What does it take to make Europe’s Energy landscape fit for future?

A joint paper of Air Liquide and Siemens Energy

Paris and Berlin in March 2023

Introduction

Europe intends to become carbon neutral by 2050[1]; therefore, French and German industrial companies are rising to the challenge by investing in many renewable and low-carbon projects to drive energy transition. Ensuring decarbonization of the European economy requires a fast and pragmatic policy approach that covers both renewable, low-carbon electricity and hydrogen.

Accelerating renewable and low-carbon electricity production in Europe will advance direct electrification. This must be planned and implemented in conjunction with locally produced renewable and low-carbon hydrogen to pave the way for clean, accessible, and affordable energy in Europe. In this context, due to the crucial role of both countries, a strong Franco-German collaboration is key to fostering European leadership in the energy transition.

Executive Summary – WHY this paper?

This paper is issued from the joint work between Air Liquide and Siemens Energy, focused on energy transmission in Europe. Air Liquide is a world leader in gases, technologies and services for industry and health, with unique hydrogen expertise developed in industry over the last 50 years. Siemens Energy is a world leader in energy technology, with one of its focus points being on development and implementation of electrical power grids. The objective is to bring together both companies' expertise and extensive experience in implementing industrial projects, to recommend a pragmatic approach going forward.

This starts by reviewing a few prerequisites needed to move forward to a European renewable and low-carbon energy system [part 1]. The following pages outline a simplified model that was used to compare electricity and hydrogen as energy carriers depending on the use case. The 2030 timeline has been considered, as the objective is to assess next decade's priorities. The cost analysis on the different energy transmission schemes, based on the two companies' project implementation experience and expected trajectories for the different technologies, highlights that, at the European scale, electricity transmissions remain the most advantageous energy carrier [part 2]. Finally, this approach allows us to compile some recommendations to move forward with a pragmatic proposal [part3].

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[1] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

Content

1. Prerequisites for a European energy transmission system

1.1. Electrification wherever possible to maximize the value of low-carbon and renewable energies

Energy consumption can be divided into three broad sectors: transportation, industry and heating. When shifting from fossil fuels to renewables or low-carbon energy sources, direct electrification should be prioritized whenever possible. It ensures the most efficient use of available power and avoids additional losses inherent to conversion processes. Nevertheless, not all applications can be directly electrified and will require other low-carbon energy carriers such as hydrogen.

1.2. Hydrogen is different than natural gas and should be managed differently

Hydrogen and natural gas use cases do not completely overlap. Hydrogen is a chemical element as well as an energy carrier. In most of its applications today – in the chemical industry, refining, semiconductors, and food processing – it is used in chemical processes. Tomorrow, it could be used either as an energy carrier, including for storage of excess renewable and low-carbon electricity, or a feedstock to decarbonize many uses[2]. Depending on the usage, hydrogen purity could change, and it remains a key attribute.

Natural gas is primarily used to produce electricity and generate heat. Because its combustion releases CO_2, both electricity and heat production should be replaced as a priority by direct electrification. In addition, the production and distribution methods for natural gas and hydrogen are not equivalent, notably because hydrogen can be produced near its consumption.

1.3. Solutions are needed to address intermittency of renewable energy supply

Renewable energy is by nature intermittent: There is no sun at night and less wind during the summer. Back-up solutions must be implemented to provide a reliable energy supply if there is a disturbance or interruption of renewable energy generation.

In addition to leveraging demand flexibility, first and foremost, fluidity of energy circulation through interconnections is the most effective means to achieve energy security. Reinforcement of cross-border electrical power interconnectors at the European level can provide additional back-up of national power grids at hourly or daily intervals, but also in seasonal time frames and thereby enhance grid stability.

Ultimately, energy storage solutions can be envisioned, and technologies are available for overcoming different time constraints:

- Power electronics-based converter solutions for stabilizing in the second/millisecond ranges
- Battery storage for hourly/daily support

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[2] The Hydrogen Council's study "Path to hydrogen competitiveness" indicates that these uses could cover 22 applications, 17 of which are for industry: steel, fertilizers, refining, chemicals/methanol, and mobility.

- In the long term, the amount of locally produced renewable energy will become significant. Therefore, additional solutions to manage renewable power intermittency will be required. Locally produced and stored hydrogen as well as energy imports through hydrogen and its derivatives, could then provide a seasonal power generation backup.
  It should be ensured, however, that such energy imports do not generate more CO_2 emissions in the exporting countries than locally produced energy. This must apply even if the energy supply of exporting countries is still based on fossil fuels.

1.4. Integration of Europe’s gas and electrical power grids

Sector coupling with power-to-gas or gas-to-power solutions is essential to balance the inherent consequences of using renewable energy. The different sectors of the energy systems and their respective transmission systems need to be planned as one integrated system, acknowledging that financial resources should be allocated in priority to the most efficient and urgent solutions. The following figure illustrates such an integrated energy system:

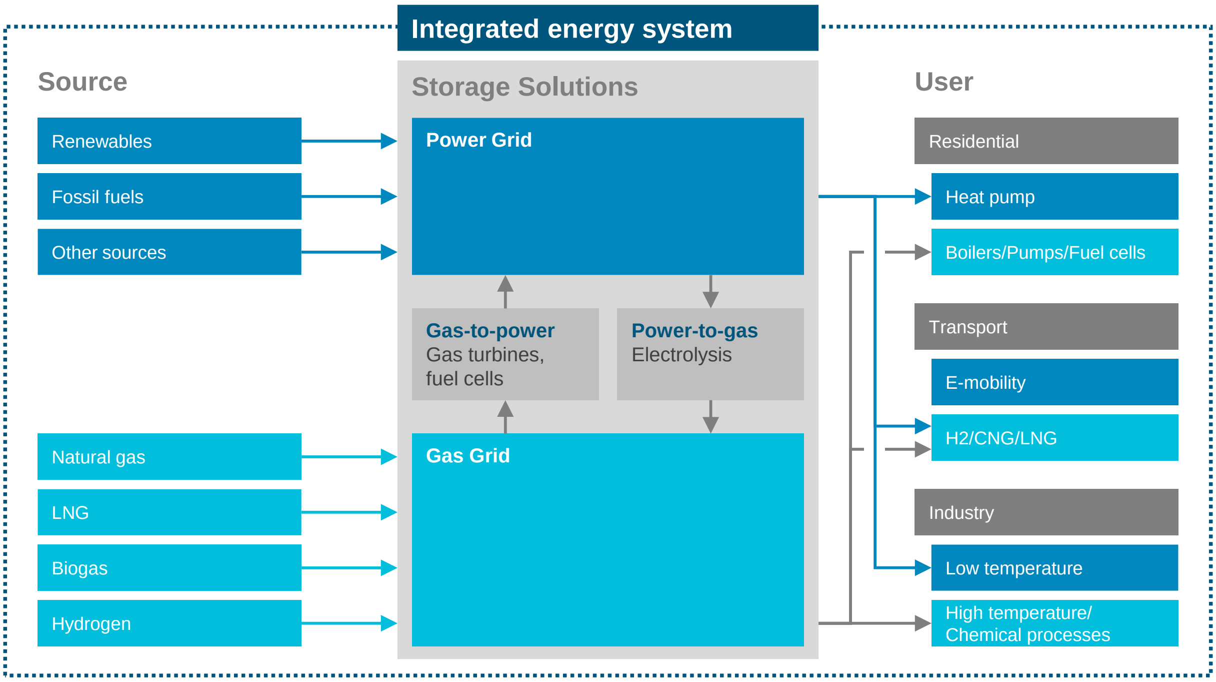

Figure: Schematic view of an integrated energy system, Adapted from ENTSOG 2050 Roadmap for Gas Grids 2022

2. Evaluation criteria for the energy transmission grid within the defined assumptions

2.1. Different low-carbon energy carriers

The current European carrier mix shows the following energy carriers contributing to the demand: electricity (20%), methane (21%), liquids (40%), solids (5%), biomass (7%) and others (7%)[3].

Significant changes need to be considered, however, when looking at the future of the energy supply system. The progressive decrease of fossil-based carriers like natural gas, coal or gasoline being utilized in favor of developing low-carbon energy carriers will be driven by the use and the respective properties of each carrier.

Electricity as an energy carrier is expected to grow significantly and will develop in priority for heating purposes and light usages including light mobility, households and light industry. The predicted shift from fossil sources to low-carbon and renewable power shows an urgent need to focus priority on planning and addressing without delay the inherent structural challenges related to the management of the Renewable Energy (REN) intermittency in the long term. This must include the restructuring of the European energy market which is currently not adapted to the massive incorporation of REN. In this regard, the reinforcement and the ramp-up of electrical infrastructure constitutes a priority and is required in different voltage levels of the power grid. Local and decentralized systems in the distribution levels need to be supported by robust, centralized power transmission schemes at a national and international level. Intensified digital solutions make it possible to monitor system conditions and to optimize load flows.

Hydrogen is already being utilized in several industrial sectors. Decarbonizing existing usages through all available technologies, including CCS[4], should be a priority. In addition, hydrogen will be key in the decarbonization journey, thanks to its critical role in sectors where it has true added value compared with alternative solutions; i.e., for sectors that cannot be directly electrified: less in heating and power sectors, more for industry and transport sectors. Indeed, hydrogen is mainly seen as applicable for decarbonizing heavy-duty mobility and aviation, as well as industrial processes where it can be directly utilized in its chemical form. Considering the energy losses at each conversion step – power to hydrogen and hydrogen to power – large-scale uses of hydrogen for heating or to generate electricity, as a substitute for natural gas, should not be a priority compared with available alternatives such as electrical heating or heat pumps for heating or the direct use of renewable electricity.

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[3] ENTSO-E / ENTSOG, „TYNDP 2022 Scenario Report (April 2022),“ 2022. [Online]. Available: https://2022.entsos-tyndp-scenarios.eu/wp-content/uploads/2022/04/TYNDP2022_Joint_Scenario_Full-Report-April-2022.pdf.

[4] CCS: Carbon Capture and Storage.

2.2. Power and transmission cost analysis

To have an even basis of comparison between the different technologies, notably comparing hydrogen and power transmission, a holistic approach that includes generation, transformation, when relevant, and transmission costs is necessary.

The following simplified model provides an overview of expected costs for a **renewable energy production** facility of **10 GW capacity** and compares different energy schemes for **transmission distances of 1,000 km and 2,000 km relevant at European scale**. Generally, the costs are determined by distance and by amount of power. The **2030 timeline** has been considered, as the objective is to assess the next decade's priorities. Only investment costs[5] were considered in the model, without additional financing costs, operating and maintenance costs, etc.

The following scenarios were investigated (see results in table below):

1. Renewable electricity produced and used locally

This scenario is used as a baseline to estimate the cost of generating 10 GW of renewables without transmission. It assumes that the energy is used in the vicinity of the production facilities.

2. Power transmission via High Voltage Direct Current (HVDC)

This scenario covers the case where electrical energy is to be consumed but needs to be generated in distant places. As of today, for existing voltage levels and cable systems, the transmission of power over long distances is typically limited in Europe to power ratings of 2 GW per system and is attractive for lengths up to 2,000 km. The average losses for such a system are approximately 9%. Typical cost drivers for transmission are converter stations (~36%) and DC cables (~64%).

3. Power-to-gas generation & transmission

This scenario covers the case where energy is to be consumed in the form of hydrogen and it is generated at the renewable energy facility location and transported via pipelines to the point of usage. In this case, electrolyzers are the main cost drivers (~69%), while the transport itself can be realized with mature technology, like compressors and pipelines.

4. Power-to-gas generation, transmission & re-electrification

As described in section 1.3, one challenge of renewables is the fluctuation of supply over time. To cope with this situation, energy backup through re-electrification, i.e. via hydrogen may be used. Scenario 4 encompasses the same creation and transmission of hydrogen as in scenario 3, but with an additional final re-electrification step, in our case through a combined cycle power plant.

Be aware that the following parameters are not covered in this study, but they will need to be considered when addressing infrastructure planning:

- **For scenario 2**, there are **significant additional benefits** resulting from:
  (i) **the power grid operating both directions**, which provides additional cross-border flexibility, and ensures back-up capabilities of national power grids at hourly/daily intervals as well as for seasonal time frames and enhances grid stability at the European scale.

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[5] Model assumes access to natural resources at competitive prices (copper, zinc, nickel, etc.)

- (ii) the already **existing European electrical infrastructure** that will ensure distribution to the end customers of the renewable energy, with limited additional investments.
- **For scenario 3**, the simplified model does **not take into account the additional costs** related to the implementation of local **hydrogen distribution pipelines** to end customers. Indeed, additional hydrogen pipelines will need to be invested and deployed at the arrival point of the transmission network in order to reach the end consumer point.
- **Need for hydrogen demand to reach a critical size to ensure the efficient deployment of hydrogen transmission infrastructure (i.e., "backbones")**. Indeed, the focus should be primarily to satisfy the initial demand in Europe with the domestic production of renewable and low-carbon hydrogen within the industrial clusters, where the demand already exists and considering mobility as a beneficiary of such synergies.

Results analysis:

		Energy carrier on demand side	Available power on demand side (GW)	Estimated efficiency (%)	Total cost 1,000 km (bn EUR/GW)	Total cost 2,000 km (bn EUR/GW)	Estimated CO_2 abatement volume [Mtpy]
1	**REN Generation**	Electrical	10.0		1.0	1.0	9
2	**REN Generation and Transmission via HVDC**	Electrical	9.5/9.1[6]	95%/91%[6]	2.9	4.5	8
3	**REN Generation and Transmission via Hydrogen**	Hydrogen	6.0	60%	4.2	4.7	5
4	**REN Generation and Transmission via Hydrogen & Re-electrification**	Electrical	3,7	37%	8.8	9.4	3

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[6] Values for 1,000 km/2,000 km respectively

This **simplified model** gives the following guidelines to expand transmission infrastructure:

1. Develop renewable capacities as near to the point of demand as possible (scenario 1).

The ideal case is indeed if renewable energy is generated right where it is also consumed, leading to a cost factor of approximately 1 bn EUR/GW. Should this renewable electricity generation allow the shutdown of a fossil power source, this scenario would lead to approximately 9Mtpy of CO_2 abatement.[7]

2. Transmission of electricity (scenario 2)

is the most cost-effective while maximizing the CO_2 abatement of renewables (approximately 8 Mtpy of CO_2 under the same assumptions as scenario 1) as well as maximizing use of the generated renewable power (~91% efficiency). **Given the scarcity of renewable power, this solution should be favored whenever local consumption is not possible at the production location**. The estimated power transmission via HVDC gives a cost factor of 2.9 bn EUR/GW for 1,000 km and 4.5 bn EUR/GW for 2,000 km and increases almost linearly with the distance.

3. Transmission costs via hydrogen are only marginally impacted by the distance of transmission, the main cost driver being the electrolyzer.

Transmission costs via HVDC remain more competitive at a European scale versus hydrogen transmission (1,000 to 2,000 km), while avoiding ~34 – 36% of energy loss through the conversion (comparing scenario 2 with 3). As a reminder, the cost of the local pipes connecting the backbone to the end customers have to be added, which creates a further gap compared to HVDC.

4. Given the energy losses inherent to the additional hydrogen to power conversion (scenario 3 with 60% and scenario 4 with ~37% efficiencies)

When hydrogen is transported, the use of such hydrogen should be exclusively dedicated to decarbonizing hard-to-abate sectors where electrification is not an option. Re-electrification of hydrogen leads to almost doubling the costs compared to transmission of electricity while losing two-thirds of the original energy. Such an option should therefore be excluded.

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[7] Reference emission factor of 330 kg CO_2 / MWh eq. to the best available technology for fossil power generation

3. Recommendations for a European integrated energy system

Electrical power and hydrogen transmission should be seen as complementary. Both technologies need to be considered to achieve the overall targets for decarbonization of the European economy. Considering the urgency of achieving Europe's climate objectives and at the same time ensuring energy security, we recommend a pragmatic approach based the three recommendations derived from the above argumentation:

1. Electrification should be the main investment priority.

Guaranteeing access to abundant and competitive renewable and low-carbon electricity is key. In this regard, accelerating investments in such power generation and transmission systems should be facilitated, including **an acceleration of electricity interconnections across European countries. Direct electrification** will also more efficiently replace fossil fuels like coal or natural gas for its main applications, namely heat and power generation, **and maximize the utilization of the already scarce renewable energy**. Localizing power sources close to the demand is also recommended when possible.

2. Regarding hydrogen, priority should be given to investments and projects localized in key industrial clusters.

Both the existing demand and many future new large-scale applications are in such localized clusters. The **limited resource should therefore be allocated to addressing such demand by incentives for domestic production**, before creating new import dependencies. Meanwhile, transmitting hydrogen over large distances is not a necessity as it can be locally produced. Given the ambition to decarbonize the European economy, **all hydrogen production technologies** should be considered based on their carbon footprint. To such an extent, low carbon hydrogen including notably through Carbon Capture and Storage must be developed simultaneously with renewable hydrogen. This will require the swift development of CO_2 transportation and storage infrastructures. **Policies** that support the adoption of hydrogen by industry and mobility sectors also **need to be clarified and harmonized without delay** to ensure the sustainable development of hydrogen projects.

3. Level playing field and an integrated planning of infrastructure in different energy sectors is crucial

When demand has grown to a level that justifies it, domestic hydrogen production could be supplemented by imports. It will, however, be important to ensure that **imported and domestically produced hydrogen can compete on a level playing field**. The environmental impact throughout the entire lifecycle, including transportation, should be assessed, and the CO_2 content methodology should be standardized. At that point, regulated **hydrogen backbones may emerge, because hydrogen's role in the energy system will have reached maturity in terms of markets**, volumes, and localization, because of the development of the major demand clusters. They should coexist with private, non-regulated, high-purity, high-pressure supply networks in industrial hubs. **Adequate and coordinated planning of infrastructures in the different energy sectors** – including hydrogen storage for flexibility management and the appropriate modification of European and national laws to enable a CCUS (Carbon Capture, Utilization and Storage) solution – **and industrial clusters** will therefore be essential to developing a reliable and cost-efficient low-carbon energy system in Europe.

Imprint

As a world leader in gases, technologies and services for Industry and Health, **Air Liquide** is present in 73 countries with approximately 67,100 employees and serves more than 3.9 million customers and patients. Oxygen, nitrogen and hydrogen are essential small molecules for life, matter and energy. They embody Air Liquide's scientific territory and have been at the core of the company's activities since its creation in 1902.

Air Liquide
75, quai d'Orsay
75007 Paris
France

airliquide.com

Siemens Energy is a leading energy technology company. Together with its customers and partners Siemens Energy works on energy systems for the future, thus supporting the transition to a more sustainable world. With its portfolio, Siemens Energy covers almost the entire energy value chain – from power generation and transmission to storage. Siemens Energy employs around 92,000 people worldwide in more than 90 countries.

Siemens Energy AG
Otto-Hahn-Ring 6
80333 Munich
Germany

siemens-energy.com