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No-regret #hydrogen:
Charting early steps for H■ infrastructure in Europe.

■Summary of conclusions of a new study by @AgoraEW @AFRY_global @Ma_Deutsch @gnievchenko (1/17)
https://t.co/YA50FA57Em

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.** Steel, ammonia, refineries and chemical plants are widely distributed across Europe. To reduce and eventually eliminate their process emissions, 300 TWh of low-carbon hydrogen are required. This number does not factor in the production of high-temperature heat, for which direct electrification should be considered first.

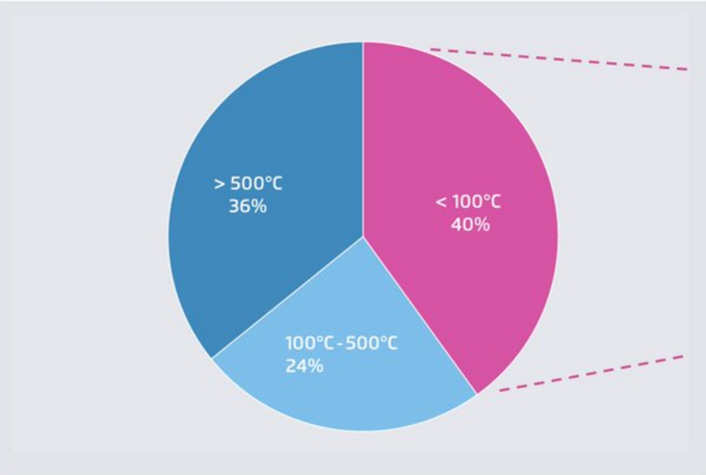
2. **The investment window for fossil-based hydrogen with carbon capture remains open, but in the long run renewable hydrogen will emerge as the most competitive option across Europe.** Given the current asset lifecycle and political commitments, fossil-based hydrogen with carbon capture will remain a viable investment until the 2030s, but strong policies for renewable hydrogen will shorten the investment window for fossil hydrogen, likely closing it by the end of the 2020s.

3. **We identify robust no-regret corridors for early hydrogen pipelines based on industrial demand.** Adding potential hydrogen demand from power, aviation and shipping sectors is likely to strengthen the case for an even more expansive network of hydrogen pipelines. However, even under the most optimistic scenarios, any future hydrogen network will be smaller than the current natural gas network. A no-regret vision for hydrogen infrastructure needs to reduce the risk of oversizing by focusing on indispensable demand, robust green hydrogen corridors and storage.

The idea behind this study is that future hydrogen demand is highly uncertain and we don't want to spend tens of billions of euros to repurpose a network which won't be needed. For instance, hydrogen in ground transport is a hotly debated topic https://t.co/RlnqDYVzpr (2/17)

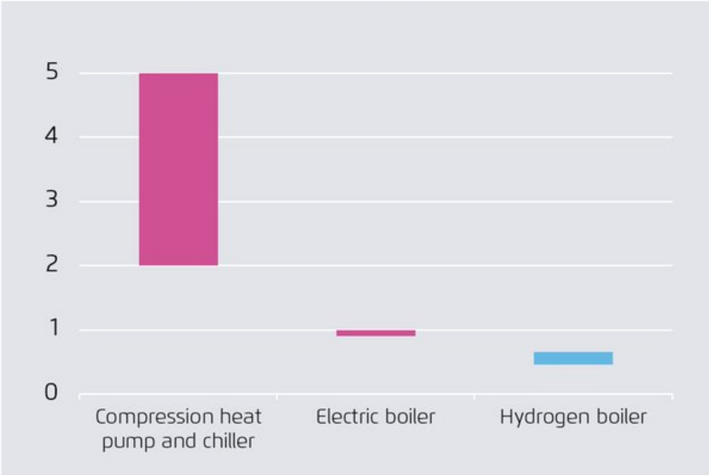
Similar things can be said about heat. 40% of today's industrial natural gas use in the EU goes to heat below 100°C and therefore is within range of electric heat pumps – whose performance factors far exceed 100%. (3/17)

Natural gas final energy consumption 2017 in the EU industry sector



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

kWh heat output per kWh electricity input

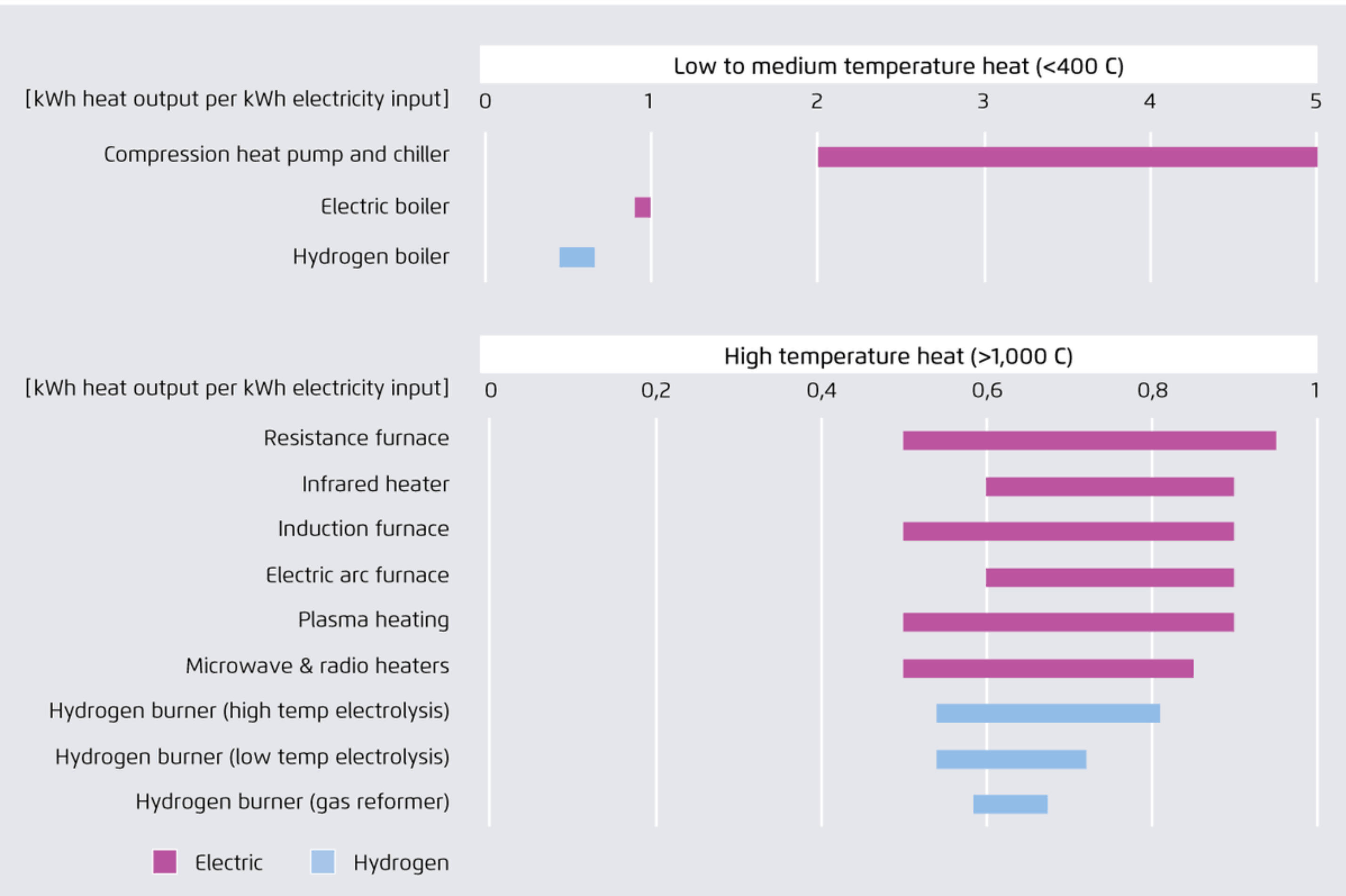


Agora Energiewende (2021)

Even for higher temperatures, a range of power-to-heat (PtH) options can be more energy-efficient than hydrogen and should be considered first. Available PtH technologies can cover all temperature levels needed in industrial production (e.g. electric arc furnace: 3500°C). (4/17)

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

Figure 4



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.
Madeddu et al. (2020), IEA (2019), Lowe et al (2011).

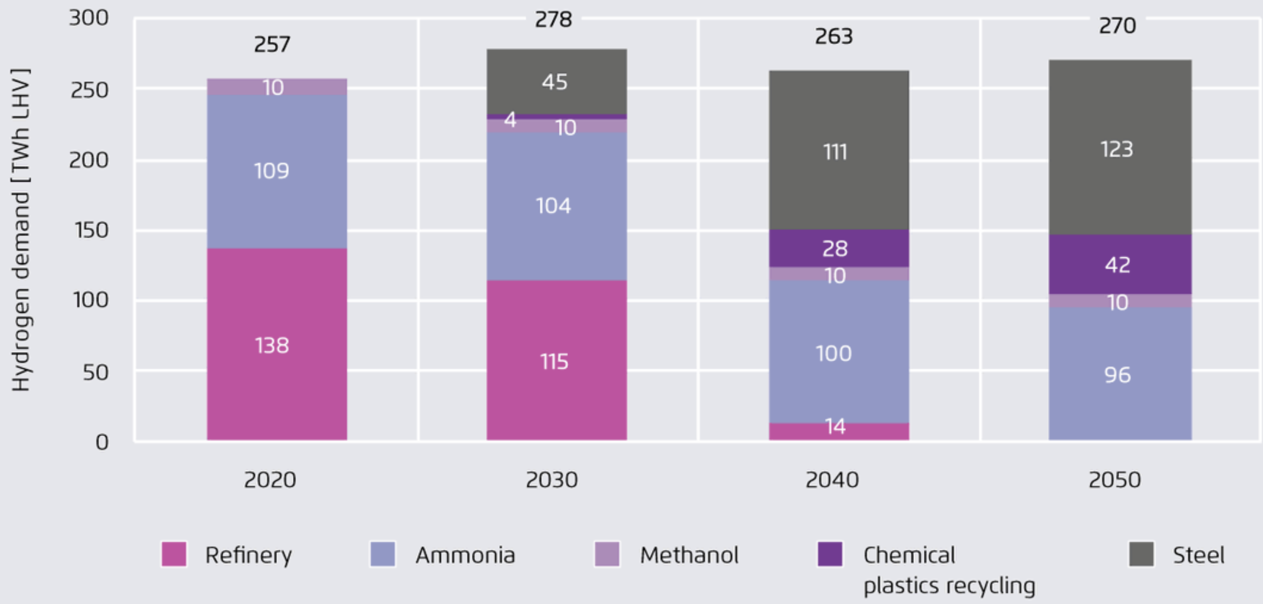
In our view, hydrogen use for feedstock and chemical reactions is the only inescapable source of industrial hydrogen demand in Europe that does not lend itself to electrification. Examples include ammonia, steel, and petrochemical industries. (5/17)

We see strong demand for hydrogen from steel in particular as producers all over Europe ([redacted]) plan to move to direct reduced iron (DRI) processes – and so do others around the globe, as recent announcements from China and Korea have shown. (6/17)

Project, Site	Country	Company	Status Quo	Fuel	Timeline
HYBRIT, Lulea		SSAB	Started pilot operation with clean hydrogen in 2020 (TRL 4-5)	Green H_2	2020: pilot plant 2026: commercia
DRI, Galati		Liberty Steel	MoU signed with Romanian government to build large-scale DRI plant within 3-5 years Capacity: 2.5 Mt/DRI/year	Natural gas, then clean H_2	2023-2025: commercial
tkH2Steel, Duisburg		Thyssen-krupp	Plan to produce 0.4 Mt green steel with green hydrogen by 2025, 3 Mt of green steel by 2030	Clean H_2	2025: commercial
H-DRI-Project, Hamburg		Arcelor Mittal	Planned construction of an H2-DRI demo plant to produce 0.1 Mt DRI/year (TRL 6-7)	Grey H_2 initially, then green H_2	2023: demo plant
SALCOS, Salzgitter		Salzgitter	Construction of DRI pilot plant in Salzgitter	Likely Clean H_2	n.a.: pilot plant
DRI, Donawitz		Voest-alpine	Construction of pilot with capacity of 0.25 Mt DRI/a	Green H_2	2021: pilot plant
DRI, Taranto		Arcelor Mittal	Plans to build DRI plant, ongoing negatiations with Italian government	n.a.	n.a.
IGAR DRI/BF, Dunkerque		Arcelor Mittal	Plans to start hybrid DRI/BF plant and scale up as H_2 becomes available	Natural gas then Clean H_2	2020s

Given the 2050 climate neutrality target, we see the demand from refineries vanish, to be replaced with demand from steel. Overall, by 2050 we expect that almost 300 TWh of low-carbon hydrogen will be required. Remarkably, that is similar to hydrogen demand in 2020. (7/17)

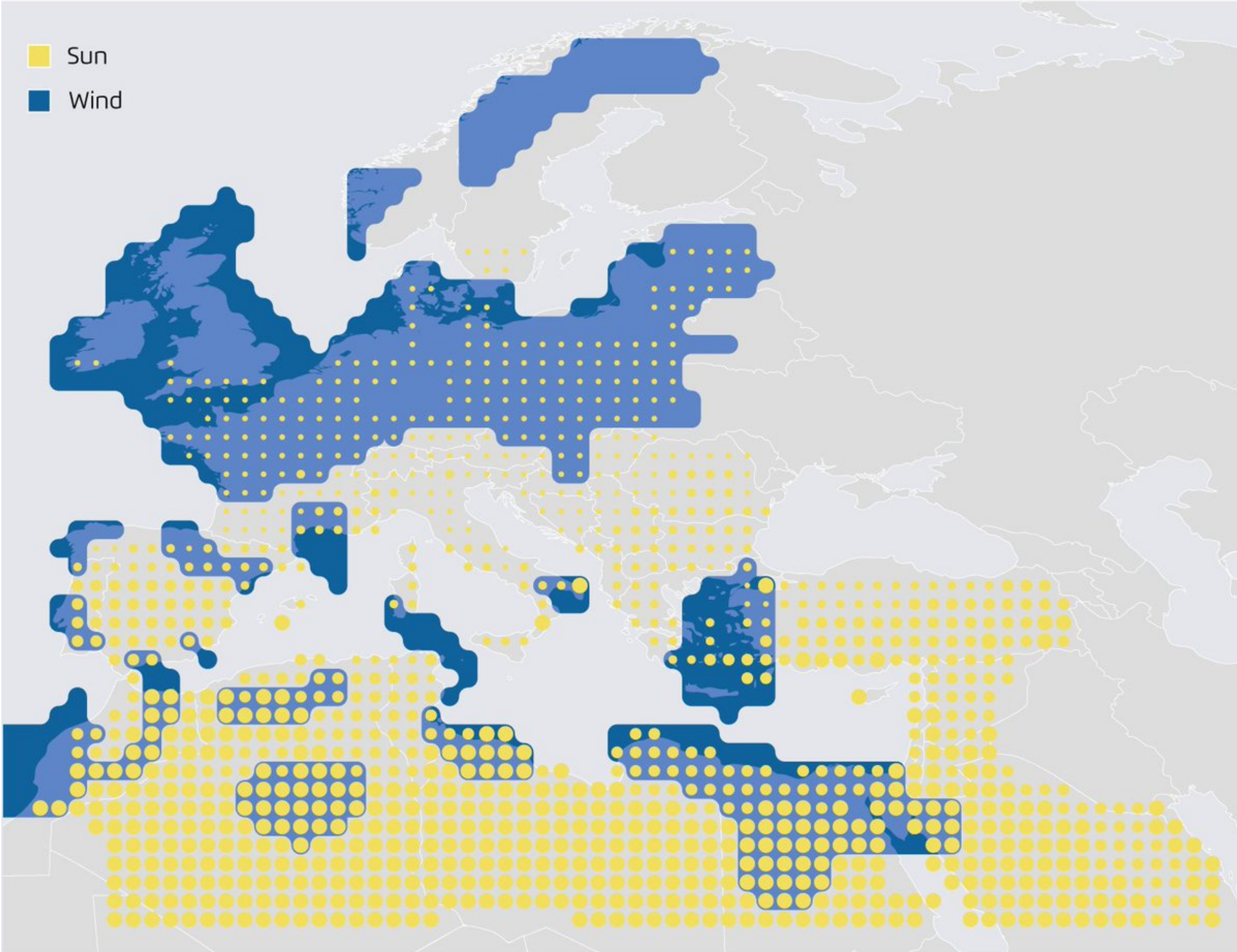
Industrial hydrogen demand from 2020 to 2050 within the specific demand sectors in TWh per year — Figure 1



AFRY (2021).

Having established inescapable demand, we can start thinking about matching supply. European and neighbouring countries have a high renewable energy potential that can be tapped for direct-electric applications and renewable hydrogen production. (8/17)

Solar and wind potential in Europe and the MENA region Figure 5

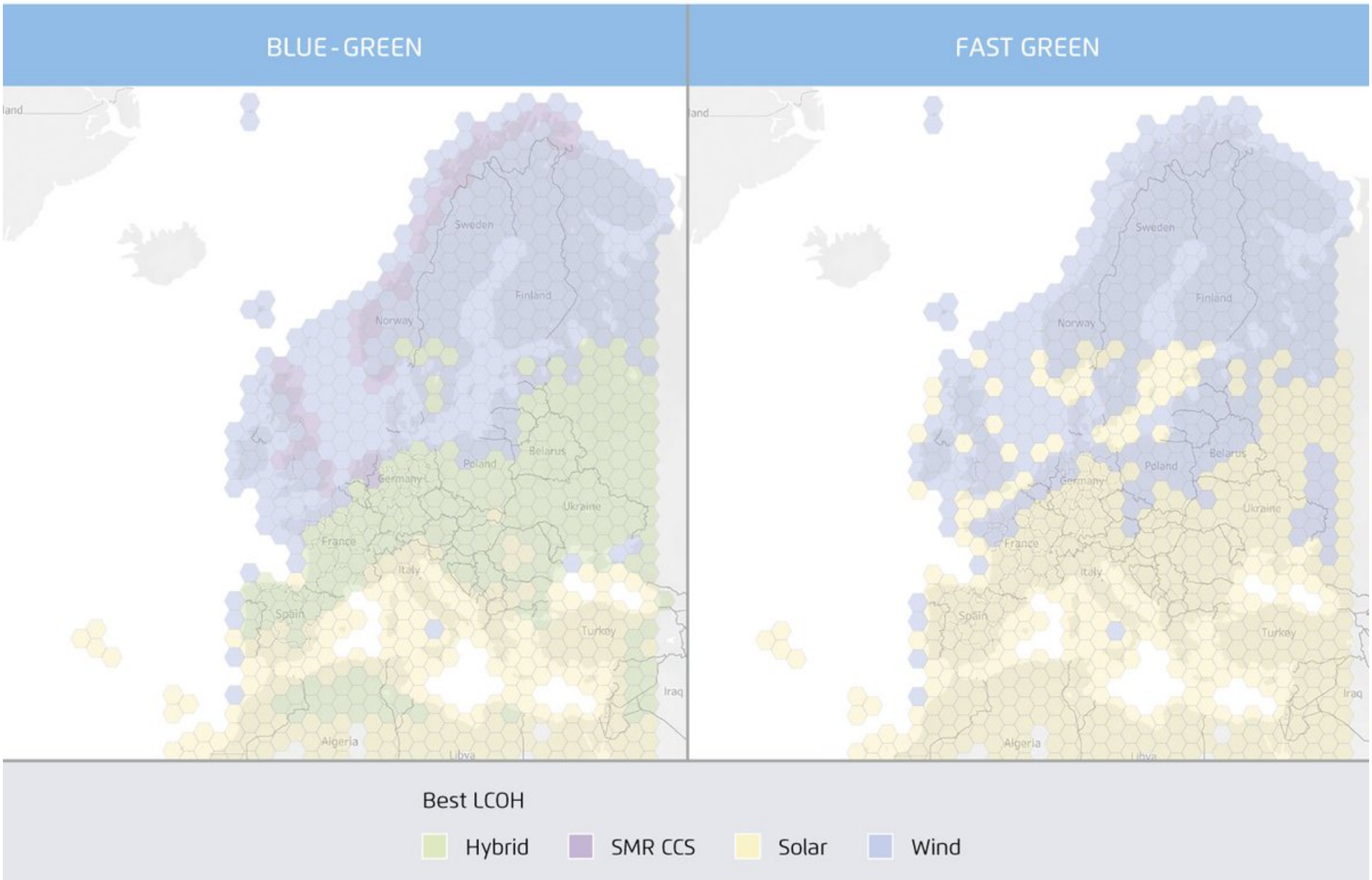


Dii & Fraunhofer-ISI (2012).

In our analysis, we consider two scenarios with renewable hydrogen production: The BLUE-GREEN scenario also includes SMRCCS as an option in [redacted] because those countries are actively developing the technology. (9/17)

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, … (10/17)

Best levelised costs of hydrogen in the BLUE-GREEN and FAST GREEN scenarios for 2030 Figure 6



AFRY (2021). Hybrids use both solar PV and wind. In the BLUE-GREEN scenario, SMR CCS is restricted to the Netherlands, the UK and Norway.

… strong policies for renewable hydrogen will shorten the investment window for fossil hydrogen, likely closing it before the end of the 2020s as is the outcome of the FAST GREEN scenario which is in line with EU Hydrogen strategy electrolyser targets. (11/17)

But producing the required quantities of H2, especially with renewables, is only one piece of the puzzle. Geography adds to the challenge: steel, ammonia, refineries and chemical plants are widely distributed across Europe. Their demand can vary by an order of magnitude. (12/17)

Distribution of industrial hydrogen demand projected for 2050 in TWh per year

Figure 2

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

Ensuring reliable supply means accounting for various weather and seasonal effects. In our analysis, we model salt caverns to take care of the variation in renewables to produce “flat hydrogen”. That led us to derive least-cost pipeline corridors for hydrogen transport. (13/17)

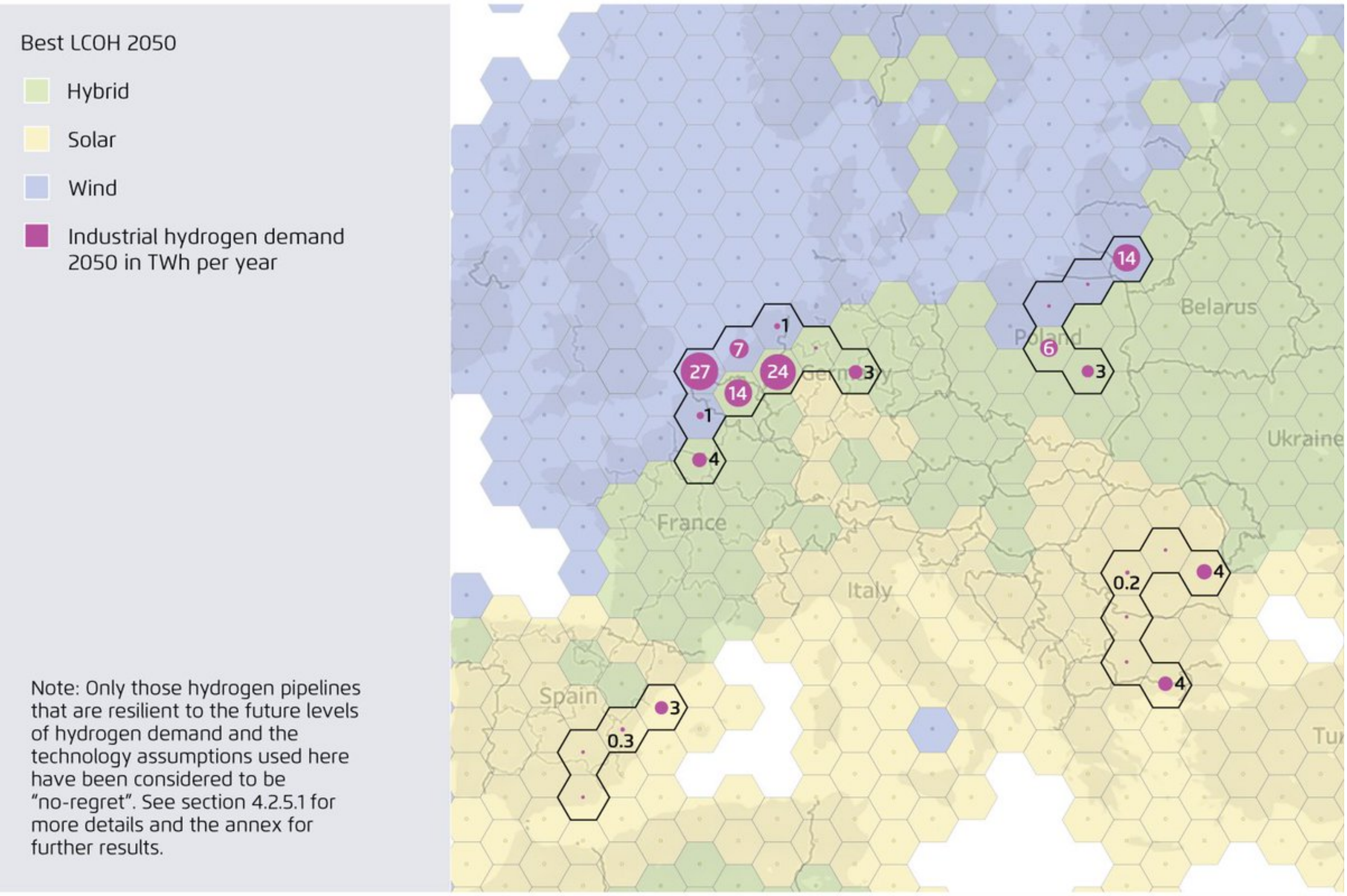
Salt strata in Europe

Figure 13

AFRY after HYUNDER (2014)

Consequently, we identify 4 robust no-regret corridors for early hydrogen pipelines and storage based on industrial demand in different parts of Europe. The demand identified is unlikely to justify a large, pan-European H2 backbone. (14/17)

No-regret pipeline corridors with industrial hydrogen demand in TWh per year in 2050 Figure 7



AFRY (2021).

We do note, however, that our assumptions are limited to inescapable demand from industry. Adding potential hydrogen demand from power, aviation and shipping sectors is likely to strengthen the case for a more expansive network of H2 pipelines. (15/17)

Nonetheless, even under most optimistic scenarios any future H2 network will be smaller than the current natgas network. A no-regret vision for H2 infrastructure reduces the risk of oversizing by focusing on inescapable demand, robust green hydrogen corridors and storage. (16/17)

You can access the underlying maps and data here: (17/17)

https://t.co/5W7hyqGOIg

Categorised Demand | Demand Hexamodel | Levelised Costs BlueGreen Sce... | Levelised Costs FastGreen Sce... | Delivery Systems | Clear No-Regret Routes

Delivery Systems

Blue Green Scenario 2030	Blue Green Scenario 2050	Blue Green Scenario levelised costs of smooth hydrogen 2050	Fast Green Scenario 2030	Fast Green Scenario 2050	Fast Green Scenario levelised costs of smooth hydrogen 2050