No-regret Hydrogen

Charting early steps for H₂ infrastructure in Europe

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Matthias Deutsch, Agora Energiewende

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Study conducted by AFRY Management Consulting
Hydrogen is a potential vector that can support massive decarbonisation. It’s really good…

…because it’s also going to rescue the oil and gas industry… right?

**AFRY Management Consulting**

- AFRY 17,500 mostly engineers and designers, headquartered in Stockholm, Sweden
  - ÅF – 1895 steam bioler & pipe association
  - Pöyry – 1958 forest industry
- AFRY Management Consulting
  - 250 consultants focussed on Energy sector
  - Advise industrial clients, energy companies, banks, regulators, governments… and Agora Energiewende
  - Strong presence in hydrogen topics advising on corporate and investment strategies, economics and regulation – sometimes involving some of our engineers
  - Our electricity model, BID3, is used by many electricity TSOs for capacity and network planning, and now also incorporates hydrogen production and consumption

**Angus Paxton, AFRY Management Consulting**

- Gas transport, storage, regulation, market design, digitalisation, biogas/biofuels, hydrogen…
- 15 years AFRY – consulting
- 10 years National Grid Gas – NTS planning
- Looking at 2050s decarbonisation in the 2020s is like looking at the 2020s from the 1990s
The project was naturally divided into three separate components studying potential demand, supply and then delivery systems that might be required.

**Demand**
- “No-regret” demand - hard to decarbonise industrial sectors
  - Steel
  - Ammonia
  - Methanol
  - Petroc./chem.
- Sector projection
- Conversion factors
- Location

**Supply**
- BLUE-GREEN / FAST-GREEN
  - Dedicated RES production
  - SMR only where CCS available
  - Technology costs – large reduction in electrolyser costs
  - Levelisation assumptions
- Range of costs – big geographical variance

**Delivery systems**
- Pipeline unit cost assumptions
- Repurposed pipelines
- New build
- Maritime NH3 / LH2
- Storage cost assumptions
  - Salt cavern
  - Above-ground
- Cheapest source and route for each demand hexagon?
  - ‘Volatile’ hydrogen to storage
  - ‘Smooth’ hydrogen to demand

Image credits include Open Street Map, Solargis, ESMAP
The modelling produced lots of routes where demand is better served by hydrogen produced elsewhere in Europe: there is clear value in establishing hydrogen delivery systems.

Large number of results

Extracting the common themes

No-regret infrastructure

- No-regret selection criteria:
  1. Infrastructure spans more than one hexagon
  2. Demand is > 3 TWh in either 2030 or 2050
  3. Demand in both 2030 & 2050 is ‘sizeable’
  4. Appear across 3 or 4 scenario/year combos
- Plus additional hexagons where close to identified clusters

Map: OSM. Interim results not included in final report.
In any given scenario, the infrastructure opportunity is greater than the no-regret infrastructure.

Many routes are identified that use repurposed gas pipelines. Assumptions on storage location are a big influence on routes.

Figure 31: Many routes are identified that use repurposed gas pipelines.

Assumptions on storage location are a big influence on routes.

Hyunder (2014); OSM.
The study assumes co-located, dedicated RES. But... if you locate electrolysers correctly you can drive additional value. You must model both power *and* hydrogen networks to value hydrogen properly.

<table>
<thead>
<tr>
<th>Electrolysers can provide valuable locational services to grid</th>
<th>Build-out of electrolysers – what’s the story?</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Image]</td>
<td>• Initial deployments 10s MW demo plant at consumers</td>
</tr>
<tr>
<td></td>
<td>• Sites/clusters 100s-1000s MW scale</td>
</tr>
<tr>
<td></td>
<td>• Some shared electrolysis and on-site storage</td>
</tr>
<tr>
<td></td>
<td>• Local hydrogen distribution pipes</td>
</tr>
<tr>
<td></td>
<td>• Electricity network constraints</td>
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<tr>
<td></td>
<td>• <em>may</em> frustrate some low-priced production hours</td>
</tr>
<tr>
<td></td>
<td>• <em>may</em> pay for demand-side services</td>
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<tr>
<td>[ENTSO-E]</td>
<td>• Then... larger clusters established: 10s-100s GW, possibly interlinked</td>
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<tr>
<td></td>
<td>• At what point can remote production, with bundled bulk storage and delivery costs, undercut the variable cost of local production?</td>
</tr>
<tr>
<td></td>
<td>• Then there could be opportunities for extra hydrogen demand en route – establishing the wider backbone</td>
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</table>
The decarbonisation challenge is hard. Getting it done is possible. Getting it done right is harder.
Conclusions drawn by Agora Energiewende
Hard-to-abate industrial sectors represent a major area of hydrogen demand in the future due to a lack of alternative decarbonization options.

Industrial hydrogen demand from 2020 to 2050 in TWh per year

- Hard-to-abate directly with renewable electricity are chemical feedstocks and reaction agents, i.e. ammonia, methanol, iron ore reduction, petrochemicals for plastics and fuels, plastics recycling
- ~300 TWh of low-carbon hydrogen will be required to reduce and eventually eliminate their process emissions.
- Assumption: H₂ demand from refineries in Europe will vanish, given the climate neutrality target.
- By 2050, ammonia and steel are the most important demand sectors.
Steel, ammonia, refineries and chemical plants are widely distributed across Europe.

AFRY (2021). 2050 demand is mainly driven by ammonia and steel production.

Industrial hydrogen demand projected for 2050 in TWh per year

- Demand differs by more than an order of magnitude:
  - < 1 TWh vs. 10-30 TWh

- High demand for hydrogen
  - in BE, NL, DE with large cluster of chemical installations and steel plants
  - in Eastern Europe
  - and along the Mediterranean.

AFRY (2021). 2050 demand is mainly driven by ammonia and steel production.
Steel producers all over Europe plan to move to direct reduced iron (DRI) steel – and so do others around the globe.

**EU steel companies' plans for Direct Reduced Iron (DRI) plants before 2030**

<table>
<thead>
<tr>
<th>Project, Site</th>
<th>Country</th>
<th>Company</th>
<th>Status Quo</th>
<th>Fuel</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYBRIT, Lulea</td>
<td>Sweden</td>
<td>SSAB</td>
<td>Started pilot operation with clean hydrogen in 2020 (TRL 4-5)</td>
<td>Green H	extsubscript{2}</td>
<td>2020: pilot plant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2026: commercial</td>
</tr>
<tr>
<td>DRI, Galati</td>
<td>Romania</td>
<td>Liberty Steel</td>
<td>MoU signed with Romanian government to build large-scale DRI plant within 3-5 years; Capacity: 2.5 Mt/DRI/year</td>
<td>Natural gas, then clean H	extsubscript{2}</td>
<td>2023-2025: commercial</td>
</tr>
<tr>
<td>tkH2Steel, Duisburg</td>
<td>Germany</td>
<td>Thyssenkrupp</td>
<td>Plan to produce 0.4 Mt green steel with green hydrogen by 2025, 3 Mt of green steel by 2030</td>
<td>Clean H	extsubscript{2}</td>
<td>2025: commercial</td>
</tr>
<tr>
<td>H-DRI Project, Hamburg</td>
<td>Germany</td>
<td>Arcelor Mittal</td>
<td>Planned construction of an H2-DRI demo plant to produce 0.1 Mt DRI/ year (TRL 6-7)</td>
<td>Grey H	extsubscript{2} initially, then clean H	extsubscript{2}</td>
<td>2023: demo plant</td>
</tr>
<tr>
<td>SALGOS, Salzgitter</td>
<td>Germany</td>
<td>Salzgitter</td>
<td>Construction of DRI pilot plant in Salzgitter</td>
<td>Likely Clean H	extsubscript{2}</td>
<td>n.a.: pilot plant</td>
</tr>
<tr>
<td>DRI, Donawitz</td>
<td>Austria</td>
<td>Voestalpine</td>
<td>Construction of pilot with capacity of 0.25 Mt DRI/a</td>
<td>Green H	extsubscript{2}</td>
<td>2021: pilot plant</td>
</tr>
<tr>
<td>DRI, Taranto</td>
<td>Italy</td>
<td>Arcelor Mittal</td>
<td>Plans to build DRI plant, ongoing negotiations with Italian government</td>
<td>n.a.</td>
<td>n.a.</td>
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<tr>
<td>IGAR DRI/BF, Dunkerque</td>
<td>Italy</td>
<td>Arcelor Mittal</td>
<td>Plans to start hybrid DRI/BF plant and scale up as H	extsubscript{2} becomes available</td>
<td>Natural gas then Clean H	extsubscript{2}</td>
<td>2020s</td>
</tr>
</tbody>
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→ Those plans support the assumed strong **growth** in demand for low-carbon hydrogen by 2050 in the steel sector.

→ Recent announcements from **China and Korea** to pursue the DRI route.
40% of today’s industrial natural gas use in the EU goes to heat below 100°C and can be supplied with electric heat pumps – with performance factors exceeding 100%.

FFE (2020). See the publication for distribution by EU member state.

Agora Energiewende (2021)
Even for higher temperatures, a range of power-to-heat options can be more energy-efficient than hydrogen and should be considered first.

### Performance factors of power-to-heat technologies vs. heat from burning hydrogen derived from electrolysis

<table>
<thead>
<tr>
<th>[kWh heat output per kWh electricity input]</th>
<th>High temperature heat (&gt;1,000°C)</th>
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<tbody>
<tr>
<td>Resistance furnace</td>
<td>Electric</td>
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<tr>
<td>Infrared heater</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Induction furnace</td>
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<tr>
<td>Electric arc furnace</td>
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<tr>
<td>Plasma heating</td>
<td></td>
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<tr>
<td>Microwave &amp; radio heaters</td>
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<tr>
<td>Hydrogen burner (high temp electrolysis)</td>
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<tr>
<td>Hydrogen burner (low temp electrolysis)</td>
<td></td>
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<tr>
<td>Hydrogen burner (gas reformer)</td>
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</table>

Note: Values refer to lower heating value. Hydrogen burner efficiency of 90%. Efficiencies do not consider midstream losses. Hydrogen produced by gas reforming has gas as its energy input.


- Available power-to-heat technologies can **cover all temperature levels needed** in industrial production.
- Example: electric arc furnace in steel production: **3500°C**
- Appear to offer **additional benefits** such as more flexibility than conventional convection heating technologies.
European and neighbouring countries have a high renewable energy potential that can be tapped for direct-electric applications and renewable hydrogen production.

Solar and wind potential in Europe and the MENA region

**Renewable energy sources:**
- Central-North Europe: Wind
- South Europe: Solar PV
- Parts of MENA: hybrid solar and wind

**Two scenarios** in this study:
- BLUE-GREEN: renewable H₂ and H₂ from SMRCCS in NL, NO, UK
- FAST GREEN: no SMRCCS; assumes aggressive reduction in electrolyser costs, in line with targets set by the EU hydrogen strategy.
The investment window for fossil-based hydrogen with carbon capture remains open, but in the long run renewable hydrogen will emerge as the most competitive option in Europe.

Taking into account asset lifecycles and political commitments in the BLUE-GREEN scenario, fossil-based hydrogen with carbon capture will remain a viable investment until the 2030s.

However, strong policies for renewable hydrogen will shorten the investment window for fossil hydrogen, likely closing it by the end of the 2020s.

Ambitious policy will be needed to drive down the cost of renewable hydrogen.

Best levelised costs of hydrogen in the two scenarios for 2030

AFRY (2021)
We identify four robust no-regret corridors for early hydrogen pipelines based on industrial demand in Central-West Europe, East Europe, in Spain and in South-East Europe.

Based solely on the assumptions considered in this analysis, there is no justification for creating a larger, pan-European H₂ backbone.

Adding potential hydrogen demand from power, aviation and shipping sectors is likely to strengthen the case for a more expansive network of H₂ pipelines.

Even under the most optimistic scenarios any future H₂ network will be smaller than the current natural gas network.

A no-regret vision for H₂ infrastructure reduces the risk of oversizing by focussing on inescapable demand, robust green hydrogen corridors and storage.

AFRY (2021) Only those hydrogen pipelines that are resilient to the future levels of hydrogen demand and the technology assumptions used here have been considered to be “no-regret”.
### Key conclusions

| 1 | Hard-to-abate industrial sectors represent a major area of hydrogen demand in the future due to a lack of alternative decarbonization options. |
| 2 | The investment window for fossil-based hydrogen with carbon capture remains open, but in the long run renewable hydrogen will emerge as the most competitive option across Europe. |
| 3 | We identify robust no-regret corridors for early hydrogen pipelines based on industrial demand. |
Thank you for your attention!

Questions or Comments? Feel free to contact us:

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Agora Energiewende is a joint initiative of the Mercator Foundation and the European Climate Foundation.
### Publications on hydrogen and industry

<table>
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<th>No-regret hydrogen: Charting early steps for H₂ infrastructure in Europe</th>
<th>Breakthrough Strategies for Climate-Neutral Industry in Europe</th>
<th>A Clean Industry Package for the EU</th>
<th>Building sector Efficiency: A crucial Component of the Energy Transition</th>
<th>The Future Cost of Electricity-Based Synthetic Fuels</th>
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<td>&gt; full study</td>
<td>&gt; summary</td>
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> PtG/PtL calculator