BUILDING DECARBONIZATION PATHWAYS FOR EUROPE

ENGIE'S SCENARIO

JUNE 12, 2023

OUR 5 BELIEFS

1 Activate all possible levers for decarbonization

4% / annual reduction in emissions

To achieve « Net zéro » carbon in less than 30 ans

2 Combine electricity and molecules for a successful transition

450TWh of low-carbon gas by 2030

to meet “Fit for 55” objectives

3 Massive development of renewable power

80% increase

in electricity demand **in Europe** by 2050

x6

increase in power generation from solar and wind

4 Act now to anticipate flexibility needs

~x4

increase in flexibility needs **by 2050**

5 Energy efficiency is compatible with growth

34%

reduction in energy demand by 2050

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AN ANALYSIS DERIVED FROM GLOBAL EXPERIENCE

ALL LEVERS OF DECARBONIZATION

AN INTERNATIONAL FOOTPRINT

A PRAGMATIC APPROACH TO DECARBONIZATION

Mature and emerging technologies

All energy vectors & markets

European and national regulatory frameworks

NET ZERO CARBON

COST OPTIMIZATION

RESILIENCE

A DECARBONIZATION PATHWAY THAT MEETS THESE 3 CRITERIA

A ROBUST METHODOLOGY

A European vision

- Modelling of **15 European countries**, with their strongly interconnected energy systems

A model that incorporates a diverse range of energy vectors

- Based on **interactions between electricity, methane, hydrogen, e-molecules and heat**
- Modelled with a **fine-grained hourly timeline** to meet reliability and resilience criteria

A realistic approach to technical and economic choices

- Based on **mature low-carbon technologies** (e.g. excluding marine energy and nuclear fusion)
- Incorporates **societal factors** (e.g. limitations to the deployment of carbon capture and storage)
- Uses **external studies and benchmarks** for issues outside our area of expertise, e.g. agriculture, forestry (European Commission, ADEME, etc.)

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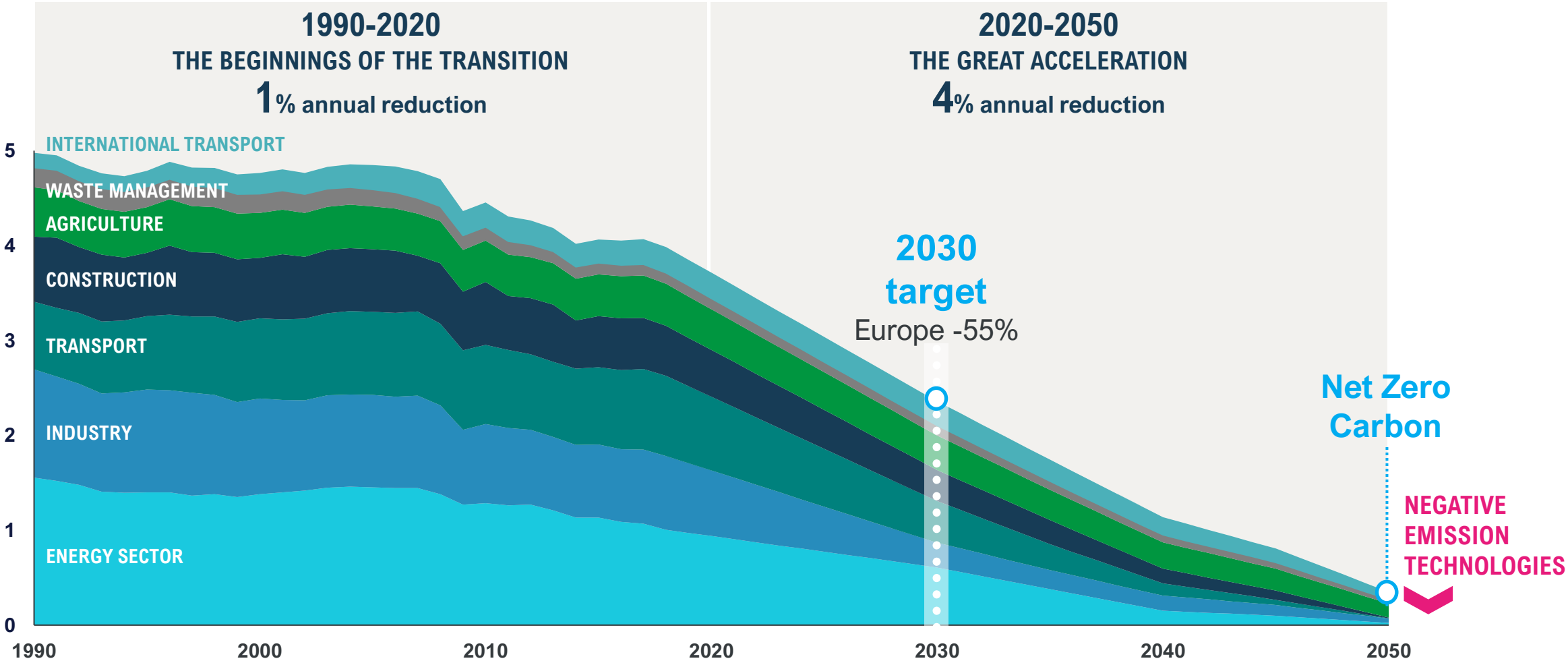
A NECESSARY INCREASE IN EMISSIONS REDUCTION EFFORTS

Greenhouse gas emissions

CO_2e, Gt / year

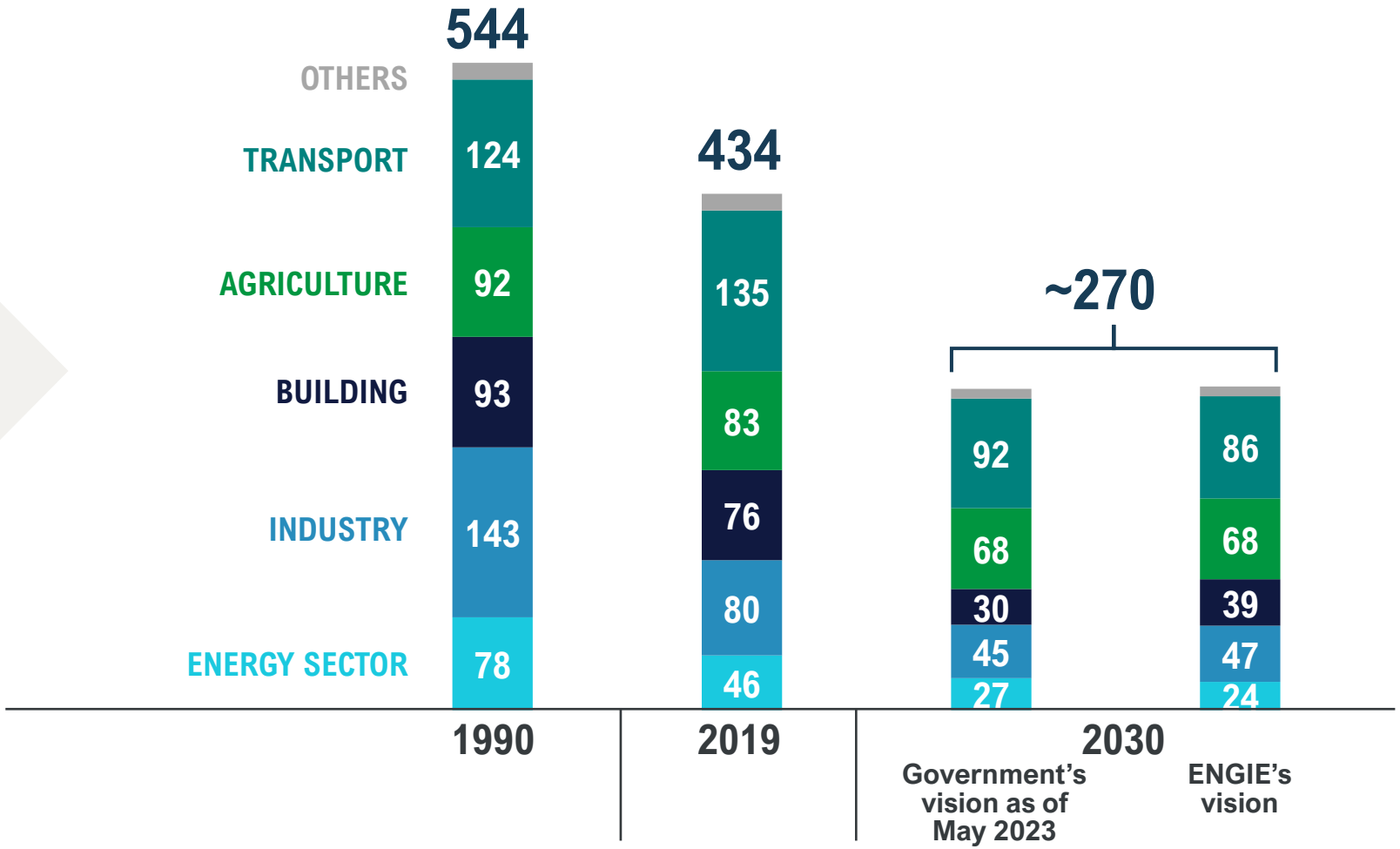


DIFFERENT ROUTES EXIST TO REACH FIT-FOR-55 TARGETS

OUR APPROACH OPTIMIZES COSTS WHILE maintaining CO_2 emission reduction targets

Greenhouse gas emissions

Mt CO_2e, 2030



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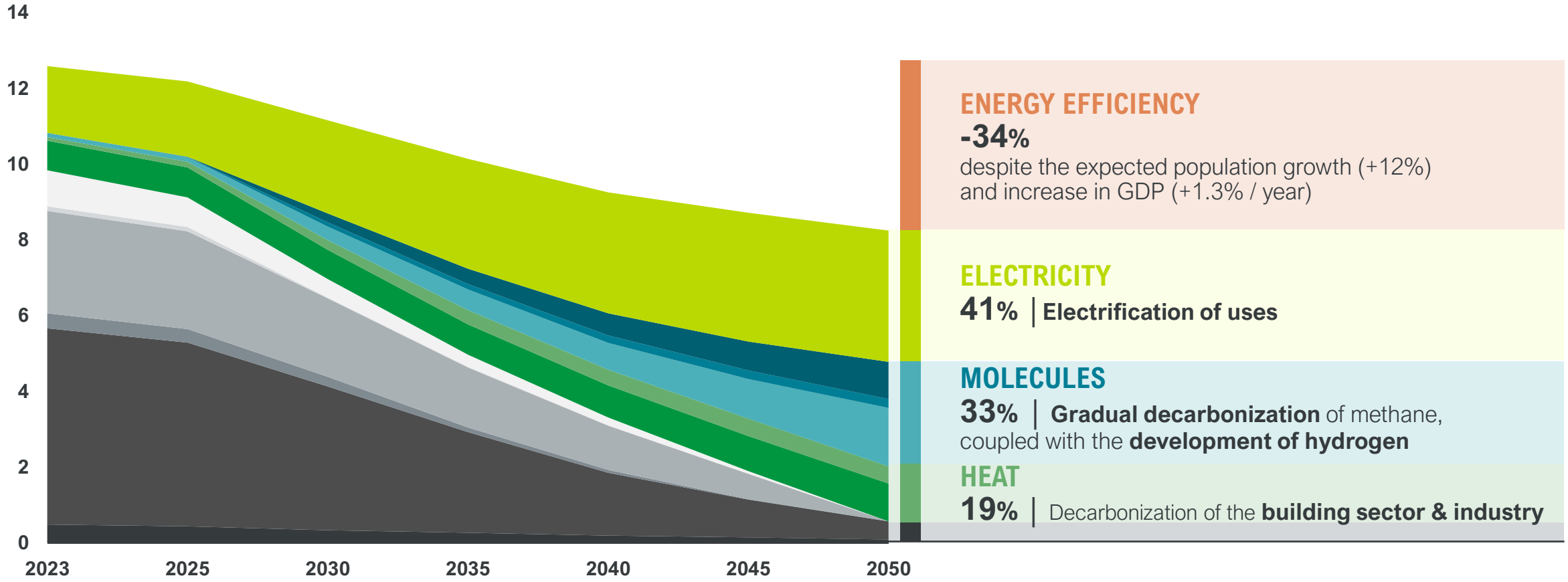
ALL LEVERS ARE REQUIRED TO ACHIEVE DECARBONIZATION

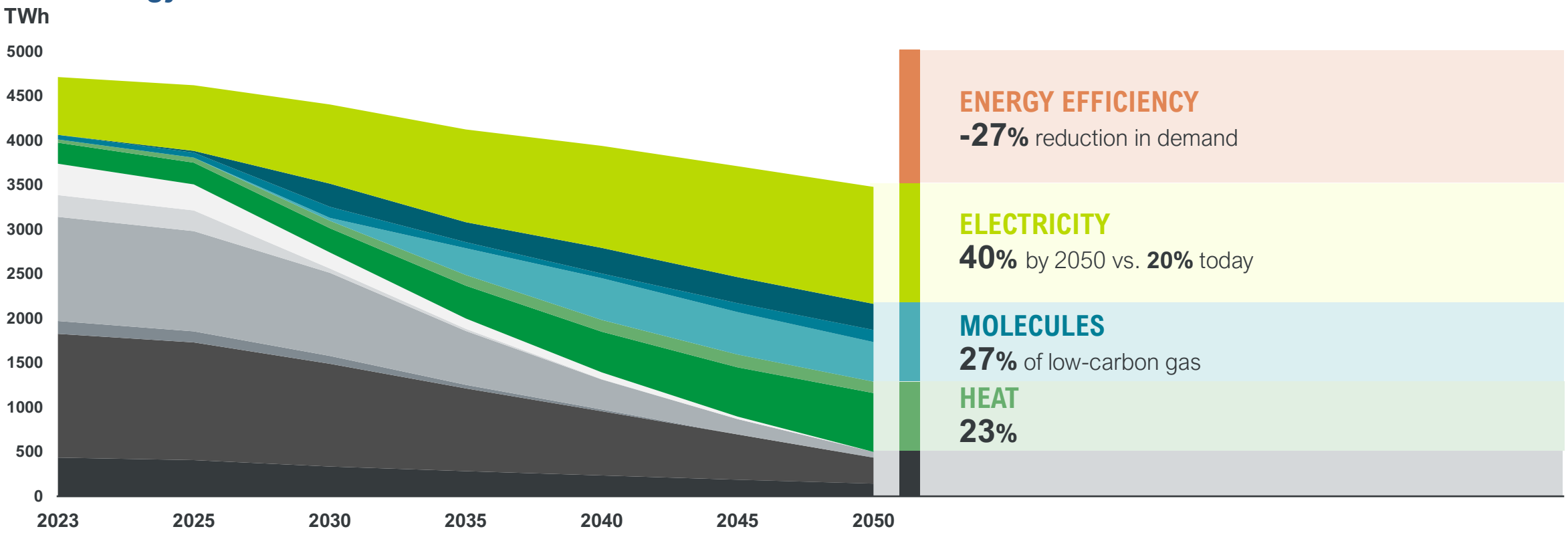
Final energy mix

Thousand TWh



INDUSTRY: ELECTRIFICATION AND DECARBONIZED GASES ARE THE DRIVERS OF THE TRANSITION

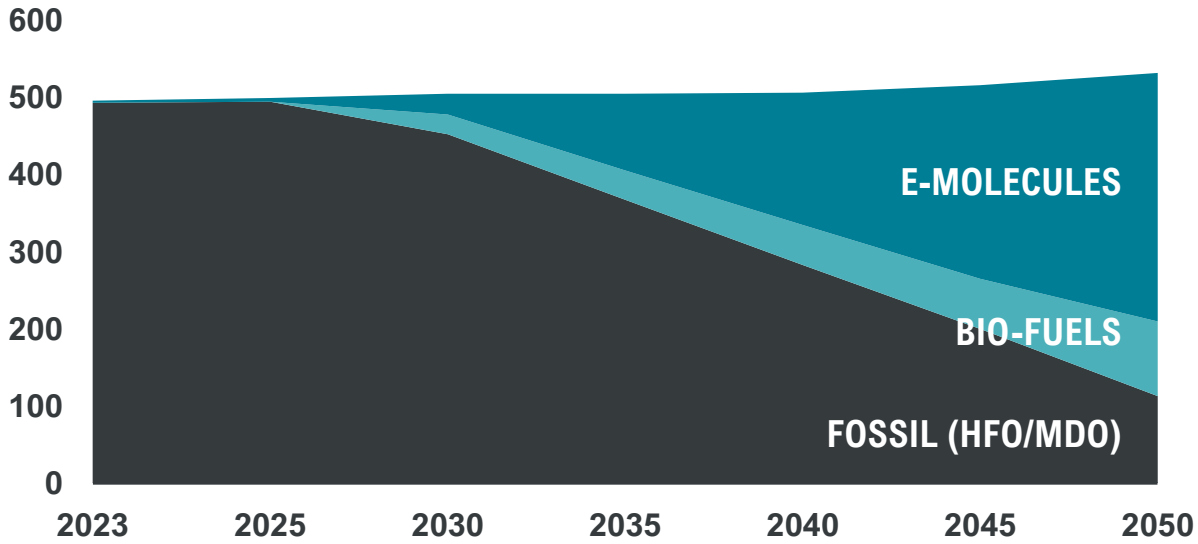
Final energy mix for the industrial sector

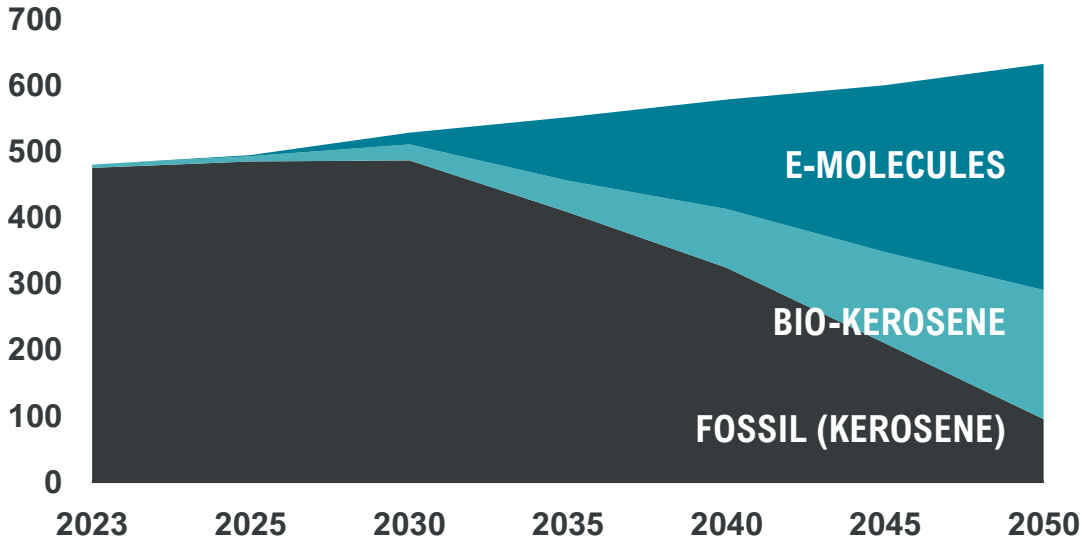


MARITIME AND AIR TRANSPORT: GREEN MOLECULES, MAIN VECTOR FOR DECARBONIZATION

Final energy mix

TWh





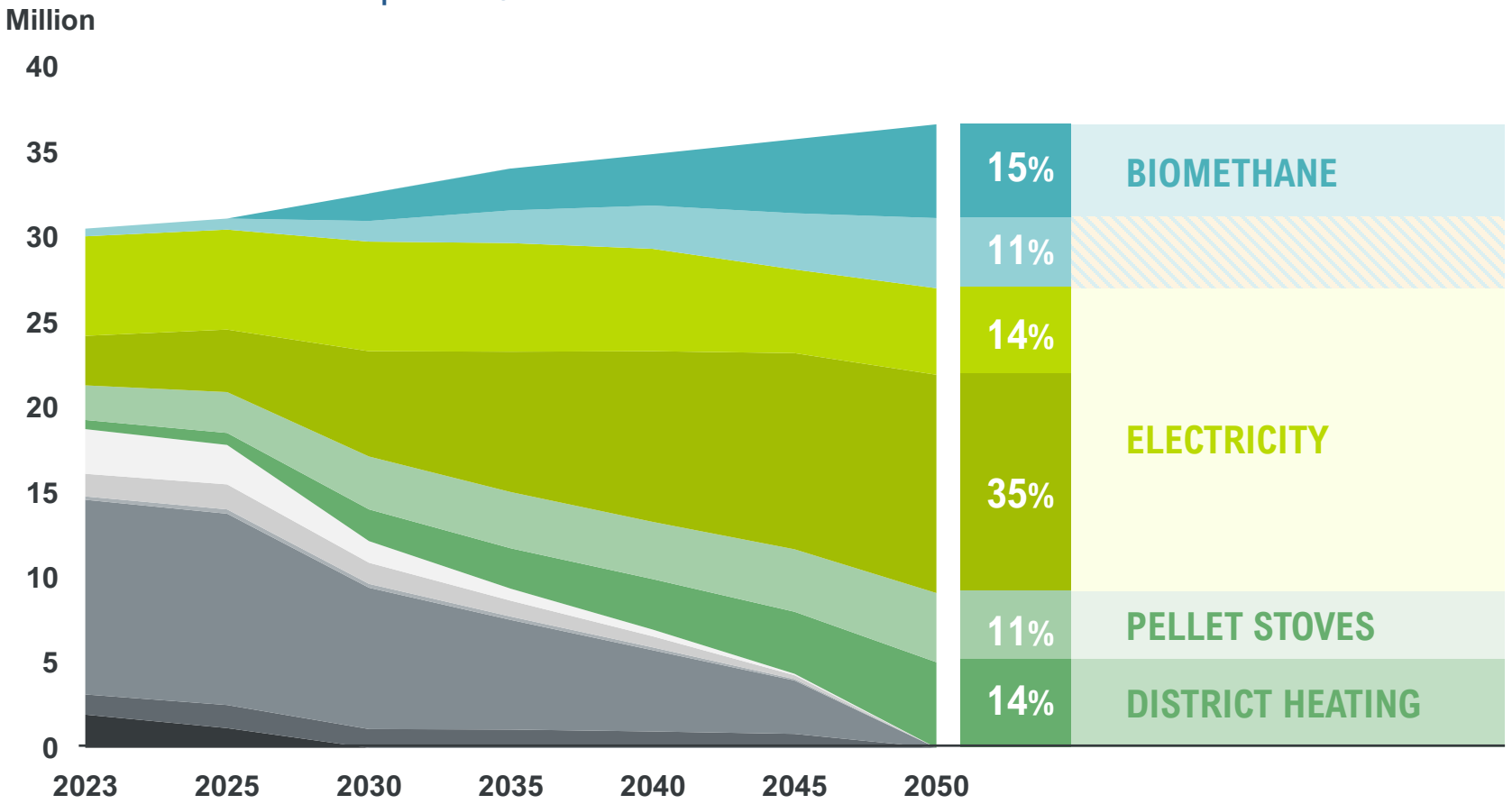
80% EMISSION REDUCTION TARGET ACHIEVED THROUGH USE OF

- e-molecules derived from low-carbon hydrogen
- bio-LNG and bio-diesel for Maritime Transport
- bio-kerosene for Aviation

HFO: Heavy Fuel Oil,
MDO: Maritime Diesel Oil

BUILDING: NEED FOR A RANGE OF SOLUTIONS

French households | Heating solutions



Fuel oil
Heating networks
Gas boilers
Hybrid heat pumps
Heat pumps
Convection heaters
Heating networks
Pellet Stoves
Convection heaters
Heat pumps
Hybrid Heat Pumps
Gas boilers (Biomethane)

EFFICIENT RENOVATION BY 2050:

0.3 to 1.5% / year
Very strong increase
in the overall rate of renovation

50%
Buildings
fully renovated

BUILDINGS: HYBRID HEAT PUMPS NEEDED TO ENSURE SYSTEM RESILIENCE AND TO REDUCE COSTS

STRESS TEST

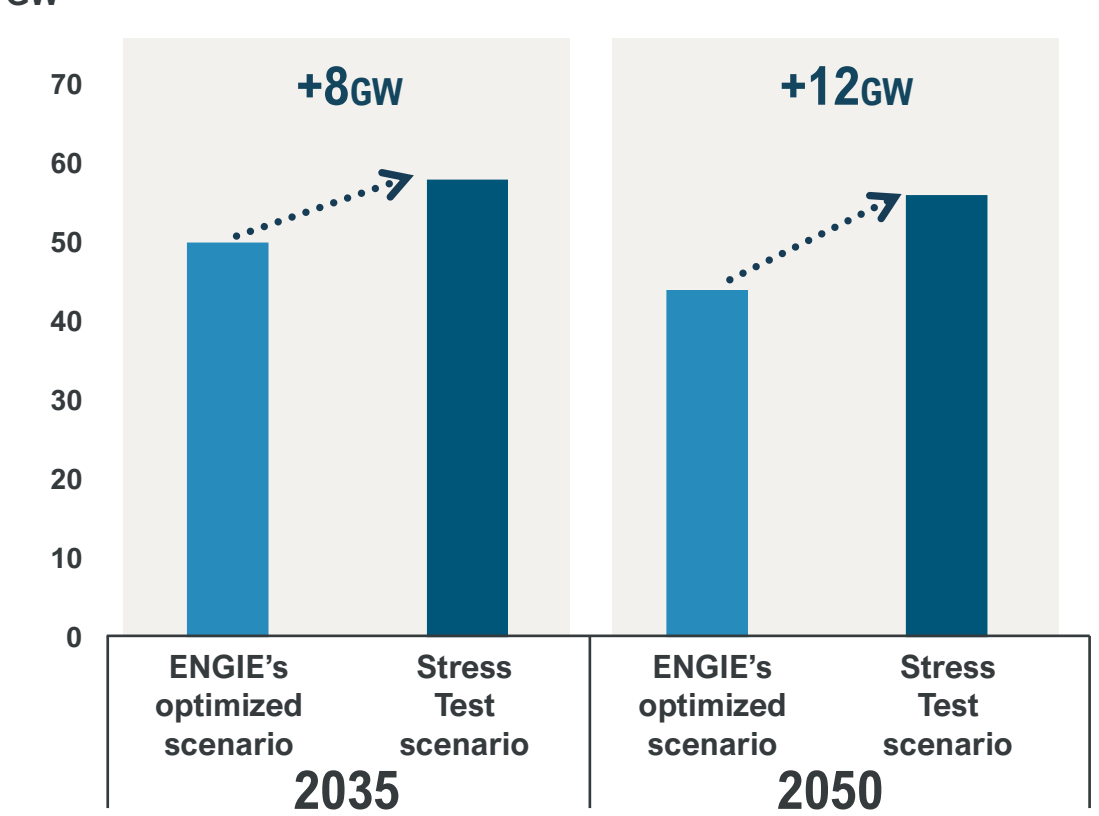
No installation of hybrid heat pumps

Replaced as follows:

- 80% by heat pumps
- 20% by convection heaters

IMPLICATIONS

Contribution of heating to the electric peak



+€2.7bn/year

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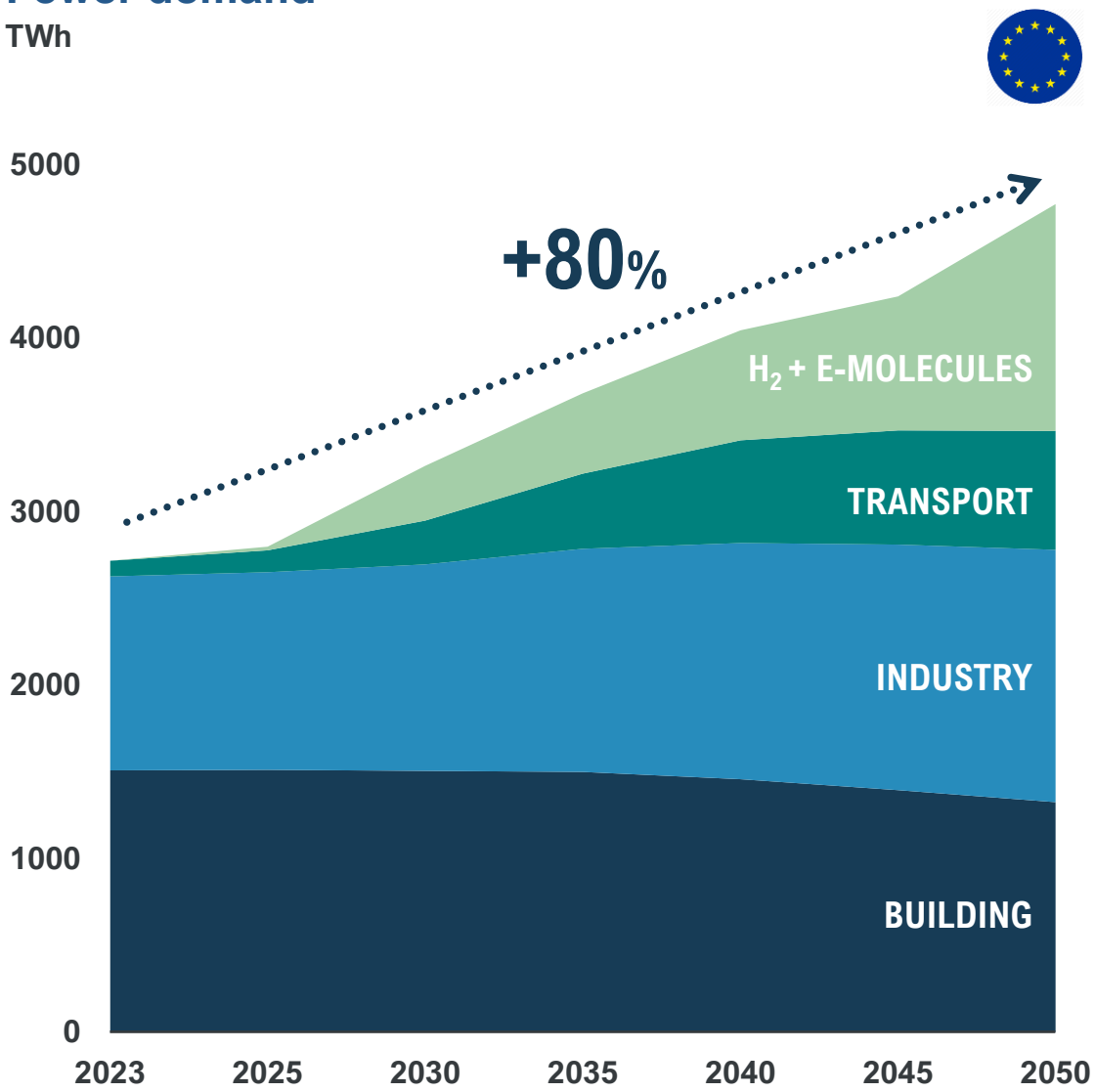
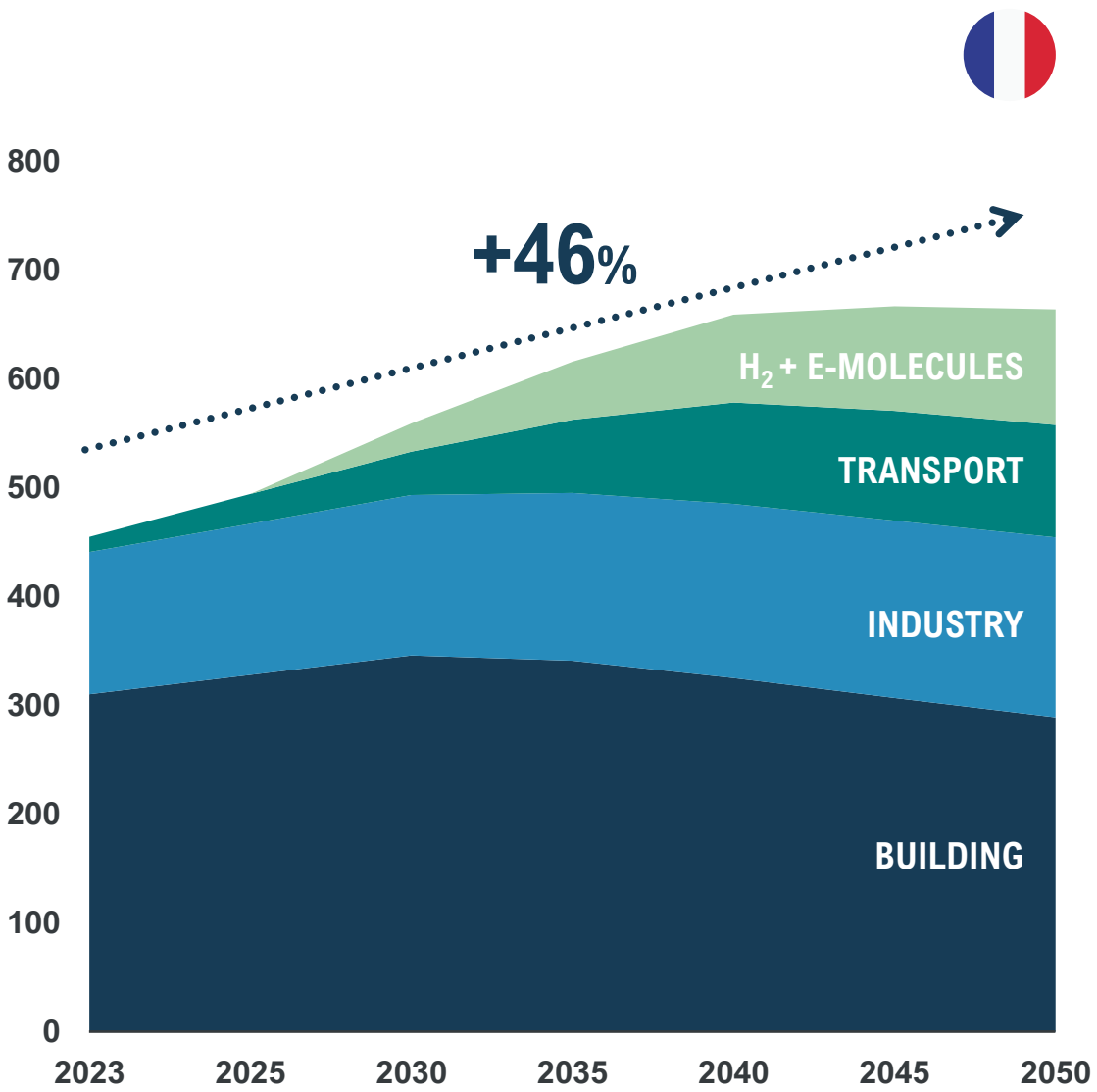
STRONG INCREASE IN POWER DEMAND BETWEEN NOW AND 2050

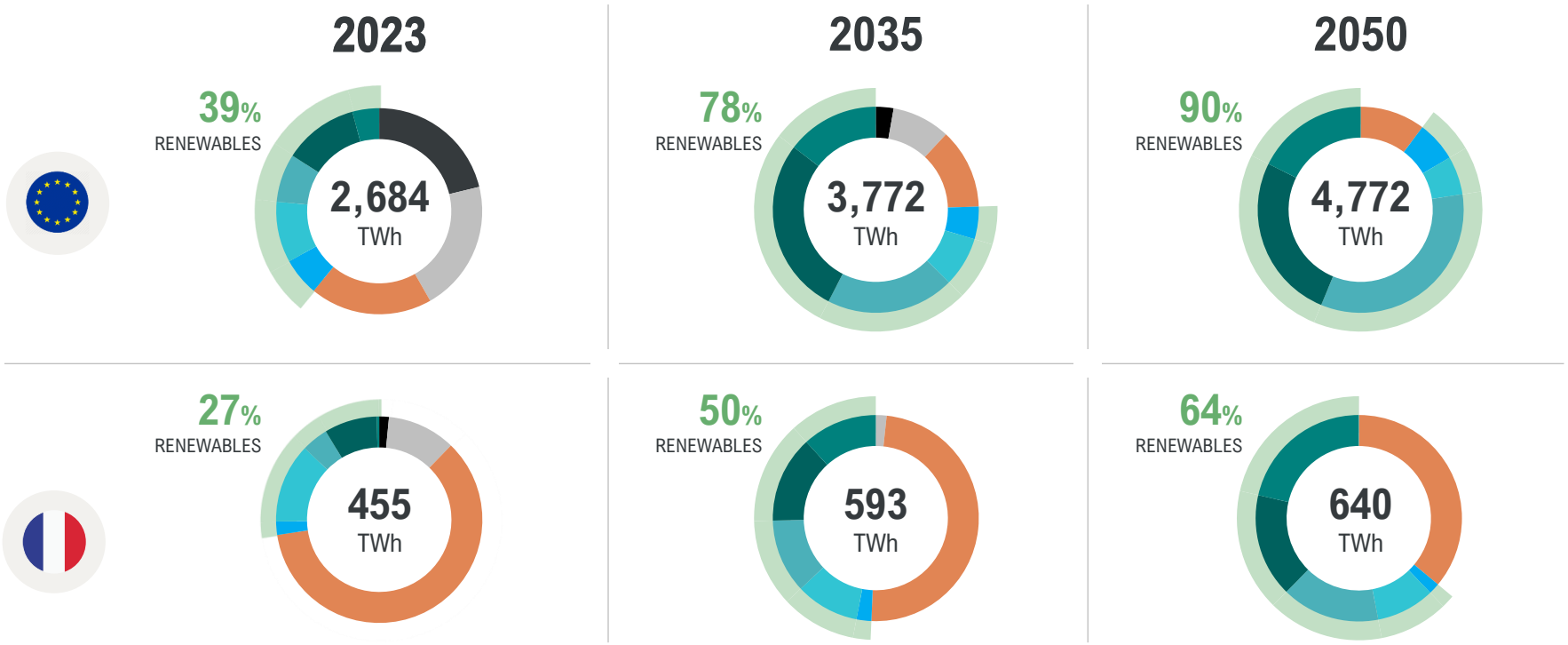
Power demand

TWh





MASSIVE INCREASE IN RENEWABLE POWER GENERATION



Solar and wind generation

x6

by 2050

FOSSIL FUELS

- Coal, Lignite & Oil
- Fossil gases

LOW-CARBON EMISSION ENERGY SOURCES

- Nuclear
- Decarbonized thermal
- Hydraulic
- Solar
- Onshore wind
- Offshore wind

RENEWABLES: ACCELERATION CRITICAL TO MEET CLIMATE GOALS AND KEEP COSTS DOWN

STRESS TEST

5-year delay
in developing solar,
wind power
and the associated grid

IMPLICATIONS

“Fit-for-55” targets not reached

+3Gt CO_2

+€4bn/year until 2050

GROWTH IN RENEWABLES, INSURANCE AGAINST THE CHALLENGES FACED BY NUCLEAR POWER IN FRANCE

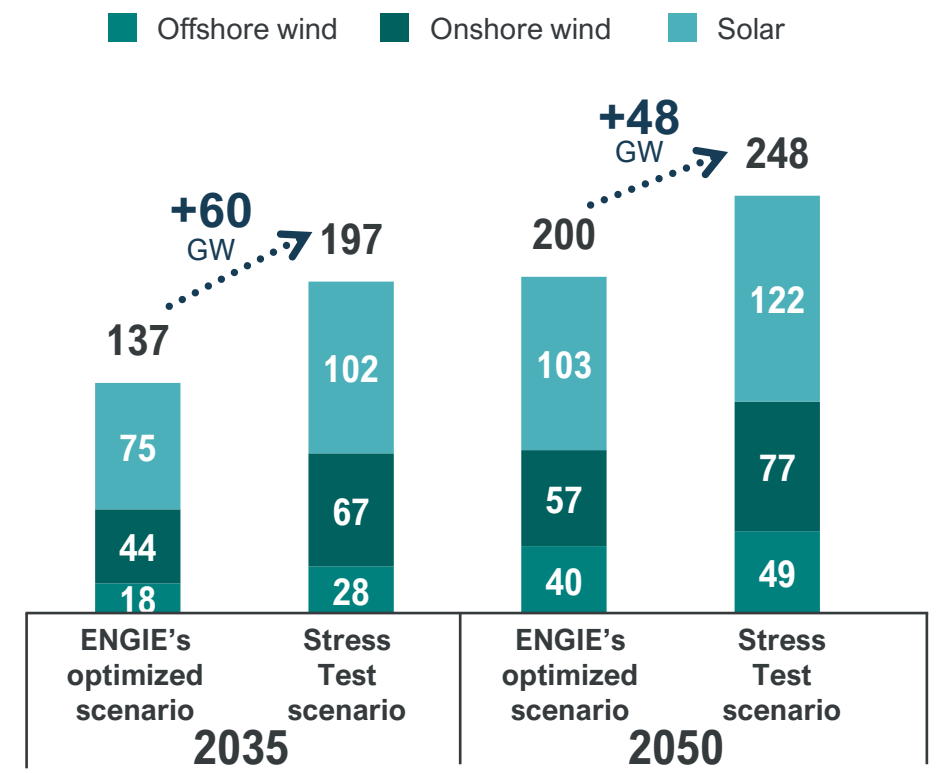
STRESS TEST

Lower availability of nuclear power

5-year delay in building new EPRs
(10 EPRs in 2050)

IMPLICATIONS

Installed renewable power capacity
GW



Additional renewable power generation **will ensure climate targets are met**

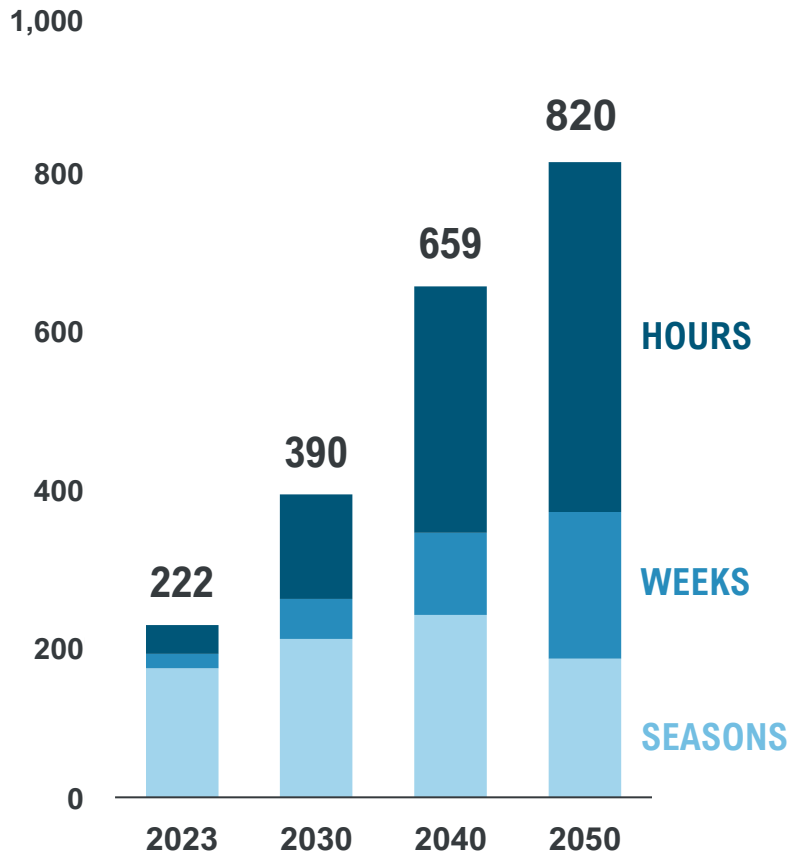
ASSUMING THE STRESS TEST DOES NOT MATERIALIZE

- Limited additional costs: **€2bn/year**
- Additional emissions avoided: **320Mt CO_2e**
- **Accelerated development** of green hydrogen and e-molecules

FLEXIBILITY LEVERS, A NECESSARY COMPLEMENT TO INTERMITTENT RENEWABLE POWER SOURCES

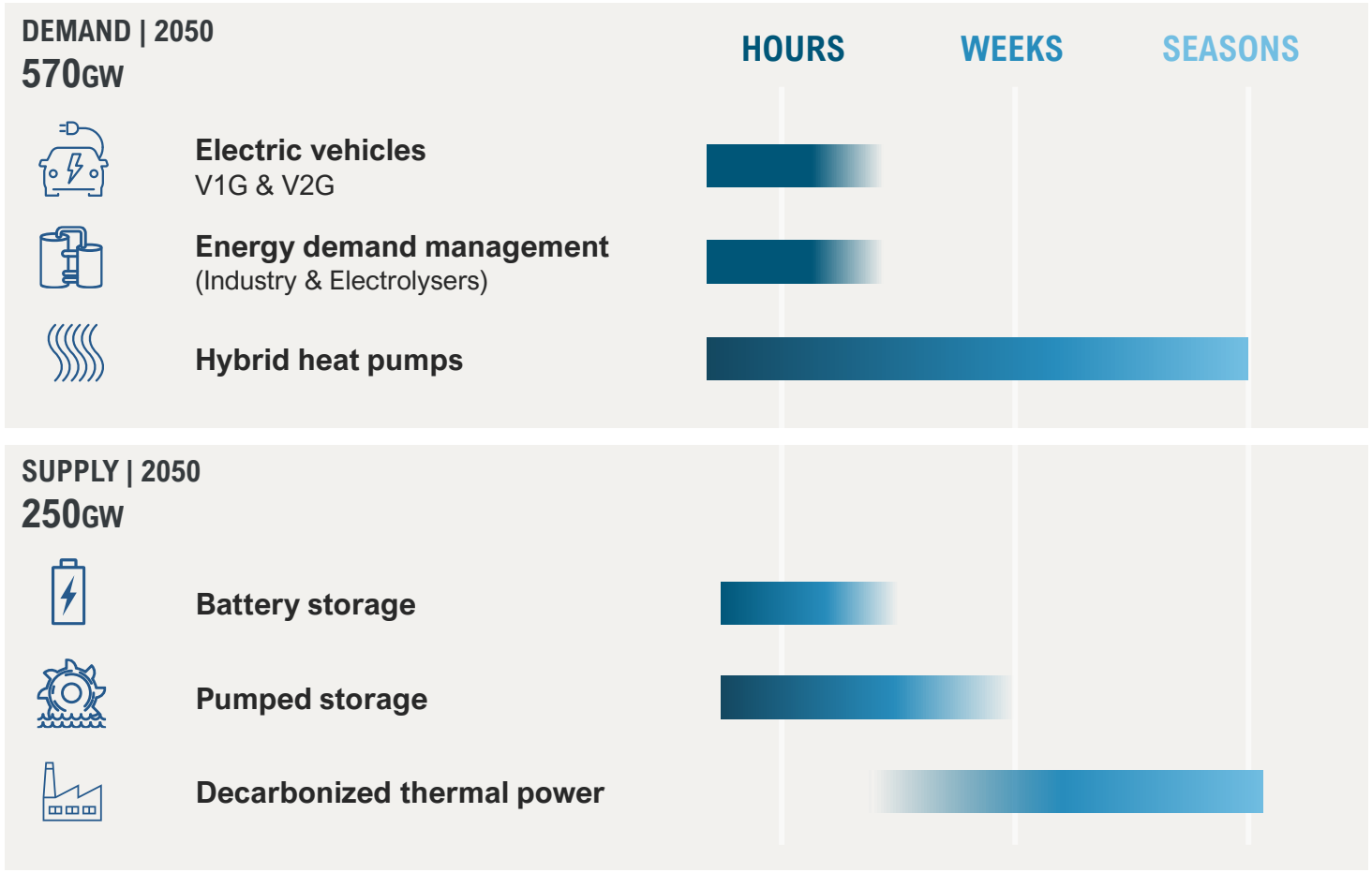
Flexible capacity

GW



Flexibility technologies

Various technologies for meeting specific needs



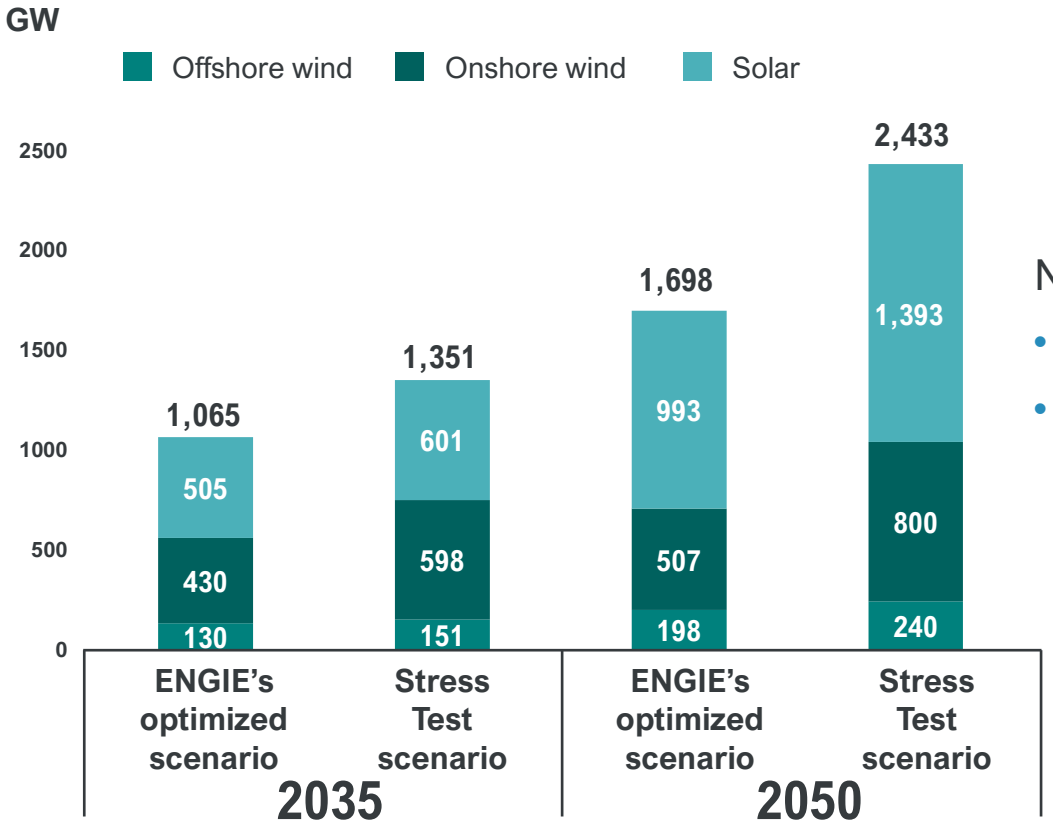
DECARBONIZED THERMAL POWER PLANTS ARE NECESSARY TO ENSURE SEASONAL FLEXIBILITY

STRESS TEST

No additional development of decarbonized thermal (105GW)

IMPLICATIONS

Renewable Energies



Need to install an additional

- **+700 GW of renewables**
- **+200 GW of batteries**

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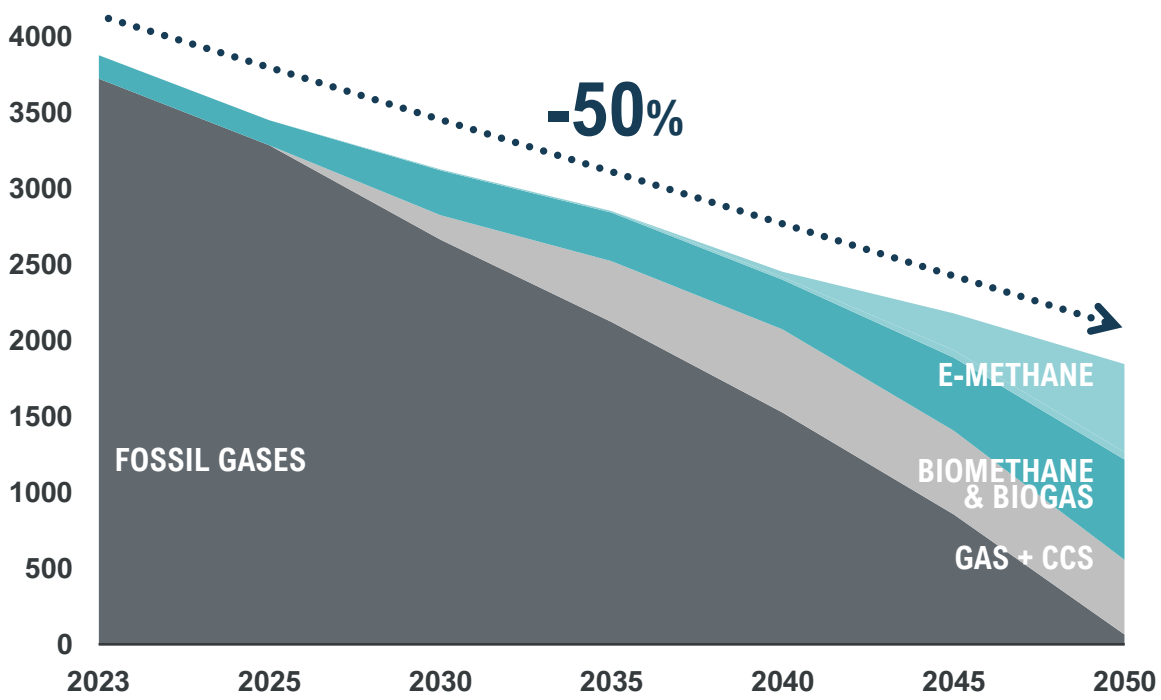
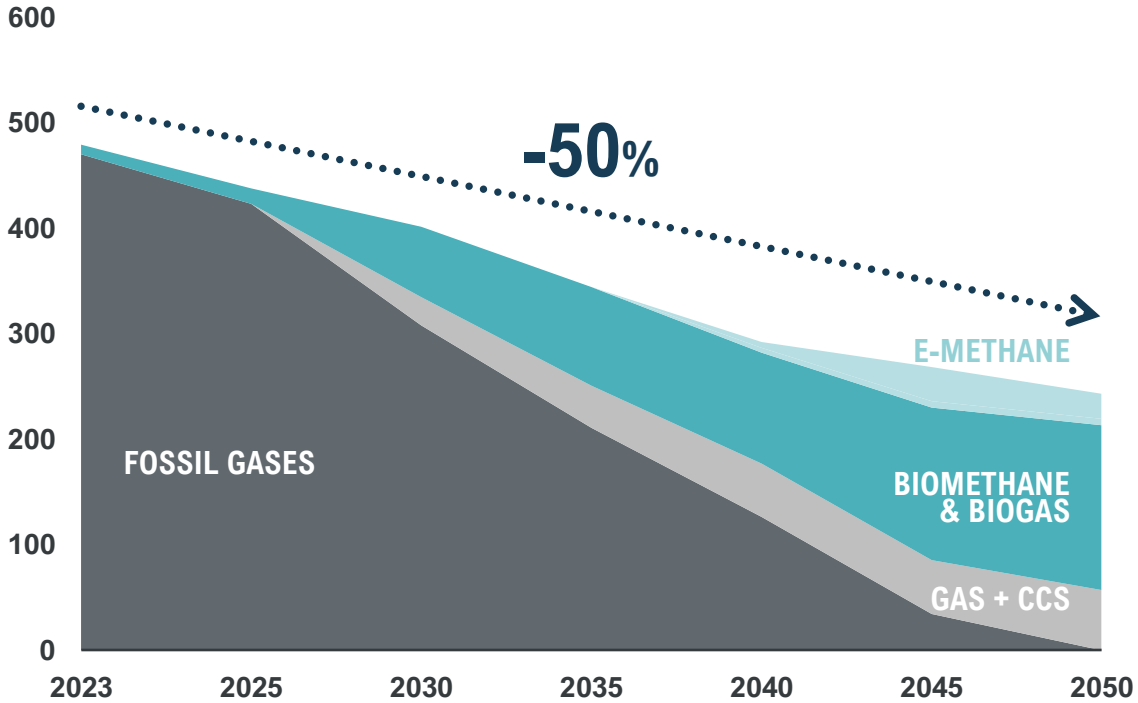
METHANE: DEMAND IS HALVED AND MET BY DECARBONIZED SOURCES BY 2050

Methane demand

TWh



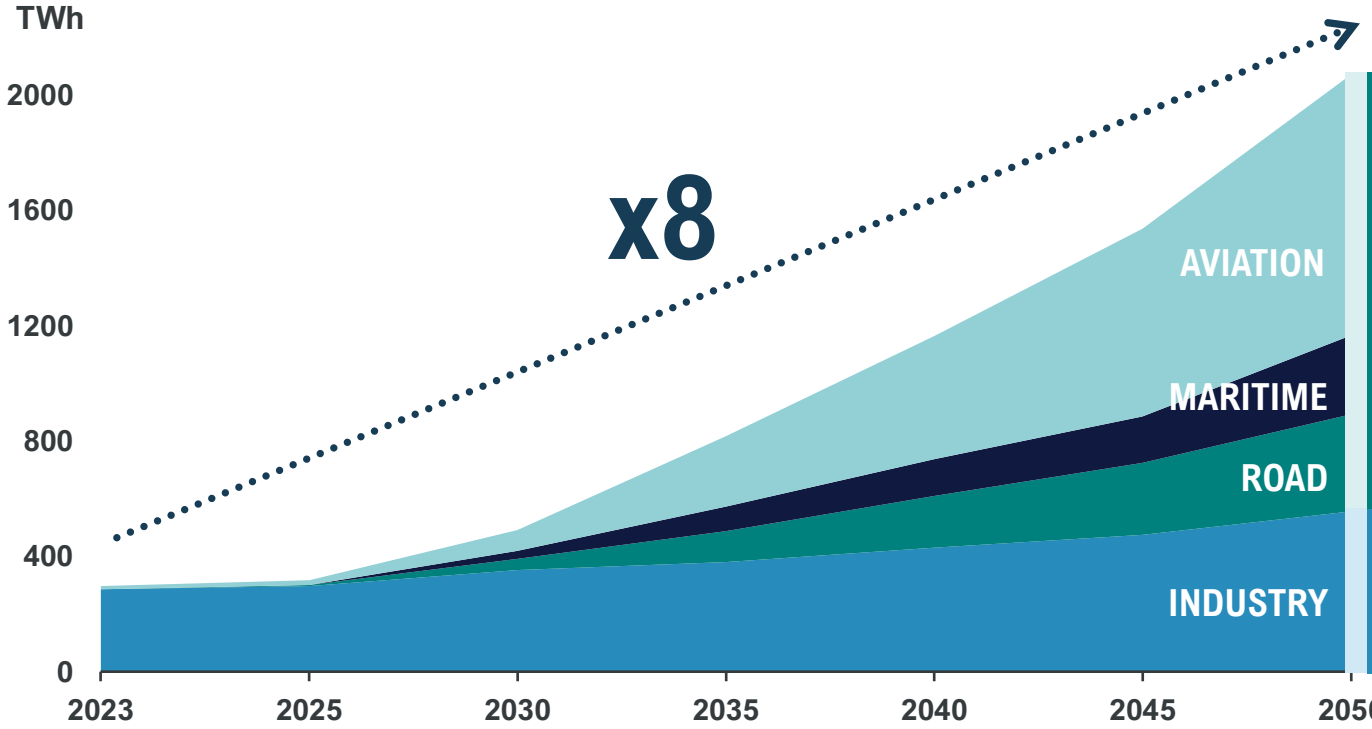
- **450 TWh** of low-carbon gas needed **to reach "Fit-for-55" targets by 2030**
- Imports will be **25% below** current levels



- **245 TWh** demand for fully decarbonized gas by 2050
- Biomethane plays a **key role (two-thirds of the demand in 2050)**

HYDROGEN AND E-MOLECULES: DEMAND DRIVEN BY HEAVY-DUTY TRANSPORT AND INDUSTRY

Sectors of the hydrogen economy

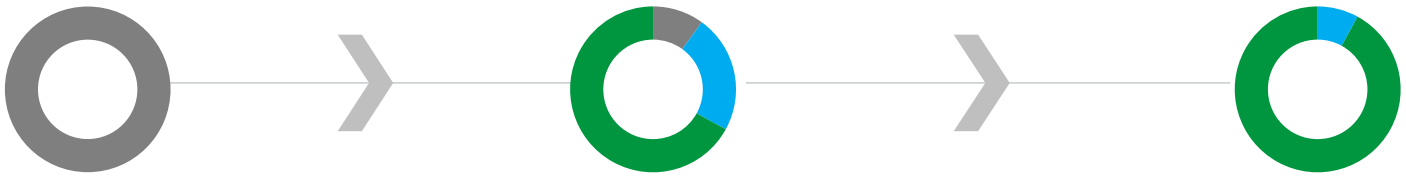


TRANSPORT

75% of the hydrogen demand, through e-molecules[1]

25% used for industrial sectors that are difficult to decarbonise (**steel and high temperature**)

Half of hydrogen demand locally produced in 2050



H_2 mix

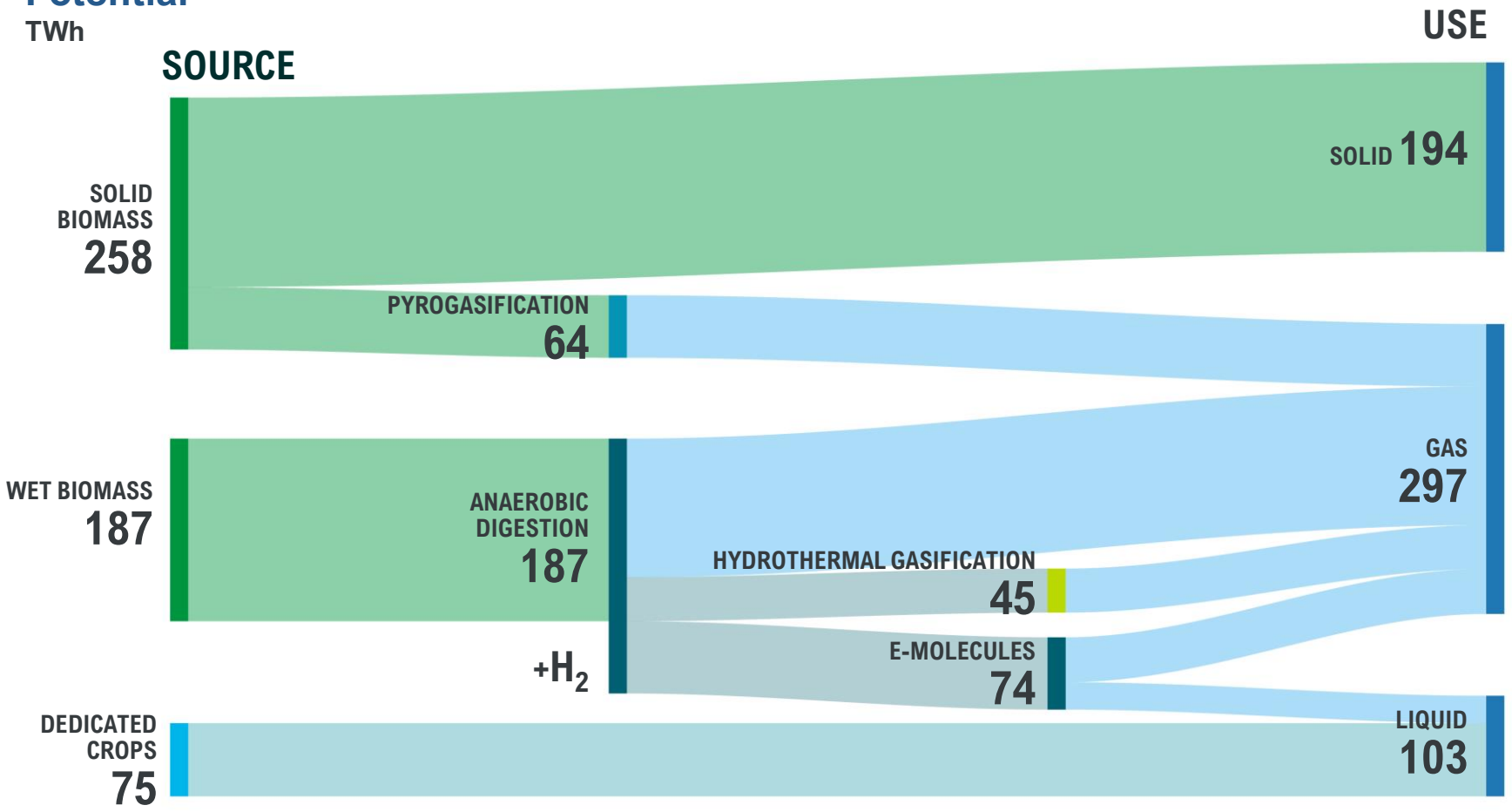
Gray Blue Green

[1] e-ammonia, e-methane, e-methanol, e-kerosene, e-diesel

BIOMASS: SUFFICIENT RESOURCES EXIST TO MEET PROJECTED NEEDS

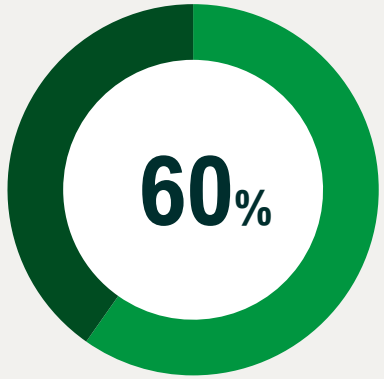
Potential

TWh



Sources: ADEME, IGN and INRAE, IPCC & France Agrimer

USE OF TOTAL BIOMASS POTENTIAL 2050



Mobilized in ENGIE's optimized scenario

Estimated potential including the effects of climate change

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ENERGY INFRASTRUCTURE: AN ESSENTIAL LEVER FOR SUCCESSFUL DECARBONIZATION

ELECTRICITY
Investments significantly increase until 2040

Cross-border interconnections
+€2 bn/year

Transport and distribution associated with increasing electrification
+€21 bn/year

Charging infrastructure for transport
+€16 bn/year

METHANE & HYDROGEN
Rely on existing infrastructure

Adaptation of part of the network to hydrogen and construction of new corridors
€2 bn to €8 bn/year

Modernisation of the network to incorporate low-carbon gases
+€1.5 bn/year

The electricity infrastructure allows the deployment of renewable energies
The gas infrastructure plays a crucial role in meeting demand peaks and making the energy system more flexible

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A BALANCED ENERGY MIX HAS MULTIPLE BENEFITS

NET ZERO ACHIEVED

Alignment with European targets

No technological gamble

Balance between contributions from the various sectors

OPTIMIZED COST

Use of a wider range of competitive decarbonization options

Better use of existing infrastructure / facilities

Optimization at the European and global level through carefully considered imports

INCREASED RESILIENCE

Diversified mix providing insurance against industrial risks

Optimization of flexibility solutions

Enhanced reliability of the energy system

SOME CONCRETE BARRIERS MUST BE ADDRESSED

ACCELERATION OF RENEWABLE POWER AND GAS

- Stabilize the **investment framework**
- Facilitate and speed up network **connections** and **permitting**

DEVELOPMENT OF HYDROGEN
by taking action throughout the value chain

- Finalize the **European regulatory framework**
- Ensure that **appropriate public funding** is granted quickly and that H_2 **conversion** of gas infrastructure is financed

MAXIMIZING BIOMETHANE POTENTIAL
by activating all levers

- Ensure effective **production support mechanisms** (prices and inputs) in France and in Europe

DEVELOPMENT OF FLEXIBILITY TECHNOLOGIES

- Develop **suitable remuneration models** (load management, batteries, decarbonized CCGT, etc.)
- Speed up **permitting**

DECARBONIZATION OF THE BUILDINGS SECTOR
by supporting all solutions

- Accelerate development of **green heating networks**, including geothermal energy
- **Prioritize the use of biomethane** for buildings **and hybrid solutions** (heat pump, hybrid heat pump, boiler replacement, etc.)
- Simplify access to **housing aid** with a one-stop shop grouping current mechanisms

DECARBONIZATION OF INDUSTRY

- **Step up the use of waste energy (**guarantee fund and threshold reduction)
- Maintain **funding** over time (BCIAT fund in France)
- Maintain **local biomass** as an RE

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