DECARBONIZATION PATHWAYS FOR EUROPE

ENGIE'S SCENARIO

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A SCENARIO TO ENLIGHTEN THE FUTURE

The world is facing climate and ecology crises. In addition, the current geopolitical crisis has further exacerbated the challenges of security of supply, European energy sovereignty and the reliability of the energy system.
Central to these challenges is the reduction of greenhouse gas emissions.

CO_2 emissions have already been reduced at a pace of 1% yearly in the 15 European countries studied by ENGIE to elaborate its scenario. But it is now imperative to up the pace to achieve a 4% reduction annually, so as to meet the targets set by the European Union for 2030, ("Fit for 55").

This acceleration will be possible thanks to the electrification of usages, energy savings, the development of renewable energies and decarbonized gases (biomethane, hydrogen, e-molecules). Post-2030, this pace should be maintained through 2050 so as to reach carbon neutrality.

Yet a range of uncertainties could compromise the desired decarbonization pathway. Will the pace of development of solutions be the right one? How to win the acceptance of local populations? Will the chosen transition model be economically sustainable? Do we avail of the necessary infrastructures and industrial strength?

In the face of such uncertainties and at a time when the challenges of decarbonization are more than ever at the heart of public debates, ENGIE is publishing its European-scale transition scenario. Based on the strength of our experience and our role as an energy player committed for many years now to an ambitious decarbonization pathway, our analysis demonstrates the benefits of a balanced energy mix to guarantee a resilient and reliable energy system. To address the climate emergency, every day counts: private companies, hand in hand with public authorities, must play a key role in accelerating the energy transition.

FORGING A NEW PATHWAY

Our scenario is underpinned by respect for 3 criteria: alignment with the European Climate ambition, optimizing costs for the wider community, and guaranteeing the safety of the energy system. By weighing up every possible solution against these three criteria the new pathway we are forging capitalizes on the most relevant existing decarbonization levers, while leaving room for emergent technologies.
It is an approach that is both pragmatic and systemic.

OUR METHODOLOGY FOR A COST-OPTIMIZED DECARBONIZATION PATHWAY

This scenario is underpinned by a robust methodology enabling the modeling of the energy systems of 15 Western European countries. (Austria, Belgium, the Czech Republic, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Spain, Switzerland, the United Kingdom) through 2050. **A large panel of low-carbon and mature technological solutions** has been mobilized, the goal being to rely on the interactions between electricity, methane, hydrogen, e-molecules and heat. Modeling was carried out using an hourly temporal granularity to endure the criteria of reliability and resilience.
With a population increase of 1.8% and a yearly rise in GDP of 1.3%, the scenario results in a 34% fall in energy consumption through 2050. We are indeed convinced that energy efficiency coupled with a change in energy consumption behavior is totally reconcilable with continued economic growth.

OUR CONVICTIONS

Our scenario offers five key takeaways on which we have forged our convictions for a successful transition.

1 **Our core objective is decarbonization** and to achieve this, it requires a non-dogmatic approach: all existing levers and those undergoing development must be activated to make Net Zero Emissions within 30 years a reality. To guide transition choices, we advocate a pluri-technological approach.

2 **The reduction of energy consumption, across all sectors, is a prerequisite for energy transition.**
Energy efficiency efforts must be stepped up, in particular by way of massive energy performance retrofitting of buildings.
Changes in consumption behavior will also play a central role in meeting energy austerity targets.

3 **Electric renewable energies (solar and wind) will play a considerable** role in the decarbonization pathway.
Their large-scale development must be maintained in all countries as they alone can rapidly and economically provide for the rapidly growing electrification of usage needs.

4 **The future energy system will require a capacity for greater energy flexibility** as it will rely on mainly renewable and decentralized electricity production. The deployment of the many flexible solutions that will be needed in ten years' time must be anticipated as of now.

5 **The only answer to meeting the ambitious objectives of the energy transition is to combine two key drivers: gas and electricity**. We call this "the alliance of the electron and the molecule".
In conjunction with biomass, and in particular biogas, the benefits of e-molecules (hydrogen, methane, etc.) must be valorized.
The strengthening of expertise in these technologies and the utilization of gas infrastructures for new usages will generate cost reductions for the wider community and ensure the resilience of the system.

KEY FIGURES FOR THE SCENARIO IN EUROPE FROM 2023 THROUGH 2050

- 34%
Energy consumption

x 1.8
Electricity consumption

x 6
Solar photovoltaic and wind farm electricity production

+ 600 GW
Flexibility needs

÷ 2
Methane consumption

x 8
Demand for hydrogen

x 4.6
Biomethane and biogas production

THE CHALLENGES OF MASS ELECTRIFICATION

ENGIE's scenario takes into account a major rise in the **electrification of usages in the 2030/2050 timeframe.** In a balanced mix scenario, this rise in electricity needs will lead to a growth in demand to reach 4879 TWh in Europe and 664 TWh in France by 2050. Although electric usages will intensify in buildings for heating purposes (heat pumps) and in industry, consumption will remain relatively stable thanks to energy efficiency gains. However, mobility (the development of public transport and electric vehicles) and the production of hydrogen via electrolysis represent new, rapidly rising sources of electricity consumption.

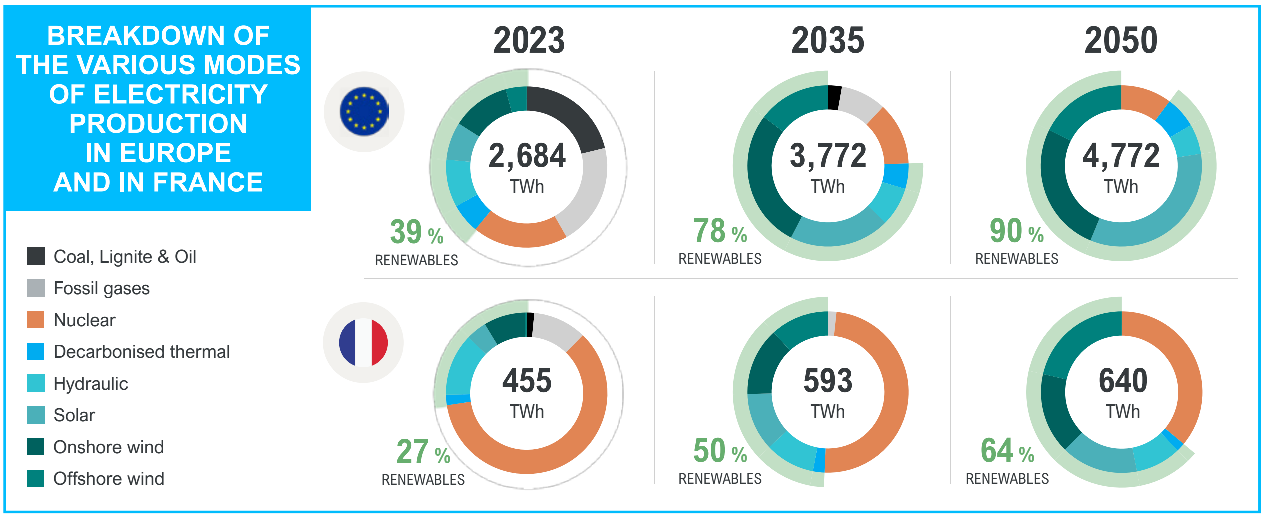
To satisfy energy needs due to electrification over the next decade **it is vital to mass develop renewable energies throughout Europe.** The falling costs of solar photovoltaic and wind farms over the past few years have made these technologies essential for the future, all the more so in that they strengthen the continent's energy sovereignty.

FOCUS ON THE FRENCH ENERGY MIX

In France, according to our scenario, renewable technologies will be the leading source of electricity production in 2050 with an installed capacity of 103 GW for solar photovoltaic farms, 57 GW for onshore wind farms and 40 GW for offshore wind farms. Hydroelectricity will remain close to current levels. We have integrated a share of nuclear energy in keeping with governmental energy policy: 16 GW from reactors still in operation in 2050 and 14 new EPRs (22.4 GW). This "renewable and nuclear complementarity" will enable France to be a net exporter of electricity in Europe as of 2035.

WIND AND SOLAR OUTPUT X 6 BY 2050

According to ENGIE's scenario, **wind and photovoltaic farm electricity production in Europe has to more than triple by 2035 and increase six fold by 2050.** Thus the entire palette of renewable electricity sources (wind, solar, hydro, renewable hydrogen, biomethane and biomass) will supply 78% of electricity in 2035 and 90% in 2050. Thanks to this deployment of renewables, the European energy sector will be far less dependent on fossil fuels by 2035.



NO TRANSITION WITHOUT FLEXIBILITY

An energy system that increasingly relies on renewable energies inherently requires managing greater production variability due to fluctuations in wind and sun availability. Securing the operation of the electrical system thus requires the addition of flexible means.

Traditional storage solutions such as pumped storage facilities are vital for providing this flexibility but must be complemented by other solutions.

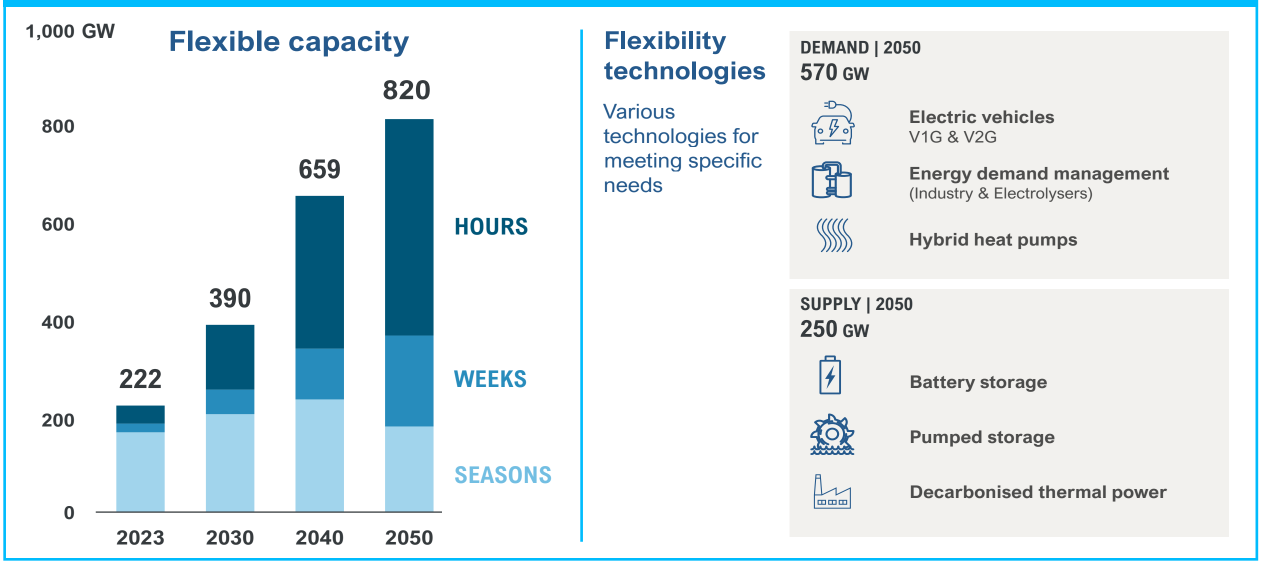
Our scenario takes into consideration Europe-wide flexible capacity needs by 2050. The various technologies are evaluated according to how they positively impact security of supply across different timeframes.
They are divided into two main families:

- Flexibility of demand, to a level of 570 GW, by way of EV batteries to grid, control of energy demand (industry and electrolysis) and hybrid heat pumps;
- Flexibility of production, for a total of 250 GW, via the use of stationary battery storage, hydroelectric pumped storage and decarbonized thermal power plants.

UPPING THE PACE OF INSTALLATION

Currently, in Europe, the average pace of installation is 14.5 GW/year for solar photovoltaic farms, 9.5 GW/year for onshore wind farms and 1.2 GW/year for offshore wind farms.
If we want to align with the REPowerEU ambitions these figures must be increased to 65 GW/year, 29 GW/year and 11 GW/year, respectively, by 2030. According to our scenario, these ambitions are reachable for offshore wind farms, but not for solar and onshore wind farms, unless obstacles to the development of renewable energies are lifted.

ENERGY FLEXIBILITY CAPACITY IN EUROPE THROUGH 2050



THREE QUESTIONS FOR…

NICOLAS LEFEVRE-MARTON
DIRECTOR OF STRATEGY
ENGIE

"RENEWABLE ENERGIES PLAY A BACKUP ROLE"

How do you see the development of France's electricity generation fleet?

Nicolas Lefevre-Marton: France has an industrial tradition and model for power generation largely based on nuclear energy. We must of course maintain this key asset for our decarbonization pathway: in our scenario, nuclear power plants will ensure 35% of electricity production in 2050. Nevertheless, we must keep in mind the challenges facing the French nuclear sector, namely the challenges of availability and the rapid development of new capacities.
In this context, we feel that renewable energies, in particular photovoltaic and onshore and offshore wind farms,
are best placed to play a backup role, given their economic competitiveness and their speed of installation.
By creating employment country-wide and generating low cost decarbonized electricity, they are a no-hesitation option.

How to drive these new renewable, more variable, production facilities?

Solar and wind energy production is indeed subject to weather factors. Yet this does not prevent us from driving a reliable energy system. Accurate weather forecasting and the accelerated growth of renewable installations countrywide allow us to offset this variability. We can also factor in the modulation of electricity consumption, by asking industrial operators, for example, to temporarily halt production during consumption peaks. Lastly, we can develop and implement flexible means so as to manage electricity production variation by the hour, the day, the week or the season.

Will we really need thermal power plants through 2050?

Yes, we think we will. But we won't use these power plants in the same way as before. Gas-fired power plants can produce electricity very quickly and in great quantity. By using decarbonized gases they will be able to meet peak needs, especially in winter. If we did not have this decarbonized thermal capacity in Europe, we would have to over-size the renewables installed base and invest in other means of flexibility: the additional cost to do so would be several tens of billion euros annually through 2050. So the wider community can only benefit from the use of green thermal power!

TOWARDS 100% DECARBONIZED GAS IN 2050

For a successful energy transition, the gas industry faces a dual challenge: it must modify its economic model by halving consumption and switch from fossil-based methane to fully decarbonized gases.

The range of such gases is quite large:

- First generation biomethane, produced by methanization (anaerobic digestion of organic matter such as agricultural waste);
- Second generation biomethane, produced by processes such as the pyrogasification of waste;
- Renewable hydrogen, produced by water electrolysis powered by renewable electricity;
- E-molecules (methane, methanol, ammoniac, etc.) produced from hydrogen;
- Natural gas in conjunction with CO_2 capture and storage (CCS).

The potential of these various solutions could enable the complete decarbonization of gas consumption in Europe in 2050. To meet the European “Fit for 55” targets, 450 TWh of decarbonized gas must be mobilized by 2030.

The existing infrastructures for methane transport, distribution and storage can of course be used to supply decarbonized gases. On a European scale, these infrastructures would enable the transit of 600 TWh of biomethane, to which can be added 300 TWh of synthetic methane imported via LNG terminals.

COMBINING THE ELECTRON AND THE MOLECULE

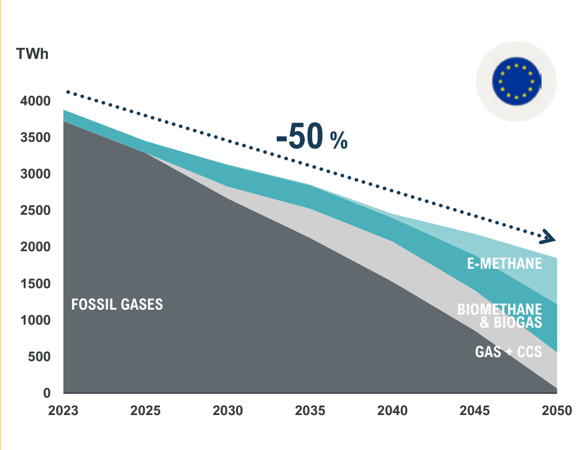
The alliance of the electron and the molecule can ensure both the reliability and the competitiveness of the energy system.

The molecule has many qualities as it is transformable, storable, exportable and importable. Decarbonized gases are complementary to electric solutions. By enabling the implementation of a balanced energy mix, they offer two key advantages: they reduce electrical peak demand needs, especially in winter and engender a lower overall cost for the wider community.

STRUCTURAL FALL IN GAS CONSUMPTION

In the years ahead, gas consumption is set to fall by half. This considerable fall is largely due to the electrification of usages, in particular for heating along with improved energy efficiency in buildings.
In ENGIE’s scenario, European consumption of methane will drop from 3880 TWh in 2023 to 1750 TWh in 2050.
In France, demand is set to fall from 470 to less than 245 TWh.

METHANE CONSUMPTION IN EUROPE



THREE QUESTIONS FOR...

PIERRE-LAURENT LUCILLE
CHIEF ECONOMIST
ENGIE

"FRANCE HAS AMONG THE HIGHEST BIOMETHANE POTENTIALS IN EUROPE"

What role will biomass play in the energy transition?

Pierre-Laurent Lucille: Biomass is a key resource for meeting the decarbonization ambitions of Europe and France. It comes in three main forms: fuelwood, which is central to the greening of urban heating networks; biofuels, whose volumes need to be controlled to avoid being in competition with food production; and biogas, which will enable the continuance of gas usages vital to a balanced energy mix. In this respect, biomass is an essential common resource that must be preserved over the long term.

Yet can biogas be developed to the expected level?

Our scenario shows that the potential of biogas/biomethane in Europe is sufficient to cover almost half of European gas demand by 2050. It can already supply over 300 TWh of green gas by 2030.
This potential takes into account the effects of climate change and the evolution of agricultural practices and it also avoids having recourse to dedicated crops so as not to compete with food production. France has an exceptional biomethane potential of around 300 TWh yearly, across all sectors: to harness this potential, the methanization industry must be supported. This is an opportunity that should be used to leverage economic development in the regions.

Will decarbonized gases use the existing gas infrastructures?

Yes, to minimize costs it is essential to capitalize on the existing gas infrastructures, namely transport and distribution networks as well as storage facilities: they will be the natural relays for delivering biomethane and synthetic methane molecules. In parallel, it is vital to maintain structures such as LNG terminals to provide importation capacities and develop *ad hoc* structures for hydrogen.

INFRASTRUCTURES, AN ESSENTIAL LEVER

Investments are necessary to maintain and develop energy infrastructures.
Through 2040, the most important investments will be in electric infrastructures to enable the roll-out of renewable energies: €39 bn annually for transport and distribution networks, cross-border interconnection and transport charging infrastructures. As for gas infrastructures (methane, hydrogen) they will play an essential role in terms of peak supply and flexibility with a lower investment envelope of around €6 bn yearly.

THE ESSENTIAL AND PIVOTAL ROLE OF HYDROGEN

STRONG GROWTH IN ELECTROLYSIS

Of all the decarbonized gases, hydrogen has a special place in the energy transition. Indeed, this molecule has a pivotal function enabling the articulation of electricity and synthetic methane. Hence, our scenario provides for:

- Very strong growth in the European means of production of hydrogen by water electrolysis, to reach 270 GW of electrolysis capacity by 2050. This capacity also provides a source of electrical flexibility;
- The combination of hydrogen with CO_2, via methanation, to produce synthetic methane, to reach 200 TWh in Europe in 2050.

Thus, hydrogen truly interfaces electric and gas systems. Furthermore, it will facilitate the decarbonization of certain sectors, such as the steel industry, and heavy mobility (aviation and maritime sectors).
To a lesser extent, hydrogen could be used directly via injection into methane networks or for land-based mobility.

SECURING OTHER SOURCES OF HYDROGEN

Half of Europe's hydrogen requirements in 2050 will be produced locally. The industrial challenge for hydrogen development by electrolysis is huge. Even though economies of scale will lead to a fall in green hydrogen production costs in Europe, prudence calls for the provision of other sources of supply, in particular in high-sunlight countries, which could produce gas at a low cost.

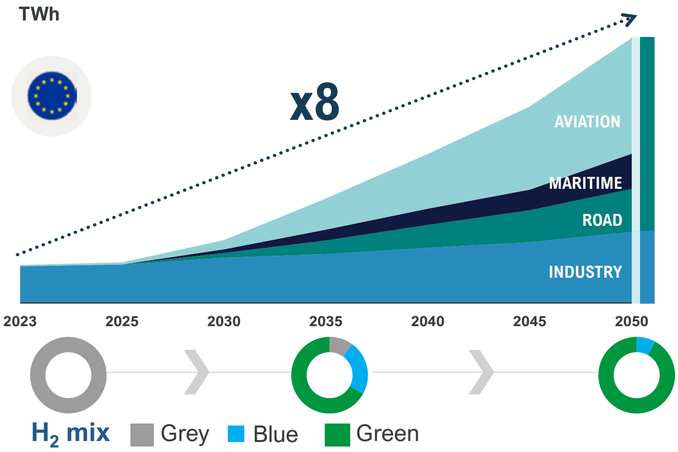
The importation of decarbonized hydrogen between European countries and from neighboring countries will depend on the conversion of existing transport networks or the construction of new hydrogen dedicated pipelines.
The creation of a European hydrogen backbone would pave the way for a mutualization of production means and enable the transit of over 100 TWh of hydrogen at a competitive cost from the south of Europe (Spain, France, Italy) towards the north (Germany, Poland). Hydrogen will also play a crucial role in replacing Russian gas and in avoiding recourse to coal.

x 8
hydrogen consumption through 2050

75%
of hydrogen will be transformed into other e-molecules

80%
of hydrogen will be low carbon by 2030

USE OF HYDROGEN IN EUROPE BY SECTOR



A FRONT LINE SECTOR

PRIORITY: RETROFITTING

Responsible for 40% of Europe's energy consumption, residential and service sector buildings have no other choice but to undergo an in-depth transformation. To help meet decarbonization goals, it is vital that they reduce their energy needs. To this end, energy efficiency retrofitting of buildings is a priority, supported by the development of energy efficiency and consumption management solutions.

The annual target pace of retrofitting, which has to increase 5 fold, being hard to reach, the choice of heating solutions must therefore take all the various challenges into consideration: reducing emissions, costs for households, etc.

DIVERSIFYING HEATING SOLUTIONS

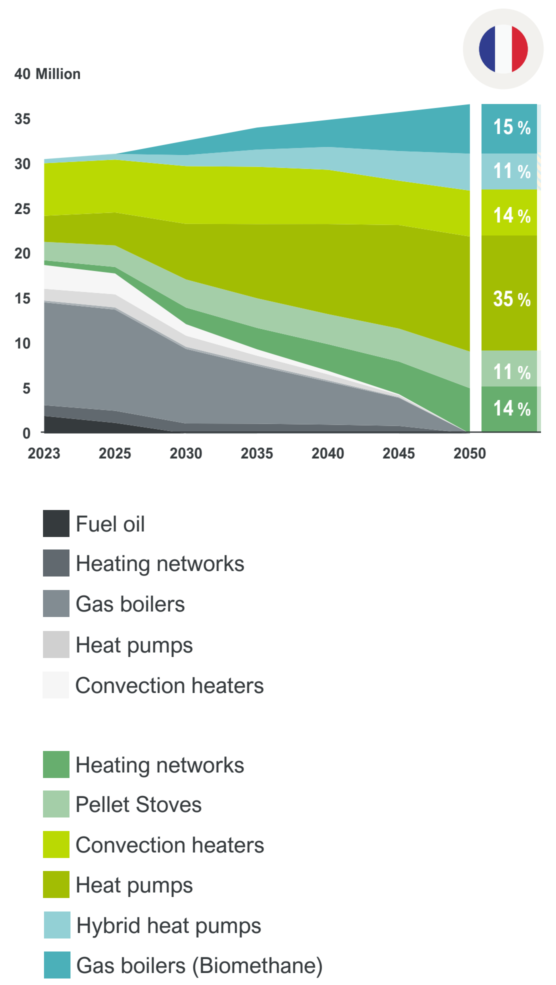
In our scenario, the demand for heating will fall by 67%. Electricity would play a major role in the heating of residential buildings. This can be explained by the retention of a share of direct electric heating and the expected development of heat pumps. Nevertheless, to reach decarbonization goals and reduce electricity needs during winter consumption peaks, we feel it is important to use all existing solutions, such as:

- Hybrid heat pumps, which thanks to their coupling with a gas-fired boiler, can avoid having to use electricity when the electrical grid is under pressure;
- Biomethane-fired gas boilers;
- Fireplace retrofits / wood-burning stoves;
- Urban heat networks, which should be increased twofold, and which enable better heating cost control in densely populated zones. These networks should also favor more renewable energy usage (geothermal, biomethane, wood-fuel, etc.).

SAVINGS THANKS TO HYBRID HEAT PUMPS

As outlined in our scenario, the installation of hybrid heat pumps by 2050 would have a very positive impact. To understand why, one only has to imagine the outcome of not doing so. If they were to be replaced by traditional heat pumps and electrical convector heaters (respectively to a level of 80% and 20%), winter peak capacity needs would increase by 12 GW for an additional cost of 2.7 billion euros yearly.

BREAKDOWN OF HOME HEATING METHODS IN FRENCH HOUSEHOLDS BETWEEN 2023 AND 2050



TWO MULTI-ENERGY APPROACHES

INDUSTRY: SEVERAL LEVERS TO ACTIVATE

Building on the progress made in recent years, the European industrial sector can continue to improve energy efficiency and thus reduce its energy consumption by 27% through 2050. As in other sectors, the electrification of industrial processes is on the rise: over the same period, the share of electricity will increase from 20% to 40%.

Despite the fall in consumption, industry has two challenges to face: find solutions for certain processes that cannot efficiently switch to electricity; and avail of new molecules or technologies to replace currently used fossil resources. ENGIE's scenario envisages several levers:

- The retention of gas solutions for high temperature industrial processes. Decarbonized gases (biomethane, hydrogen, gas in conjunction with carbon capture and storage) will override traditional fossil fuels;
- The valorization of biomass in boilers, along with waste heat recovery;
- The use of hydrogen for the making of new molecules (ammoniac, methanol) or for the steel industry.

For industrial production processes where fossil energy material resources (oil and coal) are not substitutable, the resulting CO_2 emissions must be offset.

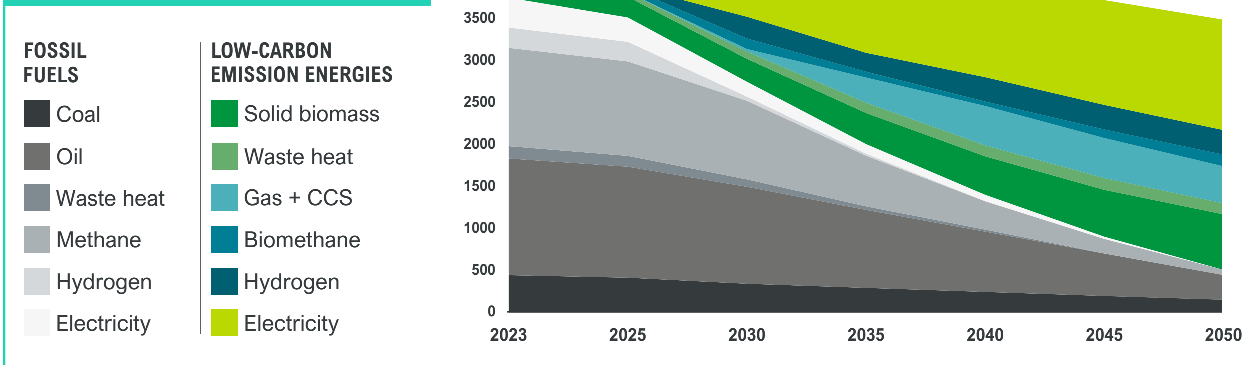
NEW MOLECULES FOR HEAVY MOBILITY

The electrification of mobility is relevant for light-weight vehicles. But in the case of heavy mobility (trucks, buses, boats, planes), the battery volumes required for sufficient range is a real obstacle. Alternative solutions do exist.

Thermal engines can be easily adapted to run on other molecules: bioNGV for trucks and buses; biodiesel, ammoniac, bioLNG and synthetic methanol for maritime transport; bio-kerosene, decarbonized hydrogen, or synthetic kerosene for air transport.

In this way, the maritime and air transport sectors could reduce their greenhouse gas emissions by 80% by 2050, while increasing traffic. In our scenario, almost 75% of hydrogen demand in Europe comes from heavy duty transport, whether road, maritime or air.

CONSUMPTION OF INDUSTRIAL ENERGY AND NON-ENERGY USES IN EUROPE



TWO MAJOR RISKS TO BE AVOIDED

Two stress-test simulations were carried out in order to analyze the consequences of situations that deviate from the optimized scenario put forward by ENGIE. Thanks to these simulations, the benefits of certain solutions become all the more clear (renewable energies, decarbonized thermal equipment).

SIMULATION NO. 1 - EUROPE

Extra cost in the case of non-development of wind and photovoltaic farms

Hypothesis: There is a 5-year delay in the development of wind and photovoltaic farms and their associated electric grids.

Consequences: In this case, the European Union for 2030, "Fit for 55" objectives have not been reached (+3 $GtCO_2$) and costs are higher (+€4 bn yearly through 2050).

Implications? The acceleration of renewable energies is essential and public policy must remove all obstacles to their development.

SIMULATION NO. 2 - EUROPE

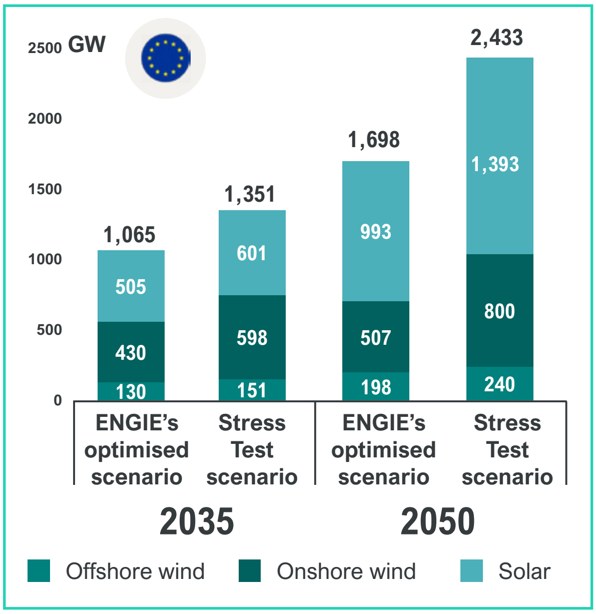
Extra cost in the case of the non-use of decarbonized thermal

Hypothesis: The governments of the various European countries do not authorize the 105 GW of additional development of decarbonized thermal power plants (as outlined in the ENGIE scenario).

Consequences: In this case, to compensate the output no longer provided by power plants during electricity consumption peaks would require the development of far more renewable energy (+700 GW in 2050 compared to the optimized ENGIE scenario) and battery capacity (+200 GW) for an additional cost of €37 bn yearly.

Implications? To manage electricity consumption peaks, the over-dimensioning of renewable energies does not make economic sense, even if it in fact engenders lower CO_2 emissions (-80 Mt). Decarbonized thermal equipment ensures the security and resilience of the electrical system at a lower cost.

SIMULATION OF THE NON-USE OF DECARBONIZED POWER PLANTS



OUR RECOMMENDATIONS: OBSTACLES TO OVERCOME

- **for renewable energies, electric and gas: stabilize the investment framework,** facilitate and accelerate connections (to electric grids) and the issuance of the permits required for projects;
- **facilitate the development of the hydrogen sector across the entire value chain: finalize the European regulatory framework** by making provision for rapid review clauses; ensure the granting of **adapted public financing** as well as financing for **gas infrastructure redevelopment;**
- **develop flexible capacities**: implement **adapted remuneration models** (demand-side management, batteries, decarbonized CCGT, etc.) speed up the issuance of permits required for projects;
- **maximize the potential of biomethane, activate all levers**: ensure the existence of efficient production support mechanisms) in France and Europe;
- **decarbonize buildings, support all solutions:** strongly develop connections to **virtuous heat networks** including geothermal; **prioritize the use of biomethane** in buildings **as well as hybrid solutions** (heat pumps, hybrid heat pumps, boiler backups, etc.); simplify access to **home subsidies** with a “one stop shop” approach comprising all current provisions;
- **for the decarbonization of industry: accelerate waste heat recovery**; long-term financing; continue to mobilize local **biomass as a renewable energy source.**