Clean Energy Transitions

The Future of Energy

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with key input from

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QUT ife Institute for Future Environments

Clean(er) Energy – Transition by 2040/50

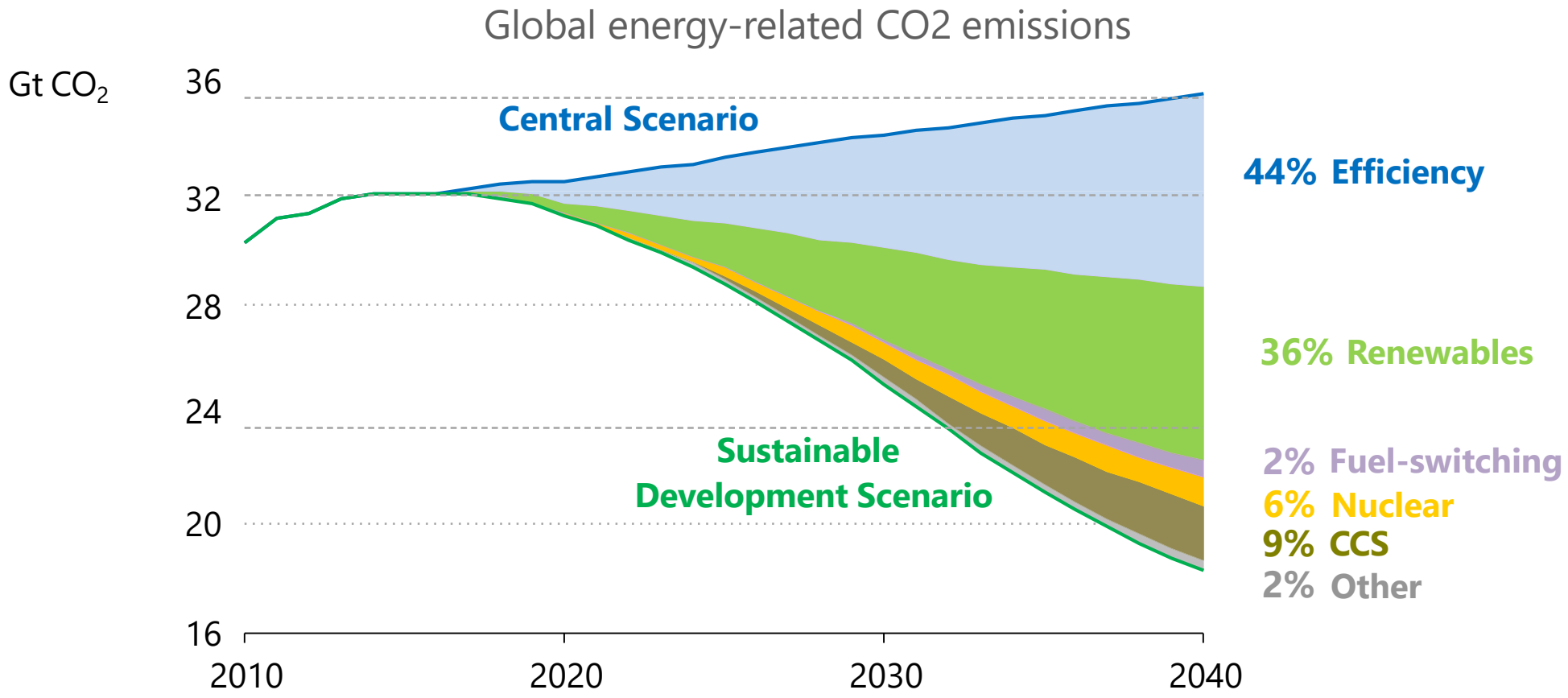
Drivers of the global energy transition

- Population ~10 billion by 2050
- Resource constraints – water, land, air; food, housing, workplace
- “Decarbonisation” – reduce GHG emissions; zero emissions targets
- Legislation in developed countries – positive and/or negative
- Corporate investment and market development
- International Peak Bodies – policy advice, data, statistics, tech watch

Global energy trends

- Take-up of new technologies – dominantly renewable; including fossil fuel
- Energy efficiency – multiple benefits across economies
- Decoupling of electricity generation and emissions – 2017/18
- Regional shift of energy demand by 2040 – to China, India, Africa

Development Pathway

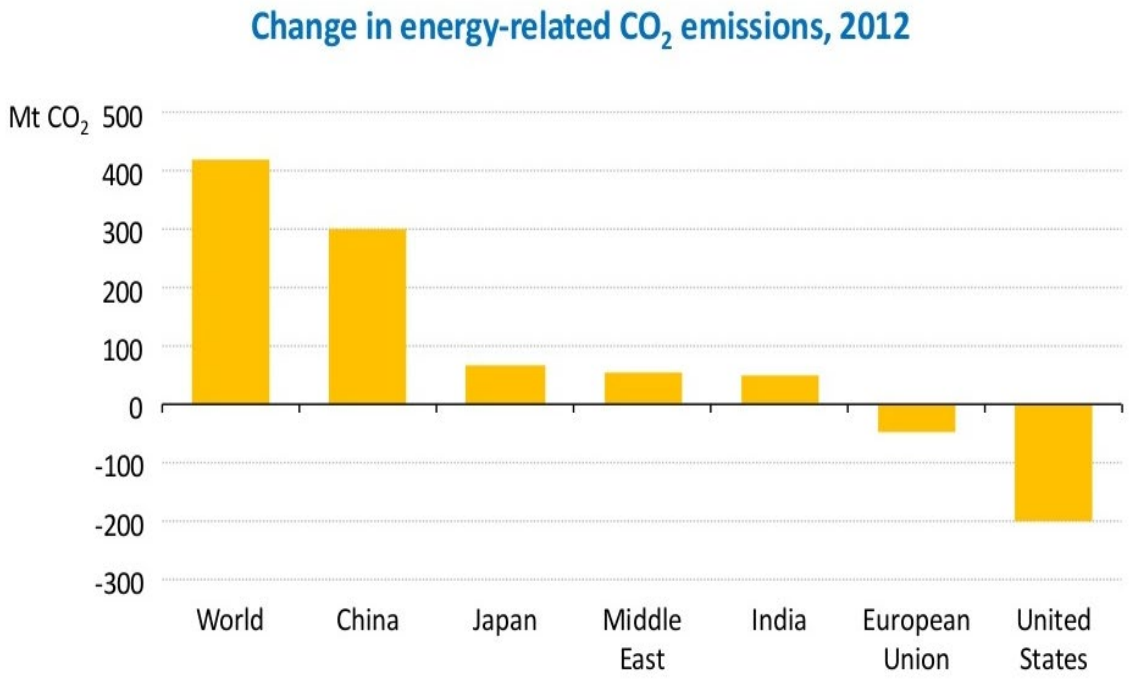


A wide variety of technologies is necessary to meet long-term climate goals

https://www.iea.org/tcep/

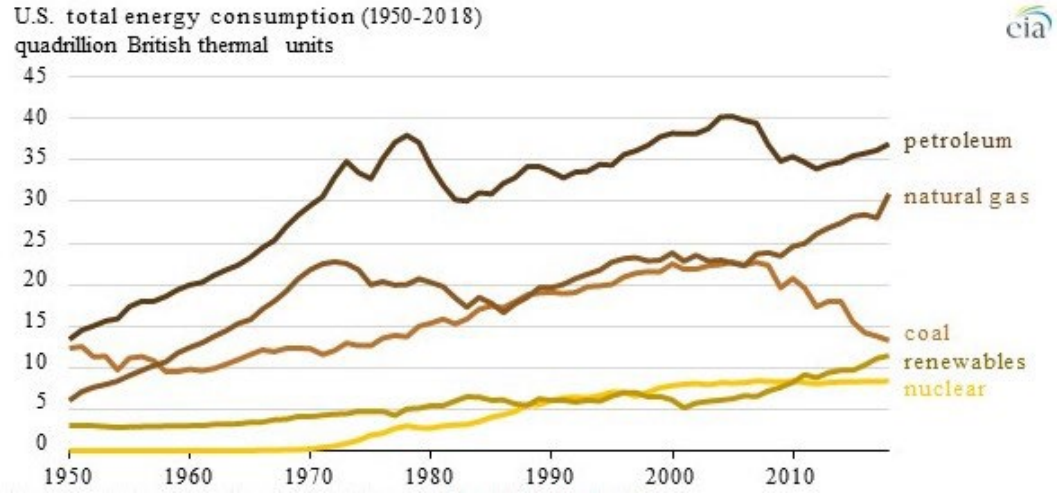
Global Emissions – Energy Generation

Unintended Consequences

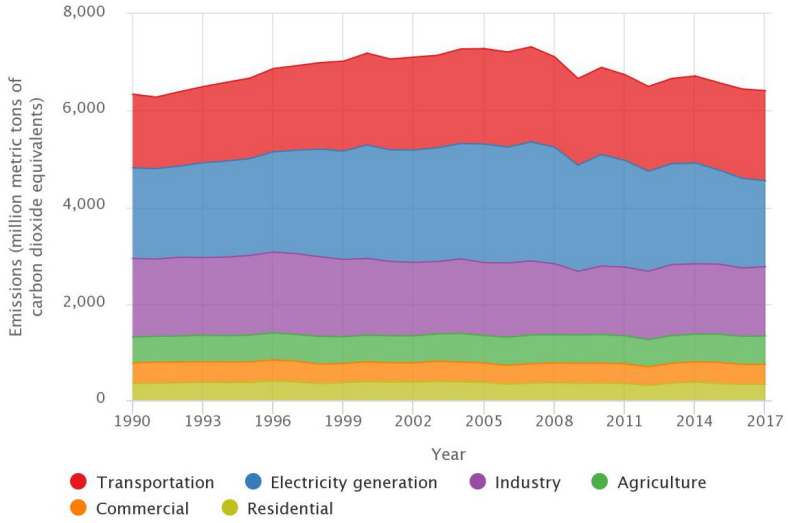


CO_2 emissions grew by 1.4% to reach 31.6 Gt in 2012, but trends vary by country

Johnson, L. et al., Too late for two degrees ? pwc Report, November 2012; www.pwc.co.uk/economics



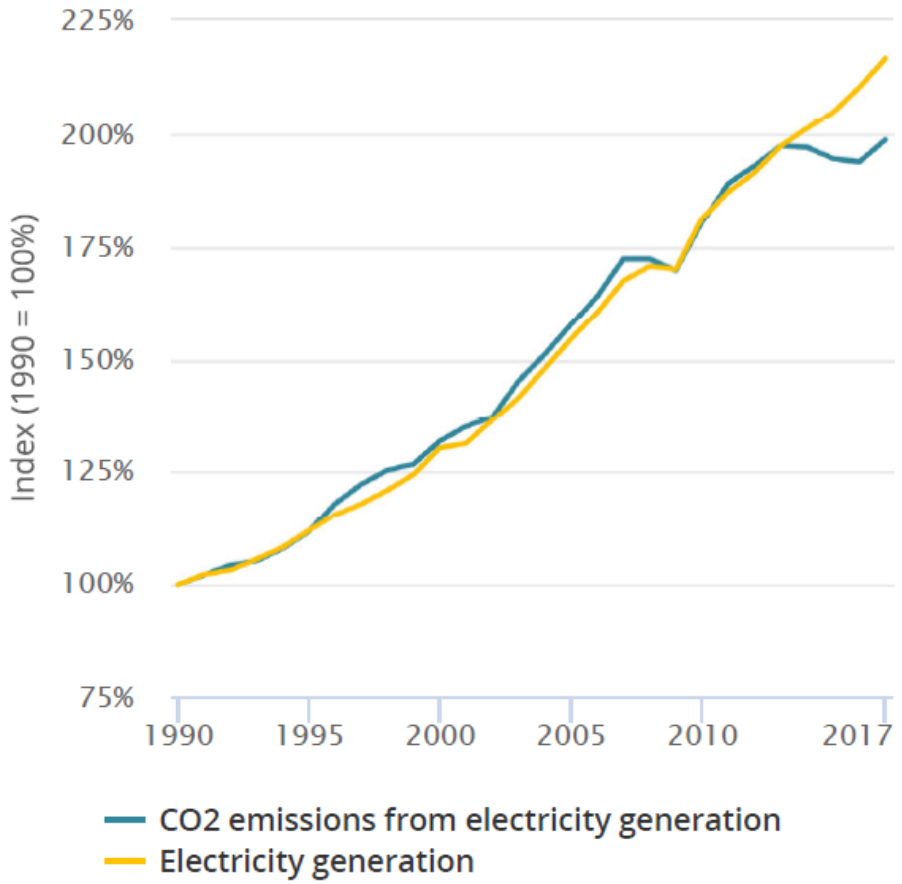
https://www.eia.gov/todayinenergy/detail.php?id=39092; June, 2019

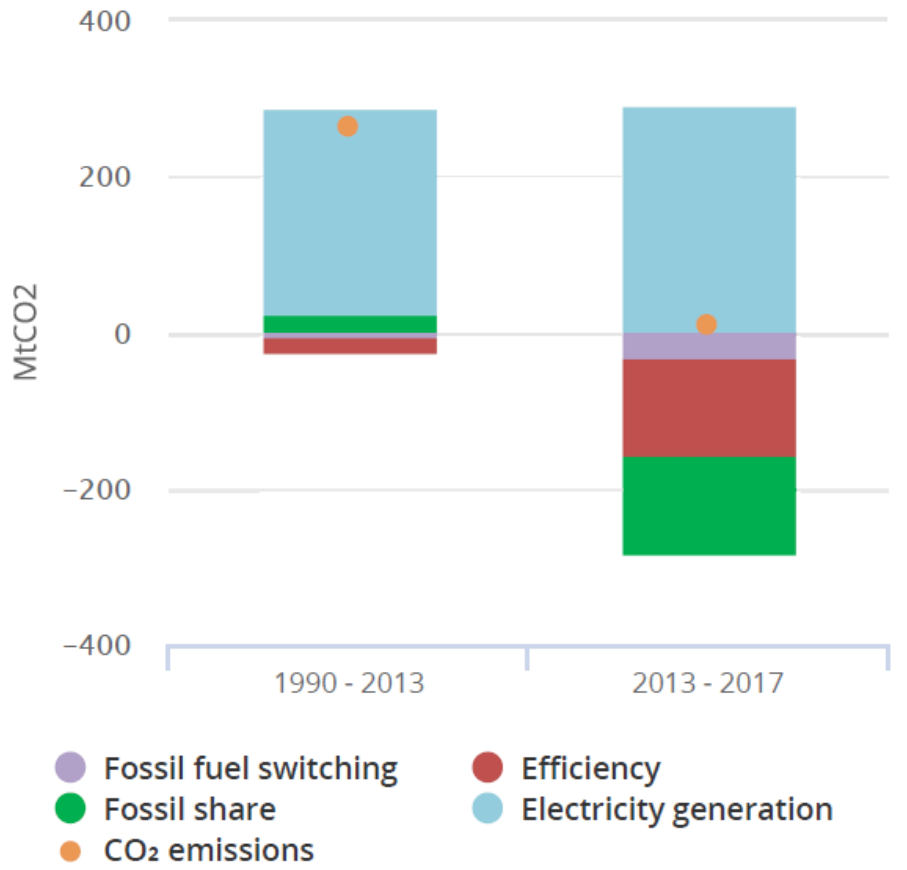


Emissions
1990-2017

US EPA, June 2019

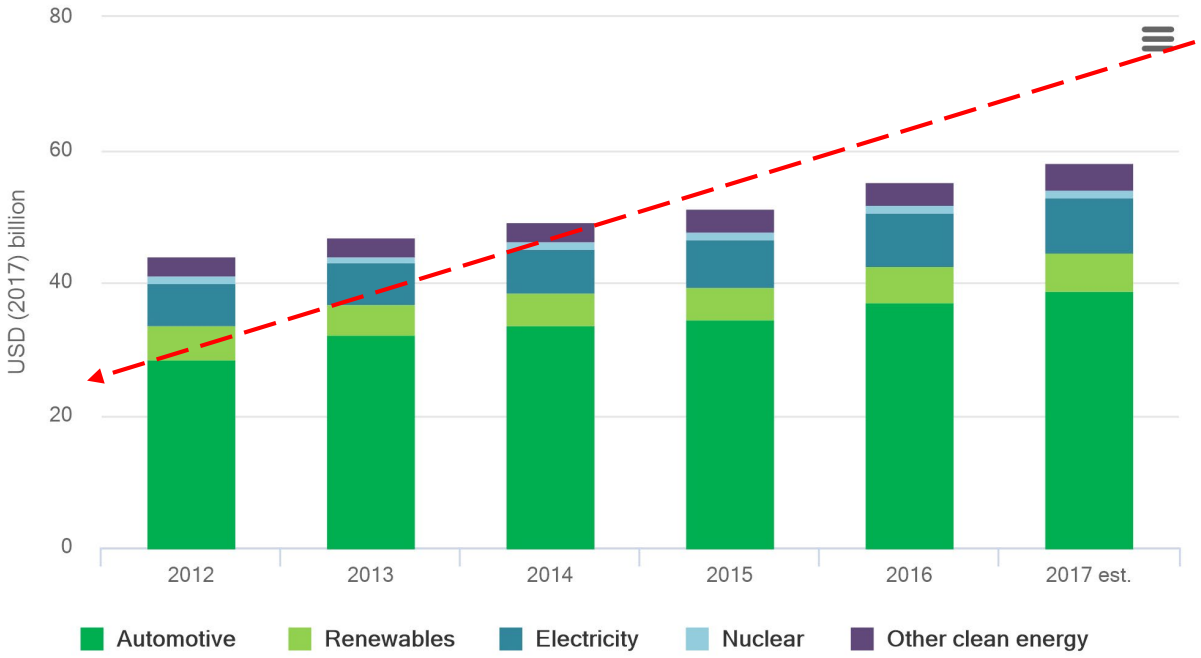
Energy Generation and Emissions
Global Outlook



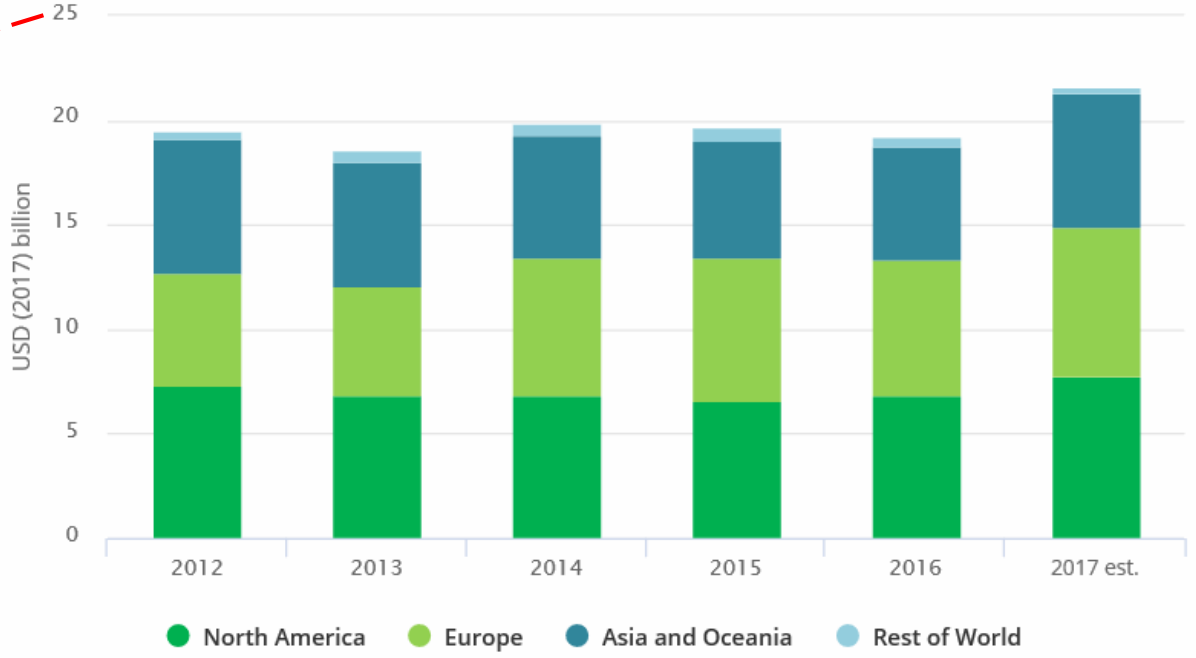


Clean Energy Innovation - Delivery

Corporate Sector R&D Spend



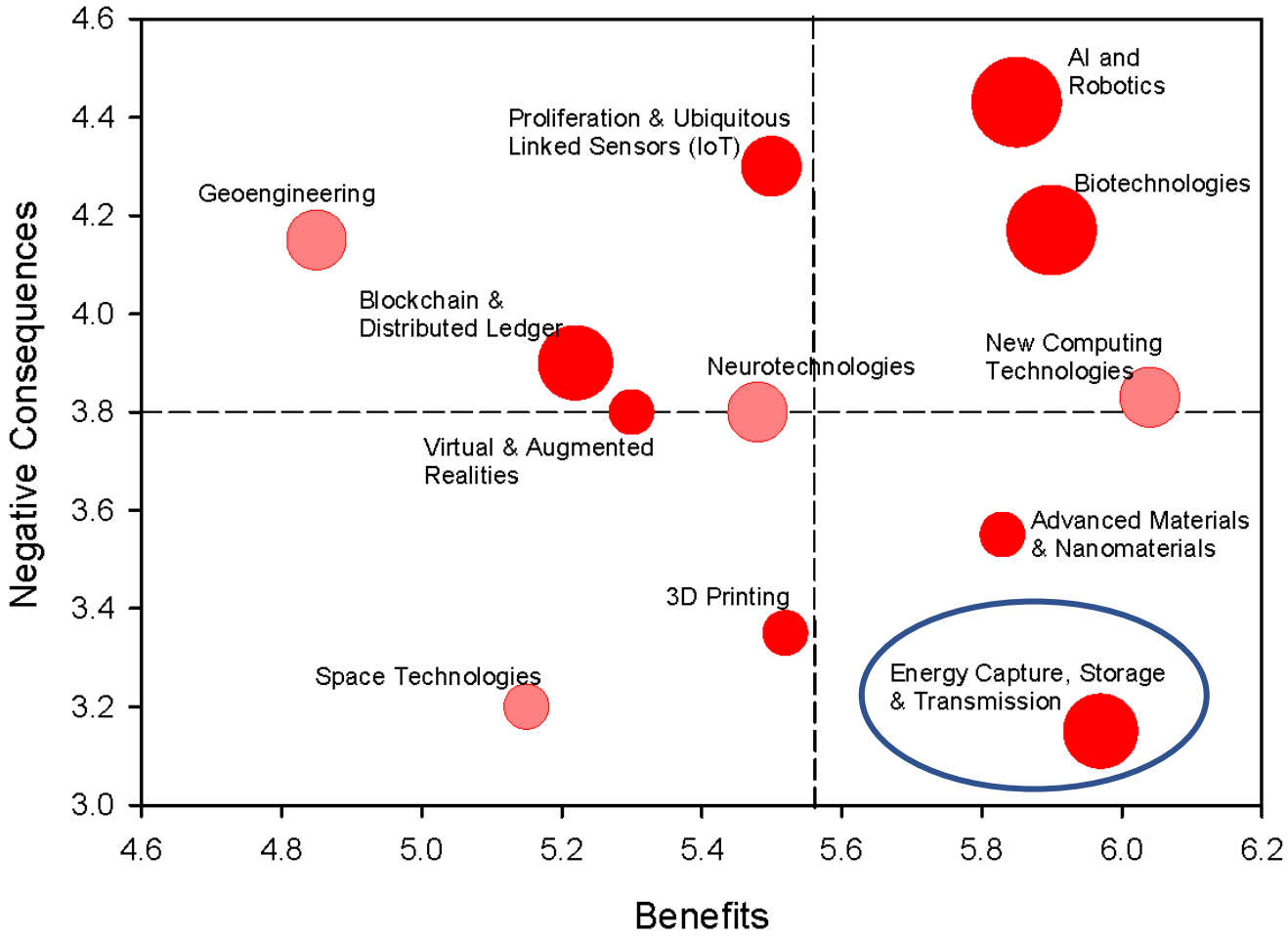
Public Sector R&D Spend



In 2017 ~US$80b/yr on R&D

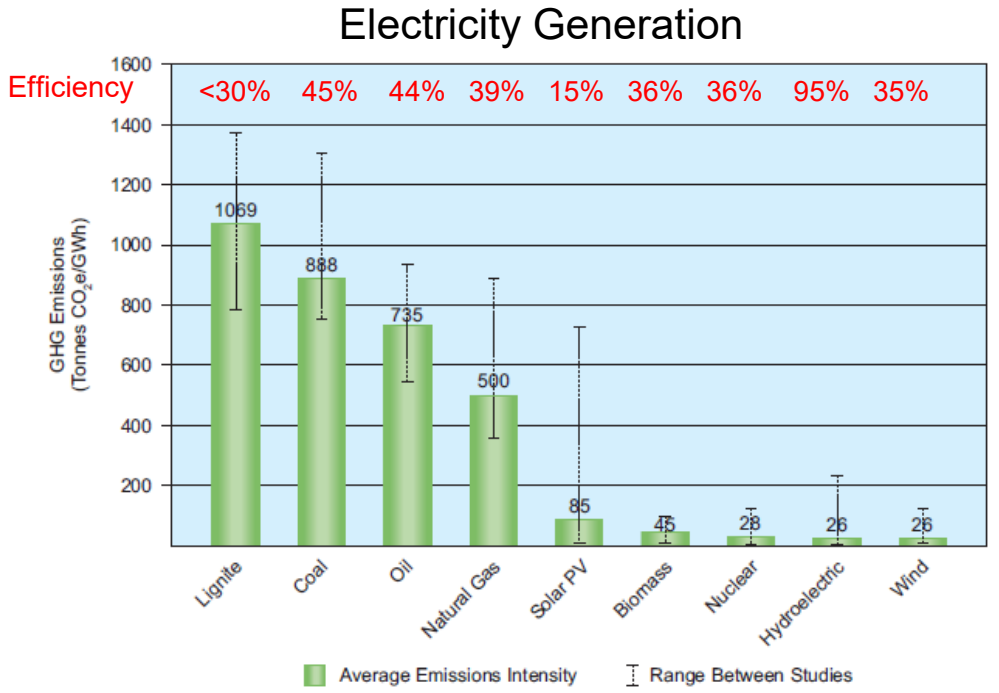
Technology Risks Landscape

12 Key Emerging Technologies



Global Risks Report 2017, 12th Edition, World Economic Forum

Circle size: need for governance



WNA Report: “Comparison of lifecycle greenhouse gas emissions of various electricity generation sources”, 2010

Hydrogen Production*

Known Scalable/Scaled Technologies

<u>Existing Market</u>

- By reforming methane
- ~US$130 billion per year

- Rapidly evolving market; Qld Biofutures Policy
- ~US$70 billion in 2016; ~US$100 billion in 2022

"Brown" H_2: from coal (or "Grey")

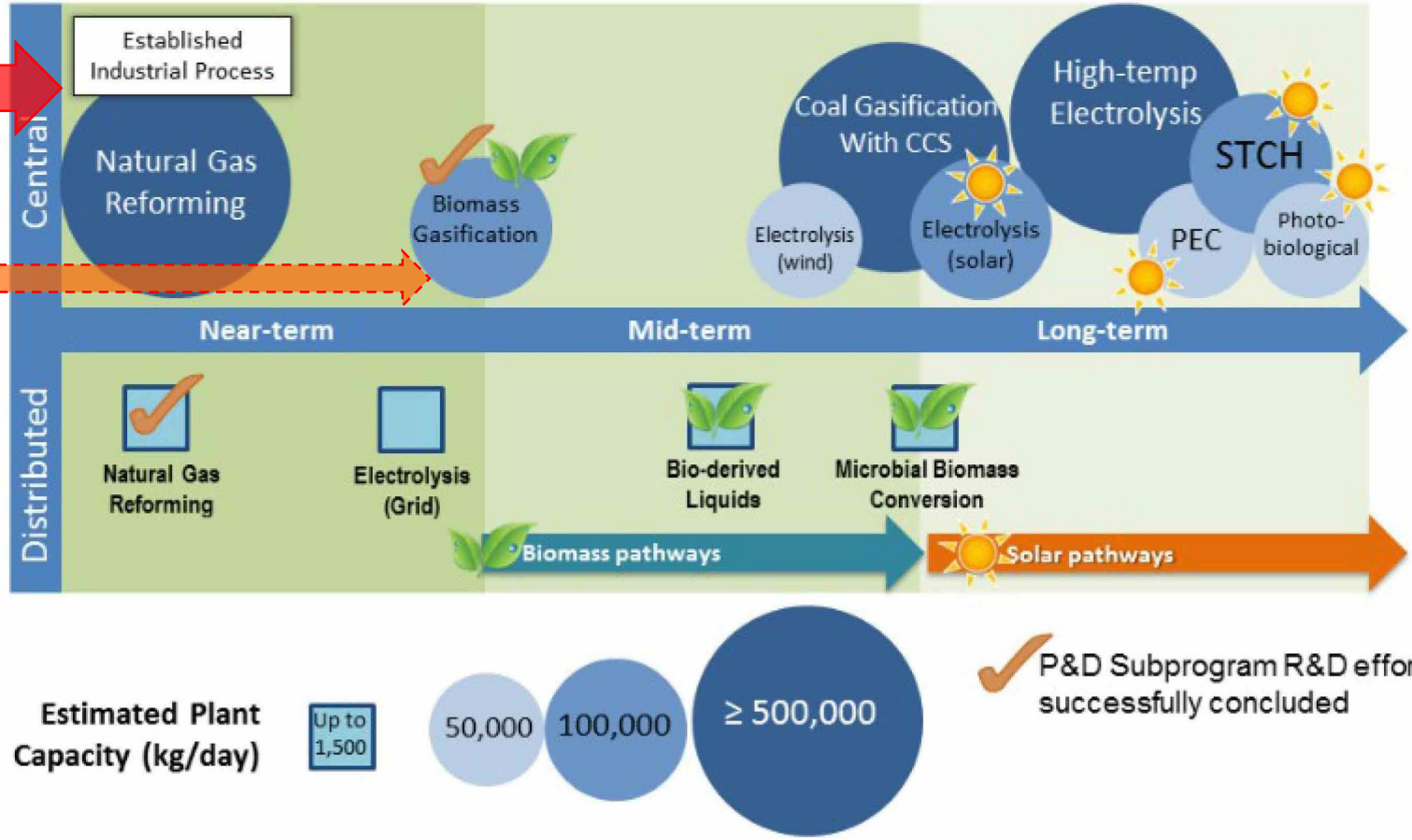
- Gasification or partial oxidation

"Blue" H_2: from natural gas, oil or chemicals

- Steam reforming; ferrosilicon process

"Green" H_2: from water or biomass

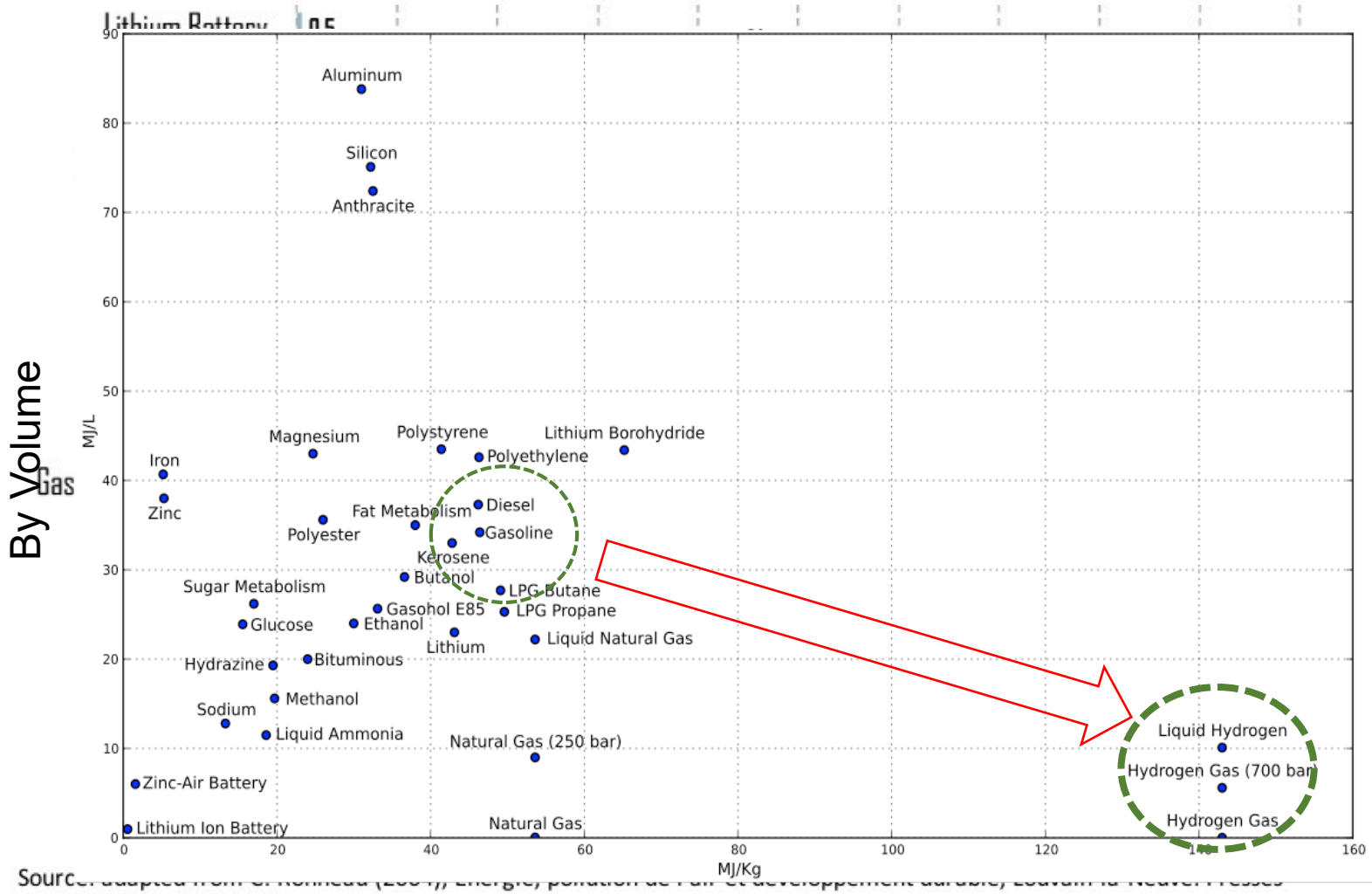
- Solar/wind powered electrolysis of water;
- Biomass gasification; biogas reforming;
- Fermentation; photobiological algae;
- Blue H_2 with carbon capture & storage



* "Global Hydrogen: A US$2.5 trillion industry ?" Morgan Stanley Research, July 2018.

Energy Density

Comparison of Energy Materials



By Volume

By Weight

Source: adapted from C. Nonneau (2004), Energie, pollution de l'air et développement durable, Louvain-la-Neuve: Presses Universitaires de Louvain.

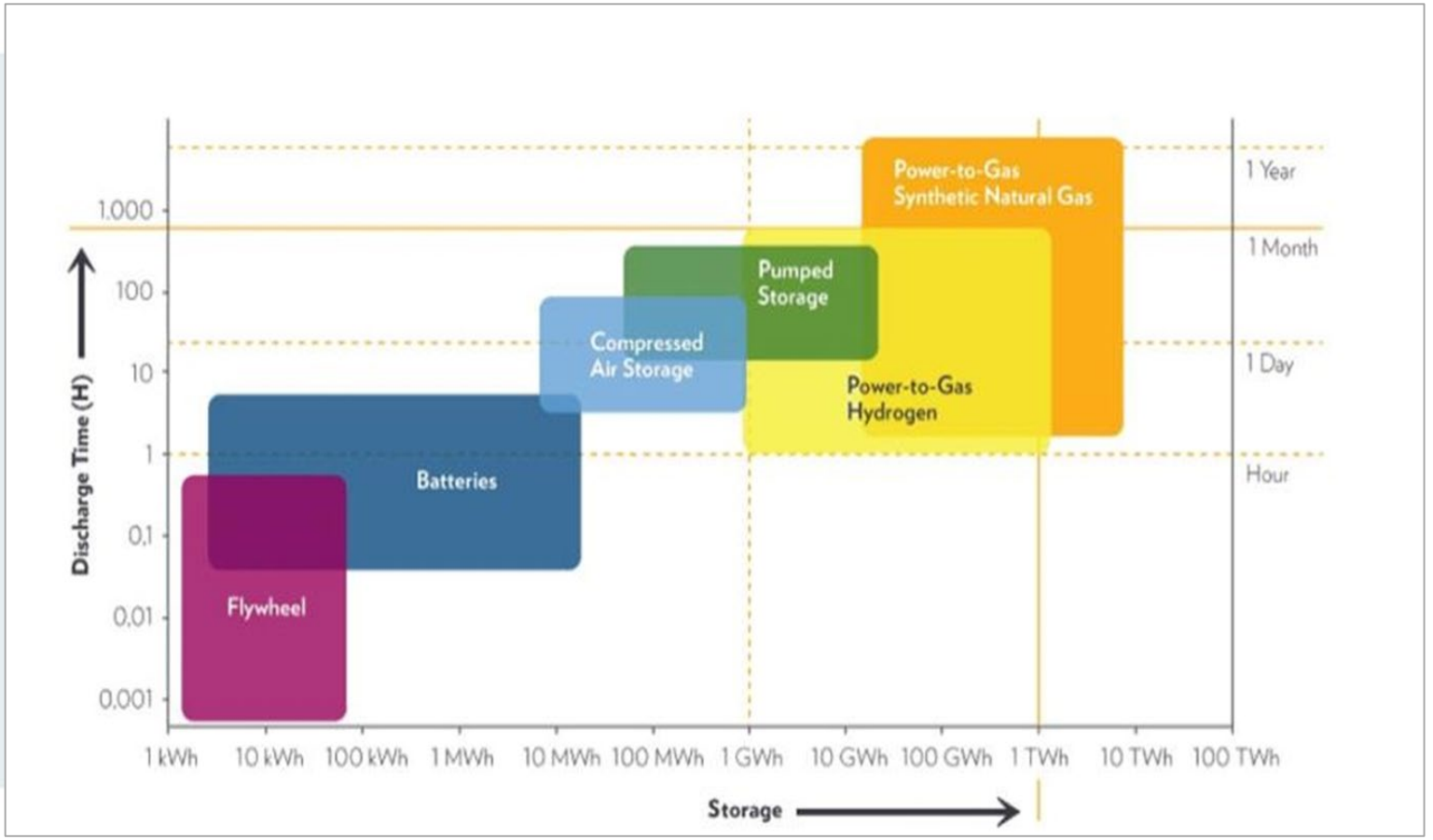
POWER-TO-GAS: ENERGY STORAGE

HYDROGEN ENERGY SYSTEMS

ITM POWER
Energy Storage | Clean Fuel

P2G Rationale:

Sector:	Throughput:	Storage Capacity:
Power	336 TWhrs/yr	None
Gas	897 TWhrs/yr	100 days



Power-to-gas is efficient | long duration | huge capacity | low energy cost

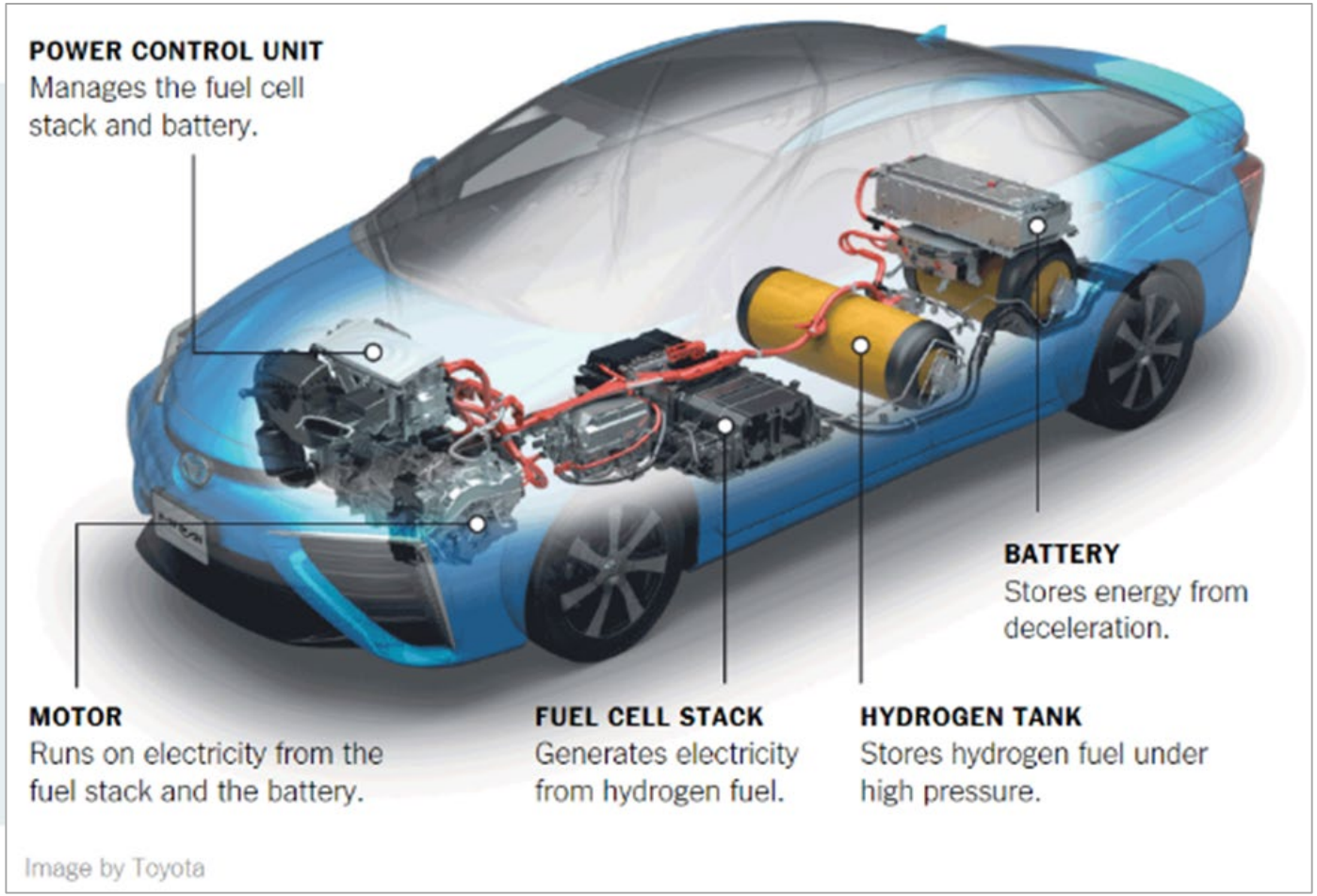
WHY HYDROGEN?

HYDROGEN ENERGY SYSTEMS

ITM POWER
Energy Storage | Clean Fuel

Power | Storage | Fuel:

- Refuel in 3 mins
- Range 350 miles on 5kg Hydrogen
- Derived from renewable power
- Managed energy export



FCEV: An EV drive train that's refuelled rather than recharged

10MW | 30MW | 50MW HRS SYSTEMS

HYDROGEN ENERGY SYSTEMS

ITM POWER
Energy Storage | Clean Fuel

Buses | Trucks | Trains | Ferries

- Buses: 30kg/day
- Trucks: 75kg/day
- Trains: 180kg - 400/day
- Ferries: 500kg/day

Buses | Trucks | Trains | Ferries

Energy: batteries and fuel cells

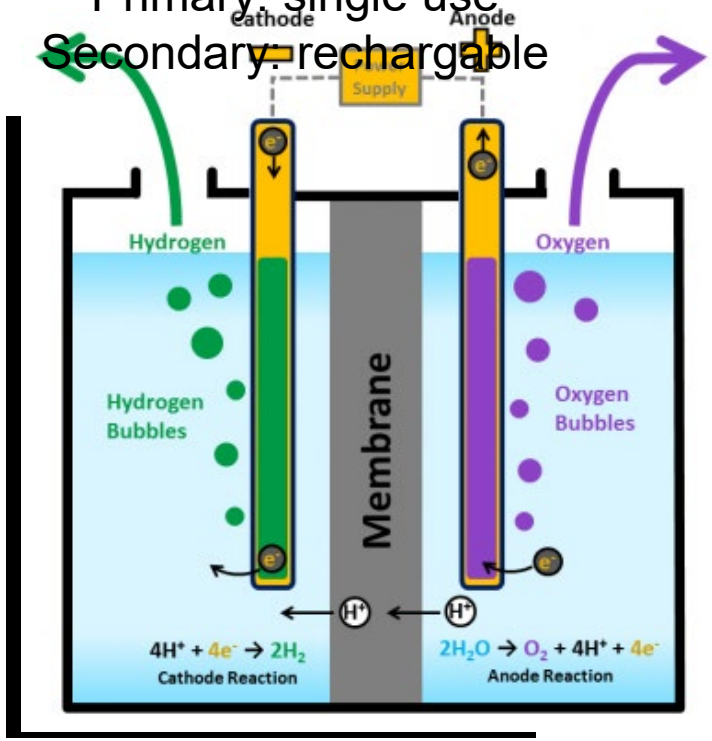
Chemical Energy ⟺ Electrical Energy

Electrolytic Cells

Battery

Primary: single use

Secondary: rechargable



e
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e/Current

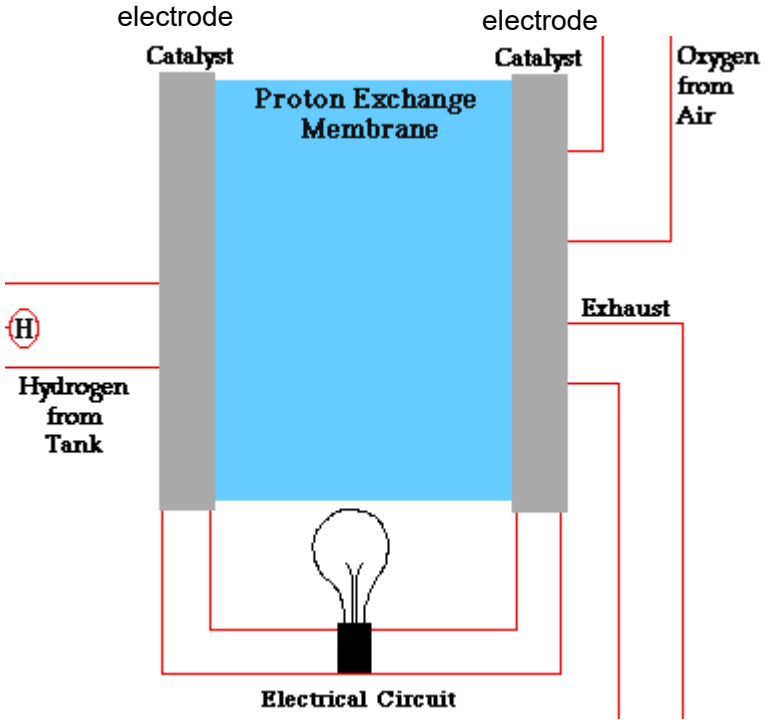
PEM FC
PEM EC

Alkaline FC
Alkaline EC

Solid Oxide FC
Solid Oxide EC

Phosphoric Acid
Direct Methanol
Molten Carbonate
.....

Fuel Cell



Electrical Energy ⟹ H_2 (& O_2) production

Fixed chemical energy

Continuous feed of reactants

Long-term Energy Policy

Responding to Global Trends and Crises

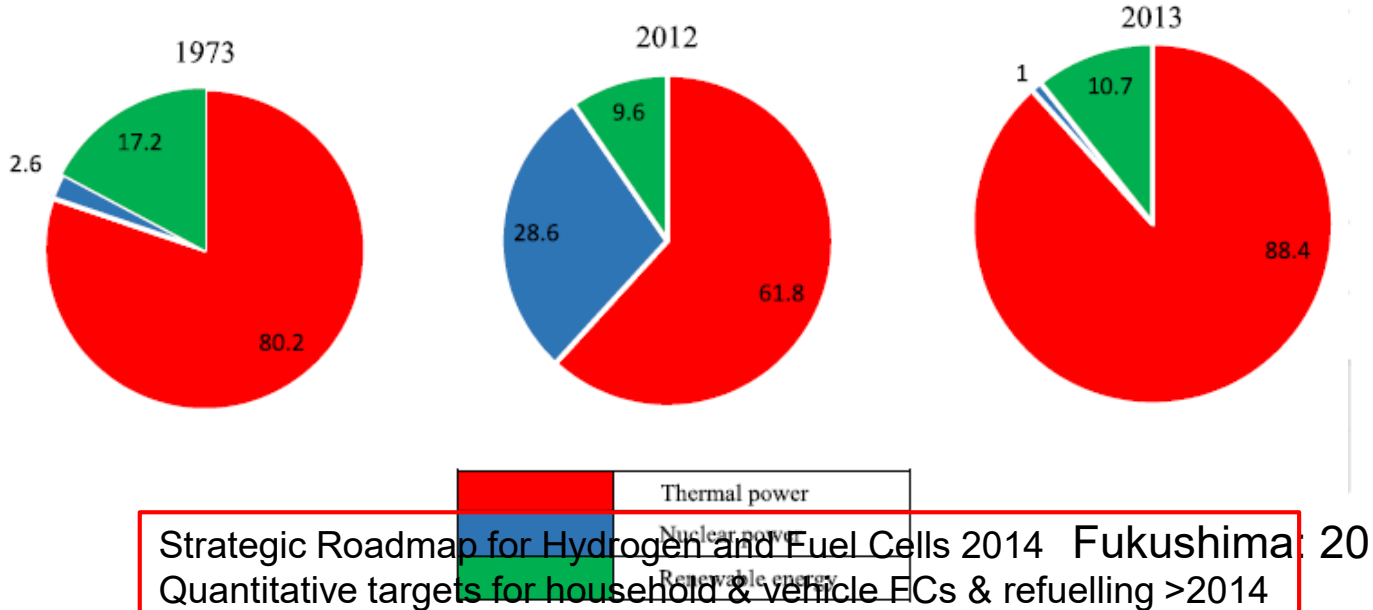
Government-Private Total Investment in Fuel Cell R&D, Total - $21.8 Billion, 2002-2015

Science and Technology Basic Law 1995
Technology Transfer Law 1998
Fuel Cell and Hydrogen Framework Policy 1999

14

12

Energy Sources: Japan

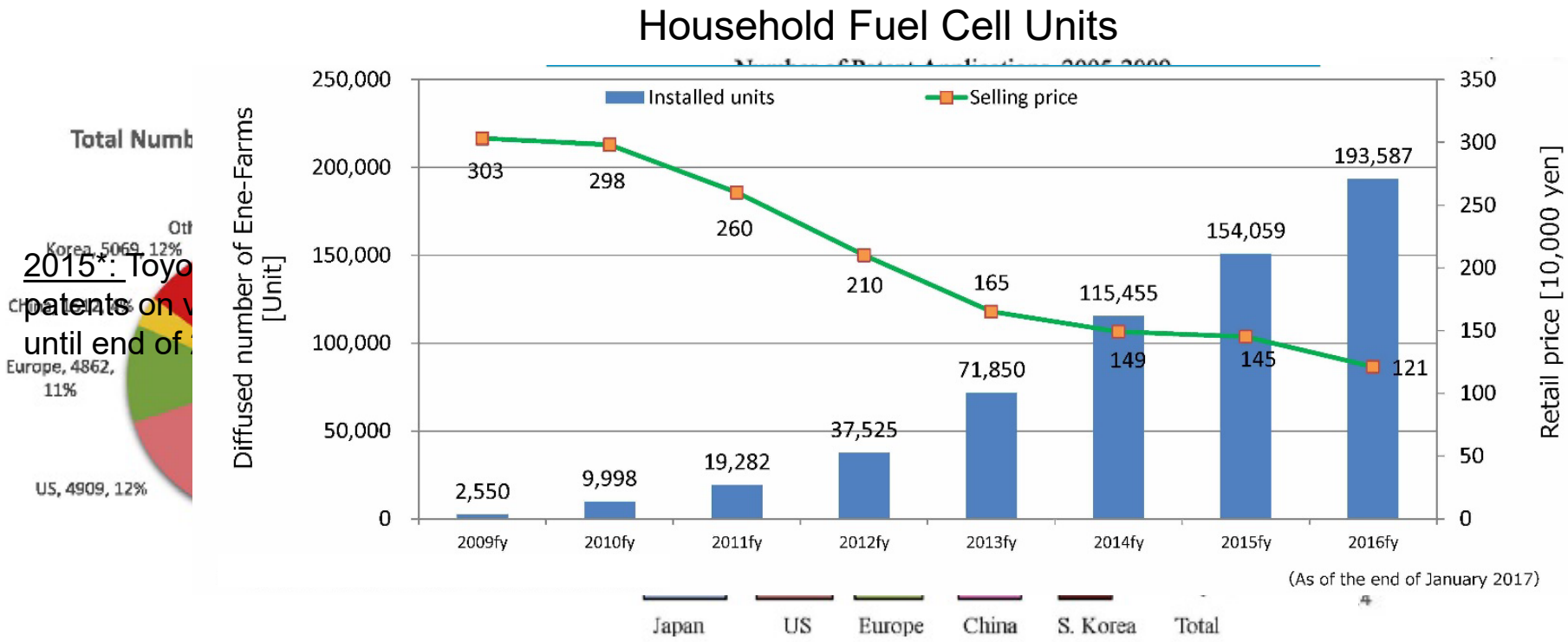


Strategic Roadmap for Hydrogen and Fuel Cells 2014 Fukushima: 2011
Quantitative targets for household & vehicle FCs & refuelling >2014

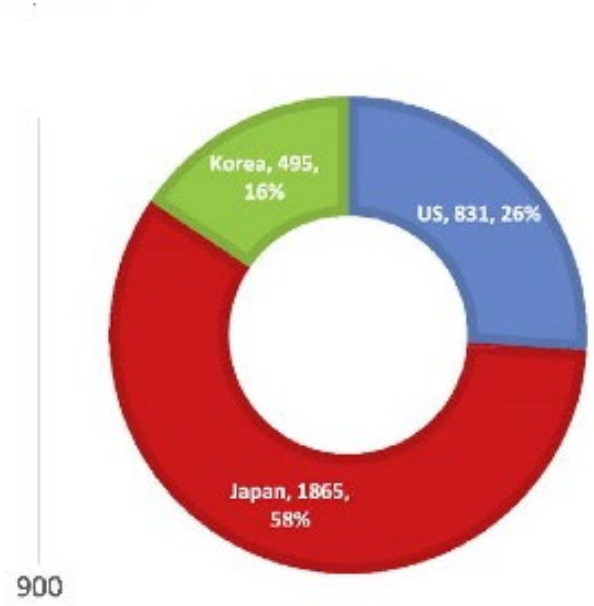
Behling *et al.*, *Economic Analysis and Policy*, 48, 204-221, 2015.

Fuel Cell Technology Evolution

Impact of R&D (2002-2014)



2015*: Toyo
patents on v
until end of



*J. Fogelson, *Forbes Magazine*, January 5th 2015

Behling *et al.*, *Economic Analysis and Policy*, 48, 204-221, 2015.

Future Energy Needs

Japan's Hydrogen and GHG Ambition

Need for the imported renewable energy

Sumitomo Corporation

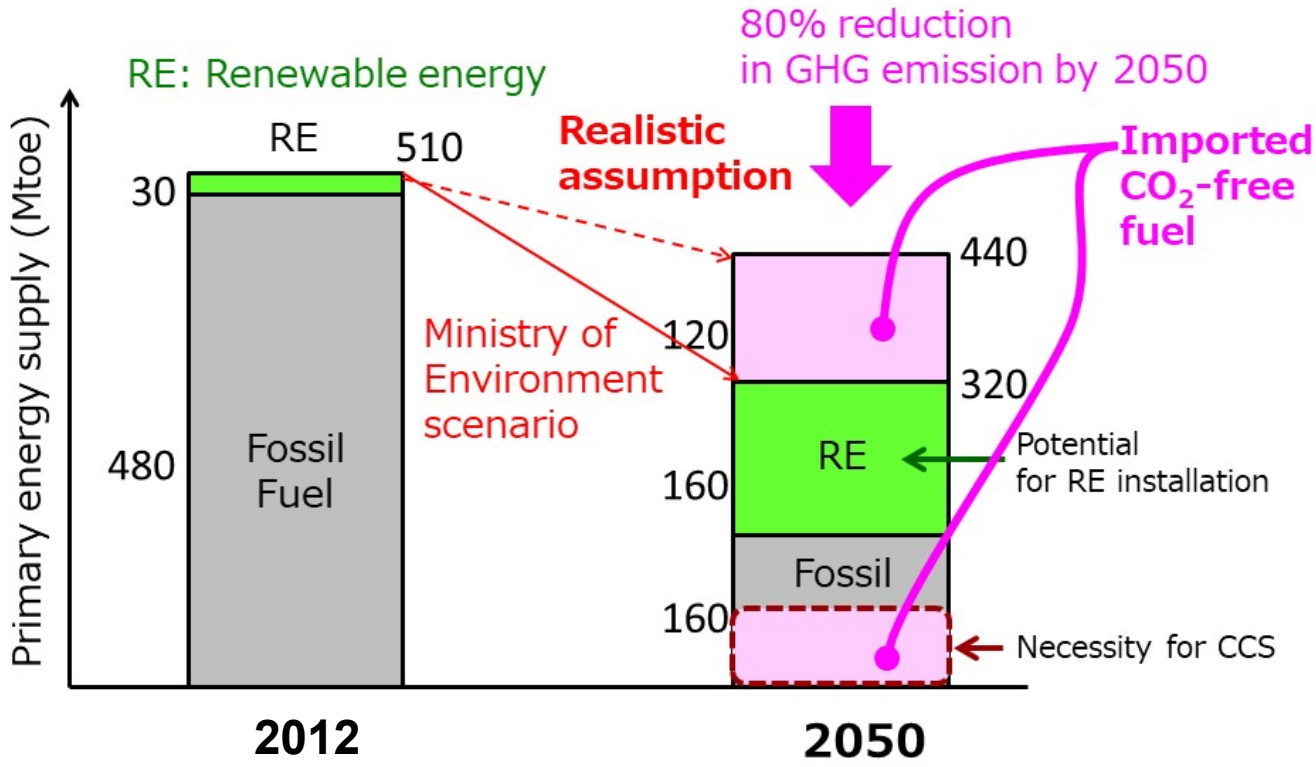
METI Roadmap

	2030	2040	2050
FCV	800,000 NEDO Target	3,000,000 5% of Total No. of Cars	6,000,000 10% of Total
H2	1 Power Plant	10% Base Load	20% Base Load

H2 : Power Plant ~50% capacity of LNG
FCV : 10,000km/Y/Car, Fuel Cost:10km/Nm3

FCV ~600 km/tank

10% base load: H_2 ~15x FCV requirements



Source: Mr. Kidoshi, Japan Research Institute

Hydrogen Technology Evolution

Indicative Timeline**

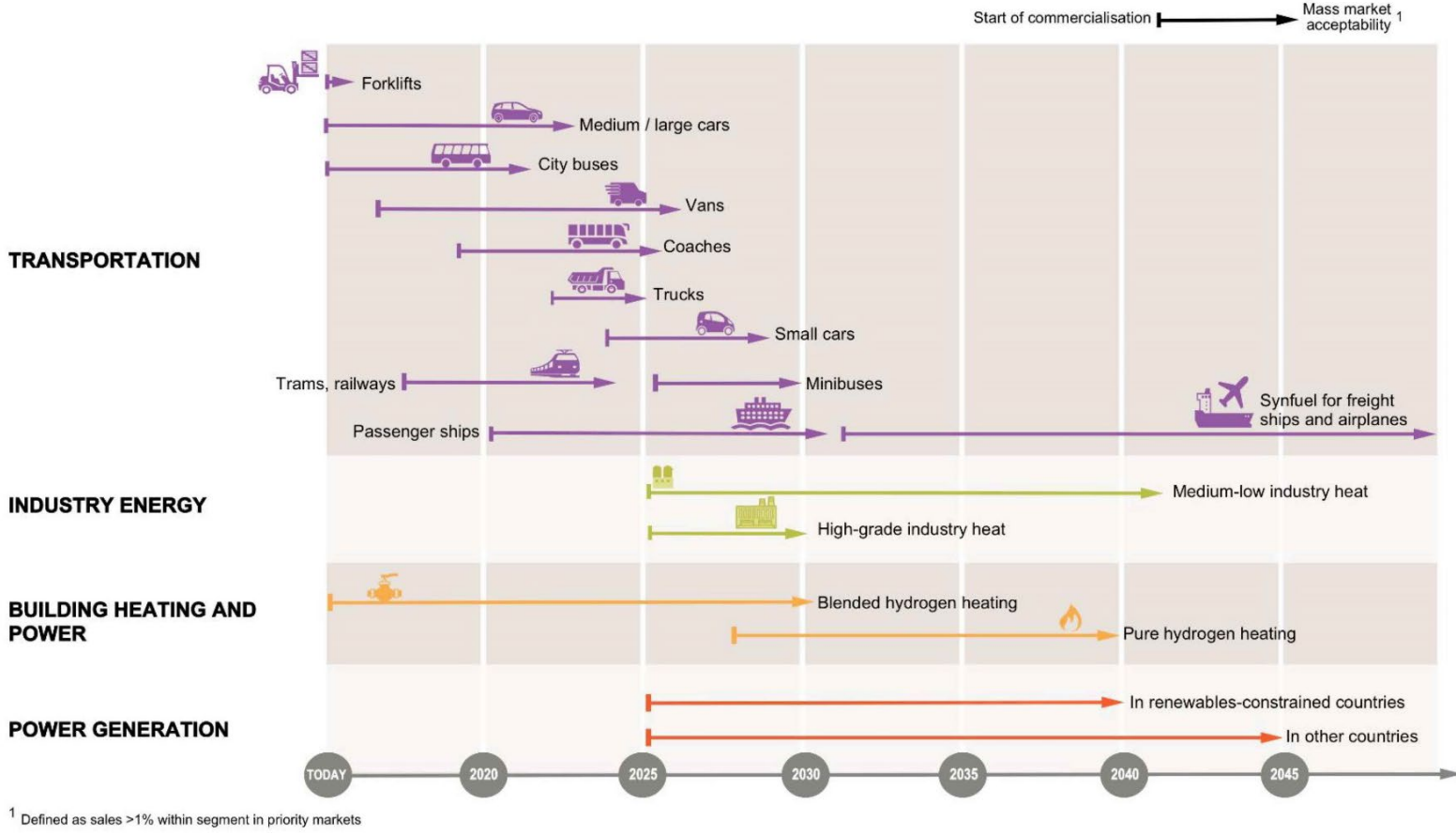
- >2,300 FC Buses operating worldwide at Q4 2018*
- ~600 FC Buses operating or on order for 2020 in Europe

- >6,300 FC vehicles in USA
- ~6,000 FC vehicles in Japan
- Target of ~80,000 for 2023 in Korea
- Target of 1,000 trucks in Korea (2023)

~100 H_2 refuelling stations in Japan

H_2 Fuel Cell Transportation = zero (CO_{2eq}) emissions

Vehicle refuelling stations can utilise H_2 from either electrolysis or steam reforming



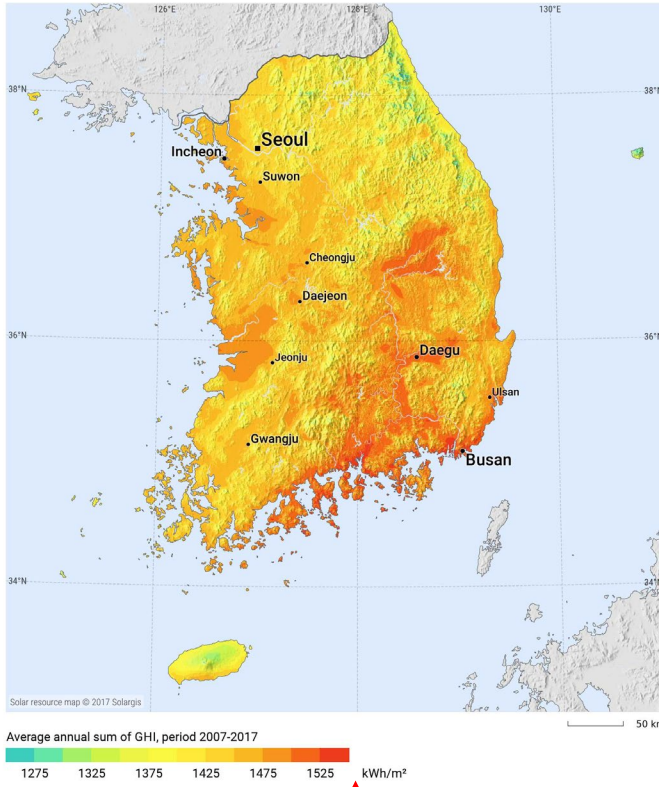
SOURCE: HYDROGEN COUNCIL (2017), HYDROGEN SCALING UP, A SUSTAINABLE PATHWAY FOR THE GLOBAL ENERGY TRANSITION. PAGE 26-27, EXHIBIT 7.

*Eudy, L. and M. Post, 2018. Fuel Cell Buses in U.S.Transit Fleets: Current Status 2018. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-72208.

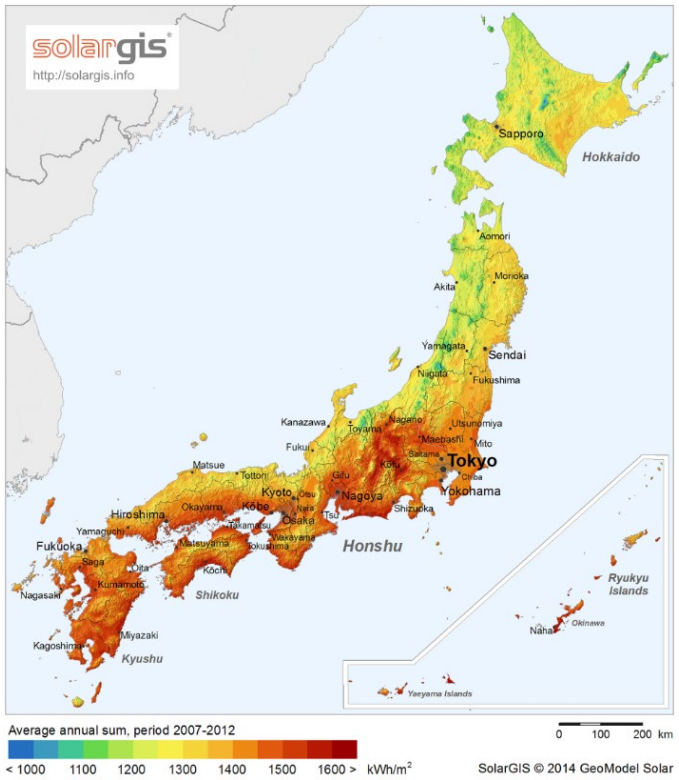
** "Opportunities for Australia from Hydrogen Exports", ACIL Allen Consulting for ARENA, August, 2018

Australia's Advantage

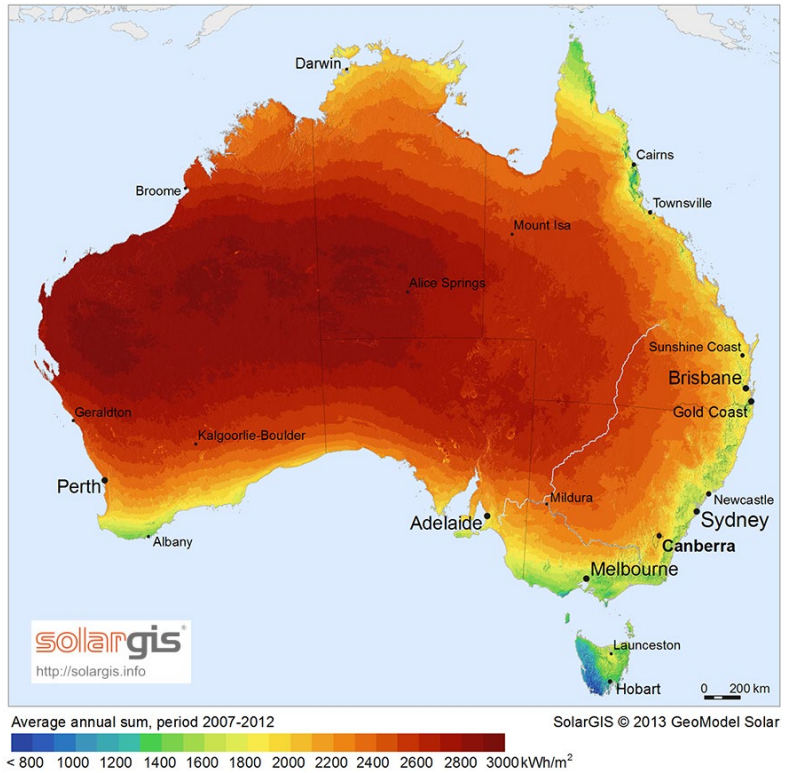
Solar Incidence and Available Land



Korea
100,210 km²
Population: 52 million



Japan
380,000 km²
Population: 127 million



Australia
8,000,000 km²
Population: 25 million

Global Hydrogen Demand

Recent Projections** and Data

Renewable Energy Generation

Dec 2018: 14.8 GW committed*
45% growth in commercial solar in 2018
(Total: ~2 GW)

2020 Large-Scale RE Target: 33TWh

Estimated RE Required by 2030
"medium": 15 GW to 68 GW
Average ~ 32 GW

Potential for use of increased RE power and H_2 Production

*Clean Energy Australia Report 2019, Clean Energy Council, April 2019

Export Potential

TABLE ES 2 PROJECTED GLOBAL DEMAND FOR HYDROGEN ('000 TONNES)

Country	2025			2030			2040		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Japan	88	516	1,338	875	1,761	3,858	1,896	4,131	9,573
Republic of Korea	74	223	493	373	728	1,562	1,001	2,175	5,304
Singapore	3	15	31	27	51	103	96	168	481
China	48	226	698	1,028	3,318	7,009	7,853	17,430	40,989
Rest of the World	98	448	1,170	1,053	2,678	5,729	4,958	10,927	25,758
Total	**311**	**1,429**	**3,731**	**3,357**	**8,536**	**18,260**	**15,804**	**34,831**	**82,105**

SOURCE: ACIL ALLEN ANALYSIS

TABLE 5.1 POTENTIAL ADDITIONAL GENERATION REQUIRED FOR HYDROGEN EXPORTS (TWH)

Heading	2025			2030			2040		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Japan	1.09	6.67	17.29	11 .46	23.15	50.50	24.66	53.59	124.44
Republic of Korea	0.50	1.50	3.33	2.52	4.91	10.53	6.76	14.69	35.81
Singapore	0.50	0.13	0.26	0.24	0.47	0.95	0.79	1.42	3.93
China	0.02	0.16	0.50	0.73	2.36	4.99	5.59	12.40	29.17
Rest of the World	0.03	0.12	0.30	0.27	0.69	1.48	1.28	2.82	6.64
Total	**1.67**	**8.58**	**21.68**	**15.22**	**31.58**	**68.45**	**39.07**	**84.92**	**200.00**

SOURCE: ACIL ALLEN

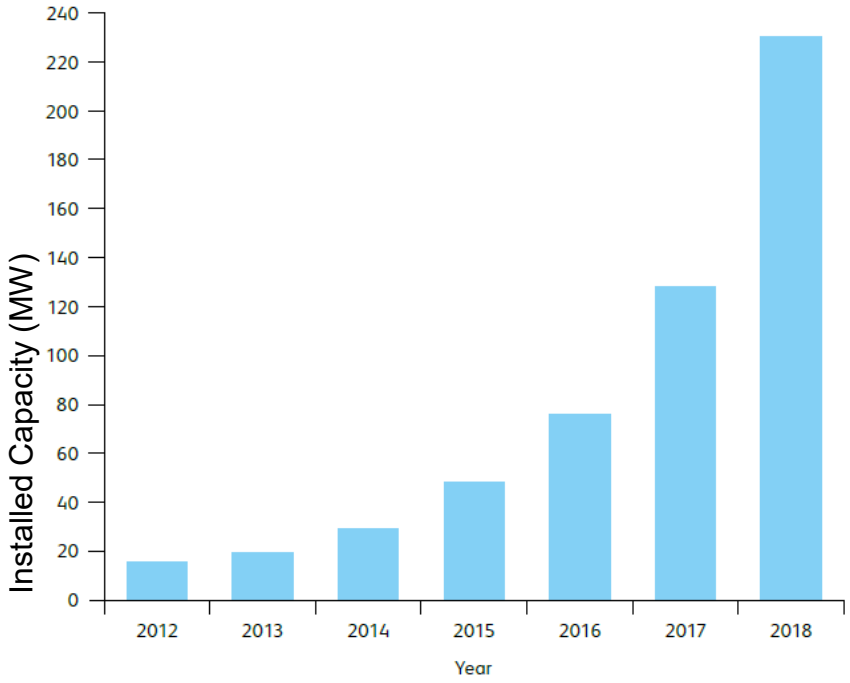
** "Opportunities for Australia from Hydrogen Exports", ACIL Allen Consulting for ARENA, August, 2018

Solar PV Installations – Australia

(excludes “household scale”)

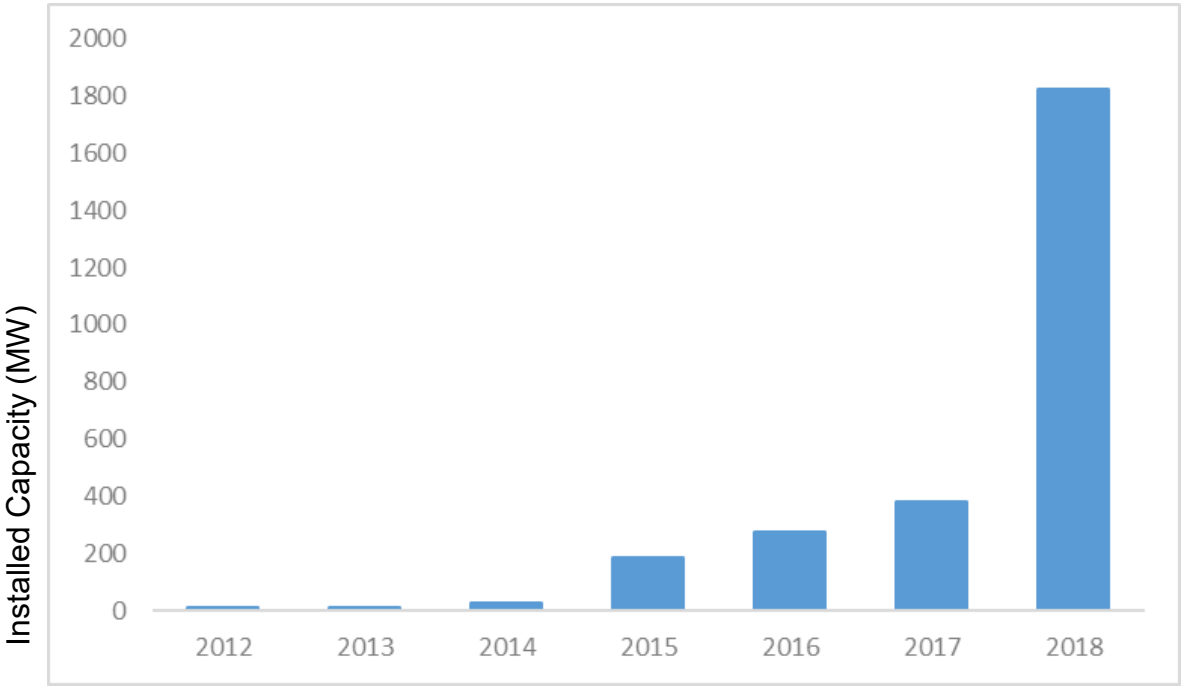
Medium-scale Systems*

(100kW to 5MW)



Large-scale Systems*

(> 5MW)

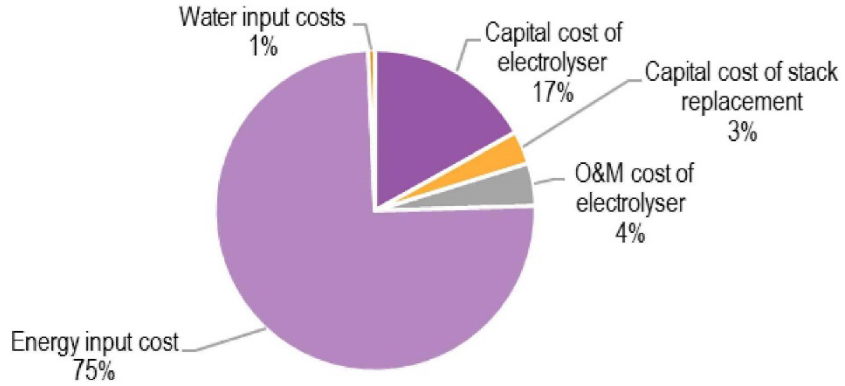


Total Solar PV Generation for 2018* ~11,600 GWh;
(~24% of Total RE Generation)

*Clean Energy Australia Report 2019, Clean Energy Council, April 2019

Hydrogen by Electrolysis
Australian Export Market

2015-16 Water Use** (Gigalitres)	
Agriculture	9,604
WW Treatment	2,014
Other Industries	2,615
Households	1,899
TOTAL	16,132



Note: Annualised cost shares. CSIRO has assumed 93 per cent capacity for renewable electricity.
SOURCE: CSIRO NATIONAL HYDROGEN ROADMAP 2018

TABLE 4.4 WATER NEEDED FOR AUSTRALIAN PRODUCTION OF HYDROGEN FOR EXPORT (GIGALITRES)

Scenarios	2025	2030	2040
Low H_2 demand scenario	0.238	2.179	5.592
Medium H_2 demand scenario	1.228	4.519	12.154
High H_2 demand scenario	3.103	9.796	28.623

SOURCE: ACIL ALLEN CONSULTING ESTIMATES

Projected Water Use for Electrolysis
By mid-2030: ~0.03% of current total water use

For H_2 Fuel Cells – Water is the exhaust

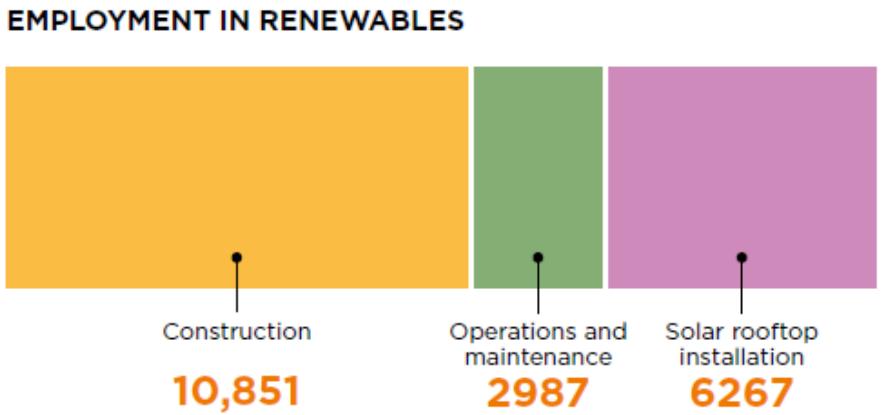
** "Opportunities for Australia from Hydrogen Exports", ACIL Allen Consulting for ARENA, August, 2018

Does this mean JOBS ?

Existing Renewable Energy Industry

Clean Energy Council*
2018

	Australia	Qld
RE Power (GW)	14.8	4.9
Investment ($b)	24.5	10.0
Jobs	13,233	4,681



*Clean Energy Australia Report 2019, Clean Energy Council, April 2019

Hydrogen Export Industry

**

TABLE 5.4 TOTAL ECONOMIC CONTRIBUTION OF HYDROGEN PRODUCTION FOR EXPORT

	Value-add		
	2025	2030	2040
Economic footprint	A$m	A$m	A$m
Low H_2 demand scenario	92	806	1,972
Medium H_2 demand scenario	473	1,672	4,287
High H_2 demand scenario	1,196	3,625	10,095
Employment footprint	**FTE**	**FTE**	**FTE**
Low H_2 demand scenario	164	1,439	3,519
Medium H_2 demand scenario	788	2,787	7,142
High H_2 demand scenario	1,898	5,754	16,024

SOURCE: ACIL ALLEN ESTIMATES

Regional Benefit: FTE locations near RE generation

** "Opportunities for Australia from Hydrogen Exports", ACIL Allen Consulting for ARENA, August, 2018

Hydrogen Transport

Current and developing methods

Current

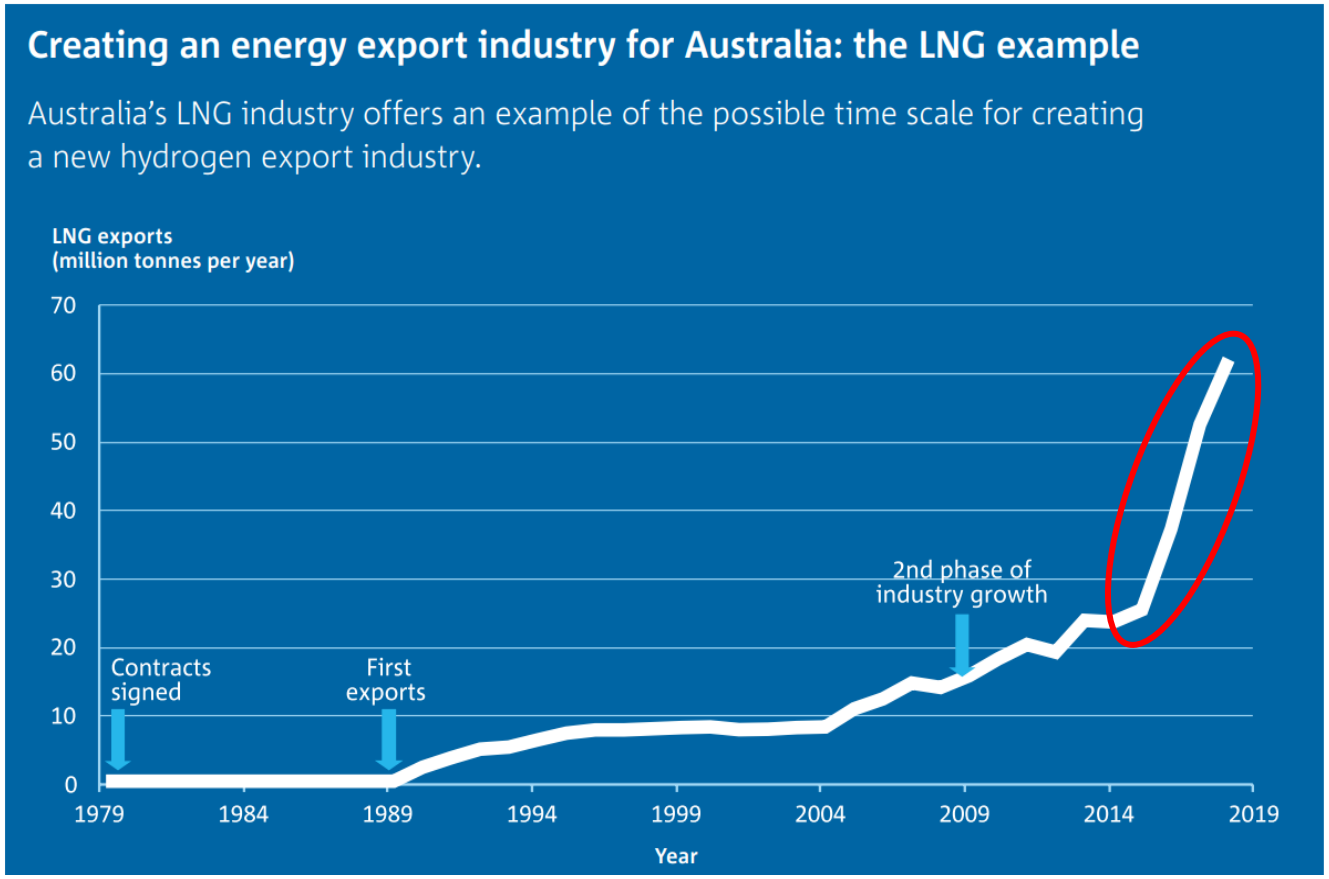
- ✓ Compressed gas cylinders or tube tankers (small to modest)
- ✓ Liquid tanks/trucks (insulated cryogenic tanks) – rail, ship
- ✓ Pipelines as H_2 or blended with natural gas
- ✓ As CH_4 or NH_3 – gas or liquid formats

Developing

- ✓ Liquid H_2 in shipping tankers
  - similar to LNG but colder by ~100 ^oC (*i.e.* -253 ^oC)
  - LNG shipped at -160 ^oC; competitive w pipelines > 2,500km
- ✓ As hydrogenated toluene (methyl cyclohexane) – a benign liquid
  - recovered at point of use; recycle toluene
  - bio-toluene w solar powered hydrogenation – “green” transport

Queensland's Future Industries

Lessons from the recent past*



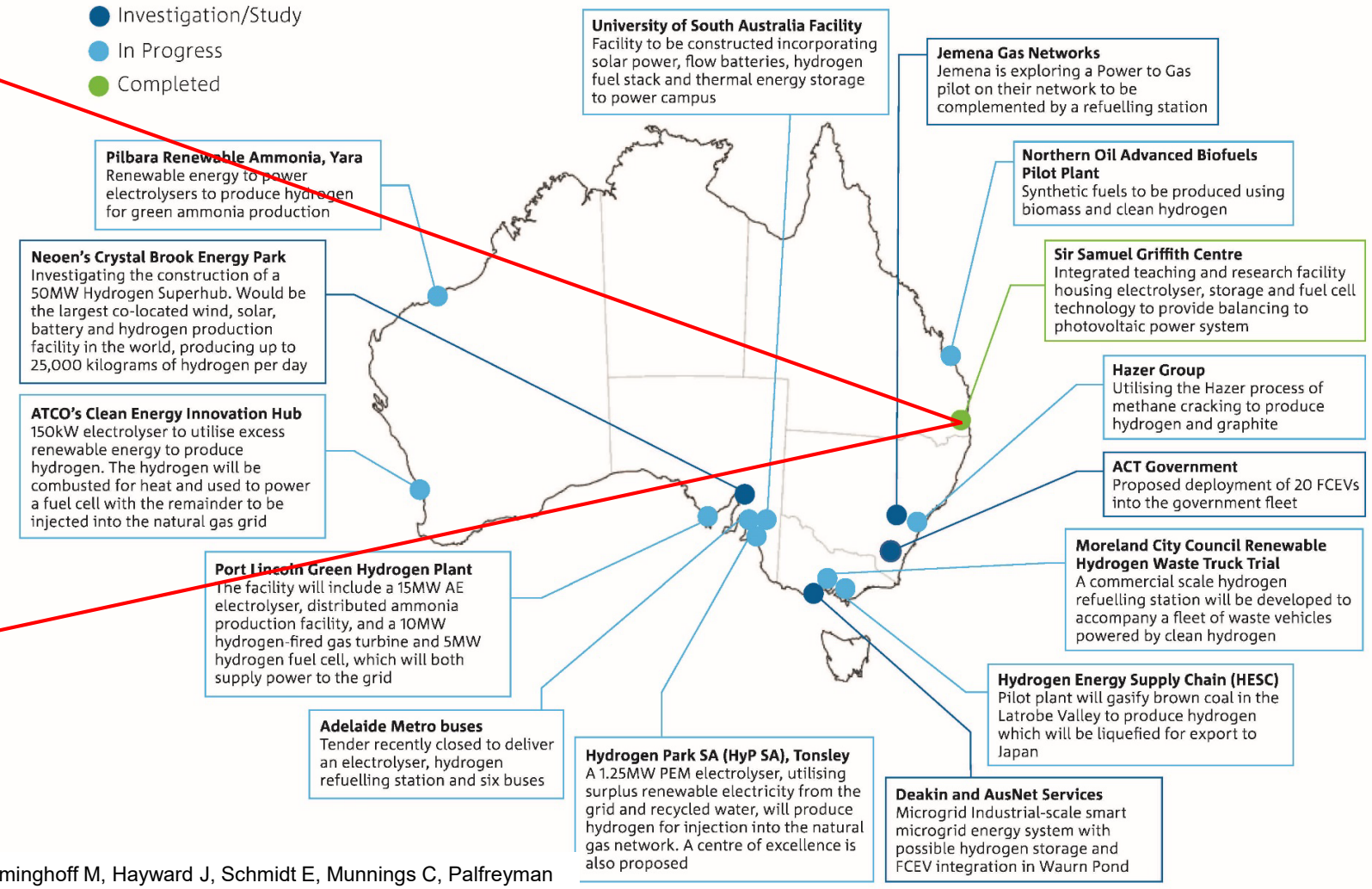
*Source: 'Hydrogen for Australia's Future, Commonwealth of Australia, 2018'.

Next Steps: H_2 Economy

- ✓ Policy Development – Federal & State
  - Encourage domestic use and export
- ➢ Industry Development – early stage
  - ✓ Blue H_2 – strong
  - Brown/grey H_2 – modest; increasing
  - Green – nascent but solar farm opportunity
- ➢ Allied Renewable Energy Industry
  - ✓ Solar/Wind – strong
  - Batteries – diverse; increasing market
  - Infrastructure – grids; integration
- ➢ Skills Development
  - ✓ Existing gas industry
  - All sectors – trades, professional
  - Demonstrations and pilot plants
- ➢ End-Users – domestic and export
  - Back-to-base: first movers
  - Consumers: fast followers

Australian Hydrogen Projects*

- 6000 m^2 building, intended to collect its energy from within footprint
- Demonstrator for clean energy technology
- Fully instrumented and monitored energy system

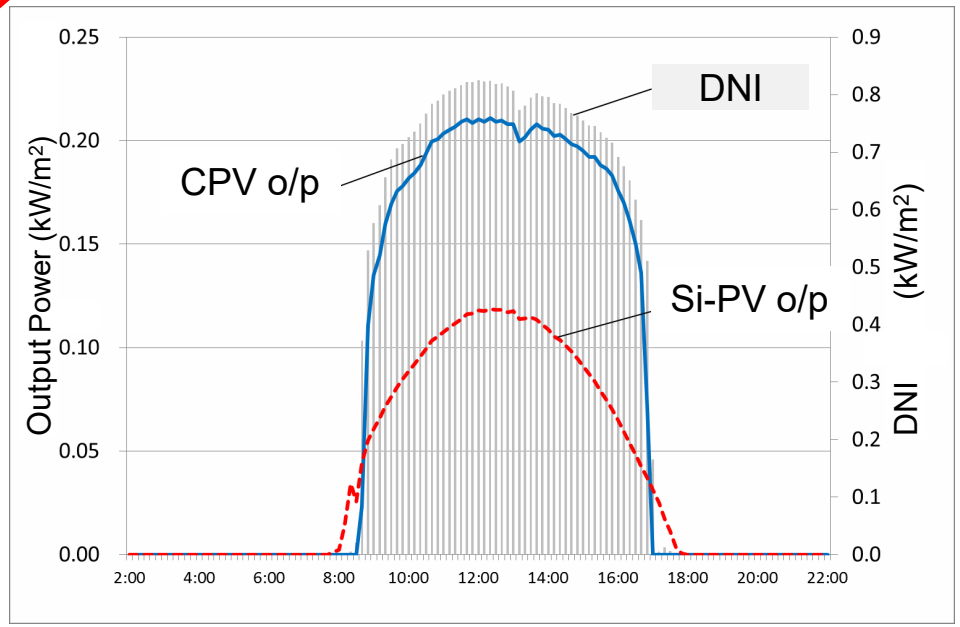


* Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D, Hartley P (2018) National Hydrogen Roadmap. CSIRO, Australia.

Redlands Research Facility

Qld Dept Agriculture and Fisheries

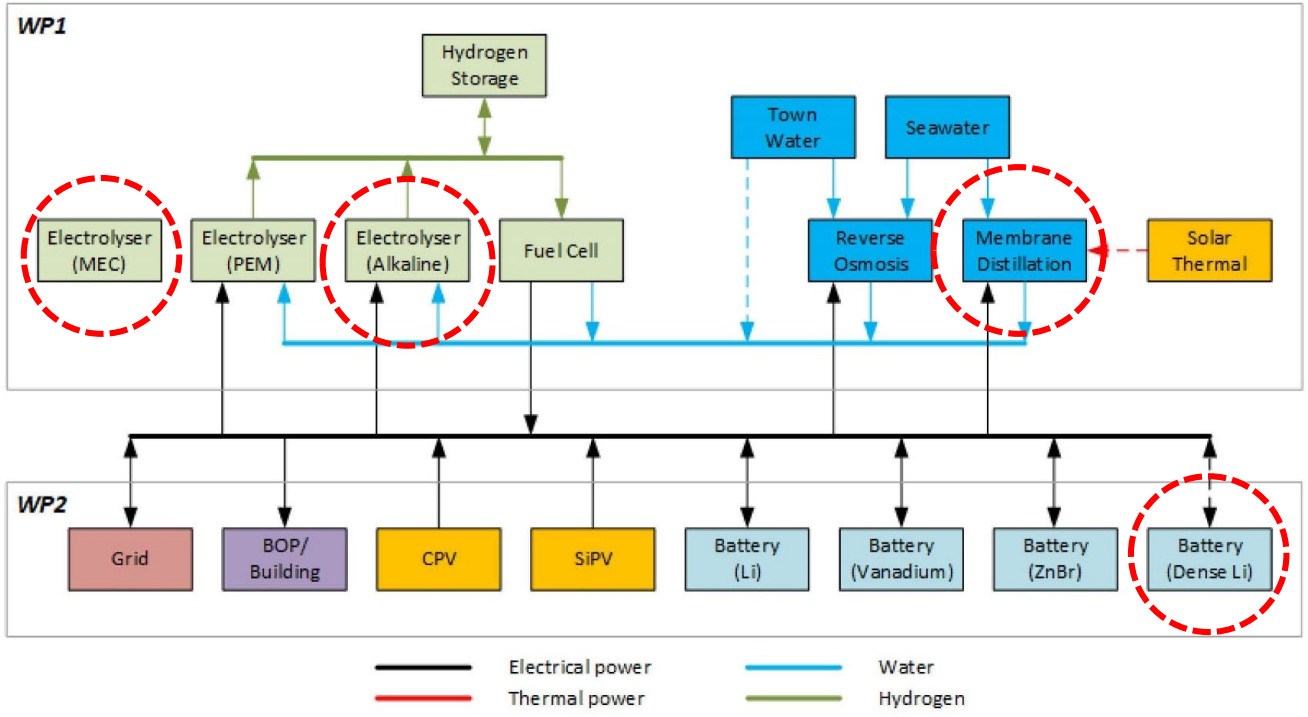
- Controlled glasshouses
  - Sugar cane, bananas, etc
- Agbot – field manouvers
  - Weed trials
- Cropping field trials



H2Xport project

Cost Effective Renewable Hydrogen through Materials, Modelling and Process Innovation

WP1: Enhanced H_2 Production - Electrolysis
WP2: Sustainable Power and Systems Integration
WP3: IoT Based Sensing System
WP4: Modelling, Design and Optimisation



Project Partners:

- QUT (lead)
- Griffith University
- Swinburne University
- Univ of Tokyo
- Sumitomo Electric Industries
- Energy Developments Ltd
- ARENA

Key Differentiation:

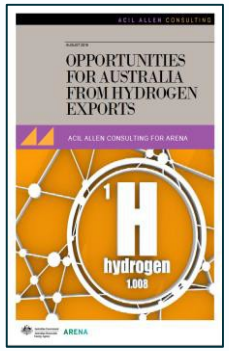
- DC-DC micro-grid at ~100kW scale
- “plug and play” utilisation
- Data analytics validates enterprise models
- Flexible benchmarking facility
- Compares CPV and/or Si-PV at scale
- Three electrolysers – capacity, response
- Optimisation of multiple components

Recent Policy/Background Actions

Australia

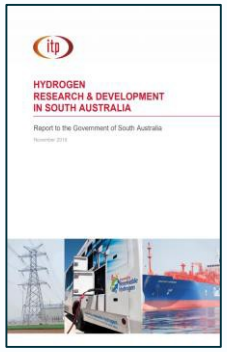
August 2018

National Hydrogen Roadmap is released by CSIRO



August 2018

Hydrogen for Australia's Future, by the Hydrogen Strategy Council for COAG Energy Council

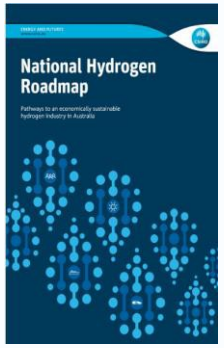


December 2018

COAG Energy Council approval for National Strategy Taskforce

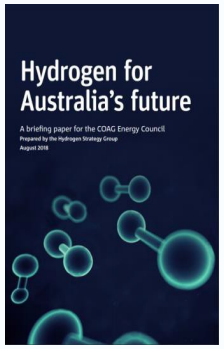
December 2019

COAG Energy Council: National Hydrogen Strategy



August 2018

Australia's Hydrogen Export Opportunities, commissioned by ARENA



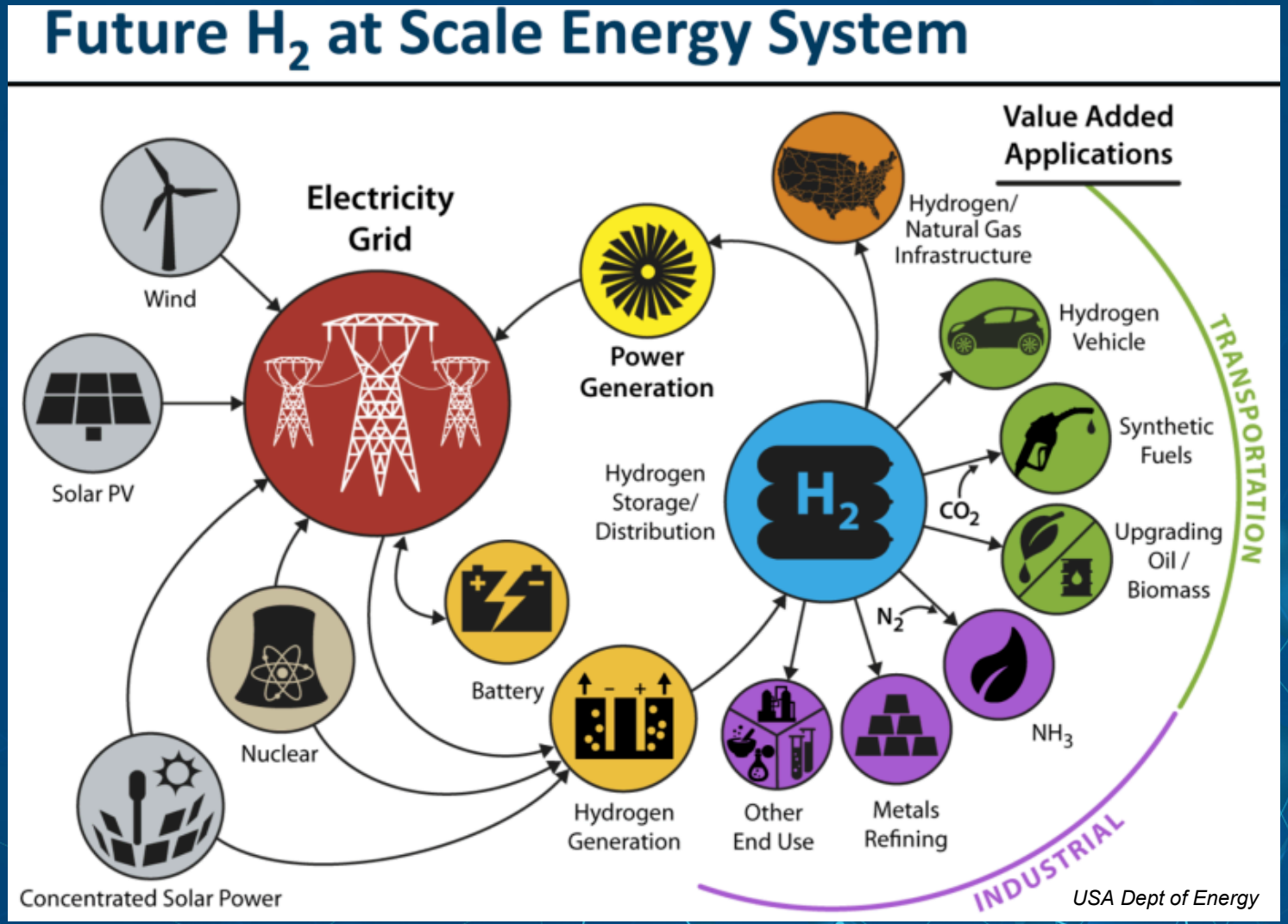
November 2018

Report: Hydrogen R&D in South Australia

Today 2019

Proposal for Hydrogen RD&D: Opportunities & Priorities for Australia

…Just the beginning……..



QUT ife Institute for Future Environments