The world of energy: problems, but always with solutions

Prof. Damien Ernst

Co-authors: Victor Dachet, Antoine Larbanois, Samy Mokeddem, Thibaut Techy, Maurizio Vassallo

LIÈGE université

In the energy sector, economic and technical obstacles are often treated as if they were inevitable and impossible to overcome.

**However solutions do exist.**

This presentation highlights eight problems frequently raised in energy debates and shows how each of them can be addressed.

Some of the solutions presented come from research conducted by the Smart Grids Laboratory at the Montefiore Institute, University of Liège.
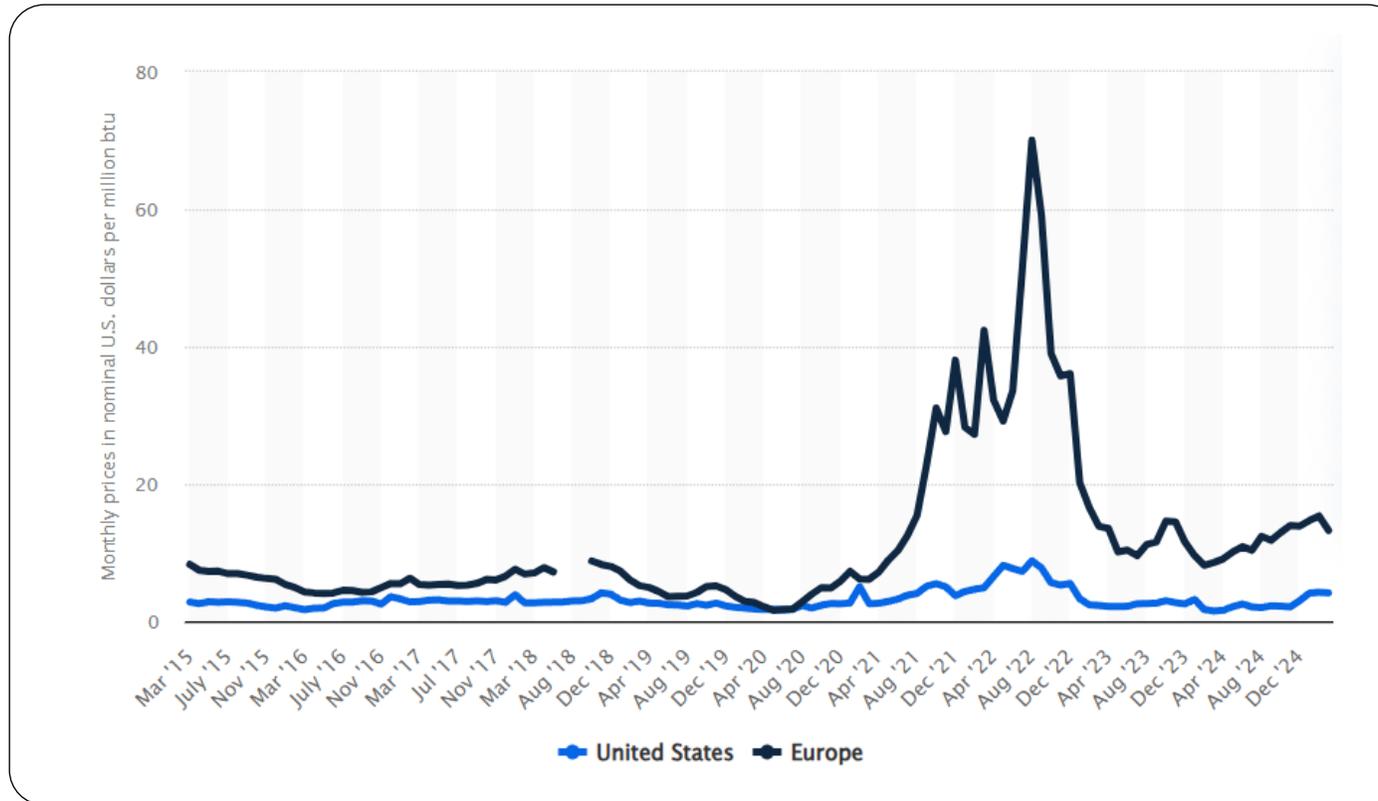
1st problem

Gas prices are far too high

In February 2022, Russia's invasion of Ukraine caused a sharp rise in natural gas prices on the European market, where the Dutch TTF is the benchmark price.

Natural Gas EU Dutch TTF (EUR/MWh) 34.622 1.999 (+6.13%)
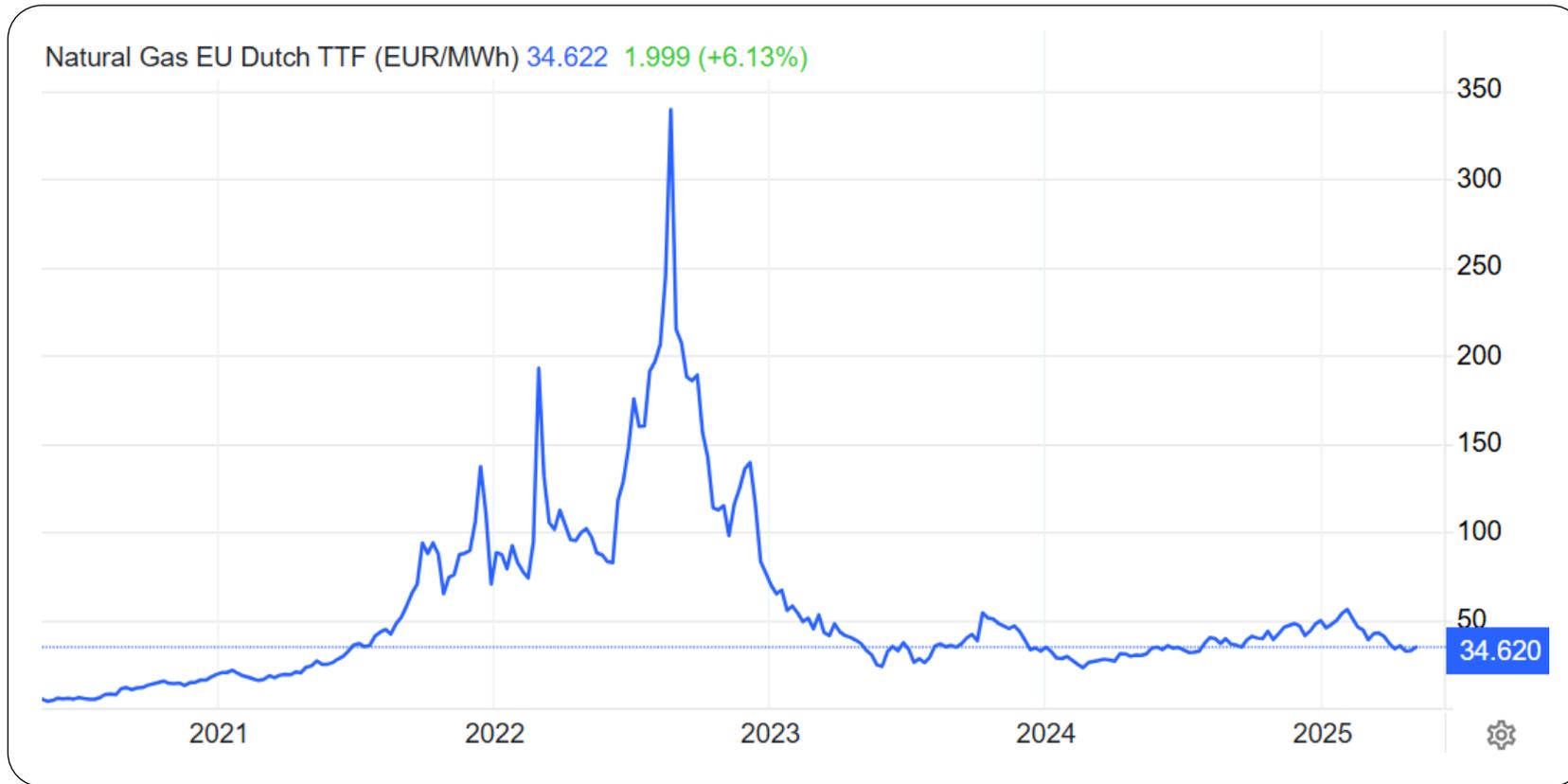
In 2025, gas is still on average three times more expensive in Europe than in the United States.*

→ Major competitive disadvantage for US companies.

→ Growing risk of gradual deindustrialization in Europe.

* The gas price shown in the figure is expressed in $/MMBtu, a unit commonly used in North American markets. One MMBtu is approximately equal to 0.293 MWh.

Will gas prices in Europe stay high forever, putting Europe's competitiveness with the U.S. at risk?

**There are very positive signs that solutions are emerging.**

Today, Europe is the largest customer for U.S. liquefied natural gas (LNG).

In 2024, **53%** of U.S. LNG exports were sent to Europe.

If Europe and the rest of the world show a desire to increase their purchase volume of North American LNG at a good price, US producers will prioritize exports.

This will lead to the development of new LNG terminals, reducing the supply available on the domestic market.

As a result, gas prices in the US are likely to rise, moving closer to European levels, and reducing the competitive gap.

1600 TWh/year early 2025 → 2000 TWh/year late 2026*
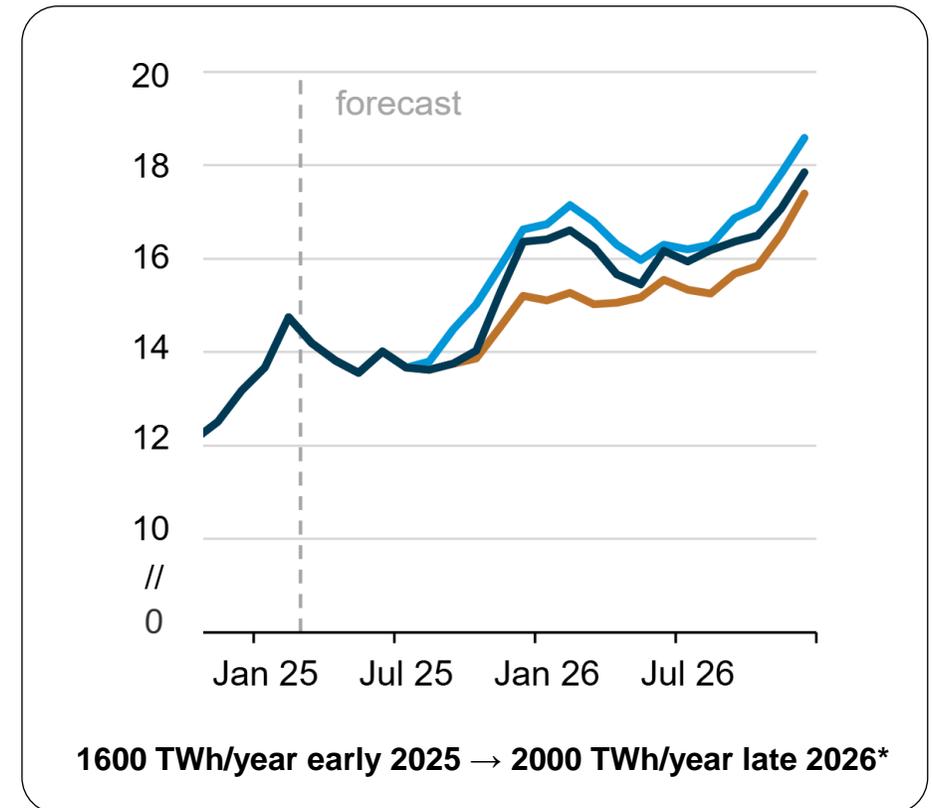
U.S. LNG export forecasts (Jan. 2023 - Dec. 2026) in billion cubic feet per day.[1]

* Gas volumes in the figure are expressed in billions of cubic feet per day (bcf/d), a unit commonly used in North American markets. One billion cubic feet equals approximately 293 GWh.

[1] Eia (2025, April 23). How will start-up timing of new US LNG export facilities affect forecasts? Eurasia Review.

LNG export contracts are signed with new producers.

Examples of emerging export sources include:

Qatar

One of the lowest production costs in the world, as low as **€1/MWh**.[1]

Mozambique

Strong investment by TotalEnergies, with an estimated production cost of **€15/MWh**.

With the rise of these new, abundant and inexpensive sources, we can even hope that the price of gas available to Europe in the future will be determined by its marginal production cost.

This is already the case for coal which is currently the only fossil fuel whose markets are not subject to manipulation.

As of May 15, 2025, the price of coal was $100 per tonne, or €12/MWh.

[1] Nikolay Kozhanov (2024, May 21) Qatar's LNG expansion plans and the issue of market oversupply. Middle East Institute.

The EU could consider a partial resumption of Russian gas imports if a lasting peace agreement is reached.

Technically, three routes still allow Russian gas to be transported directly to Europe. Together they could cover a significant share of the EU's annual consumption which is around 3,500 TWh[1].
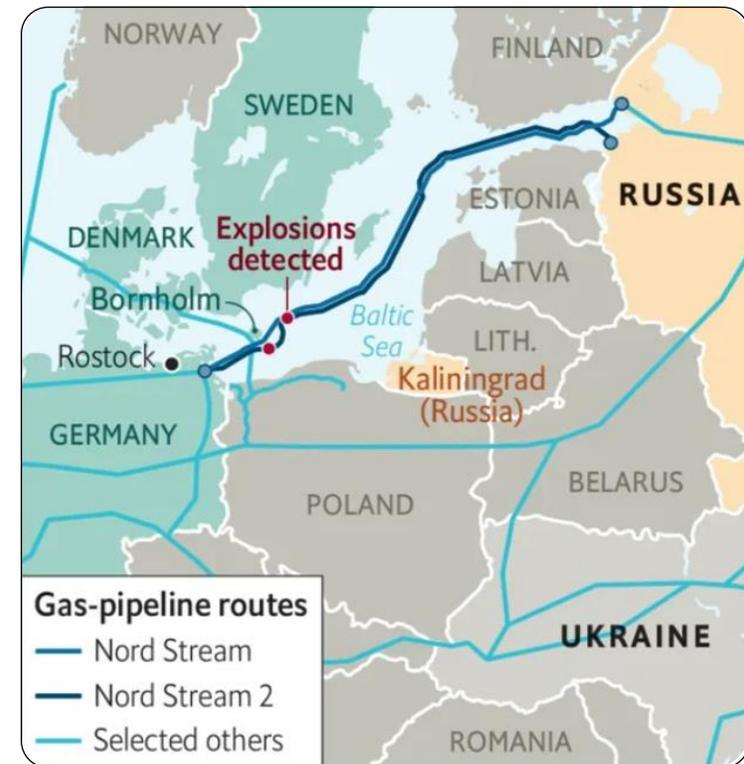
Nord Stream 2
Half of the pipeline remains operational;
Capacity: 250 TWh/year.

Yamal-Europe
Transit through Poland has been suspended, but the infrastructure remains intact;
Capacity: 350 TWh/year.

Brotherhood
The Ukrainian grid is (almost) fully functional;
Capacity: 1,100 TWh/year.

[1] R. Fernández-Blanco et al (2024, June) Natural gas consumption estimation in the European Union, Energy Reports, Volume 11.

Europe boosts gas production in the North Sea.

In April 2025, the Netherlands restarted gas production in its offshore zone.

The goal is to extract up to 100 billion cubic meters of reserves. Considering that one cubic meter of gas contains 11 kWh, this corresponds to around 1,100 TWh.

That is nearly a third of the EU's average annual gas consumption (3,500 TWh/year).

Platform N05-A
Installation topside

Installation of the N05-A gas platform in August 2024.
Its electricity supply will be provided by offshore wind power.

2nd problem

# Inverters tripping in photovoltaic systems

When photovoltaic (PV) production exceeds local consumption, the surplus electricity is injected into the low-voltage grid.

This leads to overvoltage.

As soon as the voltage exceeds certain thresholds, inverters automatically disconnect to protect the equipment.

If the voltage remains above 253 V (+10% relative to the nominal 230 V) for **ten consecutive minutes**, the inverter trips. If the overvoltage persists after this period, an additional ten-minute window is added before the inverter can reconnect.

If the voltage reaches 264 V (+15% relative to the nominal 230 V) , disconnection is **immediate**.
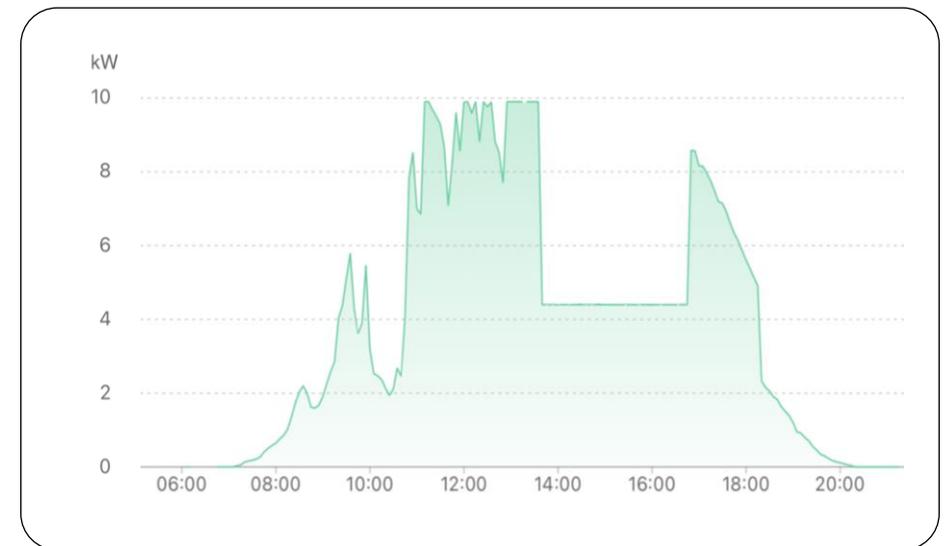
Production curve of a PV system equipped with two inverters. Shortly before 2pm, one of the inverters disconnects.

Installing a battery allows excess PV production to be absorbed locally instead of being fed into the grid, helping to mitigate power surges.

Battery costs have never been so low. Like PV panels, their prices have dropped significantly over the past decade, making this type of solution increasingly affordable.
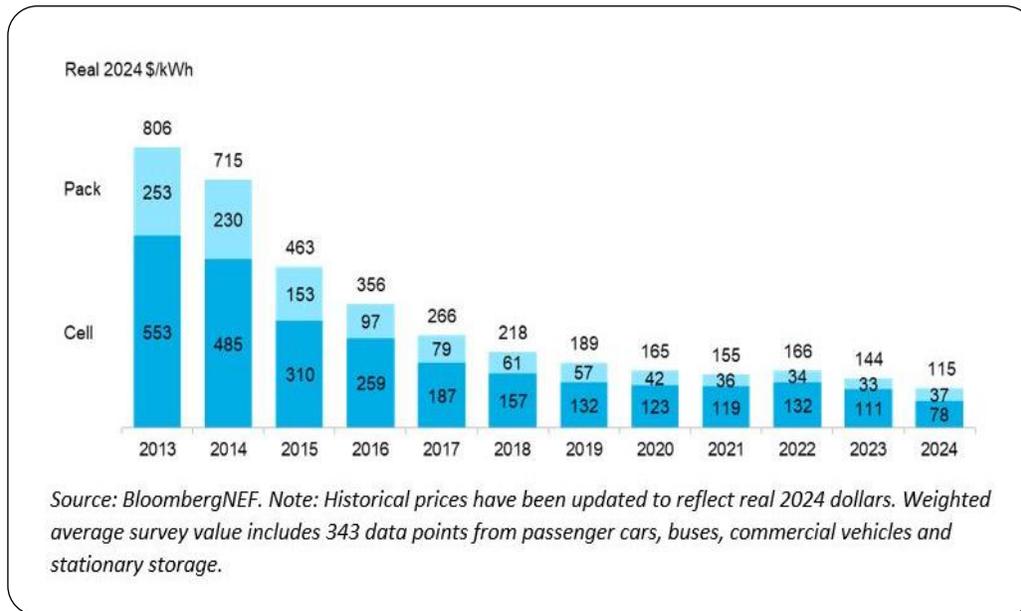
Average price trend for lithium-ion battery packs and cells, 2013-2024.[1]
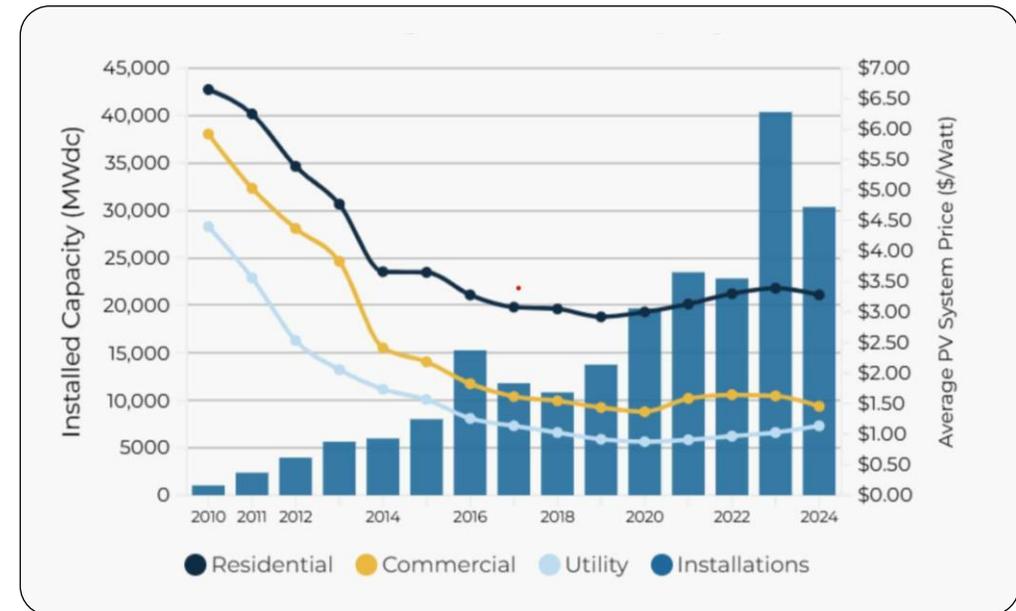
Price trends and deployment growth for PV in the United States, 2010-2024.[2]

[1] BloombergNEF. (2024, December 10). Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $ 115 per Kilowatt-Hour.

[2] Native Solar (2025, May 2). What's happening with the cost of solar and battery storage in 2025?

A properly sized PV system coupled with a battery can help mitigate power surges on the grid and enable islanding mode when needed.

But that is not all:

– It also **maximizes self-consumption**, avoiding taxes and grid charges on electricity used locally;

– When combined with a dynamic tariff, it creates **economic opportunities** by charging or discharging the battery at the most cost-effective times.
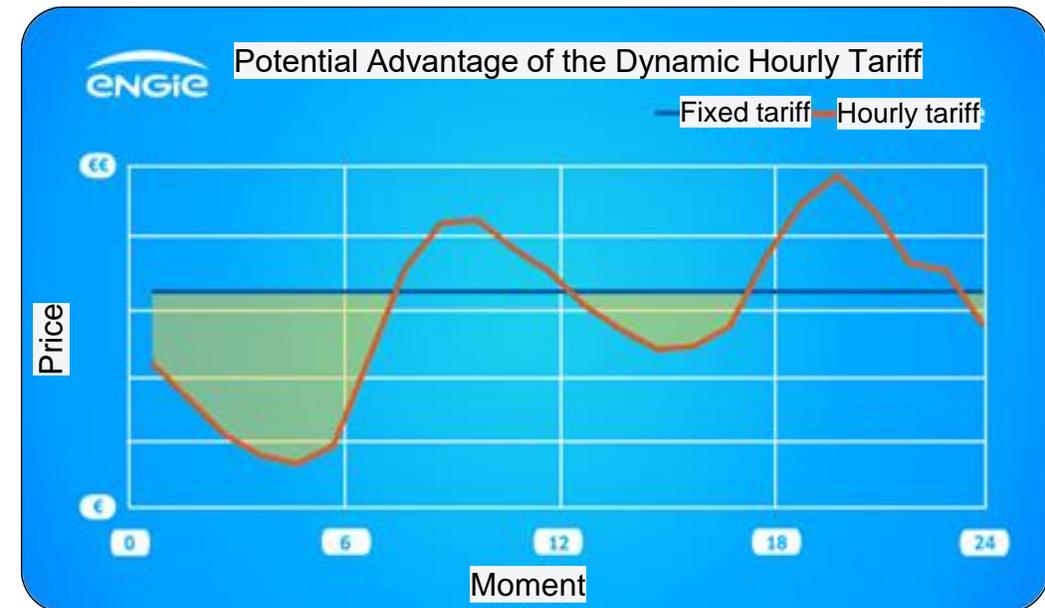
Engie's Dynamic tariff over a typical day.

3rd problem

The grid is saturated, and the injection is being refused

The massive integration of decentralized renewable sources like PV combined with the growing adoption of electric vehicles (EVs) is profoundly reshaping electricity flows in distribution networks.

This shift creates **new technical challenges**, such as power surges and local congestion. In response, the distribution network operator (DSO) may reject new connection requests for PV systems or EV charging stations.

LE SOIR

Fernand Grifnée (ORES):
"We will have to learn to share electrical power like any other scarce resource."

In an interview with Le Soir on March 31, 2025, the CEO of ORES, one of Belgian largest distribution network operator, acknowledged that it will not be possible to invest enough in infrastructure to fully prevent these bottlenecks.

To prevent overvoltage and congestion issues, heavy investments in cable or transformer upgrades are not always necessary.

An alternative is to make smarter use of existing capacity by allocating it intelligently among users.

A new operational network management paradigm, developed by the Smart Grids Laboratory at the Montefiore Institute, University of Liège, enables more efficient use of current infrastructure.

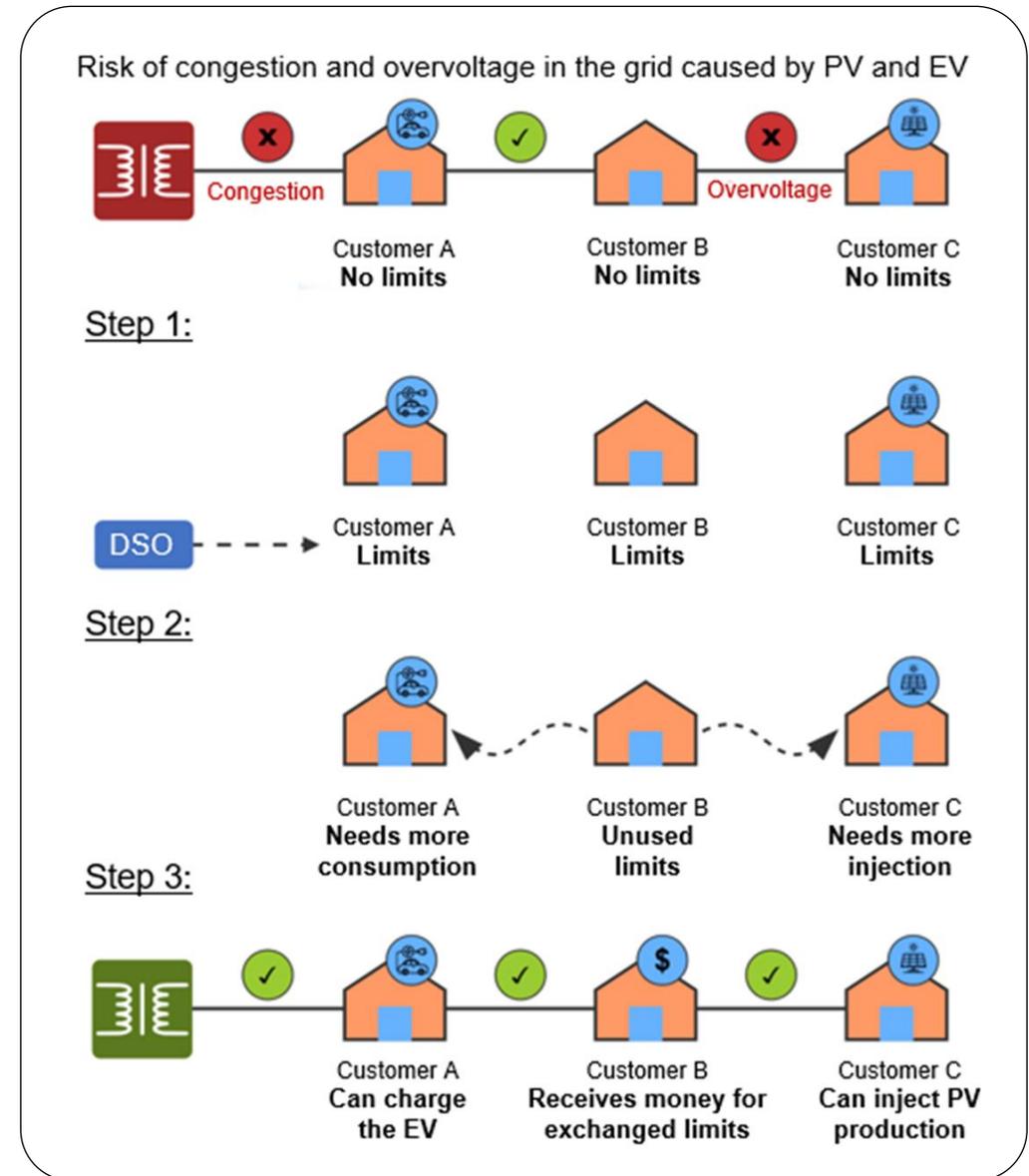Here is the three-step solution behind the new paradigm.[1]

Step 1:
The DSO assigns dynamic consumption and injection limits to each user, calculated to **avoid all problems** on the grid during every market period.

Step 2:
An exchange system then allows users to buy or sell part of their limits according to their needs.

Step 3:
Each transaction is monitored by the DSO to ensure that it does not cause overloads or imbalances as long as users stay within their assigned limits.

[1] Vassallo, M., Khaskheli, S., et al. (2025). A new Paradigm for Bilateral Trading of Dynamic Operating Envelopes in Electricity Distribution Networks. ORBi-University of Liège.

Concrete benefits for all.

The proposed paradigm offers several advantages for both customers and the grid:

– Fewer consumption or injection refusals, thanks to better use of network capacity;

– Improved valorisation of local production, helping to reduce energy losses;

– Participants in the limit market receive compensation, which encourages flexibility;

– The system can be deployed quickly without major investment, relying on existing infrastructure such as smart meters.

4th problem

Electrifying and/or decarbonizing all sectors is too complicated

Electrification alone is not enough for all sectors: some rely on molecules that are essential to their processes.

Heavy industry

Hydrogen (H_2)
→ refining

Agriculture

Ammonia (NH_3)
→ nitrogen fertilizers

Chemical industry

Methanol (CH_3OH)
→ acetic acid
→ plastics

Air transport

Saturated hydrocarbon
(C_nH_{2n+2})
→ kerosene

**To decarbonize these uses, we need to turn to e-fuels.
These are synthetic fuels produced using renewable electricity.**

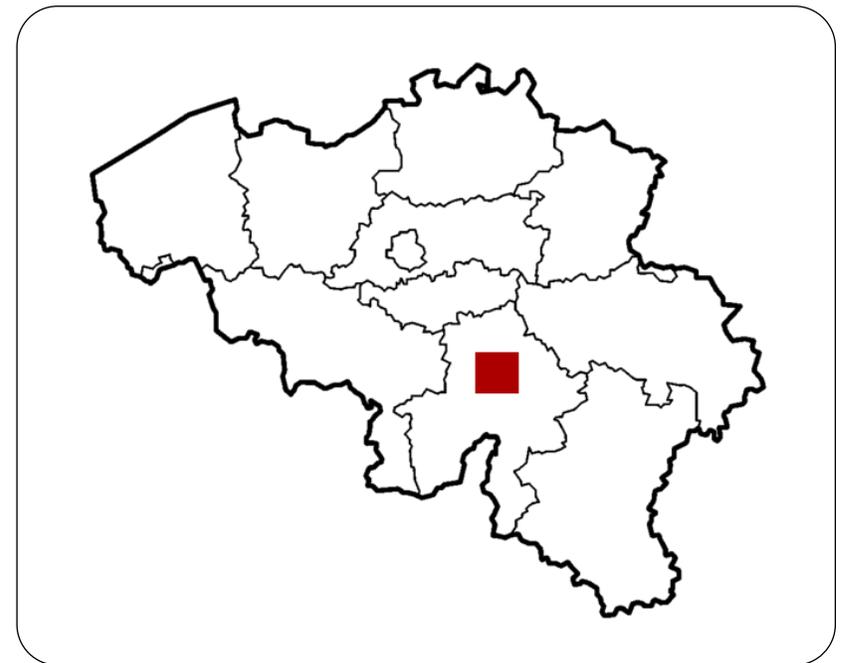E-fuels can be made from various base molecules:

– Water (H_2O) to produce hydrogen (H_2) via electrolysis;

– Nitrogen (N_2) to convert hydrogen into ammonia (NH_3);

– Carbon dioxide (CO_2), captured for example from the air, to synthesize saturated hydrocarbons of the C_nH_{2n+2} type.

Producing e-fuels is both an economic and technological challenge. It comes with two major obstacles.

First, low-cost electricity is needed, which is not a problem in itself since solar PV is relatively cheap.

Above all, large amounts of low-carbon electricity must be available continuously. This is difficult to ensure in densely populated areas or regions with limited renewable resources.
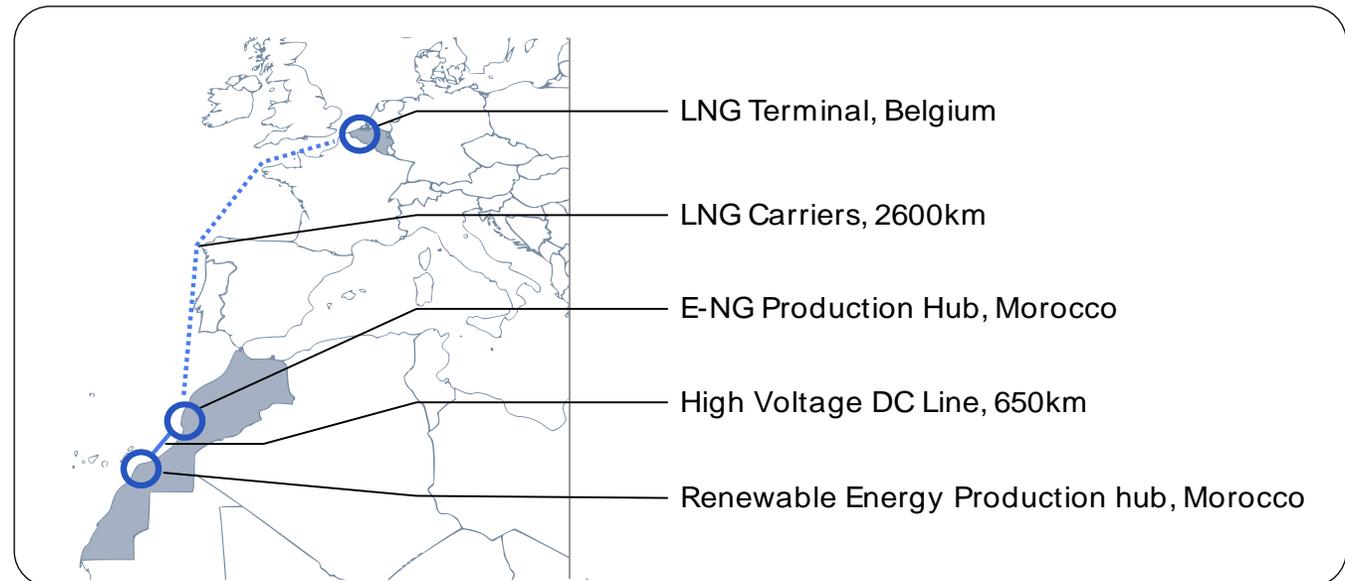
Example: To meet Belgium's entire national demand for kerosene by converting solar energy into e-kerosene, around **405 km²** of the country would need to be covered with PV panels.*

* The methodology, along with the data and assumptions used for these calculations, is detailed in Appendix 1.

To overcome these obstacles, e-fuels can be produced in Remote Renewable Energy Hubs (RREHs).

An RREH is a site located far from consumption centres characterized by strong wind and solar potential as well as high land availability. Renewable energy is harvested and (frequently) converted into e-fuels at these sites before being transported to consumption centres.

Example: An RREH in the Moroccan desert captures wind and solar energy, transports it to the coast via an HVDC link, converts it into e-methane, and exports it to Europe by sea.

LNG Terminal, Belgium

LNG Carriers, 2600km

E-NG Production Hub, Morocco

High Voltage DC Line, 650km

Renewable Energy Production hub, Morocco

An example of an RREH technology graph for e-methane production based on direct air capture (DAC) of CO_2.
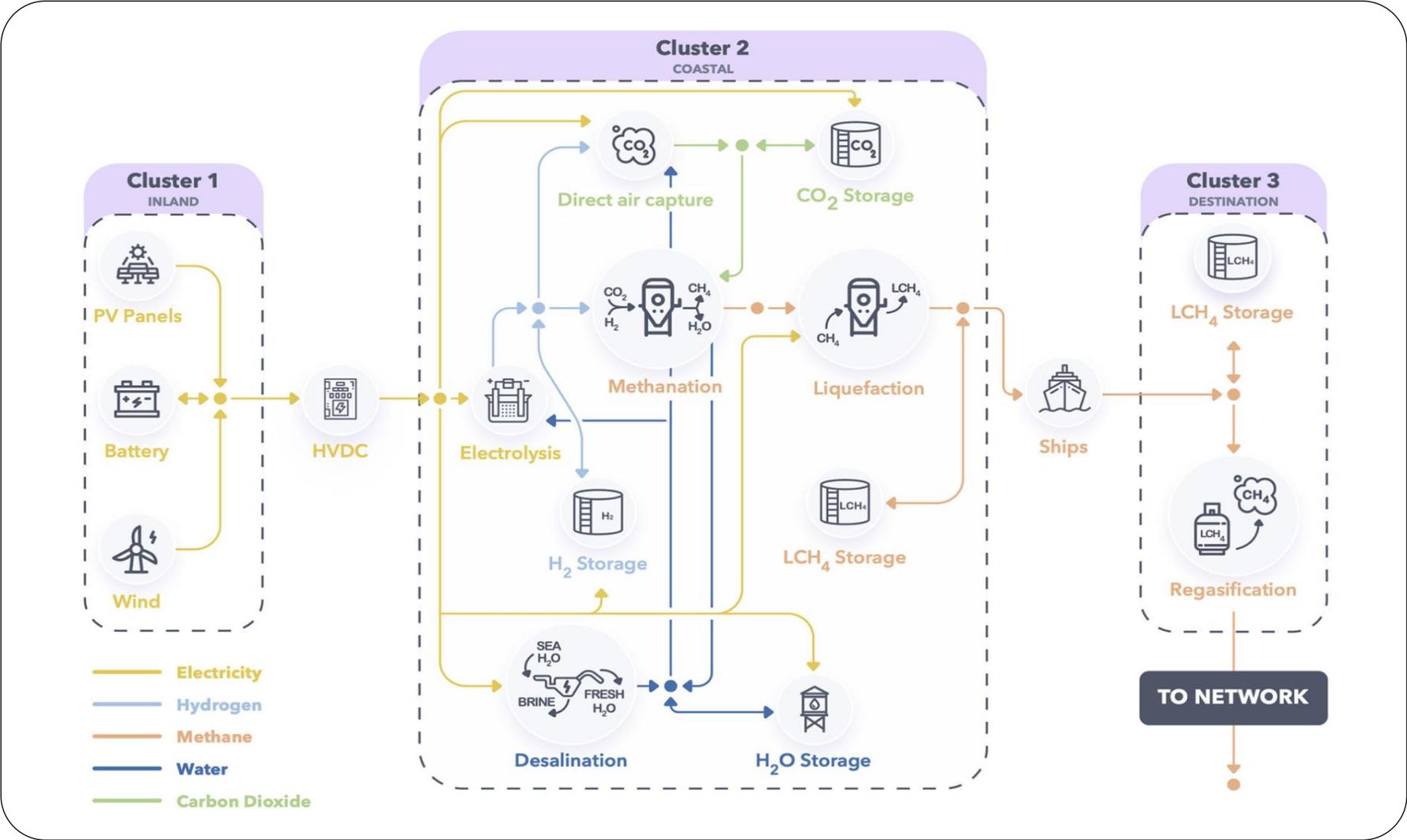
RREHs can be developed in remote areas or within Europe itself to strengthen energy security.

Example: **Extremadura, Spain**

- High solar irradiation: 200 W/m² (compared with 110 W/m² in Belgium);
- Low population density;
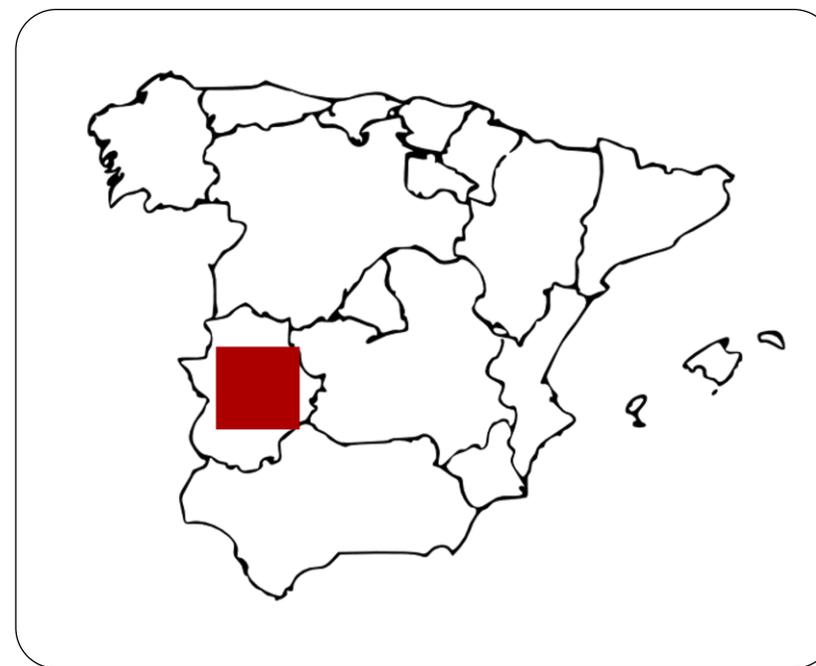- Direct access to the gas grid for transporting e-fuels.
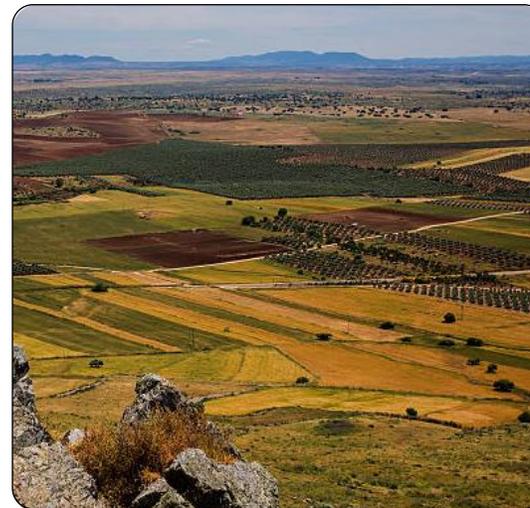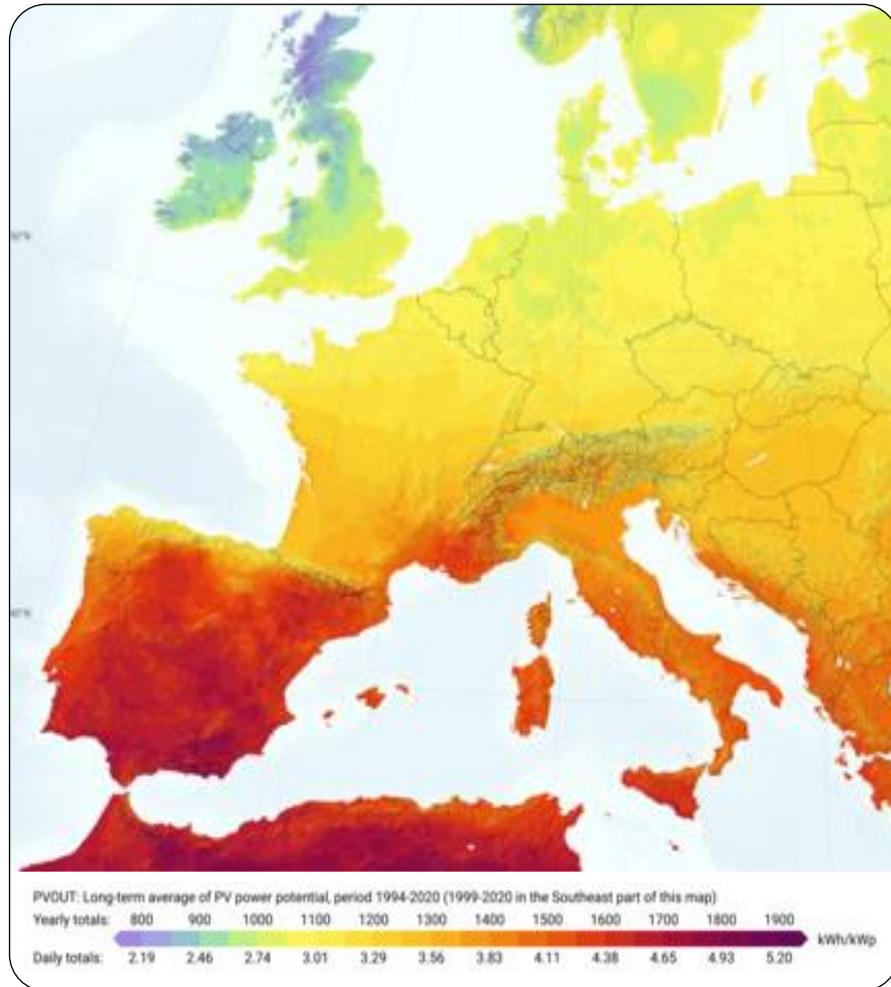
Let us do a little bit of math:
What surface area of PV panels would be needed to cover the EU 'entire gas demand?

The EU's average gas consumption is 3,500 TWh/year.

Around **16,000 km²** of PV panels would be required to meet this demand using PV production and power-to-gas technology. This estimate assumes solar irradiance of 200 W/m², a PV load factor of 25%, and 50% losses in the conversion process.*

That is "only" **40%** of the surface area of Spain's Extremadura region.

* The methodology, along with the data and assumptions used for these calculations, is detailed in Appendix 2.

28

5th problem

Belgian e-fuels will never be cost-competitive with imported ones, leaving the country reliant on importing all energy-dense molecules

Producing e-fuels locally in a region with limited renewable potential like Belgium may seem of limited relevance

E-fuel production is highly energy-intensive. However, in Belgium, sunshine is moderate and wind regimes are generally weak especially for onshore wind power. The cost of supplying renewable energy can quickly rise under these conditions. In addition, Belgium has limited available land to capture this renewable energy.
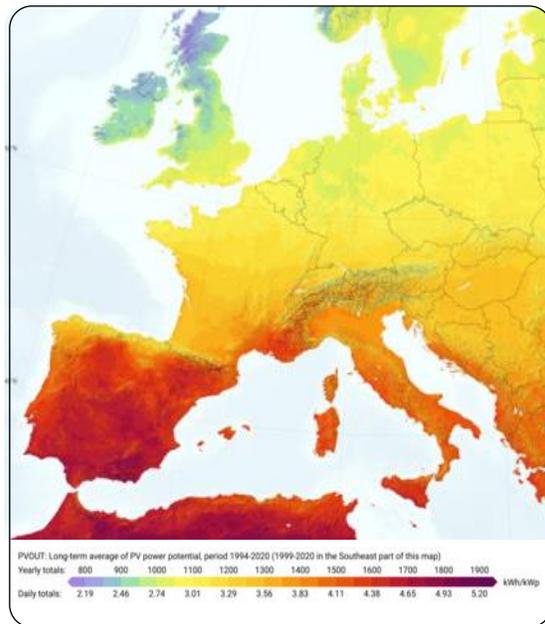
Annual solar irradiance map for PV potential in Europe.[1]
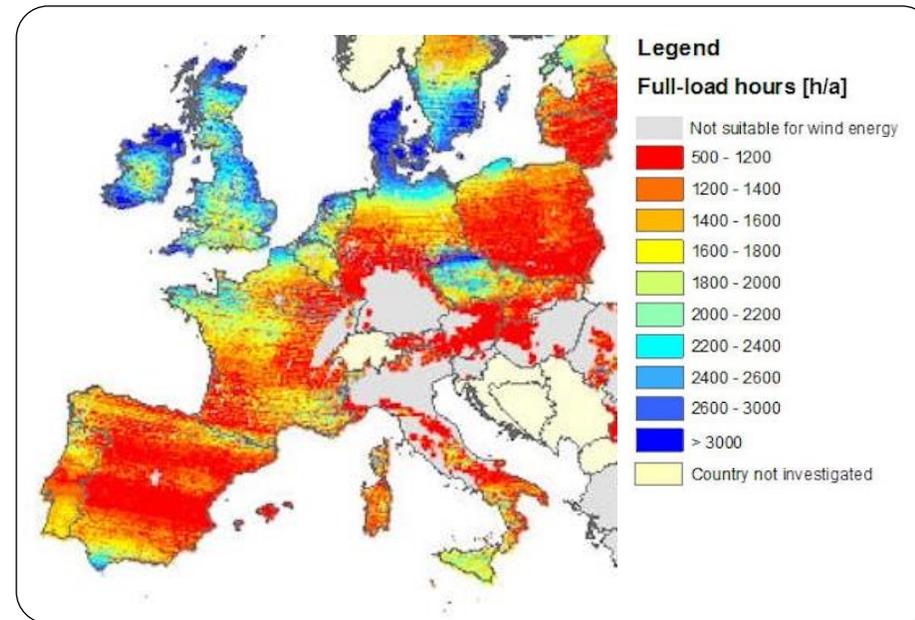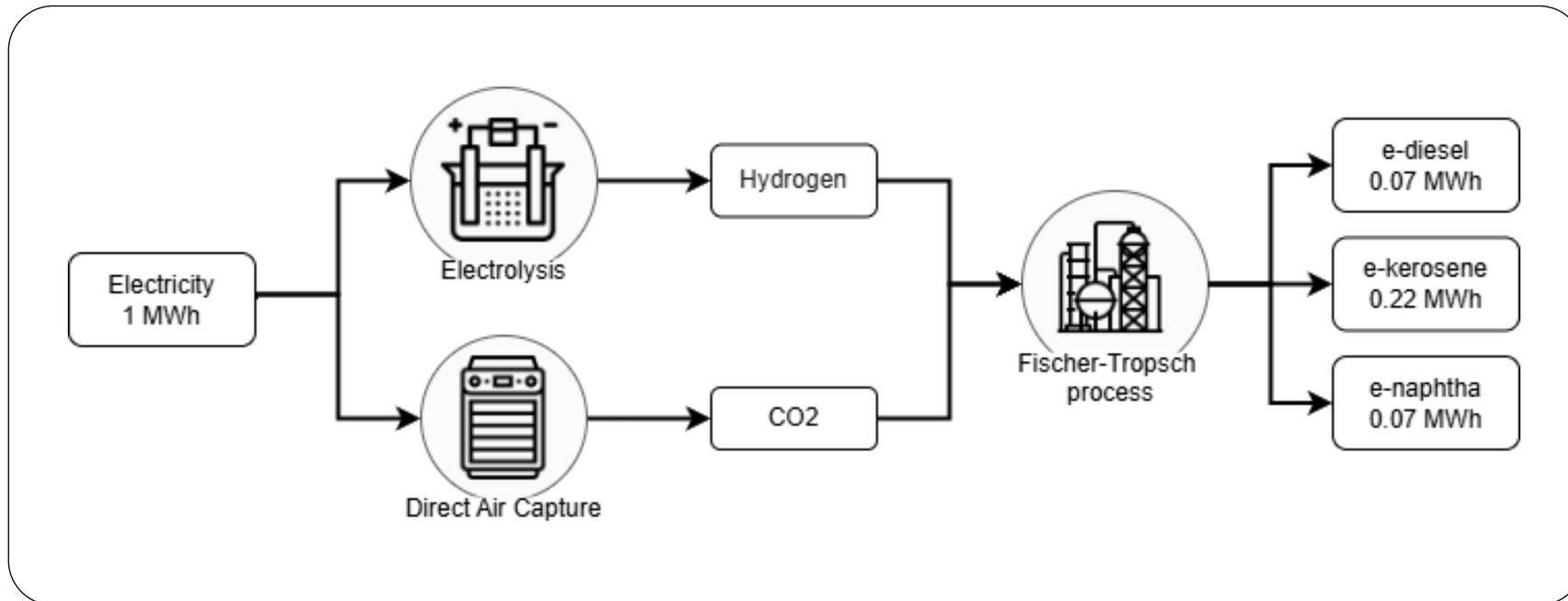

Map of full-load hours production for wind power potential in Europe.[2]

[1] SolarGIS (2011) Solar Radiation Map of Europe.
[2] Smith, A. Z. (2015, June 22). Why onshore wind isn't as cheap as it should be in the UK. The Conversation.

It is unrealistic to expect this basic scheme for e-fuels production to be developed in Belgium.

Production of e-diesel, e-kerosene and e-naphtha using the Fischer-Tropsch process.

**However, an alternative is emerging:
integrated e-fuel production using co-products.**

Integrated production reduces the need for energy and raw materials by reusing industrial by-products that are currently under-utilized, such as **CO_2-rich gases** from industries that are difficult to decarbonize.
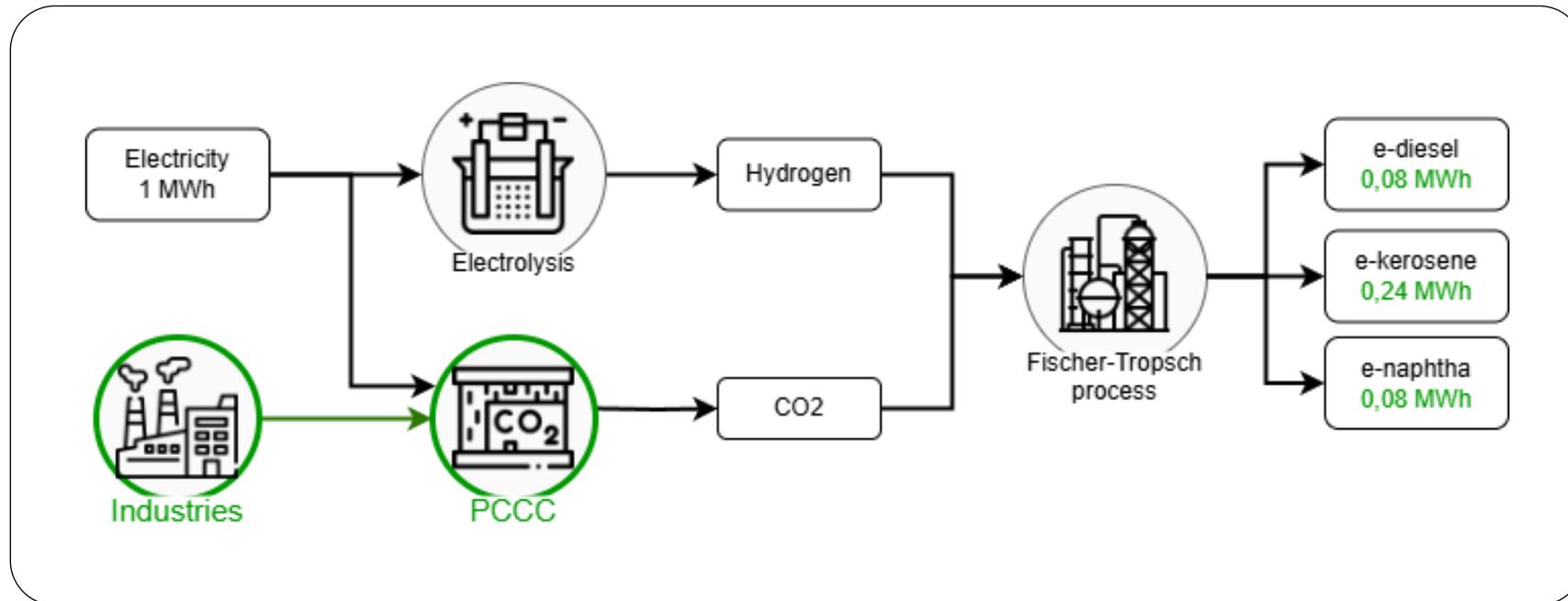
Production of e-diesel, e-kerosene and e-naphtha using the Fischer-Tropsch process.

Equipping these industries with post-combustion carbon capture (PCCC) provides a much less energy-intensive carbon source than direct air capture (DAC), resulting in significantly **higher efficiency**.

Co-products from e-fuel production can also be reused. For example, the oxygen generated during electrolysis can be sold on **local markets**. This helps to lower overall production costs.
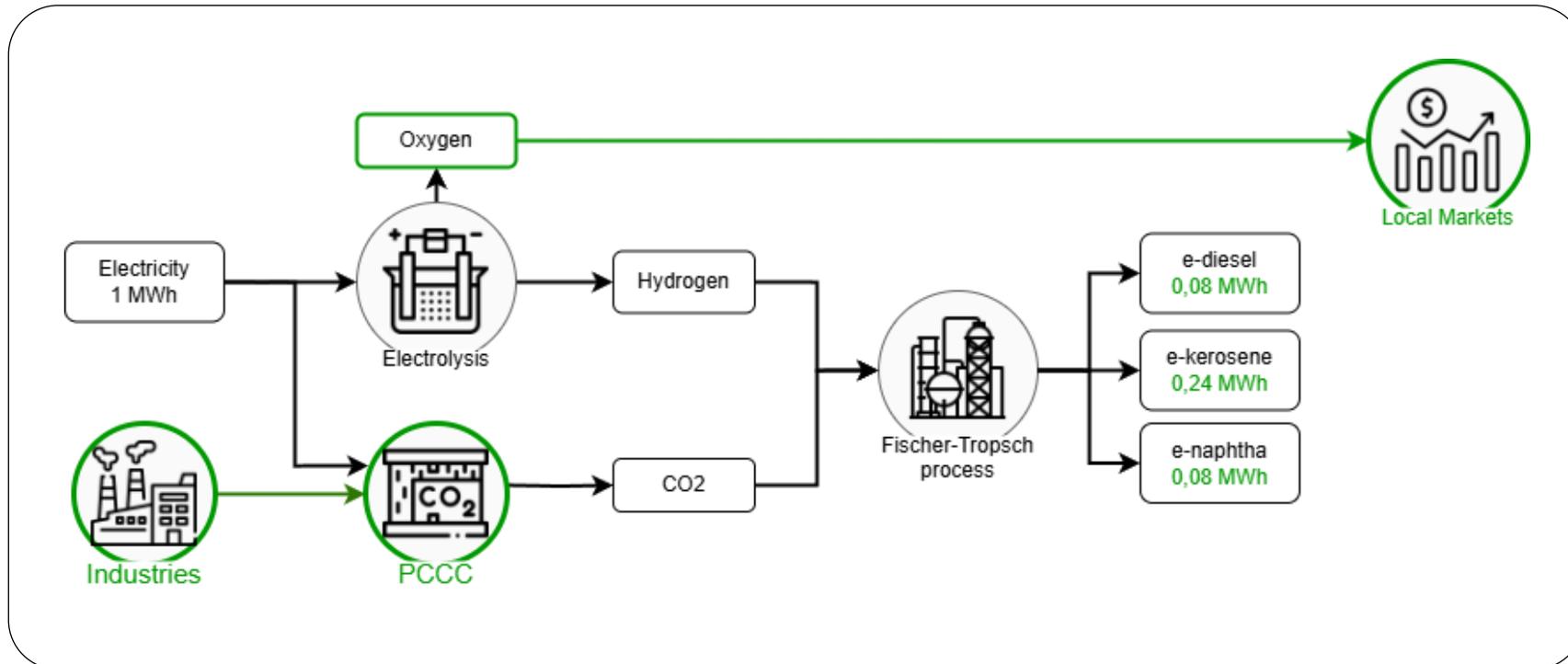
Production of e-diesel, e-kerosene and e-naphtha using the Fischer-Tropsch process.

Producing carbon-free e-fuels locally can give access to **CO_2 emission allowances**, making the process even more economically attractive.
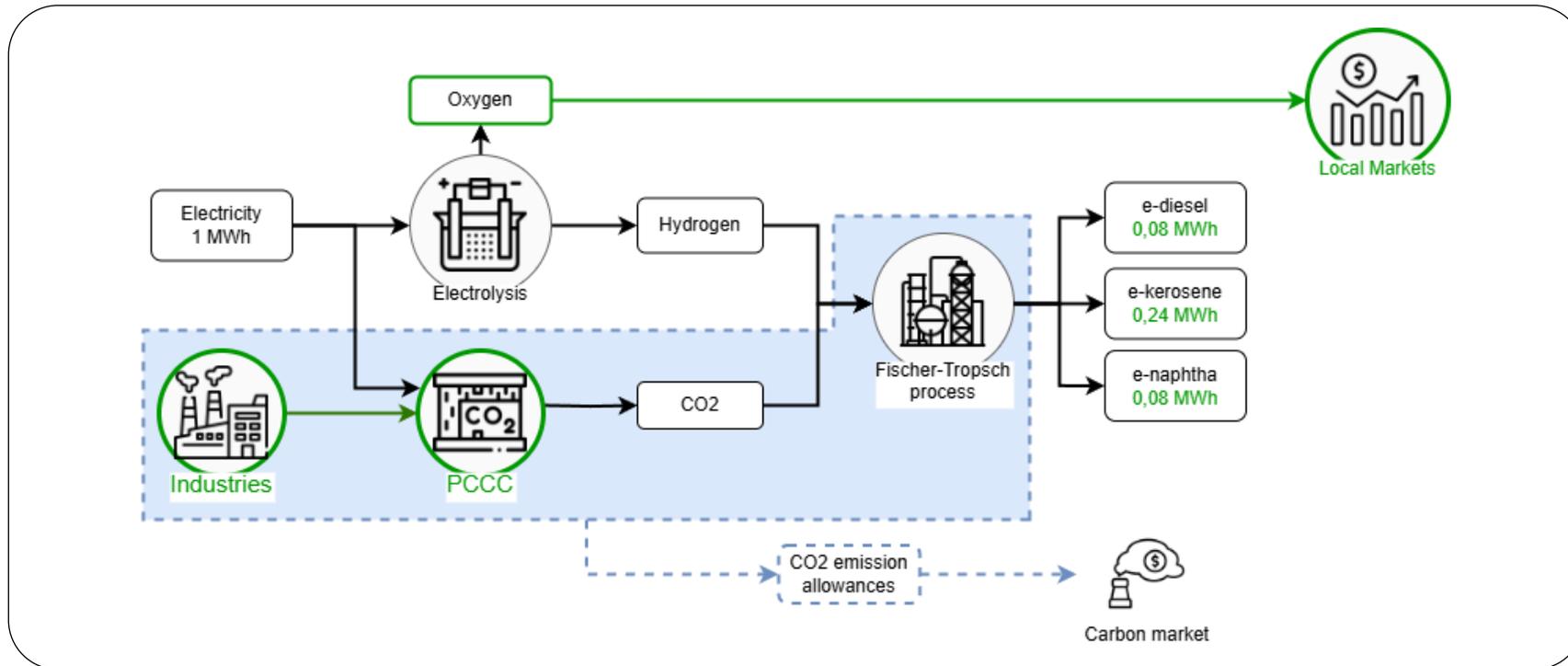
Production of e-diesel, e-kerosene and e-naphtha using the Fischer-Tropsch process.

The waste heat generated during the various conversion stages can be recovered and reused in a **local heating network**.
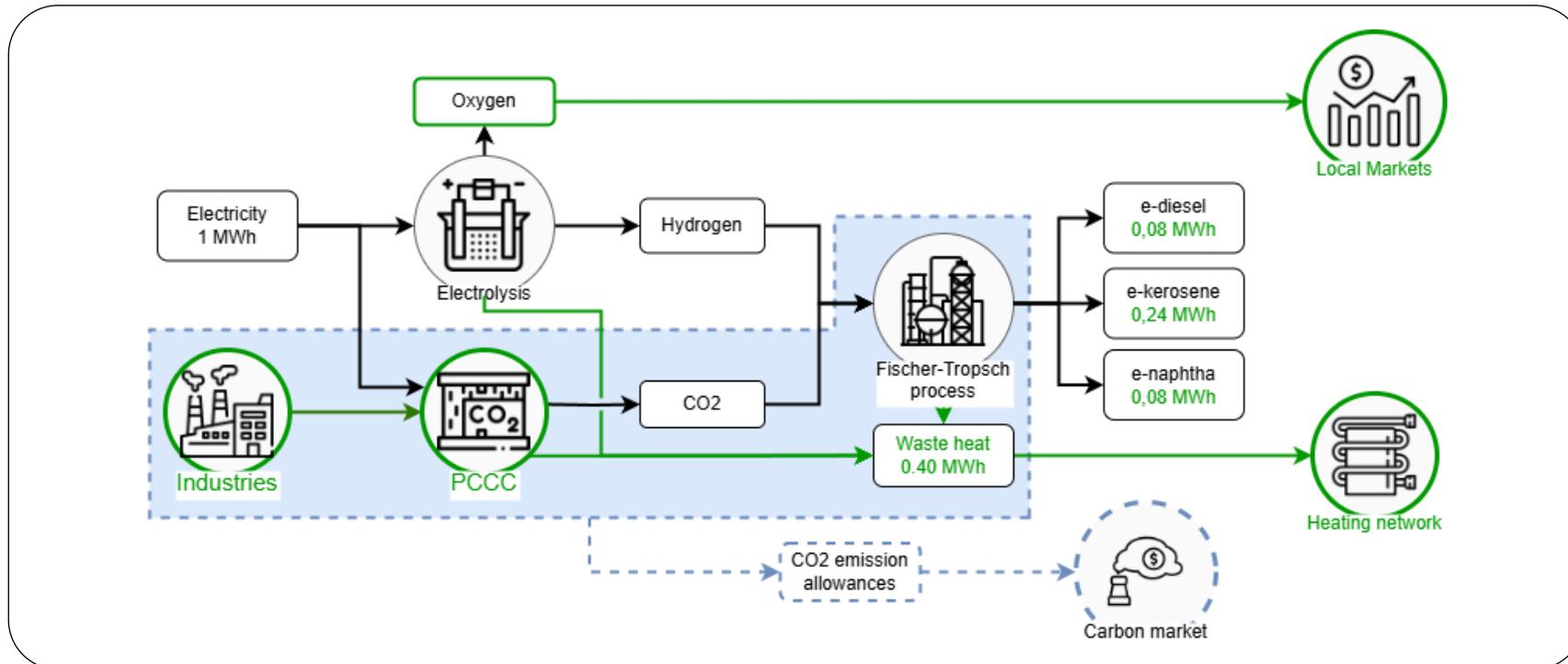
Production of e-diesel, e-kerosene and e-naphtha using the Fischer-Tropsch process.

Initial experimental results show that integrated e-fuel production can reduce production costs by up to **40%** compared with a non-integrated approach*.

Scenario	S1	S2	S3	S4	S5
Waste heat recovery	✗	✗	✗	✗	✔
Oxygen recovery	✗	✗	✗	✔	✔
CO_2 emission allowances	✗	✗	✔	✔	✔
CO_2 source	DAC	PCCC	PCCC	PCCC	PCCC
Production cost (€/MWh)	234	209 (-10.7%)	191 (-18.4%)	177 (-24.4%)	141 (-39.7%)

* Production costs are expressed per MWh of Fischer-Tropsh mix, taking into account a selling price of heat at €40/MWh, oxygen at €40/tO_2 and CO_2 emission allowances at €80/tCO_2.

Mokeddem, S., Miftari, B., Dachet, V., et al. (In press). Distributed e-fuel hubs: Concept and case study, ORBi-University of Liège.
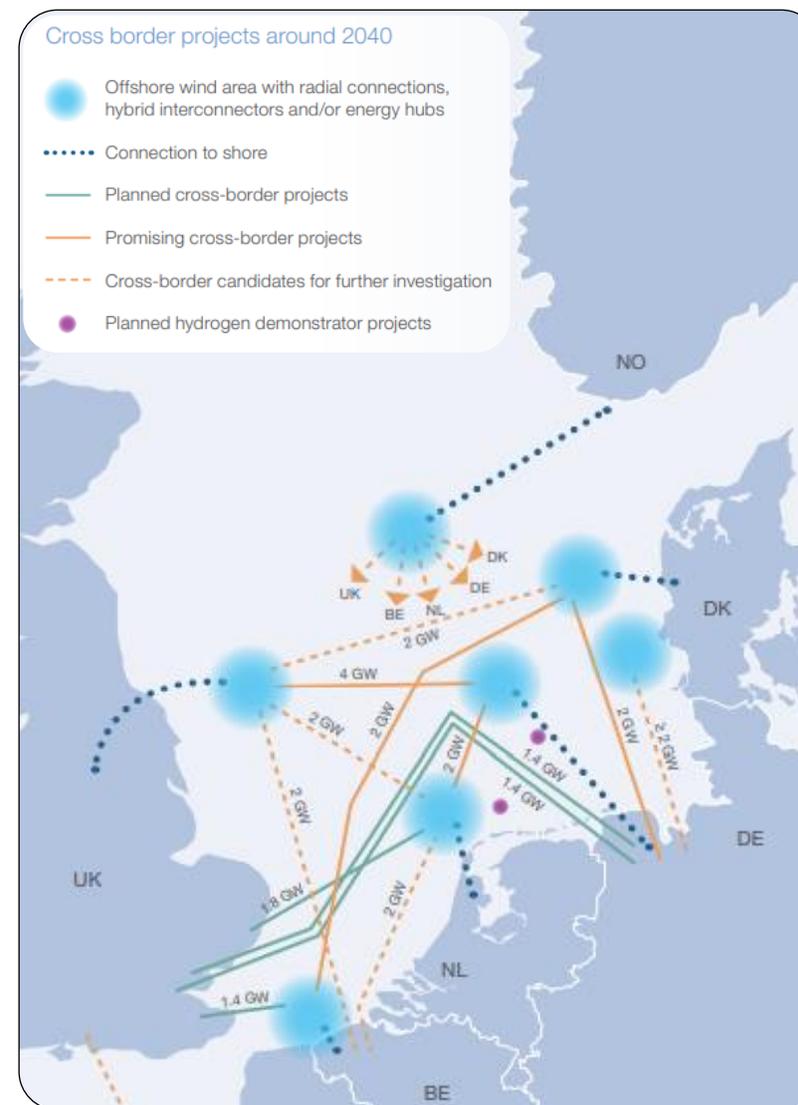
6th problem

A prohibitive price for the construction of an offshore grid in the North Sea

Europe is clearly committed to large-scale offshore wind development, with a target of around 400 GW. This goal requires the creation of extensive offshore grid infrastructure.

For instance, it plans to add up to 3.5 GW of offshore wind capacity in the Princess Elisabeth zone.

However, **electricity infrastructure costs are now surging**, a trend that was largely underestimated at the outset. In response to these rising costs, the government has started to reconsider certain projects.

Cross border projects around 2040

- Offshore wind area with radial connections, hybrid interconnectors and/or energy hubs
- Connection to shore
- Planned cross-border projects
- Promising cross-border projects
- Cross-border candidates for further investigation
- Planned hydrogen demonstrator projects

An alternative to offshore grids could be the use of battery boats.

These vessels are equipped with high-capacity batteries and can connect to a collector cable at the wind farm's output.

Once charged, the battery boats return to shore to feed the energy back into the grid at the most opportune time.
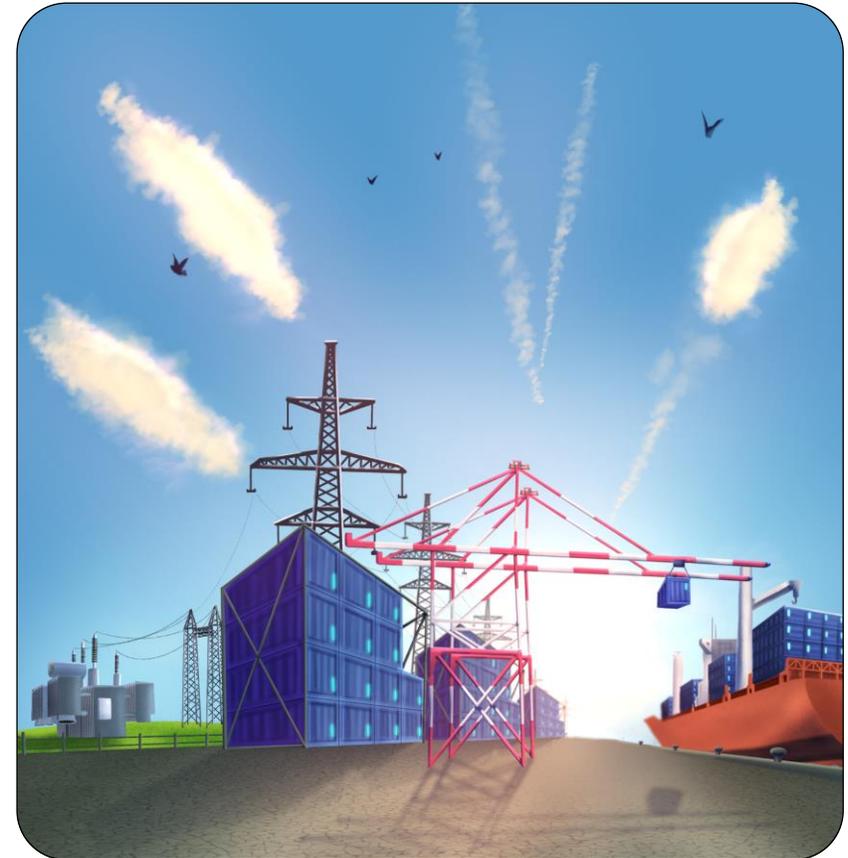
Combining battery boats with unmoored floating offshore wind turbines could unlock the full renewable potential of seas and oceans.

Conventional wind turbines can only be installed in shallow coastal waters, typically up to depths of around 60 meters.

Unmoored floating turbines are currently under study. Equipped with a propeller-based positioning system, they could be deployed much farther offshore and in significantly deeper waters.
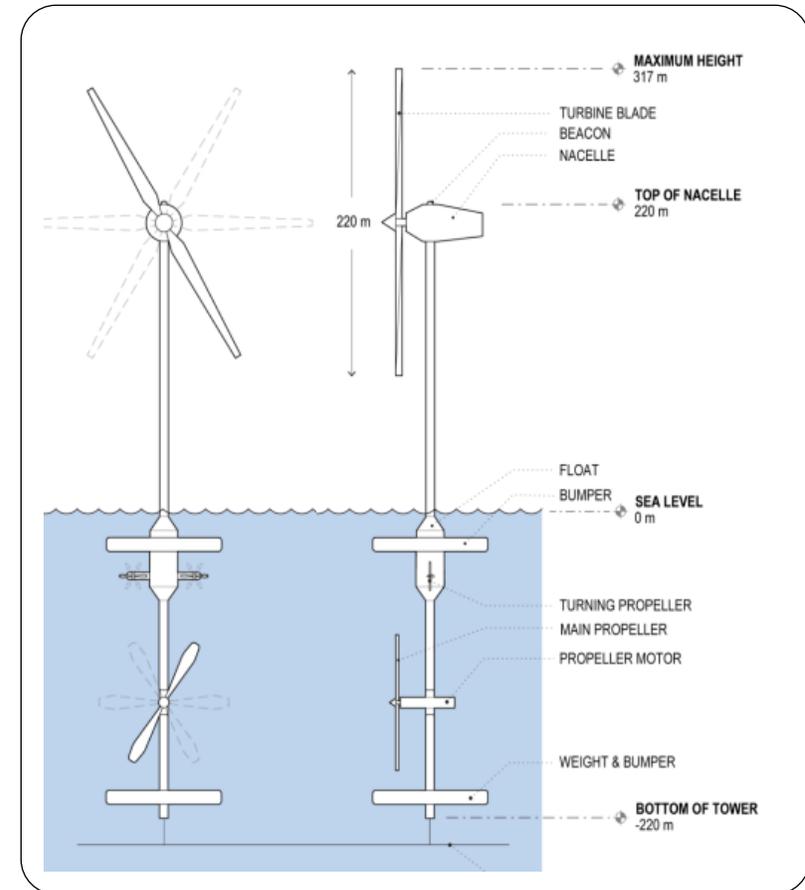

Proposal for an unmoored floating wind turbine.[1]

[1] Raisanen, J. H., Sundman, S., & Raisanen, T. (2022). Unmoored: a free-floating wind turbine invention and autonomous open-ocean wind farm concept. Journal of Physics Conference Series, 2362(1), 012032.

Battery boats and unmoored floating wind turbines open the way for the creation of **Renewable Energy Hubs in the High Seas** (REHS).

In an REHS, electricity can be generated by wind turbines held in position by propellers. The energy is then stored on battery boats, which transport it back to shore. Once docked, the electricity generated by the wind turbines and stored in the batteries is fed into the grid through an inverter.
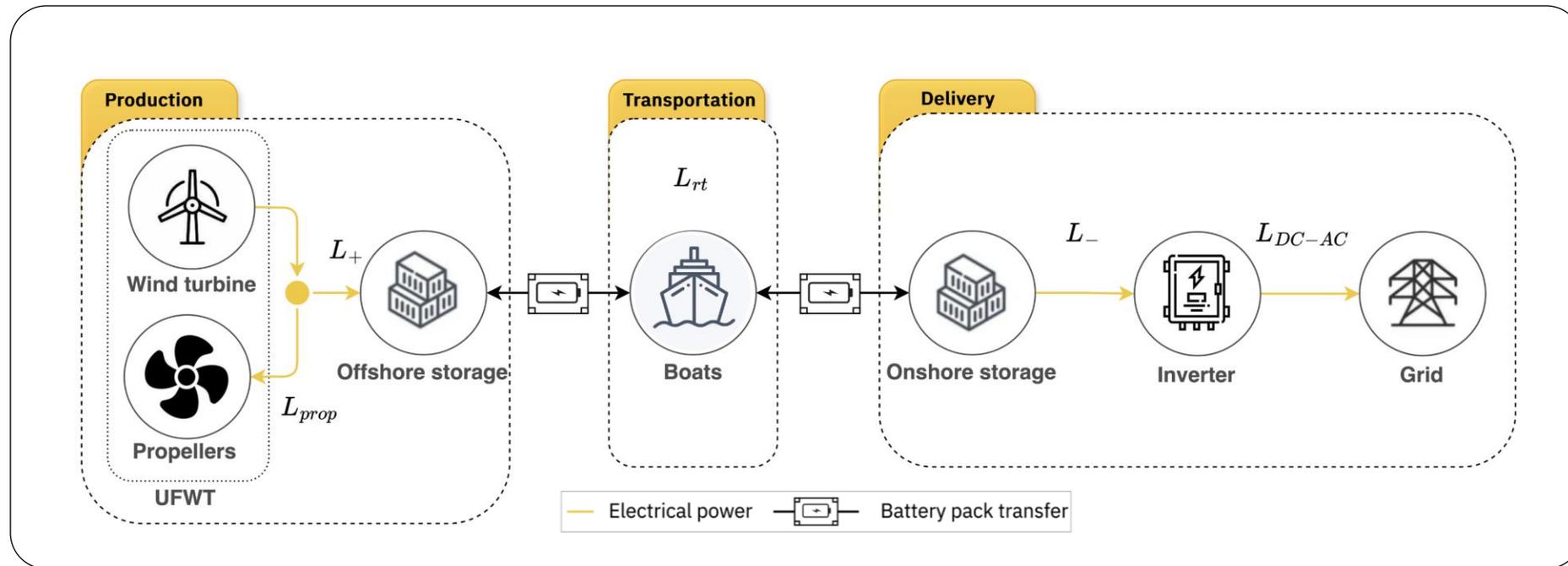
A recent research project conducted by the Smart Grids Laboratory at the Montefiore Institute, University of Liège, aims to quantify both the load factor* and the cost of an REHS system, depending on its distance from the coast.

Distance (km)	Load Factor (%)	Cost ($/MWh)
150	17.4	160
400	17.3	204
2000	16.7	497

Estimated cost per MWh as a function of the distance to the coastal grid.[1]

* The load factor represents the percentage of energy injected into the grid relative to the wind turbines' theoretical maximum output.

[1] Dachet, V., Maio, A., Counotte, P., & Ernst, D. (2025). Remote renewable energy hubs in the high seas: A battery-based fully-electric ecosystem. ORBi-University of Liège.

# 7th problem

New nuclear power will always be too costly

Recent projects, notably the European Pressurized Reactor (EPR), have faced major delays and cost overruns.

Some sites, such as Flamanville, are up to 12 years behind schedule with costs multiplied by a factor of six.

These setbacks have intensified criticism of the economic and industrial viability of large-scale nuclear reactors.
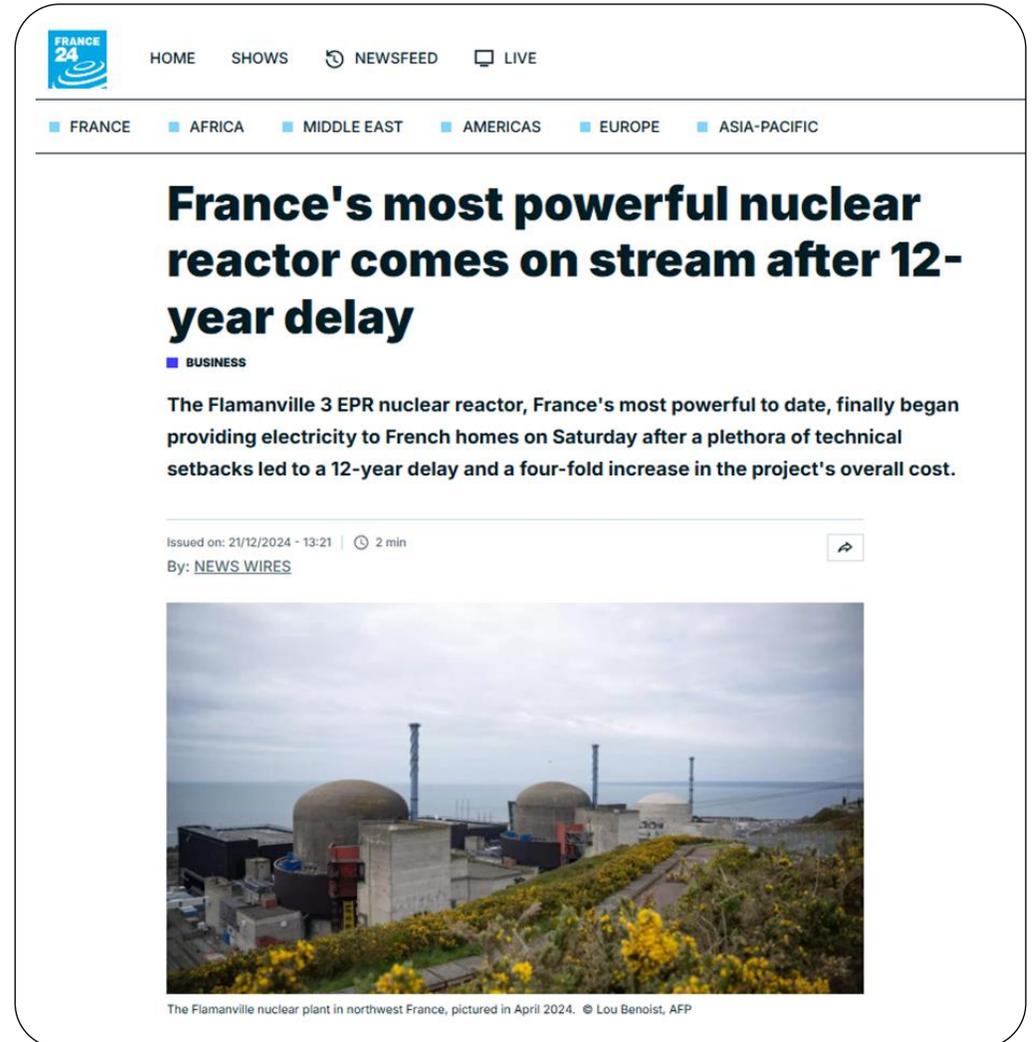
FRANCE 24

HOME   SHOWS   NEWSFEED   LIVE

FRANCE   AFRICA   MIDDLE EAST   AMERICAS   EUROPE   ASIA-PACIFIC

France's most powerful nuclear reactor comes on stream after 12-year delay

BUSINESS

The Flamanville 3 EPR nuclear reactor, France's most powerful to date, finally began providing electricity to French homes on Saturday after a plethora of technical setbacks led to a 12-year delay and a four-fold increase in the project's overall cost.

Issued on: 21/12/2024 - 13:21   2 min
By: NEWS WIRES

The Flamanville nuclear plant in northwest France, pictured in April 2024. © Lou Benoist, AFP

However, today a new generation of nuclear reactors known as SMRs (Small Modular Reactors) is currently under development.

An SMR is a low-power reactor (up to 300 MW electrical), designed as **compact factory-prefabricated modules** capable of producing both heat and electricity.

SMRs are based on a high level of standardization unlike conventional reactors which are custom-built on site. This approach could significantly reduce costs, construction times, and industrial risks.

Small Modular Reactor
20 MW – 300 MW

Large-Scale Reactor
300 MW – 1,000+ MW
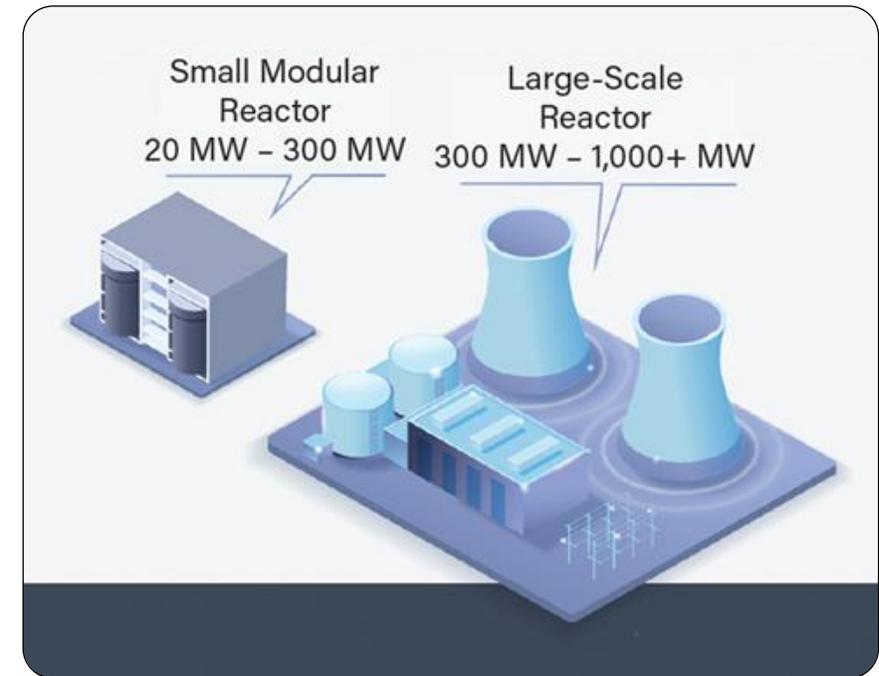
Three additional advantages of SMRs are emerging in the market:

1) Some models include passive safety systems, meaning they can operate without human intervention or external power supply;

2) Some SMR designs aim to reduce the amount of long-lived radioactive waste and recycle previously used fuel;

3) Thanks to their more compact size and ability to produce high-temperature heat, SMRs can be installed near industrial sites that can recover and use large quantities of the heat produced.

Energy systems integrating SMR-LFR (Lead-cooled Fast Reactor) with strong connections to industrial sites are being studied at the Smart Grids Laboratory of the Montefiore Institute, University of Liège.

The objective of this research is to explore different strategies for reducing costs, particularly through the recovery of high-quality heat generated by these SMR-LFR reactors.

This recovered heat can be used for various important industrial applications, such as hydrogen production, ammonia synthesis, district heating, and seawater desalination.

Study of different configurations for supplying electricity and heat to an off-grid industrial site.

"Battery" configuration: battery storage only

"Hydrogen" configuration: battery and hydrogen storage

"Ammonia" configuration: battery, hydrogen and ammonia storage

Hydrogen → | Electricity → | Heat → | Ammonia → | Nitrogen →
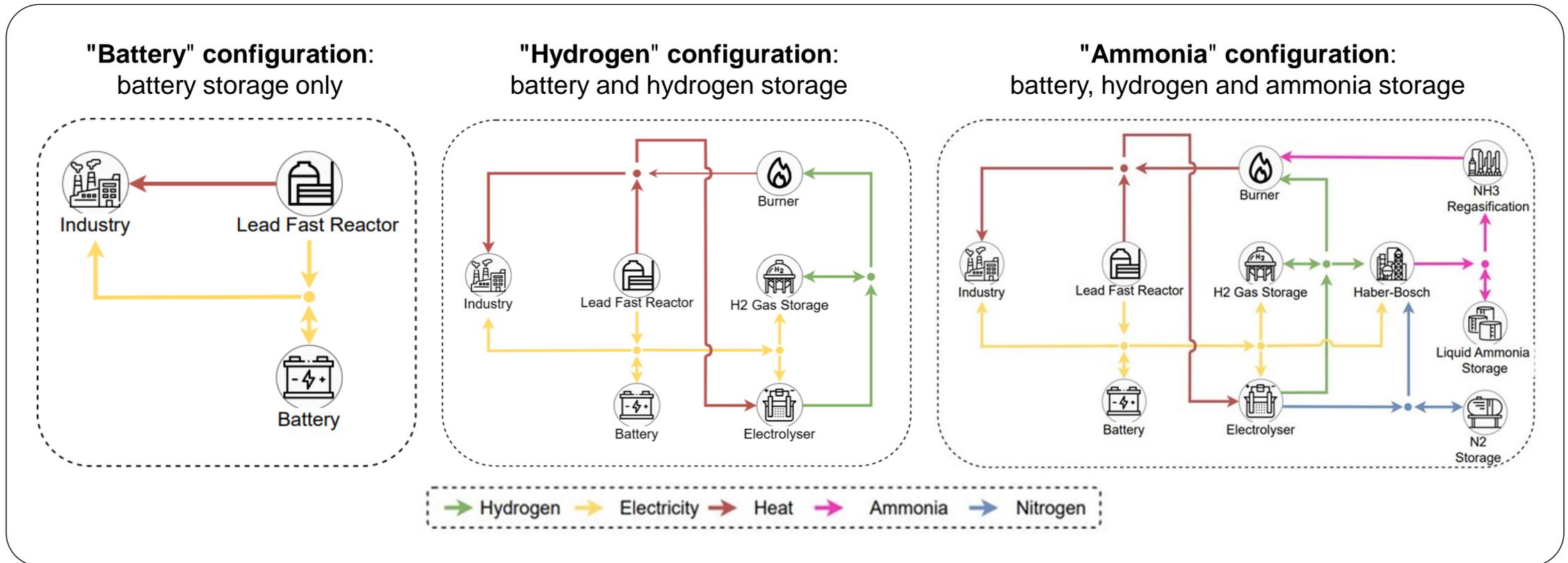
SMR-LFR deployed at an industrial site without grid connection, with three possible storage configurations.

This research aims to jointly optimize the sizing of the various components in the three configurations as well as their respective control strategies to cover all the heat and power needs of an industrial site.

In configurations that include hydrogen and/or ammonia, the system also enables these molecules to be produced, stored, and reused at the most opportune time, depending on the site's needs.*

	"Battery" Configuration	"Hydrogen" configuration	"Ammonia" configuration
Electricity cost (€/MWh)	92.3	59.0	57.9
Heat cost (€/MWh)	38.8	24.8	24.3

Table of average costs per unit of electricity and heat.

* To assess the cost of each configuration, we (i) define the total system cost, (ii) relate this cost to the quantity of useful heat, i.e. the heat consumed by the industrial site and the heat used by the turbine to generate electricity, and (iii) calculate the electricity price per MWh by dividing the cost of useful heat by the turbine's efficiency.

8th problem

Nuclear power depends on foreign resources

By 2022, **100%** of the natural uranium consumed in the EU came from outside the Union (Niger, Kazakhstan, Russia, etc.).

This fact fuels criticism from nuclear opponents who argue:

"What is the point of producing our electricity in Belgium if we are still dependent on foreign raw materials?"

Niger Is a Major Uranium Supplier to the EU

Share of uranium delivered to EU utilities in 2022, by origin country (in %)

- Kazakhstan
- Niger
- Canada
- Russia
- Uzbekistan
- Others

5.2
3.8
26.8
16.9
22.0
25.4
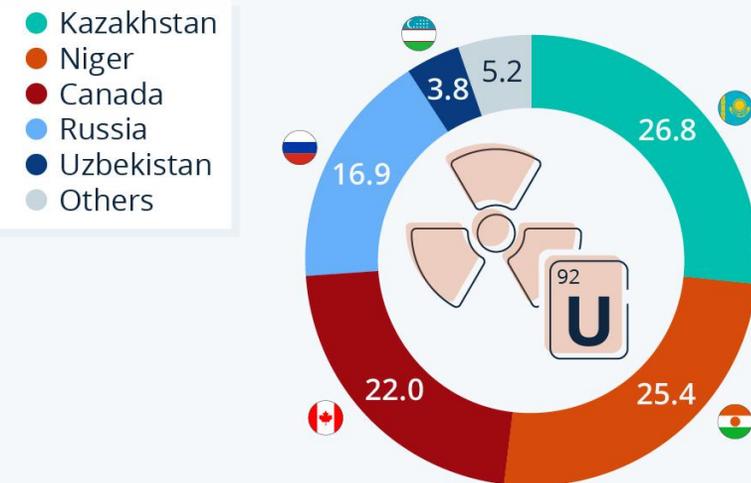
Source: Euratom Supply Agency

This dependence on uranium imports can be put into perspective, given its **very high energy density**, which makes it much easier to amass large reserves compared to fossil fuels.

Belgium, for example, holds a stock of enriched uranium sufficient to cover about two years of consumption. Achieving a similar level of reserve with gas or oil would be far more difficult, due to the massive volume of storage infrastructure that would be required.


Reserves in Belgium

Natural Gas
12 days

Oil
90 days

Uranium
2 years

Nuclear forum

One way to reduce dependence on imported uranium could be to develop technologies capable of **extracting it directly from seawater.** The oceans are believed to contain around 4.5 billion tonnes of uranium, at an estimated concentration of 0.003 grams per tonne of seawater.

In a Japanese experiment carried out in the late 1990s, researchers succeeded in harvesting 1 kg of uranium in 240 days, i.e. around 1.5 kg per year, using a device with a surface area of 64 m².

In 2022, when all the reactors at the Doel and Tihange power plants were still in operation, Belgium's annual consumption of natural uranium was approximately 1000 tonnes.[1]

A total surface area of **43 km²** of this floating Japanese device would be required to meet the above demand using seawater extraction. This is just a small fraction of Belgium's **3,500 km²** maritime zone in the North Sea.*
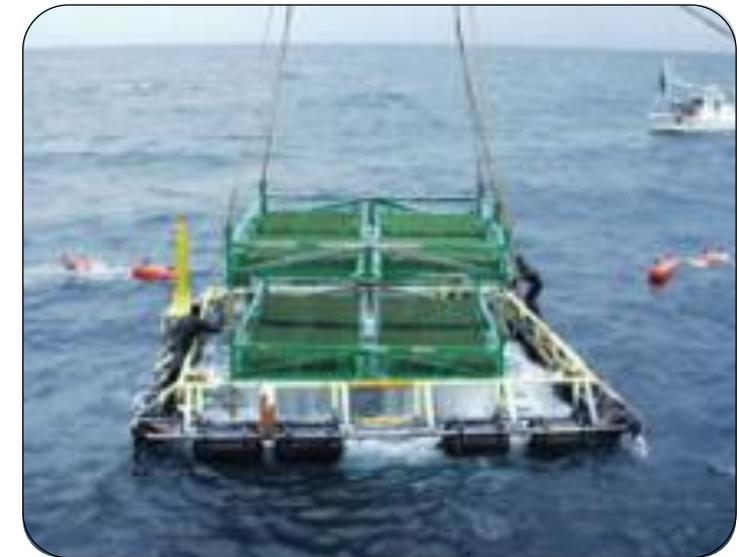
Floating moored device used off the Japanese coast to extract uranium from seawater.

* The methodology, along with the data and assumptions used for these calculations, is detailed in Appendix 3.

[1] Counasse, X. (May 5, 2022). 40% of uranium used in Belgian nuclear power plants is linked to Russia. Le Soir.

Other techniques for extracting uranium from seawater which do not rely on high specific surface area materials are currently being developed.

One innovative method uses a bipolar electrochemical cell operating at very low voltage (0.6 V) capable of capturing uranium by direct and indirect electrochemical reduction.

This technology requires neither complex membranes nor costly chemical reagents, yet achieves a capture rate of over 85%.[1]
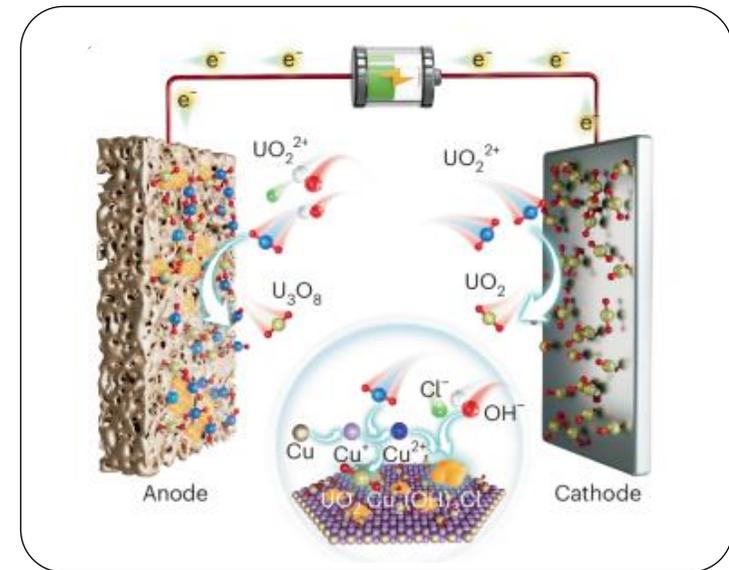
Schematic diagram of the bipolar uranium extraction process, combining indirect uranium reduction assisted by anodic electrochemistry and direct electrochemical reduction at the cathode.

[1] Wang, Y., Wen, G., Liu, Z. et al. (May 2025). Bipolar electrochemical uranium extraction from seawater with ultra-low cell voltage. Nature Sustainability.

Scientific contributions from our laboratory

> **3rd problem**
>
> The grid is saturated, and the injection is being refused

Vassallo, M., Khaskheli, S., Dong, L., Ha Thuc, A., Anvari-Moghaddam, A., Vergara, P., Duchesne, L., Gerard, S., & Ernst, D. (2025). A new Paradigm for Bilateral Trading of Dynamic Operating Envelopes in Electricity Distribution Networks. *ORBi-University of Liège.* https://orbi.uliege.be/handle/2268/331735

> **4th problem**
>
> Electrifying and/or decarbonizing all sectors is too complicated

Dachet, V., Dubois, A., Miftari, B., Fonteneau, R., & Ernst, D. (2024, December 19). Remote renewable energy hubs: A taxonomy. *Energy Reports, 13, 3112-2120.* https://doi.org/10.1016/j.egyr.2025.02.040

Berger, M., Radu, D.-C., Detienne, G., Deschuyteneer, T., Richel, A., & Ernst, D. (2021). Remote Renewable Hubs for Carbon-Neutral Synthetic Fuel Production. *Frontiers in Energy Research.* https://orbi.uliege.be/handle/2268/250796

5th problem

Belgian e-fuels will never be cost-competitive with imported ones, leaving the country reliant on importing all energy-dense molecules

Mokeddem, S., Miftari, B., Dachet, V., Derval, G., & Ernst, D. (In press). Distributed e-fuel hubs: Concept and case study. *ORBi-University of Liège.* https://orbi.uliege.be/handle/2268/327044

Dauchat, L., Dachet, V., Fonteneau, R., & Ernst, D. (2024). Waste heat recovery in remote renewable energy hubs [Paper presentation]. *Proceedings of ECOS 2024.* https://orbi.uliege.be/handle/2268/313825

6th problem

A prohibitive price for the construction of an offshore grid in the North Sea

Dachet, V., Maio, A., Counotte, P., & Ernst, D. (2025). Remote renewable energy hubs in the high seas: A battery-based fully-electric ecosystem. *ORBi-University of Liège.* https://orbi.uliege.be/handle/2268/327232

7th problem

New nuclear power will always be too costly

Larbanois, A., Miftari, B., Mouchamps, A., Ayyildiz, K., Schryvers, V., Derval, G., & Ernst, D. (2025). Lead-cooled Fast Reactor SMR integration: An off grid study case based on a real-life demand. *ORBi-University of Liège.* https://orbi.uliege.be/handle/2268/331891

Co-authors

Victor Dachet

ULiège

PhD student

Antoine Larbanois

ULiège

PhD student

Samy Mokeddem

ULiège

PhD student

Thibaut Techy

ULiège

Energy expert

Maurizio Vassallo

ULiège

PhD student

Appendices

Appendix 1

What area of Belgium would need to be covered with PV panels to fully satisfy Belgium's annual kerosene demand in 2024 with e-fuels produced from solar energy?

Kerosene consumption in Belgium will amount to 2,267.2 million liters in 2024. Given that one liter of kerosene contains 10.3 kWh, this represents an annual consumption of 23.4 TWh.

We make the following assumptions:
– solar irradiance: 110 W/m²;
– PV panel efficiency: 25%;
– overall efficiency of the conversion chain (power-to-kerosene): 24%.

The area of PV panels required to cover this annual demand of 23.4 TWh would be:

$$\frac{23.4 \times 10^{12}}{110 \times 0.25 \times 0.24 \times 8{,}760 \times 10^{6}} \approx 405 \text{ km}^2.$$

Appendix 2

What area of Spain's Extremadura region would need to be covered with PV panels to meet the European Union's entire gas demand of 3,500 TWh/year, by converting renewable electricity into synthetic gas?

We make the following assumptions:
– average solar irradiation: 200 W/m²;
– PV panel efficiency: 25%;
– overall efficiency of the power-to-gas conversion chain: 50%.

The area of PV panels needed to cover the EU's gas demand would be:

$$\frac{3{,}500 \times 10^{12}}{200 \times 0.25 \times 0.5 \times 8{,}760 \times 10^{6}} \approx 15{,}982 \text{ km}^2.$$

Appendix 3

What surface area in the North Sea would be needed to meet Belgium's annual natural uranium requirements, using a system similar to the one tested off the coast of Japan in the 1990s?

The Japanese experimental system was capable of extracting 1.5 kg of uranium per year from an active surface area of 64 m².

The amount of uranium that could be extracted per km² per year is:

$$\frac{1.5 \times 10^6}{64} \approx 23{,}438 \text{ kg/km}^2.$$

Assuming that Belgium consumes around 1,000 tonnes of natural uranium per year, the area required to cover this demand would be:

$$\frac{1{,}000 \times 10^3}{23{,}438} \approx 43 \text{ km}^2.$$