ENGIE Research

Emerging Sustainable Technologies

60 years Laborelec event

28 March 2022

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Visiting Professor @Ugent

Content

1

Context: what does the 2 Degree Scenario mean?

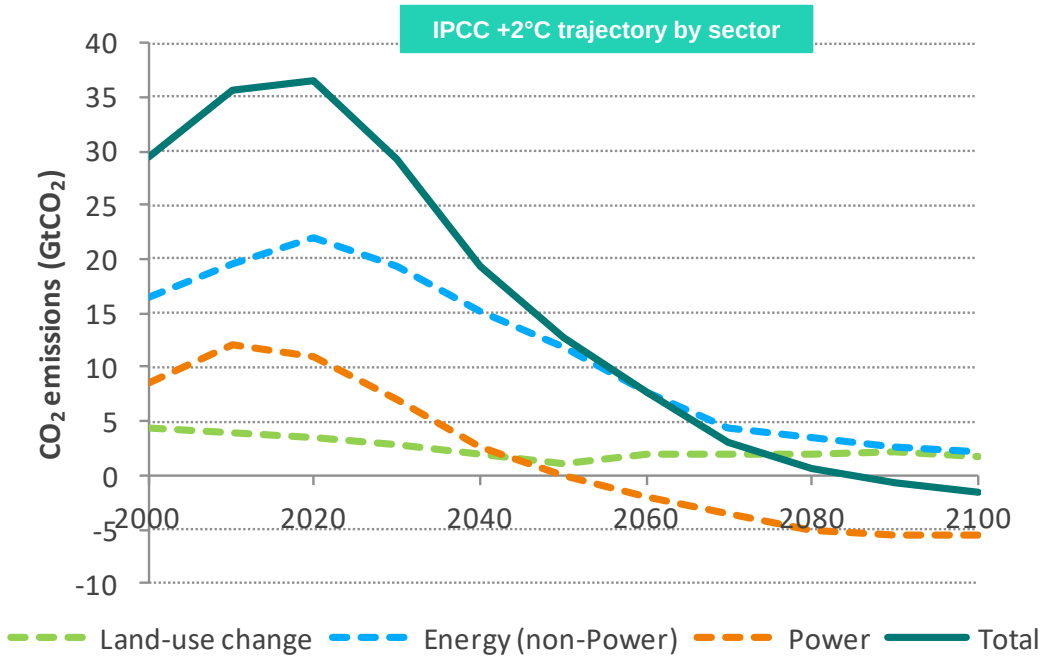
In December 2015 (@ CoP21 in Paris), 161 member states agreed upon the 2DS

- For the first time in December 2015, 161 states officially adopted in Paris at the CoP 21 the target of max temperature increase 2°C by 2100.

- The CoP 21 agreement includes **3 goals** :
  - Containing the rise of global mean temperatures "well below 2°C above pre-industrial levels, and to pursue efforts" to limit the warming to 1.5°C.
  - "Increasing the ability to adapt to the adverse impacts of climate change" by promoting resilient and low-carbon development.
  - Making financial flows "consistent" with a low-carbon develo

Source: ENGIE Corporate Strategy CODIR 20/07/2015 scenario for a +2°C target - Adapted from IPCC, AR5-WG1 and AR5-WG3

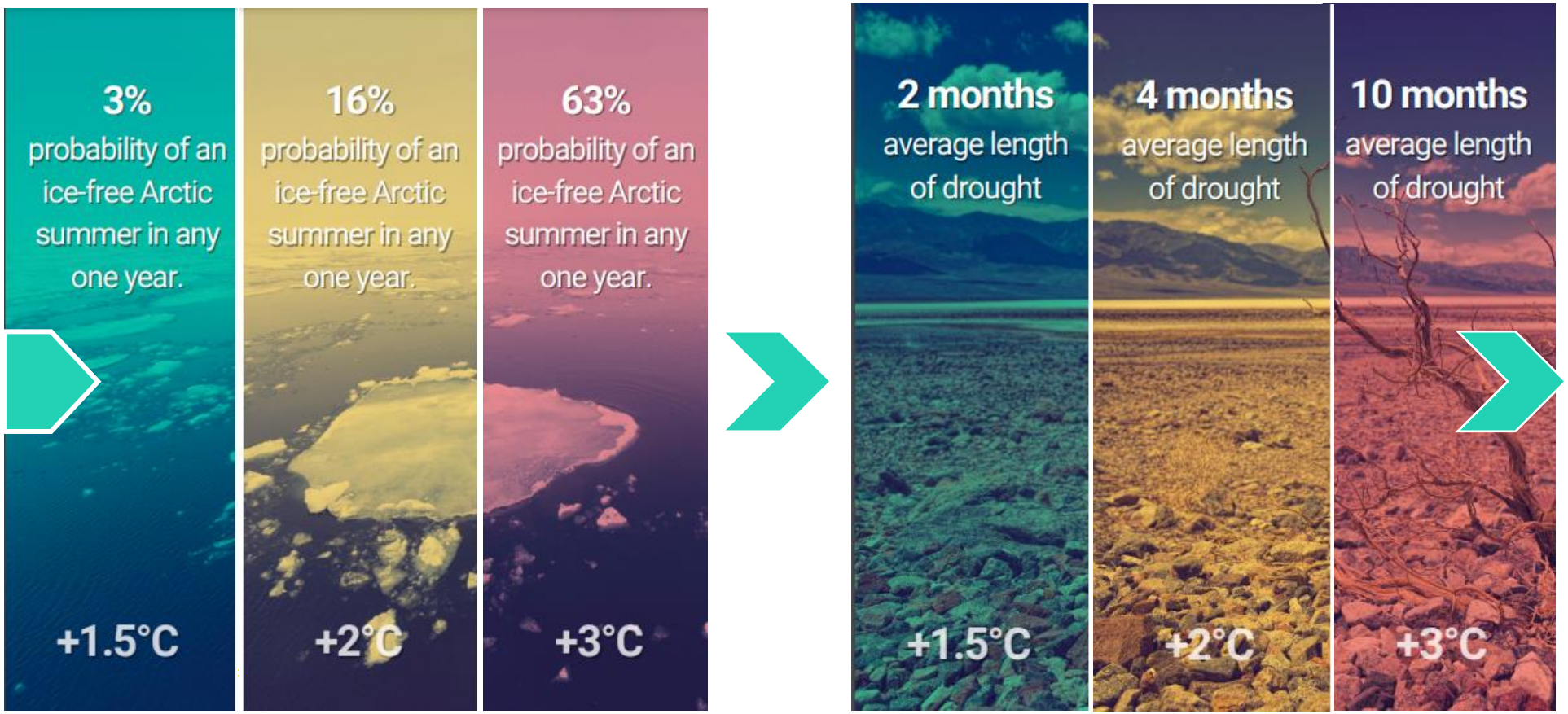
- **Scenario from the IPCC shows that the power sector should become CO_2 negative by 2060 if we are to achieve the 2°C target**



The difference between 1.5°C, 2°C or 3°C average global warming can sound marginal but...

...in fact, they represent **vastly different scenarios** for the future of humanity.

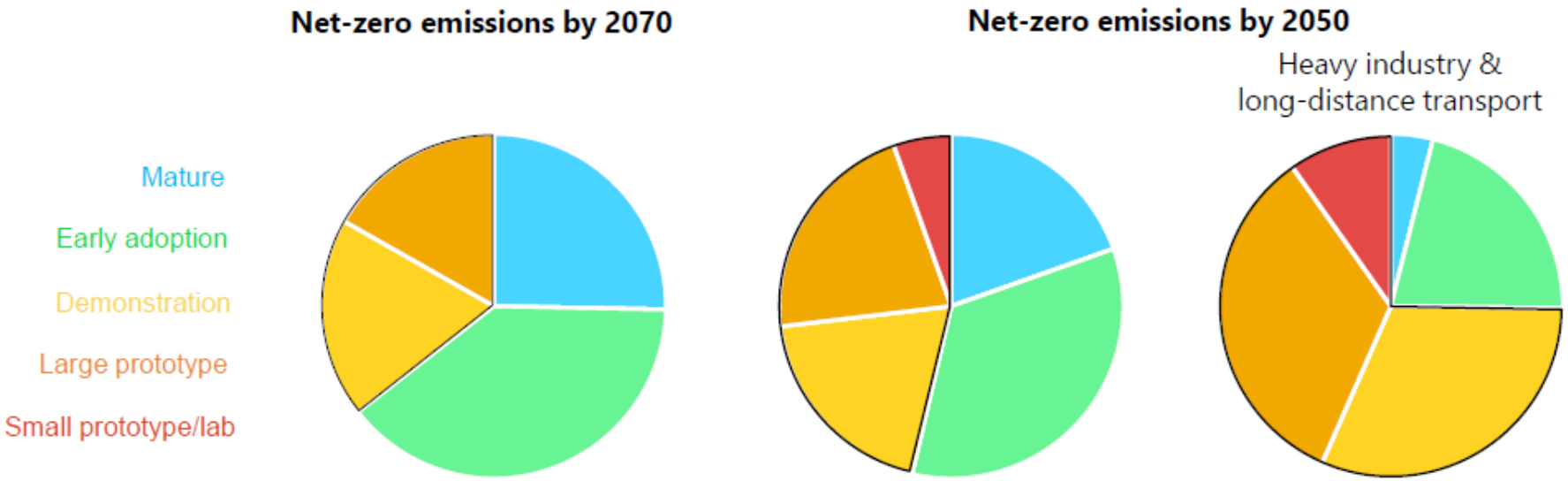
The frequency of disasters...



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!

Clean energy technology progress hinges on innovation

Cumulative emissions reductions relative to baseline trends by technology maturity



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!'

We must prove the alarming roadmaps wrong!

Good news:

(i) Some companies are taking the lead (today mostly digital companies)

(i) All current alarming roadmaps do not take breakthrough technologies into account!

So research & innovation can help prove these alarming roadmaps wrong!

Microsoft wants to capture all of the carbon dioxide it's ever emitted

The company wants to be carbon negative by 2030

By Justine Calma | @justcalma | Jan 16, 2020, 12:30pm EST

SHARE

Microsoft President Brad Smith, Chief Financial Officer Amy Hood, and CEO Satya Nadella

Apple commits to be 100 percent carbon neutral for its supply chain and products by 2030

Already carbon neutral today for corporate emissions worldwide, the company plans to bring its entire carbon footprint to net zero 20 years sooner than IPCC targets

October 20, 2021
3:06 PM GMT+2
Last Updated 5 months ago

Sustainable Business

Amazon and others commit to using zero-carbon shipping fuels by 2040

The logo of Amazon is seen at the company logistics centre in Boves, France, October 6, 2021 REUTERS/Pascal Rossignol

LONDON, Oct 19 (Reuters) - Amazon.com Inc **(AMZN.O)** and IKEA are among commercial users of container shipping that will opt for zero-carbon marine fuels by 2040 in a new initiative aimed at speeding up decarbonisation in the maritime sector, executives said on Tuesday.

And what about the war?

Fatih Birol (IEA's Executive director) in Brussels on 24 February 2022:

" Today can be the day on which the EU starts a historic redesign of its energy priorities & policy: build its own(ed) secure, affordable and clean EU energy future! "

BUT…

ANALYSE **Loskomen van Russisch gas? Er zit een reukje aan Amerikaans schaliegas: goed voor portemonnee, niet voor mens en milieu**

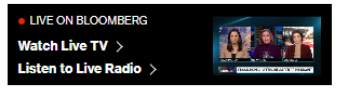
In het huidige conflict in Oekraïne belooft de VS om de EU dit jaar 15 miljard kubieke meter méér LNG (liquid natural gas oftewel vloeibaar aardgas) te leveren zodat we voor onze energie minder afhankelijk zijn van Rusland. Maar dat zal niet voldoende zijn om echt onafhankelijk te worden van de Russen. Bovendien bestaat dat Amerikaanse LNG voor 80 procent uit schaliegas. Dat schaliegas wordt niet bepaald milieuvriendelijk ontgonnen én het is niet ongevaarlijk: bij de ontginning zijn al tientallen doden gevallen.

Bloomberg

Germany May Extend Coal Use to Replace Russian Gas

- Invasion of Ukraine sparks push toward energy independence
- 'A warmonger is not a reliable partner,' vice chancellor says

By Angela Cullen and Birgit Jennen
February 28, 2022, 9:21 AM GMT+1 *Updated on February 28, 2022, 11:33 AM GMT+1*



Will war fast-track the energy transition?

The sudden push to reduce Europe's dependence on Russian gas and oil could trigger a paradigm shift to clean energy sources that might be quickly scaled up.

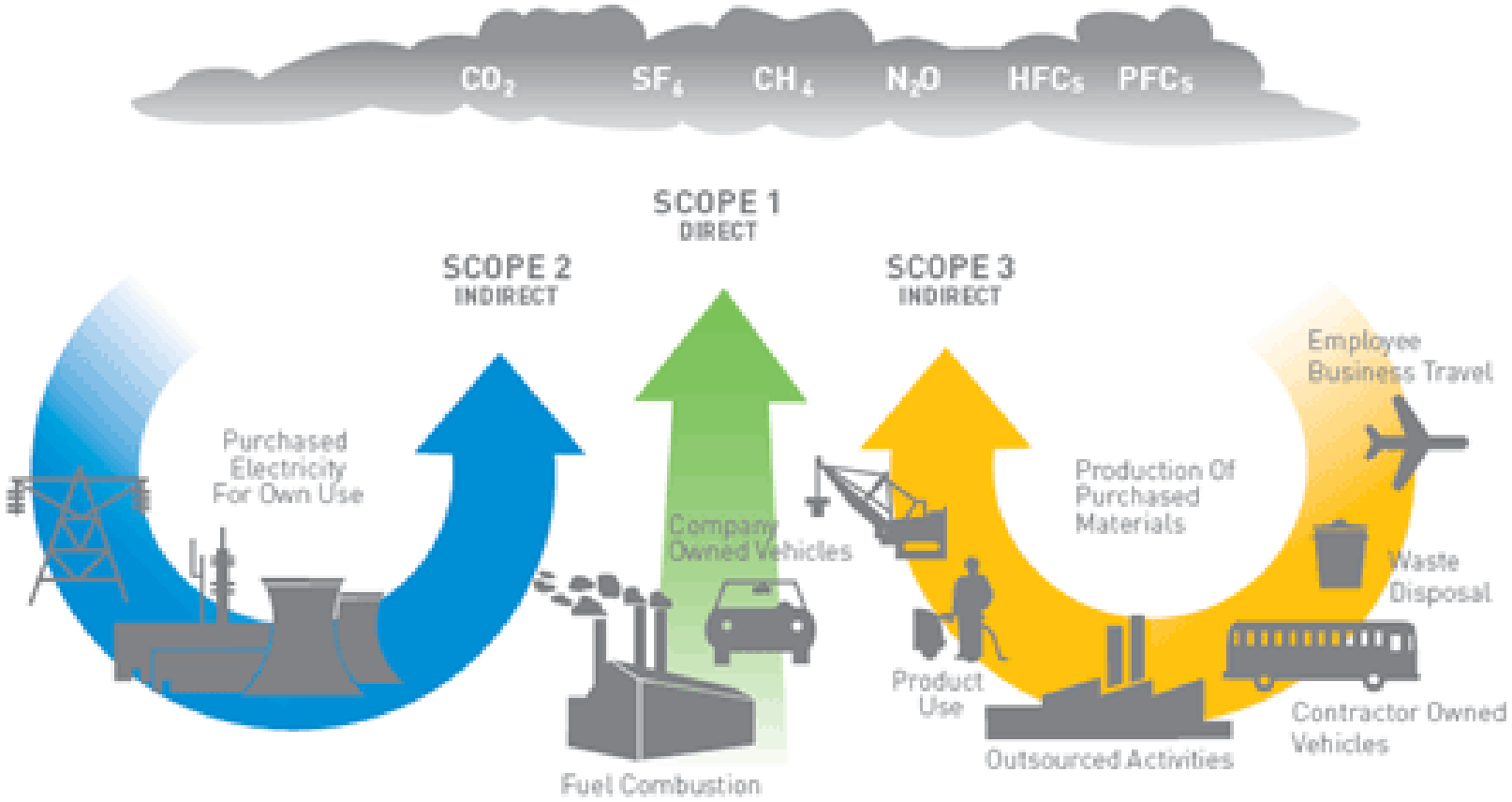
INFO EUROPE 1 - Le gouvernement envisage de repousser la fermeture de la centrale à charbon de Saint-Avold

Maud Descamps, édité par Thibault Nadal • 06h27, le 24 mars 2022, modifié à 12h41, le 24 mars 2022

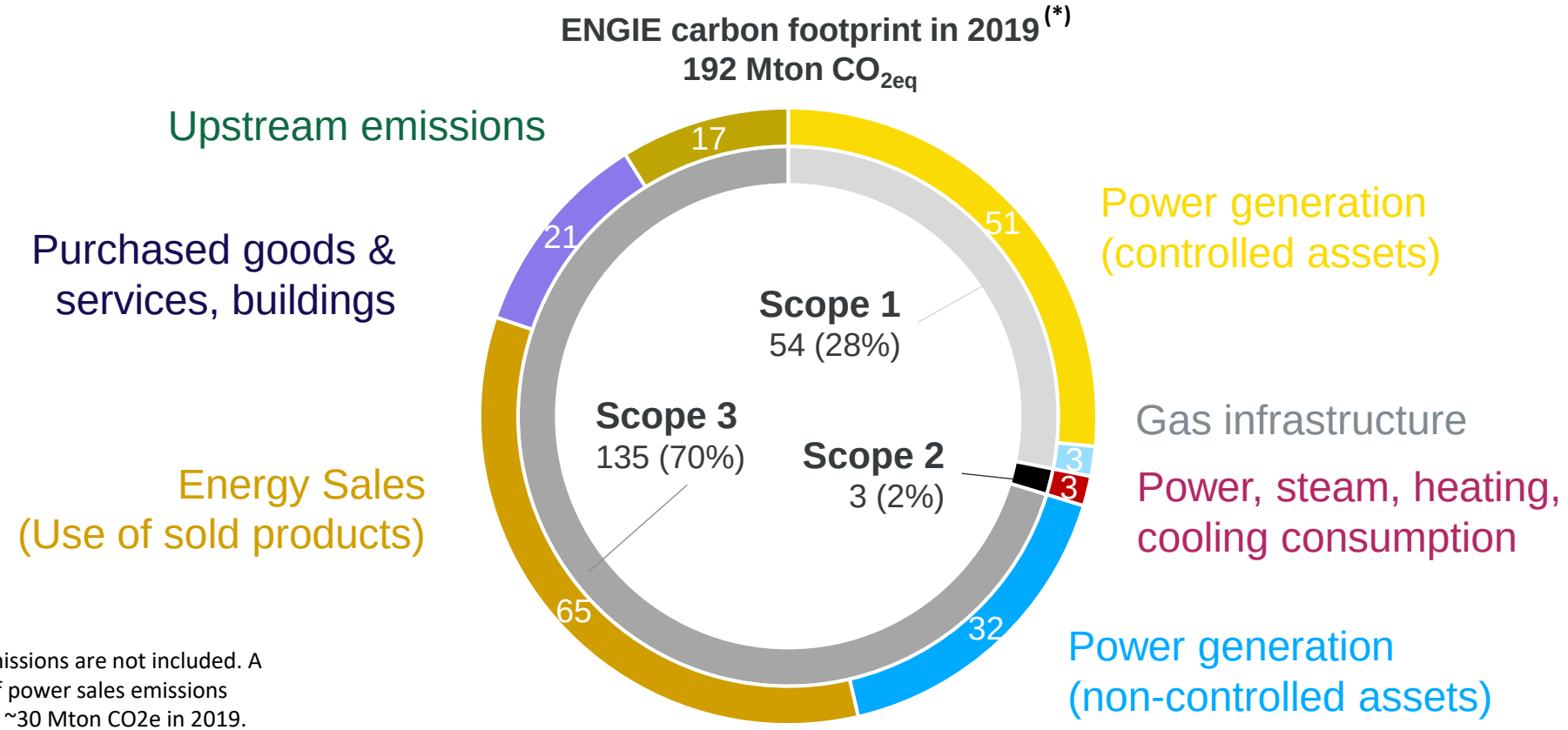
En raison de la guerre en Ukraine et de la hausse du prix de l'électricité, le gouvernement envisage de reporter la fermeture de la centrale de charbon de Saint-Avold en Moselle, comme celle de Cordemais, dont l'arrêt a été repoussé à 2024.

ENGIE & ENGIE Research

ENGIE announced to be carbon neutral on all 3 scopes by 2045:



ENGIE's ambition covers all 3 scopes, including direct emissions as well as all indirect emissions



(*) power sales emissions are not included. A first assessment of power sales emissions estimates these at ~30 Mton CO2e in 2019.

Proposed net zero ambition by 2045 covers all scopes including procurement and upstream emissions, but intermediate targets are limited to energy generation and sales, the two most important sources of emission

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

gaya

France

Battery Storage

Belgium

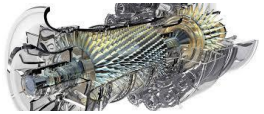
Bifacial Solar testing

Chile

Decentralized Energy System for Islands

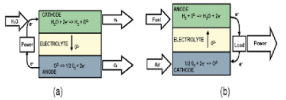
Singapore

H_2 co-combustion in gas turbine



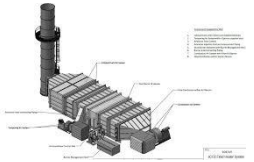
Belgium

High temperature SOEC/SOFC



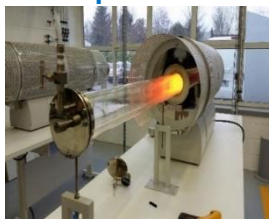
France

Supercritical CO_2 cycle



US

Solar-H_2 panels



France

OPV for Buildings Heliatek

Heliatek

HeliaFilm®

Global

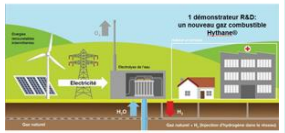
Floating Wind turbine

Portugal

High Altitude Airborne Wind

Germany

H_2 injection in natural gas grid



France

Power to methane

France

Solar cooling

France

3 pathways towards Carbon neutrality

3 pathways towards Carbon neutrality

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

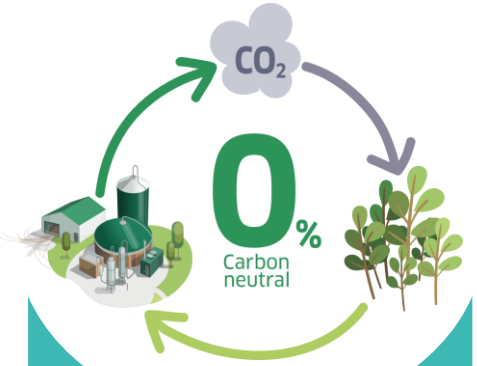
From waste TO green GAS : clean, local, circular...
...but the challenge is to achieve volume production at scale

1. Collection

Organic waste are collected and transported to the methanization site

2. Anaerobic Digestion

Organic waste goes through an anaerobic fermentation process which produces **digestate** and **biogas**.



Biomethane is considered carbon-neutral

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

Its combustion produces biogenic CO_2 emissions

Compensation effect: almost no impact on greenhouse gas emissions.

Digestate

Is used as natural fertilizer

Biogas

A renewable fuel to generate heat (hot water or steam) and electricity (CHP) on site

RGGO **1 RGGO = 1 MWh green gas injected**

4. end-uses

Biogas is purified to be injected into the gas grid for industrial and domestic uses, such as heating or cooking

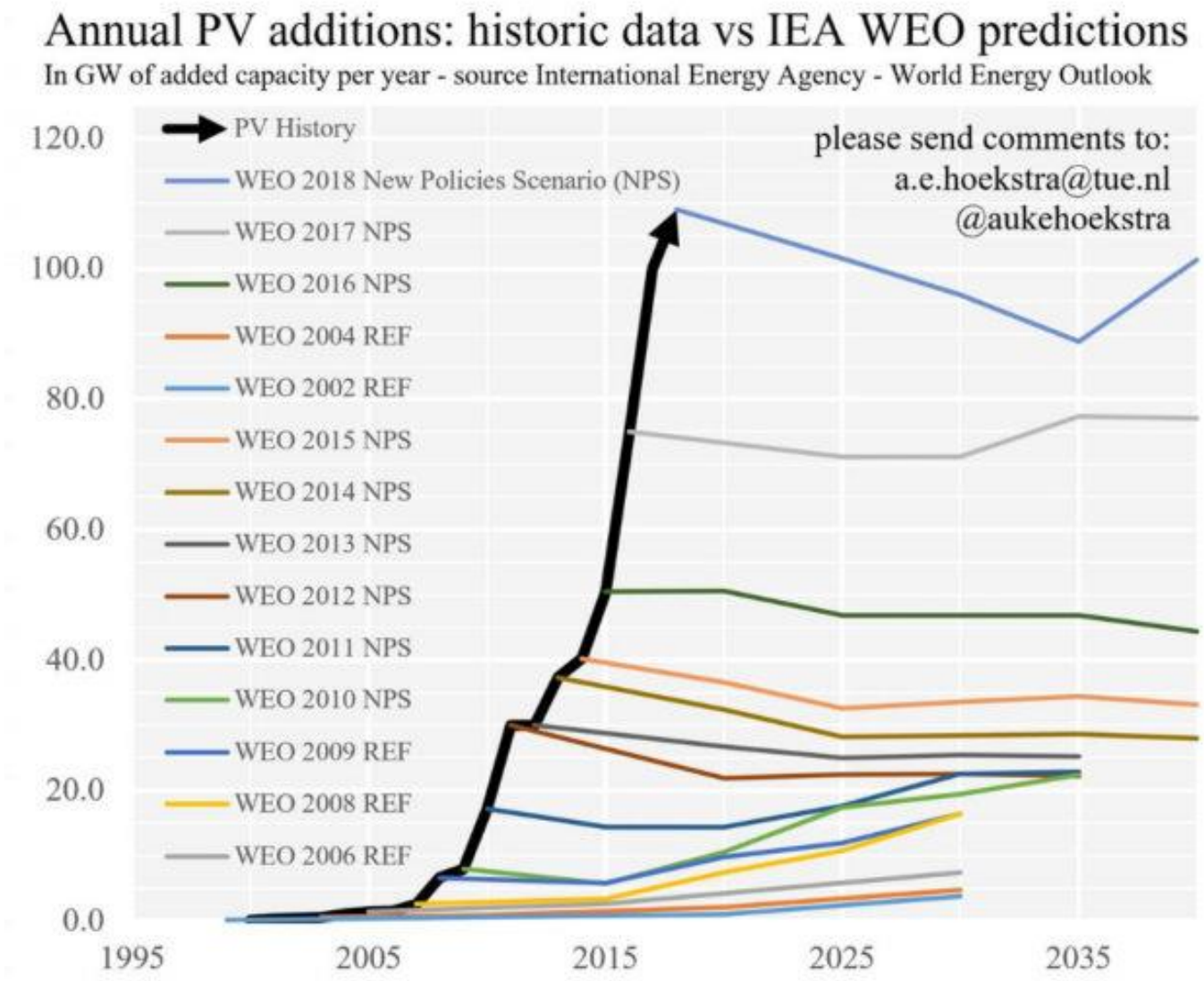
3. Upgrade

3 pathways towards Carbon neutrality

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

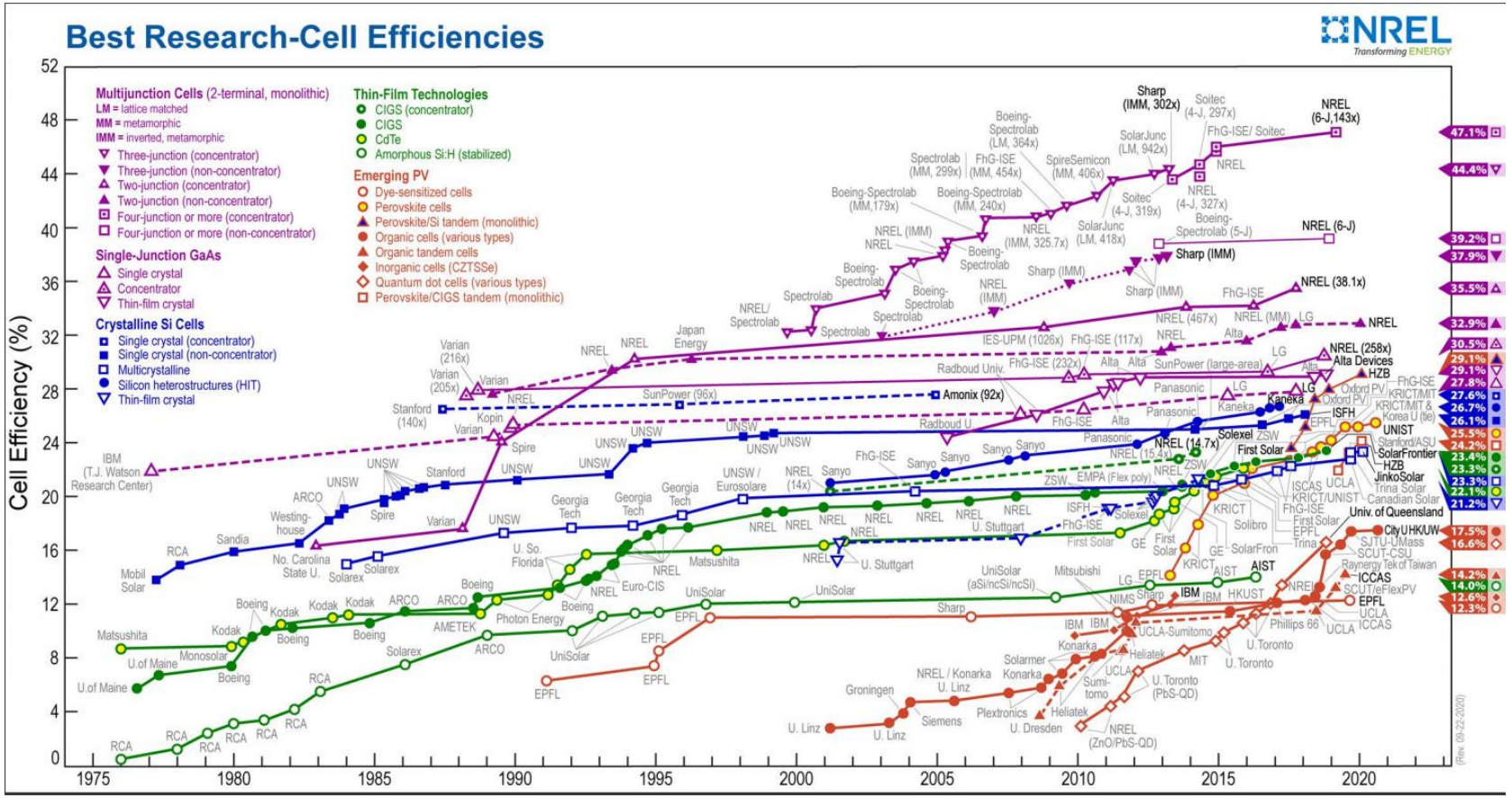
(ii) Electrify as much as possible (far beyond electric cars)

We have proven the roadmaps wrong...

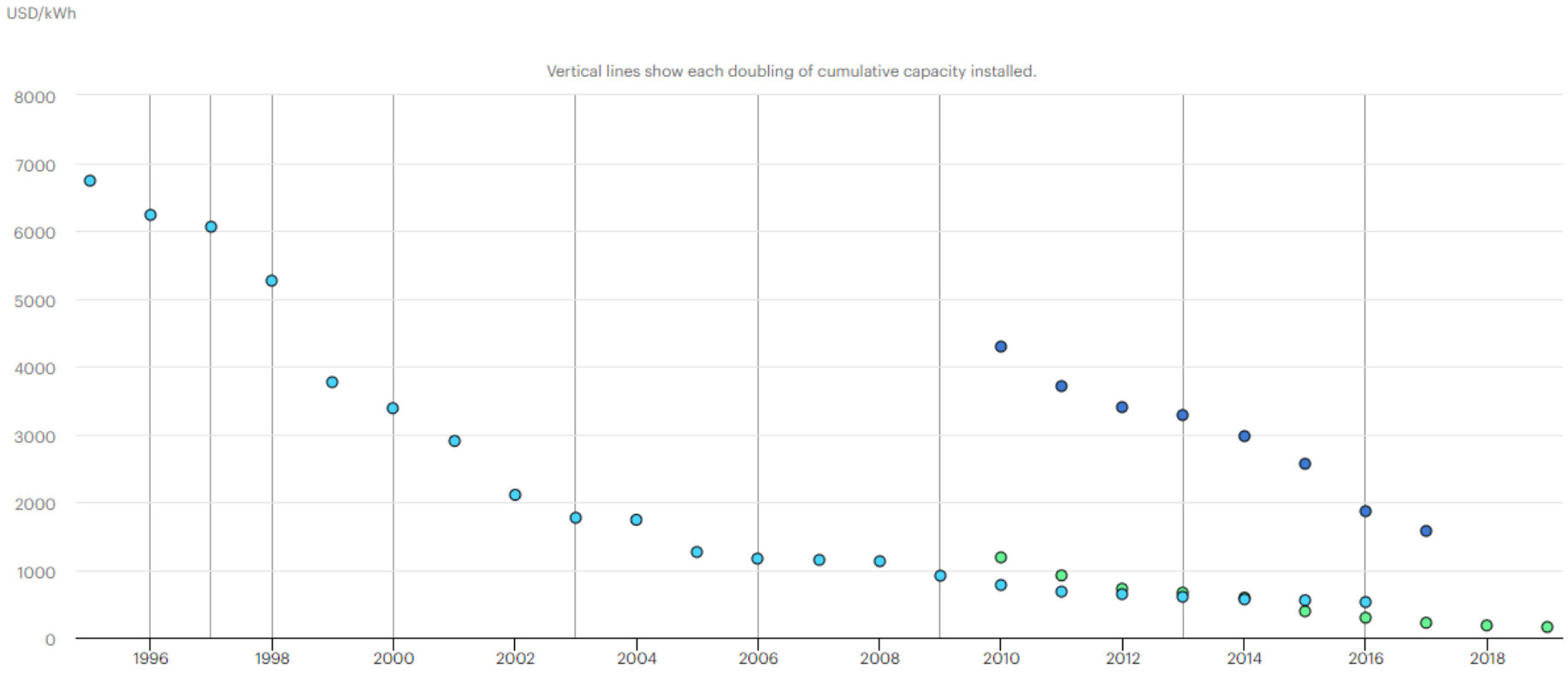


PV efficiency will continue to increase, thanks to the industry's continuing R&D efforts

- Over the last 4 decades, the PV industry has continued to find ways to increase the efficiency of the photovoltaic effect and this will not stop. But the real challenge is the cost: even for Silicon-based PV, significant R&D is necessary to reach the efficiencies between 24 and 26% in a cost-effective way.



Batteries are experiencing similar drastic cost reductions as PV and Wind in the past; but remain expensive and business model not always easy



Consumer electronics (cells) Utility scale (projects) Automotive (packs)

Flexibility and Demand side management will be crucial for a successful electrification

Provide flexibility locally and in the system

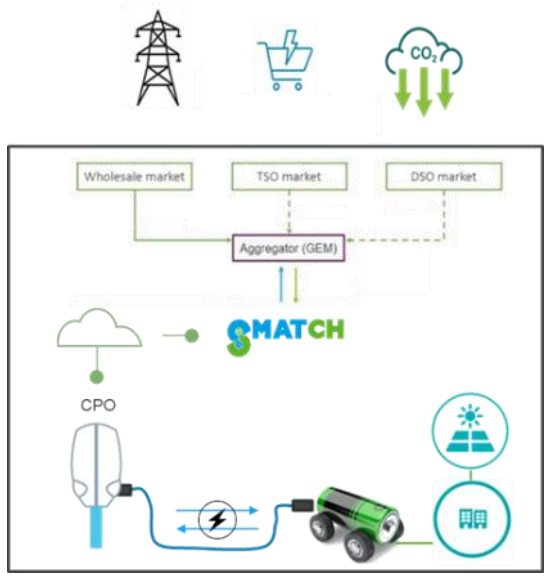
EMS, aggregation – Hybridisation with storage – Vehicle to grid – …

Operational R&D pilot with 5 different OEM battery solutions delivering **ancillary services**

Carbon neutral industry – battery, PV, wind, cold process, EV, EMS, battery health monitoring

Oud-Heverlee pilot, local **B2C LEC** with battery and V2G

Power quality with EMS for cattle farm with manure-based biogas plant



Sector coupling EM and Energy markets via smart charging – Flexibility pilot for low CO2 energy supply at Rotterdam for 58 chargers

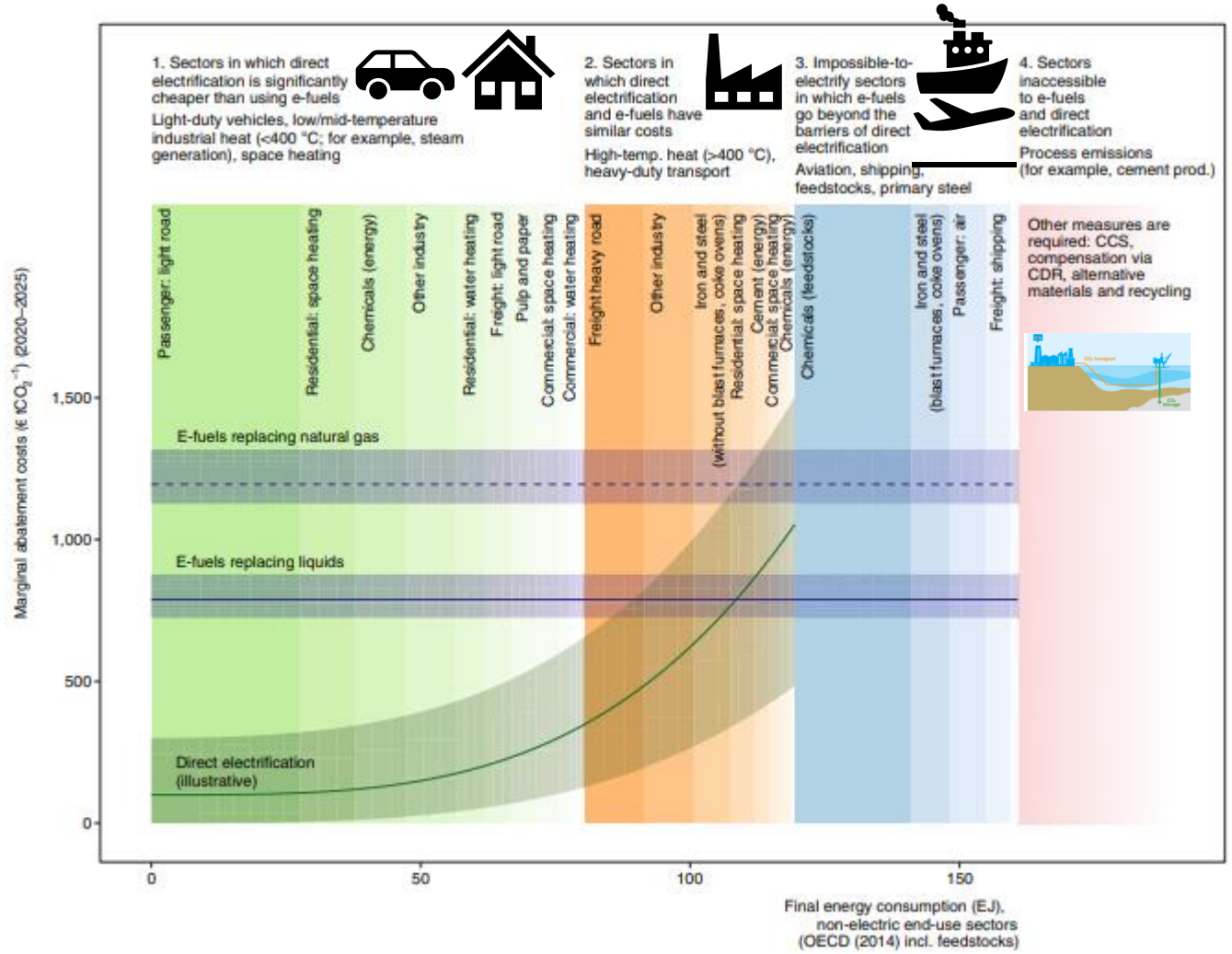
Four out of the six technologies in our 2021 document deal with electricity!

PART 1
New emerging technologies to watch out for

Marginal abatement costs differ as a function of the industry for the different pathways towards carbon neutrality

3 pathways towards carbon neutrality (order is important!):

1. Increase efficiency
2. Electrify what is possible
3. Need for molecules

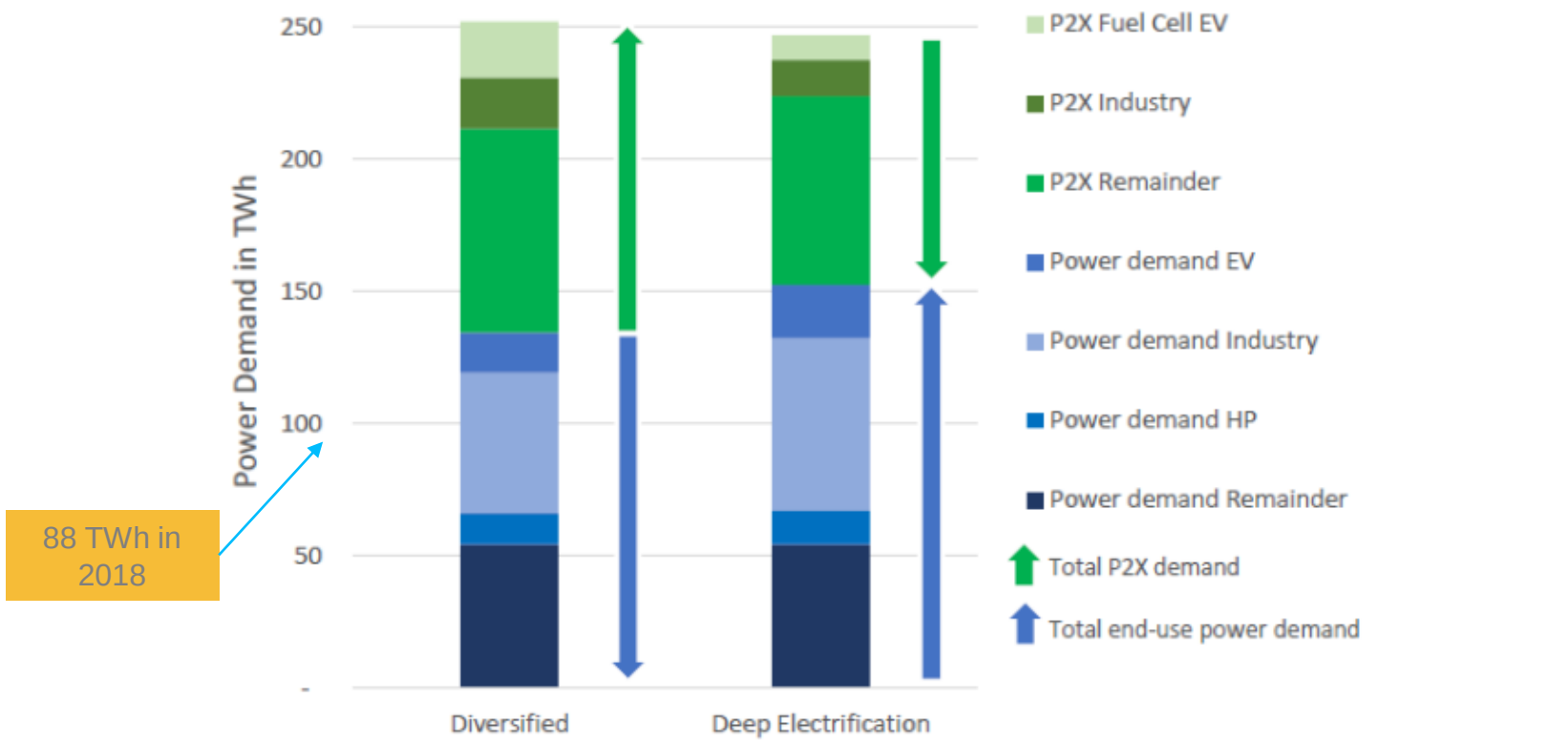


Falko Ueckerdt, Christian Bauer, Alois Dirnaichner, Jordan Everall, Romain Sacchi, Gunnar Luderer. **Potential and risks of hydrogen-based e-fuels in climate change mitigation**. *Nature Climate Change*, 2021; DOI: 10.1038/s41558-021-01032-7

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 will be important and need new emerging technologies (P2X)

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.

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'*

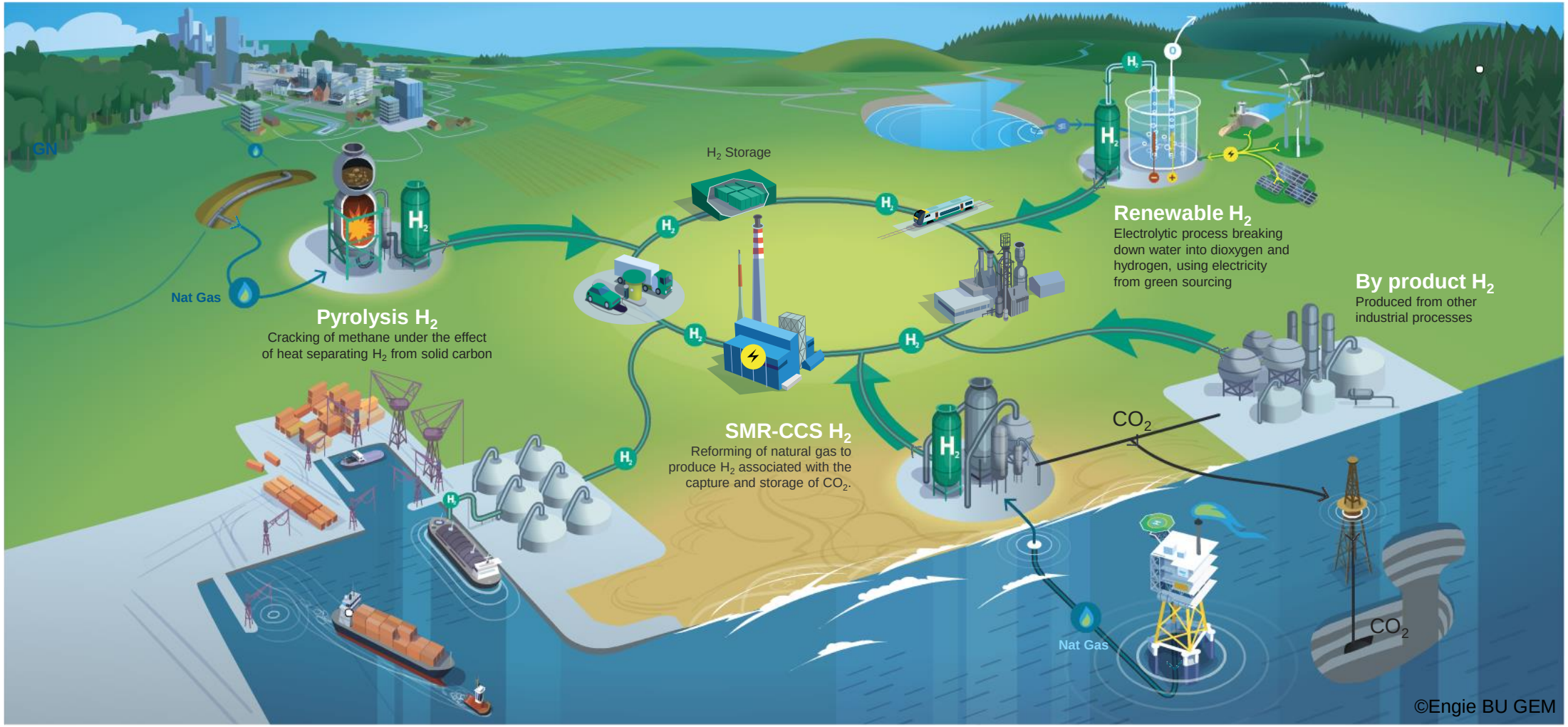
3 pathways towards Carbon neutrality

(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 …

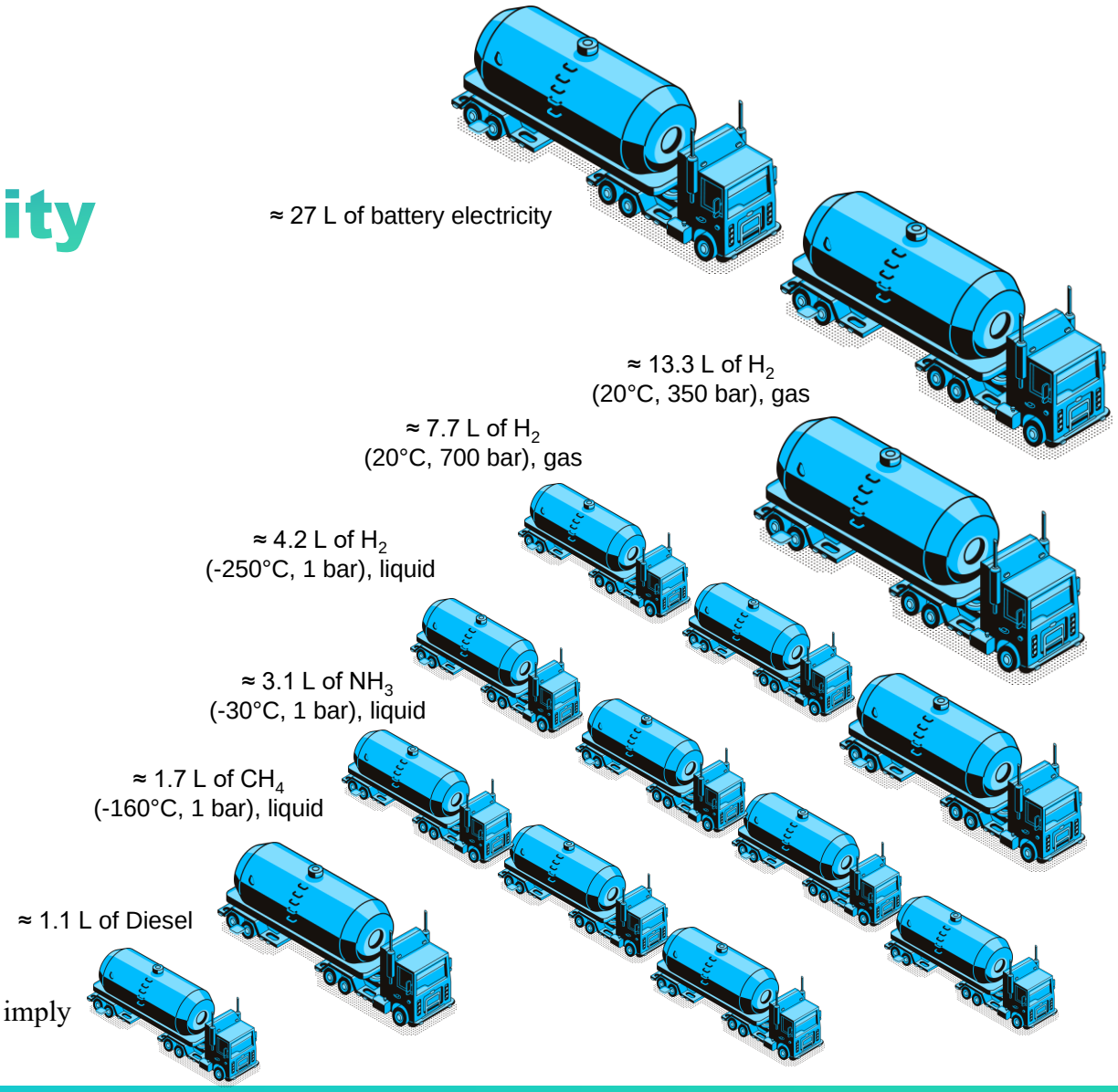


but

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

→ Need for synthetic hydrocarbons!*

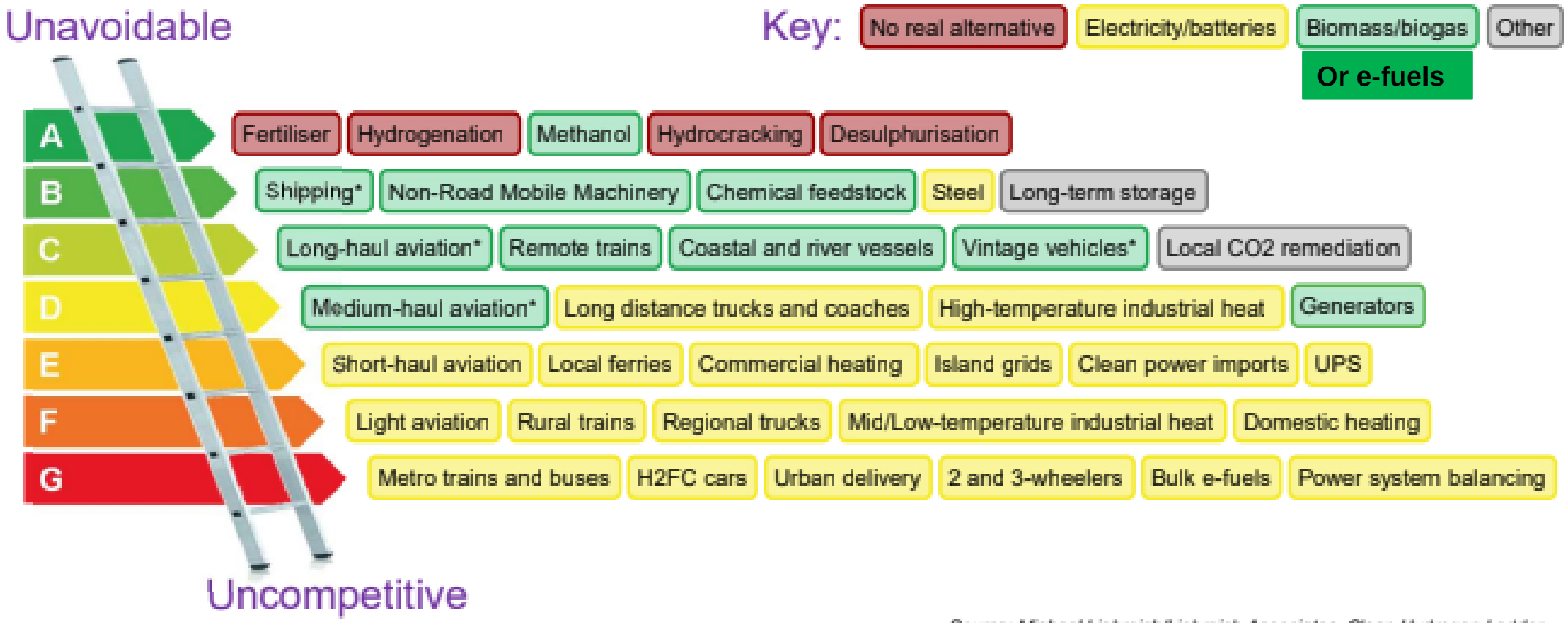
How to transport or store 10kWh of energy?



* 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

Clean Hydrogen Ladder: Competing technologies

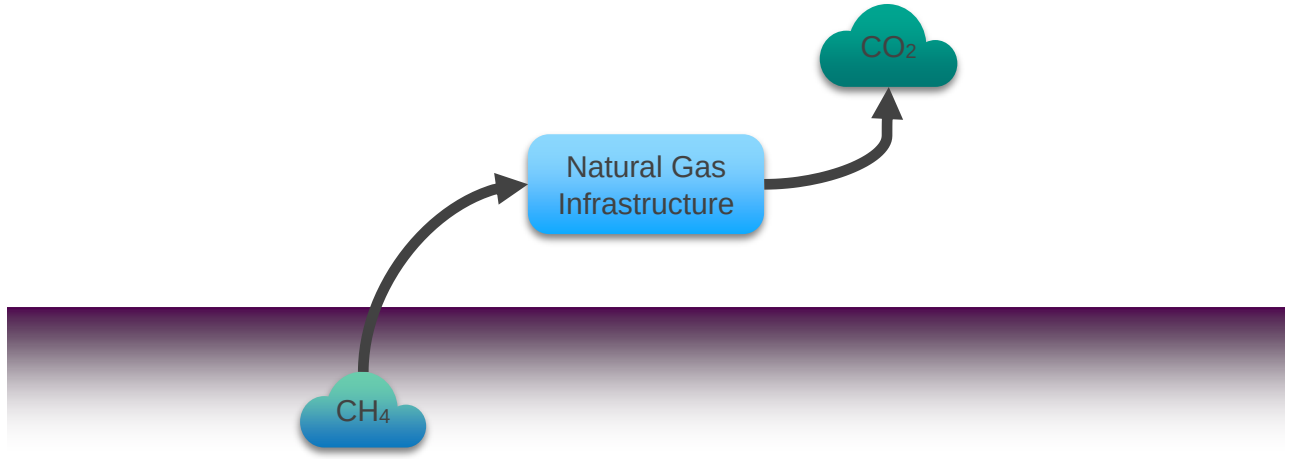
Liebreich Associates



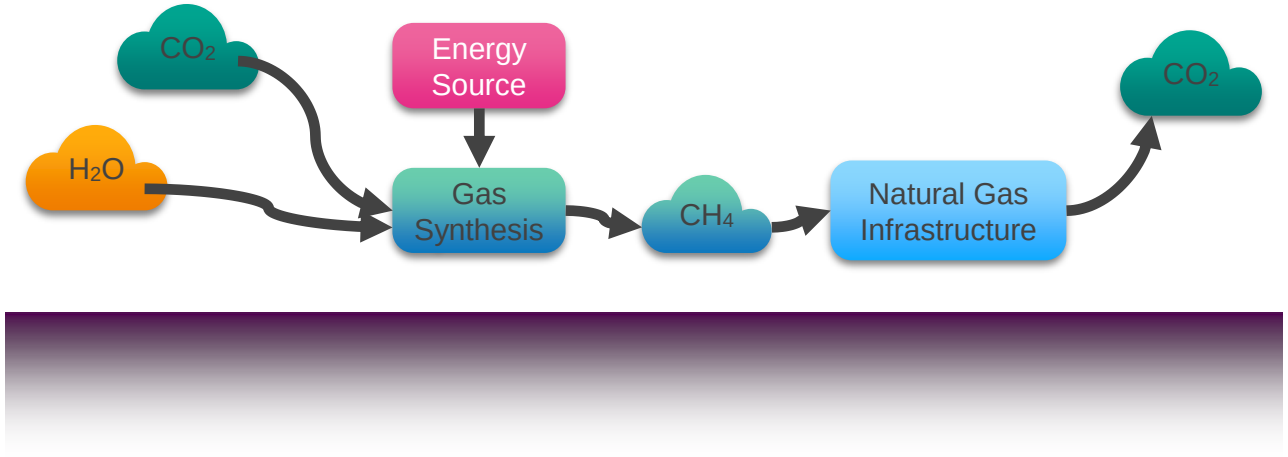
** Most likely via ammonia or e-fuel rather than H2 gas or liquid*

Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 4.1, 2021.Concept credit: Adrian Hiel, Energy Cities. CC-BY 3.0

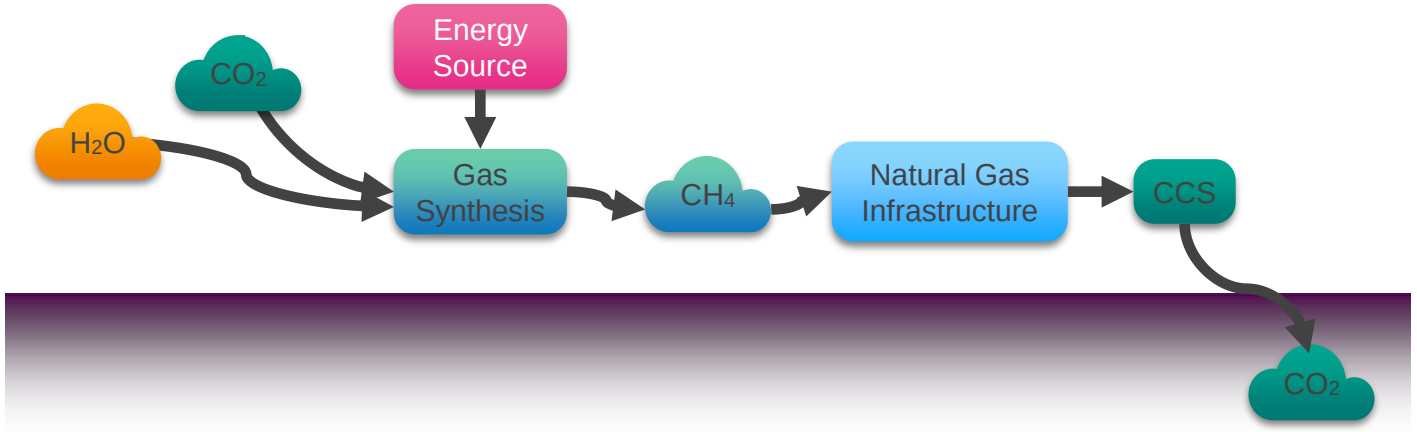
Today's Gas System Takes Carbon From The Earth's Crust and Puts It Into the Atmosphere



Tomorrow's Gas System Could Take Carbon From The Atmosphere To Make The Gas

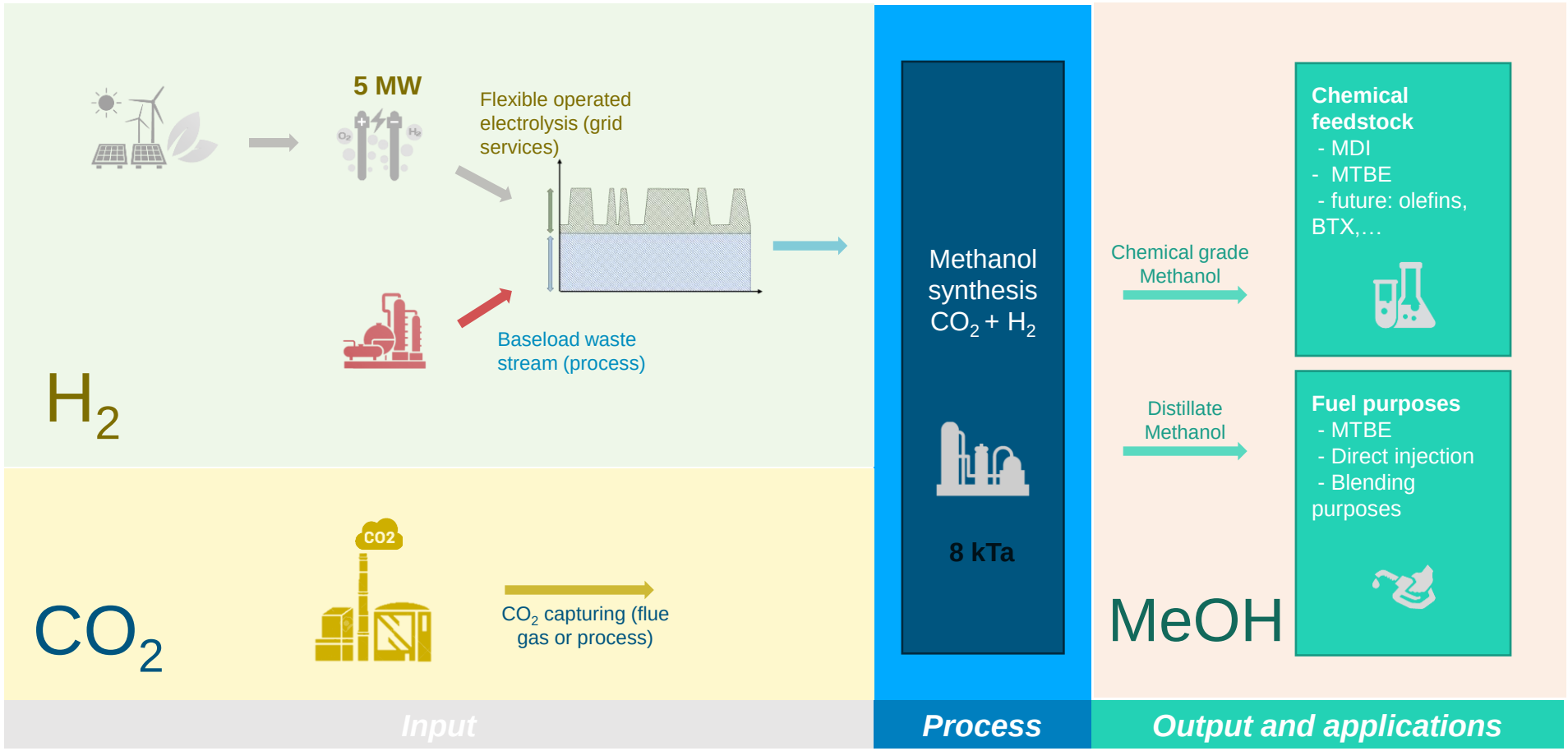


The Day After Tomorrow's Gas System Could Take Carbon From The Atmosphere And Put It Into Products or The Crust



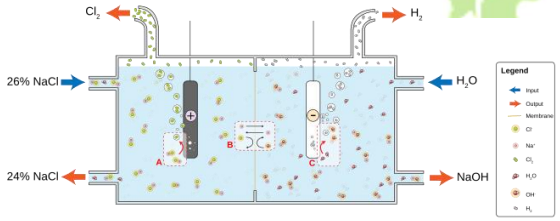
Power to Methanol Antwerp

The concept is based on a high level of flexibility both regarding the feedstock input, the process capability as well as the output and applications.



Demonstrator host site: INOVYN Lillo

Chlor-alkali process as ideal location to have access to fatal H_2



Chemical industry in Antwerp: from fossil-Chemistree to e-Chemistree implying a huge requirement of green electricity and molecules!

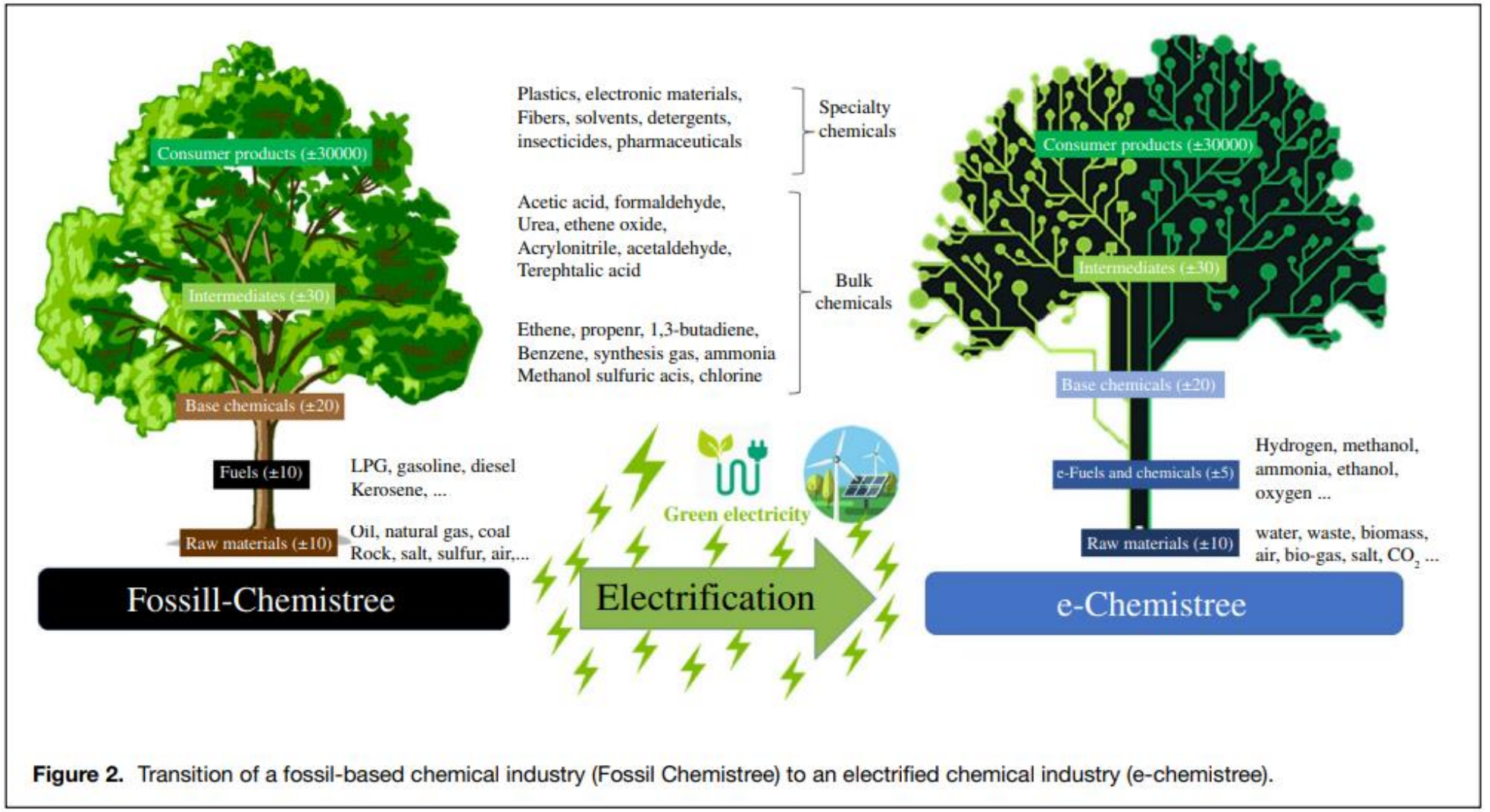


Figure 2. Transition of a fossil-based chemical industry (Fossil Chemistree) to an electrified chemical industry (e-chemistree).

K. M. Van Geem and B. M. Weckhuysen, 2021. Toward an e-chemistree: Materials for electrification of the chemical industry. MRS Bulletin,46, 1-10

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
EC
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)

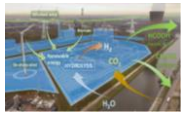
Demonstration

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

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

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

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


ENGIE
Research
Emerging Sustainable Technologies
2021 Edition

Editorial

How were the technologies selected?

Current efforts to limit global warming to 2 degrees above pre-industrial levels, as agreed in 2015 at the

COP 21 in Paris, are insufficient.

The IPCC 2021 report — like all other forecasting efforts — makes no mention of possible breakthrough technologies which could emerge and speed up our pathway to carbon neutrality. One could consider this a conservative approach, justified by the huge difficulty of predicting the next technology breakthroughs and their potential.

In this Emerging Sustainable Technologies 2021 document we present topical areas we think will offer non-trivial benefits for this transition. ENGIE does not only keep a close eye on their development but also has the ambition to help bring some of these technologies to the market at an increased pace through piloting and demonstrating.

How did we select these technologies? We have tried several methods to pick them in an ‘objective’ manner using quantitative indicators such as the number of publications and of patents, mentions in other reports and in press releases. However, we have not found any one quantitative method that was satisfying on its own.

In fact, using ‘objective’ quantitative measures results in mostly digital solutions dominating the selection due to the enormous work being carried out worldwide on our digital transformation. If ENGIE adopted the same approach we would, in effect, all be reporting the same and add little value.

Instead, we decided to trust the insights of our ENGIE experts in a wide variety of domains to compile this selection. This approach implies a degree of subjectivity, reflecting our unique ENGIE expertise in game-changing scientific and technological trends in energy-related activities.

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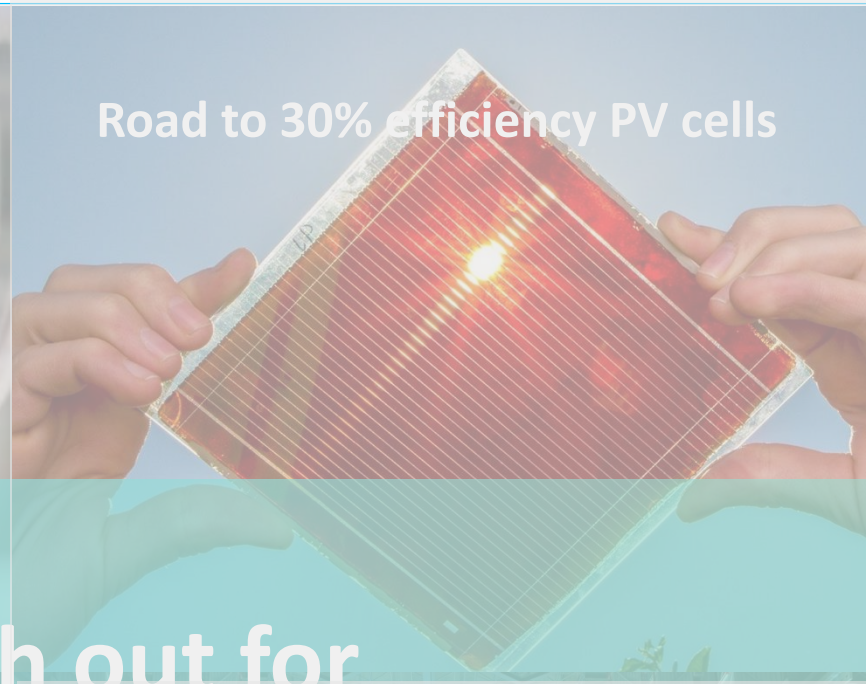
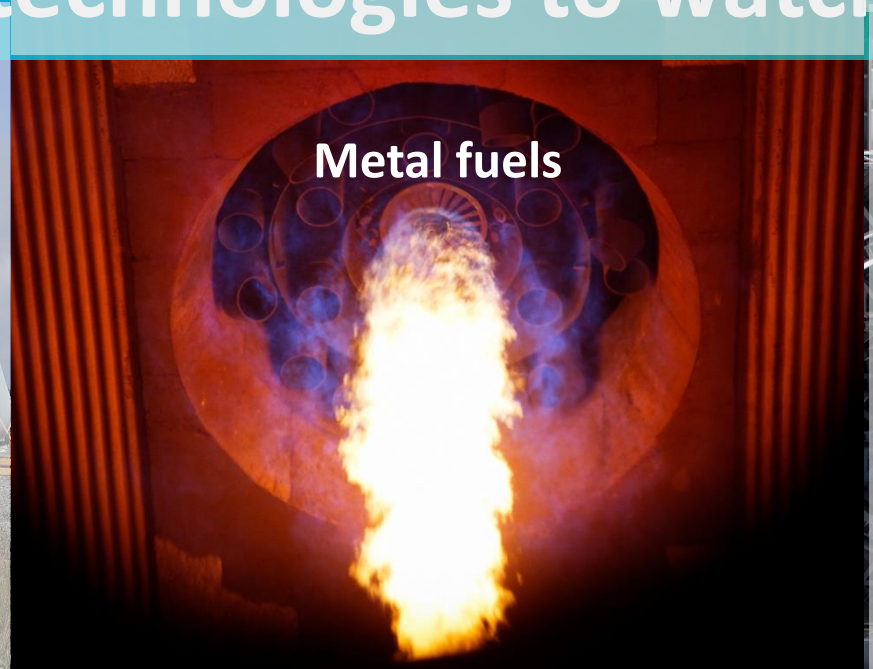


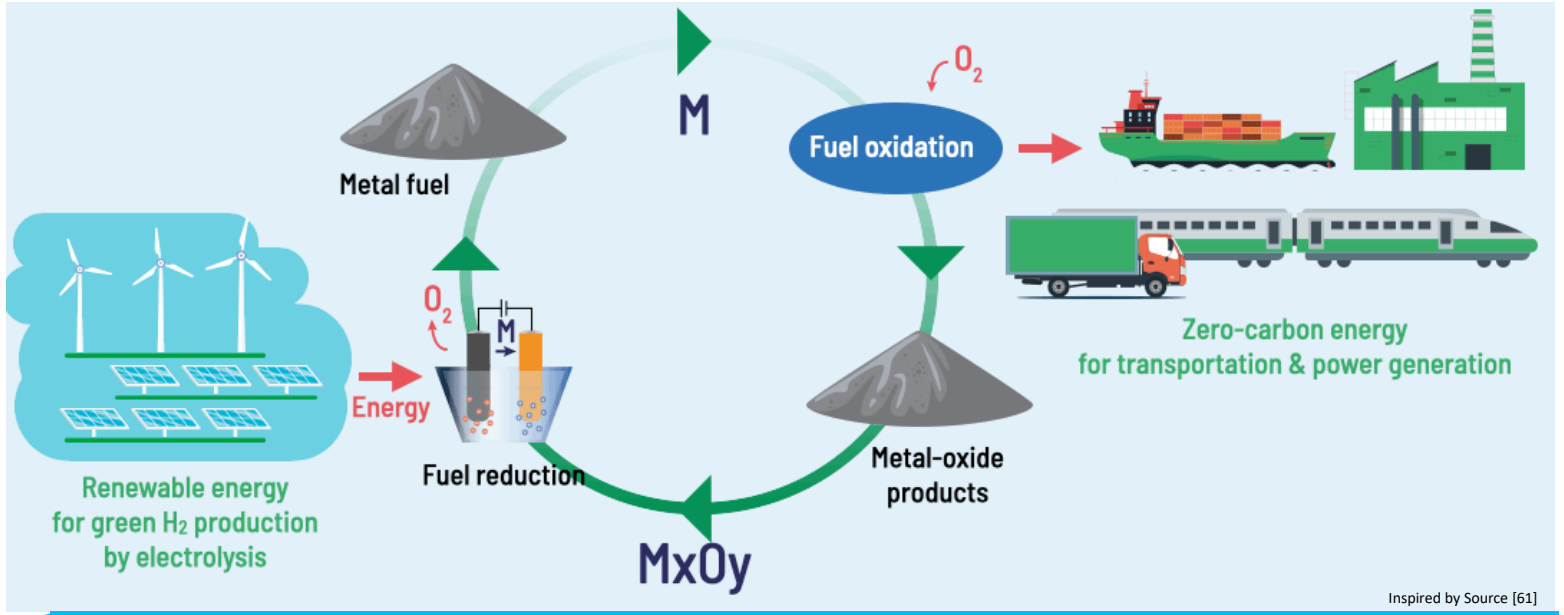
PART 1
New emerging technologies to watch out for



Metal fuels

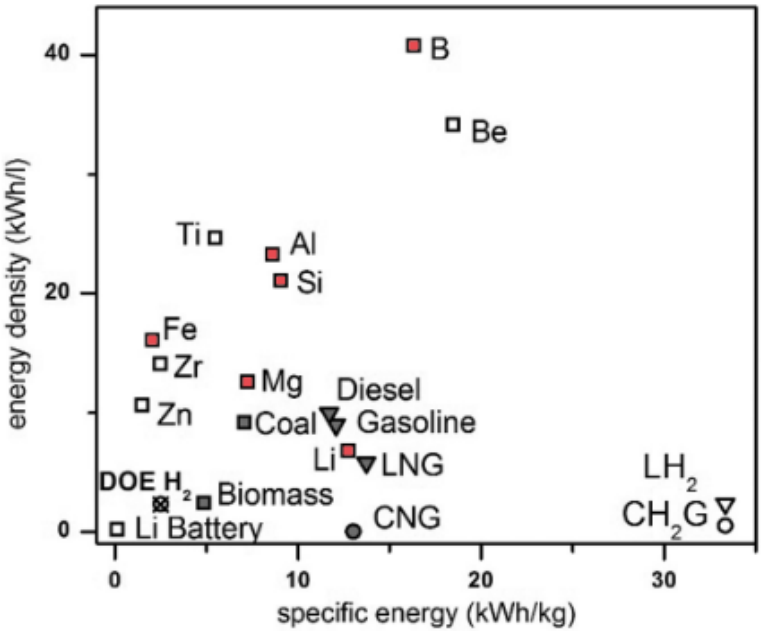
Metals as recyclable carbon neutral fuels are promising alternatives to fossil fuels

Metals have high energy densities and serve as fuels in many batteries, energy materials, and propellants. Metal fuels can be burned with air or made to react with water to release their chemical energy in a range of power-generation scales. Metal-oxide combustion products are solids that can be recycled, enabling metals to be used as recyclable carbon neutral solar fuels or electro-fuels.



Inspired by Source [61]

? Electro-fuels are primarily produced from electricity, during the reduction process to convert spent combustion/oxidation products back into reactive fuel.

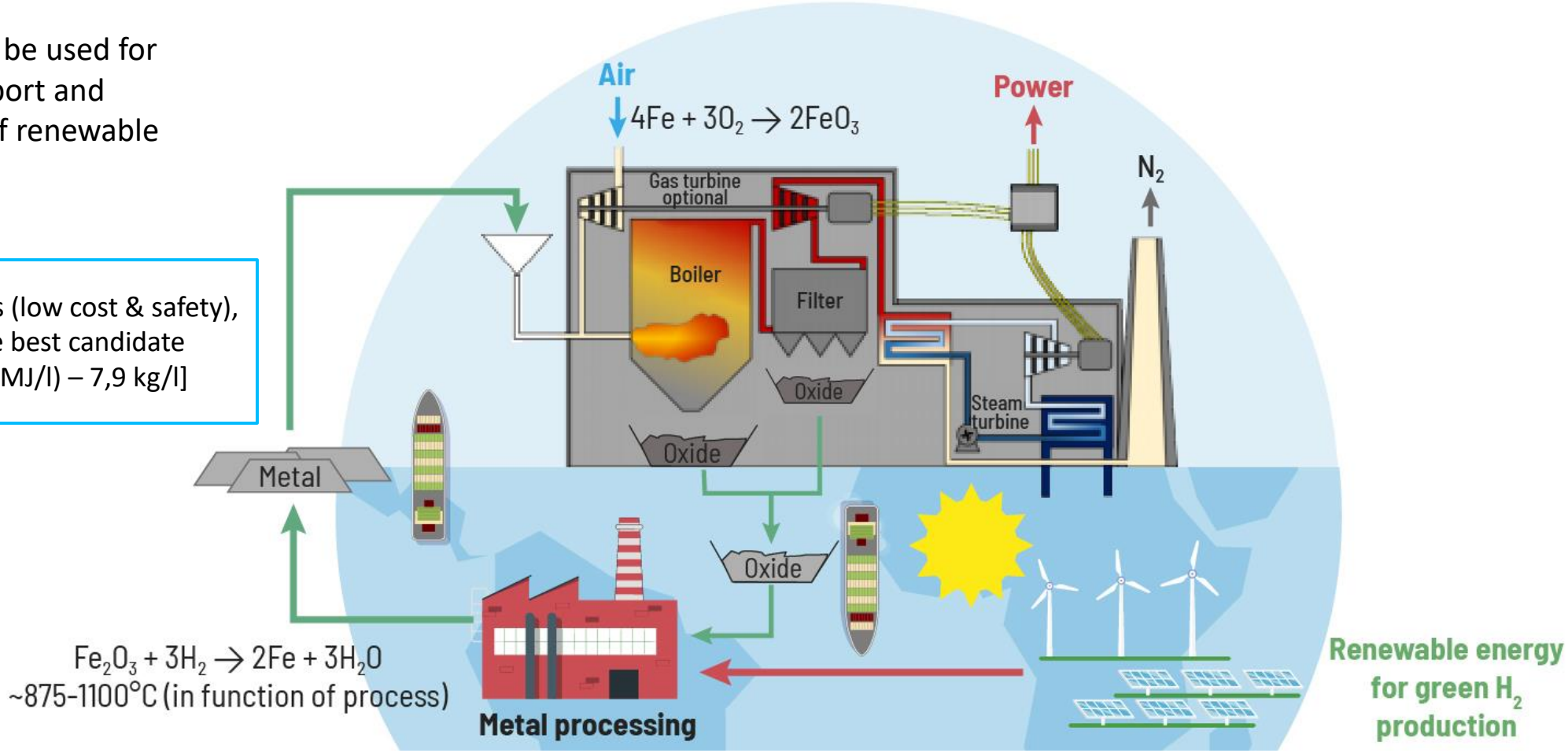


Potential metal fuel candidates. The element must be oxidized by O_2 from air, with high specific energy, be cheap and non-toxic [62]

The oxidation and reduction of metal fuels can be decoupled in terms of time and location…

…so metal fuels can be used for long-distance transport and long-term storage of renewable energy

For practical reasons (low cost & safety), Iron seems to be the best candidate [Fe= 15,8 kWh/l (57 MJ/l) – 7,9 kg/l]



Inspired by Source [63]

Advantages: using a solid fuel facilitates the CO_2 free closed loop owing to green H_2 reduction

METAL FUEL PROCESS

H_2 + Iron oxide ⇔ Iron

Energy

Iron + O_2 ⇔ Iron oxide

Energy

CARBON NEUTRAL PROCESS

CO_2 needs to be captured

$H_2 + CO_2 \Leftrightarrow CH_4$

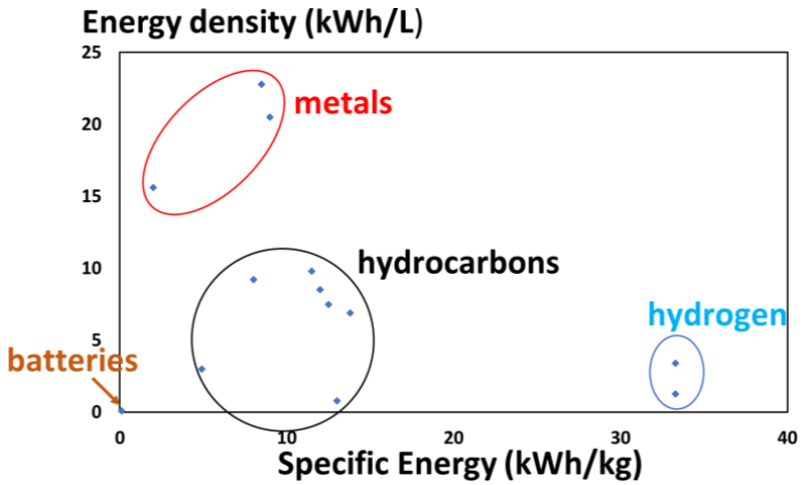
Energy

$CH_4 + O_2 \Leftrightarrow CO_2$

Energy

Advantages

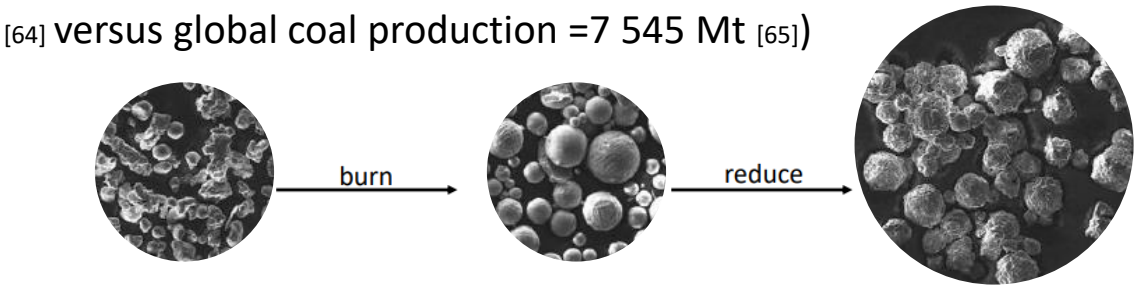
- Iron easy to transport
- CO_2/NOx/SOx free cycle
- Iron oxide easy to collect
- Metal fuels present higher energy density and specific energy than liquid fuels when oxidized



Adapted from source [61]

Challenges: a new energy generation system with a low maturity level TRL 3-5 and a few technical hurdles

- Particle emissions
- Safety during handling
- Availability of the powder:
  → 100 kW burns 50 kg/h Fe. So 1 GW during 8000 h would require 4 millions tons Fe but iron would be recycled!(global iron powder production in 2017=1,4 Mt [64] versus global coal production =7 545 Mt [65])
- Metal regeneration and overall efficiency
  → What about powder cycling/lifespan?



Diameter change during process [66]

Maturity and market players

Metal powder

- Pometon powder (IT)
- Laiwu (CN)
- JFE Steel Corp (JP)
- Hoganas (SE)
- Wuhan iron & steel (CN)
- Rio Tinto (US)
- MA Steel (CN)
- Kobelco (JP)
- CNPC powder (CN)
- Hangzhou Ytong New Material (CN)
- Anshan Iron & steel (CN)

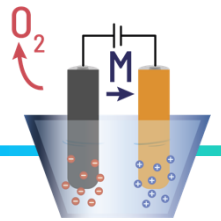
Oxidation TRL 5

- TUEindhoven
- Shell
- Uniper
- EMGroup
- Romico Hold
- Airbus
- McGill
- Ruhr Universität Bochum
- + all other players using metal powders as propellants

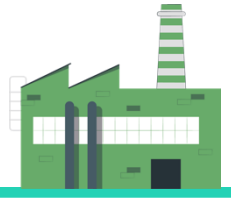
Fuel oxidation

Reduction TRL 3

- Doosan
- Vattenfal
- Swedish steel



Power plant project examples



2019-2020
Lighthouse burner
100 kW

2024
WSG Rotterdam
5 MW

2030?
MPP3 Maasvlakte
30x74 MW

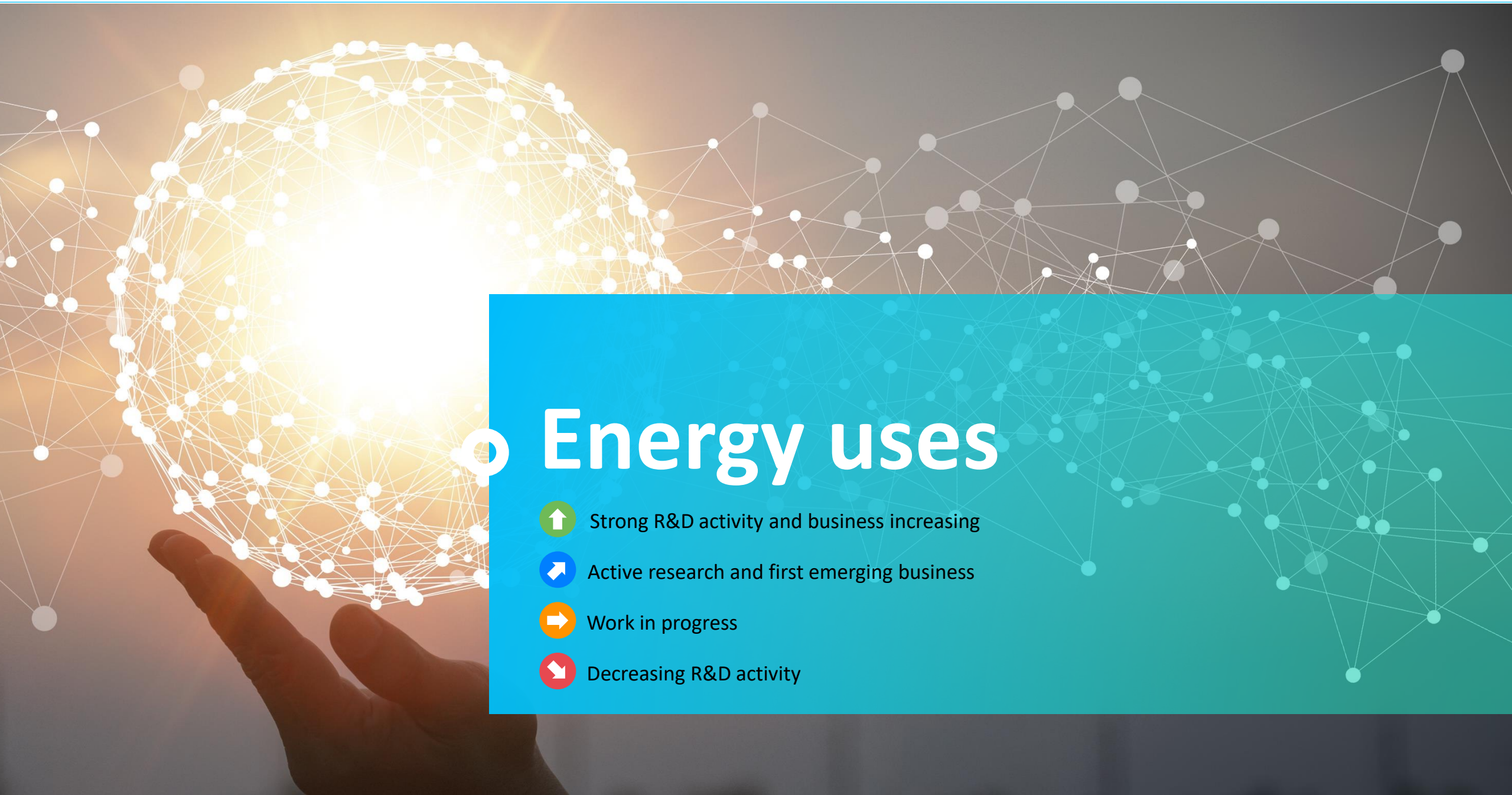
PART 2

What about the technologies we reported on in previous editions?

Sustainable energies

Energy uses

Enabling technologies



Energy uses

- Strong R&D activity and business increasing
- Active research and first emerging business
- Work in progress
- Decreasing R&D activity

Example: Direct Air Capture for CO_2 removal from ambient air using chemical processes

Where are we in 2021? **Trend** ↑

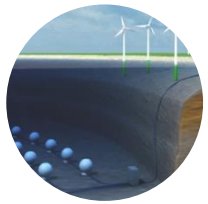
DESCRIPTION

- Carbon dioxide can be removed from ambient air via chemical processes using acid base reactions at high or low temperature. Direct Air Capture (DAC) is comparable to the human respiratory system or the photosynthesis where the process releases captured gases from the material.
- CO_2 can be permanently stored in deep geological formations or used to produce fuels, chemicals, building materials or other products containing CO_2. When CO_2 is geologically stored, it is permanently removed from the atmosphere, resulting in negative emissions.

WHAT HAS HAPPENED?

- Significant acceleration after the last IPCC report release in August 2021. DAC will be part of Carbon Dioxide Removal technologies for carbon sequestration.
- A first commercial unit, the Orca unit belonging to Climeworks has been set up in Iceland; certificates trading is in the development stage
- The project currently requires several more large-scale demonstrations to be developed in order to fine-tune the technology and reduce capture costs.

The world's largest climate-positive direct air capture plant: Orca!, 4kt/y with sequestration [89]

	Technologies	Description	What has happened?	Trend
	**Electricity storage in the sea**	To store excess wind energy, this technology makes use of a pump which empties the water contained in an underwater concrete sphere; electricity is released by a turbine which refills the sphere with ocean water.	This technology, among others, will be evaluated in the European project FORWARD2030. Development of new bio concrete and 3D concrete printers in collaboration with Holcim could increase the interest in this technology. For now, there isn't enough deep offshore wind farms to create a significant breakthrough. Source [104]	
	**Electricity storage inside wind turbine tower**	Pumped Storage Hydro is integrated into wind turbines in order to store excess electricity in turbine towers.	The GE and Max Bögl wind-hydro hybrid project for the world's tallest wind turbine in Gaildorf (DE) hasn't been developed. However, recent publications by GE and Holcim on the development of a 178m high wind turbine support using concrete 3D printers could point to a simple delay in the project as opposed to its standby.	
	**(Ambient) CO_2 to fuels using Hydrogen**	E-fuels are synthetic fuels, resulting from the combination of 'green or e-hydrogen' produced by the electrolysis of water with renewable electricity and CO_2 captured either from a concentrated source (e.g. flue gases from an industrial site) or from the air (via direct air capture, DAC). E-fuels also called PtX, include a broad range of molecules: e-methane, e-methanol, formic acid, e-jet fuel…	In Europe, more than 220 e-fuels research and demonstrator projects have either been developed, completed, or are currently being planned with a peak reached in 2018. Installed electrolyzer capacities are getting higher and higher, indicating that consolidation is taking place, as fewer projects are closer to commercialization. Projects involve a large amount of partners in order to meet significant investment costs to develop these industries. Technical demonstrators and systems integration are of major importance for integrating PtX into energy systems and qualifying the business model: processes are highly dependant on the costs of electricity for electrolysis and of CO_2. • E-methanol: the e-CO_2Met project at the Hydrogen Lab Leuna, North-C-Methanol… • E-methane: still at demonstrator phase with several megawatt scale pilots mainly based in Europe with Jupiter 1000, Methycentre, GRHYD, ZSW, Store & Go, Audi & Mann… • Formic Acid: BASF (TRL 2) • E-jetfuel: Westküste 1000, Air to fuels™, Haru Oni (Siemens Energy) • DME: C2FUEL, ALIGN-CCUS, CO2FOKUS, TNO, GTI (membrane-based reactor)… Sources [105], [106], [107], [108], [109], [110]	

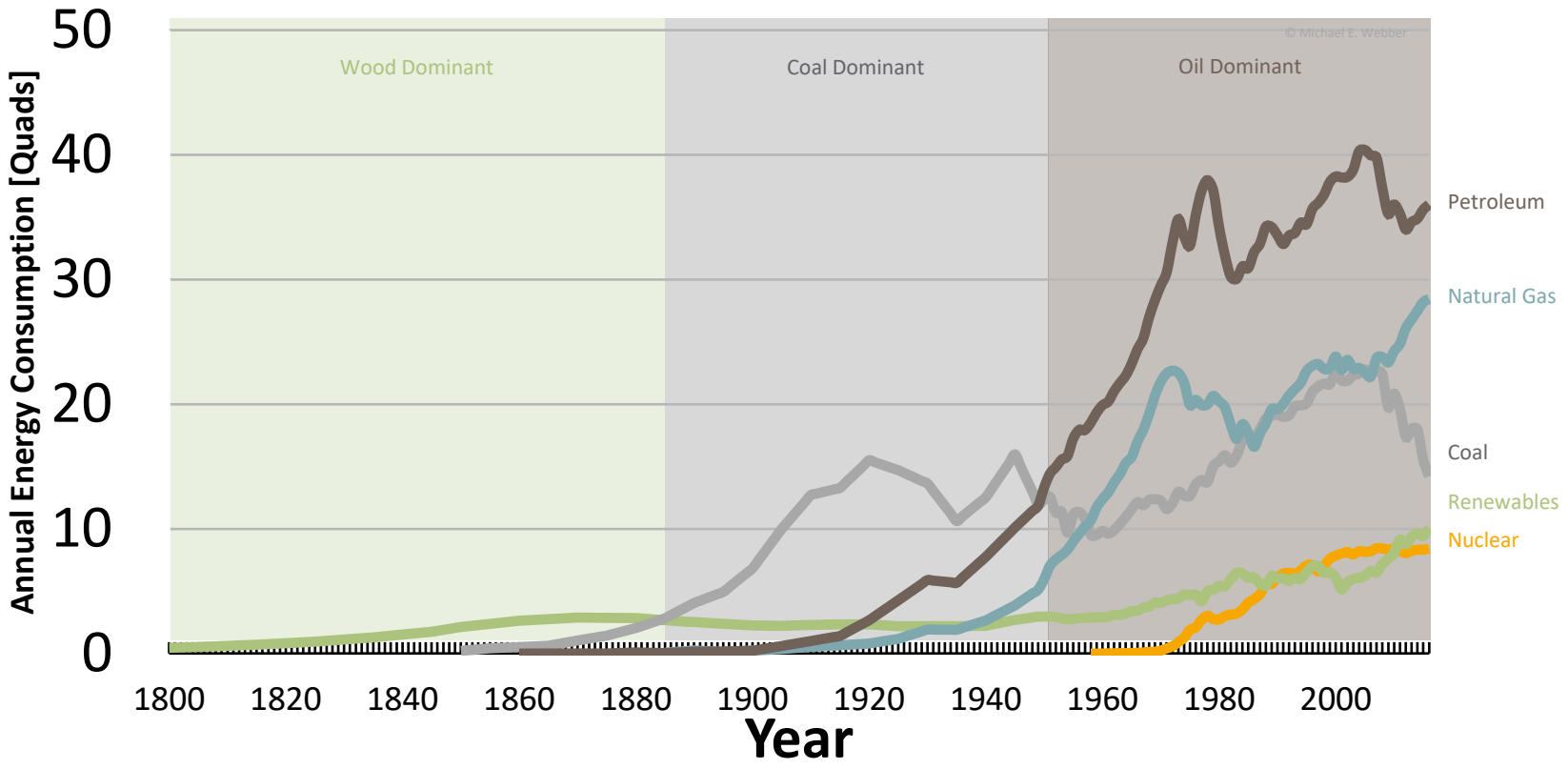
Enabling technologies

- Strong R&D activity and business increasing
- Active research and first emerging business
- Work in progress
- Decreasing R&D activity

	Technologies	Description	What has happened?	Trend
	**Biomimicry for Cybersecurity**	Cybersecurity refers to hardware and software components that protect computer devices from unauthorised access, but also to non-technical measures such as legislation and user training. The challenge is to keep systems cyber secure by using bio-inspired techniques.	A couple of trials are in place which make use of biomimicry in response to cybersecurity challenges. Cybersecurity includes a multitude of different aspects such as defense layers, counter attack, misleading attackers, protection strategies and also human error, which is often referred to as the weakest link. This domain is still at the research project stage. At this moment in time, no breakthroughs relating to biomimicry have been observed.	
	**Sustainable catalysts as energy transition enablers**	Catalysts increase the reaction rate without being consumed in order to achieve the chemical equilibrium at a suitable temperature. A catalyst is specific to each final product, reaction conditions and type of process.	Platinum group metal (PGM) catalysts dominate today's applications with the vast development of electrochemical processes, that build a bridge between the molecule-based economy and green electricity production. Alternative catalysts to replace iron, nickel and copper also exist, but they are rare and costly. As such, a significant scientific effort is being devoted to the development of low-PGM and PGM-free catalysts. Research is currently focusing on these sustainable catalysts with non-transition metals.	
	**Water harvesting from the air based on the atmospheric water generator (AWG)**	AWG is a device that extracts water from humid ambient air. Dew water collection systems are divided into three categories: i) dew water harvesting using the radiative cooling surface, ii) the solar-regenerated desiccant system and iii) active condensation technology.	Atmospheric water harvesting (AWH) is emerging as a promising means of overcoming the water scarcity in arid regions, particularly for inland areas lacking liquid water sources. These technologies haven't increased as such but now offer new possibilities thanks to their combination with Direct Air Capture research programs. Some challenges remain in order to optimize efficiency and ensure the delivery of good quality water at an affordable cost.	

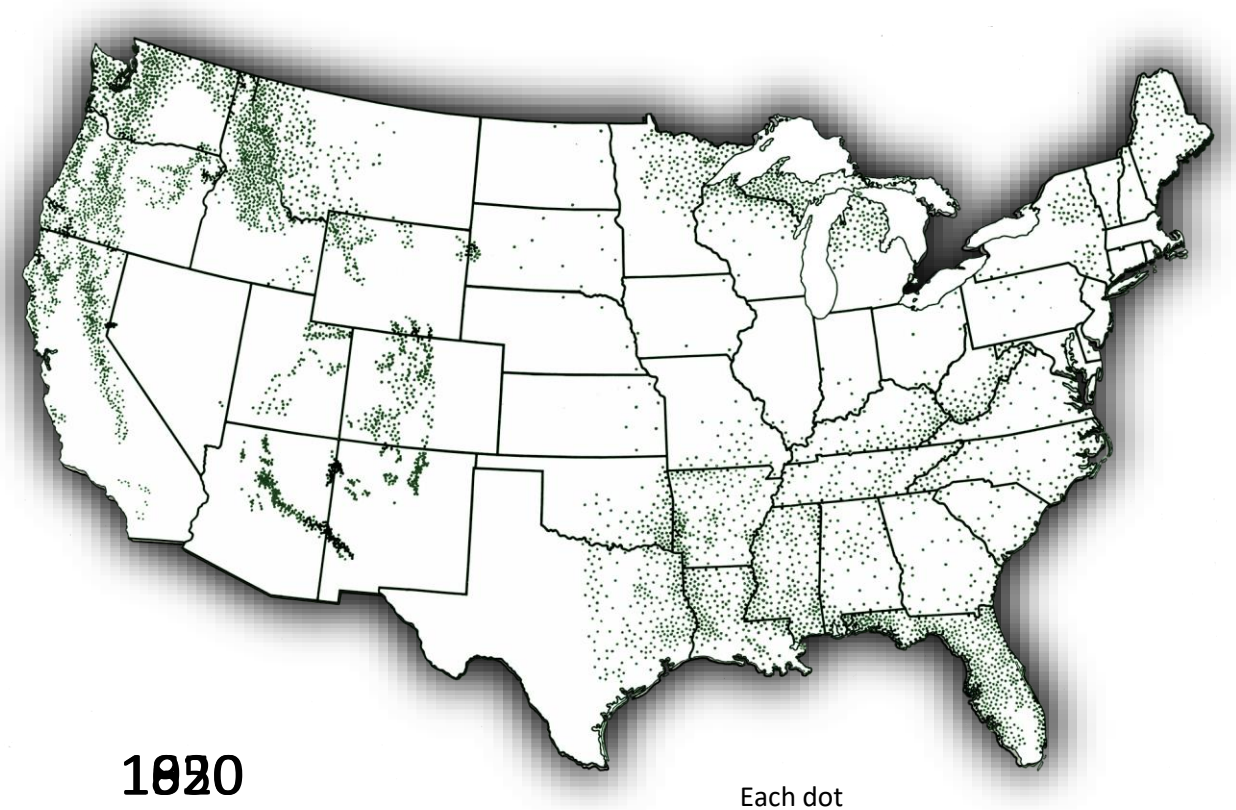
Energy Transitions implying fuel switches have happened in the past

1800–2016 U.S. Energy Consumption by Source
Source: U.S. Energy Information Administration / December 2017 Monthly Energy Review (1.3)
Graphic: Michael E. Webber, The University of Texas at Austin

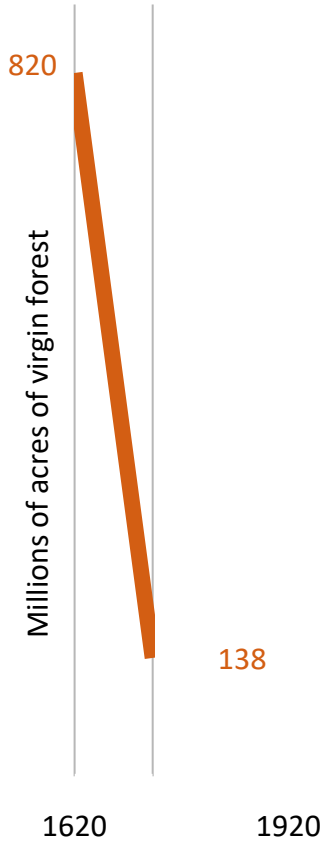


Natural gas might be the next dominant fuel within 1-2 decades (in US, what about EU given the current crisis?)

The Use of Wood as a Fuel and Feedstock Caused Widespread Deforestation Between 1620–1920



Each dot represents 25,000 acres.

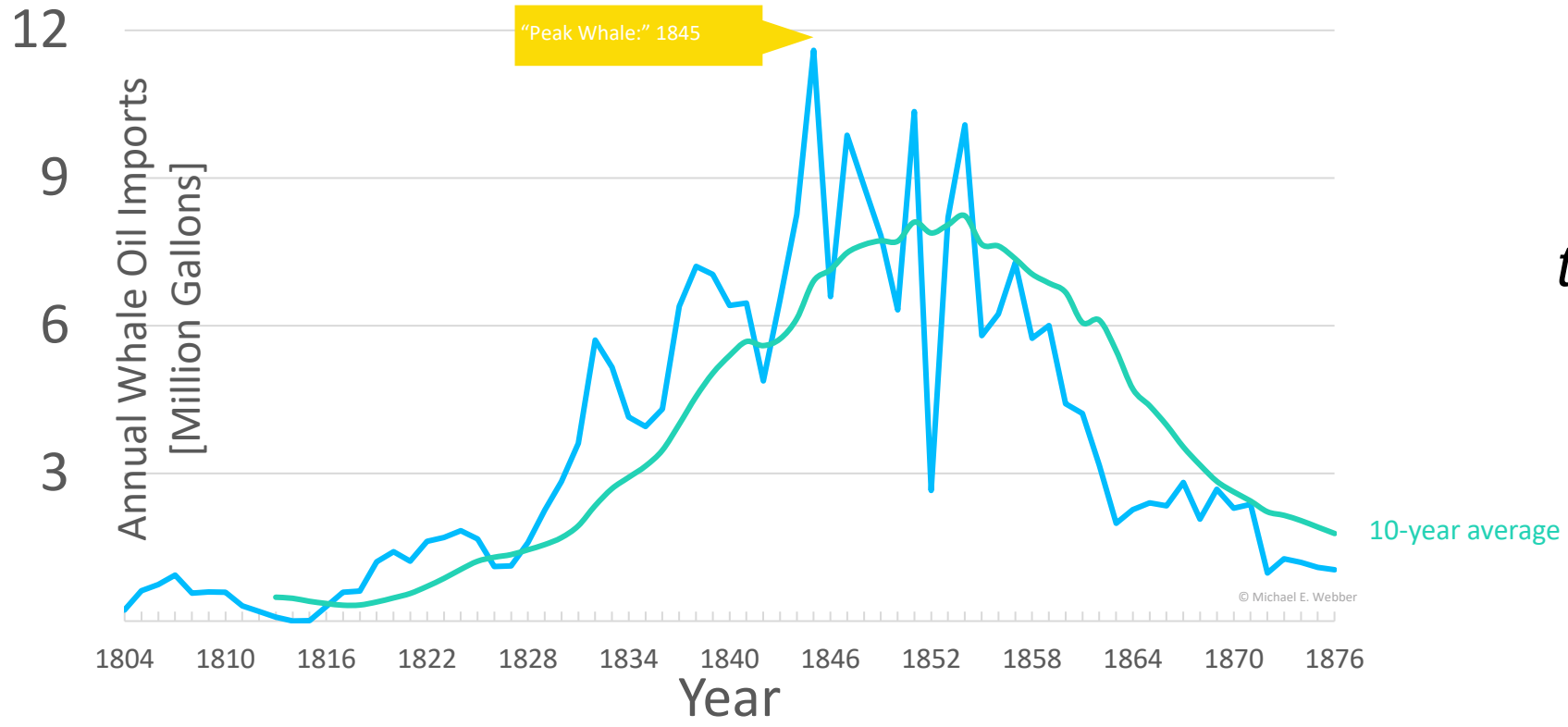


Coal saved the forests

Source: The Relation of Geography to Timber Supply, William B. Greeley, 1925 • Graphic: Michael E. Webber, The University of Texas at Austin

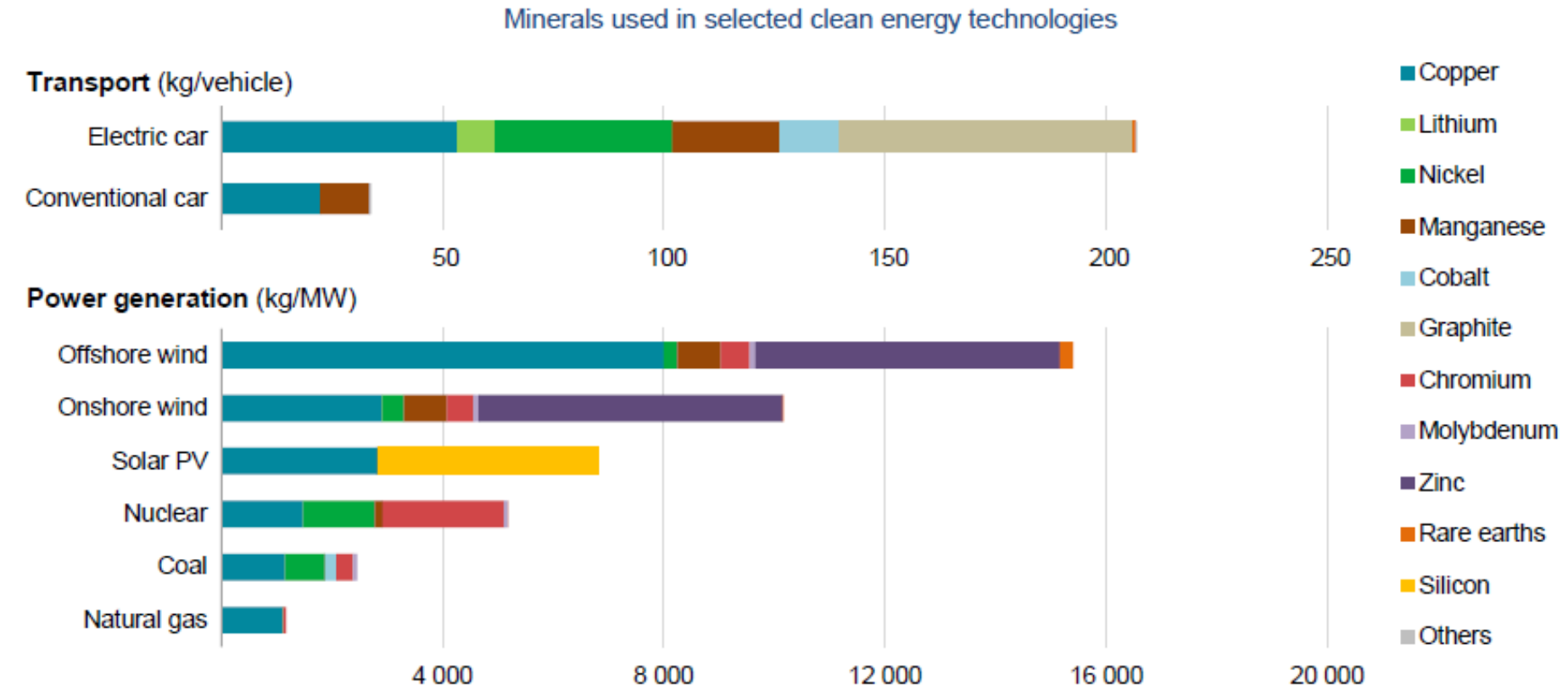
Whale Oil Supplies Peaked in the Mid-1800s

1804–1876 U.S. Whale Oil Imports from Whaling Ships
Source: Alexander Starbuck, History of the American Whale Fishery, 1878, pp. 660–661
Graphic: Michael E. Webber, The University of Texas at Austin



Oil saved the whales

So let's not forget about critical minerals in the current energy transition:

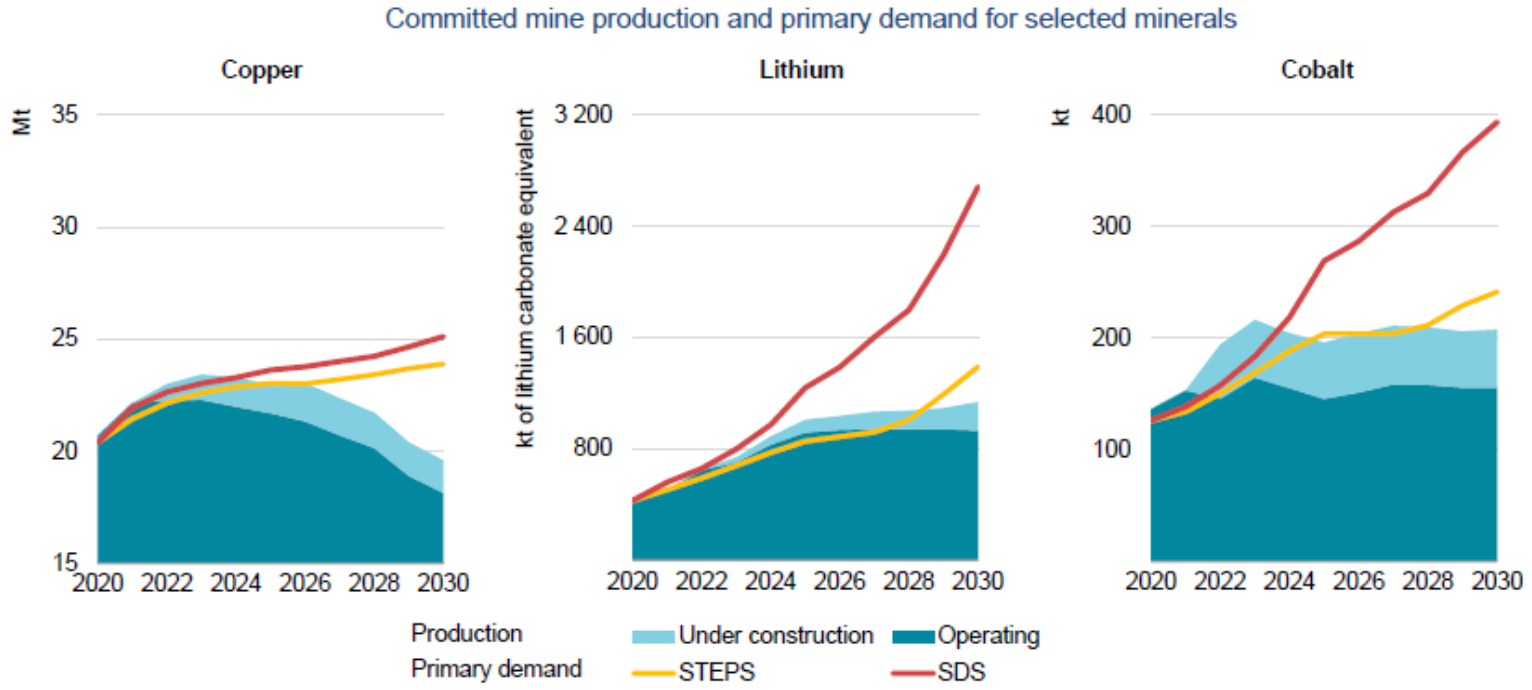


Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.

IEA, WEO special report, 2021. The Role of Critical Minerals in Clean Energy Transitions.

IEA, 2021 alerts on a mismatch between the need of critical minerals to meet our climate ambitions and the predicted supply of some important critical metals

Meeting primary demand in the SDS requires strong growth in investment to bring forward new supply sources over the next decade

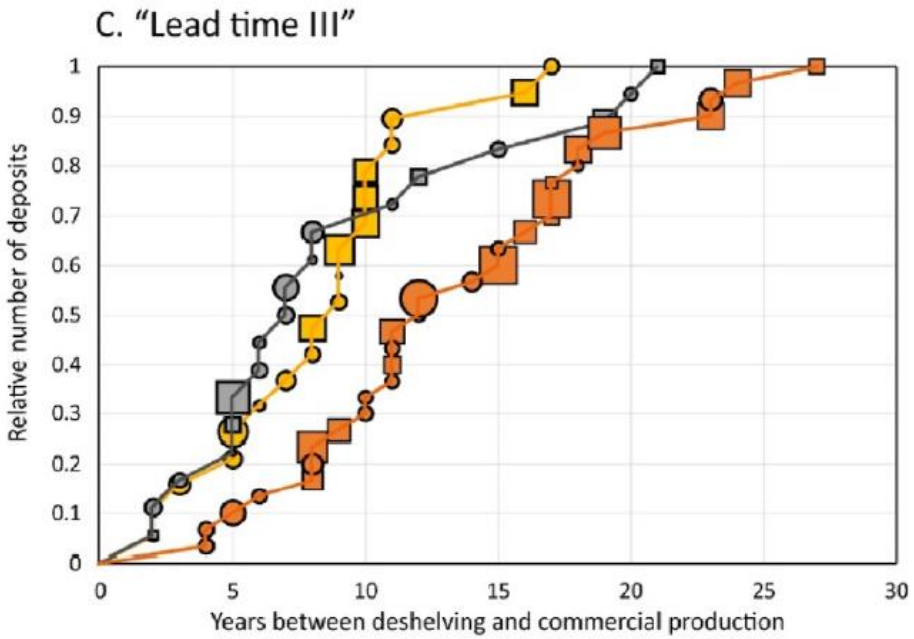


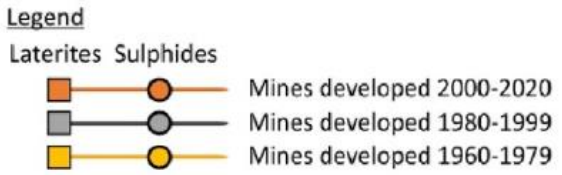
Notes: Primary demand is total demand net of recycled volume (also called primary supply requirements). Projected production profiles are sourced from the S&P Global Market Intelligence database with adjustments to unspecified volumes. Operating projects include the expansion of existing mines. Under-construction projects include those for which the development stage is indicated as commissioning, construction planned, construction started or preproduction. Mt = million tonnes.

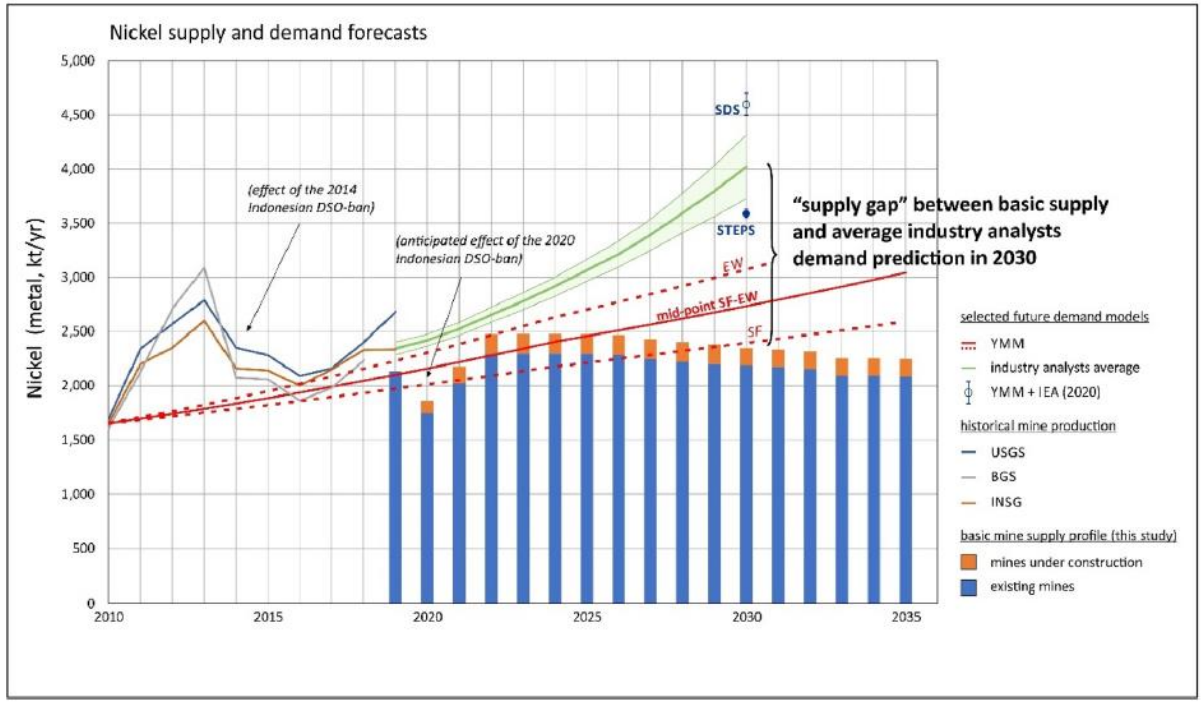
Source: IEA analysis based on S&P Global (2021).

IEA, WEO special report, 2021. The Role of Critical Minerals in Clean Energy Transitions.

Lead time of 'new' mines increased over the last decades; supply gaps will exist for battery metals Nickel and Cobalt







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Assessing the adequacy of the global land-based mine development pipeline in the light of future high-demand scenarios: The case of the battery-metals nickel (Ni) and cobalt (Co).

Wouter Heijlen [a,*], Guy Franceschi [b], Chris Duhayon [c], Kris Van Nijen [c]

[a] Tercienco BV, Spijkstraat 105, B-9040, Ghent, Belgium
[b] GF Consult BV, Antwerpsesteenweg 644, B-9040, Ghent, Belgium
[c] Global Sea Mineral Resources NV, Slijkensesteenweg 2, B-8400, Ostend, Belgium

Material extraction accounts for half of the worlds carbon emissions and causes 80 % of the overall biodiversity loss

Chile, Atacama desert, Escondida Mine, 24°16'10.7"S 69°04'18.9"W

Resource extraction responsible for half world's carbon emissions

Extraction also causes 80% of biodiversity loss, according to comprehensive UN study

▲ Massive dump trucks by the Syncrude upgrader plant, Canada. The tar sands are the largest industrial project on the planet, and the world's most environmentally destructive. Photograph: Rex/Shutterstock

Extractive industries are responsible for half of the world's carbon emissions and more than 80% of biodiversity loss, according to the most comprehensive environmental tally undertaken of mining and farming.

While this is crucial for food, fuel and minerals, the study by UN Environment warns the increasing material weight of the world's economies is putting a more dangerous level of stress on the climate and natural life-

It is not only about environmental impact of the mining of 'critical' raw materials:

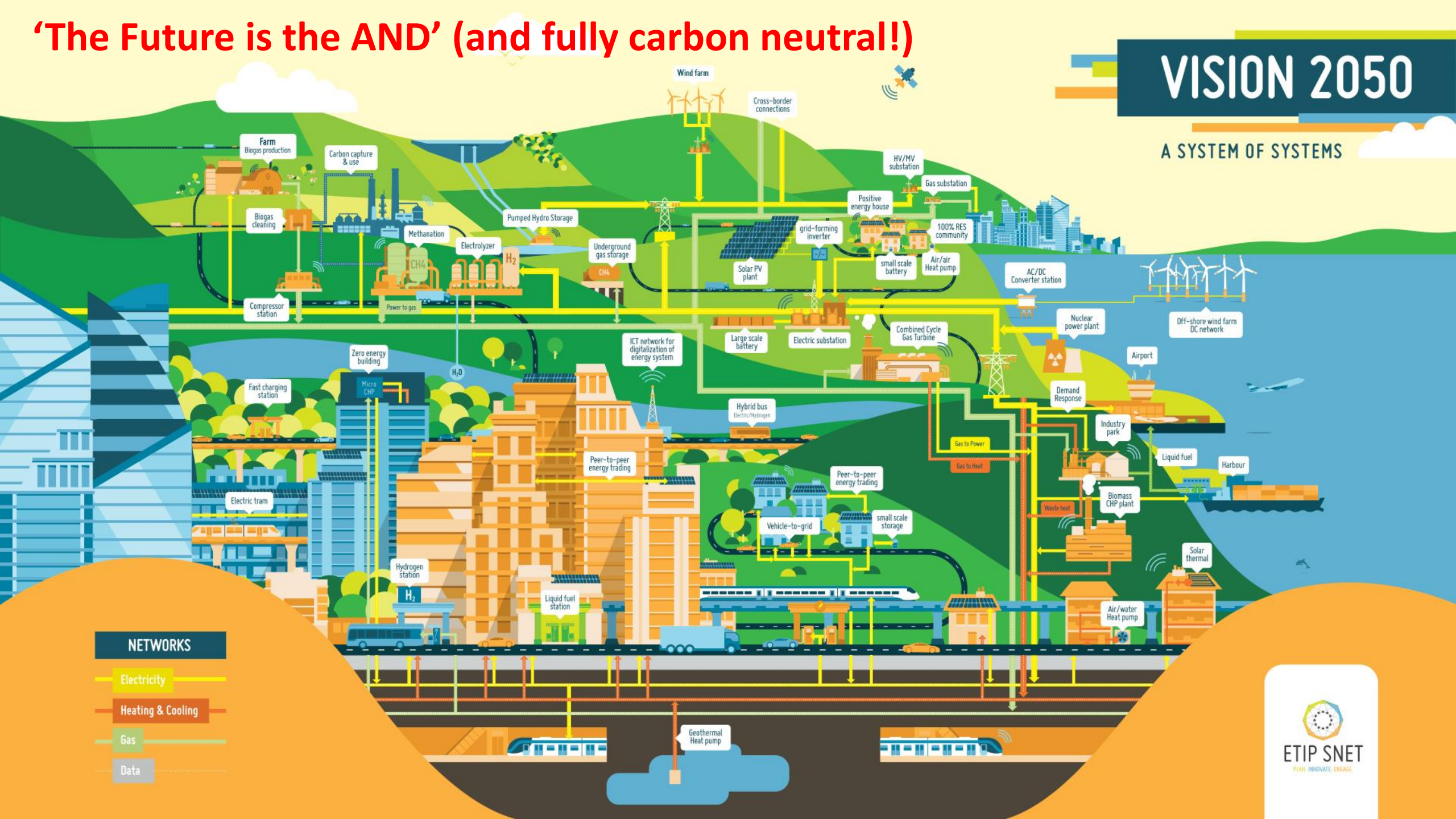
social and ethical issues are important

- Artisanal and small-scale mining:
  - Sapphires
  - Gold
  - Diamonds
  - Tantalum
  - Cobalt

- Small production volumes
  But extreme environmental (and social) impacts

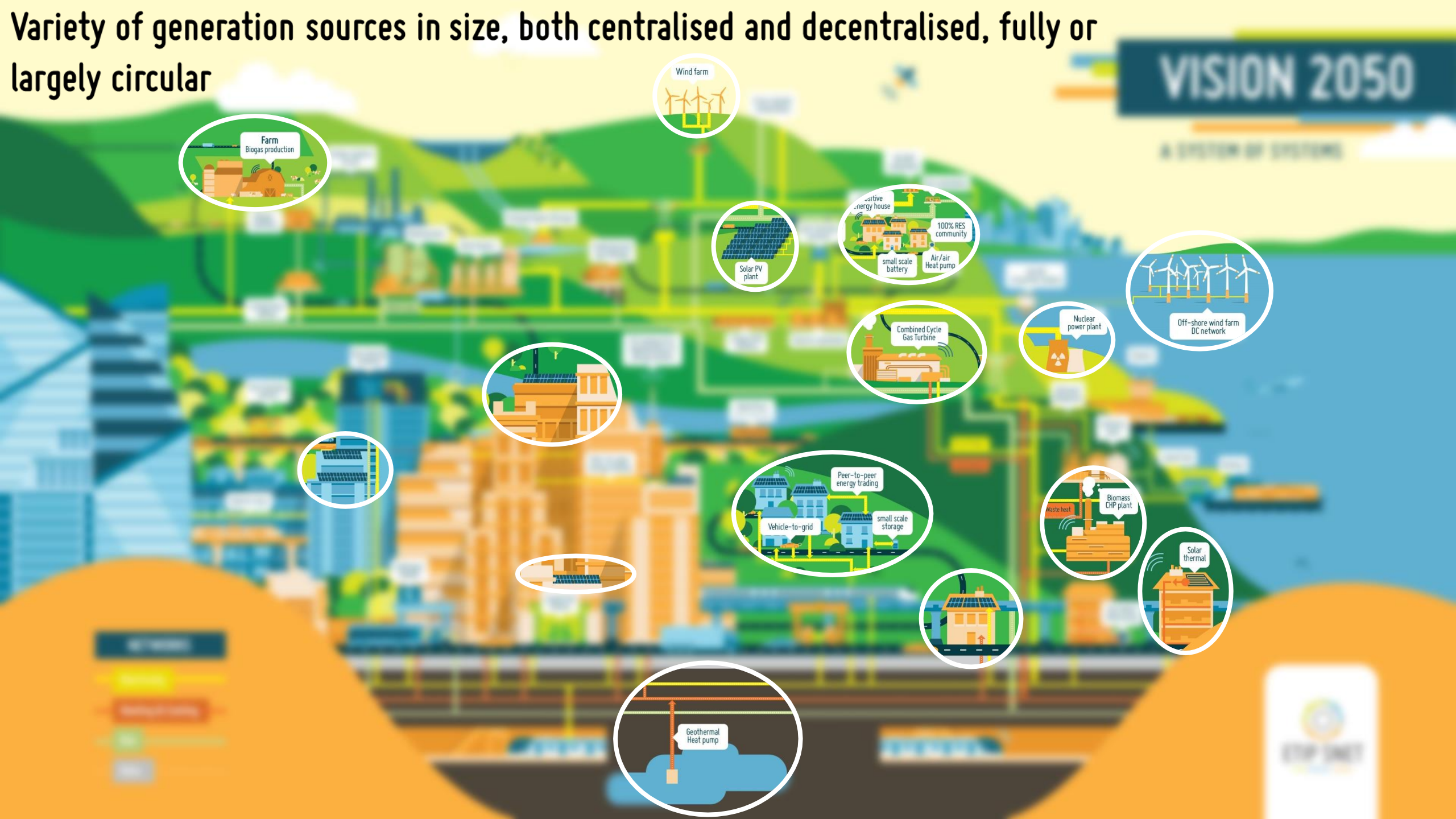
- Cobalt mining in Congo faces serious ethical and social issues

‘The Future is the AND’ (and fully carbon neutral!)



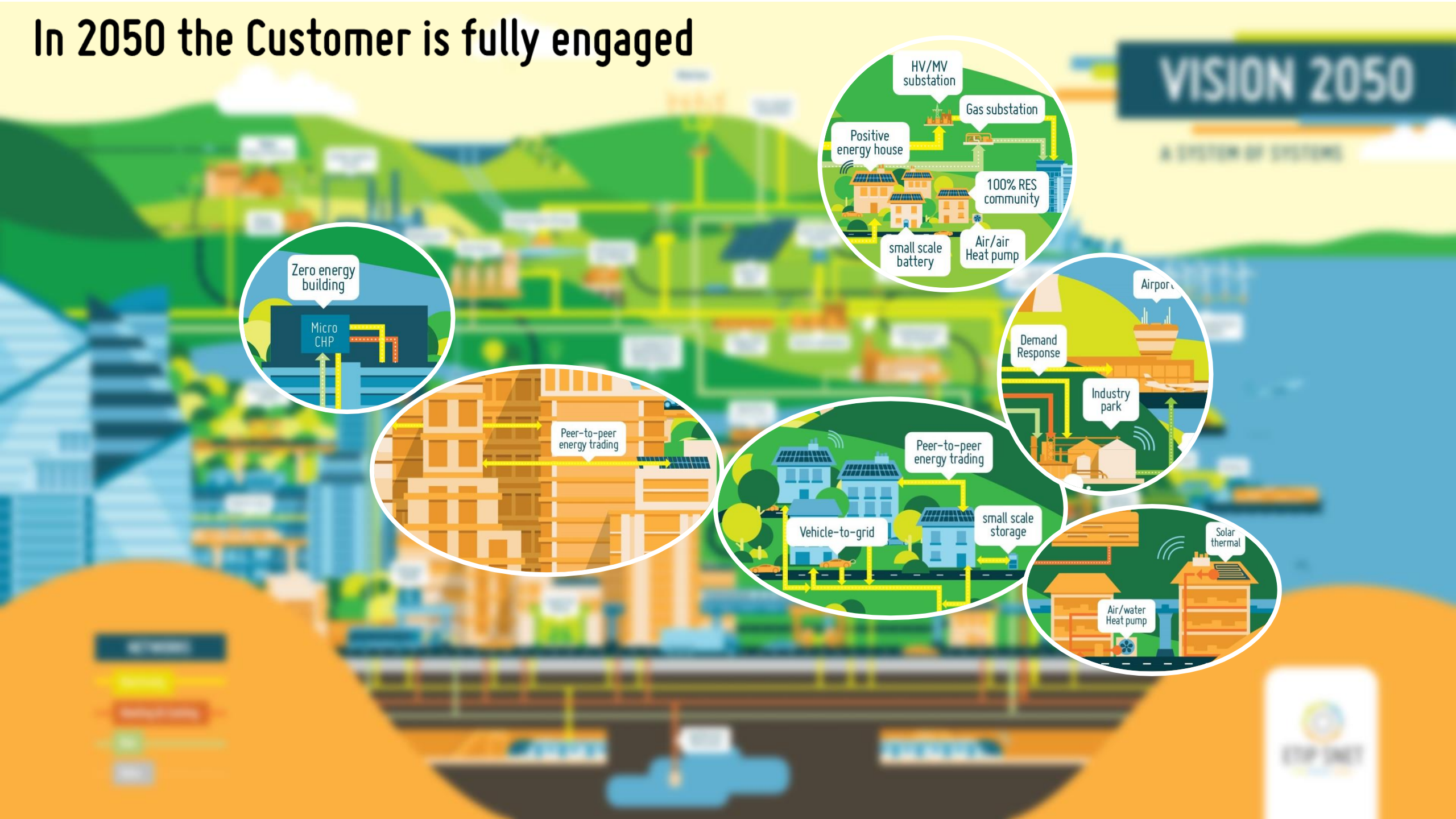
Variety of generation sources in size, both centralised and decentralised, fully or largely circular

Variety of generation sources in size, both centralised and decentralised, fully or largely circular



In 2050 the Customer is fully engaged

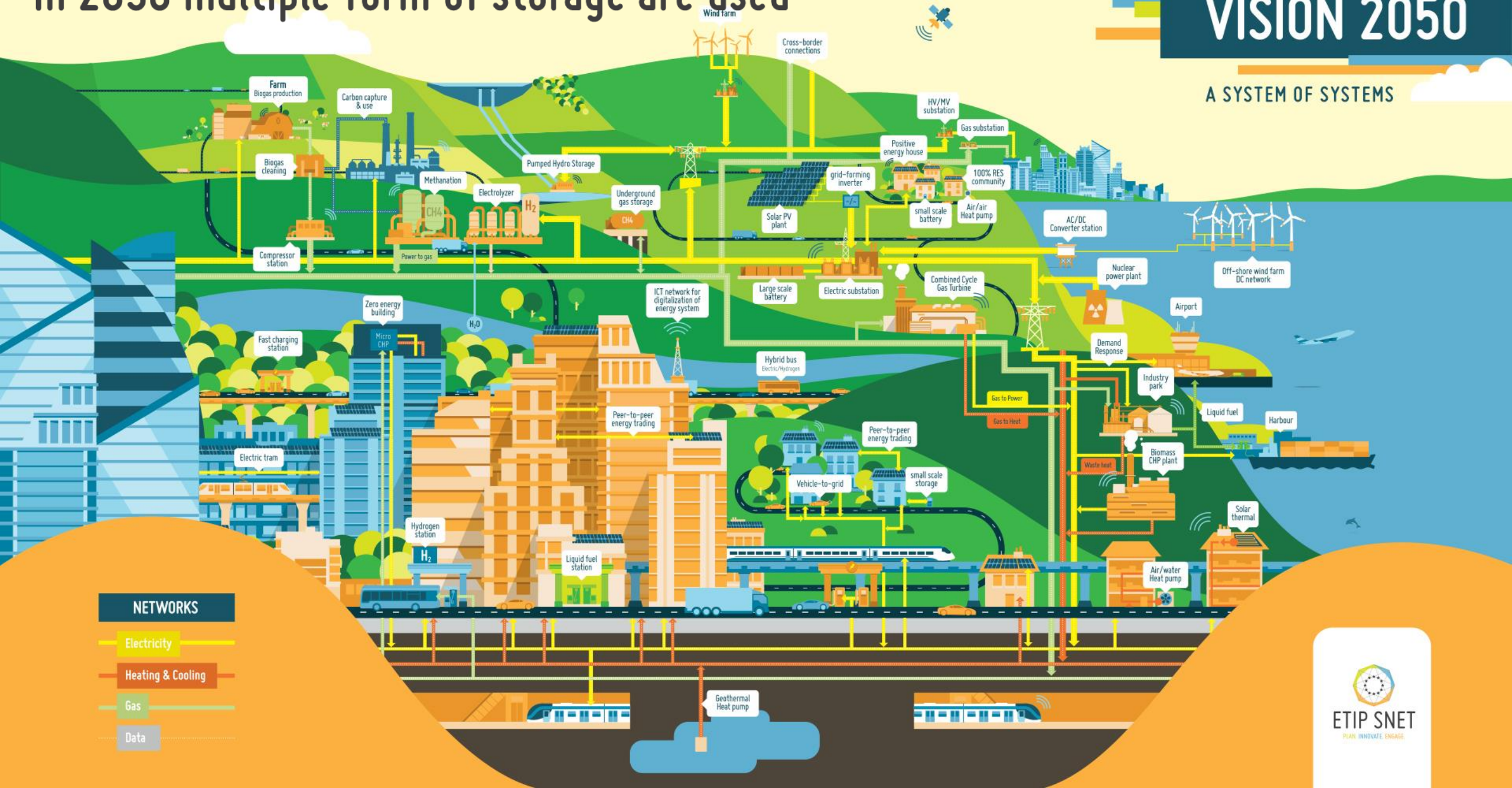
In 2050 the Customer is fully engaged



In 2050 multiple form of storage are used

VISION 2050

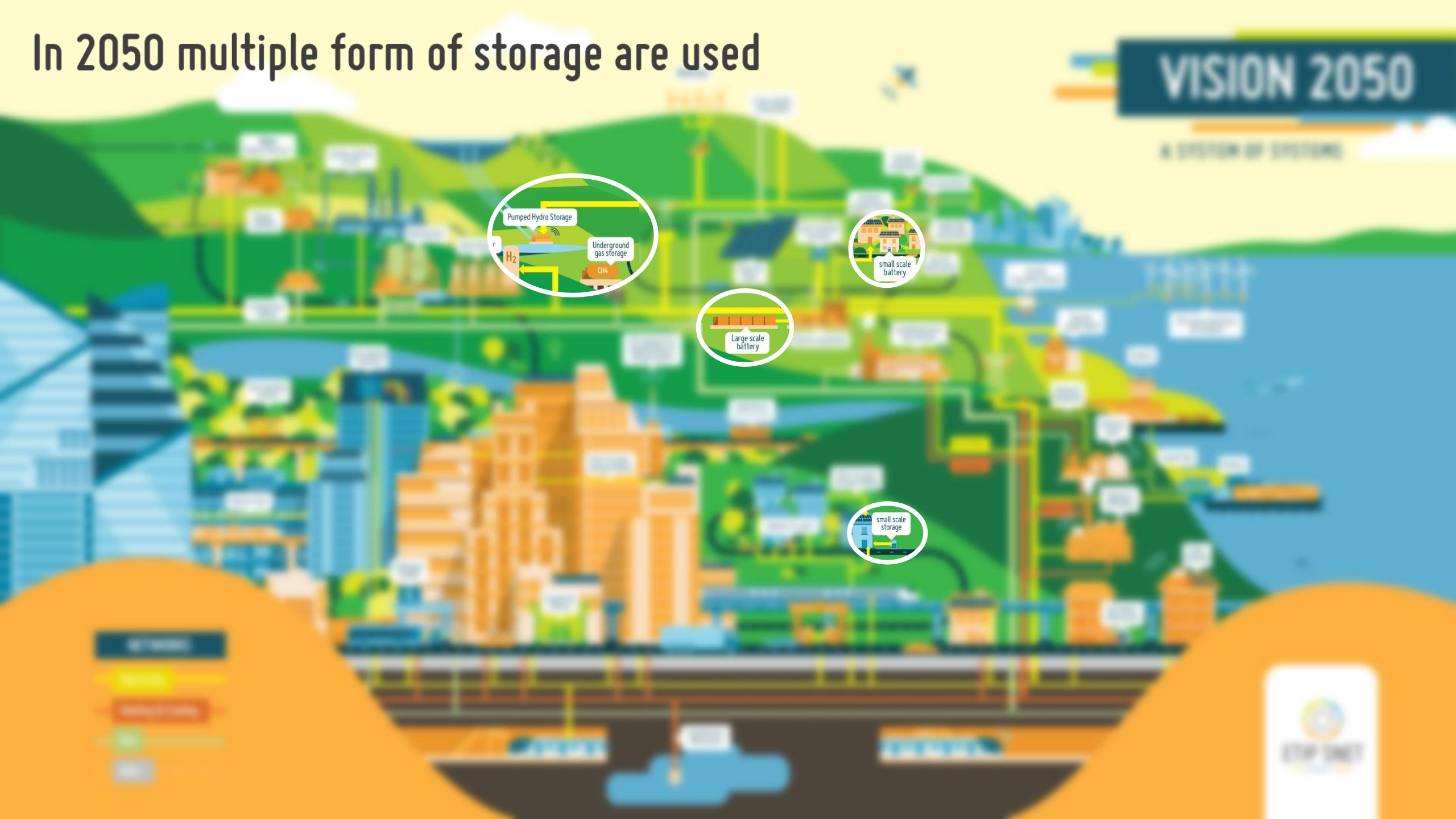
A SYSTEM OF SYSTEMS



ETIP SNET

PLAN. INNOVATE. ENGAGE

In 2050 multiple form of storage are used



Want to know more: download our latest version of our emerging sustainable technologies document:

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