We start at 4 PM,

please mute your microphone upon entry

Waterstof Industrie Cluster

January 28 2021

WIC Seminar

Shipping sun and wind to Belgium is key in climate neutral economy

Results hydrogen import coalition

Why the carbon neutral energy transition will imply the use of lots of carbon?

WaterstofNet

WATERSTOF INDUSTRIE CLUSTER

Few game rules

- Please mute your microphone
- You can use your camera if desired
- We will record the webinar
- Questions are reserved for the Q&A after the presentations
  - Please use the raise hand function if you want to ask a question, the moderator will give you the word
  - You can use the chat for questions at any time

WATERSTOF INDUSTRIE CLUSTER

WaterstofNet

- Industrial partnership
- 70 members
- Entire H2 value chain
- Collaboration
- Project development
- Policy

➔ Website

WIC webinar

- “Shipping sun and wind to Belgium is key in climate neutral economy” Results hydrogen import coalition
  - Results of the research into the import of renewable energy by means of hydrogen carriers
  - Maxime Peeters
    - Policy & Project Manager Sustainable Energy @ Port of Antwerp

- “Why the carbon neutral energy transition will imply the use of lots of carbon?”
  - The role of molecules such as green hydrogen and high energy dense molecules to reach carbon neutrality by 2050
  - Jan Mertens
    - Chief Science Officer @ Engie Research
    - Professor @Ugent Department of Electromechanical, Systems and Metal Engineering

To conclude

- Presentations and recording will be spread
- Next WIC webinar scheduled for Thursday March 25 4 PM – 5.30 PM

  → Invitation follows
- Interesting topics? Let us know!
- Next cluster meeting: Wednesday March 3 AM

Hydrogen Import Coalition

Shipping sun & wind to Belgium is key in a climate neutral economy

WIC
28/01/2021

Why we need to import renewable energy

- Large scale, cost effective solar and wind energy will be the cornerstone of a carbon neutral economy
- Solar and wind energy is not always available where we need it
  - A solar panel can produce elsewhere up to 3 times more energy than in Western Europe
  - Wind potential is space constrained in Western Europe, same for HV transport lines
  - We consume more energy than we can locally generate
- Solar and wind energy is not always available when we need it
  - Solar and wind energy require low cost, large scale, long term storage to provide a stable source of energy
  - A domestic all electric renewable scenario is unclear with regards to total system cost and system stability
- Electricity is not always the most appropriate energy vector
  - Clean renewable synthetic molecules can sometimes be the better choice (as feedstock, fuel, energy carrier)
  - Electricity is difficult to transport over longer distances
  - Lack of pace concerning transmission line build up and permitting
- Don't forget the feedstock: our chemical industry requires hydrogen and carbon

The hydrogen coalition H2C

Joins forces to investigate the importation of green hydrogen

- Climate target to reduce CO_2 emissions in Belgium by 80% by 2050 compared to 2005 levels = major challenge in terms of timing, cost and robustness

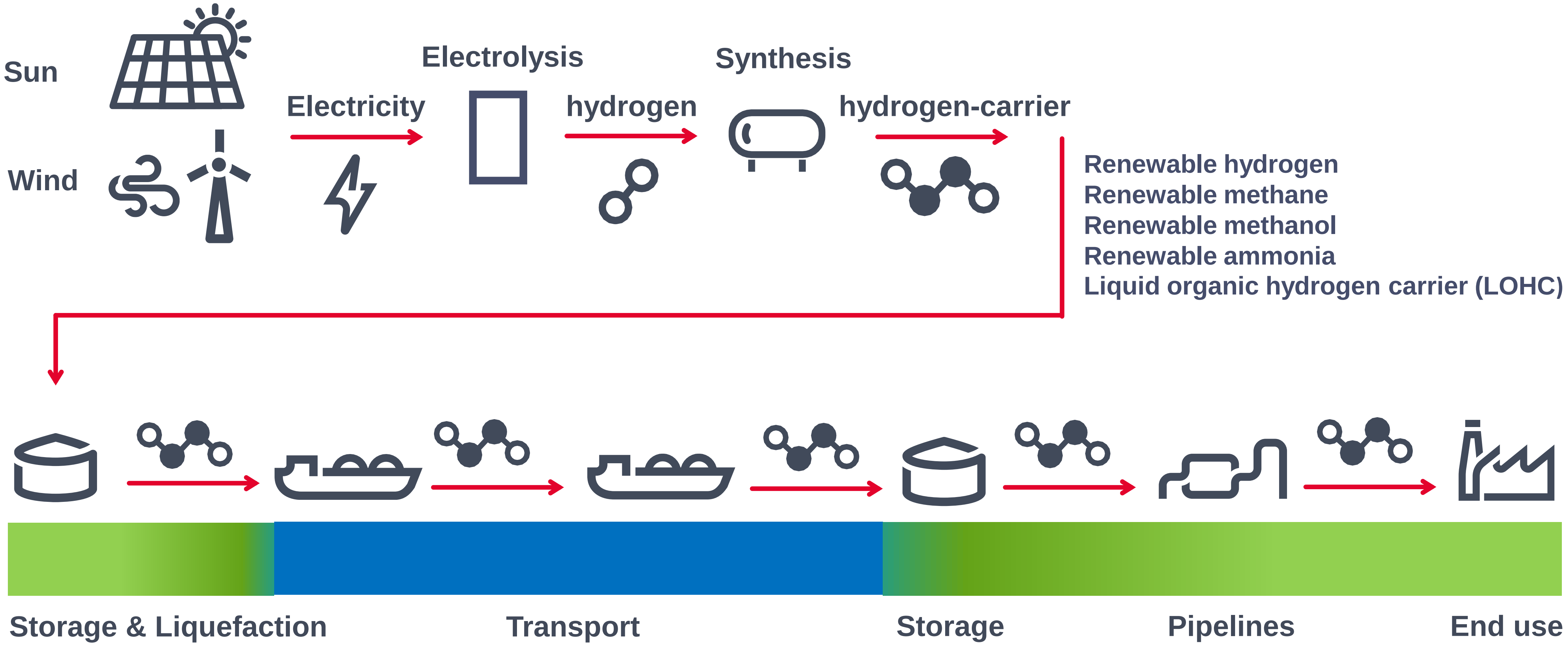
- Hydrogen/molecules have an important role to play in the mix of solutions

- Join experience and industrial knowhow (kick-off 10/2019)
  - Port of Antwerp / Port of Zeebrugge is a large-scale energyhub & the largest integrated chemical cluster in Europe
  - Investement driven private-public industrial coalition with know how & network, capable of scaling up
  - Covering each step of a renewable hydrogen import value chain

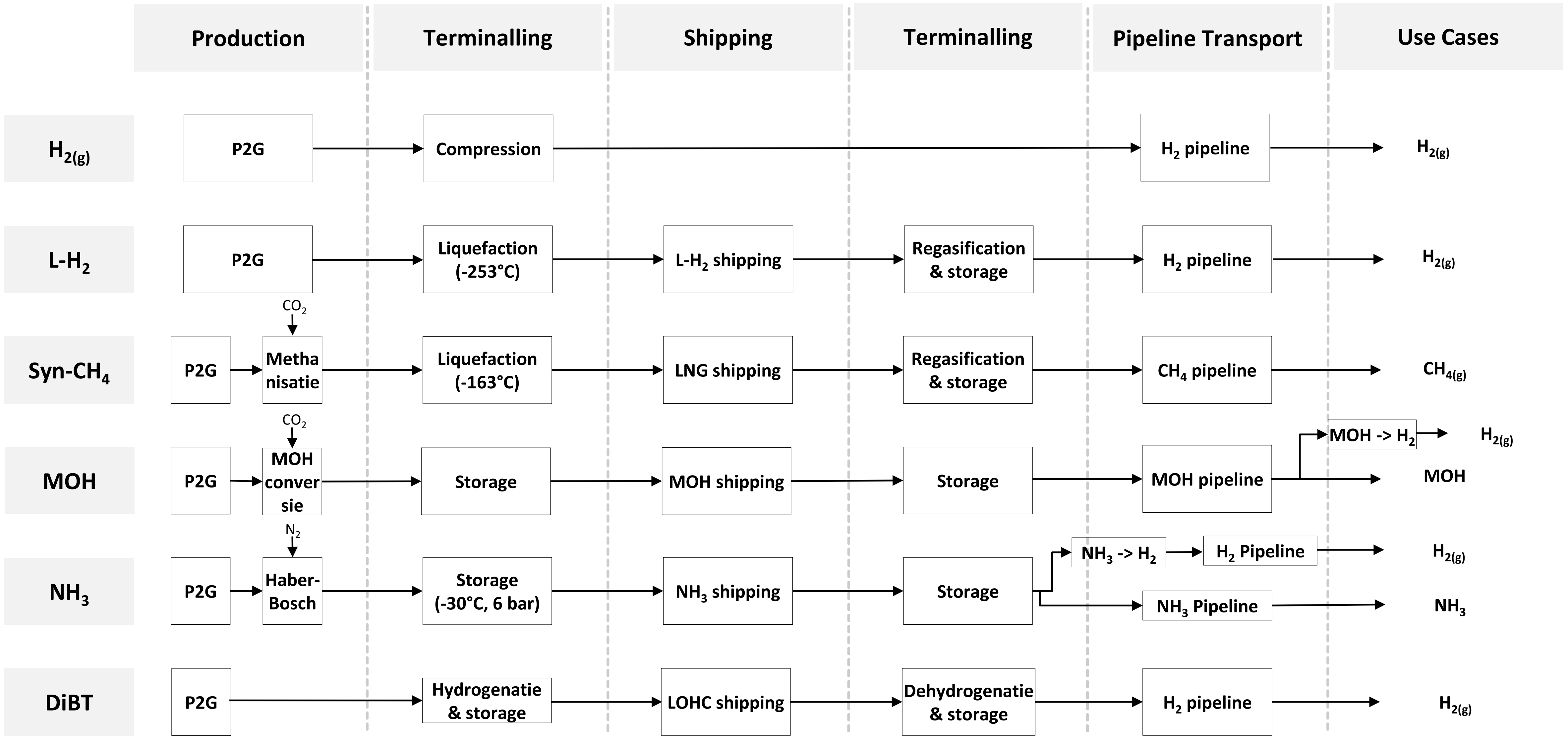
DEME · ENGIE · EXMAR · fluxys · Port of Antwerp · Port of Zeebrugge · WaterstofNet

Renewable molecules – green hydrogen value chain

From remote wind and sun to end-user market



Block Diagram

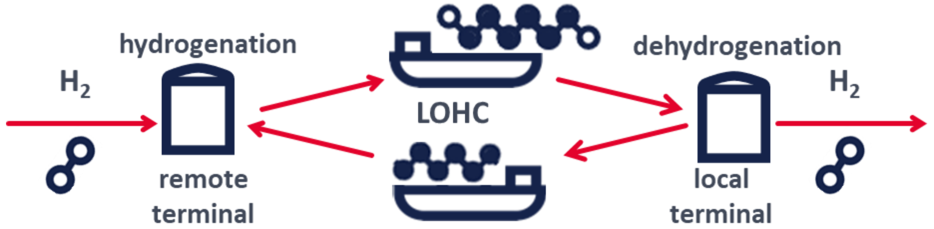


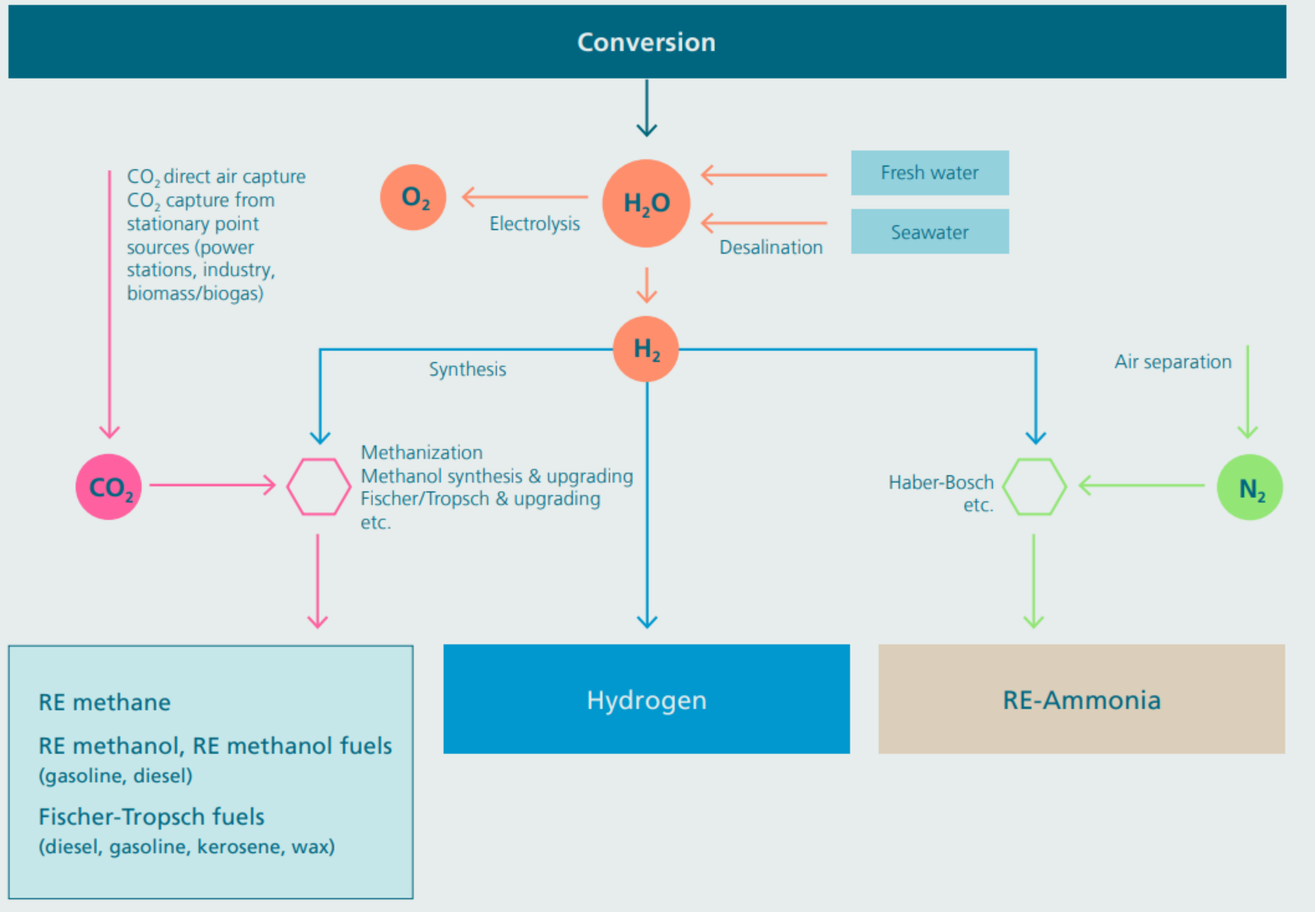
The carriers

Hydrogen can be transported as hydrogen, or with the help of carrier molecules

3 groups of carriers were studied

1. Pure hydrogen
   - Pressurized
   - Liquified @ -253°C
2. E-fuels – synthesis with C or N
   - Methane - liquified @ -162°C – LNG
   - Methanol – liquid
   - Ammonia - liquified @ -34°C
3. Liquid Organic Hydrogen Carriers (LOHC)
   - Represented by DiBT





Source: Fraunhofer institute

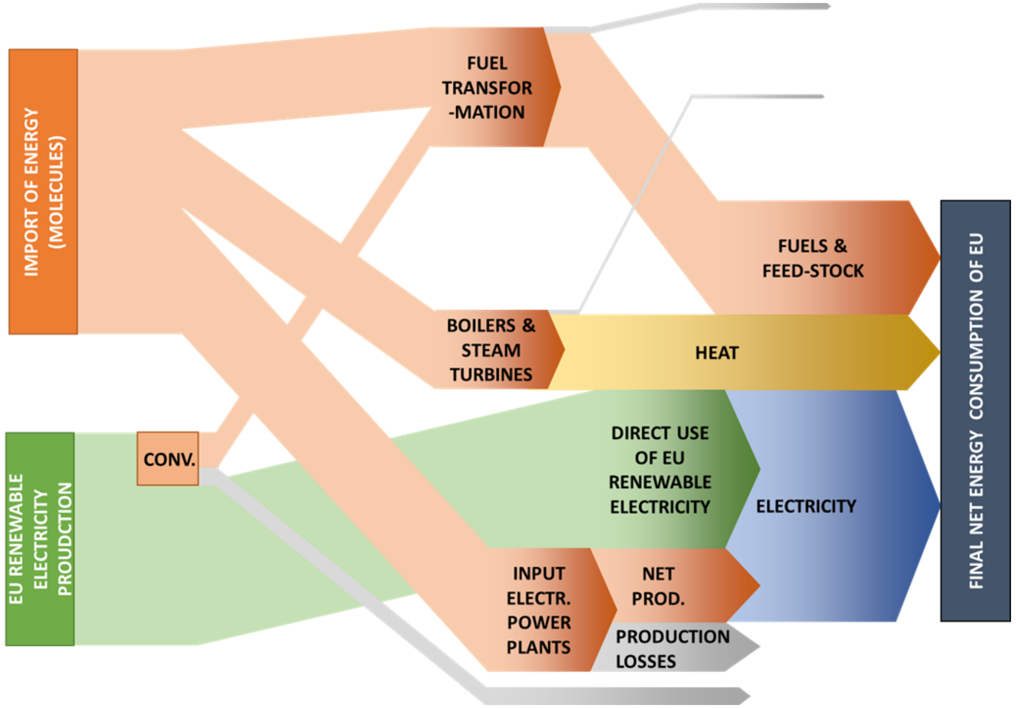
Key assumptions

More than half of our energy demand will have to be imported

By 2050, a renewable energy import system supporting the Western European energy and feedstock transition will require thousands of TWh of energy imports per year

- Same order of magnitude as ambitious local renewable production targets
- Exceeds the scale of what is existing today
- Complementary to local renewables, biomass, carbon capture, energy efficiency and circularity

annual +/- 30%	EU	Belgium
2050	**7.000 TWh**	350 TWh local *+ 400 TWh transit*
2035	1.050 TWh	**110 TWh import**



Orders of magnitude

Reference scenarios

- Scenario EU – 2050: 7.000 TWh/yr – 3.150 GW electrolyser capacity to be installed
- Scenario BE – 2035: 110 TWh/yr – 50 GW electrolyser capacity to be installed

Reference numbers 2020

- *Offshore wind in Belgium – 2GW – 8 TWh/yr*
- *Yearly electricity demand Belgium – 80 TWh/yr*
- *European gas consumption: 5.000 TWh/yr*
  - *of which Belgium: 180 TWh/yr*
- *Installed electricity production capacity in Belgium ~20GW*
- *Energy shipped over the oceans: 37.000 TWh/yr*
- *Oil terminal of Rotterdam import up to 1.200 TWh/yr*
  - *of which 465 TWh transported by pipeline to Antwerp*
- *LNG terminal of Zeebrugge imports up to 80 TWh/yr*
- Current electrolyser capacity installed worldwide ~20GW, in Europe a few GW

Key assumptions

A system that is designed to be absolutely security in its supply

- Solar and wind do not provide base-load electricity by themselves
- Adequate buffering is integrated in our system design to ensure a baseload hydrogen carrier output out of each individual export location
- This base load design requires
  - renewables over-dimensioning
  - battery power storage to optimize electrolyser & synthesis operation
  - Hydrogen storage to allow carrier synthesis optimization
  - combined with the inherent storage in ships, terminals and pipelines
- This results in a solid but conservative cost estimation
  - no grid synergies are considered and all costs addressed in the own business model as an off-grid independent baseload-capable design
- The baseload design assumption assures that the imported renewable energy of molecules can unmistakably be considered as fully additional to existing renewable energy sources.

Ship options

Large scale solutions to ship methane, methanol, ammonia are existing
Hydrogen much more difficult to deploy on large scale

Liquified Hydrogen

Only one ship under construction
Several concepts for larger vessels
(up to 0.43 TWh/vessel)

Ammonia

Significant fleet existing
(scalable up to 0,7 TWh/vessel)

Methanol

Transport in VLCC - large fleet existing (up to 1.61 TWh/vessel)

LOHC

Transport in VLCC - large fleet existing (up to 0.72 TWh/vessel)

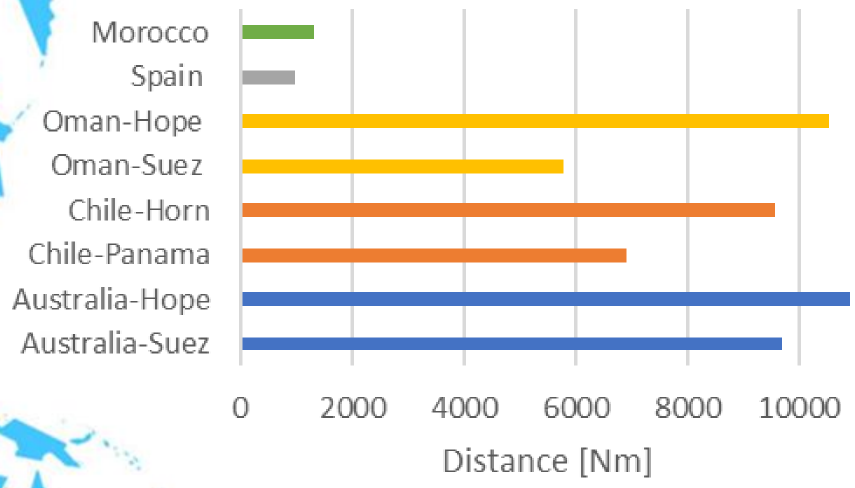
LNG - methane

Large fleet existing
(up to 1.73 TWh/vessel)

VLCC = Very Large Crude Carrier

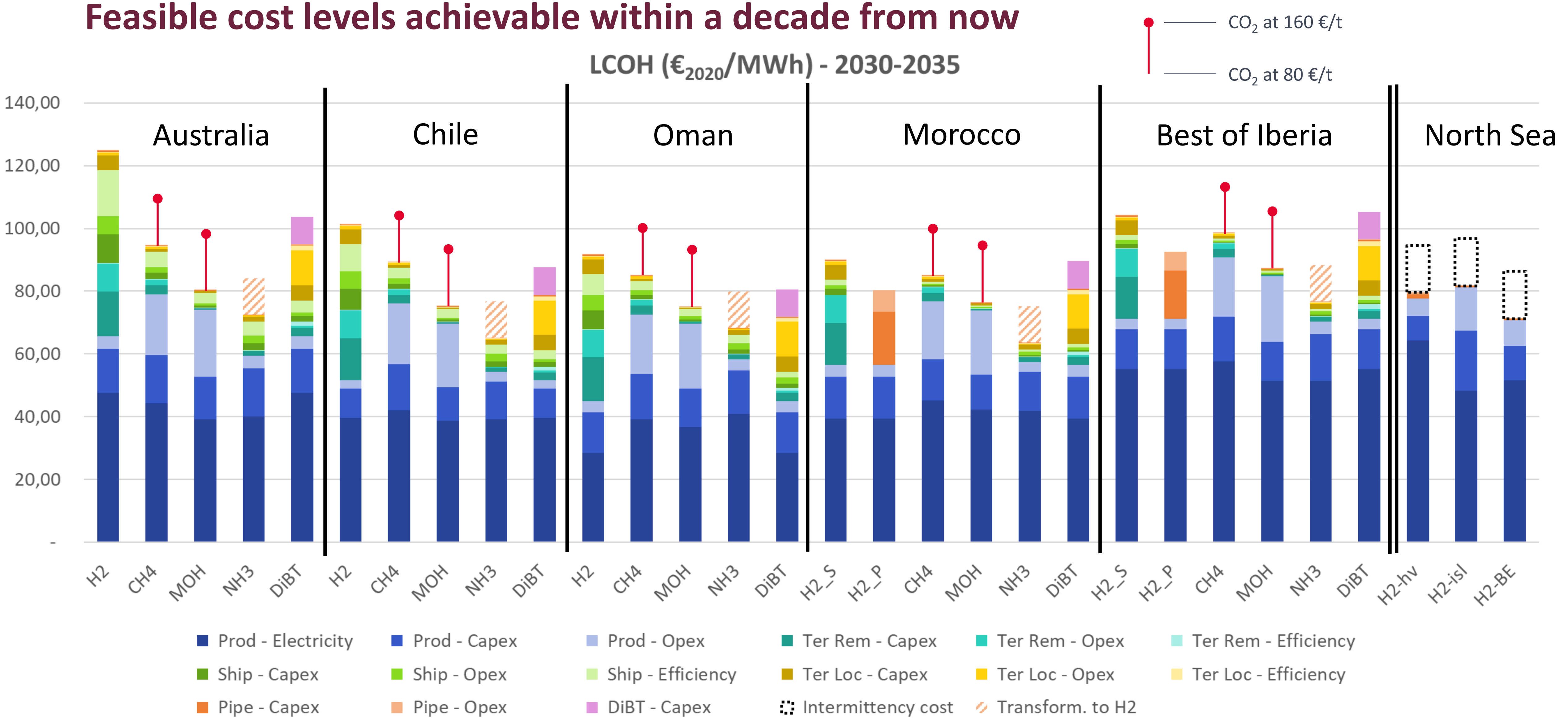
Locations and shipping routes

A representative sample of possible regions providing low cost renewable energy



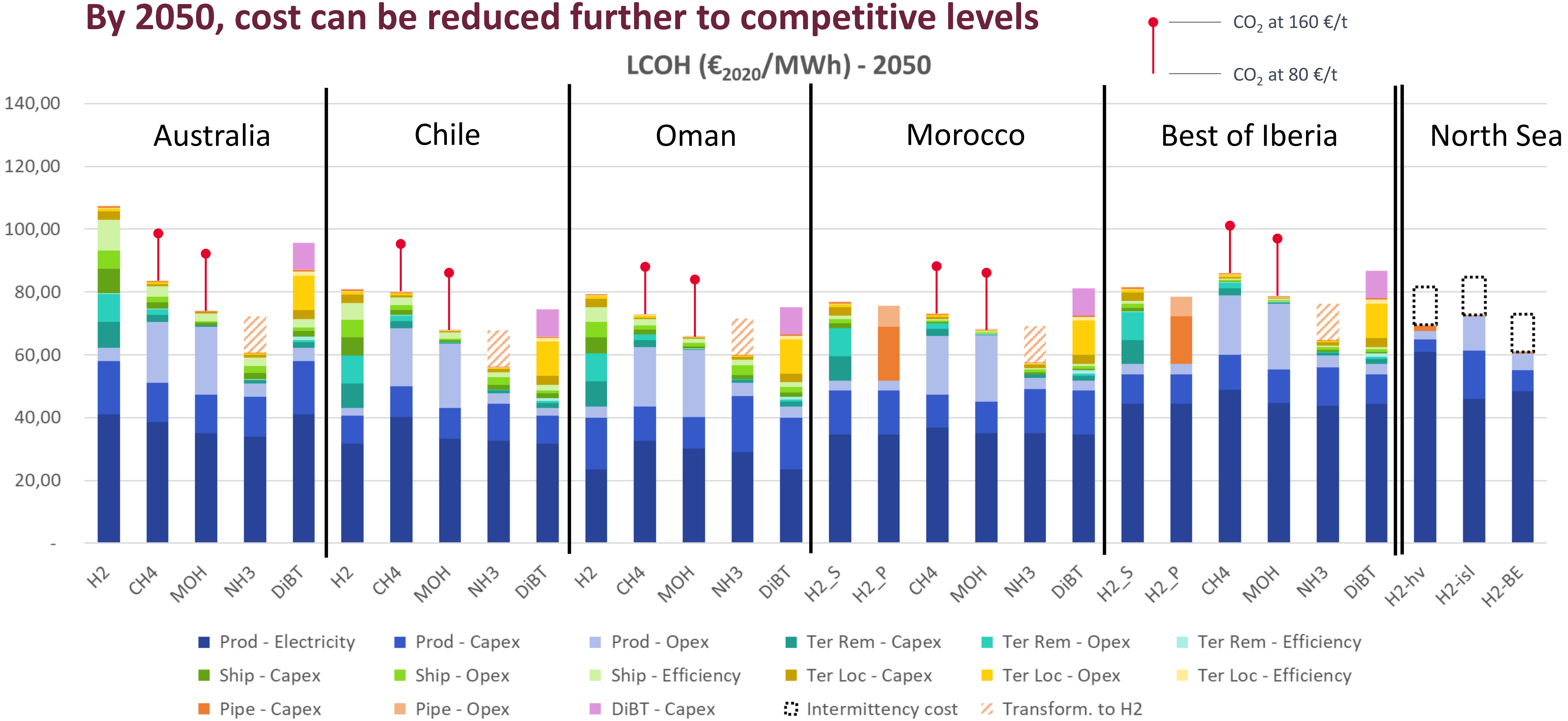
Overall cost to deliver green energy to Belgium

Feasible cost levels achievable within a decade from now



Overall cost to deliver green energy to Belgium

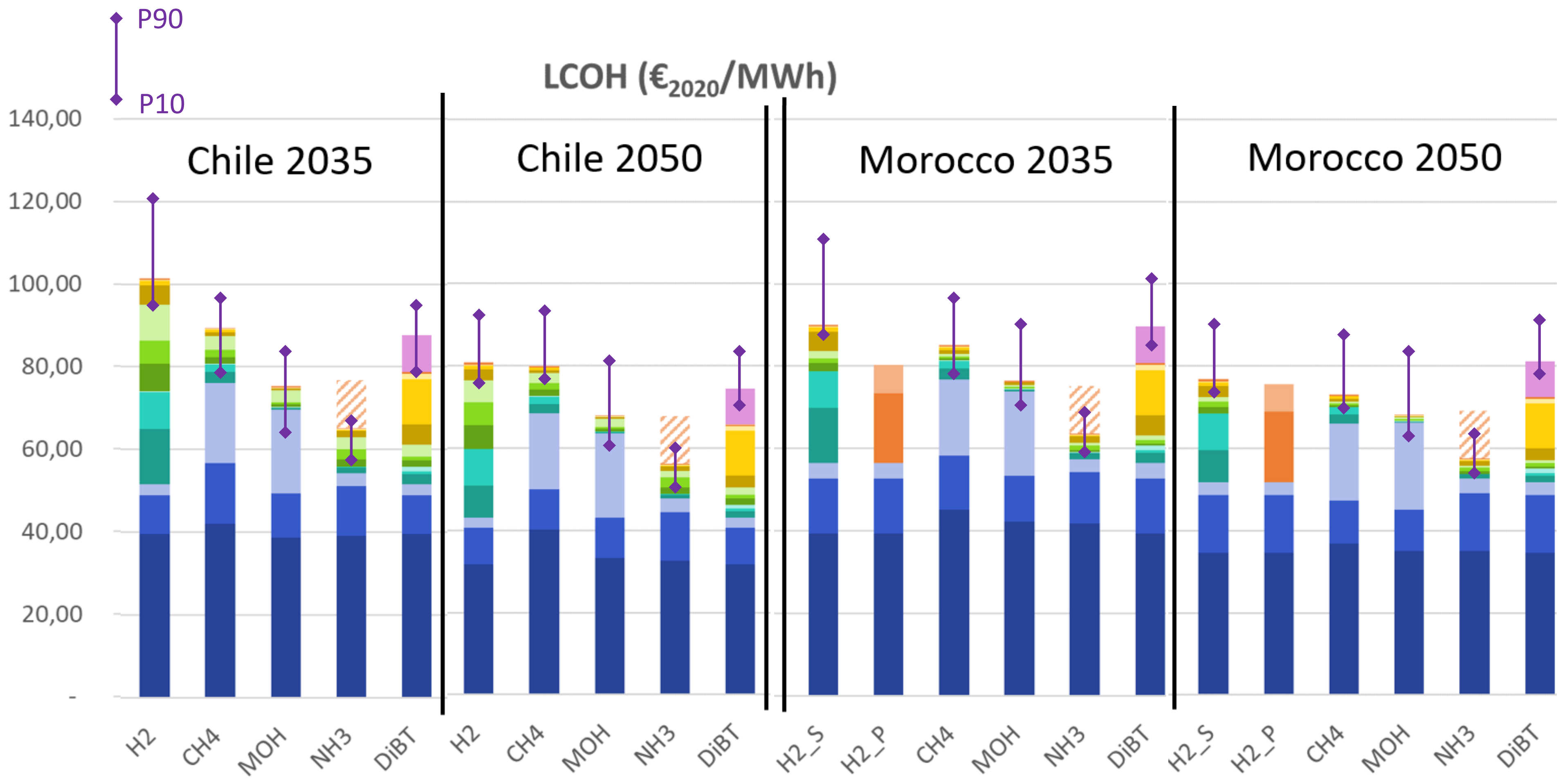
By 2050, cost can be reduced further to competitive levels



Overall cost

The uncertainty range in our study

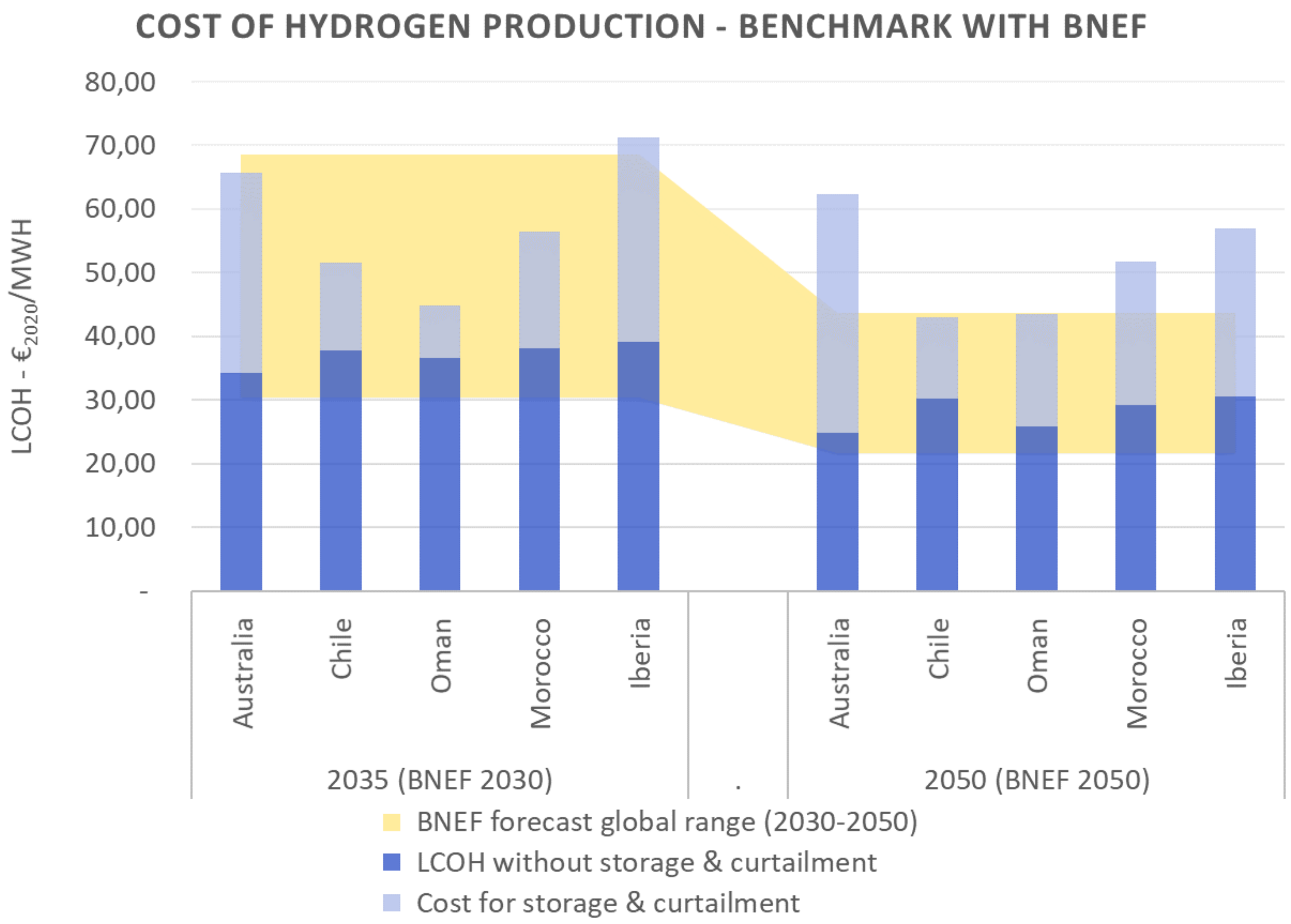
uncertainty driver	H2	CH4	MOH	NH3	DIBT	offshore
1st	term.capex	CO_2 cost	CO_2 cost	LCOE	LCOE	prod. capex
2nd	LCOE	LCOE	LCOE		DiBT & term.capex	



- H2 has largest uncertainty reflecting technology challenges
- CH4 and MOH exhibit a similar uncertainty profile despite more mature technology, mainly driven by CO_2 cost uncertainty
- NH3 benefits from the lowest uncertainty, however without considering H2 splitting (low TRL) and not accounting for potential safety considerations
- DiBT suffers from uncertainty around the cost of the DiBT carrier molecule and technological challenges regarding DiBT terminal design

Final Results
External benchmark

- H2 coalition takes an industrial conservative approach towards cost evolutions
- However, more optimistic cost reductions can be achieved by reducing the impact of storage and curtailment
  - No full baseload required per production site
  - Improved, lower cost storage
  - More flexible components, i. e. lower technical minima for electrolyser, synthesis and liquefaction
- Comparison with a more optimistic benchmark requires identification of the impact of curtailment & storage



Use Cases

Analysis of use case economics - renewable vs fossil

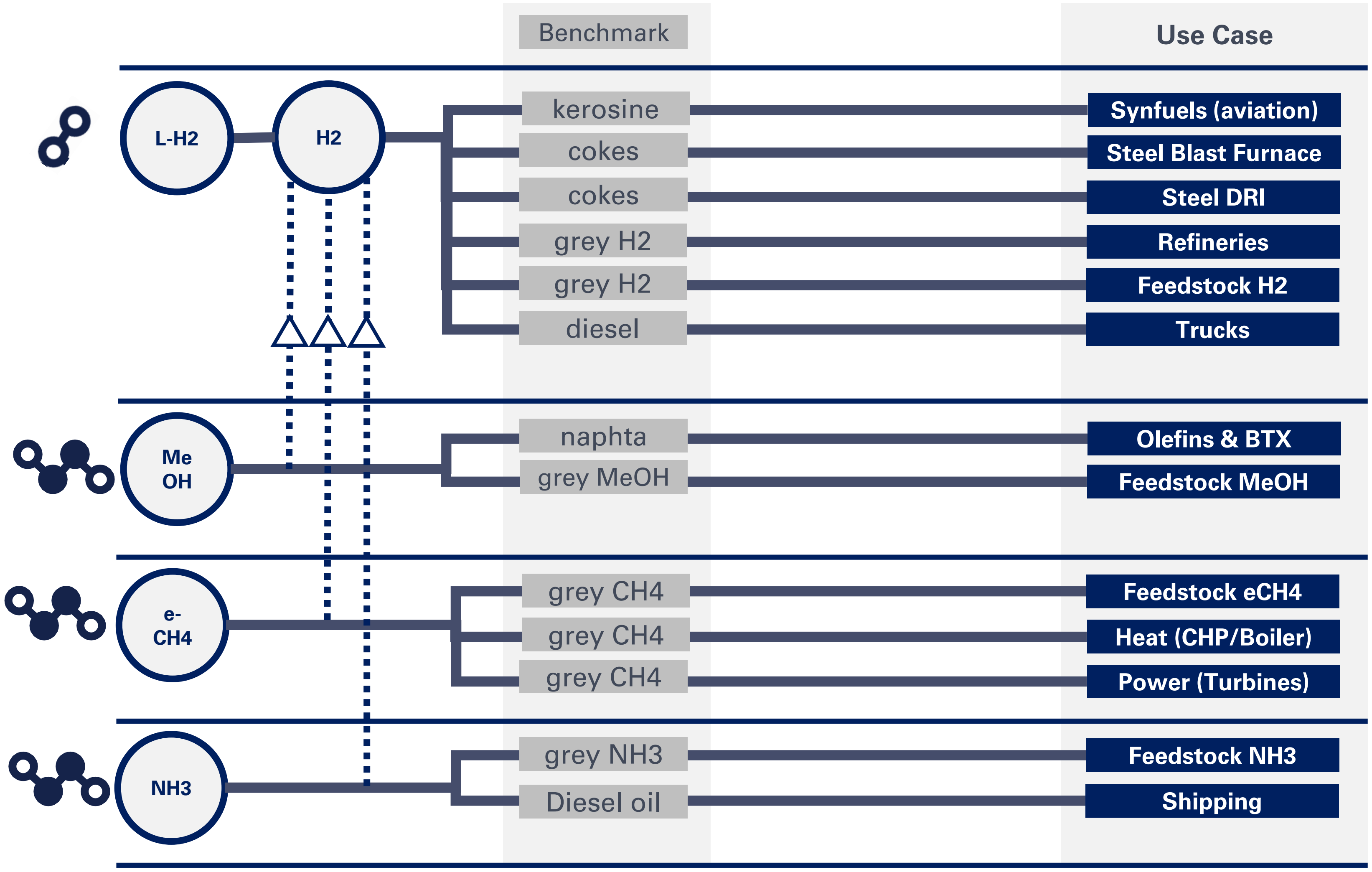
INDUSTRIAL USE CASES OF H2 CARRIERS

Feedstock
– new processes (capital inv.)
– direct replacement

Heat
– medium grade (100-500°C)
– high grade (>500°C)

Power

Transport



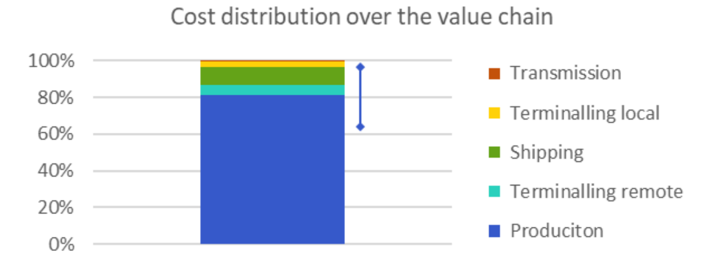
Use Cases

Interesting use cases for first movers

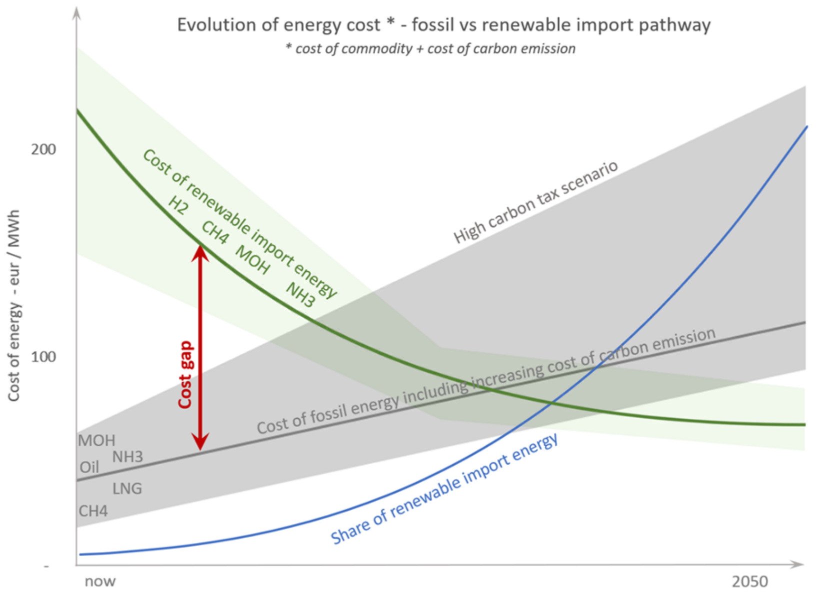
			Investments *capex*	Technology *TRL*	Policy *as today*	Fuel cost gap *2035 vs benchmark*
Drop-in for kickstart of import pilots, 'the enablers'	hydrogen	Refineries	Green	Green	Green	Yellow
	methanol	Fuel (RED II)	Green	Green	Green	Green
	ammonia	Fertilizers	Green	Green	Yellow	Green
Possible end-users in 2030 w/ application investments	hydrogen	Steel: Blast Furnace	Yellow	Yellow	Yellow	Red
	hydrogen	Trucks (FC)	Yellow	Green	Green	Yellow
	All carriers	Shipping (ICE)	Green	Yellow	Yellow	Yellow
Possible end-users in 2035-2050 w/ large investments	hydrogen	Steel: DRI process	Red	Green	Red	Yellow
	methanol	Olefins	Red	Green	Red	Green
Possible end-users in 2035-2050 w/ large cost-gap but no competitive carbon-neutral alternative	hydrogen / methane	Peak power (Turbines)	Green	Green	Red	Red
	ammonia / methanol	Peak power (Turbines)	Yellow	Yellow	Red	Red
	All carriers	HT Heat	Green	Green	Red	Red
	hydrogen	Syn-kerosine (aviation)	Red	Green	Yellow	Red

General conclusions

1. The carrier proposition validated
   - Import of renewable energy by means of carriers molecules is a feasible and economically sound solution
   - Mainly methane, methanol & ammonia are mature, H2 is promising
   - Carriers make it economically attractive to import low cost renewable energy from remote locations where renewables are more abundant
   - Carbon neutral feedstock supply to our organic chemistry sector
2. Renewable imported molecules will become essential in the European energy mix to achieve full decarbonisation
   - Necessary and complementary to domestic renewable energy
   - Market economics will determine optimal balance between domestic renewable energy and carrier imports
3. Scaling up – the role of public private funding
   - Level playing field by internalizing climate cost to fossil alternatives
   - Several use cases and carriers are attractive to start up with
   - Carbon contracts for differences & capex funding for offtakers



Renewable electricity accounts for the vast majority of the overall molecule cost : 60%-95% depending on the scenario
➔ Preference for production locations with low LCOE



The renewable import pathway will become competitive on the longer term thanks to significant cost reduction potential. ➔ Financial incentives are required on the short term in order to support industrial scale up.

Next steps

1. Policy & regulatory actions

- Feasibility analysis import terminals for Belgium, including spatial policy – port planning & infrastructure corridors
- General policy and regulatory context open to importing renewable energy and feedstock in addition to domestic production
  - Setting clear targets for different end-users (eg.: RED II)
  - Creating a level playing field (Carbon Border Adjustment Mechanism, ETS CO2 prices…)
  - Financial support: a) Opex through 'Carbon Contracts for Difference' is vital for kick-off phase; b) Capex for new applications where existing assets need to be replaced in markets with small margins; c) Also R&D support will be needed.

2. Roadmap

- Many public and private interdependent actions required over time
- Create a roadmap to create clarity on goals, milestones and actions

3. Spin off projects

- Not only analyse, but also act and contribute to national transition economy
- Deploy concrete pilot projects, requiring broad public – industrial partnerships
- Open call for action to public and private stakeholders to forge partnerships

Why the carbon neutral energy transition will imply the use of lots of carbon?

Jan Mertens
Chief Science Officer @ ENGIE
Visiting Professor @ Ugent

Thursday 28 January 2021

Content

1 **Engie & Engie Research**

2 **3 pathways towards Carbon neutrality**

- Increase energy efficiency and increase circularity where waste becomes a feedstock
- Electrify as much as possible (far beyond electric cars)
- The need for molecules: (green) hydrogen and synthetic hydrocarbons

3 **Conclusion**

1

Engie & Engie Research

ENGIE, a global reference in low-carbon energy and services

"Our purpose is to act to accelerate the transition towards a carbon-neutral world, through reduced energy consumption and more environmentally-friendly solutions, reconciling economic performance with a positive impact on people and the planet."

Relying on power & gas, renewable energy and services to offer competitive solutions

#1 global independent power producer, with a renewable power production capacity of ~27GW in 2019, *incl. hydro(16), wind(7), solar(3), biomass/biogas(1) i.e. 28% renewables in our energy mix*

#1 Gas infrastructures (distribution & storage) and **#3 Natural gas importer** in Europe

Committed to green gas, adding clean hydrogen to the energy mix

#1 Biomethane player in France and **#1 H2 stations** worldwide

KEY FIGURES

€60.1Bn
Turnover in 2019

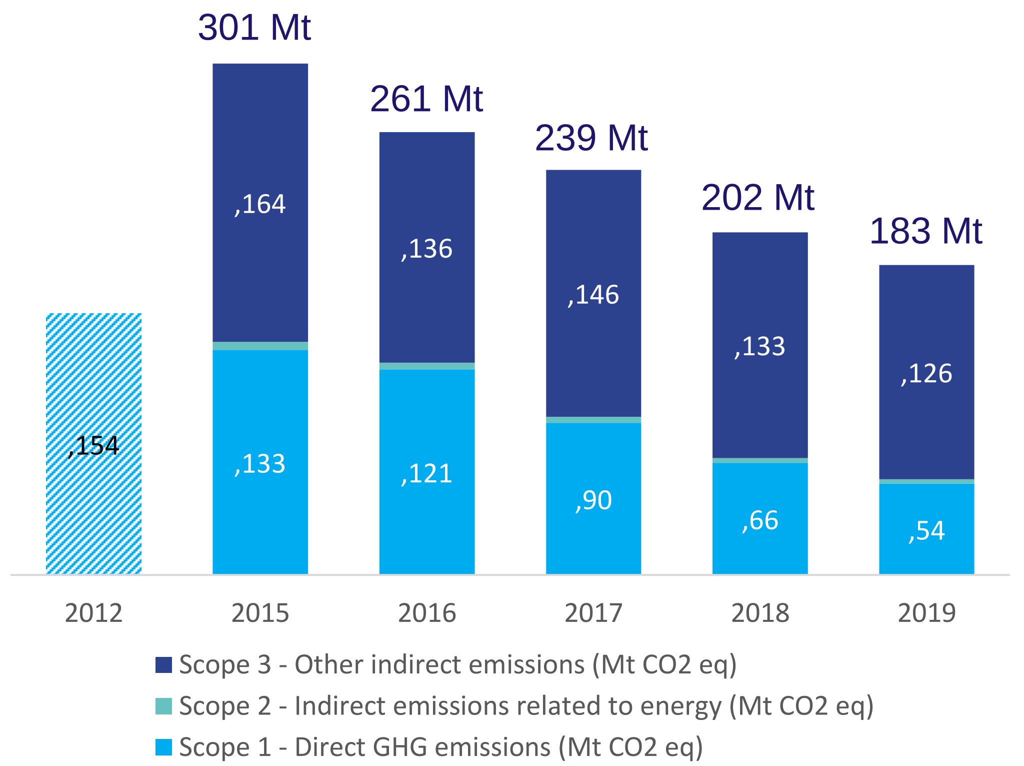
Operating on
5 continents

171,000
employees around the world

A CLIMATE PERFORMANCE COMMITTED SINCE OUR TRANSFORMATION

-39% OF TOTAL GHG EMISSIONS COMPARED TO 2015

GHG evolution of ENGIE



2019 carbon footprint (all scopes)

Power production(1) → **80 Mt** *-50% since 2015*

Use of products sold → **61 Mt** *-47% since 2015*

All other emissions → **42 Mt**

(1) Include all power production units, regardless of ownership (scope 1 & 3)

ENGIE has 900 researchers, Engie Research organized in 23 Thematic Labs

New Energies

- Biomass, Biogas and Biowaste
- Solar
- Wind, Hydro & Marine
- Hydrogen
- Small Scale Liquefaction
- Geo Energy
- Green Thermal Generation (NEW)

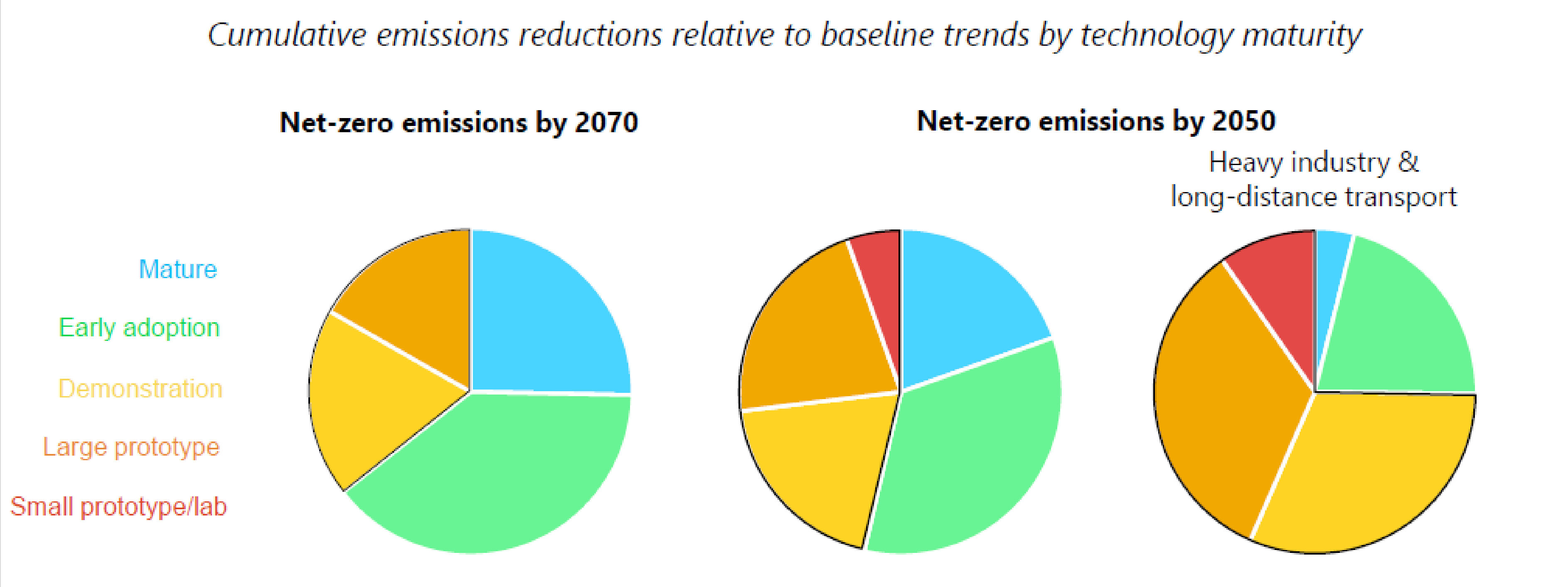
Enabling Technologies

- Computer Science & Artificial Intelligence
- Nanotech, Sensors & Wireless
- Environment & Society
- Energy System Simulations
- Robots & Drones
- Advanced Materials Technologies (NEW)

New Uses of Energy

- Future Collectivities & Homes
- Future Building & Cities
- Future Industry
- Energy Storage
- Smart Grids & Industrial Cybersecurity
- Green Mobility
- CO_2 as a resource
- Air Quality
- Lighting
- Water & Chemistry Lab (NEW)

More than half of the emission reduction will have to come from technologies that are today not mature: Innovation and R&D are crucial and need to speed up!



Almost half of the emissions reductions required to reach net-zero by 2050 rely on technologies that are not yet commercial today. The share jumps to three-quarters for heavy industry and long-distance transport.

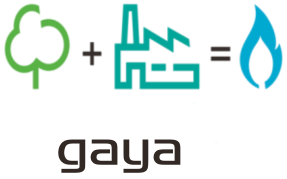
Fatih Birol, IEA September 2020: 'CCUS, Batteries and H_2 are today where PV was 10 years ago. GOVERNMENT need to support their development now!'

ENGIE

Pilot projects with academic, industrial and government partners are important to co-develop, test and demonstrate new solutions

Pilots are key for ENGIE and a large part of the research budget

Biomass gasification Gaya



France

Battery Storage

Belgium

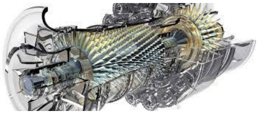
Bifacial Solar testing

Chile

Decentralized Energy System for Islands

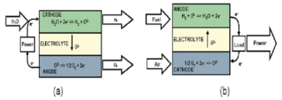
Singapore

H_2 co-combustion in gas turbine



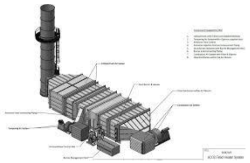
Belgium

High temperature SOEC/SOFC



France

Supercritical CO_2 cycle



US

Solar-H_2 panels

France

OPV for Buildings Heliatek

Global

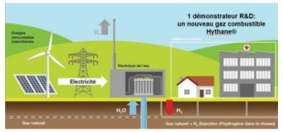
Floating Wind turbine

Portugal

High Altitude Airborne Wind

Germany

H_2 injection in natural gas grid



France

Power to methane

France

Solar cooling

France

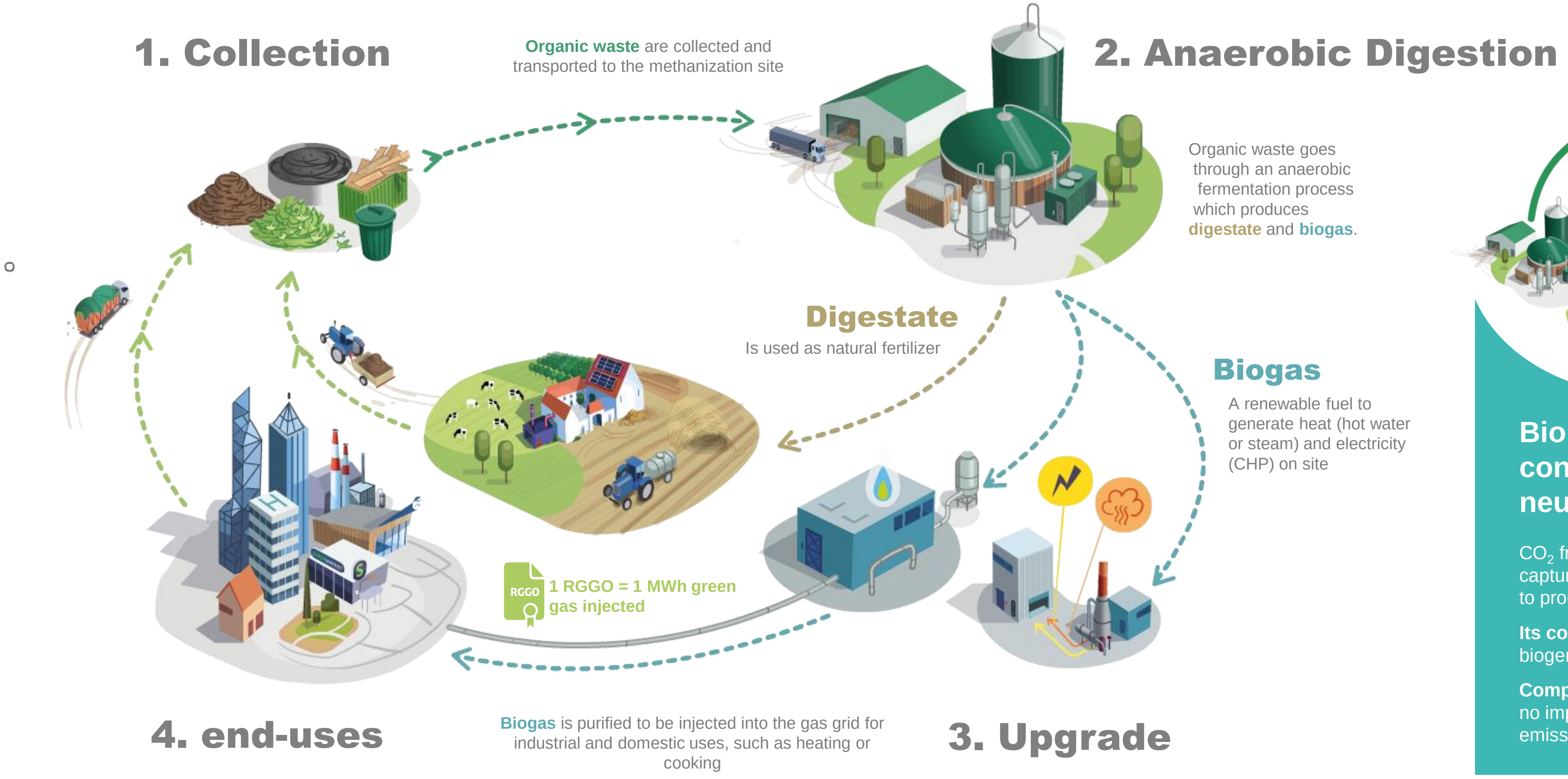
2

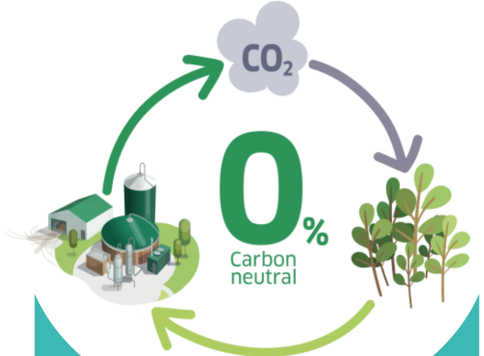
3 pathways towards Carbon neutrality

3 pathways towards Carbon neutrality

(i) Increase energy efficiency and increase circularity where waste becomes a feedstock

From waste TO green GAS : clean, local, circular...
...but the challenge is to achieve volume production at scale





Biomethane is considered carbon-neutral

CO_2 from the atmosphere is captured by organic waste used to produce biomethane

Its combustion produces biogenic $C0_2$ emissions

Compensation effect: almost no impact on greenhouse gas emissions.

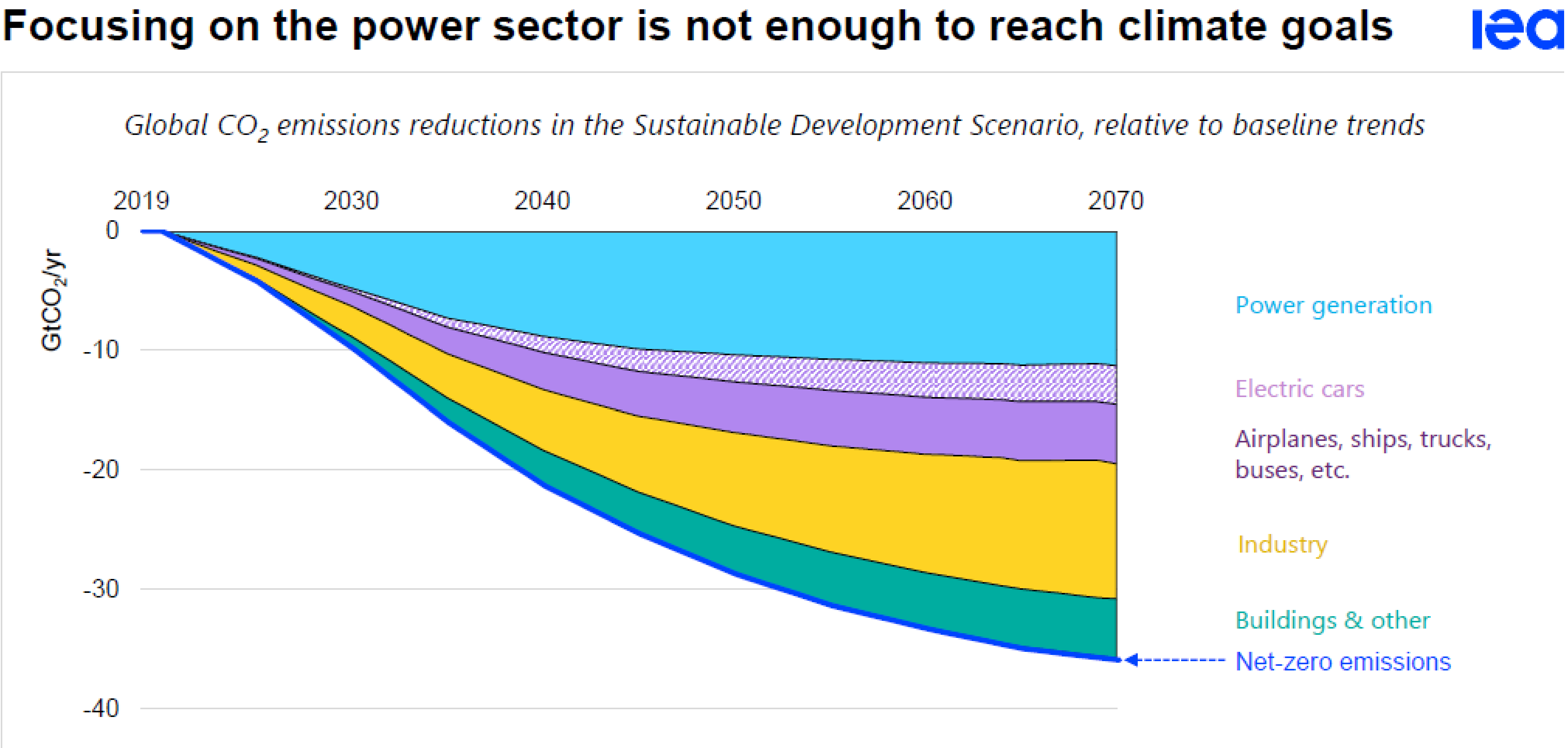
3 pathways towards Carbon neutrality

(i) Increase energy efficiency and increase circularity where waste becomes a feedstock

(ii) Electrify as much as possible (far beyond electric cars)

Making sure all our electricity generation is green is crucial but is not sufficient as it will only reduce our overall emissions by 38 %.
Industry, transport and building account for half of emissions today! (IEA, ETP 2020)

Focusing on the power sector is not enough to reach climate goals

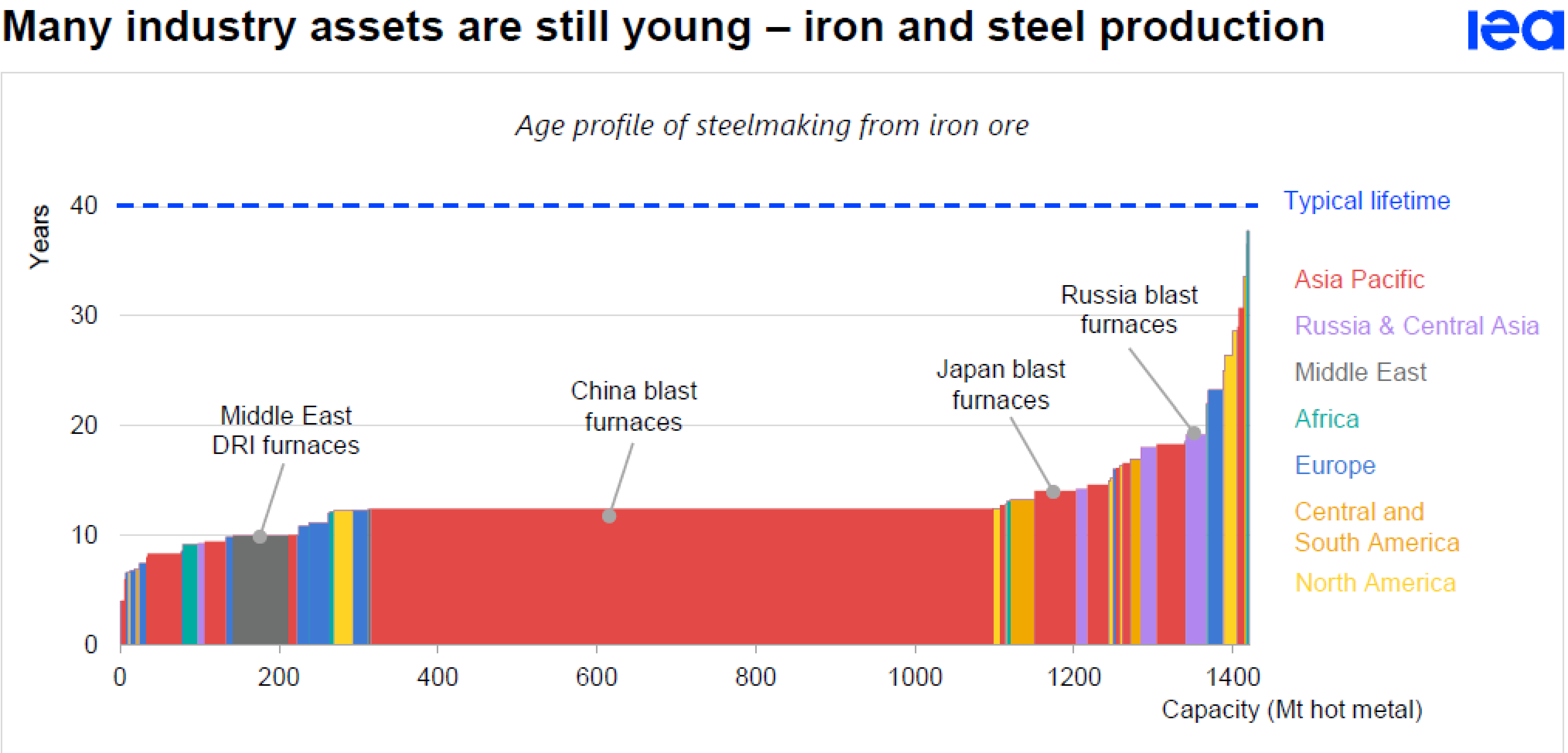


Clean energy technology progress in the power sector and with electric cars is encouraging, but alone not sufficient to reach climate goals. About half of all CO_2 emissions today are from industry, transport and buildings.

We must not only build new clean aluminum, cement, iron and steel, chemical, … plants BUT must address emissions from EXISTING infrastructure since many assets are still young!

CCUS and H_2 will be required.

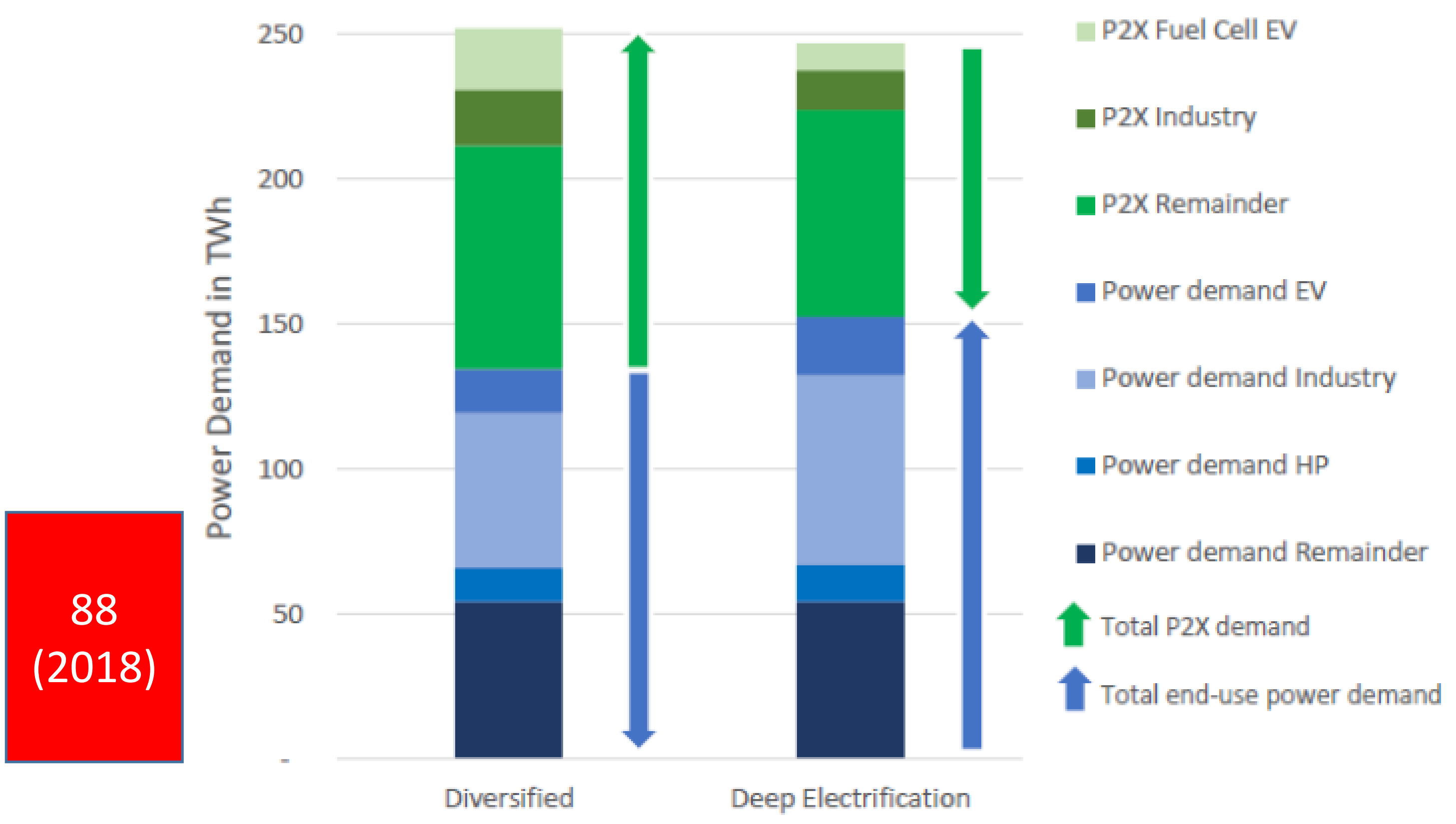
Many industry assets are still young – iron and steel production



China's middling-to-young production capacity accounts for upwards of 50% of the global total in key industrial sub-sectors. India and the Middle East are also key regions.

Belgian's federal planning bureau estimated that even in the deep electrification scenario (electrify as much as possible also in industry), molecules and import of renewable Energy remain important

Graph 7 Total power demand in both scenarios, Belgium, year 2050
TWh



Source: Artelys.
Note: The direction of the arrows indicates the relative level of the specific (P2X or end-use) electricity demand: upwards (downwards) means a higher (lower) level compared to the other scenario.

Import of renewable energy remains important and both scenarios do not diverge (much) in terms of their annual net import position in 2050: 29.4 TWh in *'Diversified Energy Supply'* and 29.0 TWh in *'Deep Electrification'*

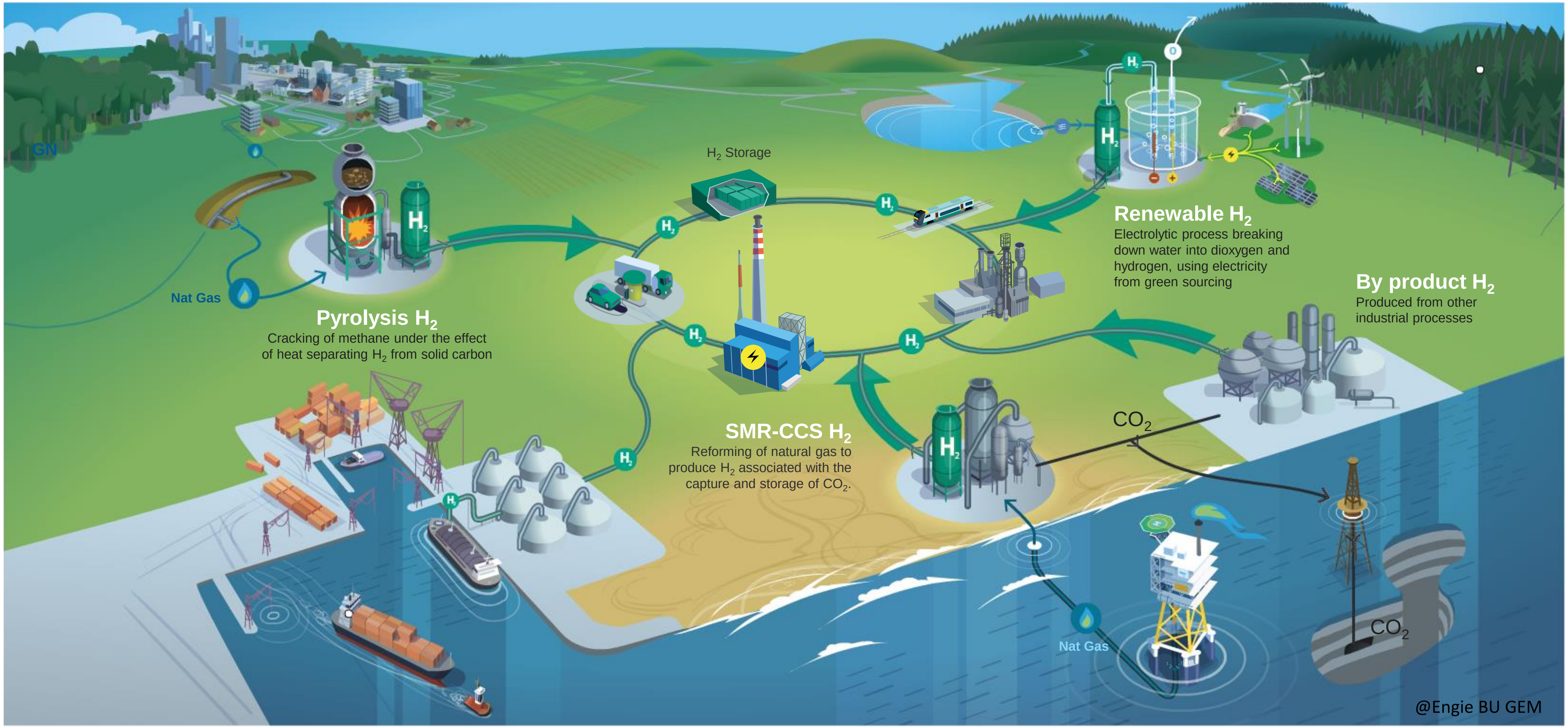
3 pathways towards Carbon neutrality

(i) Increase energy efficiency and increase circularity where waste becomes a feedstock

(ii) Electrify as much as possible (far beyond electric cars)

(iii) The need for molecules: (green) hydrogen and synthetic hydrocarbons

Hydrogen is a low carbon energy solution with a lot of potential but ...

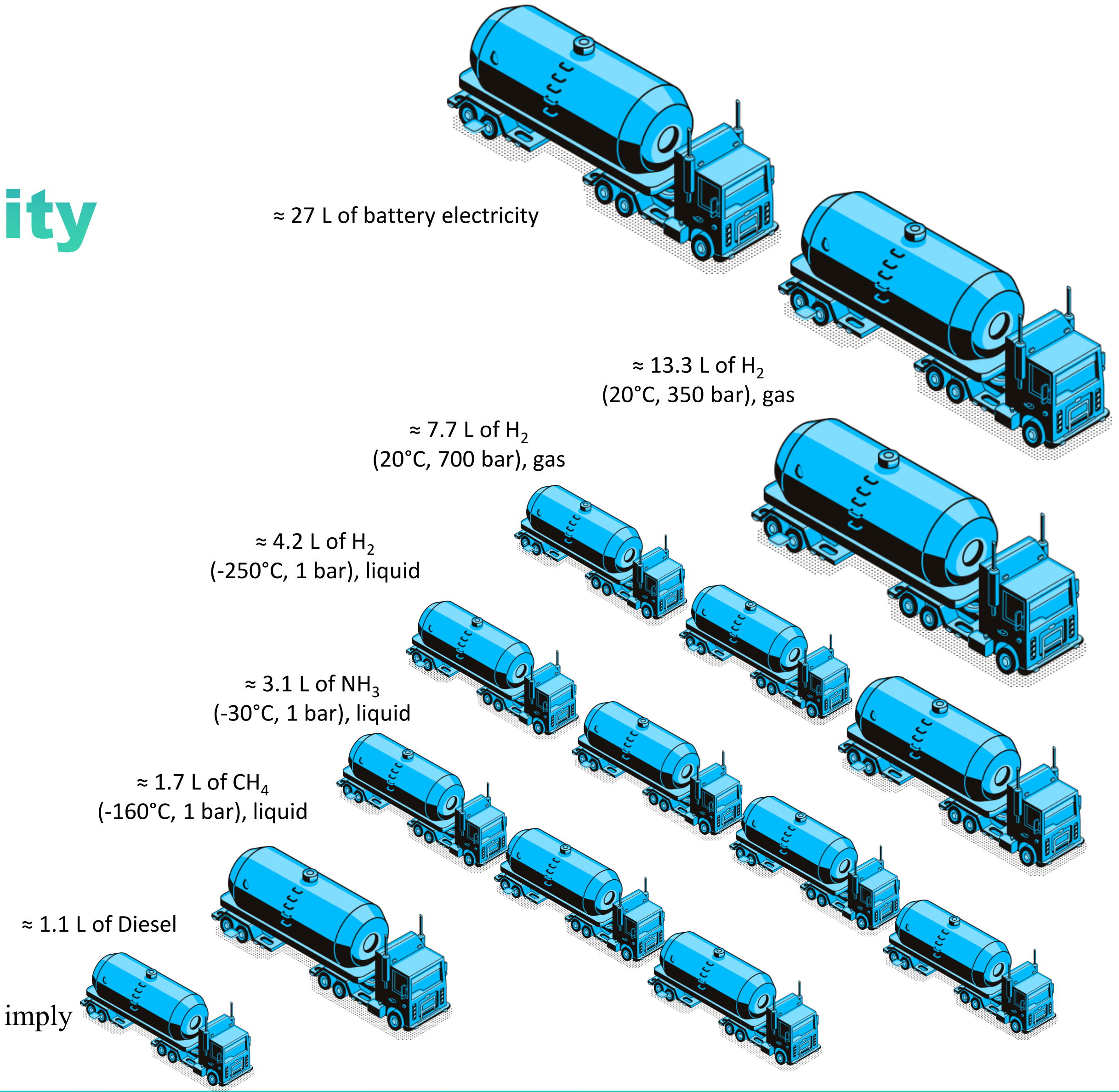


but

Has a very low energy density and is thus extremely hard and expensive to store and move around

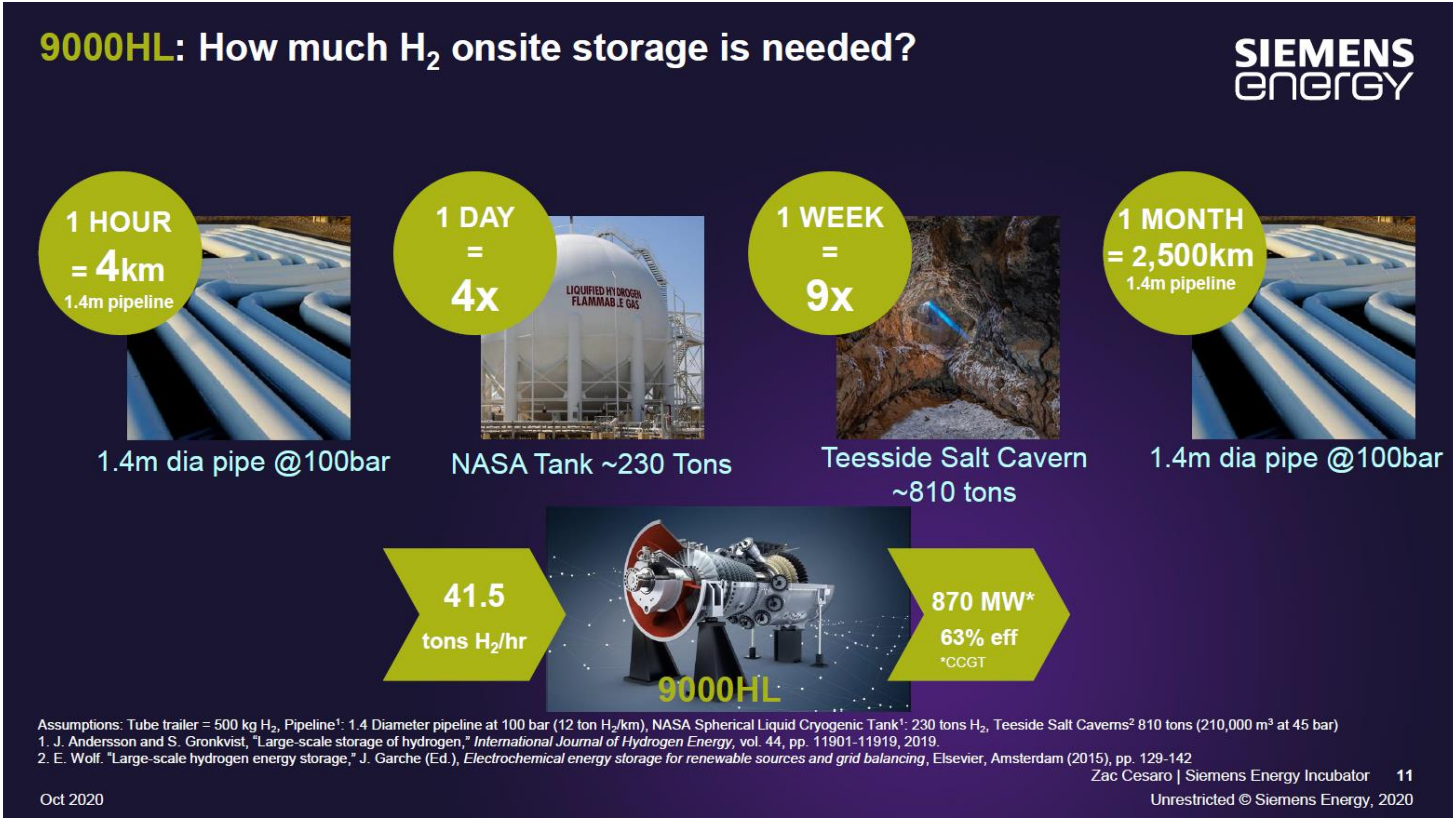
→ Need for synthetic hydrocarbons!*

How to transport or store 10kWh of energy?

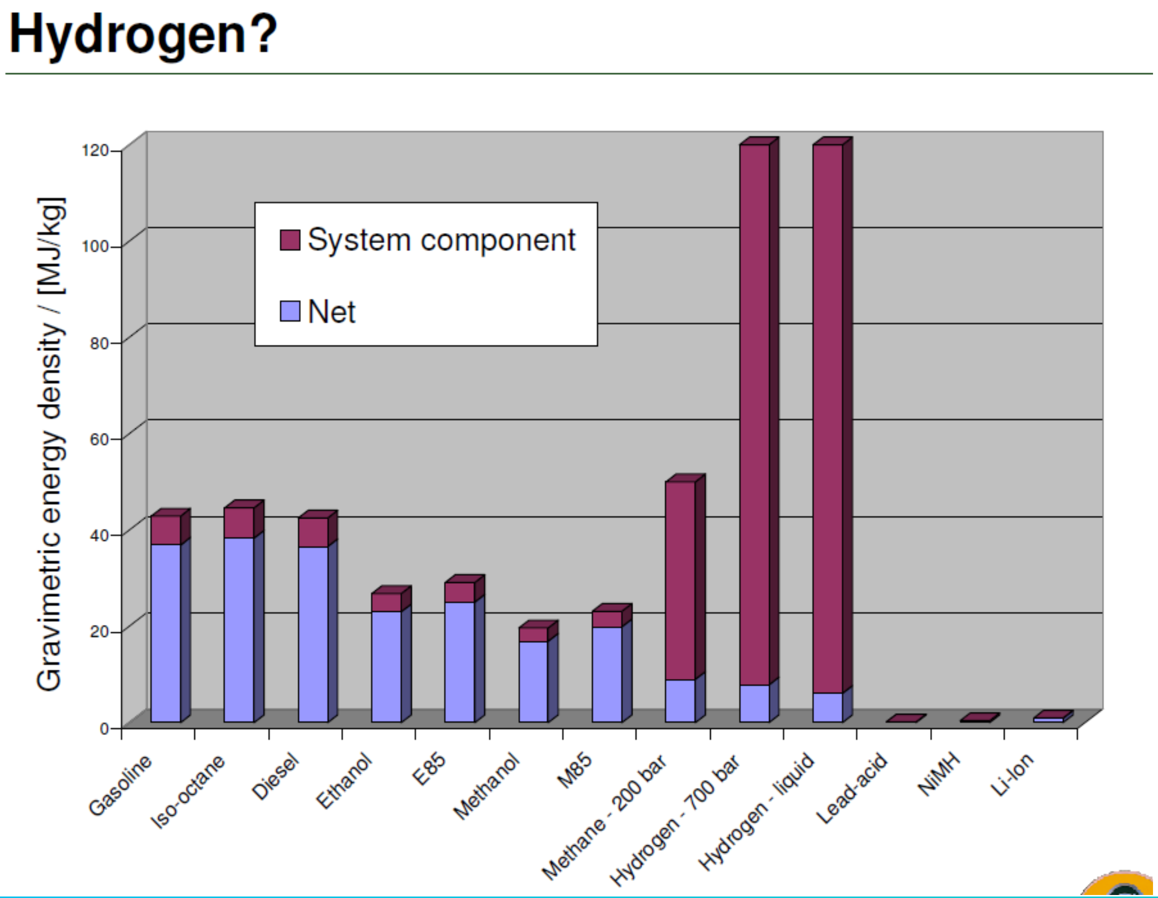


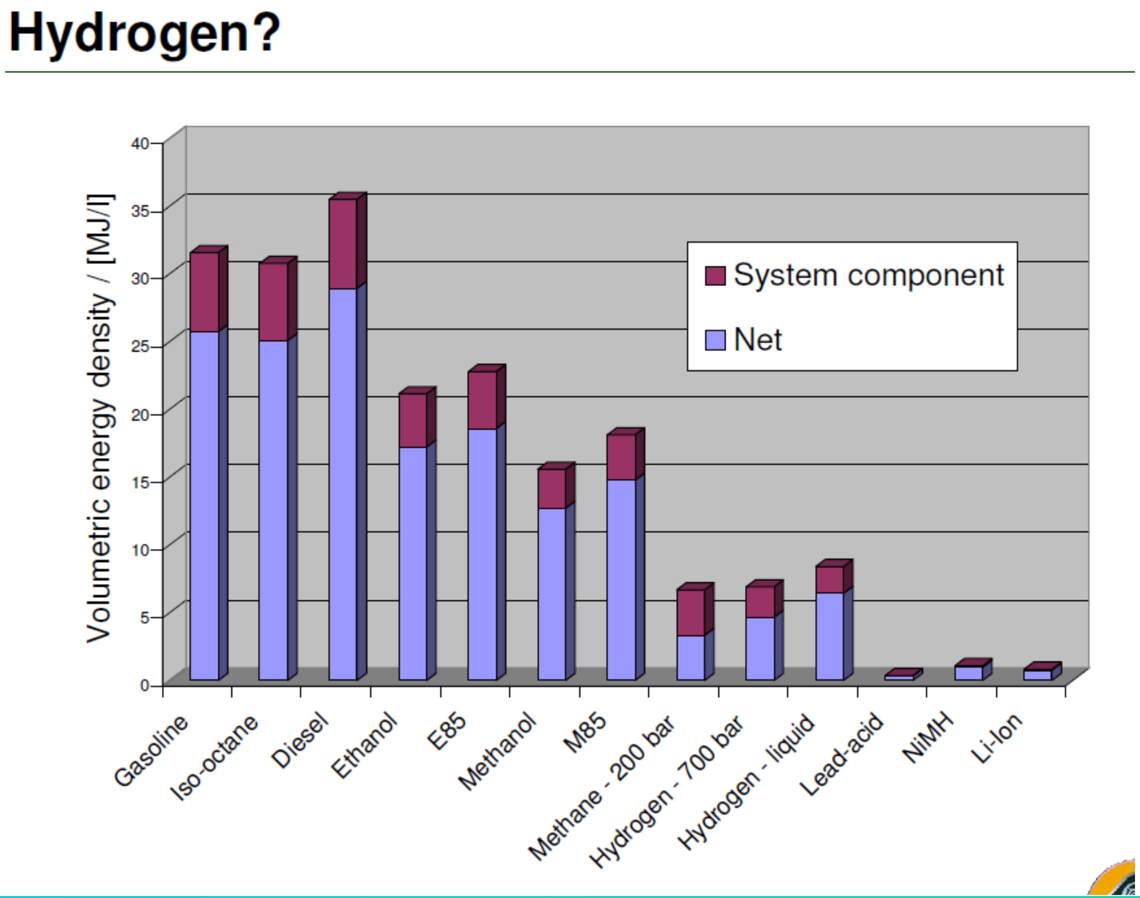
* Mertens, J., R. Belmans and M. Webber, 2020. Why the carbon neutral transition will imply the use of lots of carbon. *C-Journal of Carbon research*, 6 (39), 1-8

Fueling a gas turbine with 100 % H_2 seems practically ‘difficult’



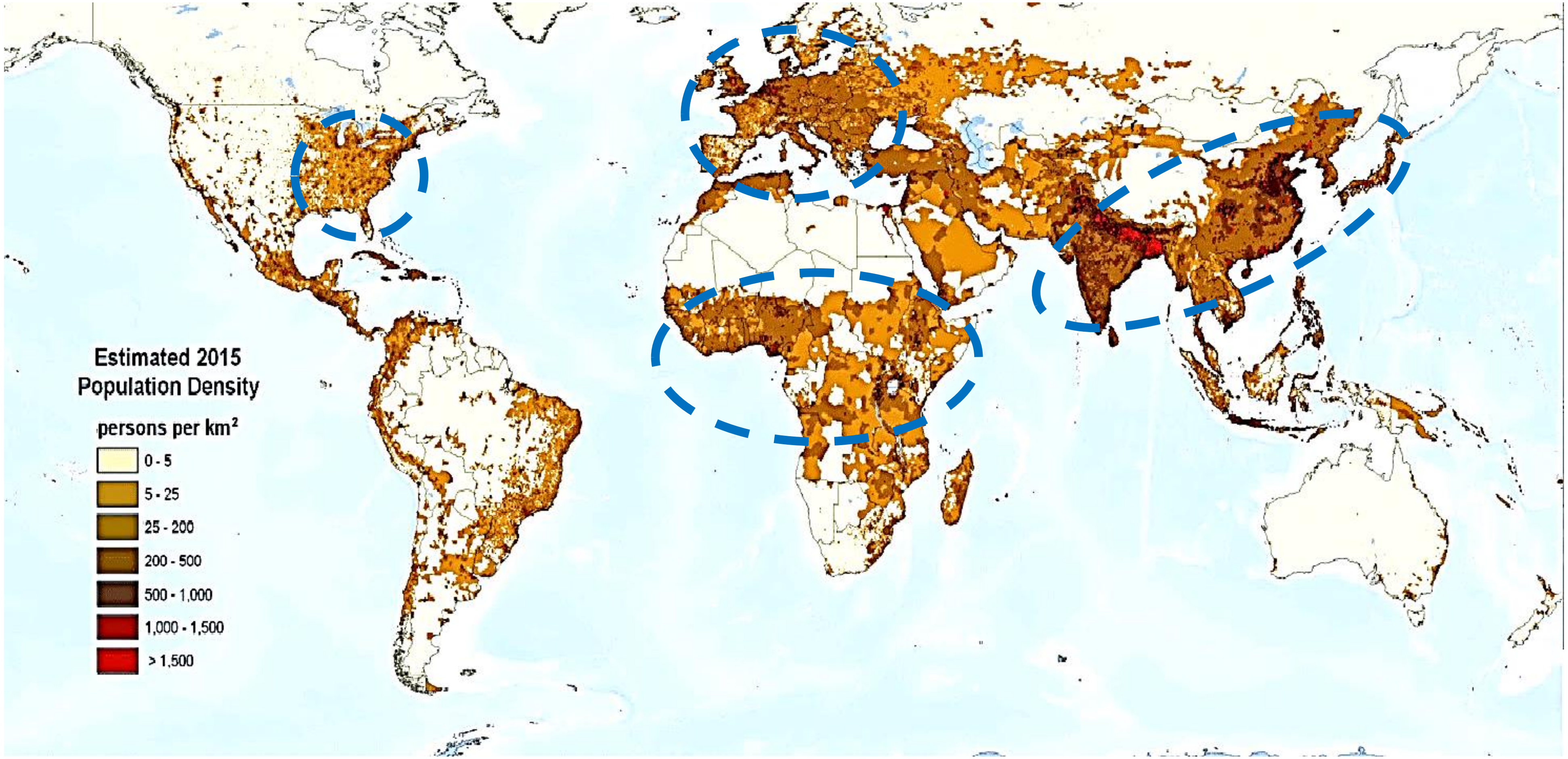
Even from a gravimetric point of view, H_2 remains challenging to store and transport if containment is taken into account





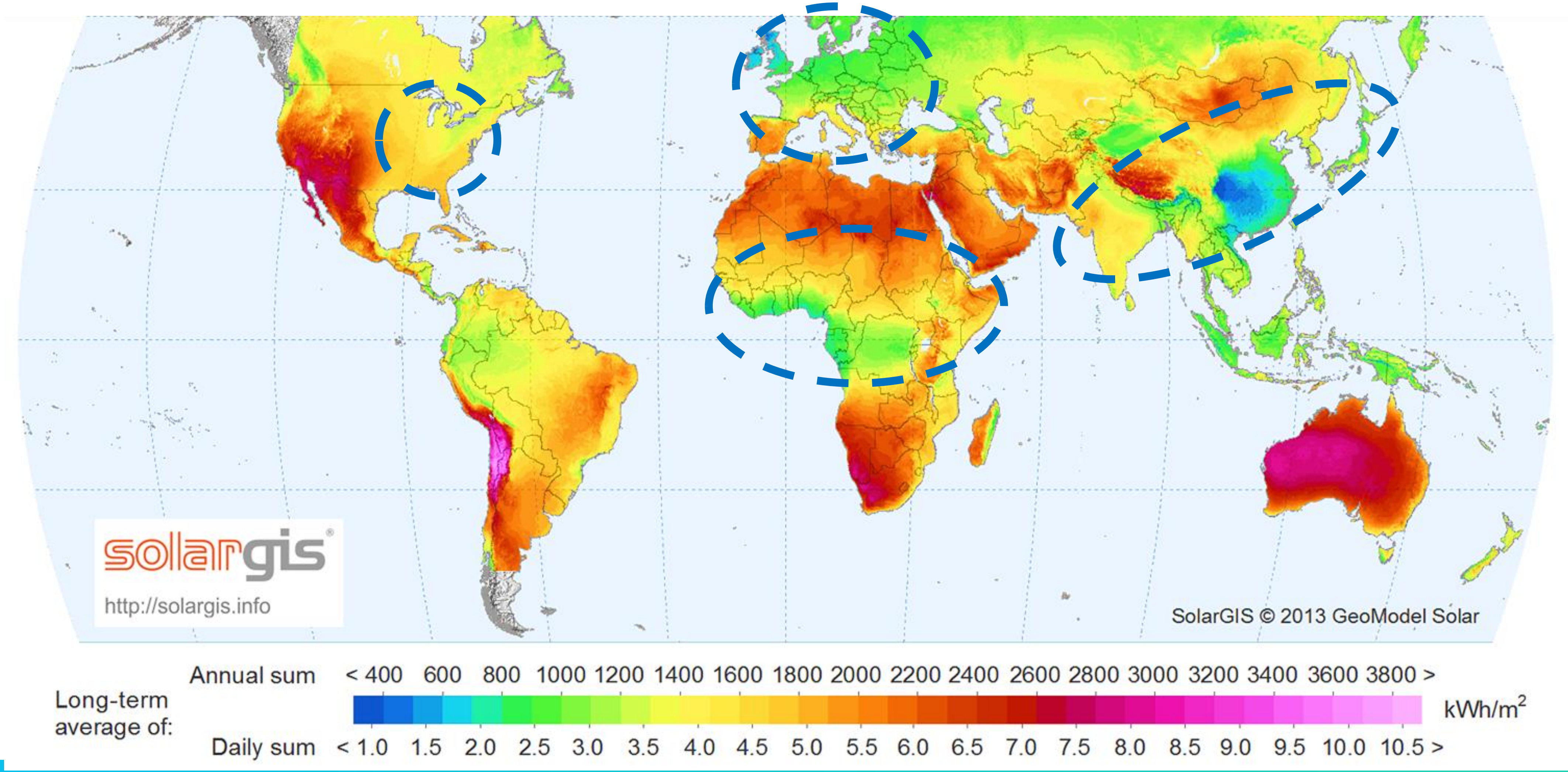
How to transport renewable energy ?

Discrepancy between where people live

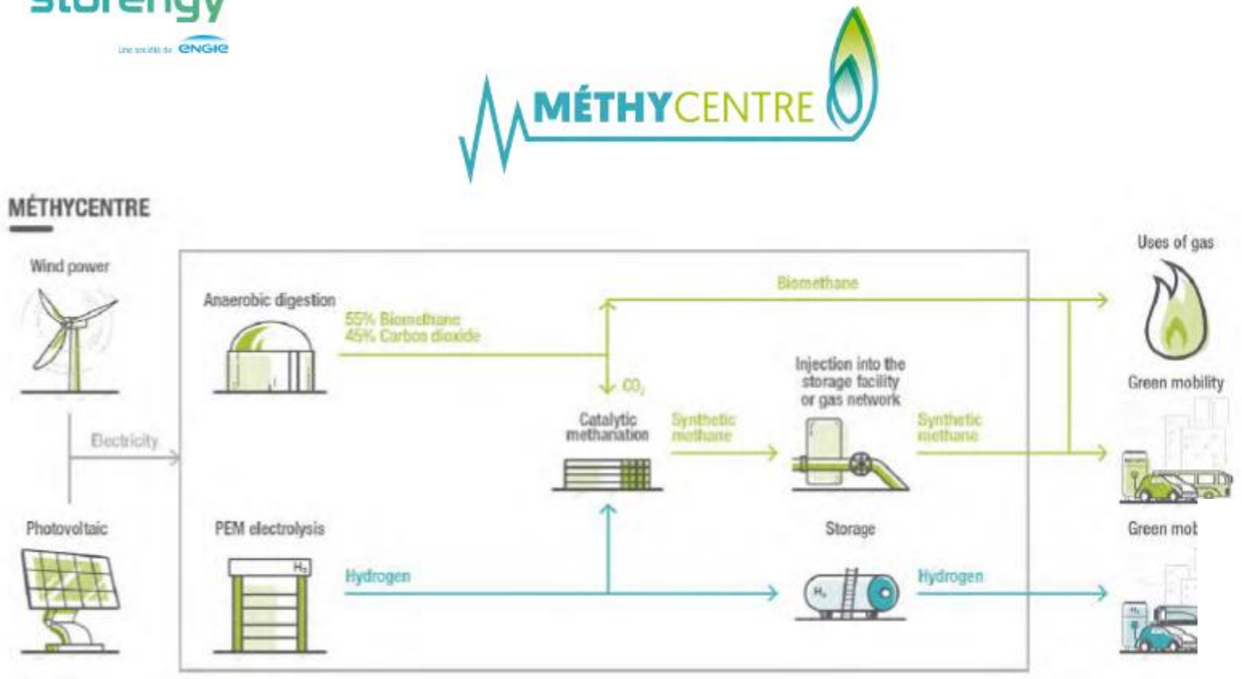


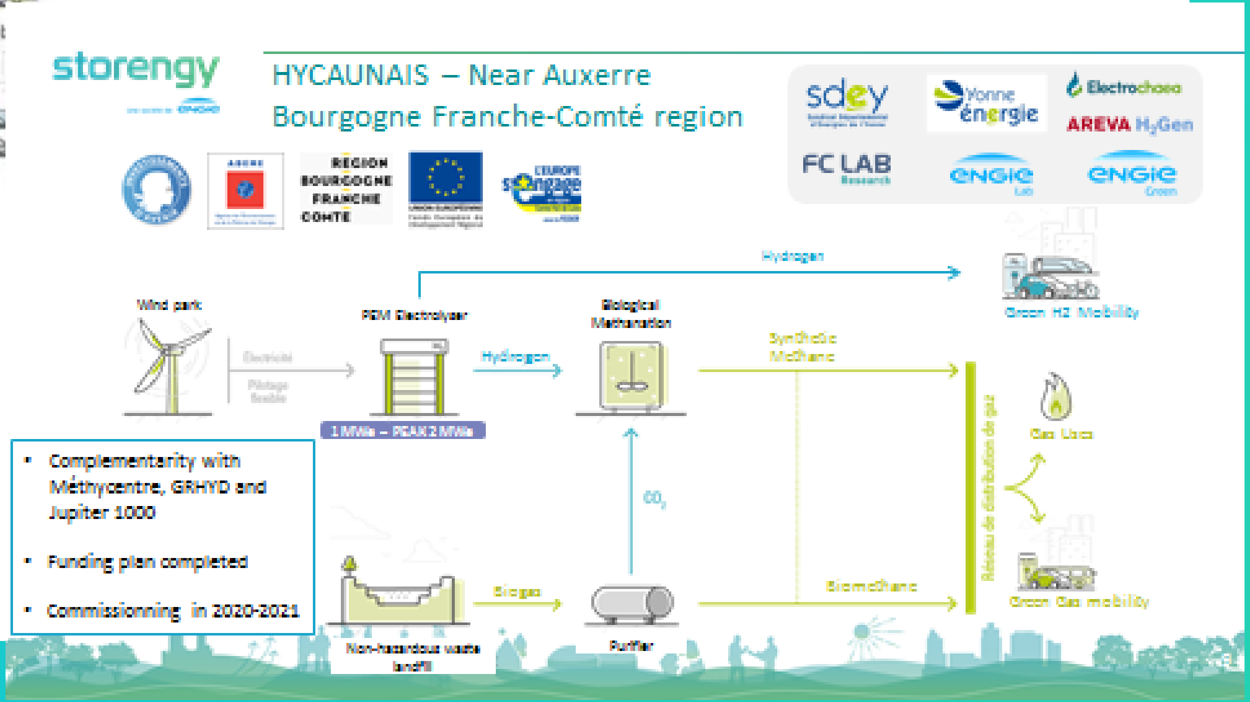
How to transport renewable energy ?

Discrepancy between where people live and abundant solar resources



Power – to – e-methane: example of Methycentre & Hycaunais





It will be AND hydrogen AND methane AND methanol AND FT fuels AND ….

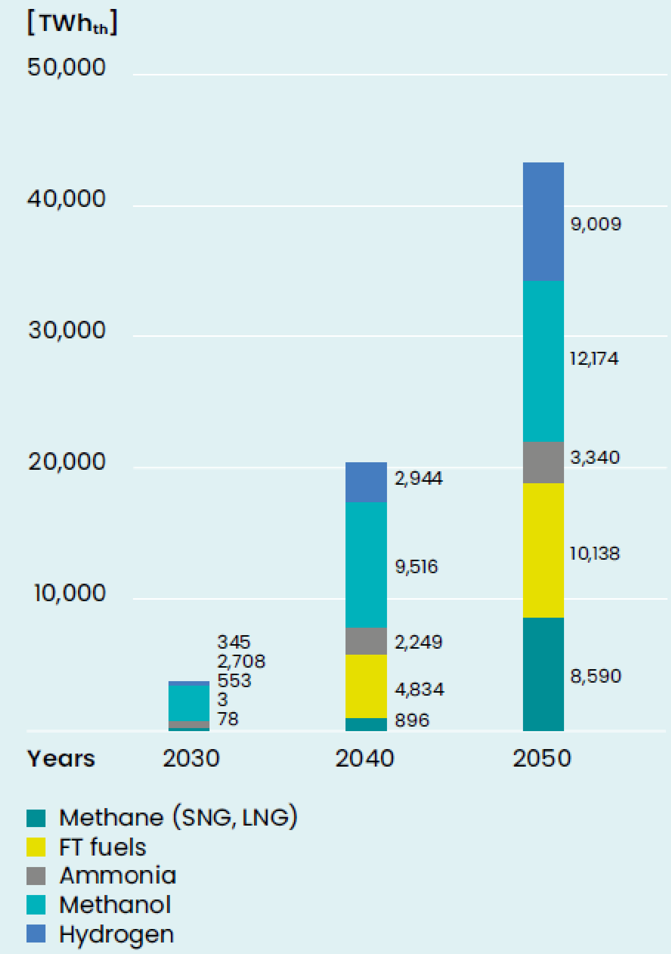


Figure ES1: Global powerfuels demand across the transition.

Figure ES2: Global CO_2 demand for powerfuels production across the transition.

- Powerfuels will play an important role in a carbon-neutral energy system in 2050, covering about 28 % of the final energy demand globally[d] (43,200 TWh of 152,200 TWh in 2050) with significant demands in all sectors (see Figures ES1 and

Global trade will reduce the levelised cost of powerfuels by up to 30 % in some regions compared to a self-supply scenario. In a scenario with international trade, the global average equilibrium cost levels for synthetic renewable ammonia, methanol, methane, and Fischer-Tropsch fuels range from about 45 to 75 €/MWh in 2050 (down from approximately 120 to 140 €/MWh in 2030), after trade, pre-shipping. The resulting global trade

Ram M., Galimova T., Bogdanov D., Fasihi M., Gulagi A., Breyer C., Micheli M., Crone K. (2020). Powerfuels in a Renewable Energy World - Global volumes, costs, and trading 2030 to 2050. LUT University and Deutsche Energie-Agentur GmbH (dena). Lappeenranta, Berlin.

Molecules will be important in transport and chemical and heat sector! Cost will be halved between 2030 and 2050.

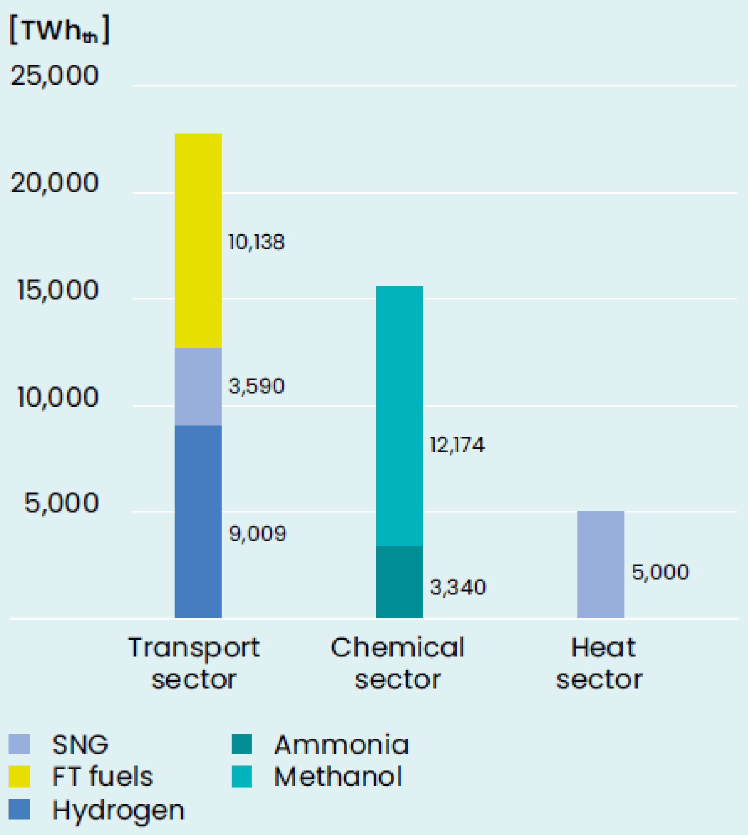


Figure ES3: Global powerfuels demand by sector in 2050.

Global powerfuels markets are more diverse than today's markets for fossil fuels, both in variety of supplying countries as well as in distribution of internationally traded energy carriers and feedstocks. South America, sub-Saharan Africa and, to a lesser extent, the Middle East and North Africa emerge as key exporters, while Europe, Eurasia, Northeast Asia, and Canada (within North America) emerge as key importing regions. The market shares for synthetic renewable fuels in 2050 break down to 28 % methanol, 23 % Fischer-Tropsch fuels, 21 % hydrogen, 20 % methane (SNG/LNG), and 8 % ammonia. Methanol is expected to become the new central bulk chemical in the global chemical industry, and is traded globally.

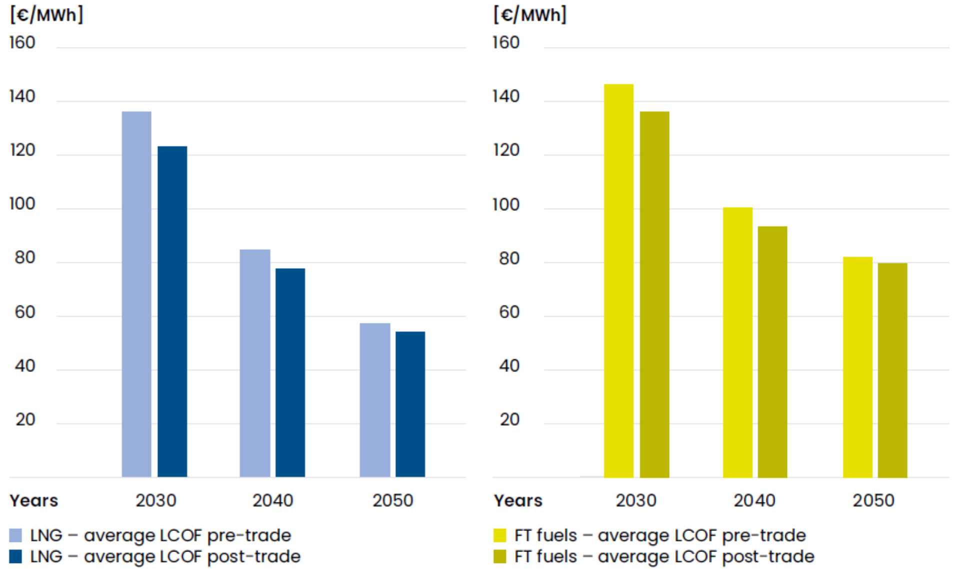


Figure 43: Global average pre-trade and post-trade levelised cost of fuel for LNG (left) and FT fuels (right) through the transition from 2030 to 2050.

Ram M., Galimova T., Bogdanov D., Fasihi M., Gulagi A., Breyer C., Micheli M., Crone K. (2020). Powerfuels in a Renewable Energy World - Global volumes, costs, and trading 2030 to 2050. LUT University and Deutsche Energie-Agentur GmbH (dena). Lappeenranta, Berlin.

E-fuels high on the agenda of many ENGIE's BU's: From R&D over pilot to demo

Engie ecosystem

BU-GEN, BU-H_2, BU-MESCAT
STORENGY   AXIMA
ENGIE Impact   ENGIE Disruption
GRTgaz   TRACTEBEL
ELENGY   GEM
GRDF   ENGIE Research

R&D

ENCO2RE
BIOCON-CO2
EnAlgae
power to PROTEIN
wetsus
Sunrise
SUN ERGY
CO2 VALUE EUROPE

Pilot

Jupiter 1000 — **E-methane** — GRTgaz
(2014 - …)
Thermocatalytic hydrogenation
H_2 electrolyser (2 * 0.5 MWe)

C2FUEL — ENGIE Lab — **Formic acid DME**
Thermocatalytic hydrogenation
H_2 electrolyser (1 Nm_3/h -15 bar)

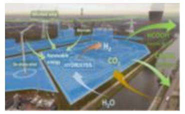
Port of Antwerp — **E-methanol**
Thermocatalytic hydrogenation
H_2 electrolyser @ 3 MWe

Hycaunais — **E- methane**
Electrochaea — storengy — ENGIE Lab
Bioconversion
H_2 electrolyser @ 1MWe

Methycentre — **E-methane**
KHIMOD ALCEN — storengy
Thermocatalytic hydrogenation
H_2 electrolyser @ 250 kWe

Demonstration

CCU Hub Ghent — **E-methanol**

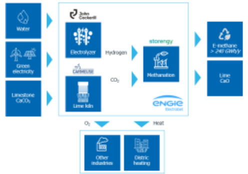


Thermocatalytic hydrogenation
H_2 electrolyser @ 63 MWe

HyNetherlands

100 MW (2024/2025)

Charleroi — **E-methane**

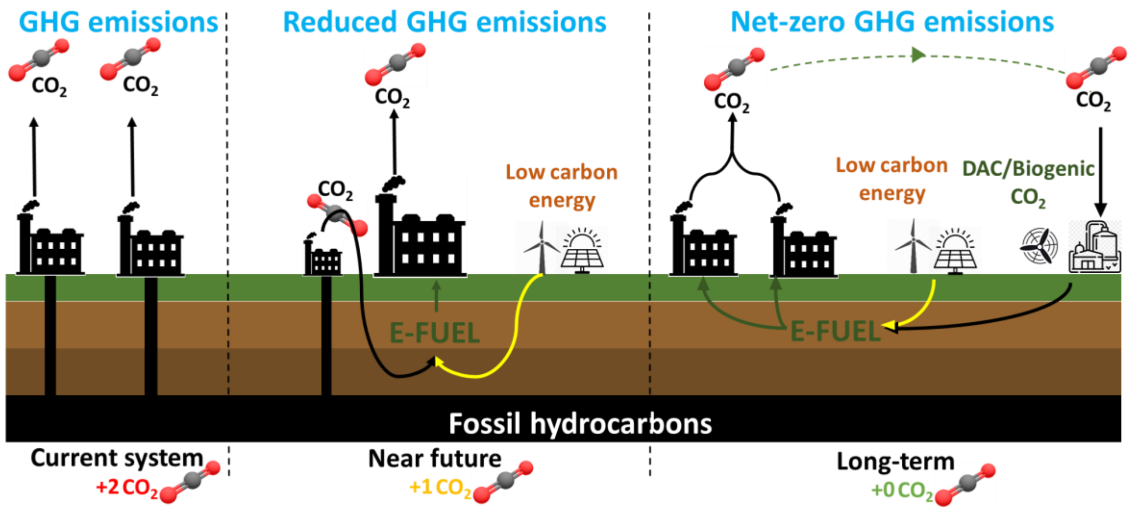


Bioconversion
H_2 electrolyser @ 75 MWe

3

Conclusion

- Energy efficiency and circular economy are first crucial steps towards carbon neutrality
- Electrification using renewable electricity of many processes (beyond electrical vehicles) is a good idea!
- Hydrogen is difficult to store and move → where possible, direct and local use
- Turning hydrogen into another molecule (e.g. NH_3 or **synthetic hydrocarbon like** methane, methanol, …) makes transporting its energy possible and we have existing infrastructure to do so!
- CCU makes sense:



- **So carbon will play an important role in the carbon neutral energy transition!**