Natural gas markets

Lecture ULiège

Ghislain Detienne (ghislain.detienne@fluxys.com)
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Contents

Who is Fluxys?

4 facts about Fluxys

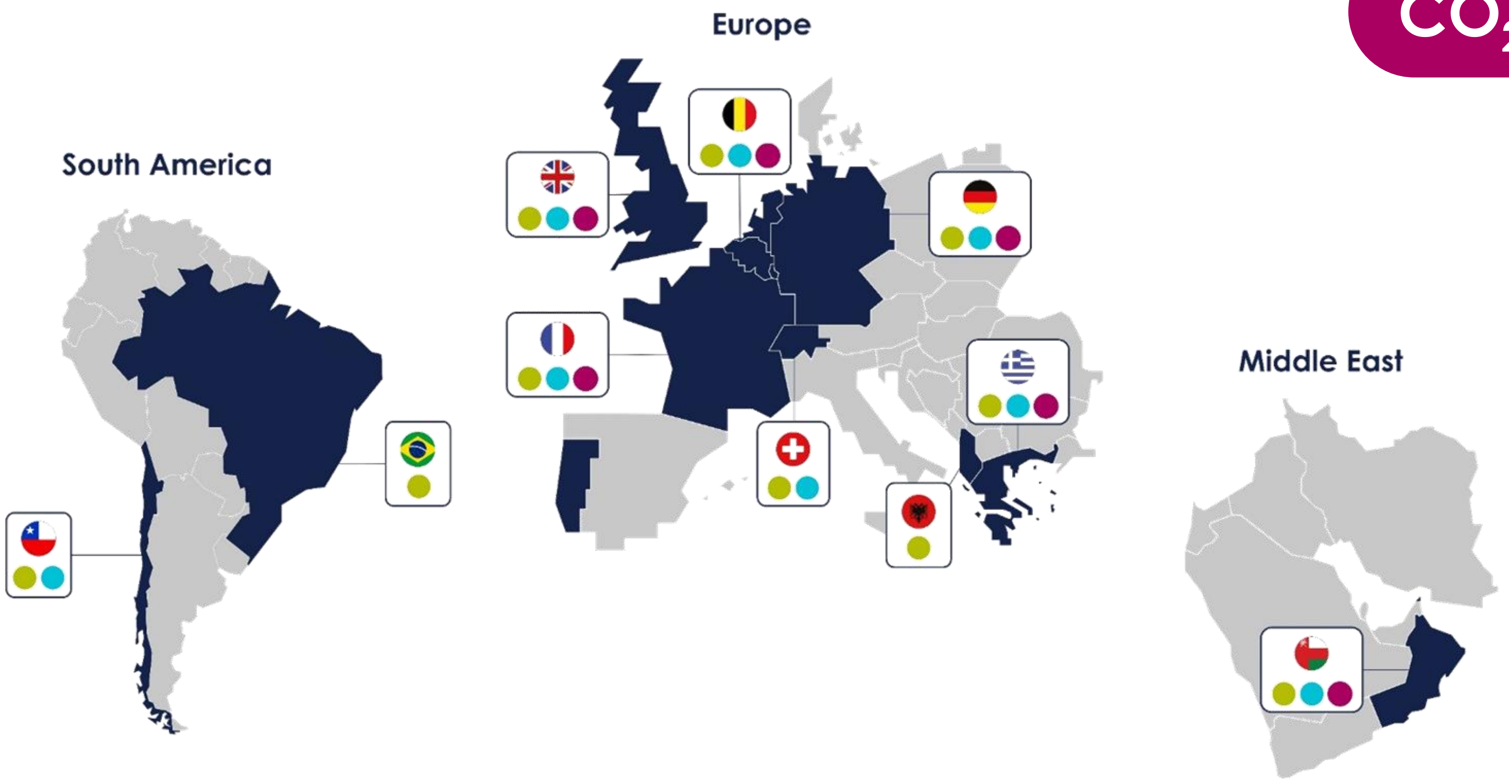
CH_4

H_2

CO_2

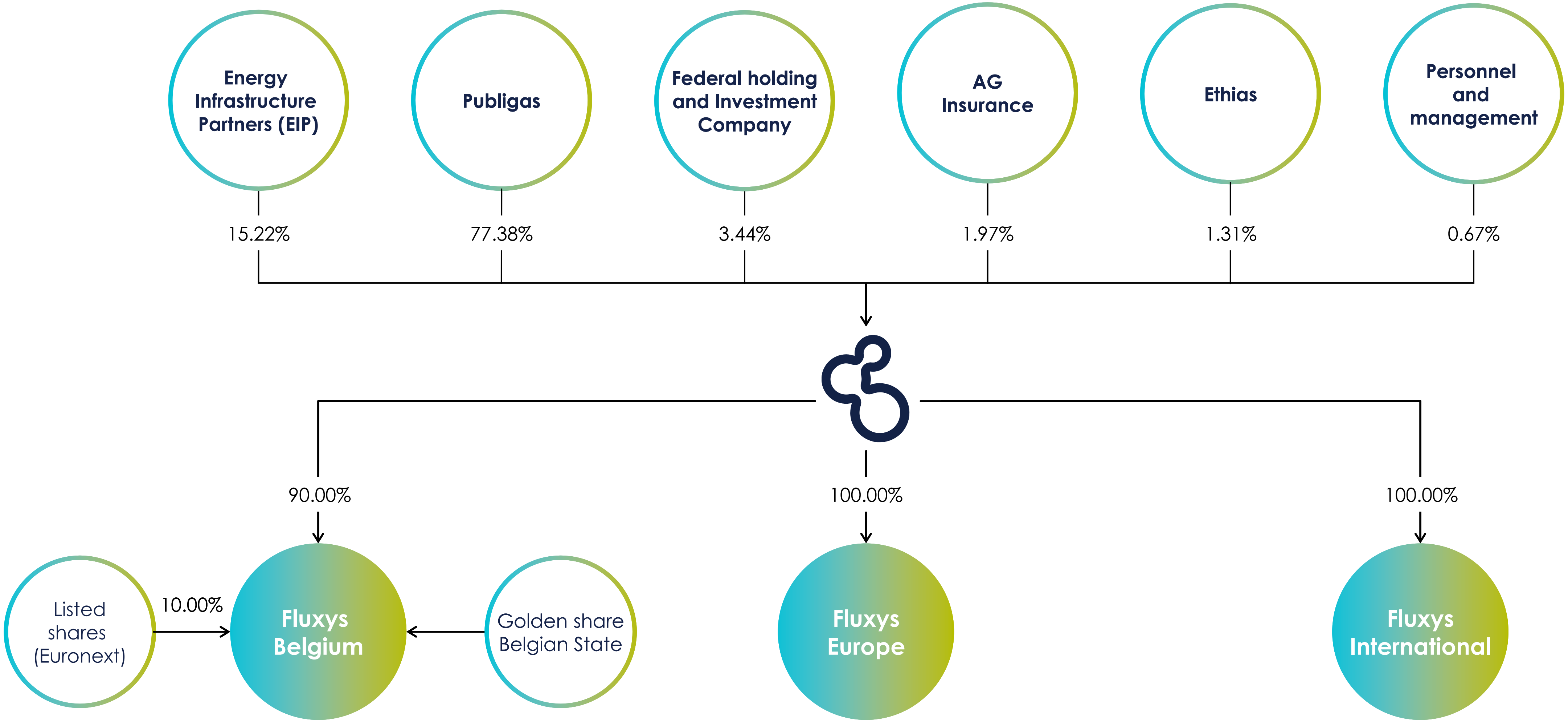
1. Multi-molecule infrastructure partner headquartered in Belgium
2. Strong European presence with associated companies across Europe, South America and the Middle East
3. A growing group of 1300 employees sharing respect, reliability and open-mindedness
4. Purpose-driven company committed to the energy transition with a dedicated sustainability vision

shaping together a bright energy future



Who is Fluxys?

Shareholding & group structure



Who is Fluxys?

We are a multi-molecule infrastructure company with 3 core activities

CH_4

H_2

CO_2

Terminalling

Transmission

Storage

Overview Fluxys infrastructure

International presence

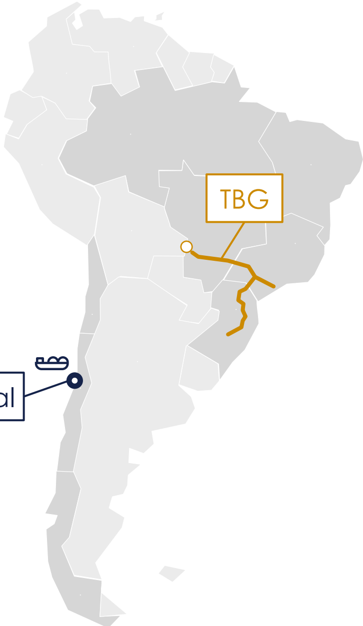
CH$_4$

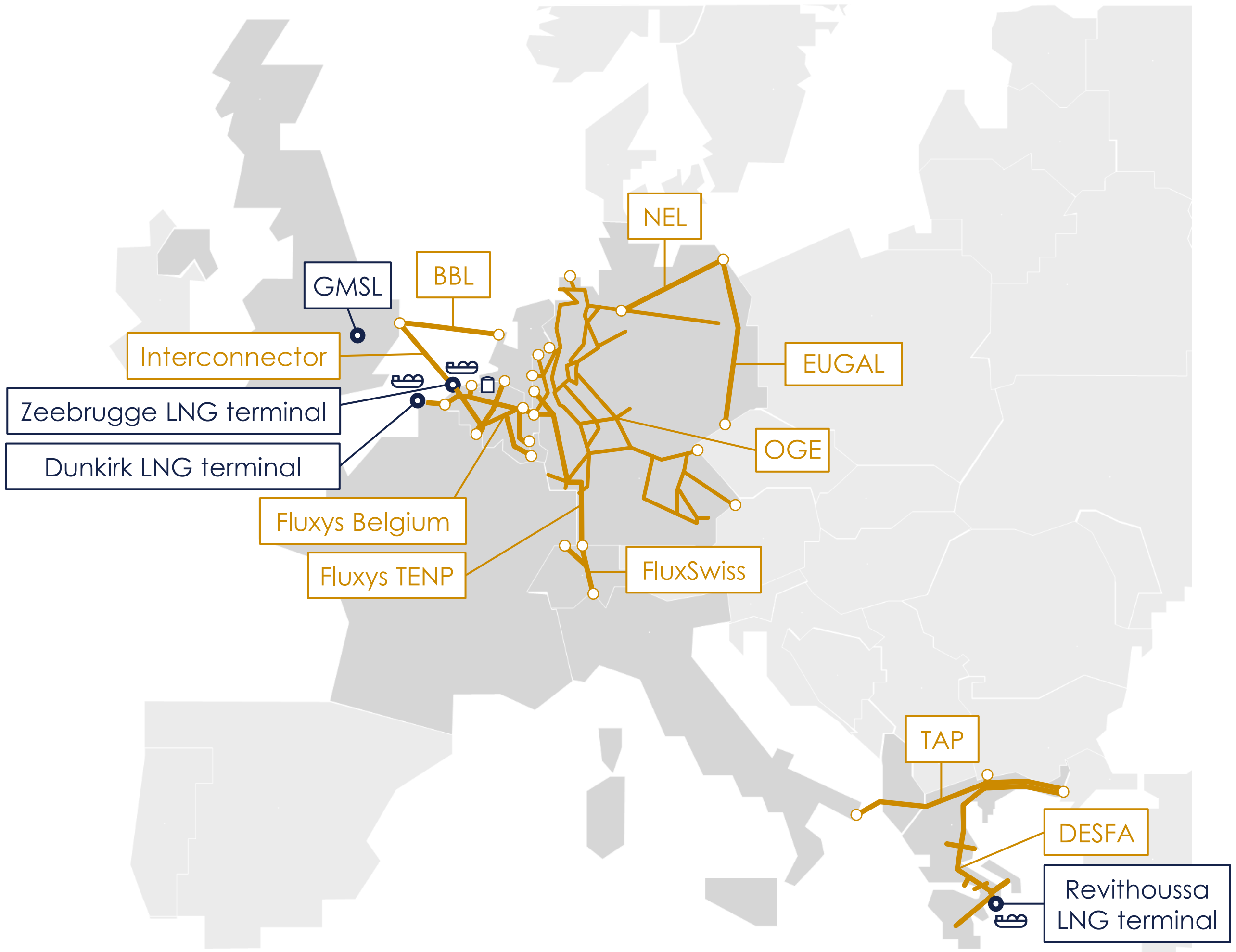
our activities

Transmission
28 000 km
pipelines in operation

LNG terminalling
450 TWh/y regasification
capacity in Belgium, France,
Greece & Chile

Storage
7610 GWh
underground gas storage
capacity in Belgium





https://www.fluxys.com/en/company/fluxys-group/about-fluxys

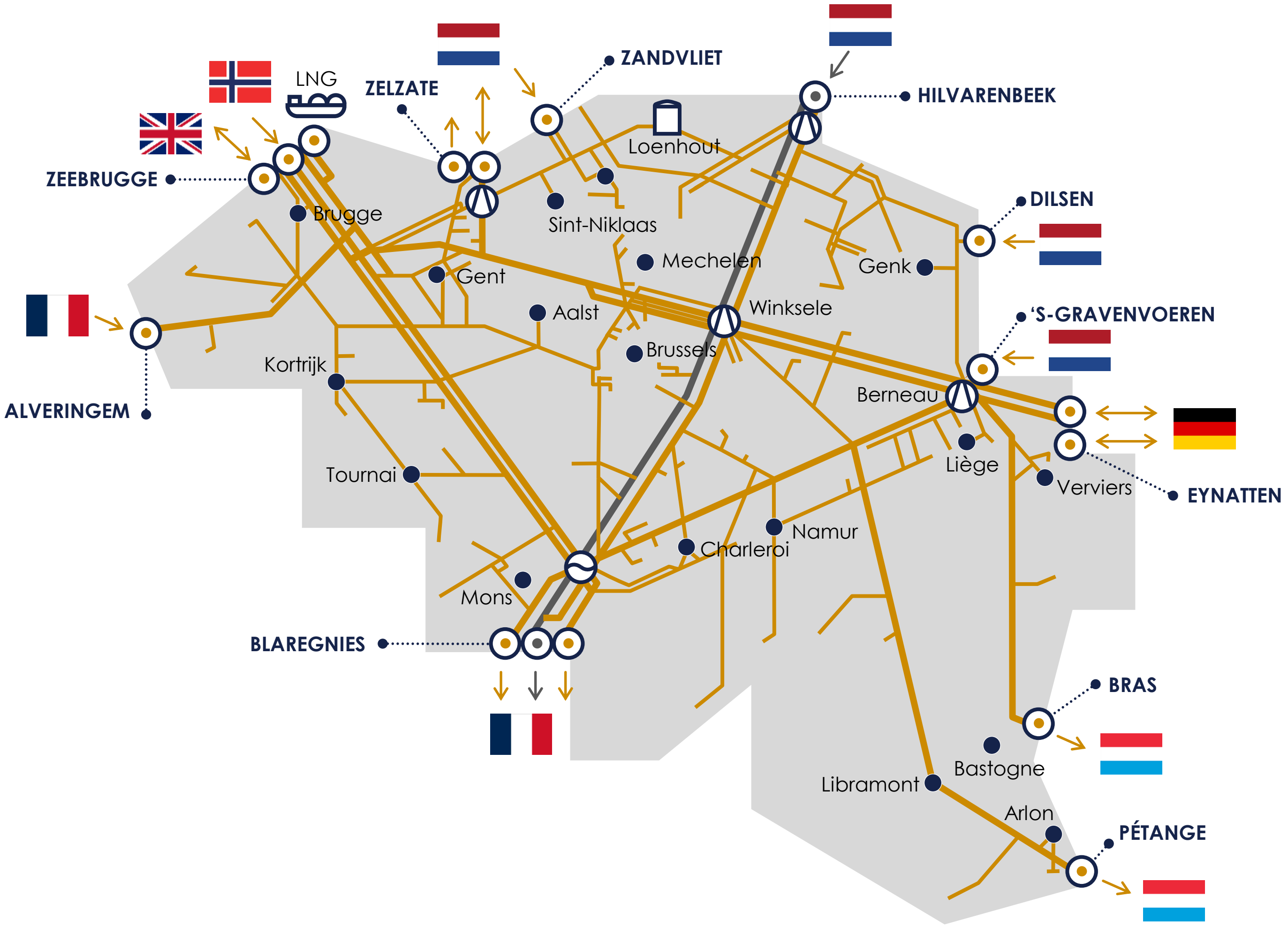
Overview Fluxys infrastructure

High pressure (15-80 bars) transmission infrastructure in Belgium

CH$_4$

4,000 km pipelines in 417 municipalities

- High calorific gas (11,3 kWh/m³(n))
- Low calorific gas (9,8 kWh/m³(n))
- Physical interconnection points
- LNG terminal
- Compressor stations
- Blending stations
- Storage



Overview Fluxys infrastructure

Fluxys role on the Belgian market

CH$_4$

Total imports pipe & LNG
~1250 TWh/y entry capacity

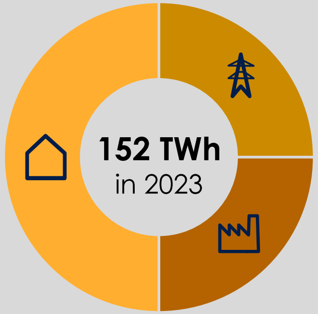
510 TWh
in 2023

→

Fluxys grid
4,000 km
High pressure

→

Transmission for supply in Belgium



19 power stations

193 Large industrial end-users
19 Combined Heat & Power Units

Grids of Distribution System Operators
75 000 km Low pressure

450 000 SMEs

3.1 million households

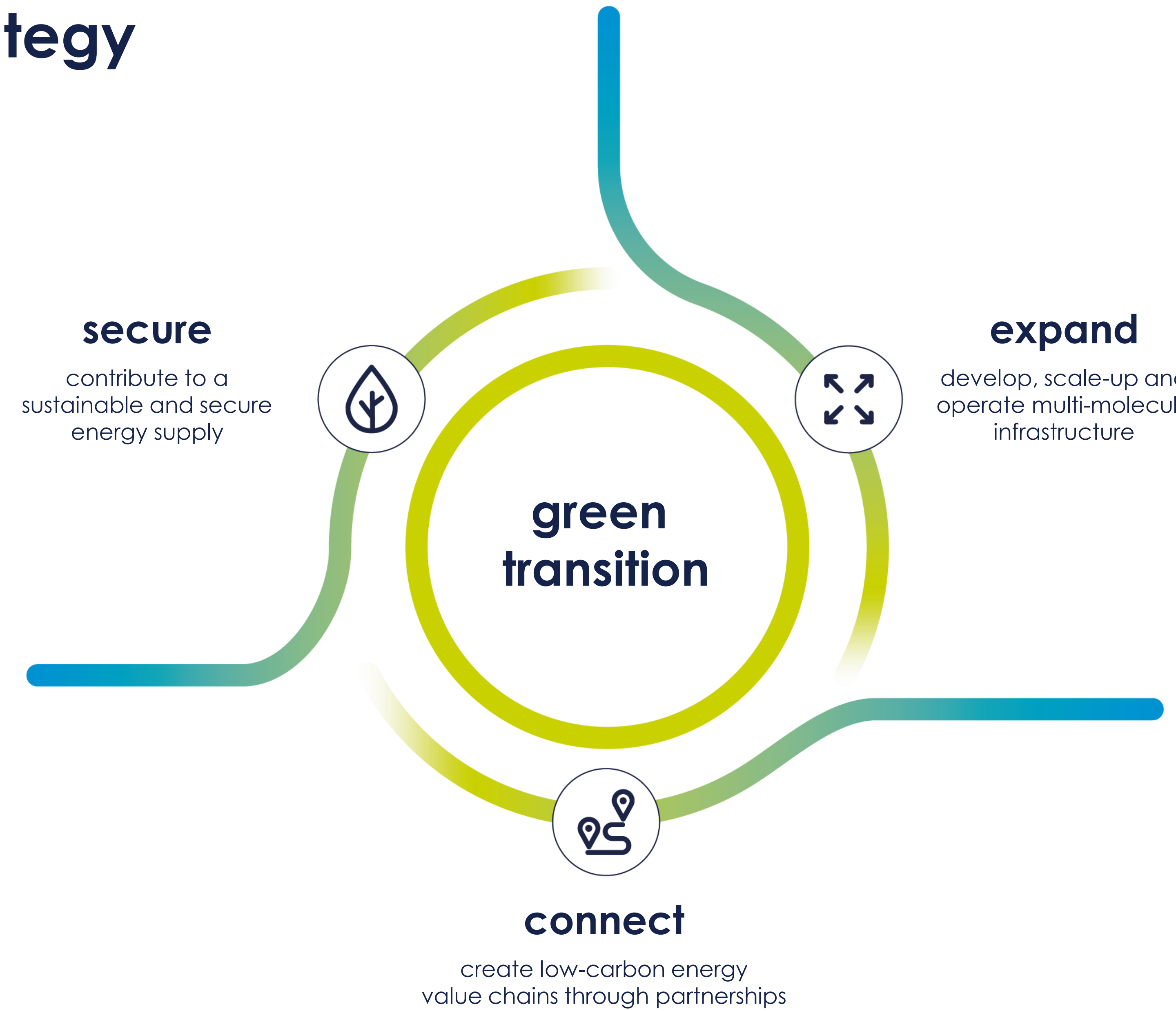
↓

Total transit to surrounding countries
~850 TWh/y exit capacity

357 TWh
in 2023

Fluxys strategy

CH_4
H_2
CO_2



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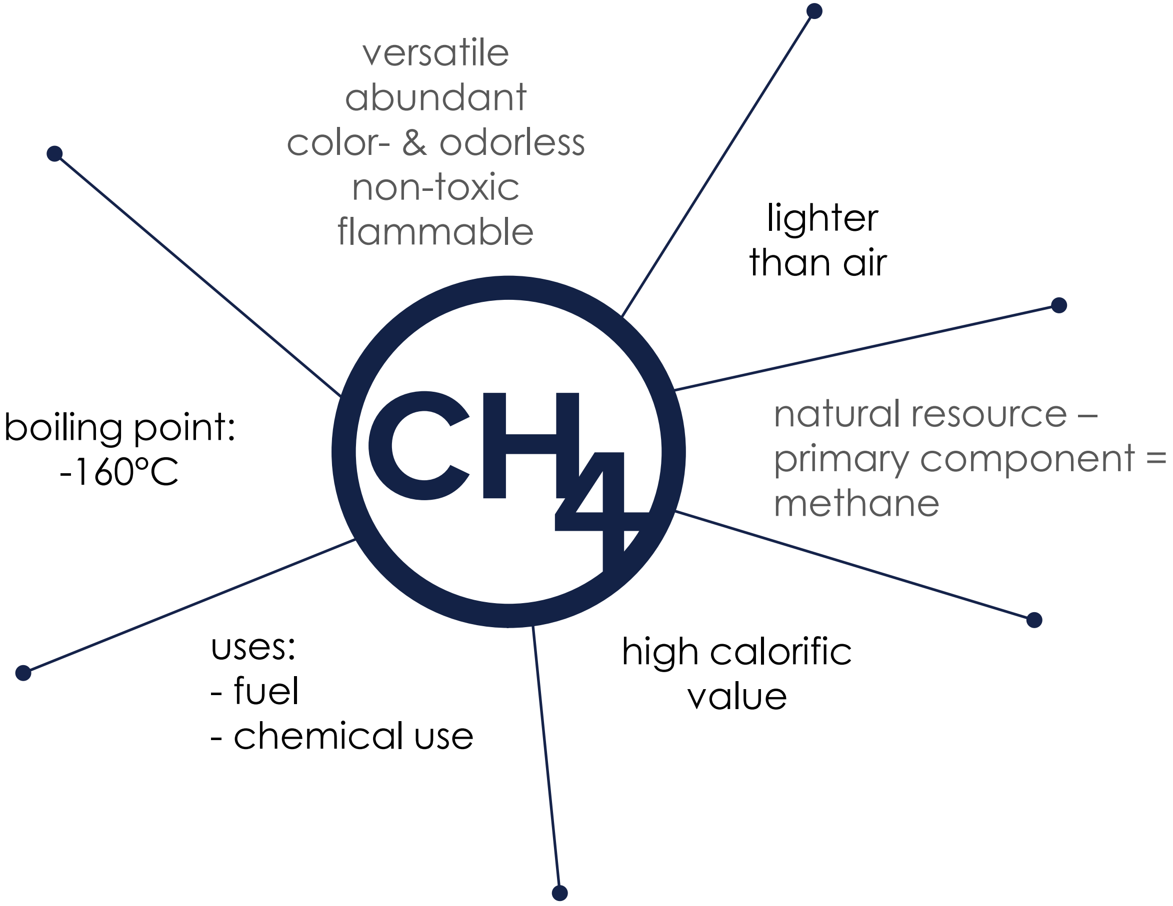
What is CH_4 or natural gas ?



Average volumetric composition

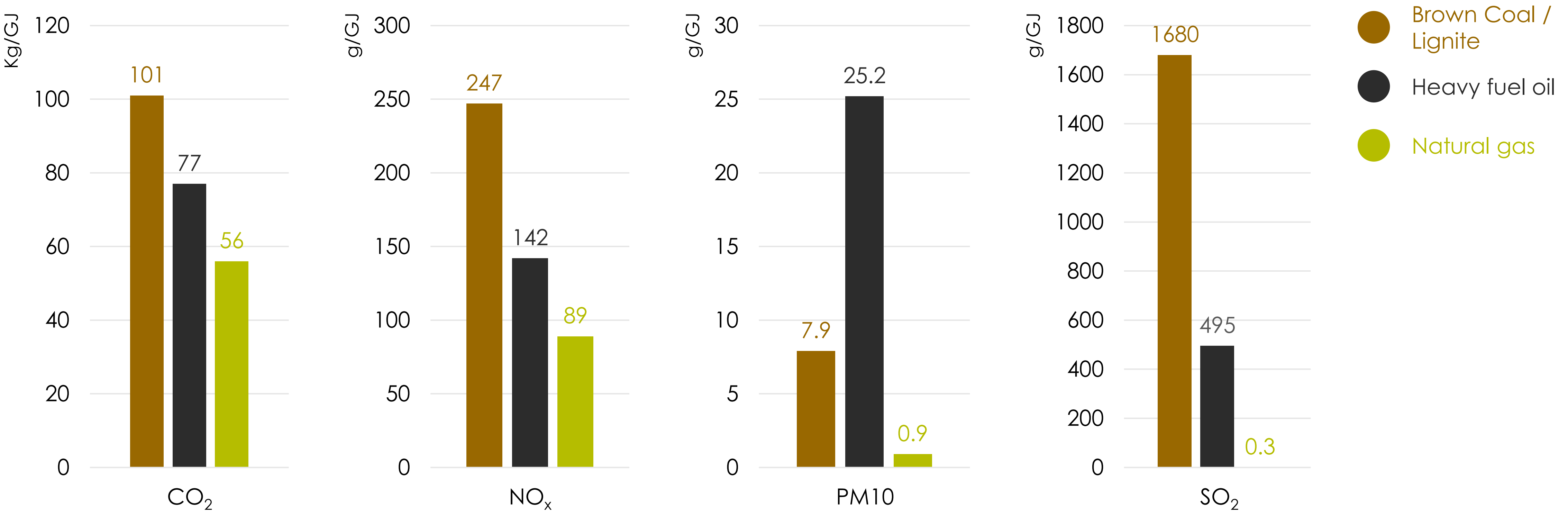
CH_4

Source: Fluxys metering 2017

GAS COMPONENTS	GRONINGEN (NL) %	EYNATTEN 1 (DE) %	LNG %	IZTF (UK) %	ZEEPIPE (NORWAY) %
Methane (CH4)	83,903	96,263	93,100	90,642	90,748
Ethane (C2H6)	3,718	2,694	6,244	4,787	4,739
Propane (C3H8)	0,646	0,138	0,139	1,111	1,123
Butane (C4H10) (ISO and NORM)	0,228	0,068	0,026	0,338	0,425
Pentane (C5H12) (ISO and NORM)	0,056	0,008	-	0,075	0,425
Hexane and superior HC (C6+)	0,057	0,005	-	0,046	0,092
C. Dioxyde (CO2)	1,375	0,409	-	1,230	1,714
Nitrogen (N2)	9,981	0,403	0,491	1,735	1,071
Helium (He)	0,035	0,012	-	0,035	0,013
GAS CARACTERISTICS	GRONINGEN (NL) kWh/m³(n)	EYNATTEN 1 kWh/m³(n)	LNG kWh/m³(n)	IZTF (UK) kWh/m³(n)	ZEEPIPE (NORWAY) kWh/m³(n)
GCV	10,321	11,243	11,563	11,447	11,508
WOBBE	12,905	14,811	15,064	14,589	14,617

Natural gas

Fossil fuel of choice from an environmental point of view



Source:
European Environment Agency - EMEP/EEA air pollutant emission inventory guidebook 2016
Public electricity and heat production - dry bottom boiler

Specific advantages for power generation

Gas-fired power generation ideal for replacing coal-fired power generation and back-up of choice for power generation from renewables with variable output

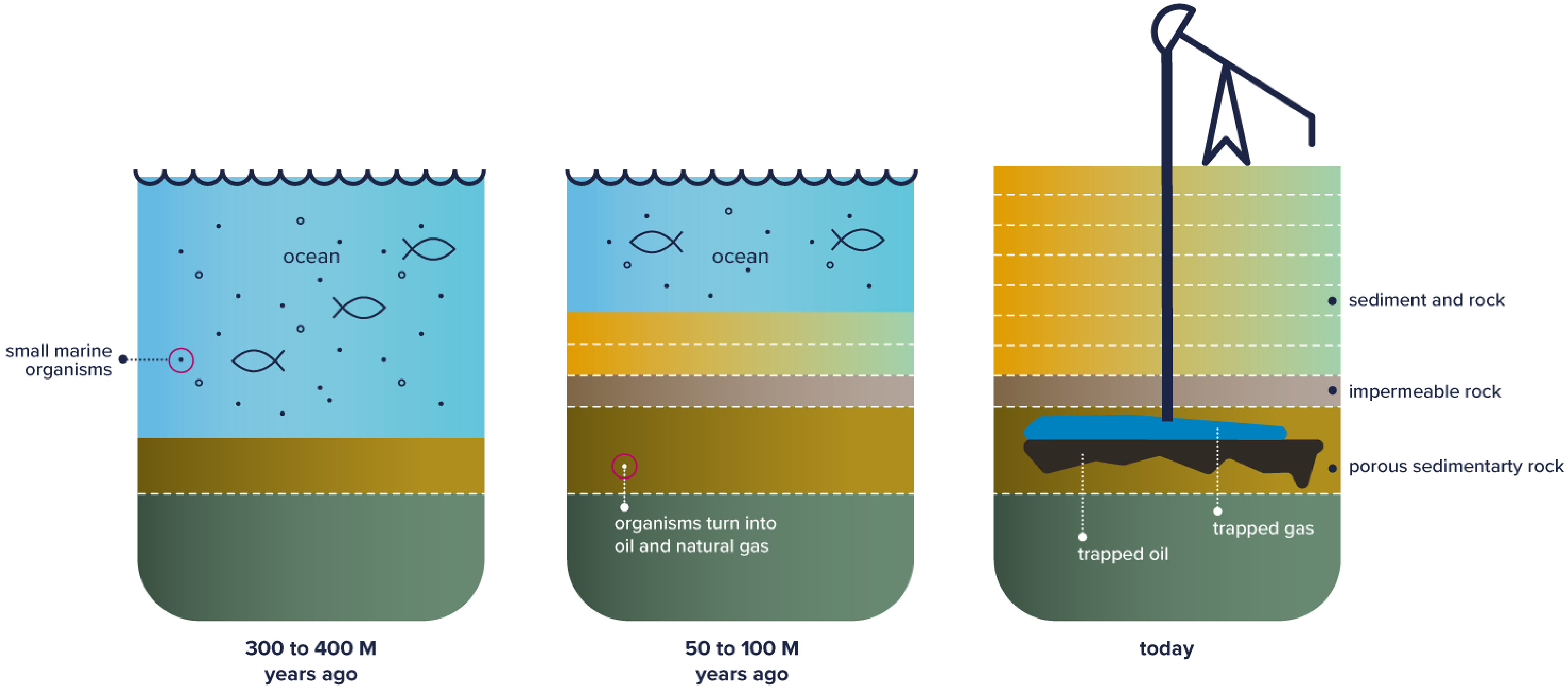
2.5 MWh of thermal energy → **Coal** (Efficiency 34-35%) → **1 MWh** of electricity; 0.9 tons CO_2

2 MWh of thermal energy → **Natural Gas** (Efficiency 48-58%) → **1 MWh** of electricity; 0.4 tons CO_2

Information only - non binding

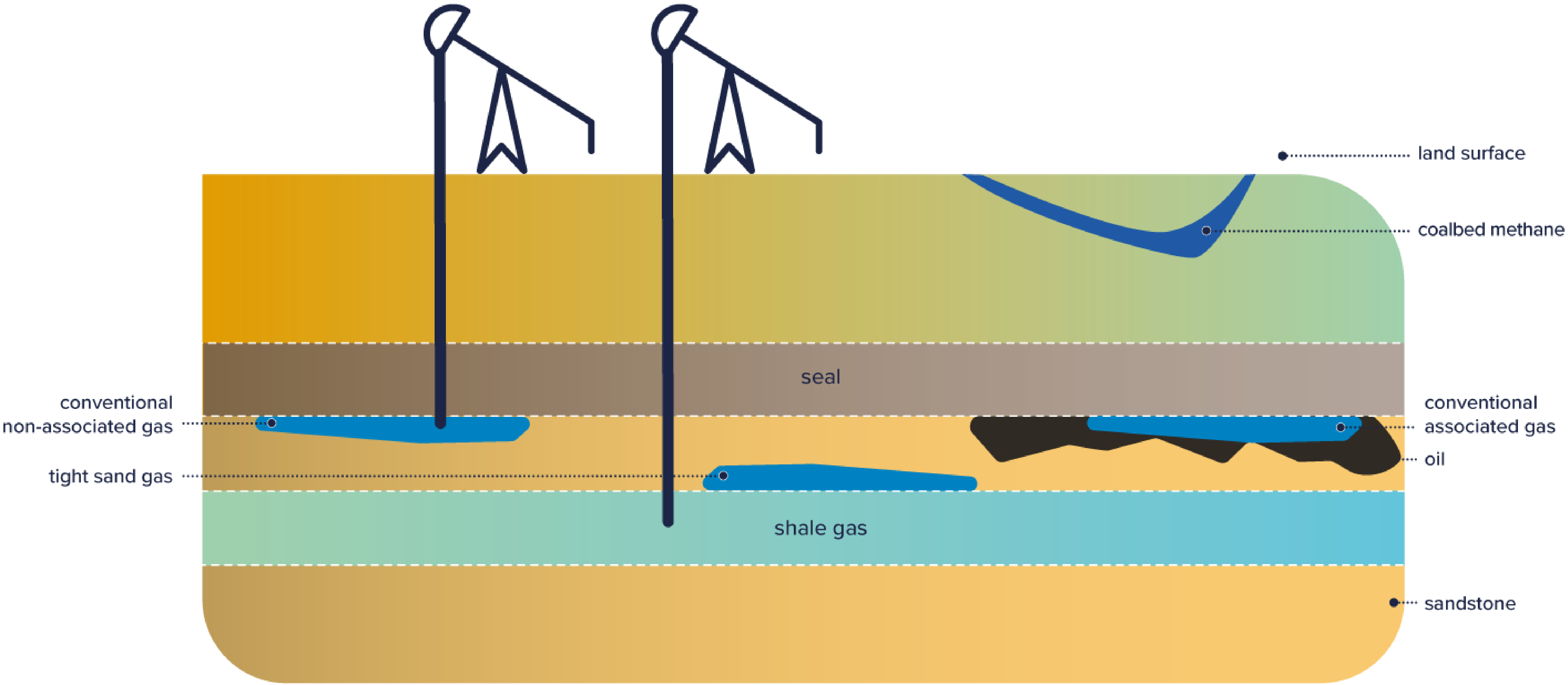
CH_4

Formation of oil and natural gas



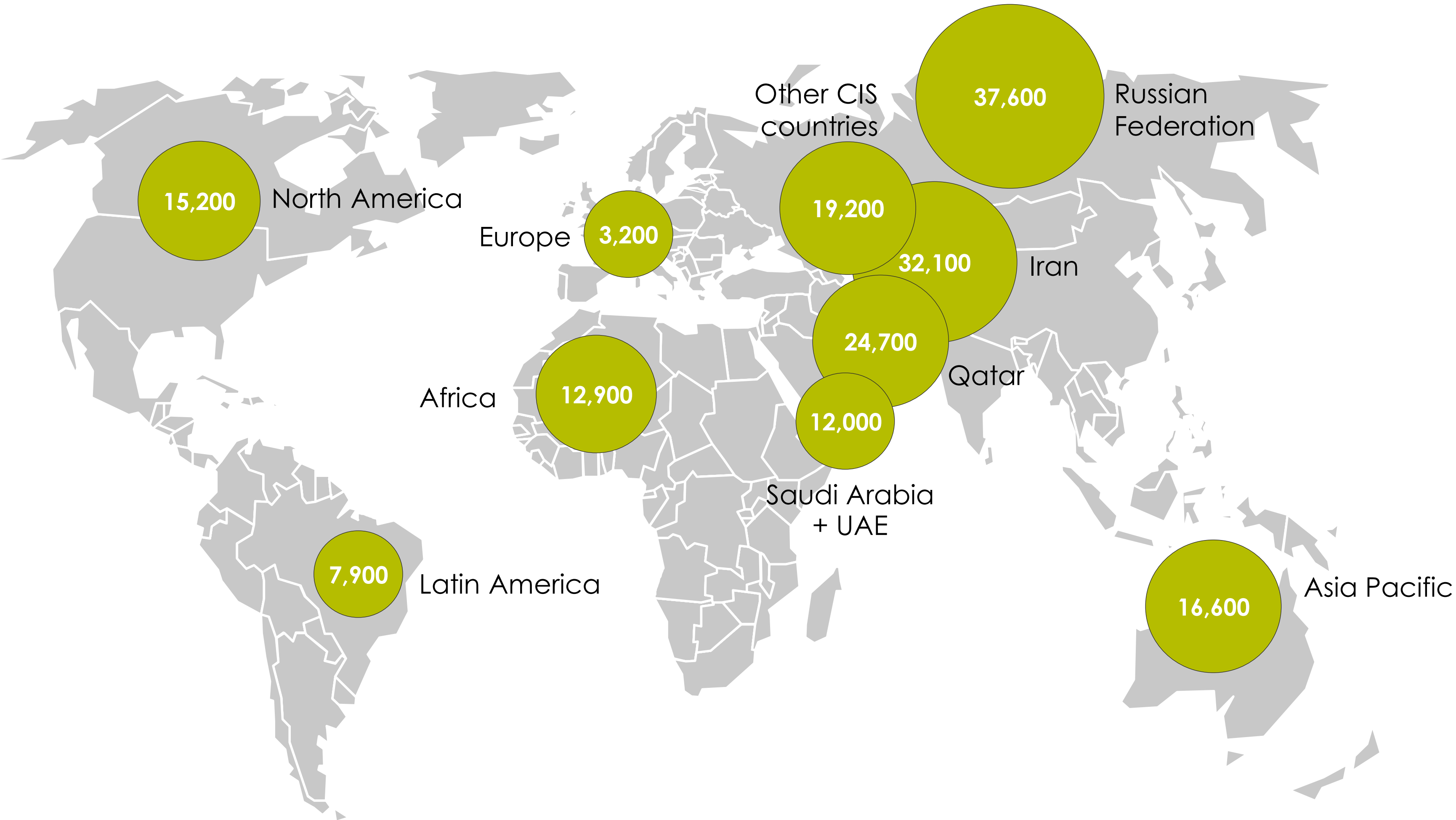
Oil and natural gas sources

CH$_4$



Conventional natural gas is abundantly available

Proven (= economically) conventional natural gas reserves (bcm)

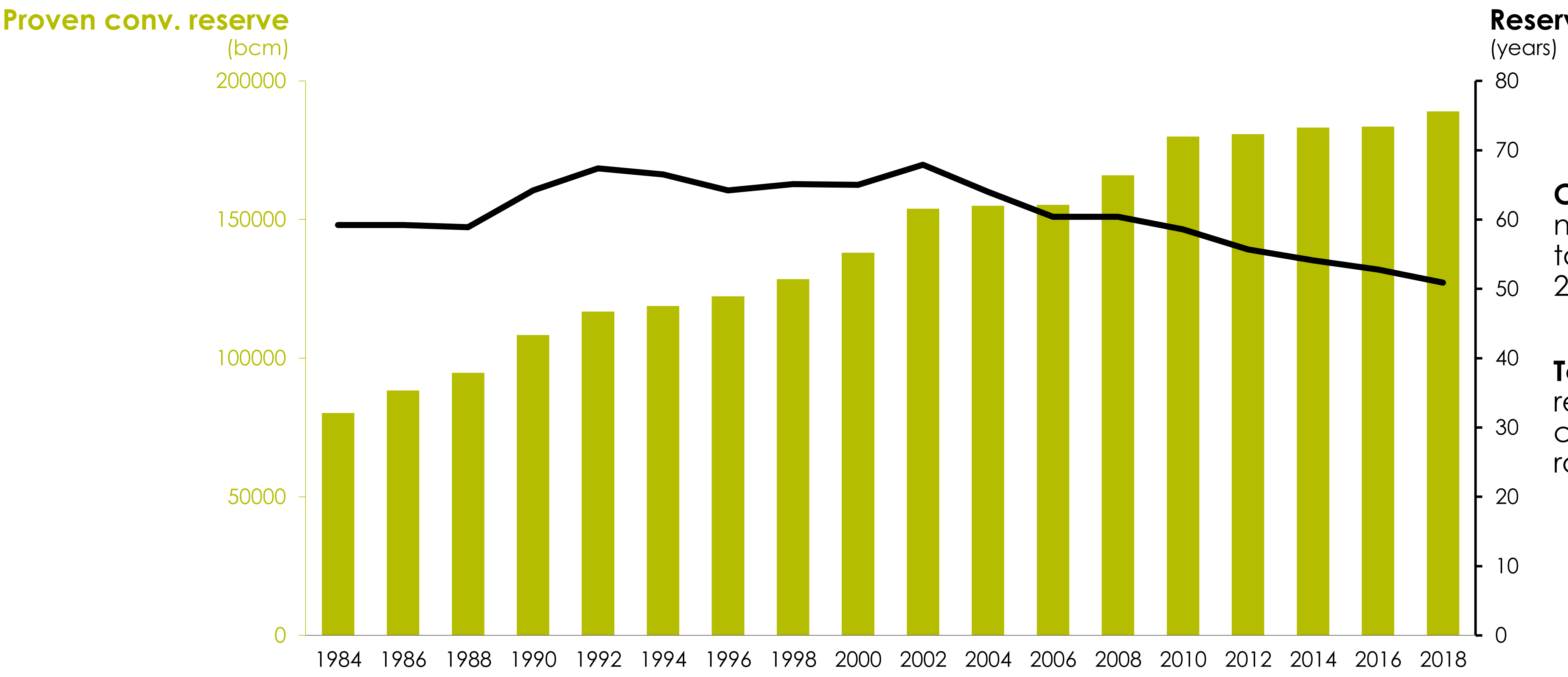


Source: BP Statistical Review of World Energy Full Report 2022

Conv. CH_4

Conventional natural gas is abundantly available

Proven (= economically) conventional natural gas reserves (bcm)



Conventional natural gas reserves to outlast oil by 20 years

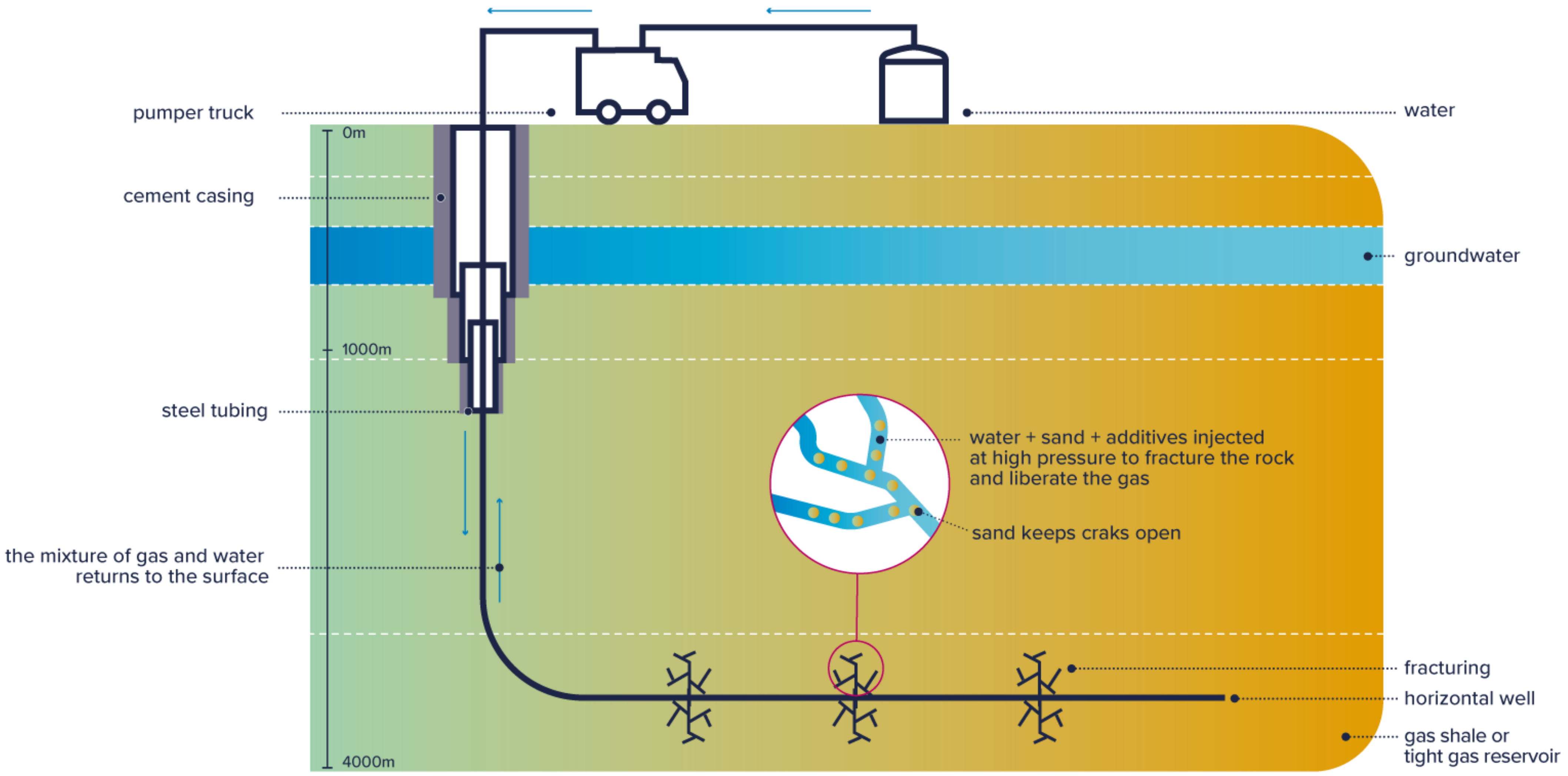
Total: sufficient reserves to keep up current production rate for 50 years

Source: BP Statistical Review of World Energy Full Report 2022

Shale CH$_4$

Important source of unconventional gas: shale gas

Hydraulic fracturing

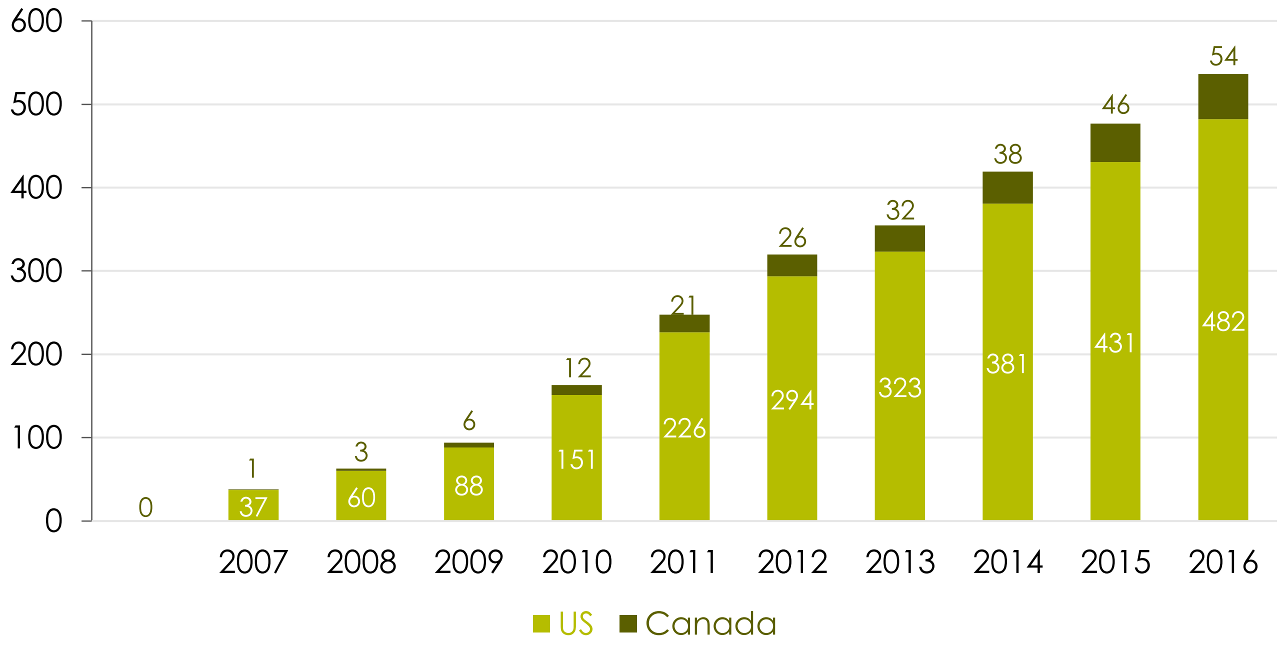


Important source of unconventional gas: shale gas

Estimated shale gas reserves

- Shale gas: natural gas reserves in harder rock formations until recently considered unexploitable
- Technique developed in the US: shale gas exploitation is economically profitable
- Also potential in India, China and Indonesia
- Europe: initial explorations are being conducted but public resistance will likely prevent any production

Evolution of shale gas production in the US and Canada (bcm)

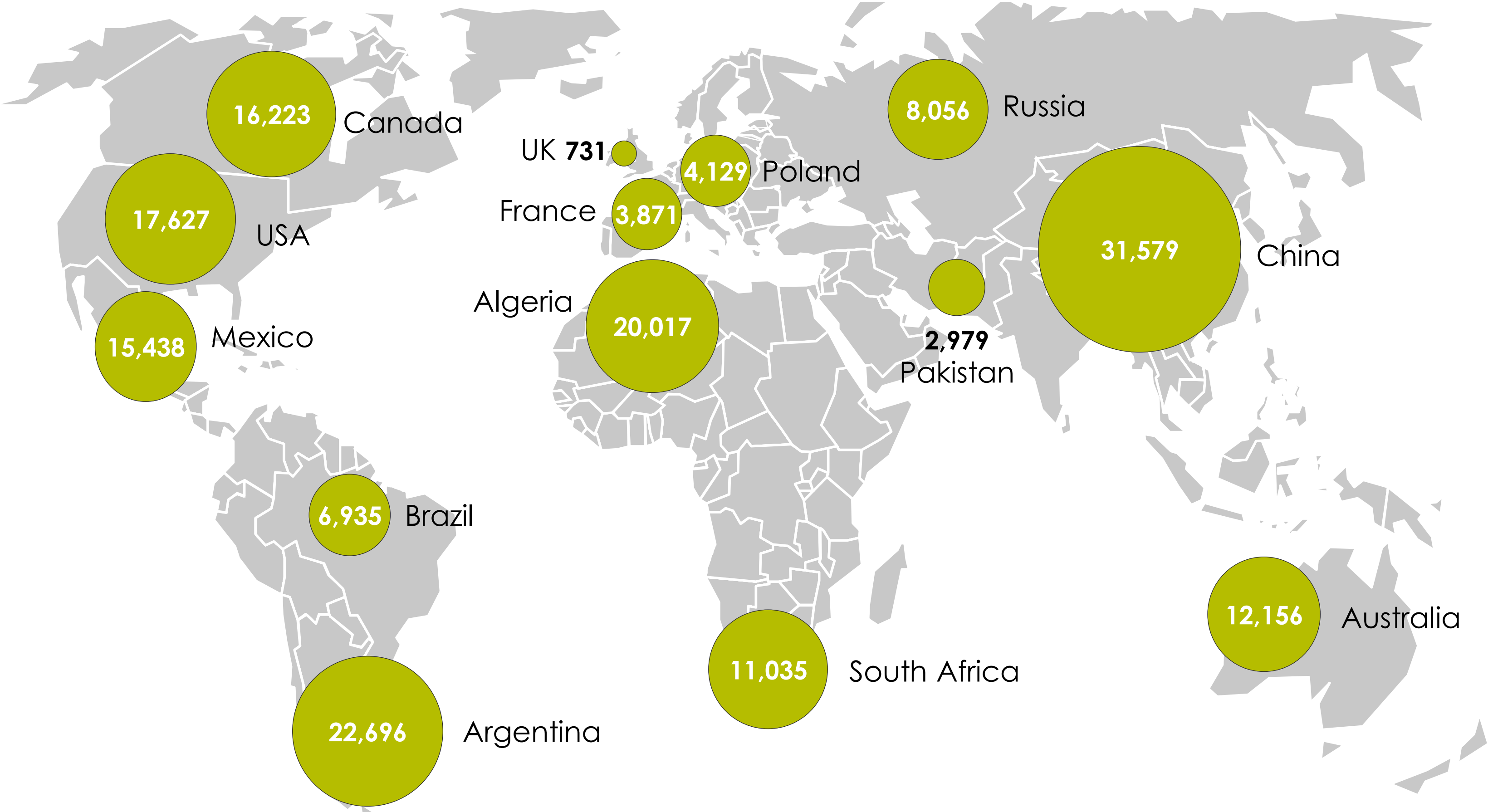


Source : EIA Shale Gas Production, National Energy Board - Natural gas production

Shale CH₄

Important source of unconventional gas: shale gas

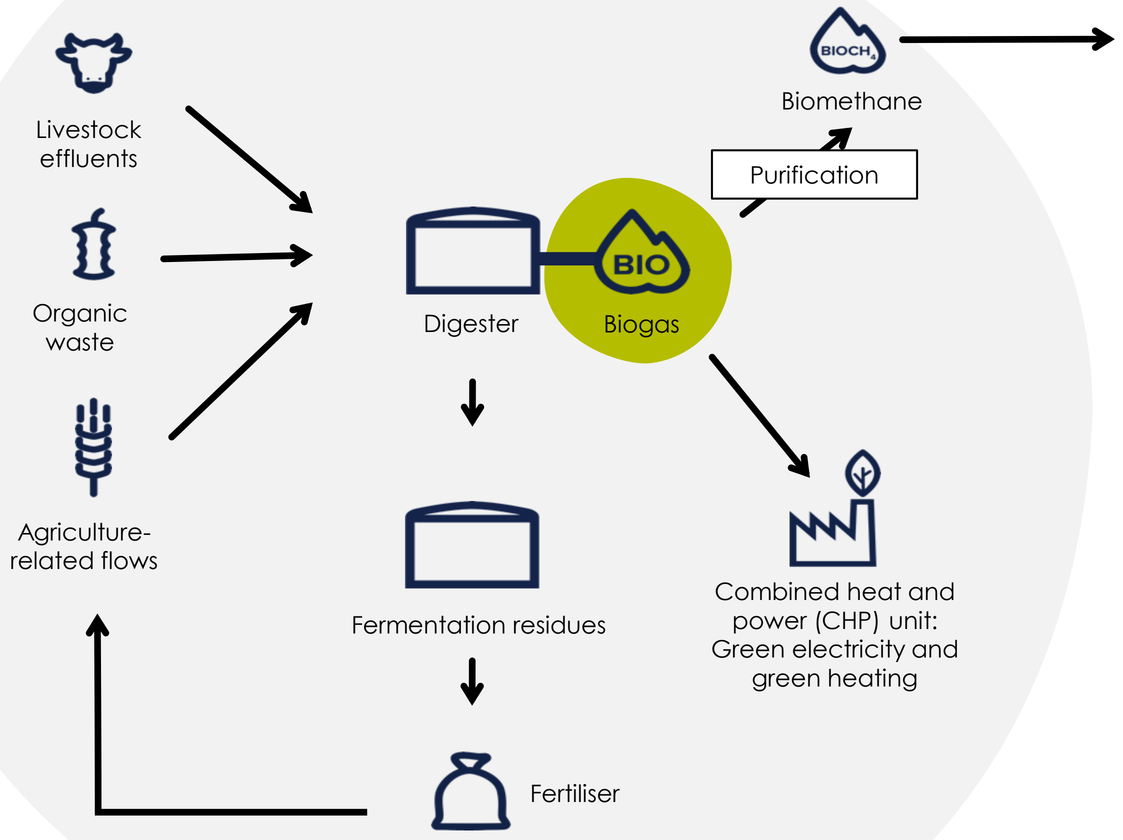
Estimated shale gas reserves (bcm)



Source: EIA – World Shale Resource Assessment (September 2015)

Natural gas can be (very) low-carbon

Biogas and biomethane

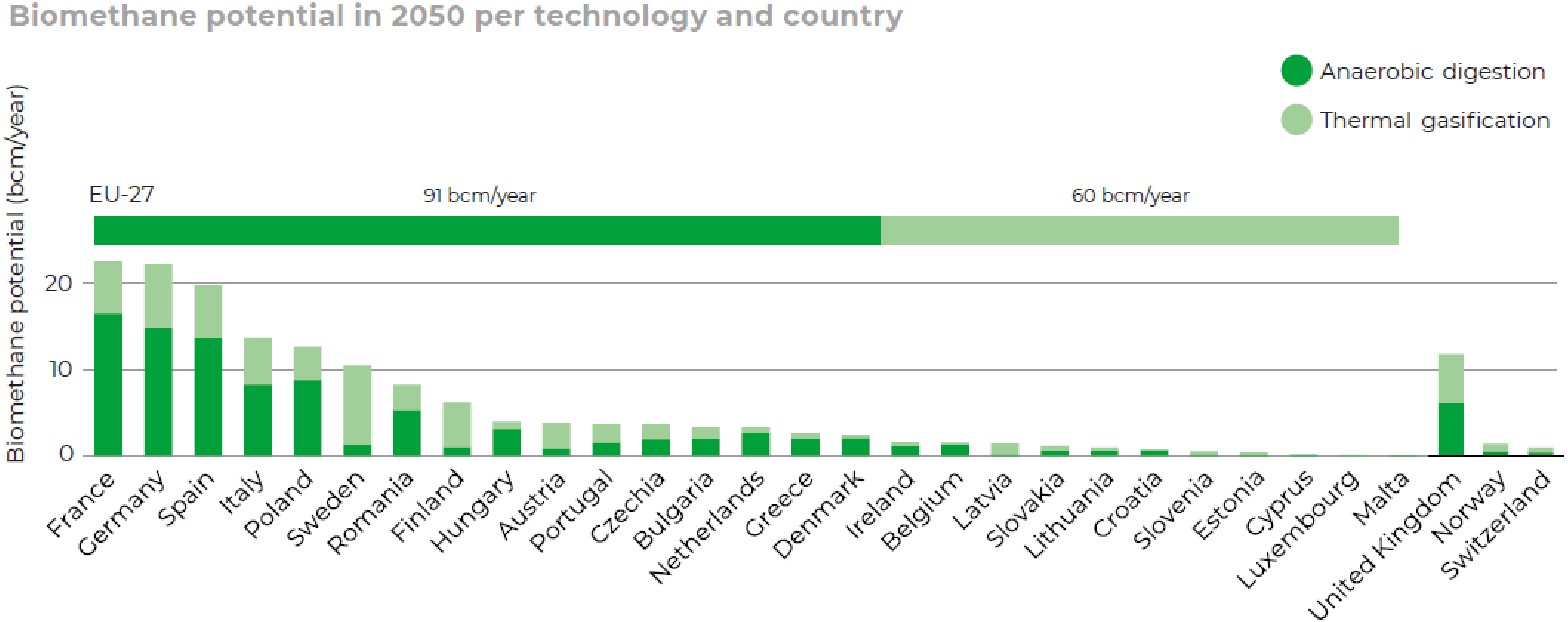


Biomethane composition similar to natural gas: 100% compatible for injecting into the existing system

Natural gas can be (very) low-carbon

Biomethane production potential in Europe

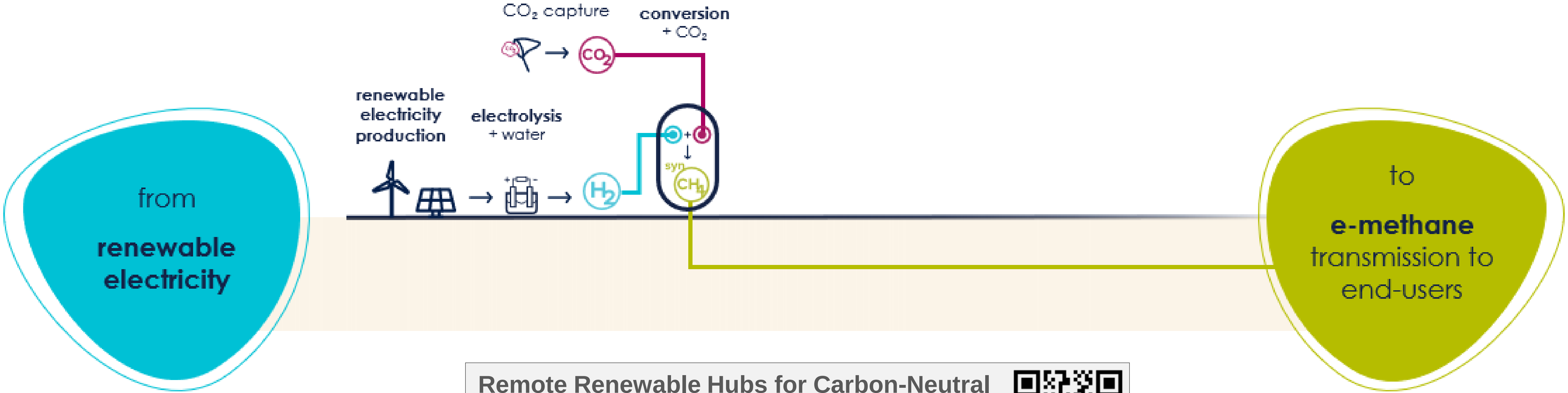
BioCH4 CH4



Source: Gas for Climate study, 2022
(https://www.europeanbiogas.eu/wp-content/uploads/2022/07/GfC_Biomethane-potentials_2022.pdf)

Synthetic methane or e-methane

Carbon-neutral methane can be produced from green hydrogen (produced from renewable electricity) and captured CO_2



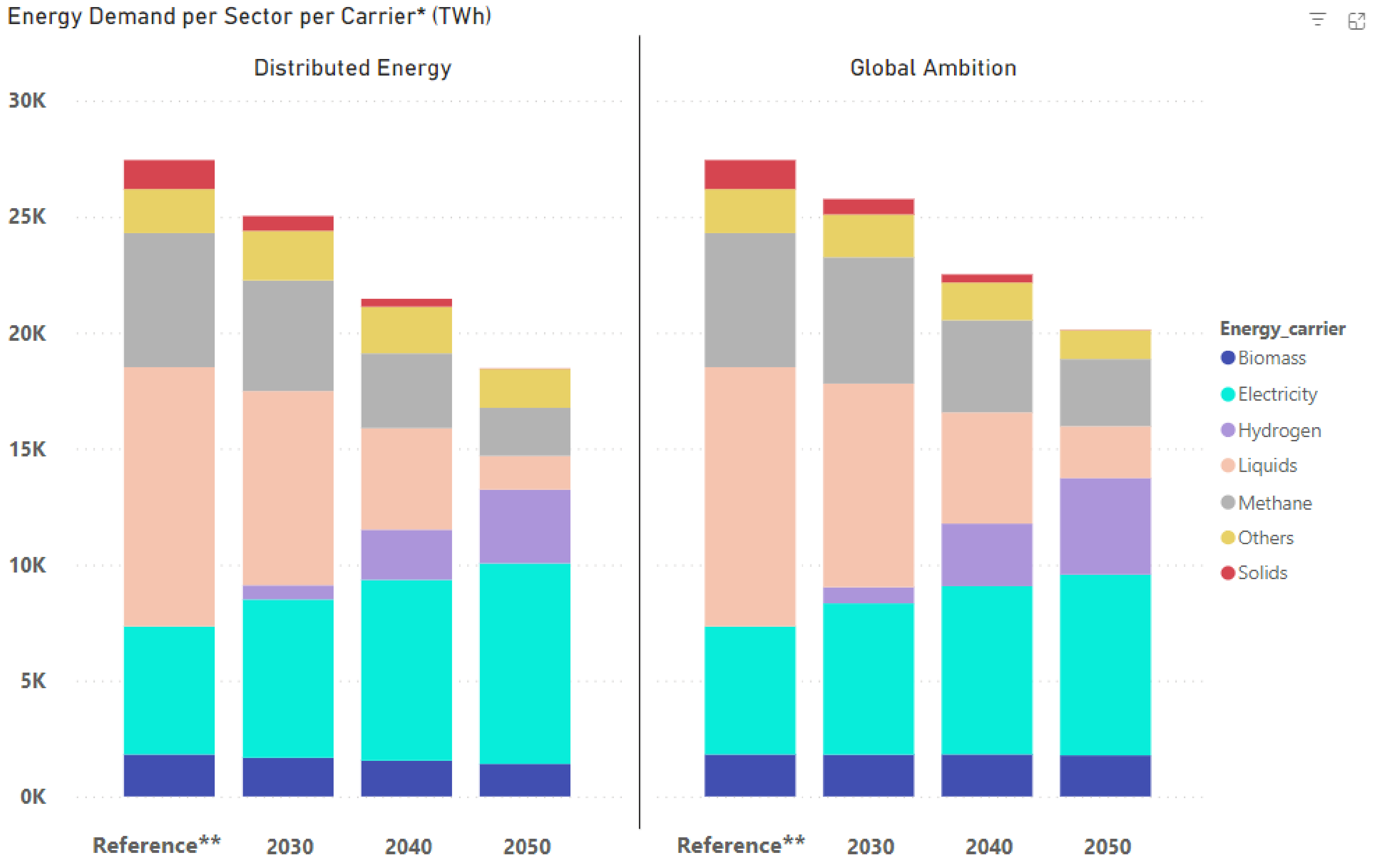
Remote Renewable Hubs for Carbon-Neutral Synthetic Fuel Production

Mathias Berger, David-Constantin Radu, Detienne Ghislain, Thierry Deschuyteneer, Aurore Richel, and Damien Ernst

2021 – in *Frontiers in Energy Research*
https://orbi.uliege.be/handle/2268/250796

Natural gas is part of the total energy demand

Some scenario's for EU27 + UK



Source: ENTSOG & ENTSO-E TYNDP 2022 Scenario Report (https://2022.entsos-tyndp-scenarios.eu/visualisation-platform/#final-demand)

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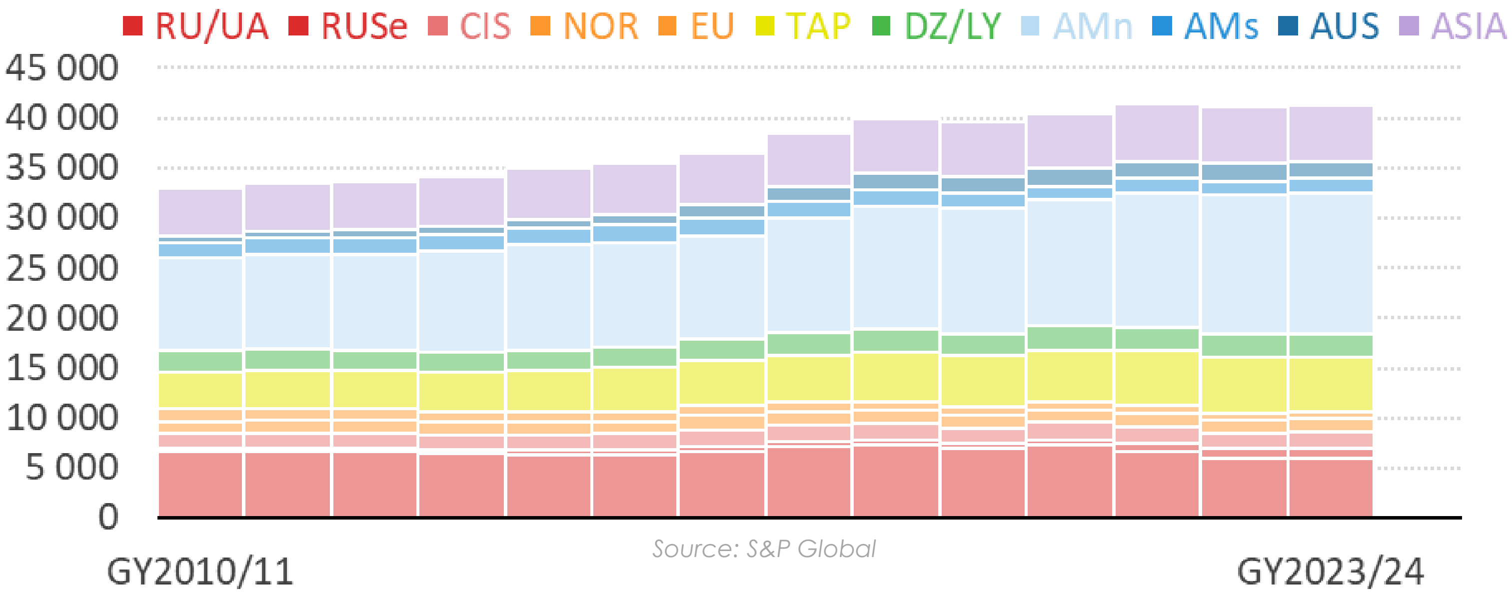
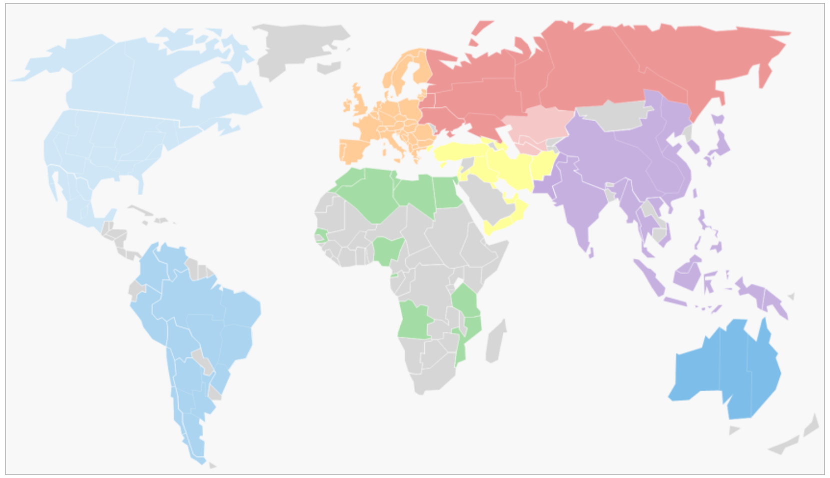
Natural gas (and LNG) is a global business

LNG = liquefied natural gas

World gas production by region [TWh/y]

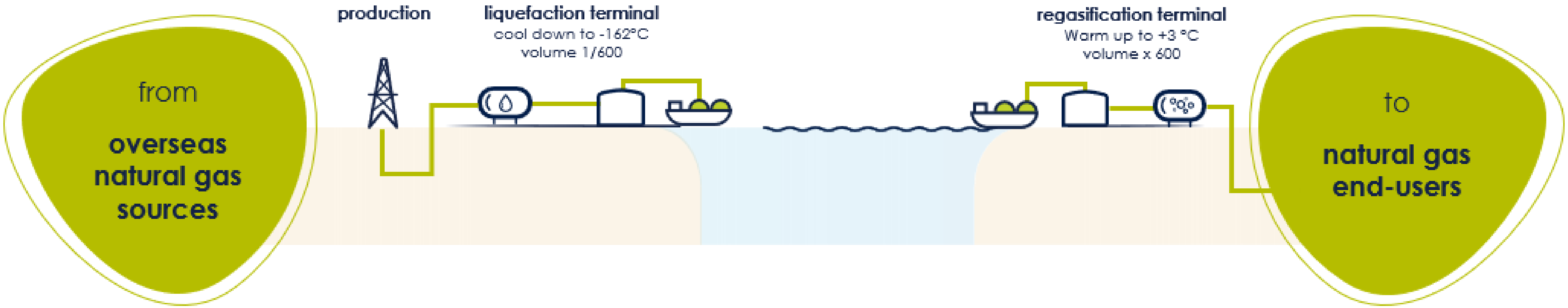


Source: S&P Global



Overseas liquefied natural gas chain (LNG)

LNG = liquefied natural gas

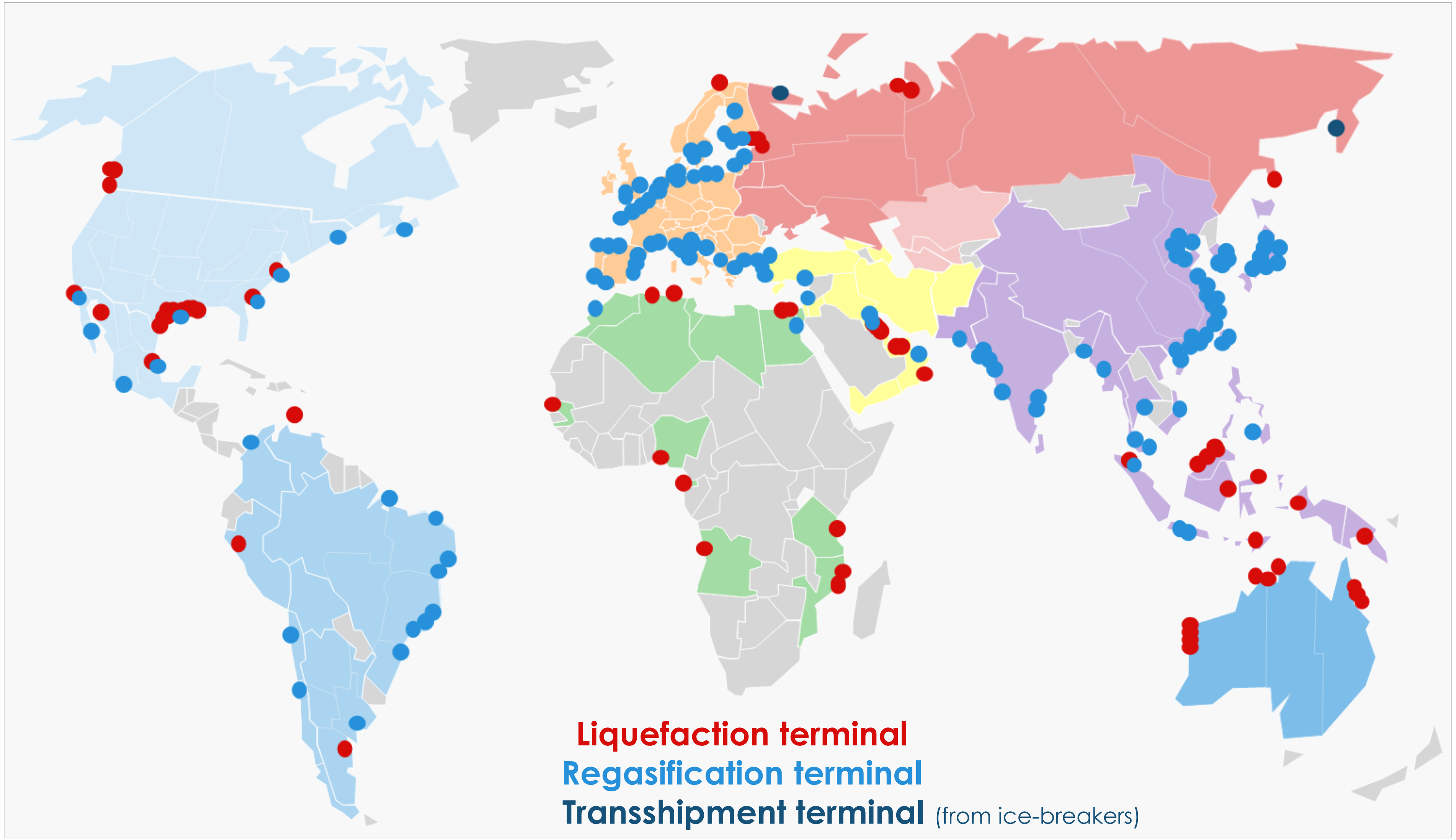


Why LNG?

- LNG offers competitive advantage over pipe gas for transmission over longer distances
- Easy diversification of sources
- Easy flexibility in destination markets

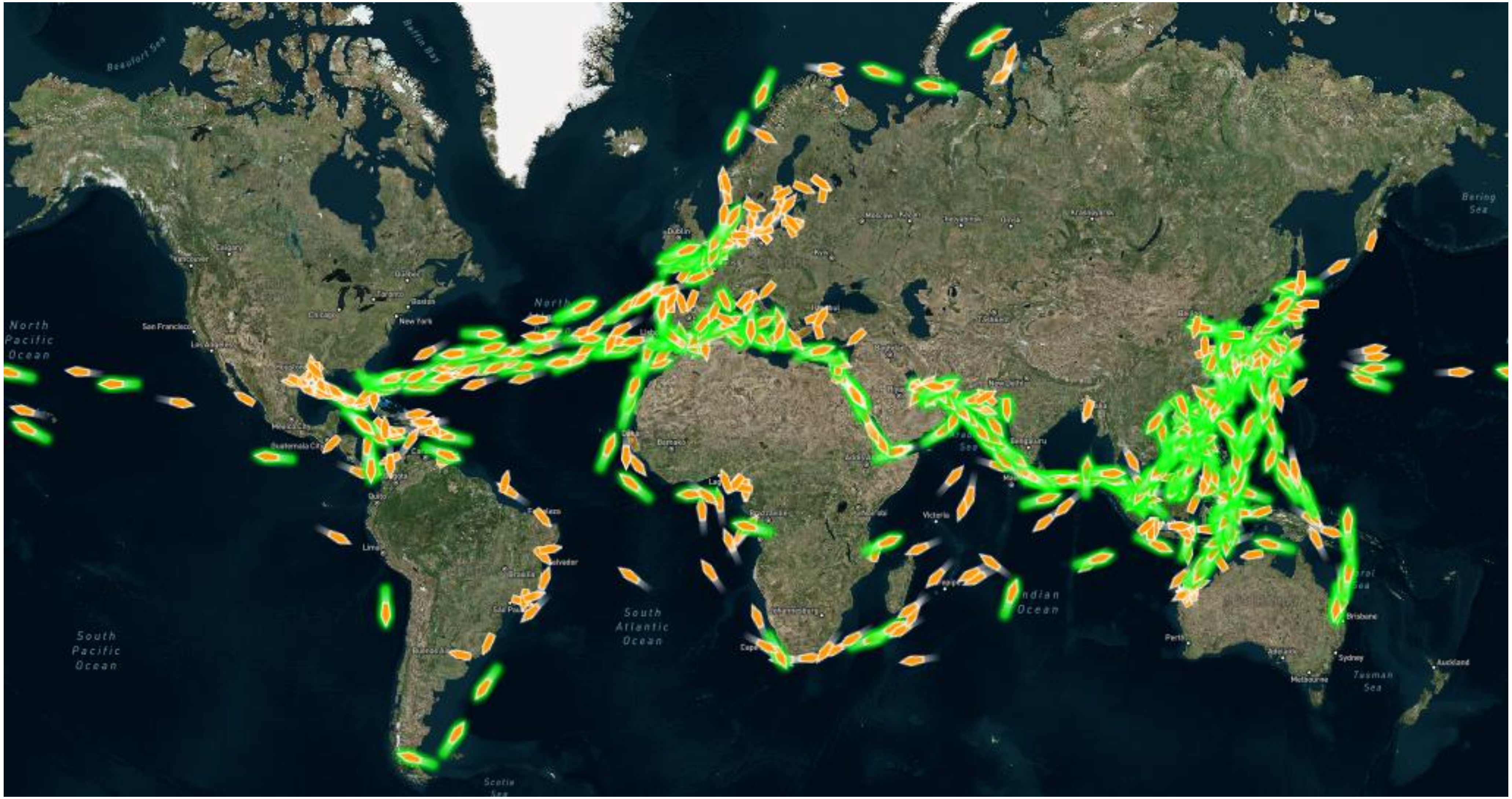
World LNG infrastructure

LNG CH4



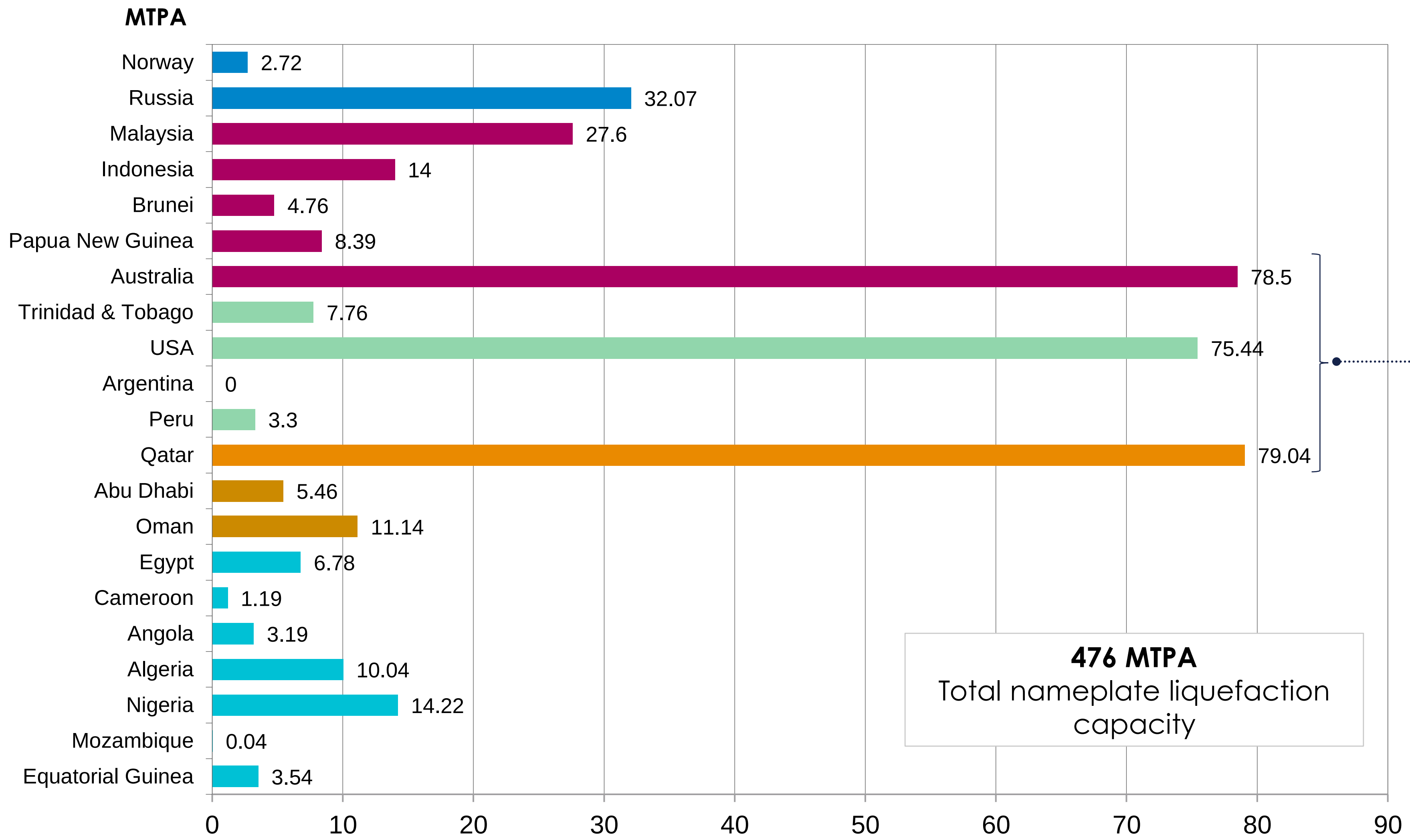
Sources: GIIGNL 2024 & S&P Global

LNG tankers underway



Source: S&P Global

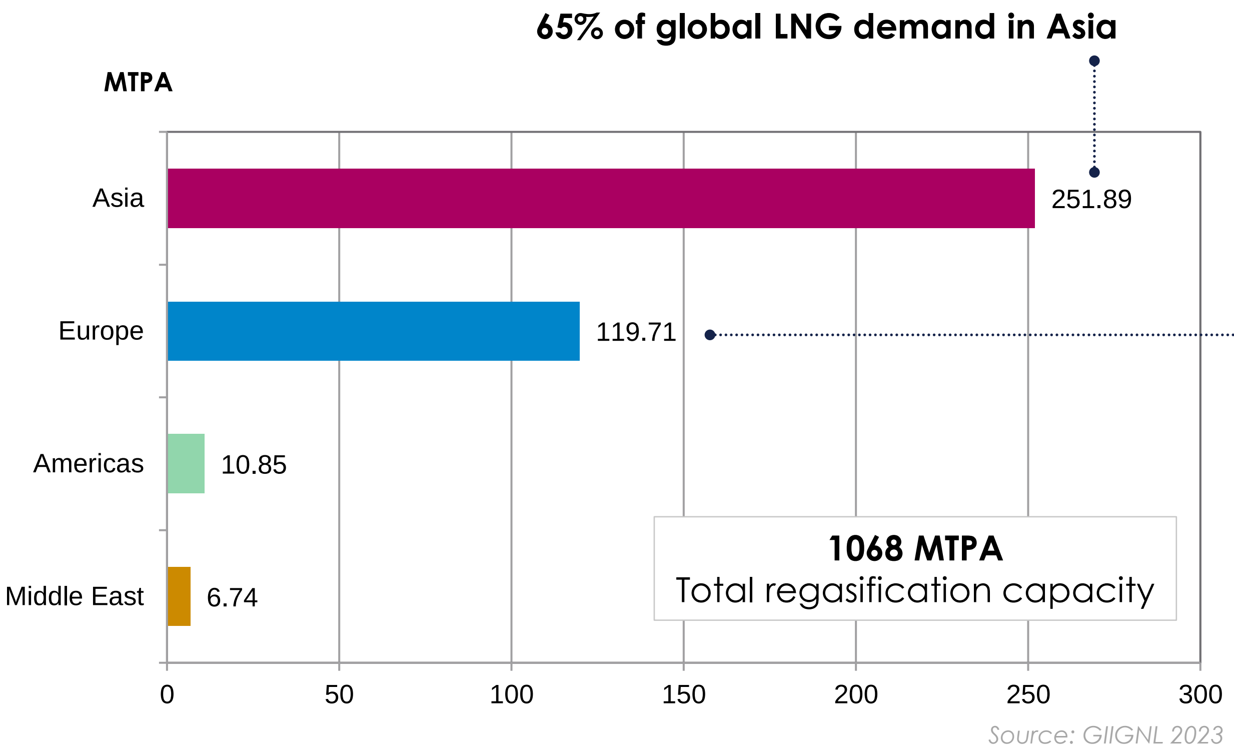
World LNG exports (2022)



~60 % of global LNG volumes supplied by Qatar, Australia & USA

Source: GIIGNL 2023

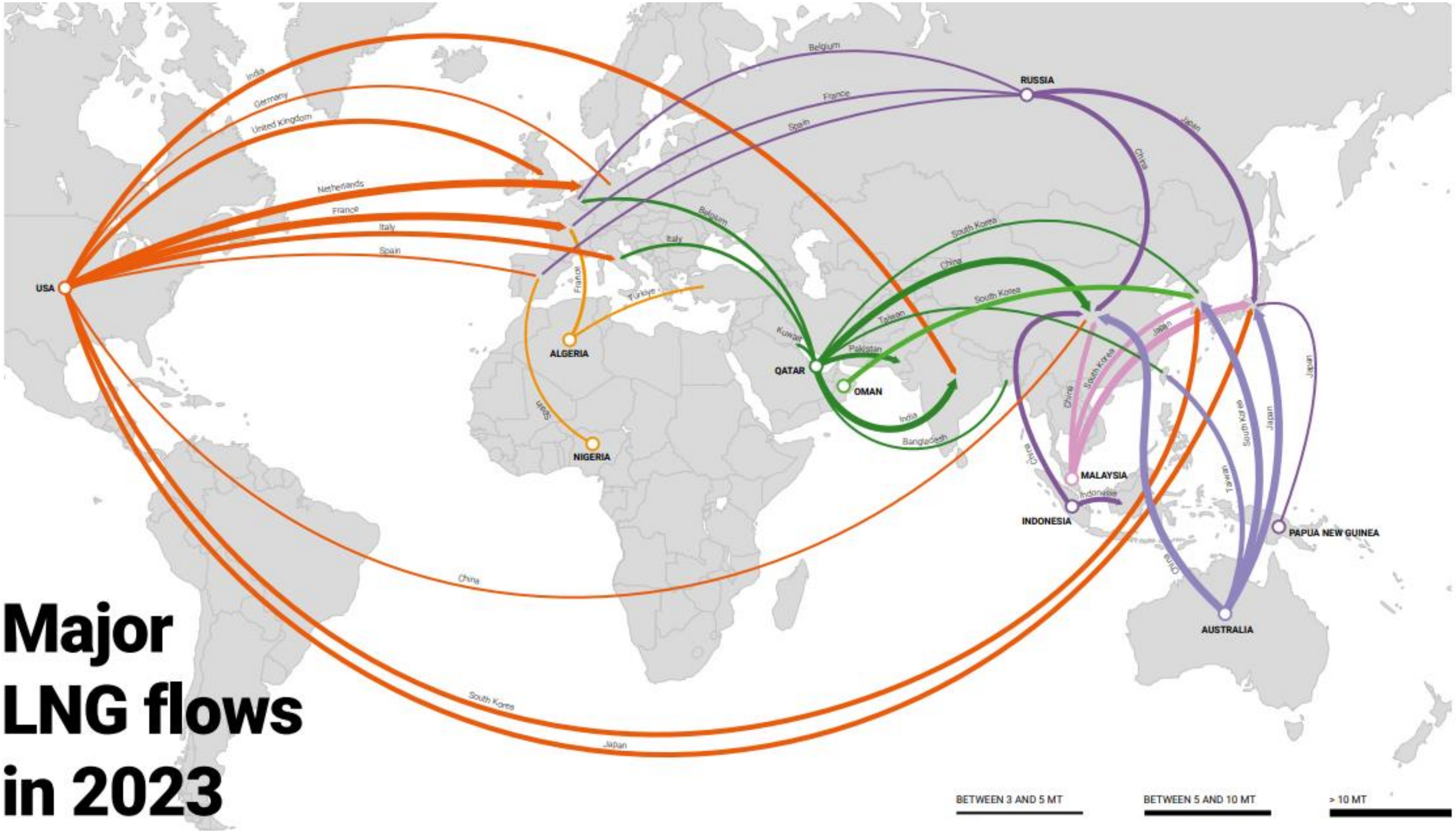
World LNG imports (2022)



43 % of European LNG imports comes from USA, 16% from Qatar.

60% increase in European LNG imports versus 2021

World LNG flows (2023)



Source: GIIGNL 2024

LNG chain

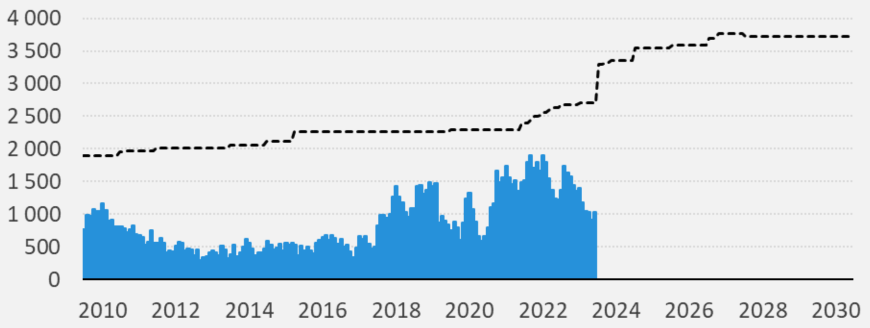
Regasification terminal in Zeebrugge

- LNG carriers: small - standard - Q-flex - Q-max (2,000 m³ to 266,000 m³ LNG)
- Over 300 different ships docked at the terminal to this day
- 5 storage tanks - 560,000 m³ LNG = 4 standard LNG ships of 140,000 m³
- Send-out flow rate: 2,500,000 m³(n)/h = 1 standard LNG ship in about 1.5 days

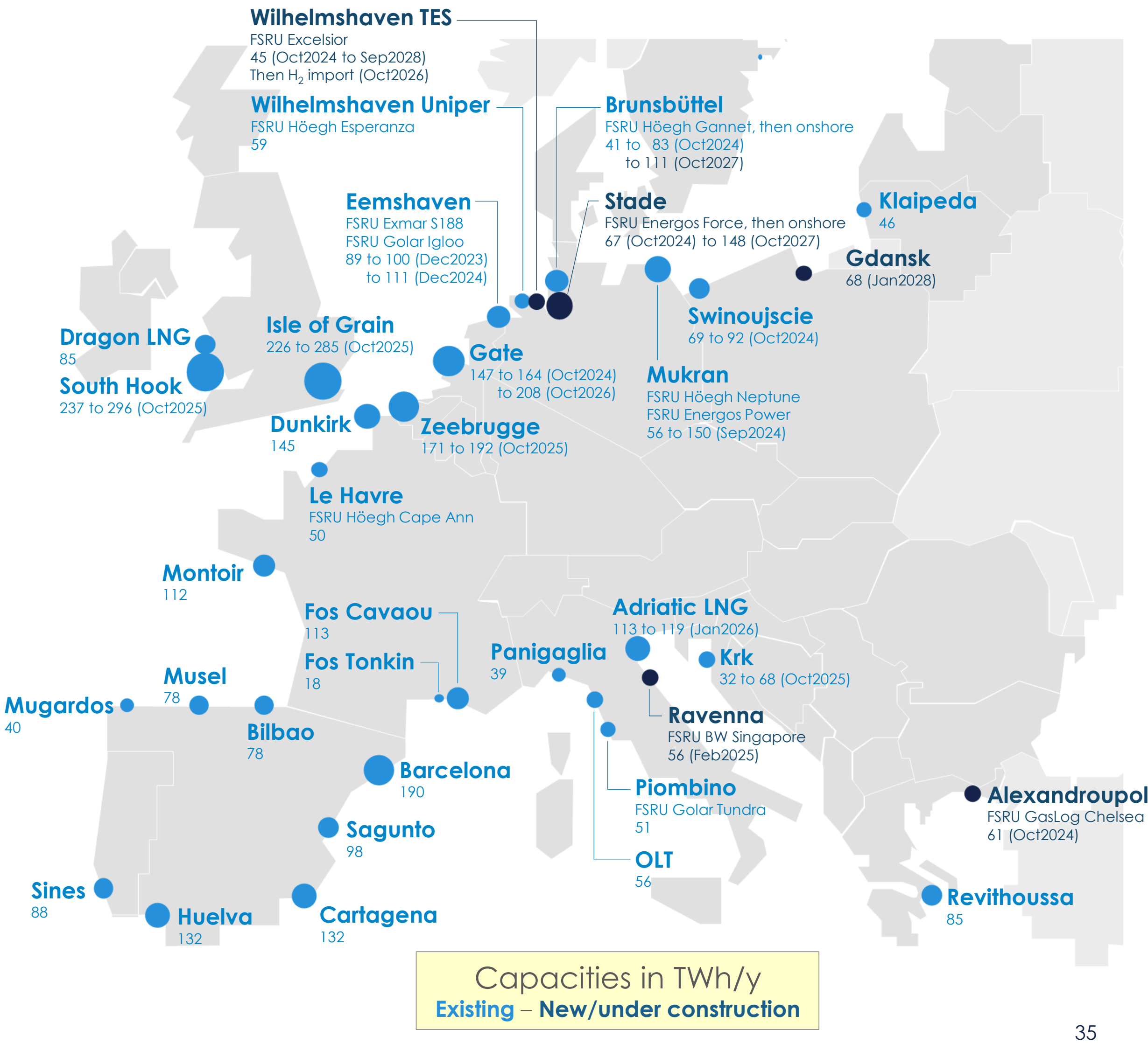
Gas infrastructure in Europe

LNG regasification terminals

EU regasification capacity and LNG imports [TWh/y]



Source: all data on this page were compiled by Fluxys in October 2024 from ENTSOG, Platts, ICIS, S&P Global and https://alsi.gie.eu/



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Gas infrastructure in Europe

Pipelines

Source: maps and data are open access – see https://www.entsog.eu/maps and https://transparency.entsog.eu/#/map

Gas infrastructure in Europe

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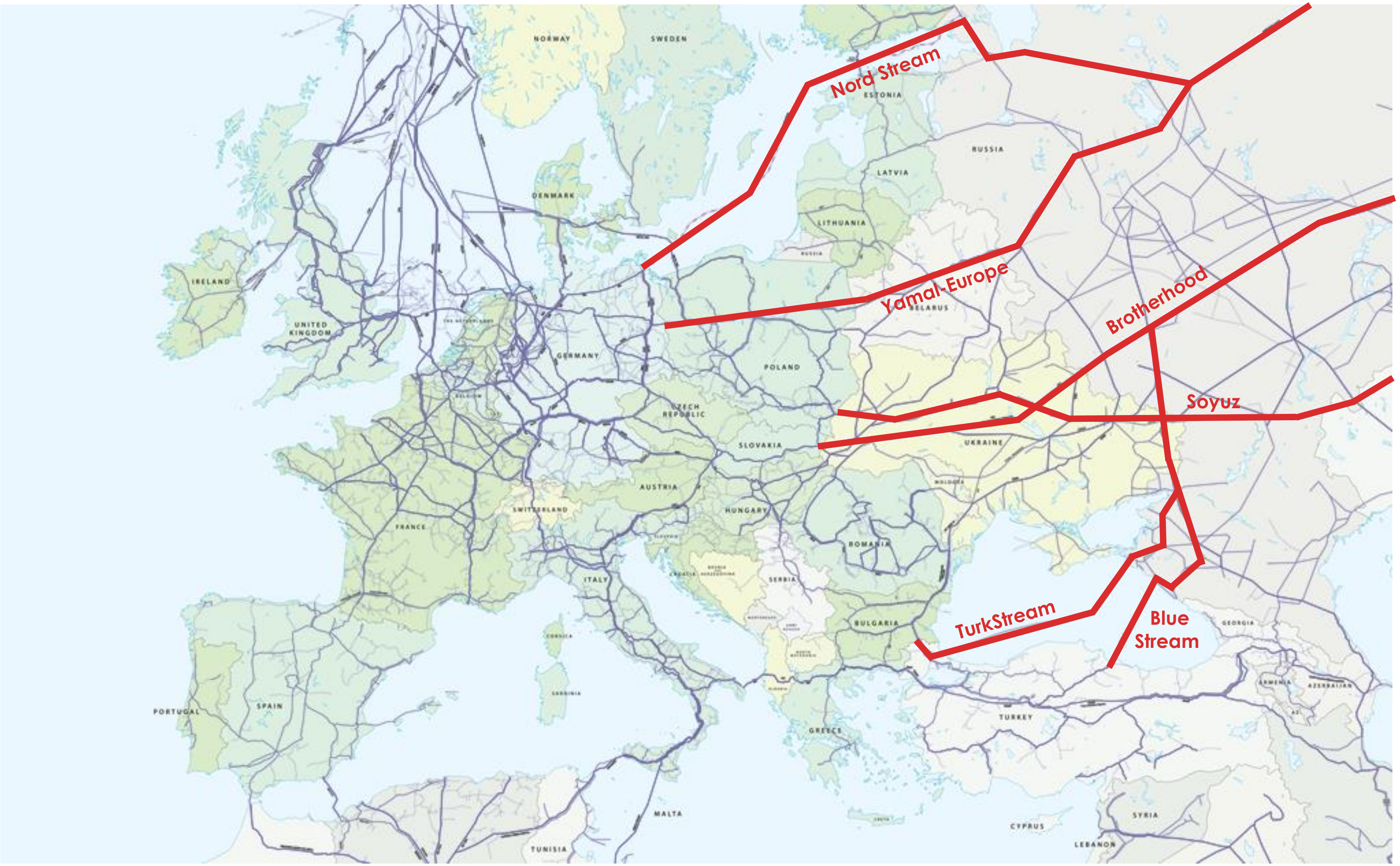

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Gas infrastructure in Europe

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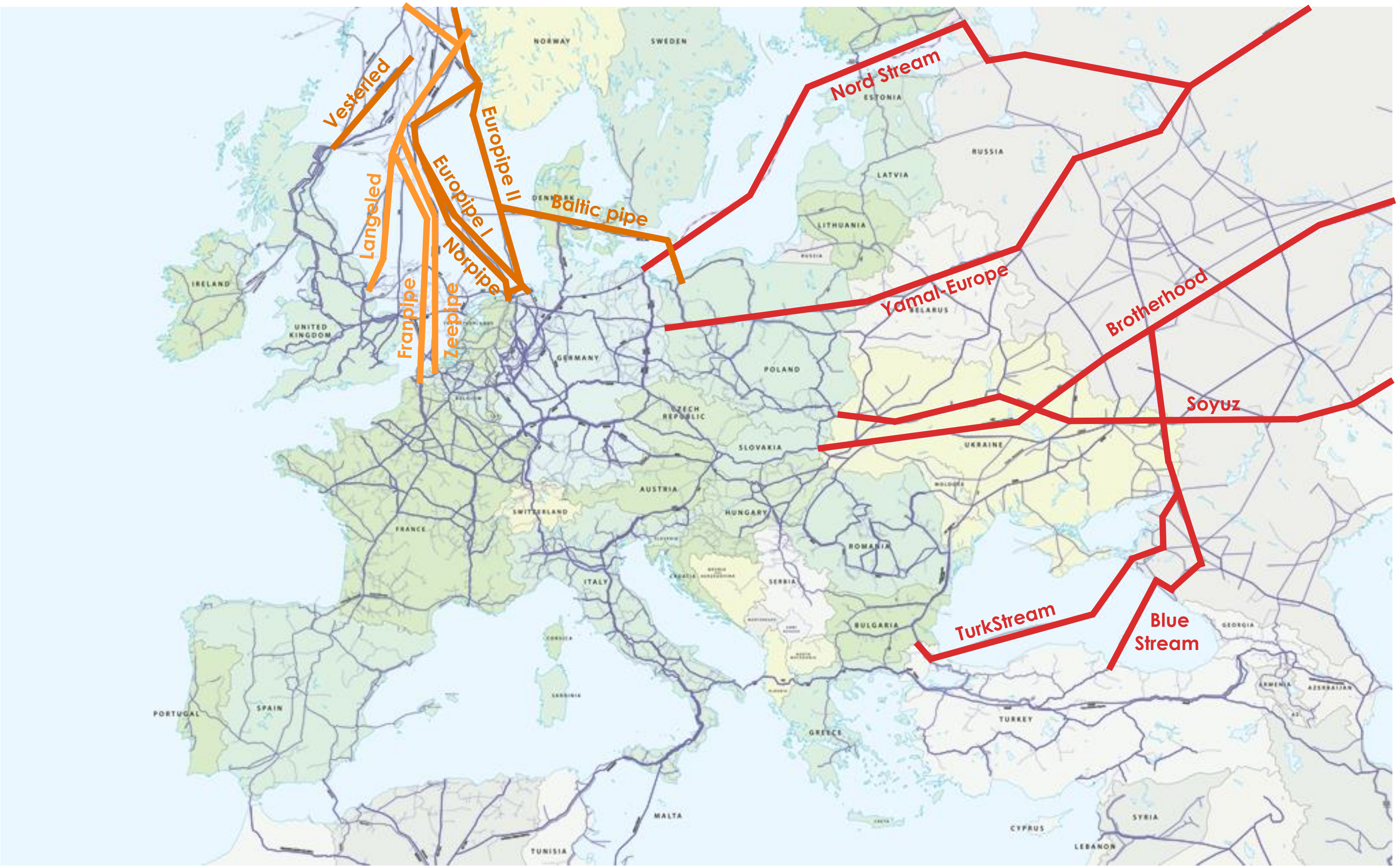

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Gas infrastructure in Europe

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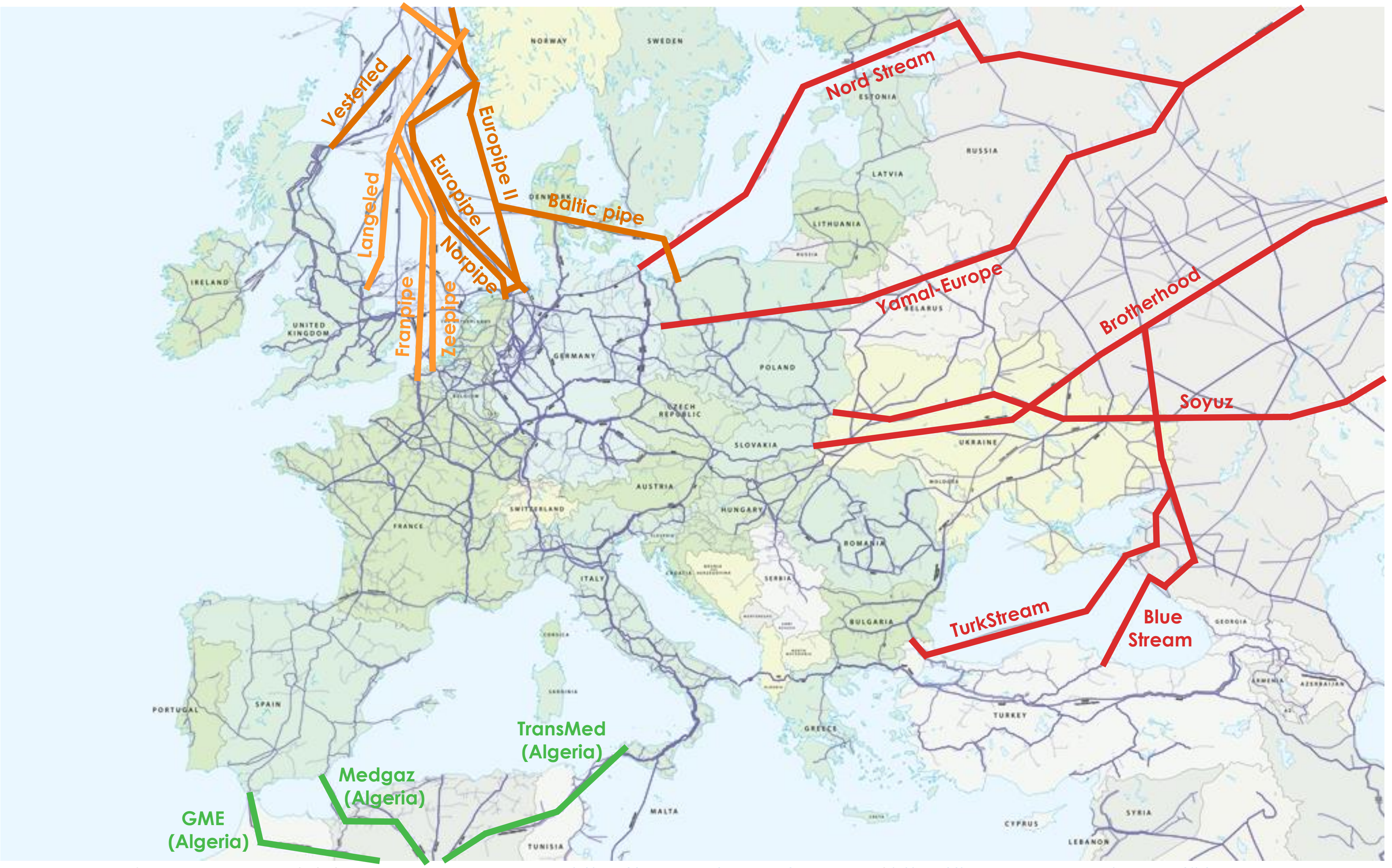

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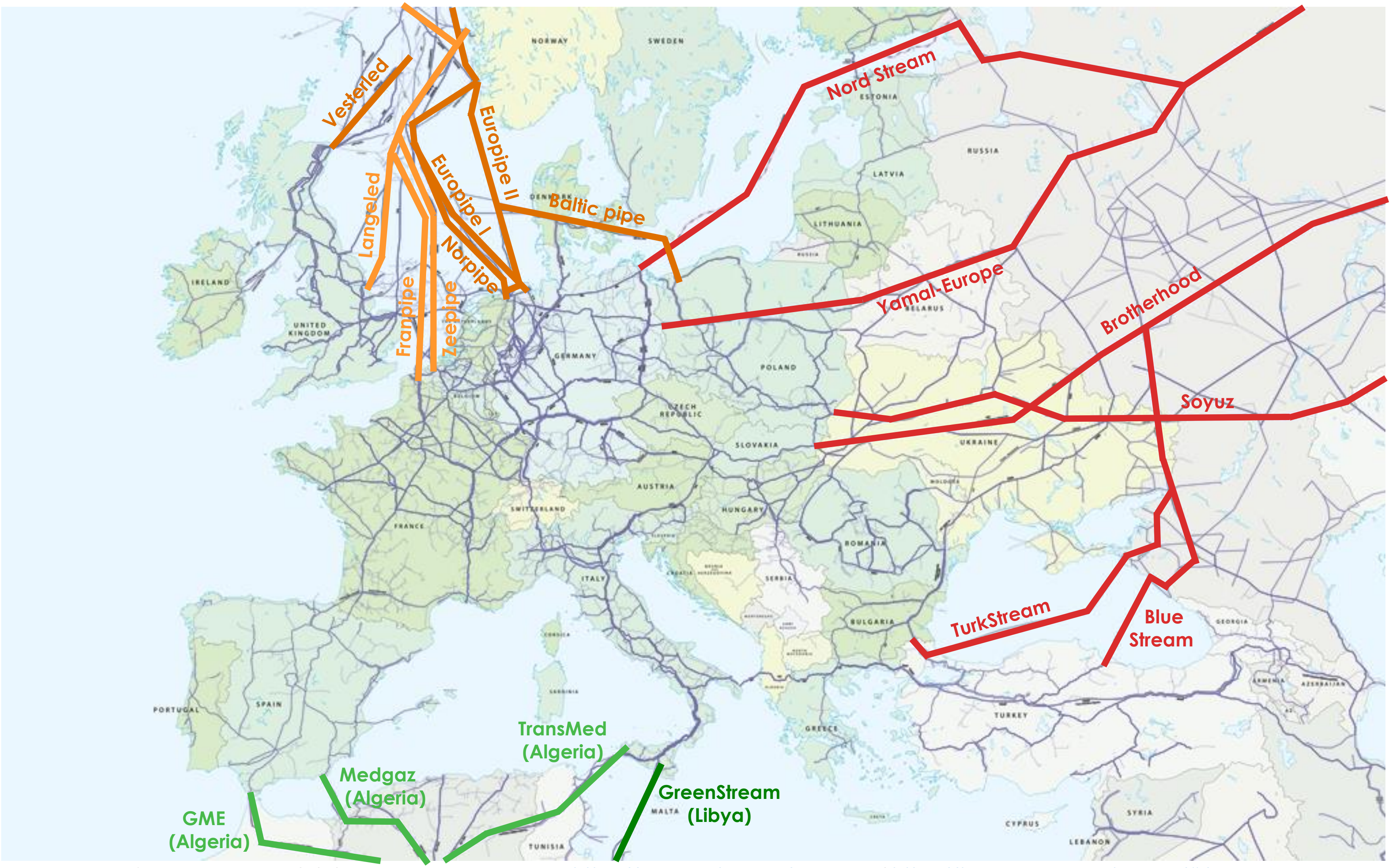

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Gas infrastructure in Europe

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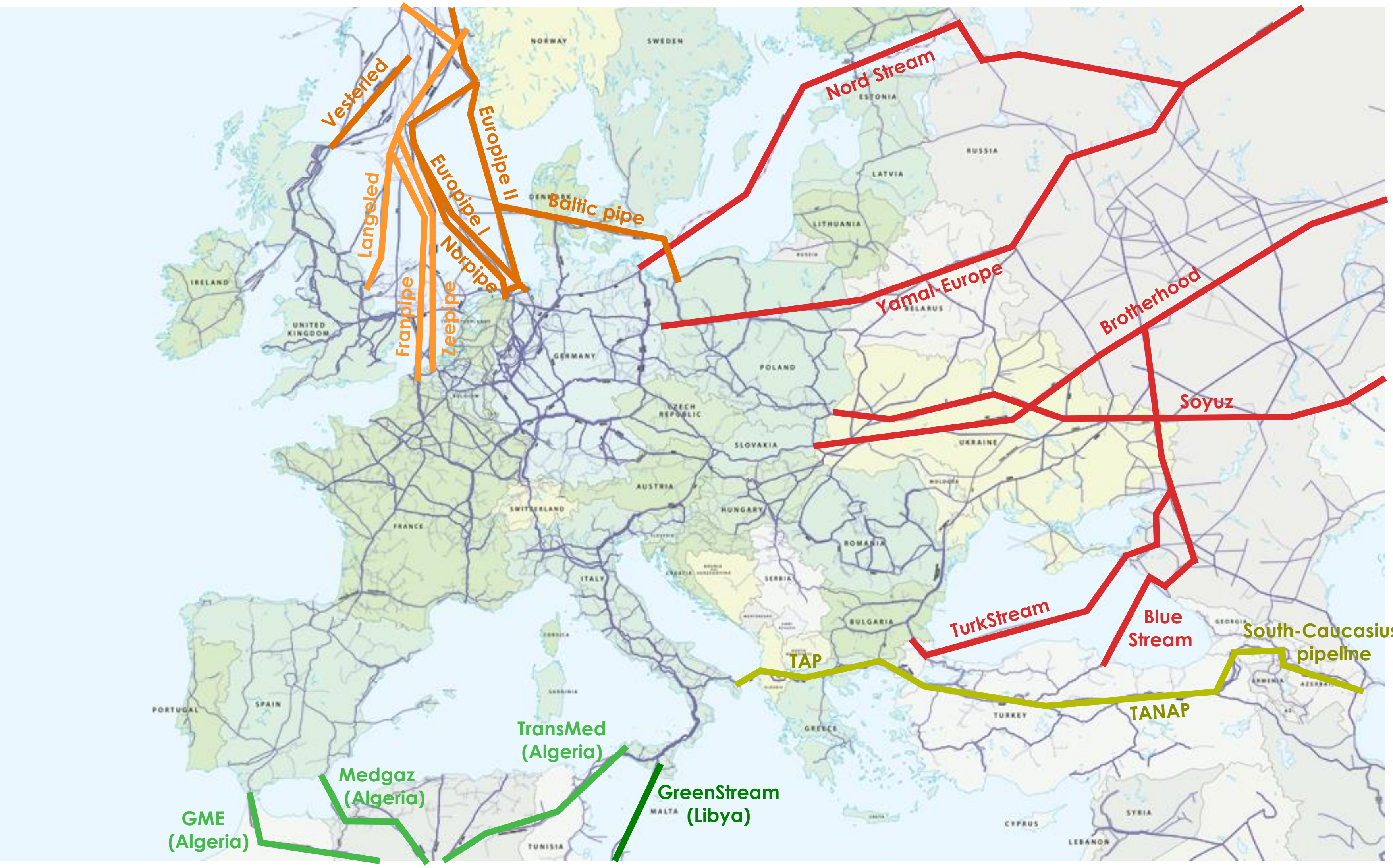

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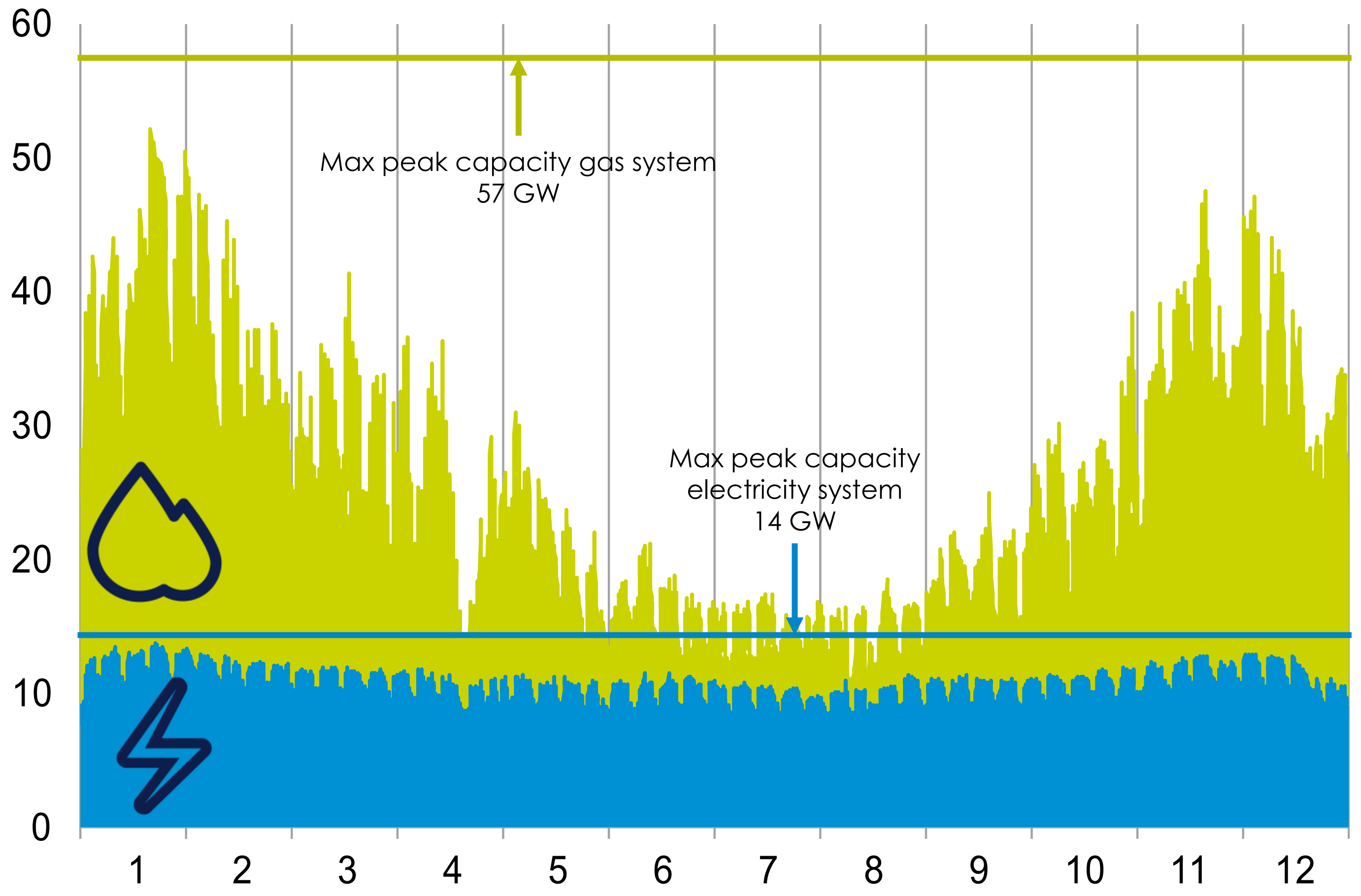
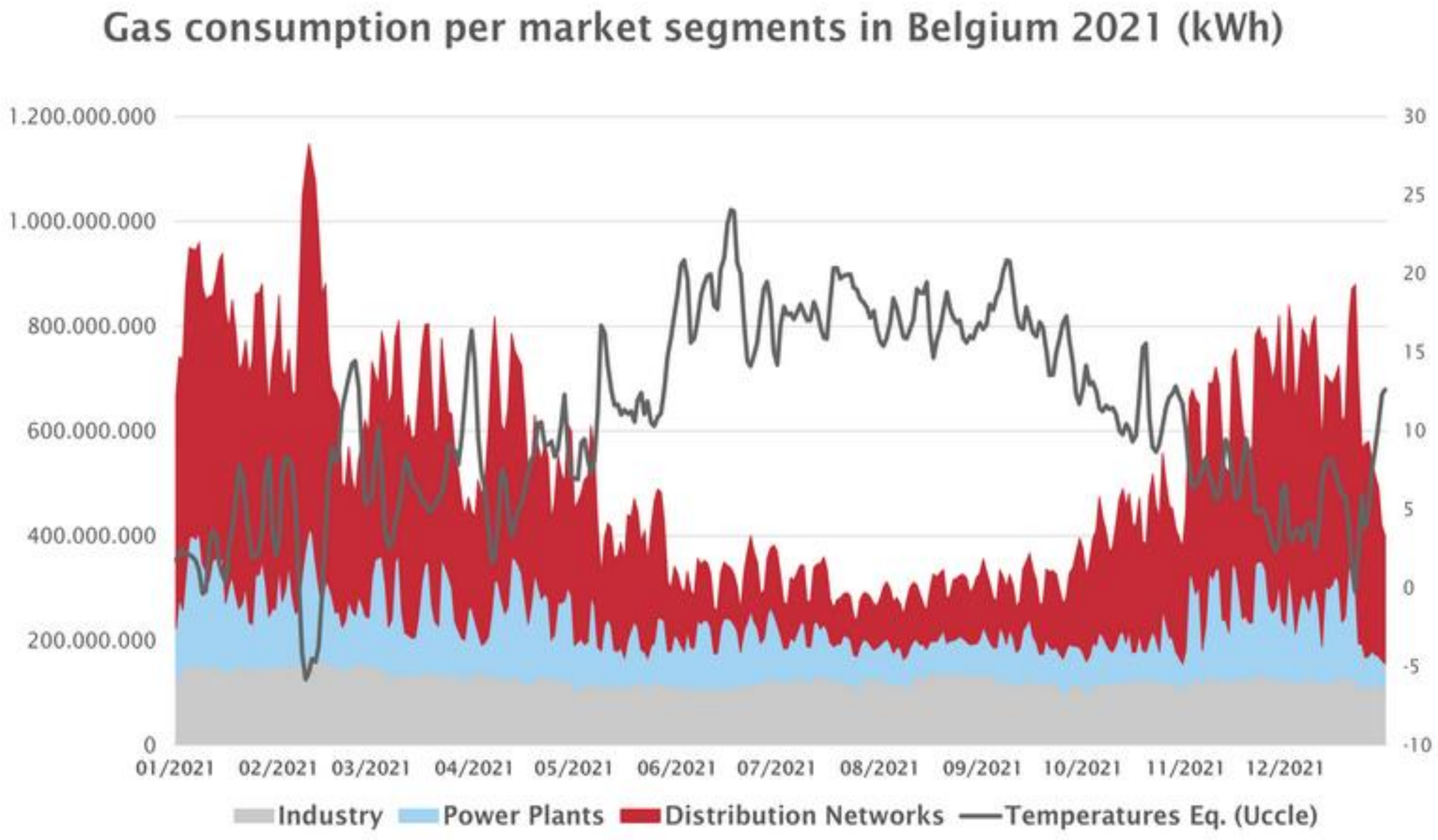
Gas system to provide the flexibility required



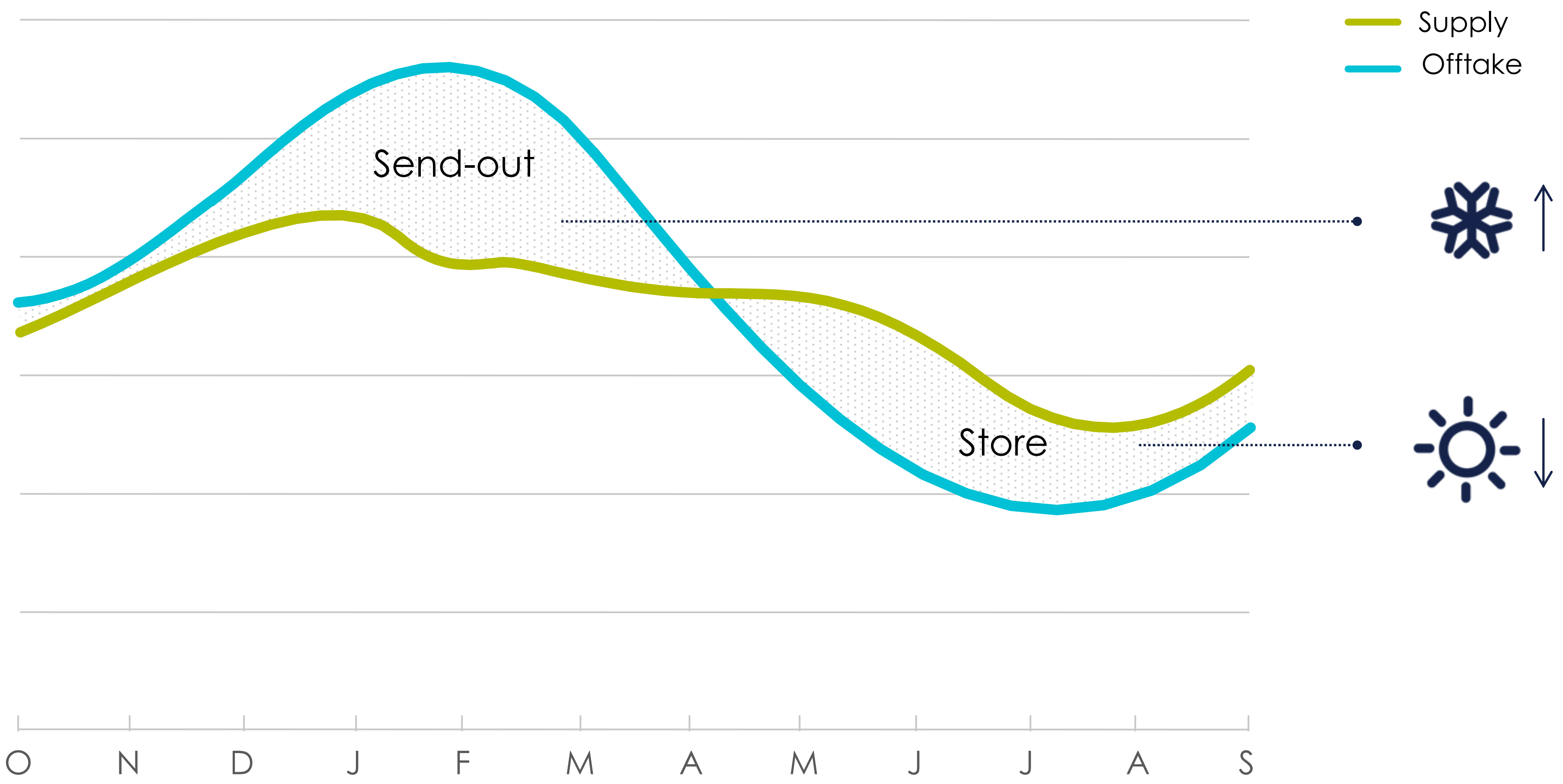
Seasonal demand profile



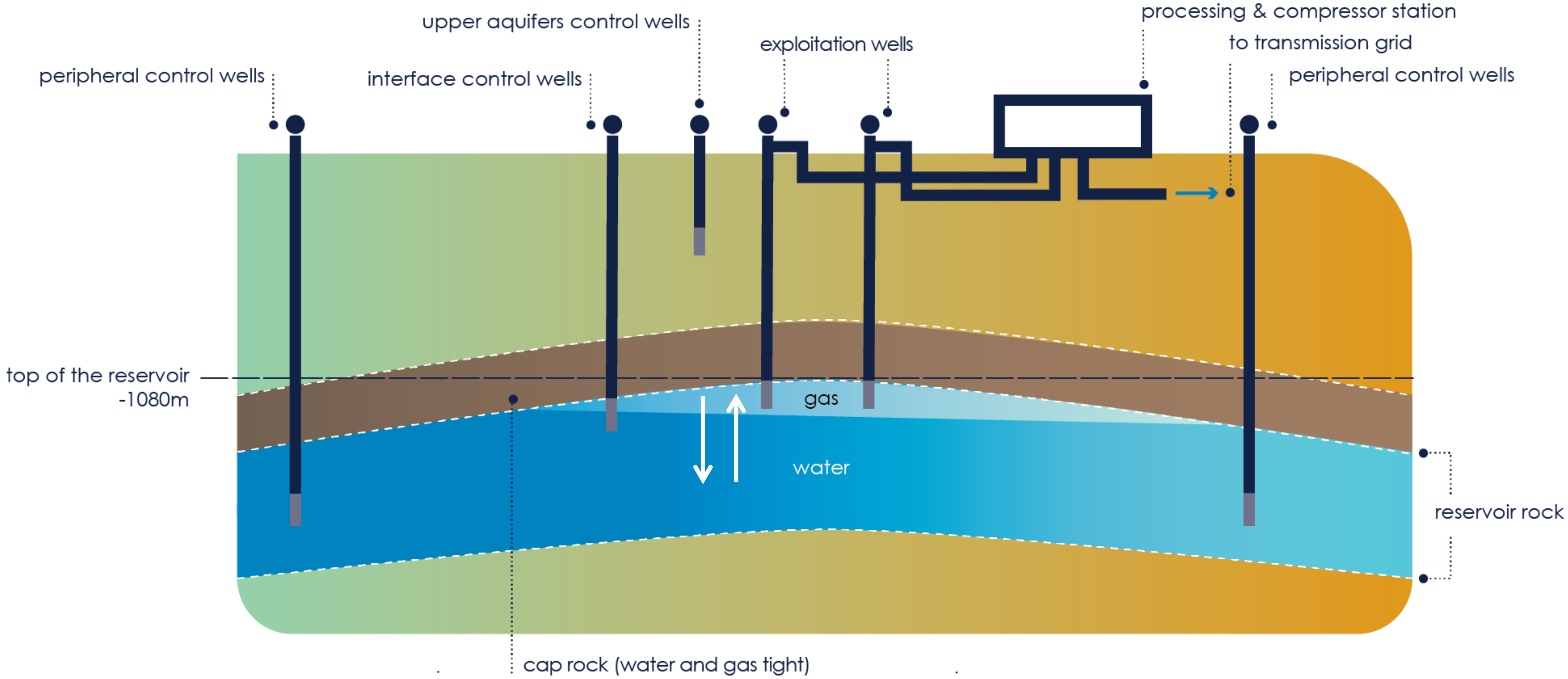
https://www.febeg.be/statistieken-gas

- Gas consumption has a strong seasonal profile
- Household consumption typically stops when temperature above 16°C
- Winter demand is typically 2,5 times summer demand, mainly due to domestic consumption
- Industrial consumption and power plants have a very slight seasonal profile

Why storage?



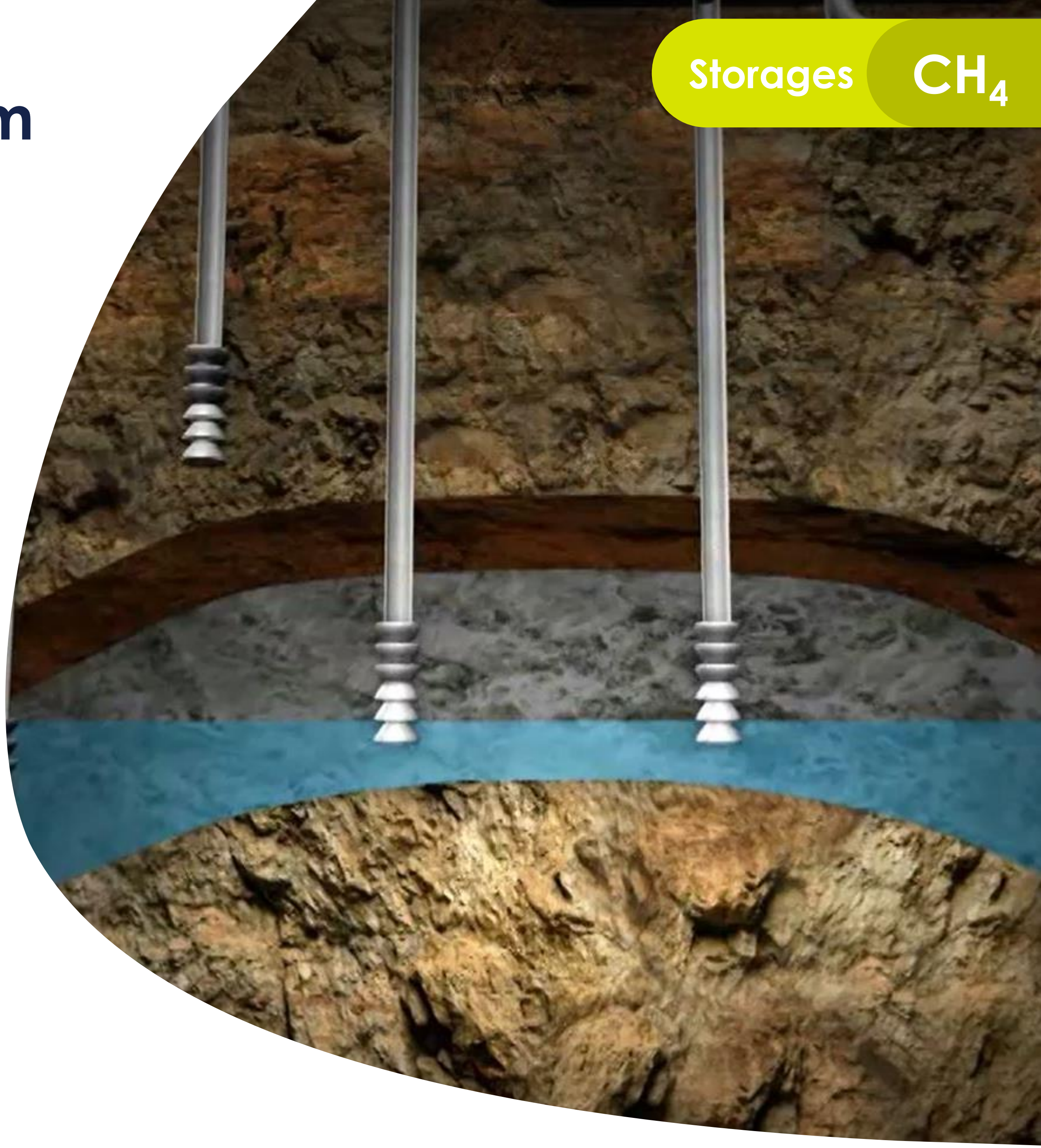
Underground storage in aquifer: how?



Loenhout storage site in Belgium

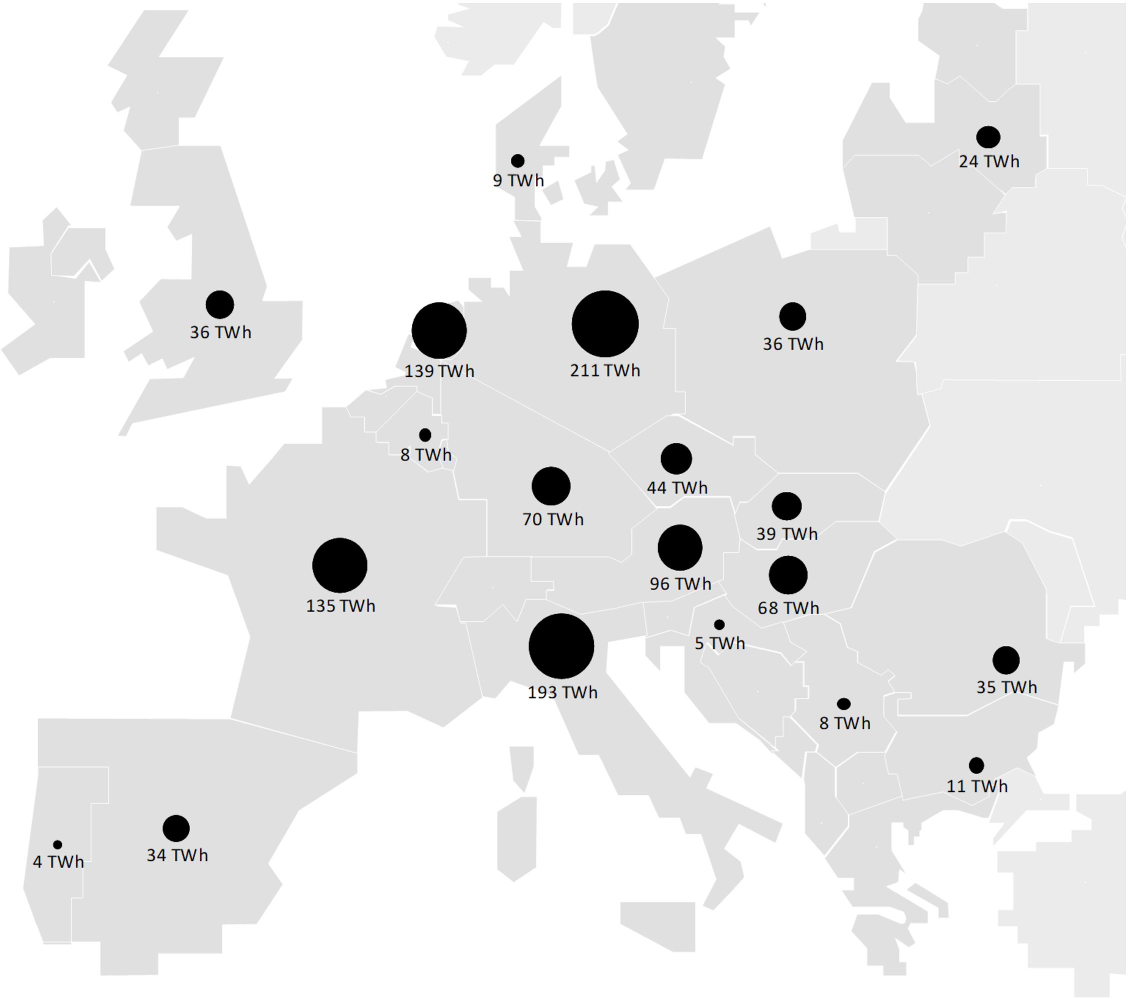
Unique natural conditions

- **Unique soil** conditions allow storing large amounts of energy
- So-called aquifer, a porous rock that acts **like a sponge**
- More than a **kilometer underground**
- **Safe** storage - no connection with atmosphere, therefore no combustible mixture can be formed
- Storing natural gas since **1985**, in the future potentially hydrogen



Gas infrastructure in Europe

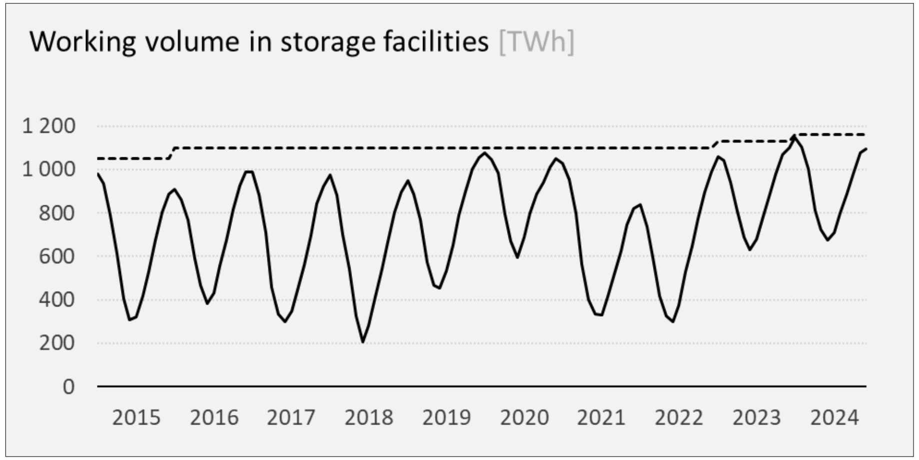
Underground storage facilities

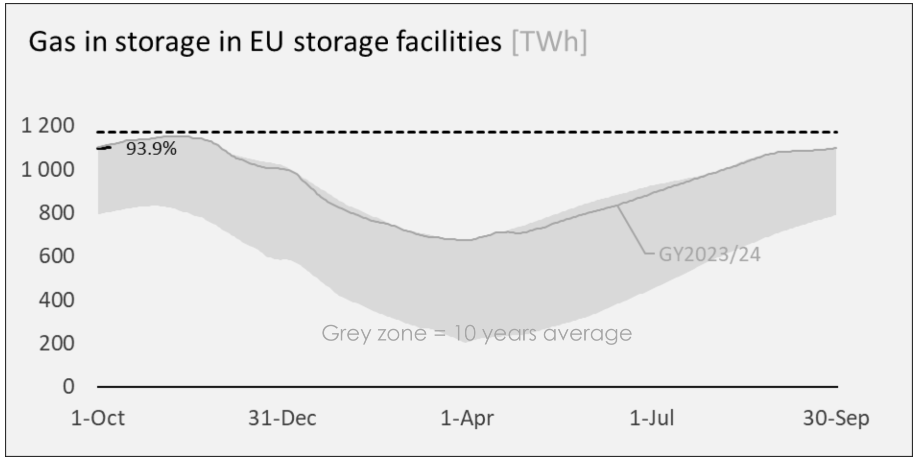


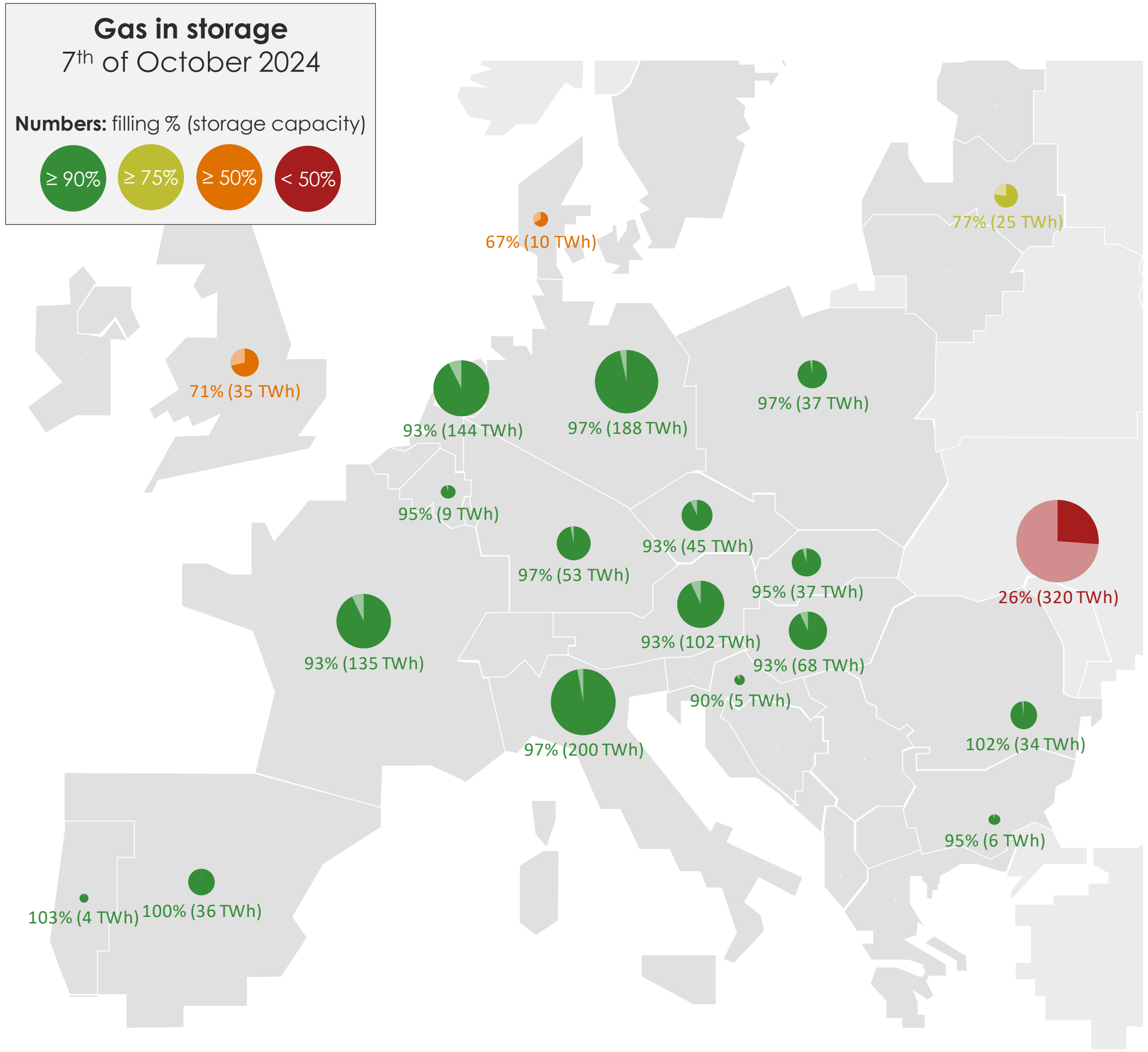
Source: all data on this page were compiled by Fluxys in November 2023 from ENTSOG and https://agsi.gie.eu/

Storage situation in Europe on October 7th

Sources: data from GIE AGSI and National Grid







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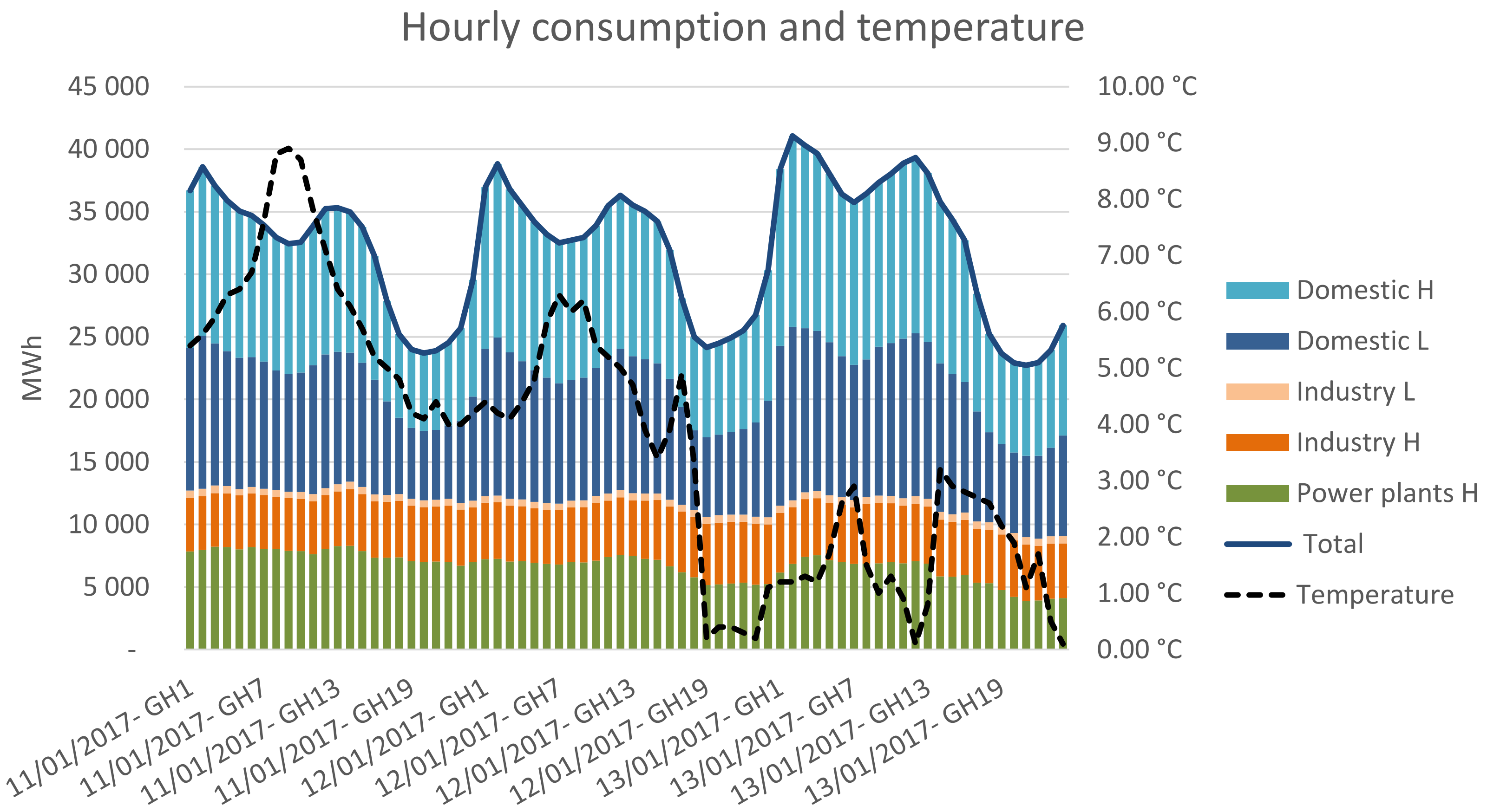
Hourly demand profile and temperature

CH$_4$



- The first gas hour (GH1) starts at 6h in the morning
- Hourly demand has a morning peak starting at 8h AM and an evening peak around 19h PM
- Peak demand is typically 1,5 times night demand in winter
- Household (domestic) demand is temperature driven
- Power plants have slight decrease during night hours
- Industry has almost flat offtake

Pressure drop in pipes

Pressures drop is a non-linear function depending on gas speed, gas properties and pipe dimensions

Gas compressibility factor KPT is a function of temperature T and pressure P

$$K_P = K_{REF} - \frac{(P_{IN} - 50)}{525}$$

$$K_{PT} = \frac{0.98515}{\left(1 + \frac{0.98515 - K_P}{0.75672\, K_P}\right) e^{-0.018584\, T}}$$

Gas density is computed from the Gas Law

$$\rho = \frac{\rho_0}{K_{PT}} \frac{T_0}{T} \frac{P_{IN}}{P_0}$$

Gas speed (m/s) is derived from gas flow (m3/h)

$$v = \left|\frac{Q}{\pi D^2/4}\right| = \left|\frac{Q_n}{\pi D^2/4} \frac{P_0}{P_{IN}} K_{PT}\right|$$

$$Re = \frac{vD}{\nu}$$

The Reynolds number is calculated from speed, pipe diameter and gas viscosity

$$\lambda = \left[0.8685 \ln\left(\frac{1.964 \ln(Re) - 3.8215}{Re} + 3.71 \frac{D}{K}\right)\right]^{-2}$$

The 'lambda coefficient' (approaching the friction factor) is based on empirical formula

$$\Delta P_{rug} = \rho \frac{\lambda}{D} \frac{v^2}{2} L$$

Pressure drop due to pipe rugosity and gas speed can now be calculated

Pressure drop in pipes

Pressures drop is a non-linear function depending on gas speed, gas properties and pipe dimensions

CH_4

Pressure drop due to pipe rugosity and gas speed

$$\Delta P_{rug} = \rho \frac{\lambda}{D} \frac{v^2}{2} L$$

Pressure drop due to potential energy (height of pipe)

$$\Delta P_{pot} = 9.81 (h_{OUT} - h_{IN})$$

Total pressure drop:

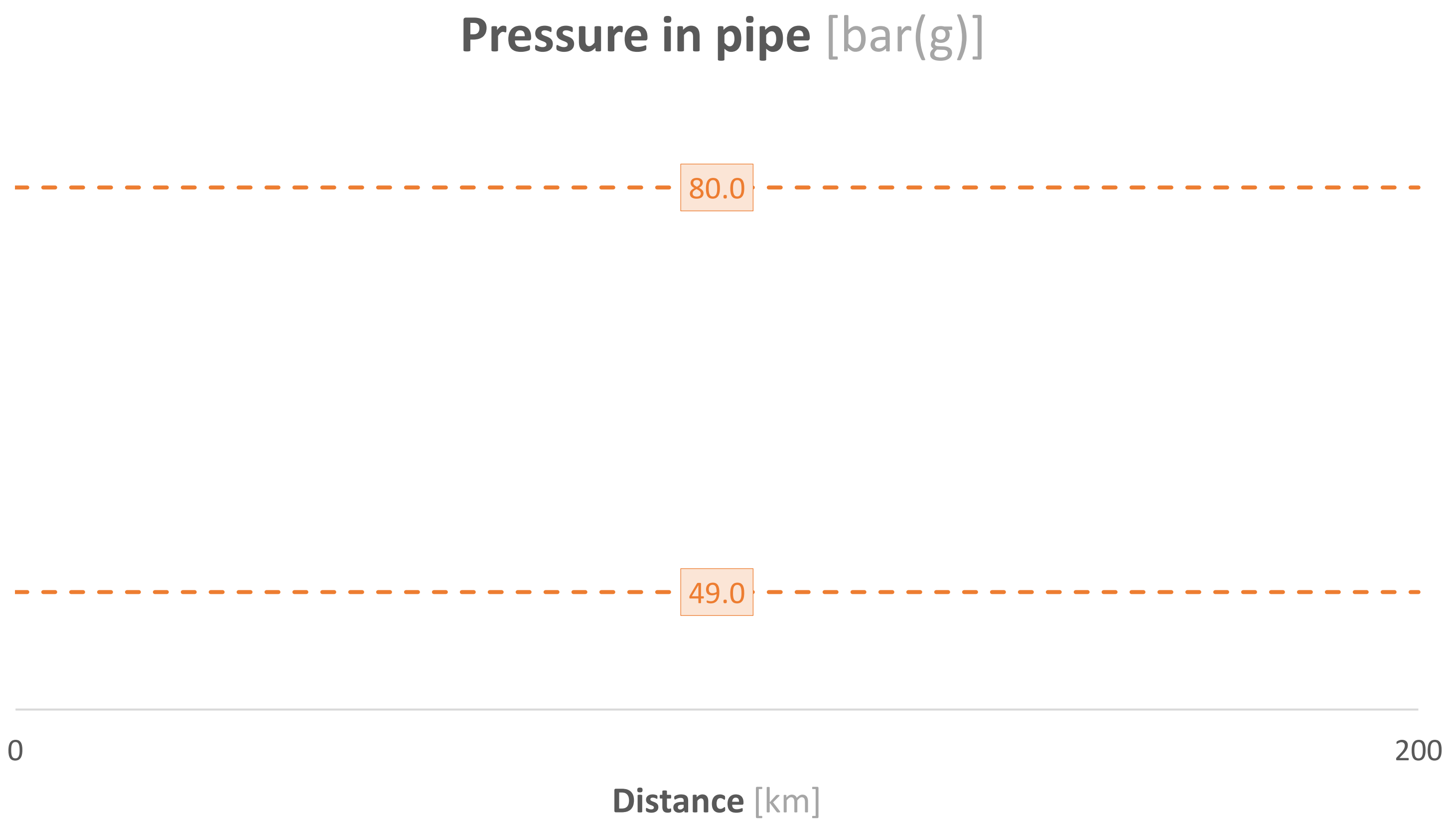
$$P_{OUT} = P_{IN} - \text{signe}(Q_n) * \Delta P_{rug} - \Delta P_{pot}$$

Volume of (compressed) gas in pipe:

$$\text{Linepack}_{Section} = \frac{2}{3} \frac{P_{IN}^3 - P_{OUT}^3}{P_{IN}^2 - P_{OUT}^2} \frac{273.15}{273.15 + T} \frac{GCV}{K_{PT}} V$$

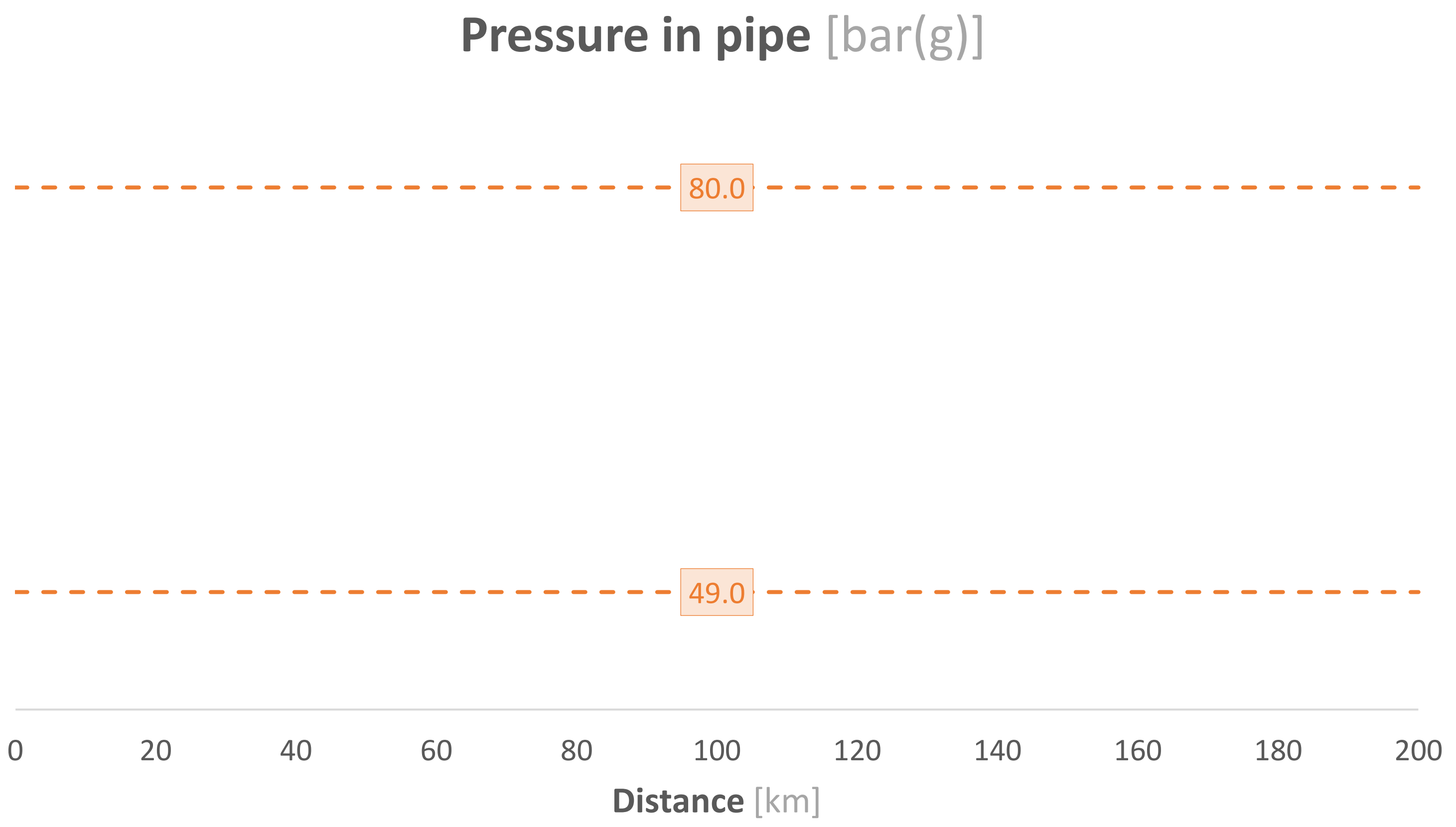
Pressure drop in pipes

Let's take a 200km pipeline (diameter 1000mm) and represent its typical pressure limits



Pressure drop in pipes

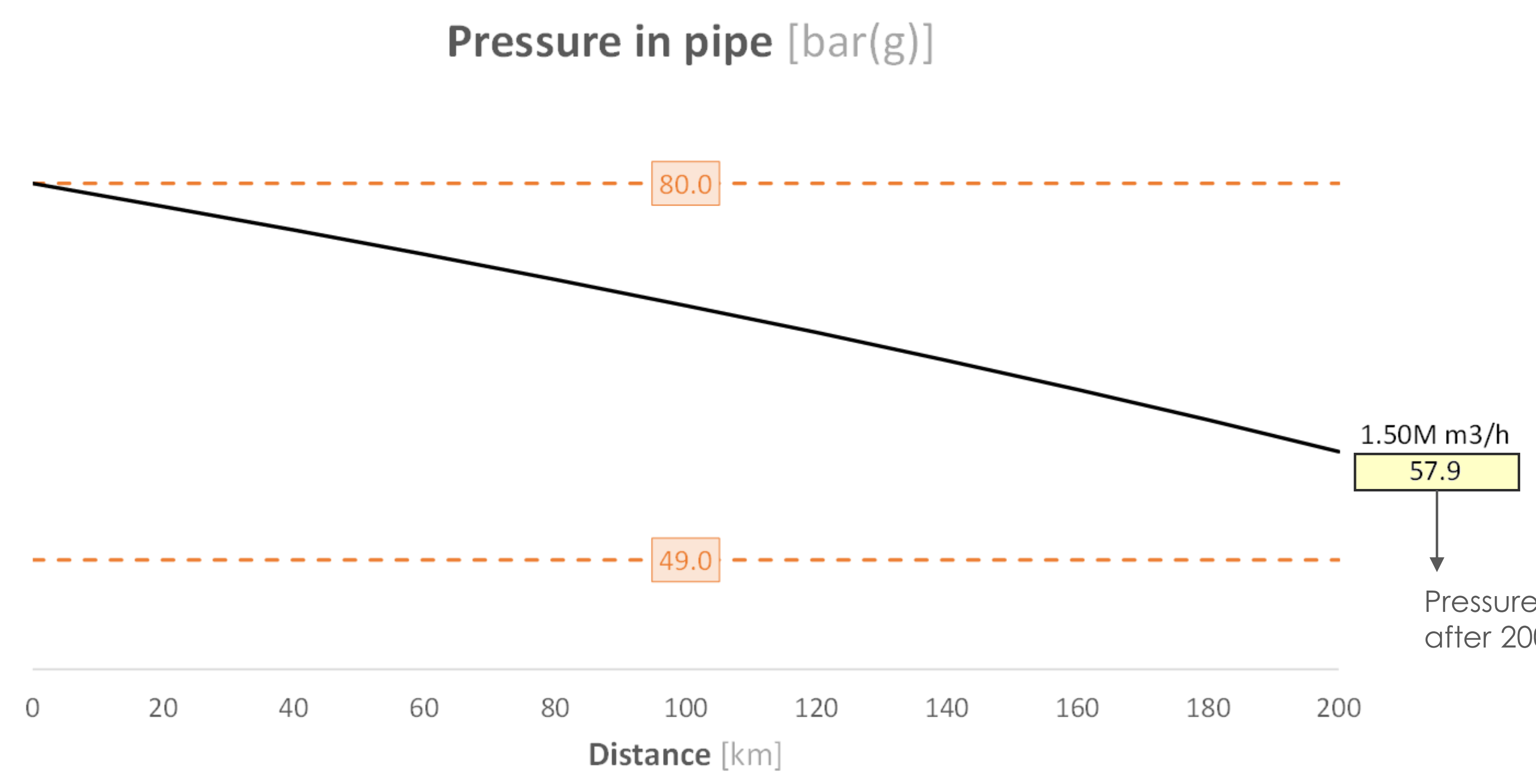
For this example, pressures will be computed every 20km



Pressure drop in pipes

Let's assume a 1500000 m3/h flow, equivalent to ~16.6 GW or ~400 GWh/day (this is a typical value for a 40in pipeline) and let's start with a maximum entry pressure

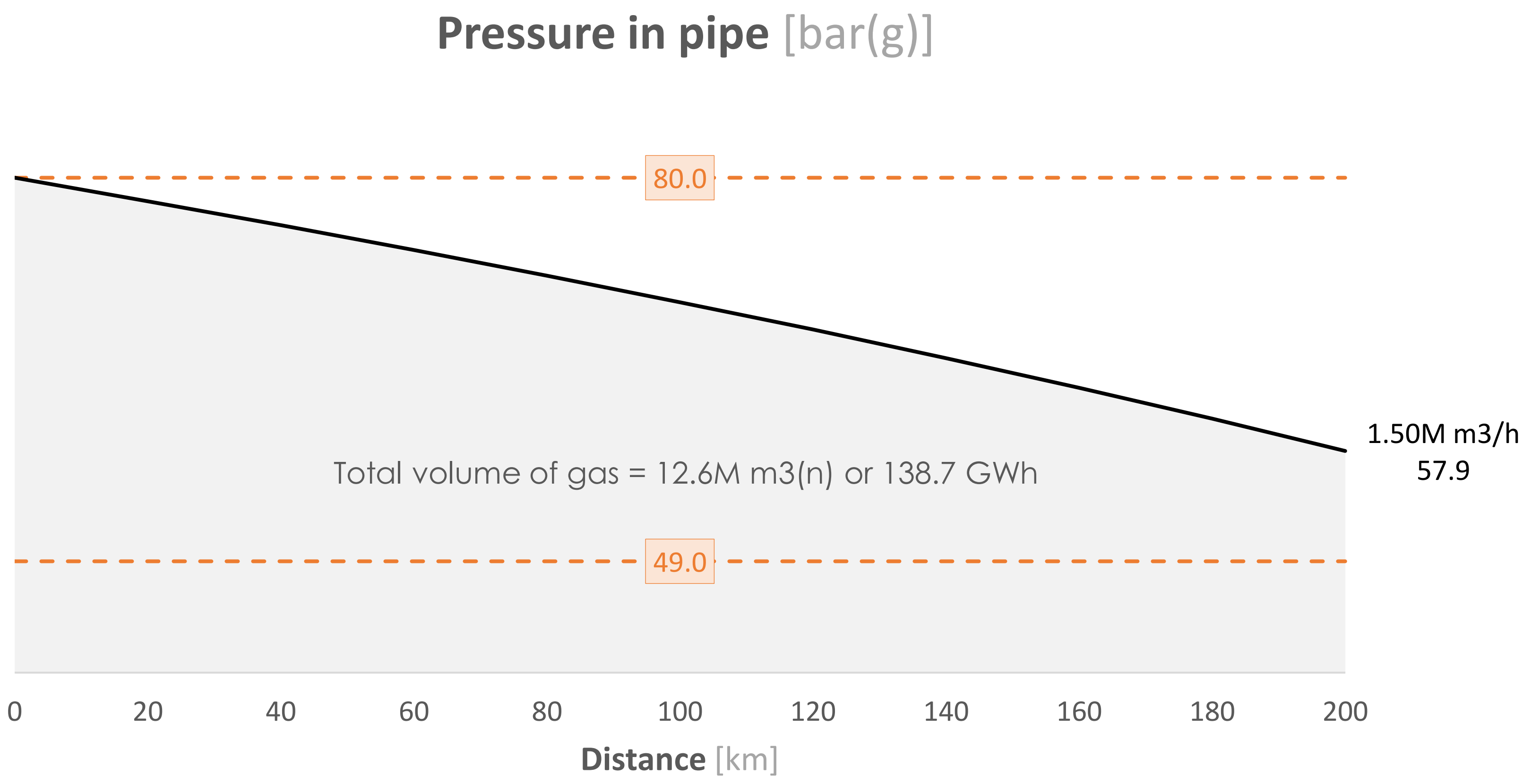
CH_4



Pressure drops at 57.9 bar(g) after 200km

Pressure drop in pipes

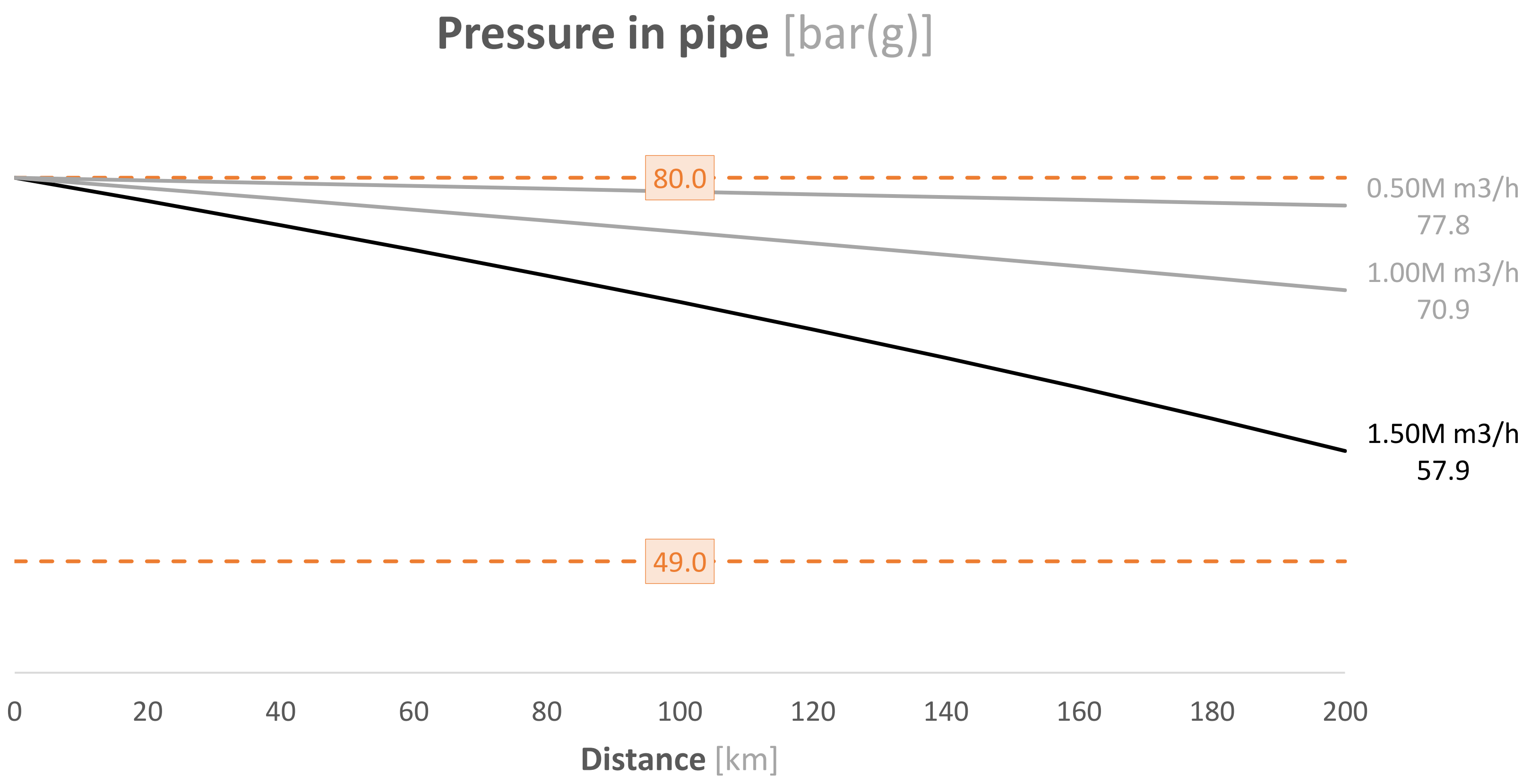
The area represents the amount of gas in pipe, derived from the Gas Law



Information only - non binding

Pressure drop in pipes

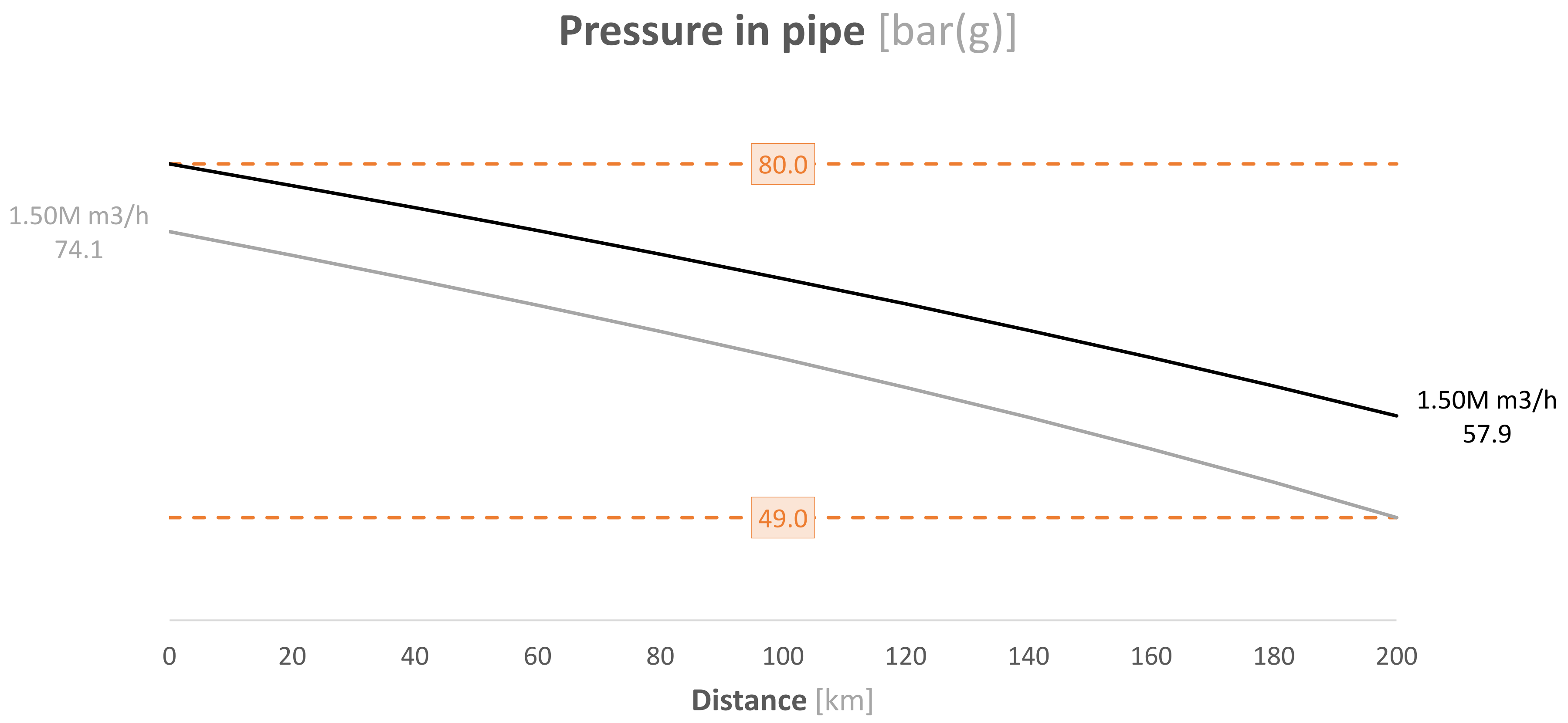
Pressure drops is significantly impacted by the gas velocity



Pressure drop in pipes

With the same gas velocity, a range of entry pressures respects pressure limits

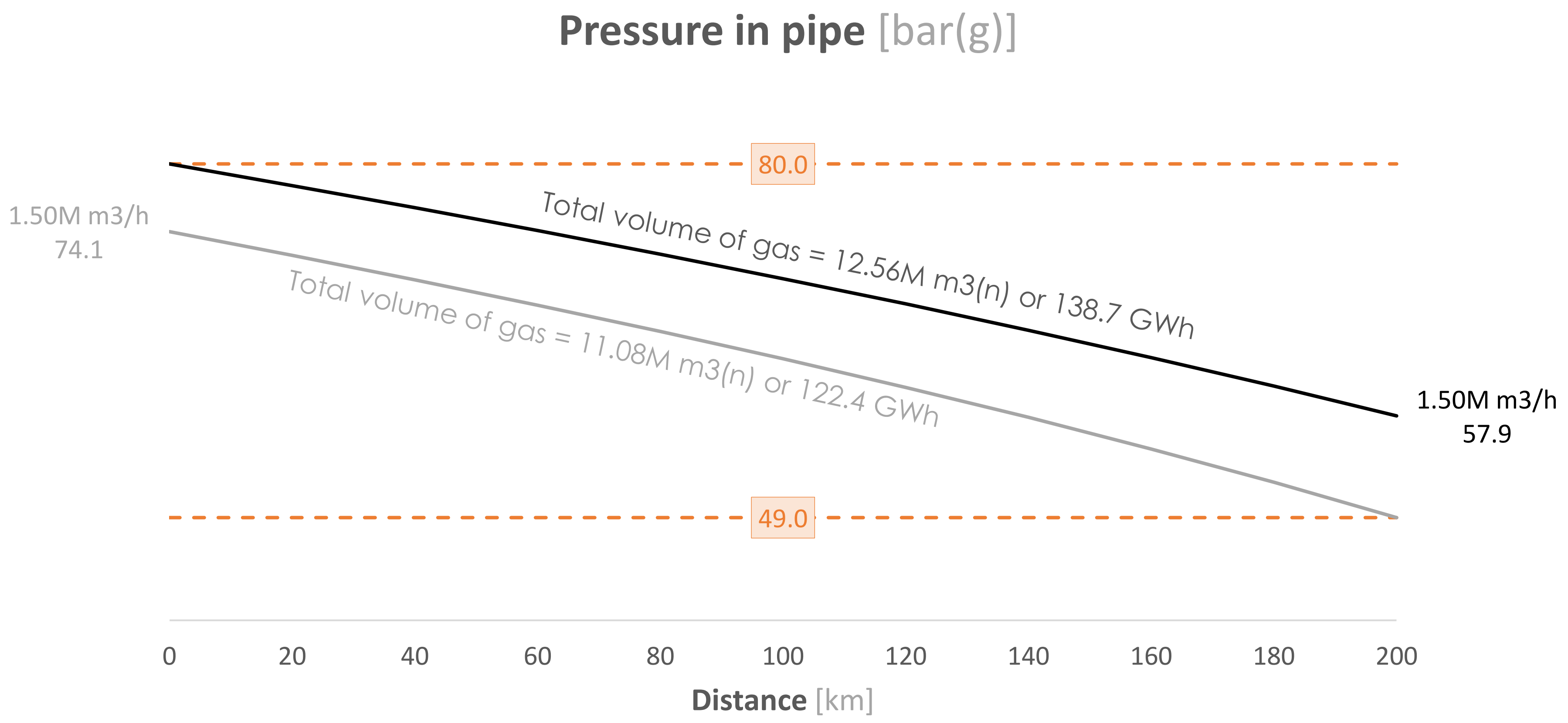
CH_4



Pressure drop in pipes

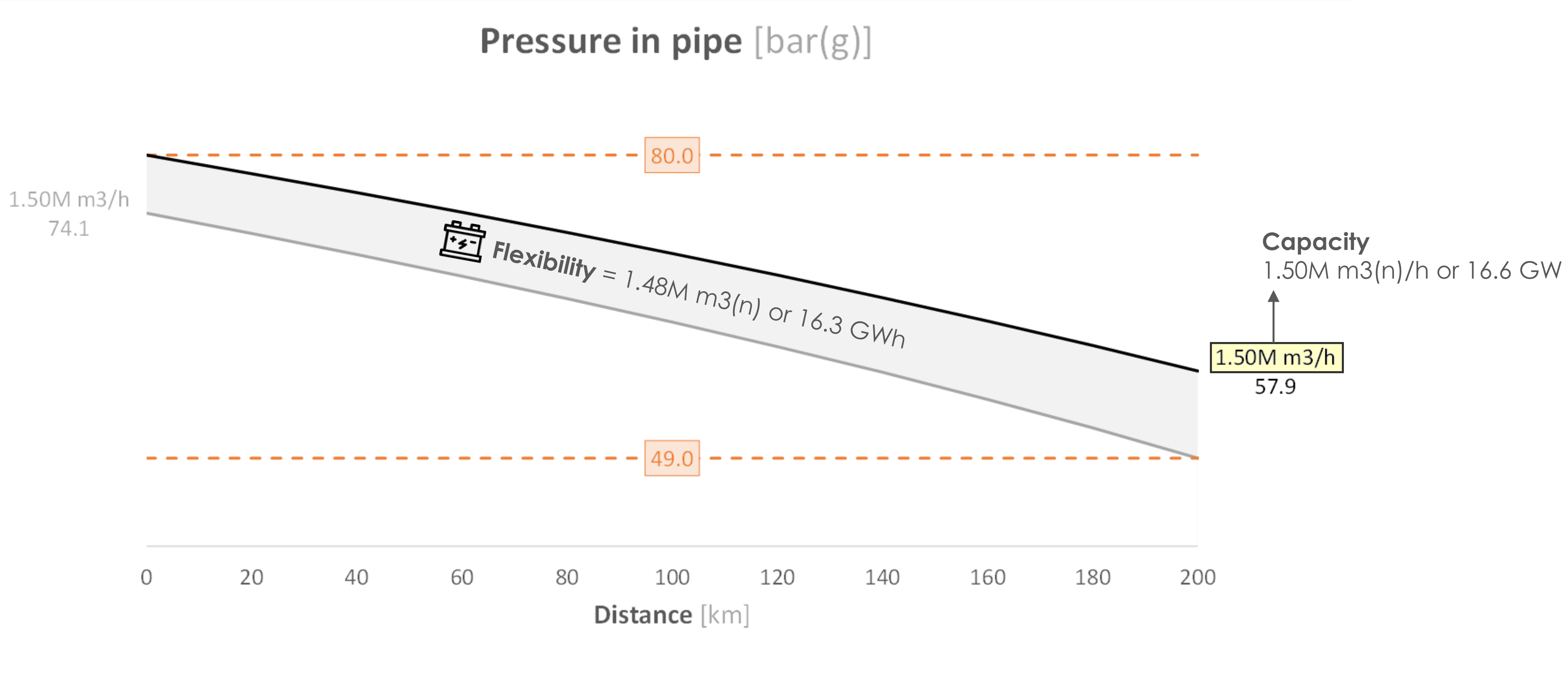
Depending on the overall pressure profile, different amounts of gas can be stored in the pipeline

CH_4



Pressure drop in pipes

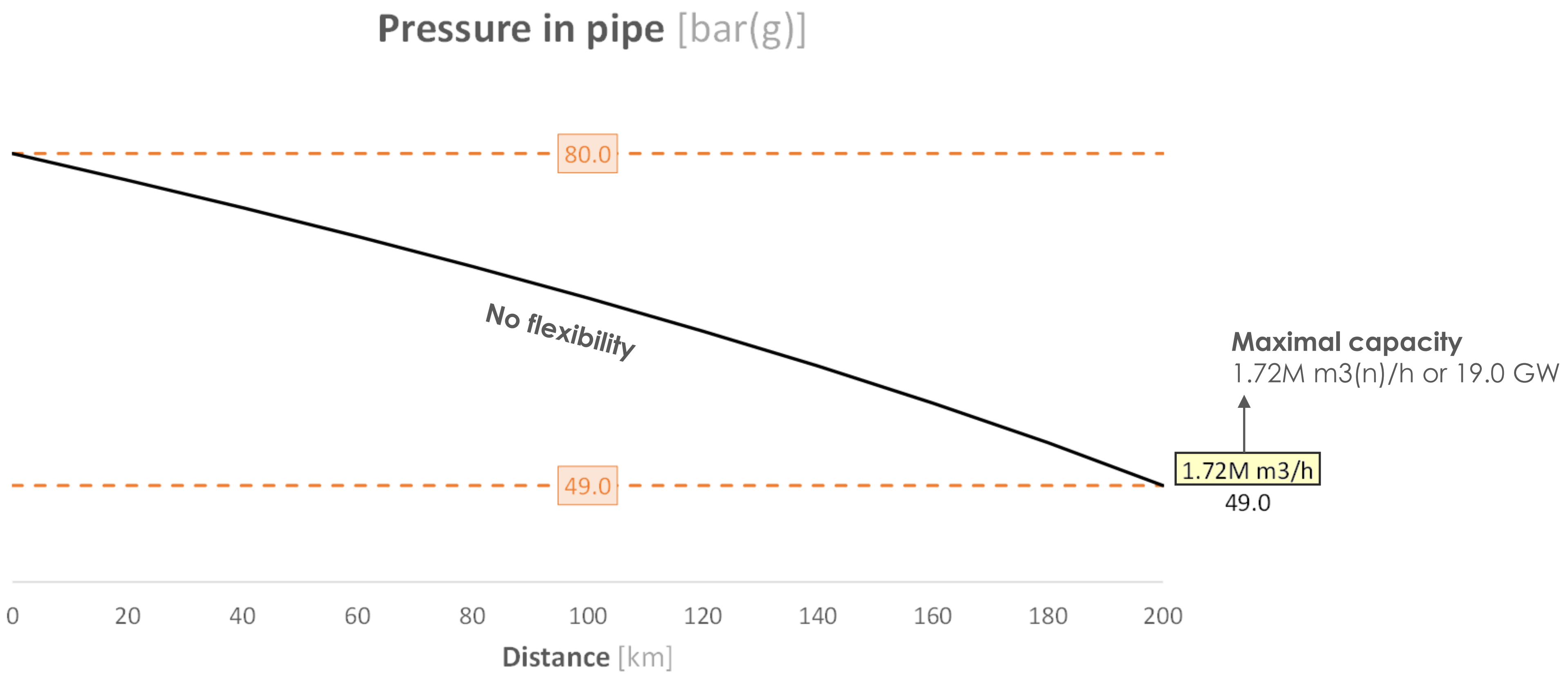
The range of gas volumes that can be stored is the flexibility of the pipe for a given flow (in this case the flexibility is typical and equal to one hour of capacity)



Pressure drop in pipes

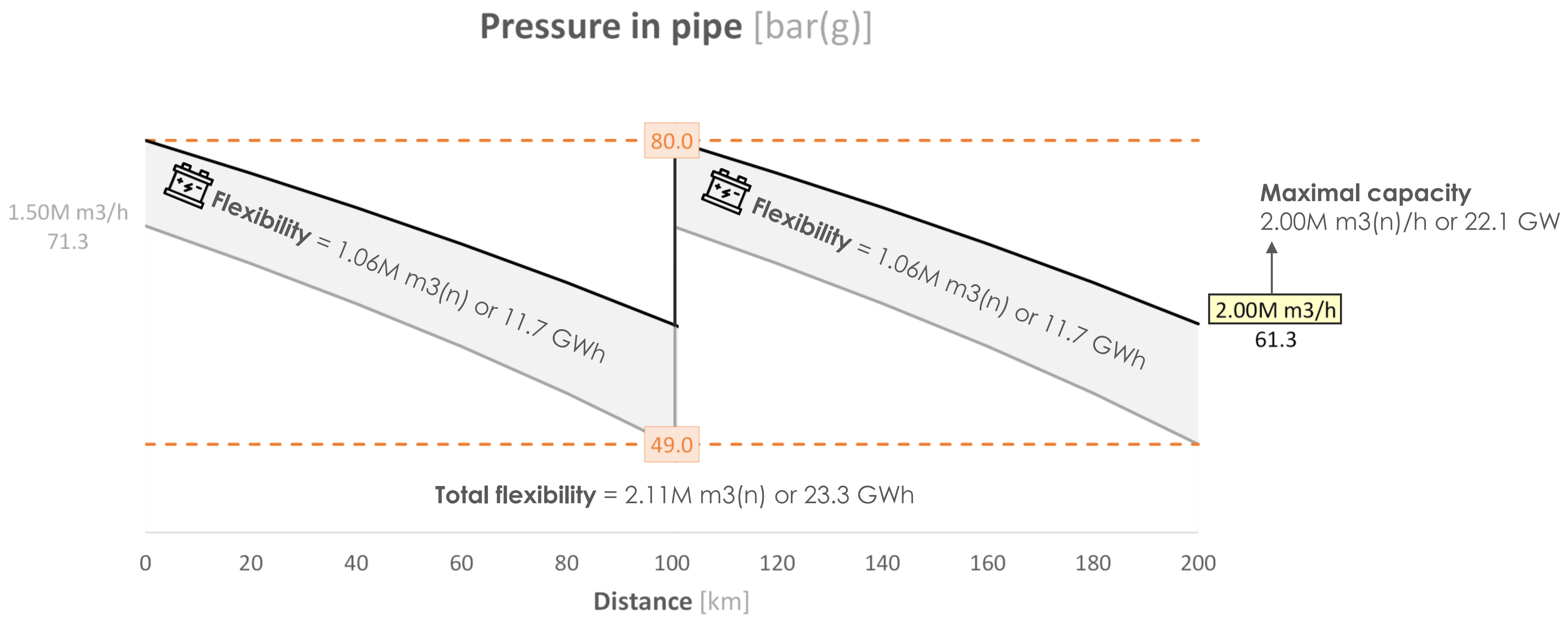
The pipe capacity can be maximized by removing any flexibility – but this will not allow to cover any demand fluctuation

CH_4



Pressure drop in pipes

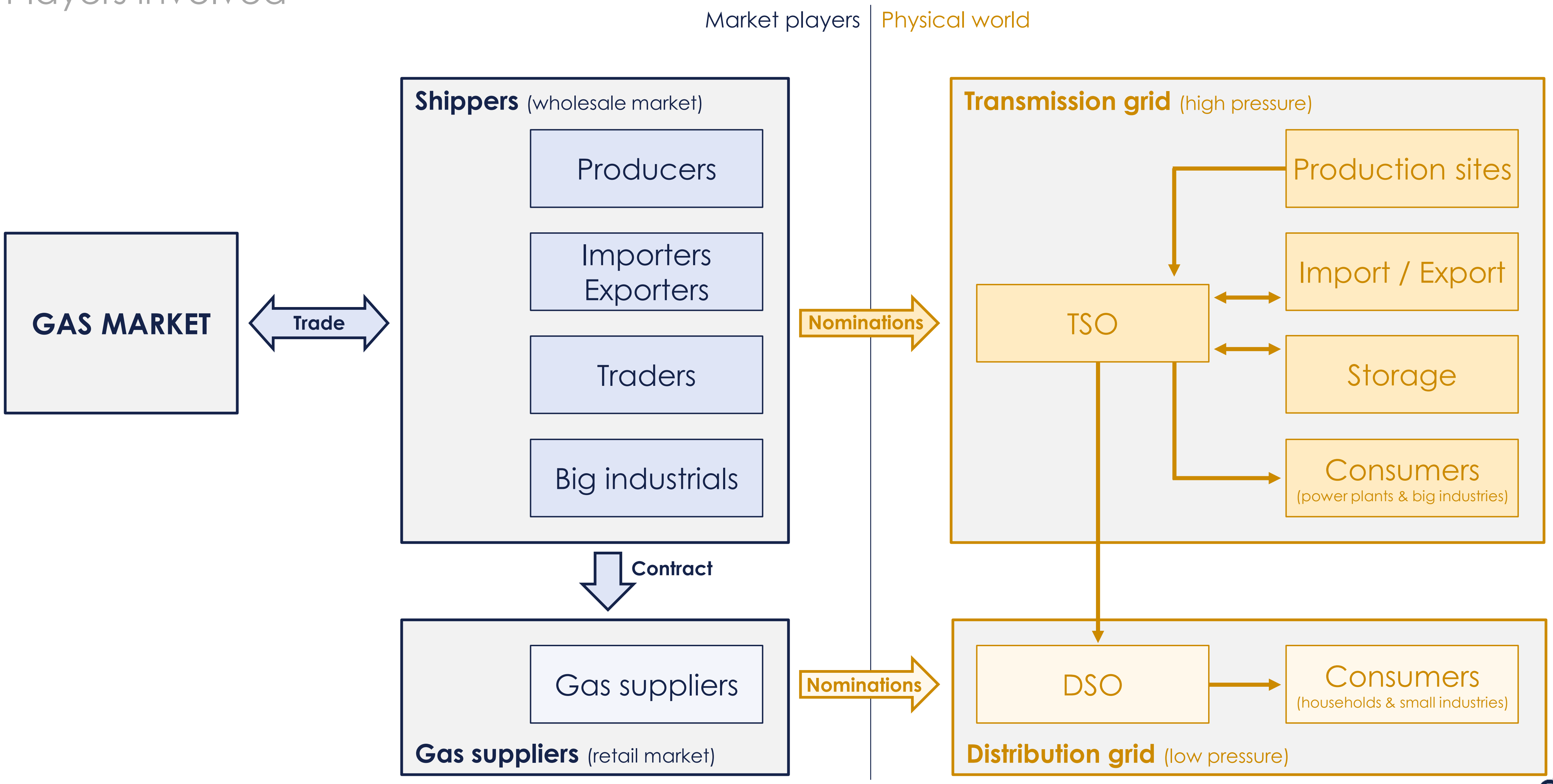
Another way of increasing the pipe capacity is to build compression stations



Contents

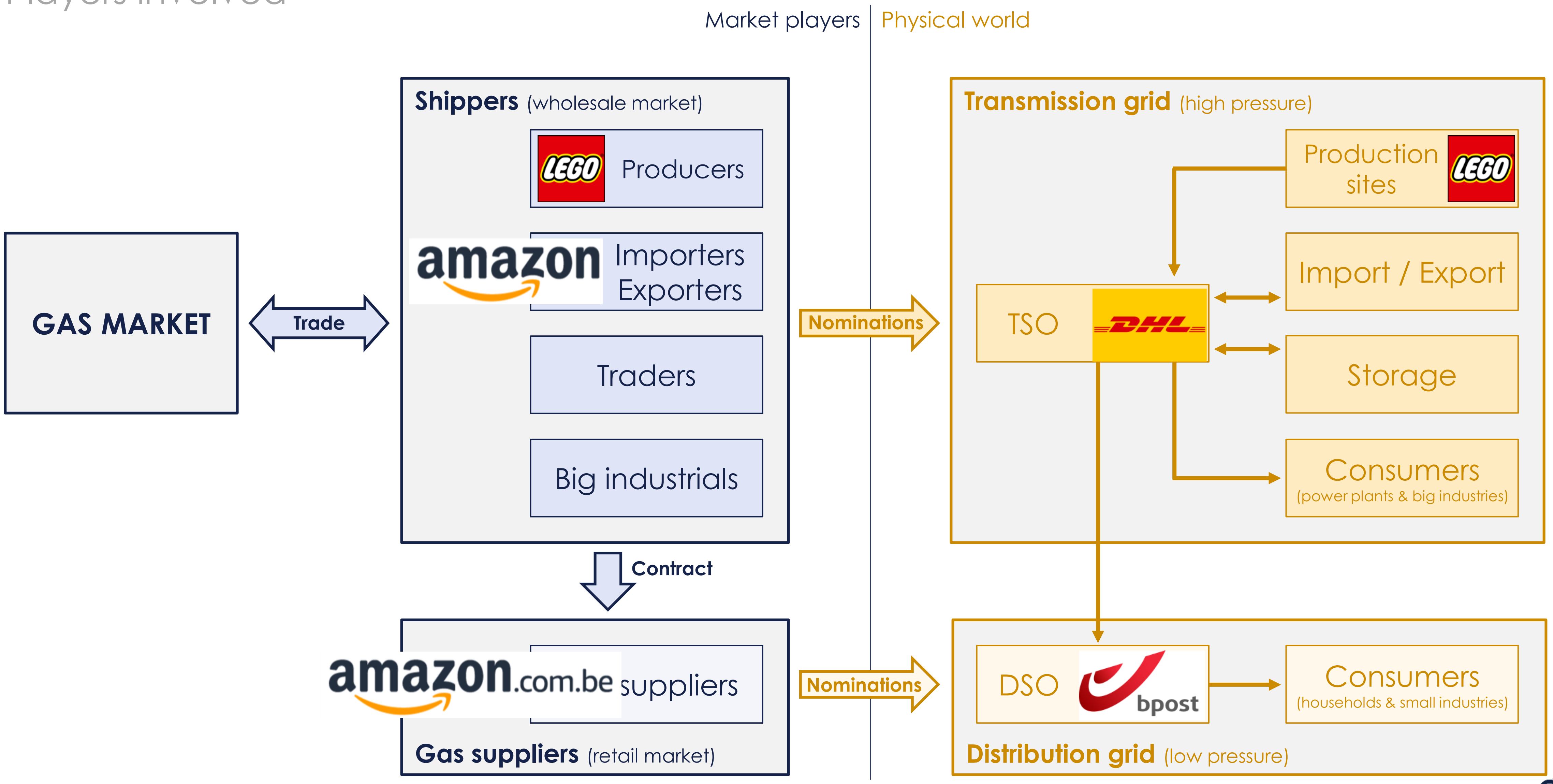
Gas markets

Players involved



Gas markets

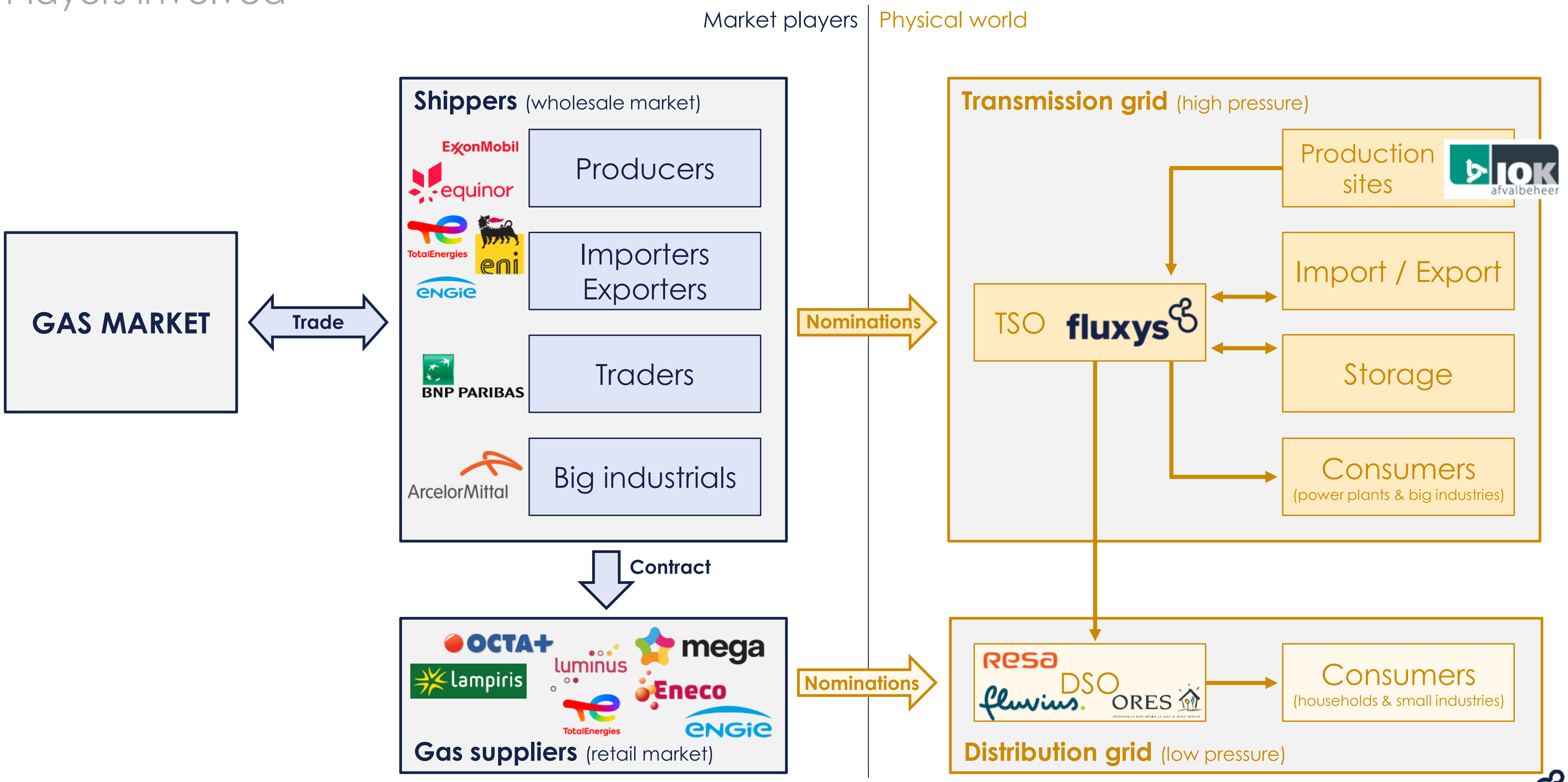
Players involved



Information only - non binding

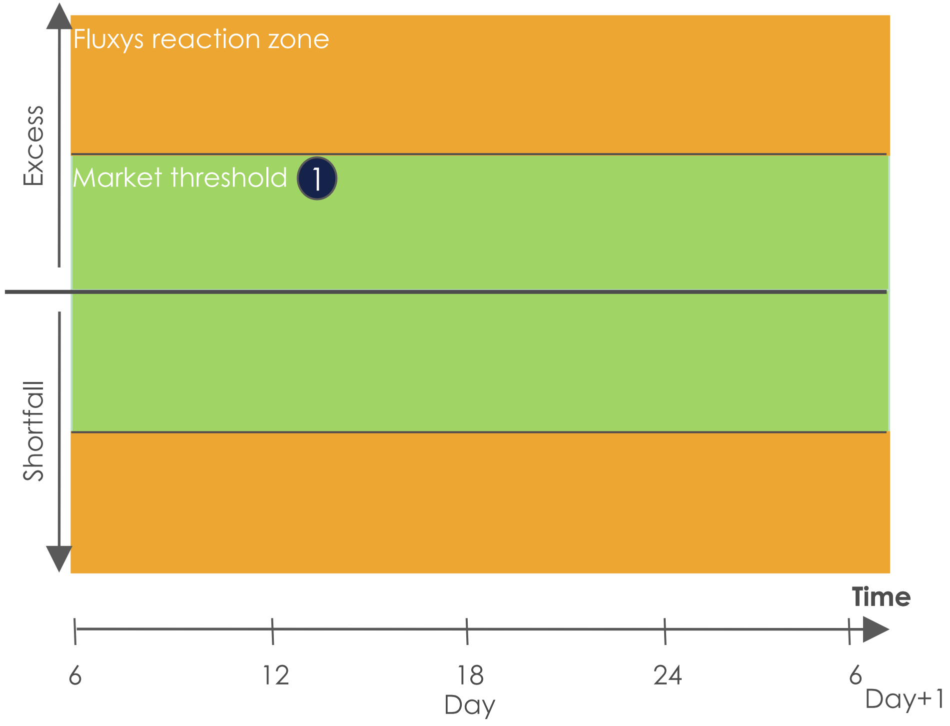
Gas markets

Players involved



Gas markets

The shippers are responsible for daily balancing



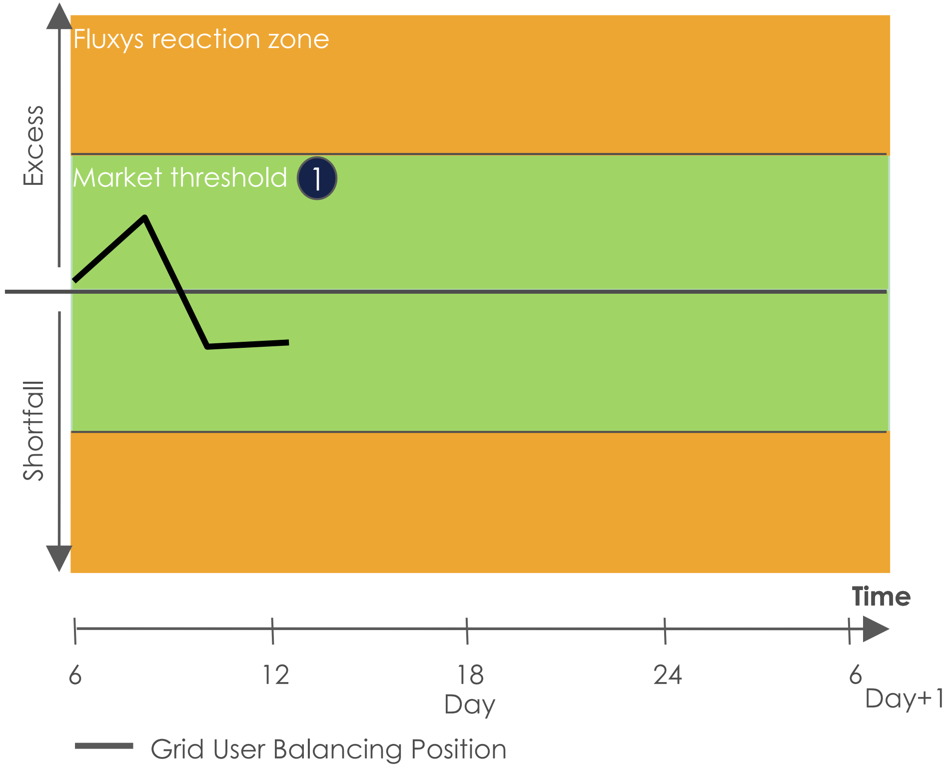
Daily Market Based Balancing

1. Thresholds to limit the aggregated market imbalances, sized to domestic market needs

The physical linepack is translated into commercial (intraday) flexibility for the market, but at the end of the gas day all gas must be balanced

Gas markets

The shippers are responsible for daily balancing



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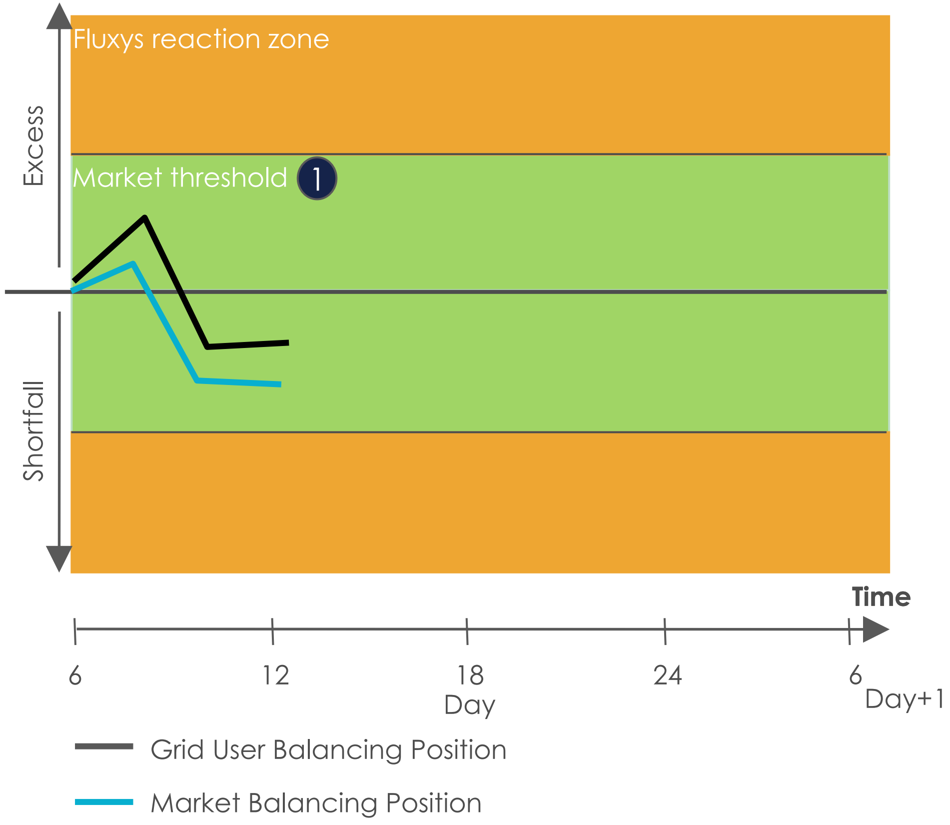

Daily Market Based Balancing

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Gas markets

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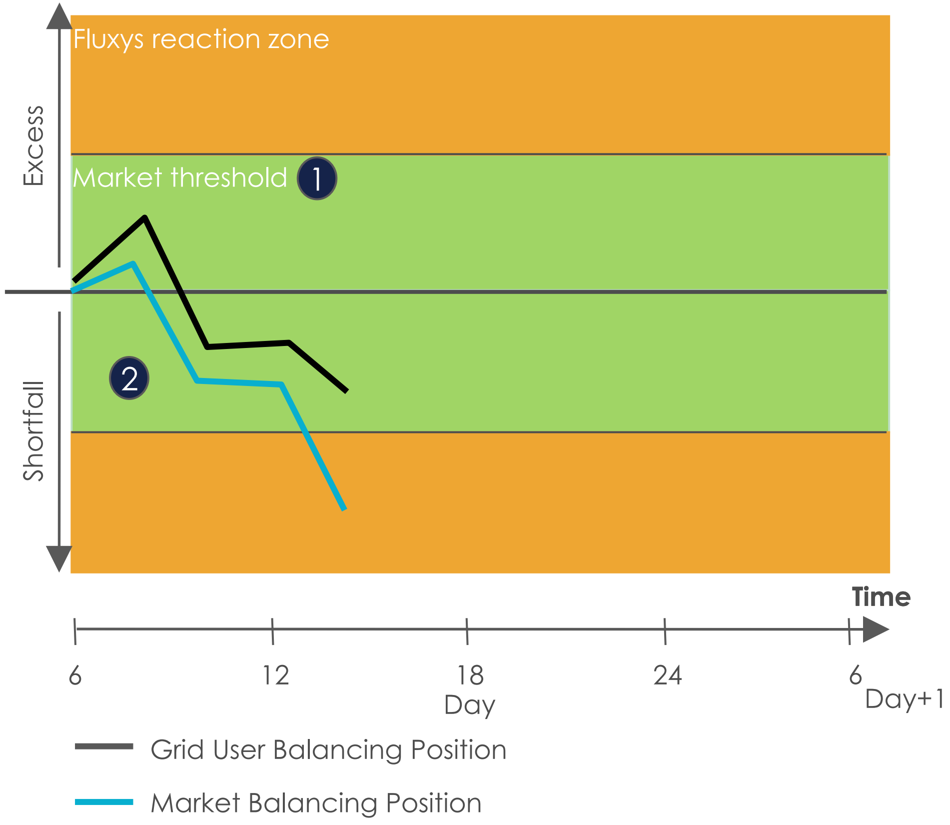


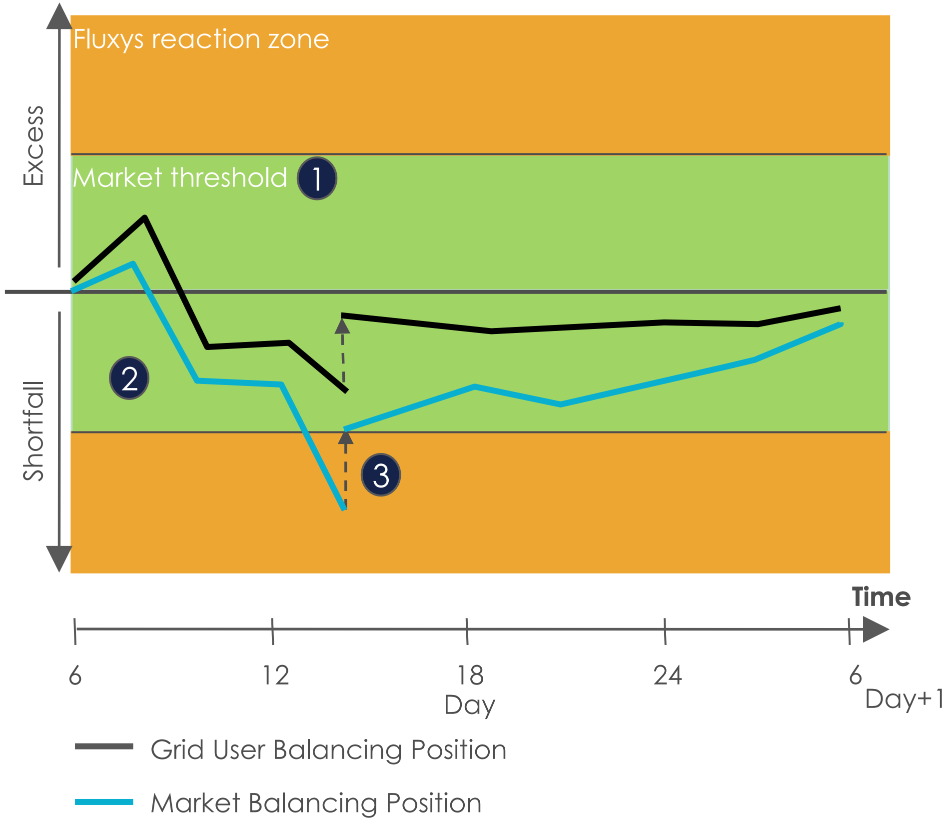
Daily Market Based Balancing

1. Thresholds to limit the aggregated market imbalances, sized to domestic market needs
2. No Fluxys Belgium action intra-day and no impact on market parties as long as market imbalance is within market threshold

The physical linepack is translated into commercial (intraday) flexibility for the market, but at the end of the gas day all gas must be balanced

Gas markets

The shippers are responsible for daily balancing



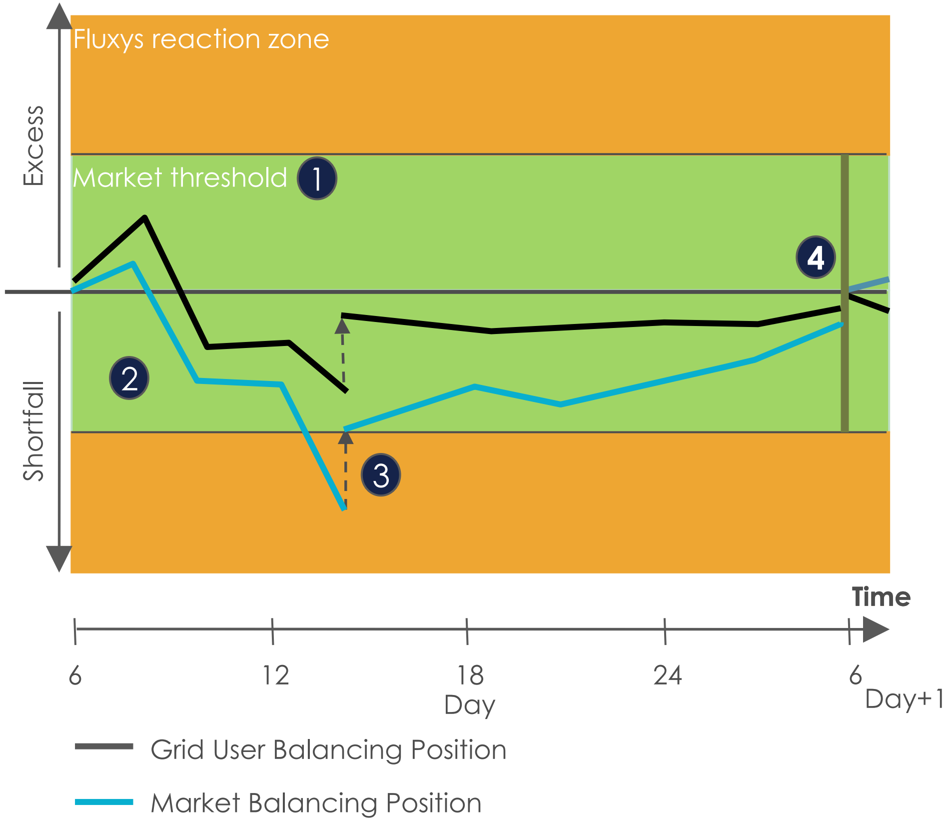
Daily Market Based Balancing

1. Thresholds to limit the aggregated market imbalances, sized to domestic market needs
2. No Fluxys Belgium action intra-day and no impact on market parties as long as market imbalance is within market threshold
3. Residual action initiated by Fluxys Belgium on the exchange when market position goes beyond market threshold, with cash compensation for causers

The physical linepack is translated into commercial (intraday) flexibility for the market, but at the end of the gas day all gas must be balanced

Gas markets

The shippers are responsible for daily balancing



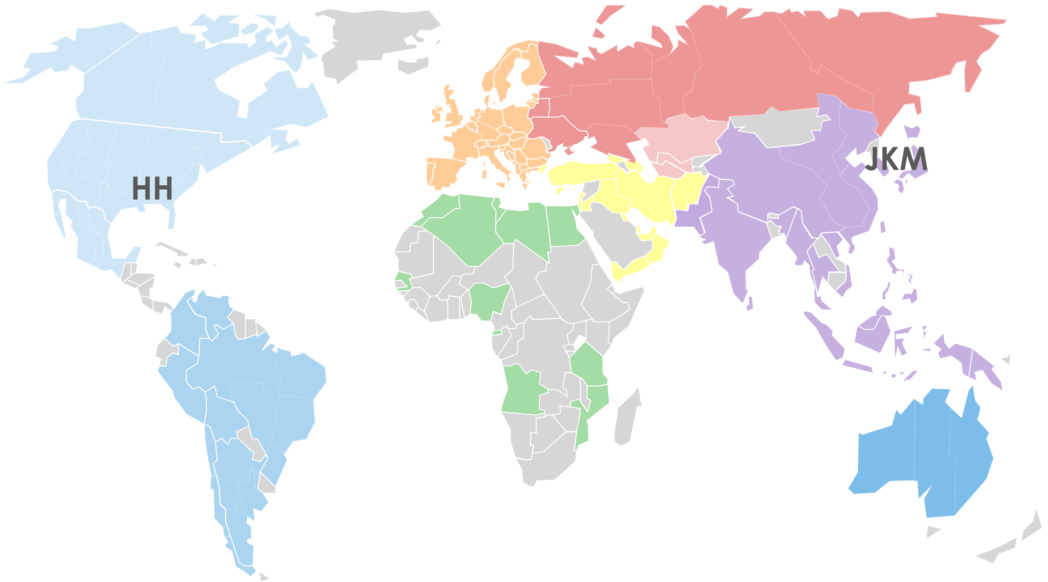
Daily Market Based Balancing

1. Thresholds to limit the aggregated market imbalances, sized to domestic market needs
2. No Fluxys Belgium action intra-day and no impact on market parties as long as market imbalance is within market threshold
3. Residual action initiated by Fluxys Belgium on the exchange when market position goes beyond market threshold, with cash compensation for causers
4. Residual end-of day imbalance settled in cash

The physical linepack is translated into commercial (intraday) flexibility for the market, but at the end of the gas day all gas must be balanced

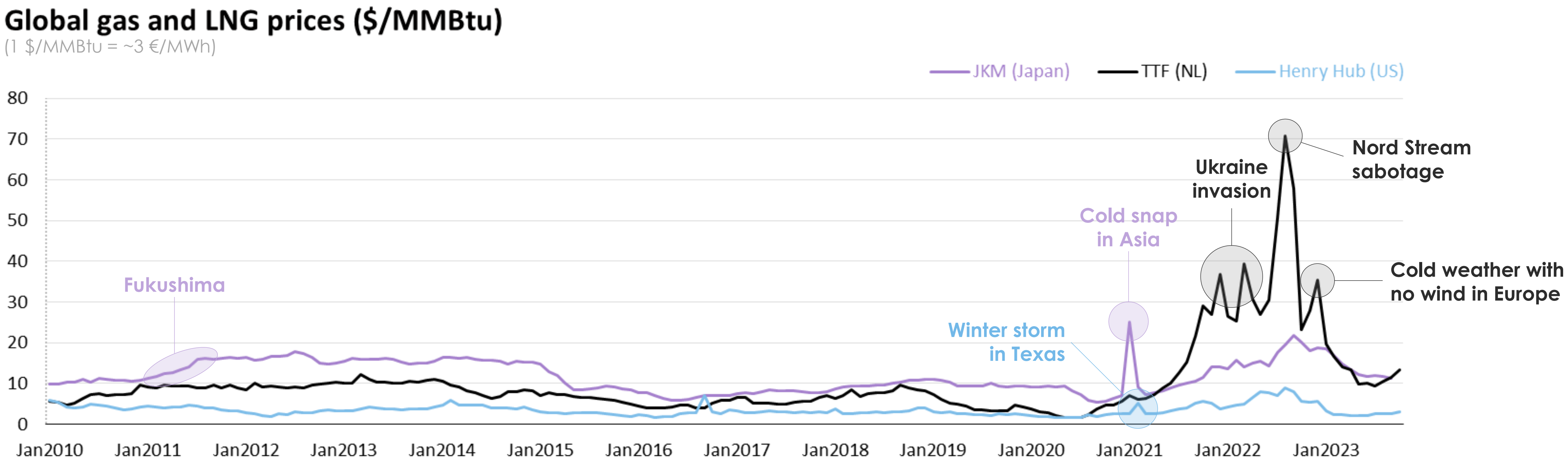
Gas markets

Major hubs and gas price indexes in the world



Gas markets

Major hubs and gas price indexes in the world



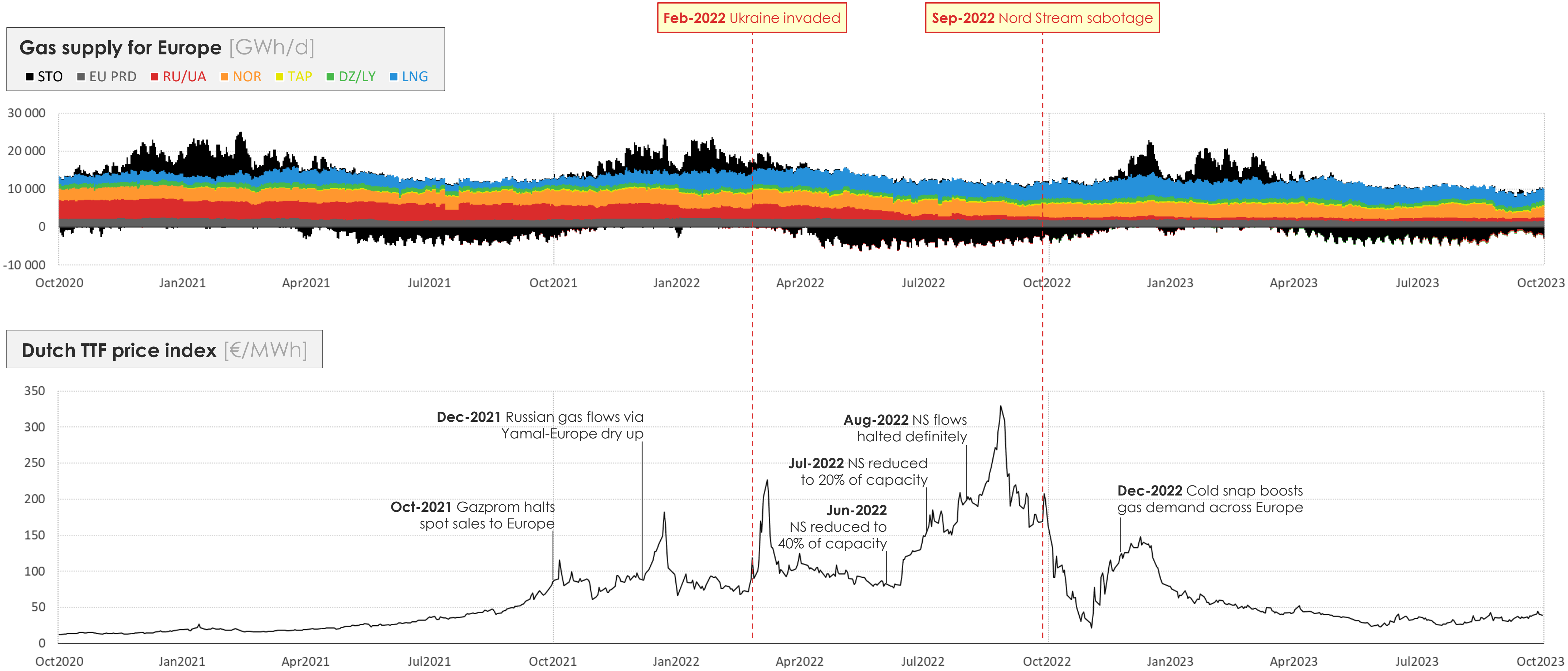
Data compiled Nov. 08, 2023.
Source: S&P Global Commodity Insights, Japan Ministry of Finance

Contents

Sources: data from ENTSOG transparency platform, GIE ALSI, GIE AGSI, Platts and National Grid

Natural gas supply for Europe

Europe = EU27 + UK + Switzerland + Balkans

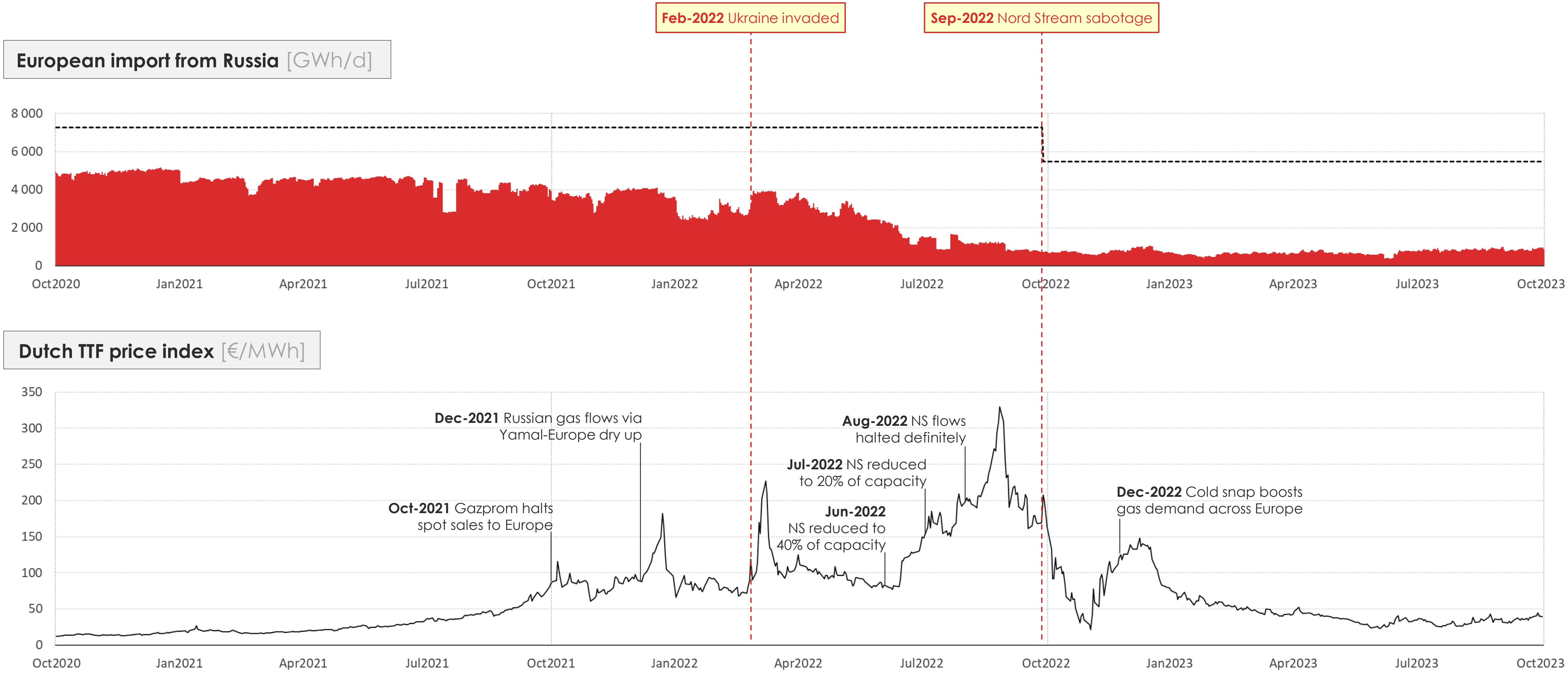


Sources: data from ENTSOG transparency platform, GIE ALSI, GIE AGSI, Platts and National Grid

CH4

Natural gas supply for Europe

Europe = EU27 + UK + Switzerland + Balkans

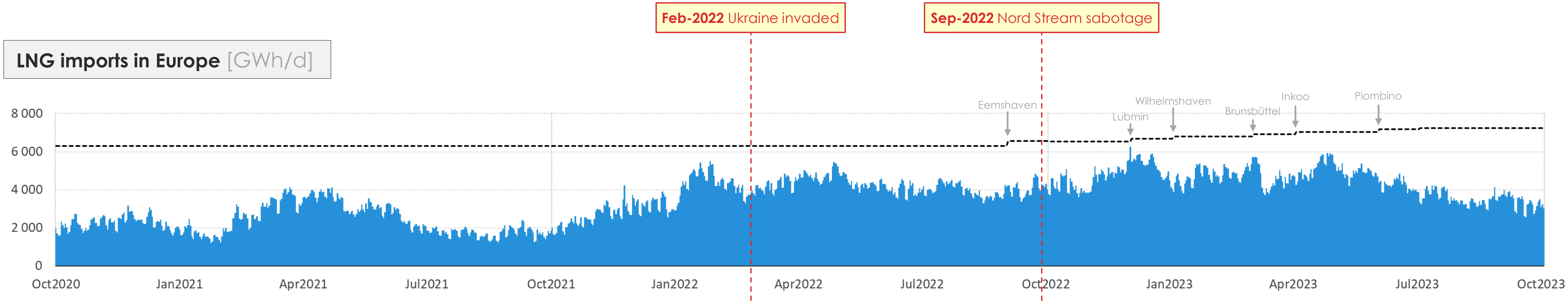


Sources: data from [ENTSOG transparency platform](), [GIE ALSI](), [GIE AGSI](), Platts and [National Grid]()

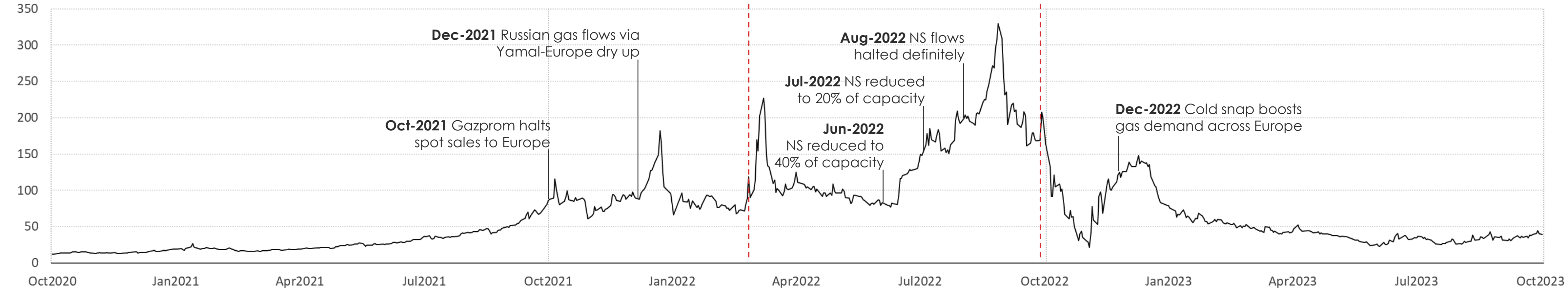
Natural gas supply for Europe

Europe = EU27 + UK + Switzerland + Balkans

LNG imports in Europe [GWh/d]



Dutch TTF price index [€/MWh]



Sources: data from ENTSOG transparency platform, GIE ALSI, GIE AGSI, Platts and National Grid

CH_4

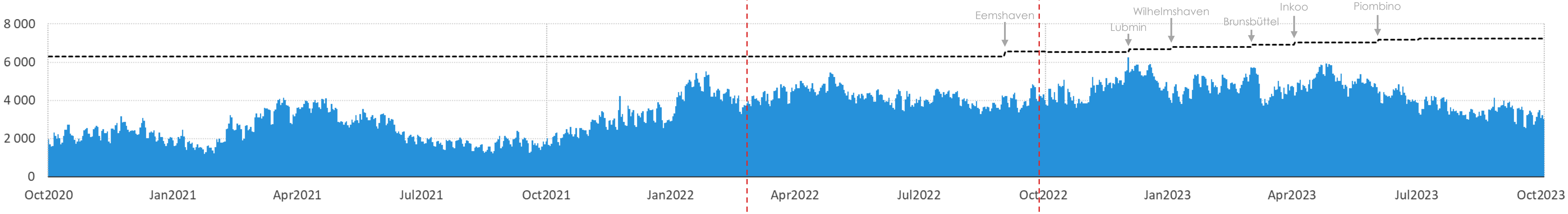
Natural gas supply for Europe

Europe = EU27 + UK + Switzerland + Balkans

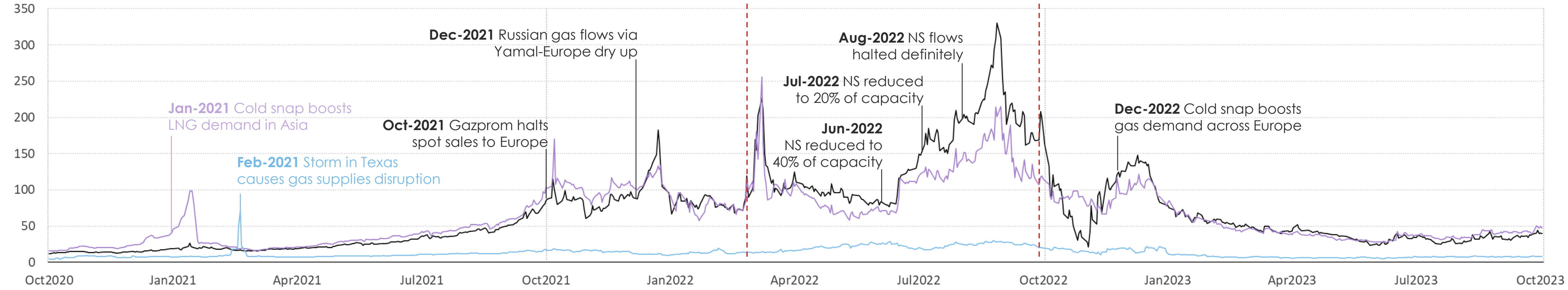
Feb-2022 Ukraine invaded

Sep-2022 Nord Stream sabotage

LNG imports in Europe [GWh/d]



Dutch TTF, Japan JKM and US Henry Hub price indexes [€/MWh]

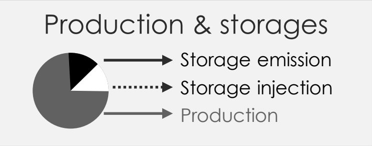


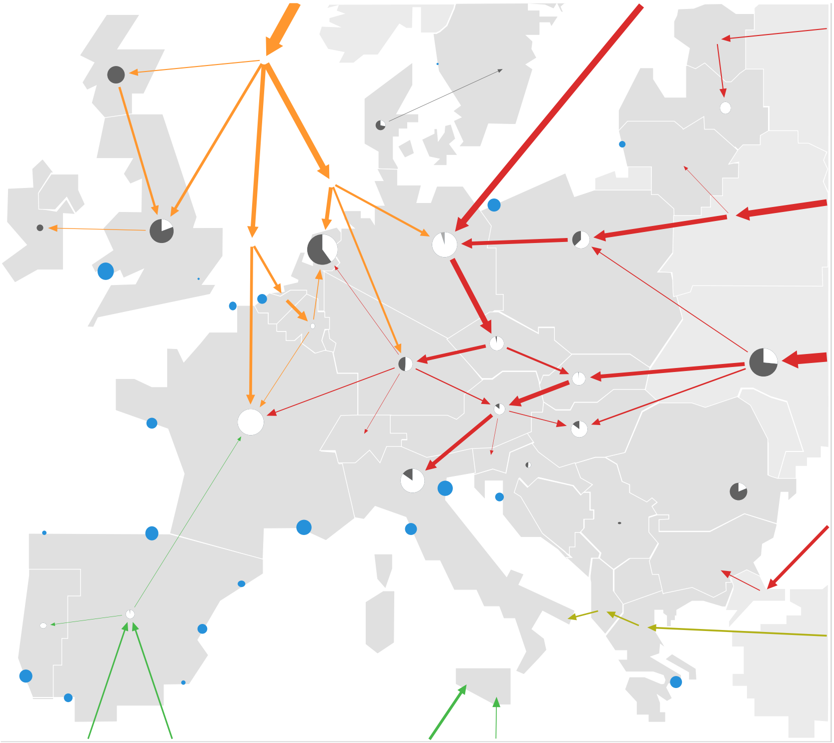
CH_4

Natural gas flows in Europe

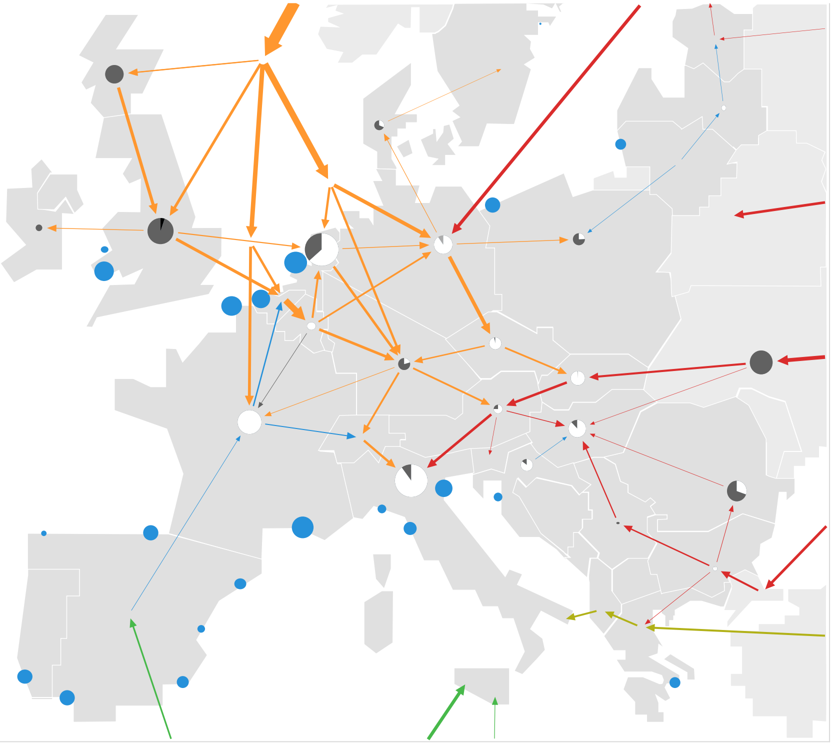
Europe = EU27 + UK + Switzerland + Balkans

Sources: data from ENTSOG transparency platform, GIE ALSI, GIE AGSI, Platts and National Grid

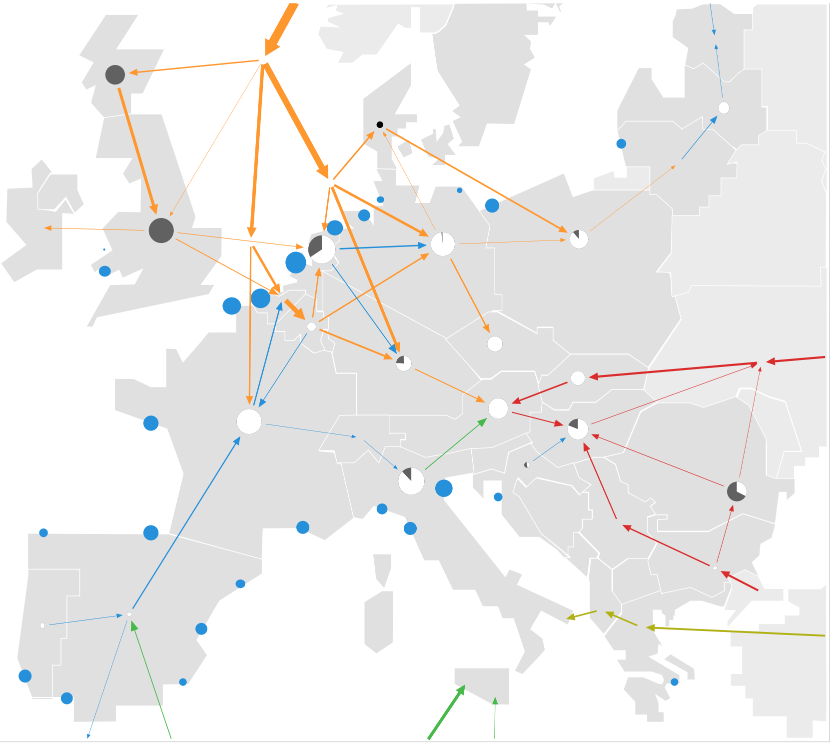




June 2021



June 2022



June 2023

■ STO ■ EU PRD ■ RU/UA ■ NOR ■ TAP ■ DZ/LY ■ LNG

Congestion in Europe

Europe = EU27 + UK + Switzerland + Balkans

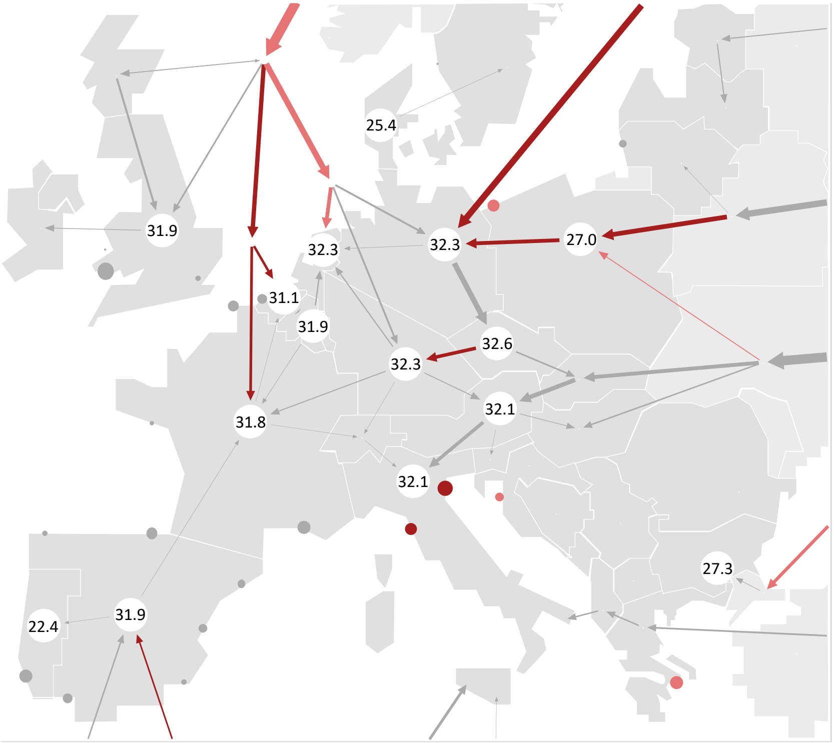
Sources: data from ENTSOG transparency platform, GIE ALSI, GIE AGSI, Platts and National Grid

CH_4

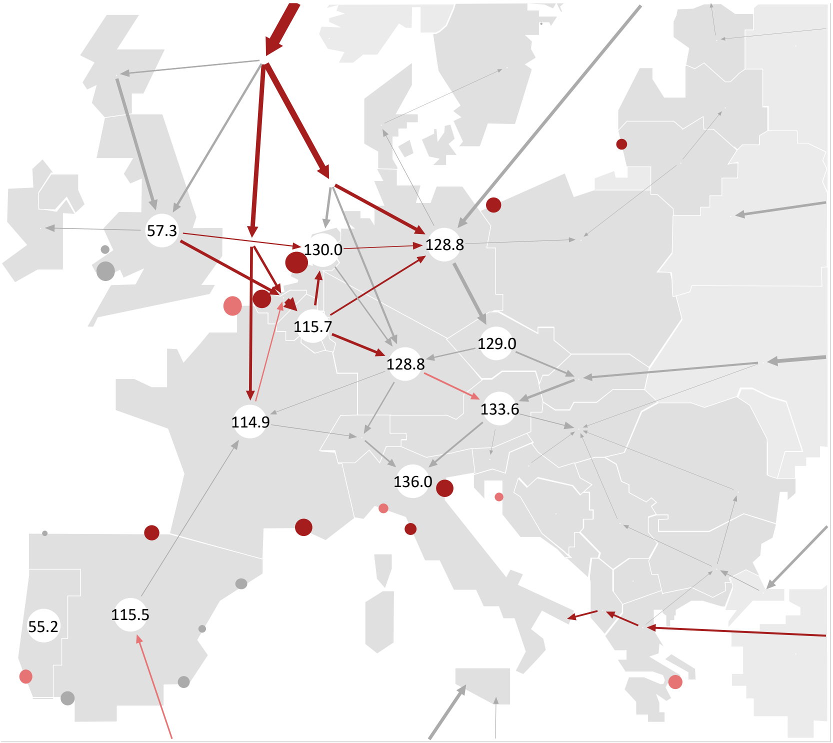
Mean utilization rate (HCG only)

> 90% > 75%

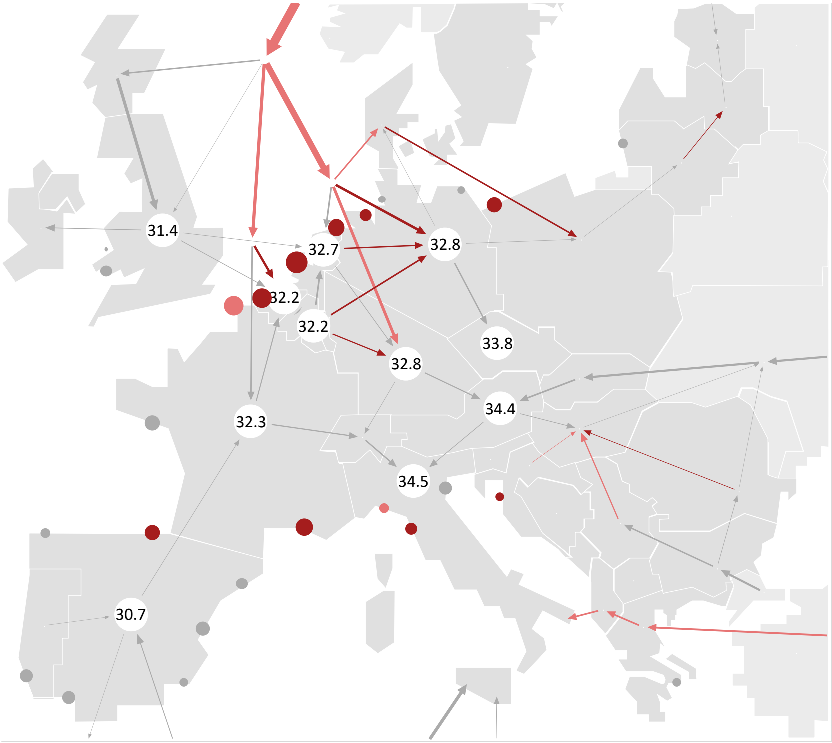
31.6 Market prices (€/MWh)



June 2021



June 2022



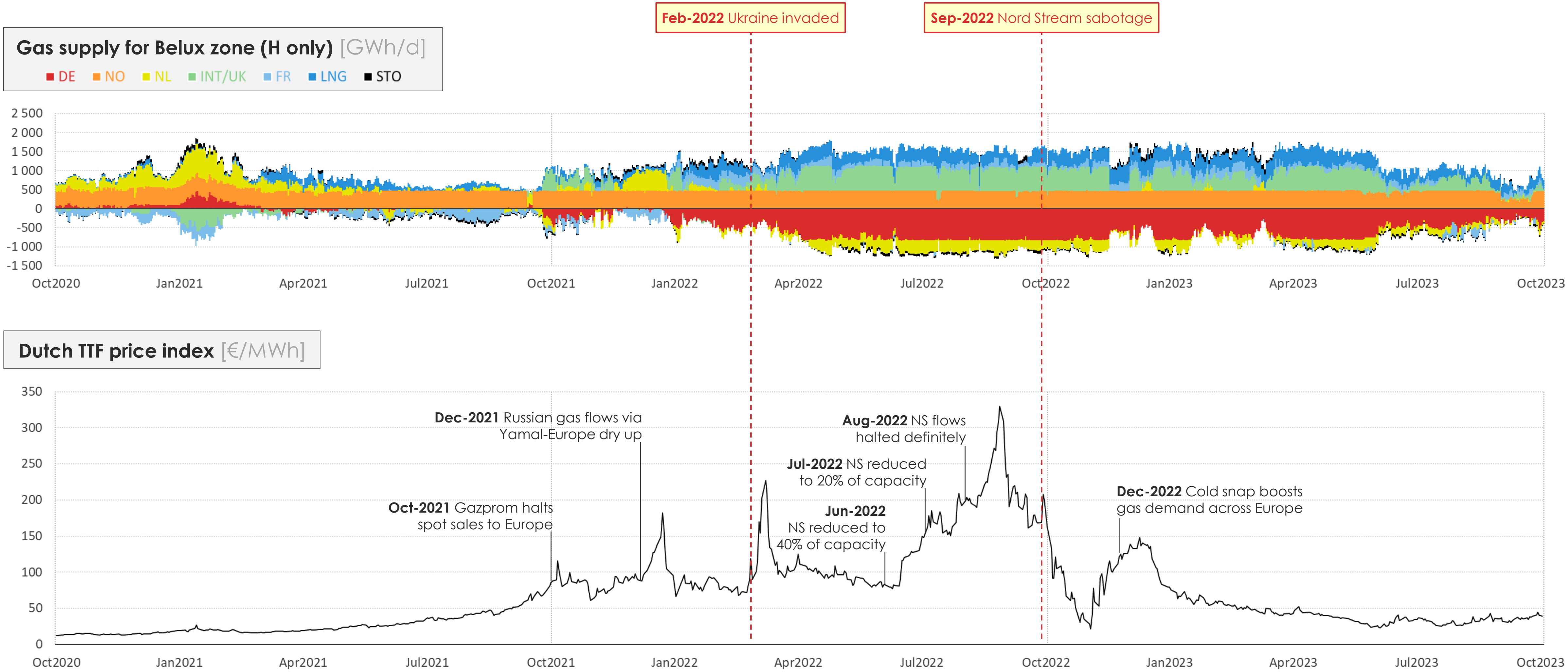
June 2023

Sources: data from ENTSOG transparency platform, GIE ALSI, GIE AGSI, Platts and National Grid

CH_4

Natural gas flows in Belux zone

Net flow = entry flow – exit flow



Contents

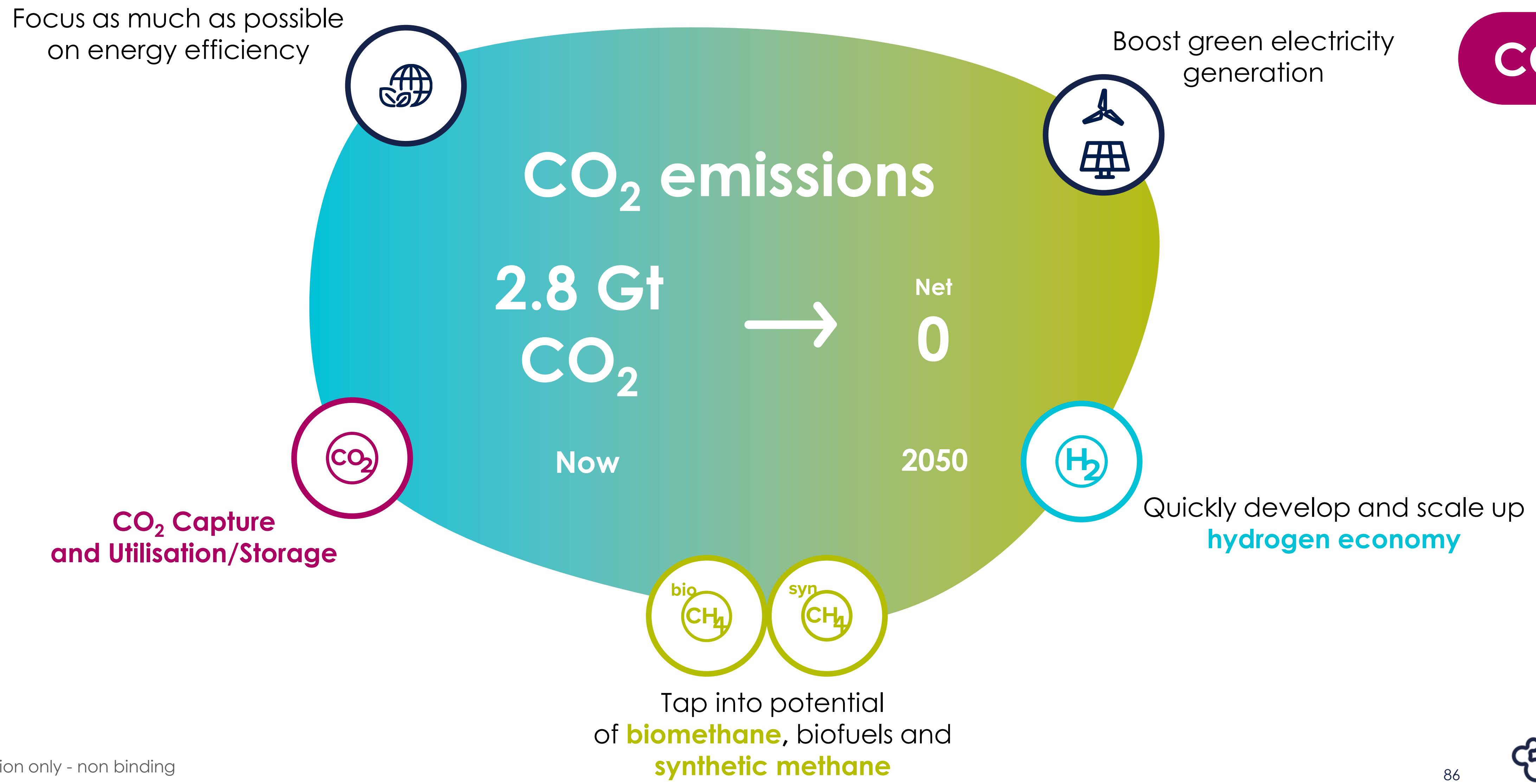
EU Green Deal

We need a mix of solutions to achieve the net zero target

CH_4

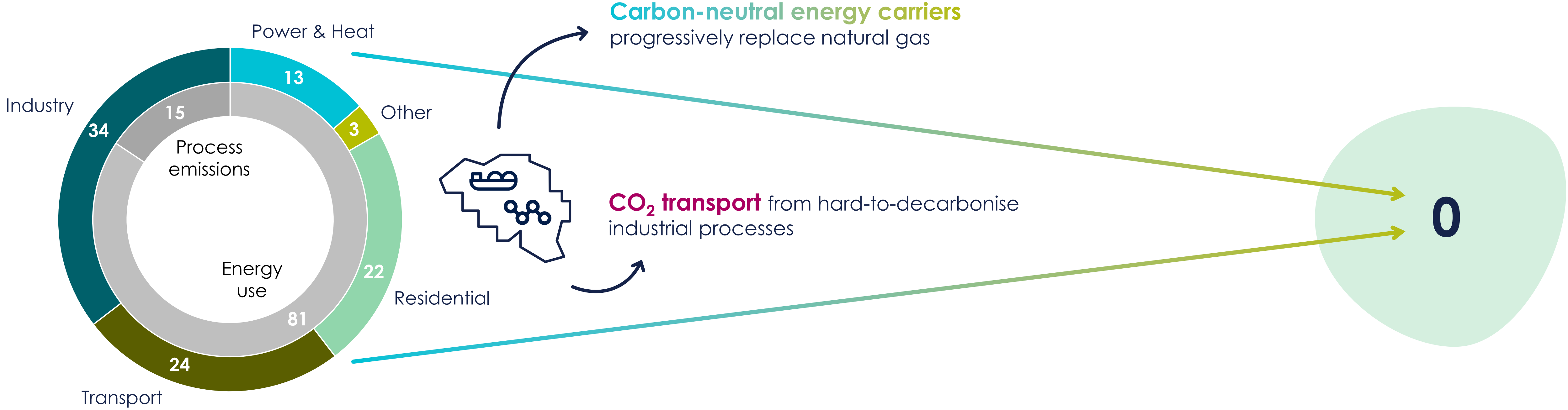
H_2

CO_2



CH_4
H_2
CO_2

Our infrastructure as key contributor to net zero



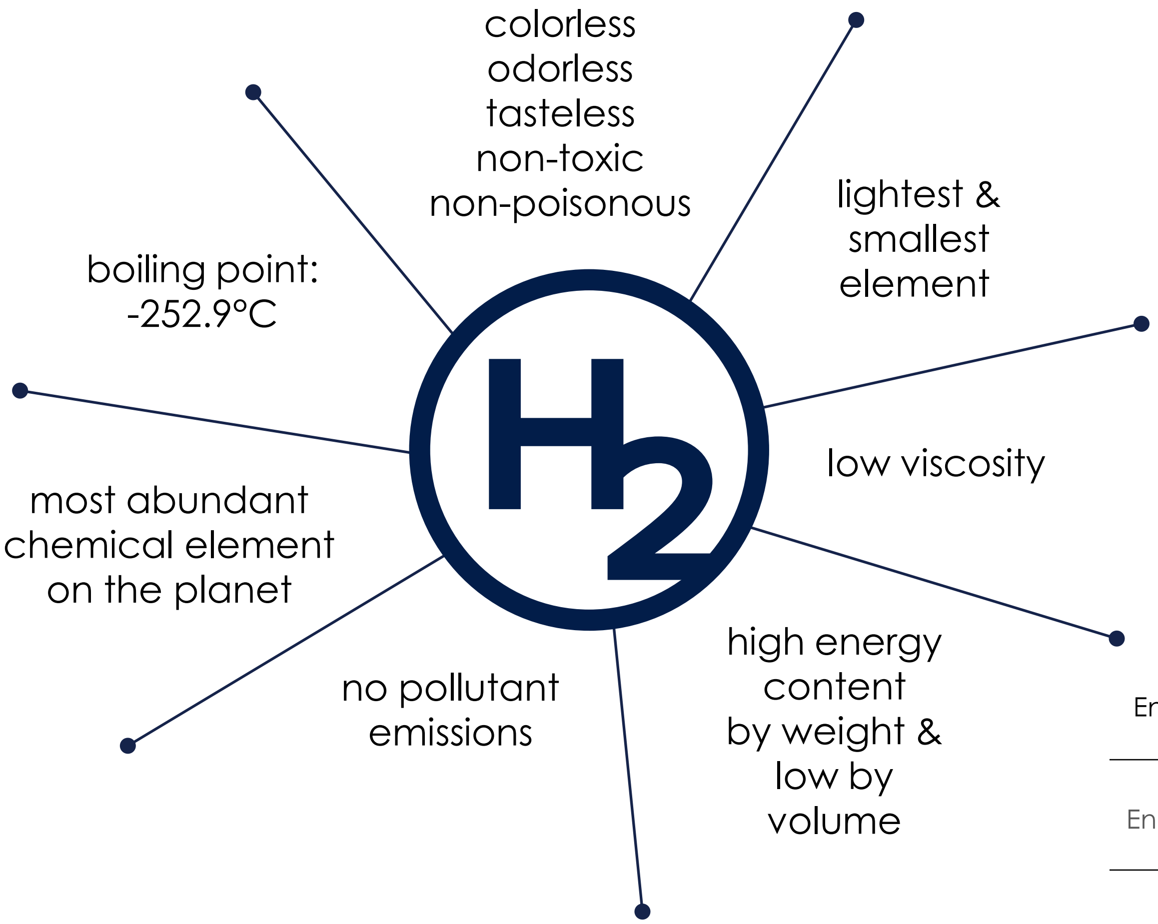
2021

CO_2 emission
96 million tonnes/year

2050

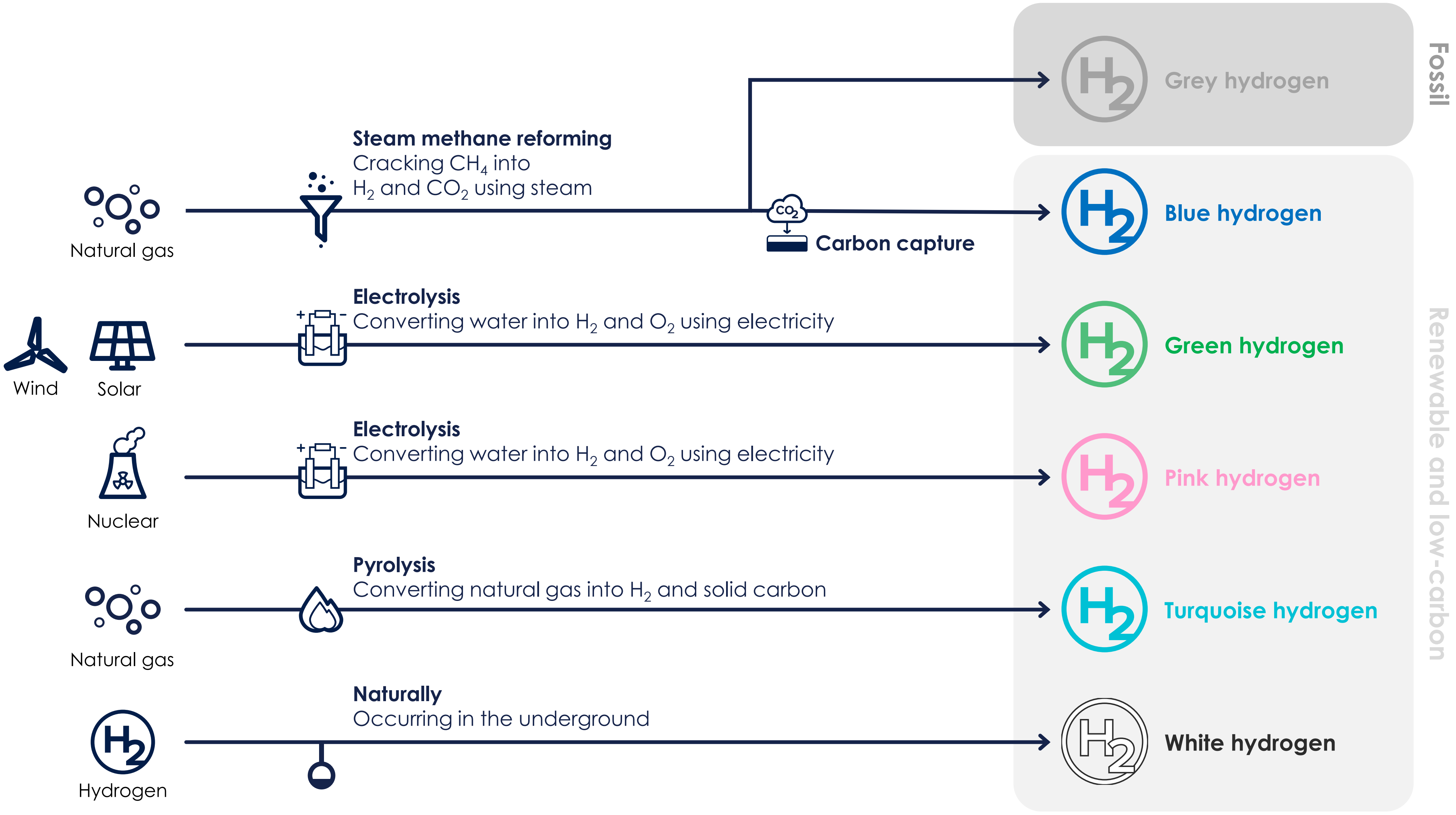
No CO_2 emission

What is H_2 or hydrogen?



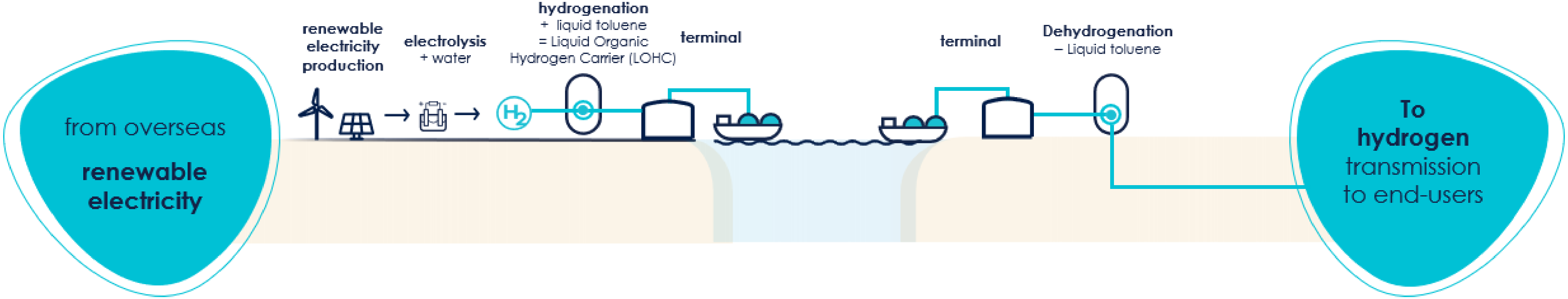
Energy content by weight	CH_4	X 2.5	H_2
Energy content by volume	H_2	X 3	CH_4
Volumetric density	H_2	X 8	CH_4

The colours of hydrogen



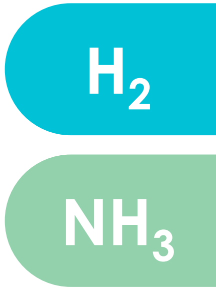
Hydrogenation

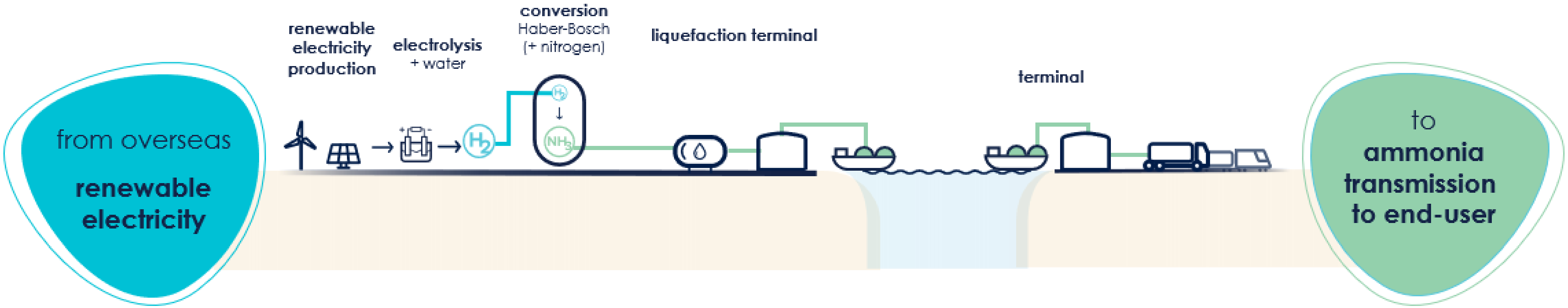
Long distance transport possible with hydrogenation

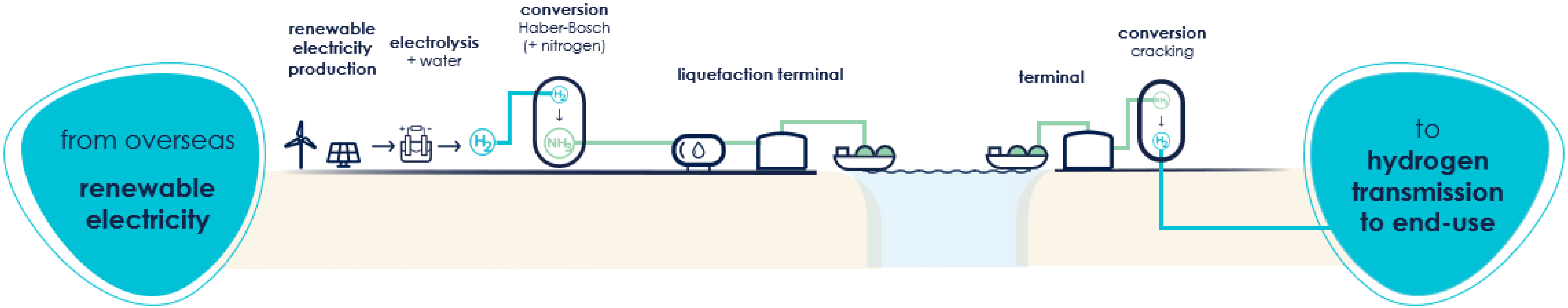


Renewable hydrogen and renewable ammonia

Long distance transport also possible thanks to ammonia

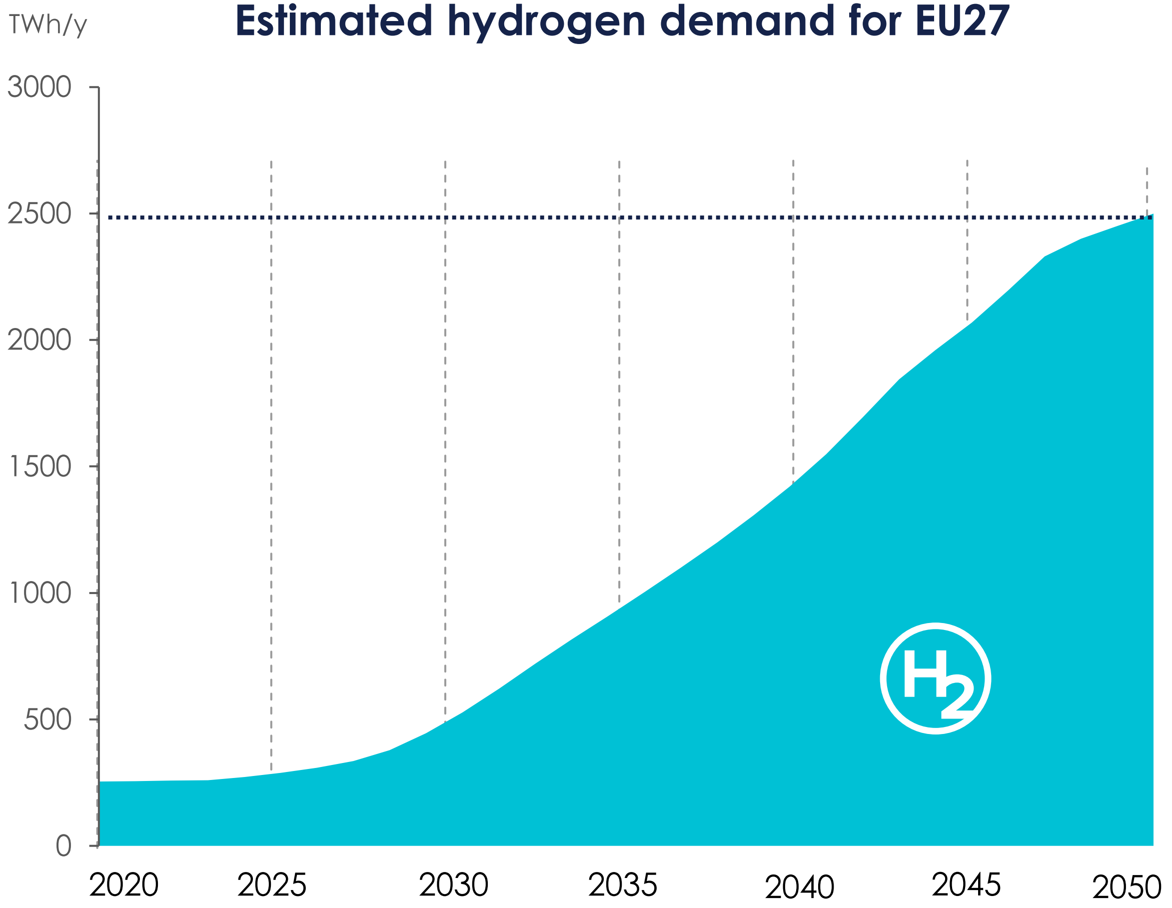






Hydrogen, the all-rounder for a climate-neutral economy

Estimated hydrogen demand for EU27



Source: ENTSOG

EU27 potential 2050
1 600 – 2 500 TWh/y

700-800 — **industry**
feedstock, reducing agent (steel), fuel for high-temperature processes

500-700 — **transport**
fuel for shipping, aviation, buses, heavy-duty vehicles

200-500 — **power**
fuel for peak & back-up capacity, medium for energy storage and transport

200-500 — **buildings**
fuel for heating in areas where district heating systems and heat pumps are challenging

What is CO_2 or carbon dioxide?

colorless
odorless
relatively non-toxic
non-combustible

heavier than air

boiling point: -78°C

CO_2

soluble in water

Uses:
- freeze food
- control chemical reactions
- as a fire extinguishing agent
- …

forms carbonic acid, a mild acid

CO_2

Carbon capture and storage/utilisation crucial for industry to decarbonise while keeping competitive

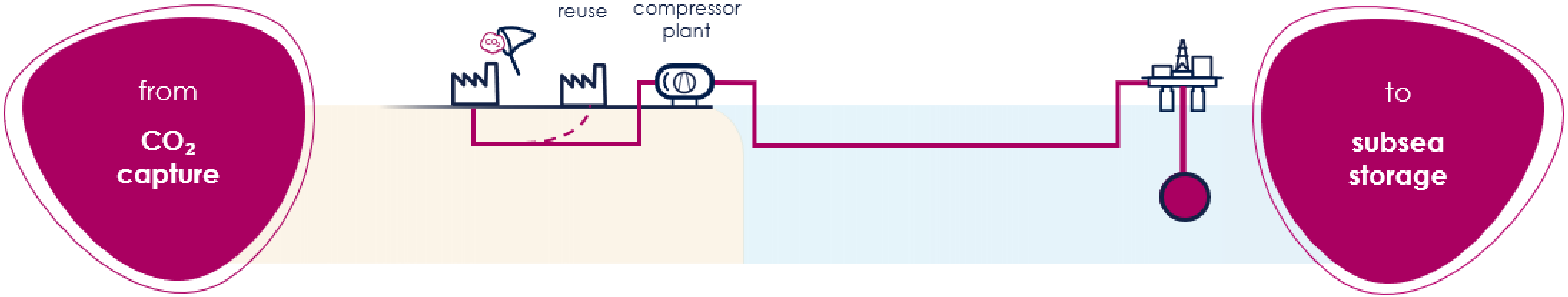
Do-or-die decarbonisation solution for **hard-to-abate industry**

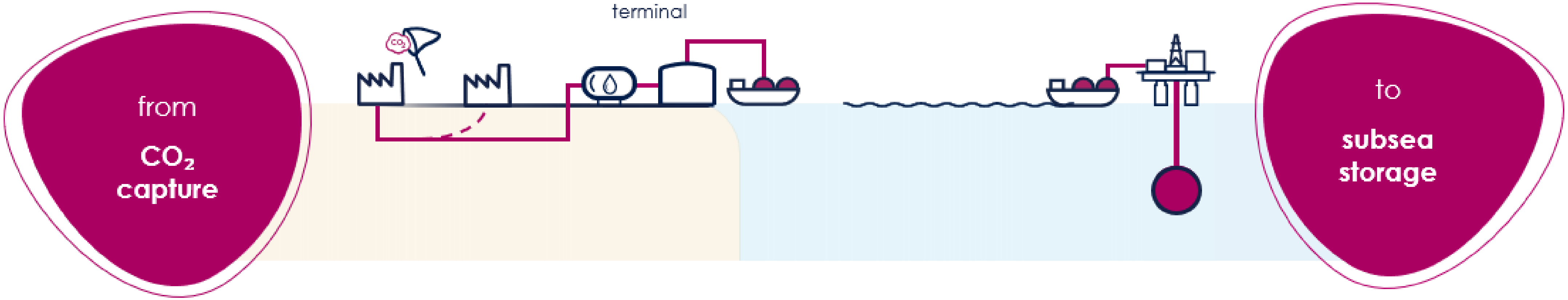
Essential for large volumes of affordable **low-carbon hydrogen**

Key for **low-carbon electricity generation** to keep the lights on

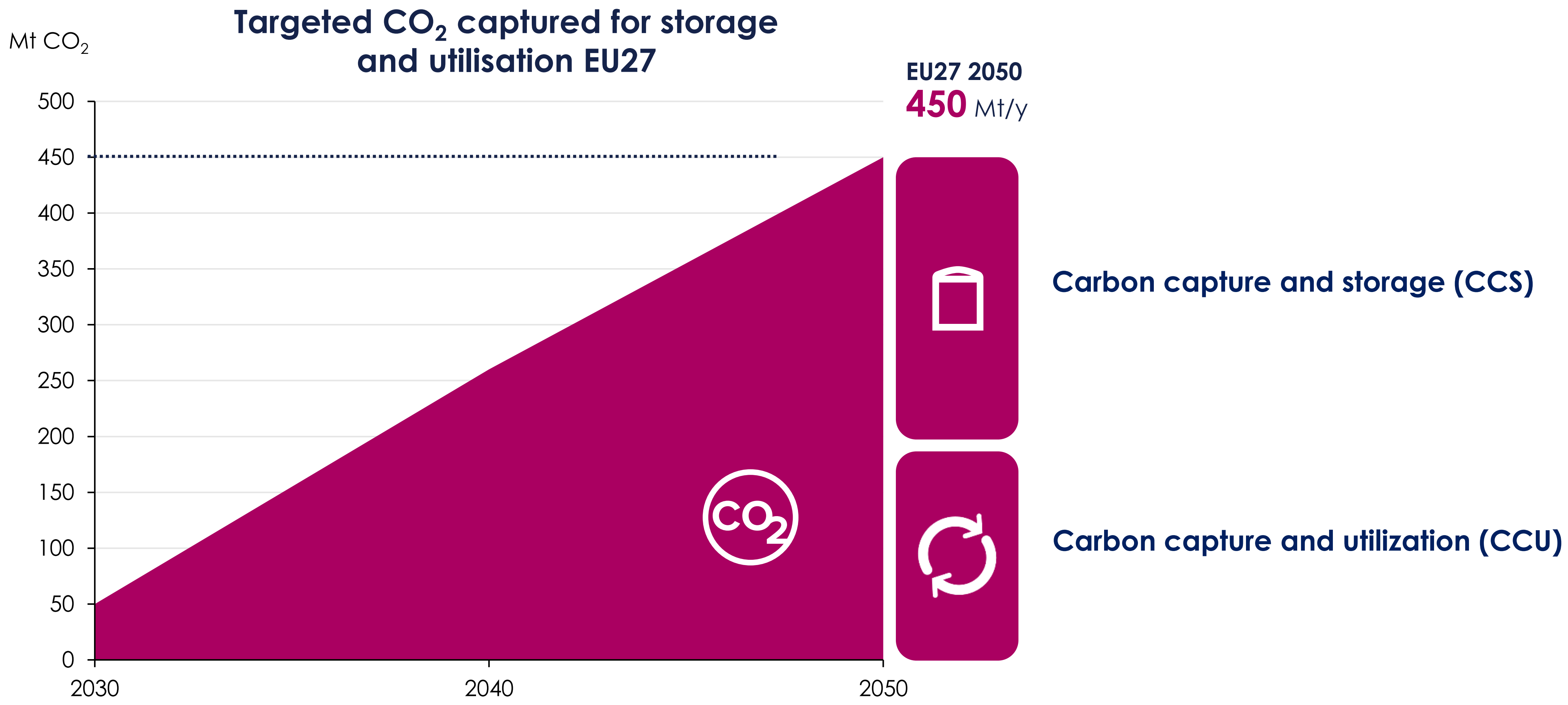
CCUS value chain

CO_2





Carbon capture and storage/utilisation increasingly important mitigation pathway



Source: EU Industrial Carbon Management Strategy

'INTEGRATION' model

This multi-energy model, co-developed by Fluxys and ULiège, allows to study how to reach net-zero

fluxys

LIÈGE université

INPUTS	MODEL	OUTPUTS	INSIGHTS
Energy demand (yearly values + hourly time series) **Renewable production** (max potential + hourly time series) **Import assumptions** (availability & cost) **Technical parameters** (for technologies & infrastructure) **Cost assumptions** (CAPEX, OPEX, WACC…) **CO_2 reduction target** (max budget & emission factors)	**Goal: simulate the interactions between electricity and molecules in a carbon-neutral energy system** CH_4 · H_2 & derivatives · CO_2 **Scope?** → Belgium, with offshore – coastal – inlad regions → 2050, hourly resolution **How?** → linear optimization → investments & dispatch **Modelling assumptions** → central planning / one player → perfect foresight (no uncertainty, no 'N-1 SoS') → no distances within countries	**Optimal capacities** (investments in infra & technologies) **Optimal dispatch** (hourly flows) **Energy not served & curtailments** **CO_2 emissions** (global & by country) **Global system cost** **Marginal prices** (energy supply & CO_2 abatement cost)	**H_2 and CO_2 transport** Which factors impact the transit through Fluxys potential pipelines? **Flexibility to the system** How, where and when can the molecules help to compensate the intermittency of renewables? **Impact of electrification** How does the system cost change for different demand scenarios? **Import dependency** Impact of import costs? How to reduce import dependency? …

This model has been built for Belgium by ULiège & Fluxys during an **ETF project financed by SPF Economie**

Results can be seen on https://integrationdemonstrator.github.io/)

Academic papers linked to the 'INTEGRATION' model

The Role of Power-to-Gas and Carbon Capture Technologies in Cross-Sector Decarbonisation Strategies

Mathias Berger, David-Constantin Radu, Raphaël Fonteneau, Thierry Deschuyteneer, Ghislain Detienne, and Damien Ernst

2020 – in *Electric Power Systems Research, 180*
https://orbi.uliege.be/handle/2268/235110

Remote Renewable Hubs for Carbon-Neutral Synthetic Fuel Production

Mathias Berger, David-Constantin Radu, Detienne Ghislain, Thierry Deschuyteneer, Aurore Richel, and Damien Ernst

2021 – in *Frontiers in Energy Research*
https://orbi.uliege.be/handle/2268/250796

GBOML: Graph-Based Optimization Modeling Language

Bardhyl Miftari, Mathias Berger, Hatim Djelassi, and Damien Ernst

2022 – in *Journal of Open Source Software*
https://orbi.uliege.be/handle/2268/289210

Graph-based optimization modeling language documentation

Bardhyl Miftari, Mathias Berger, Hatim Djelassi, and Damien Ernst

2022 – online documentation
https://gboml.readthedocs.io/en/latest/

GBOML: A Structure-exploiting Optimization Modelling Language in Python

Bardhyl Miftari, Mathias Berger, Guillaume Derval, Quentin Louveaux, and Damien Ernst

2023 –in *Optimization Methods and Software*
https://orbi.uliege.be/handle/2268/296930

Integration of offshore energy into national energy system: a case study on Belgium

Jocelyn Mbenoun, Amina Benzerga, Bardhyl Miftari, *et al*
.

2024 – submitted to *Applied Energy*, under review process
https://orbi.uliege.be/handle/2268/314586