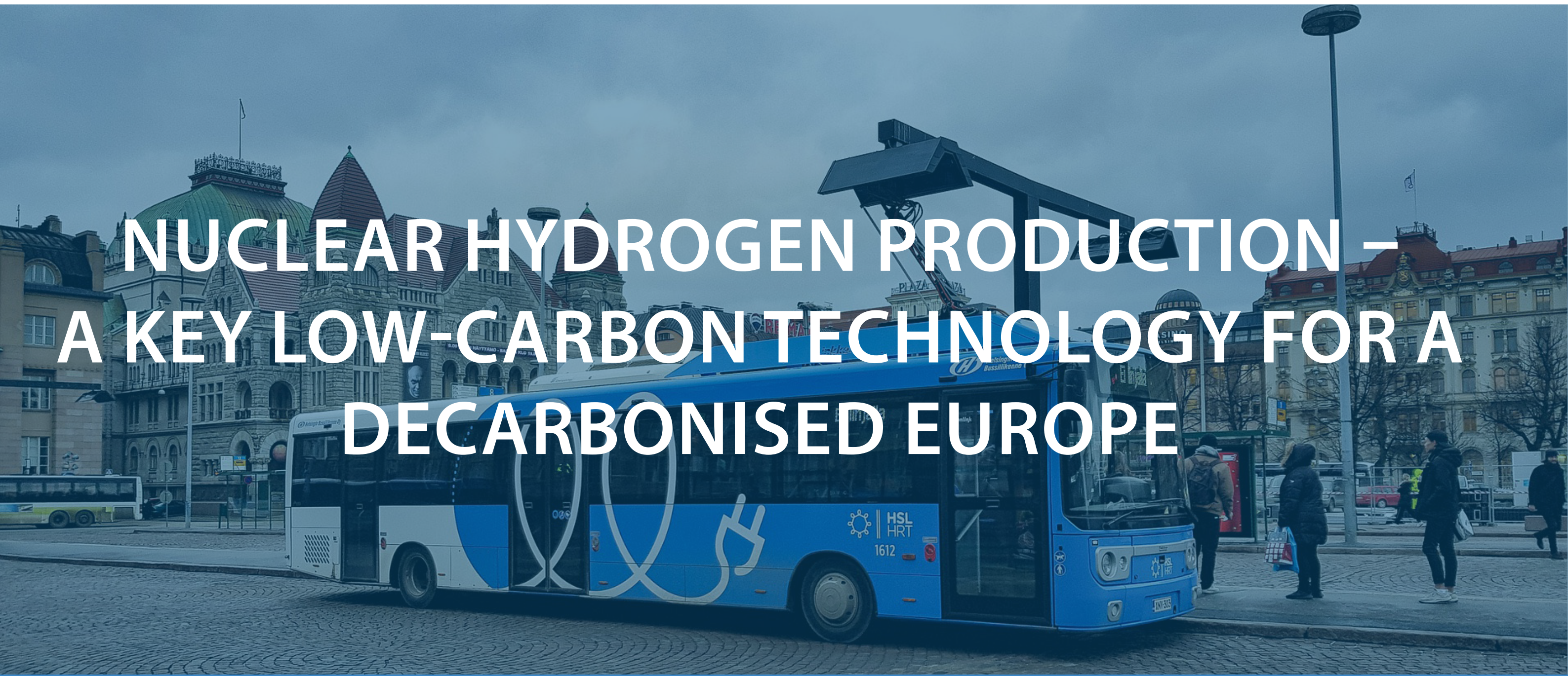
FORATOM
THE VOICE OF THE EUROPEAN NUCLEAR INDUSTRY

NUCLEAR HYDROGEN PRODUCTION – A KEY LOW-CARBON TECHNOLOGY FOR A DECARBONISED EUROPE



NUCLEAR

Is a low-carbon energy source

Ensures security of supply

Is environmentally, economically and socially sustainable

EU NUCLEAR INDUSTRY IN NUMBERS

Accounts for **26%** of electricity

Almost **50%** of low-carbon electricity

Supports around **1 Mn** jobs

Turnover of **100bn** per year

May 2021

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Abbreviations

AEL	Alkaline Electrolyser
AEMEL	Anionic Exchange polymer Membrane Electrolyser
CAPEX	Capital Expenditure
CCfD	Carbon Contracts for Difference
CCS	Carbon Capture and Storage
CCUS	Carbon Capture and Use/Storage
EU	European Union
EU ETS	EU Emission Trading System
FCH	Fuel Cells and Hydrogen
GoO	Guarantees of Origin
HEEP	Hydrogen Economic Evaluation Programme
HTE	High temperature electrolysis
HTGR	High-Temperature Gas-Cooled Reactors
HTR	High Temperature Reactor
IPCEI	Important Projects of Common European Interest
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Hydrogen
NC2I	Nuclear Cogeneration Industrial Initiative
NCBJ	Polish National Centre for Nuclear Research
NECP	National Energy and Climate Plans
NPP	Nuclear Power Plant
PEMEL	Proton Exchange Membrane Electrolyser
PPA	Power Purchase Agreement
R&D	Research & Development
R&I	Research & Innovation
SET-Plan	Strategic Energy Technology Plan
SMR	Small Modular Reactor
SNETP	Sustainable Nuclear Energy Technology Platform
SOEL	Solid Oxide Electrolyser
SZC	Sizewell C
VHTR	Very High Temperature Reactor

1. Context

a. European Green Deal: 2050 climate ambitions

The climate objectives of the European Green Deal, in particular transforming Europe into the first climate-neutral continent by 2050, offer the perfect opportunity to further develop and deploy ready-to-use nuclear-produced hydrogen technologies in Europe. Synergies between the EU's *Integrated clean energy system strategy* and the *Clean Hydrogen strategy* will support Europe's transition to a climate-neutral economy, guaranteeing a secure supply of affordable energy, and helping the EU recover after the COVID-19 crisis.

In FORATOM's opinion, it is essential that the EU adopts a technology neutral approach based on the potential which each technology offers in terms of helping the EU achieve its ambitious CO_2 emission reduction targets. This means leveraging all mature low-carbon energy sources capable of producing hydrogen within Europe. We therefore urge the EU to acknowledge the important role that the nuclear energy sector will provide in this context.

In its 'A Clean Planet for all' strategy, the European Commission confirmed that nuclear, together with renewables, will form the backbone of a carbon-free European power system. Therefore, the upcoming EU Hydrogen Strategy must support all activities which will enable the production of low-carbon hydrogen – and this includes nuclear.

b. Smart sector integration and hydrogen strategies in the European Green Deal

The EU strategy for energy system integration[1] outlines a vision to create a smarter, more integrated and optimised energy system, in which all sectors can fully contribute to the decarbonization objectives. Hydrogen is an important element of the strategy, but its key role and its wider scope warrant a specific approach and therefore the Commission also adopted a strategy dedicated to hydrogen in Europe[2]. The goal of this second strategy is to bring together different strands of action, from research and innovation, production and infrastructure to the international dimension.

The hydrogen strategy proposes 2 main categories:

- *'Clean hydrogen' which refers to renewable hydrogen*
- *'Low-carbon hydrogen' which encompasses fossil-based hydrogen with carbon capture and electricity-based hydrogen, with significantly reduced life-cycle greenhouse gas emissions compared to existing hydrogen production.*

In the second category, "electricity-based hydrogen" refers to low-carbon electricity and thus includes nuclear electricity production. However, the low-carbon hydrogen category is seen more as a short- and medium-term solution which supports the transition to clean hydrogen.

[1] Released on 8 July 2020

[2] Also released on 8 July 2020

In terms of ambitions, the strategy proposes the following path:

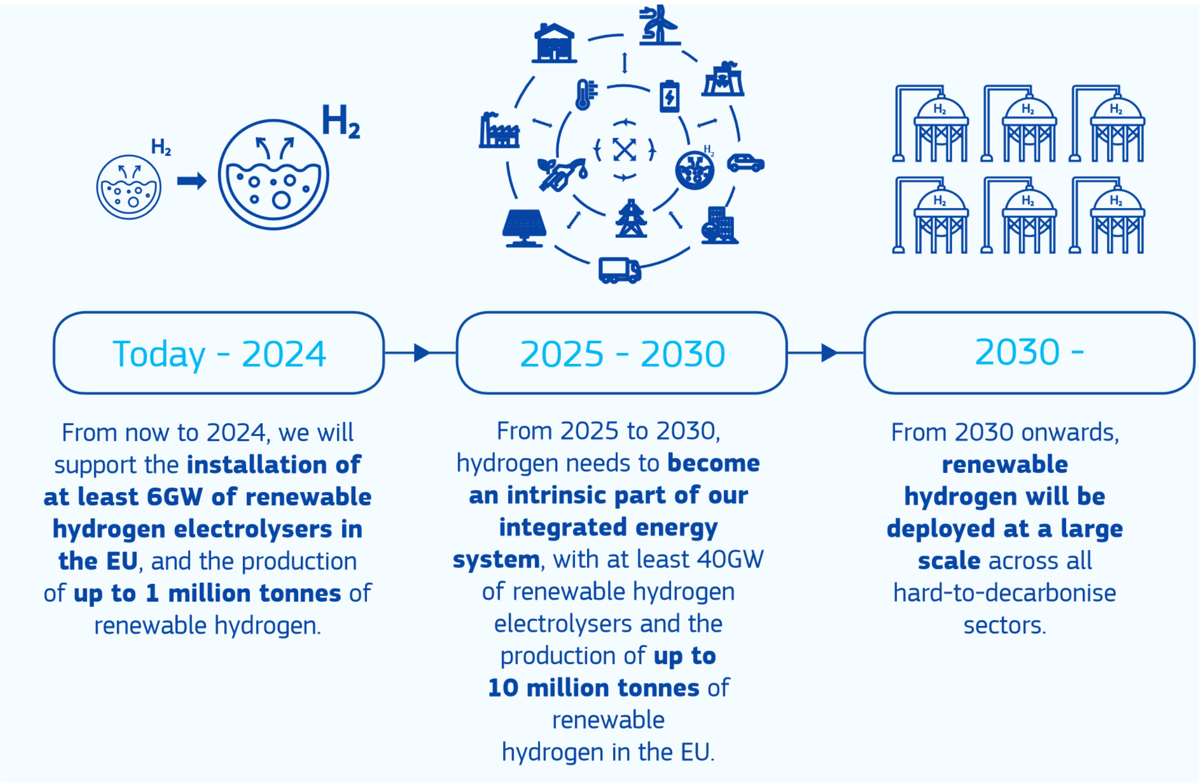


Fig. 1 - The path towards a European hydrogen eco-system step by step[3]

The Commission has high ambitions for EU hydrogen production. Although it only mentions renewable hydrogen, such production targets will be impossible to meet without low-carbon hydrogen produced primarily from low-carbon electricity. The other option under the low-carbon hydrogen category – fossil fuels plus CCS - is still far from reaching industrial maturity and financial viability within the given timeframe.

c. Hydrogen production forecasts in the National Energy and Climate Plans (NECPs) of the EU27 Member States

Introduced under the Regulation on the governance of the energy union and climate action (EU/2018/1999), Member States submitted their final NECPs to the Commission in 2020[4]. Following on from this, the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) commissioned a study[5] by Trinomics which analyses the role renewable and low-carbon hydrogen can play in the short and medium term in the different Member States.

[3] European Commission (2020, 8 July), *EU Hydrogen Strategy Factsheet*

[4] European Commission (2019, 23 January), National Energy and Climate Plans (NECPs)

[5] Gérard et al (2020), *Opportunities for Hydrogen Energy Technologies consideringthe National Energy & Climate Plans*, Rotterdam: Fuel Cells and Hydrogen 2 Joint Undertaking

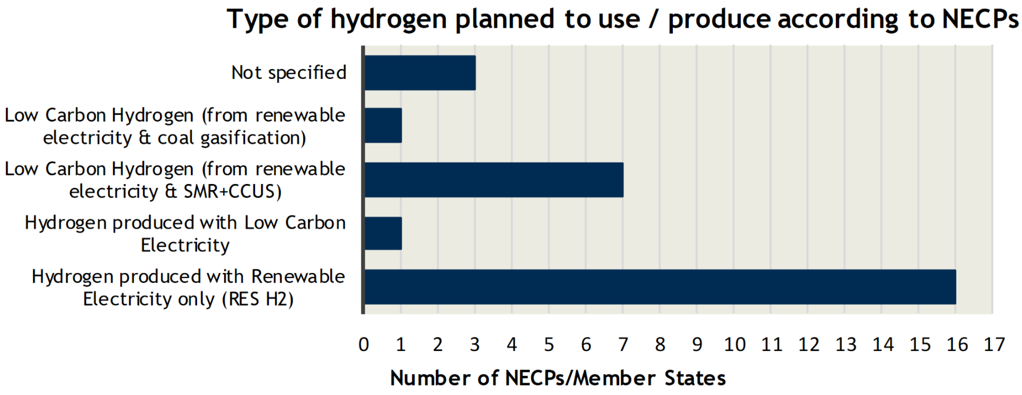


Fig. 2 - Number of Member States indicating in their NECP the type of hydrogen they plan to use/produce[6]

Whilst the study focuses mainly on renewable-based hydrogen production, it includes the following statement on nuclear: "*A specific opportunity for hydrogen production using electrolysis is identified in countries that utilize nuclear energy. The electricity produced in nuclear power plants typically covers the "base load", since these power plants have comparatively low variable costs. As the flexibility of nuclear power plants is limited and taken into account that they need a high load factor in order to cover their fixed costs, their power output not utilizable on the power market could be converted into low-carbon hydrogen.*"

The study puts forward two (high and low) scenarios relating to hydrogen demand in 2030 (42 and 183 TWh/year respectively for the EU28). To cover hydrogen demand as estimated in the two scenarios, **13 and 56 GW respectively of electrolyser capacity will have to be installed**, assuming an average annual **utilisation rate of 4.800 full load hours.** To this end, 68 and 291 TWh/year respectively of renewable power will be needed, based on an electrolysis efficiency of 69% (power to gas). "Surplus" electricity from the markets in times of low electricity wholesale prices can be used for this purpose as well.

The study also includes an analysis of specific countries such as Bulgaria[7]: "*The existence of nuclear power generation capacity in Bulgaria may represent a specific opportunity for deploying hydrogen; as the variable cost of nuclear power plants is very low, they could be used at full load while converting 'excessive' output into hydrogen. This approach would also enhance the load factor of power-to-hydrogen installations, and improve their economic feasibility.*"

Country specific overviews for Sweden[8], Czech Republic[9] and Slovakia[10] also contain similar statements.

Several NECPs refer to ways in which Member States plan to continue supporting the use of nuclear energy. In some instances, they also refer to R&D activities to aid the deployment of hydrogen. For instance, Poland has earmarked funding for the development of a high temperature reactor which could produce both electricity, industrial process heat and hydrogen.

[6] Ibid.

[7] Gérard et al (2020), Bulgaria - Opportunities for Hydrogen Energy Technologies consideringthe National Energy & Climate Plans, Rotterdam: Fuel Cells and Hydrogen 2 Joint Undertaking

[8] Gérard et al (2020), *Sweden - Opportunities for Hydrogen Energy Technologies consideringthe National Energy & Climate Plans,* Rotterdam: Fuel Cells and Hydrogen 2 Joint Undertaking

[9] Gérard et al (2020), *Czech Republic - Opportunities for Hydrogen Energy Technologies consideringthe National Energy & Climate Plans,* Rotterdam: Fuel Cells and Hydrogen 2 Joint Undertaking

[10] Gérard et al (2020), *Slovakia - Opportunities for Hydrogen Energy Technologies consideringthe National Energy & Climate Plans,* Rotterdam: Fuel Cells and Hydrogen 2 Joint Undertaking

d. Nuclear energy: beyond baseload electricity

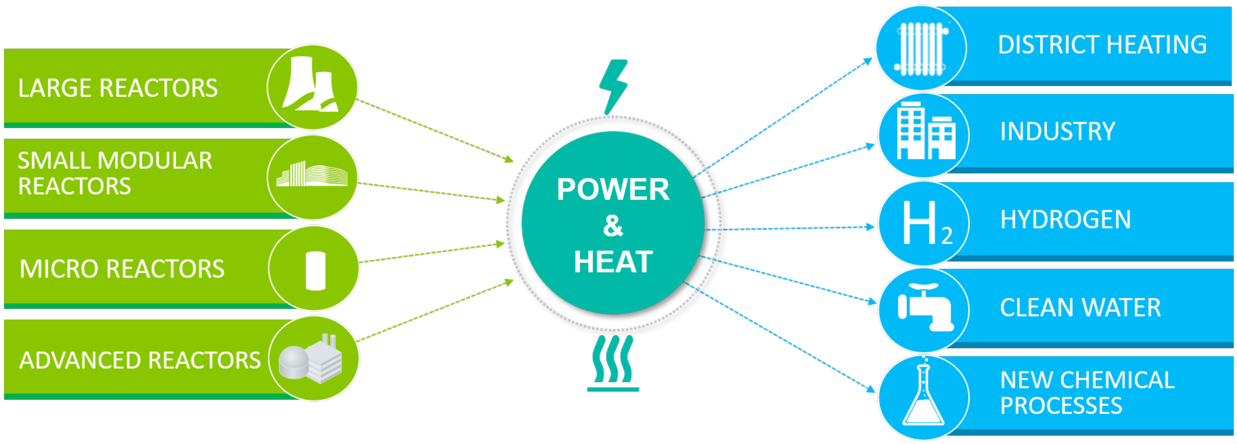


Fig. 3 - Current and future nuclear applications for industry – sector coupling

The role of nuclear is not limited to power production. Nuclear can be used for many other applications. For example, nuclear reactors are capable of delivering heat for use in applications such as district heating, industrial processes[11], hydrogen production[12], chemicals refinement and seawater desalination.

Thanks to a wide range of clean energy solutions, nuclear is capable of supporting several of the EU´s manufacturing industries by providing the low-carbon hydrogen - produced through electrolysis - required for the different industrial processes. This can be provided by both the existing fleet of nuclear reactors and new, innovative and advanced reactors.

Previous EU Research and Innovation (R&I) programmes have supported projects linked to the production of hydrogen from nuclear. This experience should be built upon and considered in the delivery of the EU hydrogen strategy.

Low-carbon gases will play an important role in decarbonizing the economy, complementing areas where direct electrification cannot be implemented.

In order to achieve the decarbonisation targets, a level-playing field must be ensured between the different sources of low-carbon or decarbonised gases. In this respect, the focus must be on technologies which will enable the greatest CO_2 emission reductions. Furthermore, policies should be developed to enable a well-functioning market. This would allow utilities to produce and sell decarbonized gases such as hydrogen as a commodity in addition to providing clean and reliable electricity to the grid.

The main opportunity when discussing low-carbon gases is hydrogen. Whilst it should play an important role, it is essential that the EU strategy takes into account the broad range of production options capable of decarbonising the energy sector. Therefore, in FORATOM's opinion **hydrogen should be classified on the basis of a detailed life-cycle assessment of the carbon intensity of the source used to produce it**. So instead of referring to renewable (or green) hydrogen, the EU should use the term low-carbon or decarbonised hydrogen as this would include all low-carbon sources such as nuclear. Indeed, academia, industry and several international organisations have

[11] International Atomic Energy Agency (2017), *Opportunities for Cogeneration with Nuclear Energy*, Nuclear Energy Series No. NP-T-4.1, Vienna: IAEA

[12] International Atomic Energy Agency (2013), *Hydrogen Production Using Nuclear Energy*, Nuclear Energy Series No. NP-T-4.2, Vienna: IAEA

indicated that low-carbon hydrogen produced from nuclear is a viable option. This is particularly relevant when we bear in mind that the biggest challenge facing the deployment of hydrogen is how to source large volumes of low-carbon hydrogen at a reasonable cost.

e. EU Sustainable Finance Taxonomy

Although the first draft Delegated Act[13] of the Sustainable Finance Taxonomy does not currently include (nor exclude) nuclear[14], the EU Sustainable Finance initiative might have an important impact on future hydrogen production. In a leaked version of the updated Delegated Act on climate mitigation and adaptation, the proposed threshold applied to the production of clean hydrogen is 3 $tCO_2/eqtH_2$ (equivalent around 50 gCO_2/kWh). This is a very low threshold which only a very small number of countries will be able to meet (France and Sweden). However, given that certain renewables, such as wind and solar, do not currently need to meet a CO_2 threshold according to the same document, this would suggest that only these technologies will be taxonomy compliant.

2. Key technologies for the hydrogen economy and the role of nuclear energy

a. Current status

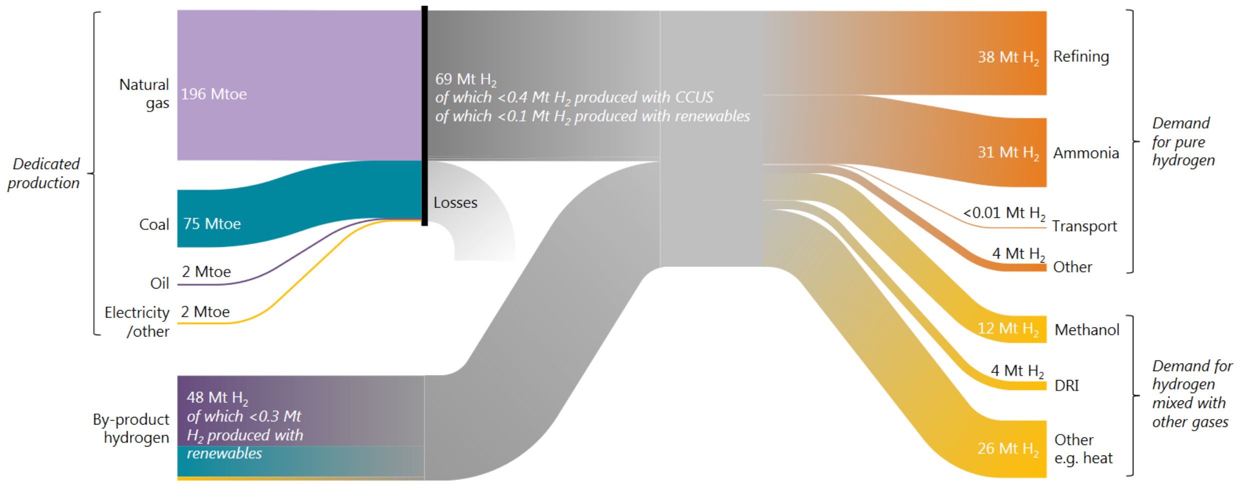


Fig. 4 - Today's world hydrogen value chains[15]

Low-carbon hydrogen production routes are critical if hydrogen is to help the EU achieve its decarbonisation goals. Figures 4 and 5 show that most of the hydrogen used today is produced through emissions-intensive natural gas reforming and coal gasification.

[13] European Commission, Implementing and delegated acts

[14] The assessment of nuclear was undertaken by the Commission's Joint Research Center with a view to including it under the taxonomy in the future.

[15] International Energy Agency (2019), *The Future of Hydrogen*, Paris: IEA

However, producing low-carbon hydrogen from a reliable source of low-carbon electricity (like nuclear) via the process of water electrolysis may be close to becoming an alternative solution.

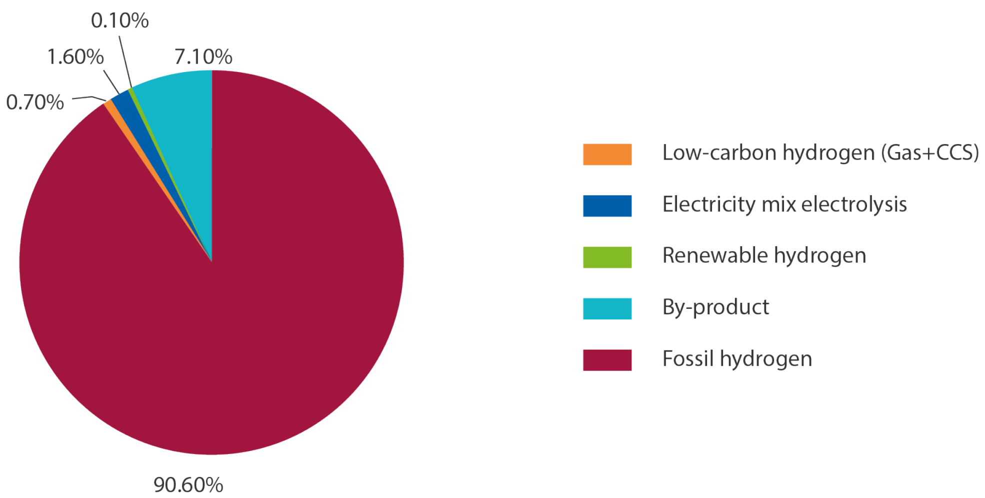


Fig. 5 - Current EU hydrogen production[16]

While electrolysers are a well-known technology which have been used for a long time in a variety of industrial sectors, their fastest-growing market is for uses that serve energy and climate objectives: vehicle fuelling, potential hydrogen injection into the gas grid, using hydrogen in industrial processes, electricity storage and synthetic fuel manufacturing. All of this will require an increase in new hydrogen production within Europe.

In recent years, installed electrolyser capacity has expanded, growing from less than 1 MW in 2010 to more than 25 MW in 2019 globally. Furthermore, the size of the projects have increased significantly: most projects in the early 2010s were below 0.5 MW, while the largest in 2017-19 were 6 MW with the others falling into the 1 to 5 MW range[17]. This is a good trend for the hydrogen economy but there is still a long way to go. Only by making full use of all low carbon energy sources in Europe, will it be possible to establish a truly viable near-term hydrogen economy.

The electrolysis process enables the production of hydrogen from electricity and water. It is a mature process which can be considered as an alternative to fossil fuel-based hydrogen. In a nutshell, it involves passing an electric current through water, which separates the hydrogen and oxygen molecules. However, the process does involve considerable amounts of energy to break the strong molecular bonds within water. It is regarded as being 60–76% efficient, and further energy losses occur when hydrogen is stored, compressed, or converted into other fuels. Fuel cells and combustion also generate further losses, so the round-trip efficiency of hydrogen (from electricity into electrolysis back to electricity in a fuel cell or an engine) can be at best 45% and at worst 16%[18]. Given this, it is essential that coordinated efforts are made at EU level to utilize the most efficient route for producing hydrogen, such as via coupling with nuclear power.

[16] Hydrogen Europe (2020), *Hydrogen Europe 2020 monitor*

[17] International Energy Agency (2020), Hydrogen, Paris: IEA

[18] Ingersoll, E., Gogan, K. (2020), Missing Link to a Livable Climate: How Hydrogen-Enabled Synthetic Fuels Can Help Deliver the Paris Goals, LucidCatalyst

b. Producing hydrogen from nuclear technologies

Nuclear power plants can produce hydrogen through a variety of ways by taking advantage of their constant supply of thermal energy and electricity. The existing nuclear fleet can produce high quality steam at a lower cost than natural gas boilers, and this can be used in many industrial processes, including the steam-methane reforming process that is widely used today for hydrogen production. The fact that nuclear can provide a steady supply of electricity and heat is well known, and this is ideal for hydrogen produced via electrolysis.

Electrolysis[19] has various technical characteristics which make it suitable for coupling with electricity provided by nuclear generation. Furthermore, there are several R&D initiatives which aim to optimise electrolysis technologies and performance over the next decade via coordinated programmes[20] that will make coupling with nuclear power even more beneficial. Because nuclear reactors provide a constant supply of electricity, they are at a unique competitive advantage as this reduces the need to ramp electrolysers up or down, as would be the case if they were only supplied by variable/intermittent renewables. Coupling electrolysers with nuclear can result in a much more efficient process which will ultimately lead to a lower hydrogen price and lower CO_2 emissions per kg of hydrogen.

The current status of electrolyser performance and opportunities for reaching certain targets established within the hydrogen community by 2030 can be found under Table 1.

Parameter	Unit	AEL		PEMEL		SOEL		AEMEL	
		2020	2030	2020	2030	2020	2030	2020	2030
Electricity consumption at nominal capacity[21]	kWh/kg	50	48	55	48	40	37	55	48
Heat demand at nominal capacity[22]	kWh/kg	N/A	N/A	N/A	N/A	9.9	8	N/A	N/A
Hot idle ramp time[23]	sec	60	10	2	1	600	180	30	1
Cold start ramp time[24]	sec	3,600	300	30	10	12 (hrs)	4 (hrs)	1800	10
Footprint[25]	m2 /MW	100	40	50	25	150	50	90	50
Stack Degradation[26]	%/1,000hrs	0.12	0.10	0.19	0.12	1.9	0.5	>1.0	0.15

Table 1 – Overview of electrolyser performance now and towards 2030[27]

[19] AEL: Alkaline Electrolyser; PEMEL: Proton Exchange Membrane Electrolyser; SOEL: Solid Oxide Electrolyser; AEMEL: Anionic Exchange polymer Membrane Electrolyser.
[20] Hydrogen Europe (2020), *Strategic Research and Innovation Agenda*
[21] Electrical energy demand at nominal hydrogen production rate of the system at standard boundary conditions.
[22] Heat demand is the heat absorption of the system at nominal capacity (mostly provided by steam).
[23] Time required to reach nominal capacity in terms of hydrogen production rate when starting the device from hot idle (warm standby mode - system already at operating temperature and pressure).
[24] Time required to reach nominal capacity in terms of hydrogen production rate when starting the device from cold standby mode.
[25] Average specific space requirement of a MW system comprising all auxiliary systems to meet standard boundary conditions in 1) and built up as indoor installation.
[26] Stack degradation defined as percentage efficiency loss when run at nominal capacity. For example, 0.125%/1,000h results in 10% increase in energy consumption over a 10-year lifespan with 8,000 operating hours per year.
[27] Target as indicated in Hydrogen Europe and Hydrogen Europe Research (2020), *Strategic Research and Innovation Agenda*

- ### Water electrolysis

Using electricity to split water into hydrogen and oxygen via electrolysis can be achieved by coupling the electrolyser with nuclear produced electricity. This low-temperature electrolysis can be delivered from Alkaline (AEL), Proton Exchange Membrane (PEMEL) and Anionic Exchange polymer Membrane (AEMEL) electrolysers.

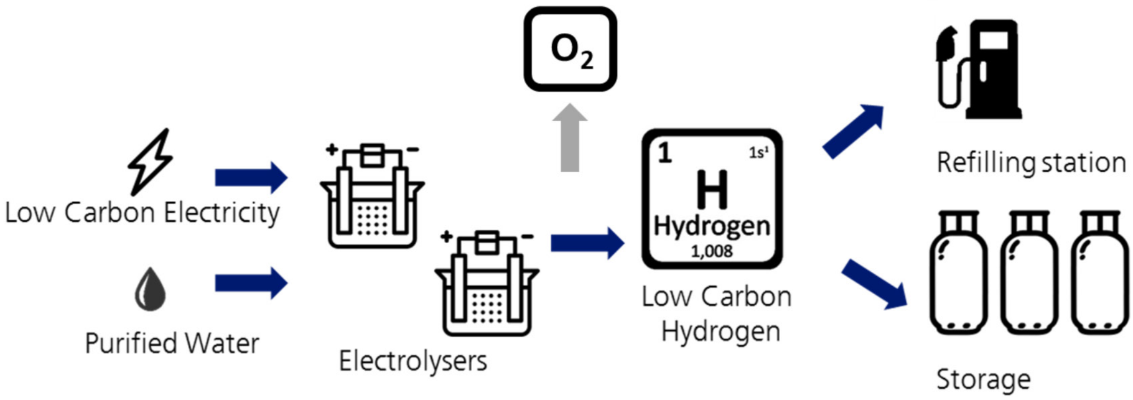


Fig. 6 - Electrolysis basic components and process[28]

Table 1 shows that the performance of an electrolyser depends heavily on multiple parameters and whether it starts up from hot idle or from cold. The ability to utilize regular and planned amounts of electricity from nuclear to power the electrolysers is a key benefit of coupling nuclear and hydrogen production. The ability to divert a planned amount of electricity produced by a nuclear power plant to a water electrolysis process is an already existing concept which has been proven by feasibility studies and demonstration projects as highlighted later on in this section.

- ### Steam electrolysis

One unique ability of nuclear power is that it can produce both electricity and usable heat for the steam electrolysis process which requires much less electricity than traditional cold-water electrolysis. Coupling Solid Oxide (SOEL) type electrolysers with nuclear provides the option of utilizing the heat produced under normal nuclear operations via a small amount of steam taken-off from the secondary circuit in a nuclear power plant. This helps raise the temperature of the hydrogen production process, which can enable better efficiency compared to standard cold-water electrolysis. For instance, initial analysis undertaken by EDF indicates that it is technically feasible to use low temperature heat (c. 150-200°C) from UK European Pressurized Reactors (EPRs) to support steam electrolysis via heat exchangers in order to achieve the required operating temperatures[29]. In this respect SOEL can be considered as belonging to both the electrolyser & thermal routes. Specifically, SOEL uses thermal plant energy via the steam in order to reduce the cell potential (voltage) and improve efficiency. Small modular reactors could also play a role in SOEL electrolysis and thus further ease deployment in the future.

[28] EDF Energy R&D UK Centre (2019), *H2H - Hydrogen to Heysham feasibility report* (Hydrogen Supply Programme), London: EDF Energy

[29] Nuclear Industry Association (2021), *Hydrogen Roadmap*, London: NIA

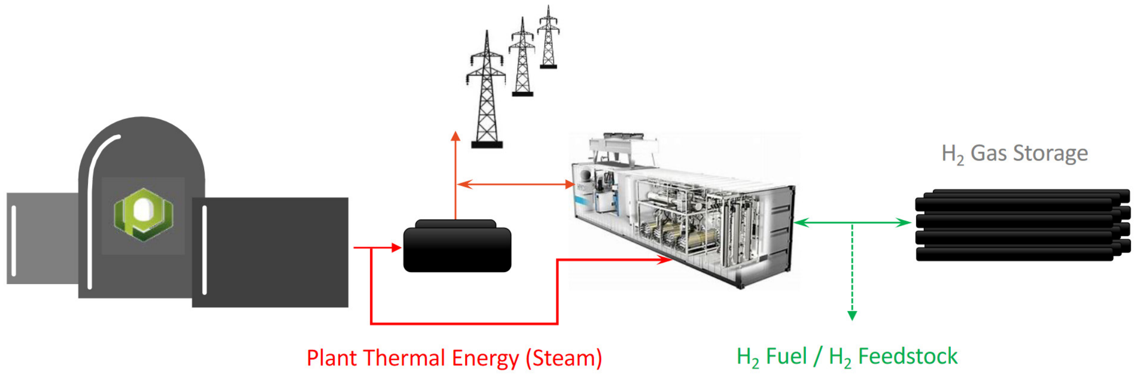


Fig. 7 - Existing nuclear power plant being utilized to support efficient hydrogen production via steam electrolysis at a site within the US[30]

This approach is being funded within various projects worldwide (USA[31]) and as indicated later on within this paper.

- ### Thermochemical water splitting

The utilization of high temperature heat ranging from 600-900°C produced by advanced nuclear reactors provides another avenue for even more efficient hydrogen production. Using this heat in chemical catalysts can cause water to split into hydrogen and oxygen. Examples of R&I projects being developed to utilize high temperature reactors to potentially produce hydrogen are highlighted later in this paper.

c. Current initiatives relating to nuclear produced from hydrogen

There are many international, national and company projects focusing on hydrogen produced from nuclear. This should be acknowledged within the EU's policies and strategies. One readily available option of producing hydrogen from nuclear is conventional low temperature electrolysis, which uses off-peak electricity from existing nuclear power plants. This is the concept behind the recent Hydrogen2Heysham Project in the UK. The first phase of the project was funded by the UK government and has shown great potential for coupling a hydrogen producing electrolyser with electricity from a nuclear power plant[32]. Coupling nuclear power with hydrogen production is also being deployed at three nuclear power plants in the United States via a government-funded project. This clearly highlights the international trend of interest in this field[33].

Installing an electrolyser which is connected directly to a nuclear power plant (NPP) is technically possible. However, there are important safety/regulatory considerations, as well as legal and competition aspects which require stakeholder consensus. Some preliminary analysis has outlined paths to be followed in order to achieve consensus on this option [34].

[30] Brown, J. (2020). In *Clean Nuclear Energy for Industry* [Webinar]. GAIN, EPRI, NEI
[31] Idaho National Laboratory (2020), *Private-public partnership will use nuclear energy for clean hydrogen production*
[32] EDF Energy R&D UK Centre, *op. cit.*
[33] Patel, S. (2019, 11 September), "Three More Nuclear Plant Owners Will Demonstrate Hydrogen Production", *PowerMag*
[34] Tractebel (2020), *The rise of nuclear technology 2.0: Tractebel's vision on Small Modular Reactors*

In some cases, the enhanced value of producing hydrogen with low-carbon nuclear by connecting electrolysers directly to the grid, rather than the NPP, may be a more appropriate option if an abundance of capacity is available. However, this depends on local conditions, taxation and system costs.

In the short term, and on an industrial scale, there is no technical or economic limitation to installing an electrolyser on a NPP site. Additionally, there are also options to connect the NPP directly to a hydrogen production facility that is sited outside the NPP's perimeter via a direct cable supply. As the electricity would be directly supplied from the NPP to the electrolysers, constraints such as grid network charges would not apply, and so this would provide additional economic benefits.

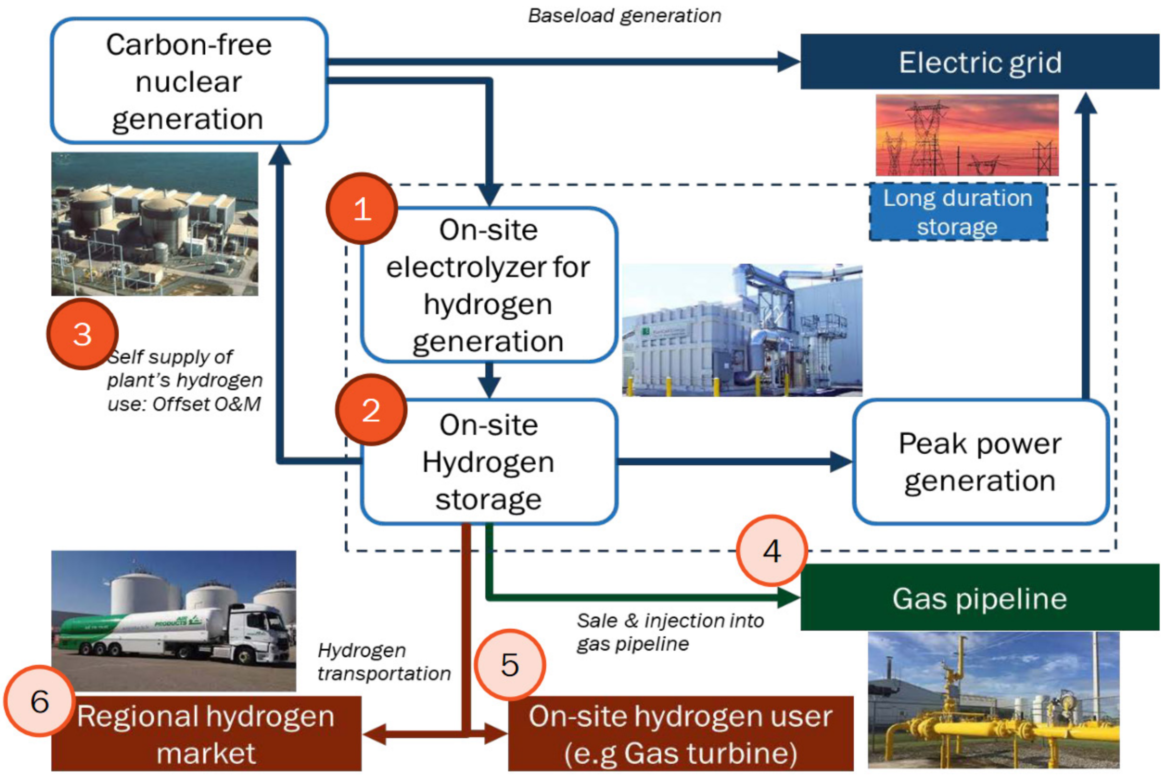


Fig. 8 - Example of a demonstration project within the US: Repurposing Nuclear Plants using Hybrid Hydrogen Approach[35]

This demonstration project will install 1MW PEM electrolyser at one of Exelon's operating nuclear power plants to demonstrate dynamic production of hydrogen from nuclear electricity.

d. Overview of R&I, demonstration projects and initiatives

The interest and scale of coupling nuclear technologies with hydrogen production can be seen across many stakeholders and regions. This alone highlights the need for coordinated action at EU level to bring forward the opportunities that nuclear technologies can offer to help grow the hydrogen economy within Europe.

[35] Otgonbaa, U. (2020). In Clean Nuclear Energy for Industry [Webinar]. GAIN, EPRI, NEI

European examples

- Sustainable Nuclear Energy Technology Platform - NC2I Roadmap[36]
- UK Sizewell C (SZC) seeks partners to develop Hydrogen[37], Expression of Interest Hydrogen demonstration project[38]
    - When constructed, SZC will provide clean low-carbon heat as well as electricity and intends to make some of this heat available for heat assisted steam electrolysis to produce low-carbon hydrogen at scale.
    - The longer-term hydrogen strategy (after the Demonstrator Project) at SZC is still under consideration and SZC is looking at options to utilise a steam-assisted electrolyser which could use steam tapped off from an operational SZC station, adding efficiency to the hydrogen generation process.
- Shearwater Energy Project[39]- A new wind-SMR and hydrogen production hybrid energy project in North Wales, could produce over three million kilograms of low carbon hydrogen a year for the UK's transport sector.
    - "When fully developed, an SMR-wind plant at Wylfa will provide 3 GW of reliable, zero-carbon electricity at a fraction of the cost of a conventional nuclear power station with surplus energy generation focused on the production of hydrogen to support the transport sector's transition to low-carbon fuels. Power generation at Wylfa could begin as early as 2027."[40]
- A Polish[41] Consortium led by the National Centre for Nuclear Research[42] initiated a project to develop the High Temperature Gas Reactor (HTGR) in cooperation with Japan. The reactor is intended primarily for the production of heat and hydrogen for use within industry.

The Fuel Cells and Hydrogen Joint Undertaking Strategic Research Agenda also recognises that the high temperatures produced from Generation IV nuclear reactors could potentially be used in the production of Hydrogen[43]. Several FCH projects[44] also underline the importance of producing hydrogen from low-carbon nuclear energy:

- "Therefore, the development of carbon lean technologies producing hydrogen at reasonable price from renewable or low CO_2 emitting sources like nuclear is of utmost importance." Project SOPHIA[45]
- "High temperature electrolysis (HTEs) produce H_2 efficiently utilizing electricity from renewable sources and steam from solar, geothermal, or nuclear plants." Project ELECTRA[46]

The Commission has also highlighted that "*Coupling nuclear reactors with non-electric applications can provide policy makers with alternatives to decarbonise transport (for example, by producing hydrogen using nuclear heat and electricity), process heat applications and energy system storage*"[47] within one of its own reports about the progress of clean energy competitiveness.

[36] NC2I (2020), *A Roadmap for the Deployment of Industrial Nuclear Cogeneration in Europe*
[37] EDF Energy (2020, 23 November), *Sizewell C seeks partners to develop Hydrogen and Direct Air Capture*
[38] SizewellC (2020), Expression of Interest –Sizewell C Hydrogen Demonstrator Project, London: EDF Energy
[39] Burgess, M. (2021, 15 January), "Shearwater Energy SMR wind-hybrid energy project progresses", *H2 View*
[40] Shearwater (2021), *Shearwater Energy selects NuScale Power's Small Modular technology for SMR wind-hybrid energy project*
[41] Euratom Supply Agency (2020), *Annual Report 2019*
[42] " Prof. Wrochna: New HTR nuclear reactors - perfect for the industry" (2016, 29 Decmber) *Science in Poland*
[43] European Hydrogen & Fuel Cell Technology Platform (2005), *Strategic Research Agenda,* p.15-30
[44] Fuel Cells and Hydrogen 2 Joint Undertaking, (n.d.) *Hydrogen Production and Distribution*
[45] Fuel Cells and Hydrogen 2 Joint Undertaking (2018), *SOPHIA: Solar integrated pressurized high temperature electrolysis*
[46] Hydrogen Europe (n.d.) *Project ELECTRA*
[47] European Commission (2020), Clean Energy Transition –Technologies and Innovations - Accompanying the document REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL on progress of clean energy competitiveness (SWD(2020) 953 final), Part 4/5

International examples

- Japan
  - JAEA Achieves 150 Hours of Continuous Hydrogen Production Toward Utilization of Heat from HTGRs[48]
- USA
  - Private-public partnership will use nuclear energy for clean hydrogen production[49]
  - Various demonstrators will prove the ability and competitiveness to couple hydrogen production technology to nuclear power plants.
- Canada
  - Canadian Nuclear Laboratories is accelerating the transition to a hydrogen economy with advanced hydrogen production and energy storage technologies.[50]
  - Canadian SMR action plan includes strategic actions to develop hydrogen production with SMR technologies.[51]
- China
  - In the near term, the demonstration of advanced nuclear reactors, such as the two-unit industrial prototype high temperature pebble-bed reactor currently finalizing construction in China, could also become a heat source for thermochemical water splitting, with some reactor designs having coolant outlet temperatures of 800–1000°C thus providing high efficiency for the hydrogen production.
- IAEA Hydrogen Economic Evaluation Programme (HEEP)[52]
  - An open tool which can be used to assess the economics of large-scale hydrogen production using nuclear energy.
  - The software can be used to evaluate the economics of the four most promising processes for hydrogen production: high and low temperature electrolysis, thermochemical processes including S-I process, conventional electrolysis and steam reforming.
- IAEA Hydrogen Calculator (HydCalc)[53]
  - HydCalc was developed as a single window calculator to make a rough estimate of the hydrogen production cost utilizing different technologies. It uses current price estimates from publications and articles in open literature and provides a cost value of hydrogen production based on an average estimated CO_2 release. It also considers the effect of a CO_2 tax on the production cost.
- Clean Energy Ministerial, Nice Future Initiative, Flexibility Campaign[54]

[48] Yamada, K. (2019, 1 February) *JAEA Achieves 150 Hours of Continuous Hydrogen Production Toward Utilization of Heat from HTGRs*, Japan Atomic Industrial Forum

[49] Idaho National Laboratory, *op. cit.*

[50] Canadian Nuclear Laboratories, *Hydrogen Research*

[51] *Canada's Small Modular Reactor Action Plan*

[52] International Atomic Energy Agency, *Nuclear hydrogen production*

[53] Ibid.

[54] NICE Future (2020), Flexible Nuclear Energy for Clean Energy Systems (Technical Report NREL/TP-6A50-77088)

- GenIV Hydrogen Production Project Management Board[55]
    - The VHTR hydrogen production program aims at developing and optimizing high temperature thermochemical and electrolysis water splitting processes, as well as defining and validating technologies for coupling any Gen IV Nuclear Reactor system to such plants safely and securely through an international collaborative program.

Several think tanks and other studies have recently highlighted the benefits and role of nuclear in producing hydrogen:

- Missing Link to a Livable Climate How Hydrogen-Enabled Synthetic Fuels Can Help Deliver the Paris Goals[56]
- Zero-Carbon Hydrogen: An Essential Climate Mitigation Option[57]

e. Hydrogen produced from nuclear: development needs

At EU level, investments in R&I should focus on:

- Projects which analyse the socio-economic values of hydrogen production and the Levelised Cost of Hydrogen (LCOH) within the EU from various forms of energy including existing nuclear reactors, small modular reactors and advanced nuclear technologies such as Generation IV reactors.
- Enabling technologies, such as Generation IV nuclear reactors, for high temperature hydrogen production[58]. Coupling to processes such as Sulphur Iodine Process, Copper Chlorine Process, High Temperature Steam Electrolysis and Hybrid-Sulphur Process.
- Leveraging existing initiatives like the SET plan[59] (which includes nuclear) to bring together all the strategic research agendas and their synergies to enable more cross cutting R&D to support hydrogen production at scale.
- Providing a clear definition of hydrogen guarantees of origin (GoO) that highlight the role of low-carbon nuclear energy.

[55] Suppiah, S. (2020), "GIF VHTR Hydrogen Production Project Management Board" [Presentation]. In *GEN IV International Forum*

[56] Ingersoll, E., Gogan, K., *op. cit.*

[57] Energy Options Network (2020), *Zero-Carbon Hydrogen: An Essential Climate Mitigation Option - Nuclear Energy's Potential Role*

[58] Suppiah, S., *op. cit.*

[59] Magagna et al (2020), *Implementing The Set Plan: Making The Set Plan Fit For The EU Green Recovery*, European Commission Joint Research Center

3. Economic and operational features of hydrogen production

Most of the hydrogen that is currently being produced in the EU and worldwide comes from fossil fuels – either by steam reforming of natural gas or gasification of coal. If hydrogen is to realise its potential as an energy vector in a decarbonised economy, it needs to be produced on a mass scale in a sustainable way. But in order for that to happen, clean hydrogen needs to become cost-competitive with conventional fuels.

The main parameter highlighted when discussing about the economics of hydrogen is the production cost per kg. While the hydrogen production costs using natural gas without Carbon Capture and Usage/Storage (CCUS) in different regions in 2018 ranges between less than 0.85€ / kg H2 and up to 1.45€ / kg H2, with CCUS it ranges between less than 1.3€ / kg H_2 and up to 2.04 € / kg H_2[60]. Hydrogen produced via electrolysis is currently more expensive than other methods due to capital costs and dependence on electricity costs. Water and steam electrolysis demonstration projects for AEL, PEMEL and SOEL technologies of up to 10 MW scale are currently operational. Projects of around 20 to > 100 MW are under development. The current cost of hydrogen produced through these technologies ranges between 2.6-9.5 €/kg H_2.

According to different sources, the cost of producing renewable and low-carbon hydrogen will need to fall by over 50% by 2030 in order to transform **hydrogen into a viable alternative to conventional fuels**. As mentioned above, the two components which have an important impact on hydrogen production costs are CAPEX and the cost of electricity.

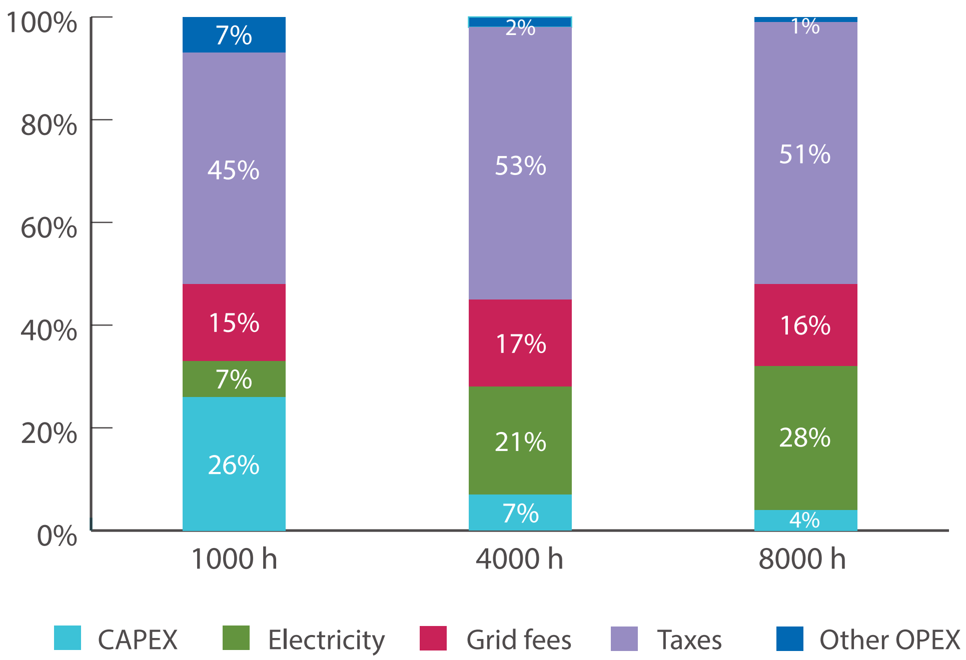


Fig. 9 - Comparison of the share of hydrogen production with grid connected electrolysis in Germany, depending on the number of operating hours (adapted from the HydrogenEurope report[61])

[60] International Energy Agency, *op. cit.*

[61] Hydrogen Europe (2020), *Hydrogen Europe 2020 monitor*

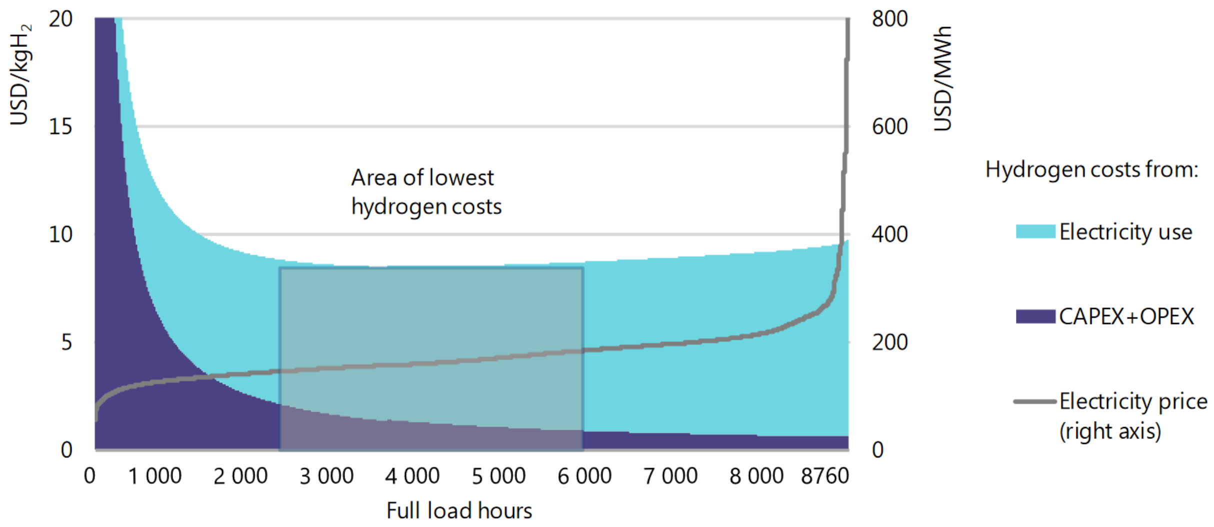
a. CAPEX of hydrogen electrolysis installations

The CAPEX for the various electrolysis installations differs depending on the source or on what is taken into consideration (just the electrolysis stack or the entire installation for hydrogen production). This paper uses the Hydrogen Europe "Strategic Research and Innovation Agenda" 2020[62] as a reference, as it is of relevance to Europe and includes forecasts for 2030.

Technology/Year	2017	2020	2024	2027	2030
AEL	750	600	480	440	400
PEMEL	1200	900	700	600	500
SOEL	6950	2130	1250	760	520

Table 2 - Capital costs for electrolysers (€/kW)

The IEA states[63] that "*With increasing full load hours, the impact of CAPEX on hydrogen costs declines and the electricity becomes the main cost component for water electrolysis*".



Notes: CAPEX = USD 800/kW$_e$; efficiency (LHV) = 64%; discount rate = 8%.
Source: IEA analysis based on Japanese electricity spot prices in 2018, JEPX (2019), *Intraday Market Trading Results 2018*.

Fig. 10 - Hydrogen costs from electrolysis using grid electricity[64]

As shown in Figure 10, the CAPEX share will decrease with an increase in the capacity factor of the electrolyser, confirming that an optimal functioning time could be somewhere between 3000h-6000h. In this respect, the IEA raises an important point in its report: in electricity systems with increasing shares of variable renewables, there are some hundreds of hours when electricity might be curtailed. Producing hydrogen through electrolysis and storing it for later use could be one way to take advantage of excess electricity. **But if surplus electricity is only**

[62] Hydrogen Europe and Hydrogen Europe Research (2020), op.cit.

[63] International Energy Agency, *op. cit.*

[64] Ibid.

available on an occasional basis, relying on it to keep costs down does not really make sense. Running the electrolyser at high full load hours and paying for the additional electricity can actually be cheaper than just relying on surplus electricity with low full load hours.

b. Electricity price

Figure 10 shows that the electricity price is low if the electrolyser functions only for 1,000h/year, mainly due to the usage of renewable produced power and avoiding curtailments as much as possible. The price starts to increase together with an increase in the capacity factor as this would require other power sources (including nuclear). At a utilisation rate of around 4000h/year, the share of electricity in the price is 3 times more than for 1,000h/year. At a utilisation rate of over 7000h/year, the price of electricity includes some spikes, making the share even higher.

This clearly demonstrates that, **in order to decarbonise different industrial processes at an affordable cost, electrolysers will need to run constantly on low-carbon electricity.** With nuclear – either on its own or complementing variable renewables (wind and solar) - supplying constant power for low-carbon hydrogen production, this will ensure a quasi-baseload electrolyser which will trigger decreasing production costs.

A similar conclusion has been reached by the French Academy of Technologies in a recent report[65].

	LCOE (€/MWh)	Load Factor	CAPEX/Production Cost	
			1000€/kw	500€/kw
Amortized nuclear (long term operation)	***32***	***90%***	***2.75€/KG***	***2.25€/KG***
New Nuclear	***80-100***	***90%***	***5.4-6.5€/kg***	***4.9-6€/kg***
PV	65	15%	8.5€/kg	6€/kg
Onshore Wind	74	23%	7€/kg	5.6€/kg
Offshore Wind	140 70	40%	9.6€/kg 5.7€/kg	8.6€/kg 4.8€/kg
Market	40-50	90%	3-4€/kg	2.5-3.25€/kg

Table 3 - Summary of the impact of electricity prices and load factor of different technologies on the final costs of hydrogen

[65] Académie des Technologies (2020), *Rôle de l'hydrogène dans une économie décarbonée*

c. Business models

For hydrogen produced via electrolysis, the following scenarios were identified:

Criteria	Grid connected electrolysis	Direct connection to nuclear	Direct connection to RES
Carbon intensity	Carbon intensity of the grid	Zero-carbon (100% nuclear)	Zero-carbon (100% renewable)
Electricity costs	Wholesale electricity price	Nuclear levelized cost of electricity (LCOE)	RES levelized cost of electricity (LCOE)
Network costs, taxes and fees	Applicable	Not applicable	Not applicable
Scale	Large	Large	Smaller (does not necessarily mean small)
Capacity factor	Result of an optimisation of running time and wholesale energy price. Around 4,000 h full load equivalent.	Equal to the capacity factor of the nuclear it is connected to.	Equal to the capacity factor of the RES it is connected to.

Table 4 - Different hydrogen production scenarios (adapted from the HydrogenEurope report[66] by adding a fully dedicated nuclear scenario)

Each scenario is analysed from the nuclear power perspective.

- ### Grid connected electrolysis

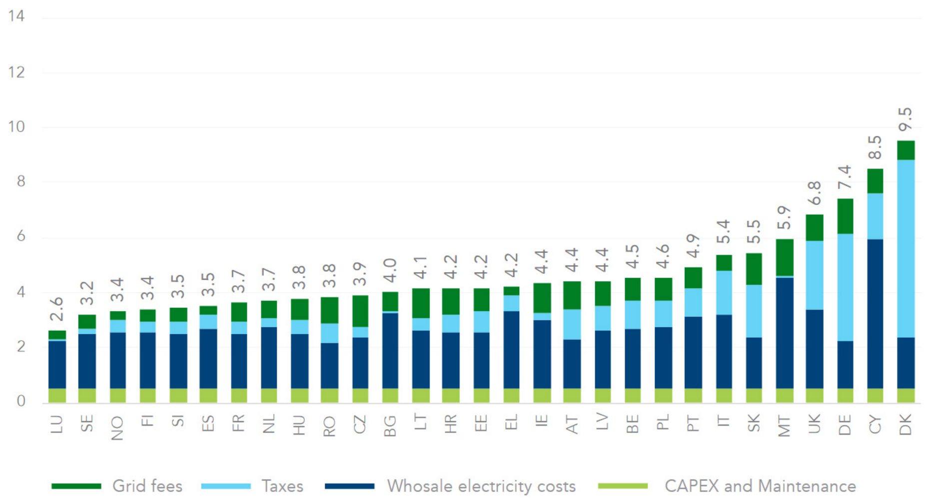


Fig.11 - Grid connected electrolysis hydrogen production costs in the EU in 2019 (in € per kg)[67]

There are at least two reasons why such large differences in the costs of hydrogen produce via electrolysis exists between countries. The main reason is the difference between **wholesale electricity prices**, which make the biggest contribution to the final cost of hydrogen in most countries, combined with **high taxes** that are charged on top of the wholesale electricity price. Although the EU does not play a direct role in setting tax rates, it ensures that taxes do not affect the free movement of goods, services and capital in the single market, that they do not

[66] Hydrogen Europe (2020), *Hydrogen Europe 2020 monitor*

[67] Ibid.

confer an unfair advantage over competitors in another country and that they are not discriminatory.

In this respect, the Energy Taxation Directive 2003/96/EC establishes exemptions, reductions and minimum levels of taxation that may enable, on the one hand, existing differences in national levels of taxation to be reduced and, on the other, avoid adverse distortion of the functioning of the internal market. In light of the Green deal, ensuring that taxation is aligned with the climate objectives appears to be essential. Indeed, the current Directive does not provide for any special tax treatment for low-carbon fuels and applications as compared to fossil fuels.

In addition to a roadmap and public consultation, the Commission will propose a revision of this Directive in June 2021 that focuses on environmental issues and aims to underpin incentives for alternative energy sources (e.g., sustainable biofuels, clean hydrogen).

Nuclear can have a positive impact on this scenario for two reasons:

- It produces low-carbon electricity
- As shown above, it has very competitive wholesale prices

For this scenario, grids from Member States like France, Sweden and Finland can support low-cost hydrogen production (3.2 – 3.7€/kg of hydrogen). Also, in other countries, nuclear can have a positive impact by providing electricity through Power Purchase Agreements (PPAs), thus avoiding the impact of a carbon intensive power mix. In terms of business model, electrolysers can be deployed next to large hydrogen consumers (such as industry), thus avoiding hydrogen transport costs.

One of the results of the analysis done by Compass Lexecon for FORATOM (an update of the "Pathways to 2050: role of nuclear in a low-carbon Europe"[68]), shows that the carbon intensity of the power system, and consequently of the hydrogen depends on the nuclear installed capacity.

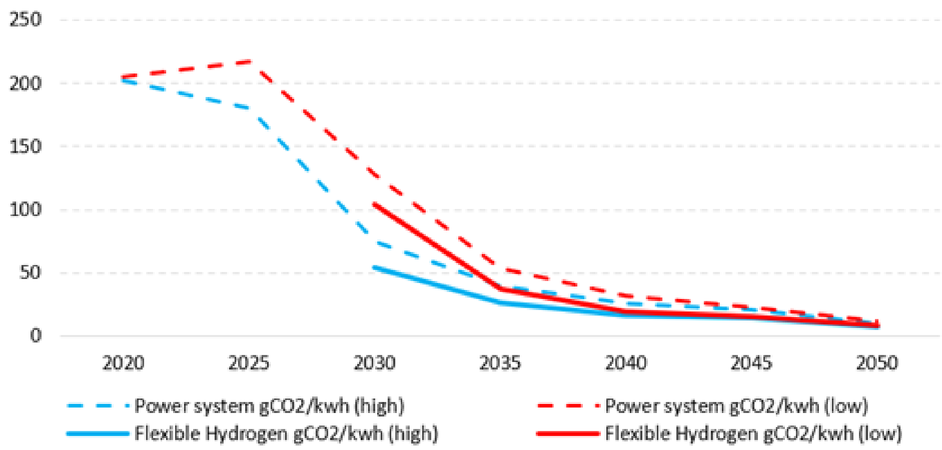


Fig. 12 - Carbon content of EU power by scenario*(gCO2/kwh)

* The nuclear scenarios defined in the report are:

- Low nuclear scenario, where in 2050 the forecasted nuclear installed capacity is 28 GW (no lifetime extensions of the current fleet and no nuclear new build other than the ones already announced and in advanced phases of development).
- High nuclear scenario, where in 2050 the forecasted nuclear installed capacity is 132 GW (lifetime extension of the current fleet and consideration of nuclear new build)

[68] FTI Compass-Lexecon (2018), *Pathways to 2050: role of nuclear in a low-carbon Europe*

- ### Direct connection to nuclear

Producing hydrogen via electrolysis with a direct connection to a nuclear energy source avoids a number of electricity cost items like network costs and taxes. Another advantage is that the electrolyser can have a similar capacity factor as the nuclear reactor (>90%), which has a positive impact on CAPEX. The only disadvantage of this scenario might be the hydrogen transport costs.

Regarding the price of hydrogen produced with electricity from a nuclear reactor directly connected to the electrolyser, some indicative values are presented in Table 3.

- ### Direct connection to renewables

This scenario doesn't have a direct impact on nuclear but acts rather as an alternative. Considering the above explanation regarding the economics of an electrolyser and the impact of capacity factor on CAPEX, the only technology which might get closer to the expected functioning time (4,000h-6,000h or even above) is offshore wind. But this technology has a similar LCOE to nuclear. The other variable renewables technologies – solar and onshore wind - are far from delivering enough power to enable the electrolyser to achieve the expected capacity factor, the only solution being to use complementary grid electricity.

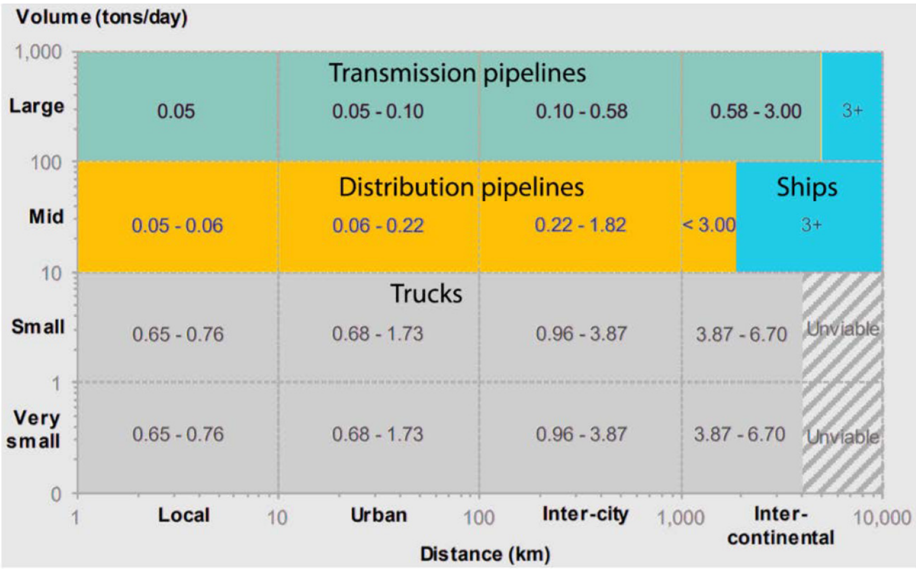


Fig. 13 - Hydrogen transport costs based on distance and volume ($/Kg) – FEEM report[69]

It should be noted that the costs for the Table 3 (see page 21) do not include either hydrogen transport costs nor taxes. In the report mentioned above, the hydrogen transport costs could add up 10 to 15€/MWh for large installations, resulting in 0.5-0.8€/kg of hydrogen. A good summary of the transport costs can be found in Figure 13 above.

To avoid the high transport costs for large hydrogen outcomes, production facilities would ideally have to be located near the large industrial consumers. This might be possible in the case of a low-carbon grid connection. Alternatively, having the hydrogen installation next to the low-carbon electricity source (nuclear or RES) can be considered, and this would avoid power system costs. It should be noted that the intermittency issue of RES remains to be solved.

[69] Scita et al (2020), *Green Hydrogen: The Holy Grail of Decarbonisation? An Analysis of the Technical and Geopolitical Implications of the Future Hydrogen Economy* (Working Paper No. 13.2020), FEEM

d. Opportunities for financing the development of a decarbonised hydrogen industry

As for any other innovative/complex infrastructure, hydrogen projects need to receive the backing of capital providers and lenders over a long timeframe. The role of financing mechanisms in contributing to the first-of-kind projects and the scale-up of this industry is crucial.

• EU-ETS carbon pricing

As the cornerstone of the EU's policy to combat climate change, the EU's Emission Trading System (EU-ETS) is regarded as a support scheme. The Commission anticipates that the existing EU-ETS regime and the proposed expansion already announced as part of the European Green Deal, should encourage the required uptake.

Since the latest revision of the framework (including the implementation of a Market Stability Reserve for phase 3 of the EU-ETS), carbon prices have risen significantly (from 5 to over 40 €/tonne CO_2). According to the Commission's strategy "Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people", carbon prices are estimated between 36 to 65 €/tonne CO_2 by 2030 depending on the scenario. According to the Commission's Hydrogen Strategy, carbon prices in the range of 55-90 €/tCO_2e would be needed to make low-carbon hydrogen competitive with fossil-based hydrogen, based on estimated costs. Regardless, uncertainty about carbon pricing dynamics means that such an instrument cannot provide an efficient price formation and forward price visibility.

		BSL	MIX-50	REG	MIX	MIX-non CO_2	CPRICE	ALLBNK
Carbon Price in €15/tCO_2	2030	32	36	32	44	44	60	65

Table 5 - The carbon price level under the Commission's 2030 scenario analysis[70]

• State aid - carbon contracts for difference

According to Commission's Hydrogen Strategy, support schemes will be required to scale-up low-carbon hydrogen (renewables, nuclear) until they become cost competitive compared to fossil-based hydrogen. It might take the form of carbon contracts for difference ("CCfDs"), which work by ensuring that an investor gets the difference between the CO_2 strike price and the actual CO_2 price under the EU-ETS regime.

CCfDs serve two purposes: removing the large long-term uncertainty associated to carbon prices, hence reducing financing costs, and conveying a premium over expected carbon prices, as a way to support emerging technologies.

An ongoing review of the State aid framework and the State aid guidelines for energy and environmental protection aims to make "CCfDs" compliant with State aid rules.

• Important Projects of Common European Interest (IPCEI)

The IPCEI instrument enables State Aid to address market failures for large cross-border integrated projects for hydrogen and fuels derived from hydrogen that significantly contribute to achieve climate goals.

[70] European Commission (2020), Impact assessment - Accompanying the document COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Stepping up Europe's 2030 climate ambition: Investing in a climate-neutral future for the benefit of our people (SWD(2020) 176 final)

Following a report by the Strategic Forum for IPCEI, the Commission will follow-up on the recommendations, ie to promote well-coordinated or joint investments and actions across several Member States aimed at supporting a hydrogen supply chain.

An ongoing review of the IPCEI Communication aims to:

- Clarify certain notions and provide further guidance on certain criteria set out in the Communication.
- Facilitate the involvement of SMEs, in line with the Industrial Strategy and the SME Strategy.
- Ensure the wide European character of important projects of common European interest by enhancing their openness and consistency with EU policies, notably the European Green Deal.

The draft Communication "*Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest*" outlines the following:

- General cumulative criteria must be fulfilled to determine a common European interest: "*The project must respect the 'do no significant harm' principle and ensure the phasing out of environmentally harmful subsidies, as recalled by the European Green Deal*".
- In addition to cumulative criteria, the Commission will consider general positive indicators such as "*The project takes into account the Taxonomy Regulation*".

• Funding programmes

The recently launched Recovery Plan for overcoming the economic crisis comprises the Next Generation EU fund and the revised EU budget. It includes two instruments with a total budget of €1.8 trillion for the period of 2021-2027. This Recovery plan will also benefit the Member States with ambitious plans for sustainable hydrogen development. Moreover, the Commission also published the European Hydrogen Strategy and presented the Clean Hydrogen Alliance which expects a cumulative investment for green hydrogen from €180 to €470 billion by 2050 and in the range of €3-18 billion for low-carbon fossil-based hydrogen.

Several support mechanisms recently launched or under development present interesting opportunities that can sustain the investments needed for hydrogen projects in the medium and long term. These include the 100MW Electrolyser Call and the Green Ports Call for proposals under Horizon Europe, the Important Projects of Common European Interest (IPCEIs), and the Innovation Fund which launched a call for proposals on 3 July 2020 with a budget of €1 billion per year.

4. Hydrogen Certification System

a. Definition

Guarantees of origin (GoOs) aim to compute the relevant characteristics of energy to be purchased for various purposes. GoOs require a set of rules and regulations concerning several aspects, including the eligibility and accreditation of a producer or plant, the issuance of the GoO, the transfer of the GoO, and the restitution of a GoO. In addition, rules will cover the information content of a GoO, its size and validity.

GoOs should include a range of information such as the geography of the source of energy used to produce the hydrogen, the lifecycle GHG content and other externalities.

b. Why low-carbon or nuclear Hydrogen GoOs?

As hydrogen could be produced through renewable or low-carbon sources, GoOs would be needed to enable companies to demonstrate the nature and GHG content of the hydrogen purchased, and to prove that they had met their own emission reduction targets.

In light of the reform of the EU-ETS in 2021, which is likely to increase the cost of CO2 for the industry given the gradual phasing out of free emission allowances, GoOs will be needed so that companies purchasing low-carbon hydrogen instead of fossil fuels can demonstrate the resultant CO2 savings in the context of their EU ETS-related reporting.

The decarbonization of heating systems would require a combination of different power technologies, such as Small Modular Reactors, producing low-carbon hydrogen directly to heat water and/or with a fuel cell to power a heat pump. GoOs with GHG content blend specifications would be useful in informing consumers of their specific GHG content and in driving consumers to more climate-friendly technologies.

GoOs would also facilitate trading and the uptake of a specific energy form. They aim to ensure the traceability by providing the end consumer with useful information on the origin of the hydrogen consumed, as well as promoting low-carbon and renewable hydrogen. A GoO would be issued by kg of low-carbon hydrogen generated according to information on the nature of the source and its geographical origin.

However, it is physically impossible to determine the generation source of hydrogen delivered to a given customer at a given time. Suppliers may use the GoOs to simply attest that an equivalent amount of low-carbon hydrogen sold to the customer has been injected into the grid in France or elsewhere in Europe, for example.

One way to address that issue would be to render low-carbon and renewable guarantees location-based (for instance hydrogen produced with nuclear on-site).

c. Conclusions from the EC Hydrogen Strategy[71]

The Commission intends to establish a certification framework based on the following criteria:

- GoOs for all forms of low and zero-carbon hydrogen on an objective basis.
- Establish reference values for GHG content.
- A standard approach to defining the criteria that any certification body must respect, based on the approach adopted regarding EU-ETS certification/ renewable energy GoOs, will be implemented.

d. CertifHy[72] - the EU project on GoO system

The CertifHy project "*Designing the 1st EU-wide Green and Low-Carbon Certification System*" has developed a Green and Low Carbon Certification pilot that has led to the issuance of 76,000+ Guarantees of Origin, of which 3,600+ have been used so far. The CertifHy scheme intends to inform consumers about the origin of the product and its environmental attributes and facilitate the needs of market actors to meet regulatory requirements.

The CertifHy scheme includes two different GoO Labels:

- CertifHy Green Hydrogen (from renewable sources and below a defined threshold)
- CertifHy Low Carbon Hydrogen (having a greenhouse gas balance below a defined threshold)

The CertifHy definition says that "*Low-carbon hydrogen is hydrogen from a production batch or sub-batch having a greenhouse gas footprint equal to or lower than a specified limit. This limit will be defined based on requirements defined in the Renewable Energy Directive recast of 2018. For the time being, the specified limit for low carbon CertifHy is 36.4 gCO$_2$eq/MJ which represents a reduction of 60% compared to the benchmark process.*" The certification scheme uses a lifecycle assessment in order to determine the GHG impact of the hydrogen.

Regarding the eligibility of a hydrogen source, the CertifHy criteria document[73] states "*If the greenhouse gas footprint of the hydrogen produced by the production device since registration with CertifHy or during the latest period of 12 months where data is available, but with a starting date not longer than 24 months ago, which is neither qualified as CertifHy Green hydrogen nor as CertifHy Low-carbon hydrogen is below the benchmark value, the production device is eligible to produce CertifHy Green hydrogen or CertifHy Low-carbon hydrogen; otherwise it is not.*"

[71] European Commission (2020), COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A hydrogen strategy for a climate-neutral Europe (COM(2020) 301 final): "*In addition, it would include a comprehensive terminology and European-wide criteria for the certification of renewable and low-carbon hydrogen possibly building on the existing ETS monitoring, reporting and verification and the provisions set out in the Renewable Energy Directive48. This framework could be based on the full life-cycle greenhouse gas emissions49, considering the already existing CertifHy50 methodologies developed by industry initiatives, in consistency with the EU taxonomy for sustainable investments. The specific, complementary functions that Guarantees of Origin (GOs) and sustainability certificates already play in the Renewable Energy Directive can facilitate the most cost-effective production and EU-wide trading*"

[72] CertifHy

[73] CertifHy (2019), CertifHy-SD Hydrogen Criteria

Without inclusion of a renewable share		With inclusion of a renewable share						
		0%	10%	...	50%	60%	70%	80%
EU Mix	217,1	Not Elegible to produce Low Carbon or CertifHy Green H2				86,8	65,1	43,4
Coal	423,7							84,7
Natural gas	191,5					76,6	57,5	38,3
Nuclear	7,5	7,5	6,8	...	3,8	3,0	2,3	1,5
Specific mix	50,0	50,0	45,0	...	25,0	20,0	15,0	10,0

Red : facility is NOT allowed to produce H2 with a CertifHy GoO

Fig. 14 - Carbon intensity (gCO_2/MJH_2) of "Non-CertifHy H_2" in function of the electricity mix used[74]

When discussing the energy mix of the Member States there are very few which might be able to fulfil the carbon intensity threshold proposed, and of those that do, several rely intensively on nuclear (France, Sweden or Finland).

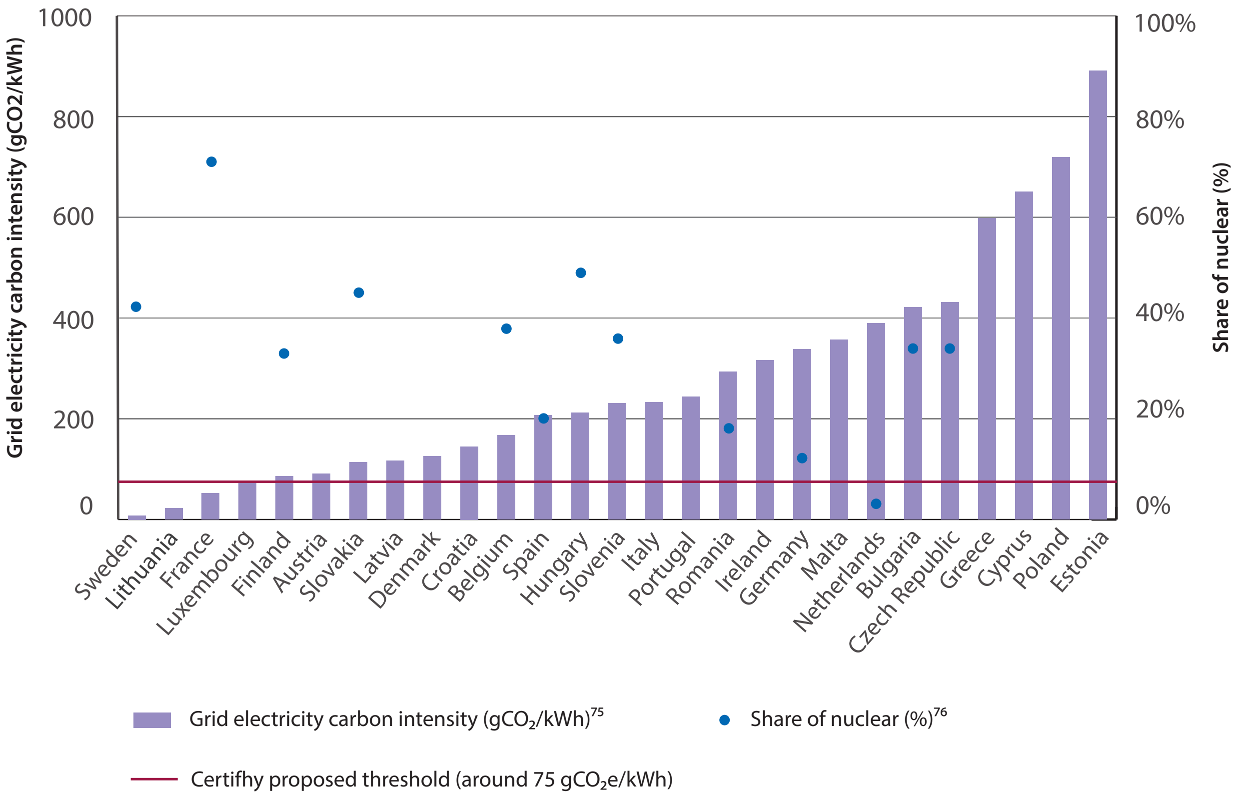


Fig. 15 - Grid electricity carbon intensity in the EU-27 Member States[77]

[74] CertifHy (n.d.), CertifHy – Developing a European Framework for the generation of guarantees of origin for green hydrogen: Definition of Green Hydrogen [Presentation]

[75] European Environment Agency (2020), Greenhouse gas emission intensity of electricity generation [Data visualisation]

[76] European Commission. Directorate General for Energy. (2020). EU energy in figures : Statistical pocketbook 2020. Publications Office.

[77] European Environment Agency, *op. cit.*

5. Policy recommendations

During a recent FORATOM event[78], a representative of CEFIC (European chemical Industry Council) drew several conclusions that are valid for all the energy intensive industries and which shape our policy recommendations:

- Electricity needs to be low-carbon, cost-competitive and abundant.
- A sufficient volume of carbon-free electricity needs to be available for both direct and indirect electrification.

Taking into account the above, the main policy recommendations identified by FORATOM are:

a. Addressing a hydrogen production in order to achieve the decarbonization targets

- **Acknowledge the positive role which low-carbon nuclear energy can play in the EU Hydrogen Strategy**
- **The classification and guarantees of origin should be done based on a detailed life-cycle assessment of the carbon intensity of the source used to produce hydrogen**. In addition, the future hydrogen legislation should **adopt a low-carbon, technology neutral approach** and review process. The assessment should also determine a decreasing carbon intensity trajectory of the hydrogen produced which is inline with the EU's decarbonization pathway.
- GoOs should cover all forms of renewable and low-carbon hydrogen produced in the EU and imported for broad hydrogen applications.
- **Nuclear to be considered in any EU initiatives or programmes relating to the hydrogen strategy** such as the "Clean Hydrogen Alliance".
- Adapting the Hydrogen Strategy to align it to the most decarbonised Member States– i.e. France or Sweden which have achieved a high level of decarbonisation thanks to a combination of nuclear and renewables

b. Creating a competitive hydrogen market

- Economic transition towards large-scale hydrogen deployment by triggering investments
- In order to ensure rapid development and that low-carbon hydrogen becomes competitive, much more attention should be given to economic and reliability aspects to fulfil industrial needs.
- Prioritise assessment of full smart system costs including LCOE and LCOH (Hydrogen) which includes an assessment of nuclear technologies utilized within the production process.
- Encourage the implementation of support schemes such as carbon contracts for difference (CCfD) that would scale-up renewable and low-carbon hydrogen before they become cost-competitive.
- Encourage Member States to set up support mechanisms to create a hydrogen market whilst restructuring what already exists to make it more efficient.
- Encourage the hydrogen supply chain (electrolysers, systems, services providers...) to develop products suitable for coupling to nuclear technologies. This will generate greater European and International market potential opportunities

[78] Webinar on "Achieving industrial decarbonisation through affordable low-carbon hydrogen" – 22 February 2021

c. Innovation, research and development on low-carbon hydrogen production technologies

- Support Innovation, Research and Development also in low-carbon hydrogen
- **Recognise previous research into nuclear-produced hydrogen in Europe** and at international level and provide details on how this can be reflected in the EU hydrogen strategy.
- **Increase synergies between the SET Plan actions, Horizon Europe and Euratom R&D programmes in relation to low-carbon hydrogen production.**
- **Dedicated R&D programmes should be set up within Horizon Europe to exploit the synergies and common areas required for sector coupling with nuclear technologies** – for example, hydrogen production from electricity powered electrolysis coupled to the existing and future European nuclear fleet.
- Development of a common EU agenda and innovation roadmap, which will pave the way for the implementation of multilateral pilot projects that demonstrate the value of hydrogen produced at NPP level in Europe.
- Leverage international and inter-governmental R&D projects and results that can be utilised within a European context to advance hydrogen production from existing and future nuclear technologies. Considering the inclusion of socio-techno studies, technology modelling, hybrid energy systems and innovate business models.

d. Establishment of an initiative at EU level on low-carbon hydrogen production from nuclear technologies

- FORATOM believes that the revised Energy Taxation Directive should first differentiate the minimum level of taxation for hydrogen based on the source of energy used. Hydrogen produced via electrolysis from low-carbon energy sources should benefit from a lower tax rate or be exempted. Secondly, it should provide equal treatment between technologies following the principle of technology neutrality.
- FORATOM calls for the revised communication on "*Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest*" to ensure equal treatment between technologies and to follow the principle of technology neutrality. Given the fact that the Taxonomy is still under development, and no final decision has been taken yet regarding the inclusion of nuclear, it would seem premature to establish a connection between the two mechanisms.

Appendix

Examples of projects and initiatives that should be considered in the delivery of the EU Hydrogen Strategy and which show the positive role nuclear energy can deliver in hydrogen production ecosystems.

- Hydrogen 2 Heysham Project: feasibility assessment carried out on the viability of low-carbon hydrogen production by electrolysis using nuclear generated electricity at the Heysham nuclear power station.

- HyNoVi, a strategic project for massive decarbonation of industry, creation of a leading French and European hydrogen sector and relocation of production of a strategic resource for the chemical, pharmaceutical and energy fields.

- Central-Danube Region: A comprehensive hydrogen pilot project which consider for the electricity supply both Packs Nuclear Power Plant and Solar Park

- Joint Use Modular Plant (JUMP) program: Idaho Nuclear Laboratory (INL) and US Department of Energy (DOE) are conducting research to demonstrate safe, secure and resilient microgrid systems. One SMR module will be designated strictly for research activities. The research is expected to focus primarily on integrated energy systems that support the production of both electricity and non-electric energy products.

- Nuclear–Renewable Hybrid Energy Systems for Decarbonized Energy Production and Cogeneration, IAEA: With more than 170 parties having ratified the Paris Agreement under the United Nations Framework Convention on Climate Change, viable, financially sound and integrated solutions for providing low-carbon, affordable, energy are of critical interest. This encompasses the development of resilient production processes for the generation of electricity, heat, chemicals and fuels for deep decarbonization. Two principal options for low-carbon energy are renewables and nuclear. While many institutions have expressed interest in one or the other, few have explored the possible synergies between them.

- Guidance on Nuclear Energy Cogeneration, IAEA: Cogeneration, i.e. the production of electricity and heat, has proven to be a highly efficient and environmentally attractive option for energy conversion. Nuclear cogeneration could be considered as an option in light of actions on climate change. However, nuclear cogeneration is not widely deployed. This publication provides a quick introduction to the advantages, experience, and future planning for implementation of nuclear cogeneration. It also highlights some demonstration projects that were developed in the past in connection with industries, describing technical concepts for combined nuclear-industrial complexes.

- Nuclear Cogeneration Industrial Initiative: Nuclear cogeneration is an innovative energy solution for decreasing CO2 emissions and securing the energy supply of European industries. It is part of the EU's Strategic Energy Technology Plan (SET-Plan) as a key low-carbon technology

- Nuclear Innovation 2050 (NI2050): An NEA initiative to accelerate R&D and market deployment of innovative nuclear fission technologies: the concept of "energy transition" is high on many policymaking agendas. It will be critical to ensure the right balance in the energy mix of the future, based on the three pillars of a sound energy policy and which deliver sustainable development: i) global environment protection, ii) affordability and competitiveness, and iii) security and reliability of energy supply.

- Steel Production: The production of steel is an energy intensive process. Furthermore, European producers face fierce competition from other parts of the world, which is in part due to higher energy costs. There is currently a project to produce hydrogen from non-fossil based energy in Sweden for use in steel manufacturing[79].

[79] HYBRIT Project: The main energy source for the HYBRIT concept is fossil free electricity in Sweden. Note: the energy mix in Sweden has a large proportion of nuclear energy. (IEA data)

- High Temperature Reactors: The most advanced high-temperature gas-cooled reactor (HTR) project is China's HTR-PM, based on its successful HTR-10 prototype. The demonstration unit being built in Shidaowan links twin 250 MWt units with 750°C outlet temperature to a 210 MWe steam turbine. The Nuclear Cogeneration Industrial Initiative (NC2I), part of the Sustainable Nuclear Energy Technology Platform (SNETP) in the European Union, focuses on HTRs producing 550°C steam for a variety of industrial applications. The Gemini+ project launched in September 2017 is an outcome of this, involving the EU and international partners (Japan, South Korea and the USA) and coordinated by the Polish National Centre for Nuclear Research (NCBJ). This project is funded under the Euratom programme and aims to provide a conceptual design of a high temperature nuclear cogeneration system that supplies process steam to industry, a licensing framework for this system and a business plan for a full-scale demonstration.
- Use of GenIV and advanced reactors such as Molten Salt Reactors and Liquid Metal Fast Reactors in future hydrogen production scenarios
- Thermochemical processes (CuCl, CNL)

About us

The European Atomic Forum (FORATOM) is the Brussels-based trade association for the nuclear energy industry in Europe. The membership of FORATOM is made up of 15 national nuclear associations and through these associations, FORATOM represents nearly 3,000 European companies working in the industry and supporting around 1.1 million jobs.

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