Decarbonization Wedges Exercise

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H_2 VEHICLES

1. State of the art and current development in different world regions

H_2 vehicles involve 4 elementary technologies which displays several challenges.

Technology 1: Electrolyzers
Electrolysis is used for hydrogen production. Three techniques are involved with hydrogen production: alkaline electrolysis (which is the technology deployed on the industrial scale); PEM[1] electrolysis; and SOEC[2], the latter having the best yield. All three techniques transform electricity into H_2.
However one should keep in mind that the current hydrogen production involves either another process — which is methane reforming— or coal.
These two processes are not assessed in this template. If it is possible to deploy CCS at an industrial and economic scale, this technology could have a significant impact on which CO_2-free processes are favored for hydrogen production.

Technology 2: Storage technologies for mobility
Mobile storage technologies have a different pressure, volume, mass, resistance, etc. than static storage technologies. Costs for high-pressure containers —which are the most studied technology— must be reduced and their operating and security levels must stay as high as they are now.

Technology 3: PEM Fuel Cell for mobility
PEMFC for mobility involve a fuel cell to convert hydrogen into electricity. PEMFC is a different technology than fuel cells for stationary applications as requirements for PEMFC specify its use e.g. on/off frequency, its volume and mass, and its temperature range.

Technology 4: Infrastructures and auxiliary
All technologies linked to distribution, transport and hydrogen storage pertain to infrastructures and auxiliaries, which are an essential element to cost reduction.
For the sake of simplicity this template will not assess the different vehicle designs —e.g. full power, 'range extender' with both a fuel cell and a battery.

[1] PEM: Proton Exchange Membrane
[2] SOEC: Solid Oxide Electrolysis Cell

2. Maturity level and technological perspectives

Maturity of H2 vehicles

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
Electrolyzers	5 (alkaline) 4 (PEM) 2 (SOEC)	5 4 3	5 5 4	5	5
Storage technologies for mobility	4	4	5	5	5
PEMFC	4	4	5	5	5
Infrastructure and auxiliary	4	4	5	5	5

For **technology 1**, electrolyzer maturity varies according to each type of electrolysis: alkaline electrolysis has been known for a long time and is a mature technology; however this is not the case with SOEC, which is still at the R&D level. However it is estimated that all three electrolysis techniques will be mature and much used by 2040.

Technology 2 currently manufactured at an industrial scale. Costs are the main issue with this technology, mostly because of materials and of high safety coefficients. However the deployment of storage technologies for mobility at the large scale will occur by 2030.

PEMC technologies for mobility are also marketed at a small scale. It is estimated that a few hundreds or a few thousands of H_2 vehicles will be sold by 2016.
There are already infrastructures and auxiliary technologies but they are not used at an industrial scale yet and the industrial chain is not implemented either for this technology. Current gas stations adapted to H_2 vehicles —around 200 to 300— are very expensive and lack standards and industrial technologies. A framework needs to be implemented and subcontracting strategies need to be designed for this technology to develop —this will probably take 15 extra years.

Potential development of H_2 vehicles

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

	2020	2030	2040	2050
H_2 vehicles	0	1	2-3	4

A first deployment phase —from 2015 to 2030— will probably involve a gradual development in some countries only, specifically Germany, Japan, Korea, California, Nordic countries; at least three car models are available on the market now from Toyota, Honda and Hyundai; as a matter of fact Germany is estimating that 1.8 million private vehicles will run on hydrogen by 2030 —Germany is planning to cut down its CO_2 emission by 3 to 4%. The impact of hydrogen vehicles on the CO_2 emissions reduction in the transport sector can be estimated to be higher than 5%.

3. Technological, economic and social bottlenecks

Methodological information:

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.

Technology		Research & technological bottlenecks	Financial bottlenecks (investment, risks)	Regulation & institutional environment	Resources & environmental impacts	Safety & security	Socio-technical feasibility
Electrolyzer	Rank	6	4	5	3	2	1
	Key-words	Yield, flexibility, renewable sources Scaling up production	Business models for Power to H2	Binding regulations	Need for platinum	Mixture H2/air in confined space	
Vehicle*	Rank	3	6	1	4	2	5
	Key-words		High financial risks at early stages		Need for platinum		Needs for private public partnership Public budget debt
Infra-structures and auxiliary	Rank	3	6	5	2	1	4
	Key-words		Very high risks	Different regulatory frameworks according to countries			

** The "vehicle" technology includes batteries (PEMFC) and storage technologies for mobility.*

The issue is not so much about techniques but about financial risks —indeed technologies seem to be mature and will be competitive in the long term. However there also is a financial risk in terms of upfront investments: indeed a funding regulation system calls for high upfront investments, as is the case in a competitive market and when financial actors seek profitability in the short term. There are two types of investment to be considered: infrastructure investment and vehicle investment. It will be long —probably 15 years— before the hydrogen vehicle industrial park reaches a significant size to make infrastructures profitable. However once they reach the appropriate size, hydrogen gas stations will clearly be more profitable on their own than electricity rechargeable stations which are not if only based on electricity prices.

There could also be a bottleneck with the perception of risks linked to hydrogen use: indeed populations could be reluctant either to the purchase of vehicles or to the implementation of a distribution network —e.g. gas stations and pipelines. The stakeholders of storage technologies for mobility which can reach up to public authorities will therefore have to put emphasis on security and communication aspects in order to ensure public acceptability and to help reduce the adverse effect of upcoming crises.

The regulatory framework is still very limiting in some countries, which prevents infrastructures and hydrogen production facilities from developing in a coordinated way. Efforts must be done on lifting constraints, harmonizing hydrogen production on the European scale and developing international standards in order for this technology to develop.

Eventually electrolysers and fuel cell electrodes need platinum, which is an expensive material. This is why the quantity of platinum required to operate them will need to be reduced even there is no major issue on platinum availability for the next decades.

4. Potential radical and incremental innovations

Methodological information:

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		**Research & technological innovations**	**Financial innovations** (investment, risk)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
Electrolyzers	I or R	R+I	I	R/I	R	I	
	Key-words	Development of SOEC	No business model	Different regulatory frameworks according to countries	Substitute to platinum		
Storage	I or R	I		R		I	R
	Key-words			Regulations need adapting			Fears linked to H_2 use
PEMFC	I or R	I	I	I	R	I	I
	Key-words				Pt		Adapted habits
Infra-structures	I or R	I	R	R	I	I	I
	Key-words		New financial plans	Adapted regulations in different world regions	Gas stations, land footprint for pipelines.		No particular acceptability's difficulty

Most innovations are expected for the regulation framework, which must adapt —e.g. regional (at the European level) and technological (e.g. current standard on metal containers are not adapted to H_2 carbon fiber containers) harmonization. The required platinum quantity for electrolysers and fuel cells must also be reduced, and fundamental research and R&D programs must be carried on to prepare second generation of technologies for fuel cells and hydrogen production processes. Electrolysis production of hydrogen will be able to develop thanks to the market storage technology for mobility market, but also —and certainly sooner— thanks to "Power to Hydrogen" and "Power to gas" specific markets; other forms of innovation will have to focus on overcoming financial bottlenecks —i.e. inventing new business models—, on overcoming legal and regulatory bottlenecks and on adapting existing rules to energy markets —i.e. electricity and gas markets. Energy transition to a system with more intermittent renewable energies implies rules and measures that favor storage and that bring flexibility in order to adapt energy network to this transition context. Considering the investment risk associated with infrastructures and auxiliaries, industrialization programs and radical innovations will be needed to overcome the financial bottlenecks mentioned above. New are needed to overweight this financial risk, to mutualize it and to ensure development conditions for a market that is fair with all actors eager to take part in it. Partnerships between the private and the public sectors as well as international cooperation —e.g. from the European Investment Bank, from the World Bank— will ensure bank guarantees among other things. All of these efforts are necessary for the hydrogen market to reach the appropriate size in order for the technology to develop.