Oxford University

AMMONIA: the elephant in the room?

Harwell Campus

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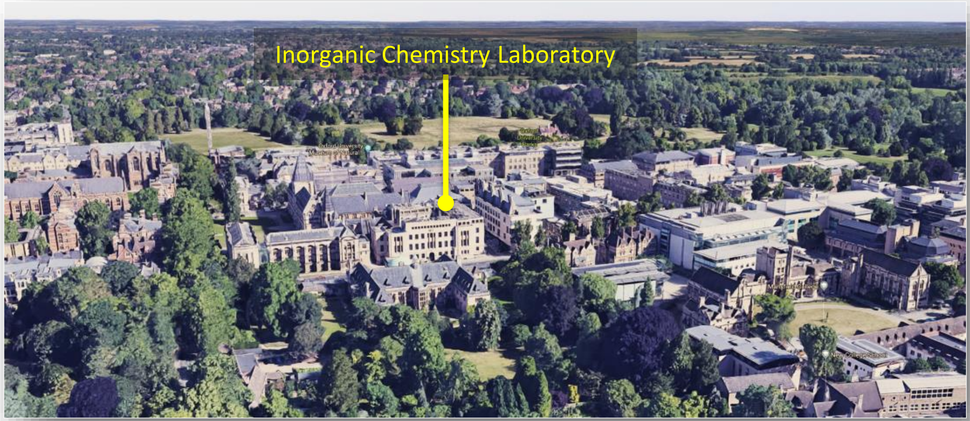
IEA-DG ENER Workshop on "Electrofuels | Brussels | 10 September 2018



Oxford (2005-)

HYDROGEN STORAGE

iea hydrogen

2001 – 2006	Task 17	Solid and liquid state hydrogen storage materials
2006 – 2012	Task 22	Fundamental and applied hydrogen storage materials
2013 – 2018	Task 32	Hydrogen-based energy storage
2019 – 2022	Task 40	Energy storage and conversion based on hydrogen

MIT Technology Review

Business Impact

Q & A: Steven Chu

The secretary of energy talks with *Technology Review* about the future of nuclear power post Yucca Mountain and why fuel-cell cars have no future.

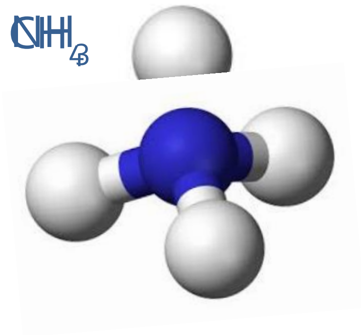
by Kevin Bullis May 14, 2009

Steven Chu

The four miracles

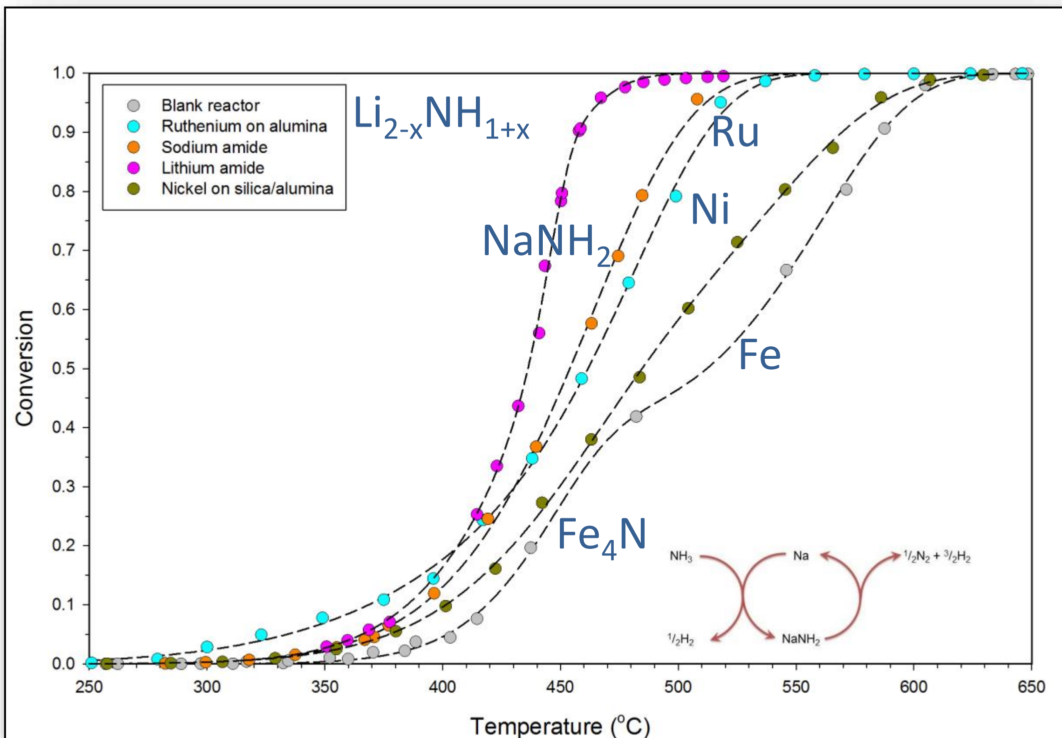
1. Right now, the way we get hydrogen primarily is from reforming natural gas. That's **not an ideal source of hydrogen**.
2. If it's for transportation, we don't have a good storage mechanism yet. Compressed hydrogen is the best mechanism but it requires a large volume. **We haven't figured out how to store it with high density**.
3. Now **fuel cells** aren't there yet.
4. The **distribution infrastructure** isn't there yet.

1. Right now, the way we get hydrogen primarily is from reforming natural gas. That's **not an ideal source of hydrogen**.

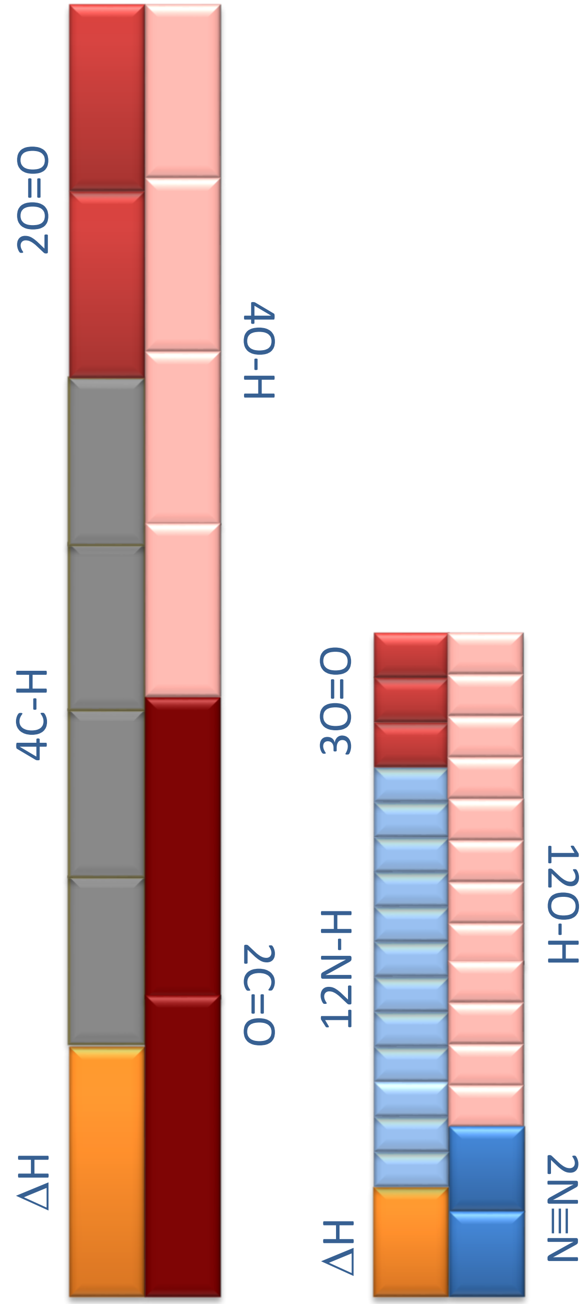


$$CH_4 + 2O_2 \longrightarrow 2H_2O + CO_2$$

$$4NH_3 + 3O_2 \longrightarrow 6H_2O + 2N_2$$



Novel ammonium decomposition catalysts

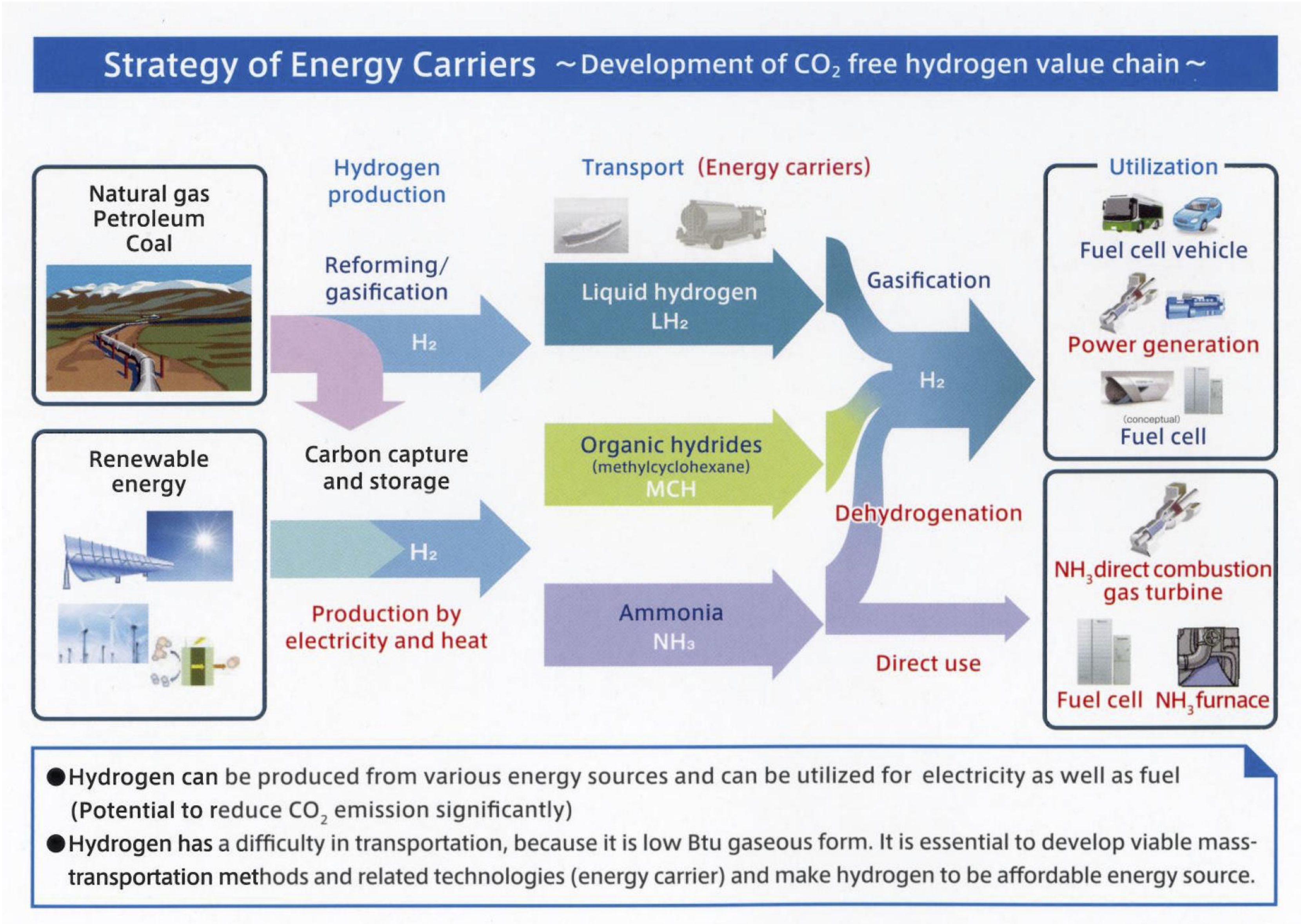


2. If it's for transportation, we don't have a good storage mechanism yet. Compressed hydrogen is the best mechanism but it requires a large volume. **We haven't figured out how to store it with high density**.

Storage method	Storage conditions	Hydrogen density (kgH_2/m^3)	H_2 release conditions	Explosive limits (%vol in air)	PEL# (ppmv)	Vapour pressure (bar @ 298 K)
Compressed CH_4	250 bar	36	Catalytic T>700°C	5-15	N/A	600
Compressed H_2	700 bar	42	Pressure release	4–75	N/A	-
Liquid H_2	<20.28 K	70	Evaporation	4–75	N/A	-
Liquid NH_3	<239.81 K @ 1bar	120	Catalytic T>400°C	15–28	50	11
Liquid NH_3	>10 bar @ 298 K	108	Catalytic T>400°C	15–28	50	11
Methylcyclohexane (MCH)	Ambient	47	Catalytic T>300°C	1.2–6.7 (MCH) 1.2–7.1 (Toluene)	500 200	0.06
Methanol	Ambient	100	Catalytic T>200°C	6.7–36	200	0.17
Formic acid	Ambient	53	Catalytic T>50°C	18–34	5	0.06

Permitted Exposure Limit, Occupational Safety and Health Administration, U.S. Department of Labor. Given as 8-hour time weighted average concentration.

3. Now **fuel cells** aren't there yet.



Cabinet Office
http://www8.cao.go.jp/cstp/gaiyo/sip/

JST Japan Science and Technology Agency
http://www.jst.go.jp/sip/k04.html

4. The **distribution infrastructure** isn’t there yet.

RENEW ECONOMY

SOLAR RENEWABLES STORAGE ELECTRIC VEHICLES

CSIRO cracks barrier to export hydrogen fuel to power cars

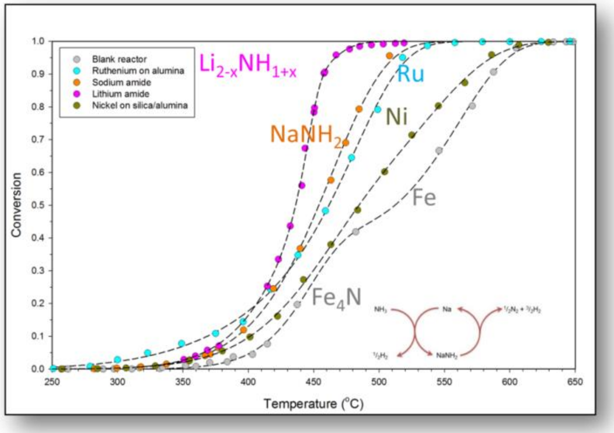
Bridie Schmidt 8 August 2018 29 Comments Share

The CSIRO team working on the membrane technology that allows hydrogen fuel to be transported as ammonia. Source: CSIRO

Hydrogen as an energy source for sustainable transport has great potential, but for use in the transport industry there is one big problem: the highly flammable gas in its pure form must be compressed and stored safely in order to be transported for use as a fuel.

Today, a breakthrough method developed by the CSIRO to transport hydrogen safely in the form of ammonia was tested in Pullenvale, Brisbane.

CSIRO Chief Executive Larry Marshall was one of the first to take a ride in the vehicles supplied by Toyota and Hyundai, both automakers who have invested considerable time and money in the development of fuel cell technology for cars.



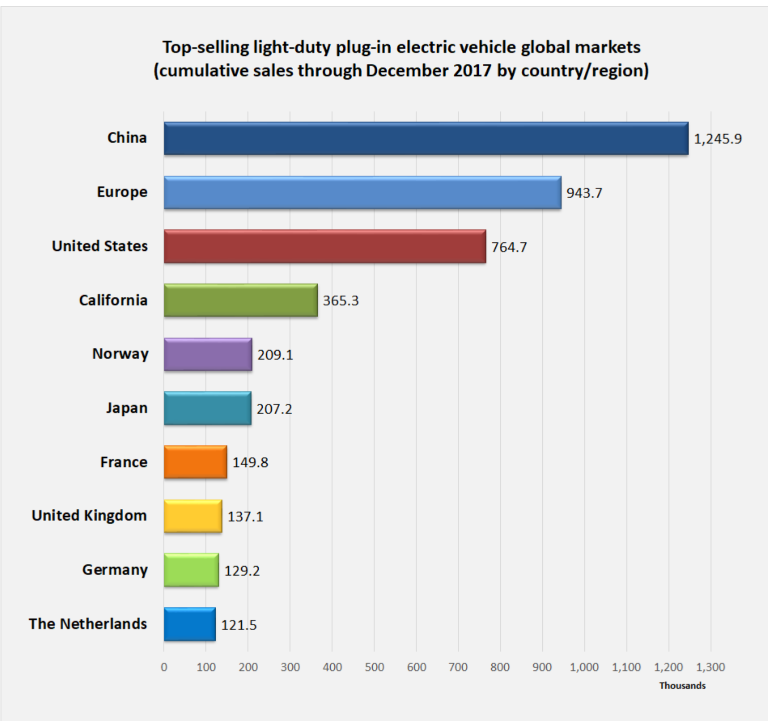
reneweconomy.com.au/csiro-cracks-barrier-to-export-hydrogen-fuel-to-power-cars-79439/

Safety on the forecourt

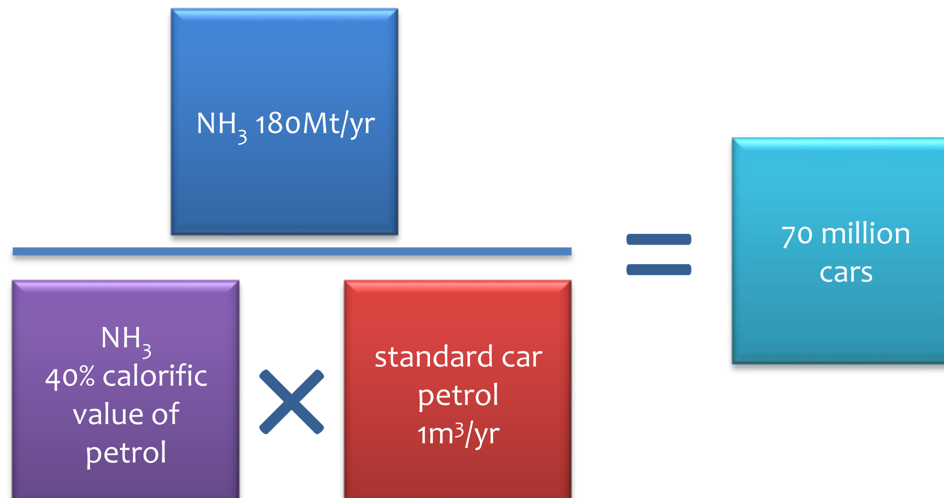
Elephantine numbers

- *ca.*180M tonnes of NH_3 produced in 2017
- *ca.* 20M tonnes of NH_3 exported (maritime)

- NH_3 has 40% of the calorific value of octane
- 94% of the energy in the production of green NH_3 comes from the production of green hydrogen



2017 | 3 million plug-in electric vehicles



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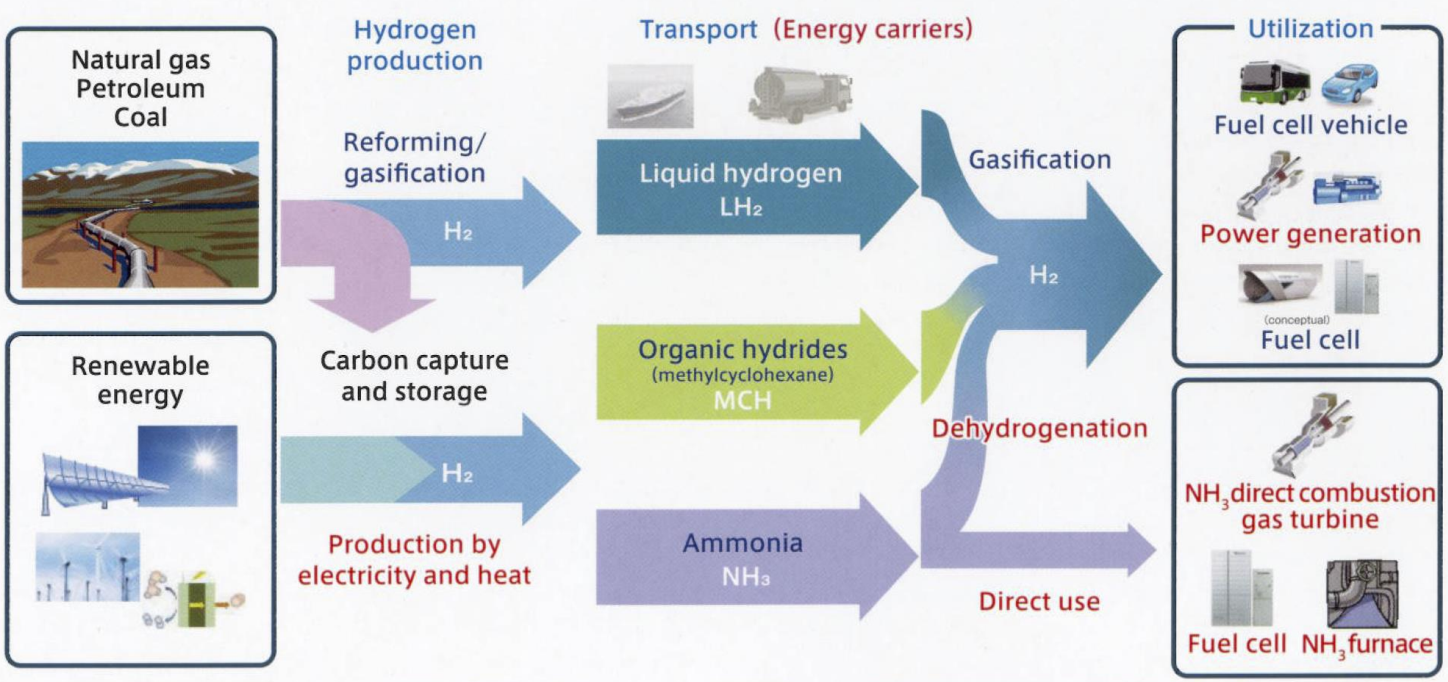
http://www8.cao.go.jp/cstp/gaiyo/sip/

JST Japan Science and Technology Agency
http://www.jst.go.jp/sip/k04.html

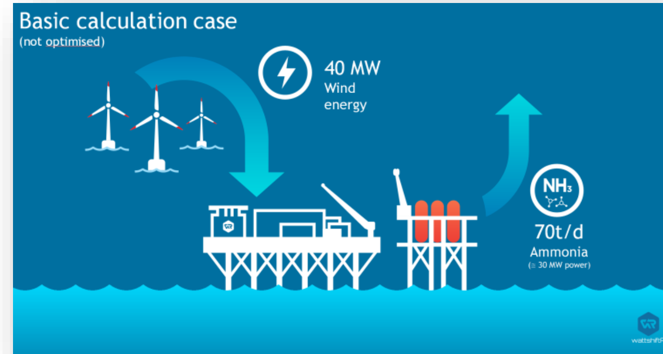
Strategy of Energy Carriers ~Development of CO_2 free hydrogen value chain~

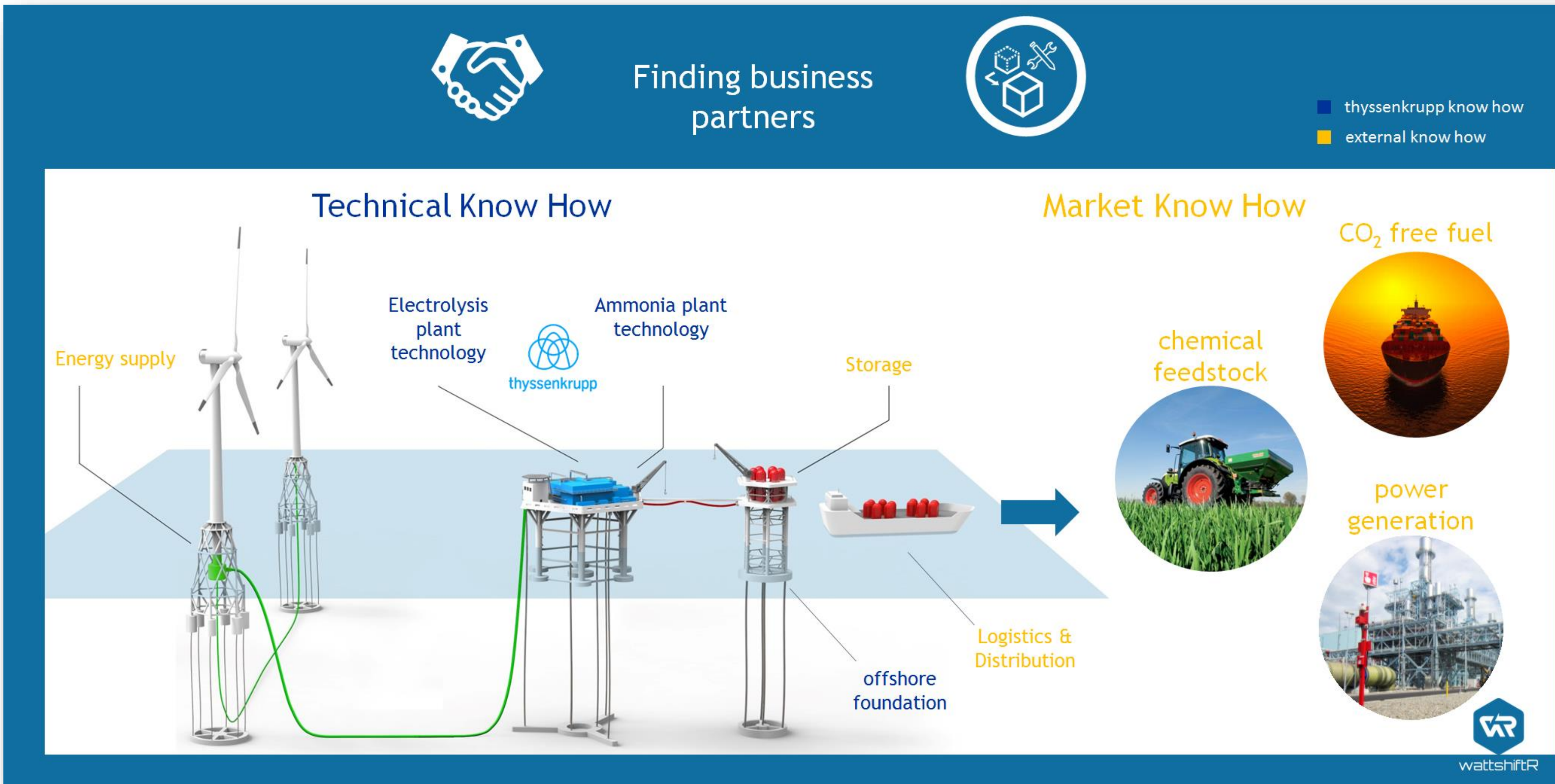


- **Hydrogen can** be produced from various energy sources and can be utilized for electricity as well as fuel (Potential to reduce CO_2 emission significantly)
- **Hydrogen has** a difficulty in transportation, because it is low Btu gaseous form. It is essential to develop viable mass-**transportation meth**ods and related technologies (energy carrier) and make hydrogen to be affordable energy source.

ThyssenKrupp

thyssenkrupp





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Morocco is building a giant thermosolar farm in the Sahara Desert

The mirrors cover an area of roughly 1.4 million square metres. The first pha this plant generated enough electricity to supply 650,000 people when it wa switched on in 2016.

By 2020, or even sooner, the $9 billion solar power plant is expected to gene 580 megawatts (MW), enough electricity to power over a million homes.

Perhaps more importantly, the solar farm, near the city of Ouarzazate – knov the gateway to the desert – could also be the doorway to a new era of clean energy production in Africa.

Image: REUTERS/Youssef

Symbolically, the name of the plant – Noor – is an Arabic word meaning "ligh and its success could mark the dawn of a new industry for a country that un recently imported 97% of its energy needs.

In the very near future, Morocco aims to become an exporter of power supp Europe, as well as to elsewhere on the African continent and the wider Arab speaking world.

www.weforum.org/agenda/2018/05/morocco-is-building-a-solar-farm-as-big-as-paris-in-the-sahara-desert/

OCP Group and Fraunhofer IMWS sign MoU

Published by David Rowlands, Deputy Editor
World Fertilizer, Friday, 03 August 2018 11:00

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OCP Group has announced that it has signed a memorandum of understanding (MoU) with Fraunhofer IMWS to work jointly on solutions for a sustainable fertilizer industry.

The MoU will see continued cooperation, with the aim of increasing the use of renewable raw materials in the fertilizer industry. The focus is on two particular raw materials: green hydrogen and green ammonia. Green hydrogen is obtained by electrolysis using electricity form renewables engines. It can be further processed into a number of products for the fertilizer industry. Green ammonia, meanwhile, consists of green hydrogen and nitrogen, and can serve as a raw material for the production of fertilizers, amongst other uses.

Ralf B. Wehrspohn, Director of the Fraunhofer IMWS, said: "Green hydrogen and green ammonia offer tremendous potential to sustain the supply of raw materials to the fertilizer industry. They also reduce the industry's dependency on oil, natural gas and any other fossil fuel. I am pleased that our many activities in the area of Chemistry 4.0 are being perceived internationally, and that we can now continue to advance these technologies with a globally leading company such as OCP, to prove that green hydrogen and green ammonia can be used on an industrial scale – and at prices that make sense for the companies."

Mostafa Terrab, Chairman of OCP, added: "Responsibility for the environment has always been important to us, not just when working in our mines, but as a fundamental principle of our circular economy approach. The use of green ammonia fits in with this strategy. It can help conserve valuable resources and provide our customers with sustainable new products. That's why we are looking forward to strengthening our cooperation with Fraunhofer."

Under the leadership of Fraunhofer-Gesellschaft, a pilot plant is already under construction in Leuna, Germany. Green hydrogen will be produced and made available for a group of companies based there from 2019. A similar platform, which is also able to produce green ammonia, will be developed in Morocco by OCP Group and the Green Energy Park in Ben Guerir, with the support of Fraunhofer IMWS. The delegation from Morocco also visited the Fraunhofer Center for Chemical- Biotechnological Processes (CBP) in Leuna, and discussed the opportunities of biotechnological phosphorus modification and electrocatalytical synthesis of ammonia.

www.worldfertilizer.com/environment/03082018/ocp-group-and-fraunhofer-imws-sign-mou/

ENERGY PRODUCTION

Hydroelectric

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Biomass

Marine

Wind

Gas

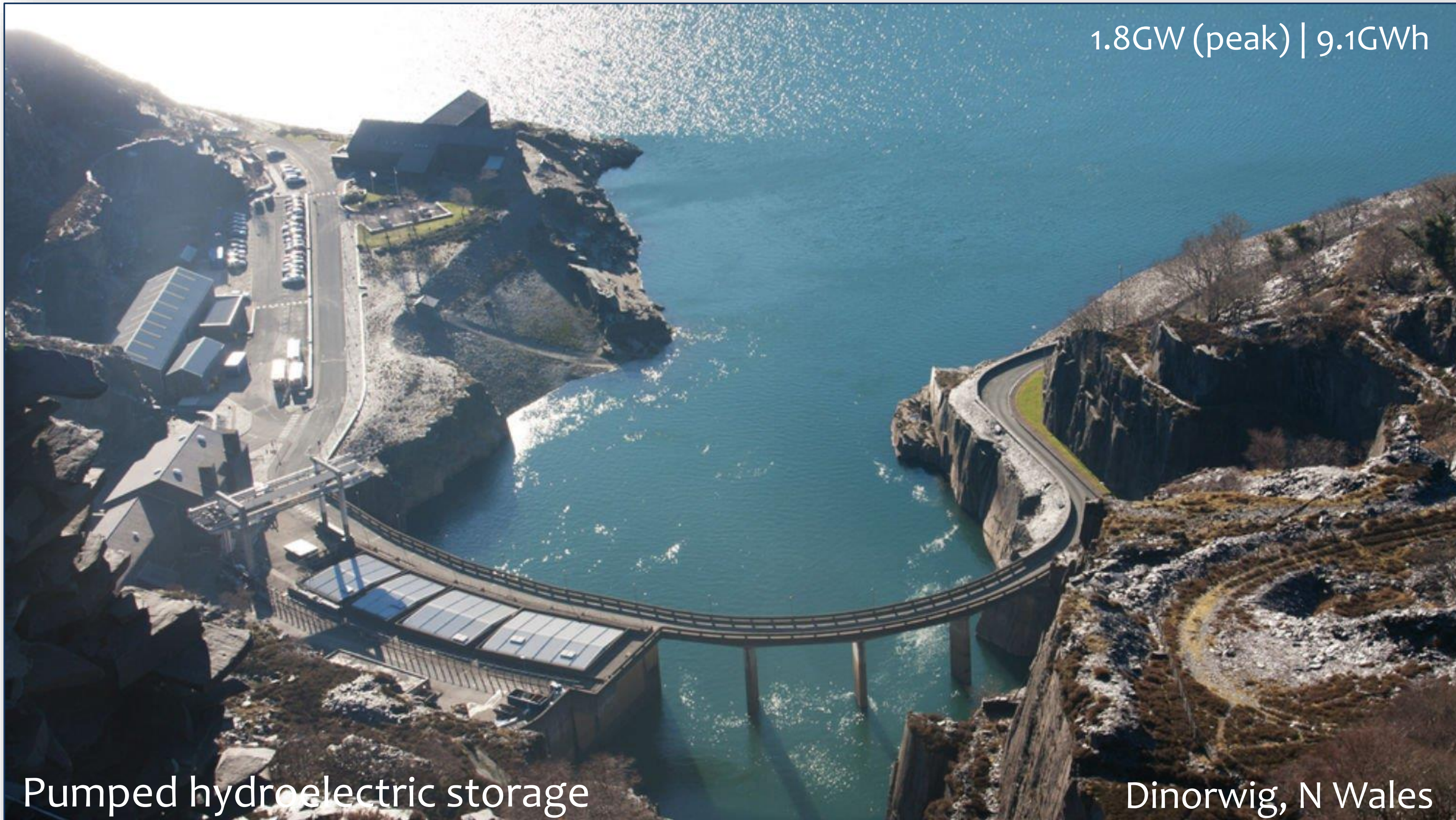
WATER

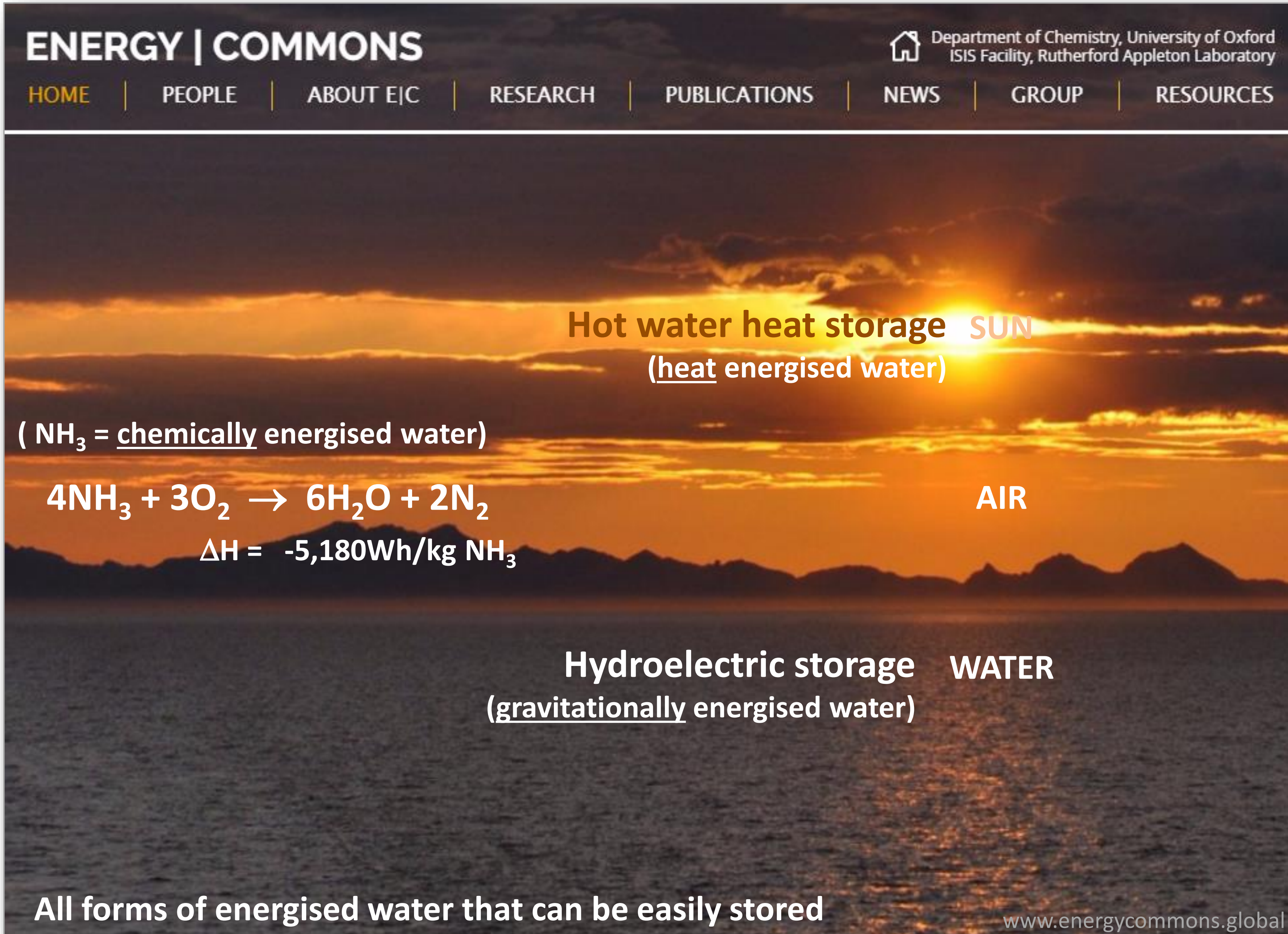
Geothermal

Nuclear

Coal

WE MUST ALSO USE THE GLOBAL COMMONS TO STORE ENERGY


1.8GW (peak) | 9.1GWh
Pumped hydroelectric storage
Dinorwig, N Wales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(heat energised water)
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(NH_3 = chemically energised water)
$4NH_3 + 3O_2 \rightarrow 6H_2O + 2N_2$
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