UNIVERSITY OF PIRAEUS
DEPARTMENT OF INTERNATION
AND EUROPEAN STUDIES

MSc in ENERGY: Strategy, Law & Economics

Master Thesis

Nuclear energy as an alternate source of energy and the production of hydrogen

Student: Dourou Efpraxia-Evangelia

Supervisor: Professor Farantouris Nikolaos

The intellectual work fulfilled and submitted based on the delivered master thesis is exclusive property of mine personally. Appropriate credit has been given in this diploma thesis regarding any information and material included in it that have been derived from other sources. I am also fully aware that any misrepresentation in connection with this declaration may at any time result in immediate revocation of the degree title.

Acknowledgements

The whole course of this master program was an inspiring and mind-opening experience, despite the challenging and hard times that there have undoubtedly been a few. The brief but multidisciplinary curriculum and the similarly multidisciplinary synthesis of the classmates, professors and supporters of the program have given new dimensions in my perception and subsequently in my professional career in the energy sector that was mostly based to my more technical background. Therefore, the first to thank, are all professors and fellow classmates that have been instrumental in such a productive and intriguing journey.

Table of Contents

1. Introduction

Too many environmentalists who are worried about global warming think nuclear energy is today's equivalent of the devil's filth. They fault it for creating and utilizing radioactive fuels as well as what appears to be a problem with waste management. In my perspective, their criticism of this reliable, low-carbon baseload energy source is unjustified. Nuclear energy is far from the devil's sludge and can and should be a vital component of our fight against a hotter, more meteorologically calamitous globe.

The use of nuclear energy has advantages and disadvantages, much like other energy sources. Due to the fact that it generates energy by nuclear fission rather than chemical combustion, it first and foremost provides baseload power without producing carbon, the harmful gas responsible for global warming[1]. Switching from coal to natural gas is a step toward decarbonization since burning natural gas produces roughly half as much carbon dioxide as burning coal. Nuclear power plants produce around the same amount of greenhouse emissions as solar electricity and 4 to 5 percent less than a natural gas-fired power station when it comes to ancillary fossil fuel consumption such as mining, processing fuel, maintaining, and decommissioning. Therefore, transitioning from coal to nuclear energy will result in a large decrease in carbon emissions.

Second, nuclear power facilities operate at far greater capacity factors than do fossil fuel or renewable energy plants. The capacity factor of a power plant is a measurement of how much of the time it actually produces electricity. All intermittent energy sources are negatively impacted. Water does not always flow through a dam's turbines since the wind does not always blow, the light does not always shine, etc.

Nuclear power plants generated about 20% of the country's electricity in 2016 with an average capacity factor of 92.3 percent, operating at full capacity 336 days out of every 365. (They were pulled off the grid the other 29 days for repair.) In comparison, only 25.1% of the time in the United States were solar power systems employed, followed by 34.5% for wind turbines and 38.2% for hydroelectric systems (138 days annually and 92 days annually). Due to considerations like fuel pricing and variations in demand throughout the day and night, even

[1] Why Nuclear Power Must Be Part of the Energy Solution, By Richard Rhodes, July 19, 2018, Published at the Yale School of the Environment

plants employing coal or natural gas only produce energy in about half the time. Nuclear power is without a doubt superior in terms of dependability.

Third, nuclear power emits the least radiation into the environment compared to other major energy sources. Since it is not general knowledge that non-nuclear energy sources send any radiation into the environment, many readers will find this assertion puzzling. It is real. The greatest offender is coal, a substance that is abundantly present in the earth's crust and includes the radioactive isotopes uranium and thorium. The organic parts of coal are gasified during combustion, while the mineral parts are concentrated in the fly ash that is left over. Because of how much coal is burnt worldwide and how much fly ash is generated, it is the main source of environmental radioactive emissions.

Nuclear power has two radiation-related drawbacks: the potential for accidents and the problem of how to properly dispose of radioactive waste.

There have been three major nuclear reactor accidents since the advent of commercial nuclear power in the middle of the 1950s: Three-Mile Island in Pennsylvania, Chernobyl in Ukraine, and Fukushima in Japan.

The partial meltdown of the Three-Mile Island reactor in March 1979 was a calamity for the owners of the Pennsylvania facility, although it only released a minimal quantity of radiation to the neighboring population. According to the U.S. Nuclear Regulatory Commission:

"The approximately 2 million people around TMI-2 during the accident are estimated to have received an average radiation dose of only about 1 millirem above the usual background dose. To put this into context, exposure from a chest X-ray is about 6 millirem and the area's natural radioactive background dose is about 100-125 millirem per year… In spite of serious damage to the reactor, the actual release had negligible effects on the physical health of individuals or the environment."

After a significant earthquake and tsunami in Japan in March 2011, the Fukushima Daiichi catastrophe occurred. When the tsunami overwhelmed the cooling and power systems of three nuclear power reactors, forcing them to melt down and explode, the reactors were breached. Radiation exposure outside of the power plant's grounds remained extremely low, despite the evacuation of 154,000 Japanese citizens from a 12-mile exclusion zone surrounding it. The International Atomic Energy Agency received the following report in June 2011:

"No harmful health effects were found in 195,345 residents living in the vicinity of the plant who were screened by the end of May 2011. All the 1,080 children tested for thyroid gland exposure showed results within safe limits. By December, government health checks of some 1,700 residents who were evacuated from three municipalities showed that two-thirds received an external radiation dose within the normal international limit of 1 mSv/year, 98 percent were below 5 mSv/year, and 10 people were exposed to more than 10 mSv… [There] was no major public exposure, let alone deaths from radiation."

Nuclear waste disposal is now technologically feasible. The majority of spent fuel is presently securely kept on the premises of operating reactors in dry casks made of impenetrable concrete and steel, and its radioactivity is gradually decreasing. To increase the lifespan of nuclear power generation by hundreds of years, more than 90% of this material may be recycled.

The nuclear industry is sometimes criticized for being overly pricey. Nuclear power would undoubtedly be less expensive than coal or natural gas if all external expenses were taken into account, but markets will eventually decide if it is too expensive.

There are other ways to combat global warming than nuclear energy. At least for balancing the flow of power when renewable energy sources are variable, natural gas has applications as well. However, the stigma and apprehensions that surround nuclear power are unjustified. It's not the modern-day equivalent of the devil's poop. It is a crucial, if not indispensable, part of the solution to the greatest energy issue in history.

The Russian invasion of Ukraine has sparked discussions on how Europe may soon reduce its heavy reliance on energy from the eastern powerhouse. The topic of the conversation gets to the heart of Central and Eastern Europe's (CEE) dwindling support for the much-touted EU energy transformation[2].

The invasion of Ukraine by Russia has made it more urgent than ever to convert to renewable energy. Over 40% of the gas utilized in the EU comes from Russia, and 90% of that gas is imported. Also imported from Russia are 46% of the coal and 27% of the oil.

The EU needs to be ready for everything. It can stop relying on Russian gas before the end of the decade. We can replace Russian gas more quickly if we diversify our supply, speed up the

---

[2] https://balkaninsight.com/2022/03/15/war-in-ukraine-triggers-energy-dilemma-in-central-europe/

adoption of renewable energy technology, and reduce our energy usage. This declaration includes fresh steps to boost renewable energy generation, diversify providers, and reduce consumption[3]. Because gas has a significant influence on the power market and has a less liquid global market than other energy sources, it is given special attention. By focussing on minimizing dependency on Russian coal and oil, for which the EU has a larger range of potential suppliers[4].

The EU's hydrogen plan's targets would be exceeded, and domestic hydrogen production would be increased, utilizing a range of resources, including nuclear energy and hydrogen produced from nuclear energy[5]. Other sources of fossil-free hydrogen, aside from nuclear-based hydrogen, also help to replace natural gas.

2. Nuclear energy: The issue with nuclear energy in Europe

Nuclear energy has benefits and drawbacks, just like all other energy sources, renewable or not[6]. Adoption or rejection of a technical or energy source sometimes entails conflicting political interests as well. The notion of the "green label" is also arbitrary because various member states accept diverse definitions of sustainable energy. The following is a list of the most popular arguments in favor of and against the use of nuclear energy:

The carbon neutrality of nuclear energy is frequently cited as an advantage. Traditional fossil fuels emit enormous amounts of carbon dioxide, which is also recognized as one of the main causes of climate change. CO2 has an impact on the growing levels of air pollution. Nuclear energy is hence free of CO2. The uranium used in nuclear power reactors, however, cannot potentially be replaced. As a result, uranium mining, processing, and preparation generate waste and create a new environmental problem (particularly once we run out of this metal). How to properly and environmentally-friendly treat the nuclear waste that power plants produce is another issue.

---

[3] Samuel R. Schubert, Johannes Pollak, Maren Kreutler. "Energy Policy of the European Union", Springer Nature, 2016

[4] European Commission, REPowerEU: Joint European Action for more affordable, secure and sustainable energy, 08.03.2022

[5] COM(2020) 301 final: A hydrogen strategy for a climate-neutral Europe.

[6] https://www.trendingtopics.eu/the-issue-with-nuclear-energy-in-europe/

One of the primary arguments in favor of nuclear energy's greenness is that it is a dependable energy source with a high power input[7]. Power plants produce a lot of energy, and unlike renewable energy sources (such as wind and solar energy), their continuous cycle of energy production is unaffected by the weather[8]. The biggest problem occurs when a nuclear reactor produces excessive heat, which results in the plant melting down. The ecosystem might be endangered by the release of radioactive materials as a result of catastrophic breakdowns.

Compared to other forms of renewable energy, such as wind and solar power, nuclear energy uses a lot less physical area. For instance, to produce the same amount of energy, a large-scale solar farm would need around 75 times more space than a nuclear power plant. But this is outweighed by the astronomically high expenses involved in constructing and maintaining a safe and well-maintained power plant.

3. EU taxonomy: Delegated acts on climate, and nuclear power

The Commission announced on April 21, 2021 that it was drafting this complementary delegated act to lay out the technical screening standards for additional economic activities in the energy sectors that were left out of the first climate delegated act, particularly in the natural gas and nuclear energy sectors. The communication was titled *"Directing finance towards the European Green Deal."*

The Regulation mandates that the technical screening criteria shall include requirements for clean energy transition-related activities in order to maintain global warming to 1.5°C above pre-industrial levels. The TSC should also ensure that the production of electricity from coal is not included in the category of environmentally favorable economic activity. No sector or technology is expressly listed in the Regulation as being excluded from the concept of "green" activities, with the exception of solid fossil fuels. Despite being restricted from "green" activities, the production of gas and nuclear energy is not expressly prohibited from "enabling" or "transition" activities.

[7] Electrical Energy Generation in Europe, 2015

[8] Lyudmila Yu. Bogachkova, Lidiya S. Guryanova, Nadezhda Yu. Usacheva. "Chapter 7 Decarbonization Trends in the Largest Post- soviet Countries and the Specifics of Their Inclusion in the Global Climate Agenda", Springer Science and Business Media LLC, 2022

Therefore, the Regulation (containing a test on waste for nuclear energy) may allow them to be classed as such if they pass the DNSH test. On December 16, 2019, Parliament and the Council reached an understanding on the Regulation's language after lengthy negotiations[9]. It is the outcome of a challenging compromise between the two co-legislators to avoid the divisive topic of nuclear and gas energy generating hampering the taxonomy as a whole.

The Commission used a two-step process to address the DNSH[10] elements of nuclear energy. It asked the JRC[11] to create a technical assessment of nuclear energy in relation to the DNSH criteria[12], which was then reviewed by experts from the Scientific Committee on Health, Environmental, and Emerging Risks and by Member State radiation protection and waste management experts who had been appointed by the Scientific and Technical Committee under Article 31 of the Euratom Treaty (SCHEER).

The JRC report came to the following conclusions: (1) deep geological repositories can be considered a suitable and secure method of isolating nuclear waste; and (2) nuclear energy can significantly contribute to the mitigation of climate change objective while at the same time not harming the other four environmental objectives. The JRC study received a satisfactory assessment from the experts.

The Commission announced in a press release that it had begun discussions with the Member States Expert Group on Sustainable Finance and the Platform on Sustainable Finance on a draft text of a complementary taxonomy delegated act covering specific gas and nuclear activities on December 31, 2021. The experts' submission deadline was initially scheduled for January 12, but it was later raised to January 21 in response to stakeholder feedback and public sentiment.

[9] Gökçe Mete. "Energy Transitions and the Future of Gas in the EU", Springer Science and Business Media LLC, 2020

[10] The Do no significant harm principle (DNSH) principle states (under the proposed EU Sustainable Finance Taxonomy regulation)

[11] The Joint Research Centre (JRC), the European Commission's science and knowledge service, Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation'), 2021

[12] Leigh Hancher. "EU Energy Governance— Moving Targets and Flexible Ambitions between Opacity and Opportunism?", Yearbook of European Law, 2022

The Platform on Sustainable Finance responded to the supplemental delegated act and released a response on January 21, 2022. The Platform acknowledged in its document that its focus is on the environmental performance of economic activities and that the taxonomy was not intended to include all economic activities, particularly energy activities that must transition because their current emissions are too high or they are causing significant harm. The Platform also emphasized that the taxonomy cannot determine policy for the transformation of the energy sector, beyond environmental performance. Instead, decisions about the energy system's transformation require for more resources to be chosen through other policy processes, including financial sources. The Platform said that it tried its best to offer views given the limited time allotted for evaluation and that there was not enough time to speak with parties outside the Platform group. Furthermore, it said it was prepared to continue assisting the Commission as it looked into and created a plan that could support investments for changing the energy supply without undermining the taxonomy's status as the classification of environmentally friendly sustainable activities for investment decisions.

On February 2, 2022, the Commission adopted a supplemental climate delegated act that, with a few caveats, added a few nuclear and gas energy operations to the EU taxonomy's list of "transitional" economic activities. Transitional activities are those that serve to mitigate climate change and may aid in the transition to a climate-neutral economy but cannot yet be replaced by technologically and commercially feasible low-carbon alternatives, according to Article 10(2) of the Taxonomy Regulation. Article 10(2) also lists the prerequisites for the classification of "transition" activities.

The nuclear and gas industries are subject to them under this delegated legislation; both must assist in the transition to a climate-neutral economy. For nuclear, this means adhering to the requirements for environmental and nuclear safety. In the case of gas, this calls for efforts to facilitate the transition from coal to renewable energy. The delegated act includes a list of additional requirements that must be met for some activities to qualify as "transition" activities. For all fossil gas-related operations, for example, the plant should have totally switched over to renewable or low-carbon gases by the end of 2035. Gas should take the place of more environmentally damaging solid and liquid fossil fuels (like coal) in power plants. Conditions for nuclear and environmental safety (including linked to waste disposal) apply to nuclear energy-related activities. As a result, the following activities are considered to be admissible under the supplemental delegated act:

Nuclear-related activities:

- cutting-edge fuel-cycle technologies (also known as "Generation IV") to promote research and development into upcoming technologies with an emphasis on safety standards and waste management;
- New nuclear power plant projects for electricity generation that make use of the greatest current technology (referred to as "Generation III Plus") will be acknowledged until 2045 (the date the building permit is obtained);
- Up to 2040 (the date of permission by the competent authority), repairs and improvements made to existing nuclear facilities will be accepted.

A number of Member States have embraced nuclear energy as one of their future energy sources as part of their efforts to minimize carbon emissions. The Commission's scenarios lead to a decarbonized energy system with a high proportion of renewable energy sources and stable installed nuclear power capacity relative to present levels. Safety changes are necessary in order to replace old systems and extend the operational life of the nuclear plants already in use.

By 2050 and as needed after that year, this ongoing process should guarantee the availability of the capacity required for the decarbonization of the energy system. As a result, through 2050 and beyond, major investments in nuclear energy will be required. It is crucial to guarantee that brand-new nuclear power plants use the most cutting-edge solutions produced by development in technology.

The technical screening criteria for these new nuclear power plants should therefore include regular reviews of each investment project and technical parameters that correspond to the best-available technology in light of the results of sustained research and development efforts and ongoing technological advancements. Specific timelines should be set in order to guarantee that new technologies compatible with sustainable decarbonization are adopted as soon as they become available.

Making ensuring that no other environmental goals are seriously affected by economic activity should be one of the technical screening criteria for the adaptation or mitigation of climate change. It is essential to ensure that the long-term disposal of waste does not cause significant and lasting environmental impact for economic activities directly related to nuclear energy, as stated in Regulation (EU) 2020/852, Article 17(1), Point (d)(iii).

It is reasonable to include explicit requirements for a radioactive waste management fund and a nuclear decommissioning fund in the technical screening criteria because waste generators should be held accountable for the costs of handling their waste. In order to prohibit the export of radioactive waste for disposal in third-party nations, it is also important to mandate the functioning of ultimate disposal facilities for all radioactive waste. at a number of Member States, low and intermediate level radioactive waste is already disposed of at near-surface disposal facilities. Over the course of decades of operation, these near-surface disposal facilities have accumulated a large amount of knowledge and know-how in waste management. The global expert community views deep geological disposal as the safest and most ecologically responsible alternative for the last stage of the management of high-level radioactive waste and spent fuel that are regarded to constitute waste. The most cutting-edge method for storing spent fuel and high-level radioactive waste is deep geological disposal.

All types of spent fuel and radioactive waste, as well as all stages of spent fuel and radioactive waste management, should be covered by Member States' national programs for the management of spent fuel and radioactive waste. Member States should still be in charge of their national policies regarding the management of their low, intermediate, or high-level radioactive waste.

In order to clearly track success, the Council Directive 2011/70/Euratom[13] specifies the key performance metrics for the national programs' content. The Member States are required to provide the Commission with regular updates on the execution of the national programs. According to member state reports from 2021, construction of the first deep geological disposal facilities on Union territory is progressing significantly. Member States will have feasible choices for building and operating these facilities by 2050. As a result, the inclusion of a relevant need in the technical screening criteria guarantees that the environment is not significantly harmed.

In the fields of natural gas and nuclear energy, technology is developing swiftly. Therefore, it is crucial to periodically review the technical screening standards relating to energy production activities in certain sectors, as required by Article 19(5) of Regulation (EU) 2020/852. This evaluation should also take into account whether the time frames mentioned

[13] Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (OJ L 199, 2.8.2011, p. 48).

in the technical screening criteria are appropriate, as stated in Article 10(2) of Regulation (EU) 2020/852.

It is necessary to make the necessary changes to Commission Delegated Regulation (EU) 2021/2178[14] and Delegated Regulation (EU) 2021/2139. The amendments to Delegated Regulation (EU) 2021/2139 and Delegated Regulation (EU) 2021/2178 do not impose investment requirements; rather, they aim to assist financial markets and investors in identifying, subject to strict conditions, relevant gas and nuclear related activities required for the transition of the Member States' energy systems towards climate neutrality in accordance with Union climate goals and commitments.

The EU Commission published its Complementary Climate Delegated Act (EU) 2022/1214 (the "Taxonomy Delegated Act")[15] on July 15, 2022. It modifies Delegated Regulation (EU) 2021/2139 with regard to economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 with regard to specific public disclosures for those economic activities to assist financial markets and investors in identifying, subject to stringent conditions, relevant gas and nuclear-related activities need.

The *"devil in the details"* of these actions is outlined below. The requirements put in place, according to the Commission, would ensure that the gas and nuclear products listed in the Taxonomy would adhere to the EU's environmental and climate goals and would speed up the transition away from fossil fuels toward a future without global warming[16].

Importantly, in order to comply with the Taxonomy Regulation and the Taxonomy Delegated Act, investment items from the nuclear and gas industries must have a transitional nature (aiding the EU's transition away from more carbon-intensive energy sources) and fulfill long-term emissions constraints. Existing nuclear power plants might be classified as "green" under the Taxonomy if they gradually switch to fuels that can withstand accidents and have

---

[14] Commission Delegated Regulation (EU) 2021/2178 of 6 July 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by specifying the content and presentation of information to be disclosed by undertakings subject to Articles 19a or 29a of Directive 2013/34/EU concerning environmentally sustainable economic activities, and specifying the methodology to comply with that disclosure obligation (OJ L 443, 10.12.2021, p. 9).

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32022R1214&from=EN.

[16] European Commission, Press Release, "EU Taxonomy: Commission presented complementary climate delegated act to accelerate decarbonisation," https://ec.europa.eu/commission/presscorner/detail/en/ip_22_711.

elaborate plans for long-term waste disposal. Products for the gas industry must abide by the same emission restrictions[17] and make a commitment to utilize low-carbon gases in the future. Here are some more thorough explanations of how the TSC relates to nuclear and gas products.

4. Nuclear Products – Technical Screening Criteria[18][19]

To accomplish some of the environmental goals, the relevant nuclear product must, among other things, conform to the following requirements:

(a) Be located in a member state which has:

1. *Adopted the "Euratom Treaties"[20] in respect of the installation and operation of nuclear activities, and of the disposal of nuclear waste products.*
2. *Made accessible the necessary resources to aid in waste management and decommissioning of nuclear operations both during and after the nuclear product's anticipated life span.*
3. *Completed the installation of facilities for the disposal and storage of spent fuel and radioactive waste[21].*

(b) Be notified to the EU Commission in accordance with the Euratom Treaties.

(c) Use the best-available technology which has been certified by the relevant national regulator.

(d) Use accident-tolerant fuels (or switch to such fuels by 2025).

---

[17] Specifically, commitments pursuant to the Paris Accords for the EU to achieve carbon-neutrality by 2050 and to cut emissions of greenhouse gases by 55 percent by 2030.

[18] The requirement for compliance with subsequent technical screening criteria is at Article 3(d) of Taxonomy Regulation 2022/8052.

[19] ss.4.26 – 4.31, Annex 1 of Delegated Regulation 2022/1214.

[20] Council Directive 2009/71/Euratom and Council Directive 2011/70/Euratom.

[21] Article 41 of the Euratom Treaty or under Article 1(4) of Council Regulation 2587/1999.

5. Response and Next Steps

The Taxonomy Regulation has received varying responses from the Member States. For instance, the Austrian government has promised to work with the Luxembourg government to pursue a legal challenge against the Taxonomy's inclusion of the gas and nuclear industries. It is uncertain if such legal concerns will prevent the Taxonomy's deployment.

Furthermore, there has been demand for the inclusion of nuclear and gas products in the Taxonomy, especially in countries that expect to benefit from them. The inclusion of gas in the Taxonomy has also received support from Germany and other nations in Eastern Europe, all of whom currently rely on gas for their energy requirements. France has argued in favor of include nuclear sector investment items in the Taxonomy due to its considerable domestic nuclear fleet.

The UK is still working on its own unilateral green taxonomy, which will be based on the Taxonomy and other taxonomies while also drawing inspiration from them. It is now uncertain if gas and nuclear items will be included in the final British taxonomy as the British government and the U.K. Financial Conduct Authority failed to respond in a meaningful way to the Motion's rejection.

There was no significant objection from the European Council before the deadline of July 11, 2022, and the Taxonomy Delegated Act is set to take effect in the EU on January 1, 2023.

6. Nuclear power is ''clean'' and efficient for the decarbonisation of the energy system

Nuclear energy-related activities are low-carbon, but they do not qualify as energy from renewable sources, as that term is defined in Article 2, Second Subparagraph, Point (1) of Directive (EU) 2018/2001 of the European Parliament and of the Council[22], as well as as it is mentioned in Article 10(1), Point (a) of Regulation (EU) 2020/852, and they do not fit into the other categories of economic activities listed in Points (b) to (i) of that provision. In the absence of a low-carbon alternative that can be scaled up sufficiently to meet the energy

[22] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (OJ L 328, 21.12.2018, p. 82).

demand continuously and reliably, such nuclear energy-related economic activities should be qualified under Article 10.2 of Regulation (EU) 2020/852. The Technical Expert Group on Sustainable Finance's Final Report from March 2020[23] also mentioned that *"evidence on the potential substantial contribution of nuclear energy to climate change mitigation objectives was extensive and clear"* and that *"nuclear energy generation has near to zero greenhouse gas emissions in the energy generation phase."* Additionally, in order to meet the 2050 decarbonization target set forth in Regulation (EU) 2021/1119 of the European Parliament and of the Council[24], some Member States' plans call for employing nuclear energy in addition to renewable energy. Finally, nuclear energy enables the deployment of intermittent renewable sources and does not impede their growth, as stipulated by Article 10(2), point (b), of Regulation (EU) 2020/852, by offering a reliable baseload of energy supply. Therefore, it should be assumed that nuclear energy-related activities complie with Article 10(2) of Regulation (EU) 2020/852.

After conducting a scientific review, experts[25] came to the conclusion that technical screening standards for nuclear energy-related economic activities should ensure that other environmental goals are not significantly harmed due to potential risks associated with the long-term storage and ultimate disposal of nuclear waste. The highest standards of nuclear safety, radiation protection, and radioactive waste management ought to be reflected in those technical screening standards, building upon the specifications stated in the Treaty establishing the European Atomic Energy Community (the "Euratom Treaty") and in laws passed in accordance with that Treaty, most notably in Council Directive 2009/71/Euratom[26]. In that Directive, there is a high-level nuclear safety goal that covers every stage of the lifetime of a nuclear site, from siting to design to construction to use to decommissioning. In that Directive, it is specifically stated that significant safety enhancements must be made in the

---

[23] The TEG report available on: https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/ 200309-sustainable-finance-teg-final-report-taxonomy_en.pdf

[24] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') (OJ L 243, 9.7.2021, p. 1).

[25] JRC report: Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation') available on: https://ec.europa.eu/info/file/210329-jrc-report-nuclear-energy-assessment_en

[26] Council Directive 2009/71/Euratom of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations (OJ L 172, 2.7.2009, p. 18).

design of new reactors, including the so-called Generation III+ reactors, and that cutting-edge knowledge and technology must be used while taking into account the most recent global safety standards. These conditions ensure the achievement of the nuclear safety goal through the defence-in-depth principle and a strong safety culture. These conditions ensure the achievement of the nuclear safety goal through the defence-in-depth principle and a strong safety culture. By using protective structures or backup cooling and electricity supply systems, for example, these specifications ensure that the effects of extreme man-made and natural hazards, such as earthquakes and floods, are lessened. They also ensure that accidents, abnormal operations, and failures or losses of control systems are avoided.

The market now offers accident-tolerant fuel for nuclear power reactors, which offers further defense against mishaps brought on by structural damage to fuel or reactor parts. The usage of such kind of fuel should be stipulated as a need in the technical screening criteria, taking into consideration its license inside the Union, in order to account for those recent technological advancements.

Global efforts are being made to develop "Generation IV reactors," or new nuclear reactor technologies, which employ methods like closed fuel cycles and fuel self-breeding to reduce the creation of high-level radioactive waste. Technical screening criteria for these Generation IV reactors should be devised given their potential contribution to the decarbonization objective and the reduction of radioactive waste, even if they are not yet commercially feasible.

A number of Member States have embraced nuclear energy as one of their future energy sources as part of their efforts to minimize carbon emissions. The Commission's scenarios lead to a decarbonized energy system with a high proportion of renewable energy sources and stable installed nuclear power capacity relative to present levels. Safety changes are necessary in order to replace old systems and extend the operational life of the nuclear plants already in use. This continuing process should ensure the availability of the capacity necessary for the decarbonization of the energy system by 2050 and as needed after that year. As a result, significant expenditures in nuclear energy will be needed until 2050 and beyond. Making sure that brand-new nuclear power plants utilize the most cutting-edge solutions made possible by technological advancement is essential. The technical screening criteria for these new nuclear power plants should therefore include regular reviews of each investment project and technical parameters that correspond to the best-available technology in light of the results of sustained research and development efforts and ongoing technological advancements.

Specific timelines should be set in order to guarantee that new technologies compatible with sustainable decarbonization are adopted as soon as they become available.

Given the extensive lead times for investments in new nuclear power capacity, extending the service life of a few chosen existing nuclear stations can help with the near- to medium-term decarbonization of the energy system. However, the technical screening criteria for such extensions should call for modifications and safety upgrades to ensure that those nuclear installations adhere to the highest practicable safety standards and to all safety objective requirements stated in legislation adopted under the Euratom Treaty.

Investments in the development and safe operation of new nuclear installations should be made using the best technologies currently available and approved by the Member States' competent authorities in accordance with applicable national law. These investments should also be subject to technical screening standards and time constraints that will encourage the creation and potential use of Generation IV reactors with closed fuel cycles in the future in light of the anticipated advancements in science and technology. The evolution of these technologies should be included in the proper evaluation of these timeframes.

Making ensuring that no other environmental goals are seriously affected by economic activity should be one of the technical screening criteria for the adaptation or mitigation of climate change. As stated in Regulation (EU) 2020/852's Article 17(1), Point (d) (iii), it is crucial to make sure that long-term waste disposal does not have a negative and lasting impact on the ecosystem. This is especially true of nuclear energy-related economic operations. It is reasonable to include explicit requirements for a radioactive waste management fund and a nuclear decommissioning fund in the technical screening criteria because waste generators should be held accountable for the costs of handling their waste. In order to prohibit the export of radioactive waste for disposal in third-party nations, it is also important to mandate the functioning of ultimate disposal facilities for all radioactive waste. at a number of Member States, low and intermediate level radioactive waste is already disposed of at near-surface disposal facilities. Over the course of decades of operation, these near-surface disposal facilities have accumulated a large amount of knowledge and know-how in waste management. The most modern approach now available for the disposal of spent fuel and high-level radioactive waste is deep geological disposal, which is universally recognized by the expert community as the safest and most ecologically benign option. All types of spent fuel and radioactive waste, as well as all stages of spent fuel and radioactive waste management, should be covered by Member States' national programs for the management of spent fuel and radioactive waste. Member States should still be in charge of their national policies regarding the management of their low, intermediate, or high-level radioactive waste. The Council Directive 2011/70/Euratom[27] establishes the essential performance criteria for the substance of the national programs in order to clearly measure progress. The Member States are required to provide the Commission with regular updates on the execution of the national programs. According to member state reports from 2021, construction of the first deep geological disposal facilities on Union territory is progressing significantly. Member States will have feasible choices for building and operating these facilities by 2050. As a result, the inclusion of a relevant need in the technical screening criteria guarantees that the environment is not significantly harmed.

For investments in the creation of fossil fuels and nuclear energy, non-financial and financial enterprises must provide investors with a high level of transparency, for which technological screening norms must be developed. To achieve this openness, specific disclosure regulations should be implemented for both financial and non-financial undertakings. Investor-disclosed information should be provided in the form of a template that specifies the percentage of fossil gas and nuclear energy operations that go into the denominator and, where necessary, the numerator of those firms' key performance metrics. In order to provide investors with a high level of transparency and ensure complete transparency throughout the entirety of those financial products, the Commission will modify or propose to modify the disclosure framework relating to the financial products mentioned in Articles 5 and 6 of Regulation (EU) 2020/852 regarding exposures to fossil gas and nuclear energy activities, for which technical screening criteria are established. To ensure that end-investors may easily recognize such information, the Commission will consider altering the regulations governing the financial and insurance advice offered by distributors.

To boost investor trust, compliance with the technical screening requirements related to fossil gas operations should be verified by a neutral third party. The independent third party must be impartial to prevent any possible conflicts of interest with the owner or funder, must not have participated in the development or management of such fossil gas operations, and must possess the resources and expertise necessary to conduct such verification. The adherence to the technical screening criteria as well as the verification technique may be subject to additional specific verification requirements that are outlined in other Union laws on

[27] Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (OJ L 199, 2.8.2011, p. 48).

sustainable financing for both financial and non-financial activities. Regulation (EU) 2020/852's Article 26(1), Point (c), requires the Commission to evaluate the provisions required to set up the systems for checking compliance with the requirements stated in that Regulation.

7. Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')

To achieve the objectives of the European Green Deal, investments must be focused on sustainable projects and activities that have their co-benefits and environmental and human health risks thoroughly assessed. The Taxonomy Regulation (Regulation (EU) 2020/852), on the development of a framework to support sustainable investments, specifies the conditions that an economic activity must satisfy in order to be deemed ecologically sustainable, including environmental objectives. The conditions for developing an EU taxonomy (the "EU Taxonomy") of commercially feasible environmental initiatives are also established.

The European Commission established a Technical Expert Group (TEG) on Sustainable Finance in July 2018 to develop recommendations for technical screening standards for economic activities that can significantly contribute to the mitigation or adaptation of climate change objectives while minimizing significantly harm to the four other environmental objectives of the Regulation:

— *sustainable use and protection of water and marine resources;*

— *transition to a circular economy;*

— *pollution prevention control; and*

— *protection and restoration of biodiversity and ecosystems.*

The European Green Deal's objectives and the EU's 2030 climate change mitigation and energy-mix targets cannot be met without investing in sustainable projects and activities while carefully evaluating their co-benefits and risks to human health and the environment. To do this, there must be consensus over terminology and a definition of what is entailed by the term "sustainable." This is why the creation of the "EU taxonomy," or a standardized classification system for sustainable economic activity, was recommended in the action plan on supporting sustainable growth.

A list of environmentally sound business practices is compiled by the EU Taxonomy categorization system. The EU will have a consistent and harmonised technique for determining whether economic activities qualify as sustainable after implementing this categorization system throughout the EU. This is essential if the EU is to become the first continent to achieve carbon neutrality by 2050 and to lessen biodiversity loss and other urgent environmental challenges. There will be two batches of this system issued, one on the climate-related goals and the other on the other four aforementioned environmental goals. It is through delegated acts that this system is being developed.

The Taxonomy Regulation (REGULATION (EU) 2020/852) gives the Commission the power to pass delegated and implementing acts in order to develop the actual list of ecologically sustainable activities and the associated technical screening criteria for each environmental aim. Despite the TEG's recognition of nuclear energy as *"climate-neutral energy,"* considerable thought is still needed to ensure that the nuclear energy life-cycle satisfies the *"do no significant harm"* standard, particularly with regard to the disposal of radioactive waste.

8. The specificities of nuclear energy

Industrialization has unquestionably tremendously helped humans. Because they have access to steady sources of power, they enjoy extremely high living standards and higher life expectancies. However, the environment is impacted by all of our industrial operations. These include, among others, greenhouse gases produced during the manufacture of concrete, steel, and other building materials, diesel emissions from trucks used to transport materials, chemical emissions from industrial processes, and the destruction of natural habitats to make way for industry. In reality, even activities connected to basic needs of life, like farming, have an impact on the environment. Because the benefits are believed to outweigh the costs, the environmental effect is usually disregarded or not given the urgency it needs. But it is now obvious that some industrial activities cannot go on as they now are and that we must begin acting in a more sustainable way, especially in view of the potential risks posed by climate change.

Every generation strives to take advantage of their legal entitlement to profit from modern industrial civilization. On the other side, there is a growing awareness of the need to combat climate change immediately because civilization does not have much more time to do so. According to the "sustainable development" tenet, this conundrum can be solved without endangering the environment, depleting its resources, or interfering with the rights of future generations who will have similar needs. This tenet states that current generations can meet their needs for economic and human advancement while also gaining from modern technology.

All industrial operations, however, include dangers that, if improperly handled, might affect the environment. Nothing in life is free. Regardless of the technology employed, activities involved in creating energy are not an exception. Some methods of power generation create significant harm not during the actual operating phase but rather during the associated upstream and downstream processes, such as the phases of fuel mining, building and deconstructing facilities, and processing and disposing of waste. As a result, in order to properly understand how a specific technology will effect the objectives of sustainable development, a complete lifecycle assessment (LCA) is required.

The Taxonomy Regulation creates a framework for the classification of commercially feasible environmental projects across the EU (the "EU Taxonomy"). It outlines six environmental objectives:

— climate change mitigation;

— climate change adaptation;

— the sustainable use and protection of water and marine resources;

— the transition to a circular economy;

— pollution prevention and control;

— the protection and restoration of biodiversity and ecosystems. For an economic activity to be included in the EU Taxonomy, it must contribute substantially to at least one environmental objective and do no significant harm to the other five.

All power generation methods have an effect on the environment, much as other industrial operations. They do so in a variety of ways and to a variety of degrees, some much more than others (for example, by producing a variety of pollutants or by exploiting a variety of natural resources). The same is true with nuclear power.

The link of nuclear energy with ionizing radiation[28] and radioactive materials[29], which draws a lot of public attention, distinguishes it from other electricity producing systems.

A nuclear power plant is a facility that produces electricity by using nuclear fission to generate heat from nuclear fuel. The heat is then converted to energy using the appropriate technological processes, often by utilizing a steam turbine to drive an electric generator and transported to the cooling medium.

The main contrast between nuclear and conventional power plants is the presence of radioactive materials inside the NPP both throughout its operating and decommissioning stages. Extremely radioactive nuclear fuel and radioactive waste are both created during reactor operation. While structural components in the reactor can also become radioactive through a process called neutron activation that is caused by neutrons escaping the fuel, radioactive nuclei are primarily created by the fission process as fission products in nuclear fuel. Radiation other than neutrons, such as alpha, beta, or gamma rays, can be released by radioactive nuclei depending on the kind of radioactive decay involved. Each of these radiation types is harmful to both people and the biota, albeit to different degrees, and the type and extent of injury depend on how powerful the ionizing radiation is.

Therefore, appropriate safety measures are implemented at an NPP to protect the operational crew, the general public, and the environment from the harmful effects of radioactive materials. Unquestionably hazardous radiation is that which exceeds specified, scientifically established criteria. The right level of protection is ensured by the facility's design, operation, and maintenance guidelines, strict controls on the release of radioactive gases and effluents, legal framework, and regulations, including overarching regulatory oversight throughout all stages of the NPP's lifecycle.

---

[28] Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Some examples are alpha, beta, gamma, x-rays, neutrons, and ultraviolet light. High doses of ionizing radiation may produce severe skin or tissue damage (http://www.naweb.iaea.org/nafa/aph/resources/nuclearglossary-APH.pdf).

[29] Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity (IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection, 2018 Edition, https://www.iaea.org/publications/11098/iaea-safety-glossary-2018-edition)

9. Comparison of impacts of various electricity generation technologies

After a brief review of nuclear energy's existing and future contributions to electricity generation, this section compares nuclear energy's environmental effects with those of other generation methods. The comparison is put up to meet the environmental objectives of the Taxonomy Regulation. To gauge how successfully nuclear energy supports the objective of reducing climate change, its lifetime impacts are first looked at. In order to prevent inflicting major harm to the four non-climate environmental objectives, this section first establishes that nuclear energy may considerably assist reduce climate change before comparing it to other power generation technologies[30]:

— *the sustainable use and protection of water and marine resources;*

— *the transition to a circular economy;*

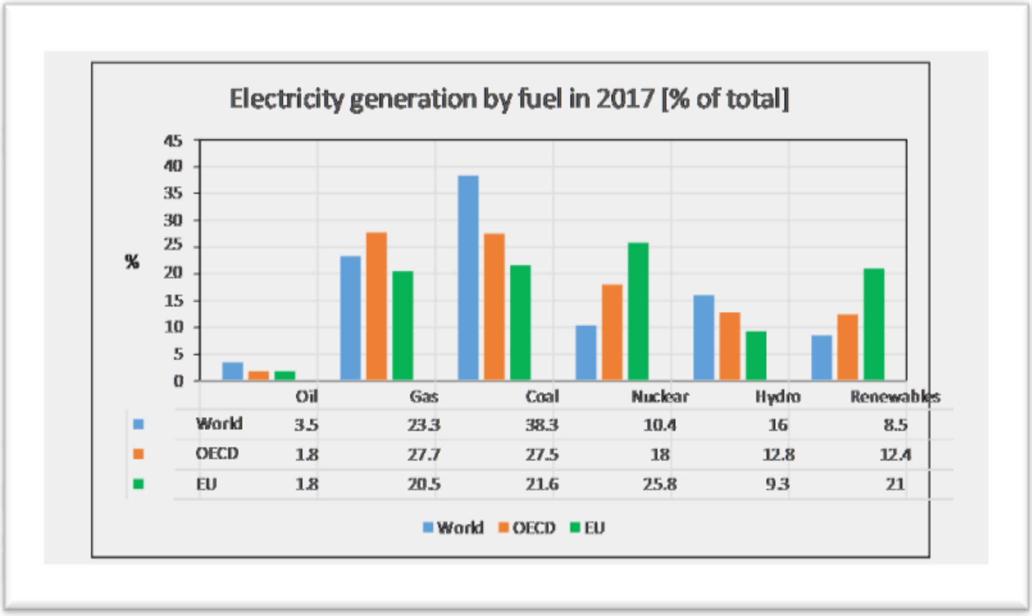
— *pollution prevention and control;*

— *the protection and restoration of biodiversity and ecosystems.*

The total global power generation in 2017 was 25.640 TWh, according to the International Energy Agency's (IEA) 2018 World Energy Outlook. Figure 1 shows how much nuclear energy there is in the world—10.4%. Low carbon generating methods (such as nuclear, hydro, and renewables) provided around 35% of the world's total electricity. Burning fossil fuels (coal, oil, and gas) provided the remaining 65% of the energy, which had a significant influence on global warming and discharged several other pollutants that were critical to the environment and public health.

[30] Some of which are included in the Taxonomy

Figure 1: Elecricity generation by fuel type in 2017



Source: Joint Research Center, Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation'), 2021

While globally nuclear contributed for around 30% of low carbon power, lagging hydro's 46%, the comparable numbers in OECD nations were roughly 42% for nuclear and about 30% for hydro. Because 56% of the total was generated by low-carbon technology in 2017, the situation in the EU-28 is particularly intriguing. Nuclear energy made up over half (46%) of these low-carbon sources. Although hydro makes up just around 17% of the EU's zero carbon generation sector, the high percentages of wind and solar (which total about 37%) assist to balance the picture.

Compared to existing capabilities, nuclear power will have the lowest generation costs in 2030. Nuclear power is still competitive and close to the levelized cost of the present power mix, even if the cost increases when further installed capabilities are taken into consideration.

10. Contribution to climate change mitigation

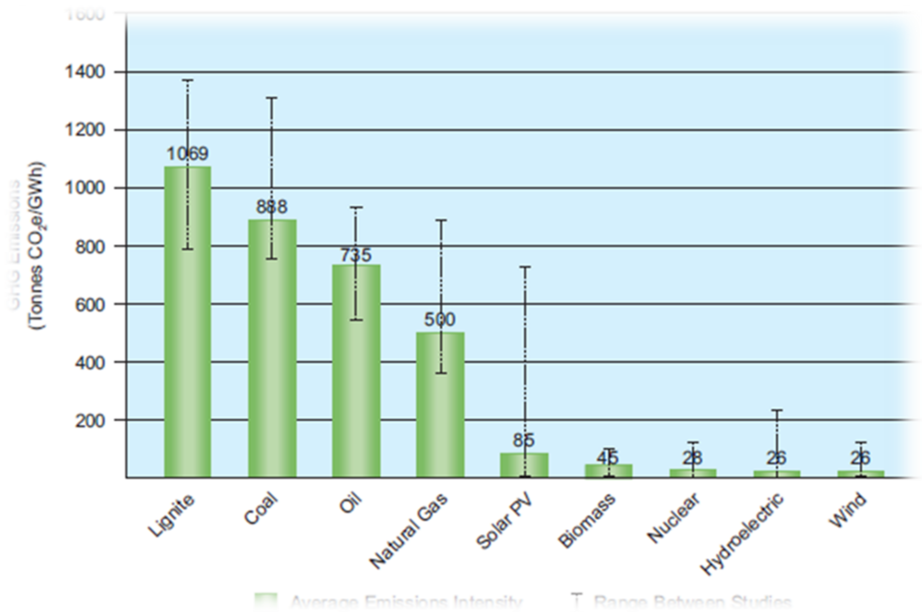
Nuclear energy can significantly help to mitigate climate change, one of the six environmental goals of the Taxonomy Regulation, and has almost no greenhouse gas emissions during the energy generation phase, as stated unequivocally in the Technical Expert Group's (TEG)

Taxonomy Report Technical Annex (see Figure 2). As a result, it is not planned to use a significant amount of this chapter to explain how nuclear energy may be utilized to slow down climate change. The complete lifetime of nuclear energy should be included when assessing any one technology's contribution to mitigating climate change, however the TEG analysis only covers the electricity-generating stage. Therefore, it is useful to present at least one example comparison from the existing literature to illustrate how nuclear energy compares to other technologies in terms of lifecycle greenhouse gas emissions.

The figures for nuclear energy's GHG emissions reported in the literature vary somewhat. The anticipated lifetime emissions can be significantly impacted by assumptions about the fuel enrichment process and the quality of uranium ore collected during the mining stage, to name only two of the sources of the disparities. The lifetime of nuclear energy might result in large GHG emissions if it is anticipated that the energy required for enrichment via the gaseous diffusion process would come from burning fossil fuels or even from the existing energy mix. It could be more reasonable to assume that the electricity required is produced either by the resultant nuclear power or a future decarbonized mix when assessing the nuclear energy chain's ability to combat climate change.

Nuclear power helps more to minimizing climate change from a bigger system viewpoint by working with renewable energy sources. A linked electrical system's power plants all interact with one another via the same grid. Nuclear power is the main dispatchable low-carbon source of electricity, followed by hydropower. Baseload technology allows adaptable operation to accommodate renewable energy sources that are intermittent. As a result, the use of wind and solar energy is more efficient. This avoids the use of extremely carbon-intensive backup creation techniques, which are routinely used. On the other hand, this integration and the power storage benefit the electrical grid by minimizing transient disruptions.

Figure 2: Lifecycle GHG emissions intensity of electricity generation technologies



Source: Joint Research Center, Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation'), 2021

Nuclear and wind energy use very less fossil fuels. Compared to wind and nuclear power, solar photovoltaics utilize a bit more fossil fuels throughout the course of their lifetime. Naturally, nuclear technology is the only one that extensively utilizes uranium resources. Thermal reactor technologies can only fully use the potential energy in naturally existing uranium that is currently extracted.

It is obvious that, even when compared to renewable energy sources, nuclear energy generates comparatively little chemical waste that needs to be stored. Of course, the most radioactive waste is generated by nuclear energy[31]. Volumetrically, the amount of radioactive waste produced by nuclear energy using PWRs (EPR) is comparable to (slightly higher than)

[31] Note that the radioactive wastes associated with the non-nuclear technologies shown in the figure mainly reflect the fact that nuclear energy is part of the energy mix supplying the different technologies with part of their energy needs.

the amount of chemical waste produced by some solar PV technologies, and somewhat less than the amount of waste produced by some fossil technologies that needs to be stored or disposed of in a repository.

In conclusion, there is no evidence that nuclear energy has a more negative impact than other energy technologies listed in the Taxonomy on the transition to a circular economy, including waste avoidance and recycling. However, it is obvious that compared to other energy production methods, nuclear energy generates a greater amount of radioactive waste.

Like many enterprises, the thermal generation of power produces waste. Regardless of the fuel used, this waste must be handled in a way that safeguards public health and has as little impact as possible on the environment.

Most of the technologies needed to dispose of all of the waste generated by the nuclear industry permanently have been created and put into use. The last barrier isn't one of technological feasibility; rather, it's one of public acceptance.

Commercially-scale reprocessing spent nuclear fuel for civil use is a well-proven procedure that has been in use for a long time. In comparison to today, radiological emissions from reprocessing plants were significantly greater in the 1970s and 1980s. When compared to the individual doses from background radiation, the doses to the reference groups of the population resulting from radiological emissions from European reprocessing facilities are incredibly low and much below the legal limitations. Reprocessing facilities in Europe have been operating successfully in recent years within the national authorities' established discharge restrictions.

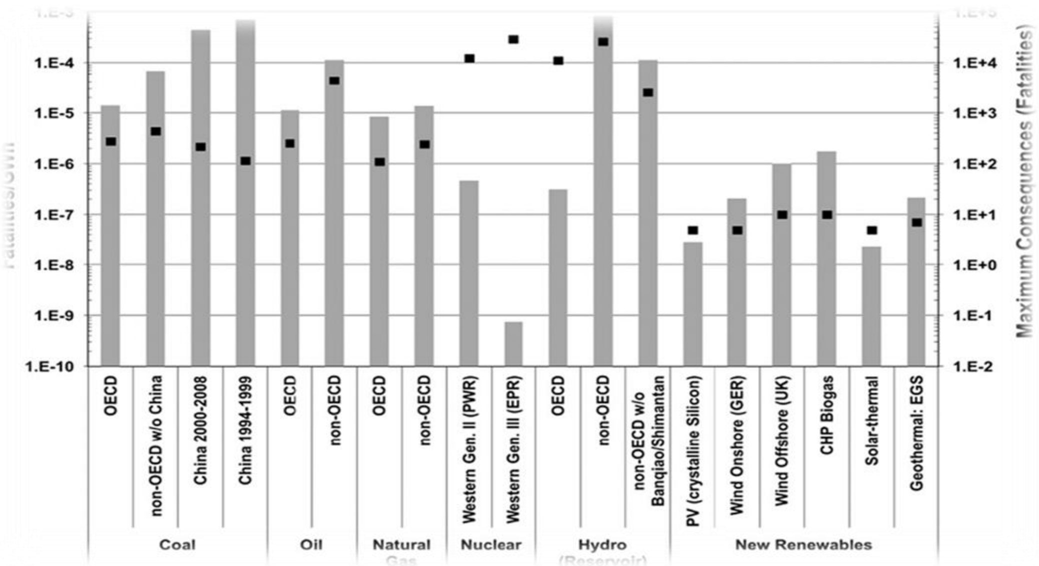
Nuclear fuel reprocessing in a closed nuclear fuel cycle often results in a lower environmental impact of the nuclear energy lifecycle compared to the open fuel cycle, principally due to the decreased need for uranium mining that occurs from closing the fuel cycle. As can be observed, nuclear fuel reprocessing activities do not materially hinder the TEG goals.

With the help of modern technology, environmental discharges of radioactive substances are managed well within legal bounds with little impact on human health. It is obvious that industrial operations involved in reprocessing spent nuclear fuel do not significantly impact either the environment or human health. As long as the associated industrial operations satisfy the required Technical Screening Criteria, none of the TEG objectives are seriously threatened.

11. Impact of severe accidents

Potentially serious incidents in the energy sector might have detrimental impacts on the environment and the general people in addition to the consequences of normal operation. It is essential to include them in any comparison. A comprehensive approach for the evaluation of accident risks in the energy business has been developed in large part because to the pertinent long-term research activities conducted at the Paul Scherrer Institute in Switzerland since the early 1990s [see Figure 3].

Figure 3: Severe accident fatality rates and maximum consequences (black points) assessed for selected electricity supply technologies with the associated energy chains



Source: Joint Research Center, Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation'), 2021

As part of this project, a method for evaluating accident risks for various energy generating systems has been created, and a database of serious energy industry accidents has been created, maintained, and enlarged[32]. Because accidents might happen at any point along the

[32] Burgherr, Peter, and Stefan Hirschberg. "Comparative risk assessment of severe accidents in the energy sector", Energy Policy, 2014.

energy chain, the database and evaluation method take the full lifespan of each energy technology into account.

Several methodological techniques are used to assess accident risks depending on how much data is in the database. For the fossil energy networks (coal, oil, and gas), there is a lot of historical accident data available, providing the risk assessment with a strong base[33]. In order to supplement the limited historical data for OECD nations, modeling of hypothetical dam failures is utilized in the hydropower industry. For new renewables, where there is a paucity of history data, a hybrid technique is employed, in which already-existing historical data, modeling, and expert opinion are used. Due to the extremely low number of historical severe nuclear accidents and their significance for risk assessment, a method based on the use of a simplified, site-specific Level 3 Probabilistic Safety Assessment (PSA)[34] is used to quantify the risks associated with hypothetical severe accidents[35].

The results demonstrate that Generation II nuclear power plants now in operation have a fatality rate that is significantly lower than that of all other fossil fuel energy sources and equivalent to that of wind and hydropower in OECD countries. This is true for the first parameter, fatality rates. Only solar energy significantly lowers the death toll.

The design of Generation III nuclear power plants complies fully with the most recent international safety standards, which are constantly revised to take into account new scientific

[33] Matteo Spada, Peter Burgherr, Pierre Boutinard Rouelle. "Comparative risk assessment with focus on hydrogen and selected fuel cells: Application to Europe", International Journal of Hydrogen Energy, 2018

[34] Probabilistic Safety Assessment is a tool for mathematically quantifying the risk associated with a nuclear power plant. Level 1 PSA estimates the probability or frequency of accidents that result in damage to the core of the reactor. The result of a level 1 PSA is referred to as the core damage frequency (CDF). Core damage does not necessarily lead to radiological releases into the environment because the reactor vessel and containment building would both have to fail, or be bypassed, for radiological releases to occur. Level 2 PSA takes the calculation a step further by estimating the frequency of accidents that release significant quantities of radioactivity into the environment. Level 3 PSA provides an end point risk assessment by estimating the frequency of accidents having specific consequences. Those consequences may be, for example, early or latent fatalities resulting from the radiation doses to the population around the plant, or damage to the environment, such as a large area of land contaminated due to deposition of radioactive material released in the accident.

[35] Three core-melt events have occurred to date in nuclear power plants: Three Mile Island (USA, 1979), Chernobyl (Ukraine, 1986), and Fukushima Daiichi (Japan, 2010). The consequences of the TMI accident were relatively low; the total collective effective dose to the public was about 40 person-Sv, which resulted in an estimation of one cancer fatality. The Chernobyl reactor design is not representative of operating plants in OECD countries using different, safer technologies, nor of reactor designs for future deployment globally.

findings and lessons learned from practical experience, including significant occurrences like the Three Mile Island, Chernobyl, and Fukushima accidents. More rigorous mitigation and prevention strategies for major accidents are included in the most recent standards. In order to achieve a very high degree of accident avoidance, additional equipment failures and other improbable occurrences have been added to the list of postulated starting events that were taken into account during the design of the plant.

After a thorough investigation into the effects of radiation exposure brought on by the Fukushima-Daichi nuclear power plant accident, it has been determined that no residents of Fukushima have experienced any negative health effects that can be directly attributed to radiation exposure from the accident[36]. Furthermore, new estimates suggest that any potential radiation-related health effects are unlikely to become apparent in the near future.

The public is fully aware of the effects of the three major disasters, Three Mile Island (1979, USA), Chernobyl (1986, Soviet Union), and Fukushima (2011, Japan), and nuclear power plants have undergone significant events with core melt. These accidents featured NPPs of different sorts (PWR, RBMK[37], and BWR), and the events that led to them took place under quite varied conditions. Severe accidents cannot be fully ruled out, even though they have a very low chance and might have very harmful consequences. Following the Chernobyl catastrophe, focused international and domestic efforts were made to create Gen III nuclear power plants. Strict regulations for the prevention and mitigation of severe accidents were followed in the construction of these plants. For instance, they ensure that, should it ever happen, the impacts of a catastrophic reactor core deterioration may be mitigated. The main objective of the design was to ensure that, even in the worst case situation, any radioactive leakage would only have a negligible influence on the environment within a few kilometers of the site boundary.

As a result, it can be argued that all possible harm to the environment and human health from the various nuclear energy lifecycle phases may be effectively prevented or mitigated. When

[36] Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2020 Report, Annex B: Levels and effects of radiation exposure due to the accident at the Fukushima Daiichi Nuclear Power Station: implications of information published since the UNSCEAR 2013 Report (Advance Copy), February 2021.

[37] The RBMK reactor is a special and differing NPP design and it was constructed in the former Soviet Union only

all specific industrial activities involved meet the relevant Technical Screening Criteria, the production of electricity using nuclear energy and its associated processes (such as uranium mining and nuclear fuel fabrication) do not pose a significant threat to any of the TEG objectives.

12. Nuclear power is a competitive option to produce and deliver low carbon hydrogen

The great majority of scenarios defining the route to net zero emissions presumptively assume that by 2050, the supply, demand, and usage of hydrogen will have significantly increased. Although the potential for using hydrogen as an energy source or a commodity to assist the energy sector lower its carbon footprint has long been understood, the breadth and ambition of the current initiatives by both public and private parties are unparalleled.

Three time periods, 2025, 2035, and 2050[38], are typically used to describe hydrogen initiatives. Priorities in the near term include decarbonizing current hydrogen uses and bridging the cost gap between water electrolysis and fossil fuels[39]. Over the medium term, it is projected that electrolytic hydrogen production would rise as new GWe hydrogen production capacity becomes available. Industrial uses continue to dominate hydrogen consumption despite emerging applications in the transportation sector. Starting in 2035, there will likely be a major increase in demand for hydrogen due to its rising application in the transportation and industrial sectors. Hydrogen will become more and more commoditized for use in industrial, transportation, or as a flexible storage vector, and markets won't be structured around distinct "hubs" or "valleys" of production and consumption. By then, due to increasingly severe carbon constraints, low and high-temperature electrolysis using low-carbon electricity will be competitively superior than steam methane reforming, which is still a widely used technique today.

[38] Nuclear Technology Development and Economics 2022-The Role of Nuclear Power in the Hydrogen Economy

[39] Reuben Joseph Soja, Muhammad Bello Gusau, Usman Ismaila, Nuraddeen Nasiru Garba. "Comparative analysis of associated cost of nuclear hydrogen production using IAEA hydrogen cost estimation program", International Journal of Hydrogen Energy, 2023

Making it feasible to decarbonize current hydrogen consumption at a reasonable cost without sacrificing other decarbonization objectives is the most pressing problem confronting the hydrogen economy. In order to manufacture competitive hydrogen, it is also necessary to account for the expenses associated with the power system as well as the costs associated with the storage, distribution, and transportation of hydrogen.

By 2035, it is projected that a considerable amount of the produced low-carbon hydrogen will be utilized to decarbonize industrial uses. The continuous flows of hydrogen production required by the technological restrictions of industry can be produced by electrolysers linked to the electrical grid and operating in baseload mode, particularly if the hydrogen storage system has deployment difficulties. In such systems, the dispatchability of nuclear power complements the stable hydrogen generation nicely, leading to smaller capacity expansions. Furthermore, systems that use a greater proportion of nuclear energy are less dependent on the electrolyser's flexibility and are therefore less susceptible to changes in hydrogen demand.

Since the hydrogen economy can take many different forms, as was already said, it is challenging to estimate with precision the cost and competitiveness of hydrogen produced by nuclear energy. However, due to more stringent carbon restrictions, it is likely that PEM electrolysis will be the primary way of supplying industrial hydrogen demands by 2035. In this broad sense, electrolysers have a choice of two operational modes. They will either use the grid, where power is produced using a variety of low-carbon arrangements, or they will be directly attached to a dedicated electrical generator.

By combining plant-level economic techniques (both hydrogen production and distribution) and system-level economic approaches, a full picture of the cost and competitiveness of nuclear-produced hydrogen by 2035 is given. It shows that nuclear power is a viable choice for generating and distributing hydrogen for industrial uses, both as specialized production units for large installations and as a crucial source of low carbon baseload power in decarbonized electrical systems. As a result, the magnitude and dispatchability of nuclear power enable hydrogen value chains to function profitably as a part of integrated low-carbon energy systems, which are required to deliver the substantial quantities of hydrogen required to achieve net zero carbon emissions by 2050.

Hydrogen is an energy transporter as opposed to an energy source. Thus, it must be made because it is rarely found in nature in its original form. Because it forms bonds with other elements (such as oxygen, carbon, and nitrogen), hydrogen is usually found in bigger molecules, such as fossil fuels, biomass, or water. The larger molecules stated above must first be removed and gathered using an external energy source in order to produce hydrogen.

The EU has set a rather aggressive goal for itself: decarbonizing its economy by 2050[40]. To accomplish this, major change will be required in the construction, energy, industrial, transportation, and industries. There will be a cost associated with it. While there are now available methods to decarbonize the power sector by 2050, it is still challenging to decarbonize hard-to-decarbonize sectors like transportation and industry. Hydrogen is now only used in a small number of businesses, but because it is produced through unrestrained coal and gas extraction, it cannot be said to be decarbonized. Thus, there are two obstacles to overcome: producing hydrogen with really minimal carbon emissions, and expanding its use to more energy-intensive businesses.

2020 saw the release of the European Commission's hydrogen strategy, which was included in the European Green Deal. This concept calls for the construction of large hydrogen reactors across the EU to provide a clean source of energy for diverse businesses. It plans to accomplish this through kindly endorsing activities, with a focus on renewable energy sources in particular. Even though it isn't mentioned expressly, nuclear power will likely have a big impact on the low-carbon hydrogen component of the strategy. When renewable energy sources like wind and sunshine are in plentiful supply, one way to use the additional energy is to make hydrogen. However, this will need a very substantial - and continuous - supply of hydrogen if sectors like transportation and industry are able to convert.

Numerous hydrogen projects are already under way, but the majority of them are powered by unregulated natural gas and even coal, making the hydrogen ineligible for low-carbon classification. Additionally, electrolysers that produce hydrogen from water and low-carbon power are available. Although it is believed that these electrolysers are a mature technology that can provide an alternative to hydrogen obtained from fossil fuels, the challenge is in growing the use of this technology on a large scale, since the worldwide electrolyser capacity now only stands at around 25MW.

An ongoing supply of low-carbon power is necessary because continuous operation of electrolysers is economically superior to intermittent operation. As a result, nuclear energy

---

[40] Foratom Paper 2022 -Nuclear Hydrogen Production – A key low-carbon technology for a decarbonised Europe

can provide the consistent flow of energy necessary to keep the electrolyser operating constantly, however employing renewable energy sources when they are available is a possibility. To do this, choose between two approaches:

- First, by connecting the electrolyser directly to the grid if there is a ready supply of low-carbon power. France, Sweden, and Finland may consider this form of hydrogen to be low-carbon since their electrical networks have been decarbonized as a result of a sizable proportion of nuclear energy generation in these countries.
- Secondly, by connecting the electrolysers of the nuclear power plant directly. The additional advantage of this method is that the plant could provide the electrolysers with both steam and energy, making it both technically and financially feasible.

The aggressive and illegal military campaign against Ukraine by Russia has gravely disrupted the global energy grid. Due to the EU's heavy reliance on importing gas, oil, and coal from Russia, high energy prices have made living difficult for certain people and sparked concerns about energy security. Russia is able to sustain its confrontation with Ukraine because to high fossil fuel prices. At the European Council in March 2022[41], EU leaders resolved to reduce Europe's dependency on Russian energy imports as quickly as is practical. They asked that the Commission, using the Commission's statement as a guide, produce a comprehensive REPowerEU strategy as soon as feasible[42]. The sanctions system will now include imports of coal and oil. Recent gas supply disruptions in Poland and Bulgaria highlight how vital it is to address Russian energy sources' unreliability.

With the goal of diversifying supply[43] and reducing the rise in energy prices, the EU has been actively working with international partners for a number of months. In line with the directive issued by the European Council in March for the voluntary collective purchase of gas, LNG, and hydrogen, the Commission and Member States formed the EU Energy Platform.

[41] European Council Conclusions (24 and 25 March 2022)

[42] Communication on REPowerEU: Joint European Action for more affordable, secure and sustainable energy, COM(2022) 108 final, (8.3.2022)

[43] EU-US_LNG_2022_2.pdf (europa.eu)

For Member States currently dependent on Russia for nuclear fuel for their reactors used for either power generation[44] or non-power uses[45], diversification alternatives are also crucial. In order to develop the conversion, enrichment, and fuel production capacities already available in Europe or among the EU's external partners, collaboration between the EU and its external partners is required. In addition to diversifying foreign sources, maintaining domestic natural gas production for Member States where this is practicable can help to improve supply security of supply.

In order to replace natural gas, coal, and oil in transportation and other hard-to-decarbonize industries, renewable hydrogen will be crucial. By 2030, REPowerEU plans to domestically generate 10 million tonnes of renewable hydrogen and domestically import 10 million tonnes of renewable hydrogen. By the Commission:

- requests that the European Parliament and the Council swiftly complete the revision of the Hydrogen and Gas Market Package and that the sub-targets for renewable fuels of non-biological origin under the Renewable Energy Directive for industry and transport be aligned with the REPowerEU ambition (75% for industry and 5% for transport);
- will treble the amount of investments made by Horizon Europe in the Hydrogen Joint Undertaking (200 million euros);
- releases two Delegated Acts on the definition and creation of renewable hydrogen for public comment;
- aims to finish the evaluation of the first Significant Projects of Common European Interest on Hydrogen by the summer;
- encourages business to expedite the development of the remaining hydrogen standards, particularly those related to hydrogen production, infrastructure, and end-use appliances;
- commencing in 2025, in close collaboration with the Member States, shall routinely report on the adoption of hydrogen and the use of renewable hydrogen in difficult-to-abate equipment in industry and transportation.

[44] Five Member States (Bulgaria, Czechia, Finland, Hungary, Slovakia) currently have VVER reactors operated on their territory, all fully reliant at present on fuel supplied by a Russian provider.

[45] Medium Power Research Reactors (MPRRs), which include reactors in Czechia, Hungary, Poland, are characterised by their original Soviet design and are still dependent for fuel on the monopoly Russian manufacturer.

To facilitate the import of up to 10 million tonnes of renewable hydrogen, the Commission will help develop three primary hydrogen import lanes via the Mediterranean, the North Sea area, and, as soon as conditions permit, with Ukraine. Green Hydrogen Partnerships will facilitate green hydrogen imports while supporting the partner countries' carbon emission reduction initiatives. Other fossil-free hydrogen sources, such as nuclear-based hydrogen, can also be used in place of natural gas (see map). The Commission will: in order to assist in achieving these goals:

- by March 2023, based on the TEN-E Regulation, map the preliminary needs for hydrogen infrastructure in a process comprising Member States, national regulatory agencies, ACER, ENTSOG, project promoters, and other stakeholders;
- obtain EU funds under the Cohesion Policy, RRF, and CEF;
- establish a specific activity stream within the EU Energy Platform for collaborative renewable hydrogen purchase.

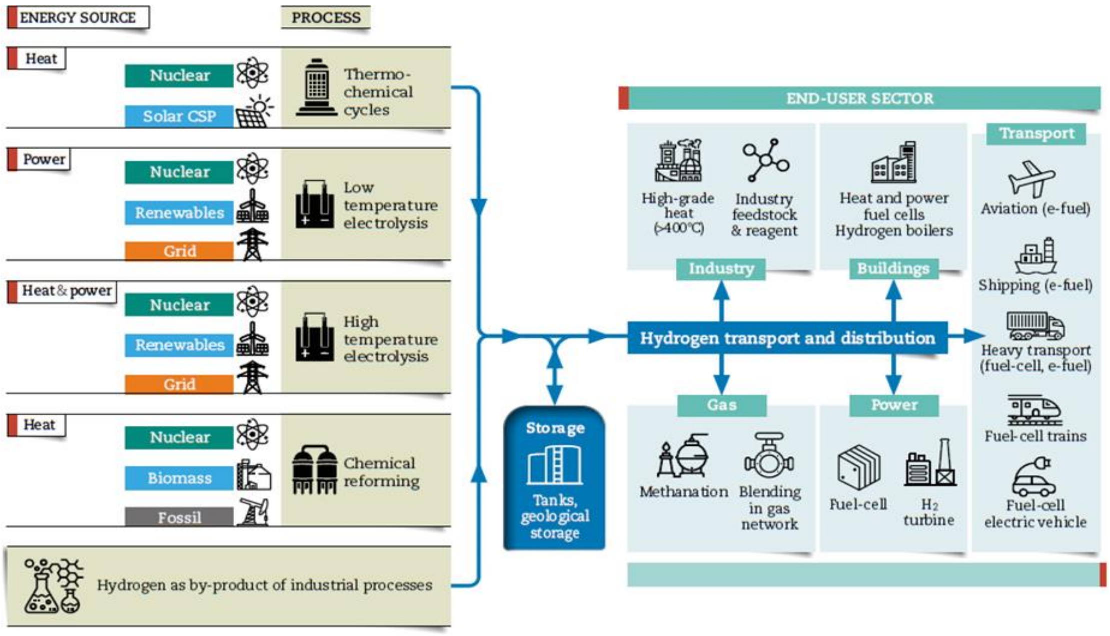
13. Hydrogen as energy vector for economic sectors that are difficult to decarbonize

Hydrogen may be used as a reagent, feedstock, or energy source in almost all economic sectors (Figure 4). The bulk of the current industrial applications for hydrogen are in chemical synthesis and oil refining, with metal processing making up the majority of the remaining industrial uses. Providing the hydrogen is low-carbon, future industrial uses of hydrogen, such as the direct reduction of iron ore and the production of high-value chemicals (HVC), might aid in the sector's continued decarbonization.

Making synthetic fuels from hydrogen might aid in the transportation sector's transition to carbon-free fuel. Hydrogen in its purest form may be used in fuel cell electric cars, which exceed battery-powered ones in terms of autonomy, power, and recharge times. The generation of low-carbon industrial heat that can be used as a feedstock for the synthesis of synthetic fuels as well as the decarbonization of heavy-duty transportation (trucks, airplanes, and ships) will both depend heavily on hydrogen. Additionally, hydrogen might be used as a standalone boiler or in conjunction with natural gas to generate heat. Large portions of industrial heat generation might theoretically be decarbonized by using hydrogen as a synthetic fuel.

Figure 4: The hydrogen economy –

energy sources, production processes and end-uses



Source: Nuclear Energy Agency, Report 2022

By 2035, the world will require millions of tons of pure hydrogen. However, profound decarbonization is the only process in which hydrogen may contribute significantly. if:

• It is created with low-carbon energy;

• after addressing other objectives like the direct electrification of the transportation sector, there is sufficient low-carbon energy production to produce it.

Hydrogen is receiving new and growing interest in Europe and the rest of the world. Hydrogen has a wide range of potential applications in the transportation, energy, manufacturing, and construction sectors. It may serve as a feedstock, a fuel, a means of transporting energy, and a storage container. Most significantly, when used, it emits no carbon dioxide and almost little air pollution. As a result, it offers a technique to decarbonize industrial processes and economic sectors where reducing carbon emissions is both important and difficult. Due to all of this, hydrogen is essential for the global effort to implement the Paris Agreement while seeking zero emissions and for the EU's commitment to being carbon neutral by 2050.

In some carbon-intensive industrial processes, such as those in the steel or chemical industries, hydrogen may also replace fossil fuels, lowering greenhouse gas emissions and improving the global competitiveness of those companies. In addition to what can be achieved through electrification and other forms of renewable and low-carbon fuel, it can offer solutions for parts of the transportation system that are challenging to ameliorate. As hydrogen-based solutions are gradually adopted, part of the existing natural gas infrastructure may be reused or repurposed, eliminating the stranding of assets in pipes.

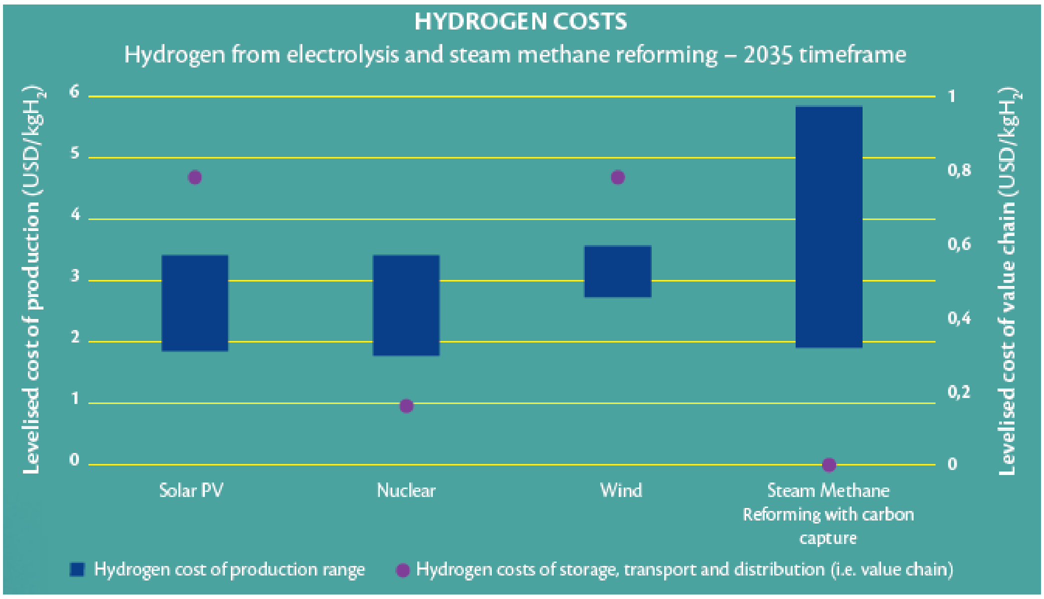
The most current OECD NEA (2022) paper, The Role of Nuclear Power in the Hydrogen Economy: Cost and Competitiveness, goes into great depth into the costs and competitiveness of producing and transporting hydrogen via water electrolysis. It reveals:

- Nuclear energy is a competitive energy source for mass production of low-carbon hydrogen. The lowest production costs, less than USD 2 per kilogram, may really be unlocked by amortized reactors in long-term operation. In most regions of the world, the cost of hydrogen from new nuclear reactors is comparable to the cost of hydrogen from variable renewable energy sources (solar and wind).

- Nuclear power can cheaply supply electricity and hydrogen to industrial centres. Nuclear energy can produce a large-scale, continuous supply of low-carbon hydrogen and heat thanks to its stability and power density. Nuclear opens up chances to reduce the cost of the infrastructure needed to distribute hydrogen and to take use of co-location with otherwise difficult to reduce industrial processes.

- The cost of the grid and the nuclear system is minimal. It would take an unprecedented amount of generation capacity to achieve net zero decarbonization targets, including expanded hydrogen production, utilizing just variable renewables. According to the NEA analysis (see Figure 5), adding nuclear power to the generating mix lowers the overall capacity needs at the system level and optimizes the cost of the global power grid.

Figure 5: Hydrogen costs- Hydrogen from electrolysis and steam methane reforming- 2035 timeframe



Source: Nuclear Energy Agency, Report 2022

Low-carbon hydrogen still has to be created, tested on a large scale, and powered by nuclear energy and other clean energy sources despite the numerous challenges[46]. In order to fulfill the rising and varied demands of all economic sectors, future energy systems will be more complex and rely on a range of clean energy and clean heat sources. System level thinking is necessary to make sure that integrated and hybrid energy systems include both variable (like solar and wind) and firm sources of energy (like nuclear and hydro). System level thinking is required to optimize the total costs of the energy system.

14. Conclusion

Climate change is a problem related to energy. When the real difficulties of achieving a clean, affordable, and reliable energy transition by 2050 start to set in, especially for the hard-to-decarbonize sectors of industrial heat, coal, and heavy transport, it will be more important

[46] I. Julian, A. García-Jiménez, A. Aguado, C. Arenal et al. "Advances in the circularity of end-of-life fibre-reinforced polymers by microwave intensification", Chemical Engineering and Processing - Process Intensification, 2022

than ever for zero-carbon advanced heat sources (advanced fission, fusion, or super-hot rock geothermal). The world can still meet the 1.5-2°C targets outlined in the Paris Agreement if enough clean, affordable hydrogen is produced to replace oil and gas in industry, transportation, and aviation.

Hydrogen-based synthetic fuels generated by Gigafactories are required in order to swiftly and economically decarbonize carbon-intensive industries like shipping, aviation, and industry, which are difficult to electrify and for which there are now no workable alternatives. The hydrogen may either be immediately fed into the existing gas networks or used for other purposes, such as making ammonia. Nuclear power may be used to generate clean hydrogen inexpensively. The next generation of nuclear power plants may be able to produce both emissions-free baseload electricity for networks and continuous high-quality heat for industries. Cogeneration of heat and electricity from nuclear reactors may be utilized simply and dependably to increase the production of clean hydrogen for a full decarbonization of significant economic sectors. Clean hydrogen is progressively emerging as one possible path to net-zero emissions due to its capacity to store energy as well as decarbonize difficult energy sectors including transportation, electricity, industry, and buildings.

Nuclear energy, which offers benefits over other energy sources, is a powerful means to manufacture hydrogen. Nuclear power plants use less land and operate at capacity factors exceeding 90% than renewable energy sources. They also enable several clean hydrogen generating techniques. First, carbon-free electricity from currently operating nuclear plants (LTE) may be used to dependably power Low Temperature Electrolysis. Since nuclear power plants can produce heat in addition to clean energy (HTE), they can collaborate with the more efficient HTE. In addition, thermochemical water splitting may be employed to create pure hydrogen even more efficiently in contemporary reactors operating at very high temperatures. Nuclear energy has unique characteristics that make it possible to integrate it with these low-cost, high-efficiency industrial processes, boosting the economic competitiveness of clean hydrogen. In this way, nuclear energy may promote the global market for clean hydrogen.

As the world moves closer to developing clean hydrogen markets from current technology, investments in possible new technologies must increase. Modern nuclear reactor designs are compatible with new hydrogen generation methods that are more effective and may cost less money. Nuclear energy is an important source of energy in Europe[47]. There are no specified research projects focused on nuclear hydrogen generation in the European Union. The research initiatives are mostly focused on either the nuclear or the hydrogen components. However, one of its most notable features, the ability to enter the non-electricity sector with hydrogen generation as a primary issue, is taken into consideration in the study on revolutionary nuclear reactor designs. A certain amount of overlap exists between the two domains as a result. However, research investigations into potential large-scale H2 generating methods may also take into account utilizing nuclear power to provide the required primary energy.

The main requirement for a nuclear power station is that radiation be completely contained within the facility, even in the event of catastrophic catastrophes, with no substantial effects happening outside the gate. Following the devastating nuclear disasters at Three Mile Island (partial core melt) and Chernobyl (complete plant destruction), researchers began looking for novel nuclear technology solutions. Potential solutions can be approached in several ways.

Nuclear futures are anticipated to cover markets besides baseload generation. Due to their high initial investment and low operating costs, all low-carbon options are pricy for the production of variable electricity. Nuclear hydrogen already has a big commercial potential because to the decreases in CO2 emissions and other pollutants. Since natural gas' primary adversary in this area is hydrogen, it is agreed that nuclear power must compete. Nuclear power is less susceptible to fuel price changes than coal or gas fired generation because uranium makes up a relatively small portion of the total cost of producing nuclear electricity and is based on sources that will be abundant for many decades and are widely distributed throughout the world. Nuclear energy is one of the most reliable and affordable forms of low-carbon electricity. The nuclear reactors of the upcoming generation should drastically reduce these expenses.

The moment has come to reduce Europe's dependency on foreign energy on a strategic level. By speeding diversification, adding additional renewable gases, giving priority to energy efficiency, and electrifying as soon as feasible, REPowerEU has the capacity to create the equivalent of the fossil fuels that Europe now imports from Russia each year. This is accomplished by well-coordinated planning, working for the good of the total, and a great deal of European unity. The climatic crisis, which has been exacerbated by Russia's aggression

[47] IAEA Nuclear Energy Series No. NP-T-4.2, Hydrogen Production Using Nuclear Energy, 2013

in Ukraine, and the EU's reliance on fossil resources, which Russia exploits as an instrument of economic and political hegemony, make it vital to reduce Europe's energy dependency. In order to accelerate economic development, maintain its position as an industrial leader, and get the continent closer to becoming carbon neutral by 2050, Europe's energy system will experience a green revolution. In order to reduce Europe's dependency on Russian energy, the European Commission makes an appeal to decision-makers, member states, regional and local authorities, as well as every individual and business, to implement the REPowerEU initiative.

References

1. Why Nuclear Power Must Be Part of the Energy Solution, By Richard Rhodes, Published at the Yale School of the Environment, 2018

2. Reuben Joseph Soja, Muhammad Bello Gusau, Usman Ismaila, Nuraddeen Nasiru Garba. "Comparative analysis of associated cost of nuclear hydrogen production using IAEA hydrogen cost estimation program", International Journal of Hydrogen Energy, 2023

3. Nuclear Technology Development and Economics -The Role of Nuclear Power in the Hydrogen Economy, 2022

4. The "Nuclear-Hydrogen Digest: The Role of Nuclear Energy in a Hydrogen Economy report, 2022

5. Leigh Hancher. "EU Energy Governance— Moving Targets and Flexible Ambitions between Opacity and Opportunism?", Yearbook of European Law, 2022

6. Lyudmila Yu. Bogachkova, Lidiya S. Guryanova, Nadezhda Yu. Usacheva. "Chapter 7 Decarbonization Trends in the Largest Post- soviet Countries and the Specifics of Their Inclusion in the Global Climate Agenda", Springer Science and Business Media LLC, 2022

7. Clifford Chance, ESG: European Commission finalises taxonomy 'technical screening criteria' for climate mitigation and adaptation, May 2021.

8. Spinaci, S., Sustainable finance – EU taxonomy: A framework to facilitate sustainable investment, Legislative briefing, EPRS, European Parliament, July 2020.

9. Gökçe Mete. "Energy Transitions and the Future of Gas in the EU", Springer Science and Business Media LLC, 2020

10. Natixis, Nuclear & gas in the EU taxonomy: integrity safeguarded despite postures and outrages, January 2022.

11. I. Julian, A. García-Jiménez, A. Aguado, C. Arenal et al. "Advances in the circularity of end-of-life fibre-reinforced polymers by microwave intensification", Chemical Engineering and Processing - Process Intensification, 2022

12. Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2020 Report

13. Matteo Spada, Peter Burgherr, Pierre Boutinard Rouelle. "Comparative risk assessment with focus on hydrogen and selected fuel cells: Application to Europe", International Journal of Hydrogen Energy, 2018

14. Samuel R. Schubert, Johannes Pollak, Maren Kreutler. "Energy Policy of the European Union", Springer Nature, 2016

15. Electrical Energy Generation in Europe, 2015

16. Burgherr, Peter, and Stefan Hirschberg. "Comparative risk assessment of severe accidents in the energy sector", Energy Policy, 2014.

17. IAEA Nuclear Energy Series No. NP-T-4.2, Hydrogen Production Using Nuclear Energy, 2013

18. JRC report: Technical assessment of nuclear energy with respect to the ‘do no significant harm’ criteria of Regulation (EU) 2020/852 (‘Taxonomy Regulation’), 2021

19. European Commission, REPowerEU: Joint European Action for more affordable, secure and sustainable energy, 08.03.2022

20. European Commission (2020), Report 301 final: A hydrogen strategy for a climate-neutral Europe.

21. Commission Delegated Regulation (EU) 2021/2178 of 6 July 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by specifying the content and presentation of information to be disclosed by undertakings subject to Articles 19a or 29a of Directive 2013/34/EU concerning environmentally sustainable economic activities and specifying the methodology to comply with that disclosure obligation (OJ L 443, 10.12.2021, p. 9).

22. The Taxonomy Regulation 2022/8052.

23. The Delegated Regulation 2022/1214

24. Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') (OJ L 243, 9.7.2021, p. 1).

25. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources

26. Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste

27. Council Directive 2009/71/Euratom of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations

28. https://balkaninsight.com/2022/03/15/war-in-ukraine-triggers-energy-dilemma-in-central-europe/