The making of Hydrogen – Definition and acceleration of a sector over 2017-2021

Issues at stake at horizon 2030 – Main Report

Joël Ruet, Baudouin Becker, Antoine Goutaland, Xieshu Wang,

« NOW » - « L'hydrogène source d'énergie propre pour la planète était un peu comme le sexe chez les adolescents : tout le monde en parlait, mais personne ne passait à la pratique.

Aujourd'hui, le procédé arrive à maturité et semble prêt à être mis en place. car tous les acteurs du marché actuel de l'énergie et de la mobilité ont quelque chose à y gagner. »

Bertrand Piccard, Solar Impulse, at WEF Davos 2017,

Official Launch of Hydrogen Council

SOON - “Electricity is the backbone of the energy transition, and hydrogen is a complementary extension of that. Hydrogen allows electricity to both scale up and reach places it cannot otherwise reach.”

Matthew Tipper, VP New Fuels, Shell New Energies,

at Hydrogen Council meeting New York

TOO LATE? - “In California, gas is not considered clean and with ambitious standards for electricity, batteries are already green. With grid storage mandates even green Hydrogen is precious. Hydrogen for passenger mobility is already passé.”

Dan Kammen, Science Envoy US Dept. of State

former Hydrogen Lab Director, Berkeley

The making of Hydrogen – Definition and acceleration of a sector over 2017-2021

A - Mobility within Hydrogen

H2 businesses but no « ecosystem »
Continued KPIs on light H2 mobility

B – Current Industry Structuring

Focus on Europe & China
Issue of Costs of Electrolysis

C – Conculsions

Regional Priorities & KPIs

Executive Summary: When Hydrogen(s) differently scale-up

1) Hydrogen system in 2018: a new and unstructured economy

- **Macro overview:** the hydrogen economy is emerging gradually (2025 -> 2030), with many uncertainties
- **Among major vehicle markets** (based on a matrix Production / Demand) => 1% of car fleet in 2030
- **Lobby & com' :** Mid term vision for producers and P2G vs. Long term vision for mobility & energy major actors as SNCF, SHELL (2050) : complementarity of timing / usages
- **Focus LDV,** major stakes: upstream development and ratio (production cost - TCO vs. environmental impacts)

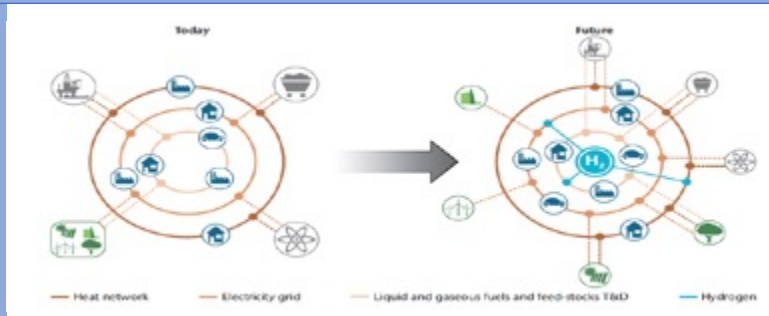
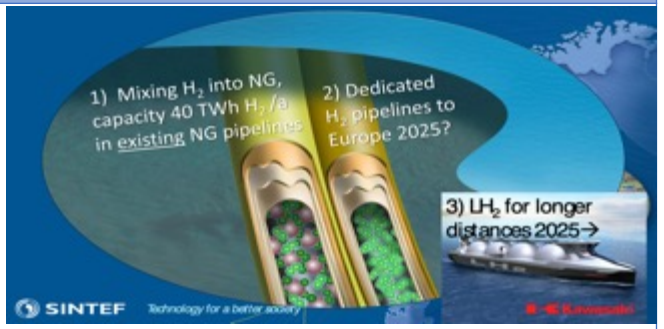
2) Hydrogen system in 2019: the Hydrogen Economy develops through early adopters but massification will be for the energy uses; mobility will follow post 2030

- **Macro overview**: many new territories develop plans, and some countries structure their upstream
- **Lobby & com'** : The lobbies aggregate an increasing number of companies, and start federating oil, gas and electric/grid companies
- **Across major markets** => HRS deployment meets differentiated hurdles in different territories: subsidies are not enough when the upstream is not involved; H2 production-demand balance needs being local
- **Focus LDV, major stakes**: The vision that LDV will come at a second stage gets increasingly accepted, studies on learning cost curves on electrolysis develop but lack territorial fine-tuning

3) Hydrogen system 2020 update : energy trend and limited passenger mobility ambitions

- Most announcements from the upstream, accentuating concerns on greening H2
- H2-Council lobby: Mission Innovation added 8th research pillar on Hydrogen Economy: "scale of the GW"
- Vehicle market: Chinese and European investments but limited ambition
- Focus LVD: except China, no noticeable investments in S2 for LDV, instead trains & buses remain the priority as expected

H2 ecosystem structure timeframe since 2017

	Mid 2017 - Mid 2018	Mid 2018 - Mid 2019	Mid 2019 - Mid 2020
H2 "system"			
Mains Plans	**China**: total public investments in H2 industry: 10,6bn€ **Europe:** **France:** 80 M€ plan for H2 **Germany:** H2 Mobility Germany is to establish a nationwide H2 infrastructure for mobility	**China:** total public investments H2 industry: 12.5 bn€ New Energy Vehicle investments in H2 energy & FC vehicle industry exceeded 3.9 bn€ **Korea:** H2 Economy Plan → Korean government will take hydrogen cars' side to become the next economic growth engine instead of the EVs **Australia:** National H2 Strategy	**Europe:** Commission H2 Strategy 180-470 bn € investment in green H2 development and 2x40 GW objective by 2040; **Germany** (9 bn€), **France** (7 bn€), **Netherlands** (3-4 electrolysis plan), **Portugal** (7 bn€)
Structuring	**H2 Council**: coalition of CEOs that has the ambition to accelerate their investments in the development and commercialization of the H2 fuel cell sector and encourage key stakeholders to increase their backing of H2 as part of the future energy mix. 92 members including large multinationals, innovative SMEs and investors that represent collectively over €18,9 trillion of total revenues.	**Mission Innovation: led by Australia, European Commission, Germany:** a inter-ministerial global level initiative to accelerate public and private clean energy innovation. - IC8 was launched in 2018 to enable H2 to be cost-competitive in the energy system - March 2019: 80 representatives from governments, industry and researcher community for a workshop on "H2 Valley"	**H2ME:** project that coordinates national programs such as H2 Mobility Germany Deutschland, Mobilité Hydrogène France, Scandinavian Hydrogen Highway Partnership, UK H2 Mobility → first pan European network of H2 refuelling stations → + Electricity – Gas grids coordination

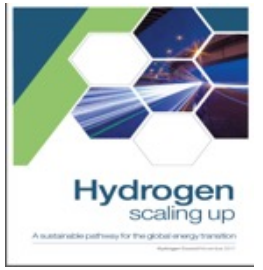
From doubts to a belief that H2-mobility is an add-on to other layers of H2 systems

1) H2 mobility (LDV, Trucks, Trains, Boat, plane, etc.) will be a huge part of mobility (1/12 vehicles in 2030)

➢ *Response 1 : There is no clue that H2 as a fuel will be available at an industrial level for this particular usage, it is more difficult to predict when you take green H2 as target that needs mass P2G.*

➢ *Response 2 : Lot of actors of this ecosystem are not aligned because of the amount of necessary investment.*

➢ *Response 3 : Territorial dynamics are far too different to establish this kind of observation (energy, cities, mobility…)*



On mobility

2) The H2 ecosystem will create positive synergies either externalities within all the industrial sectors :

➢ *Industrial coupling matters: In a given territory, which are the leading industries? H2 as a "fuel » requires upstream market to develop.*

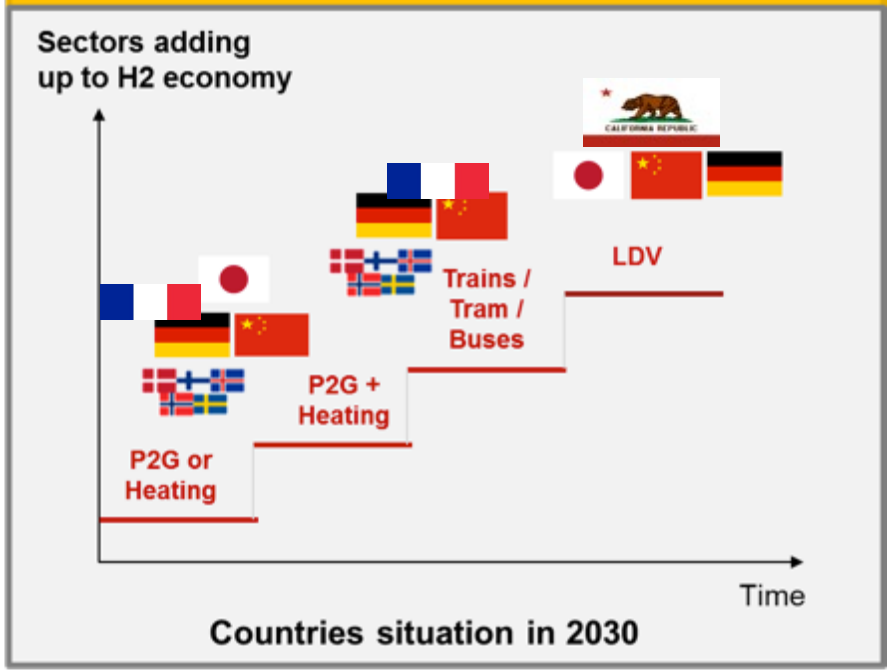
Ecosystem

3) Annual CO2 emissions could be reduced by 6 Gt in 2050

➢ *Compared to global emissions it is relatively small : less than 1% of the total energy consumption in the transportation sector*

How big is « big »?

Hydrogen mobility requires an **infrastructure** than can only be amortized if a **multi-sectorial hydrogen economy** is set-up based on industry



- **Complex Eco system to be implemented**

Sustainable production / diversity of demand from Industry -> Mobility

  - ✓ **2025**: Drivers for early rise of H2-economy
    - ➢ Power-to-H2 and Building
    - ➢ Heating sectors
  - ✓ **2030**: H2-Mobility sustainability KPIs
    - ➢ **Fuel availability for mobility ?**
    - ➢ **Green H2 ?**

- **Consortium needed**
  - ✓ Public (ambition, subsidy, commitment) / Private => Infra
  - ✓ **Across major markets => 1% of sales on some markets by 2025 / 2030**

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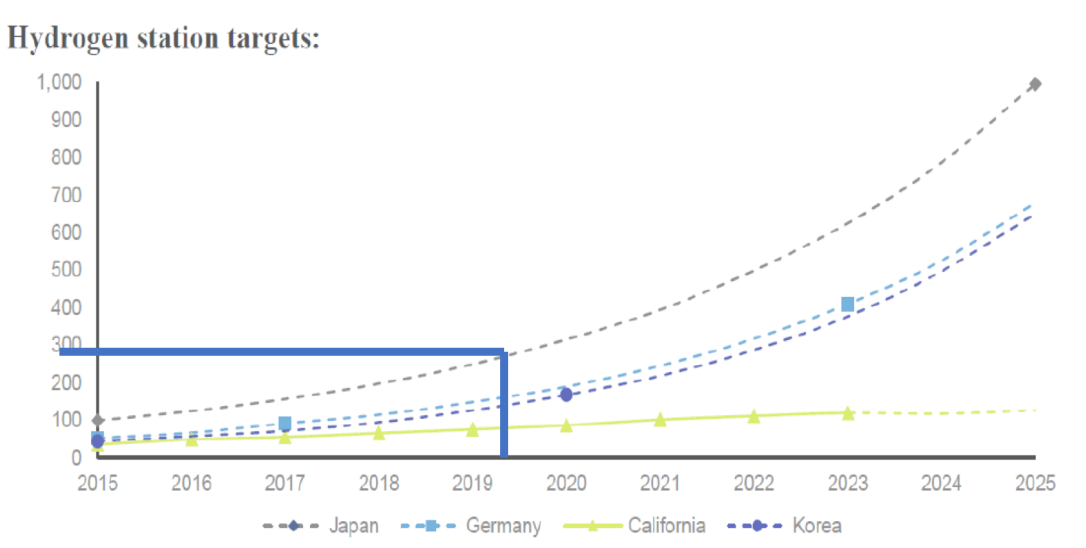
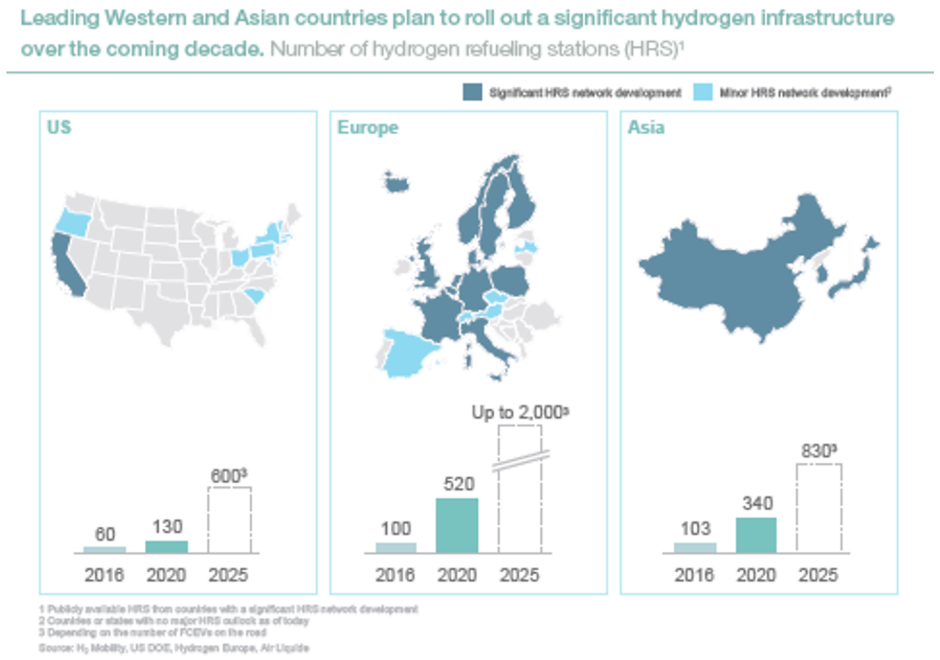
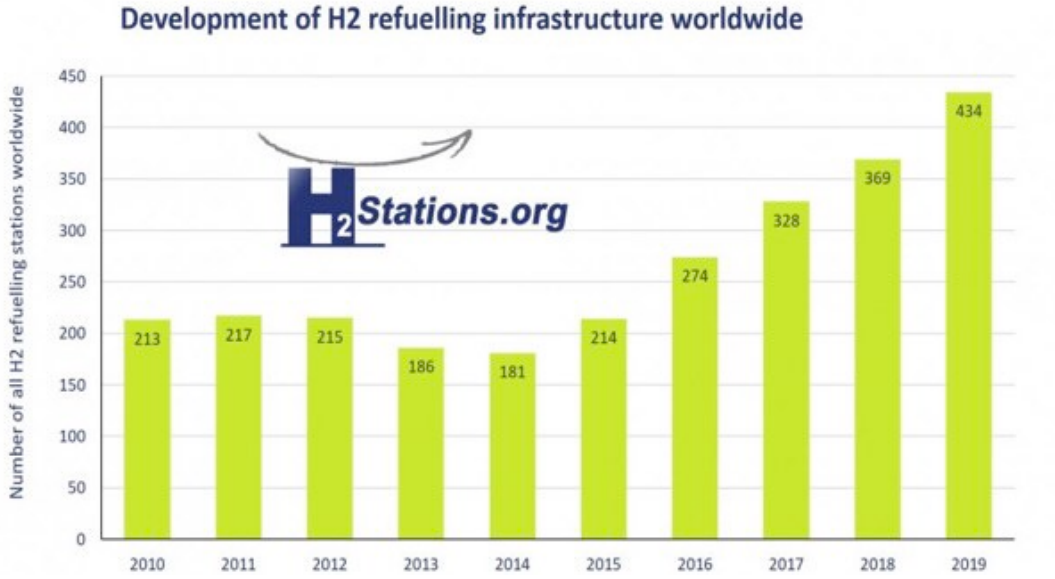
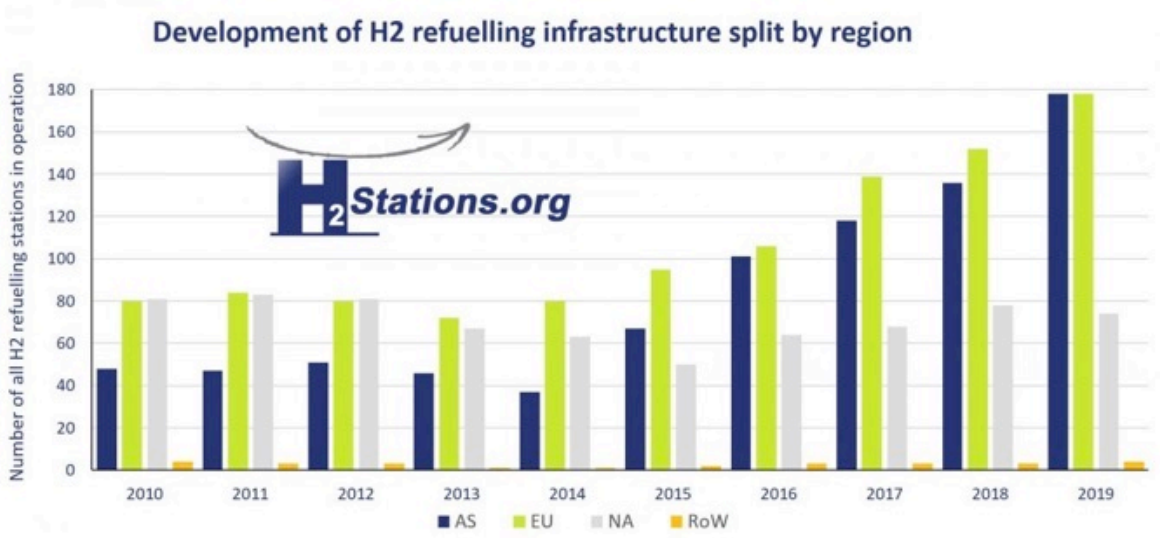
Continued KPIs on light H2 mobility

Hydrogen Recharge Stations – It didn't happen as fast as wished, though they rise

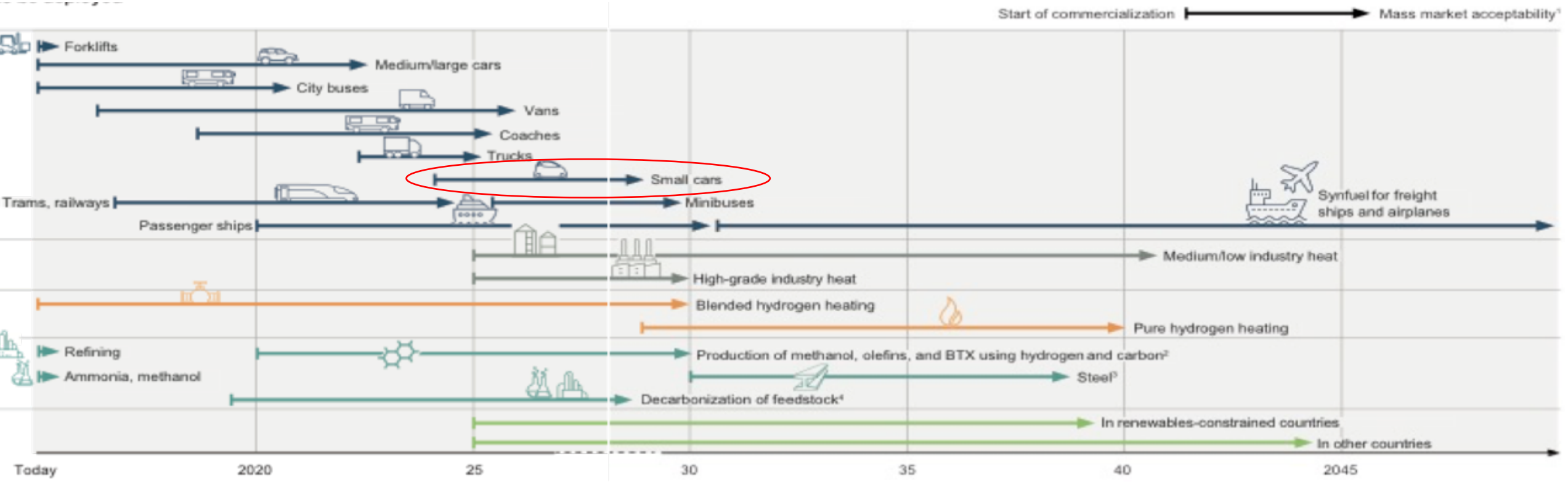




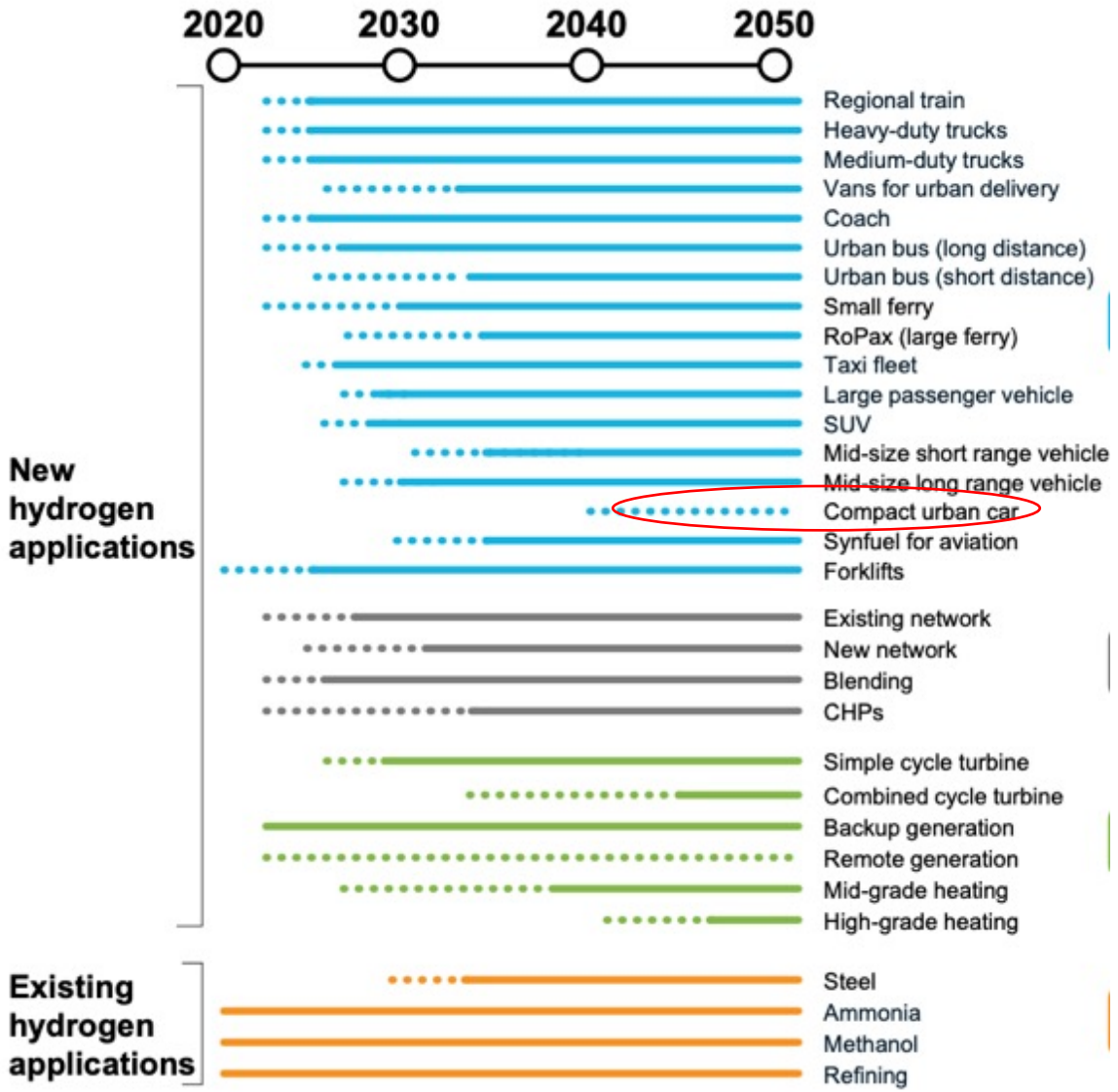




Hydrogen Council's views on Light vehicles have been pretty unstable !
LDV to have "mass market acceptability" before 2025 (2018 view)

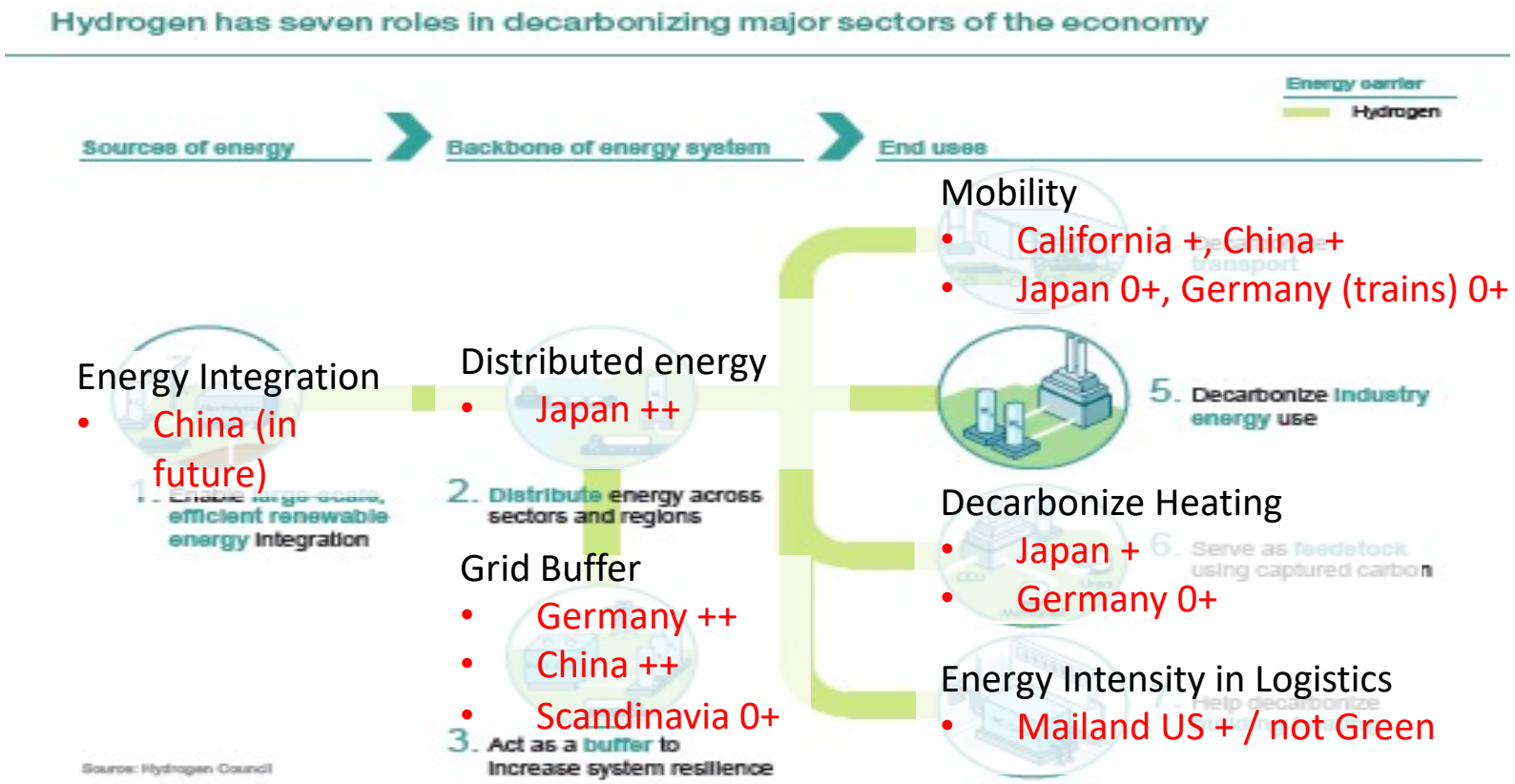


Hydrogen Council's views on Light vehicles have been pretty unstable !
Or LDV not cost competitive even by 2050 ? (2020 view)

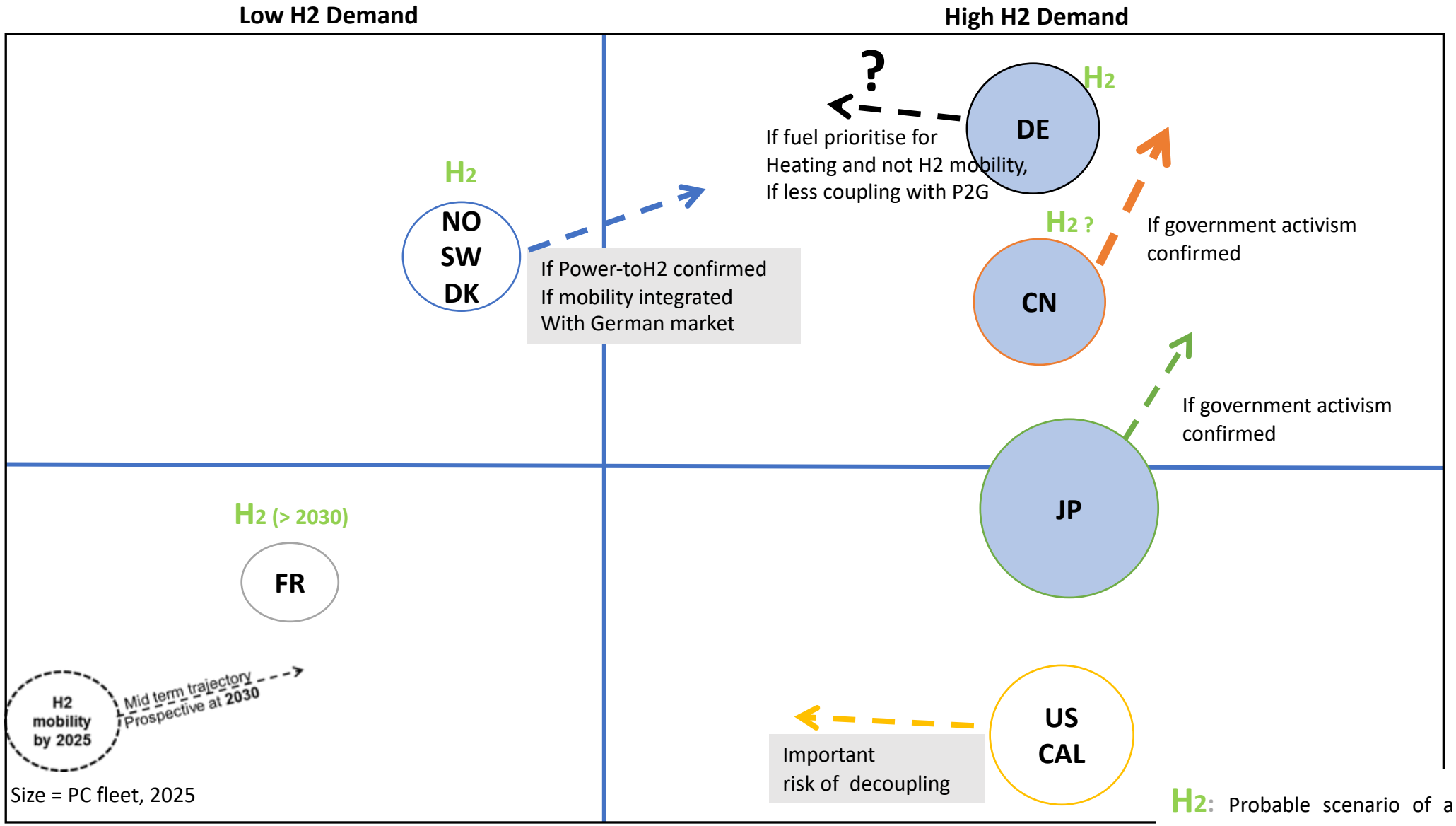


Tools 1 – Mapping the “real starters” – ecosytems are neither complete nor similar across geographies

Possible uses of H2 → **Observed early adopters**

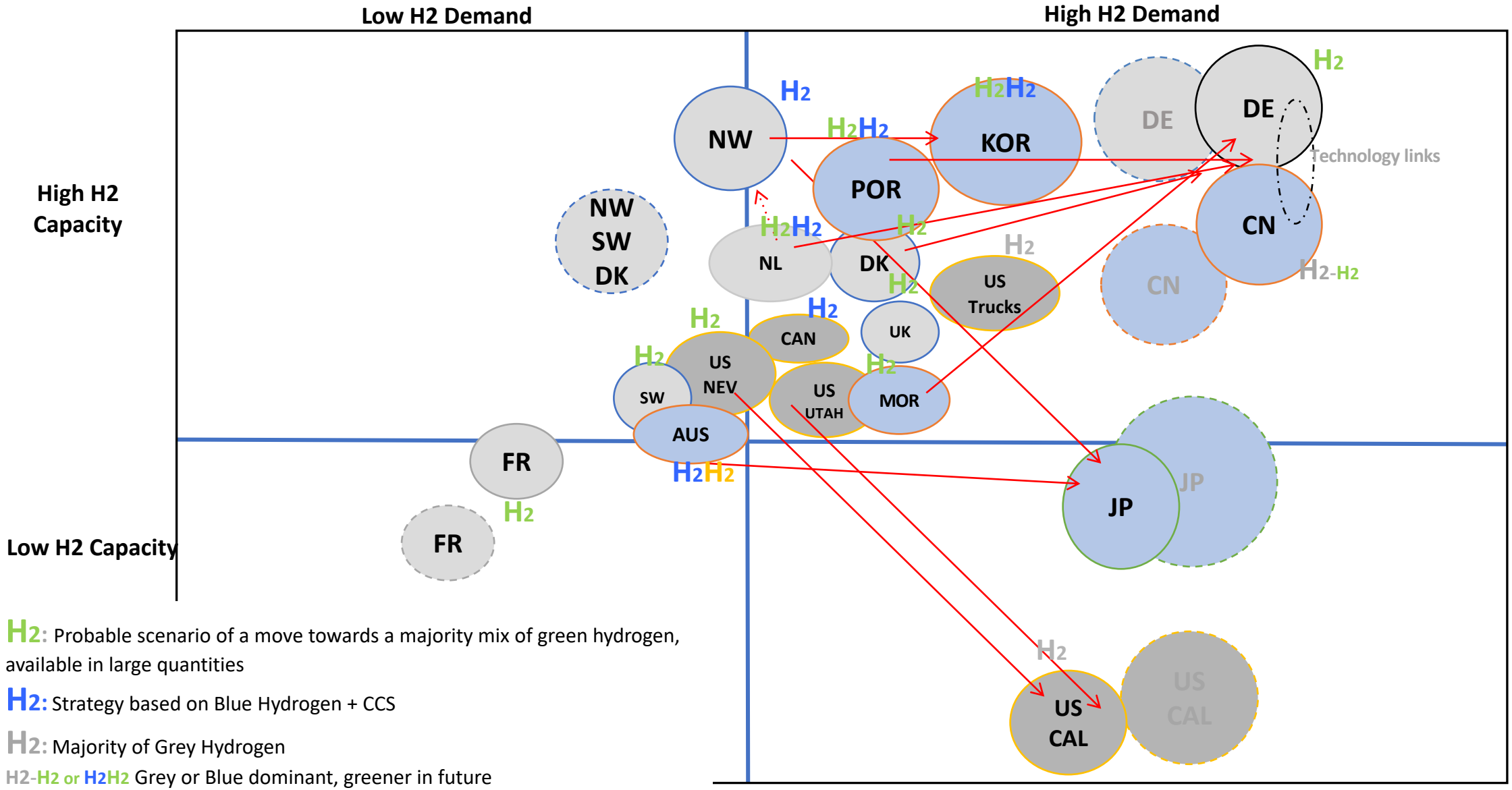


Tools 2 – Hydrogen: Market coupling by countries (2018)



H2: Probable scenario of a move towards majority mix of green hydrogen, available in lar quantities

Tools 2 – Market coupling by and across countries – (updated 2019 – 2020)



H2: Probable scenario of a move towards a majority mix of green hydrogen, available in large quantities

H2: Strategy based on Blue Hydrogen + CCS

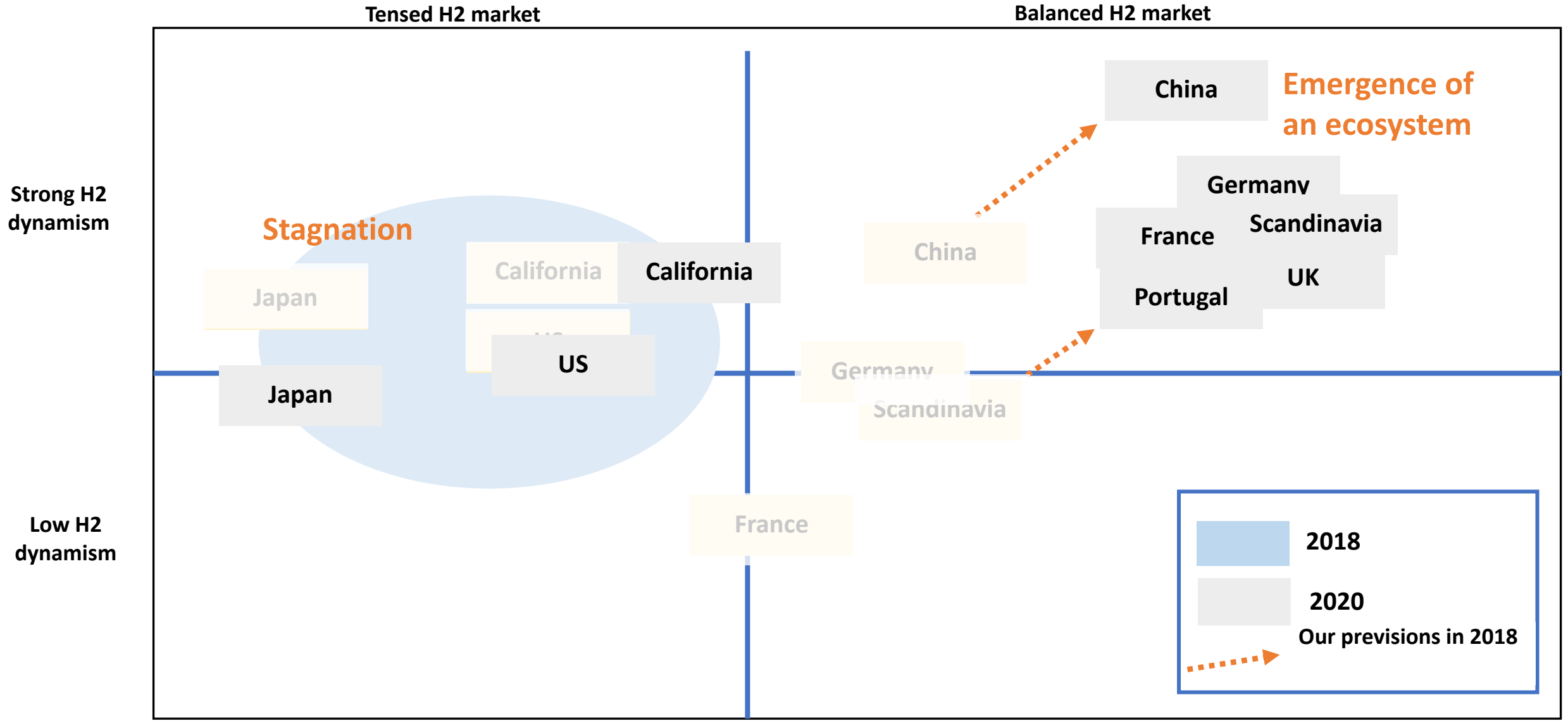
H2: Majority of Grey Hydrogen

H2-H2 or H2H2 Grey or Blue dominant, greener in future

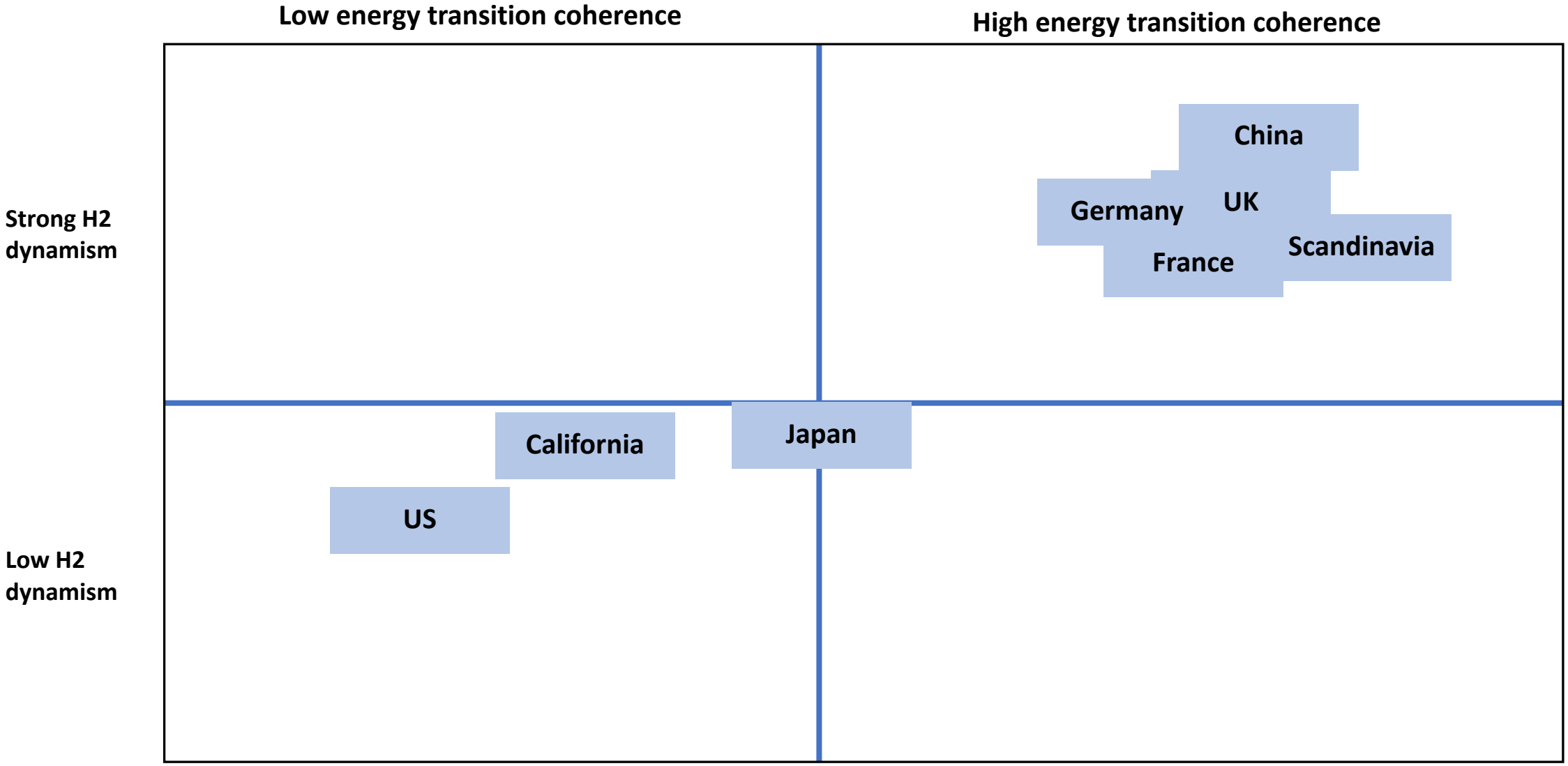
→ H2 Exports

⇢ Captured CO2 Exports

Tools 3 – Market balance vs. ecosystem dynamism from 2018 to 2020



Tools 4 - H2 ecosystem coherence vs. energy transition coherence (2020)



Necessary Condition - Hydrogen: Greening Synthesis by sourcing

Scenario perspective of Type of H2 and its availability			
Country\Horizon	**Current**	**2025**	**2030**
China	22Mt 100%grey H2	↗ 1Mt 95%grey H2	↗ 41Mt "50%green" H2/H2
Japan	0,2Mt 100%grey H2	↗ Prod multiplied by 19 H2	↗ Prod multiplied by 74 H2?
California	100%grey H2	= H2	= H2
Germany	est.1-2Mt 95%grey H2	↗ H2/H2	? H2
Scandinavia	est.0,5-1Mt 95%grey H2	↗ H2/H2	? H2
France	1Mt 95%grey H2	= H2	? H2/H2

China: 50% green for additional capacity
Japan: Green depends if sourced in Scandinavia or Australia
California: might import green from Asia?

Germany/Scandinavia: green if renewable P2G is confirmed
(investment + increase of total capacity in electrolysis)
France: based on 50% green announced by Air Liquide

H2 : The main production/imports is considered as grey

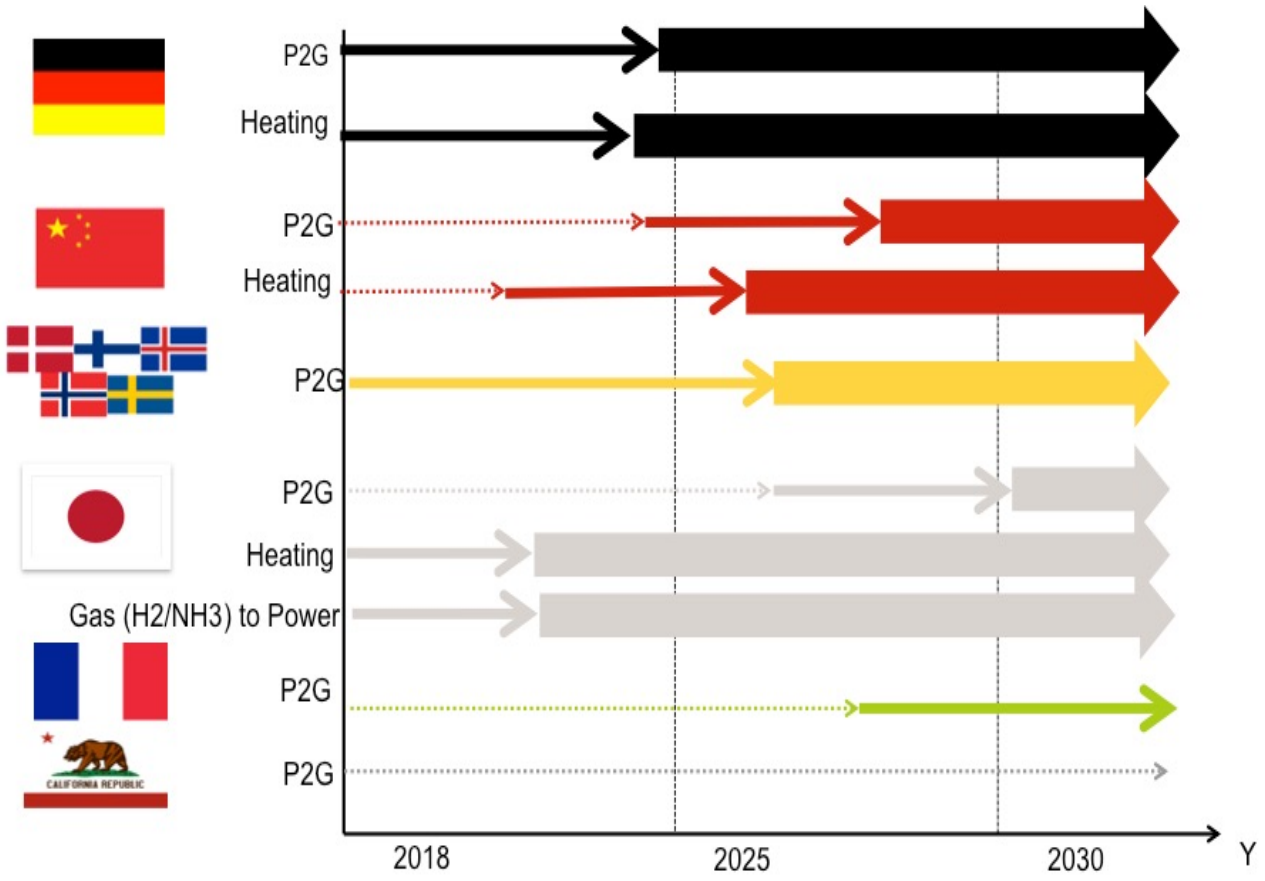
H2/H2 : Probable transition shift to green hydrogen

H2: Probable scenario of a move towards a majority mix of green hydrogen, available in large quantities

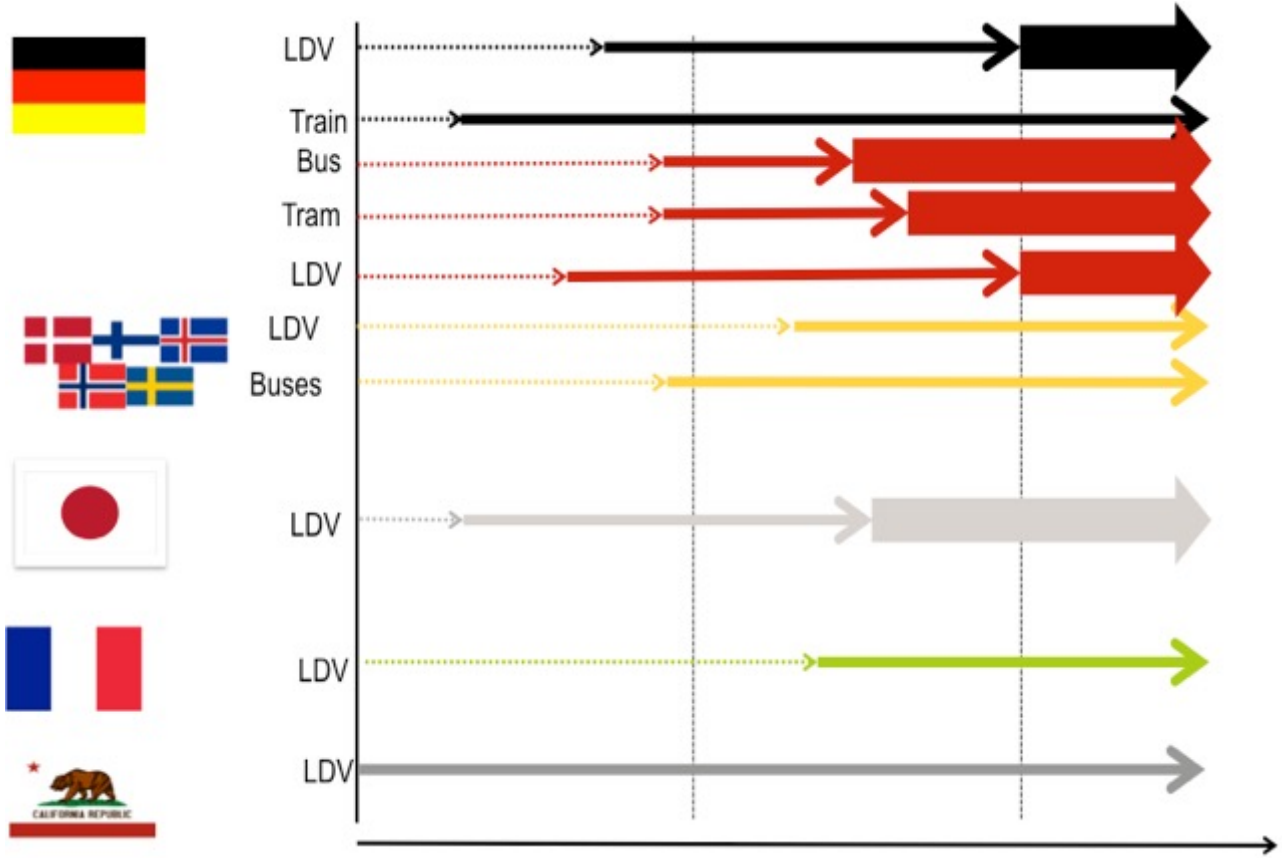
↗ Important increase of H2 production either importation

= No sign of increase or stagnation of H2 production either importation

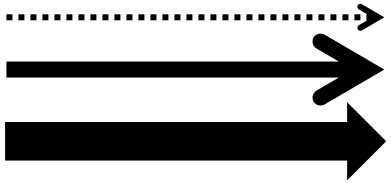
Synthesis of roll out sector ramp up by countries : P2G (*Power to H2) & **Heating** sectors*



Synthesis of roll out sector ramp up by countries : *H2 mobility*



Source: Expertise
- Intelligence over Policy/subsidy/infrastructure
- Lkeliness assessment
- Stylisation with innovation diffusion steps:



Pilot and prototype
Early adoption (no scaling effect)
Mass market and industrialization

Light Passengers Hydrogen mobility Plans by country – 1 / 2 some early adopters by 2025, unclear massification by 2030

		Japan	China	California	Germany	France	Scandinavia	South Korea
FCV	**2018** total in thousands	2 *(2020: 30)*	1,4 (2019: 6,2)	3 (2019: 8,3)	0,2	0,1	<0,2	0,9
	% FCV/stock pass. Cars	0,0032%	0,0007%	0,006%	0,0004%	0,0003%	0,001%	
	2025 total in thousands	**200** ***	50-**100** ***	**50-100** **	**100***	5 (2023) **	**50**-187*	81 **
	% FCV/stock pass. cars	**0,3**%	**0,04**%	**0,3**%	**0,2***	(commercial)	**0,4**-1,5% *	
	2030 total in thousand /	800 **	1000 ***	190 *	400 *	20-50 (2028) *	NA	850 *
	%FCV/stock pass. cars	1,15% **	0,5% ***	1% *	1%	(light		
	% FCV/sales pass. cars	8% #	(select zones)	8% #	8% #	commercial)		

Very non-homogeneous data quality…

*** Very Reliable

** Depends on:

- effective deployment (Japan & China 2030)
- or at risk because of week H2 Capacity-demand coupling
- Unreliable lobby data For FCV (to nuanced their figure, we propose an approximate range)

Hydrogen Council Report

By 2025, California, Germany and Asia have articulate plans (Norway mostly not for mobility)

By 2030, Only China and Japan have foreseeable and articulate ambitions for H2 mobility

Light Passengers Hydrogen mobility Plans by country – 2 / 2

Inconsistencies remain for HRS deployment by 2030 **– Scandinavia & France have too low a FCV/HRS ratio**

	H2 – LPV – HRS	Japan	China	California	Germany	France	Scandinavia (Norway)	South Korea
FCV	**2018** total in thousands % FCV/stock passenger cars	2 0,0032%	1,4 0,0007%	3 (2020: 7) 0,006%	0,2 0,0004%	0,1 0,0003%	<0,2 0,001%	0,9
	2025 total in thousands % FCV/stock passenger cars	**200** *** **0,03%**	50-**100** *** **0,04%**	**50-100** ** **0,3%**	**100** ** **0,2%** **	5 (2023) ** (commercial)	**50**-187* - NW fuel for 100 **0,4**-1,5% *	81 **
	2030 total in thousand / %FCV/stock passenger cars % FCV/sales passengers cars #	800 ** 1,15% ** 8% #	1000 ** 0,5% **	190 ** 1% ** 8% #	400 * 1% 8% #	20-50 (2028) * (light commercial)	NA	850 *
HRS	**2018** total stations **2020** total stations (nb. of FCV per station)	90 160 25	20 100 72	31 60 (2019) 96	60 100 33	20 >40) 5	25 8	24 (2019) 37
	2025 total stations (nb.of FCV per station)	320 *** 625	300 *** 166	200 *** 500	400 *** 1250*	100 (2023) * 50	40 *** NA	310 **
	2030 total stations (nb.of FCV per station)	900 ** 890	1000 ** 1000	NA	1000 * 1000	400-1000 * 20 (2028)	100 ** NA	520 *
ICE	**2020** total stations	30,000	110,000	10,000	15,000	11,000	4,300	11,000

*** Very Reliable ** Depends on industrial conditions * Unreliable lobby data

GLOBAL HYDROGEN SWOT 2025
How to industrially Move from Early Adoption to Scaling up Plans

S

Deepening political will (China, Japan, S. Korea, Europe)
Accelerating investment (Europe, China, USA, Australia),
Converging Regulation (in Europe)
Clarification of policies (California, Australia),
New countries projects (Morocco, Spain, Italy, Portugal…)

Key driver 1 : oil&gas companies for their diversification strategy
Despite a large technological variety, hydrogen economy is getting structured

O

Rising number of mature scaled-up projects electrolyzers but structure gap on output:
KPIs: Technological &industrial advance in the P2G field + synch with energy transitions
Optimisation of wind+solar capacities (China, Germany, Morocco)
Energy transition (Norway, California+Utah+Nevada, Japan), H2-bio-technologies S.Korea
Driver from energy intensive industries: steel (Europe China),cement (Spain)
Grid-Gas integration in Northern Europe-Germany-Italy
Rising number of mature scaled-up projects : higher potential for industrial coupling
Global optimism on Electrolyzers capacity increase and electrolysis cost decrease

S - H2 mobility:

Successful experiments in trains & trams (Germany, France, Scotland);
Large projects on trucks (USA, Germany Switzerland, Central Europe),
Many pilot projects in buses (Europe, China), Fast adoption in logistics (USA)

0 - H2 mobility:

New policy of H2 mobility in China that emulates the 2009 electric mobility policy
The overall acceleration of Green H2 production is a positive move for H2 mobiiity
HDV more profitable than LDV; global consensus on freight use

W

Risk of disconnect between fast growing industrial / inter-grids (electricity-gas) uses and slow growth domestic / heat / mobility uses : a « sector » still fragmented
Green H2 still depends too much on Electrolysis cost curves hypothesis

T

Fragmentation of structuring across different uses could limit market couplings
(which already is not a “natural market-commodity” as it has different technologies)
Geopolitical threat for French companies on Canada-Germany-China business alliances.

W - H2 mobility:

Regulation is unclear in nearly all territories (with exception to California, recently Europe)
Limited investment by car makers except in Asian geographies
Electrolysis cost + grey-green H2 mixes in gas grids first movers: entry barriers?

T - H2 mobility:

Green H2 availability to be checked for mobility in a context where H2 is increasingly linked to large RE-power-to-grid or heavy industry driven investment;
Fair access regulations will be key.

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B – Current Industry Structuring

Focus on Europe & China
Issue of Costs of Electrolysis

From Mission Innovation recognising the role of H2 in the energy transition…

Mission Innovation:

An inter-ministerial global level initiative to accelerate public & private clean energy innovation to address climate change, make clean energy affordable to consumers, create green jobs &commercial opportunities.

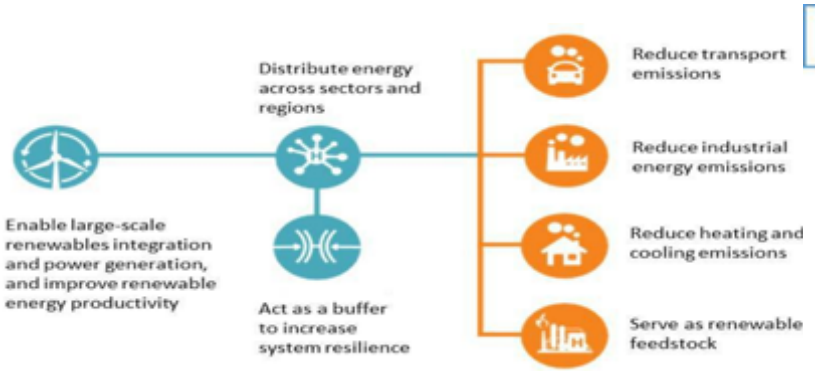
Announced by Bill Gates at COP21 on stage with Obama, Hollande and Modi.

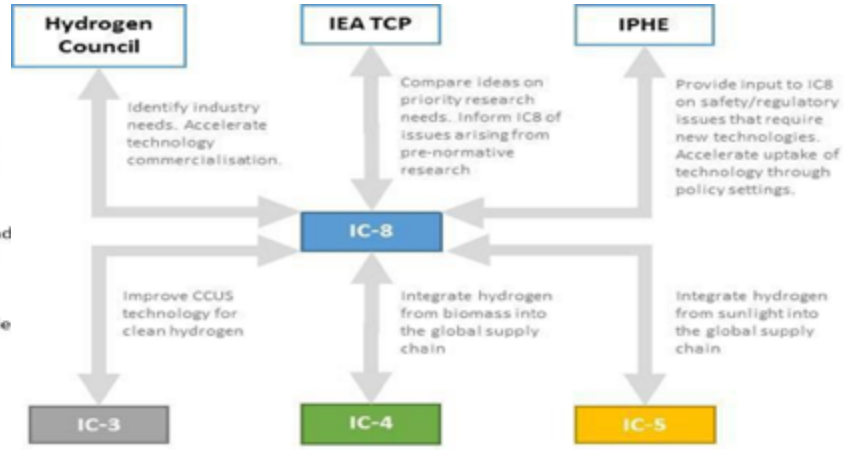
At the launch, 24 countries committed to double their respective clean energy research and development over the five years to 2020.

The eight Innovation Challenges :

1. Smart Grids –enable future powered by affordable, reliable, decentralised renewable electricity systems
2. Off-Grid Access to Electricity – develop systems that enable off-grid households and communities to access affordable and reliable renewable electricity
3. Carbon Capture –enable near-zero CO2 emissions from power plants and carbon intensive industries
4. Sustainable Biofuels –develop ways to produce, at scale, widely affordable, advanced biofuels for transportation and industrial applications
5. Converting Sunlight – to discover affordable ways to convert sunlight into storable solar fuels
6. Clean Energy Materials – to accelerate the exploration, discovery, and use of new high-performance, low-cost clean energy materials
7. Affordable Heating and Cooling of Buildings – to make low-carbon heating and cooling affordable for everyone
8. Renewable and Clean H2–accelerate the development of a global H2 market by identifying & overcoming key technology barriers to the production**, distribution, storage, and use of H2 at gigawatt scale**

- **And who pilots this? …**

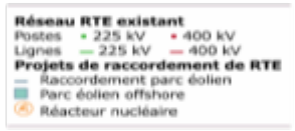


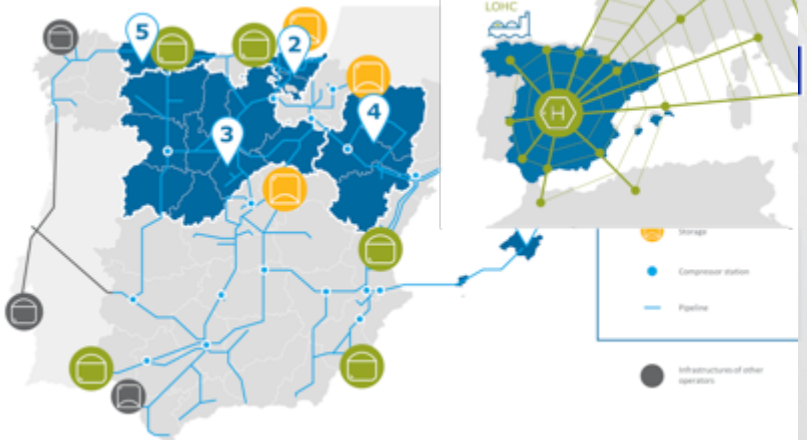


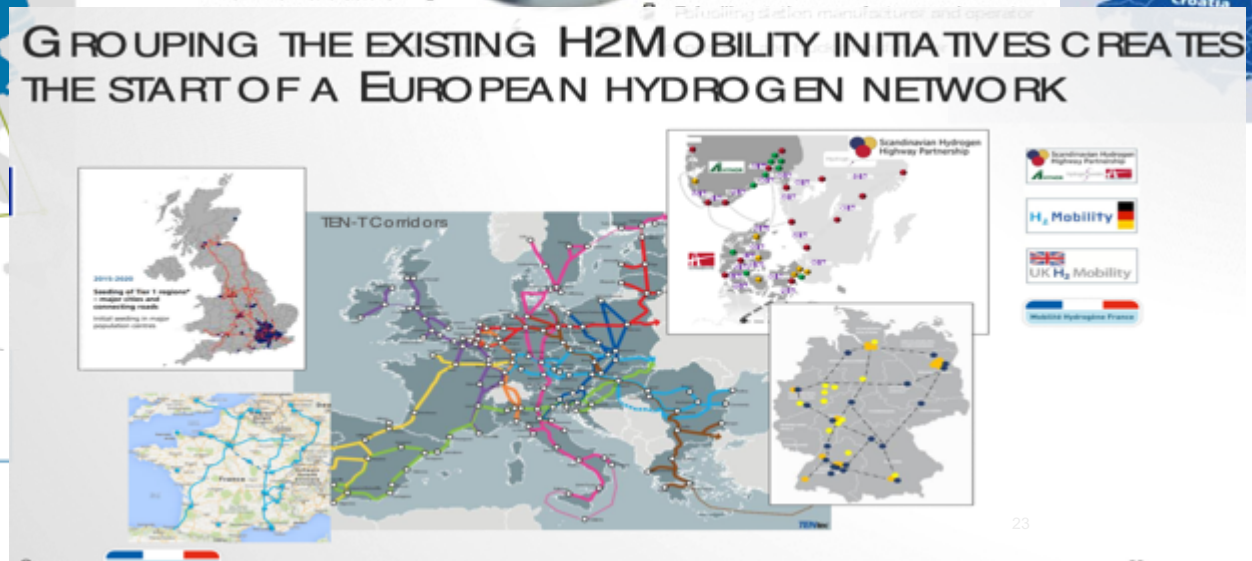
… to an array of projects that increasingly connet with eath others…

GERMANY - BP, RWE, chemicals producer Evonik and gas grid operators have signed a MoU for Germany's first network (130km) of green H2 with industrial customers by the end of 2022.

Sur le littoral de Normandie et Hauts-de-France, à l'horizon 2025 :
- *Production éolienne en mer et nucléaire : ~115 TWh*
- *Consommation : ~75 TWh*







… to the EU's 2020 Hydrogen Plans

EU strategy

180-470 bn € investment in green H2 development - 2x40 GW (EU, neighbour countries) objective 2040
Investments will be phased in 3 priority category :

Phase 1
2020-2040
Decarbonise H2.
6GW electrolysers
1m ton of RE H2
chemicals, HD
transport

Phase 2
2025-2030
H2 in integrated energy
system
40GW electrolysers
10m t RE H2
steel, power-to-gas

Phase 3
2030-2050
Massive H2
Deployment
all hard-to-
decarbonise sectors

Member states plans

Portugal
7 bn€ in RE-to-H2
Objective : 5% in transport energy mix in 2030

Germany
7 bn€ in RE-to-H2 in 5 GW electrolysis plan in + 2 bn€ in Morocco & Ukraine
Bavaria : ordered 100 H2 stations.

The Netherlands
3-4GW electrolysis plan
Highly incitative tariff and subsidy scheme.

France
7 bn € in green H2 as part of the recovery plan.
Leveraging previous investment at regional level and targeting IPCEI projects.

European regulation convergence :

- **Gas regulators** from France, Germany, Switzerland, Benelux, Austria issued common **regulation convergence strategy for H2 injection in NG network and H2 dedicated network**
- **H2 North-South** valley project from the Netherland to Northern Italy passing by Rhin and Rhone valleys.
- **Framework for common industrial and R&D projects** developed by the Commission and the alliance for H2 **: IPCEI scheme.**

Other European H2 initiative

- **Italy :** large-scale 10% H2 injection tests undertaken by historical monopoly SNAM.
- **Spain :** strong political support towards H2 investment with cross-border initiative with Portugal and H2 valley with Germany and the Netherlands
- **Weak signals** of support in Czech Republic and Poland

Germany - H2-mobility – critical discussion of the German Plan within European context

Germany
7bn€ in RE-to-H2 in 5GW electrolysis plan in Germany + 2bn€ in Marocco and Ukraine
Major concrete action in Bavaria : ordered 100 H2 stations.

National plan leverages historical dynamics…

- Regional and local historical public investments : stations, FC fleet, trains, trams
- A national combined efforts in R&D accompanied by Fraunhofer institutes and commitment to EPCEI projects
- A mature négociation between the Federation, Landers and municipalities to foster a rapid deployment

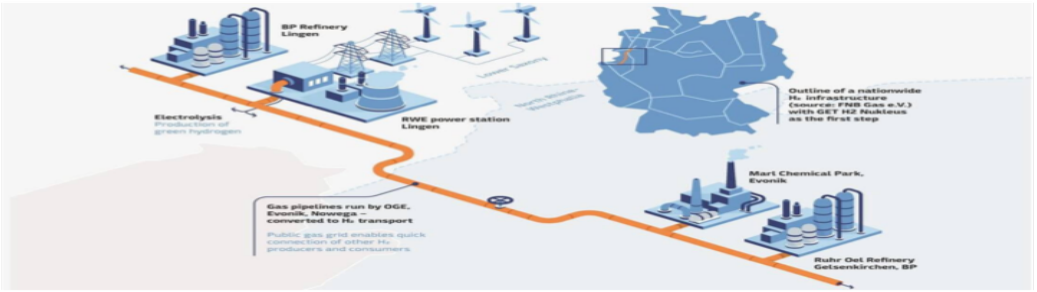
… and industrial major reconfiguration in energy-intensive industries

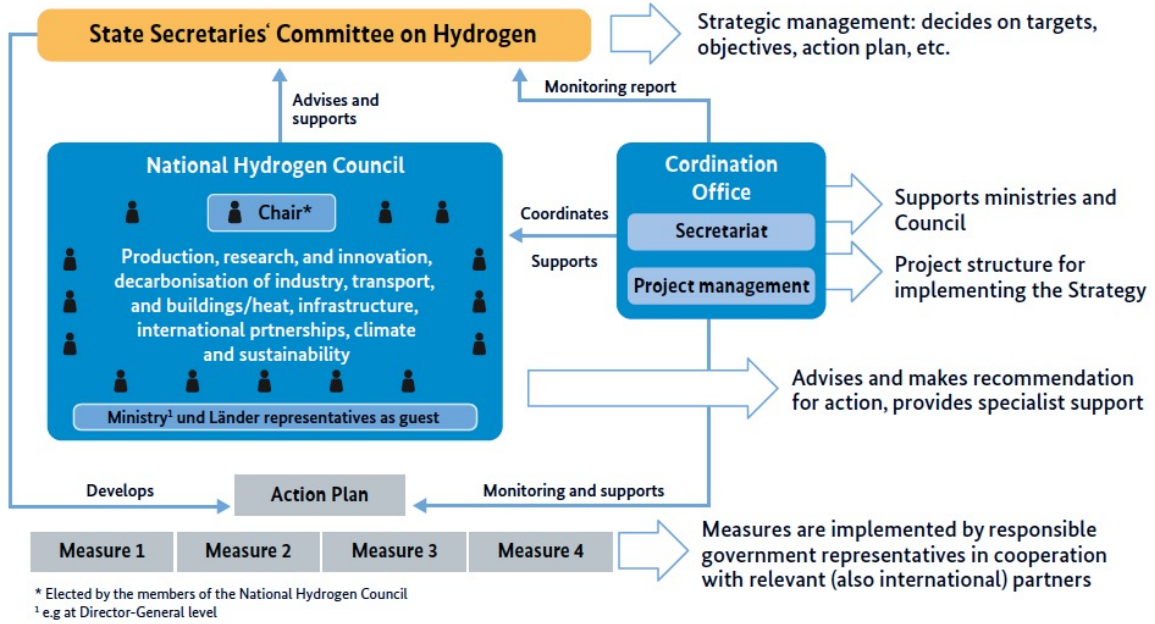
- Major utilities wish to fin new assets to rebounce **after coal phase-out**
- Reduce carbone emission for **steel** industry and **chemicals** (ammonia) in the wake of the ETS reform

Regulation for H2 distribution and injection in natural gas ready for territorial deployment

- Strong territorial support for H2 North-South valley with dedicated pipeline from the Netherlands to Northern Italy

- GERMANY - BP, RWE, chemicals producer Evonik and gas grid operators have signed a MoU for Germany's first network (130km) of green H2 with industrial customers by the end of 2022.





France - H2-mobility – critical discussion of the French Plan within European context

France's national H2 plan
7 bn € in green H2 as part of the post CoVid recovery plan.
Leveraging previous investment at regional level and targeting IPCEI projects.

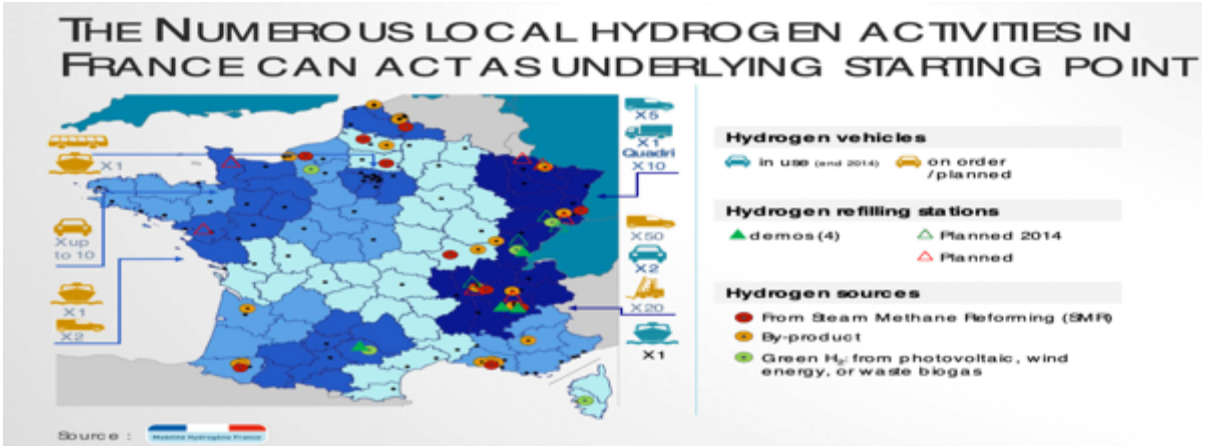
National plan leverages historical dynamics :

- Industrial commitment from industrial champions (AirLiquide, Engie)
- Regional commitment through pilots and innovation programme

Both dynamics are regrouped in the Aphypac's lobby plan

Aphypac Overview: an overtly optimistic plan… with disputable ground

- The plan for mobility builds on the idea that on-site H2 production becomes competitive at distances greater than 150km from industrial H2 production sites
- And that therefore one could see a growing onsite electrolysis production serving an organic growth of HRS networks
- Break-even point would be 2027 according to the plan which is … a long road to go !



Other Current Gaps:

NO DETAILED UPDATE YET SINCE THE EU PLAN
NOT INTEGRATING RTE STUDY ON NUCLEAR TO H2

New major innovation project are undertaken under IPCEI:

- Symbio (Michelan & Faurecia) in collaboration with MINES ParisTech (top quality data)

SYMBIO
MICHELIN
faurecia inspiring mobility
MINES ParisTech
PSL

Our China 2018 analysis - Strategic positioning of the country and possible trajectory scenarios
- good potential coupling and strong political will to lead H2 economy development

Country strategy: fast catch up

H2 ASSESSMENT

- 1908 FCV+BUS sold end of 2017; the first 17.4km H2 tram within 2018
- 2025 estimated 50 000 tons H2 for FC industry

Public Policy:

- Political will: high
- Vision: Clear
- $159M public invest by 2017; 2017 total private invest $6.3 billion
- H2 station subsidy at almost 50% of total cost

ENERGY-H2 NATIONAL LOGIC

- Replacement of coal/petroleum energy
- Pollution reduction
- Buffer for renewable energy
- Decarbonation
- Industrial restructuring

COUPLING

H2 Capacity (+)
vs.
H2 Demand (+)
⇒ **Type of coupling: industry+environment (-Coal) (-GHG emission) (+Clean energy) (+Clean mobility)**

H2 capacity: production

Summary
Limited current application, high potential backed by RE, technology bottleneck

Fuel

Production projects key figures:

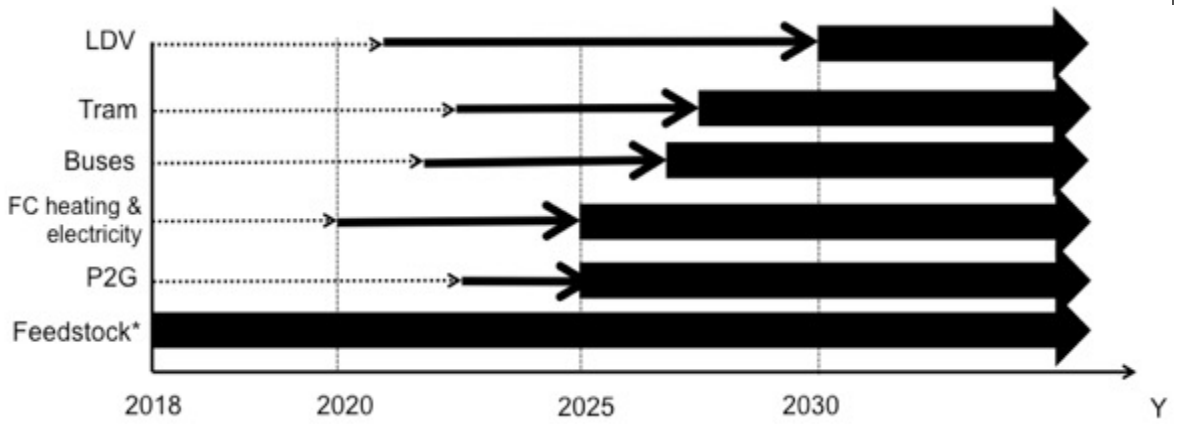
- ✓ 3 P2G pilot projects of 20 MW hydrogen energy
- ✓ 2025 potential share of green H2: 1.98/32=6.2%
- ✓ New H2/reforming projects by mega groups like Shenhua

Extra H2 production as Fuel Availability:

High potential of renewable energy produced H2

H2 consumption / main sectors

Entry mode

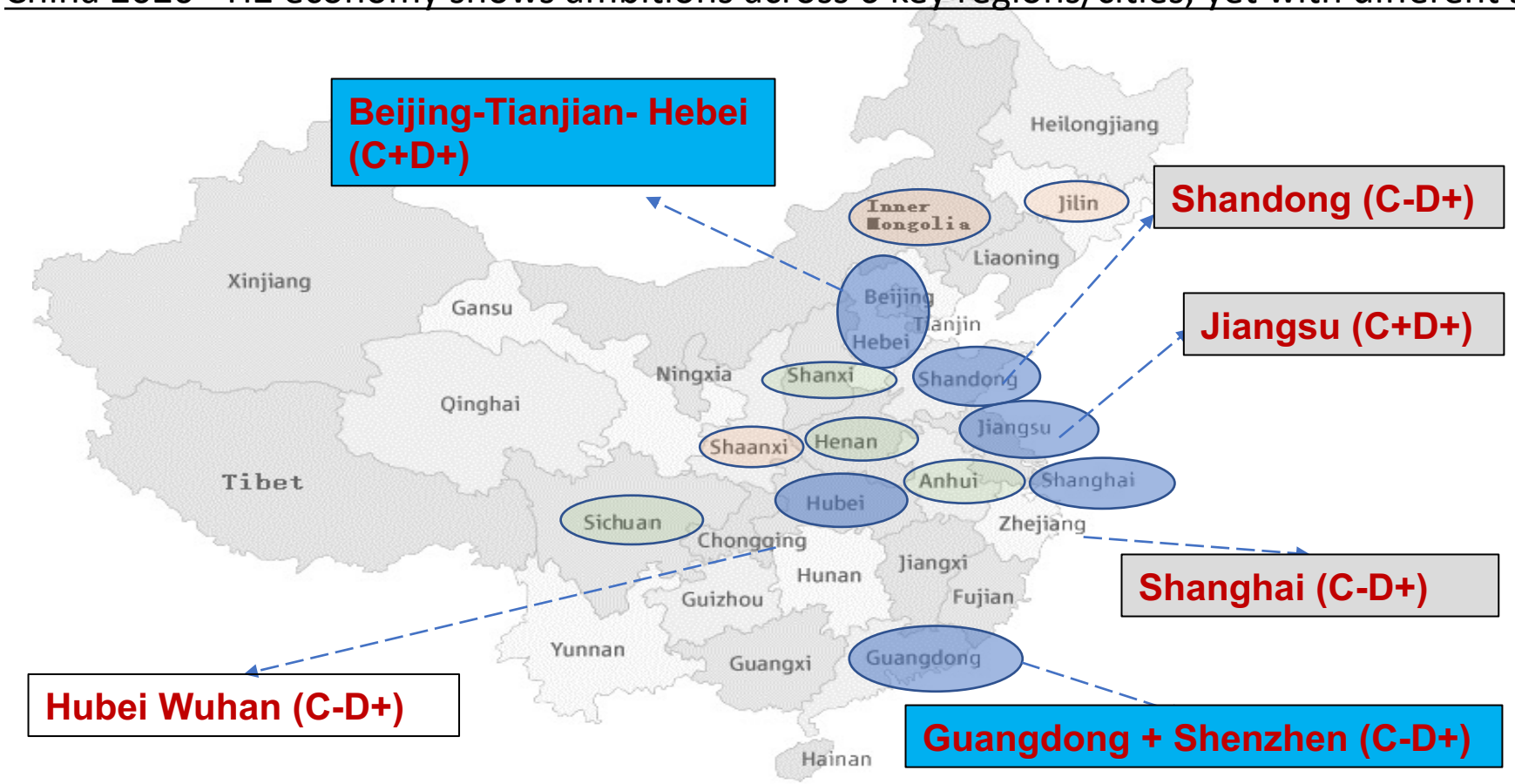


From type of coupling & possible synergies to consequences on H2 Mobility

		2018	2025
Car	Number of Refueling station	20	300
	Number of FCV+BUS	1908	50 000
	Possible synergies/coupling	Coal/petroleum with H2 industry	Renewable with H2 industry

Likely scenario: C+/D+

China 2020 - H2 economy shows ambitions across 6 key regions/cities, yet with different speeds



Tier I: strong resource orientation and overall industrial policy support

- **Beijing-Tianjin-Hebei**: 1 mega H2 industrial park in Zhangjiakou, >20 GW wind+solar to H2 projects; 2022 Winter Olympics, 19 H2 stations, H2 highway; 20 000 FCVs & 114 H2 stations by 2025; BAIC and Sinohytec as leading actors.
- **Guangdong**: 3 H2 parks; Foshan+Yunfu lead the H2 public mobility; 43 H2 stations + >11 110 FCVs by 2025; 70 000 FCVs production capacity by 2025; GAC as OEM leader.

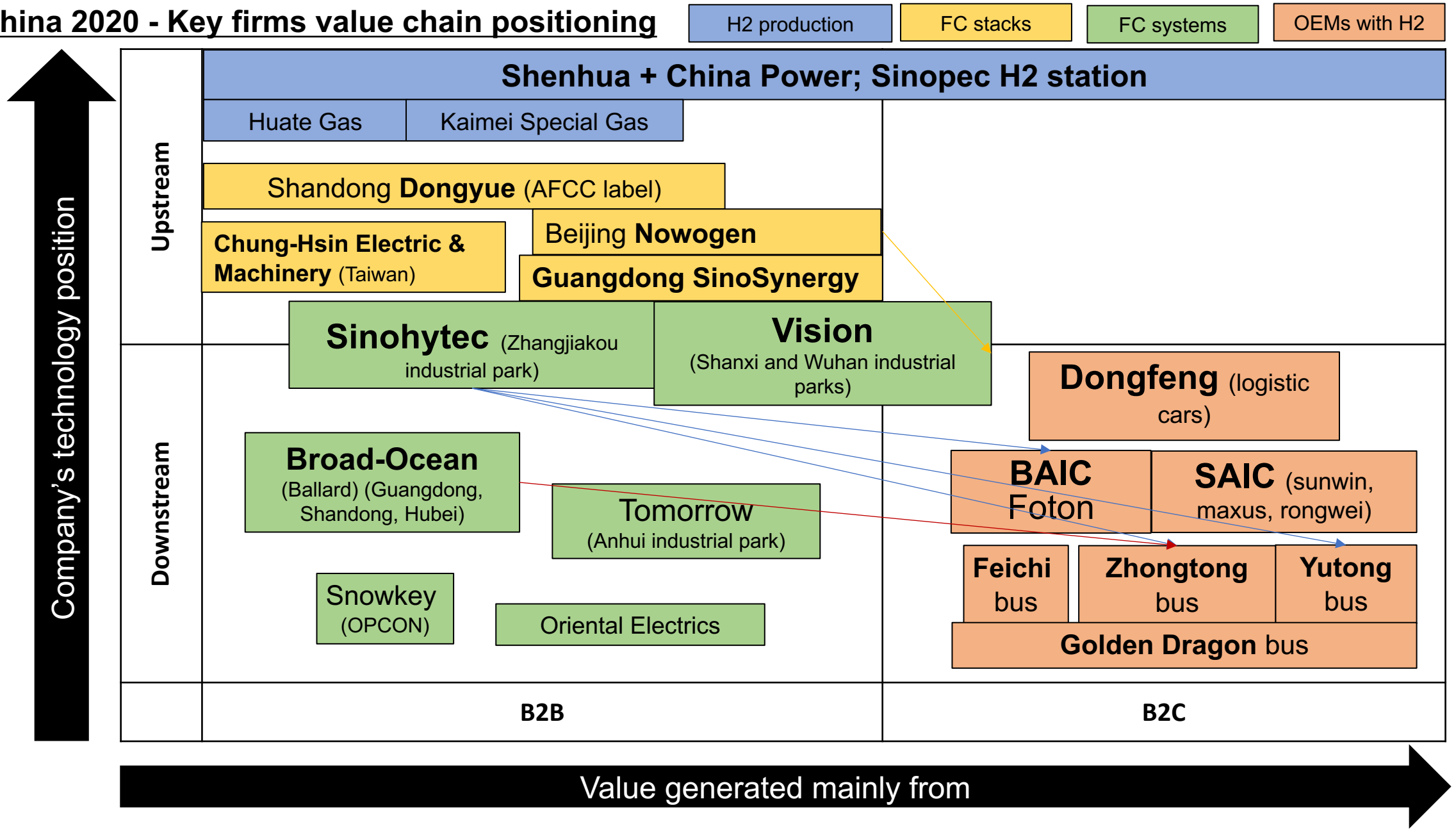
Tier II: declared ambition with less strong industrial execution

- **Shanghai**: first city to declare H2 ambition; target 30 000 FCVs, 50 H2 stations by 2025; SAIC as OEM leader.
- **Shandong**: building 170 km2 China H2 Valley; 200 H2 station by 2025.
- **Jiangsu**: 3 H2 parks; Rugao - the first Chinese ”H2 Economy Model City”; 10 000 FCVs & 50 H2 stations by 2025.

Tier III: development focus on FCV production capacity building

- **Hubei**: Wuhan – building H2 city; by 2025, 30-100 H2 stations, 10 000 - 30 000 FCVs, 1-3 million FCVs production capacity; Dongfeng logistic FCVs.

China 2020 - Key firms value chain positioning



However, challenges remain huge and China is aware

Technology lags and insufficient investment in core materials

- Some important **lags** at different points of the value chain: **basic research, key technologies,** technical standards, testing, certification and supervision systems → recent policy orientation, international cooperation projects
- Domestic investment is mainly **concentrated in upstream** hydrogen production, power reactors & systems, downstream complete vehicles; investment is still **rare in core raw materials** such as catalysts, proton exchange membranes, bipolar plates → slow to catch up, but a few new startups

Infrastructure lags, safety issue and high costs

- The construction of **hydrogen energy infrastructure** does not have a clear status/ clear strategy: issues on demonstration projects for infrastructure such as hydrogen pipe network and liquid hydrogen. → the coming 14th 5-Year Plan will probably set a clearer top-level strategy
- For the current fast-growing FCVs, the biggest bottleneck is the construction of HRS. Due to current safety regulations, **hydrogen stations should be located in the chemical industry area**, limiting their development.

National energy strategy and ecosystem: policy coordination to be observed in future

- Zhong Zhihua, deputy dean, Chinese Academy of Engineering: “it is impossible to build a complete ecosystem of H2 energy industry by enterprises & markets alone; H2 energy should be included in the national energy development plan, & only by strengthening the top-level design can we quickly seize development opportunities.”
- However, **China's “Revolutionary Strategy for Energy Production and Consumption” program regards hydrogen only as a new potential energy technology**, but has not paid full attention for its in-depth development.

KPI : We expect a likely policy-level increase within short term

The making of Hydrogen – Definition and acceleration of a sector over 2017-2021

C – Conculsions

Regional Priorities & KPIs

Territorial Trajectories for H2-mobility –
Strategic Conclusions on learning potential - 2025

- 2025 FIRST DRIVERS – SEPARATE LOGIC IS OK
- POST 2025 RAMP UP – (GREEN)-ENERGY-FUEL-MOBILITY NECESSARY

China
State-led, + large firms

- China has 15 years track record on renewable energies
- China has a 10 years old focus on new energies mobility

- **Wish to be *the* lead market** for both generic H2 and H2-mobility

China 2025, THE first ecosystem to complete by

Japan
State + Tokyo Gas led
Phased but complex policy

- **Driven not by mobility but large generation projects**
- Heating feedstock drive

- Take-off of mobility as a 2nd step from other energy-urban sectors but dynamic car firms and techno leaders

Japan & Europe

Japan 2nd market on mobility may be overtaken by Europe as Infra rises; PKI: Fuel Competition

North West Europe
Increasingly holistic & green KPI: territories integration

- **Pilots – scalability issue**
- **Technological investment by H2-equipment leaders especially in Germany**

- Can be the 3rd or 2nd market for mobility
- **H2-energy mostly for helping greening of grid**

USA California vs. rest
CAL; first H2 LV market
US Firms lead in logistics / heavy duty storage

First market for cars now but served by a Japanese company
Model at risk (subsidies for green elec) even today – mainland US grey H2

- Risk to be dependent market both on technology and green-H2

California: a learning place today, at risk 2030

Mobility as a whole

- **Trucks / buses / trams / trains as a starting point :**
- **volumic energy intensity of H2**

- Slow rise of H2 passenger cars may be predicted by other segments focus

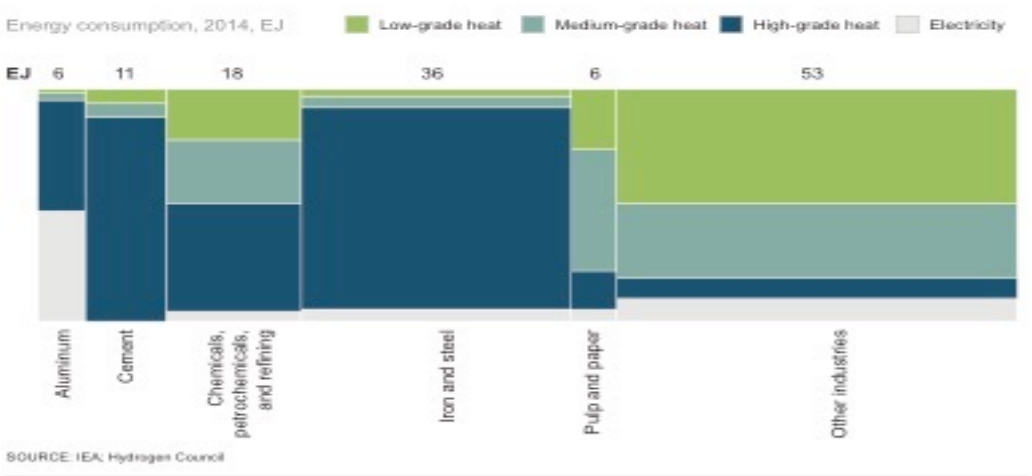
Lobbies and actors: early H2-Electricity coupling but Gas companies might lead

Depending on upstream structuring, several scenarios on H2 availability as mobility fuel

Exhibit 10: FCEVs' fuel costs will fall by 20 to 35% until 2030

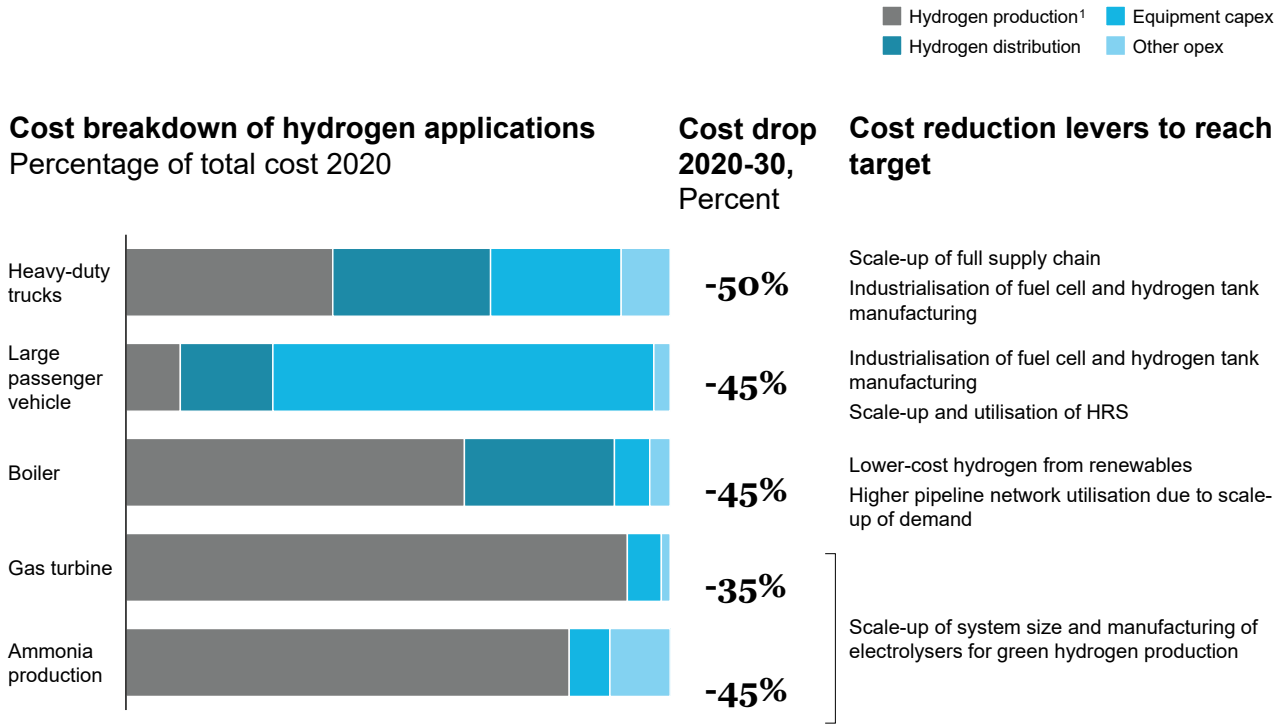
SOURCE: A Portfolio of Powertrains for Europe (2010) [Updated]

Exhibit 15: High-grade heat constitutes a large share of energy use in heavy industry



SOURCE: IEA; Hydrogen Council

Cost curves implicitly depend on upstream processes, infrastructure and whether H2 is captive or meant for fuel



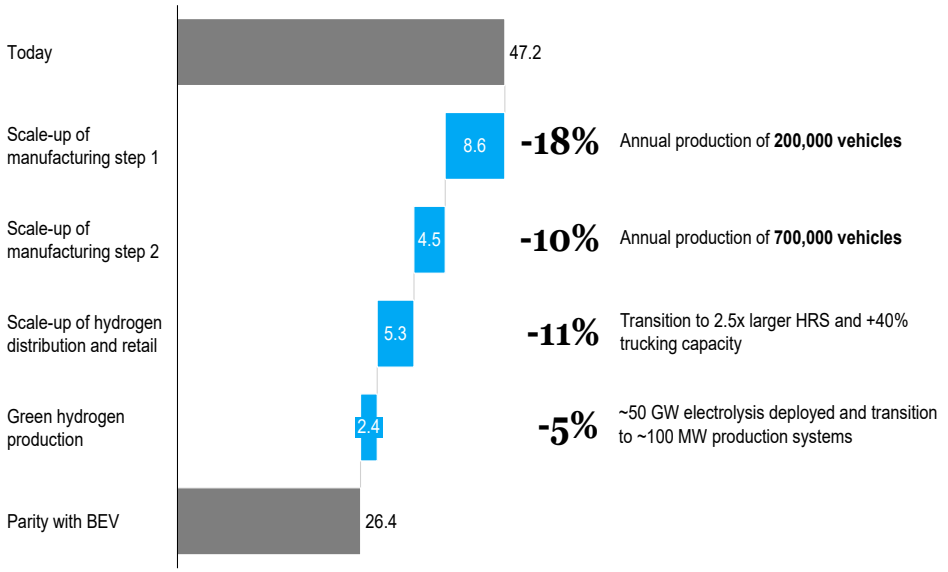
1. Assumes 50/50 blend of low-carbon and average renewable hydrogen

Green H2 & Cost curves : keep following real industry ecosystems

H2 Council pegs H2EV profitability to various non-H2 parameters:

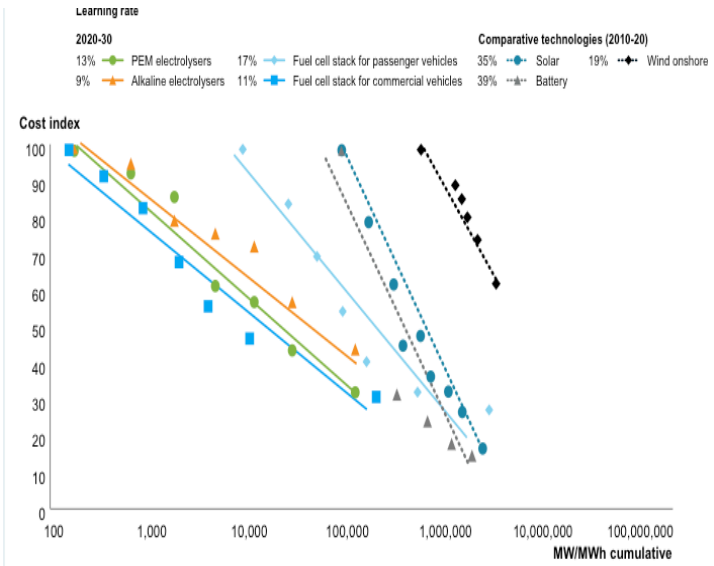
- (i) car industry (700k capacity) 28% impact,
- (ii) stations (2,5x in unit size) 11% impact
- (iii) electrolysis 50 GW in total, 100 MW/ unit) 5% impact

Total cost of ownership
USD cents/km



Insight
Majority of cost reduction in vehicle capex comes from scaling up to 200k annual production; to reach fully parity with full battery vehicles 600k annual production volumes are required.

Electrolysis for green H2: from technology forecast… to territory dependence



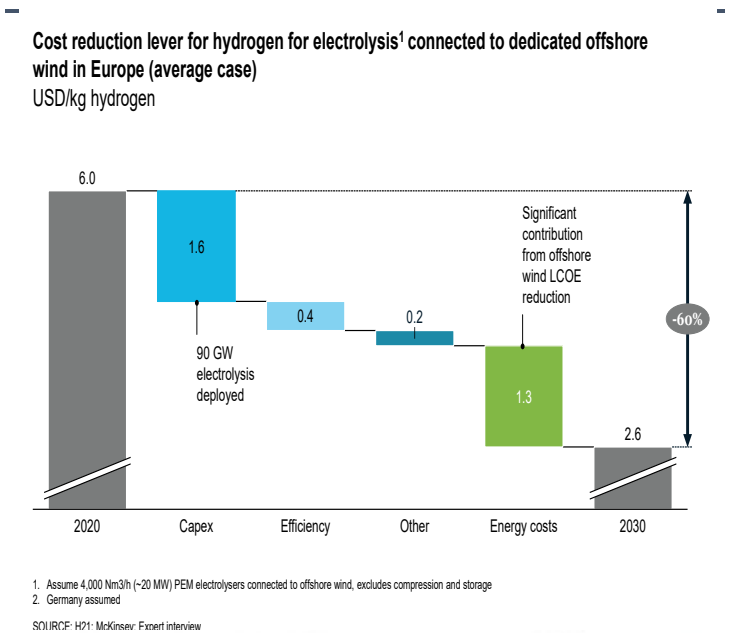
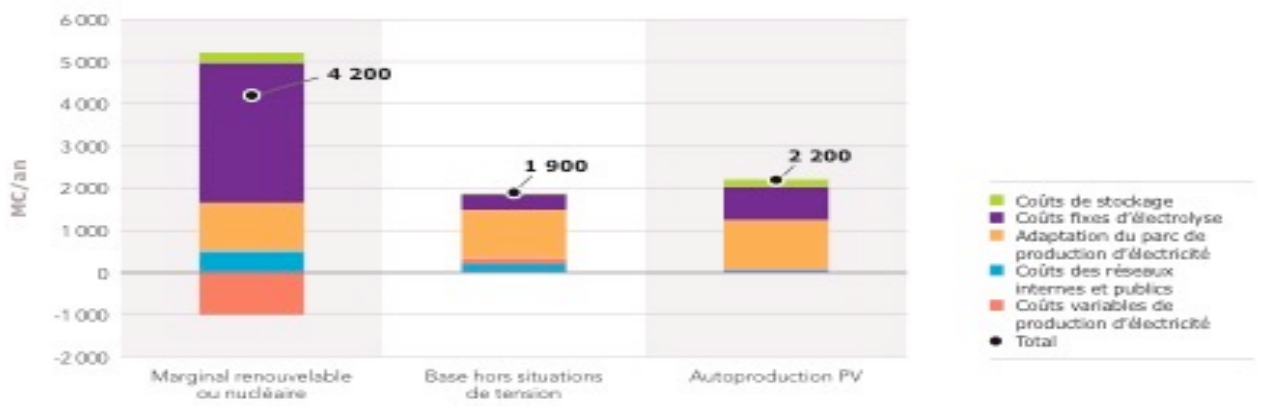


Figure 24. Coût de la production d'hydrogène bas carbone en fonction du mode de fonctionnement de l'électrolyse



H2 upstream : Strategic Conclusions on ecosystem 2030

Country	Scenario	KPIs	Technology & ecosystem diversity
N-W Europe	Scenario of strong H2 economy take-off for RE targets & optimisation **Mobility take-off slow by 2030: still depends on car makers and fuel**	- Blue/Green H2 add up; **P2G fuel availability** **- Technology lead Europe/China** **- Diverse Use of fuel competition as upstream and energy system logic system dominates ?**	Very strong upstream global tech supply H2-components industry, but their Asian market has more traction
China	Scenario of H2 economy fast take-off for RE optimisation and possibly coal exit **Very likely H2-Mobility early adoption based on capitalisation on other Low carbon / green mobilities experience**	- Diverse Use incl. mobility - Moving from subsidies to integrated provincial programs - **Industrial competition / Unstabilised models on actors**	Very strong upstream global tech supply Poor Donwstream tech IP P-to-G / (C to G) Technological race
Japan	Very specific H2 economy – energy transition and “Gas to Power” model **Risk that Mobility gets secondary**	- (P)-to-G-to-Power - External H2 supply dependence - **Pipes investment for Heating & HRS coupling**	Very strong Downstream tech supply incl. car models But mismatch with upstream strategy

ANNEX 1 - SECTORS

H2-mobility - trucks and high energy desnity confirm being the priority

Overview in heavy energy

- Hyundai announced it will build and sell 1,000 trucks in Switzerland in 5 years 2019-2023
- The world's first hydrogen train is now in service in Germany
- Norway is accelerating its pilots in shipping industry

Meanwhile HRS projects consolidate mostly in Germany

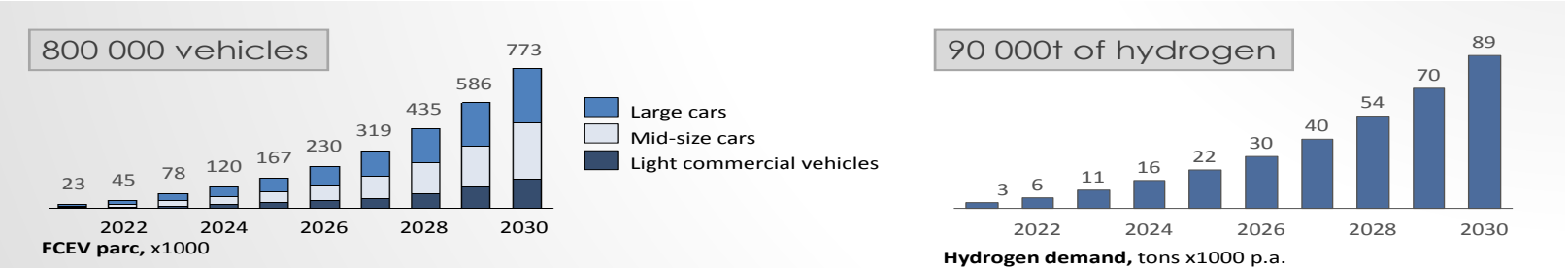
Great Wall (China) has joined the H2 Mobility consortium in Germany to become its 7th member alongside Air Liquide, Daimler, Linde, OMV, Shell and Total. The arrival of the car maker is an opportunity to participate in the deployment of the HRS infrastructure. H2 Mobility, which was created in 2015, with a goal of 100 stations by 2019 spread over 7 urban areas (Hamburg, Berlin, Rhine-Ruhr, Francforrt, Nuremberg, Stuttgart and Munich).

There will further be additional 300 HRS by 2023 to support the growth of fuel cell vehicles.

Conversely:

- US market keeps an extremely slow growth, Air liquide announced 12 stations only (across North East)
- In September several political parties in Norway stated they now believe more in EV for passenger cars rather than H2, and instead envision H2 rather for transportation and commercial use.

While new French Plan wants to optimistically believe in H2-mobility (AfHYPAC –pushed)



Monthly news – industry / structuring projects and alliances

Panorama des projets de production d'hydrogène décarboné

Projet E-CO_2MET — 2019

Electrolyse de l'eau avec électricité renouvelable

Installation d'un **électrolyseur à haute température** alimenté en électricité renouvelable pour produire l'hydrogène nécessaire à la synthèse de méthanol sur la raffinerie de Leuna en Allemagne.

TOTAL, sunfire

CRYOCAP™ — 2015

Reformage du méthane contenu dans le gaz naturel, avec CCS/ CCU

Installation d'une technologie de captation, par **procédé cryogénique, d'une partie du CO_2 émis lors de la production d'hydrogène.**

Investissement d'Air Liquide **de 30M€.**

Air Liquide

R-HYNOCA — 2021

Gazéification de la biomasse ou de déchets organiques

Projet de **production d'hydrogène vert à partir de biomasse** par le procédé Hynoca pour alimenter un réseau de bus hydrogène à Strasbourg.

R-GDS, HAFFNER energy

MONOLITH — 2020

Pyrolyse du méthane

Technologie de **transformation du gaz naturel en carbone et en hydrogène** par pyrolyse du méthane via un procédé plasma pour un site industriel de Nebraska.

AkerSolutions, Northern Natural Gas

REFHYNE — 2022

Electrolyse de l'eau avec électricité renouvelable

Installation d'un **électrolyseur PEM de 10 MW alimenté en électricité renouvelable** et pouvant produire jusqu'à 1 300 tonnes d'hydrogène par an pour une unité de raffinage en Allemagne.

SINTEF, ITM POWER, elementenergy

Freeport — 2018

Valorisation d'hydrogène fatal

Production d'ammoniac à partir d'hydrogène obtenu comme **coproduit d'activités de pétrochimie** et transporté par canalisation sur le site industriel au Texas.

YARA, BASF

H21 North of England — 2028

Reformage du méthane contenu dans le gaz naturel, avec CCS/ CCU

Projet de **conversion de 3,7 millions points de livraison de gaz**, à l'hydrogène issu de **reformage du méthane avec capture et séquestration du CO_2.**

Northern Gas Networks, Cadent, equinor

Hydrogen Energy Supply Chain (HESC) — 2030

Gazéification du charbon avec CCS/CCU

Projet de production d'hydrogène par **gazéification du charbon en Australie, pour exportation sous forme liquéfiée vers le Japon.** Capture et stockage souterrain du CO_2 issu de la gazéification.

Kawasaki, J-POWER, Marubeni, Sumitomo Corporation, Iwatani

2019 Année de mise en service du projet

Projet en phase d'étude

Nota: sélection non exhaustive de projets

Source : SIA partners

Monthly news – micro / companies news – hydrogen ecosystems

Monthly news – micro / companies news – hydrogen mobility

Classement constructeur*	Logo / Pays	Maturité: Faible	A confirmer	Forte	Commerciale
1er	Volkswagen	Malgré quelques brevets et un prototype de FCEV, le directeur de l'entreprise préfère aujourd'hui miser uniquement sur les véhicules à batterie. Aucun nouveau véhicule à hydrogène n'est prévu à court terme.			
2ème	TOYOTA	Avec 10 000 Mirai vendues depuis 2014, Toyota est aujourd'hui le constructeur le plus investi dans l'hydrogène. L'entreprise souhaite poursuivre dans cette voie avec le lancement de la Mirai II en 2020, pour servir le marché important du Japon mais également les autres pays ayant des plans de mobilité.			
3ème	RENAULT NISSAN MITSUBISHI	L'alliance s'appuie principalement sur les véhicules utilitaires de Renault avec extension de batterie (PAC fournie par Symbio) : les Kangoo Z.E. Hydrogen et Master Z.E. Hydrogen.			
4ème	DAIMLER	Le développement en 2018 de la GLC F-Cell place Mercedes dans la liste restreinte des entreprises ayant une voiture totalement hydrogène. Aucun autre modèle de FCEV n'est actuellement prévu.			
5ème	Ford	Pas d'annonce particulière à ce jour.			
6ème	GM	Un des constructeur à la pointe au niveau technologique, avec un historique très fort dans l'hydrogène. Pas de véhicule développé pour le grand public actuellement mais des usages industriels et militaires.			
7ème	HONDA	Concurrent important de Toyota sur l'hydrogène. Suite au FCX Clarity de 2007, l'entreprise relance un nouveau véhicule haut de gamme Clarity Fuel Cell et prouve ainsi son intérêt fort dans l'hydrogène.			
8ème	SAIC	Le premier constructeur automobile Chinois propose déjà 3 modèles de véhicules hydrogène. Le positionnement de SAIC reflète les ambitions fortes du pays en matière d'hydrogène.			
9ème	FCA FIAT CHRYSLER AUTOMOBILES	Pas d'annonce particulière à ce jour.			
10ème	BMW GROUP	Présentation récentes de prototypes fonctionnant à l'hydrogène, BMW prévoit de lancer une petite série de FCEV d'ici 2022 puis un vrai modèle pour 2025.			
12ème	HYUNDAI KIA	En collaboration avec Kia, Hyundai souhaite proposer à court terme des FCEV en grand nombre (700 000 par an en 2030). Fin 2019, Hyundai a annoncé que la Nexo s'était mieux vendue que la Mirai.			
13ème	PSA GROUPE	Suite au rachat d'Opel, PSA a développé un intérêt pour la technologie à hydrogène, notamment dans l'objectif de proposer des véhicules utilitaires. Les solutions seraient hybrides associées à des batteries. Un premier FCEV pourrait arriver en 2021.			

ANNEX 2 - METHODOLOGY

Countries and energy systems

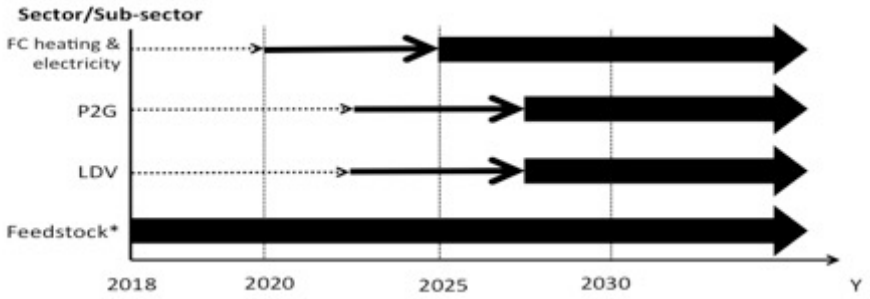
I.1) Energy

I.1) H2 CAPACITY within MIXsdf		2017		2025	2030
Energy generation	Total energy consumption / production capacity and breakdown	Total consumption 4.49 billion toe – 3.14 bn toe (1) (60.4% coal, 20.8% RE including NG, 18% oil)	2016 Total capacity 1,625 GW (58% coal, 20% hydro, 9% wind, 5% solar, 4% NG, 2% nuclear, 1% oil, 1% bioenergy) (4)	Total electricity capacity 2,466 GW (44.1% coal, 16.6% hydro, 14.1% solar, 14% wind, 6% NG, 3.6% nuclear, 1% bioenergy, 0.3% oil, 0.2% other RE) (4)	Total energy consumption estimated at 6 billion tce- 4.2 bn toe (NDRC 2017)
	Total electricity consumption / production capacity (on-grid) and breakdown	Total consumption 6,275.8 TWh (2) (73.5% coal-fire, 17.2% hydro, 4.3% wind, 3.9% nuclear, 1% solar)	Total capacity 1,777 GW (3) (62.2% coal-fire, 19.2% hydro, 9.2% wind, 7.3% solar, 2% nuclear)		1) Total electricity capacity 2,761 GW (39.4% coal, 17% solar, 16% hydro, 15.6% wind, 6.3% NG, 4% nuclear, 1.2% bioenergy, 0.3% oil, 0.2% other RE) (4) 2) Total electricity capacity 2,787 GW (42.5% coal, 17.9% wind, 16.1% hydro, 10.8% solar, 6.4% NG, 4.7% nuclear, 1.5% other) (5)
H2 production	Total H2 production (Mt)	22 Mt (about 4Mt by Shenhua) vs world 60 Mt		Estimated 32 Mt (CAGR 5%; 50,000 tons demand from fuel cell industry - Proton estimation)	Estimated 41 Mt (CAGR 5%; estimated 1 Mt demand from FC industry)
	Energy Equivalence (Mtep)				
	Estimated share of green hydrogen in total production (%)			Potential: 1.98 Mt from wasted RE (wind, solar, hydro) i.e. 6.2% of 32 Mt	
	Number of P2G projects	Wind to gas: 2 in Hebei, 1 in Jilin (6)			
	Total capacity of P2G (MW)	Hebei Guyuan 200 MW wind power to 10 MW electricity power to 17.5 million m3 H2 (1460 ton) Jilin 100 MW wind power to 10 MW hydrogen energy storage (6)			

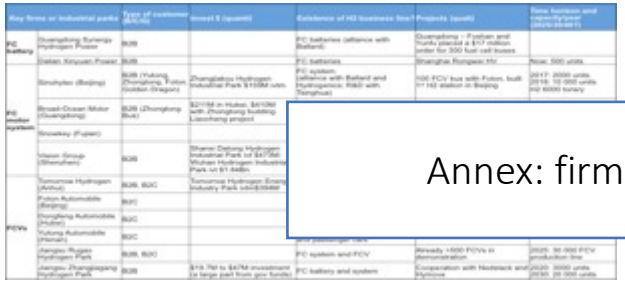
II.1) H2-sub-sectors eco

SECTOR	H2 Sub-Sector	Current development		
		Maturity Level*	Details	Numbers/units
CONVENTIONAL H2 ECONOMY	*Industry*	MMI	Current H2 almost used for industry needs	22 MT
	Feedstock	MMI	NH3 + CH3OH	55% + 27%
H2 PRODUCTION (see H2 Capacity)	*P2G/Reforming (Classic)*	MMI	20% (Natural gas and petroleum)	
	P2G (RENEWABLE)	P	3 pilot projects with the biggest using wind power in Hebei with German McPhy and Encon	20MW (300M wind), ivt $31 million
BUILDINGS	*Heating (blended within CH3OH)*	P	Guangdong: GD Hydrogen (H2 solution unit)	
Gas-to-Power	*Electricity generation (blended within CH3OH)*	P	Guangdong: GD Hydrogen (H2 solution unit)	300W to 30KW unit
TRANSPORT	*LDV*	P	Brands: Foton, Feichi, Datong	439
	Truck (logistics)	P	Brand: Dongfeng, New Youth	1000
	Bus	EA	Brands: Yutong, Golden Dragon	466
	Train	P	Guangdong Yunfu	
	Boat	P	Wuhan	
	Tram	EA	First operational H2 tramway line 17.4km within 2018 in Guangdong; China South Rail Corporation: ivt $32 billion for 1931 km tram by 2020	

II.2) rollout graph



Annex: firms analysis



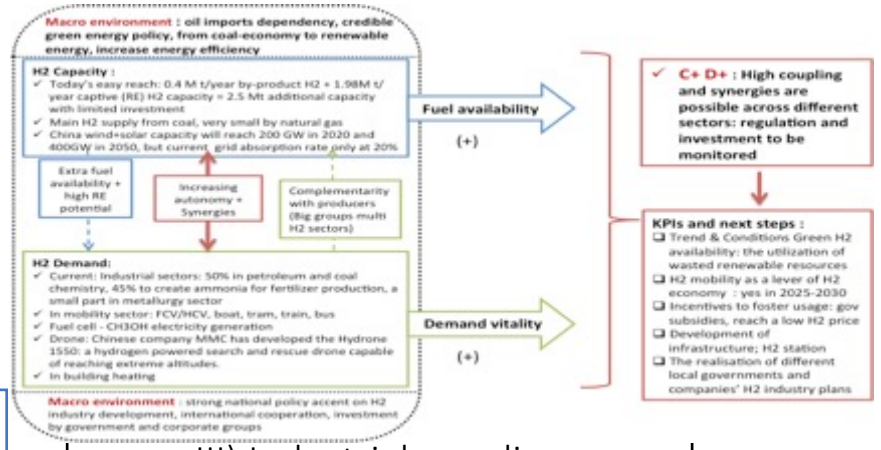
SWOTS 2025-2030

H2 Economy SWOT 2025 – early adoption (CURRENT TRENDS)

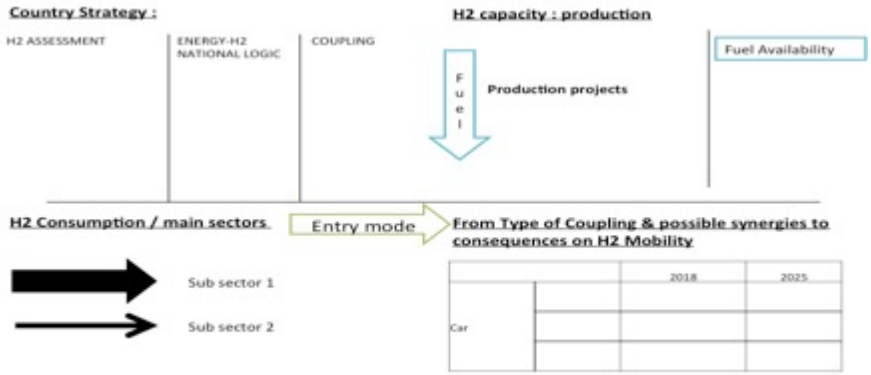
S	O
Strong policy will, green economy trend, various local projects, financial resources, dynamic success of previous technological programs **S - H2 mobility: large public + private investment, engagement of leading energy and automobile groups, municipal FCV plans**	Available renewable energy potential, global H2 industry trend, coupling of H2 mobility with other applications **O - H2 mobility: automobile sector in dynamic growth, strategic alliance with foreign suppliers & producers with core FCV technology**
W	**T**
H2 technology level still relatively low (production, storage, transport, mobility), almost no green H2 production for the moment **W - H2 mobility: need to improve core tech of FC system and FCV, current FCV with low resistance and efficiency, green H2 development**	No dedicated government department to H2 industry, H2 production costs still relatively high, long time to develop cooperative ecosystem **T - H2 mobility: H2 mobility in competition with other sectors (power, heating), FCV in competition with HEV and EV**

I.2) SIZE OF H2 MOBILITY (LDV + BUSES)		Today	2025	2030
LDV	Number of FCV (passenger+logistics)	1 439 (439+1000)	50 000 * (included bus)	1 000 000 (included bus)
	Total National LDV fleet (M=million) (passenger + logistics)	208,4M (185M+23,4M)	350M	450M
	Ratio 1 : number of FCV out of total national LDV fleet	*0.00069%*	*0.0143%*	*0.22%*
	Number of refueling station	20	300 (234**)	1000
	Ratio 2 : Utilization rate of refueling stations (Total FCV/Total Station)	*71.95*	*166.67*	*1000*
	H2 price at station (EURO/kg)	Shenhua H2 price 0.145/kg; estimated price at station 4.75/kg ***		
	GHG/km (FCV total emission)			
Buses	Number of H2 Buses	466		

I.2) Hydrogen mobility



III) Industrial coupling



(End Synthesis template:)

Firms and technologies

Objective 1 : Use cases and market segment : a usage calendar
Objective 2: Technological maturity of H2 industry and possible synergies

Objective 3: Assessment of value and its sharing within this ecosystem

Usage drivers

- Business using fuel cell or potentially link with fuel cell business

Major group: *Alstom, Air Liquide, SAFRAN, FAURECIA, MICHELIN, VALEO,* STX, *Toyota , etc*
SME's: *Symbio, Atawey, WH2*
Start up: *Pragma, Aaqius*

- transport, distribution, storage (tank)

Air Liquide, ENGIE, GRTgaz, EON, Linde, Aaqius, TIGF, ITMPower, Atawey, Haskel, Vatenfall, MacPhy

Which link?

Techno drivers

- Fuel cell producers

Ballard, Air liquide, Hydrogenics, AFC energy, CERES Power, NedStack Plug Power, Siemens, WH2, Paxitech, Areva H2 etc.

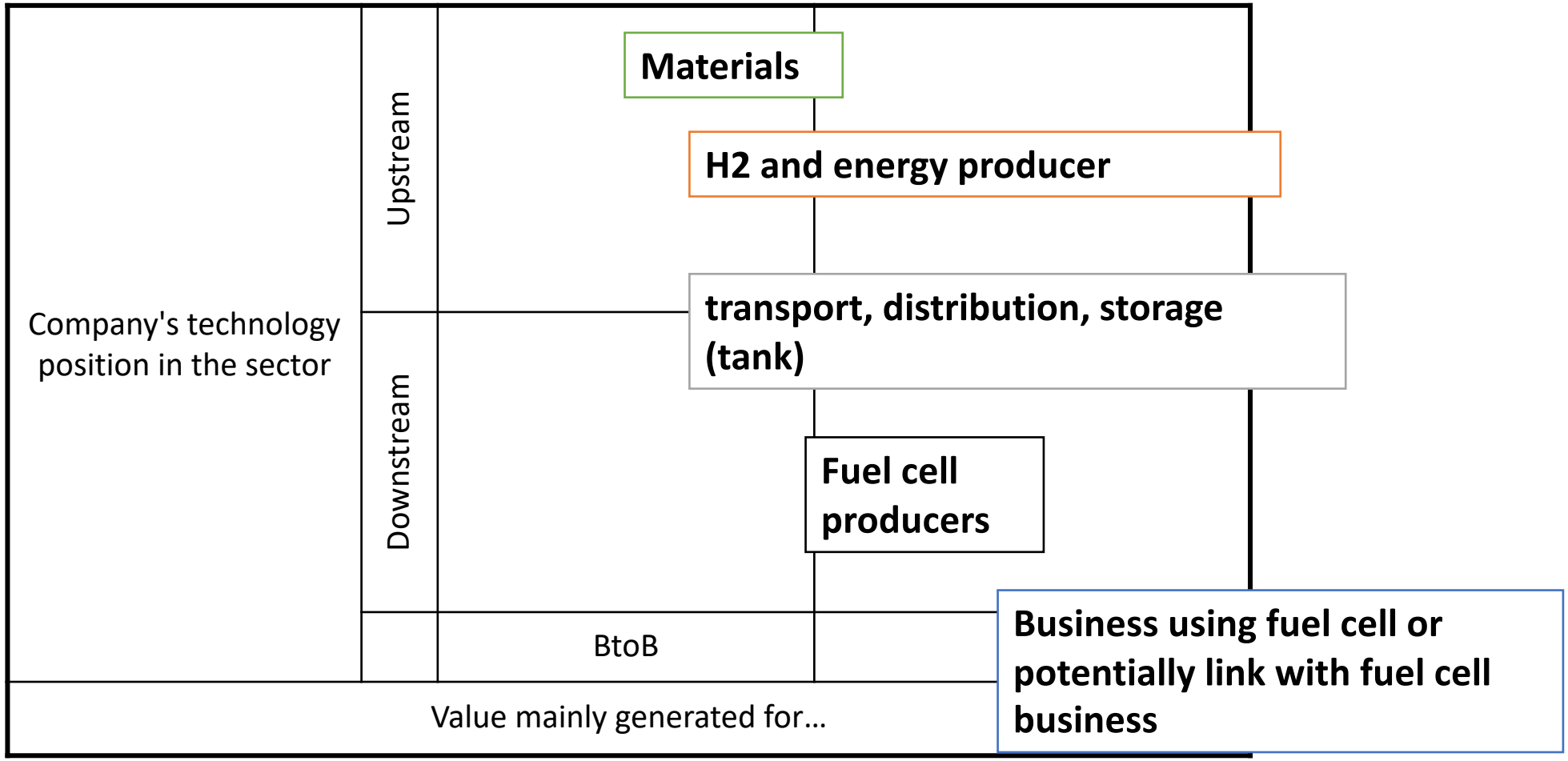
- Materials

3M, hydrogenics, McPhy, XG science, Graphenea, angtron materials (for rare minerals)

- H2 and energy producer

Air Liquide, Linde, GRT Gaz, ENGIE, Shell, Total, AREVA, etc

Markets


Company's technology position in the sector
Upstream
Downstream
Materials
H2 and energy producer
transport, distribution, storage (tank)
Fuel cell producers
BtoB
Business using fuel cell or potentially link with fuel cell business
Value mainly generated for…

Analysis of potential industrial coupling: autonomy vs. dependency/market linking across sectors

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Macro environment : What are the country's major challenges (independence, to produce green electricity thanks to green H2, renewable energy management, others,...)

H2 Capacity :
- ✓ what are the new production sectors? (P2G; CH4; etc.), are there synergies across sectors?
- ✓ What positioning for green H2 in terms of renewable energy?

Extra fuel availability ?

Autonomy? Dependency? Synergies?

Complementarity with producers?

H2 Demand:
- ✓ What are the main sectors that need H2? Are they locomotives for the hydrogen economy?
- ✓ How do they supply H2?
- ✓ Synergies across sectors?

Macro environment : National incentive to foster H2 usage? Public policies?

(+/-) Fuel avaibility

(+/-) Demand vitality

- ✓ **If C+ D+** : High coupling and synergies are possible across different sectors: regulation and investment to be monitored
- ✓ **If C+ D- :** Instable coupling ; H2 Hydrogen (green or not) will be available but no sector is driving demand or creating real synergy.
- ✓ If **- +** : low coupling possibility of decoupling, risk of lack of synergy and of own production, delay or low industrial take-off
- ✓ **If - -** : no coupling at all because of lack of capacity and demand

Risks and next steps :
- ❑ **Trend & Conditions Green H2 availability**
- ❑ **H2 mobility as a lever of H2** economy : yes now / yes in 2030 / no
- ❑ Incentives to foster usage?
- ❑ Enduring relationship/contracts/announcement
- ❑ Devlopment of infrastructure
- ❑ Etc…

Strategic positioning of the country and possible trajectories scenarios

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Country Strategy :

H2 ASSESSMENT

1) Status in 2018: (main sector, one or two key figures)

2) Public Policy:

- Political will announced: (high/low)
- Vision: (Clear/Fuzzy)
- Quantified target about H2 economy: (Public invest; national program objective)

ENERGY-H2 NATIONAL LOGIC

Clear statement about the H2 logic in the country (replacement of nuclear energy; buffer for renewable, LT decarbonation, industrial, etc)

COUPLING

H2 Capacity autonomy (+/-)

H2 Demand autonomy (+-)

=> Type of coupling (or decoupling)

H2 capacity : production

Fuel

Summary of table I.1 in one or two sentences

Production projects key figures:

- ✓ Number of P2G projects :
- ✓ Total Capacity of P2G :
- ✓ **Estimated share green H2 (today/2025)**

Extra H2 production as Fuel Availability

One sentence on risks/opportunities for H2/Green H2 availability

H2 Consumption / main sectors

Entry mode

Sub sector 1

Sub sector 2

One sentence giving the possible entry mode and major development

From Type of Coupling & possible synergies to consequences on H2 Mobility

		2018	2025
Car	Number of Refueling station		
	Number of FCV		
	Possible synergies/coupling	*(sub sector 1) (Sub sector 2) etc*	

Likely scenario : C+/D+, etc.