Hydrogen strategy

25-10-2021
Hydrogen discussions

- There are many discussions and issues concerning hydrogen, such as
  - Blue versus green hydrogen
  - Additionality for green hydrogen
  - Energy efficiency first principle
  - Biogas versus green hydrogen
  - Hydrogen from nuclear
  - Blending hydrogen in gas grid or pure hydrogen grid
  - Hydrogen Cost and availability
  - ... 

- These discussions are all fuelled and driven by interests and also emotions. But it are mainly discussions on sub-aspects in which the greater importance is often lost sight of. The greater importance is to realize a zero-greenhouse emission energy system as quickly as possible, which is affordable, reliable, secure and inclusive. For this it is necessary to develop much more from a systems perspective towards the necessary strategy, measures and policies.

- The systemic role for hydrogen in a zero-greenhouse gas emitting energy system is described in the paper ‘Hydrogen as carbon free energy carrier and commodity’. Based on this paper, the following goals, observations and recommendations for a hydrogen strategy/policy can be made.
EU Hydrogen Goals 2030

- 20 million tonnes per year renewable hydrogen from the EU and import*
- 20 million tonnes per year no-carbon fossil hydrogen from the EU and import**
- 1 million tonnes per year hydrogen from (biogenic) waste from the EU***

*25 GW solar with 2,000 full load hours produce 1 million tonnes H₂,
10 GW offshore/desert wind with 5,000 full load hours produce 1 million tonnes H₂
½ solar and ½ wind for 20 million tonnes is 250 GW solar and 100 GW wind with about 250-300 GW electrolyser capacity.

**Requires about 100 BCM natural gas which is roughly 20% of gas use in the EU

***Requires about 5 BCM biogas (at natural gas specs) is about 5% of the biogas potential from Gas for Climate study.
No carbon Electrolytic hydrogen

• Large scale renewable hydrogen production at the resource is not electricity grid connected
  • Integrating solar cells/modules or wind turbines with electrolyser stacks will result in lower overall investment cost than separated solar/wind farms and electrolyser plants and therefore lower hydrogen production cost.
  • Hydrogen transport by pipeline is more cost-effective (up to a factor of 10) than electricity transport by cable.
  • Hydrogen transport pipeline capacities (10-20 GW) are in general a factor of 10 larger than electricity transport cable capacities. And hydrogen transport by pipeline over distances of at least 5,000 km is possible and feasible.
  • Hydrogen can not only be transported by pipeline but also by ship, truck.
  • At many places on earth, at gas resource locations but also at good solar and wind resource locations, salt formations are present to realize large scale and cheap hydrogen storage. This makes base-load hydrogen transport by pipeline possible.

• Renewable hydrogen production connected to the electricity grid to alleviate grid capacity constraints
  • When part of the capacity of a solar or wind farm is connected to the electricity grid and the other part to an electrolyser, more solar and wind production capacity can be integrated into the total energy system.
  • When the electrolyser is also connected to the electricity grid [A hybrid grid-electrolyser connection] it is also possible to uptake excess produced electricity from renewables.
  • A “hybrid” connected electrolyser can deliver flexibility services to the grid.
  • The electrolyser must be able to produce sufficient volumes of hydrogen at competitive cost to meet local hydrogen demand (e.g. fuelling stations, local industry and heating). For this it is necessary to buy renewable electricity from the grid.
  • The locally produced hydrogen can be fed into a local hydrogen infrastructure that is connected to a hydrogen transport infrastructure. Surplus hydrogen can now be transported to large scale underground storage facilities for weekly to seasonal storage.
  • By using small scale fuel cell systems in buildings, neighbourhoods or in fuel cell cars, electricity can be produced locally to balance supply and demand and thereby also avoid or alleviate electricity grid capacity expansion because of increased electricity demand.

• Small scale renewable hydrogen production fully connected to the electricity grid to meet local hydrogen demand
  • Hydrogen production for difficult or expensive to electrify energy demand that needs to be decarbonized, such as the glass and ceramics industry, food processing industry, bakeries, hydrogen refuelling stations and for heating houses and buildings (old buildings/houses, country side, villages, old city centres, but above all hybrid solutions).
  • The electrolyzers are fully grid connected and buy green electricity from the grid to produce green hydrogen.
No carbon Electrolytic hydrogen

• Possible Strategy/Policy
  • Above 200 MW electrolyser capacity, the electrolyser needs to be installed at or near the renewable electricity production location (solar, wind, hydro) with no or limited electricity grid connections. This implies that new, additional, renewable energy production will be installed. There is an obligation (by TSO’s/DSO’s or another body) to connect to a hydrogen infrastructure.
  • Between 20 MW and 200 MW electrolyser capacity, the electrolyser needs to be installed at or near a new or existing renewable electricity production location whereby part of the renewable electricity production capacity is grid connected and the other part is connected to the electrolyser (a hybrid connection). There is an obligation (by TSO’s/DSO’s or another body) to connect to an electricity and a hydrogen infrastructure. And the electrolyser is allowed to connect to the grid and allowed to buy green electricity from the grid to produce green hydrogen.
  • Up to 20 MW electrolyser capacity, the electrolyser needs to be installed at or near the demand site. The electrolyser is grid connected and allowed to buy green electricity from the grid to deliver green hydrogen directly to the demand (small industry, hydrogen fuelling stations, neighbourhoods, etc.) There is no obligation for a hydrogen infrastructure connection.
No-Carbon fossil hydrogen

- Hydrogen production from fossil fuels (especially natural gas) without CO₂ emissions to the air is technologically possible and feasible
  - ATR (Auto Thermal Reforming) using part of the produced hydrogen or via renewable energy, instead of natural gas, for process heat makes 100% CO₂ capture and storage possible
  - New technology Methane Pyrolysis produce hydrogen and solid carbon, there are no CO₂ emissions to the air. If part of the produced hydrogen is used for process heat, there are also no indirect CO₂ emissions

- Converting fossil fuels into hydrogen at the resource, not at the demand, avoids a ‘natural gas/methane’ lock in and has to following other advantages
  - CO₂ can be stored into the underground, e.g. the gas field, without the need for a CO₂ infrastructure
  - The gas pipeline and storage infrastructure can be fully converted to hydrogen.
  - Full infrastructure conversion to hydrogen makes it possible to feed in renewable hydrogen faster resulting in cheaper infrastructure cost
  - Full infrastructure conversion makes scheduled full conversion area by area from natural gas to hydrogen in end-use equipment possible.
  - No post-combustion CCS is necessary which is in general more expensive than pre-combustion CCS (hydrogen production).
  - Less methane leakage at the gas production field
  - No methane leakage in transport and storage.
H₂ and CO₂ from (biogenic) waste

- Converting biogas/syngas from (biogenic) waste into H₂ and CO₂ avoids a ‘natural gas infrastructure’ lock in and has the following other advantages
  - By converting into hydrogen, there is no necessity for a natural gas infrastructure anymore.
  - When hydrogen is fed into a hydrogen infrastructure there are no methane leakage from infrastructure
  - Pure CO₂ can be transported by truck/ship or pipeline and used as feedstock for chemicals, synthetic fuels and crop growth or stored.
  - Converting to hydrogen and carbon-dioxide avoids also substantial CO₂ emissions to the air at present biogas plants.
  - Using hydrogen as feedstock or energy and CO₂ as feedstock or for storage will lead to ‘negative’ fossil CO₂ emissions.
No-Carbon fossil and biogenic hydrogen

• Possible Strategy

No carbon hydrogen production

- Moratorium on new gas, oil or coal exploration concessions.
- If concessions are granted for new gas exploration, buying out of these concessions will be expensive, but by imposing strict no-carbon emission standards for gas feed in into the infrastructure it will result in feeding in hydrogen.
- Existing gas exploration needs to convert to no-carbon fossil hydrogen fully in the period 2030-2040, every year 10% more of total volume.
- Gas import needs to be fully no-carbon (fossil or renewable) hydrogen from 2040 onwards. From 2030-2040 every year 10% more of total gas import.
- New biogas and syngas production from (biogenic) waste converting to hydrogen and CO2 obligatory from 2025 onwards, if not used on site.
- Existing biogas production conversion to hydrogen and CO2 in the period 2030-2040, every year 10% more of total volume.

Hydrogen Infrastructure

- Moratorium on new natural gas pipeline and storage facilities, only new hydrogen pipeline and storage facilities can be installed. (Eastmed and other new gas pipelines) needs to be an hydrogen pipeline from the start).
- European Hydrogen backbone, with international and intercontinental connections in place in 2030.
- Full conversion natural gas infrastructure to hydrogen in 2040 ready.
- Obligation to connect hydrogen production to a hydrogen (pipeline) infrastructure.
Background information
Additionality principle is discriminating hydrogen use versus electricity use

To show the discrimination of hydrogen versus electricity by the additionality principle for green hydrogen production, three examples.

This is allowed to do, buying green electricity via green certificates

- A bakery that normally heats his oven with gas, installs an electric oven and buys via green certificates green electricity that is OK. But he/she replaces gas, uses additional electricity and does not have to source this from new installed RES capacity?
- A house that normally is heated with a gas boiler is now installing an electric heat pump and buys via green certificates green electricity that is OK. But he/she replaces gas, uses additional electricity and does not have to source this from new installed RES capacity?
- A car owner buys a new battery electric car and replaces his diesel car. He buys via green certificates green electricity and that is OK. But he/she replaces diesel, uses additional electricity and does not have to source this from new installed RES capacity?

This is not allowed to do, buying green hydrogen that is produced from green electricity from the grid, whereby green electricity is bought via green certificates

- A bakery wants to replace his gas oven with an oven on green hydrogen. He/She replaces gas with green hydrogen but he/she cannot install an electrolyser to produce green hydrogen by buying green electricity from the grid via green certificates. No, new additional RES-E capacity needs to be installed to produce the green hydrogen?
- A house that is normally heated by a gas boiler now installs a fuel cell cogeneration system that produces heat and electricity when the solar panels do not deliver enough electricity. He/she is replacing gas and wants to buy green hydrogen, for example from an electrolyser that is installed near the neighbourhood. But now the green hydrogen can not be produced by buying green electricity via green certificates. No, new additional RES-E capacity needs to be installed to produce the green hydrogen?
- A car owner buys a new fuel cell electric car and replaces his diesel car. He/she is replacing diesel and wants to buy green hydrogen, but the green hydrogen can not be produced by electrolysers at the fuelling station connected to the grid that buy additional green electricity via green certificates. No, new additional RES-E capacity needs to be installed to produce the green hydrogen?
No-carbon fossil hydrogen avoids natural gas lock-in

New Natural gas from the Mediterranean Sea as example
Offshore floating Gas-Hydrogen; ATR with CCS or Methane Pyrolysis
Hydrogen storage in offshore salt caverns is possible (green areas)
EastMed plus Egypt connection pipelines
Gas Infrastructure in Europe can be reused for hydrogen.

Gas Pipeline Capacity 5-20 GW, Electricity cable capacity 0.5-2 GW

Gas transport cost roughly a factor 10 cheaper than electricity transport.
EastMed pipeline data

- Connecting Israel, Cyprus, Crete-Peleponessos-Mainland Greece, Italy
- 1,900 km, 1,300 km offshore, 600 km onshore, compressor stations at Cyprus 100 MW and Crete 120 MW
- 10 bcm capacity (about 100 TWh) expanding to 20 bcm in second phase
- Investment cost estimated at 7 million dollar
- Operational estimated 2025
- IGI Poseidon developer (50:50 joint venture between DEPA (public Gas Corporation of Greece) and Edison International Holding.
- Is on the EU PCI (Project of Common European Interest) list
- Has got financing from CEF (Connecting Europe Facility); Pre-engineering and design grant Euro 2 million, second grant in 2018 for 50% of the FEED studies, Euro 34.5 million.

- Issue: strong opposition from Turkey because they develop the natural gas TANAP pipeline and see this as competition
- Issue: Does a new natural gas pipeline fit/comply with the EU Green Deal?
Re-developing EastMed in hydrogen infrastructure

- Connecting Saudi Arabia (NEOM) Jordan, Egypt, Israel, Cyprus, Greece to Italy.
- Transport capacity 2.5-3.0 million ton hydrogen per year.
- Producing no and zero CO₂ emitting hydrogen from gas resources in Saudi Arabia, Egypt, Israel, Cyprus, via ATR with 100% CCS and Methane Pyrolysis no CO₂ emissions only solid carbon. (Using 5 bcm gas produces about 1 million ton no CO₂ hydrogen 2030)
- Producing green hydrogen from onshore solar and wind in Egypt, Saudi Arabia, Jordan, Israel, Greece. (producing 1-2 million ton green hydrogen in 2030)
- Producing green hydrogen from offshore solar and wind in Israel, Greece and Cyprus. (producing 1-2 million ton green hydrogen in 2035-2040)
- Hydrogen storage offshore on Israeli and Egyptian territory in salt caverns to establish baseload supply via EastMed pipeline to Italy.
- In Italy EastMed hydrogen pipeline connects to the European Hydrogen Backbone

- If Israel, Egypt, Cyprus wants to export their natural gas as natural gas it can still be done via LNG
- It could probably solve (some of) the tension with Turkey. Turkey could even connect/be involved into this hydrogen pipeline.
- The hydrogen project fits in the European Green Deal.
It is not about system **energy** efficiency, but about system **cost** efficiency!

- Energy efficiency first principle is not an independent and wrong energy policy goal.
Hydrogen is not energy efficient?

• Energy efficiency equations have to be made pure. Electricity is now the starting point in the efficiency equation, but that electricity is made from an energy source. You should actually start with that.

• Two examples about solar energy
  – The solar panels on our roof have an efficiency for converting sunlight into electricity of about 20%. But there are solar panels that have a 1.5-2.0 times higher energy efficiency. We don’t use them, because they are 5-10 times more expensive.
  – If we put the same solar panel on our roof in the Sahara, it will yield 2-3 times as much. Wouldn’t it be better to put all those solar panels in the Sahara?

• Electricity and hydrogen are both energy carriers, if you would start from hydrogen, then electricity is not efficient. And when you produce hydrogen from biogenic waste, from natural gas with no carbon emissions, the argument could by why to convert into electricity!

• This reasoning shows that energy efficiency is not a goal in itself. It is about zero greenhouse gas emissions, affordability, reliability and fairness in designing a future energy system.
Hydrogen is not energy efficient?

- In a sustainable energy system it is not about system energy efficiency, but about system cost efficiency!
- Transport of electricity is a factor of 10 more expensive and storage more than a factor of 100 more expensive than for hydrogen.
- In addition, you can import green hydrogen from areas where the costs of solar and wind electricity-hydrogen factors are lower than here.
- In the end it will become a cost competition between imported renewable electricity by hydrogen and local produced renewable hydrogen and electricity.
Learning rate electrolysers

Similar to solar PV, batteries or fuel cells, above 30%.
Technology structure electrolysers similar to solar PV, batteries, fuel cells

Electrolyzer system capex\(^1\) for different learning rates

**USD/kW**

<table>
<thead>
<tr>
<th>Learning Rate</th>
<th>Cost Range</th>
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<tbody>
<tr>
<td>2020 ((12%) learning rate)</td>
<td>~660-1,050</td>
</tr>
<tr>
<td>2030 ((15%) learning rate)</td>
<td>~230-380</td>
</tr>
<tr>
<td>2030 ((20%) learning rate)</td>
<td>~200-310</td>
</tr>
<tr>
<td>2030 (39%) for batteries</td>
<td>~130-190</td>
</tr>
<tr>
<td>2030 (35%) for solar PV</td>
<td>~130-190</td>
</tr>
<tr>
<td>2030 (19%) for wind onshore</td>
<td>~130-190</td>
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Technology structure:

- Cells as the fundamental production unit.
- Cells are grouped or stacked together in modules or stacks as a physical production unit.
- A number of modules/stacks together with balance of plant equipment is the system production unit.
- These technologies do not have mechanical components and operates at low temperatures.
- Only balance of plant cost scale with system size, but module/stack or cell cost do not scale with system size.

Electrolyser learning rates expected in same range as solar PV and batteries

Mass production of cells and stacks will bring down Capex cost rapidly.