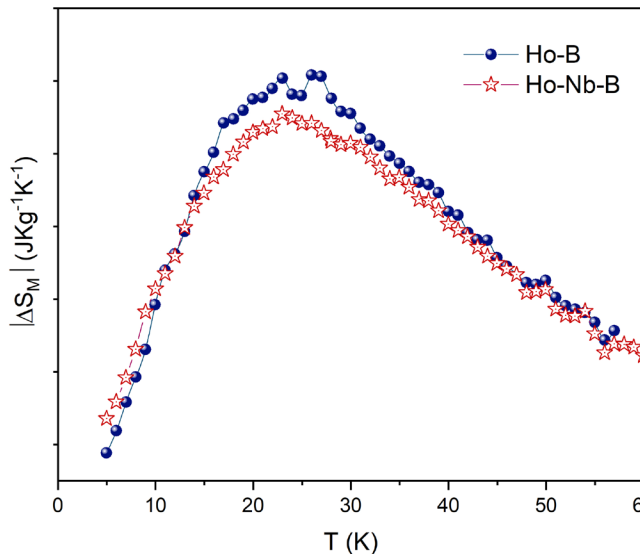
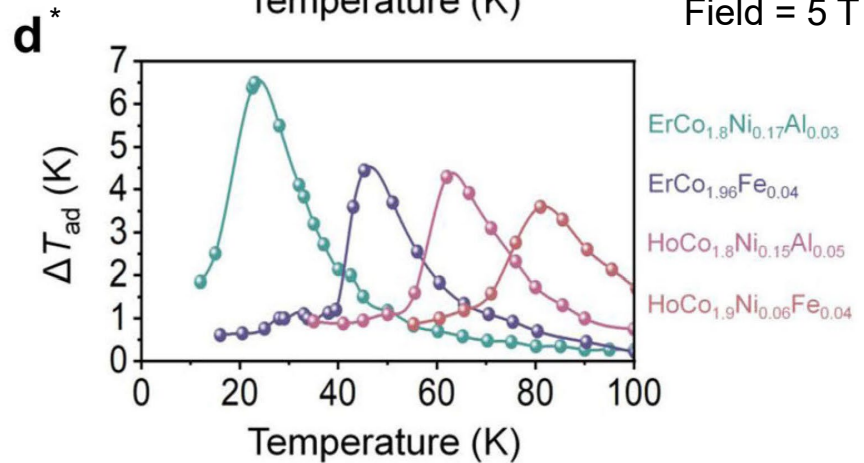
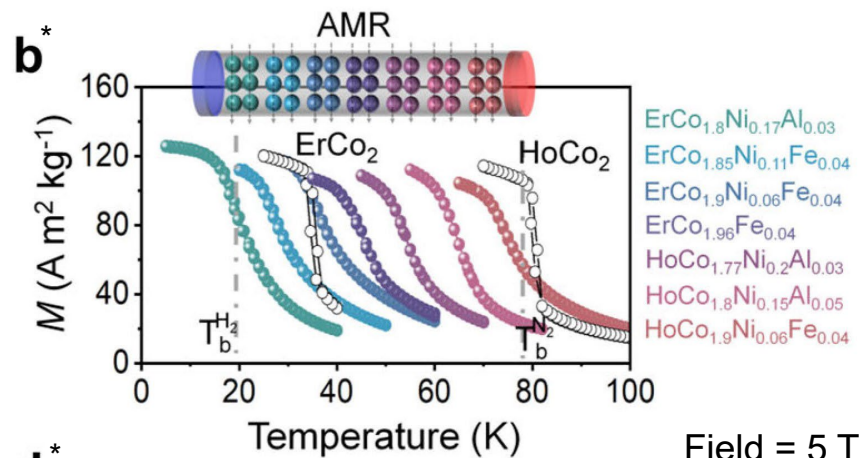


Simulation freely available in
python (hydrogen-pfmx)
<https://github.com/fsr-uwa/hydrogen-pfmx>

O'Neill, K.T., *et al.*, **Chem.Eng.Processing: Process Intensification**, 184, 109272, 2023.

Magnetic Refrigeration

Liquefaction – 80K to 20K – AMRR

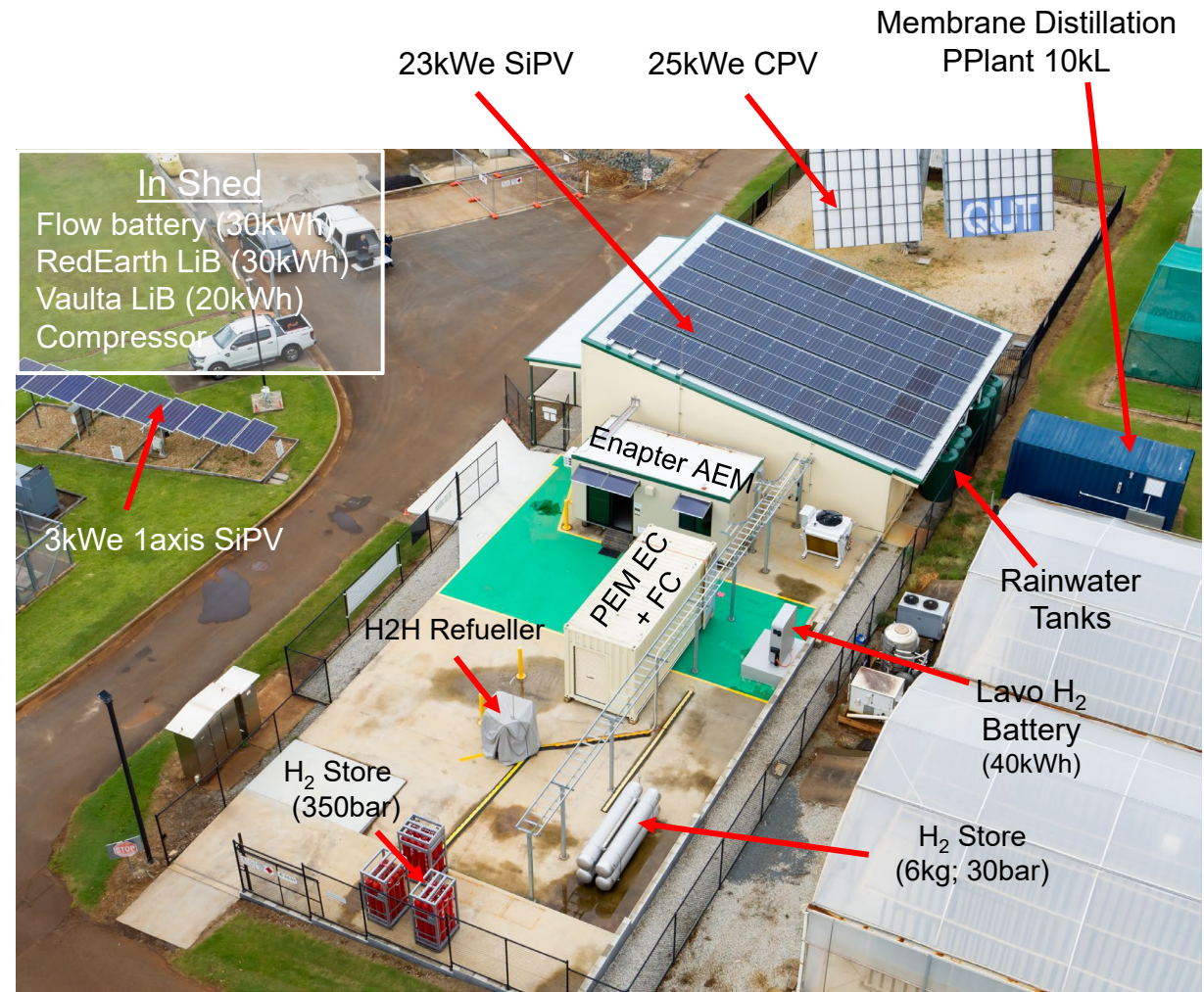
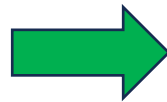
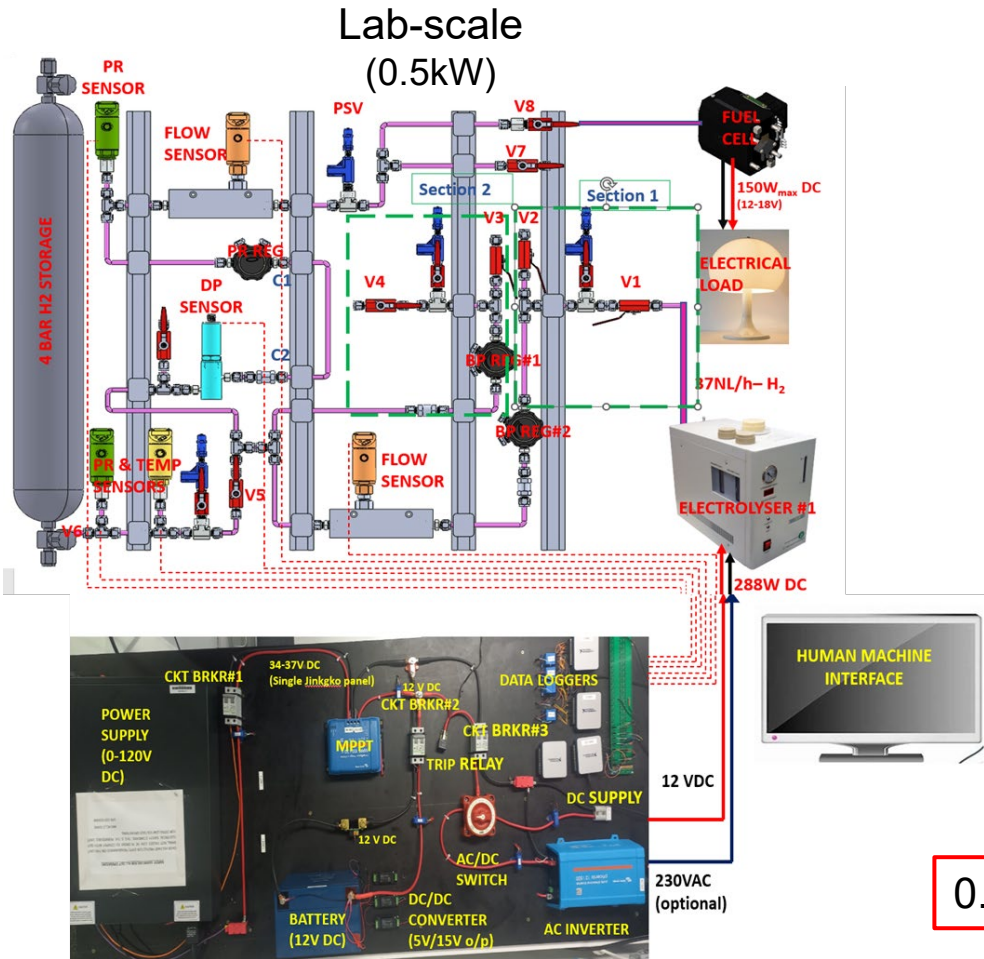


*Tang, X., et al., *Nature Comm.*, 13, 1817, 2022

Shahbazi *et al.*, unpub., 2023

Hydrogen test-beds

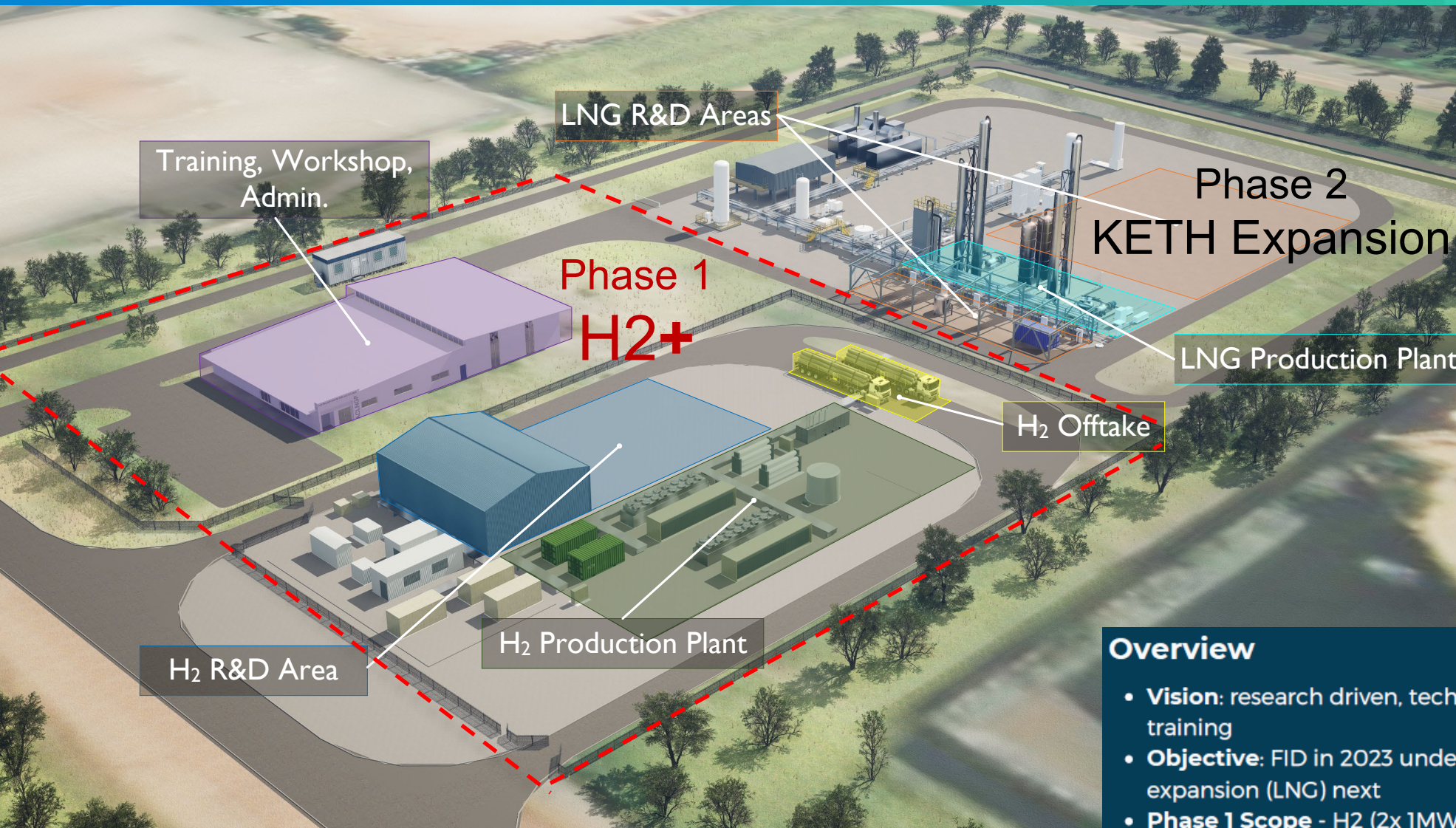
Hybrid H₂ Production – at QUT



Pilot Plant Scale (~50 kW)

0.5 kW 5 kW 50 kW

Kwinana Energy Transformation Hub – Western Australia



- Located 3 hectares of land allocated by WA Govt in the Kwinana industrial zone
- Open access, multi-user facility
- Enables Industrial PhD student placements
- Enables Research Commercialisation via industrial de-risking of process technologies
- Enables Vocational & Tertiary level Education in new energy & decarbonisation

Overview

- **Vision:** research driven, technology agnostic platform for R&D and training
- **Objective:** FID in 2023 underpinned by phased approach. H2 first, expansion (LNG) next
- **Phase 1 Scope** - H2 (2x 1MW PEMs), "+" Elements (key research value drivers), Fuel Cell and Training/R&D Facilities
- **Phase 2 Scope:** expansion to electrified LNG facility
- **Commercial status:** One industry participant by July 2023 for Phase 1 participation.

Investment Attraction Fund grant to be announced imminently
Final Investment Decision in 2023

Summary

Liquefaction in Australia

- ❑ Major exporter of energy materials – Natural Gas and Coal
 - Gradual/staged shift in product portfolio
 - “green” value chain under construction
- ❑ All Governments – substantive intent
 - Transform energy sector
 - Reduce emissions including Scope 3
- ❑ Liquefaction
 - Prominent in NG export industry
 - Nascent for other gases (e.g. H₂)
- ❑ Active R&D community
 - Novel industry-research funding models
 - Facilities suited to collaboration
 - Keen to collaborate – international value

Thank you



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