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International e-fuels Observatory.

The global race for e-fuels is on

February 2024

Numerous countries are at the starting line for structuring a domestic e-fuels production sector needed to decarbonize maritime and air transport, in a world with 11 e-kerosene and e-methanol synthesis projects of over 200 ktoe / year each*

** 200 ktoe: equivalent to 1,300,000 individual journeys from Paris to New York*

Foreword.

Charlotte de Lorgeril

Partner Energy, Utilities & Environment, Sia Partners
Spokesperson for the French E-fuels Office

With more than 15 years of experience in alternative fuels, we have developed within Sia Partners a conviction in our capacity for collective action to meet the many challenges of decarbonizing our transport and our industries. **We see the emergence of e-fuel value chains as a necessary but not sufficient condition for decarbonizing our societies.**

The first *French e-fuels Observatory* published in July 2023 wanted to provide keys to understanding the challenges specific to France for the development of new national value chains. This study sparked numerous reactions from players of the French ecosystem, reflecting questions about these still emerging solutions.

It seemed necessary to us to complete this work by proposing an international vision of the issues.

This *International e-fuels Observatory* that we are offering you today is the result of rigorous research work and consultation with numerous experts, including members of the French E-fuels Office. It is also intended to be educational. It aims to provide the keys to understanding the issues of cooperation, complementarities, but also competition between the most mature countries on these subjects.

The publication begins with an overview of the dynamics in each major geographical area, outlining a new global geography of energy.

It also proposes to deepen our reflections through dedicated focuses on European and North American countries.

The *International e-fuels Observatory* demonstrates a strong global dynamic, in which France is strongly anchored. France has the assets to position itself as a pioneering country.

Cédric de Saint-Jouan

President and Founder, Vol-V
Spokesperson for the French E-fuels Office

If the emergence of renewable energies has made it possible to decarbonize electricity production, in recent decades, **the time has come to tackle other uses that are more difficult to decarbonize,** notably heavy, air, and maritime transport.

Ambitious objectives have been set by Europe as well as the French government and e-fuel projects are emerging on our territory today.

France, which has a **significant competitive advantage thanks to a carbon-free electricity mix,** benefits from an **opportunity to reindustrialize, improve its energy sovereignty and develop know-how that will be exportable.**

This turning point requires above all making available **the necessary quantities of low-carbon electricity (renewable and nuclear)** and quickly developing additional capacities to support future needs.

Executive Summary

Solutions for the energy transition, ready to deploy

Many benefits to be expected from the industrialization of the e-fuel sectors

Leverage non-electrifiable sectors' decarbonisation	**By combining carbon-free hydrogen with CO_2 or nitrogen, e-fuels provide a decarbonisation solution for non-electrifiable sectors**, especially for heavy mobility and certain industries, **completing sobriety leverages and energy efficiency.**
Industrial and job creation opportunities	The production of e-fuels will be synonymous with the **development of new industrial sectors**. For France, the 2023 edition of the *French Observatory of E-fuels* (Sia Partners, Bureau des e-fuels) estimated a potential of 3,000 direct and indirect job creation by 2030, based on the announced projects.
Geopolitical issues, which vary across continents	Countries importing hydrocarbons will gain **energy independence** by developing sectors based on the valorization of resources (electricity, CO2). Countries that can benefit from low-cost **renewable electricity** will be able to develop export sectors.

Available technologies and many large-scale projects around the world

Mastered technologies	The synthesis of e-fuels requires the use of technologies that have reached a good Technology Readiness Level (TRL 8-9). Although the assembly of these technological bricks on industrial units has not yet been carried out, **there is no technological obstacle to their large-scale deployment**.
High-capacity projects announced all over the world	**77 projects with capacities greater than or equivalent to 200 ktoe/year (≈1,300,000 individual journeys from Paris to New York per project)** have been announced on all continents, with varied business models. However, only three of these projects have so far obtained a final investment decision.

Executive Summary

Competitive risks calling for a strategic political vision

Bringing pilot projects to fruition within a decade: a major challenge for Europeans and North Americans

An interest in building national value chains	The realization of the economic opportunities linked to the development of e-fuel value chains implies for consumer countries to carry out **all the stages of the value chain on their territories: production of electricity, hydrogen, CO_2 capture and synthesis of molecules.**
Strong international competition in the e-ammonia sector	**Many countries benefiting from access to low-cost electricity are positioning themselves as exporters of hydrogen and e-fuels** in the form of ammonia, due to difficulties in mobilizing carbon needed for other e-fuel sectors. 50 of the 77 projects with a capacity of +200 ktoe/year projects are concerned.
Technological developments on which to position oneself	If they do not position themselves, **consumer countries risk losing their advantage in terms of technological advancement** and not being able to play a pioneering role in making progress that will lead to energy efficiency gains, from 45% for the 1st industrial sites to 55% thereafter.

A key role for public authorities in supporting the first industrial-sized units

Anticipation of resource mobilization needs	The projects identified represent a need for 83 TWh of carbon-free electricity in Denmark, Spain and Sweden, 8 $MtCO_2$ and 17 Mm3 of water consumed. In North America, these values rise to 149 TWh, 17 $MtCO_2$ and 23 Mm3. **Adequate infrastructure must be anticipated**.
Support for emerging business models	Given the innovative nature of the projects, the business models of the first industrial sites must be supported. This support can take the form of **subsidies and tax credits** (European and North American models) or **demand-side regulatory obligations** (European models).

Executive Summary

European assets to capitalise on

Significant advantages for the emergence of European e-fuel sectors

A regulatory framework setting an ambitious goal	Various European texts set **mandatory targets for the incorporation of renewable or low-carbon synthetic molecules** (e-fuels and hydrogen) into our energy mix: ReFuelEU (5% in aviation in 2035), RED III (60% in industry in 2035) and FuelEU (2% in maritime in 2035*)
Ambitious hydrogen strategies	The EU and the Member States have strong ambitions for carbon-free hydrogen (e.g. by 2030, 10 Mt of renewable hydrogen produced in the EU; 6.5 GW of electrolysis capacity in France). **The e-fuel sectors will benefit from the support for this production and the efficiency gains linked to its scale-up**.
Relatively good availability of CO_2 in the short term	The sources of CO2 are relatively well distributed across Europe. **The volumes needed for the emergence of e-fuels will be available in the short term**. However, the issue of availability may arise in the long term, with the increase in the production of e-fuels.

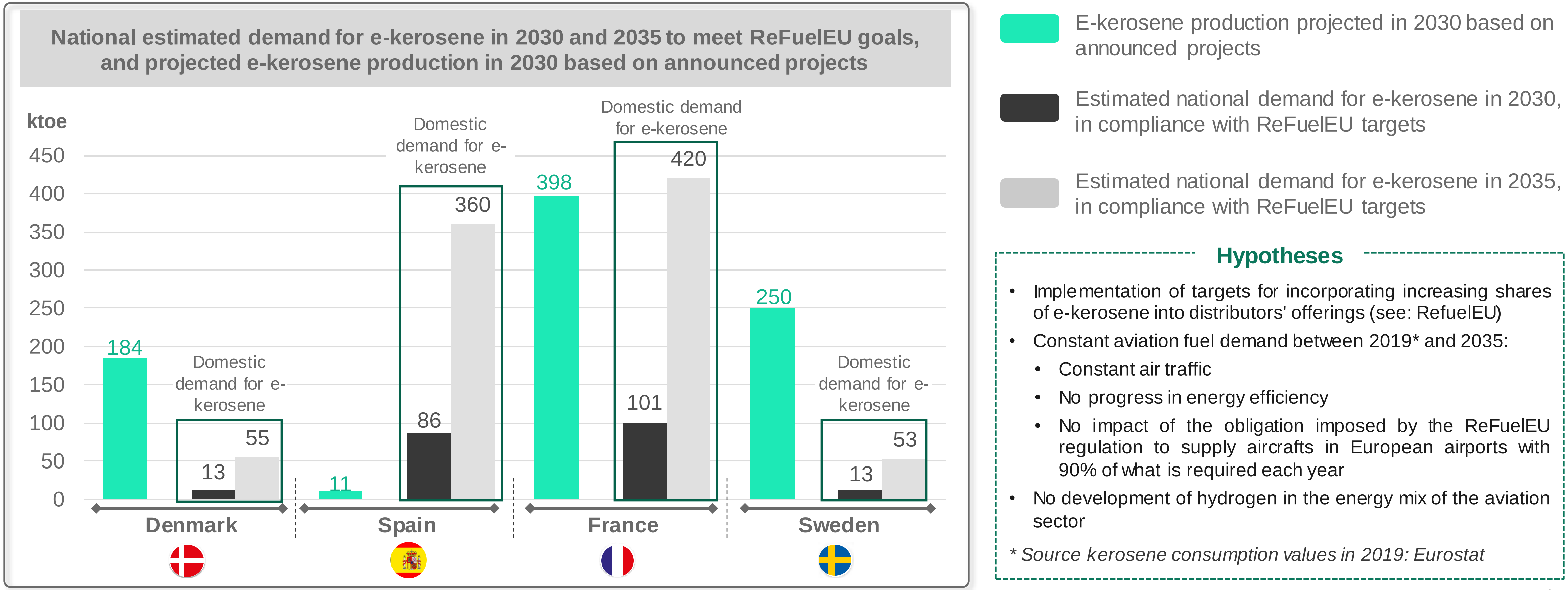
However, a scale-up of e-fuel production sectors remains to be secured

Risk of shortage of e-fuels produced with carbon in 2035	**Few projects have confirmed a final investment decision** (1.5% of planned capacity in Denmark, Spain and Sweden). However**, export projects to Europe are focused on e-ammonia**. There is a risk of shortages of e-kerosene and e-methanol for the achievement of EU targets.
A strategic political vision to be further determined	Despite ambitious hydrogen policies**, few countries have developed a strategy dedicated to e-fuels with quantified targets and specific support measures**. These gaps make the market framework uncertain and constrain resource mobilization planning.

* FuelEU target: 2% of RFNBO (Renewable Fuel of Non-Biological Origin) in the maritime sector by 2035 if the 1% target is not achieved by 2031. Applicable only to vessels with a gross tonnage exceeding 5000 tonnes.

Comparison between projected e-kerosene production capacities in European countries and national needs linked to the ReFuelEU regulation

The comparison between the projected e-kerosene production capacities in European countries and the demand that will be created by the implementation of the ReFuelEU regulation (see Part 1) reveals that the countries studied will not all be self-sufficient for the needs of their air sectors. **New initiatives must therefore be encouraged to meet regulatory obligations, supplemented by cross-border exchanges.**



Hypotheses

- Implementation of targets for incorporating increasing shares of e-kerosene into distributors' offerings (see: RefuelEU)
- Constant aviation fuel demand between 2019* and 2035:
  - Constant air traffic
  - No progress in energy efficiency
  - No impact of the obligation imposed by the ReFuelEU regulation to supply aircrafts in European airports with 90% of what is required each year
- No development of hydrogen in the energy mix of the aviation sector

** Source kerosene consumption values in 2019: Eurostat*

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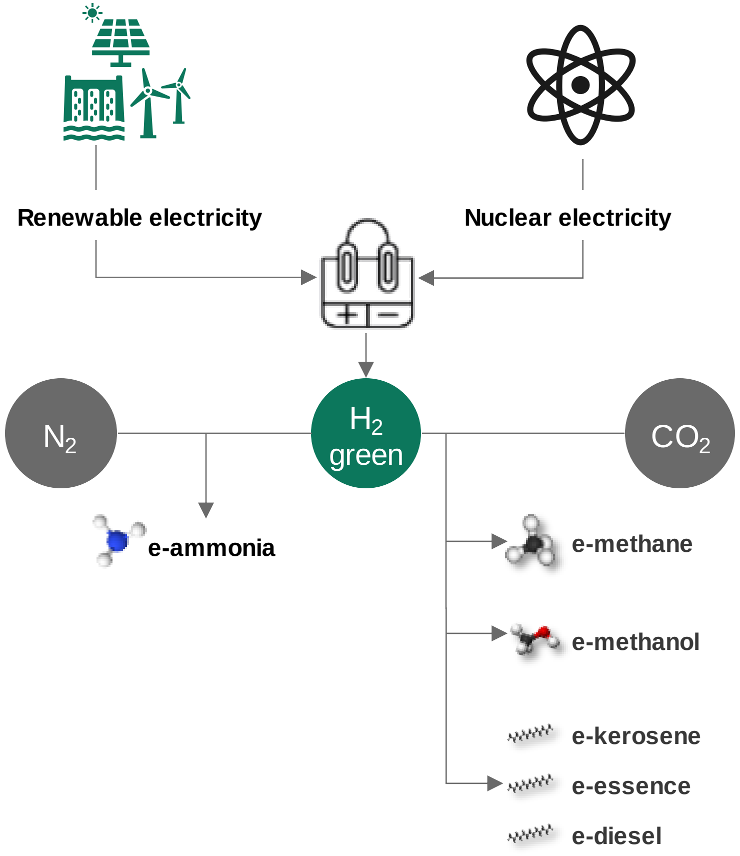
Introduction.

General context

Definitions

This international panorama provides an overview of the sector dynamics and the challenges of mobilizing resources for six synthetic fuels with promising market potential: **e-methane, e-methanol, e-kerosene, e-ammonia, e-petrol and e-diesel**. E-fuels are obtained from hydrogen, itself generated by electrolysis of water powered by **carbon-free electricity**, and **recycled carbon** from industry, the valorization of bioenergy or captured in the air. They stand out as a crucial decarbonization solution for industrial inputs and heavy mobility, complementary to the electrification of uses.

Synthesis pathways for e-fuels



e-methane

- Injection into gas networks and incorporation with biomethane to decarbonize gas uses
- Liquefaction in e-LNG* for road, rail and maritime transport to increase its energy density

e-methanol

- Conversion into olefins and ethers, low-carbon inputs for industry, chemicals, and refining
- Direct use for maritime transport or transformation into paraffinic fuels for aviation

e-kerosene

- SAF** to decarbonize air transport (including e-bioSAF by injecting hydrogen into biofuels production)
- Incremental incorporation into conventional jet fuels

e-ammonia

- Use for the production of nitrogen fertilizers, such as urea and ammonium sulfate and in the chemical industry
- Fuel in certain types of engines or replacement for diesel
- Energy vector

e-essence

- Usually obtained as a co-product with e-kerosene (Fischer–Tropsch or methanol-to-jet processes)
- Possible use for heavy or light road transport (despite the existence of alternative decarbonization solutions)

e-diesel

- Generally obtained as a co-product with e-kerosene (Fischer–Tropsch or methanol-to-jet processes)
- Possible use for heavy or light road transport (despite the existence of alternative decarbonization solutions)

** Liquefied Natural Gas ** Sustainable Aviation Fuel *** Sustainable Maritime Fuel*

Role of e-fuels in the energy transition

E-fuels constitute a necessary addition to the European toolbox to achieve short, medium and long-term climate goals. They provide **alternative solutions for sectors without alternatives**. Their development owes not so much to maturing technologies, but to the increased awareness of customers and citizens about climate issues, to a favorable regulatory framework and to voluntary initiatives from economic players. Chemical vectors of electrical energy, they allow **indirect electrification of uses to complement the improvement of energy efficiency and direct electrification**.

E-fuels: decarbonization levers whose competitiveness remains to be strengthened

ENERGETIC TRANSITION

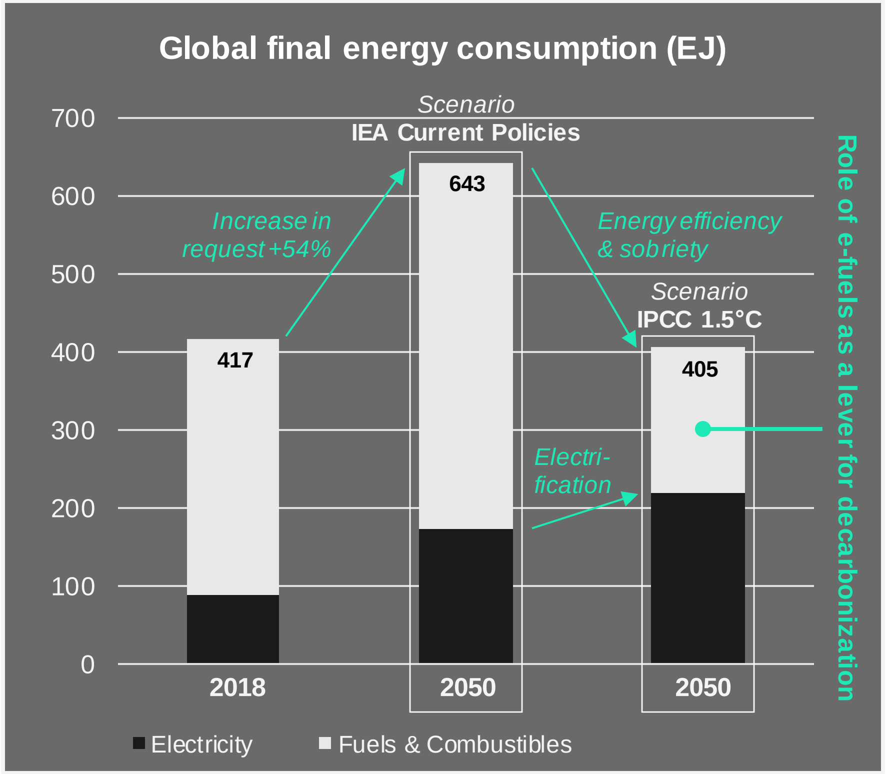
- E-fuels represent an opportunity to decarbonize transport because they are low-carbon and can be used directly in existing internal combustion engines.
- The CO_2 emitted during their combustion is equivalent to that captured to produce them. However, carbon accounting in the case of industrial capture is under discussion.

LOCALIZED PRODUCTION IN THE TERRITORIES

- The cost price of e-fuels is today 2 to 7 times higher compared to their fossil equivalents.*
- The production of e-fuels allows industrial synergies by promoting a circular economy between inputs and co-products from different sectors (steel, cement, biomass, etc.).
- They benefit from better performance than electric accumulators for long-term storage and are easily transportable by networks and vehicles.

EASE OF USE

- The distribution of e-fuels can be based on existing transport infrastructures and uses do not require major modifications to use these products.
- The acceleration of the development of synthesis processes and the industrialization of new mature technologies allow the generalization of e-fuels and the deployment of low-carbon solutions in sectors without alternatives such as air or maritime transport and various chemical industries.

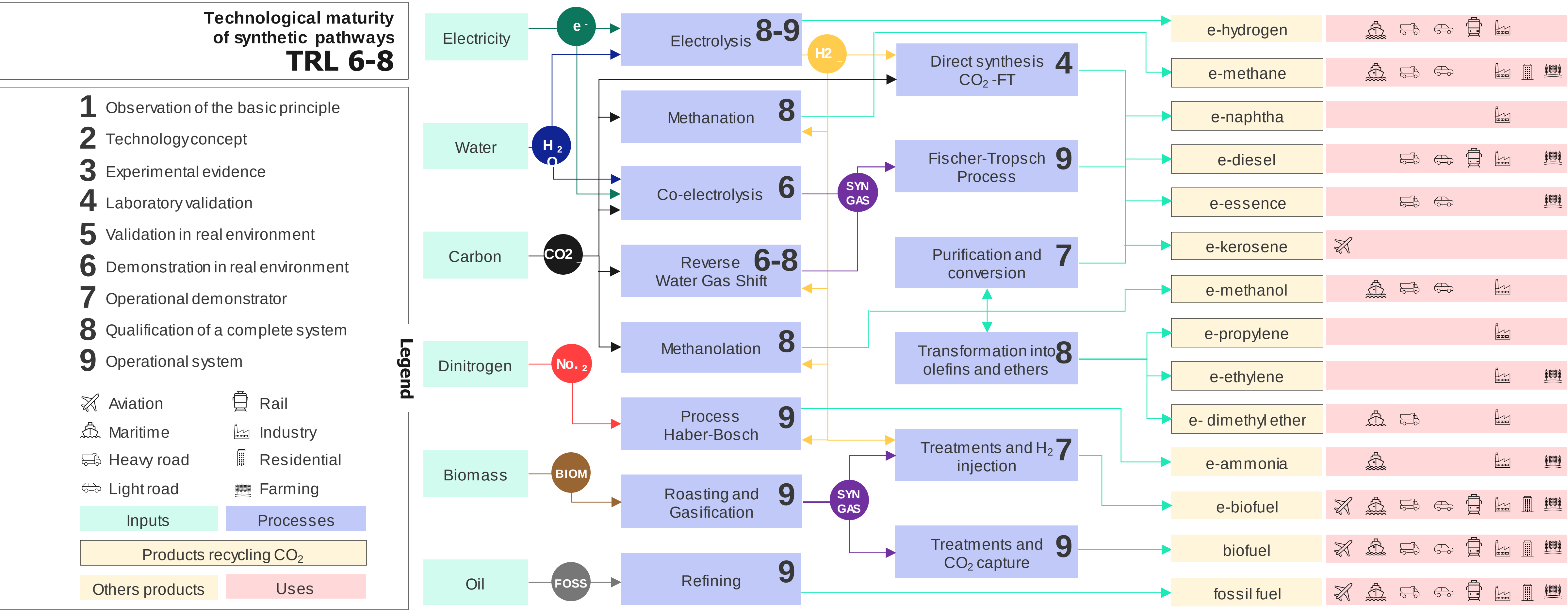


E-fuels have a major role to play in achieving climate objectives. Their development can constitute the 3rd pillar of the energy transition with electrification and energy efficiency.

* Sia Partners analysis

Maturity of the technological building blocks for the production of e-fuels

Depending on the processes deployed, the maturity of the different technological synthesis routes is **between TRL4 and TRL9**. The **manufacturing processes for the main e-fuels are generally mature but their yields are being improved**. Some e-fuels are already certified and incorporated into industry and air, sea and land transport.



A change in the technological environment to anticipate

The first industrial-sized sites will be able to use technological bricks that have already been mastered. **Beyond 2035, the integration of new efficient technologies will make it possible to strengthen the energy efficiency of value chains, while reducing the constraints linked to the supply of inputs**. The deployment of these solutions involves continuing R&D actions today to develop their maturity.

2025 / 2035 – Construction of the first industrial-sized factories, by assembling mastered technological bricks

Achievable energy efficiency: 45%

2035 / 2040 – Integration of new technological bricks and optimization of site layout

2040 / 2050 – Incremental improvement of the most efficient technological building blocks and approach to optimal yields

Achievable energy efficiency: 55%

Examples of technologies deployable beyond 2035

High Temperature Electrolysis

Challenges :

- **Improve the efficiency of electrolysers** by recovering waste heat from industrial sites or thermal power plants: up to 90%, vs. 65-80% with alkaline and PEM technologies
- Carry out **co-electrolysis of water and CO_2:** simplification of the process chain and facilitation of input logistics management

Current TRL: 6 (demonstration)

Prerequisites for deployment:

Recovery of waste heat from industrial sites

Examples of positioned actors:

GENVIA (France), TOPSOE (Denmark)

Direct Air Capture

Challenges :

- **Securing a long-term supply of CO_2** , in a context of growing competition between e-fuel project leaders for the capture of biogenic CO_2 sources
- **Overcoming the problems of locating** e-fuel production sites near CO_2 sources or CO_2 transport infrastructures

Current TRL: 6 (demonstration)

Prerequisites for deployment:

Land and renewable electricity availability

Examples of positioned actors:

climeworks (Switzerland), Carbon Engineering (Canada)

Source: Roadmap towards e-fuel production, *Academy of Technologies, 2023;* A Techno-Economic Assessment of Fischer–Tropsch Fuels Based on Syngas from Co-Electrolysis, *Ralf Peters et al, 2022*

Part 1: Overview of Markets by Major Geographic Zone

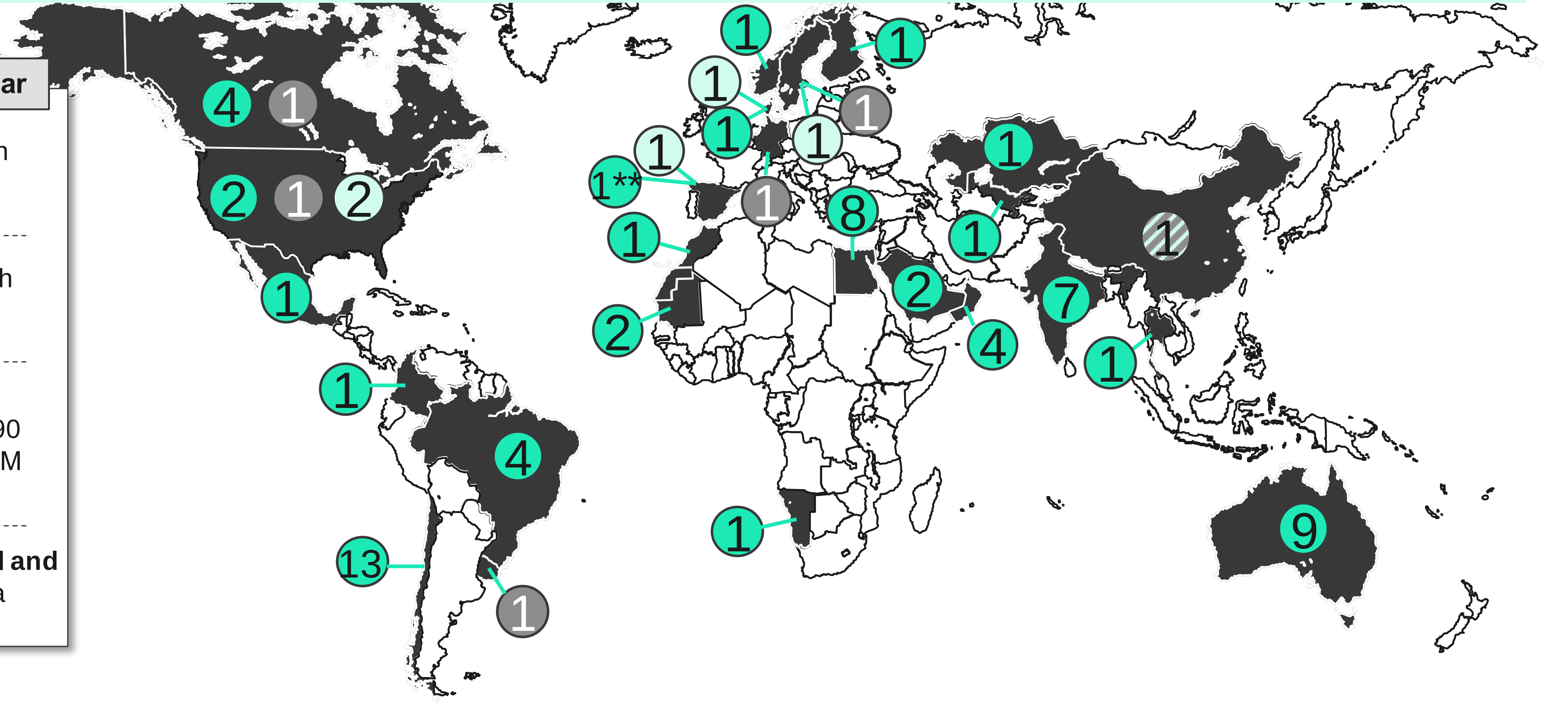
77 projects of ≥200 ktoe around the world: maturity of technological building blocks and strong industrialisation ambitions of the e-fuels sectors

As of January 2024, **77 large-scale projects (≥200 ktoe) have been announced on all continents. 3 were the subject of a final investment decision***. Electricity supply represents 50 to 75% of the final cost of e-fuels. They are therefore located in areas that can benefit from low costs of access to renewable electricity (favorable climatic conditions, limited land issues, accommodating regulations).

A large part of the projects aim to produce e-ammonia to serve global markets (50 of the 77 projects), including Europe, North America and consuming countries in Asia. **Consumer areas, however, remain pioneers in the development of large-scale projects requiring carbon valorization** (e-methanol, e-kerosene), because they maintain an advantage in their ability to mobilize these resources.

Typology of projects with capacities ≥200 ktoe/year

- 66 — **e-ammonia** production projects announced with a capacity ≥500 kt/year
- 5 — **e-methanol** production projects announced with a capacity ≥500 kt/year
- 5 — announced projects using the **Fisher-Tropsch process** for the production of **e-kerosene** (>190 kt/year), **e-diesel** and other co-products (≥180 M liters)
- 1 — hybrid project for the production of **e-methanol and e-kerosene** (methanol-to-jet) announced with a capacity >200 ktoe/year



* Projects with FID: NEOM-ACWA Power-Air Products project in Saudi Arabia, World Energy-Air products e-biofuel project in the United States; EverWind Fuels project in the United States

** E-ammonia project in Spain (Ignis): not included in the Spain sheet in part 2 because commissioning is planned beyond 2030 (2031)

E-fuels in Africa
A continent focused on internal uses and exports

The production of renewable hydrogen and its applications are generating **growing enthusiasm** in Africa. This development could allow the continent to guarantee **access to clean and sustainable energy**, while propelling it as a **major player on the global energy scene**, thanks to the exports of green hydrogen and its derivatives.

Key factors in the development of the e-fuels value chains

- Low-cost green hydrogen production taking advantage of a high potential for renewable electricity production
- Significant green ammonia export potential resulting from the development of large-scale projects

Geopolitical and commercial issues

- Launch in May 2022 of **the African Green Hydrogen Alliance** by Kenya, South Africa, Namibia, Egypt, Morocco and Mauritania, aiming to strengthen their collaboration to create favorable conditions for the development of hydrogen projects: harmonization of political and regulatory frameworks or search for common financing solutions
- Joint analysis by the European Investment Bank (EIB), the African Alliance and the International Solar Alliance revealing the **possibility of producing green hydrogen at €2/kg in Africa**, notably through efficient exploitation of solar energy, making it possible to reduce energy dependence, help decarbonize local economies, and export this resource and its derivatives
- Identification by the EIB of **4 African hubs for the export of green hydrogen and derivatives, benefiting from clear and exhaustive roadmaps:** Mauritania, Morocco, Egypt, Southern Africa and Egypt

Positioning and key e-fuels projects

- **Large-capacity**[1] or **industrial-scale**[2] projects focused on the production of **e-ammonia**, making it possible to use the continent's significant energy potential
- **Projects mainly oriented towards export to Europe and Asia, and some for domestic demand**

5 main projects in terms of production capacities

- *Amun Project (NH_3)* – CWP Global
- *Hyphen Project (NH_3)* – Hyphen
- *NH_3 Project in the Suez Canal Economic Zone* – Ocior Energy
- *Project NH_3 in Ain Sokhna* – AMEA Power
- *Nour Project (NH_3)* – Chariot Transitional Energy, TotalEnergies

[1] Large-capacity projects: > 150 ktoe [2]Industrial-scale projects: between 50 and 150 ktoe (analysis based on IEA project databases)

E-fuels in Africa

Public policies in selected countries

Public policies on renewable hydrogen and its derivatives have emerged as **key strategies for the economic development of several African countries**, including Egypt, Morocco, Mauritania and Namibia. All converge towards **exploiting the opportunities offered by green hydrogen and its derivatives**, mainly **for export purposes.**

Egypt

- **National Hydrogen Strategy** (2022): Seize 5% of the international market by 2030 and 8% by 2040, with the desire to create an international export center for hydrogen and its derivatives
- **$83 bn** mobilized by the Egyptian government in projects linked to green hydrogen, e-ammonia and e-methane
- **Tax incentives** to allow companies active in the production, storage and export of renewable ammonia and hydrogen to deduct 30-50% of their investment costs from their tax bill

Morocco

- National strategy to become a world leader in hydrogen by 2050. **Ambition primarily focused on the development of a national industry** on renewable hydrogen and ammonia to meet domestic needs. Export vision from 2030
- **Creation of favorable conditions for exports** through the implementation of maritime transport of synthetic fuels, the development of port infrastructure, as well as the deployment of production and storage facilities, with investments of between €13 and €95 bn, between 2020 and 2050

Mauritania

- National hydrogen strategy being prepared by the government which wishes to position itself as a leader in this sector
- Assessment of **Mauritania's potential for the production of green hydrogen by 2035 at 12.5 Mt/year** (IRENA[1]), sufficient to meet local needs and allow exports to international markets
- Proactive strategy for the development of green hydrogen projects and its derivatives, materialized by the **signing of agreements with major players in the sector such as CWP Global and Chariot**

Namibia

- **Green Hydrogen Strategy (2022)**: become a net energy exporter with production of 10 Mt/year by 2050
- **Development of a strategy for the e-fuels sector** (Synthetic Fuels Act) announced in 2023, aiming at guaranteeing their compatibility with international standards
- **EU-Namibia strategic partnership** on green hydrogen marked by an investment of €1 bn from the EU to improve the country's logistics infrastructure and facilitate the export of hydrogen and its derivatives

[1] IRENA: International Agency for Renewable Energy

E-fuels in North America

Large exporting region with decarbonization ambitions

The United States and Canada are two major economies producing and exporting fossil fuels, which are also themselves very carbon intensive. **They therefore have a dual challenge of maintaining their power as a major exporter of primary energy and finished products, while supporting their decarbonization on a national scale.**

Key factors in the development of e-fuels value chains

- Strong potential for low-cost renewable electricity production across their vast territories
- Ambitious hydrogen development strategies
- Major exporting powers of historic fuels

Geopolitical and commercial issues

- Dilemma over maintaining support for the production and export of hydrocarbons whose tax revenues allow investment in the transition and for which the cost for shuting down ongoing projects would be high
- Several blue hydrogen production projects **aimed at valorizing natural gas resources**
- Strong expectations for the production of domestic alternative fuels to **decarbonize the transport and industrial sectors**, in particular: Sustainable Aviation Grand Challenge in the United States (9.4 Mtoe/year of SAF in 3030) and Regulation on clean fuels for Canada (15% reduction in carbon intensity by 2030)
- **E-fuel sectors seen as potential substitutes for current hydrocarbon exports**. Ex: Sempra Infrastructure Project developed by Tokyo Gas, Osaka Gas, Toho Gas and Mitsubishi Corporation for the production of e-methane on the Gulf Coast for Japan. The production volume targeted for 2030 is 130 kt/year

Positioning and key e-fuels projects

- Projects of **all sizes**[1] , including several large projects (13 projects at +100 ktoe/year), predominantly focused on the production of **e-methanol** (28%), e-**kerosene** (18%) and **e-ammonia** (39%)
- **+10 sourced electro-bio fuel projects**

5 main projects in terms of production capacities

- *Matagorda (e-methanol)* (United States) – HIF
- *Bear Head Energy Project (NH_3)* (Canada) – Bear Head Energy
- *Paramount Project (e-kerosene)* (United States) – Air Products, World Energy
- *Imperial Ren. Diesel (e-diesel)* (Canada) – Imperial
- *Burin Peninsula Project (NH_3)* (Canada) – Everwind Fuels

[1] Analysis based on an exhaustive inventory of projects by Sia Partners

E-fuels in North America

Public policies in Canada and the United States

The United States has a target of reducing its emissions by 50-52% and Canada by 40% by 2030 compared to 2005 levels. They have published a **hydrogen strategy** (in 2023 and 2020 respectively) which identifies **strategic sectors** and deployment opportunities. The aim is to **stimulate investment** in production and use.

UNITED STATES

General decarbonization policies

Industrial Decarbonization Roadmap (September 2022): Efforts focused on the **5 industries** emitting the most CO_2 (refining, chemicals, iron and steel, cement, food and beverages). **4 pillars**: energy efficiency, industrial electrification, fuels and low carbon energy and CCUS solutions.

Sustainable Aviation Grand Challenge (September 2021): **9.4 Mtoe/year** of SAF, including e-fuels, in **2030**, with a long-term goal of **100% of SAF** in the sector's energy mix in **2050**, i.e. **110 Mtoe/ year**

Several measures are in favor of blue and green hydrogen:

- **Infrastructure Investment and Jobs Act (Nov 2021)**: **$7 bn** for regional hydrogen hubs dedicated to the decarbonization of difficult-to-decarbonize sectors
- **Inflation Reduction Act (August 2022)**: Tax credit to encourage the deployment of national production of clean hydrogen and up to $250 bn in loan guarantees for energy infrastructure upgrading projects to reduce, use or sequester GHGs

Canada

General decarbonization policies

Clean Fuels Regulations (2022): Incentives to promote **the adoption of clean fuels.** Requires suppliers to progressively reduce the carbon intensity of gasoline and diesel by approximately 15% by 2030 (compared to 2016 levels)

- **Clean Fuel Fund (2021): $1.13 bn** fund to support domestic production and adoption of low-carbon fuels
- **SIF Net- Zero Accelerator (2021)**: Fund of **$6.1 bn** to accelerate the decarbonization projects of large emitters and the industrial transformation of the energy sector
- **Tax credits for a sustainable and clean economy (2023)**: **$60 bn** to promote green energy technologies and associated infrastructure through the establishment of tax credits for investment in electricity, clean technologies and hydrogen

E-fuels in South America

Major potential, but unevenly exploited

Several South American countries are implementing development strategies and planning large infrastructures to produce renewable hydrogen and e-fuels. **Levels of commitment by country remain uneven**. E-fuels will help reduce greenhouse gas emissions, while opening up commercial prospects.

Key factors in the development of e-fuels value chains

- Gradual implementation of harmonized and coherent regulations
- Potential for substantial exports from certain countries to North American, Asian and European markets

Geopolitical and commercial issues

- Will shared by several South American countries to use renewable hydrogen and its derivatives to **strengthen energy security, decarbonize the economy and accelerate economic growth in the region, through exports**.
- Capacity of the three leading countries, Chile, Colombia and Brazil, to produce a large surplus of hydrogen compared to their national consumption, due to access to low-cost renewable energies, thus revealing a significant potential for export of renewable hydrogen and its derivatives to major global markets
- **Desire to align certification mechanisms and regulations on renewable hydrogen and its derivatives**, through regional organizations such as H2LAC[1], to avoid each country progressing in isolation, thus facilitating the development of an integrated and future marketing

[1] *Cooperation platform for the development of green hydrogen in Latin America and the Caribbean*

Positioning and key e-fuels projects

- Projects of **all sizes**[2], located in Brazil and Chile for the largest of them, mainly focused on the production of **e-ammonia**
- Projects focused on **domestic demand or** export **to North American, European and Asian markets**

5 main projects in terms of production capacities

- *Green Energy Park Project in Piaui (NH_3)* (Brazil)
- *Project in the Ceará EPZ (NH_3)* – Pecem (Brazil)
- *H2 Magallanes Project (NH_3)* – TotalEnergies (Chile)
- *Solatio Project in Piaui (NH_3)* (Chile)
- *Faraday Project (NH_3)* – Aker Clean Hydrogen, Mainstream Renewable Power (Chile)

[2] *Analysis based on IEA project databases*

E-fuels in South America

Public policies in selected countries

Colombia **has a mature political stance** in the field of hydrogen derivatives, taking a strong interest in the potential of e-fuels and setting ambitious targets. **Chile is starting to clarify its political approach** towards e-fuels, while **Brazil is focusing on the production of carbon-free hydrogen**, without a clear vision for the development of e-fuel production chains.

Brazil

- **Launch in 2021 of the guidelines of the national hydrogen program**, aimed at developing this sector to meet the needs of the domestic market and with a view to future exports
- Brazilian approach to low-carbon hydrogen development that does not set **specific capacity targets,** but focuses on improving and **strengthening the legal and regulatory framework** and removing barriers to drive development of the market
- Government commitment to hydrogen in terms of R&D for more than 20 years (1% of total energy R&D expenditure from 1999 to 2018), which has become a priority investment theme in 2021, supporting the creation of a favorable environment for technological innovations linked to green hydrogen

Chile

- **National Strategy on Green hydrogen (2020)** : produce the cheapest renewable hydrogen on the planet by 2030 and have an electrolysis capacity of 5 GW by 2025
- Strategy aimed at **building an export industry**, capitalizing on the country's wealth in renewable energies which provides access to electricity at almost zero cost, helping to generate revenues of $2.5 bn/year from 2025
- Willingness to **combine investments of public and private funds** in renewable hydrogen and its derivative products, which could reach $45 bn by 2030 and $330 bn by 2050
- Opening of a **public consultation on a new action plan for green hydrogen and its derivatives** between 2023 and 2030, mentioning massive investments and other support measures, particularly at the fiscal level

Colombia

- Design of a **strategy encompassing renewable hydrogen and its derivatives**, aiming to continue decarbonization while stimulating economic development
- Objective of developing between 1 and 3 GW of electrolysis and producing at least **50 kt of blue hydrogen by 2030**
- 40% (740 kt) of total hydrogen production in 2050 planned to supply the production of low-emission derivatives
- Use of e-ammonia envisaged in the production of fertilizers locally and in the replacement of fossil fuels in maritime transport on an international scale
- **Willingness to establish bilateral commercial partnerships** with importing countries, particularly with Germany, to position itself as a key player in the global market

E-fuels in Asia (excluding the Middle East)

A mosaic of emerging policies

Many Asian countries declare a long-term goal of carbon neutrality and acknowledge the significance of green hydrogen and its derivatives. However, a **diversity in strategic approaches** is observable, reflecting the emerging potential of a minority of countries for large-scale adoption and export of e-fuels.

Key factors in the development of e-fuels value chains

- Development of the e-fuel sector stimulated by the need for Asian countries to accelerate their energy transition and respond to growing energy demand
- Rapid expansion of renewable energies

Geopolitical and commercial issues

- **Significant commitment by many Asian countries (India, Malaysia, Japan, South Korea, Vietnam, China, etc.) to achieve ambitious carbon neutrality targets**
- **Fastest growing region in terms of energy demand and renewable energy expansion**, presenting a significant potential market for green hydrogen and its derivatives
- Crucial issues **of energy independence** on a continent undergoing rapid economic and demographic expansion
- Development by certain countries of **domestic production** to meet their demand, such as India, Malaysia, Indonesia and China. Concentration of other countries on securing **low-cost supplies**, like Japan and South Korea increasing investments abroad

Positioning and key e-fuels projects

- Projects of **all sizes**[1] spread across many countries and **primarily focused on e-ammonia**, with the exception of a large Chinese project to produce e-methanol and e-kerosene
- Projects oriented towards **domestic use**, but which can give rise to exports for the largest

5 main projects in terms of production capacities

- *Hyrasia One Project (NH_3)* — Hyrasia
- *Tata Steel Economic zone (NH_3) Project* — ACME Leading Through Innovation
- *Green Hydrogen Project of Karnataka (NH_3)* — ACME Leading Through Innovation
- *NH_3 Project in Thailand* — ACWA POWER, EGAT, ptt
- *e-SAF and e-methanol Project in Qiqihaer* — SPIC

[1] *Analysis based on IEA project databases*

E-fuels in Asia (excluding the Middle East)

Public policies in selected countries

India, Indonesia and Malaysia share the common goal **of developing substantial capacities for the production of green hydrogen and its derivatives**, with the intention of accelerating their decarbonization, meeting domestic demand, and export to the world market. China, despite its strong hydrogen ambition, does not explicitly mention the potential of e-fuels in its national strategy.

India

- National ambition to become a green hydrogen production center with **a production capacity of at least 5 Mt/year and an electrolysis capacity of 15 GW by 2030**
- Commitment by the Indian government to promote the adoption of green hydrogen in industry by increasing the capacity of renewable energies, particularly solar, and by deploying an incentive fund of $2.3 bn, distributed between 2022 and 2030
- Planned use of hydrogen for the production **of green ammonia targeting the production of fertilizers,** and other e-fuels intended to be used as fuels
- **Support from the European Investment Bank (EIB)** of €1 bn for the deployment of green hydrogen in India, also passing through the establishment of a credit mechanism with the Indian government

Indonesia

- **Hydrogen Roadmap (2023)**: using green hydrogen and ammonia with the aim of achieving carbon neutrality by 2060, meeting growing domestic demand for energy, and exporting renewable hydrogen and its derivatives on the global market
- $25.2 bn in private investment expected by the Indonesian government to develop green hydrogen until 2060
- **Pertamina**, state-owned oil and gas company, involved in the development of blue and green hydrogen and ammonia with planned investments of $12 bn by 2026
- Signing of an agreement between the Indonesian state-owned electricity company, **Persero, and HDF Energy** to develop projects combining the production of renewable energy and green hydrogen on site

Malaysia

- **National Hydrogen Roadmap (2023)** : eliminate the use of gray hydrogen and produce up to 2.5 Mt/year of green hydrogen by 2050
- Ambitious target to become a leading country in the hydrogen economy, with expected revenues of more than $85 bn by 2050
- Around $1 bn in investment promised by the government between 2024 and 2030 to accelerate the development of renewable energies, the production of green hydrogen and solutions for using hydrogen
- **China, Japan, South Korea and Singapore eyed as key export markets for Malaysia's renewable hydrogen and ammonia**

E-fuels in Europe

Policies to constrain demand and industrialize supply

Europe has integrated hydrogen and e-fuels as key levers of its long-term reindustrialization and decarbonization strategies. However, limits to domestic production appear (including costs and acceptability of renewable energy projects). **The European strategy therefore aims equally at the development of domestic sectors and imports.**

Key factors in the development of e-fuels value chains

- A regulatory framework aimed at developing domestic consumption
- Presence of global players representative of the entire e-fuel value chain

Geopolitical and commercial issues

- **Strong expectations of domestic production** to develop **new industrial activities** and **reduce the energy trade deficit of the European Union** of **€650 M in 2022**
- However, there are **prospects for massive imports** from countries that can produce hydrogen and e-fuels at low costs:
  - **Importation of e-fuels for direct use** for decarbonization purposes in the transport and industrial sectors
  - Import of e-ammonia, as **vectors for transporting hydrogen**, recovered after delivery
  - **Importation of hydrogen** that can be combined with carbon into Europe for the production of e-methanol or e-kerosene
- **Multiplication of commercial agreements** in recent years: 22 agreements concerning hydrogen and e-fuels as of 12/31/2023 (Sia Partners inventory)
- **Carbon Border Adjustment Mechanism (CBAM)** implemented in 2026 on imports of hydrogen and nitrogen fertilizers, of which ammonia is an input, in order to limit losses in competitiveness linked to a strengthened EU carbon market

Positioning and key e-fuels projects

- **Projects of all sizes**[1], aimed at testing new technologies and medium- and large-scale industrial deployments, for all e-fuels (e-methanol, e-kerosene, e-ammonia)
- **Projects geared towards European consumption**

5 main projects in terms of production capacities

- *AIR project (e-methanol)* (Sweden): Perstorp, fortum, nature energy, uniper
- *E-kerosene production with offshore wind power* (Sweden): st1, VATTENFALL
- *Fleet decarbonization (e-methanol)* (Spain): MAERSK
- *NH_3 project in Narvik* (Norway): AKER HORIZONS, Statkraft
- *Megaton Project (e-methanol)* (Denmark): greengo energy

[1] Analysis based on IEA project databases and exhaustive inventory of projects by Sia Partners in 4 European countries

E-fuels in Europe

Public policies in selected countries

The European Union's public strategy stands out from the rest of the world by the **adoption of binding and ambitious targets for the development of e-fuels in certain sectors**. It is also characterized by **support for imports**, notably via the European Hydrogen Bank. The amounts involved are substantial, as required to **compete with North America and China actions to develop their hydrogen economy.**

Norway

- Prioritization of the 2022 National Hydrogen Strategy of the use of low-carbon hydrogen (blue or electrolytic) for the **decarbonization of two sectors: energy-intensive industries and maritime**, where hydrogen could be used directly or in the form of **e-ammonia**
- **In 2022, public support of €47 M for hydrogen and e-ammonia projects in the maritime sector**, out of a total of €177 M for all hydrogen projects (*Source: RIFS Potsdam, June 2022)*

United Kingdom

- Ambition to install a capacity of 10 GW of low-carbon hydrogen (blue or electrolytic) **by 2030**, including **5 GW of water electrolysis capacity**, subject to affordability and value for money
- Low-carbon hydrogen certification mechanism expected for 2025
- **Support via funds dedicated to projects** for the production of low-carbon hydrogen or linked to the development of new uses of hydrogen and its derivatives, particularly in aviation and maritime sectors (example: eligibility of e-fuels projects in decarbonization support funds of the maritime sector representing £110 M for the year 2023)
- **Legislative text expected in 2024 setting obligations for the incorporation of e-fuels into the aviation sector's energy mix from 2030**

European Union

- REPowerEU: a **European strategy targeint 10 Mt of domestic renewable hydrogen production and 10 Mt of renewable hydrogen import by 2030**, in response to the gas crisis resulting from the Russian-Ukrainian conflict
- **Objectives for the increasing incorporation of renewable or decarbonized e-fuels into the energy consumption of certain sectors:**
  - **Industry:** 42% of hydrogen used in industry must be of renewable origin by 2030 and 60% by 2035 (RED III directive)
  - **Maritime:** 2% of RFNBO (hydrogen and renewable e-fuels) in the maritime sector by 2035 if the value of 1% is not reached in 2031. Only concerns ships with a gross tonnage greater than 5,000 t (FuelEu Maritime regulation)
  - **Aviation:** Integration of synthetic fuels (renewable hydrogen and low-carbon e-fuels) into the supply of aviation fuel suppliers (RefuelEU regulation)

See focus on next slide

- **Public financing by European funds**, notably via the European Hydrogen Bank with a budget of €3 bn from the Innovation Fund, to develop domestic production and imports. Technoloy development supported by the Horizon Europe program
- **Additional support provided by Member States** (example: total support package for the hydrogen sector of €9 bn in France)

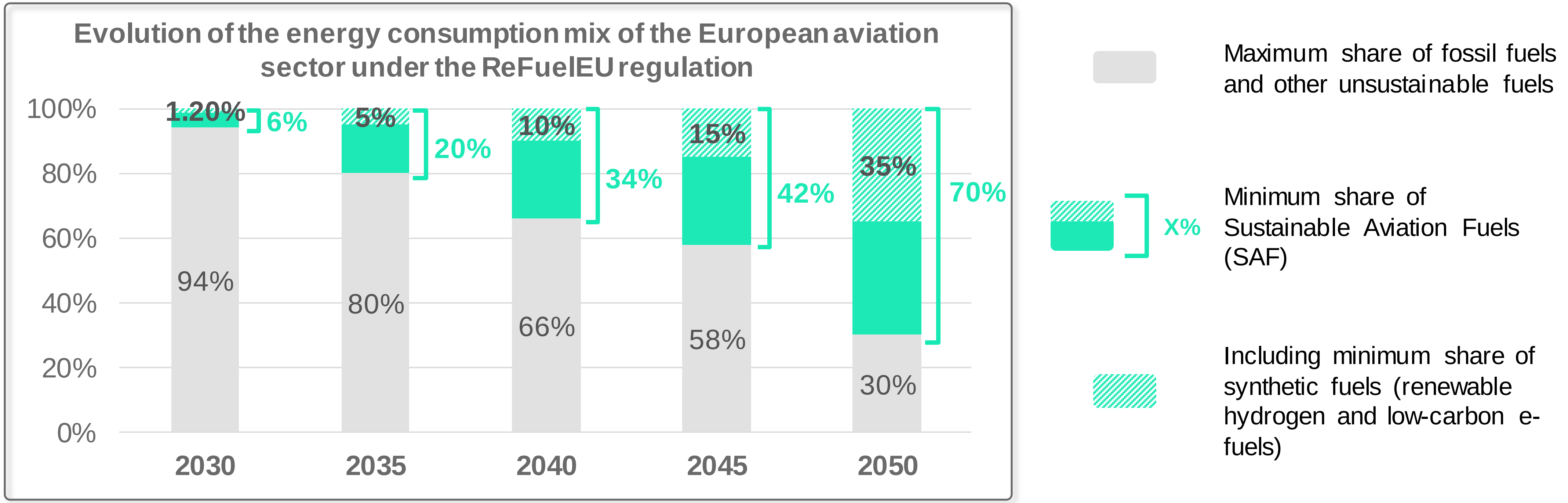
E-fuels in Europe

Focus on the goals of ReFuelEU

The European ReFuelEU regulation adopted in October 2023 requires aviation fuel distributors to gradually incorporate synthetic fuels (e-fuels or hydrogen) produced from renewable or carbon-free electricity. As such, it indirectly legitimizes the participation of nuclear electricity in achieving the decarbonization objectives of the aviation sector.

The regulation also forces planes to source 90% of each year fuels requirements from European airports, citing reasons for enhancing energy efficiency.

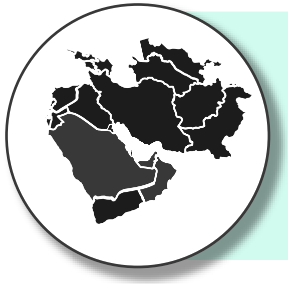
Assuming constant air traffic and no energy efficiency gains, achieving the ReFuelEU targets would entail a demand of 960 M liters (797 ktoe) in 2030 and 4 bn liters (3,320 ktoe) in 2035*.



*Consumption volume requirements: Sia Partners estimate based on AIE database (Oil 2023 publication)

E-fuels in the Middle East

A quest for leadership driven by massive investments



Countries in the Middle East have strong ambitions for the development of carbon-free hydrogen and its derivatives, with major investment plans to **position themselves as leaders in these emerging markets**. These initiatives are part of decarbonization and **export diversification** objectives, which characterize the area.

Key factors in the development of e-fuels value chains

- Investment capacity of public actors historically positioned in the oil and gas sectors
- Know-how and infrastructure linked to the oil and gas sectors, partly reusable

Geopolitical and commercial issues

- **High potential for the production of carbon-free hydrogen and blue hydrogen,** capable of covering more than 11% of global demand in 2050 by exploiting significant renewable energy generation capacity in the region (World Economic Forum)
- **Massive investments by States** (Saudi Arabia, United Arab Emirates, Oman) **and large public companies** (Aramco, OQ, etc.) in the production of renewable and blue hydrogen, aiming to generate income to replace fossil fuels
- **Strategic geographic position** of the Middle East to meet a significant portion of global hydrogen demand, particularly in the European and Asian markets, by leveraging existing oil and gas infrastructure

Positioning and key e-fuels projects

- **Large-capacity**[1] or **industrial-scale**[2] projects driven by investments **by public companies from Gulf countries**, focused on the production of **e-ammonia**
- Projects mainly focused on exports**, targeting Asian and European markets**

5 main projects in terms of production capacities

- *Neom$_1$ Project (NH_3)* – ACWA POWER, AIR PRODUCTS, NEOM
- *NH_3 Poject in Duqm* – ACME, YARA, Scatec
- *Brooge Energy Project (NH_3)* – BPGIC
- *Neom$_2$ Project (NH_3)* – KEPCO
- *HYPORT Project in Duqm (NH_3)* – POSCO, ENGIE, OQ

[1] Large-capacity projects: > 150 ktoe [2] Industrial-scale projects: between 50 and 150 ktoe (analysis based on IEA project databases)

E-fuels in the Middle East

Public policies in selected countries

Several Gulf countries aspire to become major players in the production of low-carbon hydrogen, displaying high national ambitions for future exports. **The preferred forms of these exports remain unclear**. Only the **United Arab Emirates make explicit the use of ammonia** on a large scale as a vector for hydrogen transport.

Saudi Arabia

- **Saudi Arabia's determination to position itself as a global supplier of hydrogen**, both with the production from natural gas associated with CO_2 capture technologies, and with the production from renewable energies, with the aim of achieving carbon neutrality by 2060 and diversifying its exports
- Announcement by the Saudi government of a target of **$36 bn in investments to produce 2.9 Mt/year of low-carbon hydrogen** by 2030
- **Agreement between the Japanese company JERA and the Public Investment Fund of Saudi Arabia** to promote the development of renewable hydrogen and its derivatives, notably ammonia, with a view to future exports

United Arab Emirates

- **Strategic roadmap** to becoming the world's leading producer of low-carbon hydrogen by 2031, with a production of at least 1.4 Mt/year. Exports of 4.8 to 9.6 Mt/year of hydrogen by 2050, starting with the marketing of its derivatives
- Public support aimed in particular at providing sustainable financing options at low interest rates for projects linked to hydrogen and its derivatives
- Reflection around **the idea of a fixed market price for hydrogen between 2026 and 2028**, in particular to help the development of hydrogen clusters intended to promote the development of the entire value chain

Oman

- Deployment of a **national strategy, coordinated by the independent government entity Hydrom,** to produce at least 1.15 Mt/year of green hydrogen by 2030, 3.75 Mt/year by 2040 and 8.5 Mt/year by 2050
- **$140 bn in investments** planned by the government to develop the green hydrogen economy by 2050
- **50,000 km² of land made available**, with incentives offered to attract projects for the production of green hydrogen and its derivatives, such as land rights reduced to $0.05/m², and which may even be free for the development phases
- Announcement of several projects focused on renewable hydrogen and ammonia, including an ambitious large-scale 25 GW project led by Oman's state-owned oil and gas company, OQ

E-fuels in Oceania

A policy geared to international collaboration

Australia and New Zealand have **national ambitions** in terms of green hydrogen sector development**, even global ambitions** for the former. Australia is mainly banking on **international partnerships** to develop applications for this resource. The region promotes a harmonized approach to hydrogen-related policies and standards.

Key factors in the development of e-fuels value chains

- High capacity for low-cost renewable electricity generation
- International partnership strategy with technological and commercial dimensions

Geopolitical and commercial issues

- Use of hydrogen and its derivatives considered by Australia and New Zealand as one of the means to achieve their **carbon neutrality goals in 2050** and stimulate their **economic development:** planned mobilization of hydrogen sectors for domestic uses, in particular production of fertilizers, or to structure new export sectors
- **Significant renewable electricity production capacities** that can be mobilized for the manufacture of clean hydrogen and its derivatives
- Australian Government developing a **certification scheme and associated legislative framework to support an international clean hydrogen trading system**
- Development of **international partnerships**, particularly with Asian and European countries, for better **technological collaboration** and the development of **trade in hydrogen and its derivatives**

Positioning and key e-fuels projects

- **Projects of all sizes**[1] **, concentrated in Australia** , and mainly **focused on the production of e-ammonia**
- Projects intended to advance Australia on the path to **carbon neutrality**, by integrating an **export dimension**

5 main projects in terms of production capacities

H2-Hub Gladstone Project (NH_3): Iwatani, Keppel, Kansai Electric Power, Marubeni, Stanwell

H2Perth Project (NH_3): Woodside

Western Green Energy Hub Project (NH_3): InterContinental Energy, Mirning, CWP Global

AREH project (NH_3): CWP Global

AMP Project (NH3): amp, Iron Road

[1] *Analysis based on IEA project databases*

E-fuels in Oceania

Public policies in Australia

Australia is investing heavily in its strategy to produce renewable hydrogen, with the aim **of improving its energy security** and **developing its capacity to export this resource**. However, the Australian government adopts a neutral position regarding the terms of export of hydrogen and the vectors used.

Strategic vision for the development of clean hydrogen

- Publication of a new version of the National Hydrogen Strategy in 2023 to ensure a global leadership position in this sector by 2030
- Government effort to increase demand and reduce delivery costs for hydrogen, with the **priority objective of achieving clean hydrogen production at $1.2/kg by 2030**, by valorizing renewable energies or using the valorization of fossil resources combined with CO2 capture solutions
- Willingness of the Australian government to attract private investment to develop renewable hydrogen, with a volume of projects representing amounts estimated at 300 bn Australian dollars, which would be directed to both domestic use and exports

International partnerships in the field of hydrogen

- **Agreement on hydrogen and its derivatives produced from renewable energy sources concluded with Germany**, for commercial purposes
- **Partnership with Japan** to advance technological cooperation in hydrogen and clean ammonia
- **Trade cooperation with South Korea** to secure supply of clean hydrogen and ammonia
- **$30 M partnership with Singapore** to accelerate the development and deployment of low-emission fuels, including hydrogen and its derivatives

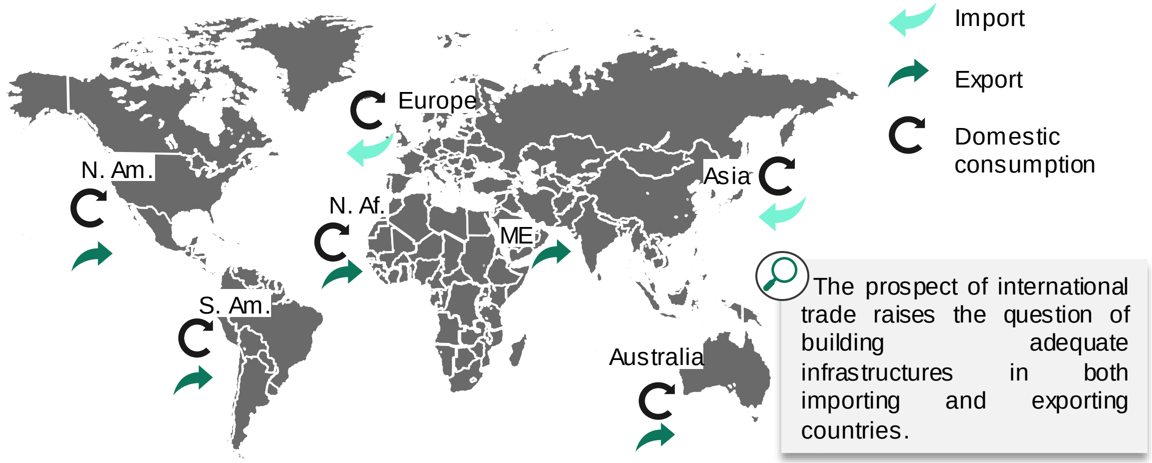
Absence of specific roadmaps for e-fuels sectors

- **Absence of public support measures dedicated to the e-fuel sector**
- **First country to experiment transportation of liquid hydrogen by boat to Japan**, thus raising questions about the means of exporting national hydrogen production in the long term

A global dynamic outlining the reorganization of international energy exchanges

Although only 3 of the 77 projects of sizes ≥ 200 ktoe listed have been the subject of a final investment decision*, the dynamics at work foreshadow the development of a new energy geography, but one that needs to be confirmed in view of the uncertainties surrounding the evolution of the market environment.

Target markets



The prospect of international trade raises the question of building adequate infrastructures in both importing and exporting countries.

Various forms of public support

Support for CAPEX (e.g. European Innovation Fund), **tax credits** (e.g. United States, Canada), provision of **land** (e.g. Oman), planning for the development of export **infrastructures (e.g. Morocco)** , **regulations on fuel demand** (e.g. Europe)

Various driving forces

Pure players H2/e-fuels, developers of renewable energy projects, large historical energy companies, producers of industrial gases or **large consumers of fossil fuels** seeking to decarbonize their supply chains (e.g. shipowners)

Different visions of decarbonization challenges

A **precise European law on the definition of RFNBO**** which must participate in the decarbonization of certain sectors, and likely to impose standards on exporting countries, which also sets a **framework for the production of carbon-free e-fuels**
Assumed ambition to produce e-fuels with blue hydrogen by other geographical areas (North America, Colombia, Indonesia, etc.)

International exchanges focused on e-ammonia

66 **e-ammonia** production projects announced with a capacity ≥500 kt/year, including 50 outside Europe and North America

Not all areas suitable for low-cost renewable electricity production have easy access to CO_2. Most large projects therefore focus on the production of e-ammonia, not requiring any carbon input.

Challenges for securing the supply of e-fuels incorporating carbon in Europe

- **Europe has set ambitious targets for developing the consumption of hydrogen and e-fuels for the decarbonization of its industry and transport**. In this way, it could become the world's leading e-fuel market in 2030
- **Few projects to date aim to export e-methanol and e-kerosene to Europe**
- Although Europe has numerous projects for the production of e-methanol and e-kerosene, few of them have been the objective of an FID* (see details in Part 2). **A risk of shortage of certain e-fuels cannot therefore be excluded by 2030/2035**

** Final Investment Decision (FID): Decision to sign binding contracts and launch the construction phase of the project*
*** RFNBO: Renewable Fuel of Non Biological Origin. Energy products including e-fuels valorization of renewable hydrogen*

Part 2: Overview of Dynamics by Country

Criteria for the selection of countries to focus on

1 Preference given to countries in Europe and North America

Focus on countries comparable to France

- Countries planning to become producers and consumers of e-fuels and possibly importers in the short term
- Ambitious public objectives for decarbonizing economies in the short and long term
- Commonalities in political systems and economic structures

2 Highlighting countries with the strongest dynamics

Number and capacity of e-fuel production projects

Significant development potential

- Strong potential for mobilizing carbon-free electricity
- Driving countries in the development and industrialization of technologies linked to the e-fuels value chain
- Significant support policies
- …

Denmark
- 14 projects – 1,229 ktoe/year

Spain
- 13 projects – 1,292 ktoe/year

Sweden
- 8 projects – 472 ktoe/year

Canada
- 19 projects – 2953 ktoe/year

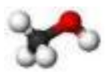
United States
- 21 projects – 2372 ktoe/year

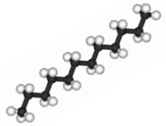
Reading Warnings

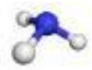
This study covers the molecules of **e-methane**, e-methanol, e-kerosene, e-ammonia, e-diesel and e-oil, whose **energy content is from decarbonised electrical sources**. **Our work does not include unsuccessful projects or closed demonstrator projects. For reasons of confidentiality, only publicly announced projects have been included.**

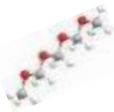
Molecules studied

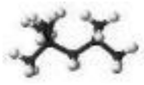

e-methane


e-methanol


e-kerosene


e-ammonia


e-diesel


e-essence

Calculation of indicators

Input data

Production capacities **are computed based on the production volumes announced** by the project owners. We do not take into account identified projects that do not communicate their production targets in the calculations. **Other indicators come from our own calculations**, based on the **assumptionscalcul presented in the appendix** .

Yield

The calculation of electricity needs is based on an **energy efficiency of the entire value chain of 45% in 2030.** The prospects of technological developments that will enable reaching yields of 55% in the long term.

By-products

During its production phase using a Fischer-Tropsch or a methanol-to-jet process, e-kerosene comes with recoverable by-products. **We assume in our yield calculations that all of the co-products are recovered and do not impact e-kerosene with the weight of the requirements needed for the synthesis of the co-products** .

Consideration of the contribution to biofuel sectors

Scope used for calculations

Strictly electro-sourced e-fuels

Fuel and combustibles whose energy content is made of low-carbon electrical sources and comes exclusively from hydrogen produced by water electrolysis and carbon not sourced directly from biomass.

Electro-sourced share of e- biofuels

Energy volume of low-carbon electrical origin included in biofuels enriched with hydrogen, corresponding to the share of final energy of e-biofuels resulting from the injection of hydrogen produced by water electrolysis.

Out of scope

Bio-sourced share of e- biofuels

Energy volume of biological origin included in hydrogen-enriched biofuels, corresponding to the share of final energy of e-biofuels resulting from the gasification of biomass.

Part 2 .

Overview of Dynamics in selected countries

Europe

Denmark

Focus on Denmark – General context

Since 1997, oil and gas production **has been a driving force** for the Danish economy. However, in 2020 the government voted for a gradual phase-out of fossil fuels. Since 2000, there has been an increase in the share of **wind power and bioenergy** in the energy mix, which is now made up of 83% renewable sources. Today, the country has a **strategy for green hydrogen** and **PtX technologies**, and relies on a structured value chain composed of players at all levels, active in R&D and marketing, as well as consumers in the transportation industry. The sector is supported by state funding.

Public support and policies

Energy Technology Development and Demonstration Program – EUDP (2007)*: annual subsidy program targeting players developing new green energy production technologies. 1,200 projects subsidized accounting for a total of €830 M since 2007.

Climate Agreement for Energy and Industry (2020): A €2.15 Bn fund to finance CCUS projects and solutions.

IPCEI* Hydrogen – Denmark (2021)***: selection of 2 e-fuel projects by the Danish parliament for European IPCEI funding: Green Fuel for Denmark (€86M) and Greenlab Skive (€10.7M).

Research Reserve from the Innovation Fund (2021-2023)**: annual allocation of financial support for research projects. Since 2021, €38 M has been earmarked each year for the MissionGreenFuels program which works for the incorporation of green fuels in the transport and industry sector.

Power-to-X 2030 (2022)**: Strategy aimed at evolving the regulatory framework, promoting the development of infrastructure and the export of products and technologies linked to green hydrogen and e-fuels. Denmark sets the target of installing 4 to 6 GW of electrolysis capacity by 2030.

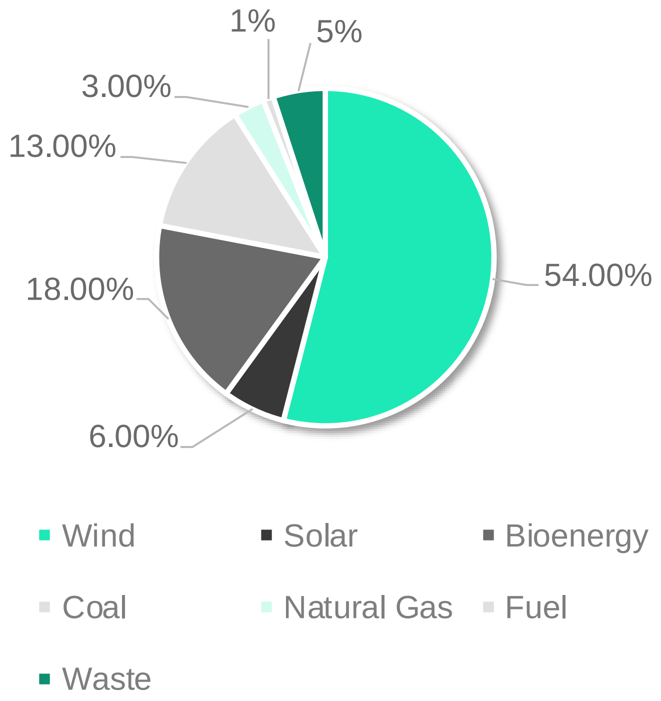
Call for tenders from the Ministry of Climate and Energy (2023)**: €170 M subsidy over 10 years to promote Power-to-X technologies, aimed at any company wishing to build new electrolysers in Denmark.

-70% of GHG emitted
by 2030 compared to 1990

4 to 6 GW by 2030
Electrolysis capacity installed

€2.5 Bn in subsidies
to promote H_2 and PtX projects

Electricity mix in Denmark (IEA, 2022)



* IPCEI: Important Projects of Common European Interest; ** Danish Power-to-X strategy; ***European Commission

Focus on Denmark – Dashboard of indicators 2030

Total projected capacities in 2030

1,229 ktoe/year

01 Production capacity of projects under works or in activity

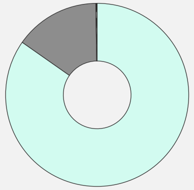
19 ktoe / year

02 Production capacity of projects with FID

0 ktoe / year

03 Production capacity of projects under study

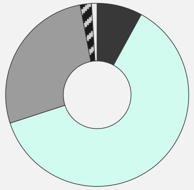
1,210 ktoe / year



04 Electricity requirement

34 TWh / year*

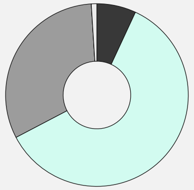
29 TWh: water electrolysis
5 TWh: synthesis of e-fuels



05 Carbon requirement

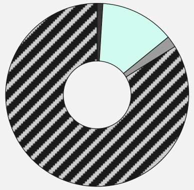
3 $MtCO_2$ / year

To be captured in biomass or industry



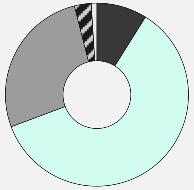
06 Water requirement (water consumed)

7.1 Mm^3 / year

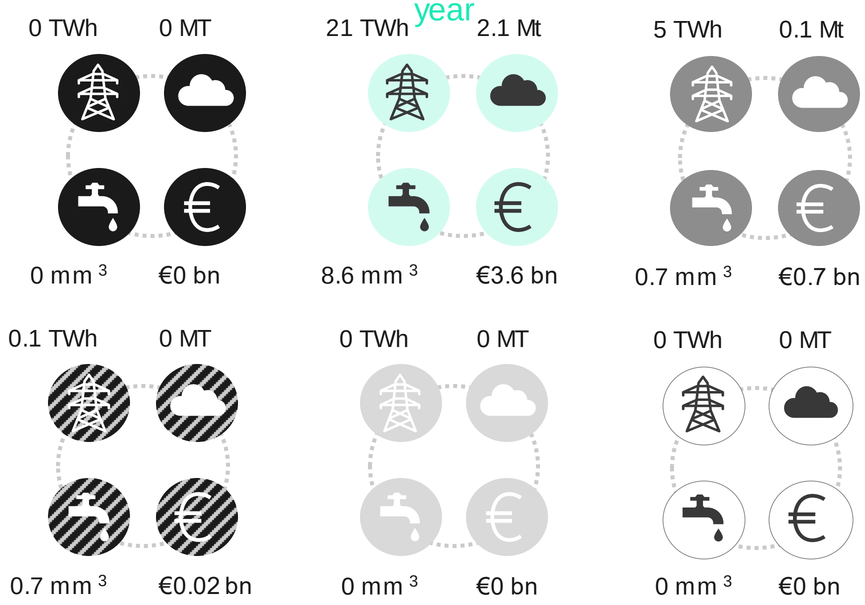


07 Financing requirement

DKK 86.6 bn
Or €11.6 bn



Quantities of resources to be mobilized per molecule / year



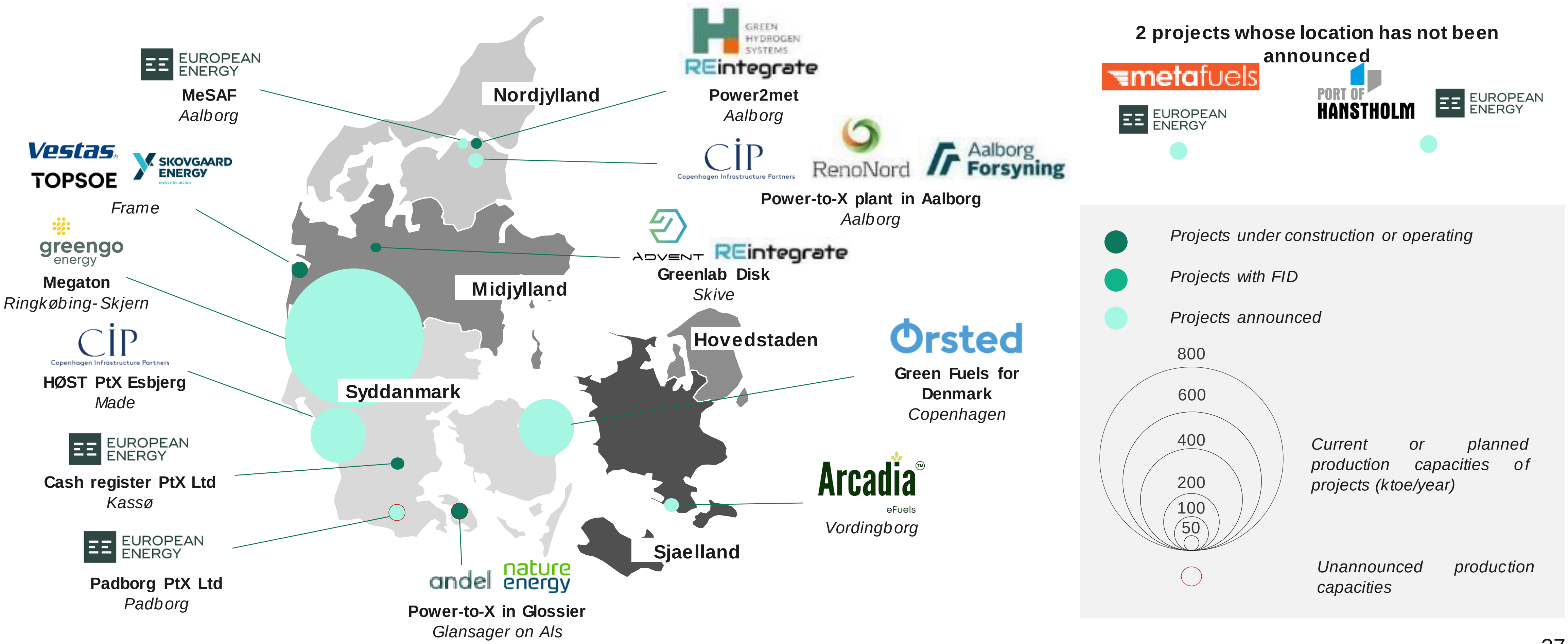
Legend

- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

* Electricity requirements: based on an hypothesis of an overall energy efficiency of 45% by 2030 for all e-fuels value chain. **55% of energy efficiency achievable in the long run.**

Focus on Denmark – Overview of publicly announced projects

We have identified **14 projects** in Denmark. These projects are at various stages of progress, with a notable number of projects having reached an FID: **1 project is operating, 3 under construction and 10 under study.** We can also mention **3 pilot projects carried out by Electrochaea which have been discontinued since**. Among these projects, 3 are carried by Nature Energy, Andel, European Energy and the port of Hanstholm which do not yet communicate the planned production capacities. The regions of Midjylland and Syddanmark are particularly dynamic with 3 and 4 projects respectively, including those representing the largest capacities.



Focus on Denmark – Actors

Denmark has a strong industrial base with **expertise in engineering, manufacturing and project development.** These projects are mainly **driven by new pure players or more diversified e-fuel players** (Reintegrate, Metafuels, Arcadia Fuels, European Energy, Skovagaard Energy). Historical players (Andel, Orsted) are less present in comparison. **European Energy** is particularly active in the country with a diversified portfolio split between wind and solar farms and e-fuel production installations.

01. Constructed and/or active

Project	Actors	Date	Product
Power2met	Green Hydrogen Systems, REintegrate	2021	e-methanol
Greenlab Skive	andel, nature energy	2024	e-methane
Kasso PtX ApS	European Energy	2024	e-methanol
	Vestas, TOPSOE, Skovgaard Energy	2024	e-ammonia
Skive PtX	Advent, REintegrate	2022	e-methanol

02. Finance

03. In the study

Project	Actors	Date	Product
MeSAF	European Energy	2024	e-methanol
Green Fuel for Denmark	Ørsted	2025	e-methanol
Padborg PtX ApS	European Energy	Unknown	Unknown
HØST PtX Esbjerg	CIP Copenhagen Infrastructure Partners	2028-2029	e-ammonia
PtX in Aalborg	CIP Copenhagen Infrastructure Partners, RenoNord, Aalborg Forsyning	2028	e- methanol
	metafuels, European Energy	Unknown	e-méthanol
Endor	Arcadia eFuels	2026	e-kerosene
Megaton	greengo energy	Unknown	e-methanol
	Port of Hanstholm, European Energy	Unknown	e-methanol

Focus on Denmark – Production capacity of e-fuels

Based on announced projects

Combined together, all identified projects up to date, have an estimated production capacity of **1,229 ktoe/year in 2030**. In detail, **1 project is active, 3 under construction and 10 under study**. The commissioning prospects focus on 2030. However, the most important project based on production capacity – carried by **GreenGo Energy (660 ktoe) – does not specify a year of commissioning**. Additionally, 3 other projects carried out by European Energy – one in Padborg , the other at the port of Hanstholm and the last in collaboration with Metafuels – do not disclose this information.

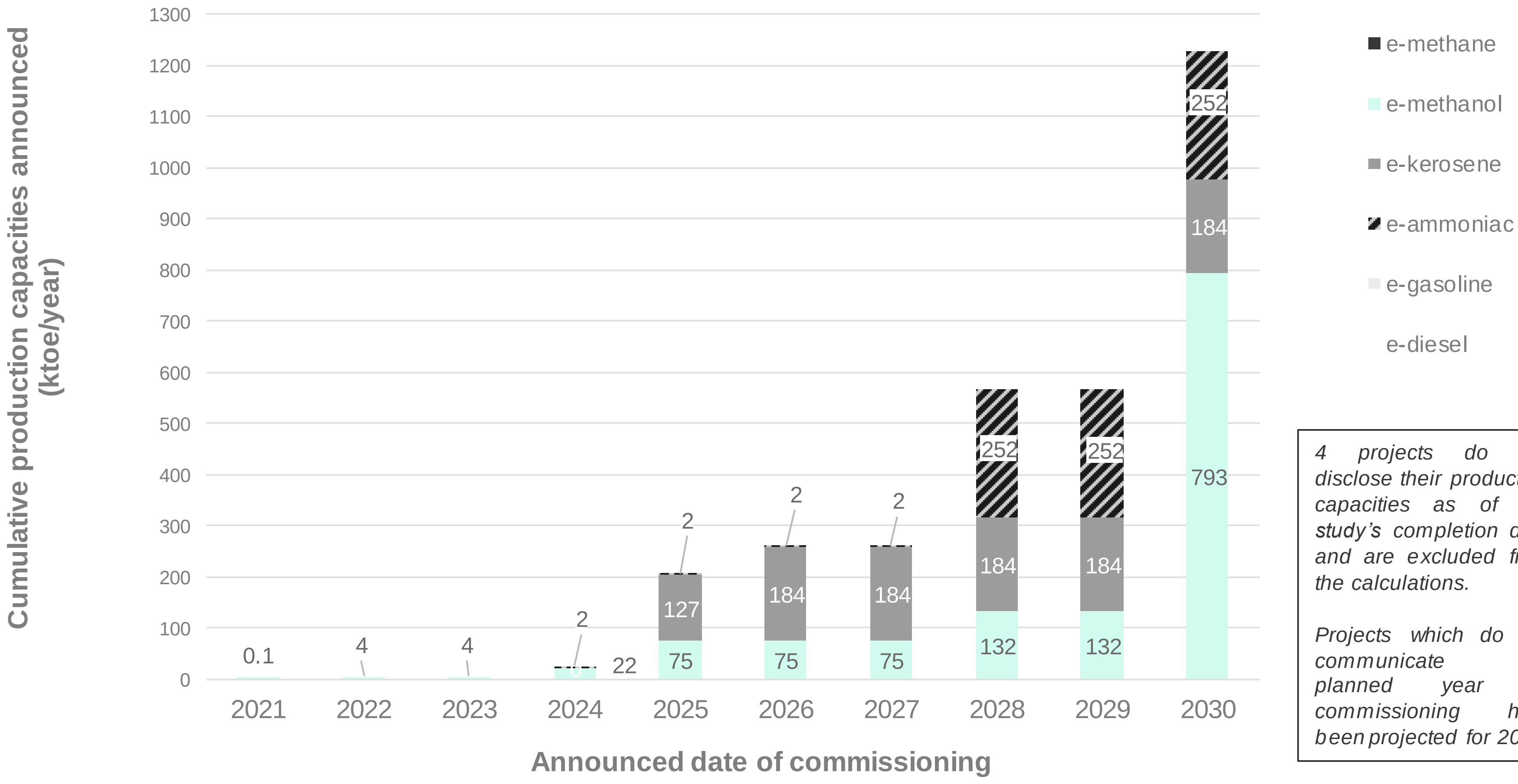
Indicators

01. **Active capacities / Under construction:**
19 ktoe/year

02. **Projects with FID:**
0 ktoe/year

03. **Projects under study:**
1,210 ktoe/year

	Production capacity (ktoe/year)	Number of projects
e-methane	0	1
e-methanol	793	9
e-kerosene	184	1
e-ammonia	252	3
e-essence	0	0
e-diesel	0	0
Total	**1,229**	**14**



4 projects do not disclose their production capacities as of the study's completion date and are excluded from the calculations.

Projects which do not communicate the planned year of commissioning have been projected for 2030.

Focus on Denmark – Electricity needs

Based on announced projects

Denmark has shifted its electricity mix towards **wind power (54% of the electricity mix) and bioenergy (18%)**. Denmark ranks 3rd in the ranking of European states with **the most stable electricity networks** (CEER). This performance is made possible thanks to **imports** and **biomass power plants**, making it possible to compensate for intermittent wind production. A **government plan** plans the **conversion of coal-fired power plants to biomass**, which nevertheless has a role to play, particularly during droughts impacting hydroelectric production in Norway and Sweden, and therefore imports.

Indicators

04.

Electrical need planned projects

34 TWh / year

Notes on reading the indicator

- 29 TWh: water electrolysis
- 5 TWh: synthesis of e-fuels

For an overall energy efficiency of 45% for the whole value chain. Overall energy efficiency of 55% achievable in the long run.

Regional electricity needs (TWh / year)

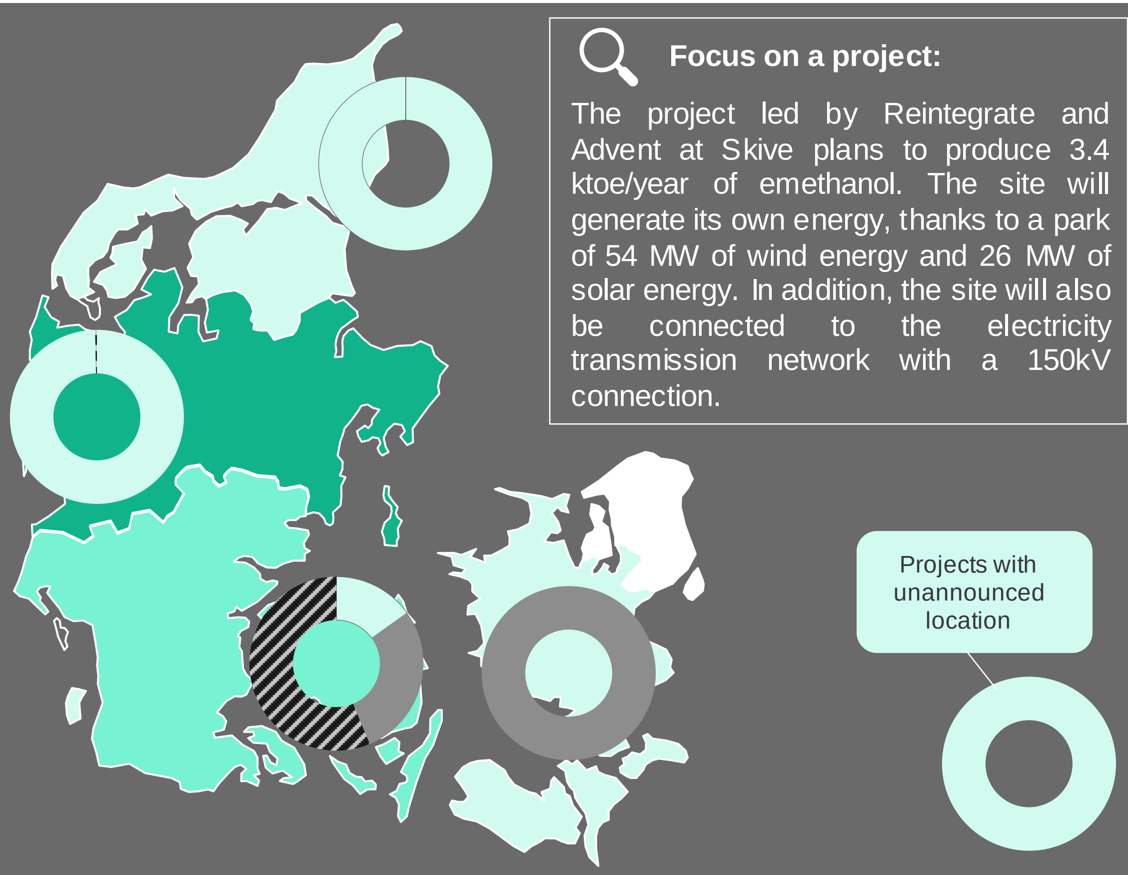
- 0
-] 0 ; 5]
-] 5 ; 10]
-] 10; 15]
-] 15; 20]
- > 20

Share of need by e-fuel

- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

Providing 34 TWh of carbon-free electricity for the e-fuel sector will be a challenge in a country which has only produced 21 TWh in 2022*. Denmark, however, has the potential to expand its fleet, particularly in the North Sea (17-27 GW according to the Danish Energy Agency). Two islands have already been designated to produce 5 GW of wind electricity, and 3 GW are curently the subject of calls for tenders.

However, 60% of the electricity mix is based on intermittent energy (solar and wind) and the country is dependent on imports from Norway to balance its grid. Nevertheless, electrolysers require a high continuous charge factor to secure business models (>90%). Production through wind or solar energy could therefore be combined with battery electricity storage.



Focus on a project:

The project led by Reintegrate and Advent at Skive plans to produce 3.4 ktoe/year of emethanol. The site will generate its own energy, thanks to a park of 54 MW of wind energy and 26 MW of solar energy. In addition, the site will also be connected to the electricity transmission network with a 150kV connection.

*IEA

Focus on Denmark – Carbon needs

Based on announced projects

In 2022, Denmark's CO_2 emissions reached **29.1 Mt.** The main emitting sectors are transport (28%), followed by agriculture (23%) and electricity production (19%)*. **Industrial processes represent only 4% of total emissions.** Efforts **made in the energy sector** , with emissions reducing by more than half since 2005, have contributed significantly to the reduction in total emissions. The **government also plans to boost renewable energy production, carbon capture and utilization technologies as well as large Power to X projects.**

Indicators

05.

Carbon requirement planned projects

3 Mt / year

Notes on reading the indicator

Carbon is used as an input, along with hydrogen, for the synthesis of e-methane, e-methanol, e-kerosene, e-diesel and e-gasoline. The production of e-ammonia, as well as the electro-sourced part of e- biofuels , does not include the use of carbon.

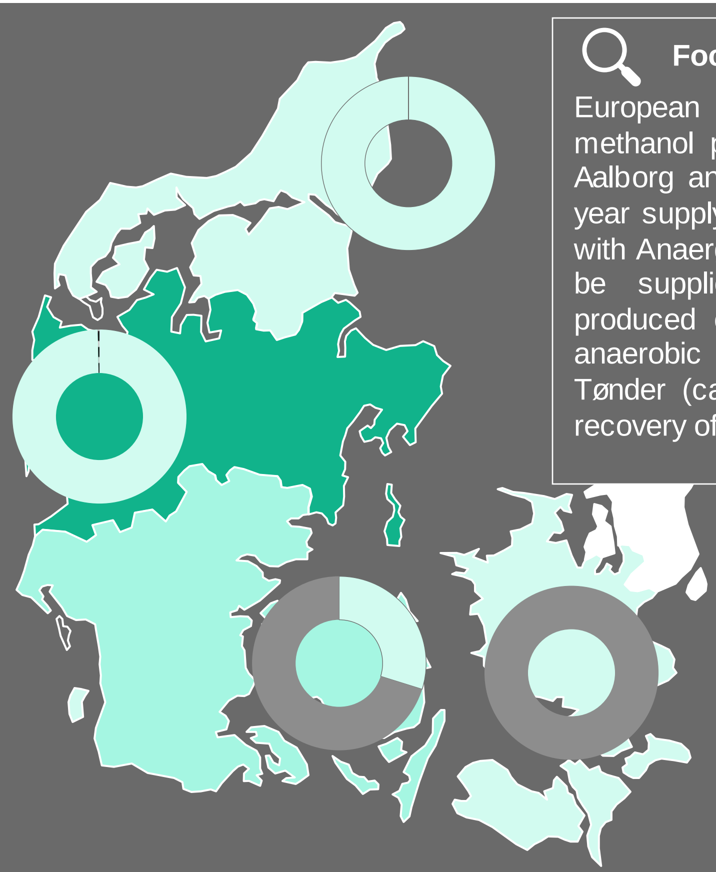
Regional carbon needs (kt / year)	**Share of need per e-fuel**
0	e-methane
] 0 ; 500]	e-methanol
] 500; 1000]	e-kerosene
] 1000 ; 1500]	e-ammonia
] 1500; 2000]	e-essence
> 2000	e-diesel

In 2023, a Danish government report estimated carbon capture capacity at 10.8 Mt/year by 2040.

Current CO_2 capture projects are primarily focused on CO_2 storage. However, support policies (CCUS Fund, NECC and GSR) do not exclude projects based on the use of CO_2, such as e-fuels projects.

Denmark is actively developing biogas production sites (20 PJ in 2020 and 94 PJ planned for 2040), which could serve as sources of biogenic CO_2 for the production of e-fuels. In its report (2022), the EBA** estimates the current captureable potential at 0.7 Mt/year.

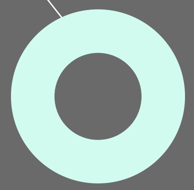
The implementation of the second part of the Danish CCS strategy also involves the analysis of the interest of DAC (Direct Air Capture) technologies and the reduction of their cost, which could benefit the e-fuels sector.



Focus on a project:

European Energy, which has 3 e-methanol production projects in Kassø, Aalborg and Padborg, has signed a 10-year supply agreement for biogenic CO_2 with Anaergia for 60kt/year. The CO_2 will be supplied in liquefied form and produced on a particularly large scale anaerobic digestion site operated by Tønder (capacity of 40 Mm3/year, with recovery of 900 kt/year of biomass)

Projects with unannounced location



* Denmark's Global climate impact report 2023 ** European Banking Authority

Focus on Denmark – Water consumption

Based on announced projects

In 2022, Denmark's total water consumption was **934 Mm³** *, of which 25% was for household consumption. Agriculture represents 59% of this consumption, followed by the manufacturing industry (6%). Denmark is not **subject to issues of shortages or scarcity of water supply**, or very exceptionally. The **quality of drinking water resources** is among the best in Europe. The **cost is also among the highest on the continent**, which also discourages unnecessary use.

Indicators

06.

Water consumption requirements of planned projects

7.1 Mm³ / year

Notes on reading the indicator

- 7.1 Mm³ consumed
- 13 Mm³ taken and returned (according to technological choices)

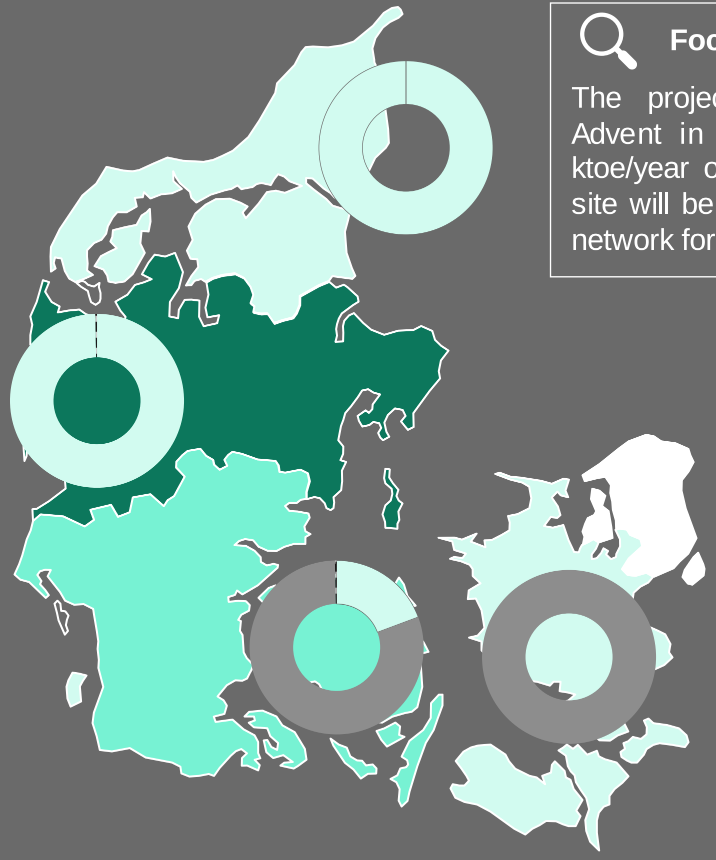
Electrolysis and CO2 capture consume water. The cooling water from electrolyzers and equipment allowing the synthesis of e-fuels can be returned to the environment.

Regional water requirements (Mm3 / year)	Share of need per e-fuel
0	e-methane
] 0 ; 1]	e-methanol
] 1 ; 2]	e-kerosene
] 2 ; 3]	e-ammonia
] 3 ; 4]	e-essence
> 4	e-diesel

Denmark has a decentralized supply structure where drinking water is produced locally in one of the country's 2,600 public water stations.

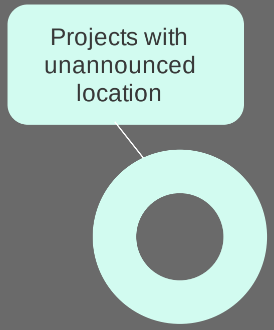
The country applies the "polluter pays" principle, meaning that those responsible for pollution must also bear the costs of managing it in order to avoid damage to human health or the environment.

As long as there is an appropriate water management plan and a guarantee on the quality of the water returned, the question of water supply does not seem to be a real issue for the development of e-fuels projects in Denmark.



Focus on a project:

The project led by Reintegrate and Advent in Skive plans to produce 3.4 ktoe/year of e-methanol. The production site will be connected to the local water network for its supply.



* Statistics Denmark, 2022

Focus on Denmark – Financing needs

Based on announced projects

The Ministry of Climate and Energy published in 2022 its **strategy for adapting** the regulatory framework, developing the necessary infrastructure and exporting products and technologies linked to e-fuels. The country has set the objective of installing **4 to 6 GW of electrolysis capacity by 2030**. Since 2021, the **Green Fuels mission,** working for the incorporation of green fuels in the transport and industrial sector, has benefited from a budget **of €38 M** allocated by the Research Reserve of the Danish Innovation Fund. In 2023, a **call for tenders** was launched by the ministry for the allocation of **€170 M in subsidies for PtX projects** over 10 years.

Indicators

07.

Financing requirements for planned projects

€11.6 bn

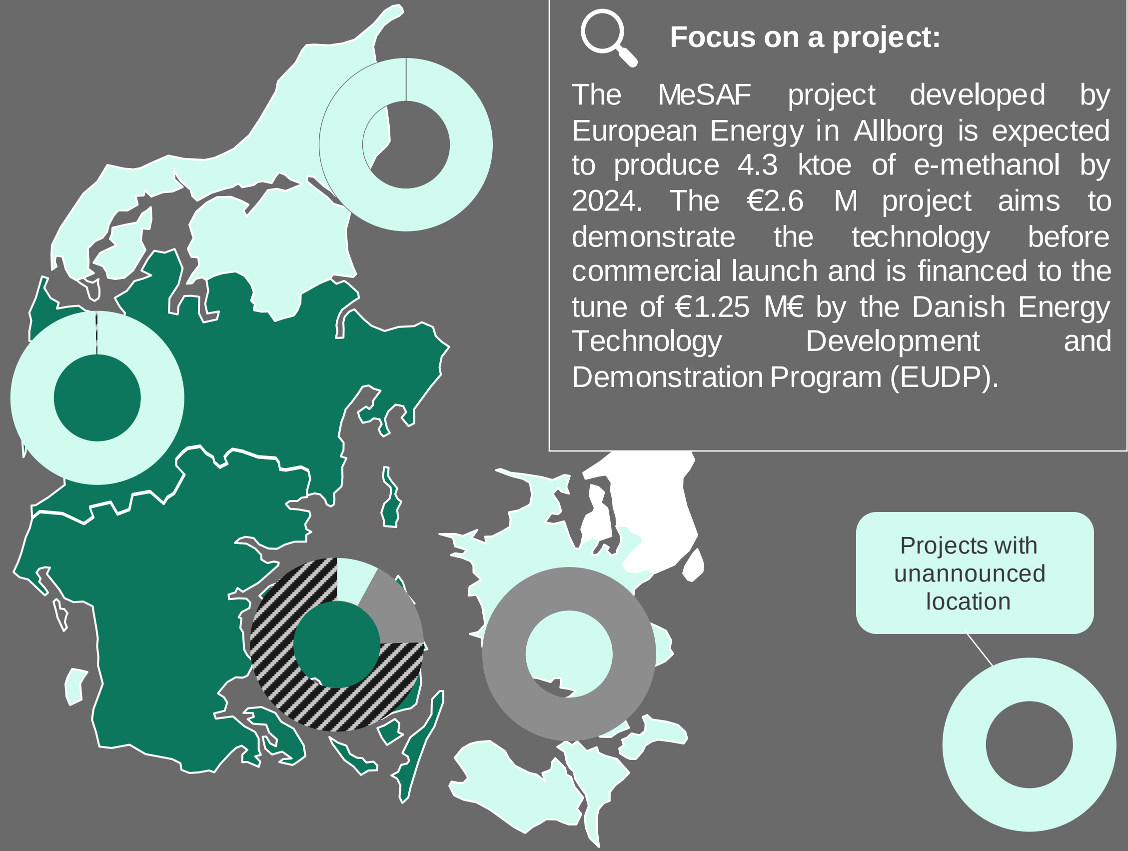
Notes on reading the indicator

Many projects do not disclose their level of investment or have not yet reached this stage. We extrapolated the financing needs by comparison with existing funded projects.

Financial need - regional cement (€bn / year)	Share of need per e-fuel
0	e-methane
] 0 ; 1]	e-methanol
] 1 ; 2]	e-kerosene
] 2 ; 3]	e-ammonia
] 3 ; 4]	e-essence
> 4	e-diesel

Slightly under half of announced projects in Denmark have reached a final investment decision and are operating (5 out of 12) showing the strength of developers' business models.

Denmark operates a €2.15 bn CCUS fund aimed at promoting CO2 capture and use technologies. The country recently launched a call for tenders in 2023. 2 e-fuels projects have been named: Padborg PtX and Kasso PtX Expansion, supported by European Energy. Several projects have also benefited from government subsidies through the UEDP: Skive, Ramme (€11M), MeSAF (€1.25M), Green Fuel for Denmark (€1.25M).



Focus on a project:

The MeSAF project developed by European Energy in Allborg is expected to produce 4.3 ktoe of e-methanol by 2024. The €2.6 M project aims to demonstrate the technology before commercial launch and is financed to the tune of €1.25 M€ by the Danish Energy Technology Development and Demonstration Program (EUDP).

Part 2 .

Overview of Dynamics in selected countries

Europe

- Spain

Focus on Spain – General context

Spain has clear potential for the development of an e-fuels sector. The country has witnessed a **significant shift towards the installation of renewable energy** to reduce its GHG emissions and is **the 3rd European country with the largest** renewable energy production capacity. Its electricity mix comes **from renewable energy production for 60%** in 2022 and **the associated electricity price is one of the lowest in Europe**, particularly for solar and wind PPAs. Spain is also facing the **challenge of decarbonizing its petrochemical sector**, which represents 6.1% of national GDP.

Public support and policies

Plan Nacional Integrado de Energía y Clima – PNIEC 2021-2030 (2020, updated 2023)*: provides 11 GW of installed electrolyser capacities, 20 TWh of biogas produced, 62 GW of wind production and 76 GW of solar and 22 GW of capacities storage. Renewable energies are expected to represent 81% of the country's electricity mix in 2030.

Hoja de Ruta del Hidrógeno (2020, updated 2023)* : identifies the challenges and opportunities related to the development of renewable hydrogen in Spain and expresses a series of measures intended to stimulate investments and aligned with the objectives set by the EU and the PNIEC .

Plan de Recuperación, Transformación y Resiliencia - PERTE (2021):** Recovery plan divided into different themes which will receive €160 Bn from the NextGeneration EU recovery fund. The « PERTE de energías renovables, hidrógeno renovable y almacenamiento » (PERTE ERHA), will receive €6.92 Bn from PERTE and €9.45 Bn from the private sector for energy transition projects. This plan especially aims at allocating €1.6Bn in public funds for the development of hydrogen projects with additional private financing of €2.8 Bn.

- **MITECO "H2 Pioneros " program (2023)***** : 2 rounds of subsidies worth €150M each. These are 31 projects rewarded in 2023, including 3 e-fuels projects in the second round (Musel GreenMet , GP H2 As Pontes, H2OSSA).
- **H2 Cadena de Valor of MITECO (2021-2023)***** : 4 call for tender programs amounting to €266 M in investments.

6 rounds of calls for tenders

For grants to H2 projects

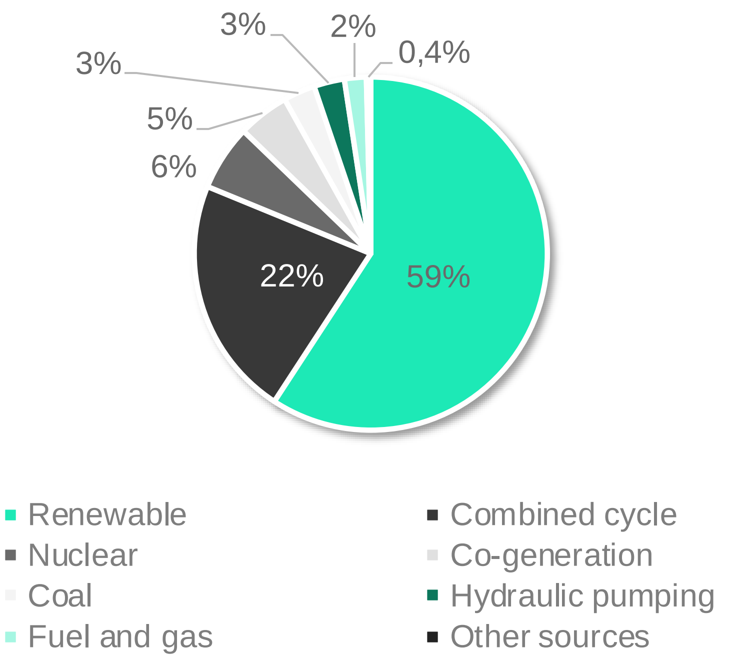
11 GW in 2030

Targeted electrolysis capacity

€4.2 Bn for H2 projects

Amount planned by the public and private sectors

Electricity mix in Spain (Red Eléctrica , 2022)



* MITECO: Ministerio para la Transición Ecológica y el Reto Demográfico , ** Plan de Recuperación, Transformación y Resiliencia, *** IDEA: Institute for Diversification and savings _ of energies

Focus on Spain – Dashboard of indicators 2030

Total projected capacities in 2030

1,292 ktoe/year

01 Production capacity of projects under construction or in activity

0 ktoe / year

02 Production capacity of projects with FID

0 ktoe / year

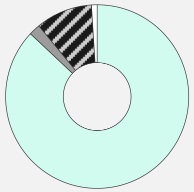
03 Production capacity of projects under study

1,292 ktoe / year

04 Electricity requirement

36 TWh / year*

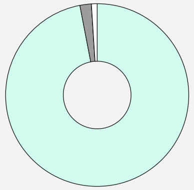
31 TWh: water electrolysis
5 TWh: synthesis of e-fuels



05 Carbon requirement

3.3 $MtCO_2$ / year

To be captured in biomass or industry

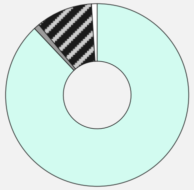


06 Water requirement (water consumed)

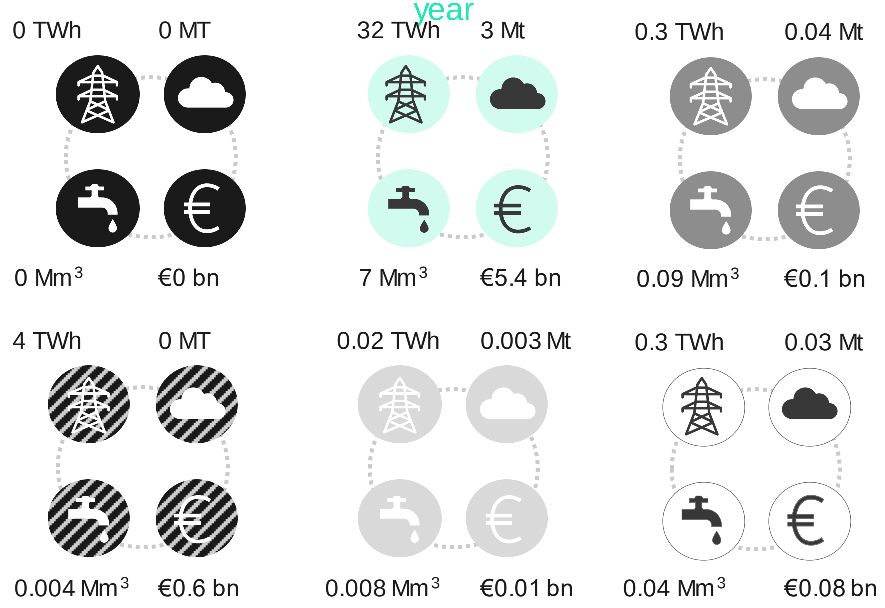
7.2 Mm^3 / year

07 Financing requirement

€10.7 bn



Quantities of resources to be mobilized per molecule / year



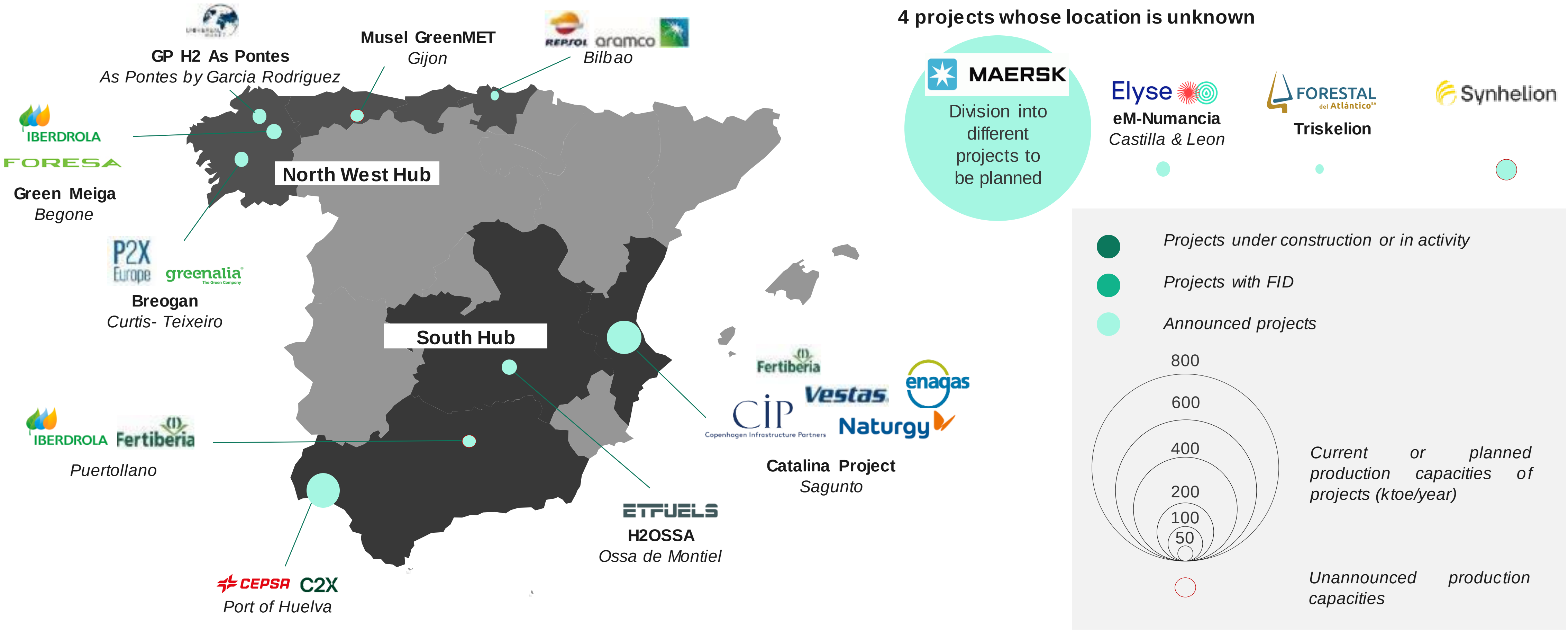
Legend

- e-methane
- e-ammonia
- e-methanol
- e-essence
- e-kerosene
- e-diesel

* Electricity requirements: based on an hypothesis of an overall energy efficiency of 45% by 2030 for all e-fuels value chain. **55% of energy efficiency achievable in the long run.**

Focus on Spain – Overview of publicly announced projects

We identify **13 projects** in Spain that are still under study. Among these projects, the company **Synhelion** does not communicate the molecule(s) it plans to develop, only the uses planned for aviation, maritime and road transport. We also do not yet have access to data concerning the production capacities planned for 3 projects Synhelion Solar, Musel GreenMEt and the one supported by Iberdrola and Fertiberia. All the projects are concentrated in **2 hubs** that we will use as subjects of our study: the **North-West and the South**. The **precise location of 3 projects remains unknown.**



Focus on Spain – Actors

The **Spanish government** is involved in the development of an e-fuel project through the **joint venture with Maersk, which represents 72% of the announced production capacities**. Overall, the announced projects are carried out by various actors. **Historical players** (Repsol, Aramco , Maersk, Naturgy) are positioned but most of the projects are carried out by **pure players** (Synhelion , ET Fuels, Elyse, C2X, P2X Europe). We also note the positioning of **developer of renewable energy projects** (Universal Kraft, Vestas , Enagas).

01. Constructed and/or acti

02. Financed

03. Under study

Repsol, Aramco 2025 e-essence e-kerosene	**Synhelion Solar** Synhelion 2025-2026 Unknown	**Port of Hueva** C2X, CEPSA 2025-2026 e- methanol	**Breogan** P2X Europe, greenalia 2027 e-kerosene e-diesel	**Catalina project** Vestas, enagas, Fertiberia, Naturgy 2027 e-ammonia	Iberdrola, Fertiberia Unknown e-ammonia	**Triskelion** Forestal del Atlántico 2028 e-methanol
Maersk Project Maersk Unknown e-essence e- methanol	**eM-Numancia** Elyse 2027 e- methanol	**Mussel GreenMet** Unknown e- methanol	**Mussel GreenMet** ETFUELS 2027-2028 e-methanol	**GP H2 As Pontes** Universal Kraft Unknown e-ammonia	**Green Meiga** Iberdrola, Foresa Unknown E-methanol	

Focus on Spain – E-fuel production capacity

Based on announced projects

all the identified projects to date combined, the production is estimated to be **1,292 ktoe/year by 2030** . All projects are still **at the study stage.** Most capacities are planned for 2030, **although 5 projects** have **not communicated a date.** It is worth to note that the construction of a production plant generally takes 3 years after a final investment decision has been taken.

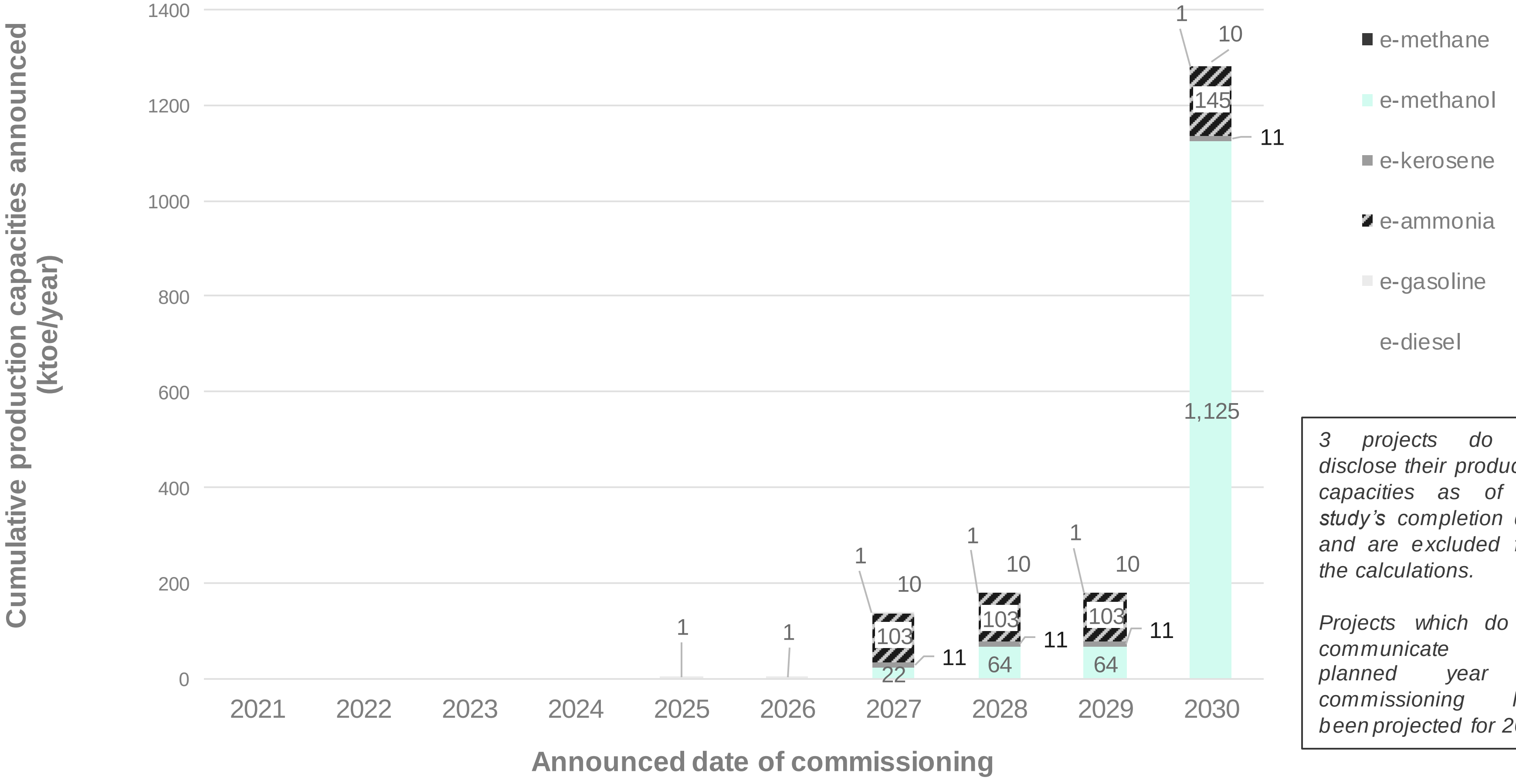
Indicators

01. **Active capacities / Under construction:**
0 ktoe/year

02. **Projects with FID:**
0 ktoe/year

03. **Projects under study:**
1,292 ktoe/year

	Production capacity (ktoe/year)	Number of projects
e-methane	0	0
e-methanol	1125	7
e-kerosene	11	2
e-ammonia	145	3
e-essence	1	2
e-diesel	10	1
Total	**1,292**	**13**



3 projects do not disclose their production capacities as of the study's completion date and are excluded from the calculations.

Projects which do not communicate the planned year of commissioning have been projected for 2030.

*Some projects are developing several molecules and have been counted for each molecule, explaining the difference between the total sum of projects per molecule and the total number of projects announced.

Focus on Spain – Electricity needs

Based on announced projects

Renewable and nuclear energies accounted for **64% of the Spanish electricity mix in 2022**. **Wind power** leads the mix (22%), with a growth of 5.3% (Nov 2022 - Nov 2023), but **solar** recorded the strongest increase (nearly 34% over the same period) and accounted for 14.5 % of the electricity mix. Over the last 5 years, these two sources of production have seen an **increase of 71.5%.** These developments represent an **integration challenge** for the electricity system which has **limited interconnection and storage capacity.** .

Indicators

04.

Electrical requirement of planned projects

36 TWh / year

Details on how to read the indicator

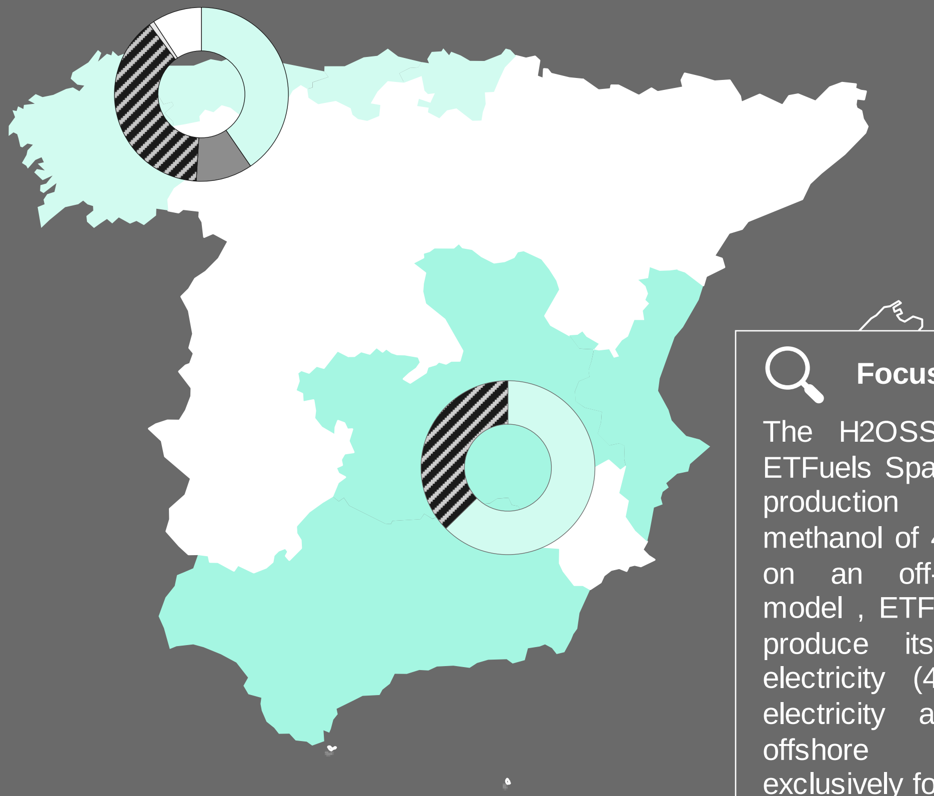
- 31 TWh: water electrolysis
- 5 TWh: synthesis of e-fuels

For an overall energy efficiency of 45% for the whole value chain. Overall energy efficiency of 55% achievable in the long run.

Regional electricity needs (TWh / year)	Share of need per e-fuel
0	e-methane
] 0 ; 5]	e-methanol
] 5 ; 10]	e-kerosene
] 10; 15]	e-ammonia
] 15; 20]	e-essence
> 20	e-diesel

Total electricity production amounted to 276 TWh in 2022, including 116.5 TWh from renewable sources. The five-year plan (2022-2027) includes the development of 1 to 3 GW of offshore wind power*. The total needs represent 9% of the renewable electricity production projected for 2030. However, the Spanish mix impacted by intermittent energies could involve the development of battery electricity storage.

Half of the e-fuel production projects announce electricity production on site or nearby. Projects wishing to obtain supplies by signing a renewable PPA contract can benefit from the lowest prices in Europe (€40.9/MWh), just behind Portugal (€39.6/MWh)**.



Focus on a project:

The H2OSSA project led by ETFuels Spain plans to reach a production capacity of e-methanol of 43k toe/year. Based on an off-grid development model , ETFuels Spain plans to produce its own renewable electricity (420 MW of solar electricity and 120 MW of offshore wind) intented exclusively for the project.

** French Ministry of Economy, Finance and Industrial and Digital Sovereignty ** El Periódico de la Energía*

Focus on Spain – Carbon needs

Based on announced projects

CO_2 emissions in Spain in 2022 were **248 Mt** (+3.1% compared to 2021). The sectors with the highest level of emissions are **transport (30%), industry (22%), agriculture (12%) and electricity generation (11%)*.** The most emitting industrial activities are the **refinery, the cement plant, the production and processing of metals, and the production of pulp and paper**. So far, Spain has done little to promote the deployment of carbon capture technologies and its use into the public debate.

Indicators

05.

Carbon requirement planned projects

3.3 Mt/year

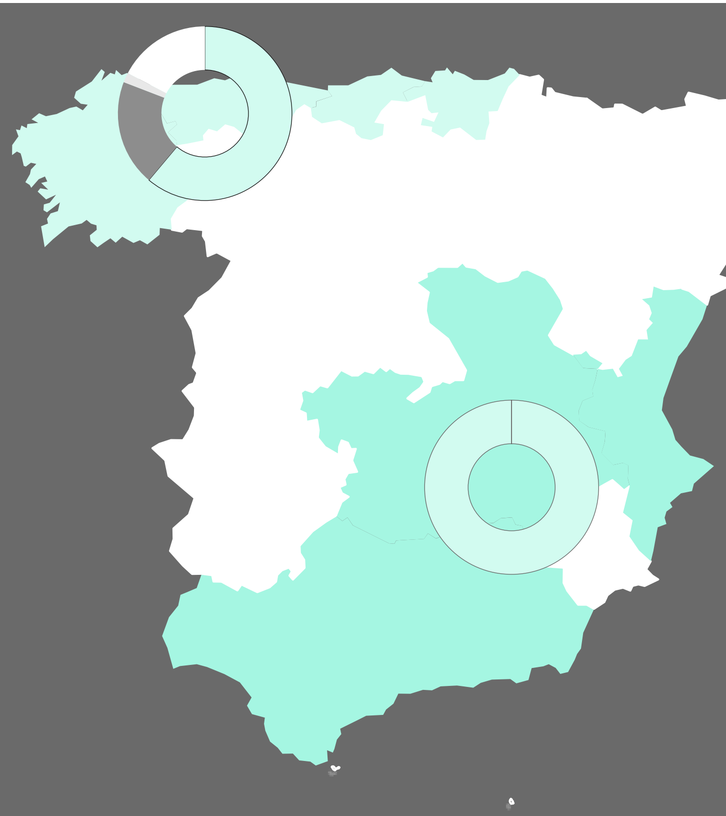
Notes on reading the indicator

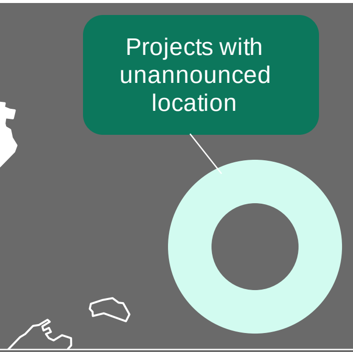
Carbon is used as an input, along with hydrogen, for the synthesis of e-methane, e-methanol, e-kerosene, e-diesel and e-gasoline. The production of e-ammonia, as well as the electro-sourced part of e- biofuels , does not include the use of carbon.

Regional carbon needs (kt / year)	Share of need per e-fuel
0	e-methane
] 0 ; 500]	e-methanol
] 500; 1000]	e-kerosene
] 1000 ; 1500]	e-ammonia
] 1500; 2000]	e-essence
> 2000	e-diesel

The country has significant potential for CO_2 capture, which is largely sufficient to meet its carbon requirements. The cement industry alone emits nearly 20 Mt of CO_2/year, with a production spread across the entire country. The North of Spain concentrates CO_2 deposits from the pulp and paper industry (3 Mt/year), iron and steel industry (5.3 Mt/year).
Existing gas pipelines can be used to transport CO_2 . The gas network serves the entire territory and is interconnected with Portugal.

All the 4 projects reporting on their CO_2 supply plan to obtain biogenic CO_2 from nearby sources.





Focus on a project:

Greenalia and P2X Europe project in Curtis-Teixeiro will produce 10ktoe/year of e-kerosene and 10ktoe/year of e-diesel by 2027. The project operators anticipate a need of around 70,000 t/year and plan to use biogenic CO_2 captured from Greenalia's nearby biomass cogeneration plant.

** Norvento Enerxia*

Focus on Spain – Water consumption

Based on announced projects

According to the hydrographic basin management plans, water consumption in Spain in 2020 was around **2,291 Mm³ /year***. **Irrigation and agricultural uses represent approximately 80.5%**, followed by **urban consumption which represents 15.5%.** The **rest is for industrial use** (food, paper and chemical industries). Spain is facing a **water management challenge** and the government has adopted different **action plans for the Minor Sea and the Doñana Park** and a **strategic plan for wetlands** . MITECO** is also engaged in revising and updating the **Special Drought Plans** .

Indicators

06.

Water consumption requirements of planned projects

7.2 Mm³ / year

Notes on reading the indicator

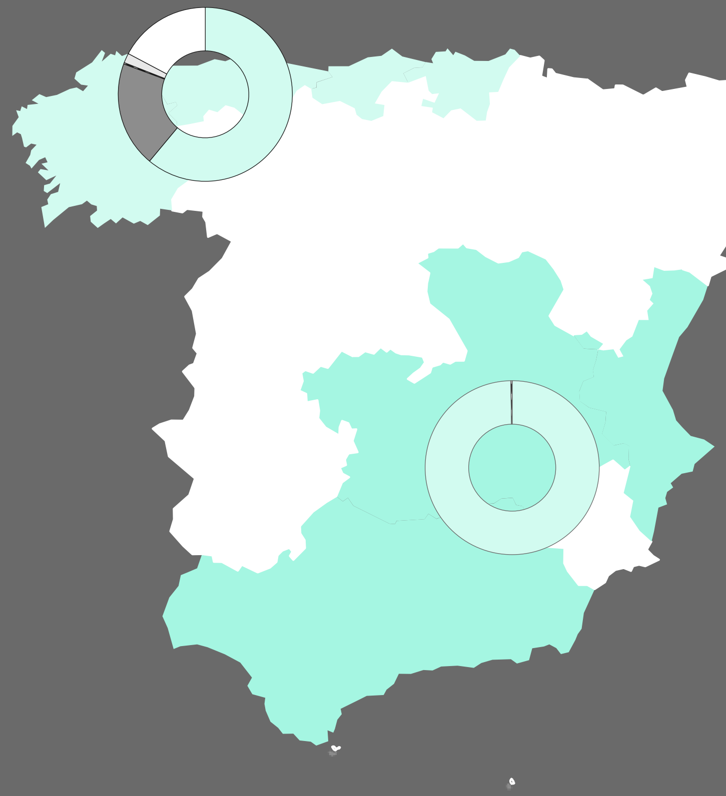
- 7.2 Mm³ consumed
- 12.6 Mm³ taken and returned (according to technological choices)

Electrolysis and CO2 capture consume water. The cooling water from electrolyzers and equipment allowing the synthesis of e-fuels can be returned to the environment.

Regional water needs (Mm3 / year)	Share of need per e-fuel
0	e-methane
] 0 ; 1]	e-methanol
] 1 ; 2]	e-kerosene
] 2 ; 3]	e-ammonia
] 3 ; 4]	e-essence
> 4	e-diesel

The water requirement, which amounts to 19.8 Mm³, including withdrawn and returned water, represents a supply challenge. 67% of the country is affected by desertification. The rainfall rate is only 85% of the European average. As a result, most hydrographic basins do not reach 60% of their total water reserve capacity.

The unequal distribution of resources creates competition and rivalries between autonomous communities, especially regarding the waste of resources. The North Hub is a region with few shortages, unlike the Southern Hub, a large agrarian region. However, the Southern hub already has a significant number of projects.



Focus

The IRENA (International Renewable Energy Agency) report published in December 2023 estimated that 40% of hydrogen projects, strategically located in the sunniest areas for the production of renewable energy, were in regions under high water stress. The Southern Hub already has 4 e-fuels projects.

** Institute Nacional de Estadisticas , 2020 **MITECO = Ministerio para la Transición Ecológica, Ministry of Transition ecological*

Focus on Spain – Financing needs

Based on announced projects

The development of an e-fuels or alternative fuels sector is not the aim of a specific financing policy in Spain, but **a Hydrogen roadmap** was published in 2020. **PERTE* 2021**, a recovery plan divided into different themes, includes **public and private funding for hydrogen projects to the tune of €4.2 bn**.

Indicators

07.

Financing requirements for planned projects

€10.7 bn

Notes on reading the indicator

Many projects do not disclose their level of investment or have not yet reached this stage. We extrapolated the financing needs by comparing them with existing funded projects.

Regional Financial requirements (€bn / year)

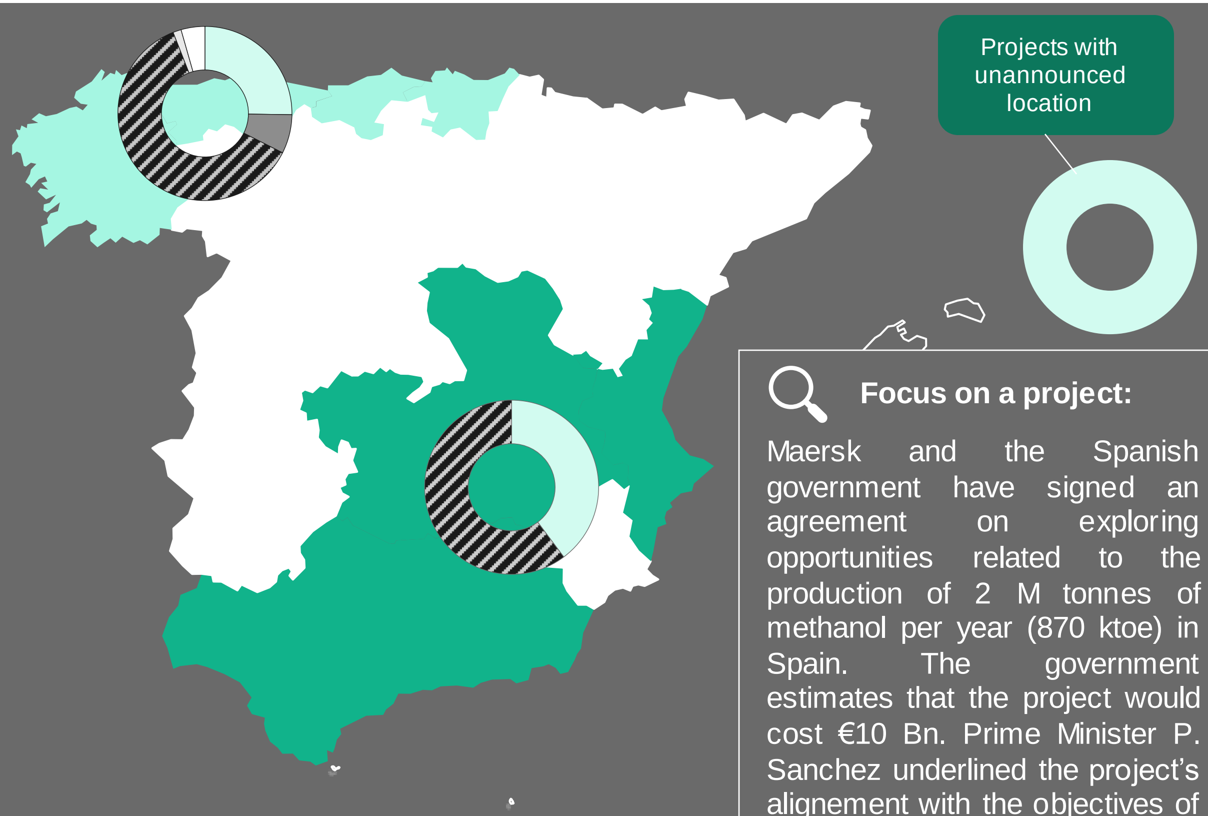
- 0
-] 0 ; 1]
-] 1 ; 2]
-] 2 ; 3]
-] 3 ; 4]
- > 4

Share of need per e-fuel

- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

So far no e-fuels project has reached a final investment decision. The funding announced by the government can help to secure business models. The two subsidies rounds for 2023 from MITECO's "H2 Pioneros " program granted €300 M to 31 projects, including 3 e-fuels projects in the second round: Musel GreenMet , GP H2 As Pontes and H2OSSA.

The first subsidies linked to PERTE-ERHA for 2023 projects have started to be distributed (including €25 M for hydrogen production).



Focus on a project:

Maersk and the Spanish government have signed an agreement on exploring opportunities related to the production of 2 M tonnes of methanol per year (870 ktoe) in Spain. The government estimates that the project would cost €10 Bn. Prime Minister P. Sanchez underlined the project's alignement with the objectives of the hydrogen roadmap.

** Recovery, Transformation and Resilience Plan*

Part 2 .

Overview of Dynamics in selected countries

Europe

- Sweden

Focus on Sweden – General context

With an almost carbon-free electricity production, Sweden is positioning itself as a leader in the transition and seeks to achieve **carbon neutrality by 2045** . Two challenges lie ahead: decarbonizing industrial processes and the transport sector. The government has set ambitious targets associated with funding programs but these are not focused on specific applications. Thanks to the impulsion of the EU, **national interest has quickly grown. The regions have taken initiatives, taking advantage of European subsidies, to position themselves in emerging hydrogen sectors (green hydrogen, e-fuels).**

Public support and policies

GHG reduction mandate (2017)**: Fuel suppliers must reduce their GHG emissions each year by a certain percentage, through **the incorporation of biofuels and e- biofuels .**

Fossil Free Sweden (2015)*: Initiative launched by the government bringing together private and public stakeholders to propose policy measures presented to the government **and leading in to the publication of a hydrogen strategy in 2021** .

National Hydrogen Strategy (2021)**: Formulated by the Swedish Energy Agency, it overlaps with the main provisions of the EU strategy and Fossil Free Sweden . It sets a target for installed electrolysis capacities of 5 GW by 2030 and 15 GW by 2045.

Climate Leap (2015)**: the Environmental Protection Agency offers financial support for low-carbon projects in sectors that are not covered by the EU-ETS. Over the period 2015-2022, 74 applications for hydrogen-related projects were received, including 49 in 2021, and 41 received a grant, including 29 in 2021. Financed by the NextGenerationEU fund to the tune of €810 M.

Industrial Leap (2018)**: The Swedish Energy Agency promotes research and demonstration projects to decarbonize industry. Financed by NextGenerationEU to the tune of €287 M.

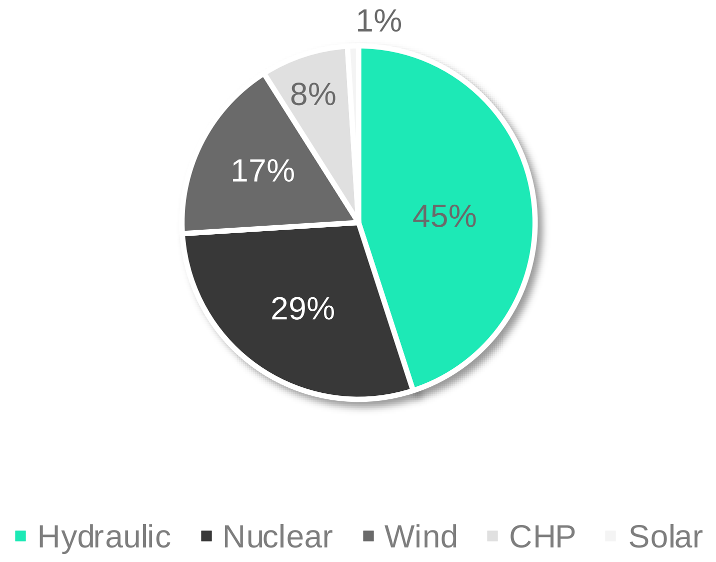
IPCEI Hydrogen – Sweden (2021)*: the Swedish Energy Agency ensures national participation by allocating funds (€18 M in 2021 and 2022).

41 projects
Subsidized by Climate Leap 2015-2022

5 GW in 2030
Electrolysis capacity

€1.1 Bn to invest
In R&D and low-carbon projects

Electricity mix in Sweden (Swedish Energy Agency, 2022)



** Fossil Free Sweden ; ** RIFS Potsdam: Potsdam Research Institute for Sustainable Development*

Focus on Sweden – Dashboard of indicators 2030

Total projected capacities in 2030

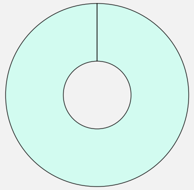
472 **ktoe/year**

01 Production capacity of projects under construction or in activity

0 ktoe / year

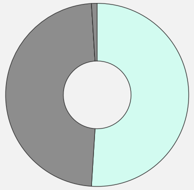
02 Production capacity of projects with FID

22 ktoe / year



03 Production capacity of projects under study

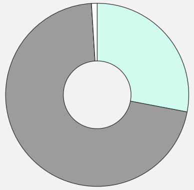
450 ktoe / year



04 Electricity requirement

13 TWh / year*

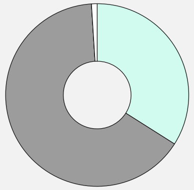
11 TWh: water electrolysis
2 TWh: synthesis of e-fuels



05 Carbon requirement

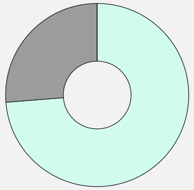
1.4 $MtCO_2$ / year

To be captured in biomass or industry



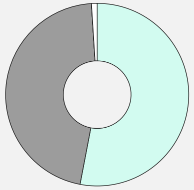
06 Water requirement (water consumed)

0.6 Mm^3 / year



07 Financing requirement

36.1 SEK
€3.2 bn



Quantities of resources to be mobilized per molecule / year

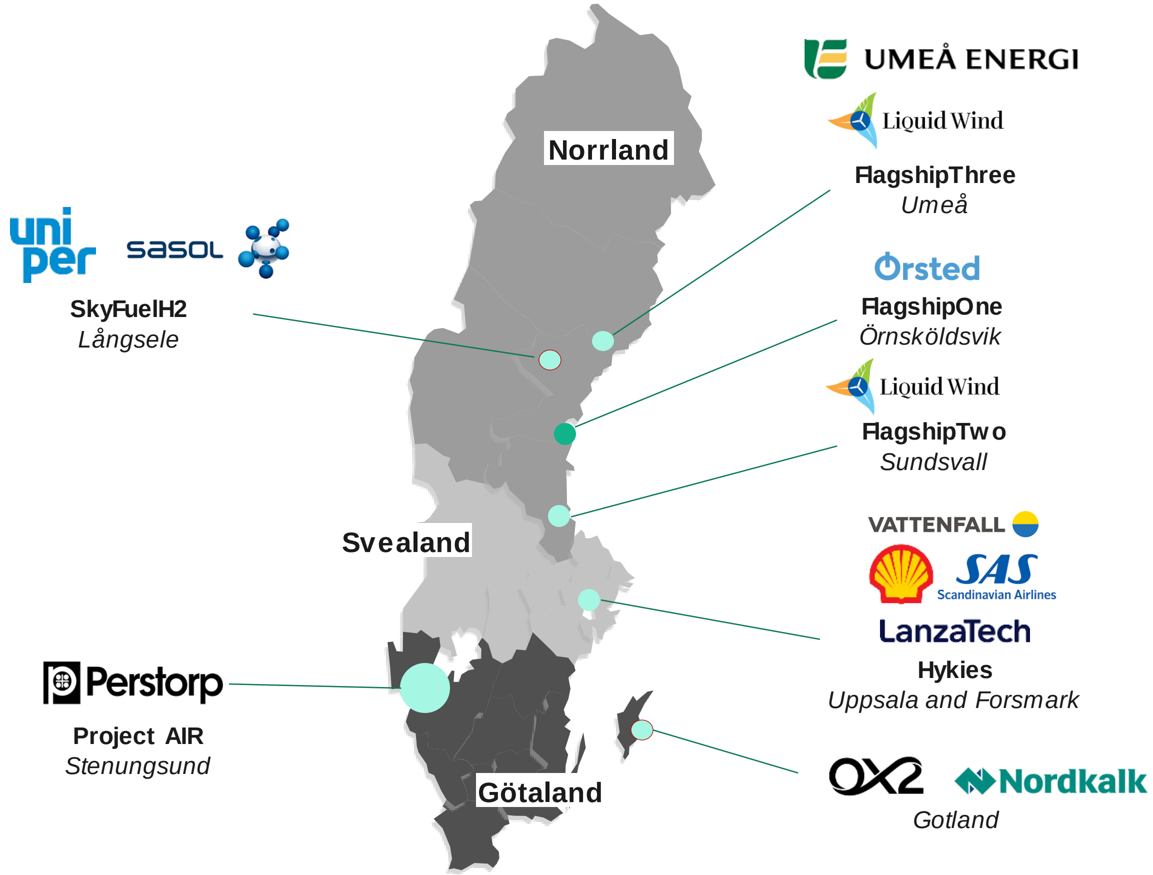
Legend

e-methane
e-methanol
e-kerosene
e-ammonia
e-essence
e-diesel

* Electricity requirements: based on an hypothesis of an overall energy efficiency of 45% by 2030 for all e-fuels value chain. **55% of energy efficiency achievable in the long run.**

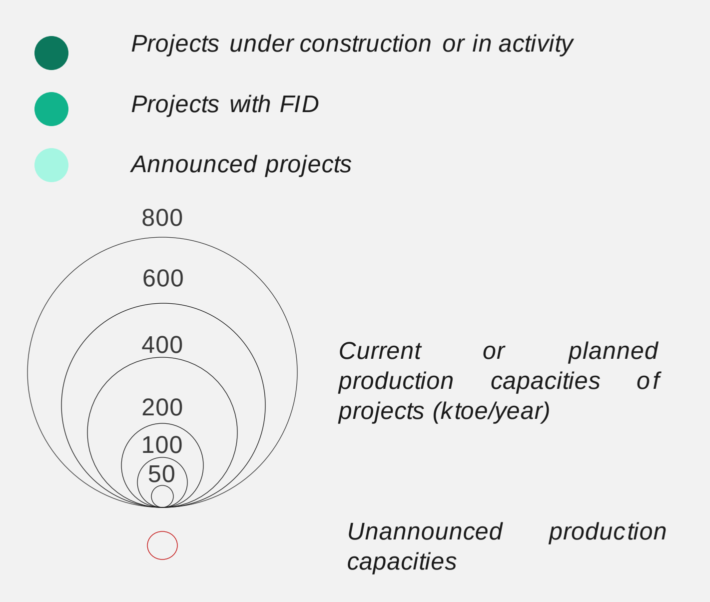
Focus on Sweden – Overview of publicly announced projects

We have identified **8 projects in Sweden**, at various stages of development: **1 project benefits from an FID and the 7 others are still under study**. Among these projects, the project led by OX2 and Nordkalk has not yet communicated the planned production capacities. Vattenfall and st1 have not yet communicated the exact location of their project. All projects are concentrated on the east coast of Sweden. The **Norrland region accounts for half of the projects**, but the **Götaland region accounts for more than a third of the capacities**.



1 project whose location is unknown

VATTENFALL, st1



Focus on Sweden – Actors

Projects in Sweden are almost all still at the study stage. Two players are particularly active: **Liquid Wind and Vattenfall**. Liquid Wind, a pure player created in 2017, operates 2 projects and recently sold the FlagshipOne project to Orsted. **The major historical energy companies carry out numerous projects** (Vattenfall, Sasol, Uniper, Orsted, Shell, Perstorp). Lanzatech and ST1 are also positioning themselves in **collaboration with large historical energy companies** (Vattenfall and Shell), while operating in related activities: biofuels for Lanzatech while ST1 is diversifying further towards CCUS technologies and renewable energies.

01. Constructed and/or acti

02. Financed

FlagshipOne
Orsted
2025
e- methanol

03. Under study

Project	Actors	Date	Product
FlagshipTwo	Liquid Wind	2026	e- methanol
FlagshipThree	Liquid Wind, UMEÅ ENERGI	2026	e- methanol
HySkies	Vattenfall, Shell, LanzaTech, SAS Scandinavian Airlines	2027	e-kerosene, e-diesel
Project AIR	Perstorp	2026	e- methanol
Gotland	OX2, Nordkalk	Unknown	Unknown
SkyFuelH2	Uniper, Sasol	2028	e-kerosene
Vattenfall and St1 Nordic Oy	Vattenfall, st1	2029	e-kerosene

Focus on Sweden – Production capacity of e-fuels

Based on announced projects

Combined together, all the identified projects to date, represent an estimated production capacity of **472 ktoe/year by 2030.** Most projects are still **at the study stage**, only 1 project has passed the FID stage. The projections for the commissioning of all the extend beyond 2025, knowing that one **project has not communicated a commissioning date and another one has not communicated the planned production capacities**. NotIt is worth noting that the construction of a production plant generally takes 3 years after a final investment decision has been taken.

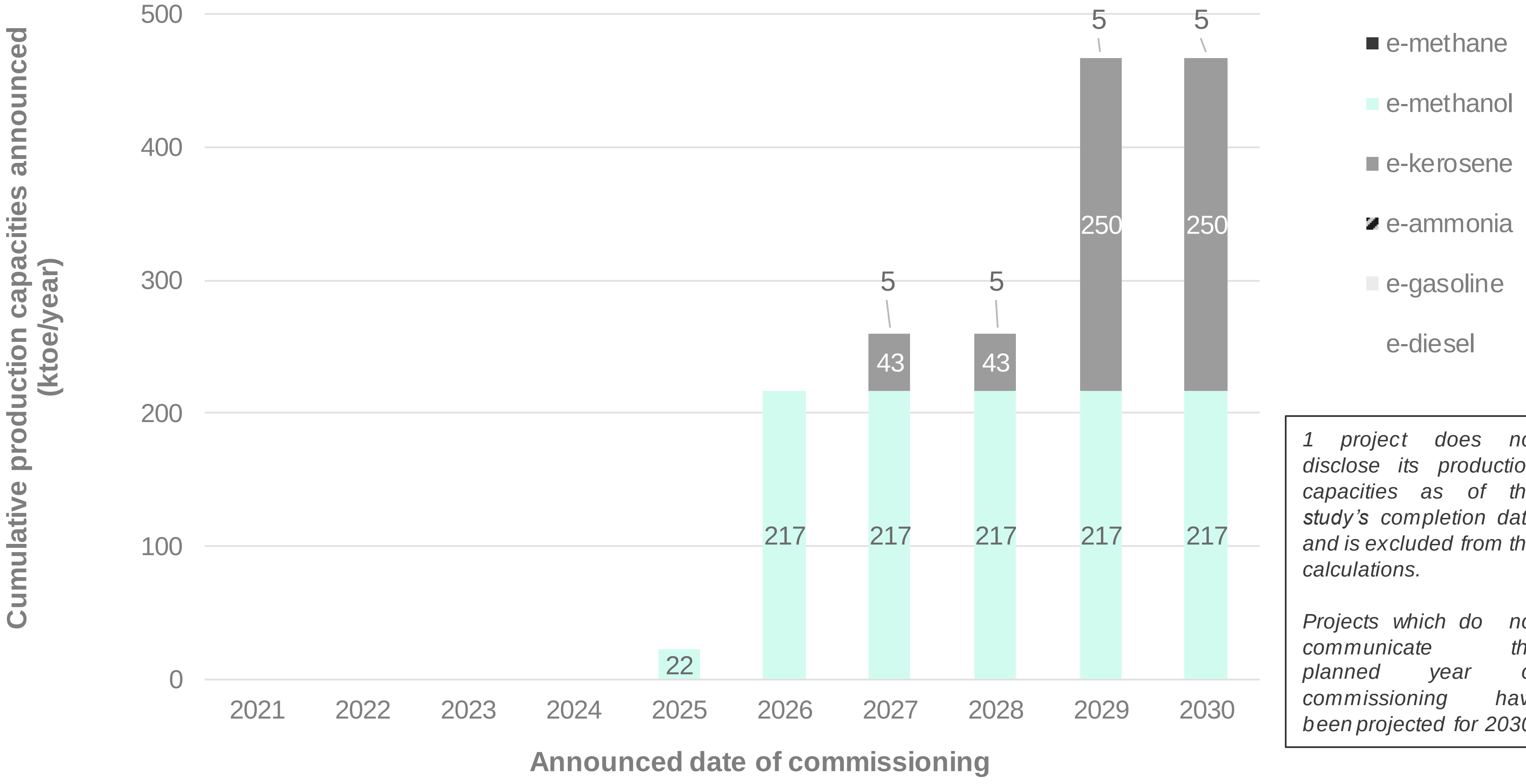
Indicators

01. **Active capacities / Under construction:**
0 ktoe/year

02. **Projects with FID:**
22 ktoe/year

03. **Projects under study:**
450 ktoe/year

	Production capacity (ktoe/year)	Number of projects
e-methane	0	0
e-methanol	217	4
e-kerosene	250	3
e-ammonia	0	0
e-essence	0	0
e-diesel	5	1
Total	**472**	**8**



1 project does not disclose its production capacities as of the study's completion date and is excluded from the calculations.

Projects which do not communicate the planned year of commissioning have been projected for 2030.

Focus on Sweden – Electricity needs

Based on announced projects

Sweden's electricity mix is almost entirely decarbonized, with **over 60% coming from renewable sources**. Hydropower represents 45% of the mix, nuclear 29%, wind 17% and cogeneration 8%. Sweden is also a net exporter of electricity, exporting **33 TWh to its neighbors** (Finland, Denmark, Poland and Lithuania). With a target of **100%** renewable energy **by 2040** , the country keeps working on integrating renewable sources, mainly wind power.

Indicators

04.

Electrical need planned projects

13 TWh / year

Details on how to read the indicator

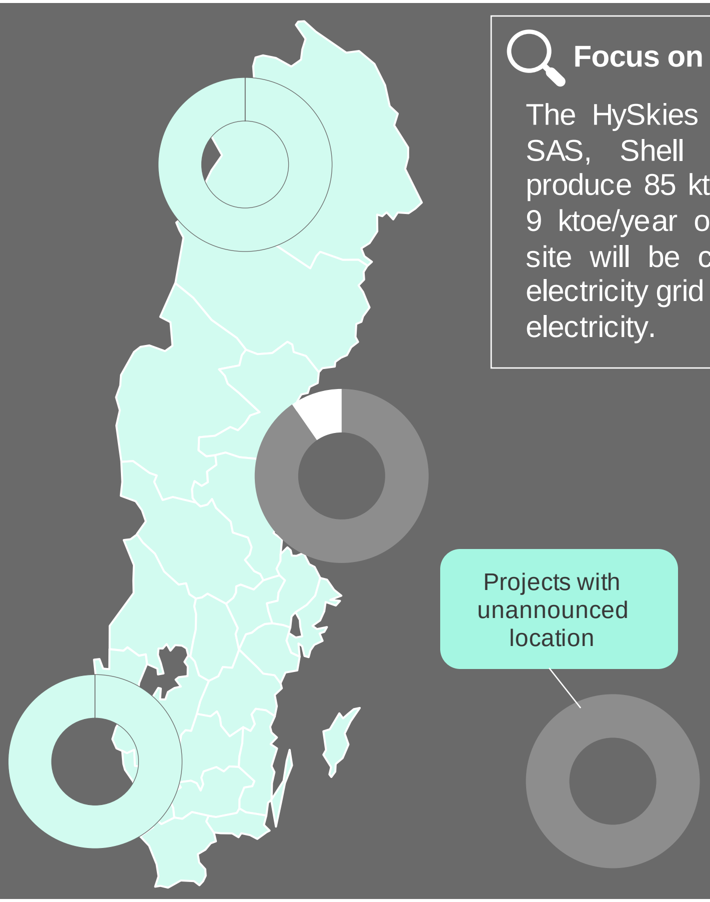
- 11 TWh: water electrolysis
- 2 TWh: synthesis of e-fuels

For an overall energy efficiency of 45% for the whole value chain. Overall energy efficiency of 55% achievable in the long run.

Regional electricity needs (TWh / year)	Share of need per e-fuel
0	e-methane
] 0 ; 5]	e-methanol
] 5 ; 10]	e-kerosene
] 10; 15]	e-ammonia
] 15; 20]	e-essence
> 20	e-diesel

The issue of renewable electricity supply does not seem to be a major issue compared to other countries. The country's electricity mix is almost carbon-free, with 74% nuclear and hydropower, enabling the production of electricity with a high load factor. Sweden is also a net exporter of electricity and is aiming for 100% renewables by 2040.

In January 2022, the government unveiled its intention to produce 120 TWh of offshore wind power in the coming years, according to a plan determined by December 2024. A significant increase as the country's 2022 consumption was 173 TWh . The Swedish Energy Agency has identified three areas in the Gulf of Bothnia, the Baltic Sea and the North Sea, with a total wind power generation potential of 30 TWh per year.



Focus on a project:

The HySkies project led by Vattenfall , SAS, Shell and Lanzatech aims to produce 85 ktoe/year of e-kerosene and 9 ktoe/year of e-diesel. The production site will be connected to the Swedish electricity grid for the supply of renewable electricity.

Focus on Sweden – Carbon needs

Based on announced projects

In 2022, Sweden emitted **40.8 Mt of CO_2***. While being the country with one of the highest per capita energy consumption rates in the EU and the world (TheGlobalEconomy, 2022), Sweden has managed to establish itself as **a global leader in decarbonization** (IEA, 2019). The electricity and heating sectors in Sweden have been largely decarbonized. The main remaining challenge is to **reduce emissions from industrial processes and transport**. The **Climate plan adopted in 2017** include in the carbon emissions reduction strategy, **the use of BECCS/U carbon capture technology.**

Indicators

05. **Carbon requirement planned projects**

1.4 Mt/year

Methodological point

Carbon is used as an input, along with hydrogen, for the synthesis of e-methane, e-methanol, e-kerosene, e-diesel and e-gasoline. The production of e-ammonia, as well as the electro-sourced part of e- biofuels, does not include the use of carbon.

Regional carbon needs (kt / year)

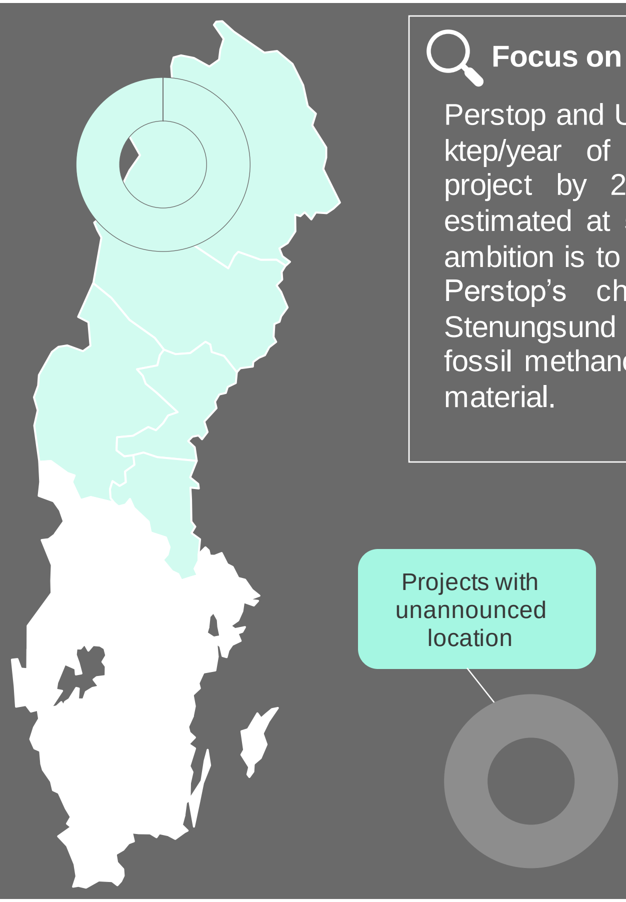
- 0
-] 0 ; 500]
-] 500; 1000]
-] 1000; 1500]
-] 1500; 2000]
- > 2000

Share of need by e-fuel

- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

The Swedish government has allocated €3.3 Bn for the period 2026-2046, for CCUS projects applied to bioenergy valorization activities (BECCS/U), making it possible to capture and store or use CO_2 of biogenic origin. The Swedish Energy Agency will call for tenders and provide economic support to the winning respondants.

Sweden has particularly favorable conditions for BECCS/U in existing biomass combustion facilities, including cogeneration plants, paper and pulp mills and waste incineration plants. Most sites are located in the south and on the west coast of the country.



Focus on a project:

Perstop and Uniper want to produce 109 ktep/year of e-methanol with the Air project by 2026. The requirement is estimated at 500 kt of CO_2 /year. Their ambition is to capture emissions from the Perstop's chemical industrial site in Stenungsund . The objective is to replace fossil methanol currently used as a raw material.

** Statistics Sweden (2022) ** Bioenergy with CO 2 capture, storage and/or use*

Focus on Sweden – Water consumption

Based on announced projects

Sweden's total water consumption amounts to almost **3,100Mm³/year***. This consumption is broken down into **68% use by industry**, 19% by households, 3% for agriculture and finally 10% for other uses (mainly tertiary sector, construction and losses on the network)*. Water captured by industry is used by the manufacturing (88%), mining (4%) and by **the electricity and gas supply (9%)* sectors.** In addtition to this there is the seawater used by nuclear power plants (10 Bn m³). Sweden has abundant water sources and a relatively small population. Total water withdrawals represent **1% of available resources.**

Indicators

06. **Water consumption requirements of planned projects**

0.6 Mm³/year

Notes on reading the indicator

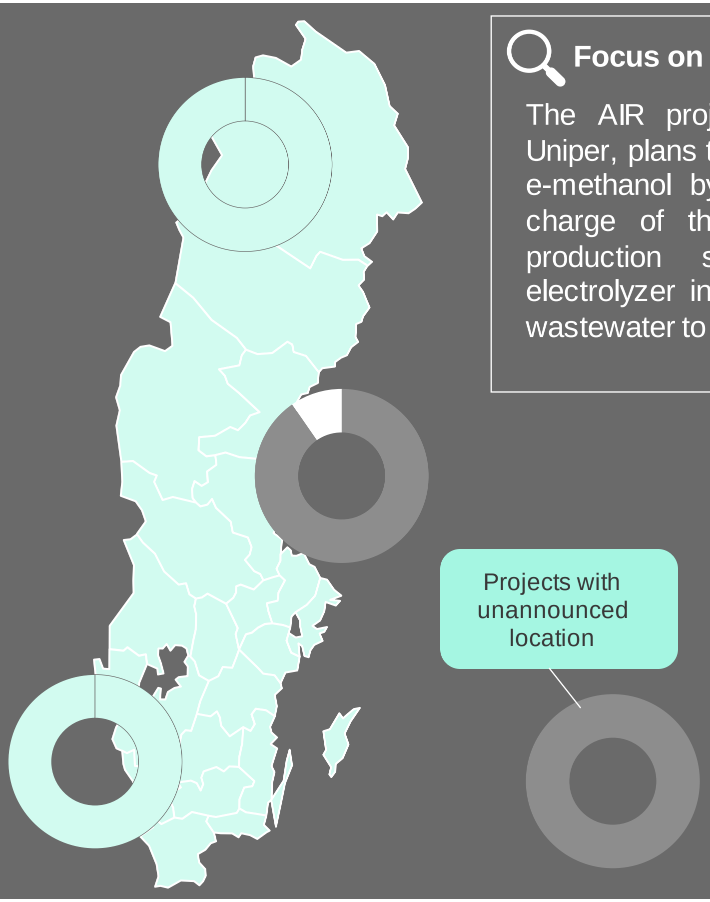
- 0.6 Mm ³ consumed
- 2.7 Mm ³ taken and returned (according to technological choices)

Electrolysis and CO2 capture consume water. The cooling water from electrolyzers and equipment allowing the synthesis of e-fuels can be returned to the environment.

Regional water needs (Mm3 / year)	Share of need per e-fuel
0	e-methane
] 0 ; 1]	e-methanol
] 1 ; 2]	e-kerosene
] 2 ; 3]	e-ammonia
] 3 ; 4]	e-essence
> 4	e-diesel

Sweden has substantial water reserves and the supply of this resource to e-fuel projects does not appear to be an obstacle to their development.

However, a reasoned management of the resource is necessary. Since 2017, more than 70 natural reserves with a limnological purpose have been created to offset the impacts of hydroelectric power stations, dams and land drainage on ecosystems and biodiversity of the aquatic environment. Only 40% of surface water points have a good ecological status, the rest is suffering from shortages, drought or floods (Third management cycle survey 2016-2021).



Focus on a project:

The AIR project, led by Perstop and Uniper, plans to produce 109 ktoe/year of e-methanol by 2026. Uniper will be in charge of the hydrogen supply. The production site will be the first electrolyzer in the world to use purified wastewater to synthesize hydrogen.

* Statistics Sweden (2020)

Focus on Sweden – Financing needs

Based on announced projects

Sweden does not have a specific policy for the development of e-fuel projects but supports projects related to hydrogen production. The **hydrogen strategy** published in 2021 was co-developed by **the Swedish Energy Agency and Fossil Free Sweden**, a government initiative bringing together public and private players. The strategy targets **installed capacities of 5 GW by 2030**. **Public financing mechanisms have been set up** to support the development of low-carbon transition projects, especially those involving hydrogen: **Climate Leap (2015)** and **Industrial Leap (2018),** for a total amount of **€1.1 Bn.**

Indicators

07.

Financing requirements for planned projects

€3.2 Bn

Notes on reading the indicator

Many projects do not disclose their level of investment or have not yet reached this stage. We estimated the financing needs by comparison with existing funded projects.

Financial need - regional cement (€bn / year)

- 0
-] 0 ; 1]
-] 1 ; 2]
-] 2 ; 3]
-] 3 ; 4]
- > 4

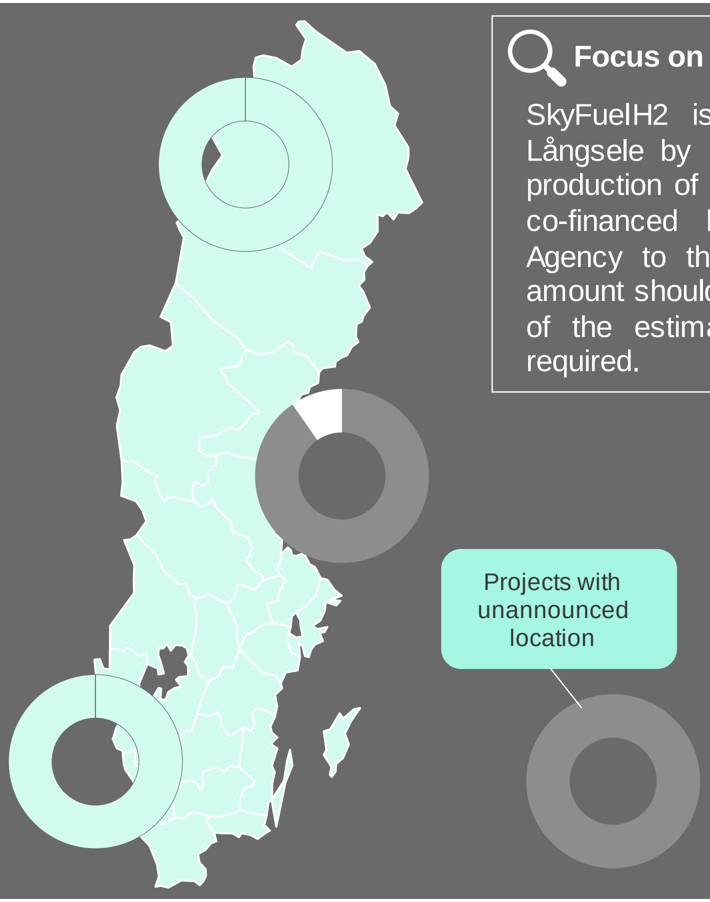
Share of need per e-fuel

- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

Only one project has passed the final investment decision out of the 8 projects announced.

The amount of public funding dedicated to decarbonization and to which the projects are eligible appears substantial in the light of needs. But these funds cover a wide range of solutions, without any particular focus on e-fuel projects.

It can be noted that Sweden has no developped gas network. Indeed, the country has long since made the transition towards heating by biomass and waste combustion. Natural gas plays a minor role in the Swedish energy mix (<2%). The development of a possible hydrogen transport network serving e-fuel production sites would therefore be particularly costly, as it would not be possible to rely on the conversion of existing infrastructures.



Focus on a project:

SkyFuelH2 is a project developed in Långsele by Uniper and Sasol, for the production of e-kerosene. The project is co-financed by the Swedish Energy Agency to the tune of €11.9 M. This amount should cover approximately 25% of the estimated €44.9 M investment required.

Part 2 .

Overview of Dynamics in selected countries

North America

Canada

Focus on Canada – General context

The stakes for decarbonization are high. The petrochemical industry represents 6% of Canadian GDP and the country is the world's 4th **largest oil producer** and the **6th for gas**. The country is also the world's **6th largest electricity producer** with **60% of its electricity mix coming from hydropower**. As a result, Canada offers a great potential for the development of e-fuel projects with **strong support at the federal level**. Electricity in certain regions is particularly affordable (Ontario, Quebec, etc.) and some states are developing their own hydrogen strategies and investment mechanisms.

Public support and policies

Hydrogen Strategy (2020)*: Document intended to stimulate investments in the production and use of hydrogen and create partnerships.

Clean Fuel Fund (2021)**: €1 bn fund to support national production and the adoption of low-carbon fuels, such as hydrogen or biofuels.

SIF Net- Zero Accelerator (2021)***: Fund of €5.3 bn to accelerate the decarbonization projects of large emitters and the industrial transformation of the energy sector.

Emissions Reduction Plan for 2030 (2022)****: strategy to tackle climate change while stimulating economic growth. Aims to reduce emissions by 40% below 2005 levels by 2030 and achieve carbon neutrality by 2050.

Clean Fuels Regulation (2022)**: incentive measures promoting the development and adoption of clean fuels, technologies and processes. It requires suppliers to gradually reduce the carbon intensity of gasoline and diesel by around 15% by 2030 (compared to 2016 levels).

Tax credits for a sustainable and clean economy (2023)****: €55 bn to promote green energy technologies and associated infrastructure through the establishment of tax credits for investment in electricity, technologies and clean hydrogen.

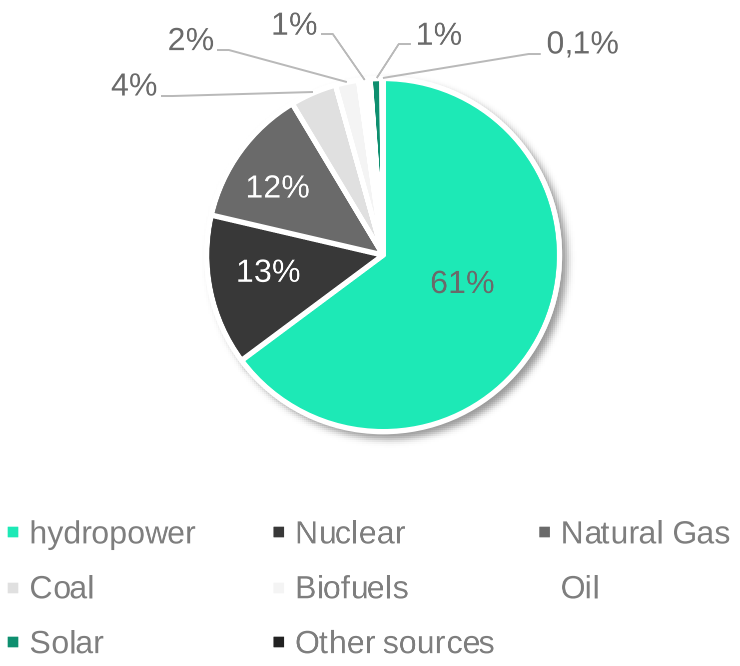
-40% GHG emissions

By 2030

$ 67.2 Bn in measures

For clean technologies

Electricity mix in Canada (IEA - 2022)



** IEA ** Canada Energy Regulator *** Invest in Canada **** Government of Canada*

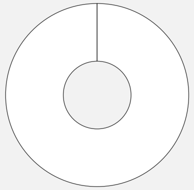
Focus on Canada – 2030 Indicator Dashboard

Total projected capacities in 2030

2,953 **ktoe/year**

01 Production capacity of projects under construction or in activity

125 ktoe / year

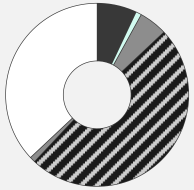


02 Production capacity of projects with FID

230 ktoe / year

03 Production capacity of projects under study

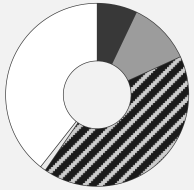
2,598 ktoe / year



04 Electricity requirement

83 TWh / year*

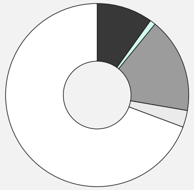
71 TWh: water electrolysis
12 TWh: summary of e-fuels



05 Carbon requirement

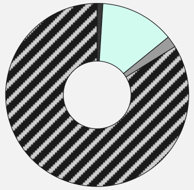
2.9 $MtCO_2$ / year

To be captured in biomass or industry



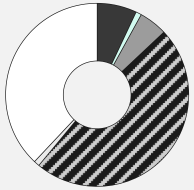
06 Water requirement (water consumed)

8.3 Mm^3 / year

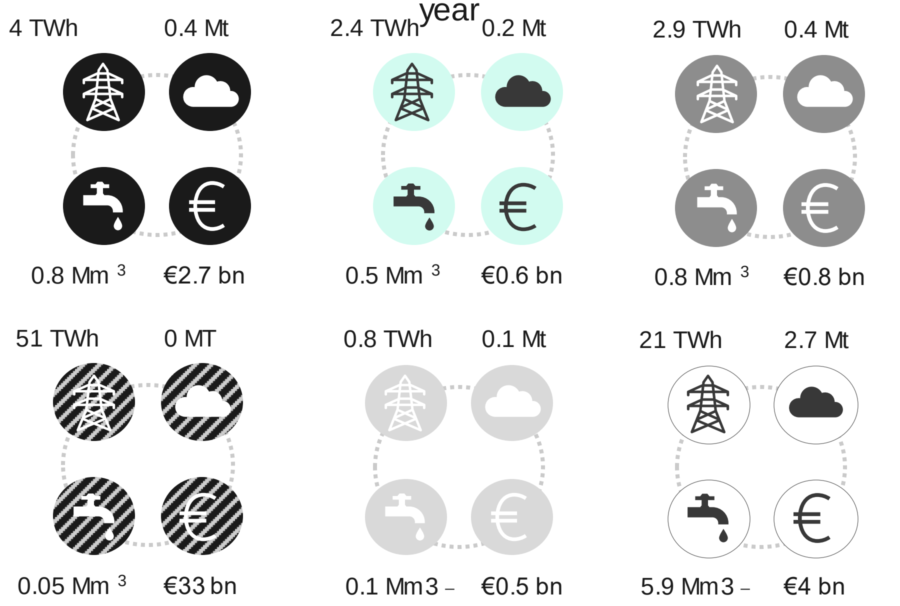


07 Financing requirement

SAF 60 bn
Or €41 bn



Quantities of resources to be mobilized per molecule / year



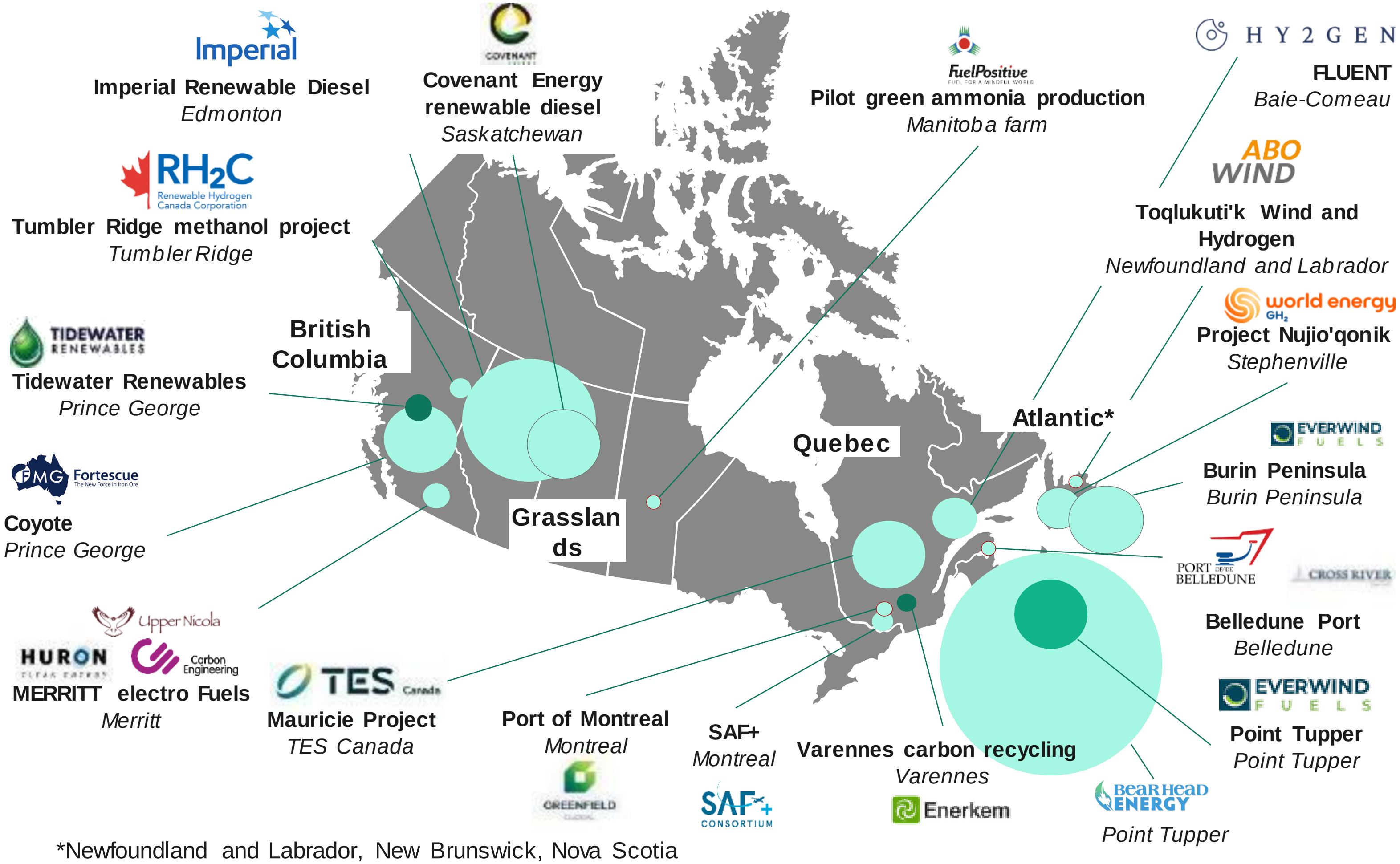
Legend

e-methane	e-ammonia
e-methanol	e-essence
e-kerosene	e-diesel

* Electricity requirements: based on an hypothesis of an overall energy efficiency of 45% by 2030 for all e-fuels value chain. **55% of energy efficiency achievable in the long run.**

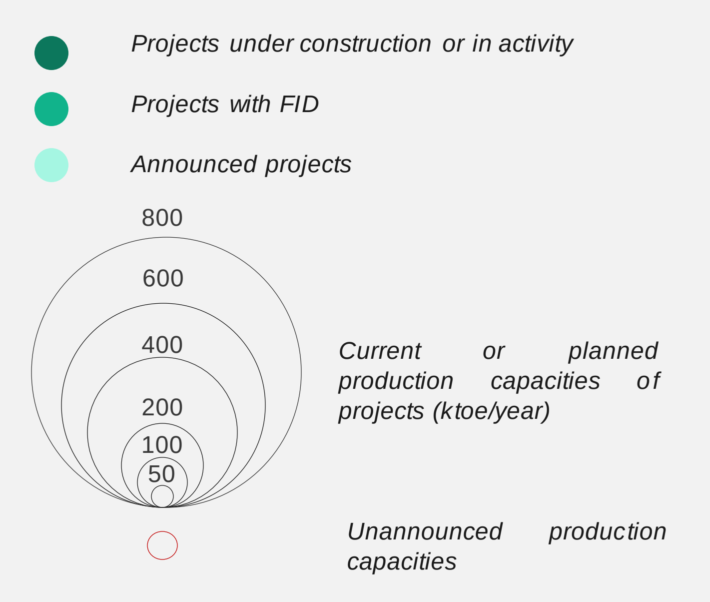
Focus on Canada – Overview of publicly announced projects

We identified **19** synthetic fuel projects in Canada. Some of them are located in eastern Canada – Nova Scotia and Newfoundland and Labrador – and are intended **for export, particularly to Europe**. **The majority of projects** (15 out of 18) **are still under study, 1 project is in activity, 1 under construction and a final one is in FID.** The dynamics of the e-fuels sector appear balanced in southern Canada: the number and capacities of projects are comparable between **British Columbia, the Prairies (Alberta, Saskatchewan, Manitoba), Quebec and the Atlantic.**



1 project whose location is unknown

MÆRSK
Biomass green methanol pilot project



*Newfoundland and Labrador, New Brunswick, Nova Scotia

Focus on Canada – Actors

The dynamic is driven by **pure players** whose activity is centered on the production of e-fuels or "green fuels": **Hy2gen, World Energy, Bear Head Energy, EverWind Fuels, SAF+ consortium, Fuel Positive, TES, Covenant Energy and Enerkem**. Oil and gas producers **are less present** on the Canadian scene: Tidewater and Imperial Oil. A few more diverse players complete the panorama including Fortescue (mining company), ABO Wind, a renewable energies developper, the large Danish shipowner Maersk which operates several projects around the world and Cross River Bank with the Port of Belledune.

01. Built and/ or active

Project		VCR
Actor	Tidewater Renewables	Enerkem
Year	2023	2025
Fuel	e-diesel	e-diesel

02. Financed

Project	Point Tupper
Actor	EverWind Fuels
Year	2025
Fuel	e-ammonia

03. Under study

Project	Covenant Ren. diesel	Toqlukuti'k Wind and H2	MERRITT electro Fuels	SAF+	Project Nujio'qonik	Burin Peninsula	Imperial Ren. Diesel	
Actor	Covenant	ABO Wind	Upper Nicola, Huron	SAF+ Consortium	World Energy GH2	EverWind Fuels	Imperial	Bear Head Energy
Year	2026	2030	2026	2028	2026	2027	2025	2027
Fuel	e-diesel	e-ammonia	e-essence/ kerosene/diesel	e-kerosene	e-ammonia	e-ammonia	e-diesel	e-ammonia

Project	Coyote	Belledune Port	Pilot Manitoba farm	Mauricie Project	Port of Montreal	Green methanol pilot	COURANT	Tumbler Ridge
Actor	FMG Fortescue	Port of Belledune, Cross River	FuelPositive	TES Canada	Greenfield	Maersk	Hy2gen	RH2C Renewable Hydrogen Canada Corporation
Year	Unknown	2027	Unknown	2028	Unknown	Unknown	2028	2028
Fuel	e-ammonia	e-ammonia	e-ammonia	e- methane	e- methanol	e-methanol	e-ammonia	e-methanol

Focus Canada – E-fuel production capacity

● Based on announced projects

Out of the 2,953 ktoe of projects planned for 2030, **only 355 ktoe have been secured** by final investment decisions. The majority of projects concern the production **of e-ammonia (mainly for export) or e-diesel**. 2025 and 2026 are key years for synthetic fuels in Canada where the majority of projects will become a reality. However, it is worth to noting that **several projects have already postponed their commissioning date at least once** (SAF+, Covenant Energy Renewable Diesel, etc.).

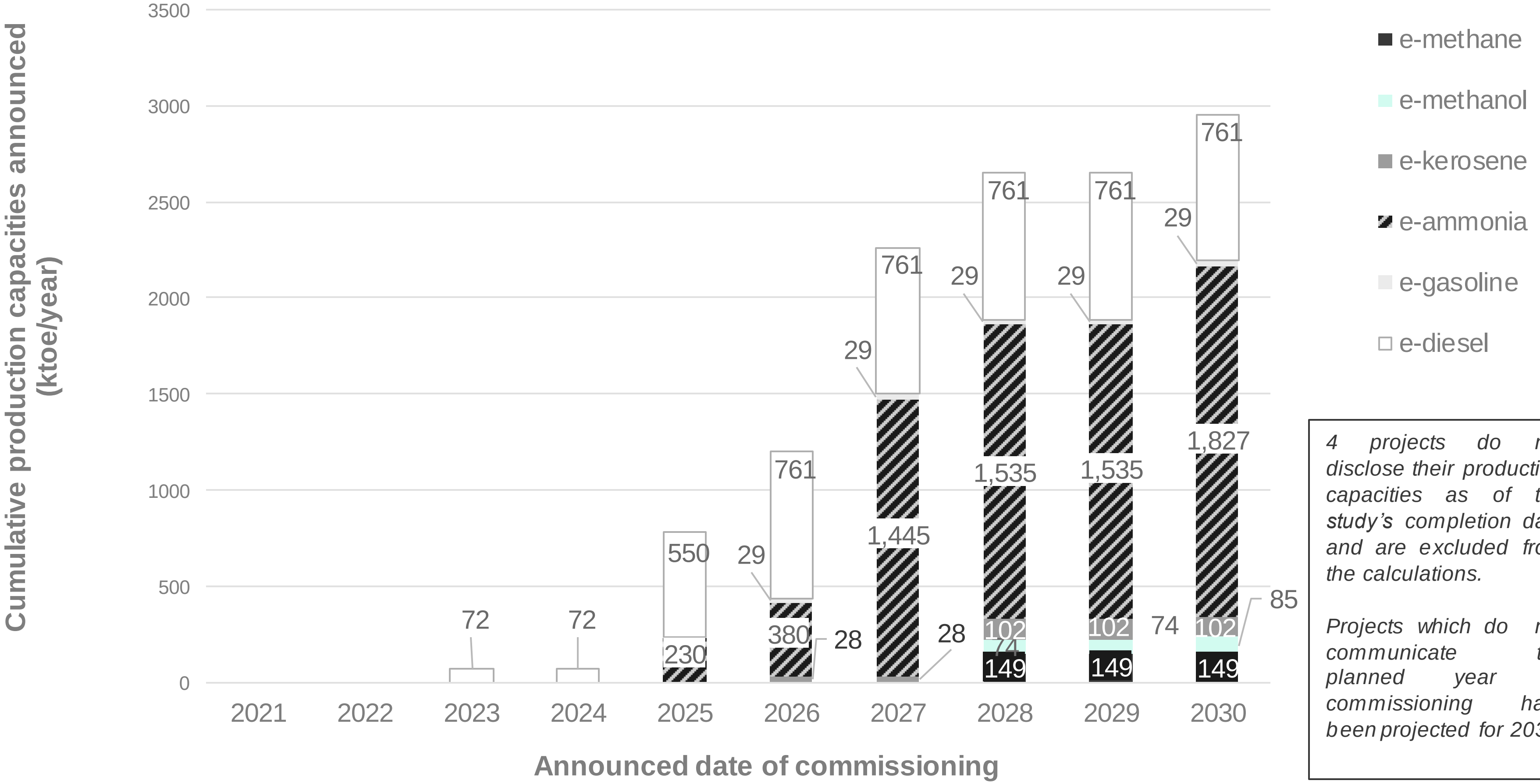
Indicators

01. **Active capacities / Under construction:** **125 ktoe / year**

02. **Projects with FID:** **230 ktoe / year**

03. **Projects under study:** **2,598 ktoe / year**

	Production capacity (ktoe/year)	Number of projects
e-methane	149	1
e-methanol	85	3
e-kerosene	102	2
e-ammonia	1,827	9
e-essence	29	1
e-diesel	761	5
Total	**2,953**	**21**



4 projects do not disclose their production capacities as of the study's completion date and are excluded from the calculations.

Projects which do not communicate the planned year of commissioning have been projected for 2030.

* Some projects are developing several molecules and have been counted for each molecule, explaining the difference between the total sum of projects per molecule and the total of announced projects.

Focus on Canada – Electricity needs

Based on announced projects

Canada's electricity mix is carbon-free overall with **67%** of production coming from **renewable energies** (including 61% from hydropower and **13%** from **nuclear power**. Total electricity production amounts to **656 TWh** for a **total consumption of 656 TWh.** Canadian production is sufficient to satisfy demand and the country. The country is also an importer and exporter of electricity. The development of **wind power** has experienced strong growth in recent years (+1.8 GW in 2022), just as has **solar energy** (1/4 of installed capacities in 2022). .

Indicators

04.

Electrical need planned projects

83 TWh / year

Details on how to read the indicator

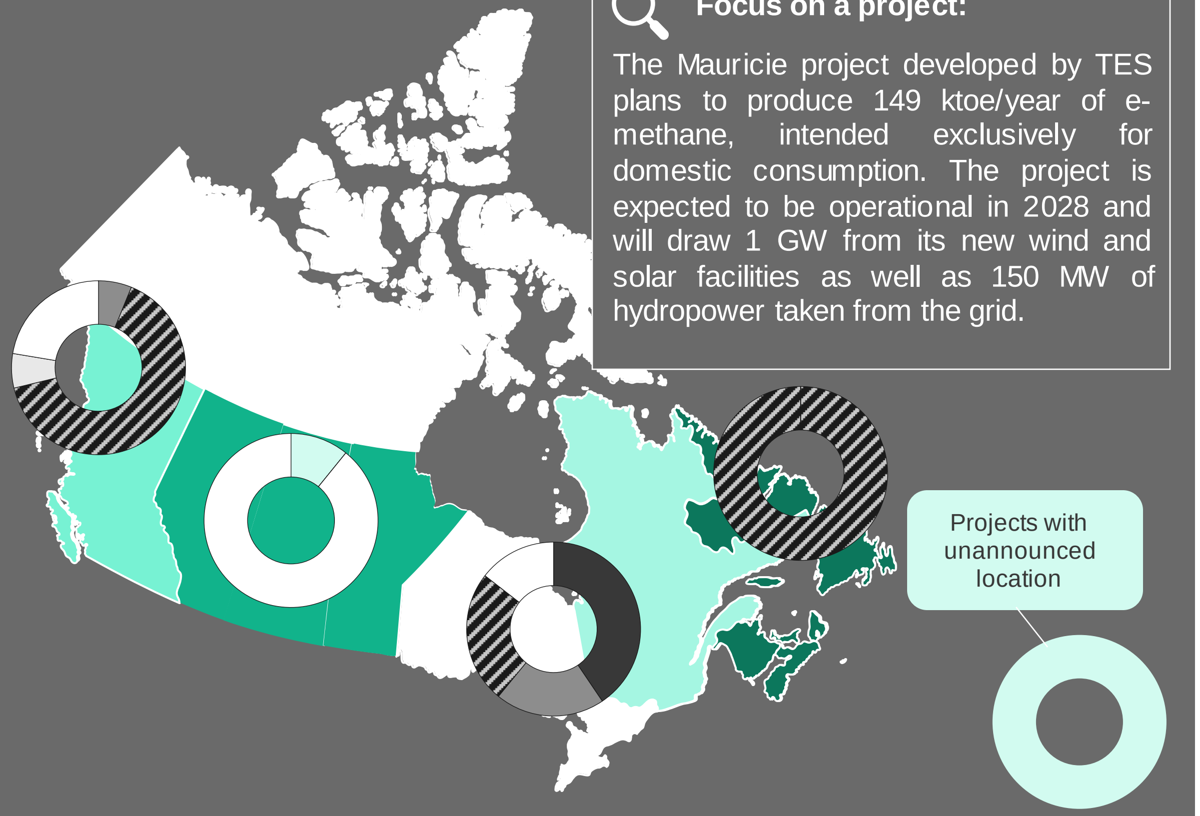
- 71 TWh: water electrolysis
- 12 TWh: summary of e-fuels

For an overall energy efficiency of 45% for the whole value chain. Overall energy efficiency of 55% achievable in the long run.

Regional electricity needs (TWh / year)	Share of need per e-fuel
0	e-methane
] 0 ; 5]	e-methanol
] 5 ; 10]	e-kerosene
] 10; 15]	e-ammonia
] 15; 20]	e-essence
> 20	e-diesel

Canada has abundant low-carbon electricity resources, especially hydropower, which has a high load factor. The country seems to have sufficient resources to support its e-fuel production sector, especially as it has significant potential for installing solar and wind power infrastructures. By 2030, according to a global Net 0 scenario in 2050, Canada plans to add about 270 TWh of renewable energy, as well as increasing its nuclear potential*.

The price of electricity in Canada is low. For the industry, the cost varies from 3.6 to 9.6 ct€ per KWh in 2022, which is particularly interesting for producers of e-fuels.



Focus on a project:

The Mauricie project developed by TES plans to produce 149 ktoe/year of e-methane, intended exclusively for domestic consumption. The project is expected to be operational in 2028 and will draw 1 GW from its new wind and solar facilities as well as 150 MW of hydropower taken from the grid.

*Government of Canada

Focus Canada – Carbon needs

Based on announced projects

Canada's total greenhouse gas (GHG) emissions in 2021 amounted to **670 Mt**, of which **28% from oil and gas activities** and **22% from transportation**. With some of the world's first large-scale projects, **favorable geology**, **cutting-edge R&D** and **a supportive policy and regulatory environment** at the federal and provincial levels, Canada is positioning itself as a key player in CO_2 management. About **one-seventh of the world's large-scale CCUS projects are located in Canada*.**

Indicators

04.

Carbon requirement planned projects

2.9 Mt/year

Notes on reading the indicator

Carbon is used as an input, along with hydrogen, for the synthesis of e-methane, e-methanol, e-kerosene, e-diesel and e-gasoline. The production of e-ammonia, as well as the electro-sourced part of e-biofuels, does not include the use of carbon.

Regional carbon needs (kt / year)

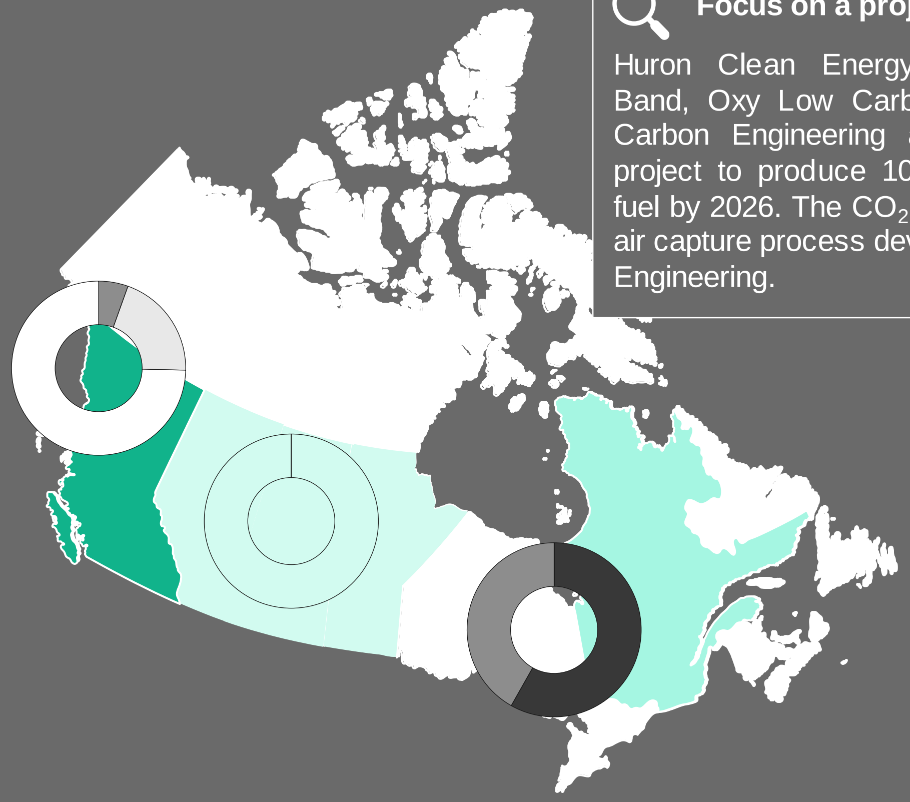
- 0
-] 0 ; 500]
-] 500 ; 1000]
-] 1000 ; 1500]
-] 1500 ; 2000]
- > 2000

Share of need per e-fuel

- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

As part of the 2023 federal budget, Canada unveiled subsidies measures of CAD $12.5 Bn aimed at covering up to 60% of the CAPEX of carbon capture, transport and sequestration projects. These subsidies, combined with carbon tax systems, facilitate the creation of profitable economic models for project leaders.

Another important aspect of the 2023 budget is the introduction of contracts for difference for carbon, thus providing sufficient visibility for project developers to build business models. The Canada Growth Fund is also committed to devoting up to CAD $7 Bn to the implementation of various contracts for difference.



Focus on a project:

Huron Clean Energy, Upper Nicolas Band, Oxy Low Carbon Ventures and Carbon Engineering are developing a project to produce 100 Ml of synthetic fuel by 2026. The CO_2 will come from the air capture process developed by Carbon Engineering.

*IEA Database, 2023

Focus on Canada – Water consumption

Based on announced projects

Canada's water consumption amounted to nearly **36,000 Mm³ in 2019***. It is divided into **92 % industrial use** (mainly electricity generation, specialized agriculture and pulp and paper manufacturing)* and 8% for homes and other uses. It is an abundant resource all over the country. Mainly **available in the North of the country**, it is more difficult to access it in the South where the population density is higher. Canada also faces numerous management challenges including **insufficient investment in water infrastructure** and **fragmented governance at level of water distribution infrastructures**.

Indicators

06.

Water consumption requirements of planned projects

8.3 Mm³ / year

Notes on reading the indicator

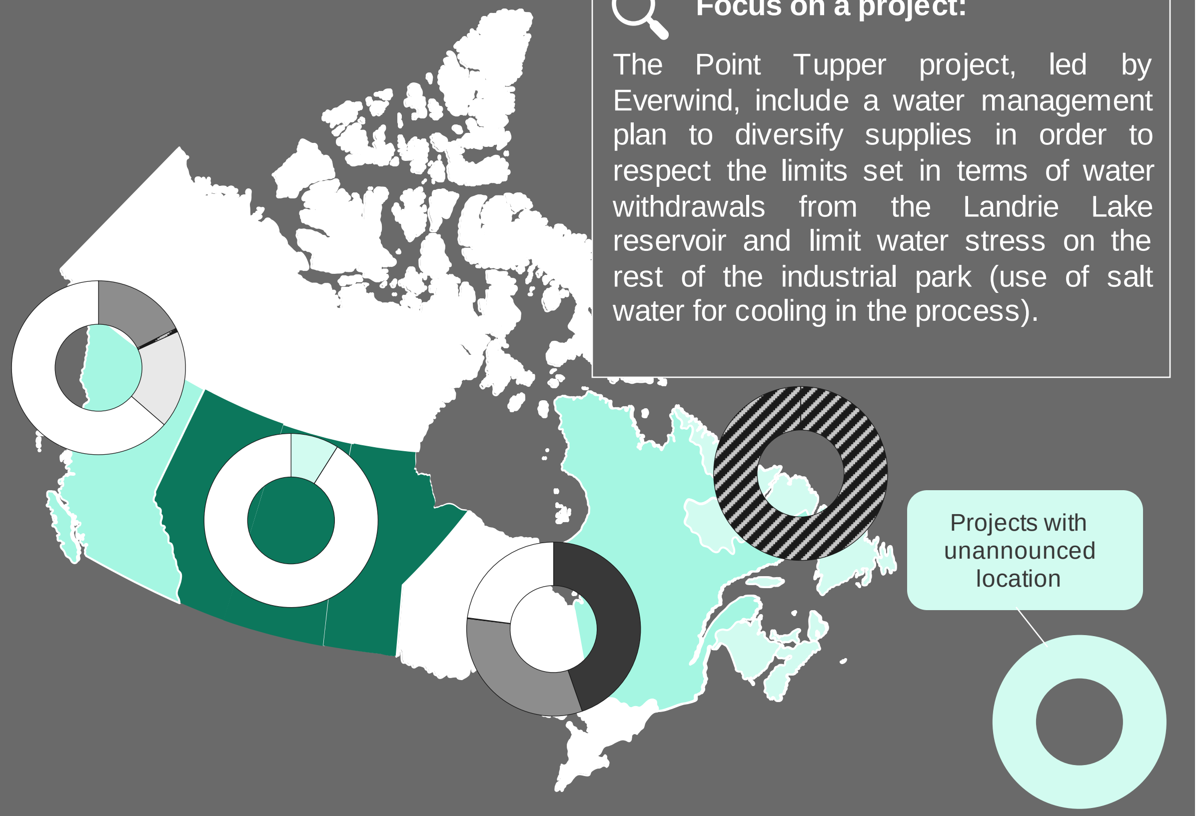
- 8.3 Mm³ consumed
- 34.9 Mm³ taken and returned (according to technological choices)

Electrolysis and CO2 capture consume water. The cooling water from electrolyzers and equipment allowing the synthesis of e-fuels can be returned to the environment.

Regional water needs (Mm³/year)	Share of need per e-fuel
0	e-methane
] 0 ; 1]	e-methanol
] 1 ; 2]	e-kerosene
] 2 ; 3]	e-ammonia
] 3 ; 4]	e-essence
> 4	e-diesel

Canada has significant water reserves and the supply of this resource to e-fuel projects does not appear to be an obstacle to their development as long as reasoned management guaranteeing its availability for other essential uses is implemented.

Some potential solutions regarding natural infrastructure are being implemented to ensure water availability for local Prairie communities: today 2.67 Mha of marshlands have been restored and conserved and 7 feasibility studies are underway for similar projects across the region (The State of Play Report for Natural Infrastructure on the Canadian Prairies 2023).



Focus on a project:

The Point Tupper project, led by Everwind, include a water management plan to diversify supplies in order to respect the limits set in terms of water withdrawals from the Landrie Lake reservoir and limit water stress on the rest of the industrial park (use of salt water for cooling in the process).

* *Statistics Canada (2019)*

Focus Canada – Funding needs

Based on announced projects

In 2020, Canada published its **hydrogen strategy**, sharing its vision for 2050, detailing territorial resources and commercial opportunities. The country aims to **produce 4 Mt/year** of low-carbon hydrogen by **2025-2030**. This production will contribute to reach the objectives set by the **Emissions Reduction Plan for 2030** (-40% by 2030) and the **Clean Fuels Regulations** of 2022 for the adoption of sustainable fuels. Several financial mechanisms support these initiatives, including the **Clean Fuel Fund** or the **Tax Credits for a Sustainable and Clean Economy** (in response to the American IRA).

Indicators

07. **Carbon requirement planned projects**

€41 bn / year

Notes on reading the indicator

Many projects do not disclose their level of investment or have not yet reached this stage. We extrapolated the financing needs by comparison with existing funded projects.

Financial need - regional cement (€bn / year)

- 0
-] 0 ; 1]
-] 1 ; 2]
-] 2 ; 3]
-] 3 ; 4]
- > 4

Share of need per e-fuel

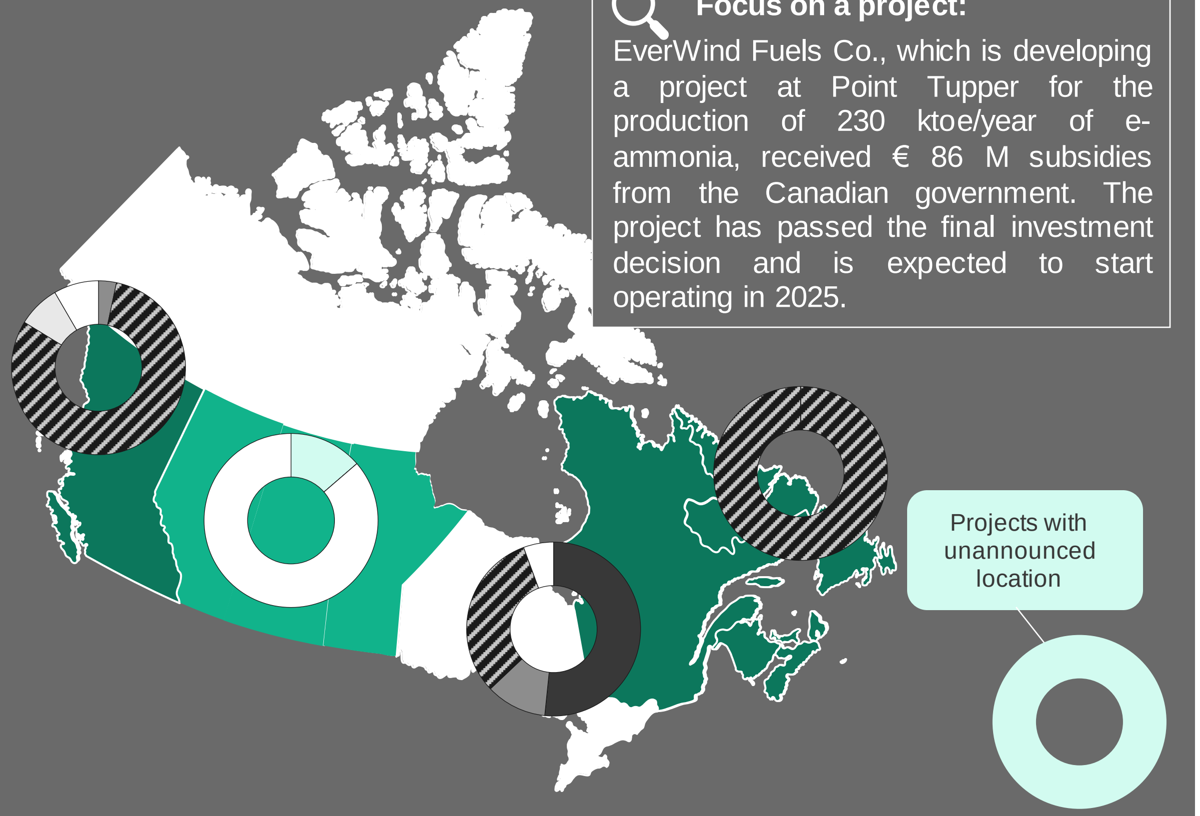
- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

So far only 3 projects out of the 18 announced have reached a final investment decision. However, the recent decisions taken by the Canadian government, against the backdrops of US announcements, may provide financing opportunities for projects.

Canada has introduced a whole series of complementary measures in favor of the e-fuels sector: Energy innovation program – clean fuels and replacement of industrial fuels, Hydrogen strategy, CCUS strategy, clean fuel standard, Net 0 accelerator of the Strategic Fund for Innovation… thus representing a total amount of €46.02 Bn in favor of clean energies.

Focus on a project:

EverWind Fuels Co., which is developing a project at Point Tupper for the production of 230 ktoe/year of e-ammonia, received € 86 M subsidies from the Canadian government. The project has passed the final investment decision and is expected to start operating in 2025.



Part 2 .

Overview of Dynamics in selected countries

North America

United States of America

Focus on the United States – General context

The United States has a huge **potential for the production of e-fuels**. It has a large supply of renewable electricity at competitive prices, which vary depending on the region. The industrialization of the entire value chain for decarbonized molecules is a solution to the decarbonization challenges of the petrochemical and gas sector, while allowing the country **to remain a major exporter** of energy and chemical products (3rd in the world for petroleum products and 7th for fertilizer). The **federal government's support** for developing hydrogen hubs could play a **role in accelerating the scaling phase** of the sector.

Public support and policies

Industrial Decarbonization Roadmap (September 2022)* : Focusing efforts on the **5 industries** emitting the most CO_2 (refining, chemicals, iron and steel, cement, food and beverages). **4 pillars** : energy efficiency, industrial electrification, fuels and low carbon energy and CCUS solutions.

Sustainable Aviation Grand Challenge (September 2021)* : **9.4 Mtoe/year** of SAF, including e-fuels, in **2030** , with a long-term objective of **100% of SAF** in the sector's energy mix in **2050** , i.e. **110 Mtoe /year**

Infrastructure Investment and Jobs Act (Nov 2021)* : $7 bn for regional hydrogen hubs dedicated to the decarbonization of difficult-to-decarbonize sectors.

Inflation Reduction Act (August 2022)* : Tax credit to promote the deployment of domestic clean hydrogen production and up to $250 bn in loan guarantees for energy infrastructure upgrade projects aiming at reducing, using or capturing GHGs.

E-fuel projects are also eligible for various broader decarbonization subsidy programs covering R&D and comemrcialization of new technologies.

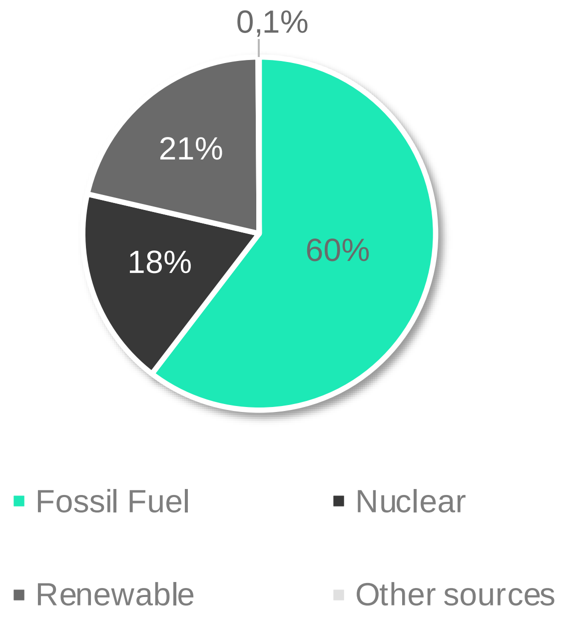
- 50% GHG emissions targeted by 2030

Across the entire economy

0 emission targeted for 2050

$1/kg H_2 target cost decarbonized in 2030

Electricity mix in the United States (EIA, 2022)



*US Department of Energy

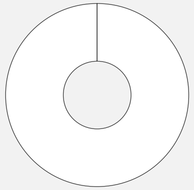
Focus on the United States – Dashboard of 2030 indicators

Total projected capacities in 2030

2,372 ktoe/year

01 Production capacity of projects under construction or in activity

182 ktoe / year

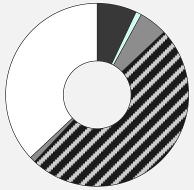


02 Production capacity of projects with FID

534 ktoe / year

03 Production capacity of projects under study

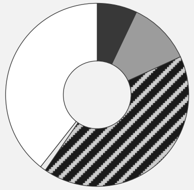
1,656 ktoe / year



04 Electricity requirement

66 TWh / year*

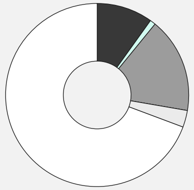
56 TWh: water electrolysis
10 TWh: e-fuels synthesis



05 Carbon requirement

7 MtCO$_2$ / year

To be captured in biomass or industry

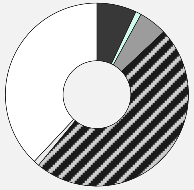


06 Water requirement (water consumed)

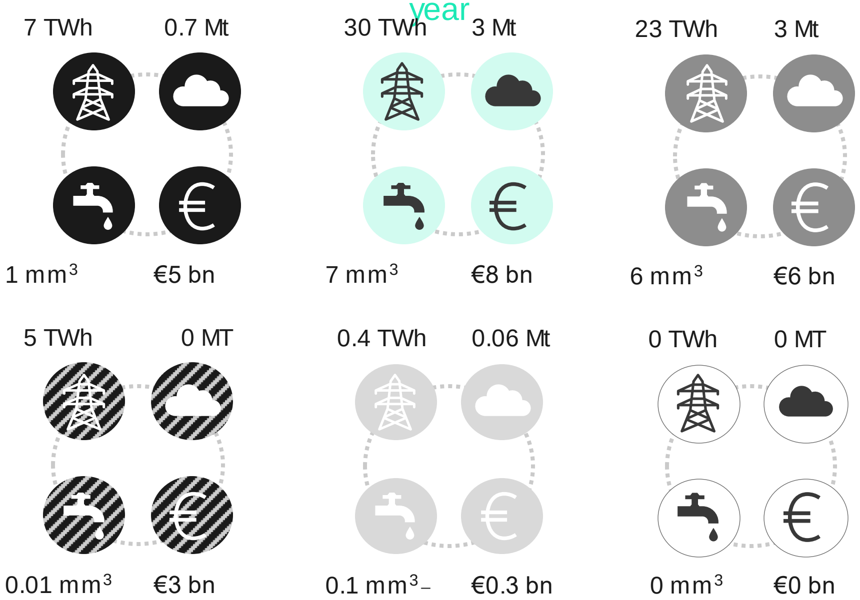
15 Mm3 / year

07 Financing requirement

$23.8bn
Or €22 bn



Quantities of resources to be mobilized per molecule / year



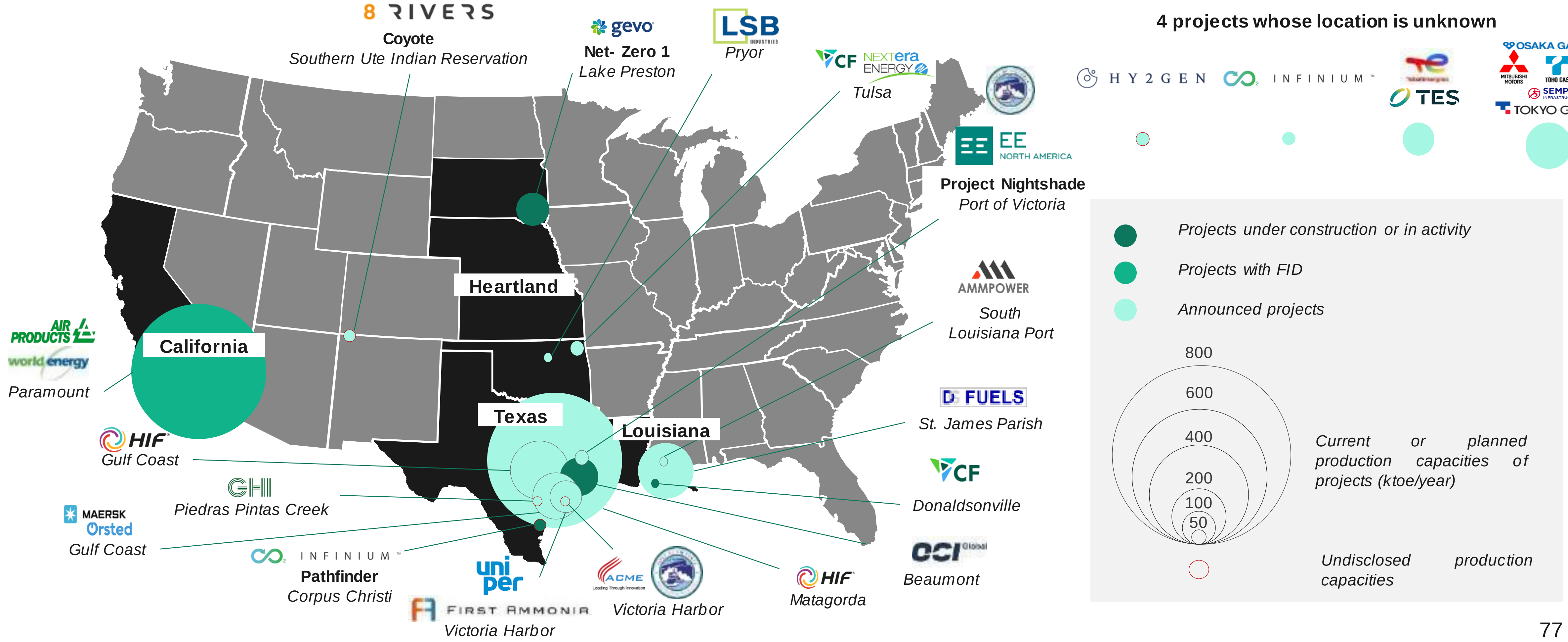
Legend

e-methane	e-ammonia
e-methanol	e-essence
e-kerosene	e-diesel

* Electricity requirements: based on an hypothesis of an overall energy efficiency of 45% by 2030 for all e-fuels value chain. **55% of energy efficiency achievable in the long run.**

Focus on the United States – Overview of publicly announced projects

We identified **21 projects** in the United States, at various stages of progress: **4 projects are under construction or in operation, 1 project is currently FID and 11 projects are under study**. Among these projects, 1 is carried by Infinium and does not yet communicate the planned production capacities as well as for a Hy2gen project. All the projects are concentrated in 4 hubs, which we will take as a subject of study: **Californian Hub, the Texas Hub, Louisiana and the Central Hub (Heartland).** The 4 projects whose location is not known will be analyzed together.



Focus on the United States – Actors

Until 2019-2020, the United States had not significantly developed e-fuel production projects. The dynamic was quickly set up by new pure players (HIF, Gevo , Infinium , DG Fuels, World Energy or even TES), followed later on by historic players in the sector, who received **public support and that of players within the technologic industry** (Microsoft, battery electric vehicle industry, Amazon). Projects can consolidate sufficiently to reach FID, thus enabling the **United States to become one of the leaders in the sector to date.**

01. Built and/ or active

Project	Actors	Date	Molecule
NET- Zero 1	gevo	2026	e-kerosene e-essence
Pathfinder	INFINIUM	2023	e-kerosene e-diesel
Beaumont	OCI Global	2025	e-methanol
Donaldsonville	CF	2023	e-ammonia

02. Financed

Project	Actors	Date	Molecule
Paramount	world energy, AIR PRODUCTS	2025	e-kerosene

03. Under study

Project	Actors	Date	Molecule
Matagorda	HIF	2026	e-methanol
Louisiana	AMMPOWER	Unknown	e-ammonia
Pryor	LSB Industries, Bloomenergy, thyssenkrupp	Unknown	e-ammonia
Road Runner	INFINIUM	2026	e-kerosene
	ACME	Unknown	e-ammonia
Gulf Coast	MAERSK, Orsted	2025	e-methanol
Tulsa	CF, NEXTera ENERGY	Unknown	e-ammonia
Coyote	8 RIVERS	Unknown	Unknown
	TotalEnergies, TES	Unknown	e-methanol
	OSAKA GAS, MITSUBISHI MOTORS, TOHO GAS, SEMPRA INFRASTRUCTURE, TOKYO GAS	2029	e-methane
	HY2GEN	Unknown	e-methanol
St. James Parish	DG FUELS	Unknown	e-kerosene
	GHI	Unknown	e-ammonia e-methane
Gulf Coast	HIF	2030	e-methanol
	uniper, FIRST AMMONIA	2026	e-ammonia
Nightshade	EE NORTH AMERICA	Unknown	e- methanol

* Some projects are developing several molecules and have been counted for each molecule, explaining the difference between the total number of projects per molecule and the total number of announced projects.

Focus on theUnited States – Production capacity of e-fuels

Based on announced projects

Combined together, all the identified projects to date, have a production capacity estimated at **2,372 ktoe/year by 2030**. Most projects are still **at the study stage** and only 5 projects have passed the FID stage, including 4 already under construction or in activity. The projections for the commissioning of all the projects are for **2025-2026** , giving the fact that **8 projects have not disclosed a date yet**. It is worth noting that the construction of a production plant generally takes 3 years after a final investment decision has been taken.

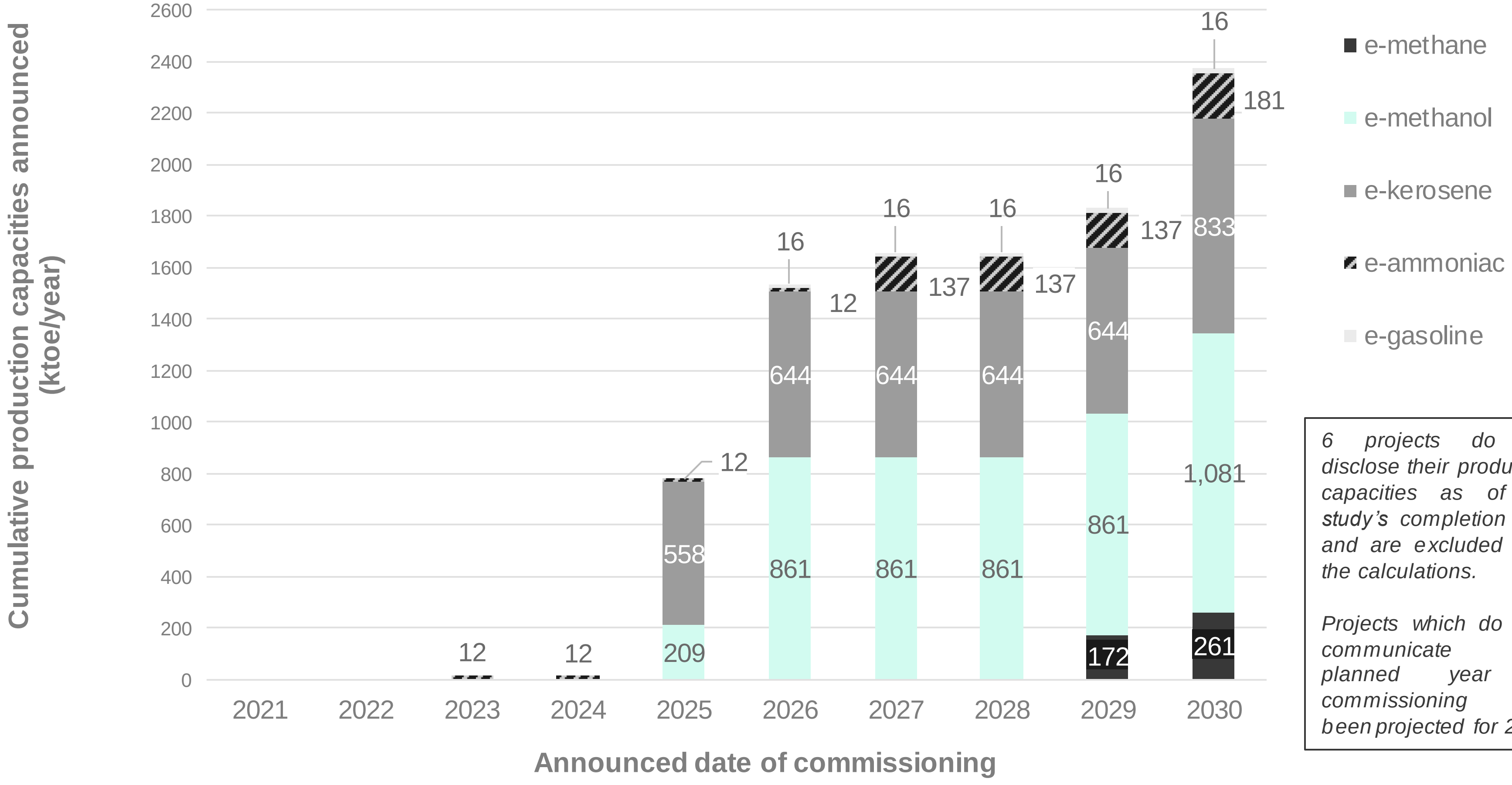
Indicators

01. **Active capacities / Under construction:**
182 ktoe/year

02. **Projects with FID:**
534 ktoe/year

03. **Projects under study:**
1,656 ktoe/year

	Production capacity (ktoe/year)	Number of projects
e-methane	261	3
e-methanol	1081	5
e-kerosene	833	5
e-ammonia	181	7
e-essence	16	1
e-diesel	0	2
Total	2,372	23



6 projects do not disclose their production capacities as of the study's completion date and are excluded from the calculations.

Projects which do not communicate the planned year of commissioning have been projected for 2030.

*Some projects are developing several molecules and have been counted for each molecule, explaining the difference between the total sum of projects per molecule and the total number of projects announced.

Focus on the United States – Electricity needs

Based on announced projects

The United States, the world's second largest electricity producer after China, has an electricity mix dominated by the use of **fossil fuels (60%).** Renewable electricity production has experienced **significant growth**, driven mainly by wind **power** with an active policy on this matter. One of the main drivers of this growth is decreasing **installation costs**. Recently boosted by the implementation of **tax credits under the Inflation Reduction Act** , the sector has been affected by **high interest rates** and **industrial cost inflation**.

Indicators

04.

Electrical requirements of planned projects

66 TWh / year

Details on how to read the indicator

- 56 TWh: water electrolysis
- 10 TWh: e-fuels synthesis

For an overall energy efficiency of 45% for the whole value chain. Overall energy efficiency of 55% achievable in the long run.

Regional electricity needs (TWh / year)	Share of need per e-fuel
0	e-methane
] 0 ; 5]	e-methanol
] 5 ; 10]	e-kerosene
] 10; 15]	e-ammonia
] 15; 20]	e-essence
> 20	e-diesel

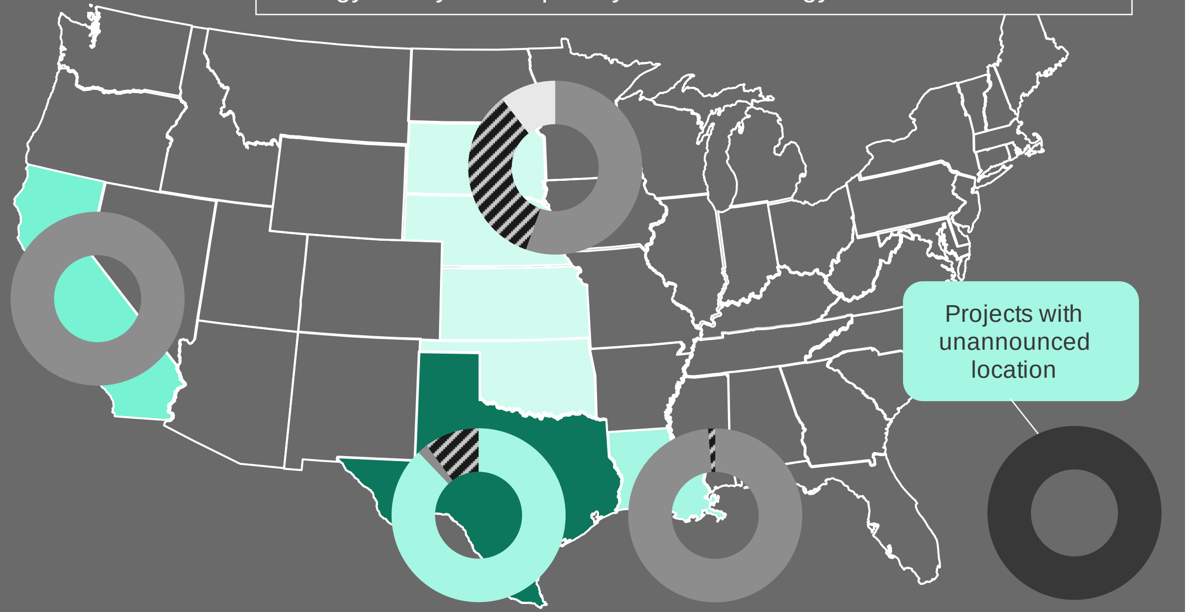
Providing 66 TWh of low-carbon electricity represents a challenge. Some states represent a significant source: the Californian mix is made up of 42% renewable and 9% nuclear. Texas electricity comes from 25% renewable and 8% nuclear.

The price of renewable electricity is relatively low. In 2021, according to the " Lazard's Levelized Cost of Energy report", the LCOE of electricity from wind power was between $26 and $50/MWh and that of photovoltaic between $29 and $44/MWh.

Increases in production capacity for 2030 are focused on wind and solar power, nuclear power is not expected to evolve significantly, which raises the question of the availability of electricity with a high load factor.

Focus on a project:

NextEra Energy and CF Industries are joining forces on a 100 MW electrolysis installation project within CF Industries' Verdigris complex (Tulsa, Oklahoma). The project aims to produce 62 ktoe/year and will be powered by a dedicated 450 MW renewable energy facility developed by NextEra Energy Resources .



Focus on the United States – Carbon needs

Based on announced projects

GHG emissions in the United States amounted to **5,769 $MtCO_2e$**, dominated by CO_2 (79%)*. GHG emissions are linked to three main sources: the transportation sector (27%), electricity generation (25%) and **industry (24%)*.** Technologies for capturing emissions from industrial sectors that are not or difficult to electrify (e.g. cement works, steel industry) exist, but may turned out to be expensive depending on the CO_2 sources concerned. Moreover, they have not been tested on a large scale, except for some applications on naturally highly concentrated fumes (e.g. bioethanol production sites).

Indicators

05.

Carbon requirement of planned projects

7 Mt / year

Details on how to read the indicator

Carbon is used as an input, along with hydrogen, in the synthesis of e-methane, e-methanol, e-kerosene, e-diesel and e-gasoline. The production of e-ammonia, as well as the electro-sourced part of e- biofuels , does not include the use of carbon.

Regional carbon requirements (kt / year)

- 0
-] 0 ; 500]
-] 500; 1000]
-] 1000; 1500]
-] 1500; 2000]
- > 2000

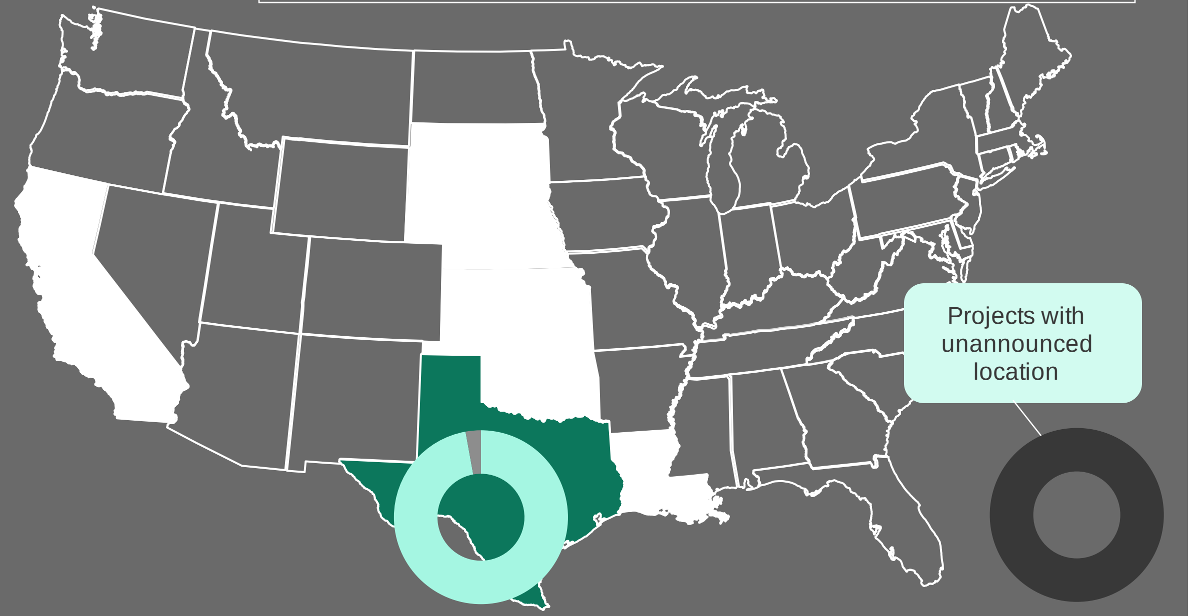
Share of need per e-fuel

- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

The United States has significant deposits of biogenic CO_2 whose distribution across the territory follows that of hydrogen hubs. Depending on the regions where the planned projects are located, the origin of biogenic CO_2 will mainly come from the production of ethanol (Midwest), cement plants (Texas and Midwest) as well as the production of pulp and paper (Gulf Coast)**.
Ethanol production represents a particularly concentrated biogenic CO_2 source (80-90%). According to the Renewable Fuels Association, about 2.7 Mt of CO_2 were emitted by ethanol production in the US in 2021. With 187 ethanol plants, the country has a captureable potential of about 44 Mt/year .

Focus on a project:

Infinium and Navigator CO_2 signed an MoU in 2023 for the supply of 600 kt/year of biogenic CO_2 to the Pathfinder project. The Heartland Greenway pipeline project, however, was canceled due to the rejection of its permit application and opposition from residents concerned about the risks in the event of a leak.



* EPA: United States Environmental Protection Agency ** Capture Map

Focus United States – Water consumption

Based on announced projects

The industrial water use varies from one sector to another, as different activities require different water inputs. Annual water consumption in the United States comes mainly from **8 sources** : public supply (54 bn m³), domestic supply (4.5 bn m³), irrigation (163 bn m³), livestock (2.8 bn m³), aquaculture (10 bn m³), industry (20 bn m³), mining (5 bn m³) and thermoelectric energy production (184 Mds m³)*. **The water requirements of the planned projects will not have a significant impact on the existing tensions around water uses, outside of very specific local contexts.**

Indicators

06. **Water consumption requirements of planned projects**

15 Mm³/year

Notes on reading the indicator

- 15 Mm³ consumed
- 24 Mm³ taken and returned (according to technological choices)

Electrolysis and CO2 capture consume water. The cooling water from electrolyzers and equipment allowing the synthesis of e-fuels can be returned to the environment.

Regional water needs (Mm³/year)

- 0
-] 0 ; 1]
-] 1 ; 2]
-] 2 ; 3]
-] 3 ; 4]
- > 4

Share of need per e-fuel

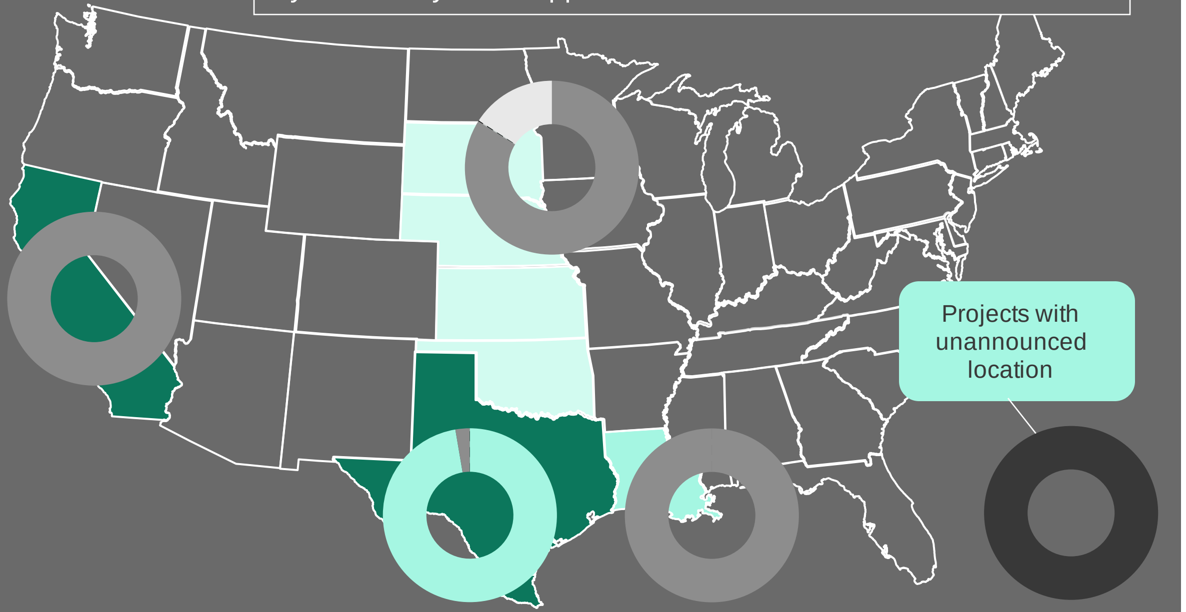
- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

The water requirement for e-fuel production should not exceed that of conventional fuel production or be problematic at a national level. Compared to other uses, the need for water remains relatively low. According to data provided by the US Geological Survey (USGS) in 2015, the pulp, paper and related products industry in the United States used approximately 22.3 bn L/day or 8.1 bn m3 /year.

However, some territories are already considered to be experiencing significant water stress, such as California. The appearance of new uses may be contested, particularly by local populations and other users.

Focus on a project:

The AmmPower project, intended to be established in the port of South Louisiana, should produce 2,480 toe/year of e-ammonia, intended to decarbonize the maritime sector. The technology used presents a water requirement of 21.2L/min which can be supplied by the nearby Mississippi River.



* USGS: United States Geological Survey

Focus on the United States – Financing needs

Based on announced projects

The development of alternative fuel solutions, including e-fuels, is a pillar of Industrial Decarbonization Roadmap and the Sustainable Aviation Grand Challenge. The DOE* announced in 2023 a funding of **$6 bn** to accelerate decarbonization projects in energy-intensive industries, in particular **$260 M in R&D** and **$135 M** toward **40 emissions reduction projects**. The entity also offers **loan guarantees** up to **$3 bn** for SAF** commercial projects. The goal is to provide U.S. manufacturers with a competitive advantage in the emerging global clean energy economy.

Indicators

07.

Financing requirements for planned projects

€22 bn

Notes on reading the indicator

Many projects do not disclose their level of investment or have not yet reached this stage. We extrapolated the financing needs by comparing them with existing funded projects.

Financial need - regional cement (€bn / year)

- 0
-] 0 ; 1]
-] 1 ; 2]
-] 2 ; 3]
-] 3 ; 4]
- > 4

Share of need per e-fuel

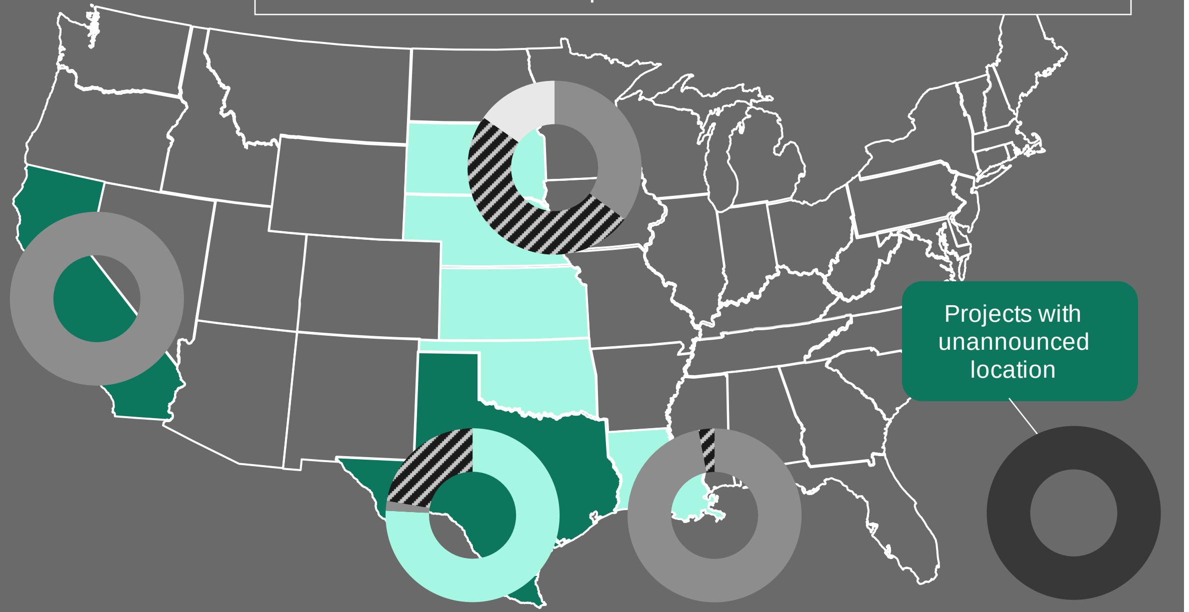
- e-methane
- e-methanol
- e-kerosene
- e-ammonia
- e-essence
- e-diesel

Few of the announced projects are already active, under construction, or even reached a final investment decision (5/21). The production hubs do not display the same scales of financing which can range from €1.5 bn for Louisiana (2 projects) to €10 bn for the Gulf Coast/Texan Hub (11 projects).

Despite high investment and production costs, the funding announced by the government can turned a positive business model possible. The conversion of former high-emitting sites or the development of emission-reducing technologies makes them eligible for funding programs from the government or the Department of Energy.

Focus on a project:

Matagorda project developed by HIF Global aims to produce 1,336 ktoe of emethanol by 2027, which makes it the largest production site in the world. The funding amounts to $6 bn. No potential buyer is known, unlike the other site operated by HIF in Chile (Haru Oni), for which Porsche has expressed interest.



* DOE: Department of Energy ** SAF: Sustainable Aviation Fuel

Part 3: Inter-Country Comparison

Organization of sectors

The e-fuels sectors in Europe and North America are structured differently. **Even if each country develops a PtX policy (hydrogen and/or e-fuels), the environmental visions displayed differ**. As major producers and consumers of gas, the United States and Canada do not exclude production of blue hydrogen and its use for e-fuel projects. More generally, unlike other geographical areas positioned on the production of e-ammonia, **Europe and North America are focusing more on the production of e-fuel mobilizing carbon** .

	Denmark	Spain	Sweden	Canada	United States
Main typologies of actors*	Developers of RES** 73%*	Shipowners 46%*	Energe-ticians 51%*	Pure players 73%	Pure Players 49%*
Molecules developed	65% e-methanol 21% e-ammonia	87% e-methanol 11% e-ammonia	46% e-methanol 53% e-kerosene	62% e-ammonia 26% e-diesel	46% e-methanol 35% e-kerosene
Targetedd markets	Domestic consumption Export of expertise	Domestic transportation Export of maritime fuels	Domestic transport Export of hydrogen-derived products	Domestic transportation and fertilizers Exports mentioned	Industry and domestic transport (despite decarbonization strategies focused on biofuels)
Energy sources used for the production of hydrogen	Dedicated renewable electricity supply	Dedicated renewable electricity supply	100% renewable electricity mix targeted for 2040	Dedicated renewable electricity supply Some projects including blue hydrogen**	Dedicated renewable electricity supply Some projects including blue hydrogen**

** Share of project capacities in which typologies of actors are positioned, out of total project capacities*

Actor networks

National Associations **have been structured** in Europe to bring together players in the hydrogen and e-fuels value chains (e.g. AeH2 in Spain), with unequal capacities for mobilizing the main stakeholders in their diversity.

Denmark seems to stand out with strong synergies between the different national players in the value chain (R&D, marketing development, consumers).

In Sweden, the government initiative Fossil Free Hydrogen aims to create synergies between public and private actors. The public hydrogen strategy is directly inspired by a roadmap developed by this structure.

In the **United States, the hydrogen industry is organized into different national hydrogen associations (FCHEA) and state hydrogean ones.**

*** RES: Renewable Energy Sources*

**** E-fuel projects based on the valorization of blue hydrogen not presented in the country sheets*

Carbon-free electricity needs

The needs of the e-fuels sector for carbon-free electricity represent **significant volumes that must be anticipated by public authorities and industrial players**. The countries studied have strong potential for increasing their production of renewable electricity, which is currently favored by project leaders. However the intermittency of these means of production raises the issue of the diversity of supply sources, given that the business models of electrolyzers are based on high load factors (>90%) and that the variability of the load degrades and prematurely ages electrolyzers.

Share of electricity requirements of announced e-fuel projects, compared to 2030 projections of renewable and nuclear electricity production volumes planned by public authorities*

	Denmark	Spain	Sweden	Canada	United States
Share	17%	10%	7%*	13%	3%
Renewable electricity production in 2022	21 TWh/year	169 TWh/year	157 TWh/year	405 TWh/year	1,738 TWh/year
Renewable electricity production targets in 2030	157 TWh/year	333 TWh/year	(Target 2040) 208 TWh / year	648 TWh/year	2,164 TWh/year

What are the tomorrow's level of energy efficiency?

A total energy efficiency of 45% can be anticipated for the first industrial projects. **An improvement in this efficiency of 10 points is possible in the long term** with the improvement of techniques and the integration of new technological components, including high temperature electrolysis.

Some projects are already positioning themselves for the deployment of high temperature electrolysis and/or co-electrolysis of water and CO_2 (Green Meiga project in Spain; First Ammonia-Uniper project in the United States) .

What energies should we consider?

Solar and wind power represent the energy sources on which investment and development efforts will focus for all the countries studied, with also an effort planned in Canada on increasing hydropower production (+15% by 2030) .

By 2030, the total installed solar and wind capacities planned for Spain are 76GW and 62 GW, 12.8 and 32.1 GW for Denmark and a total of 444 GW for the United States.

Sweden, which is aiming for a 100% carbon-free electricity mix by 2040, is focusing primarily on wind power with the production of 120 TWh of new wind capacity.

The Canadian mix is not expected to change significantly by 2030, even with the increase in wind, solar and hydro capacities. Natural gas ies expected to remain a significant source in the electricity mix (16%).

What role for nuclear power?

Positions on the role of nuclear power in the electricity mix vary depending on the country. Spain and Denmark have **stopped using it**, and Spain is opposed within EU instances to its consideration as a mean for decarbonization. Sweden has a **more ambivalent position due to the differences** between its two major political wings. The United States and Canada adopt **pro-nuclear policies** and invest in SMR** and advanced reactors.

Generally speaking, e-fuels project leaders in all of these countries tend to communicate on the development of renewable electricity.

** Indicator for Sweden: assuming a linear progression in renewable electricity production between 2022 and 2040*

*** SMR: Small Modular Reactor*

Public support provided

Considering the production ambitions expressed by the players in all the countries, the **amounts of financing programs appear relatively low.** Despite strong support for the hydrogen sector, **the absence of specific policies dedicated to e-fuels can be noted** (see Part 1). Only Denmark stands out with a single call for tenders carried out in 2023 for an amount of €170 M. However, **Europe stands out with regulatory obligations** on fuel consumers in certain sectors, unlike **North America which favors the encouragement or adoption of biofuels .**

Development strategies

Only **Denmark** has published a **specific strategy** for the development of the e-fuels sector and market prospects. Spain, Sweden, Canada and the United States have published strategies related to hydrogen to identify key sectors of application and set objectives for developing electrolysis capacities.

The relation between public and private in the framework of project development varies.

- The Spanish government signed a collaboration protocol with Maersk in 2022 to explore opportunities for large-scale e-methanol production (for a total budget planned of €10 bn)
- Denmark and Sweden have a long tradition of private companies – union – State negotitation, facilitating coordination.
- The United States and Canada have set ambitions and a regulatory framework regarding the production of clean fuels and offer associated financing.

Share of the financing needs of the projects identified in relation to the support envelopes planned for the hydrogen and e-fuels sectors*

	Denmark	Spain	Sweden	Canada	United States
Share	22%	15%	NC	NC	32%
Number of projects with FID	5 / 14 projects	0 / 13 projects	1 / 8 projects	3 / 19 projects	5 / 21 projects

Nature of financing and associated mechanisms

In Spain, funds are allocated by **call for tenders within different programs** (H2 pioneros , H2 Cadena de Valor), for a total of **€1.6 bn**.

Since 2015 and 2018, Sweden has had **2 application-based funding programs** (Climate Leap and Industrial Leap), for a total of **€1.1 bn. No funding is dedicated to hydrogen or e-fuel projects**.

Denmark **mixes different investment schemes** with its EUDP financing program for green technologies, Mission Green Fuel financed by the innovation fund and the PtX call for tenders in 2023. The amount of investments proposed amounts to **€2.5 bn**.

The United States offers various subsidy programs to which e-fuel projects can apply, as well as a package of protectionist measures (IRA) guaranteeing tax reductions and loans. The Infrastructure Investment and Jobs Act provides **$7 bn in subsidies for hydrogen hubs** spread across the country.

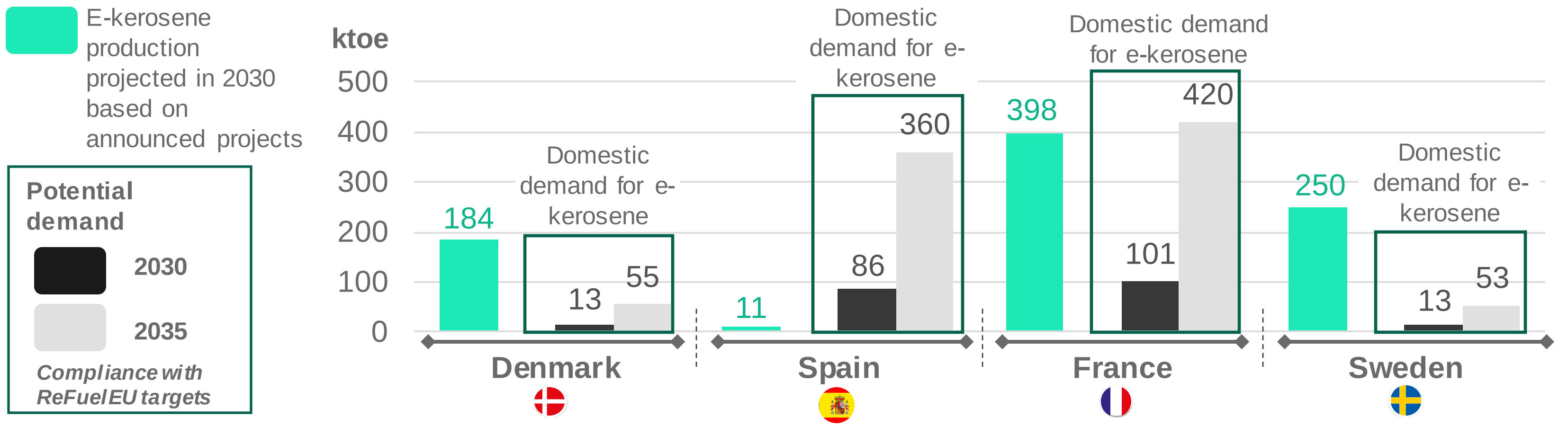
In response to the IRA, Canada announced tax credits to promote green energy. The country has also set up 2 financing funds that e-fuel projects can use: Net- Zero Accelerator and the Clean Fuel Fund. However, **no funding is specifically aimed at hydrogen or e-fuels**.

** Only taking into account subsidies earmarked for e-fuel or hydrogen projects. NC: country not offering one.*

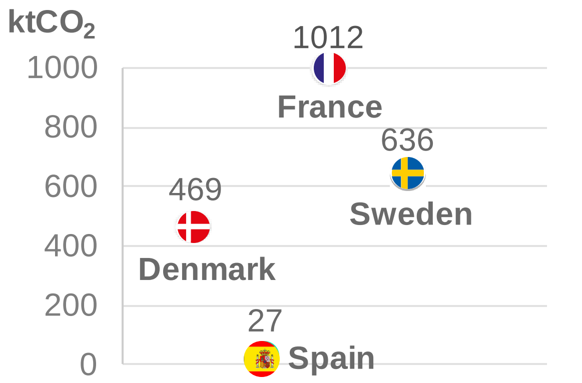
Comparison between projected e-kerosene production capacities in European countries and national needs linked to the ReFuelEU regulation

The comparison between the projected e-kerosene production capacities in European countries and the demand that will be created by the implementation of the ReFuelEU regulation (see Part 1) reveals that the countries studied will not all be self-sufficient for the needs of their air sectors. **New initiatives must therefore be encouraged to meet regulatory obligations, supplemented by cross-border exchanges.**

ReFuelEu targets and projected e-kerosene production in 2030 based on announced projects*



Minimum volume of avoidable CO_2 emissions if the announced projects are carried out***



* Hypotheses

- Implementation of targets for incorporating increasing shares of e-kerosene into distributors' offerings (see: RefeuEU) and compliance with targets for avoided CO_2 emissions .
- Constant demand for aviation fuel between 2019** and 2035: Constant air traffic, no progress in the field of energy efficiency, no impact of the obligation made by the ReFuelEU regulation to supply aircraft in European airports up to 90% of what is required each year.
- No development of hydrogen in the energy mix of the aviation sector.

*** Source of kerosene consumption values by country in 2019: Eurostat*

*** Hypotheses

- Emissions reduced by 70% compared to fossil kerosene over the entire life cycle of e-kerosene, consistent with European requirements taking into account synthetic fuels in achieving regulatory targets

What are the advantages of confirming a pioneering position for the most advanced countries?

Only 14 out of the 75 listed projects in Spain, Denmark, Sweden, Canada and the United States have benefited from a final investment decision. These represent 13% of the capacities of the announced projects. Their business models are based on an element of risk, linked to their innovative nature and uncertainties about changes in the market environment. Thowever, the countries that will see the first industrial-sized projects emerge in the coming years will benefit from several advantages in the long term.

Secure shares in markets where demand will grow gradually, in particular in line with European regulatory objectives (see Part 1)

Structure a national value chain and **develop references** that will support export initiatives based on demonstrated know-how

Play a role as a technological pioneer and get ahead of the technical and technological improvements to be anticipated in the long term

Appendices: Assumptions Used in The Construction of Country Sheet Indicators

Calculation of production capacity indicators

In order to be able to calculate the indicators of the production capacities of projects under construction or in activity (indicator 1), which have reached a final investment decision (2) and under study (3), we relied on the **volumes production, current or envisaged, communicated by the project leaders**. **We do not take into account mapped projects that do not communicate their production targets** in our calculations. The data collected was converted into **Tonnes of oil equivalent** (toe) to facilitate comparisons of the volumes obtained. Only **the electro-sourced part of e-biofuels** was taken into account.

01. **Production capacity of projects under construction or in activity**

02. **Production capacity of projects with FID**

03. **Production capacity of projects under study**

Volume and mass energy densities of the different molecules

Unit	(e-) hydrogen *Liquid*	(e-) methane *Liquid*	(e-) methanol *Liquid*	(e-) kerosene *Liquid*	(e-) ammonia *Liquid*	(e-) gasoline *Liquid*	(e-) diesel *Liquid*
m^3	4.88	2.03	2.91	1.20	3.95	1.16	1.18
L	4877.97	2025.45	2908.33	1204.08	945.22	1160.36	1177.76
kg	346.34	855.99	2300.49	963.26	2394.75	986.30	1008.22

=

Energy values (PCS basis)		
1 toe =	Boe	7.33
	Tce	1.57
	MBtu	43.10
	GJ	45.37
	MWh	12.60

We based ourselves on **the densities of fossil molecules** because synthetic molecules are identical to them in terms of chemical composition.

The energy volume of fuels produced by valorizing biomass can be more than doubled following an injection of hydrogen (ADEME, 2023; IEA, 2023). We consider that **half of the capacities of e-biofuels** can be considered **electro-sourced** .

Taking into account the contribution to biofuel sectors

Scope used for calculations

Strictly electro-sourced e-fuels

Fuel and combustibles whose energy content is of low-carbon electrical origin and comes exclusively from hydrogen produced by electrolysis of water and non-sourced carbon directly from biomass.

Electro-sourced share of e-biofuels

Energy volume of low-carbon electrical origin included in biofuels enriched with hydrogen, corresponding to the share of final energy of e-biofuels resulting from the injection of hydrogen produced by electrolysis of water.

Out of bounds

Bio-sourced share of e-biofuels

Energy volume of biological origin included in hydrogen-enriched biofuels, corresponding to the share of final energy of e-biofuels resulting from the gasification of biomass.

Calculation of the indicator on electricity needs

For the calculation of **indicator 4 of electricity needs** by country, we relied on the values calculated for indicators 1, 2 and 3 for each molecule and on an **assumption of 45% yield** of the synthesis process of the molecules at horizon 2030*, without taking into consideration the prospects of improving energy efficiency to 55% beyond this horizon*. Countries not communicating their production objectives were not taken into account in the calculations of needs.

04

Electricity requirements

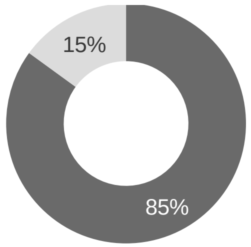
Molecule	MWh/toe
e-methane	*28*
e-methanol	*28*
e-kerosene	*28*
e-ammonia	*28*
e-essence	*28*
e-diesel	*28*

The calculation of electricity needs is based on an **energy efficiency of the entire value chain of 45% in 2030***.

Overall energy efficency **of 55% achievable** in the long run, thanks to future technological improvments.

For e-kerosene, the overall energy efficiency of 45% adopted will assume **full recovery of co-products** .

Industrial distribution of electrical needs**



Taking into account the contribution to biofuel sectors

Scope used for calculations

Strictly electro-sourced e-fuels

Fuel and combustibles whose energy content is of low-carbon electrical origin and comes exclusively from hydrogen produced by electrolysis of water and non-sourced carbon directly from biomass.

Electro-sourced share of e-biofuels

Energy volume of low-carbon electrical origin included in biofuels enriched with hydrogen, corresponding to the share of final energy of e-biofuels resulting from the injection of hydrogen produced by electrolysis of water.

Out of bounds

Bio-sourced share of e-biofuels

Energy volume of biological origin included in hydrogen-enriched biofuels, corresponding to the share of final energy of e-biofuels resulting from the gasification of biomass.

* Source: Comments from members of the French E-fuels Office; Roadmap towards e-fuel production, *Academy of Technologies, 2023;* A Techno-Economic Assessment of Fischer– Tropsch Fuels Based on Syngas from Co-Electrolysis, *Ralf Peters et al, 2022*
** Not taking into account solutions for co -electrolysis of water and CO2, possible beyond 2030

Calculation of the carbon needs indicator

For the calculation of **indicator 5 of carbon needs** by country, we relied on the values calculated for indicators 1, 2 and 3 for each molecule and on technical hypotheses taken from the reference literature regarding CO_2 needs. for a given e-fuel production volume. Countries not communicating their production objectives were not taken into account in the calculations of needs.

05.

Carbon requirements

Molecule	tCO_2/toe	Source
e-methane	2.5	Conservative case – ADEME report (ADEME, What electricity and CO2 needs? Final report, 2023)
e-methanol	2.9	
e-kerosene	6.4	
e-ammonia	0	
e-essence	3.6	e-FTL value (e-Fischer- Tropsch Liquids) – Journal of Cleaner production (T. Galimova et al, Journal of Cleaner Production, Volume 373, 2022)
e-diesel	3.6	

Carbon is used for the synthesis of e-fuels as an input with hydrogen. E-biofuels correspond to the injection of hydrogen into biofuel. **The electro-sourced portion of e-biofuels therefore does not include the use of carbon.**

Taking into account the contribution to biofuel sectors

Scope used for calculations

Strictly electro-sourced e-fuels

Fuel and combustibles whose energy content is of low-carbon electrical origin and comes exclusively from hydrogen produced by electrolysis of water and non-sourced carbon directly from biomass.

Electro-sourced share of e-biofuels

Energy volume of low-carbon electrical origin included in biofuels enriched with hydrogen, corresponding to the share of final energy of e-biofuels resulting from the injection of hydrogen produced by electrolysis of water.

Out of bounds

Bio-sourced share of e-biofuels

Energy volume of biological origin included in hydrogen-enriched biofuels, corresponding to the share of final energy of e-biofuels resulting from the gasification of biomass.

Calculation of the indicator on water consumption needs

Indicator **5** is based on the values calculated for indicators 1, 2 and 3 for each molecule and on technical hypotheses from the reference literature as to water consumption needs for a given e-fuel production volume. Countries not communicating their production objectives were not taken into account in the calculations of needs. Our calculations take into account the consumption needs across the entire e-fuel production chain for water electrolysis and CO_2 capture. It does not take into account water withdrawal for cooling equipment.

06.

Water consumption requirements

Water consumption
Water withdrawal

Water collected per tonne of H2 produced*		Water collected per tonne of CO_2 captured	
Value	Justification	Value	Justification
65 l/kgH2	• Water electrolysis: Assumption of use of purified raw fresh water (10L/kg H2) • Liquid cooling technique for electrolysers: Average of 55L/kg H2 (see: IEA, *The role of e-fuels in decarbonizing transports*, 2023)	**2.15 m^3/t CO_2 captured**	• Hypothesis of use of post-combustion technology: Average needs according to the typologies of CO_2 sources (see: *Water footprint of CCS technologies*, L. Rosa and Co, 2020.)

E-fuels	H2 and CO_2 requirements per toe produced		Water requirements linked to the cooling of equipment allowing the synthesis of e-fuels		Total water withdrawal requirements (L/toe)
	Value	Source	Value (l/toe)	Source	
e-methane	0.55 t H2/t e-fuel	Methanation, Storengy, 2022	8108	• Ratio of 1.65 between and volumes of water taken for the synthesis of e-fuels on the one hand and the production of hydrogen and the capture of CO_2 on the other hand (see: *Concawe Review*, 2019)	**13514**
	2.5 tCO2/ toe e-fuel	ADEME, *What needs*, 2023			
e-methanol	0.2 t H2/t e-fuel	*ADEME report*	9420		**15700**
	2,9 tCO_2/toe	*Rapport ADEME*			
e-kerosene	0,5 t H2/t e-fuel	*Rapport ADEME*	20687		**19428**
	6,4 tCO_2/toe	Journal of Cleaner production			
e-ammoniac	0,18 t H2/t e-fuel	*Rivaloro & co, 2019*	10501		**10529**
	0 tCO_2/toe	*Rapport ADEME*			
e-essence	0,5 t H2/t e-fuel	*Rapport ADEME*	11 659		**19432**
	3,6 tCO_2/toe	Journal of Cleaner production			
e-diesel	0,5 t H2/t e-fuel	*Rapport ADEME*	11 658		**19430**
	3,6 tCO_2/toe	Journal of Cleaner production			

* Not taking into account solutions for co-electrolysis of water and CO_2, possible beyond 2030

Calculation of the financing needs indicator

For the calculation of **indicator 7 on financing needs** by country, we relied on the values calculated for indicators 1, 2 and 3 for each molecule and on technical hypotheses resulting from an inventory of available data on the CAPEX of e-fuel production projects.
Countries not communicating their production objectives were not taken into account in the calculations of needs.

Molecule	Number of projects identified with communications on the CAPEX envisaged	Capacity range of the projects concerned (in ktoe/year)	Total capacity affected by these projects (toe/year)	Total CAPEX of the projects concerned (M€)	Assumptions retained on CAPEX requirements M€/toe e-fuel produced
e-methane	*0*	*/*	*/*	*/*	*0.0178**
e-methanol	*8*	*3 – 1,336*	*2,459,295*	*17,363*	*0.0071*
e-kerosene, e-petrol, e-diesel	*15*	*1 – 425*	*1,819,820*	*11,923*	*0.0066*
e-ammonia	*6*	*42 – 292*	*1,194,281*	*21,430*	*0.0179*

* The technical assumptions on CAPEX requirements for the e-methane sector are based on an extrapolation of data collected for other e-fuel production sectors.

Notes Regarding the Sources Used.

Perimeter

This edition of the *International E-fuels Observatory* published in February 2024 covers synthetic ammonia, methane, methanol, kerosene, diesel and gasoline whose energy content is partially or entirely obtained from hydrogen obtained by electrolysis of water. The share of the energy volume of e-biofuels resulting from the injection of hydrogen produced by electrolysis of water in a biofuel production process is also included in the scope of the *Observatory.* This share is taken into account in the calculation of the indicators .

The project maps in Denmark, Spain, Sweden, Canada and the United States include projects announced publicly and whose commissioning is effective or planned by 2030. Projects which have not been completed are not not presented, as well as closed projects and projects that are still confidential.

Sources

The indicators presented in this publication are the result of analyzes specific to Sia Partners, based on publicly available information. Sia Partners provides this tool for informational purposes only and cannot be held responsible for the accuracy or completeness of the data. The sources used are referenced on the corresponding pages. Different project databases were used and supplemented by our own research (IEA, CO2 Value Europe, etc.). The sources used come from public organizations, research work or communication from players in the e-fuel ecosystem.

Certain members of the French E-fuels Office were also contacted to confirm the relevancy of our hypotheses.

Analysis

Sia Partners regularly updates its internal database on e-fuel projects in France and their characteristics (inputs, capacities, powers, technologies, costs, etc.). The data sources are verified in order to guarantee reliable consolidation of the indicators and to ensure that the most recent versions are up to date.

Glossary.

k	Kilo, Thousand (10^3)
M	Mega, Million (10^6)
G, bn	Giga, Billion (10^9)
T	Tera (10^{12})
bn	Billion
M	Million
Ha	Hectare
L	Liter
g	gram
m, m², m³	Meter, square meter, cubic meter
t	Tonne
tce	Ton of coal equivalent
toe	Ton of oil equivalent
W	Watt
Wh	Watt hour
V	Volt
PJ	Peta joule (10^{15} Joule)

PtL / PtX	Power-to-Liquid / Power-to-X (production of hydrogen or liquid or gaseous e-fuels from water electrolysis)
CO_2	Carbon dioxide
Biogenic CO_2	CO2 from the valorization of bioenergy (wood, biogas, organic waste, etc.)
CCUS	Carbon Capture, Use and Storage
DAC	Direct Air Capture: capture of CO_2 contained in the atmosphere
e-fuel	Electro-fuel, synthetic fuel
RE	Energy, and in particular electricity, from Renewable sources
GHG	Greenhouse gas
LNG	Liquefied Natural Gas
H2	Dihydrogen (“hydrogen” in short)
H_2O	Water
NH_3 / e-NH_3	Ammonia / e-ammonia
FT / FTL	Fischer Tropsch / Fischer Trospch Liquids: technological brick making it possible to transform syngas (which itself can be obtained by valorizing hydrogen and CO_2) into several products, including (e-)kerosene, (e-)diesel, or (e-)naphtha
Blue hydrogen	Hydrogen produced by steam methane reforming with capture of emitted CO_2
Green/renewable hydrogen	Hydrogen produced by electrolysis of water from renewable electricity
Carbon-free hydrogen	Hydrogen produced by electrolysis of water from renewable or carbon-free electricity (notably nuclear electricity)
Electrolytic hydrogen	Hydrogen obtained by electrolysis of water
Blue ammonia	(e-)ammonia produced from blue hydrogen and nitrogen
Green/renewable ammonia	(e-)ammonia produced from green hydrogen and nitrogen
Carbon-free ammonia	(e-)ammonia produced from carbon-free hydrogen and nitrogen

Glossary.

€	Euro
$	Dollar
$CAD	Canadian dollar
DKK	Danish Crown
SEK	Swedish crown
LCA	Life Cycle Analysis
NB	Nota Bene
NC	Not disclosed
TRL	Technology Readiness Level (scale 1-9)

CAPEX, OPEX	Capital and operating expenses
SMEs	Small or Medium Business
PPP	Power Purchase Agreement
R&D	Research and development
Final Investment Decision, FID	Binding decision to launch a project, leading to the signing of contracts with the main industrial and financial partners and the launch of the construction phase of the project.
RED II, RED III	Renewable Energy Directive II, III
RFNBO	Renewable Fuel Of Non Biological Origin (hydrogen and green e-fuel)
SAF	Sustainable Aviation Fuel
SMF	Sustainable Maritime Fuel
EU	European Union

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