Agora Industry

Agora Energiewende

12 Insights on Hydrogen – Argentina Edition

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Preface

Dear reader,

The role of renewable hydrogen is getting more and more attention in the global pursuit of climate neutrality. The trading potential of hydrogen and its derivatives, combined with the important social and economic benefits of a hydrogen economy, is bringing new players into the hydrogen game. In addition, the global fossil fuel crisis has underlined the need for new energy suppliers and a more diverse industrial market, shifting the spotlight on renewable-rich countries.

Argentina has vast energy resources that position it as one of the potential future exporters of renewable hydrogen and Power-to-X (PtX) products. However, when embarking on the road to becoming one of the world's hydrogen hubs, certain aspects need to be carefully analysed. Energy infrastructure development, the use of natural gas, certification, and investment needs are among the hot topics currently being discussed at the national level.

This brief study aims to contribute to the discussion on the priorities and next steps that are part of the decision-making process to maximise the local benefits of scaling up renewable hydrogen production in Argentina. We also highlight the significant contribution to the global decarbonisation that the country's potential export of green products can make.

I wish you a pleasant and informative read.

Yours sincerely,

Frank Peter
Director, Agora Industry

Key findings at a glance:

1. **Renewable hydrogen will be crucial for reaching climate neutrality; however, it should be reserved for applications where direct electrification is not possible.** Argentina's national hydrogen strategy, currently being drafted, should prioritise the use of hydrogen in key sectors such as industry, shipping, and aviation, and in providing flexibility to a renewable-based power system. For other use cases, direct electrification is usually more economic and efficient.

2. **Argentina is well-positioned to become a major global producer of hydrogen due to its vast energy potential.** Argentina's renewable energy resources can produce cheap electricity that can be converted into renewable hydrogen. Natural gas with carbon capture and storage could be used as a bridge technology but should be switched to renewable hydrogen as soon as possible.

3. **Developing a renewable hydrogen economy can help decarbonise Argentina's industry and create important socio-economic benefits to the country.** Hydrogen can enable the production of green products with a high export demand potential, such as ammonia, fertilisers, and synthetic fuels. Scaling up the production of these products would stimulate sustainable industrial growth and contribute to economic diversification and job creation.

4. **International cooperation could strengthen the Argentinian renewable hydrogen economy and thus boost global decarbonisation.** Renewable hydrogen production in Argentina can greatly benefit global decarbonisation and it would therefore be in the interest of the international community to support the expansion of the country's infrastructure and industrial development. Regional cooperation would also strengthen Latin America's position as hydrogen producer in international fora on standards and trade.

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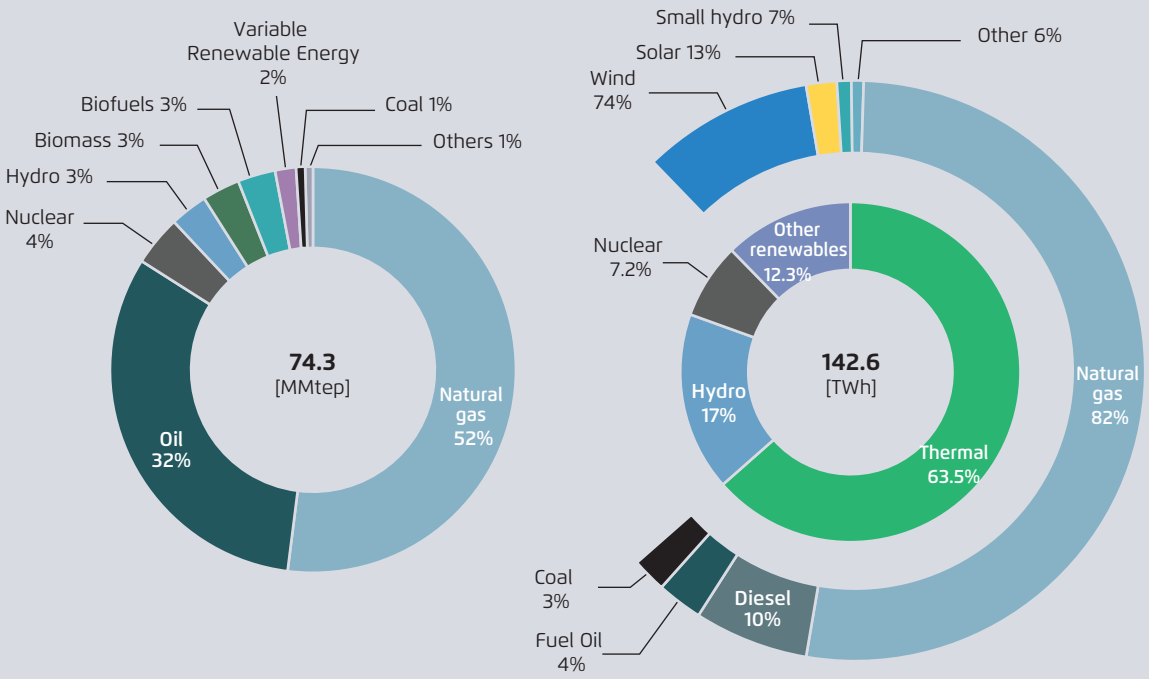
Hydrogen as a decarbonisation driver for Argentina

An overview of Argentina's energy context

Argentina is characterised by a diverse array of energy resources. It has one of the world's largest unconventional gas and oil reserves, most of which are located in the Neuquén Basin's Vaca Muerta field. Natural gas is the country's main energy source (see Figure 1). However, Argentina is an attractive market for clean energy due to its vast availability of renewable energy resources.

Argentina's energy matrix is largely dominated by hydrocarbons, accounting for 85 percent of the country's total primary energy supply, followed by nuclear and renewables (including hydro, solar, wind and bioenergy) (see Figure 1). This heavy reliance on fossil fuels is also reflected in the country's power supply, where natural gas accounts for more than 60 percent of power generation. Nuclear energy is also an important energy source, positioning the country to further explore its use. Renewable energy, especially hydropower, plays a large role in the country's electricity production. (see Figure 1). Other relevant renewable energy sources in the country include wind, solar PV, and bioenergy. It is important to note that, despite the abundance of energy resources in the country, during the winter months the local natural gas supply does not cover domestic consumption, and

Primary energy supply and power generation in Argentina, 2021 — Figure 1



Agora Energiewende, Agora Industry and Fundación Torcuato di Tella (2023) based on CAMMESA (2022)

therefore LNG, diesel, and fuel oil imports are required to meet full electricity demand.

Argentina has promoted renewable energy use in power generation for more than a decade. In 2015, the country set clear targets for renewable energy in power generation. It was the first step in a series of programmes that provide incentives and benefits for renewables generation, including distributed generation for private users. This set of policies and regulations increased the installed capacity of renewable energy by 4 349 MW between 2015 and the first half of 2022. In terms of electricity generation, the share of renewable energy increased from less than 2 to 14 percent.

Today, Argentina's energy transmission infrastructure, in combination with macroeconomic factors,[1] places major constraints on the development of the renewable energy market. The result has been a modest expansion of renewable and non-renewable power generation.

The importance of hydrogen

Argentina's energy resources make the country very attractive for both fossil-based and renewable hydrogen production. Fossil-based hydrogen with carbon capture and storage (CCS) is a possible transition technology, but policymakers should carefully consider the risks of methane leakage and the potential for stranded assets given the global appetite for renewable hydrogen and Power-to-X (PtX) products. As the hydrogen market becomes more established over the coming years, conditions may improve, setting up Argentina to become a competitive producer of hydrogen and other PtX products.[2]

Argentina's renewable energy conditions are optimal for renewable hydrogen generation. For instance, estimations of full-load hours[3] (a key factor for renewable hydrogen production) put the weighted average of the capacity factor for wind power at 47 percent in 2021 (4 149 full-load hours). In the same year, solar PV had a capacity factor of 29 percent (2 541 full-load hours) (CAMMESA, 2022). However, the capacity factor for wind and solar PV power plants is unevenly distributed across the country's vast territory. Patagonia and Buenos Aires lead in wind power (each with around 50 percent or 4 300 hours/year), while Cuyo shows the best results for solar PV (31 percent, or 2 650 full-load hours/year).

In addition, the availability of land in Argentina is also an important advantage for the production of hydrogen. This is even more significant in the Patagonia region, which has important energy resources and a low population density. New energy and hydrogen projects would have less impact on the local population and encounter less opposition. However, all projects should guarantee a comprehensive Economic, Environmental, Social, and Governance (EESG) framework to mitigate negative local impacts. The availability of land increases Argenti-

1 Over the past decades, Argentina has been affected by significant economic fluctuations and macroeconomic imbalances that have limited economic growth. This has taken a toll on infrastructure and other strategic sector, creating significant challenges for infrastructure investment and planning, and have affected investor confidence.

2 Under the umbrella of the PtX Hub, Agora Energiewende in collaboration with Öko Institut has developed the Business Opportunity Analyser (BOA), an interactive tool that promotes the export of a range of PtX molecules such as green ammonia, e-methanol, synthetic fuels, etc. The tool enables users to calculate the delivered cost of PtX molecules from an export country to an import country, highlighting the competitive edge of one country against another. Argentina is one of the deep dive countries in BOA. That is, the tool provides more detail information and local data to obtain prefeasibility information in the trade of PtX products from the country.

3 Estimations are made based on data from 99 power generation plants with a total installed capacity of 4 367 MW for the 2019–2021 period.

na's hydrogen potential, especially when compared with European countries.

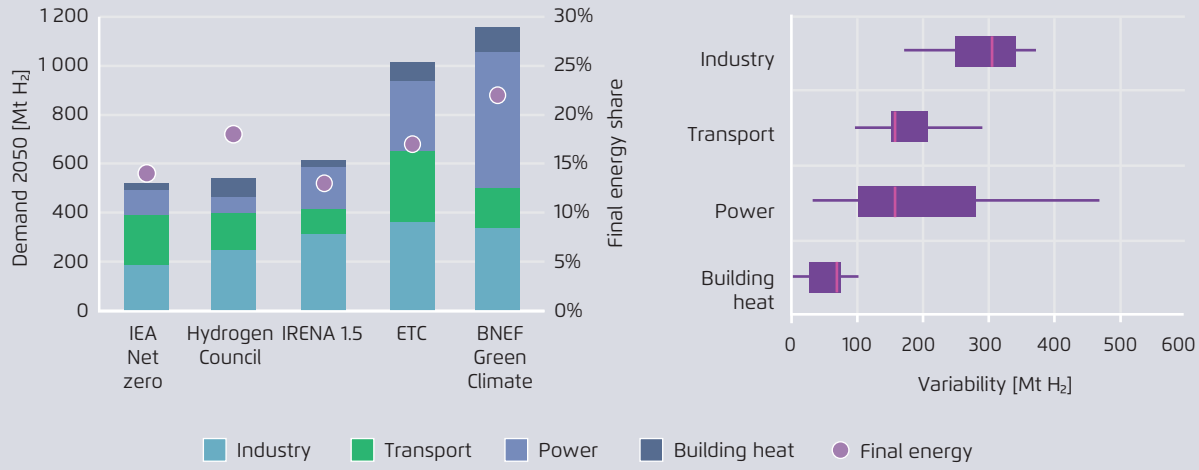
Global hydrogen demand

Hydrogen use in Latin America corresponds only to around 5 percent of global hydrogen demand (IEA, 2021), which reached 94 Mt in 2021 (IEA, 2022). Argentina is one of the top six hydrogen consumers in Latin America, using around 350 kt in 2019. Hydrogen in Argentina is mostly used for industrial hydrogen applications such as oil refining and the production of ammonia, methanol and direct reduced iron (DRI) (IEA, 2021). Given its widespread hydrogen use and renewable hydrogen potential, Argentina could be a key player in supporting global decarbonisation.

Global hydrogen demand is expected to keep growing in view of its role along the entire energy chain. As shown in Figure 2, various global energy scenarios estimate the hydrogen demand to reach more than 600 Mt in 2050. Most of the global energy scenarios agree that hydrogen demand will be driven by the decarbonisation of hard-to-abate applications in industry and transport (mostly aviation and shipping). Hydrogen use in the power sector will mostly go towards storage applications that further integrate variable renewable energy into the system. But hydrogen demand in the power sector is the most difficult to forecast since the technology landscape is even more complicated than the available options for the heat and transport sectors. However, hydrogen may be more scalable than any other technology given its many applications outside the power sector.

Some countries with greater hydrogen demand are likely to be unable to meet their own domestic demand for low-carbon hydrogen. In these cases, renewable-rich countries like Argentina can play a key role in supplying renewable hydrogen to big demand centres. For instance, in line with Germany's ambitions to achieve climate neutrality by 2045, it is estimated that the country's hydrogen

Estimates of global hydrogen demand in 2050 by selected scenarios — Figure 2



Agora Energiewende and Agora Industry (2021). Note: Final energy does not include feedstocks and other non-energy use; ETC=Energy Transition Commission; BNEF= BloombergNEF; IRENA = International Renewable Energy Agency; IEA = International Energy Agency. Final energy figures taken from respective sources.

demand will reach 1.9 Mt H_2 by 2030 and 7.9 Mt H_2 by 2045 [4] (Prognos, Öko-Institut, Wuppertal Institut, 2021). However, Germany would need to import more than two-thirds of its hydrogen demand, making it one of the most important PtX import markets in the EU.

Argentina's role in the current global energy crisis

Global fossil-fuel prices have risen rapidly since 2021. The situation has become even more critical since Russia's full-scale invasion of Ukraine, which has had a major impact on natural gas prices and has helped trigger a global economic recession that has been marked by high inflation and declining food and energy security. The impact in Europe has been severe: the price of natural gas has reached record prices up to 70 USD per mmbtu, creating uncertainty in the region's energy supply and affecting the global natural gas and LNG supply chain. High natural gas prices are also hurting the industrial sector. European companies are wondering whether to halt operations, and certain commodities manufactured from natural gas such as ammonia and steel reached record prices in 2022. For instance, global fertiliser prices have tripled since mid-2020. This will have a sustained impact on global agricultural production (IEA, 2022b).

Argentina's abundant energy resources provide the country with a unique opportunity to become a key player in addressing the global energy crisis. Argentina can contribute to the diversification of the global supply chain for fertilisers and other PtX products while also alleviating pressure on natural gas routes affected by the invasion of Ukraine. In this way, Argentina's renewable and fossil-energy resources can make a significant contribution to addressing the global energy crisis, while positioning the country as a global hub for PtX products.

4 Original values correspond to 63 TWh by 2030 and 265 TWh by 2045. Calculation based on low heating value (LHV) for hydrogen of 33.3 kWh/kg

12 Insights on Hydrogen for Argentina

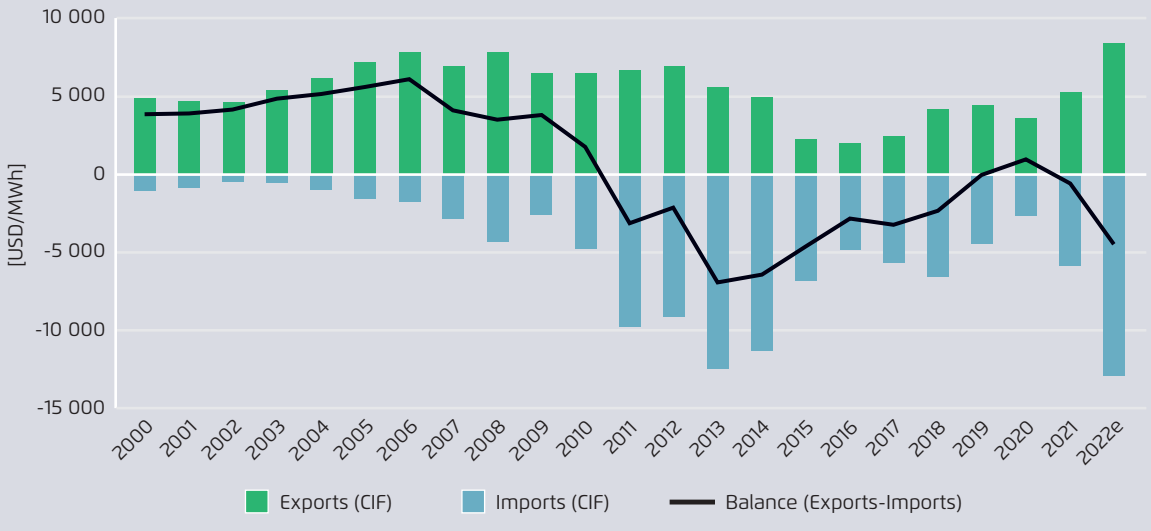
1 Diversifying the energy matrix with renewable energy will unlock Argentina's hydrogen potential

Argentina has large untapped energy resources capable of fulfilling the country's energy needs

Renewable energy can mitigate the country's dependence on fossil fuels and open up opportunities to develop a more sustainable industrial sector and more production capacity for renewable hydrogen and PtX products. Energy and power generation in Argentina is heavily dominated by fossil fuels, with natural gas playing a critical role. However, the current infrastructure does not allow the country to fully utilise its resources. For instance, the country must import LNG, diesel, and fuel oil during the winter months when energy demand is high. Figure 3 shows Argentina's energy trade balance. It can be seen that energy imports are still a significant cost for the country. Argentina can strengthen its energy security by diversifying its energy matrix so that a greater variety of sources is available to meet energy demand.

Estimates put the total gross resource potential of Argentina's solar PV, wind, hydro, and geothermal energy at 29 000 TWh/year, led by solar PV (57 percent) and wind power (42 percent) (IDB, 2017). Likewise, IRENA's estimates of Argentina's renewable energy potential compared to the global average place it at the high end for solar and wind (IRENA, 2022b). The country's untapped potential for renewables can

Argentina's energy trade balance — Figure 3



Agora Energiewende, Agora Industry and Fundación Torcuato di Tella (2023) based on INDEC (2023)

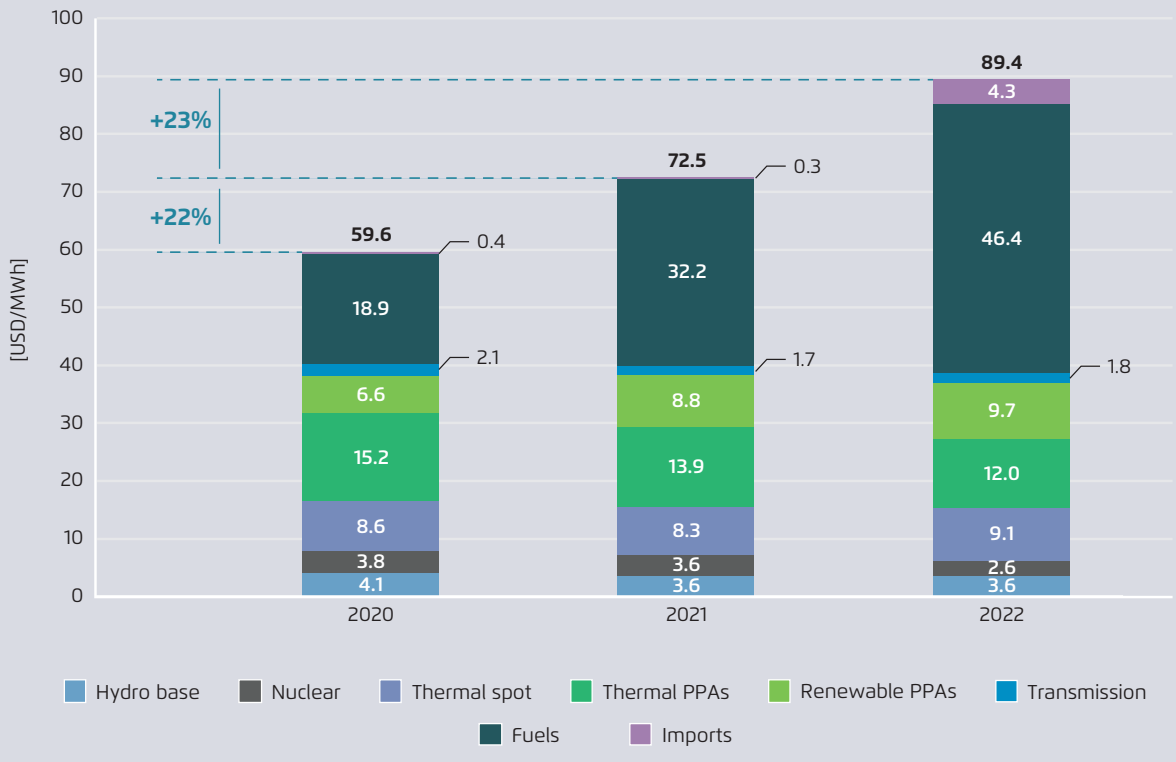
significantly help meet rising energy demand amid increasing levels of electrification and renewable hydrogen production.

Further RE development can bring important benefits to the country

Renewable energy development in Argentina can enhance energy security and decrease the need for electricity subsidies. For one, renewable energy can help to mitigate the impact of fuel prices on total system costs – the main contributor to electricity prices in Argentina, as shown in Figure 4. A reduction in the electricity price would reduce the gap covered by subisidies, mitigating this public expense. Additonally, it would provide the industrial sector with lower electricity prices, facilitating electrification and decarbonisation.

In 2021, electricity subsidies to bridge the gap between household tariffs and system costs amounted to 1.8 percent of Argentina's GDP, with electricity tariffs for households covering only 37 percent of total system costs (CAMMESA, 2021). Subsidy levels are expected to be larger in 2022 given the global crisis in fossil-fuel prices. The gap between tariffs and total system costs is likely to increase due to the dependency of electricity prices on fuel costs and to volatile foreign exchange rates (mainly between the US dollar and the Argentinian peso). Power purchase agreements (PPA) with some generators in Argentina are in US dollars. Likewise, the costs of domestic natural gas and imported fuels (LNG and liquid fossil fuels) are

Summary of system costs for power generation in Argentina — Figure 4



Agora Energiewende, Agora Industry and Fundación Torcuato di Tella (2023) based on Caratori (2022)

Infobox 1: Mitigating carbon emissions – Argentina's climate commitments

Argentina ratified the Paris Agreement in September 2016, obligating it to prepare and communicate Nationally Determined Contributions (NDCs). The revised NDC submitted by Argentina in 2021 raised the country's ambition. The new target is to keep net emissions below 349 $MtCO_{2e}$ by 2030. This is 26 percent lower compared to the NDC submitted in 2017 (483 $MtCO_{2e}$ by 2030). Additionally, Argentina has committed itself to make efforts to achieve net-zero emissions by 2050.

The energy sector is the largest contributor of carbon emissions, making up more than half (51 percent) of Argentina's total GHG emissions (energy generation, consumption and fugitive emissions). Most of the energy-sector emissions arise primarily from the combustion of fossil fuels. The second largest contributor to Argentina's emissions is agriculture, forestry and other land use (AFOLU; 39 percent), followed by industrial processes and product use (IPPU; 6 percent). The remaining 4 percent comes from landfill emissions.

Source: MAyDS, 2022

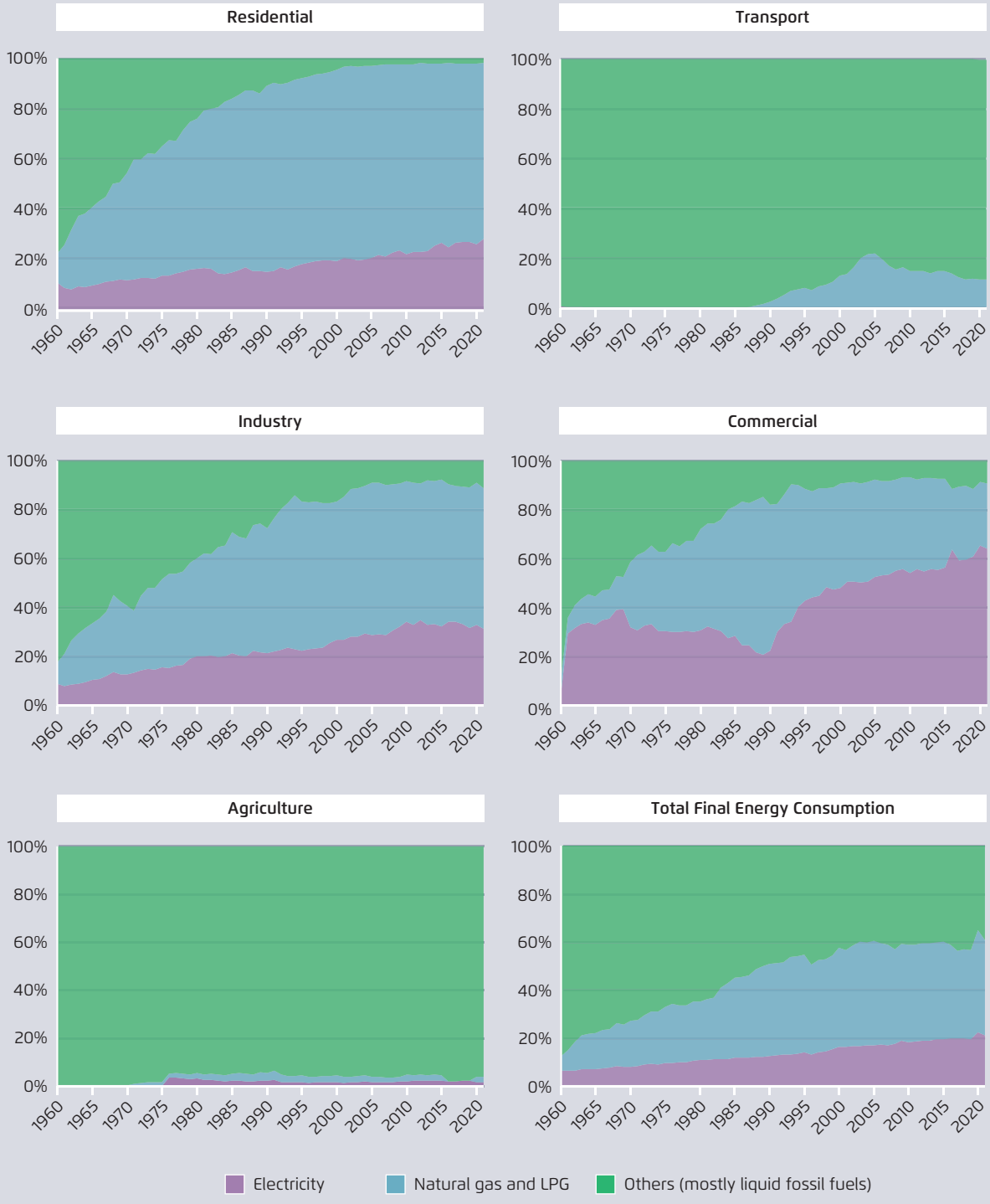
also transacted in USD dollars. The crisis in global fossil-fuel prices and the effect of climate change on Argentina's hydro generation have further exacerbated the problem, especially during winter months. In July 2022, total system costs increased by 75 percent. For industry, the situation is critical as well. The sector does not receive subsidies to defray electricity costs, so industrial users must fully cover increases in total system costs. Greater penetration by renewables could reduce total system costs by reducing fuel consumption. It could also reduce the average cost of generation as renewable PPAs are signed below average system costs.

Decarbonising the energy sector will require the use of other low-carbon technologies

Argentina could adopt a series of strategies to reduce its dependence on fossil fuels and to lower energy-sector emissions in line with its climate agreements and its ambition of achieving net zero by 2050. This would also contribute to energy security by reducing the need to import liquid fossil fuels and LNG.

The transport sector currently consumes large amounts of liquid fossil fuels (see Figure 5). Technologies such as electric vehicles (see Infobox 2) could facilitate its decarbonisation and enhance other aspects of sector coupling to increase the flexibility of the energy sector. The residential sector is a large consumer of natural gas, making up 70 percent of energy use in the sector in 2021 – primarily for water, space heating, and cooking. Argentina has the highest penetration of natural gas in the residential sector in Latin America and the Caribbean. Natural gas is critical during the winter months due to high heating demand (sieLAC-OLADE, 2022). The introduction of low-carbon technologies in this sector such as heat pumps, electric cookers, solar water heaters, etc., can have a series of positive impacts, such as (1) diversifying the sector's energy supply, thereby increasing energy security; (2) increasing the penetration of renewable energy in power generation (centralised and distributed) and in heating; (3) integrating end-use sectors to enhance flexibility in the power sector; and (4) contributing to emissions mitigation in the sector. The promotion of low-carbon technologies in the sector should be

Fuel share in the final energy consumption per sector Figure 5



FTDT (2020)

combined with strategies to further promote electrification with renewables and energy efficiency.[5]

To maximise benefits, RE development should accompany hydrogen production

The promotion of renewable energy in Argentina can have a number of positive impacts on the country's energy sector. In addition, renewable energy is at the core of renewable hydrogen development. Argentina's renewable energy resources mean that it has the potential to become a leader in hydrogen and PtX trade.

The expansion of renewable energy and the introduction of large-scale hydrogen production will require significant investment in the country's energy infrastructure. Accordingly, it is important that these efforts be coordinated in order to maximise their benefits without affecting decarbonisation. Initial off-grid renewable hydrogen production might serve as a kick-off for the country's hydrogen economy, but over the medium term consideration should be given to integrating these projects into the overall energy sector. This would strengthen Argentina's decarbonisation, sectoral integration, and energy flexibility as it develops a hydrogen economy.

5 The PtX Hub in Argentina has developed the Allocation Scenarios project. It comprises a range of detailed energy transition pathways for Argentina through 2050. The pathways show how hydrogen and PtX products can contribute to the decarbonisation of power, heat, transport and industrial systems in the country, including exports. The developed pathways are designed to help prioritise development strategies in the country's energy sector.

2 The role of hydrogen for climate neutrality is crucial but secondary to direct electrification

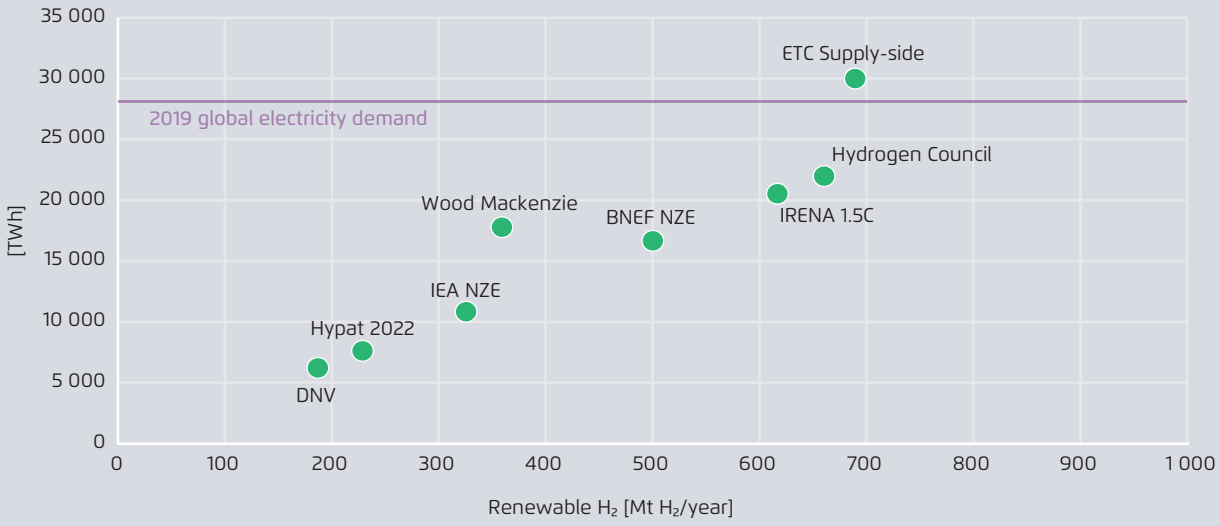
The role of hydrogen in future energy systems

Around the world, countries are raising their climate ambitions by setting long-term net-zero targets. Argentina is no exception, having committed to make efforts to achieve carbon neutrality by 2050. Many studies have analysed the pathways to achieving global net-zero pledges by mid-century. Most of these studies agree that the deployment of renewable energy will make up the largest part of the energy transition. For instance, IRENA's 1.5C Scenario shows that 90 percent of total global decarbonisation in 2050 will involve renewable energy through direct power, electrification, efficiency, bioenergy with CCS, and renewable hydrogen. However, hydrogen will contribute to mitigating only 10 percent of total global emissions by 2050 (IRENA, 2022).

Likewise, the IEA's net-zero emissions scenario highlights the role of electrification in the decarbonisation of the global energy sector. This scenario projects that electricity will dominate energy use in the end-use sectors, accounting for more than half of total final consumption by 2050 (IEA, 2022c).

Despite the significant role of electrification in global decarbonisation, some applications – most of them in the industrial and transport sectors – cannot be electrified, entailing reliance on hydrogen and its derivatives. However, the production of renewable hydrogen will require a significant amount of renewable energy deployment, as illustrated in Figure 6. Due

Renewable electricity needed to produce renewable hydrogen in global scenarios for 2050 Figure 6



Agora Energiewende and Agora Industry (2023) based on BNEF (2022); DNV (2022a); Hydrogen Council (2022); IEA (2022b); IRENA (2022); Riemer et al. (2022)

to 30 percent energy losses incurred during hydrogen production and other energy losses during use, hydrogen can be as much as 84 percent less efficient than heat pumps in delivering like-for-like energy for direct electrification in the residential sector, or as much as 60 percent less efficient than battery electric vehicles in the transport sector. Renewable hydrogen requires 2 to 4 times as much renewable energy capacity to achieve the same final energy use as direct electrification. Therefore, hydrogen is a key component in global decarbonisation, but it is secondary to electrification in the net-zero pathway.

A clear set of no-regret hydrogen applications

Scaling up hydrogen production, whether in Argentina or elsewhere, will require large amounts of investment. Again, renewable hydrogen production will demand a wide deployment of renewable energy capacity. Hence, it is necessary to prioritise hydrogen use to applications where hydrogen is the only decarbonisation option. Likewise, hydrogen ought not to compete with other more efficient decarbonisation technologies such as heat pumps or electric vehicles. To achieve a 1.5-degree world, hydrogen must complement large-scale electrification and the efficient deployment of wind and solar, backed up by geothermal, nuclear, hydro and storage.

As shown in Figure 7, Agora has developed an overview of the different hydrogen applications that should be prioritised across different end-use sectors. These applications have been identified based on a review of prominent energy system scenarios. This set of applications aims to provide a guideline for policymakers developing country

Need for molecules in addition to green electrons — Figure 7

Green molecules needed?	Industry	Transport	Power sector	Buildings
No-regret	· Reaction agents (DRI steel) · Feedstock (ammonia, chemicals)	· Long-haul aviation · Maritime shipping	· Renewable energy back-up depending on wind and solar share and seasonal demand structure	· Heating grids (residual heat load *)
Controversial	· High-temperature heat	· Trucks and buses ** · Short-haul aviation and shipping · Trains ***	· Absolute size of need given other flexibility and storage options	
Bad idea	· Low-temperature heat	· Cars · Light-duty vehicles		· Building-level heating

* After using renewable energy, ambient and waste heat as much as possible. Especially relevant for large existing district heating systems with high flow temperatures. Note that according to the UNFCCC Common Reporting Format, district heating is classified as being part of the power sector.

** Series production currently more advanced on electric than on hydrogen for heavy duty vehicles and buses. Hydrogen heavy duty to be deployed at this point in time only in locations with synergies (ports, industry clusters).

*** Depending on distance, frequency and energy supply options

Agora Energiewende and Agora Industry (2021)

strategies and roadmaps for specific hydrogen uses. For Argentina, heating grids and renewable energy back-ups might not seem like relevant applications given the decentralised development in the country's heating sector and the flexibility provided by hydropower and natural gas-based generation. However, depending on the country's energy-sector pathway, these applications might have more relevance in the future.

Electrons and molecules to decarbonise the country's economy

Argentina's hydrogen production has a large potential to decarbonise its domestic demand and produce hydrogen for export to larger energy-intensive regions such as the European Union and East Asia. As mentioned above, Latin American countries do not have a large hydrogen demand, but this demand is anticipated to increase in the coming years as the industrial sector looks for fossil-fuel alternatives. IEA estimates the hydrogen demand in the region will increase by 67 percent by 2030, reaching around 6.8 Mt H_2. The use of hydrogen will tend to decrease in oil refining but increase in the chemical, steel, cement, and transport sectors.

The current moment presents an opportunity for Argentina to make its industrial sector more sustainable while diversifying its economic activities and generating growth. The production of renewable hydrogen in Argentina can be prioritised so as to expand the industrial use of PtX products such as green ammonia, e-methanol, and synthetic fuels, along with higher value-added products such as green fertilisers and green steel. By increasing the production of green molecules and products, Argentina can actively participate in international markets, which are increasingly prioritising these materials.

First, however, Argentina needs to carefully balance the use of natural gas and renewables as it develops its domestic industry. One option is to prioritise the export of PtX products, while using natural gas locally, with the aim of switching to renewables as soon as possible. The large-scale production of renewable hydrogen can also create a more dynamic renewable energy market and promote its use in the power and industrial sectors. The sustainable development of industry based on green products will modernise the sector and make it more globally competitive. The production and use of PtX products will bring important socio-economic benefits to the country such as job creation, increased food security (through fertilisers), and improved population welfare (by mitigating energy poverty and improving health conditions). New hydrogen and renewable energy projects will need to consider local communities, protected areas, water access, and other important factors to ensure a just and fair transition, especially in regions with a high renewable energy potential. Therefore, hydrogen development will need to have a comprehensive EESG framework to maximise these potential benefits.

3 Energy infrastructure should be prioritised, and hydrogen production should be included in long-term development plans

Argentina's existing energy infrastructure limits its potential

The upscaling of a hydrogen economy will require the improvement of the country's existing energy infrastructure in order to fully utilise its energy resources. Argentina's energy planners will also need to consider the potential upcoming on-grid and off-grid renewable and hydrogen projects, to ensure their proper integration into the system in the long term. The impacts and benefits of the further integration of renewable energy and hydrogen projects need to be assessed so that appropriate measures can be taken that guarantee flexible operation.

The country's current energy infrastructure is a limiting factor for the further development of power generation, both fossil and renewable. Scaling up hydrogen production will place higher demands on the power grid. For instance, renewable hydrogen will require a wide deployment of renewable energy connected to the transmission grid. This is one of the main challenges for the further deployment of renewable energy projects in the country. Renewable-rich regions in Argentina such as Patagonia, the southern and Atlantic areas of the Province of Buenos Aires, the Northwest, and Cuyo will require significant infrastructure investments to expand high-voltage transmission capacity. Only then will these regions be able to accept more renewable energy projects and transport the energy to demand centres such as the Greater Buenos Aires area (CADER, 2022). Considering the operational requirements of the system, Figure 8 shows the grid operator's proposal for the expansion of the electrical grid up to 2026.

The government recently published its National Electricity Transmission Expansion Plan. The plan has a timeframe until 2035 and aims to prioritise some of these grid works to increase transmission capacity by 36 percent (Secretariat of energy, 2023). Total required investment is estimated at around USD 4.5 billion. In the long term, the upscaling of renewable energy in Argentina will require further improvements to the overall electricity infrastructure to allow a greater integration of renewable energy sources. It will also need more ancillary services that increase flexibility.

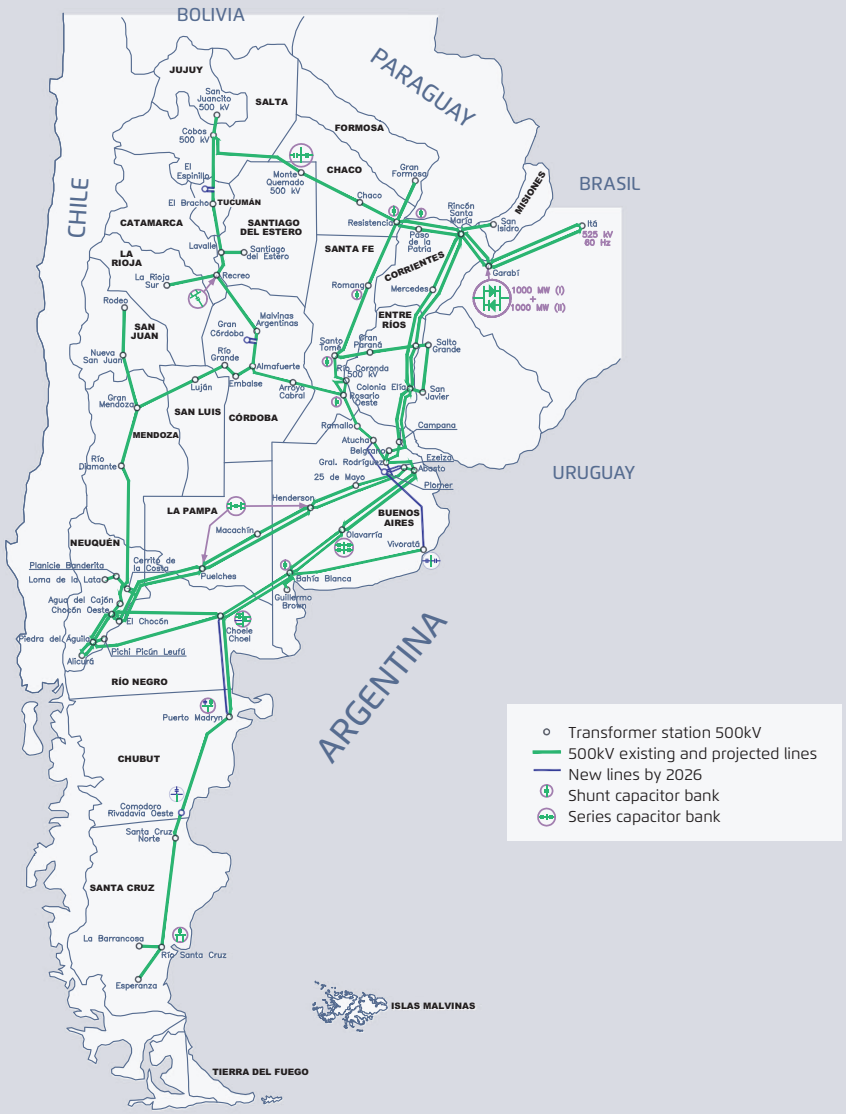
The existing gas infrastructure offers a clear advantage

Argentina already has significant natural gas infrastructure consisting of pipelines and LNG ports for imports and exports. These could eventually be retrofitted for the transport of hydrogen and PtX products. However, the existing gas infrastructure cannot connect resource areas with local demand centres and international markets. Likewise, the distribution networks would not be ideal, as residential use does not represent an expedient application for hydrogen. Here, natural gas resources are more competitive and efficient. However, in the longterm other low-carbon technologies (heat pumps, solar water heaters, etc.) should be considered to mitigate emissions in the sector.

The country's gas pipeline network is extensive, totalling around 98 000 km. The majority of this network (82 337 km) is used for gas distribution, predominantly to households. The country currently has two LNG terminals – Escobar and Bahia Blanca (the latter was reactivated in 2021). Argentina also has interconnected pipelines with Chile, Bolivia, Brazil, and Uruguay.

At the same time, the existing infrastructure is one of the factors restricting increased natural gas produc-

Plans to expand Argentina's transmission grid by 2026 Figure 8



Transener (2022)

tion in the country. As a result, the production levels have remained the same since the early 2000s. A new pipeline project is currently under construction that will connect Neuquén and the unconventional hydrocarbons resources in Vaca Muerta to the province of Buenos Aires. The first phase of this project will increase natural gas transport by 25 percent, eliminating the need for fuel imports. A second phase is still awaiting financial support. Other pipeline expansion projects are taking place elsewhere in the country. It is important to note that future natural gas infrastructure projects will need to be carefully assessed. As global decarbonisation continues over the coming decades, the demand for hydrocarbons will fall. This could lead to stranded assets for new fossil-fuel projects.

Ports and trade experience will play a more prominent role

If Argentina is to become an exporter of hydrogen and PtX products, this will require good coordination with the existing trade system, especially when it comes to ports – where most of the storage, transport, and production will take place. Argentina's wide trading experience and infrastructure will be an important asset when devising the export plans for PtX. Likewise, the ambition of upscaling hydrogen production and trade will require the expansion and retrofitting of existing infrastructure. Aligning port expansions with hydrogen and PtX ambitions will be crucial for amplifying infrastructure investments and producing co-benefits such as the use of low-carbon technologies in trade.

Argentina has a long seacoast and an extensive network of navigable inland waterways. Nevertheless, most of the waters are fairly shallow and require constant dredging and maintenance (Palomar 2011). Some 185 million tons of cargo are handled annually by one hundred port facilities across the country. Most of Argentina's grain and container cargo is handled by ports located on the Santa Fe-Ocean Trunk Inland waterway. The port activity along the coastal region of the Buenos Aires province consists mostly of fuels, agri bulks, fertilisers, and to a lesser extent, containers (World Bank, 2022). By contrast, the ports along the Patagonian seacoast are low density and highly specialised – mostly for cabotage traffic such as liquid bulk hydrocarbons.

The Ports Modernisation Plan developed by the Ministry of Transport includes a new terminal and cargo dock in the port of Ushuaia. It also includes plans for the expansion and modernisation of various existing ports and describes dredging projects to ensure navigable conditions (Ministry of Transport of Argentina, 2023). In addition, several private-sector infrastructure projects have been announced.[6]

However, for the most part Argentina's expansion plans do not spell out the role that new port infrastructure will play in the development of a hydrogen value chain. If such a chain is to materialise, the country's long-term strategic plans must indicate the location of new hydrogen industrial hubs, projections for PtX exports, and other key information.

6 YPF and Petronas have announced the development of an LNG production and export port in the Bahia Blanca region. Similarly, the Australian company Fortescue announced the development of a port in the Rio Negro province dedicated exclusively to the export of hydrogen and PtX.

4 Argentina has the potential to become a key global exporter of PtX products; it must ensure that production is accompanied by the decarbonisation of domestic hydrogen demand

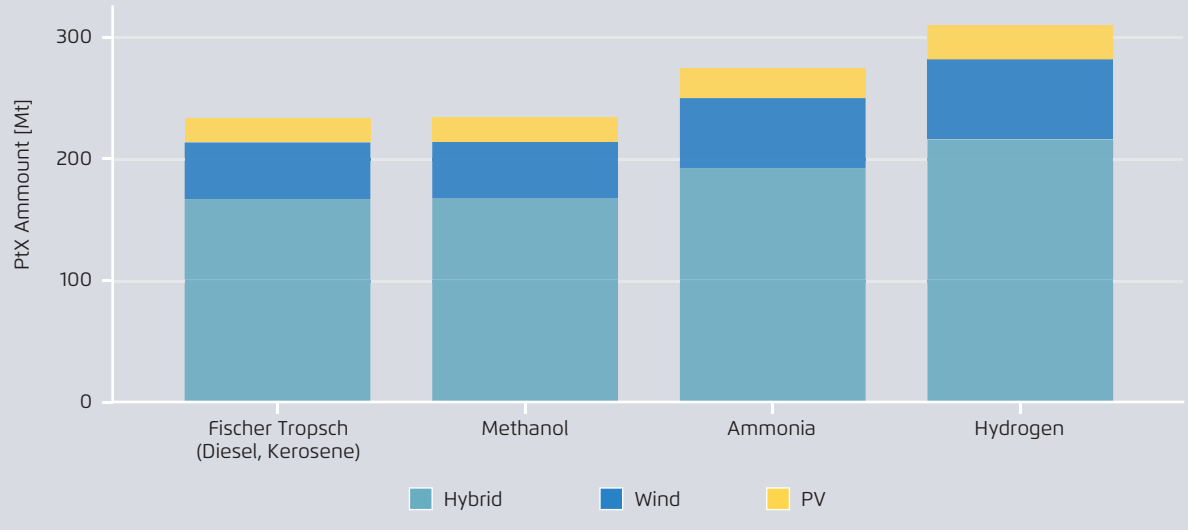
Argentina as a hub for PtX products

Thanks to its abundant renewable energy resources, Argentina has one of the world's greatest potentials for the development of renewable hydrogen and PtX products. For instance, the Global PtX Atlas finds that 80 percent of the identified global area with potential to produce PtX is concentrated in just 10 countries. Argentina has the world's third largest potential, after the USA and Australia. This potential has been identified with regard not only to renewable energy, but also to water availability, which is key in the electrolysis step for renewable hydrogen production (Fraunhofer IEE, 2021).

The identified PtX sites in Argentina include an extension of more than 150 000 km² for hybrid sites using wind and solar PV, followed by about 48 000 km² for sites using wind only and more than 26 000 km² for sites using solar PV (Fraunhofer, 2021). As shown in Figure 9, the PtX product with the greatest potential is ammonia. This is followed by methanol and Fischer-Tropsch products (synthetic fuels). Gaseous and liquid hydrogen have the potential to be used mainly at the local level and to a certain extent at the regional level, given the costs and limitations of transport. Argentina's interest in exporting overseas would be more cost-effective through PtX or more valuable products such as green fertilisers, green steel, etc.

Fraunhofer's assessment does not consider other economic aspects or complementarities with other energy sources. For example, the country's agricultural sector can also increase its green ammonia

PtX potential generation volumes for Argentina, high temperature electrolysis — Figure 9



Fraunhofer IEE-PTX Atlas (2022). Note: PTX Atlas estimates the aggregated PtX generation volumes based on the identified PtX potential areas in the country and using site-specific expansion and deployment optimizations.

potential for fertiliser production.[7] In addition, the existing bioenergy industry has the potential to be a good source of sustainable carbon for synthetic hydrocarbons (e.g., Fischer-Tropsch or e-Methanol).

Hydrogen as a tool to boost a sustainable fertiliser industry

The current production of fertilisers in Argentina does not cover local demand. Hence, the country must import more than 60 percent of its total consumption. This resulted in expenditures of 2.3 billion USD in 2021, with attendant impacts to the balance of trade. In the period between 2010 and 2020, fertiliser consumption in Argentina increased 4.6 percent annually on average (Bolsa de Comercio de Rosario, 2021). The country's growing demand for fertilisers, together with the higher international prices in 2022, indicate that the negative impact on Argentina's balance of trade will be even more significant than in previous years..

Argentina could establish strategies to promote the local production of fertilisers using green ammonia. This would decouple fertiliser production from the price volatility of natural gas, and it would position the country as a potential exporter of such products regionally and globally. The expansion of ammonia production capacity in Argentina could consider natural gas to be a bridge technology, but it should prioritise the use of renewable hydrogen. This will bring important socio-economic benefits to the country in terms of jobs creation, food security, and industrial decarbonisation. The international community could also benefit because the expansion of fertiliser production in Argentina could ease upward pressure on food prices and mitigate the demand for natural gas. The policy brief "Argentina as a hub for green ammonia" provides a more detailed discussion of potential next steps for promoting the use of renewable hydrogen in green ammonia and fertiliser production.

Decarbonising Argentina's energy-intensive industry

Hydrogen can help to enable sustainable industrial growth in Argentina by expanding the sector to cover local demand and foreign exports. As mentioned earlier, fossil-based hydrogen with CCS could be used as a transition technology to boost the sector, but in the longrun industrial strategies should prioritise renewable hydrogen, especially for export products in the international green market. The expansion of the industrial value chain should leverage existing decarbonisation strategies to promote the decarbonisation of the local supply chain and keep the industrial sector competitive.

The Argentinian industrial sector represents around 6 percent of the country's total GHG emissions, which amounted to around 21 $MtCO_{2e}$ in 2018. These emissions include those from chemical reactions when using natural gas as a feedstock in industrial processes. The National Action Plan for Industry and Climate Change (PANIyCC) proposes a series of mitigation measures focusing on energy efficiency, renewable energy, the circular economy, and emissions capture. These measures aim to promote the use of solar PV, solar thermal, and wind in industrial processes. Additionally, the plan proposes the use of biodigesters to produce biogas in industries as a means of saving energy. One of the plan's measures introduces alternative fuels in the cement industry.

There is still a need for better coordination and more sustainable practices in Argentina's steel, chemicals, and cement industries. Contemplating clear actions for electrification, modernisation, and the use of hydrogen could serve as an important step in promoting the sector while developing the local hydrogen market.

7 A more detailed policy analysis for the production of green ammonia and fertilisers in Argentina can be found in the policy brief "Argentina as a hub for green ammonia: A forward-looking development strategy for addressing the global energy and climate crises". https://www.agora-energiewende.de/en/publications/argentina-as-a-hub-for-green-ammonia/

5 The potential future market for hydrogen vehicles is shrinking daily

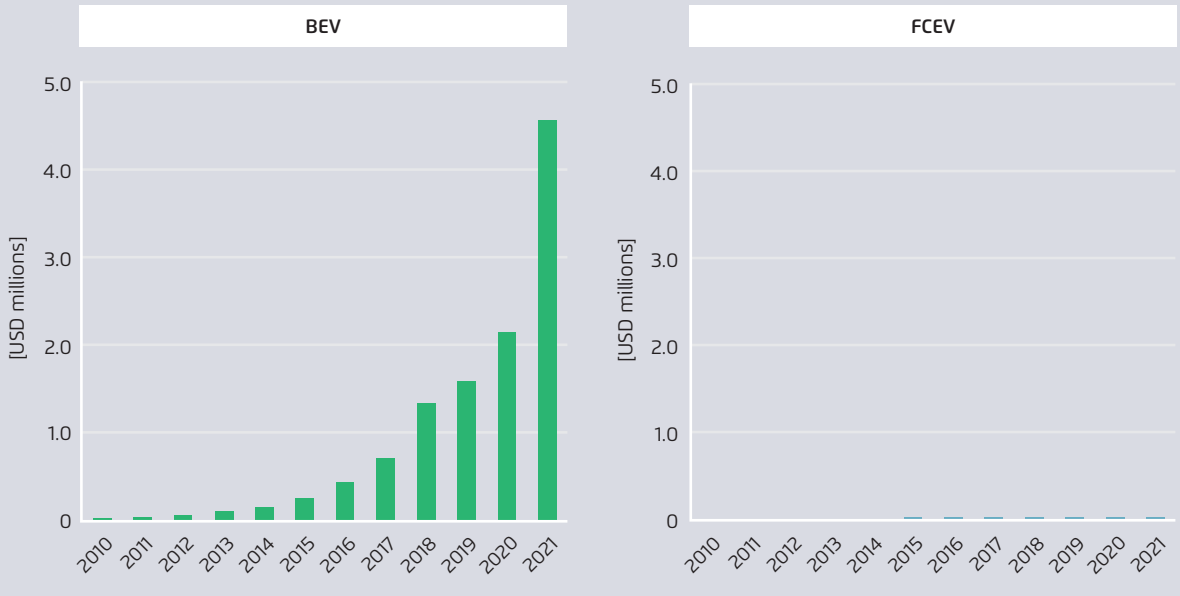
Hydrogen-fuelled transport – will fuel-cell cars play a role?

Fuel-cell electric cars were once seen as key for the decarbonisation of the transport sector. But this technology has been losing the race against battery-electric cars, which today completely dominate the market, as shown in Figure 10.

It is expected that the market will see some hydrogen vehicles, especially those built for heavy-duty purposes in long-range freight and construction. In particular, hydrogen will play a key role in the decarbonisation of transport in the mining sector, because it is one of the few viable alternative fuels for mining vehicles. Indeed, mining haul trucks are one of the six prioritised applications for hydrogen in Chile's green hydrogen national strategy. Argentina's current mining sector is not as extensive as Chile's. Nevertheless, hydrogen could be an option in helping to decarbonise its lithium mining sector as global demand for the metal surges.

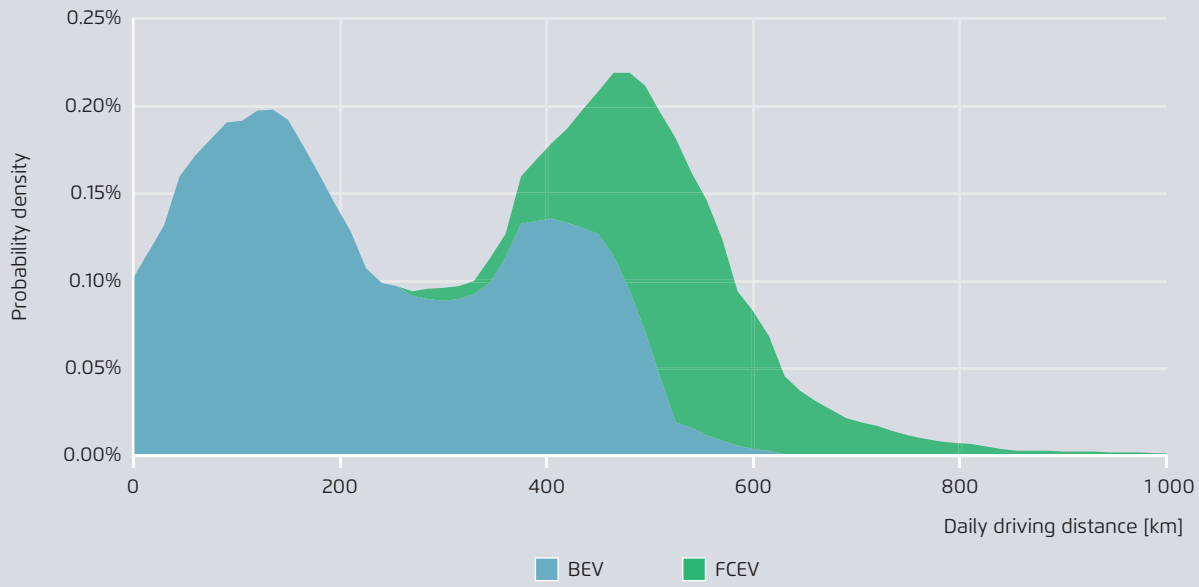
Hydrogen could play a role in some freight vehicles, but battery technology is developing fast. It is expected that battery-electric trucks will carry out most of the world's freight transport, as shown in Figure 11. This is because around 80 percent of the daily driving distance is less than 400 km, well within the range of battery technology. In Argentina, hydrogen-fuelled heavy trucks will have to compete in the short and medium term with other technologies such

BEV vs. FCEV annual sales — Figure 10



BloombergNEF (2022)

Distribution of heavy trucks by daily driving distance, 2050 Figure 11



Agora Energiewende and Agora Industry (2021)

Infobox 2: Decarbonising Argentina's transport sector

There are currently great ambitions to make Argentina's transport sector more sustainable. One key strategy in pursuit of this objective is shaping up to be the adoption of electric vehicles. The Chamber of Deputies is currently discussing an electromobility law to provide the necessary legal framework for the sector's structured development. The law includes tax incentives for technology and infrastructure, a plan to halt the sale of combustion engine vehicles in Argentina after 2041, and the creation of a fund exclusively for sustainable transport.

The private sector is very eager to develop electric transport in view of the country's renewable energy potential and lithium reserves. And the industrial sector has plans to manufacture ion-lithium batteries in Argentina, which would make the electric vehicle market more competitive in the country.

In addition to electric vehicles, it is important to consider the biofuels sector, which is already well established in Argentina. Until 2019, biofuels were the most significant mitigation measure for GHG emissions, avoiding around 4 $MtCO_{2e}$ in that year. It has now been overtaken by grid-connected renewables in the power sector. The biofuels sector may require additional reforms to address challenges related to competition, including measures to promote advanced biofuels, to open the market to new players, and to improve the international acceptance of biofuels.

Source: Ministry of Productive Development of Argentina, 2021; Y-TEC, 2021

as biofuels, compressed natural gas, and liquified natural gas, so its deployment will face even more competition than in other regions of the world.

Hydrogen-based power-to-liquids (PtL) will capture shipping and aviation markets

For other transport modes, such as long-range shipping and aviation, liquid fuels have many advantages over pure hydrogen, most significantly improved energy density, which makes them a stronger fuel.

In October 2022, the aviation community committed itself to a net-zero pathway for 2050. Low-carbon technologies such as hydrogen or battery-electric aircraft could play an important role in mitigating the negative impacts of short-haul and regional aviation in the medium to long term. Yet sustainable aviation fuels (SAFs) are the only defossilised option on long-haul routes for the foreseeable future. In the Waypoint 2050 report, the Air Transport Action Group (ATAG) presents an overview of the energy options that could contribute to the necessary emissions reductions in commercial aviation. It is likely that aviation will need between 330–445 million tonnes of SAFs per annum by 2050 (ATAG, 2021).

The deployment of PtL and SAF technologies, especially in developing countries and emerging economies, could engender positive trends for social innovation, jobs creation, and advanced education. Ultimately, the development of these technologies will depend on local resources, contexts, and sustainability considerations.

6 Argentina's bioenergy industry can significantly contribute to its PtX market

Production of PtX will require CO_2 as a feedstock

CO_2 will be a key component in the production of most hydrogen derivates and PtX products. Figure 12 shows the paths for PtX production from renewable hydrogen. CO_2 is clearly needed to produce fertilisers such as urea, synthetic fuels such as e-kerosene, and chemical products such as methanol. It is important, therefore, that Argentina identifies potential sustainable carbon sources that can be used in the production of PtX.[8]

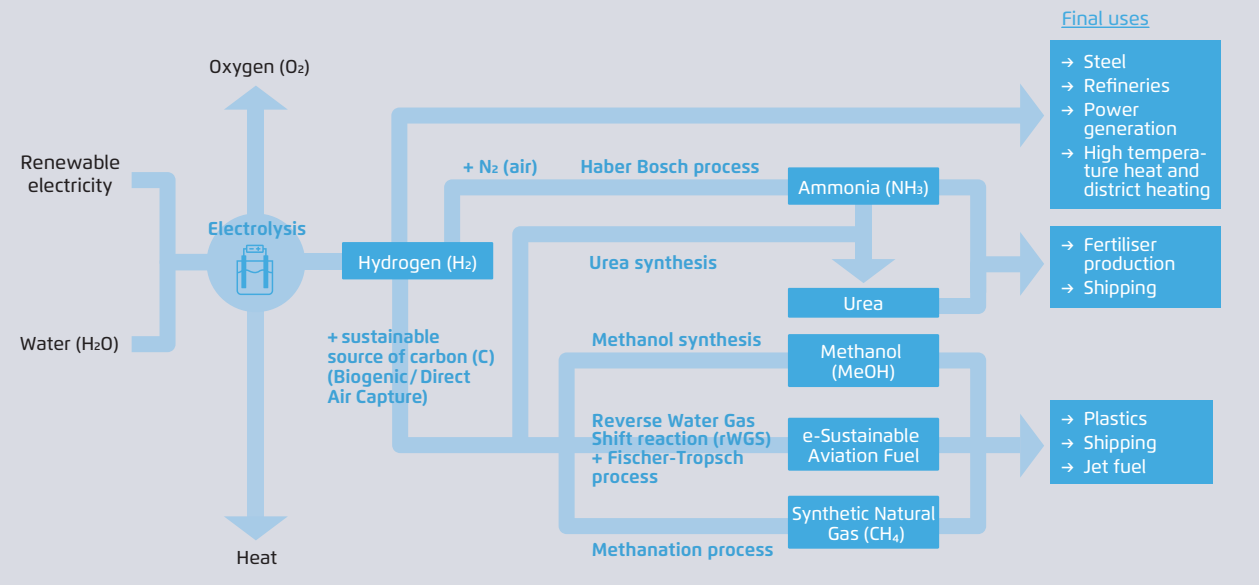
The availability and location of such carbon sources will have an influence in prioritising the path used for PtX production and in identifying potential infrastructure needs, including CO_2 transport to areas with high hydrogen potential. The location of carbon sources in Argentina might also require better coordination and collaboration with hydrogen production, as this could amplify the country's potential for the production of PtX products.

Argentina's bioenergy industry can provide a sustainable carbon source

For decades, Argentina has had a well-developed bioenergy industry. The industry can serve as an important source of sustainable carbon for the production of PtX products. The future expansion

8 Under the umbrella of the PtX Hub, DECHEMA (the Society for Chemical Engineering and Biotechnology) is leading the development of a carbon source study for Argentina that will help to map potential carbon sources for the production of PtX.

Paths for the production of PtX products — Figure 12



Agora Energiewende and Agora Industry (2023)

of the bioenergy industry[9] in the country can be assessed based on the development plans of the hydrogen industry – boosting the efforts of both industries to create more valuable products for domestic sales and export. In addition, biofuels can be integrated with other parts of the supply chain for PtX products, such as fuel for the transport of green molecules.

Argentina has widely used biofuels since 2006, when it introduced a law and regulatory framework for biofuels. The country is currently one of the largest biodiesel exporters in the world; one-third of its local production goes to the international market. Likewise, as of September 2022, annual ethanol production in Argentina reached approximately 95 000 cubic meters. Ethanol is mostly produced from maize and sugarcane (Secretariat of Energy, 2022). Recent estimates show that the available feedstock could boost the current installed capacity by 82 percent in the case of biodiesel and by 152 percent in the case of ethanol (Hilbert, et al., 2021). Over the medium term, a transition to next-generation biofuels needs to be discussed and implemented. An appropriate regulatory framework should be considered to support their development.

Ethanol production has the potential to become a sustainable carbon source for the manufacturing of PtX products. Meanwhile, biodiesel production requires more research into the use of glycerine – a secondary product from biodiesel production – as a potential source of carbon. Renewable hydrogen can also be used in the production of hydrotreated vegetable oil (HVO), which is an important decarbonisation option for diesel fuel and the aviation sector. Argentina has the potential of becoming an exporter of HVO, but this requires ensuring sustainable production practices that do not lead to deforestation and other negative environmental impacts. Policy support for the use of any kind of biofuels needs to consider direct and indirect effects on climate and biodiversity that stem from the production process and feedstock. Minimising harm to the environment should be prioritised.

The Probiomasa programme from FAO estimates the potential biogas production in Argentina resulting from feedlots, dairy, swine, and vinasse at 416 ktoe per year, mostly concentrated in feedlots (44 percent) and swine production (27 percent) (FAO, 2020). Biogas can be integrated into the PtX manufacturing chain as a source of carbon. However, biogas production is usually not centralised, and it would thus be necessary to coordinate efforts in clustering biogas production sources to maximise its potential. According to the estimates of biogas production in Argentina, the province of Buenos Aires has the largest biogas potential and a significant wind energy potential. These conditions could make it ideal for the development of a PtX industry.

9 Additional biomass demand coming from the hydrogen industry must ensure that it does not lead to environmentally harmful intensification of land use or to direct or indirect changes in land use, leading to detrimental effects on eco-systems and carbon cycles.

7 Argentina should contemplate its role in global trade to ensure the competitiveness of its exports to European and Asian-Pacific markets

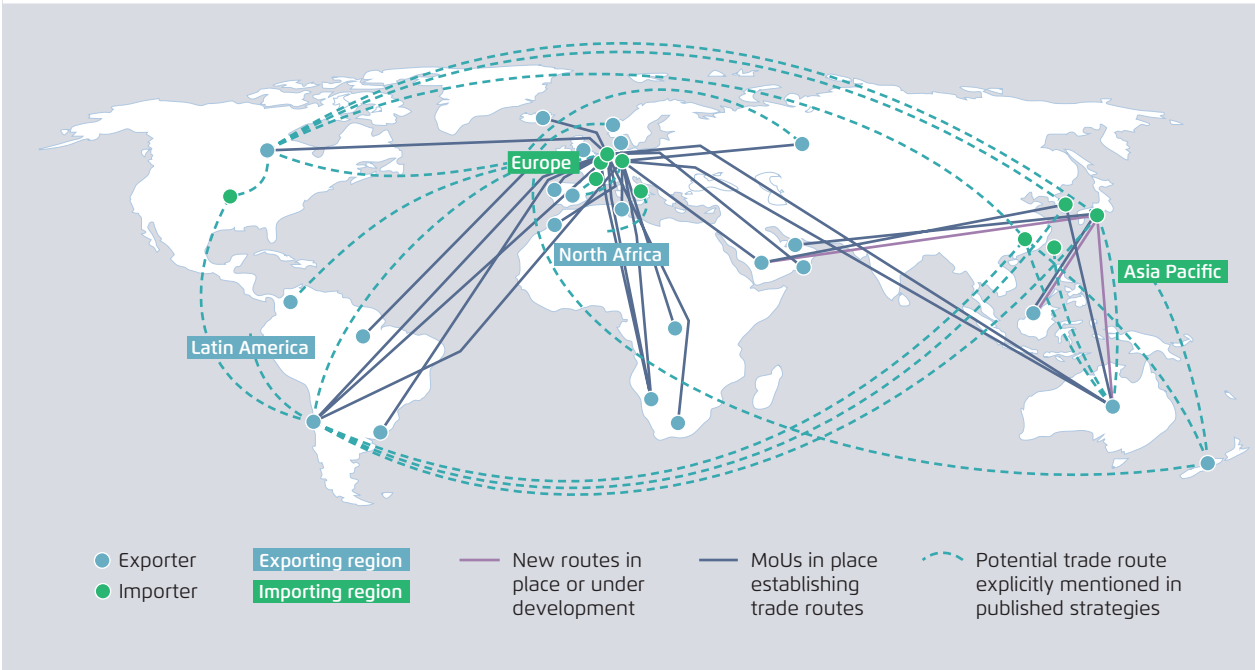
What are the potential hydrogen markets of the future?

Countries with cheap, abundant renewable energy will be in a better position to engage in hydrogen production. The rise of trade in renewable hydrogen will help to reshape energy geopolitics, as many countries that are rich in renewables are located in the Global South; renewable hydrogen export will provide an opportunity for their economic growth while also encouraging international cooperation to keep the rise in global temperature below 1.5 °C.

Large energy consumers such as Europe and the Asia-Pacific region will not be able to satisfy their hydrogen demand with domestic production, and will thus need to import PtX products from countries with abundant renewable energy resources that are capable of producing renewable hydrogen and its derivatives at a competitive price. Figure 13 shows the potential global trade routes for hydrogen. It also includes potential new routes connecting other regions such as Latin America with the Asia-Pacific region.

Argentina's export potential for PtX products is large. Based on projects under development, IEA estimates that Latin America will be the leading region for low-emission hydrogen exports by 2030. Chile, Argentina, and Brazil lead export capacities in the region, which will reach more than 3 Mt H_2 equivalents (IEA, 2022). The hydrogen market for Argentina

Potential development of hydrogen trade routes globally — Figure 13



IRENA (2022a)

will be primarily overseas, mostly in Europe and possibly in East Asia, and to some extent in other Latin American countries.

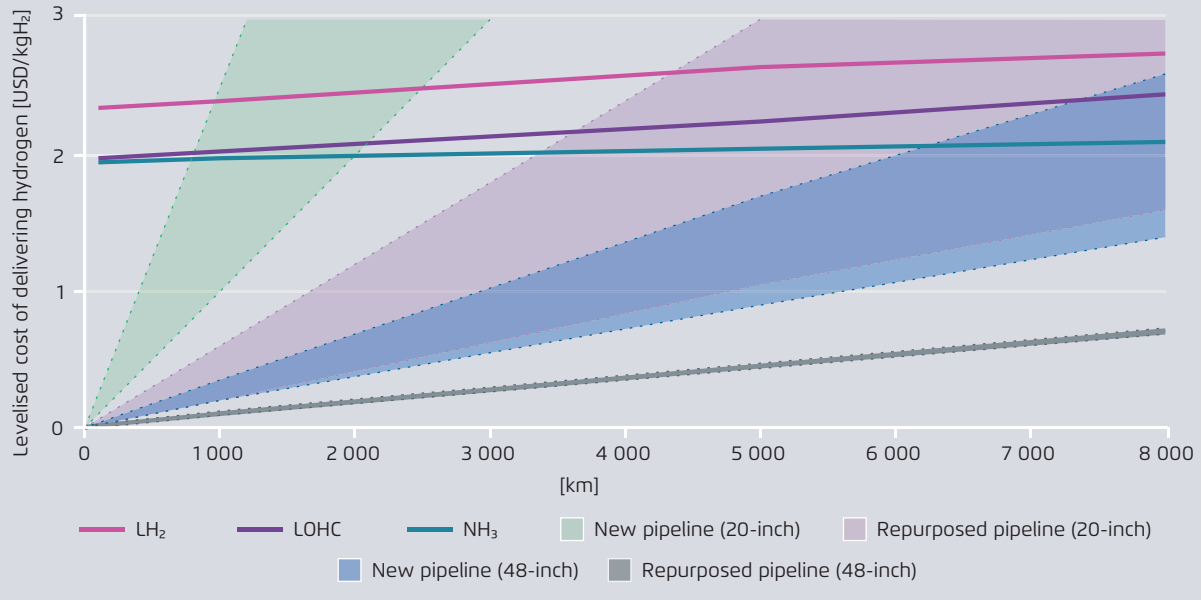
The dilemma of how to transport hydrogen …

When discussing the hydrogen trade, the competition has focused on the Levelised Cost of Hydrogen (LCOH); so far, the delivery system has played a minimum role on export potential. Thanks to its high level of renewable energy resources, Argentina can achieve very competitive LCOH by 2030, in the range of 2.0 to 2.7 USD per kg H_2 (60 to 81 USD per MWh, respectively).[10] These competitive renewable hydrogen costs will be achievable only if investment risk in the country is reduced, creating a more attractive environment for project developers in Argentina.

However, hydrogen delivery will be technically and economically constrained by transport distance. As shown in Figure 14, pipelines are the most cost-effective option over distances under 5 000 km, and retrofitted pipelines are more affordable than new pipelines. For distances longer than 8 000 km, shipping is the recommended transport option, but in this case hydrogen will compete with other green molecules such as ammonia, methanol, and synthetic fuels for shipping capacity. At distances between 5 000 and 10 000 km, options can vary depending on

10 These values are based on Agora Energiewende's calculations. Agora has developed a study analysing the aspects to be considered when calculating the LCOH with the aim of understanding the system boundaries and costs drivers from different studies around the world. A common approach to the LCOH calculation will facilitate comparison and high-level policy discussions.

Transport cost by pathway as a function of distance — Figure 14



IEA (2022)

the product being transported and the delivery location.

Argentina is expected to have a larger overseas market, where shipping will play a very important role in transporting green molecules. Green ammonia will be the low-hanging fruit for the country in the short term, as it can also provide a low-carbon option for fuelling the shipping sector. Fertilisers from green ammonia can also play an important role in this market, including in exports to big agricultural producers such as Brazil. Additionally, the bioenergy sector in Argentina favours the synthesis of other PtX products such as methanol and synthetic jet fuel by using the country's available sustainable carbon sources.

8 The hydrogen industry needs to be competitive and establish standards that are in line with global trade and industry requirements

Developing hydrogen standards in Argentina

Standards for hydrogen production are key for the development of a hydrogen economy. Standards are needed with regard to sources, production methods, and environmental characteristics. In addition, hydrogen certification can serve as a mechanism to promote fair competition, ensure high product quality, and keep the local industry competitive. Standards and certification need to be developed not only for hydrogen but also for other PtX products such as green ammonia, e-methanol, synthetic fuels, etc. Argentina should consider the development of a certification scheme in its efforts to upscale hydrogen production. This process should be designed to be participative and include consultations with different stakeholders in the hydrogen supply chain from the public and private sectors. Furthermore, the certification schemes should be flexible enough to allow periodic reviews and adaptations to the evolving market's conditions of the moment. This is especially important for an industry under development such as that of hydrogen and PtX.

Standards and certification need to reflect local conditions when setting targets for hydrogen production. However, there are some international guidelines that could help to kick off the process and develop first drafts for discussion with local stakeholders. For instance, the Interamerican Development Bank (IDB) developed a study on hydrogen certification for Latin America with a view to existing structures in the region.

Some countries and regions are already moving forward in the hydrogen certification process. For instance, Brazil has recently launched its book and claim certification process for renewable hydrogen, in an effort to leverage current momentum. Likewise, the European Union has recently published a regulatory framework for renewable hydrogen production and imports, with requirements aimed at preventing renewable hydrogen production from increasing overall grid/system emissions by appropriating existing renewables and diverting them from current users, thereby increasing dispatchable fossil production. Both are potential PtX export regions for Argentina, which is why the country should study and evaluate these initiatives as part of its certification process. Assessing the conditions set by potential importers of hydrogen and PtX can help to align the manufacturing of such products within the trade regions, facilitating commercialisation and industrial competitivity. Adopting the best international practices, which can be adapted to the local context, will enhance the country's attractiveness in the global hydrogen trade.

Against this backdrop, it would be interesting to consult with international stakeholders when developing the country's certification process. International perspectives can be very valuable especially given Argentina's growing interest in becoming an exporter of hydrogen and PtX products.

Argentina in the international standards discussion

As a potential exporter of PtX products, Argentina needs to actively participate in global discussions on standards and certification, especially for green products. Argentina should not wait for other regions and countries to set the conditions for the hydrogen trade. Common agreements between exporters and importers need to take place to guarantee a fair and

competitive market, so as to ensure achievable conditions for PtX producers.

Argentina should assess existing standards and certification initiatives to highlight any conditions that might not be domestically feasible and to identify conditions that favour the country's participation in the hydrogen market.

Regional collaboration can be key to participating in dialogues and platforms as a single block. This is because many countries in the region hope to join the international hydrogen market. Latin American countries can establish conditions that favour the competition of the region against other potential exporters, including the availability of carbon sources from the bioenergy industry, strong technical expertise and local technology development, among others.

The active participation of Argentina and other hydrogen-producing countries from the Global South in the international discussion on hydrogen standards and certification is key to avoid repeating past energy trends (mostly in the fossil-fuel industry) with regard to extractivism and neo-colonialism. This would enable a win-win situation for all countries involved in the hydrogen market.

9 Fossil-based hydrogen with carbon capture and storage (CCS) can serve as a bridge technology but will be outcompeted by renewable hydrogen

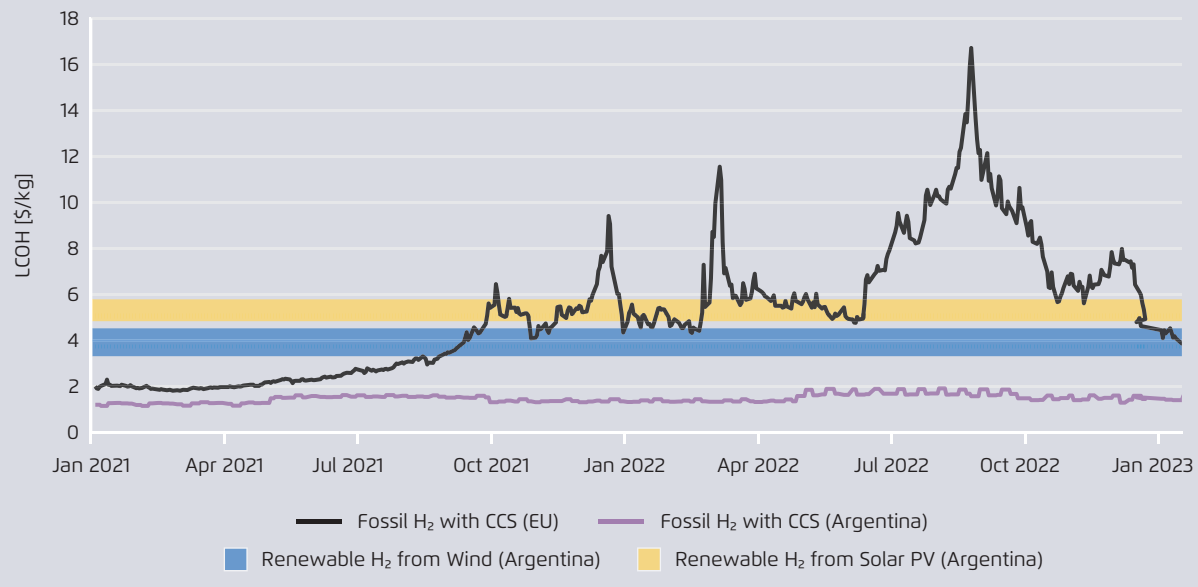
The cost of using natural gas

Natural gas prices, especially in Europe, have been severely affected by Russia's war against Ukraine. But Argentina has vast natural gas reserves and therefore has not experienced strong natural gas price variations in the past years. Between 2019 and 2022 Argentina's natural gas price has had an average annual growth rate of 2.9 percent. By contrast, the European natural gas price experienced an average annual growth rate of 167 percent over the same period.

Figure 15 shows that the volatility of natural gas prices in the European market makes renewable hydrogen much more competitive than fossil-based hydrogen with CCS. The situation is different for Argentina, where current fossil-based hydrogen with CCS is more competitive than the average renewable hydrogen estimates. Therefore, the country should prioritise policy instruments to close the gap between renewable and fossil-based hydrogen with CCS, as the latter does not need incentives for its development.

Promoting the development of fossil-based hydrogen with CCS would compete with the use of natural gas in the power and heating sectors, which may put more pressure on the country's energy security. Therefore, the domestic use of fossil-based hydrogen needs to be carefully evaluated. Specifically, policy-makers need to consider the benefits that a

Natural gas prices – renewable hydrogen vs. fossil-based hydrogen with CCS — Figure 15



Agora Energiewende and Industry (2023) based on the following data sources: Full-load hours of renewables: CAMMESA; Natural gas prices: Secretaría de Energía (ARG), TTF (EU); Fossil H_2 with CCS is based on steam methane reforming with 95% of capture rate

greater input of renewable energy into Argentina's energy matrix can bring in terms of energy security, economic diversification, and sustainable development. Furthermore, the international LNG market is very attractive for Argentina; a more active participation in it will affect local natural gas prices, creating more uncertainty regarding the use of natural gas in hydrogen production.

Fossil-based hydrogen with CCS as an option to accelerate the transition in Argentina

Argentina needs to carefully assess its hydrogen development, balancing natural gas (as a bridge technology) and renewable energy. Most of the existing international supporting mechanisms for hydrogen development are focused on renewable hydrogen. Developing fossil-based hydrogen could be a missed opportunity to access important financing support in Argentina. Furthermore, providing incentives for fossil fuel-based hydrogen can affect the country's competitiveness in the international hydrogen trade. It will also delay Argentina's decarbonisation process and limit the socio-economic benefits that renewable hydrogen can potentially provide. Regulations for CCS in Argentina are not yet in place and this discussion will face challenges related to land use/ownership for carbon storage, registration, monitoring, etc. In addition, there is currently no publicly available information covering all aspects to assess Argentina's geological capacity for carbon storage. Some studies are underway and could help to clarify the technical potential for using CCS in the country.

Argentina can be flexible in its domestic use of hydrogen by deploying natural gas resources as a bridge technology to boost local industry. New fossil-based hydrogen infrastructure with CCS should be designed that is ready for a transition to renewable hydrogen as soon as possible. Investment in new fossil fuel-based infrastructure for hydrogen production could lead to stranded assets, because the international market is clearly focused on renewable hydrogen and PtX products. In addition, investment in fossil-based infrastructure should avoid contributing to carbon lock-in. Certain hydrogen pathways, particularly those based on fossil fuels, may increase the risk of carbon lock-in by delaying the transition to renewable hydrogen (Rosenow, et al., 2021; Oh, et al., 2022). This can increase fugitive methane emissions or reliance on long-lived carbon capture assets. By contrast, renewable hydrogen can replace fossil-based hydrogen in the short to medium term.

Ensuring sustainability in the production of fossil-based hydrogen with CCS

Fossil-based hydrogen with CCS may be a technology for Argentinean policy-makers to consider given the country's natural gas resources. However, they need to evaluate the effectiveness of carbon capture and the risks that methane, carbon, and hydrogen leakage pose to the climate. Fossil-based hydrogen with CCS may have a greater climate impact than fossil-based hydrogen itself, as explained in Infobox 3.

Fossil-based hydrogen is produced using natural gas as a feedstock via steam methane reforming (SMR), which is where CCS can be applied. CCS involves capturing, compressing, transporting, and storing the CO_2 produced during SMR. However, it is important to note that the SMR process has two types of emissions.[11] First, there are the emissions from the combustion of natural gas to produce the thermal energy required for the reaction. The CO_2 concentration in this flue gas is low and its separation is therefore energy-intensive and expensive.

11 Fugitive methane emissions should also be considered when using fossil-based hydrogen with CCS. The use of natural gas, especially from unconventional sources, can result in methane leaks with a significant climate impact. Similarly, the SMR process needs to ensure good practices to mitigate fugitive methane and hydrogen emissions.

Infobox 3: Hydrogen leakage and its potential climate implications

The hydrogen molecule is much smaller than other gases such as CO_2 and methane and is therefore more difficult to store or contain. In a hydrogen-based economy, hydrogen leakage is expected at various points of the production process. In some cases, hydrogen is purged into the atmosphere. The molecule has indirect warming effects that will become more relevant when hydrogen production is scaled up. Currently, there is uncertainty about the amount of hydrogen leakage that will occur. However, more attention should be given to hydrogen leakage given its relevance in future decarbonisation scenarios.

Hydrogen molecules in the atmosphere can have indirect climate effects by extending the lifetime of other greenhouse gases. Given the impact of hydrogen leakage when combined with methane leakage, the production pathway plays an important role in assessing hydrogen's climate impact versus that of CO_2 emissions from fossil fuels. In the first 10 years, fossil-based hydrogen with CCS could have a warming impact that is 40 percent higher than fossil fuels in the worst case of hydrogen leakage. Renewable hydrogen in the same scenario could mitigate only 65 percent of the impact of fossil fuels. In the best case of hydrogen leakage in the first 10 years, fossil-based hydrogen with CCS can mitigate 65 percent of the warming impact of fossil fuels. Under the same conditions, renewable hydrogen can mitigate more than 95 percent of the warming impact of fossil fuels. The climate impact of hydrogen tends to decrease over time, but estimates show that in more than 100 years, fossil-based hydrogen with CCS will only be able to reduce up to 85 percent of the warming effect of fossil fuels in a best case.

Source: Ocko, et al., 2022

The second are process emissions from the conversion of natural gas and steam (water) into hydrogen and CO_2. These emissions have a higher concentration of CO_2.

Typically, only CO_2 process emissions are suitable for CCS, due to their higher CO_2 concentration. Combustion emissions, which account for about one-third of total SMR emissions, will still be released into the atmosphere (Ausfelder et al., 2022). To reduce the carbon footprint of fossil-based hydrogen with CCS, it is necessary to replace the natural gas used as fuel with a CO_2-neutral fuel (e.g., biogas).

The development of CCS for fossil-based hydrogen requires adequate storage space for CO_2, together with the development of infrastructure for conveying CO_2 emissions from production to storage sites.

Renewable hydrogen is expected to have greater future demand

Most countries with high hydrogen demand have focused their efforts on the production and import of renewable hydrogen, in line with their ambitious decarbonisation strategies. As a result, there have been increasing efforts in the international community to promote and finance renewable hydrogen and PtX products.

For instance, the ongoing discussions regarding the third revision of the European Renewable Energy Directive (RED III) aim at setting a target for renewable hydrogen and hydrogen-based fuels in the transport sector to at least 1 percent by 2030. Likewise, for the industrial sector, RED III has set a target of 42 percent by 2030 for renewable hydrogen (and hydrogen-based fuels)

in final energy and non-energy applications (EC, 2021).

The US's Inflation Reduction Act (IRA) of 2022 provides up to ten years of tax incentives for the deployment of clean energy technology and infrastructure (including renewables, hydrogen, and electricity grid infrastructure). For clean hydrogen, the IRA includes tax credits for production or investment, loans to expand private investment, a new $300 million alternative-fuel and low-emissions aviation technology programme, $5.8 billion in direct investment for industrial decarbonisation, and demand creation for low-carbon products (e.g., steel and cement) through government purchasing and other measures for the promotion of clean hydrogen and its derivatives.

To close the price gap between fossil-based and renewable hydrogen, some international mechanisms aim to create a green market with a compensation mechanism to make PtX products more competitive. One example is the H2Global foundation. It offers purchase auctions for renewable hydrogen-based products at a premium that will cover the effective cost of green production. Purchase contracts will have a duration of ten years to guarantee that investors who win bids can recover their costs. The green products will then be sold in Europe in annual auctions. In the event that the cost of reselling the product is lower than the purchase cost, the German government will cover the difference. The first auction to purchase ammonia was launched in November 2022. In the meantime, more European governments have joined the initiative.

10 Argentina can identify potential locations for initial hydrogen hubs by mapping complementary resources and local economies in the provinces

Diversity of resources along the territory

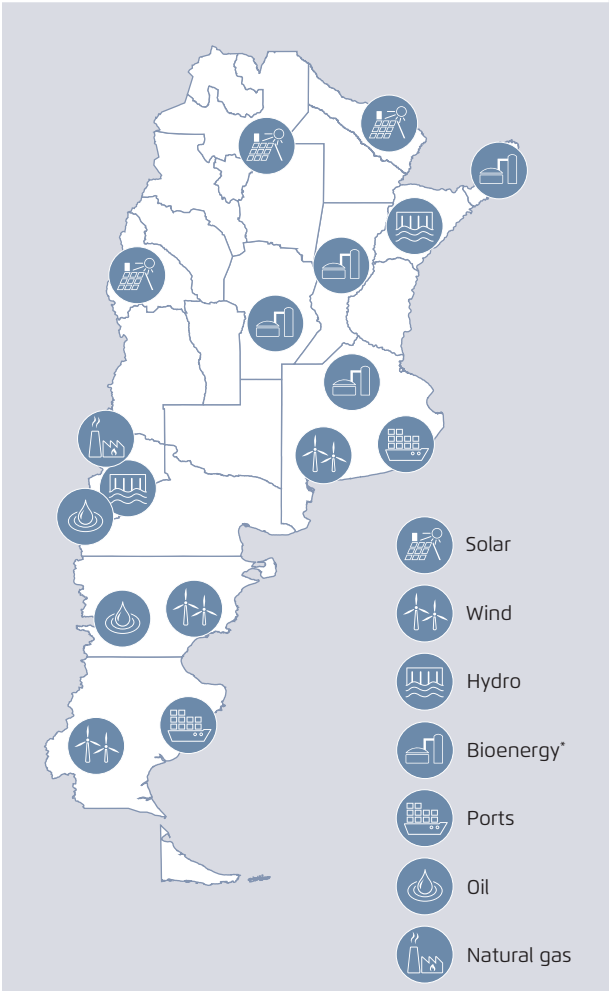
Argentina is made up of 23 provinces and the Federal District of Buenos Aires, covering a vast territory almost one-third the size of Europe. Mapping the availability of energy resources in the Argentinian territory is key for identifying complementarities and potential areas for the creation of new industrial and commercial hubs, as well as for expanding existing ones.

The country is counting on a diversity of economic activities, given the distribution of natural resources among the provinces, as Figure 16 shows. The complementarity of resources will be key to the development of a hydrogen economy in the country, as energy and water resources will be crucial for the production of hydrogen. But sustainable carbon sources, possibly from the bioenergy sector, will also be needed for the production of PtX products. Similarly, the existing industrial and port infrastructure will be crucial for manufacturing value-added products to be sold in international markets. A clear roadmap can be discussed at the provincial level targeting different PtX products depending on resource availability. For instance, synthetic fuels can be produced in provinces closer to the bioenergy industry, while green ammonia can be produced in areas where no sustainable carbon sources are available. Such an exercise will require close cooperation between provinces and national governments to ensure that the strategies are consistent with the objectives of a national hydrogen strategy.

Project development procedures will need to be consistent across the provinces

Regulations for the management of natural and energy resources are mandated at the provincial level, making them complex and uneven across jurisdictions. This is highly relevant when it comes to environmental regulations, especially when developing new hydrogen projects. Provinces should work together to agree on a common

Map with energy/natural resources distribution among the provinces — Figure 16



Agora Energiewende, Agora Industry, Fundación Torcuato di Tella (2023). * Bioenergy includes biomass, biodiesel, biogas and ethanol potentials

regulatory framework for the promotion of renewable energy and hydrogen, focusing on the protection of flora and fauna, water consumption and discharges, waste generation, the well-being of indigenous populations, and other relevant factors. The existence of a common regulatory framework for project development will ensure a level playing field in the market, the appropriate use of natural and energy resources, and the protection of the environment and the local population. Furthermore, it will help to attract developers throughout Argentina's territory.

Argentina has a long history of legislative and regulatory negotiations concerned with articulating the respective powers of the federal and provincial governments. Currently, the provinces manage their own natural and energy resources and pass environmental regulations to protect their own natural resources. In other words, environmental regulation in Argentina is complicated, with federal, provincial, and municipal laws and regulations overlapping. In some cases, it is unclear as to whether a particular regulation applies. Hydrogen projects should follow the most rigorous guidelines for sustainability and environmental protection, especially when considering hydrogen and PtX products for export. Otherwise, the new projects will impact the environment and become an extractive industry without providing any socio-economic and climate benefits. Similarly, vague environmental regulations can cause delays for project developers, increasing project costs and making the territory less attractive for investment.

The hydrogen industry can boost local development

Social and economic development in Argentina has been uneven across the provinces, but the hydrogen and renewable energy industries could help to stimulate local development if the diverse resources needed for the industry, including energy and sustainable carbon, are properly utilised. Provinces should assess the integration of renewable and hydrogen projects in the electrification of local communities or for local economic activities such as agriculture. Additionally, provinces with important fossil fuel resources should link employment in new green markets to allow a just transition away from gas industry jobs, which may become redundant in the future. The current federal fiscal system should be reviewed with the aim of ensuring a uniform distribution of revenues among the provinces and equal fiscal conditions for project developers.

Argentina is the most decentralised federal country in Latin America, with approximately 50 percent of total public spending occurring at the sub-national level. However, it has a high degree of vertical fiscal imbalance. Analysing national and provincial budgets and tax allocations, on average, about 35 percent of provincial expenditure is financed by taxes collected directly by the provincial authorities. The remaining 65 percent is financed from taxes collected by national (federal) authorities. The figures are also uneven across provinces, with some receiving more than 80 percent of their total revenue from the federal government. In this sense, the diversity of resources available throughout the country for the development of PtX value chains represents an opportunity to enhance local revenue generation and also improve the balance between provincial accounts. In addition, the hydrogen industry in Argentina can play a pivotal role in contributing to more equal economic growth by expanding the industrial sector for the manufacturing of added-value products, opening international trade, and increasing tax revenue bases, which will boost fiscal revenues throughout the country.

11 Argentina should create a clear policy framework for hydrogen production, develop adequate conditions to attract investors, and regard hydrogen as an energy and climate issue when considering access to financing instruments

The importance of creating a hydrogen policy and a regulatory framework

To create an attractive market for private and international investors, countries need to create a clear and reliable environment for renewable hydrogen development. For instance, clear policy with specific hydrogen and PtX targets in the medium and long term provides investors with a positive signal regarding the country's pathway and interest in the promotion of such projects.

Countries such as Chile, Colombia, and Uruguay have developed clear roadmaps with targets that prioritise hydrogen development. Some of these roadmaps include clear next steps while assiging responsibilities among local stakeholders, such as the creation of a regulatory framework, the development of standards for the sector, and even the creation of new financing mechanisms targeting hydrogen pilot projects. All such efforts help to create a stable and attractive financing environment that complements the hydrogen potential of the host country.

Argentina has attracted much international interest in the development of renewable hydrogen, especially given its vast renewable energy resources. But despite this interest, the country has not yet established a clear policy or regulatory framework to promote hydrogen. The government has expressed interest in promoting hydrogen, and is currently developing an update of the hydrogen law from 2006, which will include a national hydrogen promotion regime. Furthermore, the country is working on developing a roadmap and a national strategy for the development of a hydrogen value chain, in consultation with various stakeholders.

In addition, the Secretariat of Energy is developing an energy transition plan that includes the development of a hydrogen value chain as well as the use of the country's large unconventional natural gas reserves and low-emission technologies such as renewables and nuclear. Within this framework, it will be important to link the national hydrogen strategy to climate commitments, to decarbonisation plans for the industrial sector, and to energy planning and environmental policies applicable to the value chain.

Hydrogen is a cross-sectoral initiative

Hydrogen and PtX products affect the entire value chain in energy, and therefore need to be discussed with all relevant stakeholders to develop realistic and achievable strategies for their development. Additionally, the infrastructure required to scale up the deployment of PtX products will be a significant long-term investment and will therefore require the support and agreement of all involved sectors.

Scaling up hydrogen will require good planning and coordination with a variety of sectors. The first is the power sector. Coordination with this sector is needed to ensure that renewable energy projects can be integrated into the system, can contribute to the decarbonisation of the sector, and can take advantage of the flexibility that hydrogen production and storage can bring to power generation. The second is the hydrocarbons sector. As a potential hydrogen producer and infrastructure developer, the hydrocarbons sector can assess the role of fossil-based hydrogen to avoid stranded assets and ensure high sustainability standards in the CCS process. The third is the industrial sector. As a major consumer of

hydrogen, it must be scaled up to produce value added products for local consumption and export while promoting the decarbonisation and sustainability of the sector. Finally, there are other sectors such as transport and food that would need to assess the role of hydrogen in their decarbonisation efforts as well as the benefits and challenges of using PtX products.

Attracting investment for hydrogen development in Argentina

Argentina's vast energy resources have served as an important hook to attract hydrogen investment to the country, despite the uncertainties surrounding investment and project implementation. Argentina has experience in developing attractive risk mitigation mechanisms to encourage private-sector investment in renewable energy. These mechanisms include the RenovAr programme (see Infobox 4). Expanding and adjusting them could be a good strategy for attracting investment in the country's hydrogen infrastructure.

Similarly, Argentina's financial sector needs to create technical and financial capacity to assess the funding of hydrogen projects. This may require new technical skills to assess the bankability of PtX production. At the same time, given the emission mitigation potential of PtX products at the local and international levels, Argentina should consider hydrogen development as a climate mitigation strategy. This would give

Infobox 4: Mitigating risk in the promotion of renewable energy in Argentina

Despite the economic uncertainty of investment in Argentina, the country has created attractive renewable energy development programmes in the past. In 2015, for example, Argentina launched the Programme for the supply of electricity from renewable energy sources (RenovAr), which provides a framework for risk coverage through a renewable energy auction system. The offtaker in this auction process is CAMMESA, Argentina's Independent System Operator.

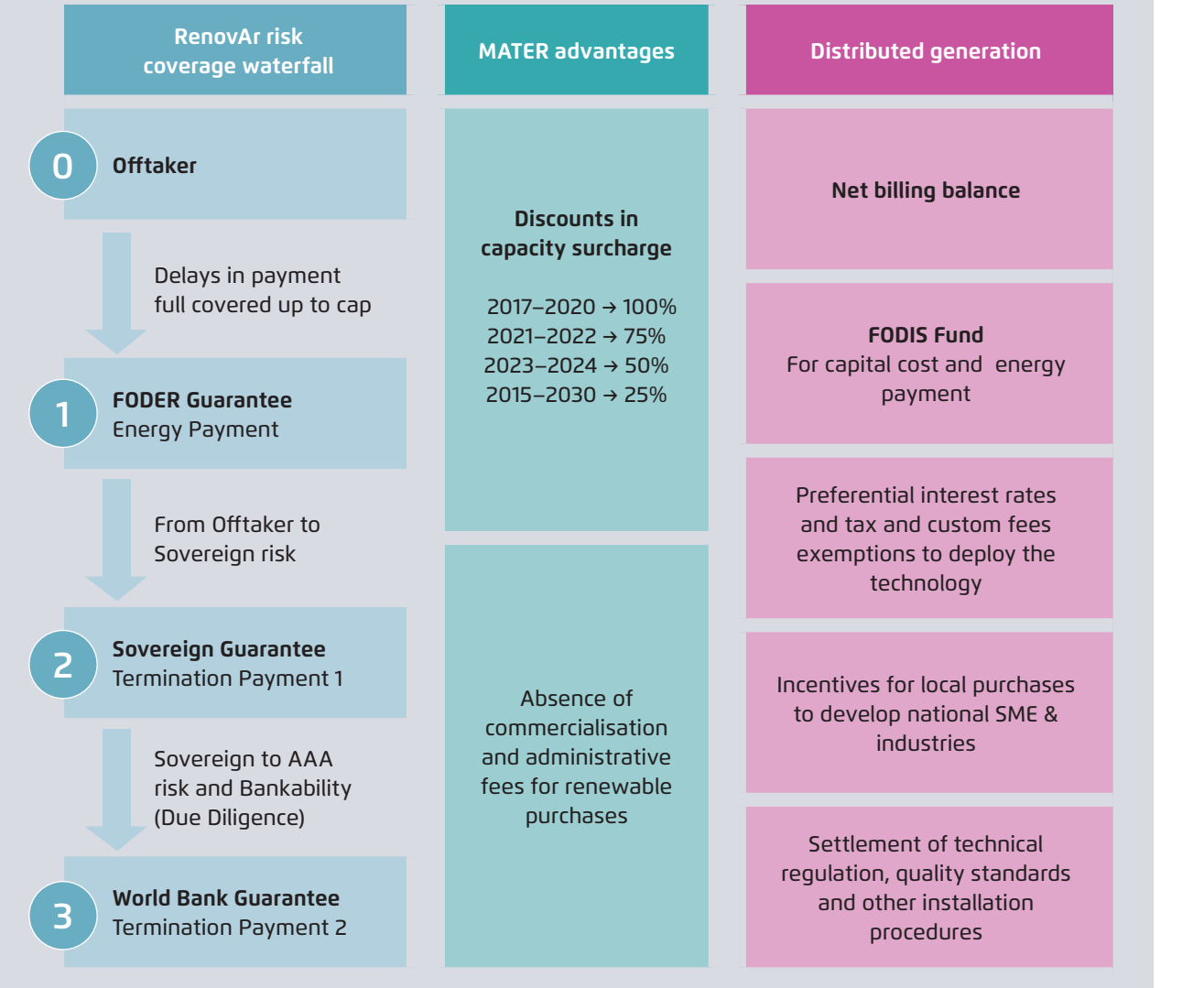
Under this framework, the Argentinian government is to establish a "coverage waterfall" consisting of (1) **a renewable energy fund (FODER) guaranteeing** coverage of eventual delays in payments to generation companies; (2) a **sovereign guarantee** that could be applied to termination payments; and (3) a **World Bank Guarantee (GCF)** to isolate RenovAr projects from country risk, assimilate the sovereign counterpart to a AAA risk profile, and improve the bankability of projects. The RenovAr programme was an international model in how to promote renewable energy, and it delivered good results in the first years of its implementation.

In 2019, the financial crisis posed new challenges for the financial closure of prospective RenovAr projects and future auction rounds. With a higher country risk and different returns than the ones expected by investors, the projects suffered delays beyond the timeframe required by the PPAs and regulation. As a result, private PPAs (MATER) have become the main driver mechanism for new renewable energy projects, driven by attractive contract prices. However, the current transmission bottlenecks are the main challenge for the further deployment of renewable energy in the country.

Figure 17 shows a comparison between the risk coverage waterfall of RenovAr, the current private renewable PPAs, and the framework developed to catalyse distributed generation projects.

hydrogen projects access to financing mechanisms aimed at mitigating climate change. In the medium term, project developers should align their hydrogen strategies to access global financing options such as the international carbon market mechanisms being developed under Article 6 of the Paris Agreement, among other climate finance options.

Promotion mechanisms for renewable energy development Figure 17



Agora Energiewende, Agora Industry and Fundación Torcuato di Tella (2023) based on Undersecretariat of Energy Planning (2019)

12 Promoting R&D and incentivising international cooperation can accelerate hydrogen production

Argentina's professionals could promote technology development

Energy and industry professionals in Argentina have the ability to establish a competitive hydrogen economy in the country. However, the large-scale development of the hydrogen industry may require an even greater number of professionals to make these ambitions a reality. The country will thus need to assess capacity needs in line with the development of strategies, plans, and roadmaps for the expansion of hydrogen and industrial production. To those ends, the country can establish partnerships with academic institutions, technical centres, and other organisations to train professionals capable of moving Argentina's hydrogen economy forward.

Several initiatives have been launched in Argentina to promote the development of local knowledge and technology in areas related to hydrogen and PtX. These serve as first steps in the creation of larger plans for capacity building and local technology development adapted to the country's conditions. Local technology development such as electrolysers or other low-carbon technologies can reduce dependence on foreign manufactures and promote domestic innovation. The current efforts to develop lithium-ion batteries in Argentina are a clear example of the country's technical and innovative capacities. Table 1 provides an overview of some of these initiatives.

Regional cooperation for a more dynamic hydrogen market in Latin America

Many Latin American countries have expressed interest in the development of hydrogen in view of their renewable energy resources, the advanced decarbonisation process that accompanies hydrogen production, and the desire to reap the economic benefits of this booming industry.

Some countries have already developed clear hydrogen roadmaps and other have initiated the development of several pilot projects aiming to scale up hydrogen and PtX production in the coming years. This growing interest in hydrogen production is a sign of the competitiveness of the Latin American hydrogen trade. Therefore, it would be beneficial for the countries in the region to have a coordinated approach to hydrogen development so they can all develop their hydrogen potential.

So far, we have seen important examples of cooperation in the region, such as the Green Hydrogen Hub in Colombia, where the Colombian and Chilean hydrogen industries have joined forces in the development of renewable hydrogen projects, combining technical and local expertise to take advantage of financial incentives in the host country. Recently, both governments signed a cooperation agreement to promote various areas of the energy transition and enhance energy integration through the development of renewable hydrogen. Further cooperation projects in the areas of technology development, capacity building, binational production projects, etc., will be key in scaling up the region's renewable hydrogen production.

Regional cooperation in Latin America can also lead to a common goal and vision for hydrogen trade, one that is adapted to the unique conditions of the region, especially in the protection and integration of local communities. Such a regional position can also help in international discussions on trade conditions, standards, and certification. Having a regional bloc with a common position and perspective would also

be relevant when discussing export conditions, sustainability criteria, industrial relocation to renewable-rich countries, and other key aspects of the hydrogen market.

International cooperation focusing on trade of PtX products

Potential importing countries are moving to secure future hydrogen supplies in line with their ambitious decarbonisation strategies and as a measure to mitigate the current fossil fuel crisis. Despite Argentina's strong interest and potential, the country is not yet part of any of these bilateral agreements on renewable hydrogen or PtX products.

Bilateral hydrogen supply agreements send positive signals for the development of a potential PtX market, attracting investment and helping to advance national discussions on the development of appropriate policy and regulatory frameworks for the production of renewable hydrogen. Most importantly, bilateral hydrogen agreements have the potential to open new trade routes for PtX products.

In addition, bilateral agreements with potential importing countries would position Argentina as an important player in geopolitical discussions on hydrogen. A first step for Argentina may be to review existing energy trade and bilateral agreements in order to identify new areas of expansion that include PtX products.

Hydrogen research and development initiatives in Argentina — Table 1

Initiative/Institution	Type	Year	Concept
Argentine Wind Energy Association (AAEE) and the Argentine Hydrogen Association	Private	1996	Potential for production of hydrogen in Patagonia, focus on liquid hydrogen.
Hychico	Private	2006	First pilot project for hydrogen electrolysis powered with wind energy in January 2009, with a capacity of 94.5 tonnes per year.
		2010	Hydrogen transport pipeline of 14.3 miles length. Pilot underground storage facilities using depleted oil and gas fields.
Institute for Hydrogen Technology and Sustainable Energies (ITHES)	Public		Small-scale hydrogen pilot plant from biofuels. (bioethanol, glycerol and biogas)
Institute for Energy and Sustainable Development (IEDS)	Public		Hydrogen production from nuclear energy; hydrogen as a by-product of bioremediation; enzymatic production.
			Use of hydrogen blended with natural gas for public and freight transport.
Consortium for the Development of a Hydrogen Economy in Argentina (H_2AR)	Public-private		Promote exchange and strategies for the technology and market development of hydrogen in Argentina.
Plataforma H_2 Argentina	Public-Private	2020	Focuses on developing energy policy and regulation for the development of renewable hydrogen. In September 2021, this platform promoted a bill for updating Argentina's hydrogen law.

Fundación Torcuato di Tella (2023)

However, the country needs to carefully assess the terms of these bilateral agreements in order to ensure that conditions are appropriate, feasible, and realistic for everyone involved. Hydrogen trade will require important components covered by a well-established EESG framework that avoids the promotion of extractive industries and provides significant socio-economic benefits for Argentina.

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