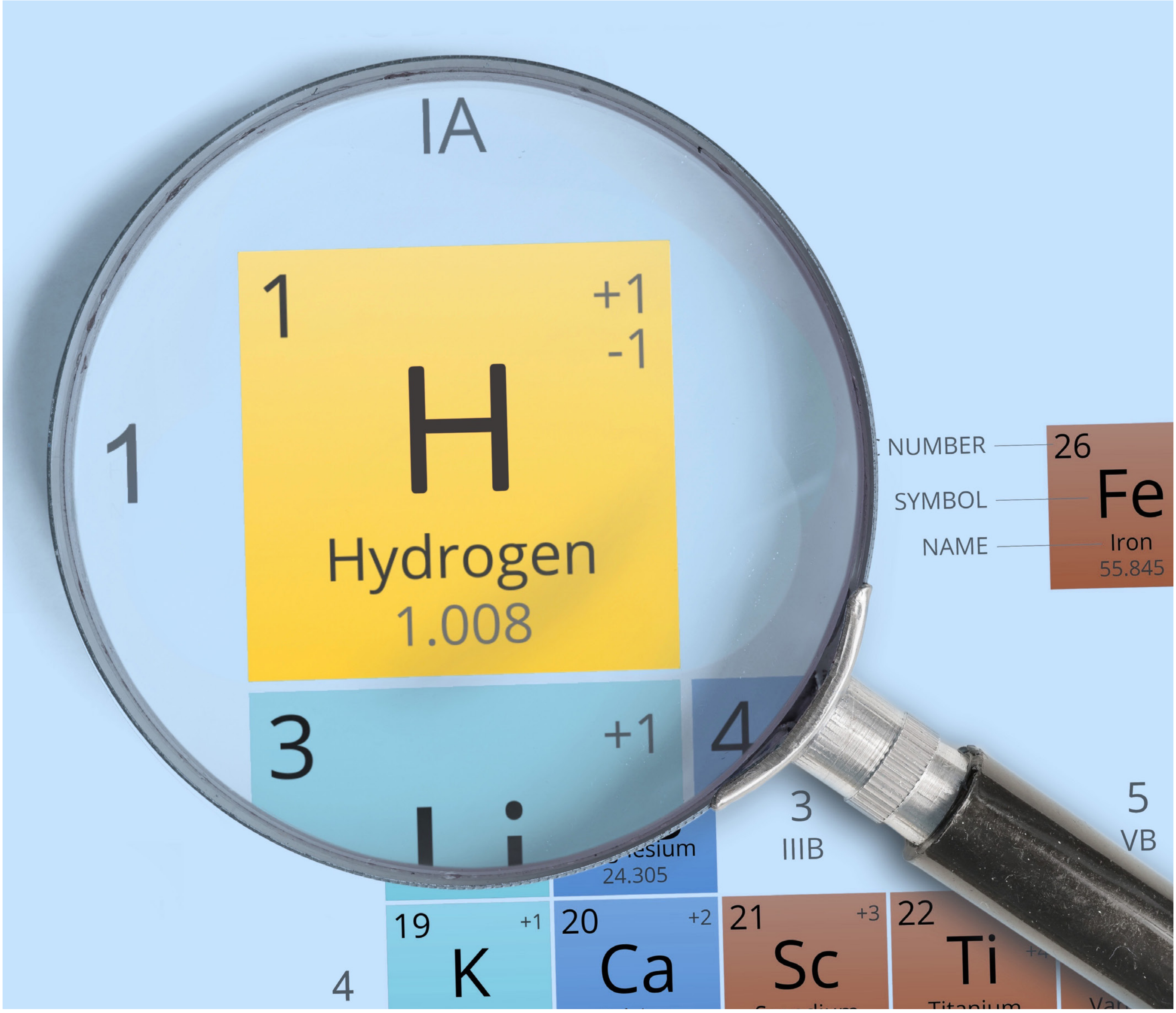
INSTITUT MONTAIGNE

POLICY BRIEF

The Challenges of a Hydrogen Policy for Industrial Decarbonization



Hydrogen is key to helping the European Union (EU), as well as other countries around the world, move to a net-zero economy. The EU has set itself the ambitious target of achieving net-zero emissions by 2050 and as part of its strategy, it wants to use low-carbon hydrogen to decarbonize European industry.

There are a number of misconceptions and unknowns that need to be clarified before we can establish a hydrogen policy that is both economically viable and conducive to net-zero strategies. As the EU revises its hydrogen directives (the Renewable Energy Directive, the Directive on Common Rules for the Internal Markets in Renewable and Natural Gases and Hydrogen, and the Directive on the Deployment of Alternative Fuels Infrastructure) and introduces new ones (as part of the new Green Deal Industrial Plan), Joseph Dellatte, Research Fellow on climate policy in Institut Montaigne's Asia Program, lays out the current state of affairs and examines the important questions surrounding the transportation and importing of hydrogen. With Georgina Wright, Director of the Europe Program, he then breaks down the major debates and issues that need to be taken into account when developing a carbon-free hydrogen policy in Europe.

1. Understanding Hydrogen

Hydrogen is neither a new energy source nor a magic substitute for natural gas, but an energy carrier. There is a wide array of potential uses for hydrogen, which scientists have been discussing since the 19th century. Today, it is used in a large number of sectors, including refining, industrial product purification, chemical production, metal manufacturing, food processing, and transportation.[1]

The drawback of hydrogen is that to be used, it must first be produced from other energy sources:

- **from fossil fuels** (currently the most common production process), via methane pyrolysis or coal gasification;
- **from electricity**, via water electrolysis or by splitting water molecules using thermochemical or photoelectrochemical processes.

There are different types of hydrogen, each assigned a "color"[2] based on their production method:

- **Grey hydrogen**, created from fossil fuels (typically from natural gas or coal). It is the most common source of hydrogen.
- **Blue hydrogen**, created from fossil fuels and using carbon capture and storage (CSS) technology to prevent CO_2 emissions from being dispersed into the atmosphere. Carbon capture is costly and requires large sites for waste disposal (for example, by storing CO_2 in decommissioned mine shafts).
- **Pink or red hydrogen**, created from nuclear-generated electricity. There are no carbon emissions, but there is nuclear waste.
- **Green hydrogen**, created using renewable energy sources like wind, solar, and hydroelectric power. It is considered the cleanest type of hydrogen since the energy used to produce it does not generate carbon emissions or residual waste.

2. Hydrogen is crucial to the Net-zero transition but there are serious constraints

How can hydrogen contribute to a zero-carbon future? The answer lies in the element's unique physical properties as well as the economic and political realities of producing and transporting it in a clean way.

Hydrogen has physical properties that influence how it can be used to support the low-carbon transition. First, producing hydrogen from electrolysis involves **an energy loss of between 20% and 30%, sometimes more, depending on the technology used**. In other words, the process of producing this form of hydrogen uses a lot of energy, some of which will be lost at the end of the process.[3] That energy loss means a higher overall product cost. Second, as the lightest element on the periodic table, hydrogen is **a gas at ambient temperature and pressure**. In gas form, hydrogen is **highly flammable**. These two properties complicate storage and transportation and increase costs.

Because of this, hydrogen has long been relegated to a minor role in the energy mix. Due to its low energy efficiency, it has always been easier and cheaper to rely on fossil fuels in the energy mix. While the global need for new zero-carbon options does change the equation, the physical properties of hydrogen do sometimes limit its potential applications compared to other green energy carriers, such as batteries.

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[1] IEA. (2022). Global Hydrogen Review 2022. *IEA*. https://iea.blob.core.windows.net/assets/c5bc75b1-9e4d-460d-9056-6e8e626a11c4/GlobalHydrogenReview2022.pdf
[2] Nationalgrid. (2023). The hydrogen colour spectrum. *Nationalgrid*. https://www.nationalgrid.com/stories/energy-explained/hydrogen-colour-spectrum
[3] Younnas, M. et al. (2022). An overview of hydrogen production: Current status, Potential, and challenges. *Fuel*. Vol.316. https://www.sciencedirect.com/science/article/abs/pii/S0016236122001867

The costs of producing green hydrogen vary depending on the techniques used, the cost of electricity, and how much renewable capacity is available. Currently, the average cost to produce green hydrogen is between $4 and $6 per kilogram of hydrogen ($/Kg$H_2$).[4] However, if prices of renewable energy and electrolysis continue to fall as rapidly and steadily as they have, and if the scale of green hydrogen production continues to increase, then green hydrogen is expected to cost between $1.3 and $4.5/Kg$H_2$[5] to produce by 2030. By 2050, the cost could fall as low as $0.65 to $1.15/Kg$H_2$, with a sharp differential (1 to 4) between regions with low production costs and high renewable capacity potential (like North Africa or Australia) and regions with higher production costs and lower renewable capacity potential (like Europe).[6] Pink hydrogen, which refers to hydrogen produced from nuclear power, may become more expensive over time - especially compared to the costs of renewable energy, which are expected to drop further. However, in areas where there is limited renewable energy capacity, pink hydrogen production costs are still expected to be similar to those of renewable sources before 2050. According to the Nuclear Energy Agency of the OECD, the estimated production cost of pink hydrogen in 2035 in such regions is expected to range from $1.9 to $3.5 per kilogram of hydrogen.[7]

Despite these constraints, carbon-free hydrogen is seen as a critical technology to achieve net-zero emissions for three reasons. First, it can be used as a replacement for fossil fuels in **heavy-duty and long-distance transportation**, including trucks and certain aircraft that cannot easily be electrified. Second, carbon-free hydrogen can be used as a substitute fuel **for energy-intensive industrial processes, such as those used in iron, steel, and chemical industries** that are challenging to decarbonize. Third, **hydrogen can be used as an alternative to batteries for storing electricity**, which can help address the intermittent nature of renewable energy and allow for surplus green energy generated during peak periods to be used during lulls.

3. Developing a hydrogen economy

A hydrogen economy needs to develop if the EU, and other countries, are planning to use hydrogen in their net zero transitions. The promises of hydrogen come with challenges that will need to be addressed, at both global and domestic levels.

There are **technical challenges**. To **produce a sufficient quantity of hydrogen with zero emissions and a cost-effective way, countries** need production sites that have access to an affordable and ready supply of green electricity. Then there is the question of **storage conditions (safety and capacity)**. Storing hydrogen is a complex task because it is a gas under normal temperature and pressure and its energy density per unit of volume is low[8] – in fact hydrogen storage is still the subject of much research.[9] Finally, **distributing hydrogen to where it is needed most** requires massive **investment in supply and transportation infrastructure (pipelines and regasification terminals)**. In other words, there needs to be more public investment in innovation and, most importantly, development of transport infrastructure and production sites. These technical challenges have already spurred a race for patents and innovation, with Europe and Japan currently in the lead.[10]

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[4] Idem or Kobina Kane, M., Gil, S. (2022, June 23). Green Hydrogen: A key investment for the energy transition. *WorldBank Blog*. https://blogs.worldbank.org/ppps/green-hydrogen-key-investment-energy-transition

[5] IEA. (2022). Global Hydrogen Review 2022. *IEA*. https://iea.blob.core.windows.net/assets/c5bc75b1-9e4d-460d-9056-6e8e626a11c4/GlobalHydrogenReview2022.pdf

[6] IRENA. (2022). Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green hydrogen cost and potential. *International Renewable Energy Agency*. https://www.irena.org/publications/2022/May/Global-hydrogen-trade-Cost

[7] NEA. (2022, Septembre). Nuclear Hydrogen Digest. Nuclear Energy in the Hydrogen Economy. *Nuclear Energy Agency*. https://www.nice-future.org/assets/pdfs/nuclear-hydrogen-digest.pdf

[8] Amount of power generated per unit of volume.

[9] Hydrogen Fuel Cell and Technology Office. (2023). Hydrogen Storage. US Federal Energy Agency. https://www.energy.gov/eere/fuelcells/hydrogen-storage

[10] IEA. (2023). Hydrogen patents for a clean energy future: a global trends analysis of innovation along hydrogen value chain. *IEA*. https://iea.blob.core.windows.net/assets/1b7ab289-ecbc-4ec2-a238-f7d4f022d60f/Hydrogenpatentsforacleanenergyfuture.pdf

There are also **political and economic challenges** that governments will need to address. The first is **lowering production, storage, and transportation costs** to make hydrogen more competitive (especially compared to carbon-emitting alternatives). The second is **developing the necessary regulations, standards, and public policies** to govern zero-carbon hydrogen production, transportation, and usage. This involves promoting the growth of industries that produce green hydrogen in an environmentally sustainable manner.

4. Creating global supply chains for green hydrogen

Some regions, like North America, have a high renewable capacity potential which enables them to produce enough green hydrogen to export it. Other regions, like Australia or the Gulf states, are positioning themselves to become major *green hydrogen hubs* for producing and exporting green hydrogen. In other cases, like Europe and Japan that have fewer renewable capacities potential, there is likely to be a mismatch between the huge amount of low-cost green hydrogen they consume to meet their industrial demand and the low-cost green hydrogen they are able to produce. Transportation will therefore be a key feature of the hydrogen economy and **regional and global supply chains** will need to be created.

There are two non-mutually exclusive models for importing hydrogen: transporting **compressed green hydrogen via pipeline** from neighboring regions and through **maritime shipping**.

Pipelines are considered to be **the most cost-effective option in the long run**. If economies of scale are achieved as predicted, costs could fall as low as $\$1/\text{KgH}_2$[11] by 2050. However, **the overall cost will be influenced by the distance that needs to be covered by pipelines**. This model shares similarities with importing gas, as well as some of the same **risks in terms of creating dependencies on potentially hostile or politically unstable countries**. To work, this import strategy would require building new pipelines or repurposing existing gas pipelines to transport hydrogen. The cost of conversion would depend on the pipe diameter and materials used in the existing infrastructure and could take up to a decade to finalize. However, the risks of leakages remain with negative consequences for the environment.[12]

The maritime shipping model is designed to import hydrogen from further afield. The advantage for lower-producing regions like Europe is that it expands their sourcing options by allowing them to import **from anywhere in the world. Diversifying sources also lowers the risk of supply-chain disruptions due to political instability or hostility**. But this option presents its own technical challenges. It is still unclear when we will be able to build sufficiently large and efficient ships to transport liquified hydrogen or whether we are able to convert liquefied natural gas port terminals to import green hydrogen. The high cost of shipping means the **economic model is also unlikely to be cost-effective in the short term**.

There are two options to ship hydrogen: **liquefied hydrogen** or **ammonia**.

Liquefying hydrogen involves cooling the gas to a temperature of -253°C, an energy-intensive process with an average energy efficiency rate currently around 30–33%.[13] There is also **challenge with the volume of liquefied hydrogen for shipping via sea routes**,[14] as its volumetric energy density is much lower compared to liquefied natural gas, which

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[11] IRENA. (2022). Global hydrogen trade to meet the 1.5C climate goal: Part II – Technology review of hydrogen carriers. *International Renewable Energy Agency*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_Global_Trade_Hydrogen_2022.pdf?rev=3d707c37462842ac89246f48add670ba

[12] Parkes, R. (2023, January 27). Evidence does not support view that existing gas network can safely handle blend of hydrogen and methane, says US government. *Hydrogen Insight*. https://www.hydrogeninsight.com/industrial/evidence-does-not-support-view-that-existing-gas-network-can-safely-handle-blend-of-hydrogen-and-methane-says-us-government/2-1-1394325. Mcfarlane, S., Bousso, R. (2022, December 22). Has green hydrogen sprung a leak? *Reuters*. https://www.reuters.com/business/sustainable-business/has-green-hydrogen-sprung-leak-2022-12-22/?utm_source=CP+Daily&utm_campaign=cff9f8ee72-CPdaily22122022&utm_medium=email&utm_term=0_a9d8834f72-cff9f8ee72-110242857

[13] As demonstrated by experience in Japan, including data reported in: Aziz, M. et al. (2019). Comparison of liquid hydrogen, methylcyclohexane and ammonia on energy efficiency and economy. *Energy Procedia*, vol. 158. https://www.sciencedirect.com/science/article/pii/S1876610219308677

[14] Hydrogen's volumetric energy density (the amount of power generated per unit of volume) works against it.

has 2.6 to 2.9 times higher volumetric energy density than hydrogen. That means using as much as triple the transport capacity to import the same quantity of energy. There is little consensus as to what the shipping cost of liquid hydrogen might look like in 2050.[15] The International Renewable Energy Agency (IRENA) puts it somewhere between $0.90 (optimistic estimate) and $1.7/KgH$_2$. Projections based on tests carried out by Japan and Australia peg low-end costs at $2.1/KgH$_2$.[16] In the meantime, the cost of transporting hydrogen could stand at two or three times the cost of producing it – a considerable cost to bear for industries located in countries that cannot produce as much green hydrogen. The costs of transporting liquid hydrogen in the long-term will depend **on the travel distance and on future technological advancements to improve maritime shipping**.

Shipping hydrogen in the form of ammonia is also highly energy-intensive as energy is needed to supply the nitrogen to transform hydrogen into ammonia, then to transport, and finally to transform it back into hydrogen upon arrival (if necessary). That said, **this model appears more efficient than transporting liquefied hydrogen**. It is more energy efficient **(34–37% – better than for liquefied hydrogen)**.[17] The ships used to transport it are also less complex (and less costly to build) than those needed to transport liquefied hydrogen. It can be shipped at a much more practical temperature of -33C°. However, converting ammonia back into hydrogen for use has a very low energy-to-cost ratio, which restricts the potential applications for decarbonisation. **The estimated cost of shipping ammonia in 2050 ranges between $0.80 (optimistic estimate) and $1.59/KgH$_2$.**[18]

All of these strategies for importing hydrogen come with an array of **environmental and economic risks** that governments will need to factor into their hydrogen strategies over the coming decades. First, exports of green hydrogen could come at the expense of decarbonization efforts in producing countries that may need this green electricty in their energy mixes. Then, there is the risk of illegal certification where carbon-emitting hydrogen is passed off as green hydrogen. Lastly, for regions with fewer renewable capacity potential, there is a risk that **some industries choose to relocate to countries where it is less expensive to source green hydrogen, rather than face high import costs**.

5. Two hydrogen strategies

There are **two approaches** governments may decide to take to establish a hydrogen strategy. The first is to focus on **procuring green hydrogen at the lowest possible cost**, which, for low renewable-capacity regions like Europe and Japan, means a lot of imports. If hydrogen is to be used primarily for industrial decarbonization, then it should be as competitive as possible in order to keep end-product costs down. The second approach is to **take advantage of the low-carbon transition to favor local production and bolster energy independence**. In Europe, this would mean using as much domestic renewable capacity as possible to produce green hydrogen and producing the remaining hydrogen with excess nuclear electricity (when and if available).

Governments need to take all of these factors – transportation, cost, and energy independence – into account when establishing their hydrogen strategy. These factors will also determine the role that governments play in the design of the hydrogen economy. Ultimately, each country will establish a strategy based on its geography, the makeup of its economy, and the size of its demand for green hydrogen.

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[15] The most sophisticated models acknowledge that with such rapidly changing variables, it's difficult to project a medium – or long-term transportation cost for hydrogen with any degree of certainty. See: Johnson, C. et al. (2022). Shipping the sunshine: An open-source model for costing renewable hydrogen transport from Australia. *International Journal of Hydrogen Energy*. vol. 47(47). https://www.sciencedirect.com/science/article/pii/S0360319922017281

[16] ARENA (2022, December 19). Could Queensland export sun and wind to Japan? *ARENAWIRE*. https://arena.gov.au/blog/could-queensland-export-sun-and-wind-to-japan/

[17] Aziz, M. et al. (2019).

[18] IRENA. (2022).

6. Challenges for Europe

In 2020, the EU published its first hydrogen strategy,[19] as part of its carbon-neutrality policy pathways. This strategy has since evolved particularly following the 2022 REPowerEU Plan,[20] which aims to reduce the EU's dependency on Russian fossil fuels, and the most recently proposed amendments to the Green Industrial Deal,[21] which aims to boost Europe's zero-emission industry and ensure its competitiveness vis-à-vis the US and China in the long run.

As we have seen, producing hydrogen requires vast amounts of energy. The EU has a much lower renewable generation capacity than other continents,[22] and **the European Commission estimates that there is not enough renewable energy to meet the growing electricity demand and to produce the amounts of green hydrogen necessary to decarbonize the EU's industry.**[23] There is also limited space available for vast production sites in Europe. In some areas, it is the public that is against the creation of renewable projects – either because they feel it spoils the landscape or because it could cause harm to animals that migrate to the areas. However, surveys suggest that the opposition is waning.

To overcome these difficulties, the European Commission is planning to import 50% of its hydrogen needs by 2030, **mostly via pipeline from North Africa.**[24] The EU is currently engaged in multiple efforts to strike partnerships with its neighbors to develop a hydrogen supply chain. The European Commission has the backing of Germany and other EU member states that are also looking to develop their own import strategies to ship hydrogen in liquid form from more distant hydrogen-producing countries.

But Europe's hydrogen-importing strategy still divides the EU. According to the European Commission, the EU will need to invest €38 billion in European infrastructure alone to repurpose existing gas transport infrastructure or to create new pipelines.

There are three planned corridors: the Mediterranean (North Africa), the North Sea (Norway) and potentially Ukraine.[25] Given some of the technical difficulties, we are unlikely to see a stable supply chain for shipping liquified hydrogen before 2050. Gambling on an import strategy before a global, multi-supplier hydrogen economy has been properly established could present risks for security of supply and for industrial decarbonization efforts during the transition period.

Furthermore, the EU's current hydrogen strategy does not factor in the high cost of transporting hydrogen. The EU has set itself the target of becoming carbon-neutral by 2050. But for the European hydrogen strategy to work transportation costs would need to drop dramatically – and soon. If the EU's only option is to import carbon-free hydrogen at high cost, some European industries could be tempted to relocate their production to countries where it is cheaper to source green hydrogen. The risk is particularly high for industries that are highly dependent on green hydrogen to decarbonize.

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[19] EU Commission. (2020, July 8). A hydrogen strategy for a climate-neutral Europe. *EU Commission.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301

[20] EU Commission. (2022, May 18). REPowerEU Plan. *EU Commission.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

[21] European Commission. (2023, Feb 1). A green deal industrial plan for the net-zero age. *European Commission.* https://commission.europa.eu/system/files/2023-02/COM_2023_62_2_EN_ACT_A%20Green%20Deal%20Industrial%20Plan%20for%20the%20Net-Zero%20Age.pdf

[22] North America could produce 15 times as much green hydrogen as Europe: irena.org/publications/2022/Apr/Renewable-Capacity-Statistics-2022

[23] Citing Frans Timmermans: Collins, L. (2022, May 4). 'Europe is never going to be capable of producing its own hydrogen in sufficient quantities': EU climate chief. *Recharge.* https://www.rechargenews.com/energy-transition/europe-is-never-going-to-be-capable-of-producing-its-own-hydrogen-in-sufficient-quantities-eu-climate-chief/2-1-1212963

[24] EU Commission. (2022, May 18). REPowerEU Plan. *EU Commission.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

[25] Assessment to be reviewed in March 2023 following the "hydrogen infrastructure map": EU Commission. (2022, May 18). REPowerEU Plan. *EU Commission.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

There is also disagreement within the EU on the role that pink hydrogen – that is hydrogen produced from surplus nuclear power – should play in the EU's hydrogen strategy and decarbonization efforts. Initially, the European Commission considered zero-carbon hydrogen only as a by-product of renewable energy, i.e. produced from surplus renewable energy that was not already destined to be used for the electricity grid.

After difficult negotiations between member states[26] and the European Parliament's energy committee[27] decision in favor of blue hydrogen, the EU Commission changed its approach and has now **included nuclear-derived hydrogen in its definition of low-carbon hydrogen**. That will allow nuclear power-producing member states with a low-carbon energy mix, such as France, to use their surplus of nuclear electricity to produce hydrogen. This decision still needs to be approved in the Council, the grouping of the 27 member states,[28] and, crucially, be included in the EU's revised hydrogen and gas package, which is still being negotiated. Including this type of hydrogen in the equation would help increase hydrogen production capacity in Europe.

7. Opportunities for France

The role of hydrogen in **Europe's industrial decarbonization strategy** presents three opportunities for the French government and private sector.

First, the low-cost green hydrogen produced in southern Europe and North Africa would need to be transported via pipeline through France before reaching Germany and other countries. This would represent an economic and strategic gain for France.

Second, France has its own production capabilities. Once they have become operational, they could produce enough green and pink hydrogen to meet domestic demand to reach France's low-carbon transition. **Some French firms are seizing this opportunity and already have the technology necessary to produce and transport hydrogen. Storage would be a concern and may require further large-scale development to help scale up production**. Some French firms with global operations are already working with countries such as China and South Korea, that are looking to incorporate hydrogen into their decarbonization strategies.

Third, if France invests heavily in renewable energy, as much as Germany has for example, while also keeping its nuclear fleet running, it could conceivably produce enough hydrogen to export some of it to the rest of Europe. This is one of the scenarios presented in a French government strategy plan first published in 2018,[29] and then revised two years later in France's national hydrogen strategy.[30]

However, producing nuclear-based hydrogen is likely to be expensive. Even if renewable hydrogen becomes more cost-effective in the future, it is unlikely that the EU will be able to produce enough domestically to meet its needs. Yet, as we have seen above, there are reasons why relying too heavily on imports of hydrogen could pose serious risks to the EU's overall energy transition and independence. While the EU should certainly continue to import hydrogen, it should

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[26] Messad, P. (2023, Feb. 3). Hydrogène bas-carbone : neuf États membres réclament son intégration dans les objectifs renouvelables de l'UE. *EURACTIV*. https://www.euractiv.com/section/energy-environment/news/nine-eu-members-want-low-carbon-hydrogen-included-in-blocs-renewables-goals/

[27] Messad, P. (2023, Feb. 3). EU Parliament backs pro-nuclear definition of 'low-carbon' hydrogen. EURACTIV. https://www.euractiv.com/section/energy-environment/news/eu-parliament-backs-pro-nuclear-definition-for-low-carbon-hydrogen/?preview_id=1877552&amp%3Bpreview_nonce=27004bd192&amp%3Bpreview=true&utm_source=piano&utm_medium=email&utm_campaign=29204&pnespid=tKhqVCNEOv4RhaPBuGWkAsyHskP0WZdxLOe5xuk09Rhm6eBKop7eVrDxbuaz_VQj566Zh.89tw

[28] European Commission. (2023, Feb 10). Supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin. *European Commission*. https://energy.ec.europa.eu/system/files/2023-02/C_2023_1087_1_EN_ACT_part1_v8.pdf

[29] Ministère de la Transition écologique (2018). Plan de déploiement de l'hydrogène pour la Transition énergétique. https://www.ecologie.gouv.fr/sites/default/files/Plan_deploiement_hydrogene.pdf

[30] Ministère de la Transition écologique (2020). Stratégie nationale pour le développement de l'hydrogène. https://www.economie.gouv.fr/presentation-strategie-nationale-developpement-hydrogene-decarbone-france

support the production of “pink hydrogen” domestically to help meet Europe's demand for carbon-free hydrogen. **France, in particular, could then take advantage of its potential to produce zero-carbon hydrogen and export it to other European countries during the energy transition** – though this will almost certainly require France to meet its energy renewables targets and upgrade its nuclear plants.

In order to seize these opportunities, France cannot go about it alone. It will need EU funding and regulations that encourage zero-carbon hydrogen production in Europe and for it to be transported across the continent.

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