THE HYDROGEN CHALLENGE:

The potential of hydrogen in Italy

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Executive Summary

The world faces a major challenge: decarbonizing the global economy. Over the past 150 years, global consumption of coal, oil and gas boomed as it fueled the world's growing business activity. This success carried a price tag, however, in the form of large amounts of greenhouse gas emissions that increased average global temperatures by 1 degree Celsius in the last century. In the coming decades, the world faces a complex challenge – continue to grow economically while simultaneously reducing CO2 emissions. To avoid a climate catastrophe, the world's economy can only emit another ~700 GtCO2 until 2100, which effectively means we need to achieve "net zero" emissions around 2050. Italy, as a signatory to the Paris Climate Conference, has committed itself to a 40% decrease of emissions by 2030 and the European Union aims for Climate Neutrality by 2050.

Italy needs to accelerate its decarbonization efforts. Greenhouse gas emissions in the last 3 decades decreased at a rate of 0.7% per year in Italy, primarily due to the combined effect of increased energy efficiency, a greater share of renewable energy sources in the power generation mix and the delocalization of industrial production. To achieve the "net zero" target by 2050, the pace of decarbonization needs to accelerate roughly tenfold. Current greenhouse gas emissions reached about 440 million tons of carbon dioxide equivalent (MtCO2e). Italy's *Piano Nazionale Integrato per l'Energia e il Clima* (PNIEC) will significantly accelerate the decarbonization process by abating approximately 130 MtCO2e by 2030. However, to achieve the 2050 target, further acceleration is necessary and additional initiatives will need to be deployed.

Why hydrogen in Italy:

- **Hydrogen can be used to decarbonize otherwise hard-to-abate sectors.** Direct electrification can reduce emissions in e.g. light transport and new buildings, but even in the most ambitious scenarios, it only accounts for 60% of final energy demand in the long term. Hydrogen can be a solution: as fuel for heavy-duty trucks, trains, ships, and airplanes; for heating of existing buildings; high-temperature heat in industries; and as feedstock for fertilizer and petrochemicals, to name a few.

- **Hydrogen can help to integrate renewables.** The PNIEC target to add 32 GW of solar and 9 GW of wind capacity until 2030, and more beyond 2030 could be foreseen, requires efficient and effective integration of these intermittent generation sources into the grid. Hydrogen can be used to convert surplus electricity for use in other sectors, for cost-effective mid- and long-term storage of energy, and for cost-effective transport leveraging existing gas infrastructure. This reduces the costs of integrating more renewables in Italy's energy system and makes them more effective in reducing emissions.

- **Italy can become a hydrogen hub.** Italy has significant potential to use its solar and wind resources for the low-cost production of hydrogen. It also has gas infrastructure that connects it with North Africa and up to the North with Europe. By putting "the solar panels where the sun shines" more, green hydrogen can be produced at a significantly lower cost, and transported using the existing natural gas pipelines to demand centers in Italy and further North to Europe, turning Italy into a hub for green hydrogen for Europe. In parallel, similar plan to create a hydrogen hub from offshore wind is being developed in Northern Europe (e.g. the Netherlands).

Hydrogen supply in Italy: green hydrogen will become the cheapest source of hydrogen by 2030, in Italy that will happen earlier than in other European markets. Given Italy's access to low-cost green hydrogen, Italy will be one of the first countries in Europe where *green hydrogen*[1] will outcompete *grey hydrogen*[2] from natural gas from 2030 onward. Compared to Germany, for example, this break even could happen 5-10 years earlier, making Italy the ideal place to begin the deployment and scale-up of electrolysis for industrial and other uses.

Hydrogen demand in Italy: hydrogen could provide almost one quarter of all energy. Hydrogen could play a major role in the Italian energy system of the future. In a 95% decarbonization scenario (needed to stay below the 1.5-degree global warming threshold), we estimate hydrogen could supply as much as 23% of its total energy consumption by 2050 – about equal in share to electricity today (20% in 2018). The biggest potential is in transport, buildings and industrial applications where some players use *grey hydrogen* today (e.g., refining, high-heat processes). Long-haul trucking should become one of the first segments to make hydrogen economic, because hydrogen ensures a range and charging experience comparable to diesel today. In these segments, hydrogen can even achieve Total Cost of Ownership[3] parity with diesel by 2030. Blending hydrogen in the grid for building heating is another area of possible adoption that could take place in the short- to mid-term.

Reference case: a showcase in Sicily could demonstrate hydrogen production and use at scale. Looking to the roll out strategy of hydrogen in Italy, it could make sense to start the deployment in an area with good availability of renewable resources, limited interconnection with the rest of Italian power grid (e.g., an island with physical constrain to be connected via submarine cables), existence of multiple local industries (e.g., refineries), already existing capillary natural gas network, interconnection with areas with low cost of renewables (e.g., North Africa). As an example, to illustrate the application of hydrogen at scale, we have developed an illustrative reference case in Sicily, which combines the production of green hydrogen from wind in an electrolyzer, its transport in (existing) pipelines, its use in a local refinery as well as in a hydrogen-fueled train and as part of the local gas grid for household heating. The first phase of this project could be realized already by 2022, including the building of a 50 MW electrolyzer. Future expansion could increase the scale of the project up to installing 2 GW electrolyzer capacity, the supply of two refineries and the replacement of a significant share (20%) of natural gas in household heating. In the long term, Sicily may become an intermediate stop-over for hydrogen produced in North Africa, utilizing the transport infrastructure connecting North Africa and Italy.

Reflections on the Italian system: enablers for hydrogen value chain development. To begin the deployment of a hydrogen value chain, industry and policymakers should work together to build a favorable regulatory framework in Italy and internationally that covers the following areas: (i) stimulate end-user demand by setting renewable gas (including hydrogen) adoption targets; (ii) support the build-up of production capacity to drive down the cost of green hydrogen production; (iii) enable Italy as a hydrogen hub for Europe by leveraging good renewables in the South of Italy and the interconnection to North Africa; (iv) support infrastructure readiness for hydrogen; and (v) invest in Research and Development to achieve technology maturity along the entire value chain.

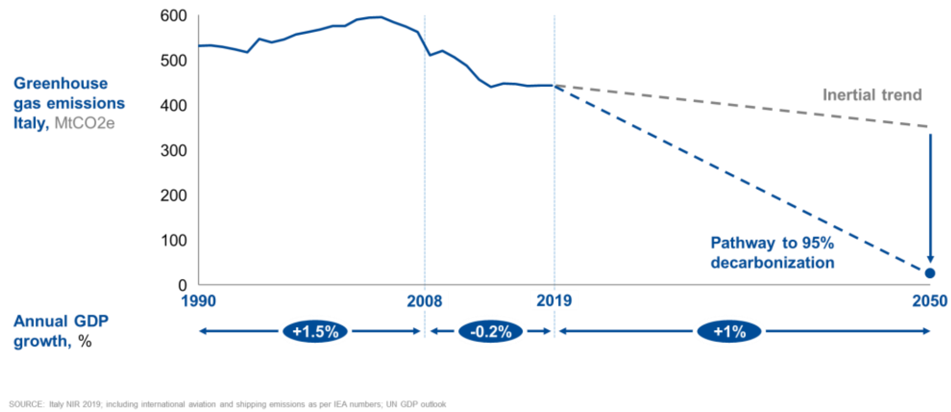
[1] Green Hydrogen is produced from water and green electricity via an electrolyzer. The process is carbon neutral.
[2] Grey Hydrogen is produced from natural gas or coal through gas reforming process. The process emits CO2.
[3] Total Cost of Ownership calculated including initial investment cost (CapEx) and operating cost (OpEx).

Why hydrogen in Italy

Decarbonization

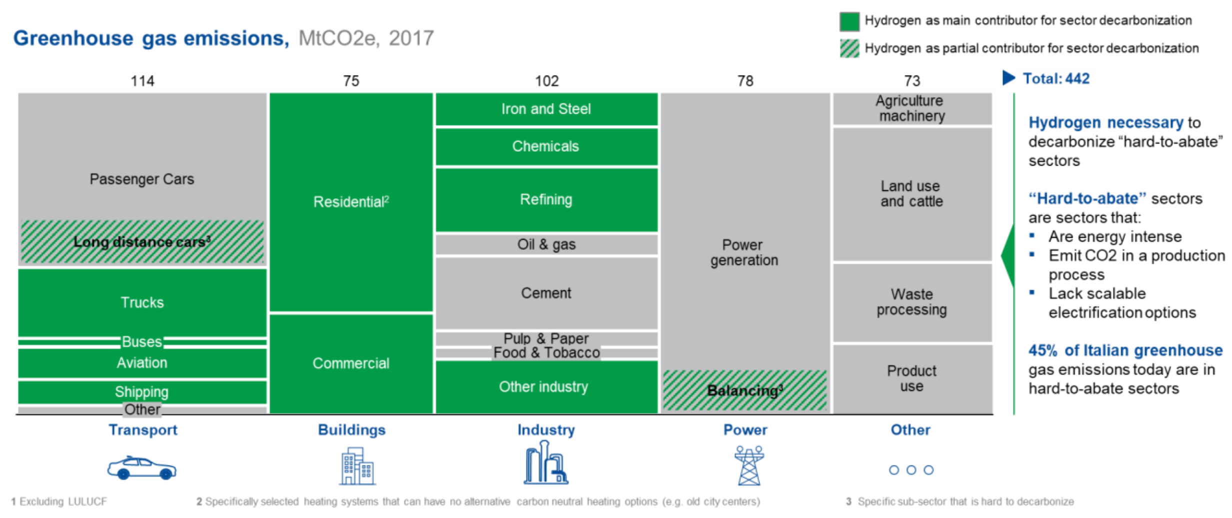
Historically, greenhouse gas emissions in Italy correlated strongly with GDP growth, reaching peak emissions in 2004 at 495 MtCO2e. Since then, emissions have been decreasing and today are 17% below 1990 CO2e emission levels. This resulted mainly from energy efficiency measures, increasing penetration of renewable sources in the energy mix, and a delocalization trend in industrial production. Looking forward, Italy's GDP is expected to grow 1% a year on average through 2050, according to the World Bank, while the country needs to reduce emissions by an additional 420 MtCO2e (-93% versus today) to achieve the 95% decarbonization target by 2050 [Exhibit 1].

EXHIBIT 1 – ANALYSIS OF CO2 EMISSIONS EVOLUTION OVER TIME IN ITALY.



While various stakeholders have acted in the last decade to reduce emissions, they need to accelerate these activities. Achieving 95% decarbonization requires fundamental abatement in all sectors, hence also the development of a credible and feasible pathway to decarbonize "hard-to-abate" sectors, which account for 45% of Italy's emissions [Exhibit 2]. Hydrogen has a unique potential to abate emissions in those sectors.

EXHIBIT 2 – MAP OF CURRENT GREENHOUSE GAS EMISSION IN ITALY BY SECTOR.



Seasonal balancing

In the mid- to long-term, continuing electrification and further penetration of wind and solar in the power generation mix will increase the need for seasonal balancing. For instance, whilst electrification of heating will increase demand primarily in winter, solar power generation peaks in summer. Hence to optimally use wind and solar power, and avoid power curtailment, seasonal storage is needed to use summer generation during autumn and winter.

Hydrogen could become the preferred solution for long-term seasonal storage. Power oversupply in summer can be converted into hydrogen and stored for the winter months. As such, hydrogen can complement other storage options like batteries and pumped hydro storage, which can help balance more short- to mid-term fluctuations on the grid.

Connect demand with supply

The best locations for renewable power in Italy are in the South of the Country or on Italy's islands (supply) while consumption occurs mainly in the North (demand). By converting renewable electricity into hydrogen, players can convey it through the already existing gas pipeline network from South to North with synergic investment with current infrastructures. In addition, hydrogen could support the penetration of renewables making them more available through the Country under wide range of conditions.

Hydrogen hub

Italy has very good natural resources (solar, wind) for the low-cost production of hydrogen. It also has gas infrastructure that connects it with North Africa and up to the North with Europe. By putting "the solar panels where the sun shines" more – i.e. in North Africa – green hydrogen can be produced at a 14% lower cost (transport cost included assuming blending in existing pipes), and transported using the existing natural gas pipelines to demand centers in Italy and further on to Europe, turning Italy into a hub for hydrogen for Europe.

Hydrogen supply in Italy: green, low-cost, and readymade infrastructure

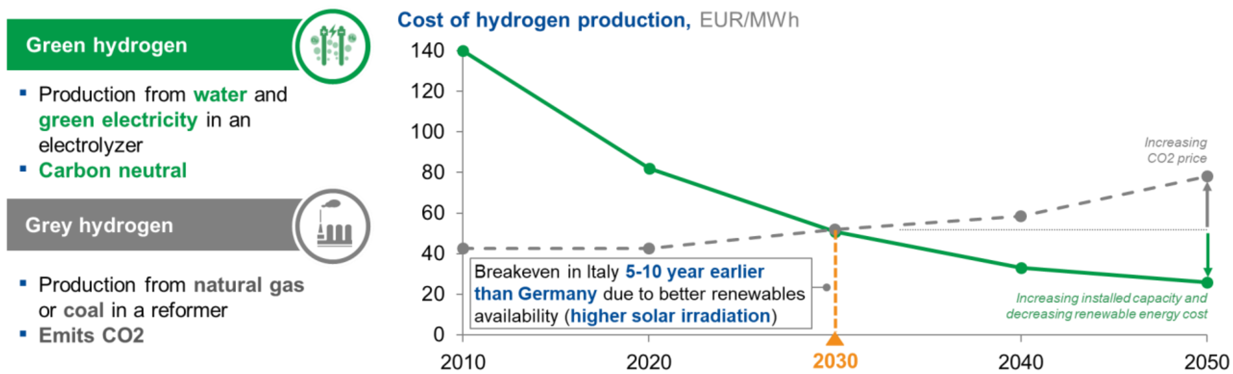
Italy has significant capacity to produce low-cost green hydrogen

Today, natural gas is the source of most hydrogen today, using a process called Steam Methane Reforming (SMR) that produces so-called "grey hydrogen" – production process requires uses of natural gas or coal, therefore emitting CO2 emissions. Alternatively, electricity can produce hydrogen via electrolysis. Using electricity from the grid or directly connected to renewables off-grid plants, electrolysis offers a flexible way to supply hydrogen. The latter solution also has the potential advantage of fully using green electricity and take advantage of falling renewable cost. The industry calls this "green hydrogen" since it only uses renewables sources – i.e., ones that do not generate CO2 emissions. In addition, there is a third methodology of hydrogen production – so called "blue hydrogen". "Blue hydrogen" is produced with Steam Methane Reforming from natural gas or coal, then CO2 emissions are captured (typically 90%) and stored (e.g., underground).

The cost of “green hydrogen” is falling sharply, driven by the declining costs of renewables and falling capital expenditures (CapEx) for electrolyzers. With a comparatively higher average number of hours of sunlight compared to other European Countries – 1,600 hours a year compared to 1,300 for Germany – Italy is a great place for renewables. Electrolyzer capex should experience a significant decrease as production volumes pick-up due to learning curve effects and investments in production process automation. Cost of electrolyzer is expected to decline at a 12% learning rate – that means a 12% cost reduction with the doubling of installed capacity. This is similarly to what happened for wind and less than solar’s 24% learning rate over the past 10 to 20 years.

Given Italy's good availability of renewables, green hydrogen will likely break even with grey hydrogen from natural gas 5 to 10 years before it does, for example, in Germany [Exhibit 3]. This means Italy is the ideal place to start the deployment and scale-up of electrolysis for industrial use.

EXHIBIT 3 – ANALYSIS OF “GREEN” AND “GREY HYDROGEN” PRODUCTION COST EVOLUTION IN ITALY.



1 Installed capacity required to achieve indicated cost reduction of green hydrogen, assuming 12% learning rate.

SOURCE: Snam analysis

Italy can leverage its gas infrastructure to connect supply and demand, including with North Africa

Italy has over 34,000 km of existing natural gas pipelines for transmission and over 250,000 km of existing natural gas pipelines for distribution. With upgrades to the current infrastructure, hydrogen can be blended in the current pipelines. And, as technology improves, share of blended hydrogen could increase over time up to potentially 100%.

Furthermore, Italy could use its existing pipelines to North Africa where hydrogen can be generated from low-cost solar power, and then transported to Italy. This would provide Italy with an almost unlimited potential supply of hydrogen at a cost ~14% below production costs in Italy, transport costs included assuming blending in existing pipes. The cost advantage comes mainly from the higher number of solar hours in North Africa. For example, in Morocco and Tunisia solar hours are in the range of 1,800 hours per year, 200 hours per year more than in the South of Italy.

Hydrogen demand in Italy: 23% of total energy in 2050

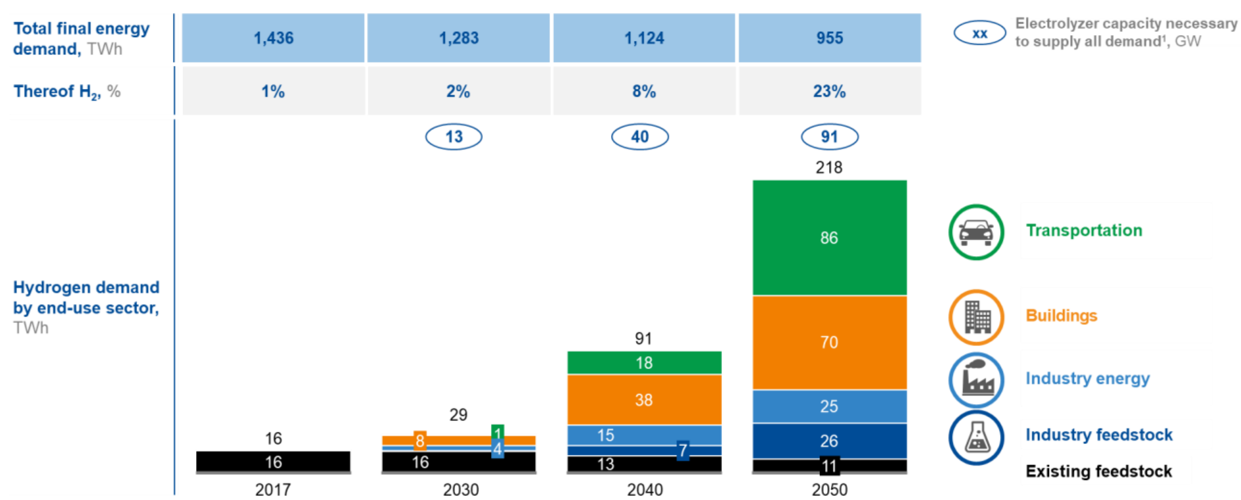
Italian hydrogen demand should grow rapidly in the coming decades, making up about 23% of the country's final energy demand by 2050

Today, hydrogen consumption in Italy is limited to feedstock uses in refining and ammonia. Typically, grey hydrogen production takes place on-site in large natural gas reformers and feeds directly into chemical processes. Currently, Italy only consumes about 16 TWh/year of hydrogen, which makes up roughly 1% of the country's final energy consumption.

In the coming decades, hydrogen consumption should expand to many new sectors, driven by two key factors. First, **green hydrogen is carbon neutral.** To reach 95% decarbonization by 2050, many sectors that lack credible and scalable decarbonization options (e.g., high temperature heating: ceramics, glass manufacturing, etc.) will need to rely on hydrogen solutions to decarbonize.

And second, **it can become cost-competitive.** As hydrogen production capacity scales up and hydrogen costs fall, many new hydrogen technologies can start to compete against oil and gas, for example, in trucking or heating. We therefore expect hydrogen demand to increase rapidly over the coming decades, doubling in size by 2030 compared to today, and reaching about 23% of total final energy consumption by 2050.

EXHIBIT 4 – POSSIBLE EVOLUTION OF HYDROGEN DEMAND IN ITALY.



1. Assuming an electrolyzer efficiency of 75% with a 35% load factor
2. Less industry demand as existing H2 demand in Italy is lower vs the rest of Europe (as gas prices are high in Italy, SMR is less competitive); More buildings uptake as green H2 costs decline faster in Italy than in the rest of Europe (due to cheap solar) and hence become competitive for heating (primarily in buildings) heating

SOURCE: IEA, Team analysis; EU Hydrogen roadmap

Achieving a 95% decarbonization target by 2050 will require hydrogen to scale up very rapidly. The necessary demand growth seems fast and ambitious [Exhibit 4], yet looking at the fundamentals that drive hydrogen uptake in each end-market segment, there is an economical case for the fast uptake for hydrogen. Take for example, the following end-market segments.

Transport

- **Long-haul trucks and buses:** By 2030, hydrogen long-haul trucks and buses can become cost-competitive with alternative technology trucks and buses (diesel, electric, LNG). As the fleet turnover rates of trucks and buses are about 10 years, a rapid uptake of hydrogen trucks and buses can be expected in the 2030-40 period.

- **Trains:** Already today, hydrogen trains, together with LNG, are a cost-effective option to replace / convert diesel trains, especially on low-utilized non-electric tracks to avoid investment in electrification infrastructure. Today, examples of hydrogen trains in operation already exist (e.g., in Northern Germany).

- **Cars:** Electrification is expected to be the major contributor to decarbonization of passenger vehicles – already today the electric vehicle uptake in the short-range transport segment is significant. However in the long run, hydrogen could play a valuable role in offering a low carbon alternative for the longer-range segment.

- **Marine and aviation:** Hydrogen-based fuels are expected to become cost competitive in 2040-50 with alternative fuels. In marine transport, hydrogen can be used to make ammonia, which can replace oil to fuel ship engines. In aviation, carbon neutral "synfuel" made from hydrogen and re-used CO2 (i.e., captured in a CCS power plant) can be used instead of kerosene. These sectors play in a global arena, and coordination in setting global industry standard is crucial for a successful transition.

Buildings

- **Urban buildings:** Blending hydrogen in the gas grid will become a cost-competitive way to decarbonize gas heating systems from the late 2020s onwards, especially in old city centers. As soon as 2030, many distribution networks could start blending hydrogen into the gas mix, thereby partly decarbonizing the Italian heating mix. By 2050, to meet a 95% decarbonization target, such networks will increasingly raise the level of hydrogen (and other green gases) blending in distribution grids. In this way, hydrogen can decarbonize up to 20-25% of the heating mix by 2050. The rest of urban building heating will be decarbonized by e.g. heat pumps or district heating.

- **Rural buildings:** Hydrogen micro-CHP[1] fuel cells can become a cost competitive heating source for rural buildings by 2040-45, especially as they can provide not only heat but also power, reducing the costs of connecting to both the gas and the power network. Hydrogen can provide 15-20% of the residential building heating mix by 2050. Solar thermal and heat pumps will be the key drivers to decarbonize the rest of the heating mix.

Industry energy

- **Refineries and ammonia:** Existing feedstock use in industry will switch to green hydrogen around 2030, driven by the improving economics of hydrogen and the increase of the EU emissions trading system (ETS) price.

- **High temperature heating:** Only a limited number of pathways to decarbonize high temperature heating exist, and none of them will become cost-competitive before 2045. To achieve a 95% decarbonization target by 2050 and drive a price drop for hydrogen, sites that produce on-site

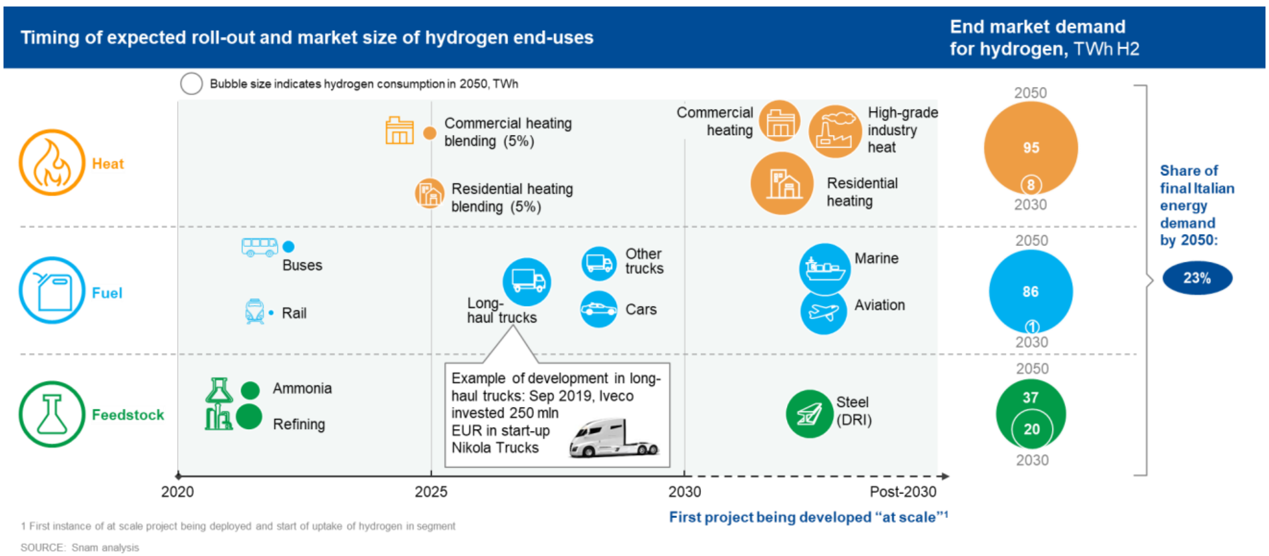
[1] Combined Heat and Power units can provide both heat and power to a building.

hydrogen (e.g., refineries for feedstock use) may increasingly blend excess hydrogen production in their gas furnaces, or even refurbish some furnaces to use a 100% hydrogen blend.

Industry feedstock

- **Iron and steel:** Reducing iron ore with hydrogen via the Direct Reduced Iron (DRI) process instead of coal in a blast furnace offers one of the few carbon-neutral alternatives for making steel. Driven by decreasing hydrogen costs and increasing ETS CO2 prices, DRI can become the most cost competitive way to make steel by 2045. Many European steel companies are developing this technology (e.g., SSAB's Hybrit project), and the first at-scale plant conversions to hydrogen should happen by 2030-35.

EXHIBIT 5 – ANALYSIS OF DEMAND EVOLUTION BY SEGMENT OVER TIME IN ITALY.



Reference case: a showcase in Sicily could demonstrate hydrogen production and use at scale

We analyzed a possible real case application of hydrogen in the Italian ecosystem with the goal of highlighting a potential *concrete* application in the short- to mid-term which is *sustainable* since it uses existing infrastructure. It's also *economically sustainable* in the mid-term for end users, and *appreciative* of local resources.

The opportunity

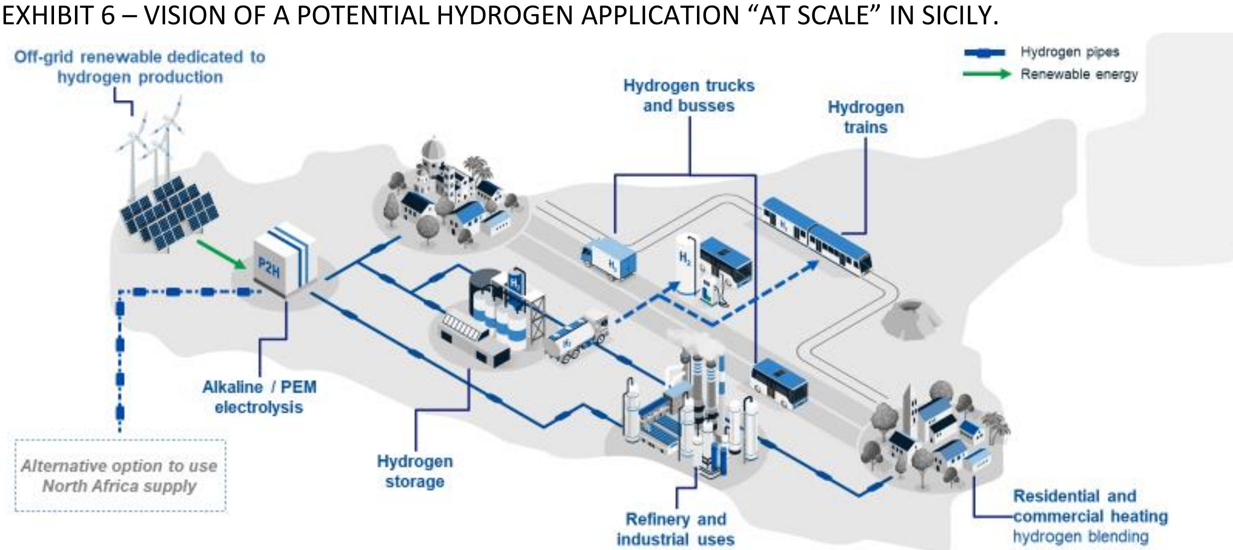
To visualize the application of hydrogen at scale, we have developed a reference case situated in Sicily, which combines renewable hydrogen production from wind power in an electrolyzer, its transport in (existing) pipelines, its use in a local refinery as well as for a hydrogen train and as part of the local gas grid for household heating.

On the supply side, Sicily is a great location for hydrogen production with the availability of cost competitive solar renewables given high solar radiation in the region, and the potential to import from North Africa at even lower cost. On infrastructure side, Sicily can make use of an extensive network of gas pipelines that already exist. The area has a transmission network of 1,100 km national pipelines and 1,500 km regional pipelines, as well as an extensive distribution network covering all major cities.

On demand side, a good mix of end-user applications make Sicily a great region to test applications at scale across multiple sectors. It has 1.6 million residential and commercial holdings heated with gas. The transport sector has 80,000 medium and heavy-duty trucks and busses, as well as 578-km of diesel railways, and Sicily also features refineries with a current production volume of 0.7 Mbbl per day. In addition, Sicily is an island – therefore interconnection with rest of national power grid system is limited via submarine cable – and high penetrations of renewables are expected over the next 10 to 30 years. Hydrogen can also potentially be used for balancing services.

Sicily is particularly favorable for hydrogen development given its characteristics, though, several other applications at scale could be envisioned in the short- to mid-term in Italy.

EXHIBIT 6 – VISION OF A POTENTIAL HYDROGEN APPLICATION "AT SCALE" IN SICILY.



Potential implementation plan

We believe stakeholders could complete the start-up phase of the project by 2022. That could require building 50 MW electrolyzer connected to wind or solar parks, then transporting hydrogen through pipelines to one refinery (covering about 5% of demand) and blending it into local districts for heating. The total cost for the initial phase estimated to be in the range of 70-90 Eur million for first 10 years of operations – including the cost of renewable electricity feeding – partially offset by avoided cost of grey hydrogen production of 30-40 Eur million over the same period.

Sicily has the potential to convert most suitable end-user segments to hydrogen on the island and achieve the 95% decarbonization target. This would be the first ecosystem on a large scale where the entire value chain uses hydrogen – from production to consumption – leveraging existing gas transport and distribution networks. That could include converting two refineries to hydrogen, the full conversion of local diesel railways, 20% blending of hydrogen for heating, and the medium- to heavy-duty range of trucks and busses converted to hydrogen. That will require an expansion in the scale of the project up to 2 GW electrolysis and calls for large scale renewable projects in Sicily / North Africa.

Benefit and challenges for implementation

The benefits for Italy of being a pioneer in the development of hydrogen cover multiple dimensions. These include the abatement of emissions, the development of a distinctive value chain in Italy in a fast-growing sector (ahead of majority of the EU and much of the world), and the increased competitiveness of local industrial sectors. That can lead to higher ability to attract international investments, create new jobs, export energy to Europe. When quantifying the benefit, the numbers are interesting. Looking to the Sicily case study, for example:

- **Environment**: A reduction of 1,250 k tons of CO_2 per year when project is at scale. To put everything in perspective, this is the equivalent to removing one million cars from the street.
- **Local economy**: It could lead to the development of the local value chain and jobs related to the development of the assets (electrolyzer capacity, renewables plants, infrastructure revamping, and so on). Other opportunities include operations and maintenance during asset lifecycles. In addition, low hydrogen costs could potentially attract international investments (e.g., ammonia producers) to open plants in Sicily.
- **End users**: As soon as hydrogen reaches TCO parity, local end-users can benefit from cost competitive hydrogen compared to alternative energy sources. The first sectors to break even should include refineries, followed by trucks and busses and trains.
- **Balancing services**: This is the opportunity to leverage curtail power from increasing solar and wind renewables production for cheaper hydrogen production during curtail hours; which will also help in managing the supply-demand unbalancing period.
- **Additional benefits**: Sicily's image will also benefit from a perception as a "green island," which can help to increase tourism attractiveness.

Reflections on the Italian system: enablers for hydrogen value chain development

The setting up of a large-scale hydrogen value chain requires coordination in developments along all steps of the value chain, from hydrogen production to transport and end markets. Policy and regulation should work in a coordinate manner in Italy and internationally to support the hydrogen value chain development:

i. **Stimulating the end user demand:** set renewable gas adoption target across end user markets – including penetration of hydrogen – with focus on energy intense sectors where hydrogen is a cost competitive solution for decarbonization;

ii. **Supporting buildup of production capacity**: set short- to mid-term incentive for installation of electrolyzer capacity, that enables acceleration of *economy of learnings* to drive down cost of hydrogen production;

iii. **Enabling Italy as hydrogen hub for Europe**: leverage Italy unique positioned to supply cost competitive hydrogen from good renewable sources in South of Italy and North Africa to Europe;

iv. **Supporting infrastructure readiness for hydrogen**: create favorable conditions for upgrading of current infrastructure (transport, storage, distribution) to hydrogen and ensure new infrastructure already being developed to be *hydrogen-ready*;

v. **Investing in Research and Development:** stimulate investment in R&D for development of mature technology across all steps of hydrogen value chain, run tests and set industry standards.