Webinar 3

Economics & Business Case

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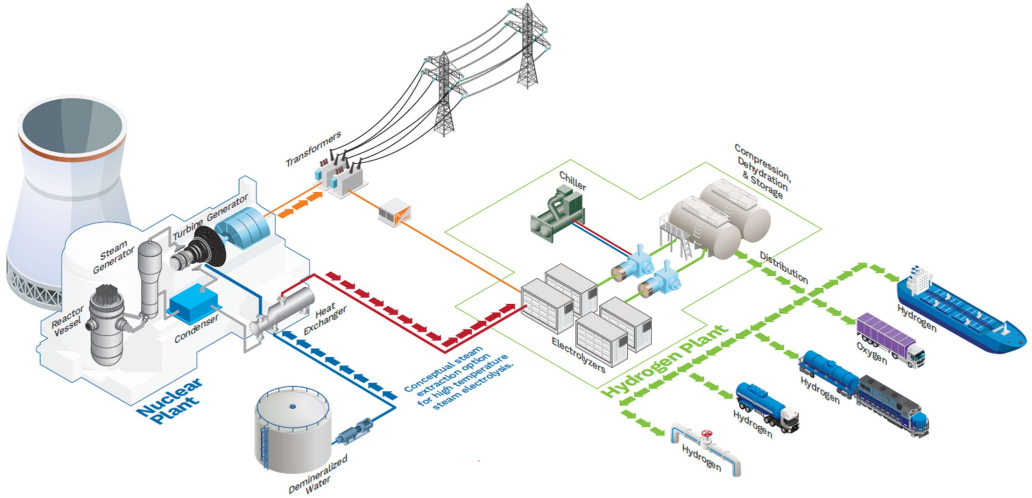
NPHyCo
Nuclear Powered Hydrogen Cogeneration

About NPHyCo

- EU research project dedicated to the production of hydrogen from nuclear power
- Funded by the EU's Euratom Research & Training programme (2021-2025) dedicated to nuclear research and innovation
- Kicked-off in the Autumn of 2022 and will run for two and a half years



The Challenge

- Full decarbonisation of the EU's economy by 2050
- Could hydrogen be part of the solution? Potentially yes *BUT*
  - to date most of the hydrogen produced comes from fossil fuels (e.g. Methane)

How can Europe ramp up production of **low-carbon hydrogen,**

at the required production rate and ensure it is affordable?

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Project goals

- NPHyCo is focusing on the potential for developing large scale, low-carbon, hydrogen production facilities linked to nuclear power plants.
- It started by assessing the feasibility of producing hydrogen near an existing nuclear power plant as well as the added value of such project.
- It takes into account the potential off-taker (e.g. steel, iron, fertilizer and petrochemical industry) and also the transportation routes.
- It is also looking at potential locations where a pilot project could be implemented.

Project Partners

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NRG Nuclear. For life.

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Work Packages

WP1: Conceptualisation
This Work Package will focus on conceptualisation of the project.

WP2: Technical Roadmap
This Work Package will focus on the technical conditions related to the coupling of a hydrogen production facility to an existing NPP.

WP3: Economic Roadmap
This Work Package aims to develop a business plan for hydrogen produced from nuclear power.

WP4: Licensing Roadmap
This Work Package will focus on licensing requirements.

WP5: Implementation Roadmap
This Work Package will put forward proposals for pilot plant locations and their layout.

WP6: Communication, dissemination & public awareness
This Work Package focuses on communication around the project.

Topic of today

Energy transition and NPPs challenges

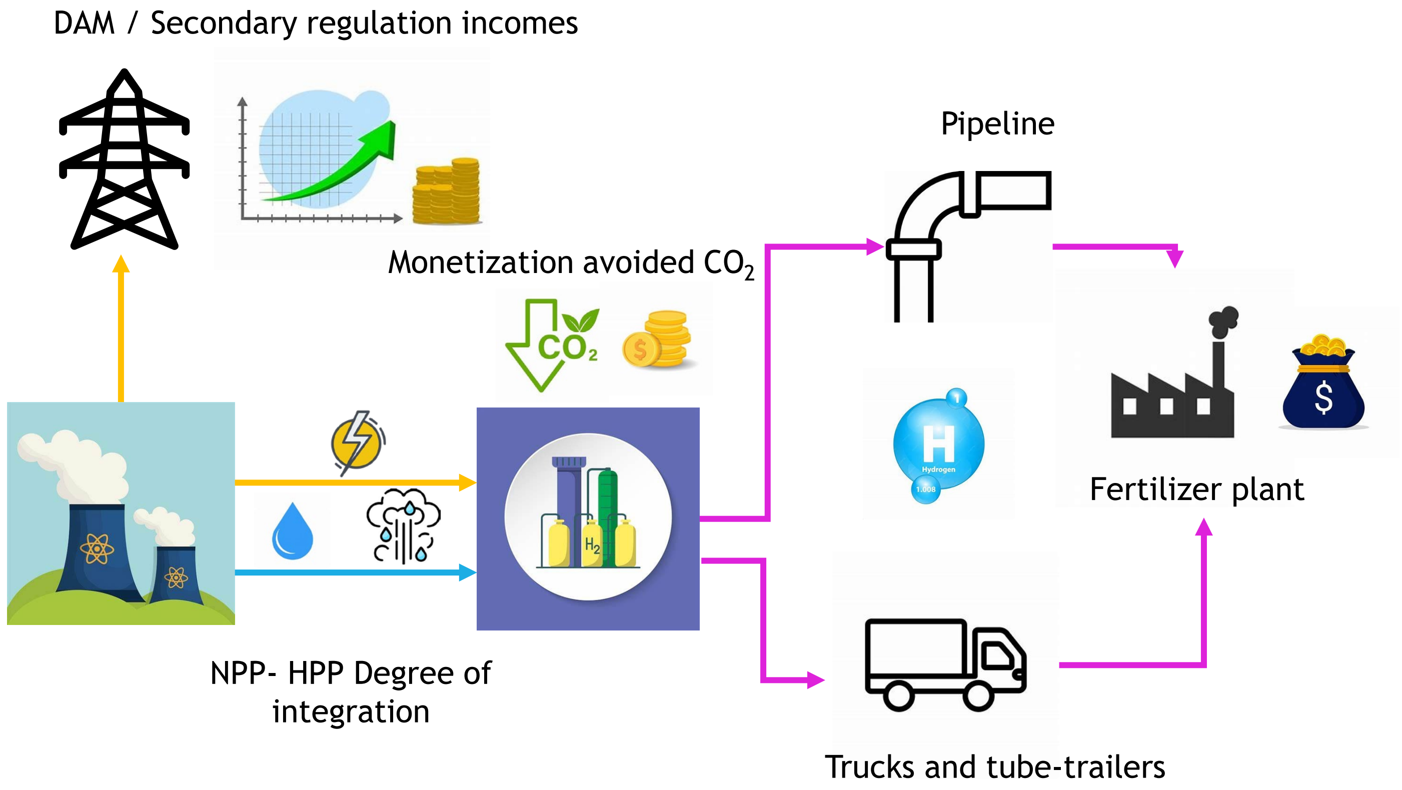
NPPs generate and provide **carbon-free electricity** in a continuous, stable and reliable basis. NPPs guarantee the electrical supply and at the same time, support the climate objectives.

The transition to climate neutrality is brining about profound changes in an energy system with an increasingly higher penetration of variable renewables. In this new context, NPPs are expected to face **NEW CHALLENGES**:

- Increasing demand for flexible operation
- Greater number of hours with market prices close to zero, and thus below the NPPs production costs.

NPHyCo consortium has been exploring and evaluating **NEW BUSINESS MODELS RELATED TO NUCLEAR HYDROGEN PRODUCTION** as a promising lever to enhance nuclear competitiveness in the new forecasted paradigm.

Economic Roadmap. Tasks overview



1. Techno-economic costs models
2. Techno- economic income models
3. Financial tool modelling
4. Sensitivity analysis for optimal configuration
5. Advanced operational strategies
6. KPIs comparison with other production methods
7. Business Plan (financial analysis)

HEEP — IAEA International Atomic Energy Agency

H2A — NREL Transforming ENERGY

PERSEE — cea

OptimHyzer — tecnatom

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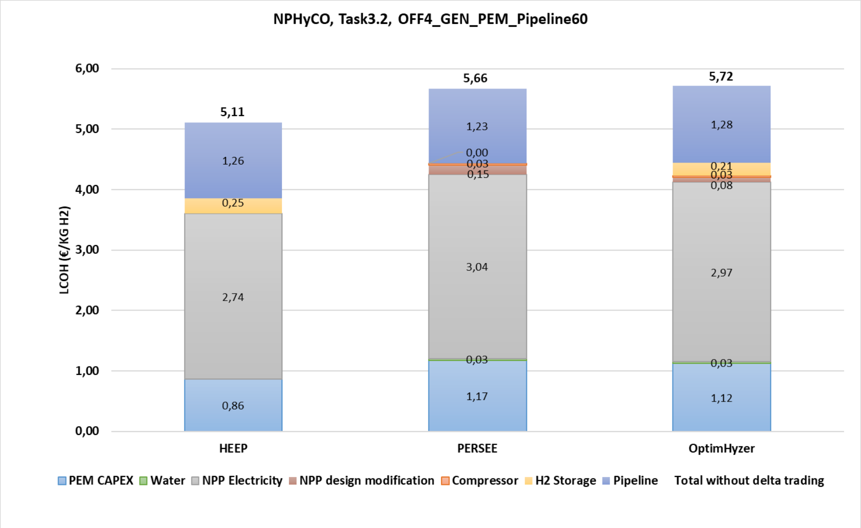
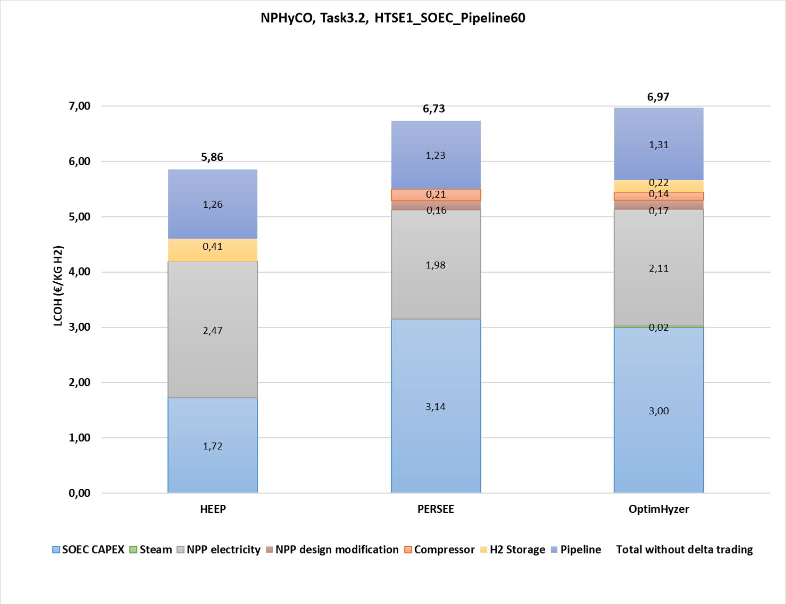
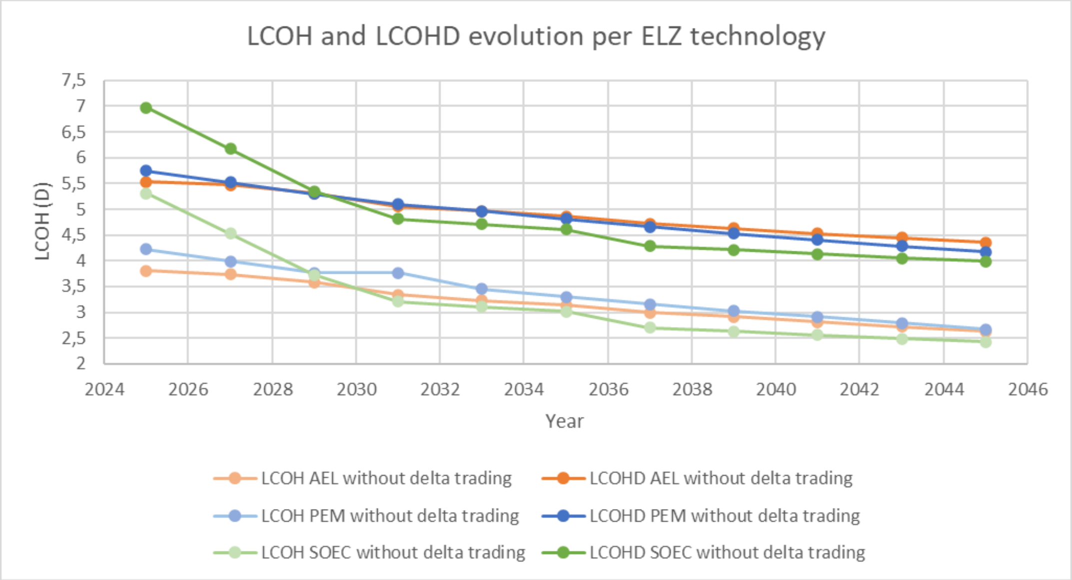
Sensitivity analyses. Some conclusions







- In case of LTE **(PEM and AEL), the most part of the LCOH weight is due to electricity consumption** made by the electrolyser. The water consumption cost is negligible. However, in case of **HTSE (SOEC), ELZ CAPEX represents the highest share of hydrogen generation costs**, and the electricity falls to a second position.

- **Currently the hydrogen produced with SOEC technology is more expensive than producing it with any of the LTE technologies.** However, according to calculations, is expected that by year 2029, SOEC is expected to reach the same level of prices as PEM technology and in year 2031, lower costs than both LTE technologies.

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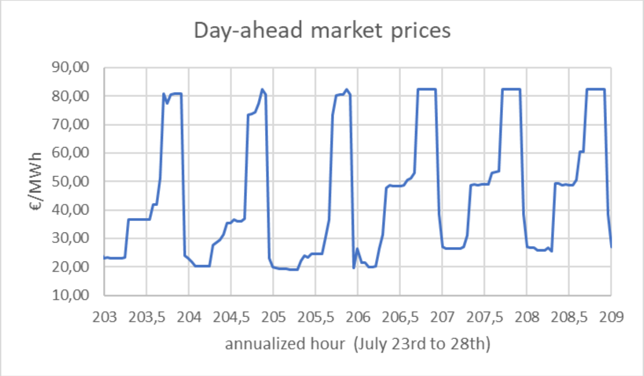
LCOH (D) is key for market competitiveness, but we need to go further...

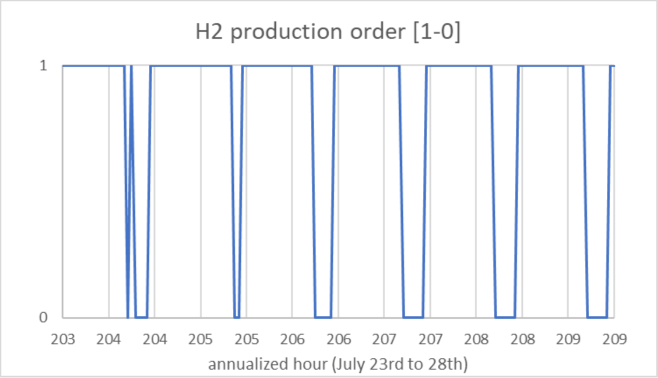
Other questions should be also answered in case a HPP coupling is envisaged to be done with an already existent NPP:

- **Is it better to continue selling electricity or also to produce hydrogen?**
- **Which is the hydrogen cost from which the benefits or the losses of the two business models are the same?**

Study case/Concept	H_2 not guaranteed. Continuous production	H_2 not guaranteed. Price-based strategy
LCOHD	5,72 €/kgH_2	6,44 €/kgH_2
“Delta trading”	1,19 €/kgH_2	0,06 €/kgH_2
LCOHD + “delta”	6,91 €/kgH_2	**6,5 €/kgH_2**



- The hydrogen production strategy combined with the type of supply contract is crucial for maximizing benefits in a hybrid system.
- In case of not penalties or delivery restrictions, produce hydrogen when electricity prices drop low and switch back to electricity whenever they rise up is the strategy that maximizes the benefits. Otherwise, produce whenever is possible.



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Financial assessment overview

- Which is the hydrogen selling price for obtaining certain level of profitability?
- Which are the conditions for making nuclear-hydrogen production competitive and besides, economically feasible from a hybrid system standpoint?

	PEM technology	SOEC technology
NPP LCOE	40,12 €/MWh	40,12 €/MWh
Hydrogen contract	Delivery not guaranteed	Delivery not guaranteed
Production strategy	Price-based strategy	Continuous production
Starting operating date	2026	2026
Hydrogen rate	494kgH_2/h (30MW)	494kgH_2/h (20MW)
CO_2 monetization	NA	NA
O_2 incomes	NA	NA
LCOH	4,5 €/kgH_2	5,53 €/kgH_2
Transport costs	1,95 €/kgH_2	1,67 €/kgH_2
"Delta trading"	0,06 €/kgH_2	0,94 €/kgH_2
LCOHD + penalties (if applicable)	6,45 €/kgH_2	7,2 €/kgH_2
IRR	21,67%	22,11%
Payback	5 years	5 years
Hydrogen price	3,5 €/kgH_2	3,5 €/kgH_2
Subvention	5,5 €/kgH_2	7,5 €/kgH_2

- For a project to be deployed by 2026, **subventions would be necessary** if the NPPs want to offer a competitive hydrogen price and besides, to get a reasonable profitability from its new business model.
- Although the current results seems not to be optimistic, the future could be promising…. BUT THERE ARE STILL CHALLENGES AND BARRIERS TO OVERCOME!

Financial assessment overview

	PEM technology	SOEC technology
NPP LCOE	36,50 €/MWh	36,50 €/MWh
Hydrogen contract	Delivery not guaranteed	Delivery not guaranteed
Production strategy	Price-based strategy	Continuous production
Starting operating date	2030	2030
Hydrogen rate	6.000 kgH_2/h (352 MW)	6.000 kgH_2/h (224 MW)
CO_2 monetization	30 €/ton	30 €/ton
O_2 incomes	NA	NA
LCOH	3,39 €/kgH_2	3,24 €/kgH_2
Transport costs	0,49 €/kgH_2	0,44 €/kgH_2
"Delta trading"	0,31 €/kgH_2	1,11 €/kgH_2
LCOHD + penalties (if applicable)	3,7 €/kgH_2	3,68 €/kgH_2
IRR	20,91%	20,78%
Payback	5 years	5 years
Hydrogen price	2,5 €/kgH_2	2,5 €/kgH_2
Subvention	2,1 €/kgH_2	2,4 €/kgH_2

CONDITIONS FOR NUCLEAR HYDROGEN ECONOMIC FEASIBILITY

- NPPs are expected to operate in LTO conditions which is favorable to decrease LCOH values.
- By 2030, LCOH for PEM and SOEC technologies are expected to be similar for the same hydrogen production rate.
- Higher production rates decrease pipeline unitary costs and it is expected that electrolysers are technologically ready to be escalated.
- For the case analyzed, hydrogen could be sold with a price of 2,5 €/kgH_2 and with an approximate subvention between 2-2,5 €/kgH_2 , the investment return will be higher than 20%.

European Hydrogen Markets (1/2)

2022

Production = 91% SMR, 0,3% ELZ

Captive H_2
87%

vs

Merchant H_2
13%

H_2 produced by an on-site facility

External distribution and sale

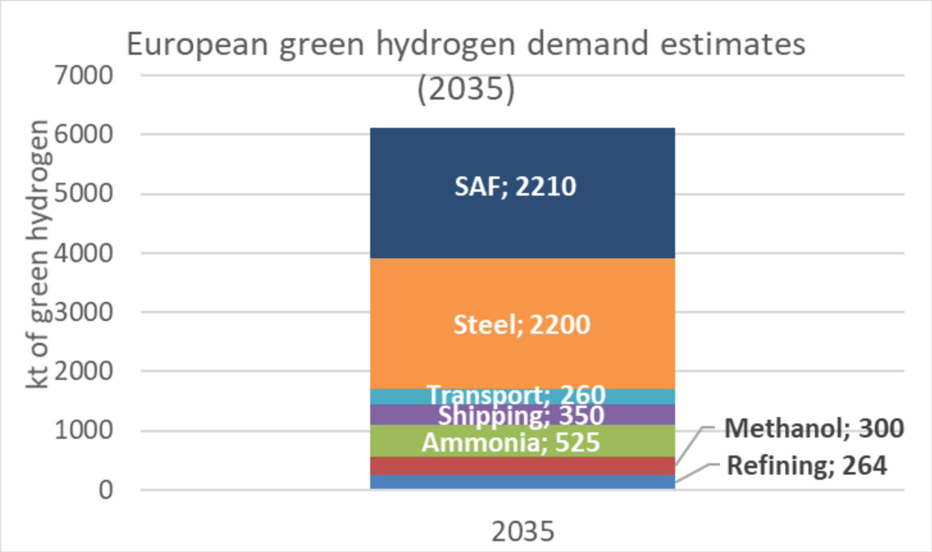
Consumption = 8,2 Mt

- Main consumers: Germany, the Netherlands, Poland and Spain (> 50%)
- Main end-use: Refining, Ammonia production, other chemicals

2035

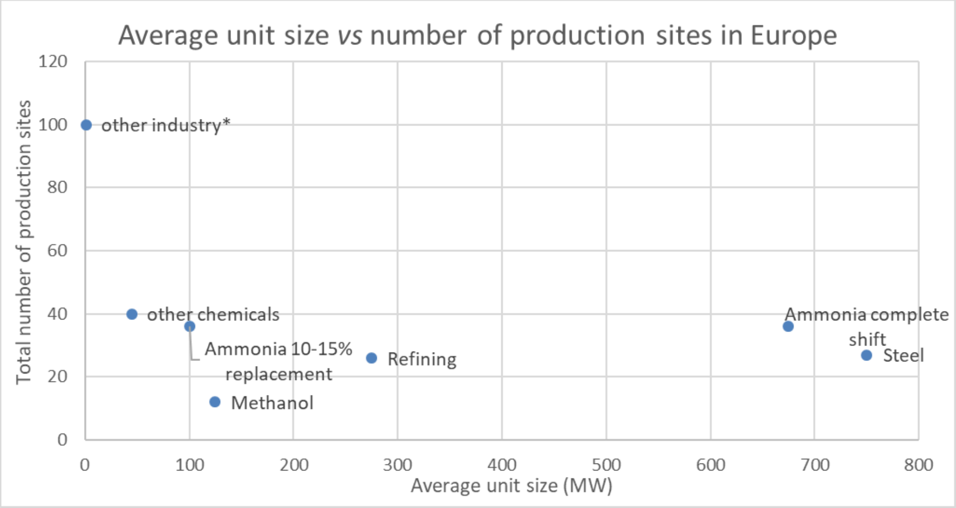
Green H_2 demand estimation:
5,7 Mt < Green H2 demand < 6,4 Mt

RePowerEU
10 Mt

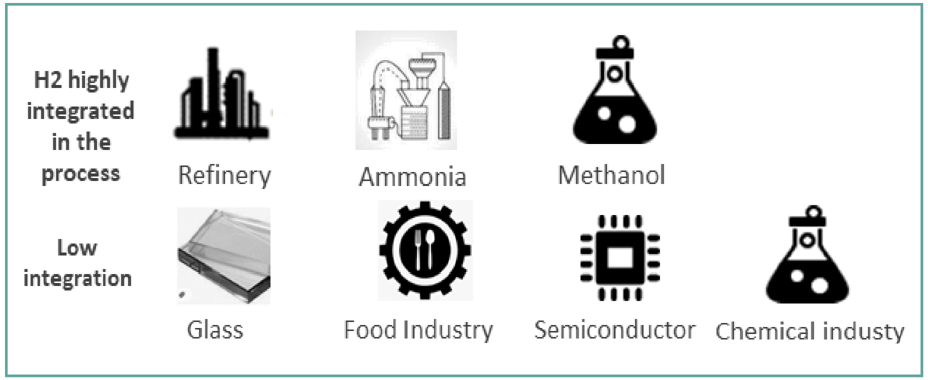


European Hydrogen Markets (2/2)

- Depending on the level of integration of H_2 production in the process, a switch to green H_2 is more or less difficult
- Other solutions exist to decarbonize existing facilities: carbon capture unit, bio-methanol, electrification (transport)
- Traditional hydrogen uses require average unit sizes over 100 MW
- Stable and incentive European regulatory framework is needed, improvement of the infrastructures (pipelines, storages, electrical grid)

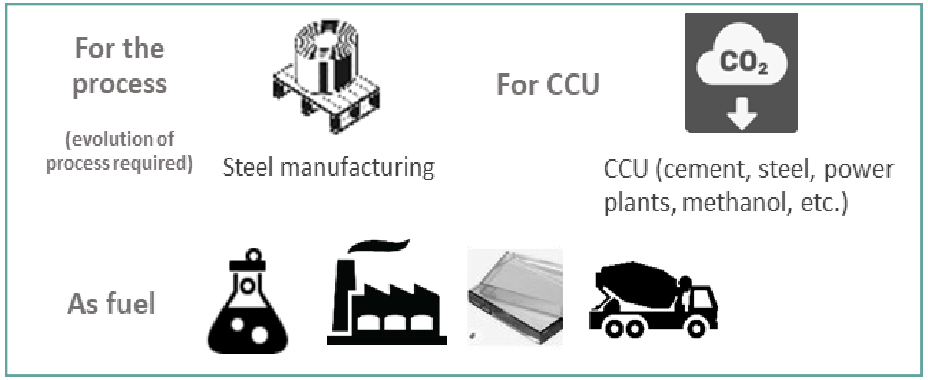


Already existing uses of hydrogen (process)



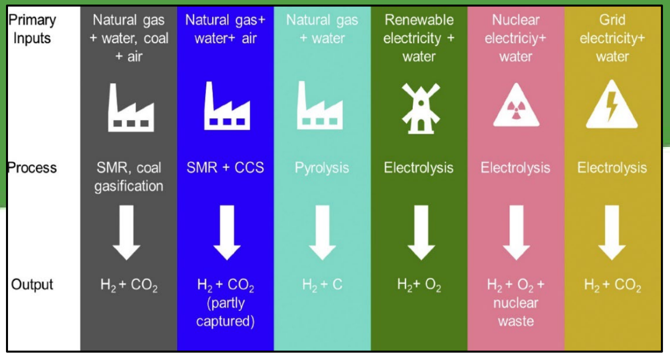
→ Green H_2 could replace grey H_2

New uses of hydrogen

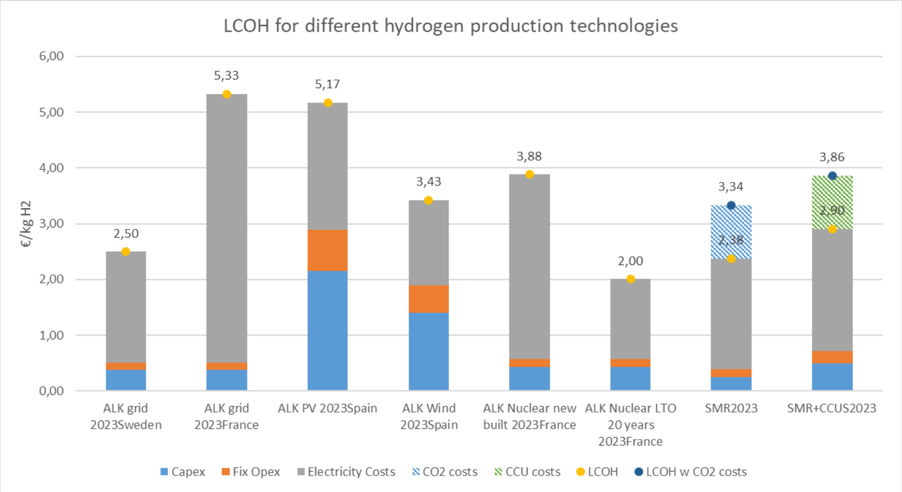


→ For CCU or H_2 as fuel, many industries could be targeted

Different means to produce H_2



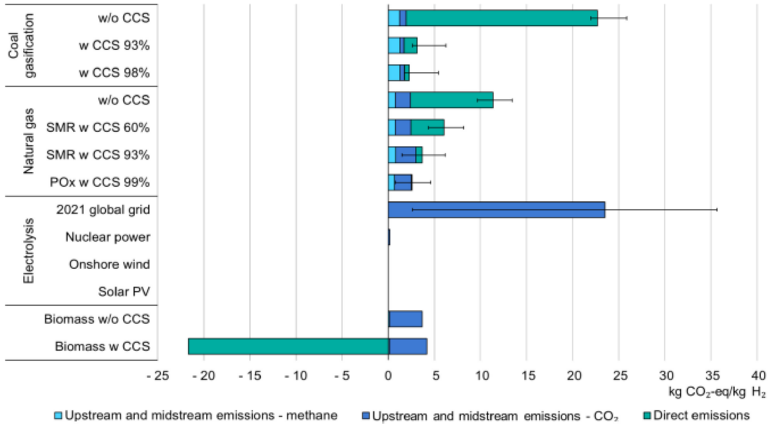
	SMR	POX	ATR	Coal gasification	SMR + CCUS	ALK	PEM	SOEC
Operating temperature (°C)	700-1000	> 1000	> 1000	700 - 1200	-	60-80	50-80	700-1000
Operating pressure (bar)	15-50	40-100	30-100	25-100	-	1-30	30-80	1-20
TRL (scale 1-9)	9	9	9	9	9	9	7-8	5-7
CRL	Mature and available	Mature and available	Early commercial	Mature and available	Mature and available	Mature and available	Mature and available	Emerging
Biggest existing system	>= 1 ktons H2/day	NA	300 kNm3/h	NA	NA	150 MWe Ningxia Solar Hydrogen Project	20 MWe Puertollano Green H_2 Plant	1 MWe H2 Lab Leuna (ongoing: 2.6 MWe MultiplHy)
Purity	High purity gas	High purity gas	High purity gas	High purity gas	-	High-purity gas	High purity gas	Pure hydrogen



Economic comparison

Technical comparison

- CO_2 intensities are really different depending on the H_2 color
- For the same H_2 color, many factors influence the LCOH:
  - Electricity prices (country, year)
  - Taxes, incentives
  - RE potential (location)



Environmental comparison

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Conclusions

- Nuclear hydrogen is the only one that can provide a reliable and constant supply, without emissions and with no dependency on natural gas prices as happens with grey hydrogen.

- The hydrogen selling price offered could be competitive in the market in medium- term but it is necessary that **new projects developed are supported by subventions.** The NPPs have to get a reasonable profitability from its new business model in case they decide to invest in a hybrid system.

- There are still challenges and barriers to overcome but if we want to make a reality nuclear hydrogen production the moment for R&D, investment and policy makers is NOW.

UPCOMING EVENTS

Final NPHyCo conference

Brussels (Belgium), 11 February 2025.

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