Flexibility with low-carbon hydrogen

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Only 4 of 10 TIMES models represented biomass gasification with CCS in our survey in 2018

Why consider hydrogen?

- Electricity is clean and efficient, but inflexible.
- Hydrogen is quite clean and adds flexibility to the system for both supply and demand.

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<th>ETSAP-TIAM</th>
<th>TIMES_PanEU</th>
<th>JMRT Japan</th>
<th>TIMES_VTT</th>
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Supporting renewable electricity generation

Energy system integration

International trade
Hydrogen could power low-carbon services across the energy system
Hydrogen can be produced from a range of feedstocks:

- Cost and emissions vary for each production route.
- We need to consider infrastructure requirements throughout a transition both to transport and store hydrogen.
- Early decarbonisation actions using hydrogen are likely to depend on the supply of hydrogen rather than the cost-optimal use on the demand side.
Production of low-carbon hydrogen from wind and solar generation will probably be more expensive than from natural gas in many countries.

Hydrogen could be produced from natural gas with CCS at about 1–2 $/kg (IEA).

Using renewable electricity to produce hydrogen costs 3–8 $/kg at present but could reduce to 1.3 $/kg in some countries by 2030 (IEA).

This map from IRENA shows even lower projected global costs in 2050.

Map from: https://www.irena.org/publications/2022/May/Global-hydrogen-trade-Cost
The results from this project will improve the modelling of large-scale H2 production facilities coupled to PV and wind systems.

**WP1 – Wind and PV Resources**
- Solar and wind resource variability
- Assessment of real-time and forecasted data from partners
- Benchmarking of nowcast methods

**WP2 – PEM Water Electrolysis**
- *Nowcasted* prediction interval for PV and wind power output

**WP3 – Techno-Economic Analysis**
- Development of modeling tools
- *Use case* analyses
- RE/H2 Energy System Management
- Advanced control strategies
- H2 system / process modeling
- PEMWE durability assessment

**RE System**

**PEMWE System**
Hydrogen Pathways 2050

Hydrogen may play a key role in the future energy system, as it provides flexibility both to the supply side and demand side. This project will examine the transition of the Norwegian society and value creation from export.

Case study setup

Does energy storage impact where and how hydrogen is produced?
- Salt caverns in Europe
- DeepPurple and offshore H2
- Linepacking of H2

How does production of hydrogen from offshore wind compete with and complement hydrogen production from natural gas under different price developments?
Producing hydrogen from natural gas with CCS requires careful management and CO$_2$ offsets

- **Howarth and Jacobson (2021)**: greenhouse gas emissions from hydrogen produced from natural gas with CCS are higher than for unabated combustion of natural gas.
- **Romano et al. (2022)**: disagreed, based on alternative assumptions.
- Hydrogen is an indirect GHG with a 100-year GWP estimated at 11±5 ([Warwick et al. 2022](Warwick et al. 2022)). **Ocko and Hamburg (2022)** emphasise the importance of minimising fugitive emissions.
- Conclusion: great care must be taken when producing hydrogen from natural gas to measure and minimise emissions, and to minimise fugitive emissions across the supply chain. A hydrogen standard accompanied by appropriate regulation is needed. CO$_2$ removal to offset unavoidable emissions are necessary.
There is high variability between models in the assumed capital costs of biomass gasification plants.

Source: Dodds et al. (2022) Modelling of hydrogen
Production of hydrogen from biomass with CCS has a similar cost to electricity production

Production of hydrogen from biomass (~3.5 $/kg without CCS) is only economic from a systems perspective.

In a typical “optimal” scenario, only two of seven TIMES models in our survey deployed biomass gasification to produce hydrogen.

Both of these models deployed higher levels of renewables and also steam-methane reforming.

Our experience with the UK TIMES model suggests that biomass plants with CCS are essential to meeting net zero, with sequestered CO$_2$ the primary output and electricity or hydrogen as a co-product, depending on the relative costs.

Source: Dodds et al. (2022) Modelling of hydrogen
Novel business models that integrate hydrogen production into the wider energy system could change the economics

Studies tend to consider production from:

1. 100% dedicated renewables (no grid costs, but low electrolyser utilisation); or,
2. 100% grid electricity (whether renewable or not), with excess renewable generation at zero cost.

A system that primarily uses dedicated renewable generation but tops-up with grid electricity when the price is low could have lower production costs (with an appropriate standard and certification regime).

Similarly a nuclear plant coupled with a solid-oxide electrolyser that exports electricity when the price is high and produces hydrogen when the electricity price is low could be economically viable.

Are there other opportunities to reduce costs through systems integration?
Flexible electricity generation from hydrogen

There are few low-carbon options to decarbonise peaking generation:

• Energy storage can meet some but not all demand cost-effectively

• Hydrogen turbines are a low capital cost option, perhaps linked to hydrogen storage.

As most energy system models have a low temporal resolution, the benefits of hydrogen turbines to the system are only resolved if a minimum capacity factor constraint is applied to all technologies (e.g. 5%).

Geography should be taken into account: only some locations have geological structures appropriate for hydrogen storage.

From: https://www.eti.co.uk/programmes/carbon-capture-storage/salt-caverns
The cost-optimal UK annual share of domestic generation from renewables is sensitive to the availability of long-term storage and flexible generation.

This graph shows the cost-optimal share of renewable generation in 2050 in the UK from the highRES electricity system model.

Only the “ALL” tech scenario includes hydrogen power-to-power storage.

Novel business cases are not considered.

Long-term storage also enables a lower cost electricity system

This graph shows the levelised cost of generation in 2050 in the UK from the highRES electricity system model.

Only the “ALL” tech scenario includes hydrogen power-to-power storage.

Hydrogen system integration

• High-resolution electricity system models can resolve the value of power-to-power storage but do not consider the situation where produced hydrogen is used elsewhere in the energy system where the value is higher (e.g. as a transport fuel).

• There is a need to bridge system models and high-resolution electricity system models to understand the wider system value that hydrogen offers due to its flexibility and potential use in a number of sectors.

• Synthetic fuel production is a rapidly evolving area using hydrogen and captured CO₂ to produce jet fuel and high-value chemicals.

• International trade offers further options for flexibility, for example to use ammonia-powered rather than hydrogen-powered systems in some countries to reduce costs.
Options for trading hydrogen and derivatives

- Hydrogen is much cheaper to store for long periods and transport over long distances than electricity.
- The key challenge is hydrogen’s low energy density.
- Trade-off between hydrogen and derivatives:
  - The choice of transport method would depend on:
    - Volume transported
    - Transport distance
    - Form of final demand
- Techno-economic models are usually used to compare the costs and efficiencies of the transport options.

Source: https://www.irena.org/publications/2022/Apr/Global-hydrogen-trade-Part-II
**Representation of hydrogen and ammonia trade in TIAM-UCL**

- TIAM-UCL has been developed to represent the global trade of hydrogen and ammonia and explore their possible role in future energy system decarbonisation.
- Model features: global (16 regions), time horizon 2005-2100, scenario analysis.

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<tr>
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<th>Hydrogen</th>
<th>Ammonia</th>
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<td><strong>Trade options</strong></td>
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<td>Liquid in ships</td>
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<td><strong>Production routes</strong></td>
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<td>Haber-Bosch</td>
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<td>Electrolysis (grid/decentralised)</td>
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<td>Synthetic fuels</td>
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<td>Gas blending</td>
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Early insights on future hydrogen trade

- In a 1.5 °C decarbonisation scenario, ammonia is traded at a larger scale than hydrogen in 2050

Hydrogen trade: 2.5 EJ

- Australia: 2.2 EJ
- Other Asia: 1.8 EJ

Ammonia trade: 17.3 EJ

- Australia: 8.3 EJ
- Japan: 0.2 EJ
- South Korea: 0.2 EJ
- Middle East: 3.2 EJ
- Canada: 0.6 EJ
- USA: 5 EJ
- Other Asia: 10.8 EJ
- South Korea: 1.4 EJ
- China: 0.7 EJ
- Western Europe: 2.3 EJ
- Mexico: 0.6 EJ
- Eastern Europe: 0.3 EJ
- UK: 0.2 EJ
Conclusions

1. Most hydrogen production projects focus on renewables and natural gas, and perhaps nuclear.

2. Production of hydrogen from biomass is likely to remain more expensive than from renewables and natural gas, but might be justified from a systems perspective in order to sequester atmospheric CO$_2$. There is high capital cost uncertainty between our models.

3. Hydrogen provides flexibility to a renewable electricity system by acting as a sink for excess generation, by providing flexible peak generation, and by providing storage. From a system perspective, power-to-power storage might not be the best use of hydrogen, but we lack the tools to properly resolve how the system could optimally work.

4. Hydrogen trade offers flexibility by enabling countries to access bulk hydrogen if they have few resources, and to reduce the impacts of seasonal changes in supply and demand. Hydrogen derivatives such as ammonia could be traded on a larger scale than hydrogen, creating trade-offs for countries as they decide between the benefits of economy and security benefits from local production, and the benefits from reduced energy costs by relying on imports.
Thank you for listening

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