Aurora keynote:

Producing hydrogen on renewables sites: what will it take to compete?

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Renewables Summit

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Premium Partners:

bp

LLOYDS BANK

Supporting Partner:

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A KOHLER COMPANY
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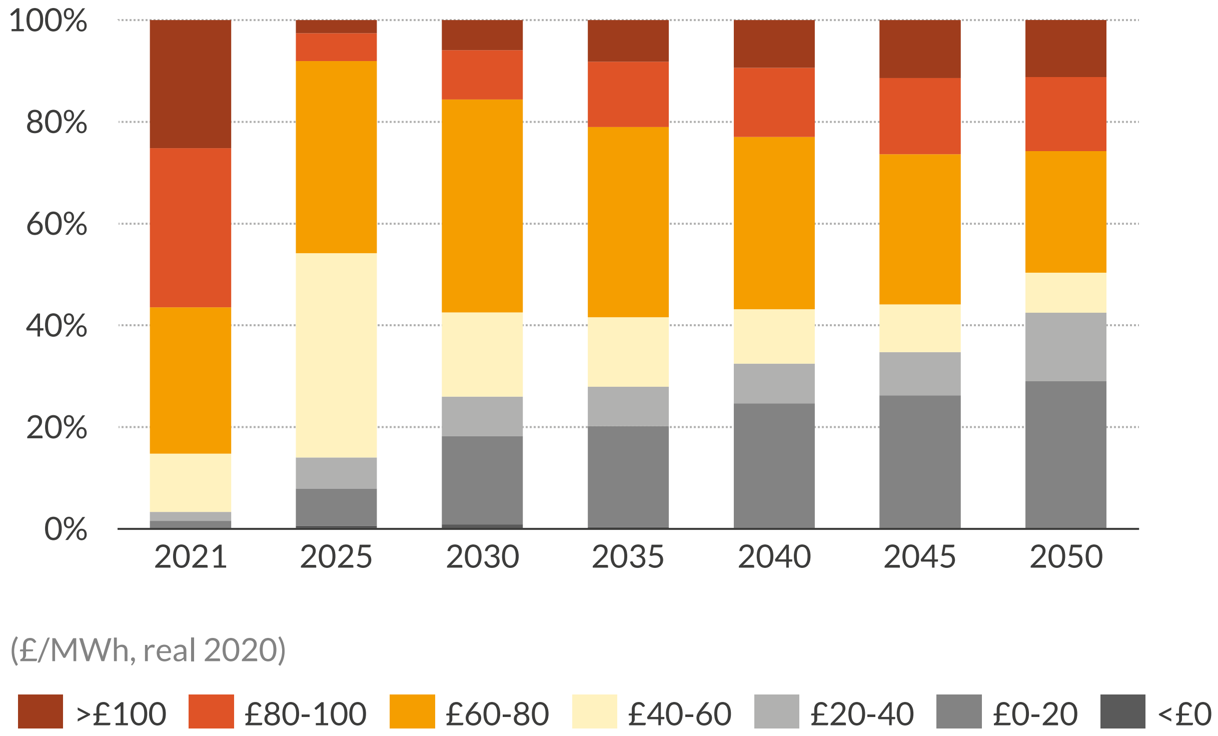
Some developers are considering co-locating hydrogen electrolysers at renewables sites to make better use of the electricity they generate

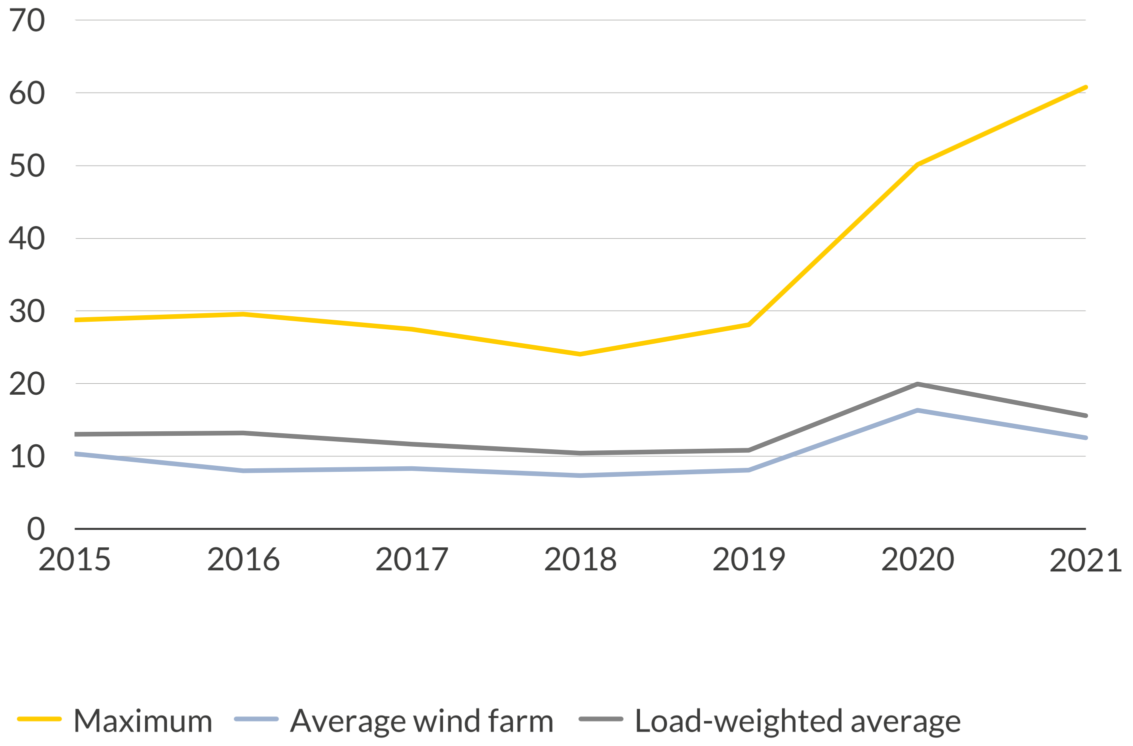
Renewables will be exposed to lengthening periods of low prices

Frequency distribution of wholesale electricity price
% of time, Aurora forecast



Over 10% of onshore wind generation is already lost to curtailment

Curtailment rates for BM registered onshore wind[1]
% of FPN, historic data to end of March 2021



1) Accepted bid volumes as tagged by National Grid in Elexon data. BM registered plants only.

Sources: Aurora Energy Research, Elexon

Electrolytic hydrogen production co-located with renewables has advantages over other forms of hydrogen production

Key forms of hydrogen production

Grey	▪ Methane reformation ▪ Most common source today ▪ High emissions
Blue	▪ Methane reformation with carbon capture ▪ Emissions reduction ~95%
Yellow	▪ Electrolysis ▪ Grid connected ▪ Emissions depend on grid carbon intensity
Green	▪ Electrolysis ▪ Co-located with renewables ▪ Potential for zero emissions

Advantages of electrolysis co-located with renewables

- **Ultra-low emissions**
  - While the electrolyser is powered by the co-located renewables, there are no carbon emissions
  - This means the carbon intensity of the hydrogen is even lower than for a grid-connected electrolyser
- **High purity**
  - Fuel cells (e.g. for use in vehicles) typically require purities of over 99.97%
  - Electrolysis provides hydrogen of this purity; methane reformation does not (without extra purification)
- **Low power costs**
  - Electrolysers drawing power from the grid are subject to costs beyond the wholesale price (e.g. network charges)
  - Electrolysers can avoid these costs by drawing power from co-located renewables

Developers will need to consider the costs of hydrogen production, the logistics of transport and storage, and competition for off-take

Key questions for renewables developers

Production

What levelised cost can I produce hydrogen at?

Logistics

What will it cost to store the hydrogen and transport it to customers?

Off-take

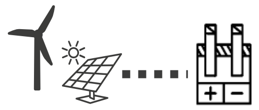
How competitive will my hydrogen be against customers' alternatives?

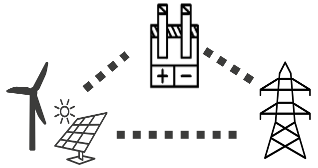
Examples of other key questions we won't focus on today:

- Which off-takers can I serve?
- What subsidy support can I access?

Several electrolyser configurations are possible; today we consider one with wind and solar generation, a grid connection and a flexible electrolyser

Electrolyser configuration options





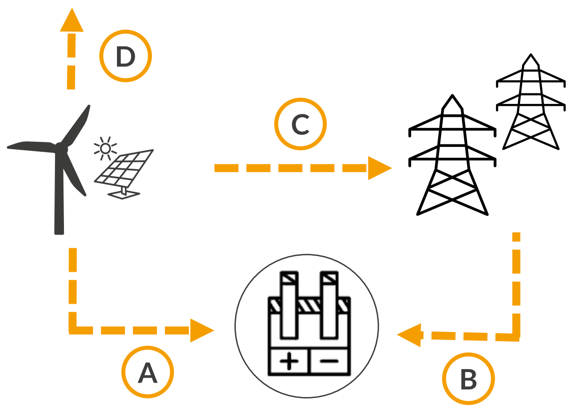
	1 Inflexible	2 Flexible	3 Co-located (Island)	4 Co-located (Grid)
Description	▪ Grid electricity **only** ▪ Runs at **95%** load factor	▪ Grid electricity **only** ▪ Ability to choose operating hours to minimise costs	▪ Electrolyser connected to renewable asset only ▪ No grid connection	▪ Direct connection between electrolyser and RES asset ▪ Both connected to grid
Properties	▪ Produces regular output of hydrogen	▪ **'Smart' operation** avoids periods of high power prices and high grid charges, accessing lower costs	▪ Availability of **zero carbon, low marginal cost renewable energy**	▪ Option to 'top up' electrolyser with grid electricity, or to sell renewable energy to the grid to increase revenues

Key competitor business model for comparison (1 Inflexible)

Focus of our analysis today (4 Co-located (Grid))

We expect a flexible electrolyser in GB in 2025 could achieve a levelised cost of production of £3.7 per kg of hydrogen

Example project configuration

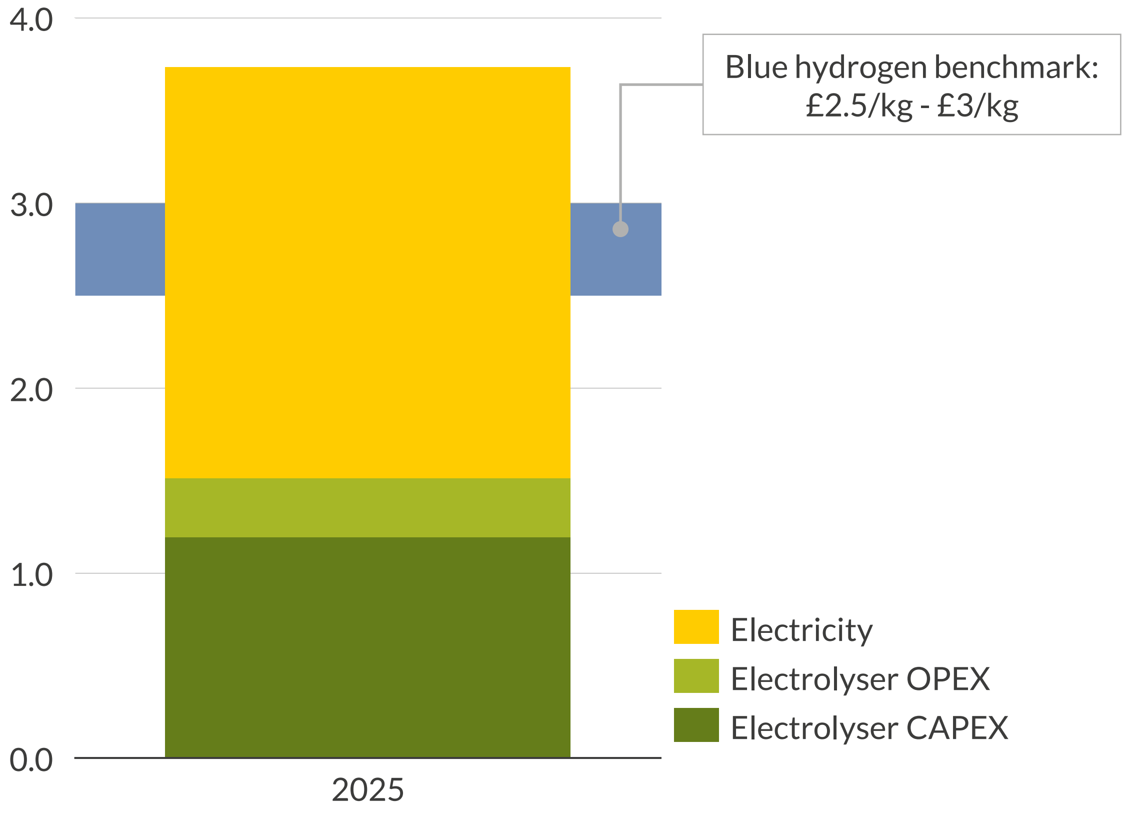


- (A) Electrolyser imports from RES
- (B) Electrolyser imports from grid
- (C) RES exports to grid
- (D) RES spills power

- Operational date: 2025
- Renewables capacity: 8.6MW onshore wind, 1.4MW solar
- Electrolyser capacity: 1MW
- Grid connection size: 7MW

Levelised cost of production

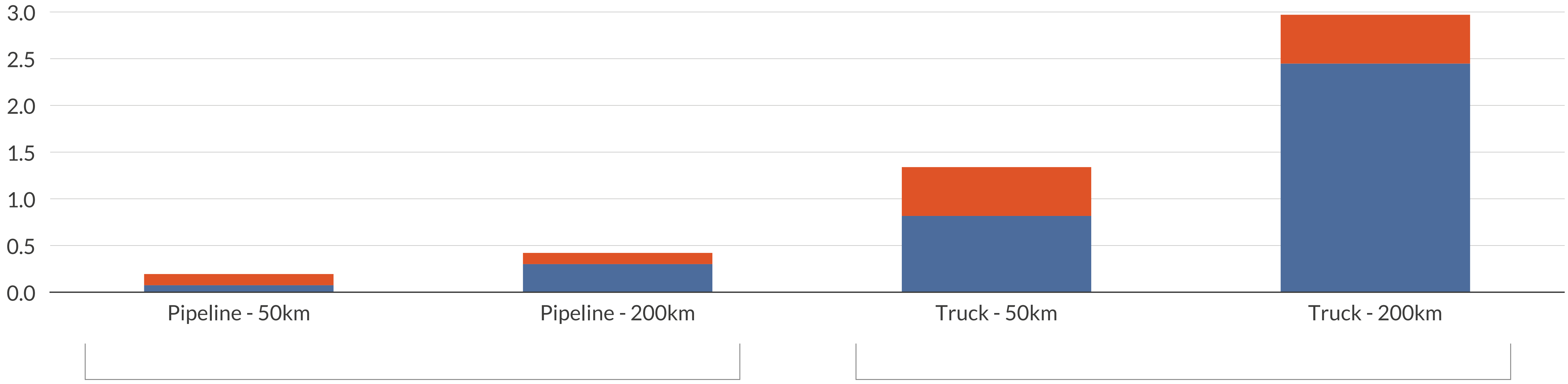
£/kg H_2



Pipelines are economical for large volumes of hydrogen transport, but for most small producers, road transport by truck will be more practical

Levelised hydrogen transport costs

£/kg



- We assume a 20” new build pipeline, with no challenging terrain en route
- Converting existing pipelines instead could save 50%-90% of the cost
- At 5,000 full-load hours per year, this would carry about 180,000 tonnes of H_2 per year, or the annual production of about 3GW of onshore wind

- For individual renewables projects, transport via truck will likely be the only viable option

Compression cost Transport cost

Source: Aurora Energy Research

The variable generation of renewables means there must be compensating flexibility elsewhere in the supply chain

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Schematic: how flexibility could be provided in the hydrogen supply chain in the long term

Producer

Consumer

Centralised storage:

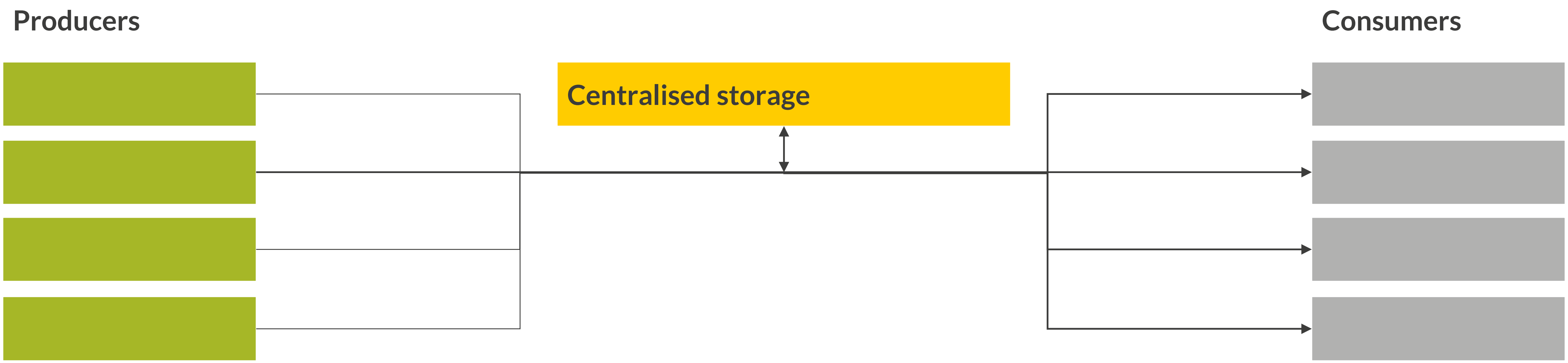
- Salt caverns
- Depleted oil and gas reservoirs

1

Centralised storage could provide lower cost flexibility at large scale

The variable generation of renewables means there must be compensating flexibility elsewhere in the supply chain

Schematic: how flexibility could be provided in the hydrogen supply chain in the long term



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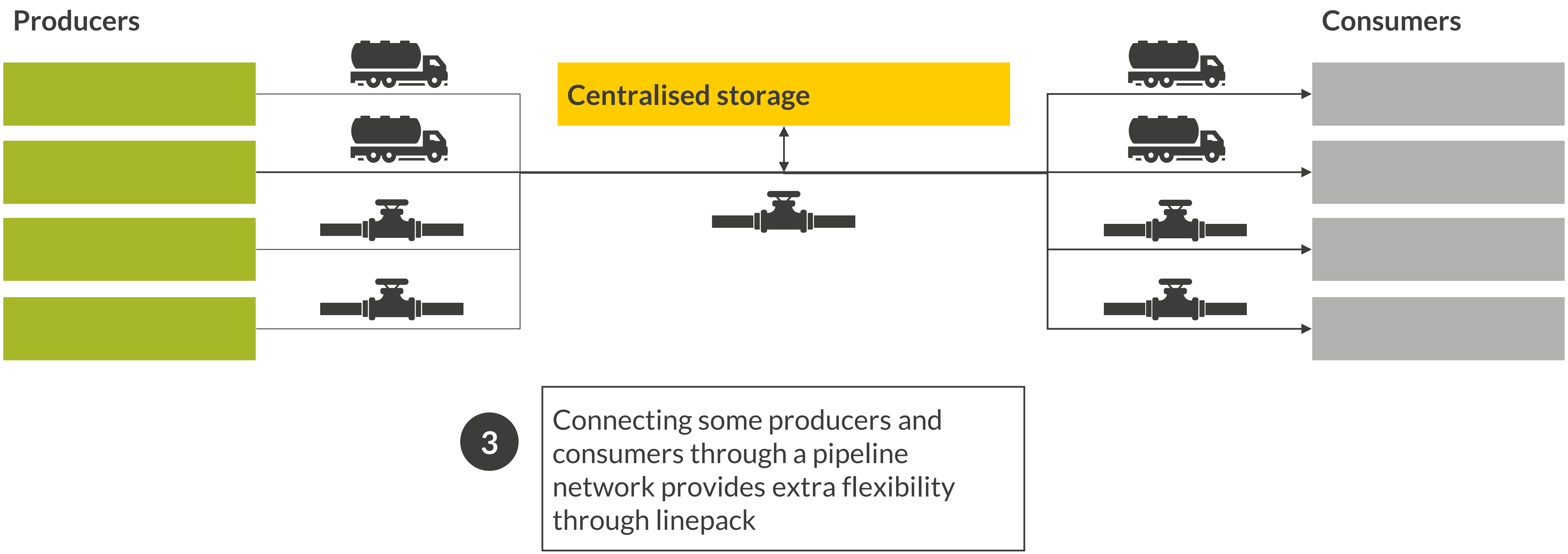
Aggregating many imperfectly correlated sources of supply and demand reduces the overall volume (and cost) of storage needed

The variable generation of renewables means there must be compensating flexibility elsewhere in the supply chain

Schematic: how flexibility could be provided in the hydrogen supply chain in the long term



We consider an example where one producer serves one consumer, with regular hydrogen deliveries by truck

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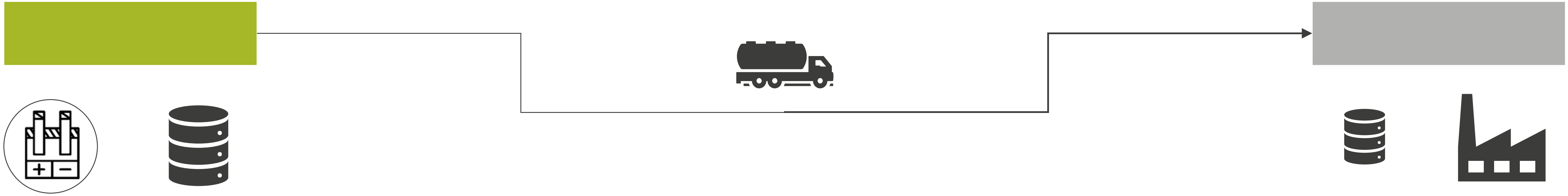
Schematic: our example for a potential near-term supply chain

Producer **Consumer**

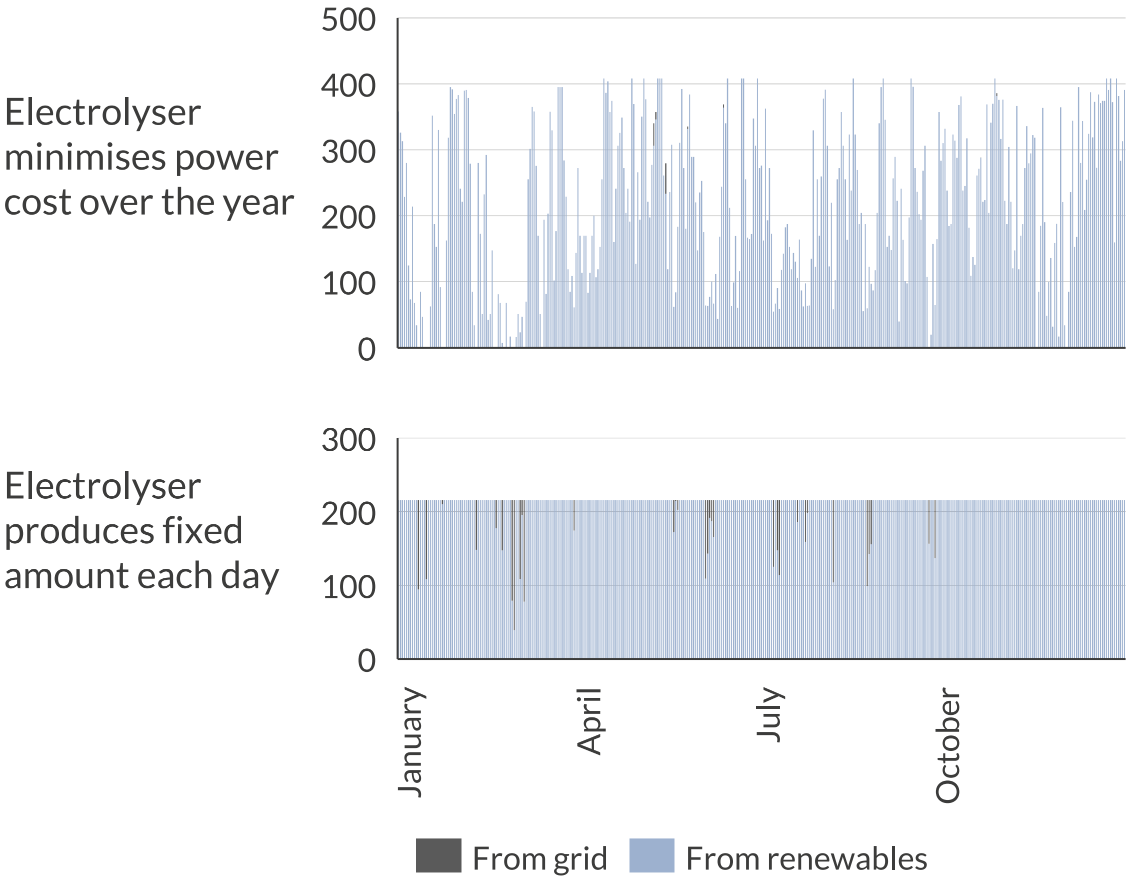


- Hydrogen produced by electrolyser (variable rate)
- Hydrogen stored in tanks on renewables site to allow for regular, fixed volume collections
- Hydrogen collected daily by tube trailer (fixed volume)
- Hydrogen stored in smaller tanks (one day's worth of consumption) on consumer site
- Hydrogen fed into industrial process (e.g. refining or chemicals manufacture) at constant rate

Constraining electrolyser operation to produce a fixed daily amount of hydrogen raises the power cost but reduces the storage cost

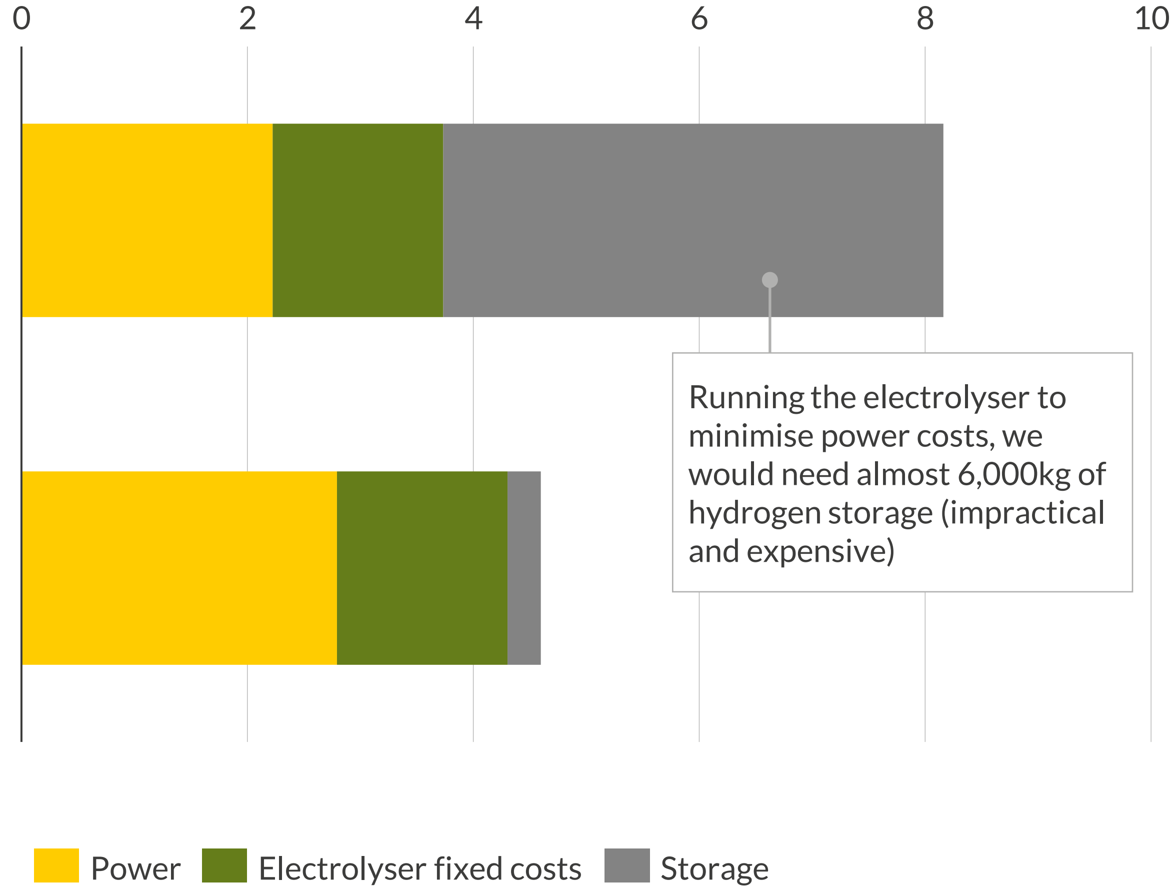
Daily hydrogen production

kg H_2



Implications for levelised costs of hydrogen

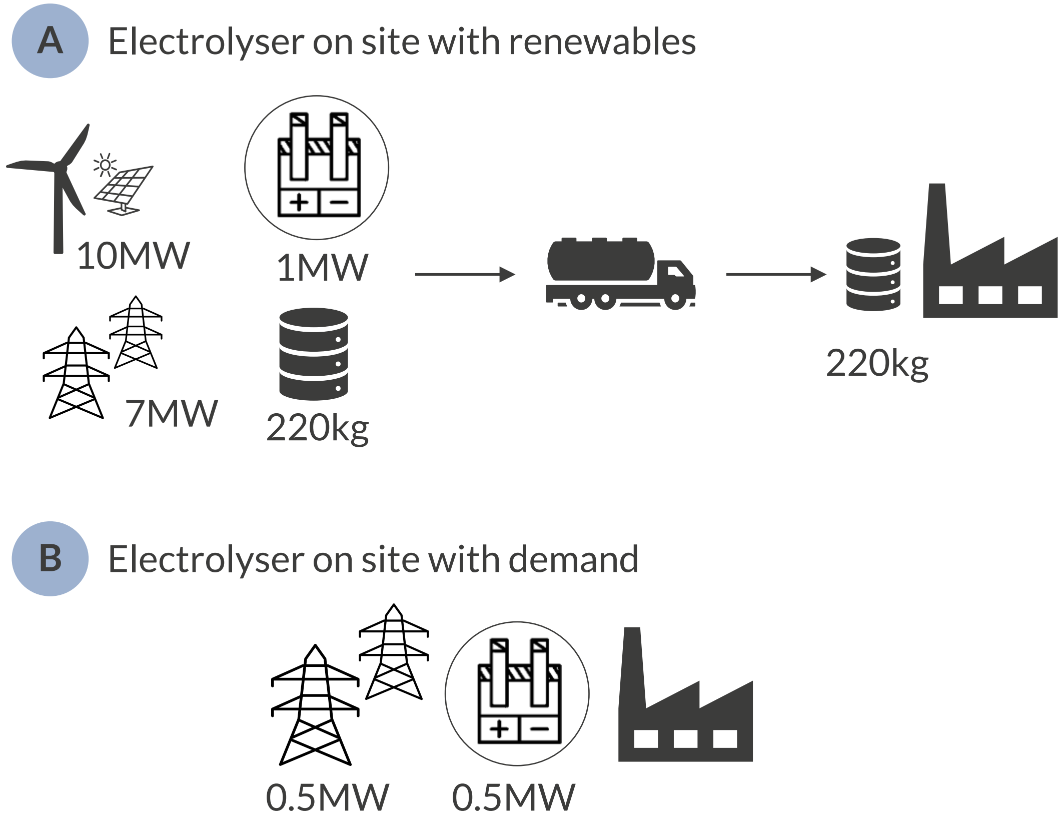
£/kg H_2



Source: Aurora Energy Research

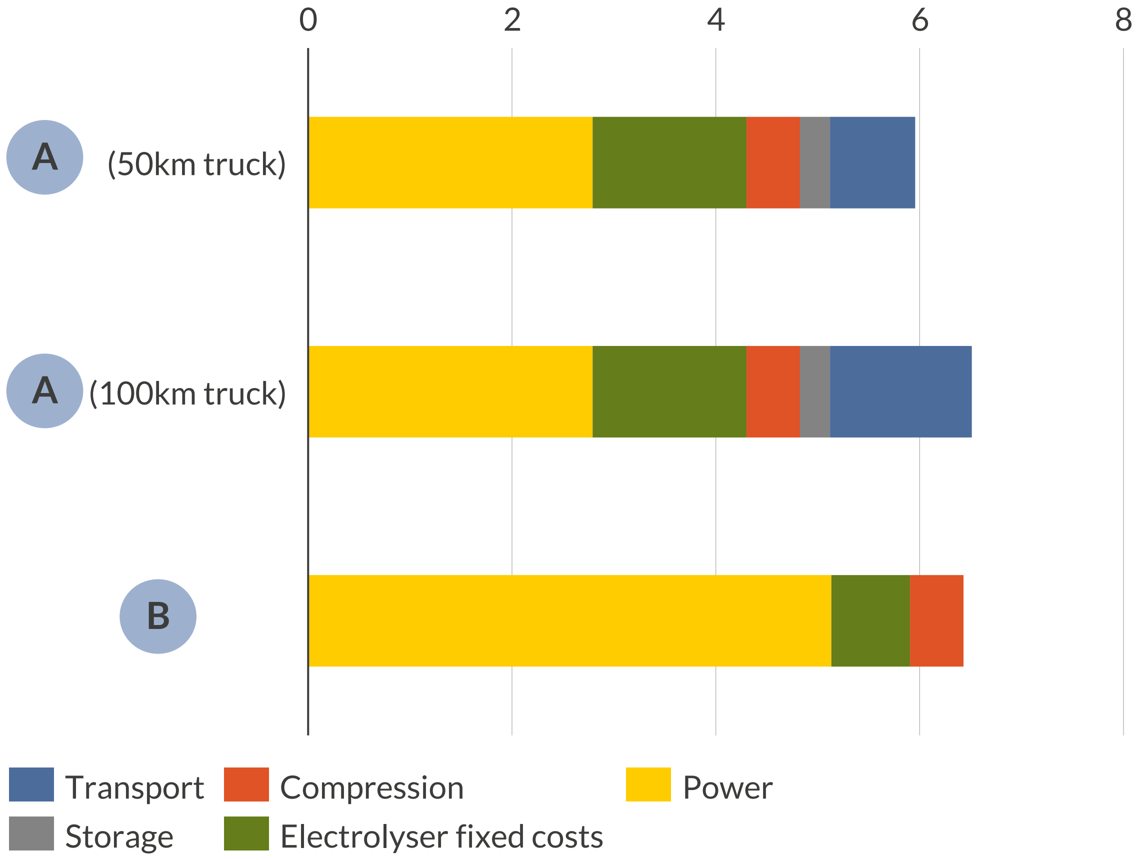
Our example project could compete against on-site grid-connected electrolysers for demand sites as far as 50km away

Electrolyser location options



Levelised cost of delivered hydrogen

Project operational in 2025, £/kg H_2



Large-scale projects to co-locate renewables with electrolysers are in development around the world, with different approaches to flexibility

Example co-located projects in development

Whitelee, Scotland

ScottishPower, ITM Power, BOC

Wind capacity today: ~540MW

Planned solar capacity: 40MW

Planned battery storage capacity: 50MW

Planned electrolyser capacity: 20MW

Planned hydrogen storage: 5,000kg

Puertollano, Spain

Iberdrola, Fertiberia

Planned solar capacity: 100MW

Planned battery storage capacity: 5MW, 20MWh

Planned electrolyser capacity: 20MW

Planned storage: 11 tanks storing 2,700kg each

Green ammonia and fertilizer production to be an integral part of the project

Hydrogen City, Texas

Green Hydrogen International

Planned solar and wind capacity: 2GW in first phase

On-site salt cavern storage, with 2 caverns (roughly 6,000kg) to be used in first phase

First phase aims to be operational in 2026

Sources: ScottishPower, Iberdrola, Green Hydrogen International

In conclusion: a flexible system of production, storage, transport and off-take is needed for an electrolyser at a renewables site to be competitive

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Success factors for an electrolyser project co-located with renewables:

- Smart sizing of electrolyser, renewables and grid connection to make best use of capacities
- Flexible electrolyser operation to capture times of low power prices
- Supply chain flexibility (e.g. storage) to accommodate variable production
- Adjustment of production patterns to balance cost of power against cost of storage
- Off-taker within economical distance

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