Artelys | OPTIMIZATION SOLUTIONS

FONDATION TUCK
The Future of Energy

Fondation Tuck

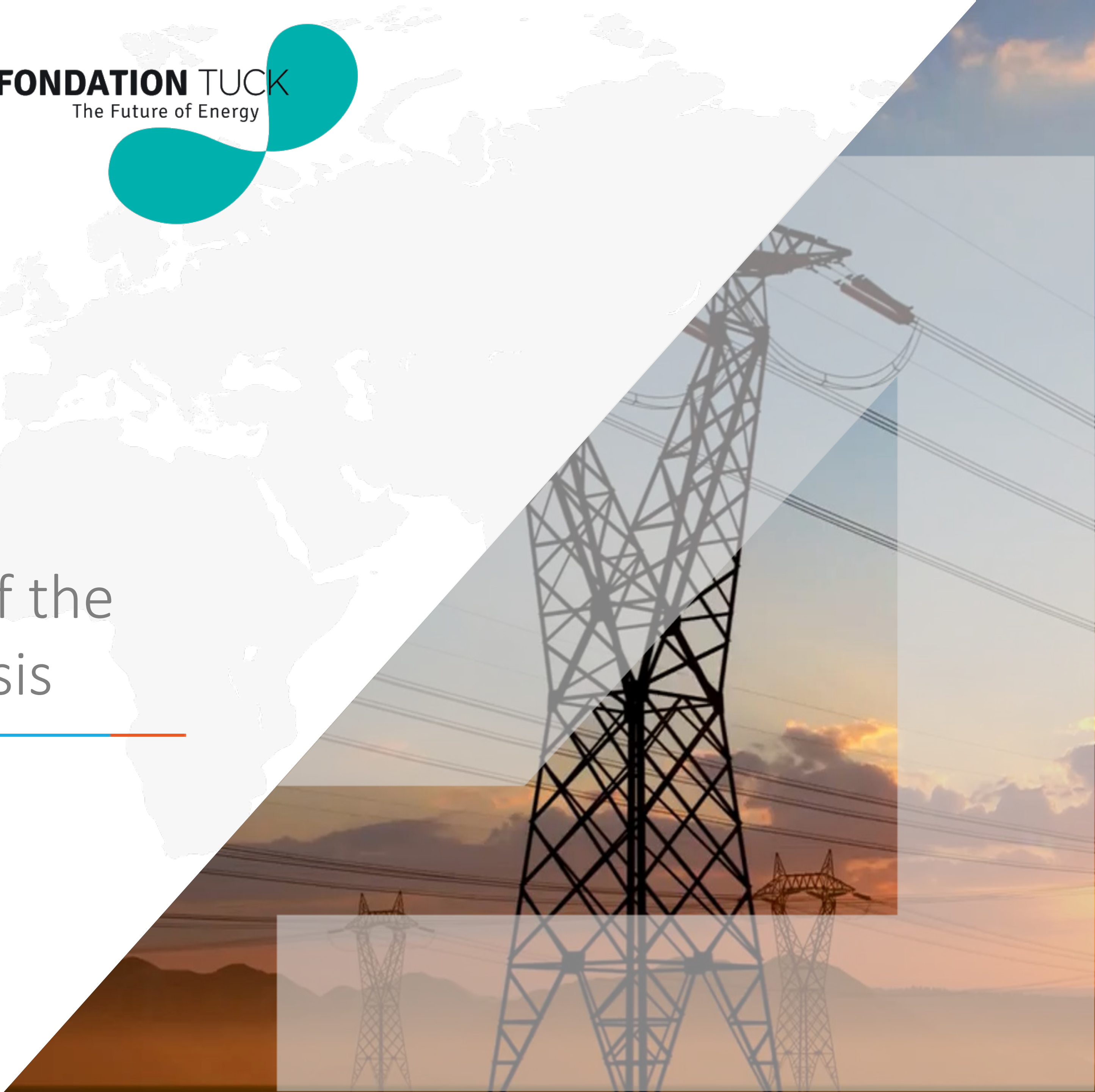
Hydrogen – Energy carrier of the future? Holistic SWOT analysis

Final event

Presentation by Christopher Andrey and Amaury Salauze

Online meeting 09/12/2021

www.artelys.com



Artelys – An overview

- Artelys is an **independent** software edition and consulting company specialised in decision support, modelling and optimisation
- Founded in **2000** by its current President, Arnaud Renaud
- More than **300 customers** in **40 countries**
- Around **100 members of staff** in Paris, Brussels, Montréal, Los Angeles and Chicago
- Artelys is active in **multiple areas**: energy, resource planning, logistics, transport and mobility

Our solutions for the energy sector

Consulting services

From a few days of expertise to large-scale consulting projects

Strategy

- Energy transition scenarios
- Cost-benefit-risk analysis of projects
- Impact assessment of policy measures
- Electricity price projections
- Development of methodologies

Operations

- Day-to-day optimisation of use of assets
- Contract valuation

Simulation tools / IT tools

Artelys Crystal software suite

✓ Distribution networks
✓ Management optimisation
✓ Urban energy systems
✓ Large interconnected systems

Tailor-made developments

✓ Power flow simulators
✓ Market clearing engines
✓ Reserve selection tools
✓ Reserve dimensioning

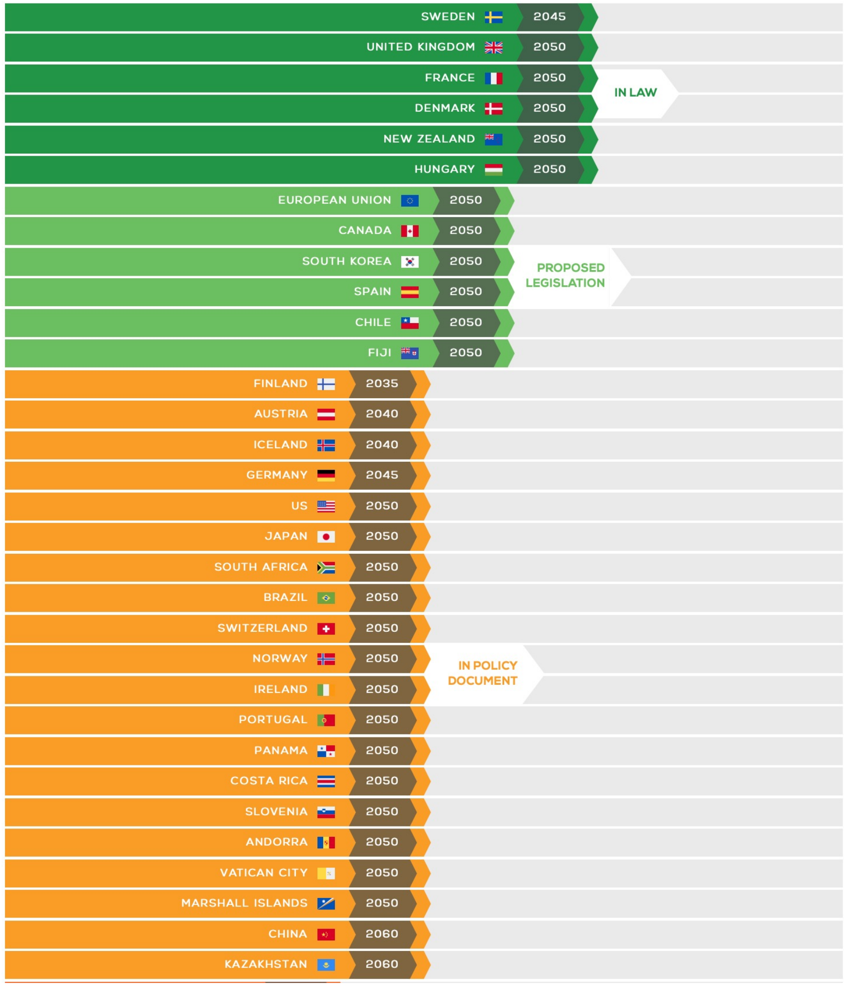
Agenda

1. Context and methodology
2. SWOT analysis – System point of view
3. SWOT analysis – Producer point of view
4. SWOT analysis – Consumer point of view
5. Reconciliation and conclusions

Context – Decarbonisation as an opportunity

- **Deep decarbonisation objectives** are being considered/announced in an increasing number of countries
  - European Union: -55% at the 2030 horizon (w.r.t. 1990 levels) and net zero in 2050
  - United States: -50 to 52% by 2030 (w.r.t. 2005 levels) and net zero by 2050
  - China: net zero by 2060
  - Germany: net zero by 2045
  - France: net zero by 2050

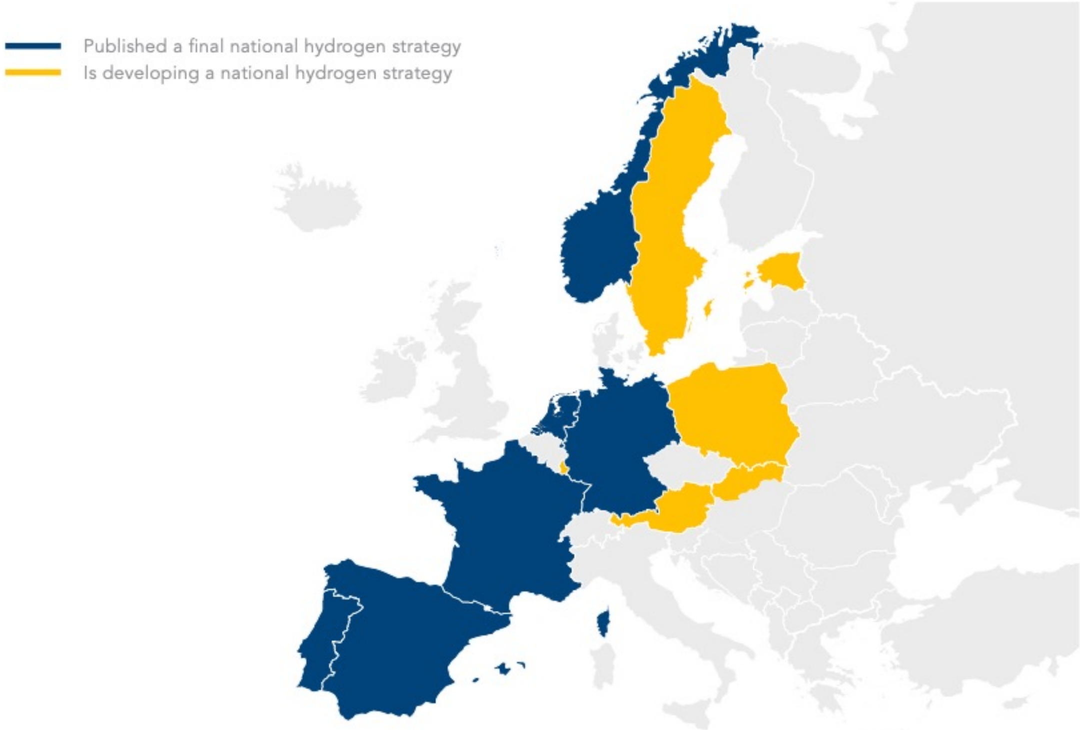
- **Hydrogen** is at the core of many deep decarbonisation strategies
  - Whilst it is generally recognised that **energy efficiency** efforts and the development of **renewables** can do most of the heavy lifting, a number of end-uses cannot be decarbonised via a direct electrification route.
  - Hydrogen is one of the options to decarbonise these hard-to-abate sectors. However, different stakeholders have **different views on the scope of the role of hydrogen**, based on:
    - Economic assessment of the trade-off between direct and indirect electrification routes
    - Origin of hydrogen (electrolysis, pyrolysis, SMR + CCS, etc.)
    - Role of alternatives (biomethane, CCS, etc.)
    - Role of the gas infrastructure
  - In Europe, the **European Green Deal**, announced in late 2019, sets challenging objectives for the decarbonisation of the economy of the EU, and foresees an important role for hydrogen, especially in hard-to-abate sectors, but not only.



Context – Hydrogen strategies

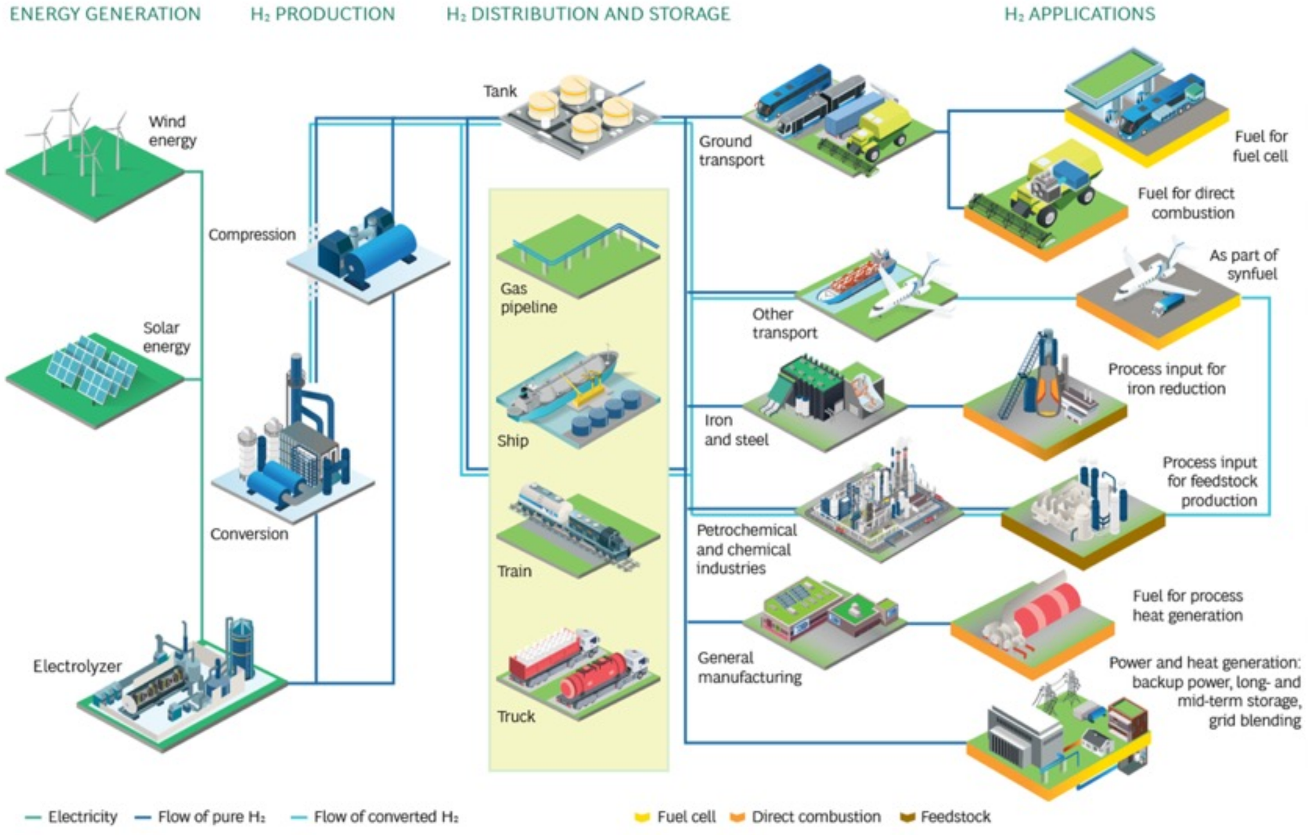
- Multiple **policy initiatives** are being taken in order to ensure the hydrogen value chains scale up and can play their role in the decarbonisation of the economy
  - The European "**Hydrogen Strategy**" proposes targets for the development of renewable hydrogen
    - 6 GW_e electrolysers by 2024 (1 MtH2 of renewable H2)
    - 40 GW_e electrolysers by 2030 (10 MtH2 of renewable H2)
  - Numerous European **countries** have announced their own objectives for the development of electrolysis (far beyond what is announced in their NECPs)
    - 6.5 GW in France by 2030
    - 10 GW in Germany, 3 to 4 GW in the Netherlands, 2 to 2.5 GW in Portugal, 4 GW in Spain, 150 MW in Belgium (2026), 1 GW in Czech Republic, 240 MW in Hungary, 5 GW in Italy, 2 GW in Poland
  - Several **regions** in France and in other countries are developing hydrogen visions.
- On the other hand, the deployment of electrolysers is subject to **rules and regulations** to mitigate the adverse impacts of uncoordinated developments
  - The revision of RED II and the potential extension of the RFNBO requirement (additionality) to all sectors (not only transport)
  - The **delegated act** related to the **additionality** principle
  - The EU **taxonomy**, requiring that emissions from electrolysis shall not exceed 3 kgCO2/kgH2 (i.e. circa 60 gCO2 per kWh_e)
  - The **revision of the TEN-E Regulation** and the upcoming Guidelines on Cost-Benefit Analysis of hydrogen and electrolyser projects (and the eligibility criteria for categories (3) and (4) related to sustainability for inclusion into PCI or PMI Union lists)

State of publication of National Hydrogen Strategies in EU/EEA Member States



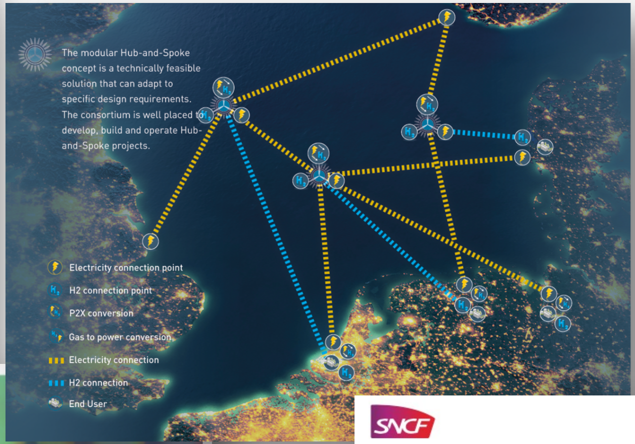
Context – Projects are emerging in all areas

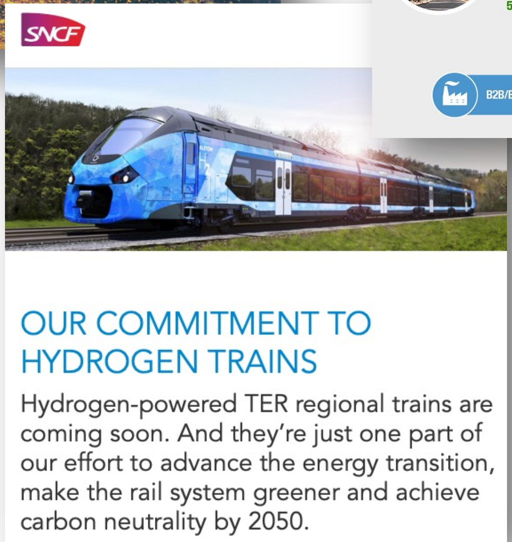
- The development of hydrogen is foreseen to have potentially deep impacts on many sectors
  - The **hydrogen ecosystem** includes a large number of components and end-uses, some being in competition with direct electrification, others with the use gases from other origins (e.g. biomethane, natural gas + CCS)
    - Industry (ammonia, steel and iron,…)
    - Residential and tertiary sector (fuel cell CHP)
    - Power sector (power to gas / gas to power, storage)
    - Hydrogen production (electrolysis competing with SMR, ATR, pyrolysis, etc.)
    - Gas infrastructure (blending, repurposing and refurbishment of pipes and storages, new investments,…)
    - Mobility (H2-vehicules, fuels for maritime and aviation)
  - Today we see **pilot projects emerge in all components of the ecosystem**, tackling complex issues such as
    - Regulation (taxes, sustainability assessment of electrolysis,…)
    - Finance (capital available for pilot projects, what about the massive investments needed to decarbonise the entire economy?)
    - Public acceptance, attractiveness of options
    - Economic aspects (learning rates, subsidies,…)

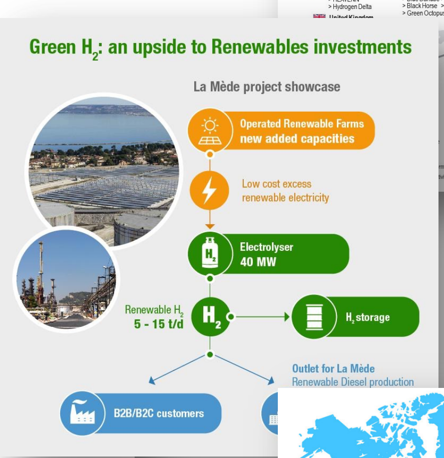


Source: BCG analysis

Context – Projects are emerging.. in a fragmented way







Hydrogen Import Coalition

Key objective of this study

- Analyse the **potential role** of hydrogen, together with its **strengths** and **weaknesses**
- Assess the risks through a discussion of **opportunities** and **threats**
- Understand whether what is desirable from a global socio-economic welfare point of view is **aligned** with what producers and consumers find desirable

Strengths Characteristics of a business which give it advantages over its competitors	**Weaknesses** Characteristics of a business which make it disadvantageous relative to competitors
Opportunities Elements in a company's external environment that allow it to formulate and implement strategies to increase profitability	**Threats** Elements in the external environment that could endanger the integrity and profitability of the business

Helicopter view of the starting point of the analysis

Reaching **deep decarbonisation** levels offers a role to hydrogen
+
Strategies are being developed at all levels (EU, country, regions)
+
Projects are emerging in all parts of the **hydrogen ecosystem** in a fragmented way

Is this *uncoordinated* development of the hydrogen ecosystem a risk to the transition or can it be an asset?

Our methodology in a nutshell

The study is based on two work streams:

- A **literature review** of circa **25 recent publications** that deal with one or several aspects mentioned in the introductory slides
- **Interviews** of around **10+ key exper**ts. While they have participated in shaping some of the arguments presented today, the views expressed herein are those of the authors only.

In order to structure our assessment, we have decided to look at the relevant aspects under **three different perspectives**, each of them having their own SWOT dimensions:

- **SYSTEM-LEVEL** (including economics, sustainability, externalities, value chain, etc.)
- **PROJECT DEVELOPERS** (from infrastructure to manufacturers of appliances via electrolysis)
- **CONSUMERS** (from industry to domestic sector via mobility)

Name	Company / Institution
Maxime Sagot	Afhypac
David Le Noc	ATEE
Pierre-Laurent Lucille	ENGIE
Guillaume Fournel	CRE
Carole Le Henaff	GIE/Storengy
Cédric Philibert	IFRI
Sylvain le Net	France Chimie
Paul Lucchese	IEA / CEA
Gniewomir Flis	Agora Energiewende
Stijn Carton	European Climate Foundation
Ines Bouacida	IDDRI
Jean-Pierre Goux	Independent expert (ex-Powernext)
Florence Delprat-Jannaud	IFPEN
Daniel Marenne	ENGIE

Today we focus on a selection of key aspects of our analysis.
Make sure to check our final report for additional insights.

Agenda

System point of view

3 major strengths:

I. H2 can be the key to decarbonise **hard-to-abate emissions**

II. H2 can provide the **missing technology for energy storage**

III. H2 can be a cost-effective way to **transport large amounts of energy**

OTHER STRENGTHS

- Low carbon H2 production can be produced via several well-known processes
- H2 can be a solution to tackle **air pollution**
- H2 enables consumers to keep **similar energy habits** as today
- H2 can serve as basis for the synthesis of several other carbon-neutral fuels

OPPORTUNITIES

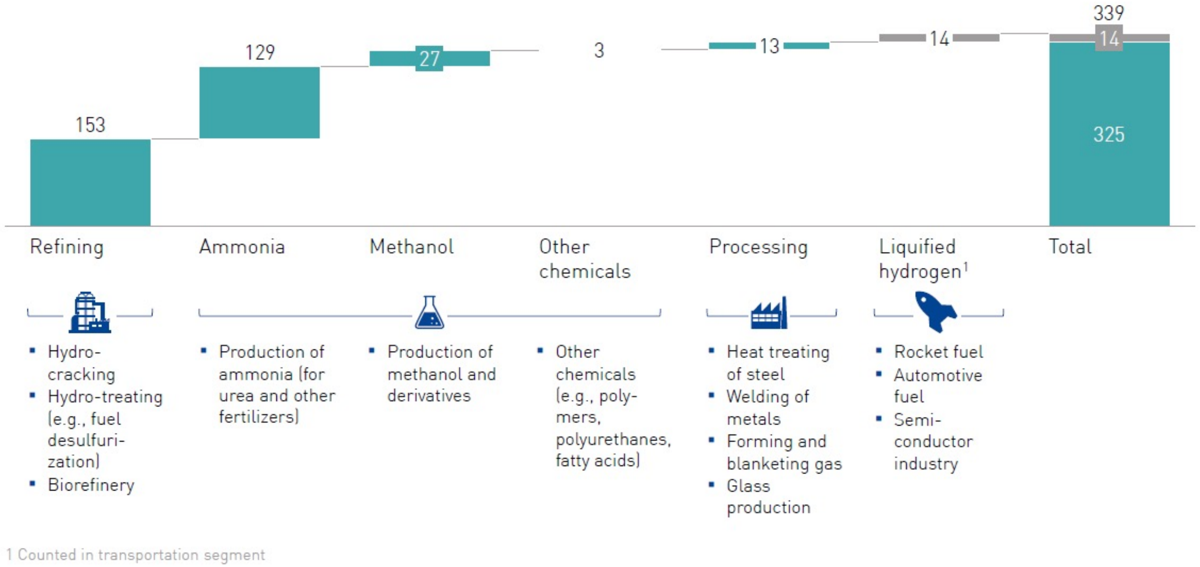
- H2 infrastructure could be the key for the development of the sector
- The public support and public **momentum** are strong
- **Blue H2** is a clear opportunity to start up the H2 sector at limited cost
- Taxation/incentives could boost H2 adoption

System point of view

H2 can be the key to decarbonise **hard-to-abate emissions**

- Current usages of H2 are mostly **feedstock usages**
- They are naturally the first sectors where low-carbon/green H2 is required
- They are the "**no regret**" targets

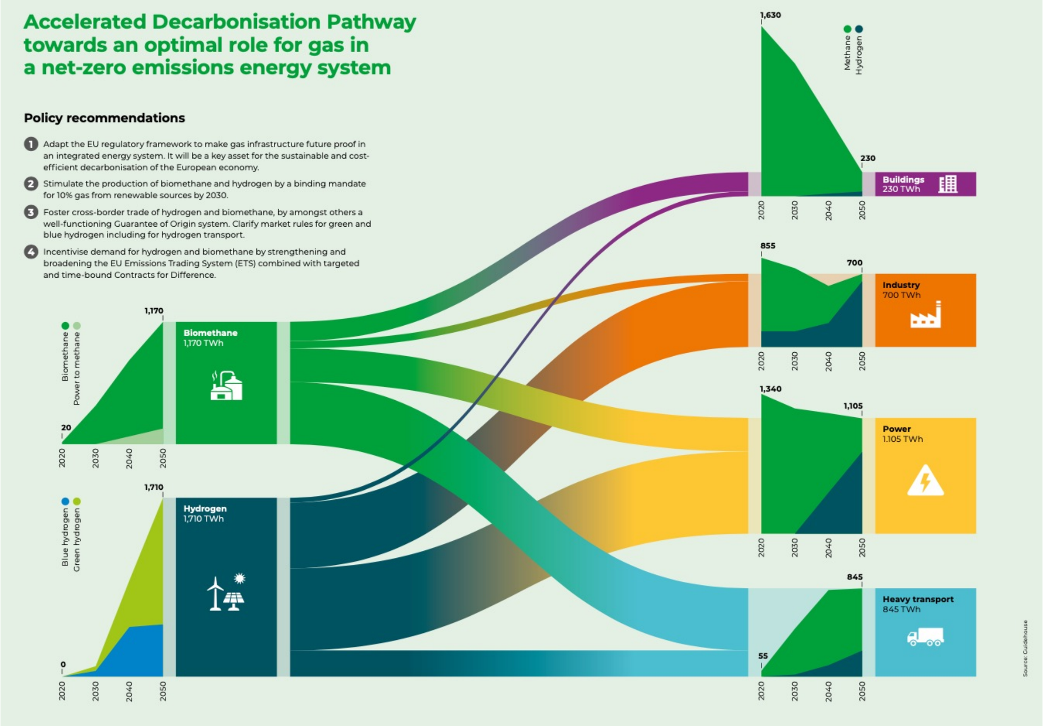
Total hydrogen use in the EU in TWh



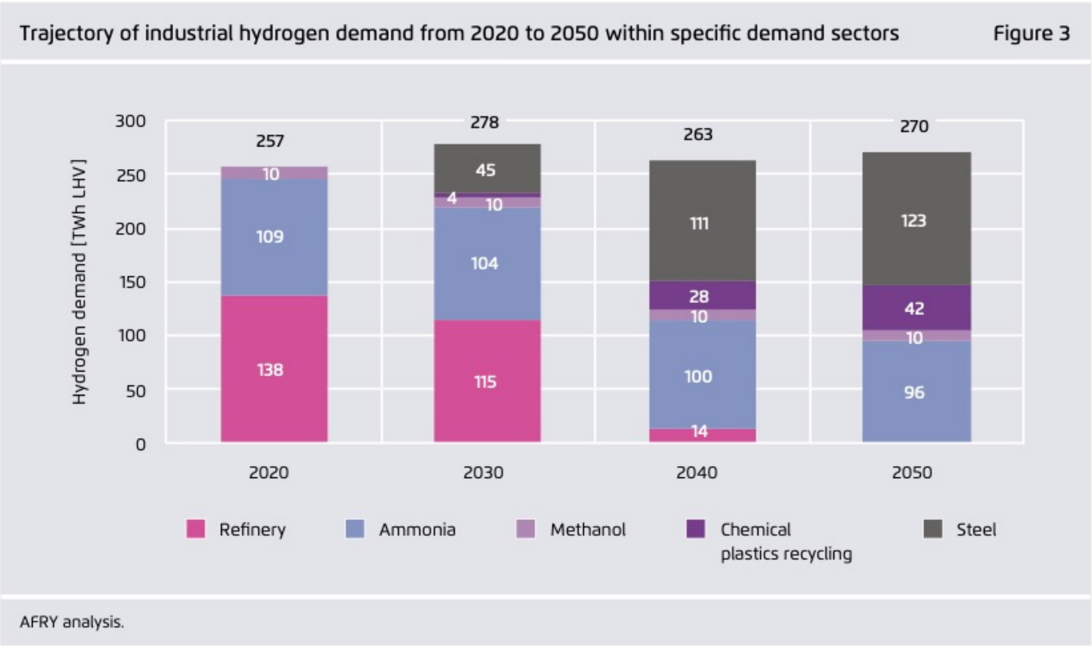
(Fuels Cells and Hydrogen – Joint Undertaking (FCH-JU), 2019)

System point of view

- Stakeholders have been found to have **widely different views on the "depth" of the role of hydrogen**
- While the key debate used to be linked to **technical feasibility** of alternative decarbonisation pathways ("it is not technically feasible to electrify end-uses"), we see the discussion orient itself towards **economic analysis**, as direct electrification routes open up in various sectors considered as hard-to-abate, including in the industry.
- Example below for the industry, where the 2050 demand reaches **630 TWh** H2 LHV (LHS) in stretch scenarios and **270 TWh** H2 LHV in more conservative scenarios (RHS).



Source: Guidehouse for the Gas for Climate consortium

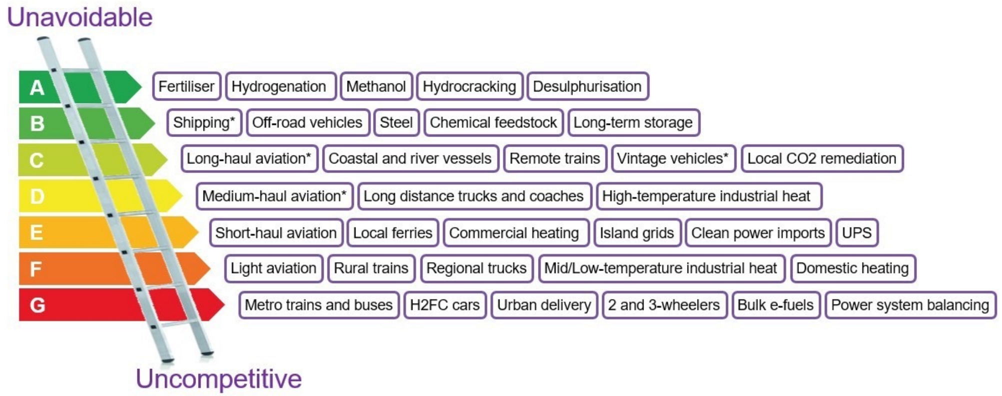


Source: AFRY for Agora Energiewende

System point of view

H2 can be the key to decarbonise **hard-to-abate emissions**

- Many new usages are under consideration with various targets and various levels of certainty
- A lot of debate focuses on the **efficiency** of hydrogen-based end-uses.
- While this is a good starting point, it is not the end of the story, as impacts in terms of infrastructure requirements are usually ignored in such arguments
- For example, although direct electrification of heating is (much) more efficient than alternatives based on consumption of gaseous fuels, it also requires an important development of electricity generation infrastructure and of flexibility solutions. This point should not be disregarded too quickly. Notably, **hybrid heating solutions** may help reduce total system costs.



** Via ammonia or e-fuel rather than H2 gas or liquid*

Source: Liebreich Associates (concept credit: Adrian Hiel/Energy Cities)

Liebreich Associates

Green molecules needed?	Industry	Transport	Power sector	Buildings
No-regret	· Reaction agents (DRI steel) · Feedstock (ammonia, chemicals)	· Long-haul aviation · Maritime shipping	· Renewable energy back-up depending on wind and solar share and seasonal demand structure	· Heating grids (residual heat load *)
Controversial	· High-temperature heat	· Trucks and buses ** · Short-haul aviation and shipping · Trains ***	· Absolute size of need given other flexibility and storage options	
Bad idea	· Low-temperature heat	· Cars · Light-duty vehicles		· Building-level heating

* After using renewable energy, ambient and waste heat as much as possible. Especially relevant for large existing district heating systems with high flow temperatures. Note that according to the UNFCCC Common Reporting Format, district heating is classified as being part of the power sector.

** Series production currently more advanced on electric than on hydrogen for heavy duty vehicles and buses. Hydrogen heavy duty to be deployed at this point in time only in locations with synergies (ports, industry clusters).

*** Depending on distance, frequency and energy supply options

(Agora Energiewende, 12 Insights on Hydrogen, 2021)

System point of view

H2 can provide the **missing technology for energy storage**

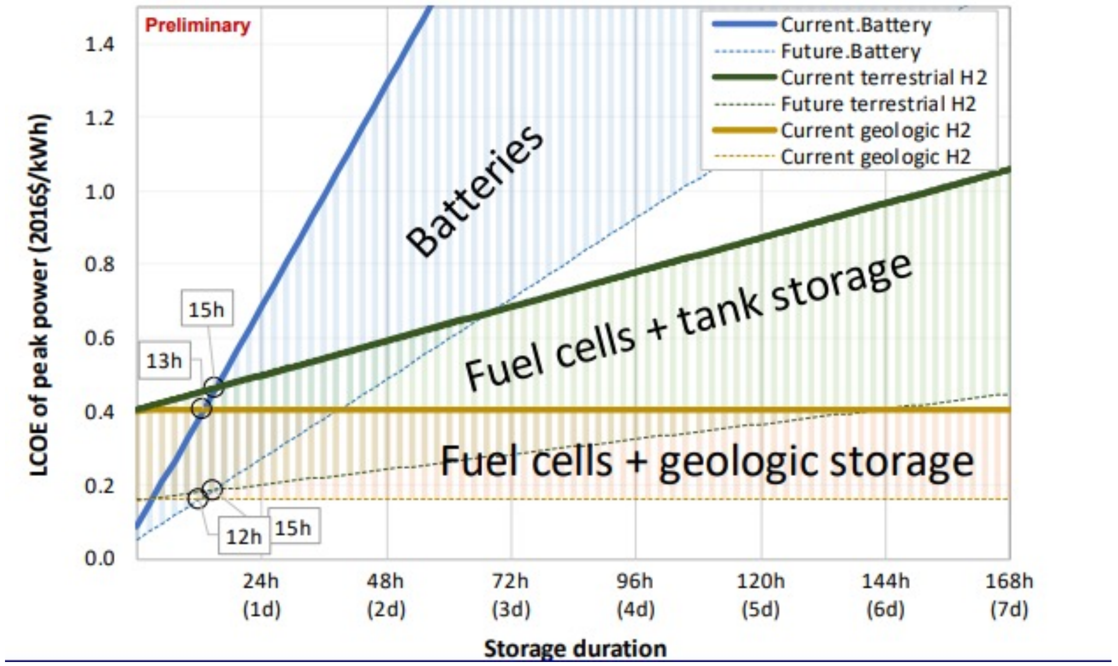
- How to respond to rising level of flexibility needs that emerge on all timescales?
- How to respond to so-called "Dunkelflaute" events?

System point of view

H2 can provide the **missing technology for energy storage**

- How to respond to rising level of flexibility needs that emerge on all timescales?
- How to respond to so-called "Dunkelflaute" events?

"How would the power system react to a long period (typically 2 weeks) of windless cold?"



Economic preference benchmark current & future hydrogen and batteries (NREL, 2019)

System point of view

H2 can provide the **missing technology for energy storage**

Short-term flexibility

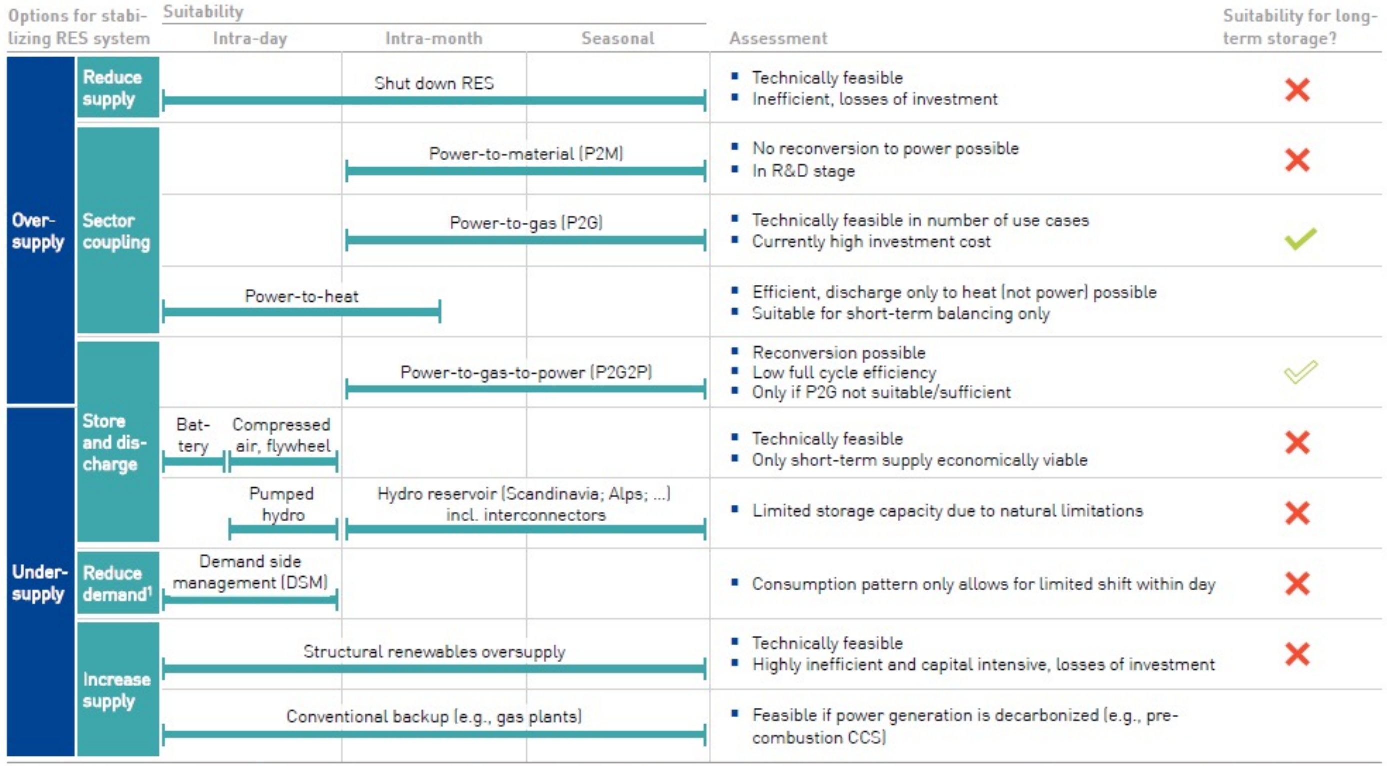
- Ideal business case for **battery storage solutions** rather than H2 systems
- Competition with other solutions: EV, demand response, stationary battery storage

Mid-term flexibility

- **Very few carbon-neutral alternatives**
- Combination of storage + H2 turbines could solve the problem.
- H2 storage or H2 imports can help avoid inefficient power to H2 to power loops.

Long-term flexibility

- The extent of seasonal flexibility needs are unclear due to change in production and consumption patterns
- In all cases, H2 storages will not provide the exact same services as natural gas storages, due to the structurally different drivers of flexibility needs (demand profiles, thermosensitivity, supply profiles)



1 Demand reduction/demand balancing beyond expected structural demand reduction and efficiency gains (e.g., via energy-efficient renovations of buildings)

(Fuels Cells and Hydrogen – Joint Undertaking (FCH-JU), 2019)

System point of view

H2 can be a cost-effective way to **transport large amounts of energy**

Only little consensus seems to exist on the cost of large-scale hydrogen networks. However, experts tend to agree on two key points

- Transporting energy through H2 is cheaper than through electricity
- Repurposing current gas infrastructure is cheaper than building new H2 infrastructure

→ H2 could be produced far from the consumption centre and be a way to "transport solar and wind energy" on long distances

→ The current gas infrastructure could be a valuable asset for H2 (via repurposing)

LCOT for H_2 transmission - refurbished natural gas infrastructure			
Units	**Value**	**Comments**	**Source**
EUR2019/MW h_{H_2} /600 km	3.7	Retrofitting existing gas infrastructure for 100% hydrogen.	(Guidehouse, 2019)

LCOT for H_2 transmission for new dedicated infrastructure				
Units	**Minimum**	**Maximum**	**Comments**	**Source**
EUR2019/MW h_{H_2} /600 km	4.6	4.6	48-inch pipeline. Includes pipeline and compressor CAPEX and OPEX and compression fuel-related costs.	(Guidehouse, 2019)
	9.6	9.6	34-inch pipeline with utilization of 75%. The source assumes the cost of transporting H_2 over 50 km. Normalised to 600 km.	(BNEF, 2019)
	11.4	11.4	Transportation over 1500 km is assumed by source, considering all capital and operating costs. Normalised to 600 km.	(IEA, 2019)
	16.1	49.8	Pipeline with a capacity of >100 t/day. The source assumes a 100 km pipeline. Normalised to 600 km.	(BNEF, 2019)
	45.0	45.0	Estimated including compression costs for pipes of diameters between 7-10 inch over 100 km as assumed by source. Normalised to 600 km.	(DNV GL, 2019)

(European Commission - Guidehouse, 2020)

System point of view

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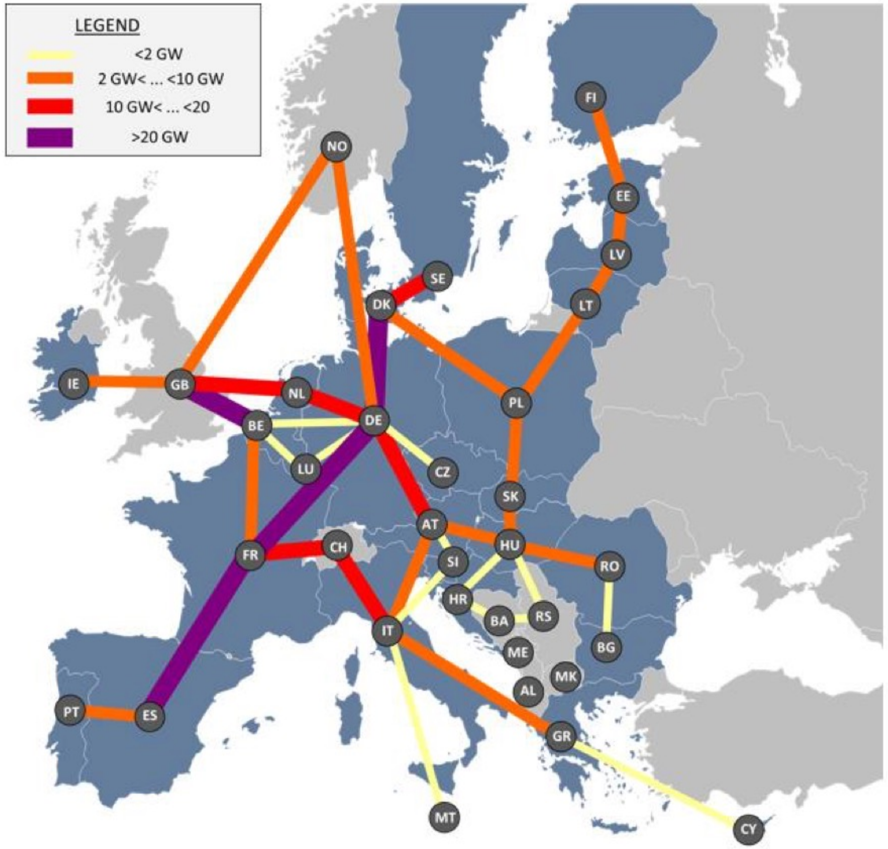


(Artelys on behalf of ECF, based on EC 1.5TECH 2050 scenario)

System point of view

3 major weaknesses:

I. H2 value chain's **efficiency is low** compared to its main competitors

II. Transition **costs are high** all across the value chain

III. H2 can be a dangerous gas and requires high **safety standards**

OTHER WEAKNESSES

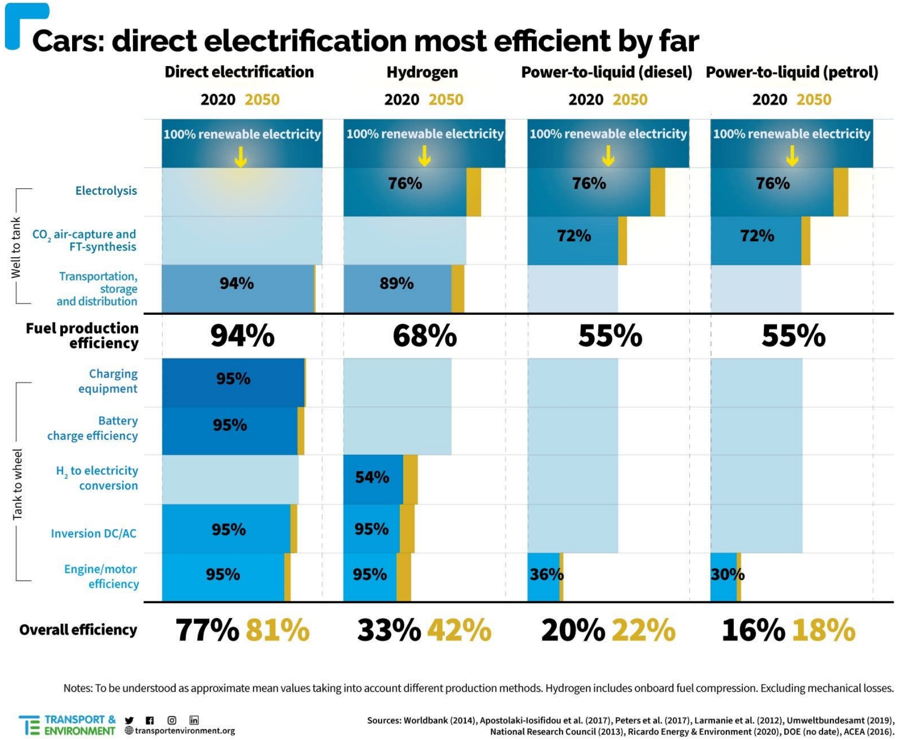
- The real systemic carbon impact of green H2 is not so clear
- Blue H2 remains a highly controversial subject

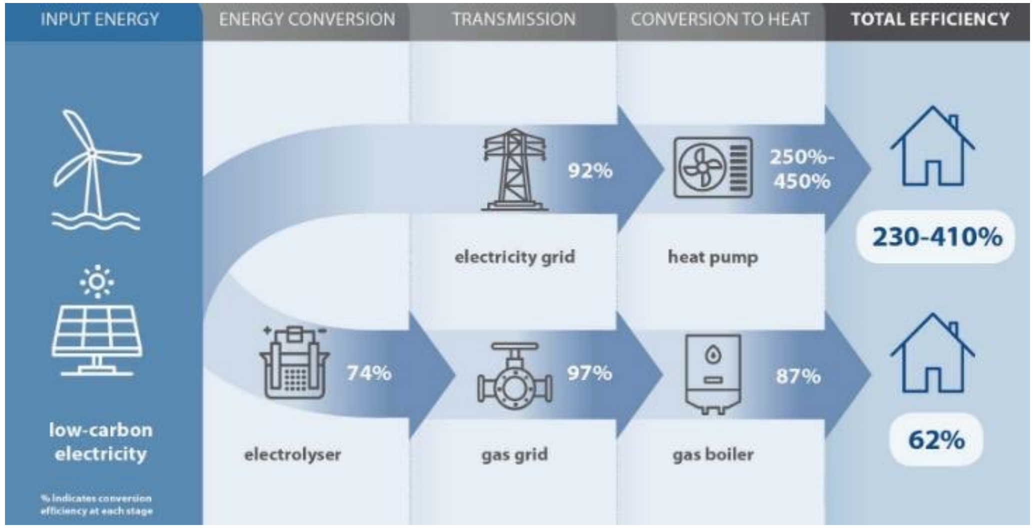
THREATS

- H2 growth expectation could be less than expected
- The switch to H2 in the industry can have important macro-economic impacts
- Risk of badly calibrated regulation
- Some game changers events could disrupt the current expectations for the hydrogen sector
- Misallocation of capital

System point of view

H2 **value chain's efficiency is low** compared to competitors (where competitors exist)





System point of view

The **systemic carbon impact of "green" H2** is not so clear

Business model for electrolytic H2 (RTE, 2020)

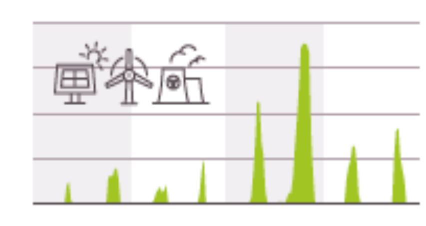
In the study ***La transition vers un hydrogène bas carbone***[1], RTE explores 3 distinct business models for electrolytic H2.

1. Base load consumption on the grid

The electrolysers use the power from the grid unless in a limited number hour hours when the prices are high.

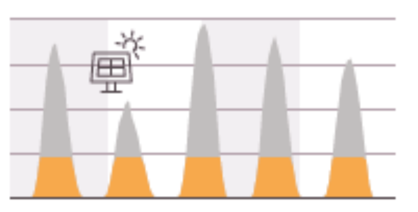
2. Grid consumption in low prices only

The electrolysers use the power from the grid only when the prices are very low. This correspond to hours when renewables or nuclear productions are marginal.



3. Of grid consumption of dedicated RES production

The electrolyser project has its associated renewable production.



- Business models with high utilization rate are the best ones to recover fixed costs
- Even if an electrolyser consumes RES electricity, **its systemic CO2 impact may not be neutral.**
- The impact of business models based on **dedicated renewables** can also be questioned as situation where electrolysis plants are running at the same time as gas-fired power plants can materialise (virtual gas to gas process)

System point of view

The real **systemic carbon impact of green H2** is not so clear

"In some configurations, grey H2 can have a lower CO2 impact than electrolytic H2"

Maximum carbon intensity of power for electrolytic H2 to have the same climate impact as SMR:

Electrolysis efficiency (LHV)	40%	50%	60%	70%	80%	90%
Maximal carbon intensity of power to match the intensity of SMR* [gCO2/kWh]	120	150	180	210	240	270

The introduction of an "**additionality principle**" can be a mechanism to avoid such issues, even if it raises other questions (fairness, impact on amount of RES-connected capacity, etc.)

**SMR = Steam Methane Reforming*

- H2 energy per unit of mass (LHV): 120.1 MJ/kg = 33,36 MWh/tH2
- Average carbon intensity of hydrogen production using natural gas of 10 tCO2/tH2 = 0,2998 tCO2/MWh (LHV) of H2

System point of view

H2 can be a dangerous gas and requires **high safety standards**

- H2 physical and chemical proprieties can raise **legitimate concerns** (no odour, no colour, high flammability, explosivity characteristics).
- Nevertheless some of its characteristics can play in the favour of its safety:
  - A light gas that would not concentrate in non confined areas.
- **Industries are used to** manipulate hazardous gases (and H2). However, the easy access for the **wider population** raises some concerns (especially for households applications).
- The biggest problem might be the **public acceptance**: a **major incident could have major impacts on the development of an H2 ecosystem**.

BUSINESS NEWS SEPTEMBER 25, 2019 / 1:07 AM / UPDATED 2 YEARS AGO

Hydrogen hurdles: a deadly blast hampers South Korea's big fuel cell car bet

By Hyunjoo Jin, Jane Chung 9 MIN READ

SEOUL (Reuters) - Aiming to cash in on a major push by South Korea to promote fuel cell vehicles, Sung Won-young opened a hydrogen refueling station in the city of Ulsan last September. Just one year on, he's thinking about closing it down.

People attend a protest against hydrogen fuel cells power plant in Incheon, South Korea, August 8, 2019. Picture taken August 8, 2019. REUTERS/Jin Hyunjoo

https://www.reuters.com/article/us-autos-hydrogen-southkorea-insight-idUKKBN1W936A

Agenda

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2. SWOT analysis – System point of view
3. **SWOT analysis – Producer point of view**
4. SWOT analysis – Consumer point of view
5. Reconciliation and conclusions

Project developer point of view

STRENGTHS

- H2 projects can represent interesting investments for a large variety of companies
- Public support and current momentum are big strengths for project developers
- The capex is expected to decrease sharply in the future

OPPORTUNITIES

- Many promising technologies are under research
- The development of H2 is an opportunity for traditional companies
- A clear future would help the business
- The local producer will have an advantage
- Regulation can boost the development of H2 projects

WEAKNESSES

- Lack of H2 off takers for the produced H2 and lack of robust business model
- Lack of long-term vision for a project developer
- Lack of roadmap among industrial to trigger synergies
- Green H2 is expected to remain more expensive than carbon intensive solutions

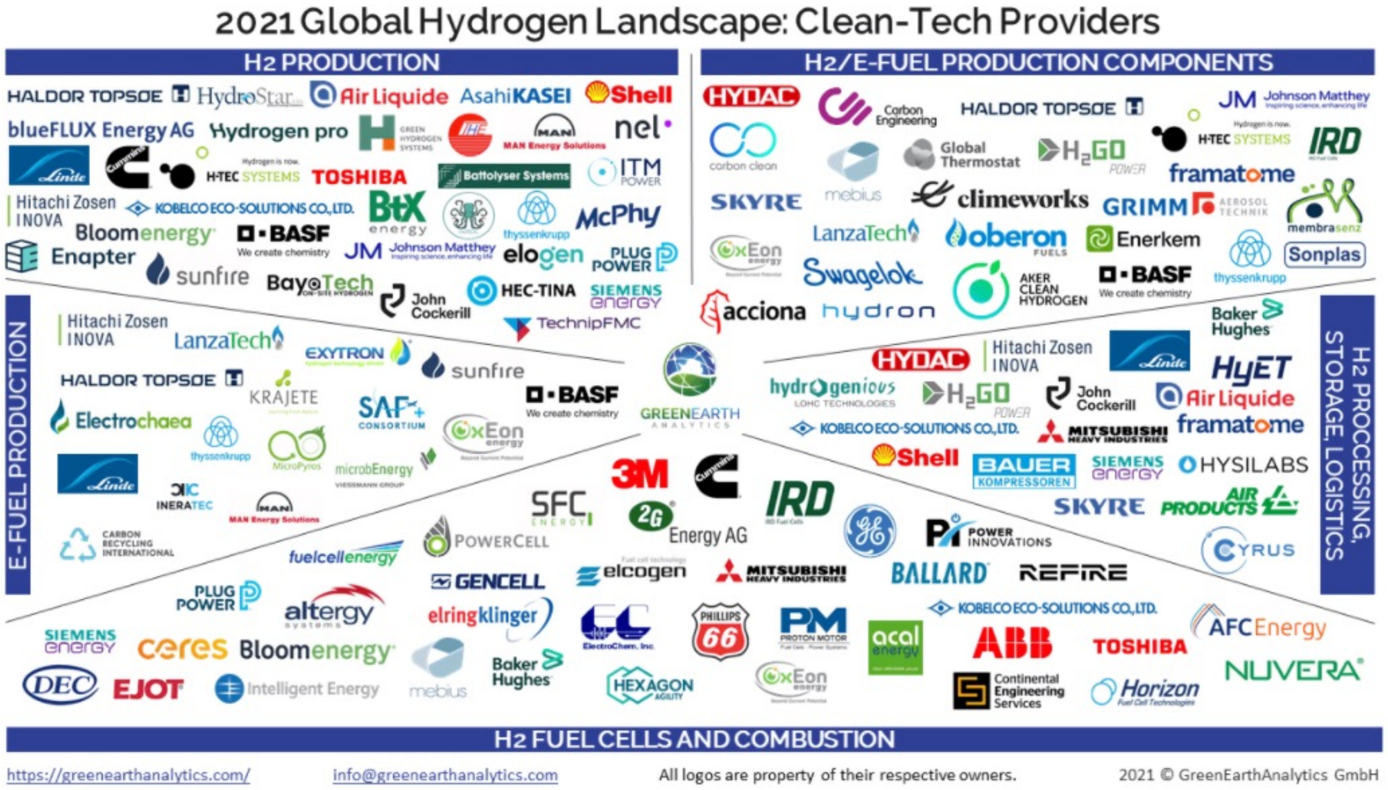
THREATS

- H2 project developers will be in competition with other technologies
- Some regulations could jeopardize the profitability of the investments in H2 projects
- Green H2 projects rentability will be heavily dependent on a cheap supply of power
- Risk to bet on the wrong technology
- Political risk to lose interest in H2
- International trading of H2 could be a deadly blow to local producers

Project developer point of view

H2 can represent business opportunities for many businesses:

- Hydrogen producers of all kinds (electrolysis, blue H2, other processes…)
- Hydrogen infrastructure project developers (pipelines, storages, terminals, compressors…)
- Technology developers (fuel cells, electrolysers, high pressure storages…)
- Power and gas companies for diversification or for investment hedges on the power sector.



https://greenearthanalytics.com/h2landscape2021/

Few of those opportunities **are real "game changers" in the favour of H2 as they do not really enable new services to appear or reduce costs of existing services**, they are mostly emerging in a context of deep decarbonisation.

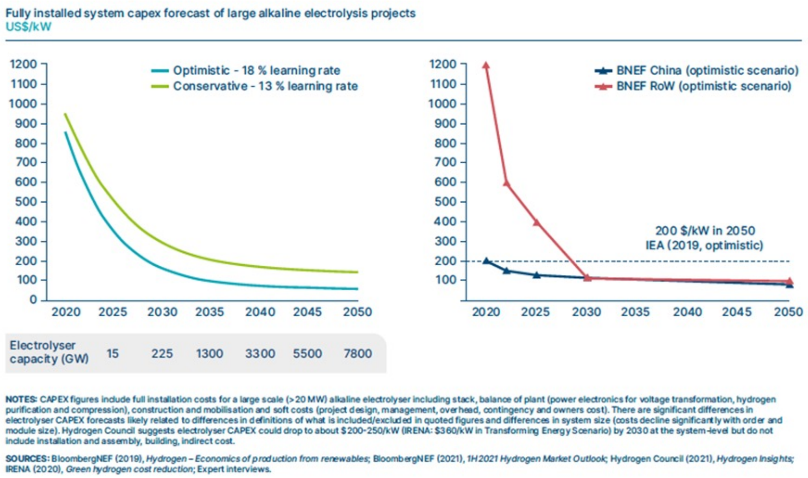
However, for project developers, an H2 economy can represent very interesting business opportunities

Project developer point of view

H2 project rentability will rely on 3 pillars:

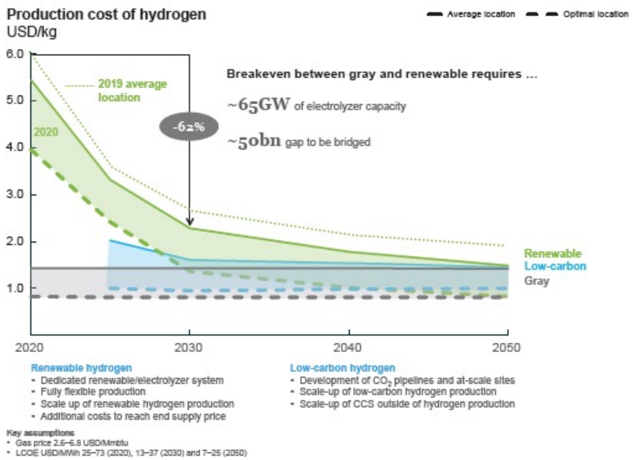
- Get technologies with low and decreasing costs: the CAPEX component of H2.
- Ensure cheap power supply for the functioning hours of the electrolyser: OPEX component of the cost of H2.
- Get a good price for the hydrogen produced.

CAPEX projection of big alkaline electrolyser projects



(Energy Transitions Commission, 2021)
(BNEF, 2019)

Hydrogen production costs by production pathway



(Hydrogen Council - McKinsey & Company, 2021)

Project developer point of view

H2 project developers will face one major problem: **finding offtakers** for the production

“Who will buy and use the hydrogen I produce?”

- As long as no H2 network exist, local injection business model similar to biomethane injection is possible, but limited
- **Blending of H2** into the gas network is one clear opportunity for producers but has many drawbacks

Many clouds remain for the project developer, making it difficult to engage in large investments:

- Some regulation concerns: **unbundling rules**, **additionality principle**, technology specific regulation
- Commodity risks: power prices are correlated to both **natural gas and CO2 prices**. CO2 price evolution can be a bad price signal for green H2.
- Competition with other technologies: **fossils energies** that remain cheaper solutions, other H2 productions, competition for the power purchase in low prices periods, competition with **other carbon neutral solutions** (biomass, biomethane, electrification, CCS,…), competition with outsiders like **SMR (Small Modular Reactors)**.
- **Political risk** to lose the current support: prospects for H2 project developers would be questioned if the 2050 carbon neutrality constraint is relaxed or postponed.

Carbon intensity [g CO2/ KWh]	
H2 with SMR (Steam methane reforming)	**300**
Power with OCGT	352
H2 with electrolyser at xx% efficiency and OCGT as marginal power producer	
60% efficiency	587
70% efficiency	503
80% efficiency	440

Zoom on blending

Blending refers to the admixture of hydrogen with natural gas, directly into the gas network, up to a certain H2 concentration. This solution benefited from a great interest in the past few years in despite of the critics of experts.

WHY BLENDING?

- By replacing a carbon intensive gas by a low carbon gas with similar characteristics, we are able to partly decarbonize the gas systems
    - Way to promote decarbonisation through the current gas system
    - For H2 project developers, it is the opportunity to inject their production into the network in a simple “bio-methane like” business model.
    - Blending can be seen as a **kickstarter** of the H2 sector, **without any dedicated infrastructure.**

IS BLENDING EVEN POSSIBLE?

- The consensus is yes… but to a certain point.
- The current consensus is that beyond **20% in volume**, blending would require heavy investments
- But the relevant questions are “to what extent?” and “at what cost?”.

Zoom on blending

IS BLENDING DESIRABLE?

- Blending modifies the calorific properties of the gas, this could require appliances adaptations or renewable.
- It is very complexes to unsure that the blending limit is met everywhere in the network:
  - Especially in frontiers with different limits.
  - Near the productions centres.
  - In appliances, households circuits, storages…
- Will the blended gas quality be compliant with the current industrial gas usages?
  - Many industrial are opposed to blending as it would mean adaptation costs or decrease in quality.
- Value dilution of a “high value, expensive, rare gas” into a “cheap, widely available gas”.
  - The business model is unlikely to emerge on market basis.
- Blending has a very low CO_2 mitigation impact.
  - It is a short term solution but the carbon impact in the short term could be negative is the power sector is not deeply decarbonized (indirect systemic CO_2 impact of green H_2)

For many experts, **the advantages of blending are too small to compensate for the drawbacks**.

Agenda

1. Context and methodology
2. SWOT analysis – System point of view
3. SWOT analysis – Producer point of view
4. SWOT analysis – Consumer point of view
5. Reconciliation and conclusions

Consumer point of view

STRENGTHS

- For companies it is a way to convey a “green image”.
- Can enable off-grid business models
- Can bring more value than other green solutions

OPPORTUNITIES

- Clear opportunity to start-up the H2 sector by relying on current H2 consumers
- Some regulation mechanism can trigger improve the profitability of industries switching to H2
- H2 market and importations could enable cheap supply of H2

WEAKNESSES

- Cost will be much higher for the consumers
- Lack of long-term vision

THREATS

- The question of who will pay for the transition has yet to be answered
- Public acceptance and security are key and could represent an important threat if poorly managed

Consumer point of view

For consumers, H2 has very few strengths:

- The main advantage for offtakers: possibility to **decarbonise the final usage**
  - For corporate image
  - To attract investors
  - To ensure a future-proof business model
  - To have an “active” impact on the economy and the society
- Carbon free off grid solutions
- In very few sectors it can really bring a usage value for the consumer: **H2 mobility is one of them despite its low system value**

On the contrary, the usage of hydrogen comes with very important drawbacks:

- High transition cost to accept H2 in the industrial process or in residential appliances.
- High H2 supply cost.
- Complexity to handle H2 and associated security issues.
- Low use value in most applications compared to fossil fuels or other carbon neutral fuels.

Consumer point of view

On the consumer point of view, it is important to break down H2 usages into two categories:

FEEDSTOCK usages

- No alternative to H2 exist today[1]: the future is quite clear for H2
- Only alternative is to find another supply source:
  - Other technology
  - Importation of H2
- The importation of the final production is the real threat:
  - Importation of ammonia and methanol instead of H2.
  - Importation of fertilisers.
- Higher H2 prices will not systematically question the H2 usage but will induce higher final product prices

ENERGY usages

- Many alternatives to H2 exist
- The future is unclear for H2
- Often "low value usage" of a molecule that is complex to synthetise
- Higher H2 prices can kill the attractiveness of H2 for consumers in sectors where alternatives exist

[1] Alternative processes, alternative feedstocks or alternative final product for a similar usage are always possibilities to keep in mind

Zoom on blue H2

Blue H2 is often stated as a good way to kick-start the H2 economy with low supply cost in order to let the demand develop.

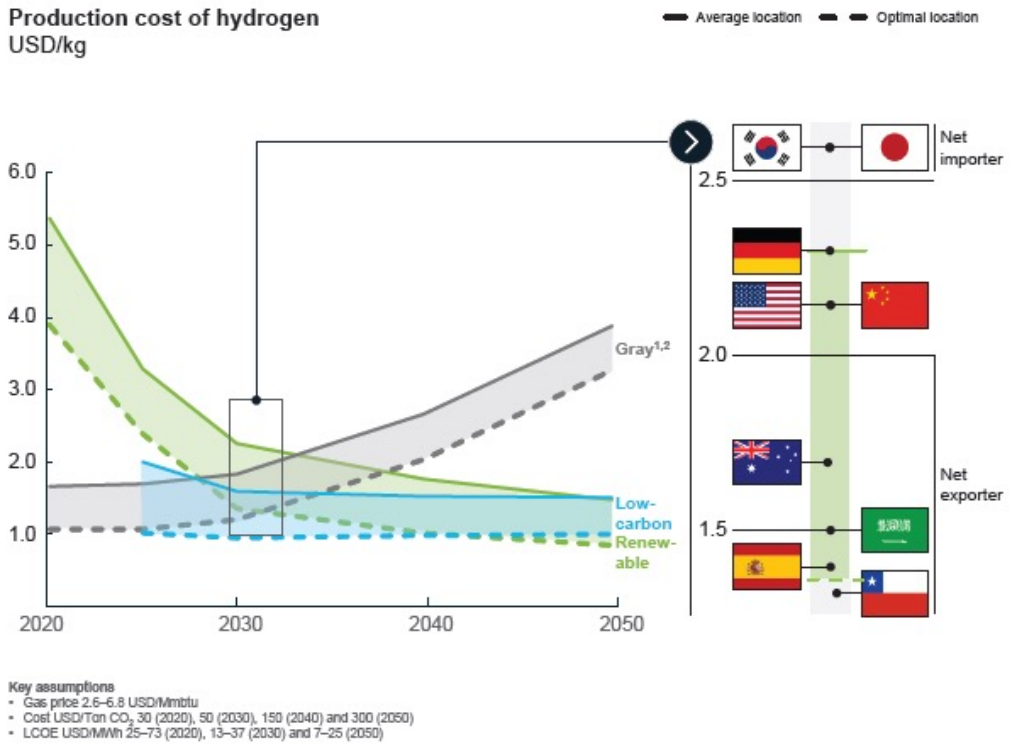
Blue H2 has indisputable strengths:

- Usage of **existing SMR and ATR facilities**
- Opportunity to kick start the hydrogen economy at contained costs
- The **switch from grey to blue** can be driven by an efficient CO2 price and will require no subsidies
- Opportunity to develop a **CO2 economy**

*"**In the short and medium term, however, other forms of low-carbon hydrogen are needed**, primarily to rapidly reduce emissions from existing hydrogen production and support the parallel and future uptake of renewable hydrogen."*

Strategy for a climate neutral Europe, (European Commission, 2020)

Production cost of hydrogen (USD/kg). The plain line corresponds to the average location and the dotted line to an optimal location



(Hydrogen Council - McKinsey & Company, 2021)

Zoom on blue H2

But the controversy on blue H2 is strong and many stakeholders ask for a direct switch from grey to green

Blue hydrogen presents a number of drawbacks:

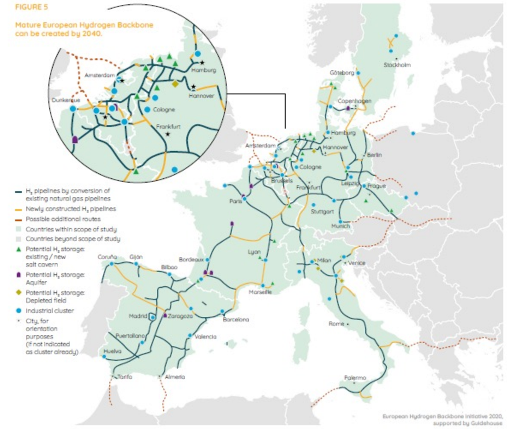
- Persistence of the **natural gas value chain**
- **Methane leakages**
- **Capture rate is not 100%,** making it incompatible with a net zero ambition
- The **CO2 that is captured** needs to be transported to be used or stored
- The risk of **lock-in effect** is often quoted but no consensus on that specific point emerges

Zoom on H2 imports

If the local production of hydrogen is seen as the base case scenario for Europe, hydrogen imports from other countries could very well be an alternative solution to get cheaper prices to supply the domestic demand.

Hydrogen imports present a number of strengths:

- Taking advantage of the most gifted regions in terms of RES production possibilities to produce cheaper H2 (electricity being a major component of H2 cost). However, low costs will not always translate in low prices.
- Diversify the supply sources to avoid being energy stressed simultaneously on power and H2
- Different solutions exist to import H2: pipelines, shipping, trucking (of ammonia, in a liquified form, etc.)



(Guidehouse, Hydrogen Backbone 2020)

<0.1 USD/kg | 0.1–1 USD/kg | 1–2 USD/kg | >2 USD/kg

		Costs				
		Distribution		Transmission		
		0–50 km	51–100 km	101–500 km	>1,000 km	>5,000 km
Pipelines[1]	Retrofitted	City grid	Regional distribution pipelines	Onshore transmission pipelines	Onshore/Subsea transmission pipelines	N/A
	New	City grid	Regional distribution pipelines	Onshore transmission pipelines	Onshore/Subsea transmission pipelines	N/A
Shipping	LH_2	N/A	N/A	N/A	LH_2 ship	LH_2 ship
	NH_3[2]	N/A	N/A	N/A	NH_3 ship	NH_3 ship
Trucking	LOHC[2]	N/A	N/A	N/A	LOHC ship	LOHC ship
	LH_2 trucking	Distribution truck LH_2	Distribution truck LH_2	Distribution truck LH_2	N/A	N/A
	Gaseous trucking	Distribution truck CH_2[3]	Distribution truck CH_2[3]	Distribution truck CH_2[3]	N/A	N/A

1. Assuming high utilization
2. Including reconversion to H_2; LOHC cost dependent on benefits for last mile distribution and storage
3. Compressed gaseous hydrogen

(Hydrogen Council - McKinsey & Company, 2021)

Zoom on H2 imports

Hydrogen imports also have weaknesses and threats:

- The transport costs are high and would be a significant part of the total cost of imported H2.
  - The repurposing of parts of the current gas network could help reduce the costs
- Additional steps are required to compress, liquify or transform H2 into another form.
- It would imply an energy dependency with a non liquid and small market
- Is long distance H2 importation really a relevant solution if this H2 is used as a feedstock? **Why not importing directly the final production** (most of the H2 feedstock usage being ammonia, a gas expected to have lower transport costs than H2). It makes more sense for energy usage but those usage are more uncertain.

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Cross examination of point of views

One **paradox**

One **major issue**

Some **solutions**

Two **dilemmas**

Cross examination of point of views

One paradox

In the long term, the consensus is that hydrogen will be required to reach a net-zero target. But when explored in details, hydrogen-based solutions seem to have in reality very few advantages for consumers.

This apparent paradox suggest that some kind of **public support** will be needed for the development of H2 as the benefits are mostly emerging when adopting a system point of view (and not partial ones).

The H2 economy is unlikely to develop "by itself", even if its value for the system is clear.

Cross examination of point of views

One big issue

How to develop the H2 economy given those mismatches of interest?

- How to provide long-term investment signals?
- How to cope with high prices for H2 usage in the industry?

Cross examination of point of views

How to provide long-term investment signals?

Some solutions:

EU ETS

Enables a market-based pricing of CO_2 emissions.

- Good tool to "select" investments
- However, the impact of the EU ETS on power prices (that are expected to remain correlated to gas-fired power plants' marginal costs), will by high on green H2
- Revision of EU ETS could be a solution

Carbon Contracts for Difference (CCfDs)

“Such a long-term contract with a public counterpart would remunerate the investor by paying the difference between the CO2 strike price and the actual CO2 price in the ETS in an explicit way, bridging the cost gap compared to conventional hydrogen production"

(European Commission, A hydrogen strategy for a climate-neutral Europe, 2020

- CCfDs could also be used to incentivise investments in new industrial processes
- Allow to gain a few years on investments leading to early adoption and earlier cost reductions
- Remove the CO2 price volatility factor
- The progressive growth of the CCfD strike price ensures a coherent allocation of capital

Cross examination of point of views

How to cope with high prices for H2 usage in the industry?

Is CBAM a good solution ?

H2 based industrial processes will be more expensive than the current carbon intensive processes. It would have the following consequences:

- Increase of prices for the final user and therefore **reduction of the global welfare**.
- Structural growth of industrial goods prices
- **Decrease of industrial production quantities** (as production cost will rise) and therefore **decrease of benefits** and **high risk of labour reductions**.
- Loss of international competitiveness of the local industries:
    - Reduction of market share for local clients
    - Reduction of exportation revenues
    - impact on the countries trading balances, inducing several monetary and financial issues.
- **Jeopardize the energy transition:**
    - **Some essential industrial goods will be more expensive:** concrete, steel and other materials essentials for the energy transition (for transport infrastructures, new buildings, wind turbines, new cars etc…).
    - Our importation abilities of important materials could be reduced as our exportations decrease

Border carbon adjustment mechanism (CBAM):

Taxing the imported goods proportionally to the amount of CO2 required for their production.

Cross examination of point of views

How to cope with high prices for H2 usage in the industry?

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Border carbon adjustment mechanism (CBAM):

Taxing the imported goods proportionally to the amount of CO2 required for their production.

- It doesn't solve the problems of high prices
- It only partially protects the local industries and does not remove completely delocalisation incitive as an industry outside can be competitive both inside the mechanism (by paying the tax) and outside. An industry inside will be limited to local consumers
- It could lead to new issues:
  - retaliation from the countries considering that this is an unfair trading limitation design to remove their own industries from the European market.
  - Some of those countries importations being a requirements for our energy transition.

No "perfect" solution found at this stage

Cross examination of point of views

1st dilemma: Investment timing

- Many H2 usages com with **high costs**.
- H2 is currently not the cheapest CO2 abatement option and it is expected to remain the case for some time. Focusing the investment on more efficient measures with clearer long term perspective is natural.
- The long term vision is unclear
- However, it is **complicated to postpone** the investment too much as it will take time for the H2 economy to emerge

2nd dilemma: Who will pay for the transition?

As H2 requires public support in order to develop, it is important to determine who will pay for H2 development.

- **Producers** need to be incentivised to switch to H2 and are unlikely to take the initiative without an appropriate regulatory framework. Moreover, the costs would ultimately be transferred onto consumers.
- **Consumers** are expected to pay for the transition through taxes on products. It raises many economical questions related to industrial competition, rise of consumer prices, etc.
- **The taxpayer** will support part of the transition costs through subsidies. Nevertheless, this is likely to mean additional costs for limited benefits, with uncertain impacts on standards of living.

The democratic issue is very important and should not be underestimated. It is all the more important that the ultimate beneficiaries (from an economic point of view) are expected to be project developers rather than consumers.

Conclusions

H2 seems seems indispensable for **deep decarbonisation** as it provides services that no other technology can provide for now.

Nevertheless, for consumers, H2 provides **few to no additional services.**

Given the complexity of H2 ecosystem and the urgency to act to decarbonise the EU economy, we need act now, even if important uncertainties remain. Nevertheless, it is important to act wisely as the launch window is quite narrow:

The **real carbon impact of electrolytic hydrogen** should be looked at carefully. But a tight additionality regime is a risk too.

One should focus on **usages that are the most complex to decarbonise**. Heating and light mobility are not priorities for a system view.

Public support is essential, but one should be careful not to cumulate subsidies (RES production, CCfDs, Power to Gas).

Competitiveness issues will arise in numerous industrial sectors.
Mitigations measures such as CBAM exist but are not perfect and might be difficult to be implemented.

First movers will face the **chicken and egg** problem.

Business models remain uncertain (notably due to regulatory risks) and will require long term certainty to counter the risks.

If the framework conditions are well designed, hydrogen will lead to **major opportunities for industrial players** alongside the value chain.
The development of an hydrogen economy could lead to **new export perspectives** in a global context of energy transition.

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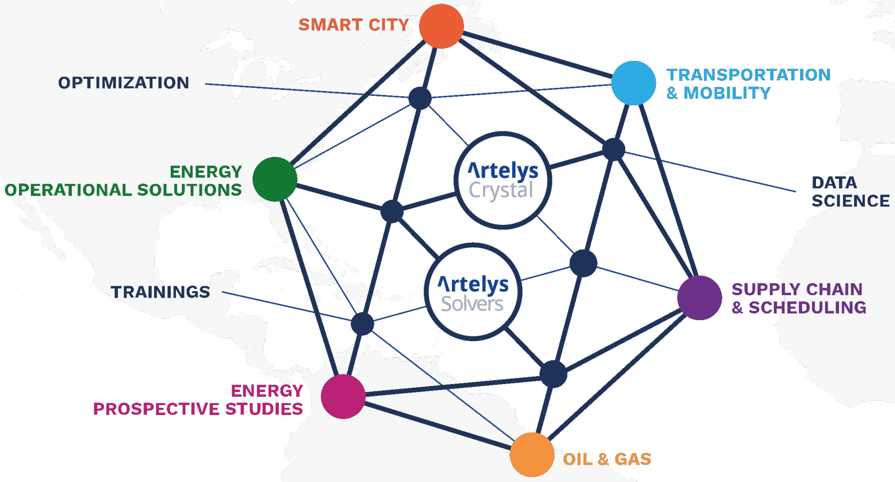
Contact



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