Research

Emerging Sustainable Technologies

Report from 2020 Technology Watch

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Based upon discussions with ENGIE LABS experts

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Edito

We must act now to accelerate our goal of a carbon neutral energy transition. The International Energy Agency published in September 2020, their Energy Technology Perspectives stating that to reach our net-zero carbon emission ambition by 2050, we will need lots of technologies that are today not mature yet. It is estimated that about 75 % of the emission reduction effort will have to come from these non-mature technologies. This does not mean, that they must be invented from scratch; but rather a fast upscaling from existing technologies in laboratories up to pilots, up to demos and finally into the market is crucial and the energy sector is not the only one concerned.

It is extremely hard to predict next technology breakthroughs but, in this document, we present topical areas that we think will offer non-trivial benefits and impacts on this transition. ENGIE is not only keeping a close eye on their development but has the ambition to help bringing these technologies to the market in an increased pace; through piloting and demonstrating.

There is not one technology that has the potential to overcome the challenge alone so working on a variety of technologies related to energy production, transport, storage and use is crucial. The challenge is also too large to overcome alone as a person/company/sector, we must collaborate. The document has little pretention apart from inspiring its readers and it is in the context of this spirit of collaboration that this document is written and published.

Dr. Jan Mertens, Chief Science Officer @ENGIE, Visiting Professor @Ugent

Dr. Elodie Le Cadre Loret, Lead Science Advisor @ENGIE

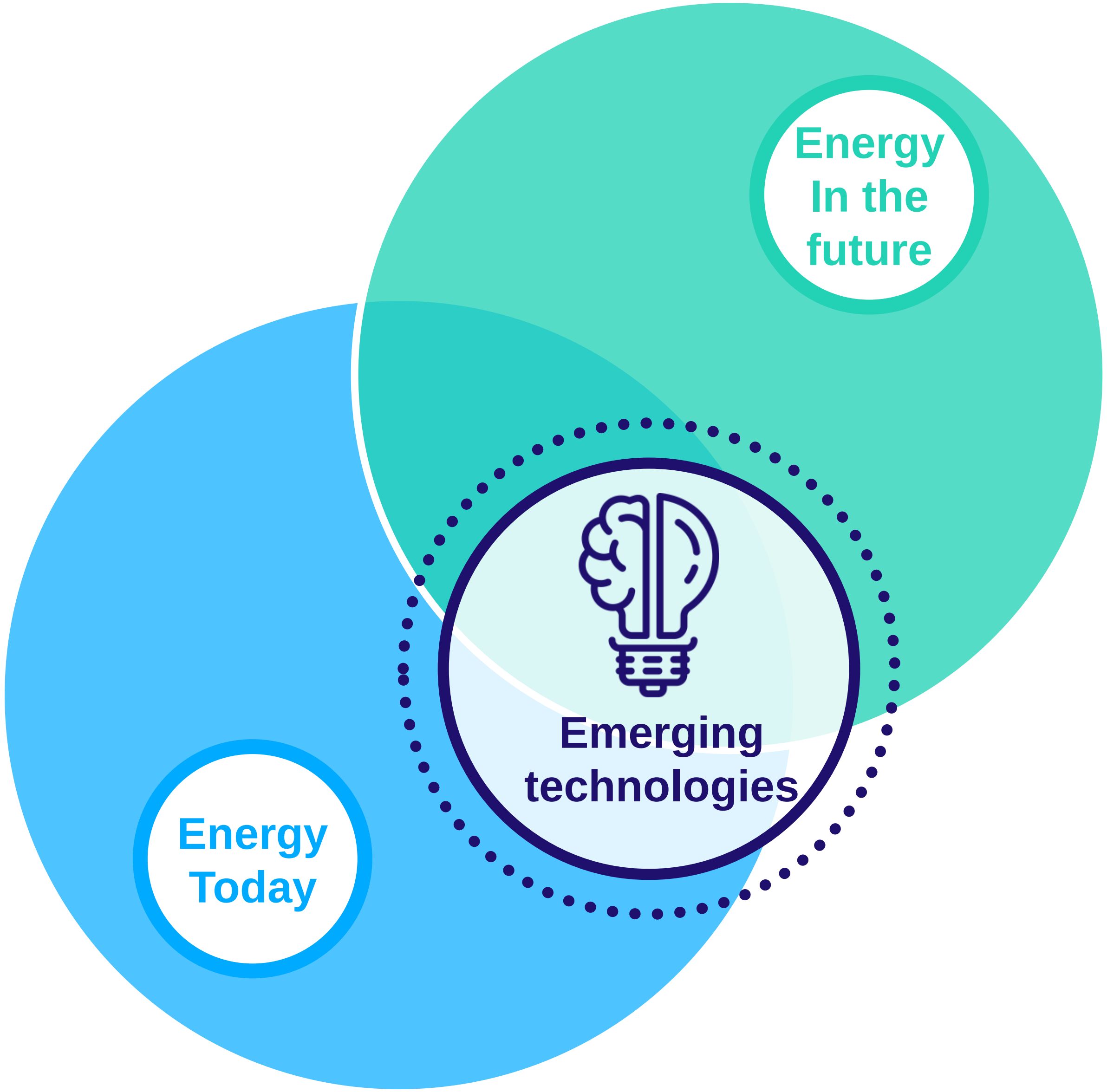
Just before the start…

Objective of this document

Present a selection of emerging technologies that:

- Impact energy today
- Very likely will impact energy in future
- May impact energy directly or indirectly even though today they seem far away from our current and 'planned' future activities…

So where possible link is made with our activities but not always straightforward TODAY…



Introduction

Green energy is the key enabler for solving the top 10 issues that we face

Only 25 % of the required CO_2 emissions to meet carbon neutrality can be achieved using mature technologies

CO_2 as a resource will be part of the portfolio of technologies required to meet carbon neutrality

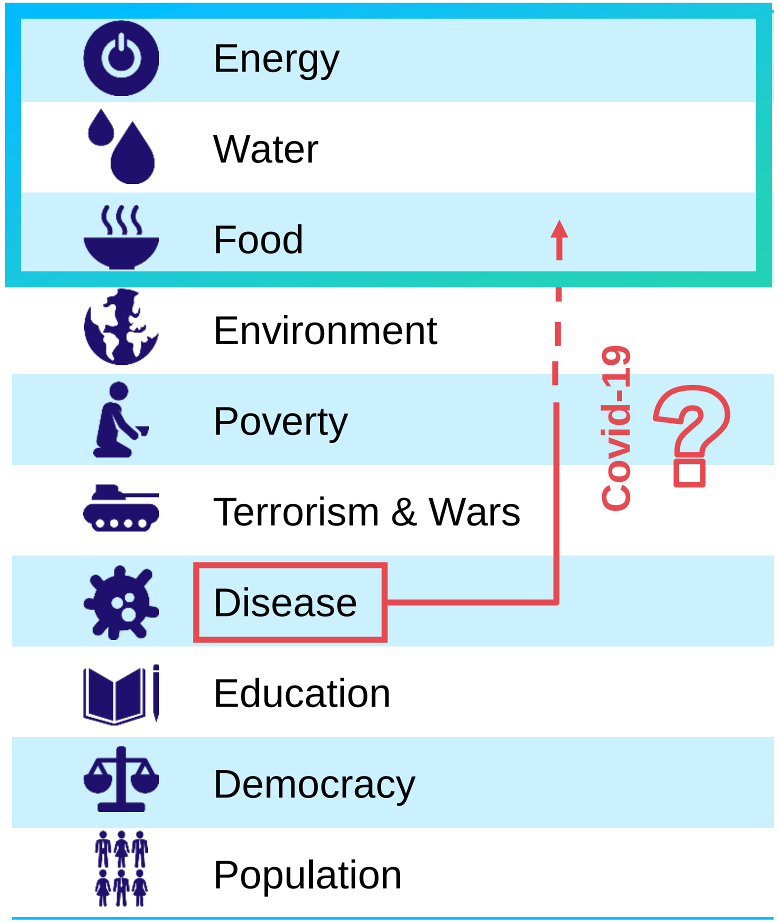
Green energy is the key enabler for solving the top 10 issues that we face

We need to adress the first three structural challenges to ensure having the means to fight the other ones!

1986 Nobel Prize-winning chemist, Professor Richard Smalley identified what he felt were the top 10 issues facing the world and their link with energy:

"Clean water is a great example of something that depends on energy. And if you solve the water problem, you solve the food problem."

R. Smalley, 2005



- Energy
- Water
- Food
- Environment
- Poverty
- Terrorism & Wars
- Disease
- Education
- Democracy
- Population

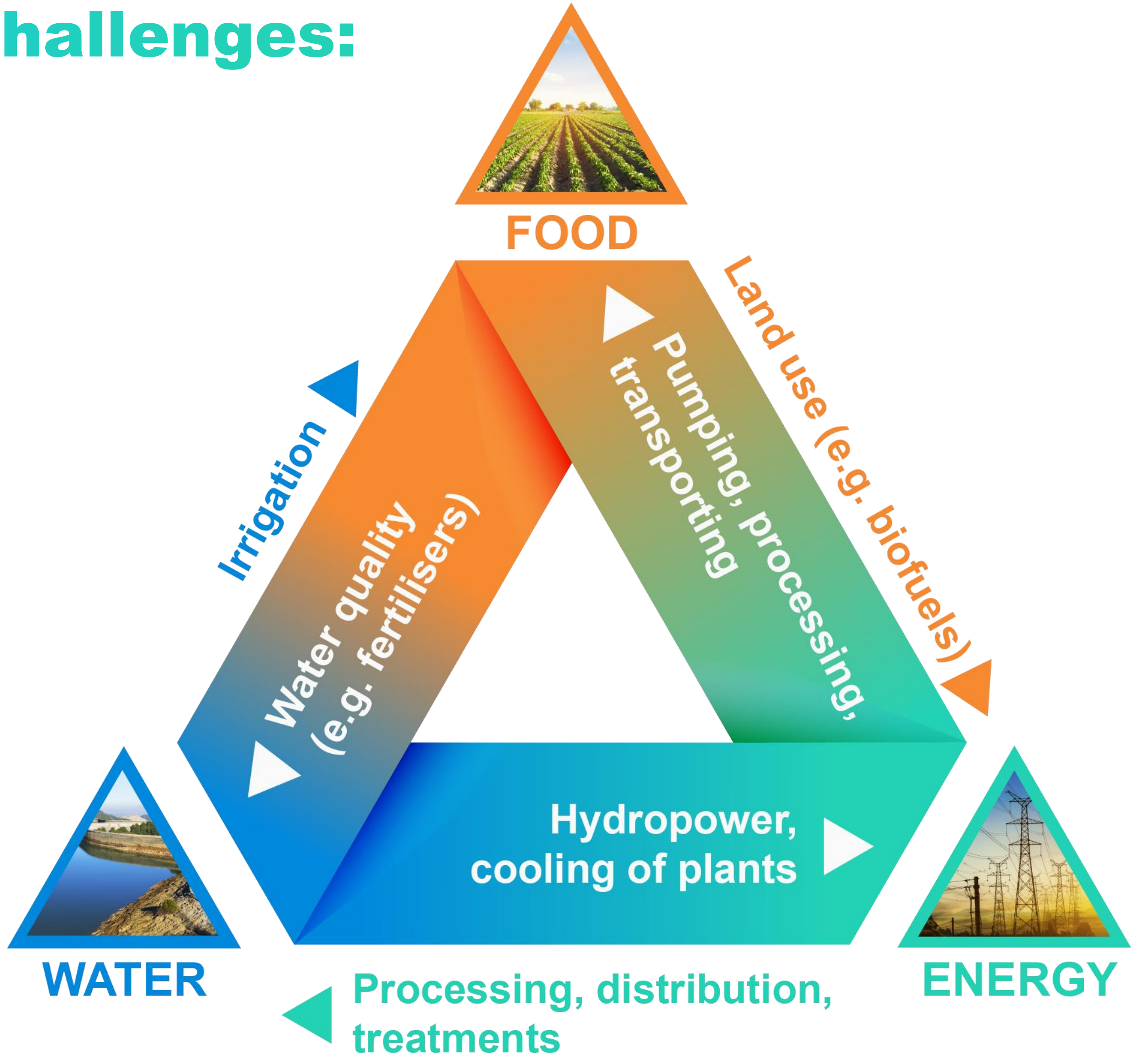
Source [1]

Let’s focus on the first 3 challenges: the nexus approach

Water ▶◀ **Food**: Water is the keystone for the entire agro-food supply chain.

Food ▶◀ **Energy**: Energy is an essential input throughout the entire agro-food supply chain, from pumping water to processing, transporting and refrigerating food.

Energy ▶◀ **Water** : While water plays a key role in energy production, energy is required to process and distribute water, to treat wastewater, to pump groundwater and to desalinate seawater.



FOOD

Land use (e.g. biofuels)

Pumping, processing, transporting

Irrigation

Water quality (e.g. fertilisers)

Hydropower, cooling of plants

WATER

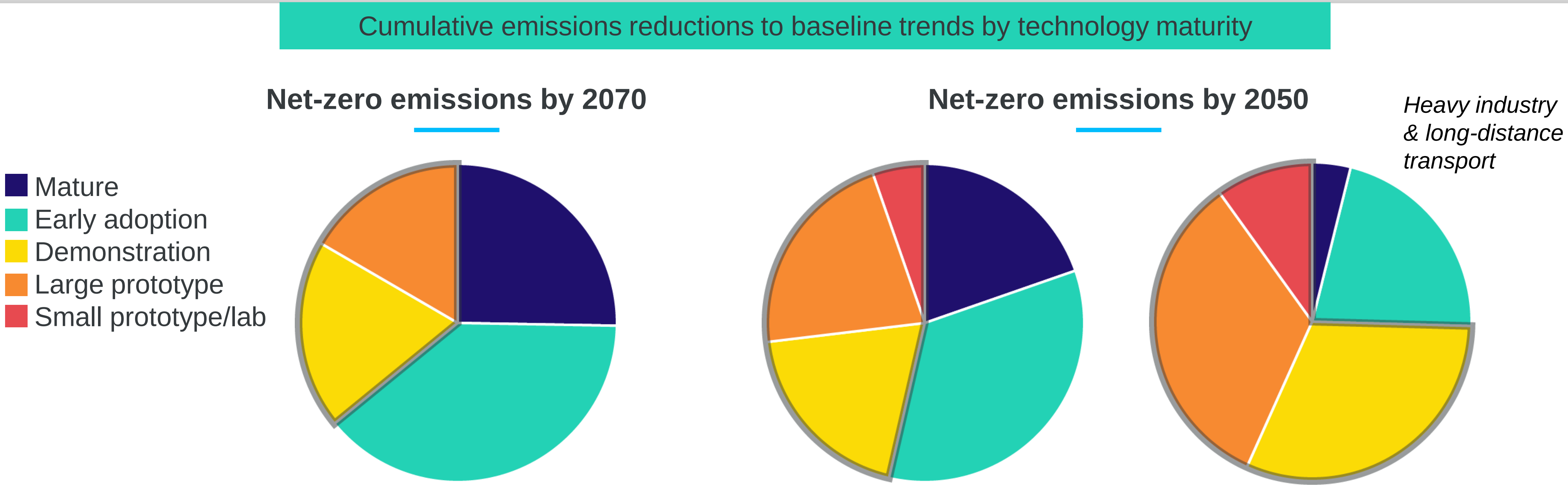
Processing, distribution, treatments

ENERGY

Source [2]

More than half of the emissions reduction will have to come from currently non-mature technologies

We need to speed up R&D and Innovation!



"CCUS, batteries and H_2 are today where PV was 10 years ago. Governments need to support their development now."

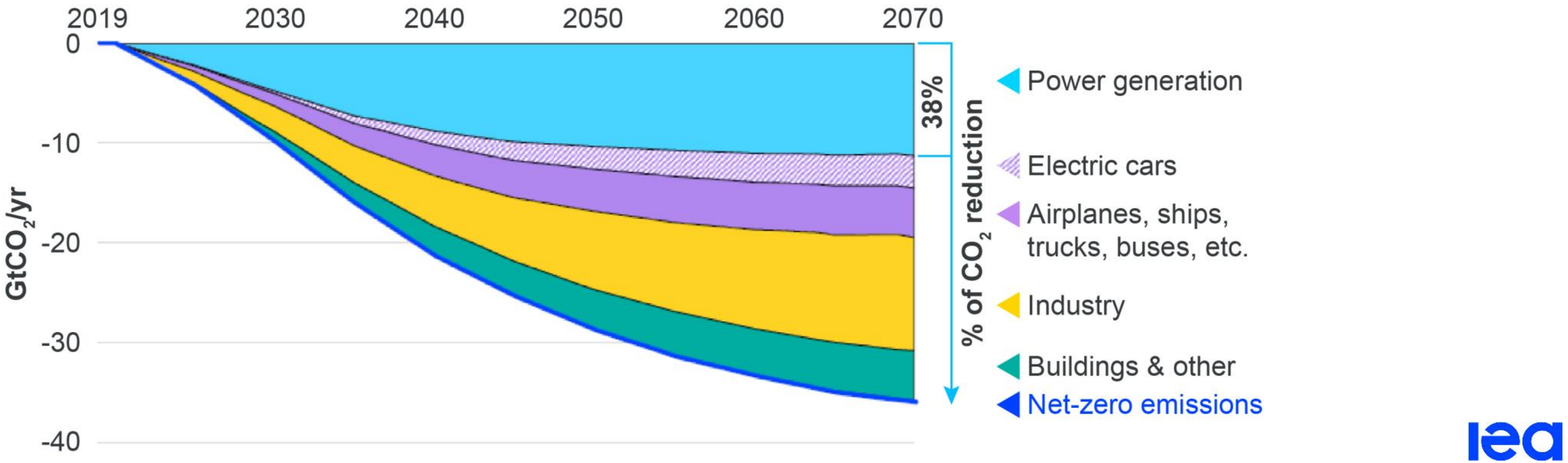
Fatih Birol, IEA, 2020

Source [3]

For these non-mature technologies, green electricity generation is crucial but not sufficent as it will only reduce our overall emissions by 38%

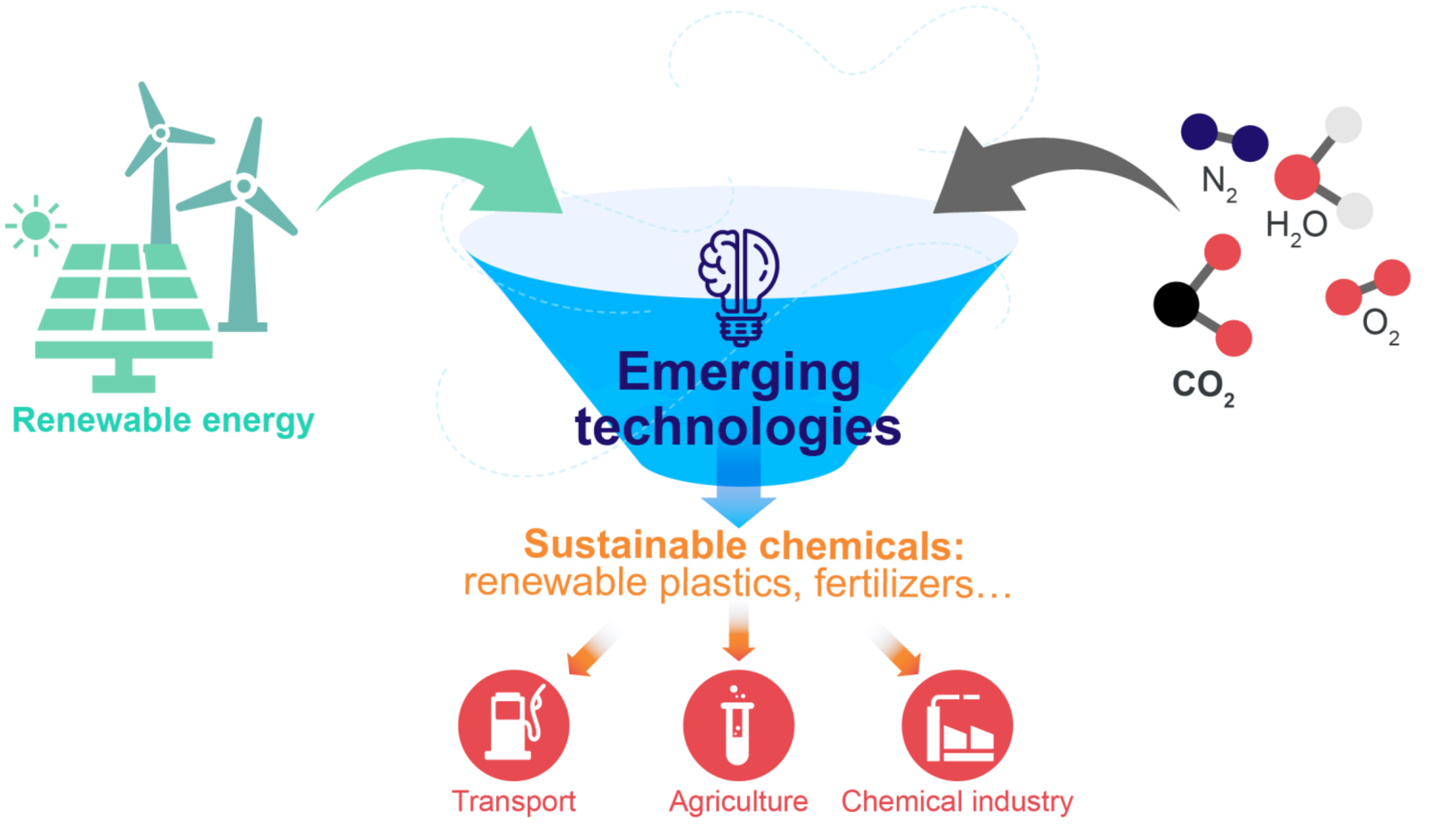
We will need also green molecules (gases/liquids) for industry, building and transport

Global CO_2 emissions redutions in the Sustainable Development Scenario, relative to baseline trends



Source [3]

Why the carbon neutral energy transition will require lots of Carbon (C)? Because *CO_2 as a resource* will be part of the portfolio of technologies required to meet carbon neutrality



Modified from Source [4]

BUT "Due to efficiency losses in capturing and converting atmospheric CO_2, the production of renewable molecules will increase the overall demand for renewable energy drastically."

Mertens, Belmans and Webber, 2020

Sources [4], [5]

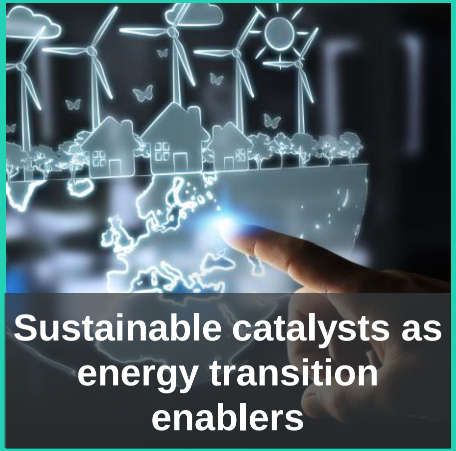
Emerging Sustainable Technologies


Direct Air Capture for circular carbon economy


Pumped Hydro Compressed Air


Small Modular Nuclear


Cybersecurity and biomimicry


Sustainable catalysts as energy transition enablers

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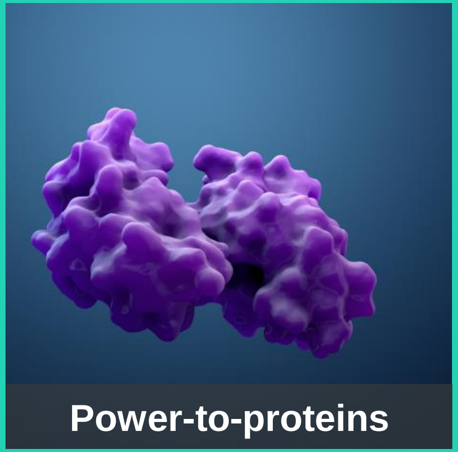
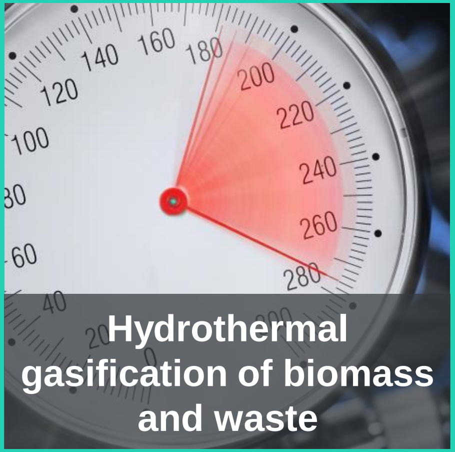

Power-to-proteins



Hydrothermal gasification of biomass and waste


© Paul Box

Pyrogasification of waste (Solid Recovered Fuel)


© DNVL

Multi-purpose offshore platforms


Green ammonia and green fertilizer


© AdobeStock

1

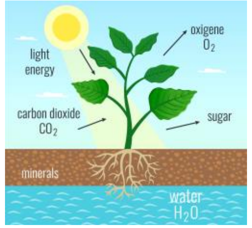
Direct Air Capture for circular carbon economy

CO_2 capture from the air: myth or reality?

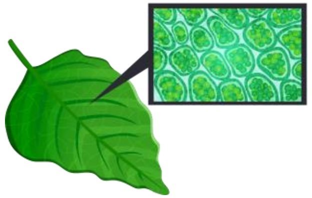
Technology wise, a reality

- Carbon dioxide can be removed from ambient air through **chemical processes based on acid-base reactions**. Direct Air Capture (DAC) is comparable to the respiratory system or the photosynthesis.

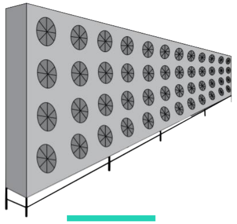
SYSTEM
The system moves the air to the process
Tree



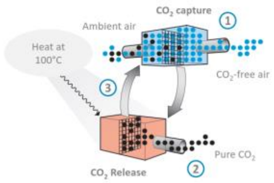
PROCESS
The process releases captured gases from the material
Photosynthesis



MATERIALS
Where the chemistry happens: capacity and selectivity
Chlorophyll



SYSTEM
Fans are processing air through large contactor arrays



PROCESS
Cyclic process: absorption on materials and desorption by heat

MATERIALS
Contactor: solvent or solid sorbent

Modified from Source [6]

	Liquid adsorbent and regeneration at high T°C (900°C)	Solid adsorbent and regeneration at low T°C (80-100 °C)
Amine based		CLIMEWORKS skytree® Global Thermostat The Carbon Negative Solution
Non-amine	OrigenPower Carbon Engineering	carbyon Closing the CO_2 cycle.

Sources [6], [7]

Why capture from the air when there are so many concentrated CO_2 sources?

Advantages

- DAC can capture the CO_2 emitted by decentralized sources (e.g. transport)
- It can be **decentralized towards sites that offer a cheap source of renewable electricity and heat**
- Deployed closed to CO_2 storage sites, DAC becomes a Negative Emission Technology (NET)
- Its modular construction means many of them can be built which can drive down cost

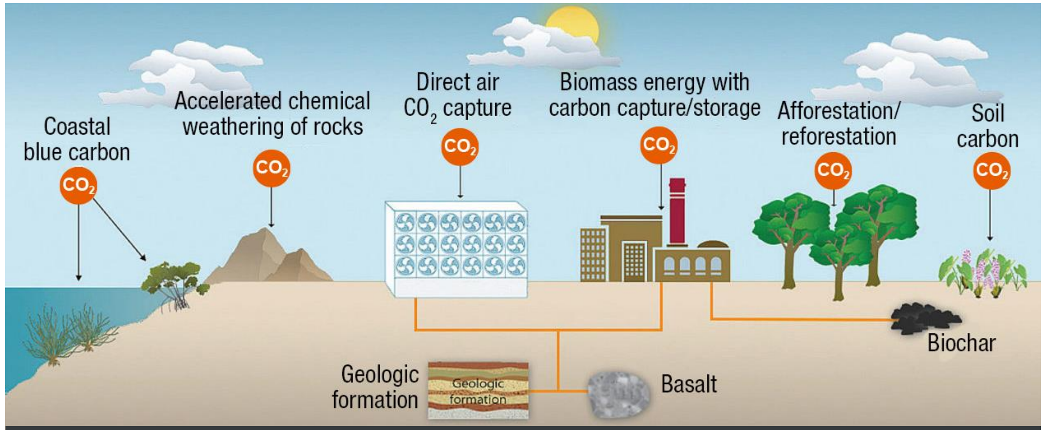
Challenges

CO_2 in the atmosphere is highly diluted (~400 ppm):

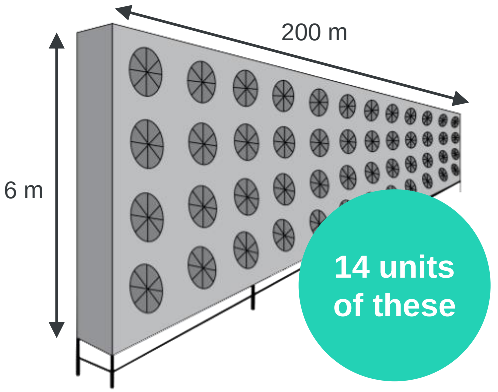
- Large energy footprint
- Cost
- Large land footprint

These challenges can be overcome by:

- Contactor development
- Low carbon energy, such as waste heat in the case of low temperature DAC



DAC with storage can be a NET, next to bio-CCS, carbon soiling, reforestation



14 units of these

=

Capture the same amount of CO_2 as this

Petra Nova – 1.4 Mt CO_2/year
115 m tall, 20 m large absorber

Modified from Source [9]

Sources [8], [9]

CO_2 capture from the air: myth or reality?

Next 5-10 years a major milestone to go from myth to reality

The leading DAC technology developers are all striving for the first large scale demonstration where the economics and technology performances will be proven in an integrated business model (Enhanced Oil Recovery,e-fuels). 2025 will be a major milestone for DAC.

Roadmap	**< 2015**	**2015- 2020**	**2025**	**2030**
	Prototype	**Pilot**	**Demo**	**Commercial**
Tons/year	1	1000	10,000	> 1,000,000
Proof	Material	Technology	Economics	Profit & Impact

© climeworks.com

Source [7]

© DR

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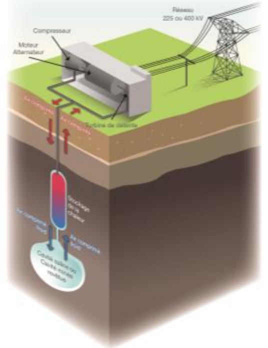
Pumped Hydro Compressed Air

Hybridization of a mechanical solution (CAES) with a thermo-dynamic cycle offers a novel energy storage

Compressed Air Energy Storage (CAES)


Hydrostor technology


A concept of underground Adiabatic CAES developped by ENGIE

Industrial development (Adiabatic CAES):
- Compressed air stored in reservoir (old mines, salt cavern, reservoir)
- Heat from compressed air stored in Thermal Energy Storage

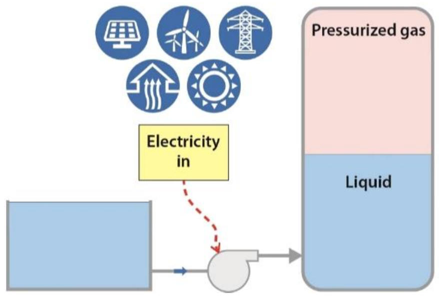
R&D development (Isothermal CAES):
- Water sprayed during compression & expansion to avoid heating and cooling of compressed air
- Thermal storage = a water tank
- **Hydraulic piston** used to improve CAES efficiency

Pumped Hydroelectric Storage (PHS)

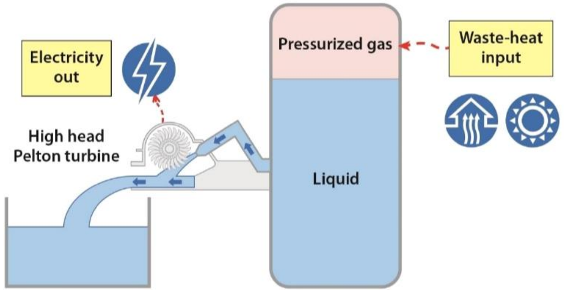
Industrial development:
- An upper and lower reservoir are needed
- Searching for the highest possible elevation to reduce soil footprint

R&D development (PHCA):
- Replacing the **elevation by compressed air cavity** (or other pressurised fluid)
- Lower reservoir can be a water reservoir, a lake, a river, a sea or a low compressed air cavity


Cliff PHS in Okinawa island



Charging Mode



Discharging Mode

Hydraulic Piston or Pumped Hydro Compressed Air (PHCA)

Hydraulic Piston based on new Pelton design to replace air expander used by CAES or to downsize PHS

Sources [10], [11], [12], [13]

Merging CAES and PHS: new opportunities for both systems

ADVANTAGES:

- Trigeneration storage can be expected: heat, cold and power can be managed separately
- Containerised and scalable
- No geographical restriction (opportunity to use abandoned mines, tunnels,…) and limited water consumption
- Large-scale energy storage for offshore market
- Benefits from PHS and CAES demonstrations around the world which are cost-effective and reliable

CHALLENGES:

- Optimisation of the pump-turbine design for increasing the cavern depth of discharge and for addressing high pressure
- Thermal management of the process to tackle different objectives:
  - Maximizing electrical power requires a gas that does not heat up too much or very fast heat exchanges to approach isothermal compression.
  - Conversely, a thermally oriented system will seek to heat and cool while limiting exchanges with the water
- Cost

Example of abandoned cavern

© AdobeStock

THESE CHALLENGES CAN BE OVERCOME BY:

- Combining different kind of turbines or using multi-stage turbines
- Including heat exchangers into the cavern to recover or to bring energy

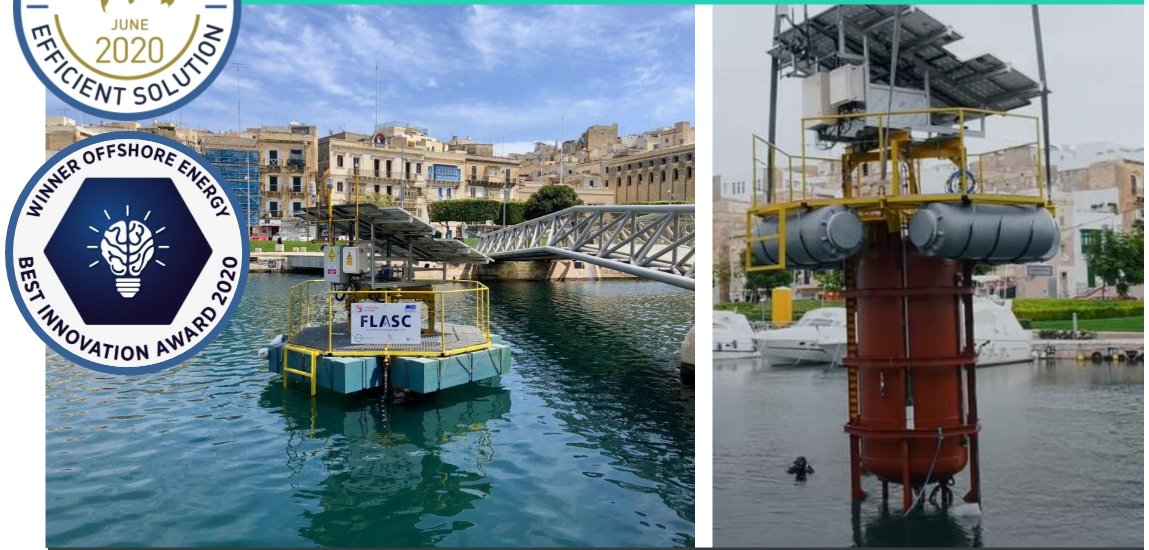
Towards the commercialisation of the offshore Hydro-Pneumatic Energy Storage (HPES) concept

Energy storage device (ocean CAES) can be integrated directly into a floating offshore platform. Thus energy is stored using a Hydro-Pneumatic Liquid Piston, driven by a reversible pump-turbine. Electrical power efficiency could be greater than 70%.

SOLARIMPULSE EFFICIENT SOLUTION JUNE 2020

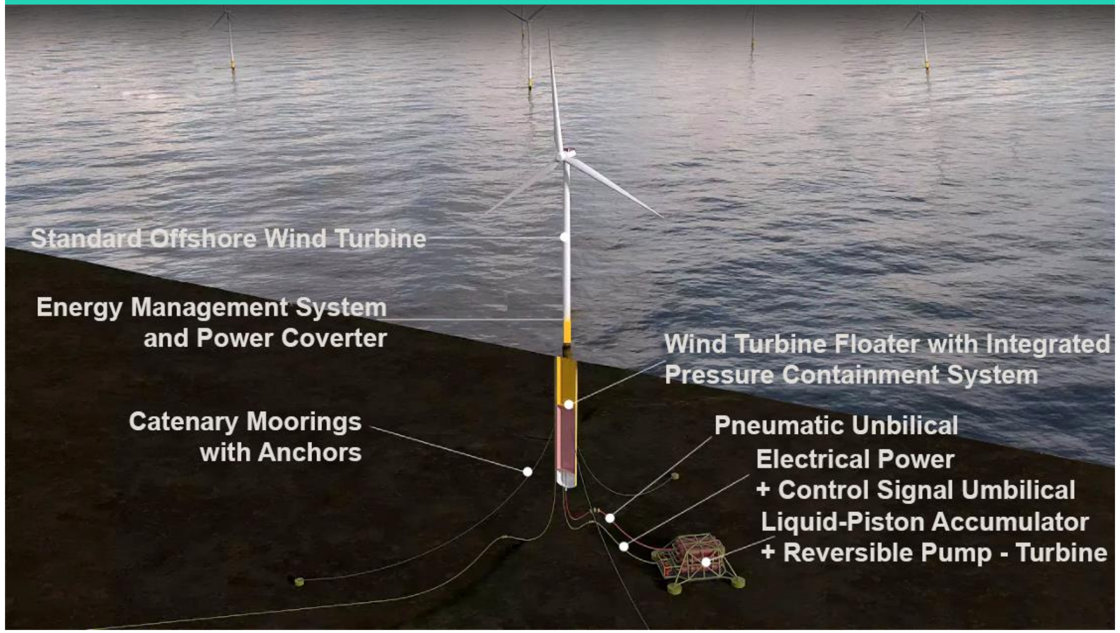
WINNER OFFSHORE ENERGY BEST INNOVATION AWARD 2020

Floating solar panels



The first FLASC prototype was deployed in 2017 in the Grand Harbour of the Maltese Islands

Floating wind turbine



Sources [14], [15]

An emerging topic with projects already developing commercial facilities

Power grid storage & Wind or PV farm integration

Ground Level Integrated Diverse Energy Storage (GLIDES) prototype since 2019. Efficiency from 70% to 82%

FLASC pilot since 2017

Remora demonstrator patented by Segula Technologies under construction (2019-2023) 15MW-90MWh

Concept/prototype

Pilot

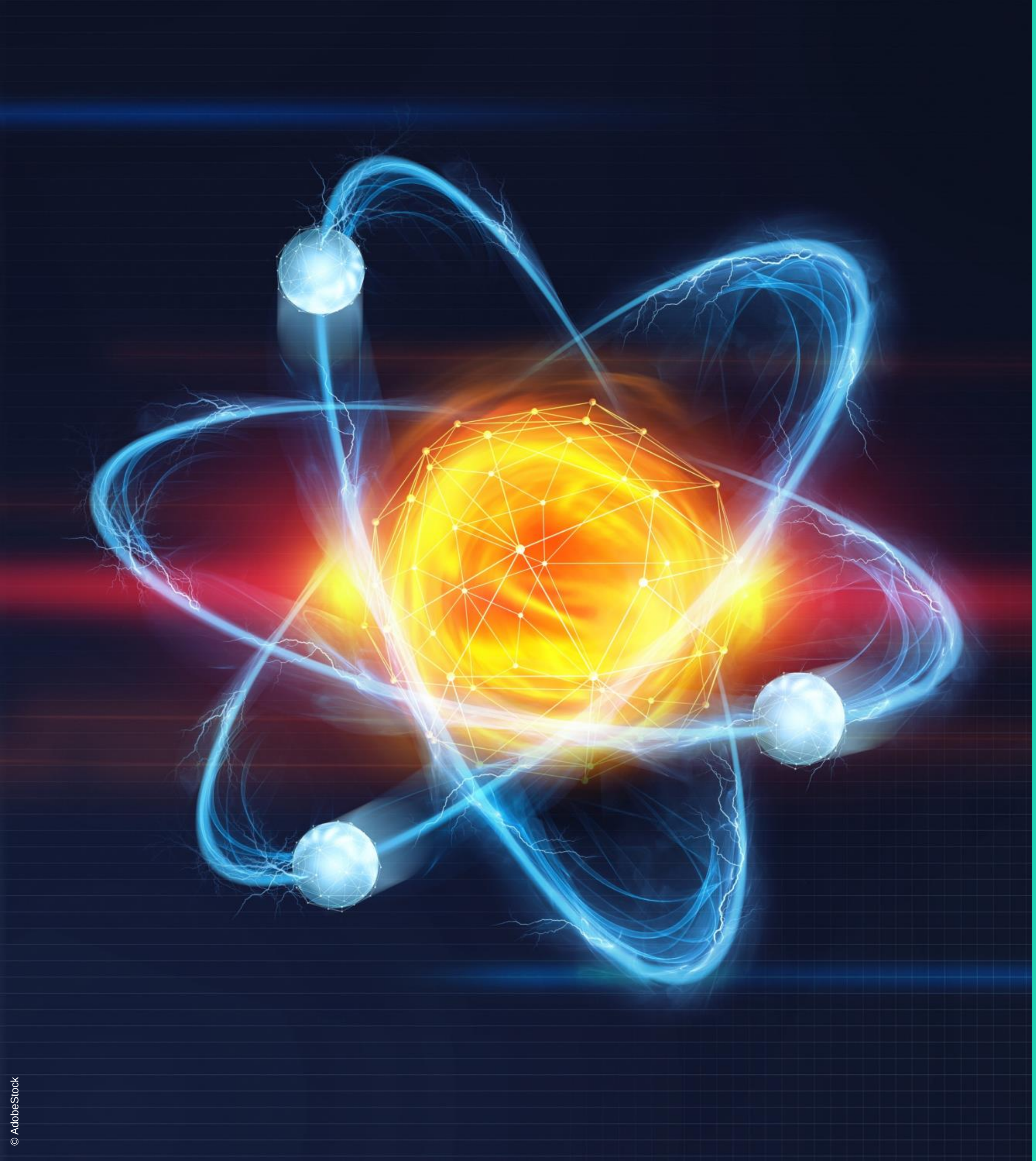
Demonstrator

Commercial (>2025)

Industry & District Heat and Cooling network

- **PackGy concept**
  2019 – trigeneration storage for agro-food industry
- **CAES** to produce and to store heat and cold for DHC network
- **Pumped Hydro Storage** to produce and to store heat for DHC network

Sources [12], [14], [16], [17]



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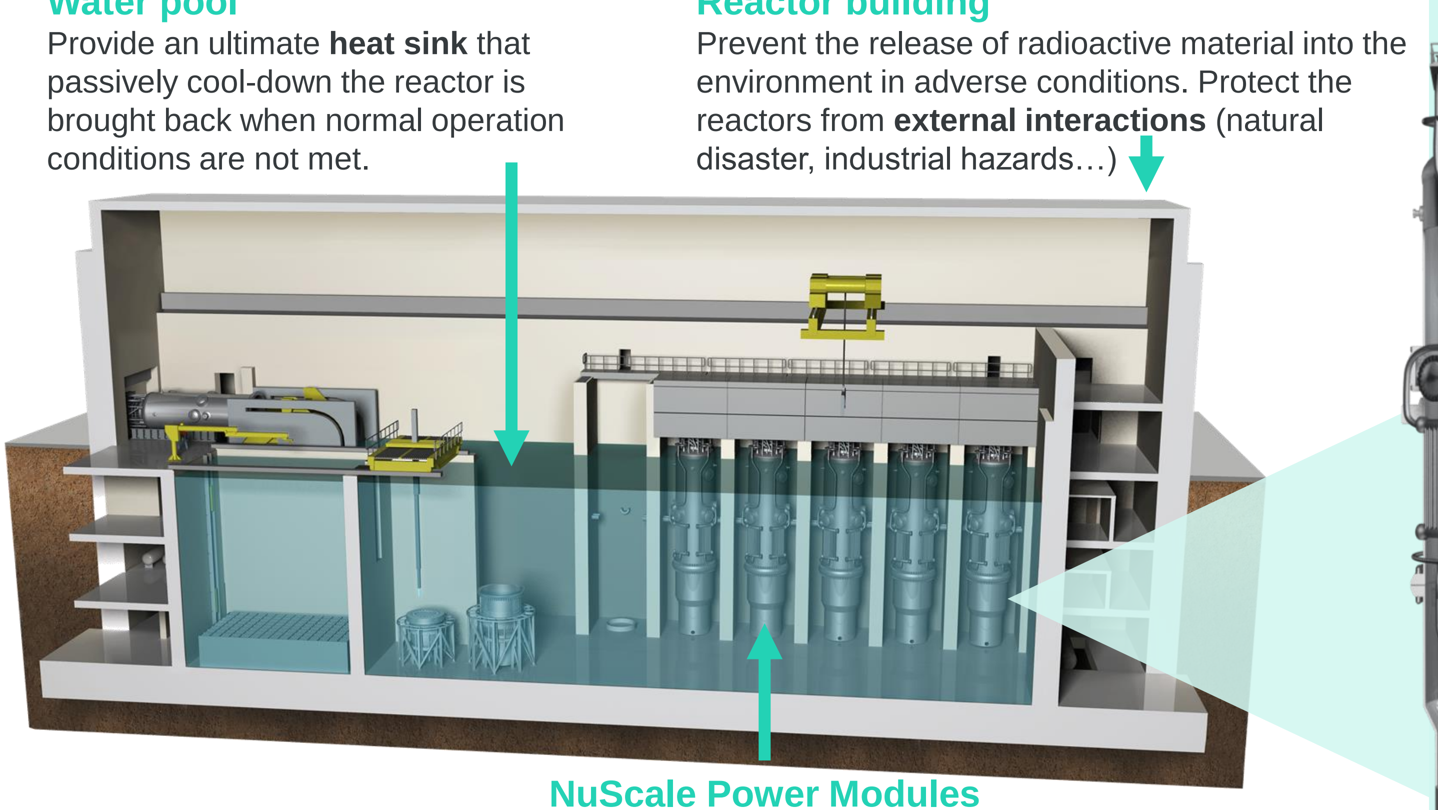
Small Modular Reactor

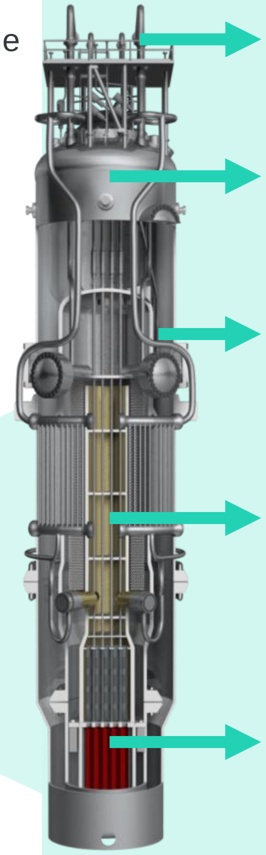
Small modular reactors (SMRs) are commonly defined as nuclear reactors of 300MWe equivalent or less, designed with modular factory fabrication



Water pool
Provide an ultimate **heat sink** that passively cool-down the reactor is brought back when normal operation conditions are not met.

Reactor building
Prevent the release of radioactive material into the environment in adverse conditions. Protect the reactors from **external interactions** (natural disaster, industrial hazards…)

NuScale Power Modules
Supply steam **independently** from the other power modules



Steam line
Transport the steam toward it's **desired applications**: turbine for electric generation or heat network for co-generation applications

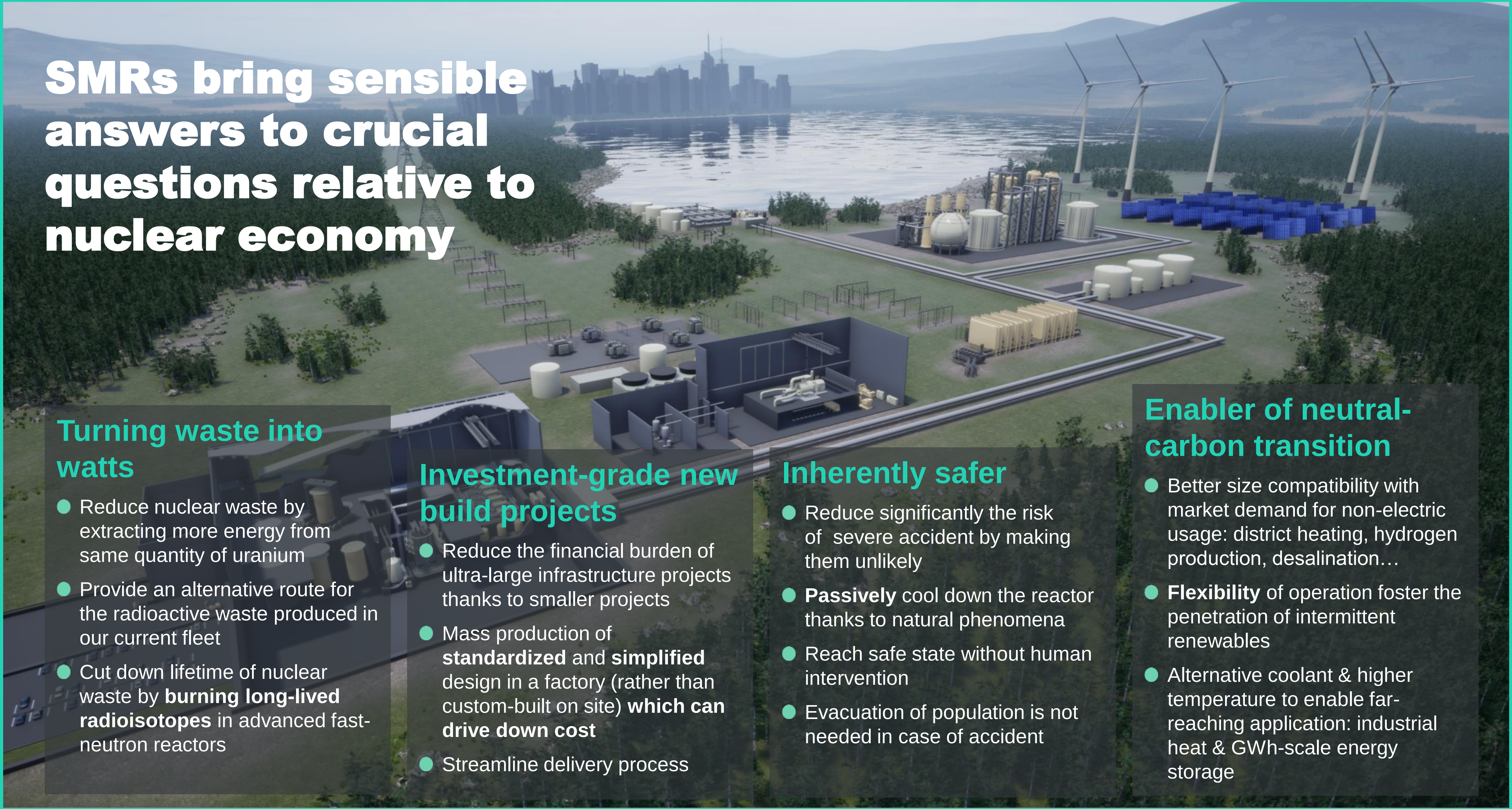
Containment Vessel
Prevent the release of radioactive materials and protect from external interaction

Reactor Pressure Vessel
Ensure the **integrity** of the primary circuit

Warm coolant rising channel
Guide the **natural circulation** of the expanding cooling water through the heat exchanger to produce steam. Concepts use alternative coolants (molten-salt, helium...)

Nuclear Core
Contain the uranium assemblies within which **nuclear reactions** occur liberating a large amount of heat

Source [18]



SMRs bring sensible answers to crucial questions relative to nuclear economy

Turning waste into watts

- Reduce nuclear waste by extracting more energy from same quantity of uranium
- Provide an alternative route for the radioactive waste produced in our current fleet
- Cut down lifetime of nuclear waste by **burning long-lived radioisotopes** in advanced fast-neutron reactors

Investment-grade new build projects

- Reduce the financial burden of ultra-large infrastructure projects thanks to smaller projects
- Mass production of **standardized** and **simplified** design in a factory (rather than custom-built on site) **which can drive down cost**
- Streamline delivery process

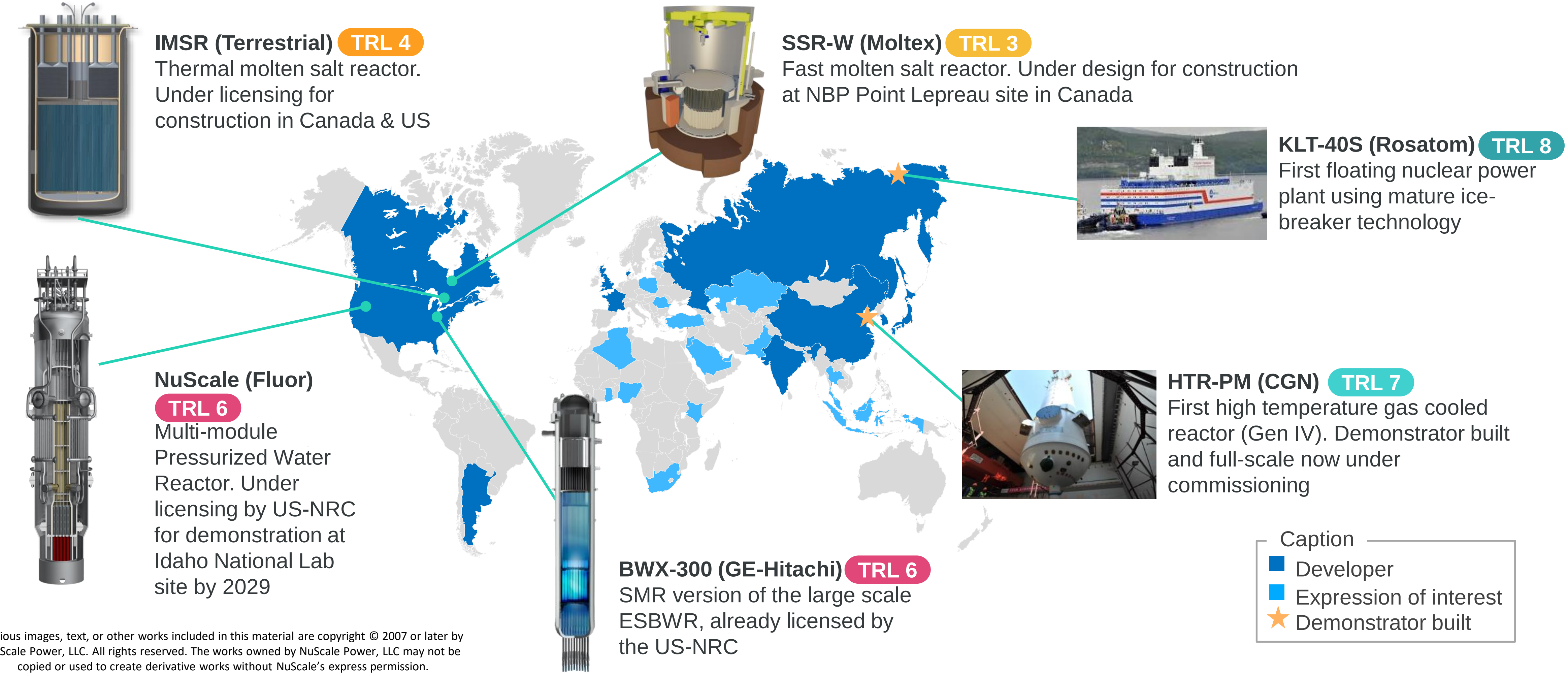
Inherently safer

- Reduce significantly the risk of severe accident by making them unlikely
- **Passively** cool down the reactor thanks to natural phenomena
- Reach safe state without human intervention
- Evacuation of population is not needed in case of accident

Enabler of neutral-carbon transition

- Better size compatibility with market demand for non-electric usage: district heating, hydrogen production, desalination…
- **Flexibility** of operation foster the penetration of intermittent renewables
- Alternative coolant & higher temperature to enable far-reaching application: industrial heat & GWh-scale energy storage

SMR is already in development globally with 2 demonstration plants already built



IMSR (Terrestrial) TRL 4
Thermal molten salt reactor. Under licensing for construction in Canada & US

SSR-W (Moltex) TRL 3
Fast molten salt reactor. Under design for construction at NBP Point Lepreau site in Canada

KLT-40S (Rosatom) TRL 8
First floating nuclear power plant using mature ice-breaker technology

NuScale (Fluor)
TRL 6
Multi-module Pressurized Water Reactor. Under licensing by US-NRC for demonstration at Idaho National Lab site by 2029

HTR-PM (CGN) TRL 7
First high temperature gas cooled reactor (Gen IV). Demonstrator built and full-scale now under commissioning

BWX-300 (GE-Hitachi) TRL 6
SMR version of the large scale ESBWR, already licensed by the US-NRC

Caption
- 🟦 Developer
- 🟦 Expression of interest
- ★ Demonstrator built

The known challenges from this high technology requires qualified and experimented human ressources

1. International Licensing strategy

- Multi-lateral **harmonisation**
- Country of origin approach: passport-like certification
- **Pre-licensing** for early regulator feedback & overall process de-risking

2. Improved value chain

- Built-in design **lessons learned** from recent projects
- Advanced manufacturing techniques for major component price crunch
- New delivery process for site decongestion

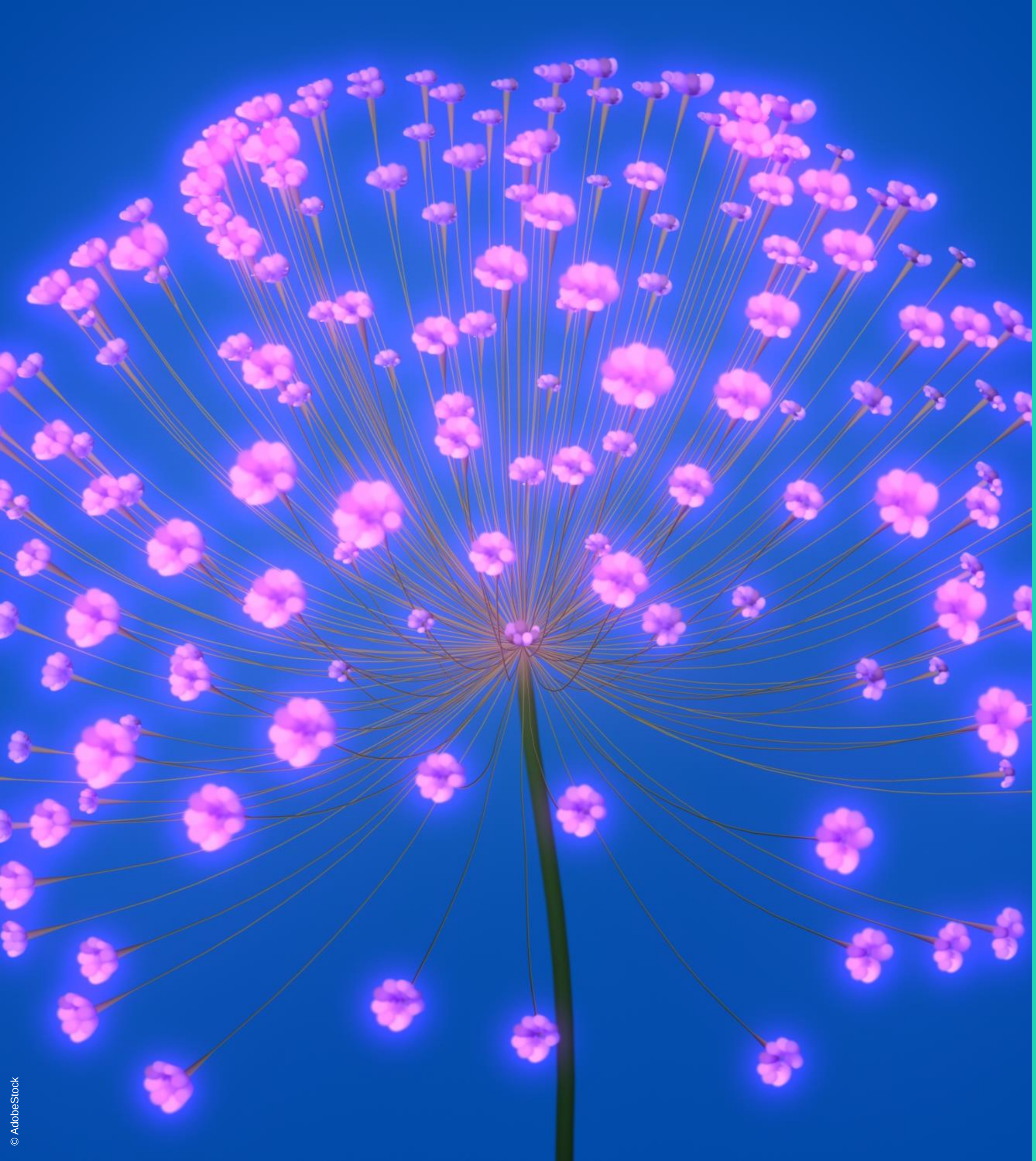
3. New stakeholder organisation

- Multi-national **alliance**
- New financing models: user-owned, crowdfunding & wealthy backers
- Canada as the world SMR **hub**
- Fermi (Estonia): the European test bench

4. Technological readiness

- New materials qualification (alloy 617…)
- “**Cook & look**” approach with test loops: physical-chemical behaviour mapping, I&C hardware development…
- Growing government funding for National and Private **Research Labs**

🟦 Challenge transversal to all SMR technologies
🟧 Challenge specific to Advanced (non-water) Reactor technologies



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Cybersecurity and biomimicry for society resilience

How to keep systems cyber-secure while enlarging the digital footprint?

Resilience is needed

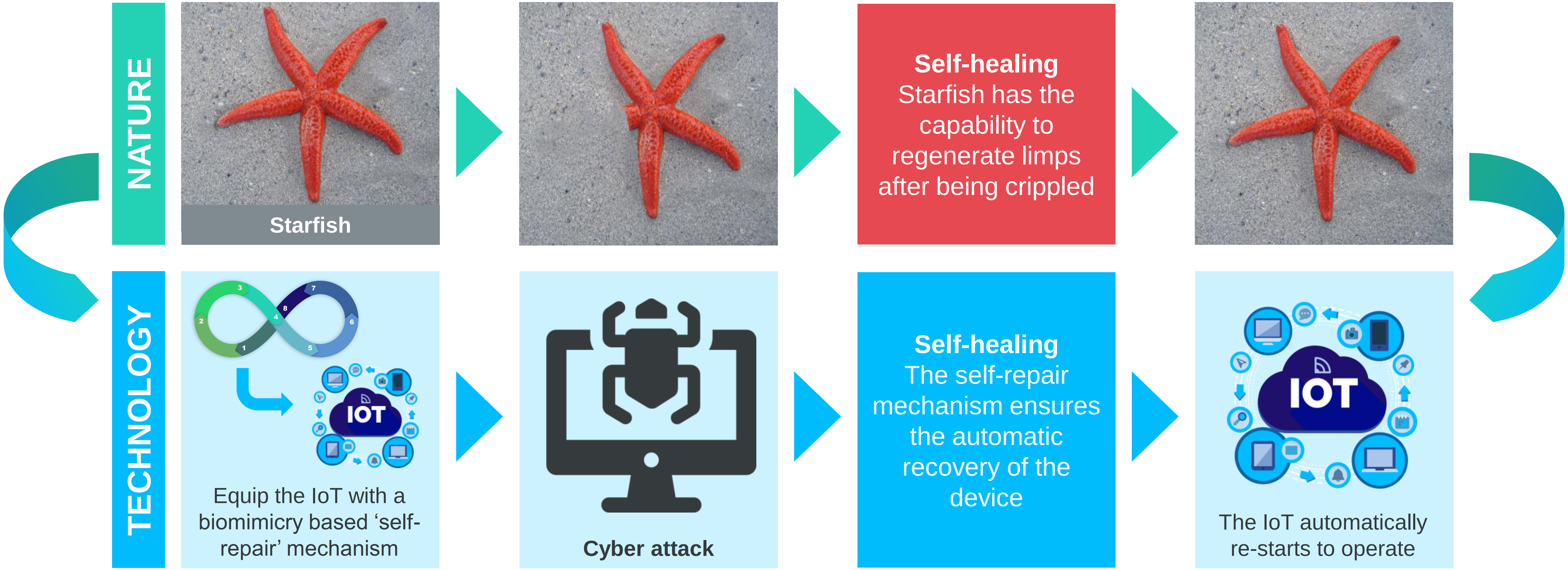
Cyber Attack on digital equipment
- Viruses
- Targeted and non-targeted attacks
- Disgruntled people
- …

Lost of
- Confidentiality
- Avalability
- Integrity

Secure operations

Impacted IoT
- Loss of production & revenues
- Damage of equipment
- Harm people
- Reputational damage
- Non-compliance

We can learn from nature on how to equip IoT devices with a mechanism to self-repair after being cyber-attacked



Starfish

Self-healing
Starfish has the capability to regenerate limps after being crippled

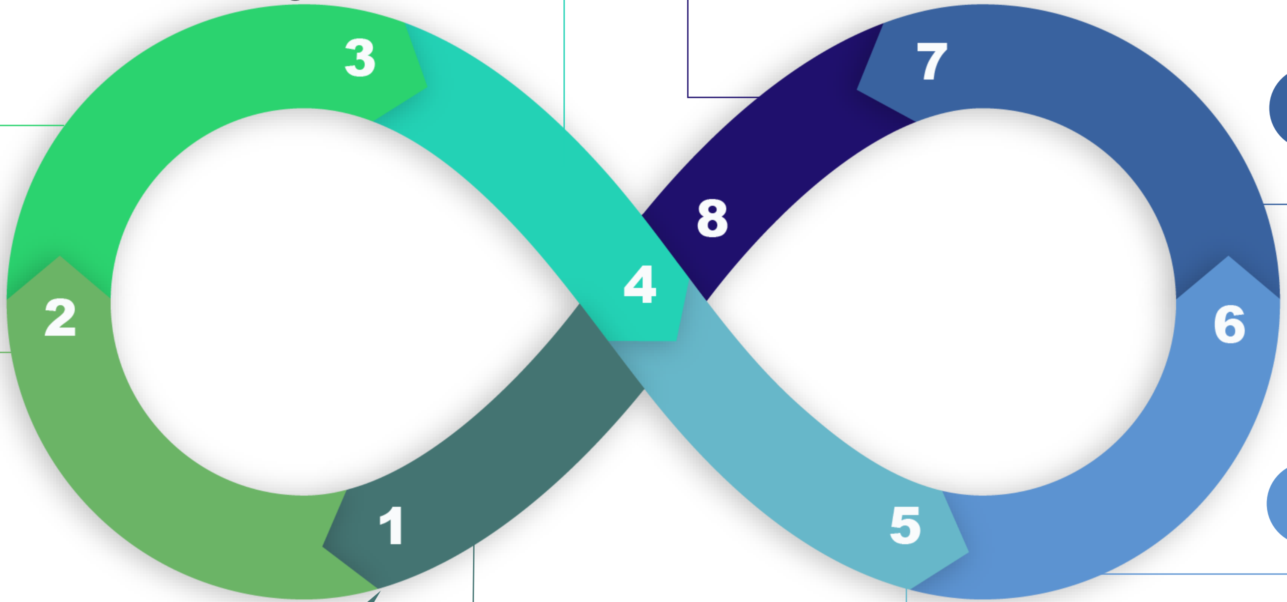
Equip the IoT with a biomimicry based ‘self-repair’ mechanism

Cyber attack

Self-healing
The self-repair mechanism ensures the automatic recovery of the device

The IoT automatically re-starts to operate

The biomimicry eight steps loop method



1 Analysis of the problem

2 Technical problem abstraction

3 Transposition to biology

4 Identification of biological models

5 Selection of the relevant one

6 Biological strategies abstraction

7 Transposition to technology

8 Tests and implementations

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Examples of biomimicry inspired solutions

Source [19]

Comparison of different biomimicry projects available around the world

0

Human Immune System– for immune response

1

SMART GRID IMMUNE SYSTEM

Bio-inspired security architecture for Smart Grids

- Bangladesh, International Islamic Universty Chittagong
- **2016**


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Self-healing

ENGIE STARFISH

Bio-inspired IoT system self-restortion

- Belgium, ENGIE Laborelec
- **2020**

2

Eusocial bahaviours in ant colonies

3

DIGITALANTS™

Ant-based Cyber Defense

- USA, Pacific Northwest National Laboratory
- **2011**

Bio-phenomena: Ant colony

4

SWARM INTELLIGENCE

Wireless Sensor Network (WSN) Cybersecurity

- India, Sri Venkateswara College of Enginnering
- **2017**

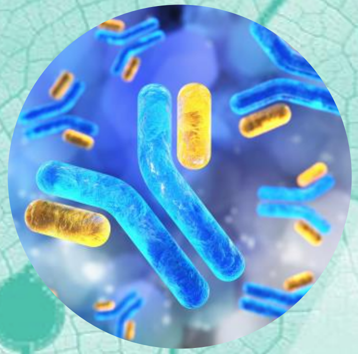
Human Immune System

5 6 7

FUZZBUSTER

Towards Adaptive Immunity from Cyber Threats

- USA, Smart Information Flow Technologies (SIFT)
- **2011**



Human Immune System-Antibodies

8 9

CYBERIMMUNITY: DARK TRACE

Enterprise Immune System

- United Kingdom Darktrace
- **2017**

X TRL:Technology Readiness Level

Sources [20], [21], [22], [23], [24], [25], [26], [27]

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5

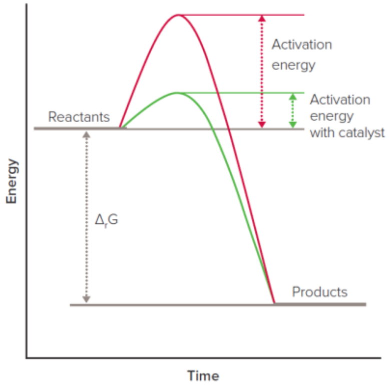
Sustainable catalysts as energy transition enablers

Catalysis is a key enabling technology for energy transition

- Both energy (heat, electrons, photons) and catalyst are required to convert thermodynamically stable molecules, i.e. H_2O and CO_2, into value-added products.
- Catalysts are chemical substances **increasing the reaction rate without being consumed** to reach the chemical equilibrium at a suitable temperature.They do not change the thermodynamics and can be used cyclically.

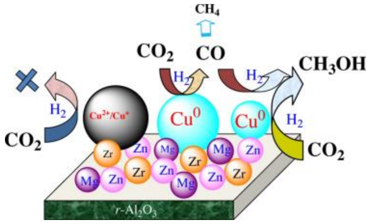
- **Its performance is driven by:**
  - Its composition (nature of the metal, enzyme…)
  - Structure / morphology / microstructure
  - Type and nature of support
  - Immobilization method
- A catalyst is specific for each final product, reaction conditions and type of process:

Comparison of activation energy with (green) and without (red) a catalyst



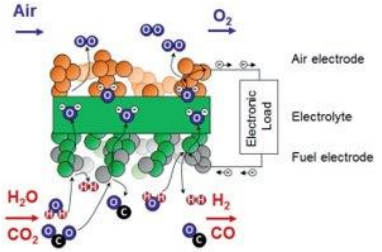
Thermocatalytic conversion

Metallic Cu catalyst



CO_2 hydrogenation into methanol

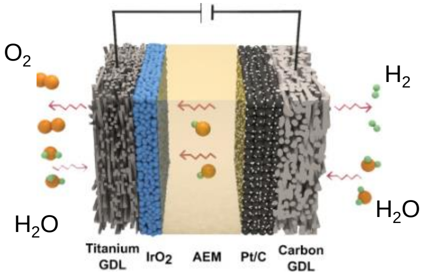
Metallic Ni supported on YSZ ceramic



Production of syngas by Solid Oxide Electrolysis (SOEC) at High Temperature

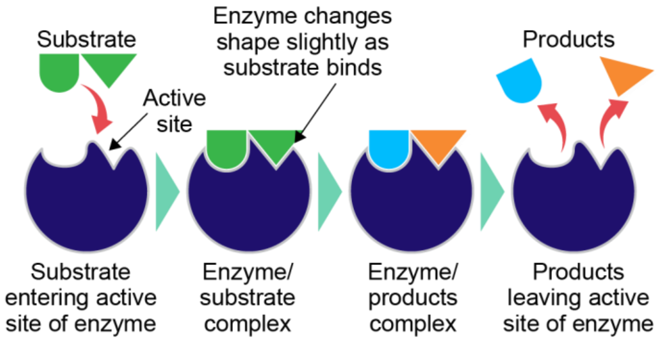
Water electrolysis

Pt/IrO_2 catalyst



H_2 production from water electrolysis

Biocatalytic conversion



Sources [28], [29], [30], [31]

Platinum group metal (PGM) catalysts dominate today’s applications

CHALLENGES

- Even at high production volumes, the PGM catalyst is expected to represent a significant part of the fuel cell cost.
- The wide development of **electrochemical processes, that bridge the molecule-based economy with a green electricity production** should avoid the intensive use of PGM materials. As such, a large scientific effort is devoted to the development of low-PGM and PGM-free catalysts.
- Developments of new catalytic materials with improved performance are focused on composition and microstructure.

2018 PEMFC Stack Cost Breakdown

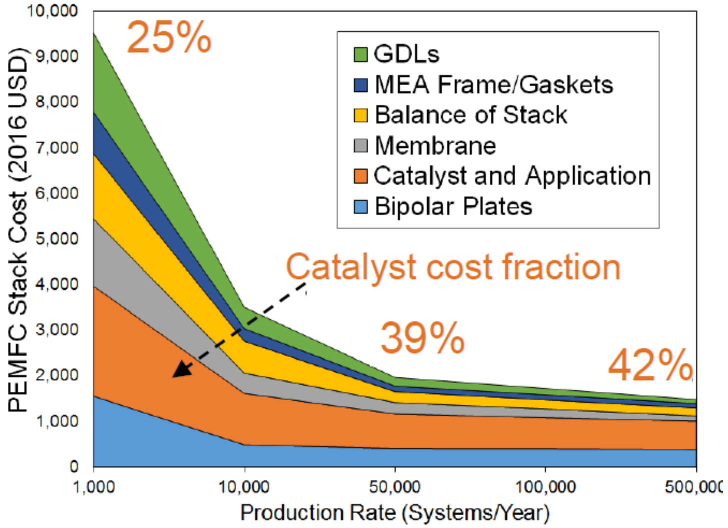
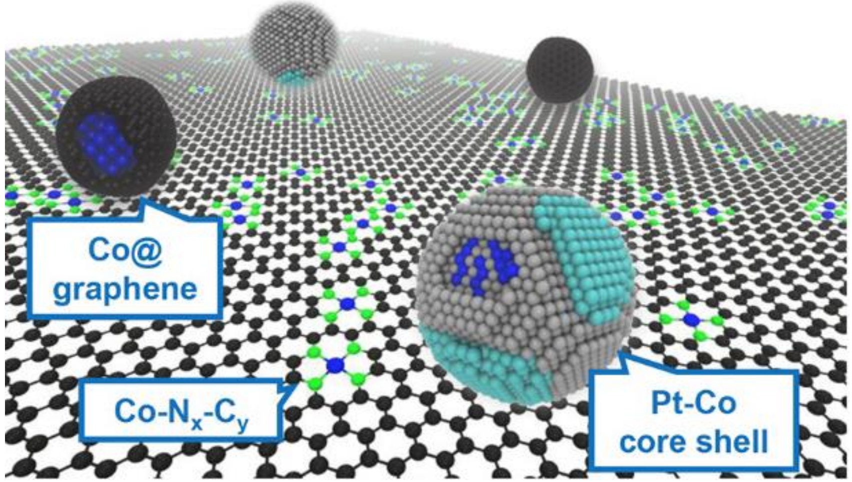


Illustration of the microstructure of a low PGM catalyst



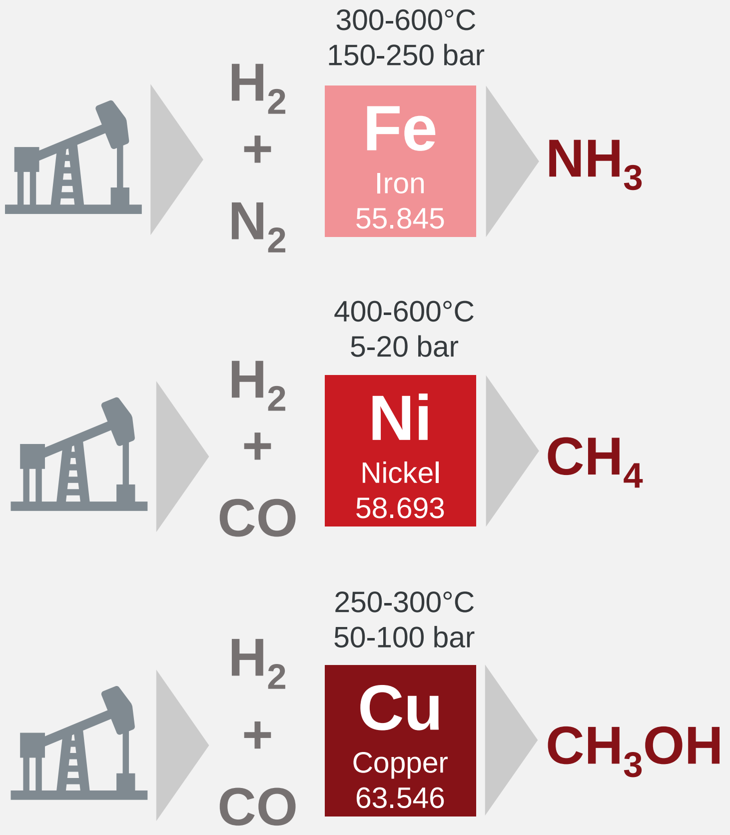
Platinum group metal

Ru Ruthenium 101.07	**Rh** Rhodium 102.91	**Pd** Palladium 106.42
Os Osmium 190.23	**Ir** Iridium 192.22	**Pt** Platinum 195.08

Sources [32], [33]

Conventional catalysts

- ☒ Fossil fuel feedstock
- ☒ Harsh reaction conditions
- ☒ Low process flexibility
- ☒ Low catalyst activity
- ☑ Abundant and cheap materials



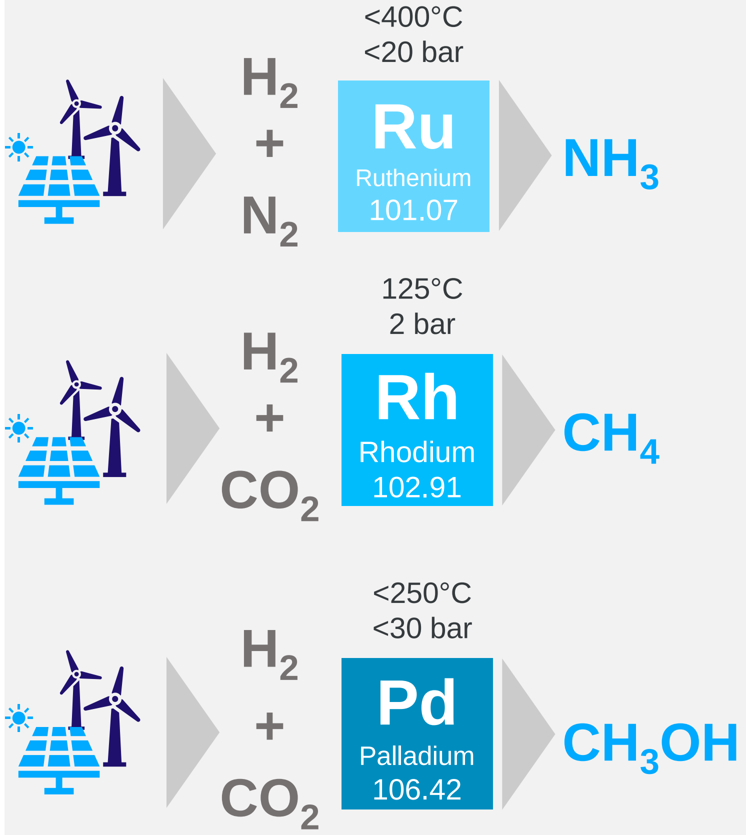
300-600°C
150-250 bar
H_2 + N_2 → **Fe** Iron 55.845 → **NH_3**

400-600°C
5-20 bar
H_2 + CO → **Ni** Nickel 58.693 → **CH_4**

250-300°C
50-100 bar
H_2 + CO → **Cu** Copper 63.546 → **CH_3OH**

Alternative catalysts

- ☑ Renewable feedstock
- ☑ Mild reaction conditions
- ☑ Higher process flexibility
- ☑ Higher catalyst activity
- ☒ Rare and expensive materials



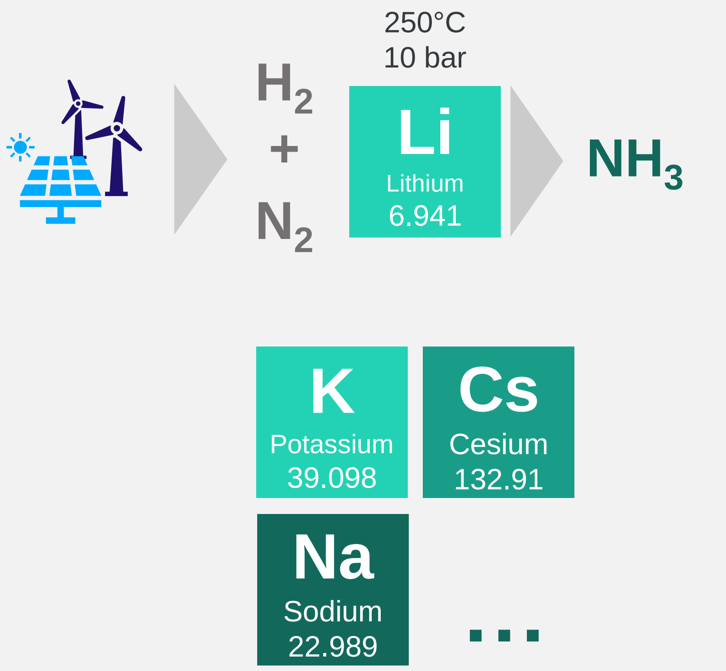
<400°C
<20 bar
H_2 + N_2 → **Ru** Ruthenium 101.07 → **NH_3**

125°C
2 bar
H_2 + CO_2 → **Rh** Rhodium 102.91 → **CH_4**

<250°C
<30 bar
H_2 + CO_2 → **Pd** Palladium 106.42 → **CH_3OH**

Tomorrow's catalysts

- ☑ Renewable feedstock
- ☑ Mild reaction conditions
- ☑ High process flexibility
- ☑ High catalyst activity
- ☑ Non-transition metals



250°C
10 bar
H_2 + N_2 → **Li** Lithium 6.941 → **NH_3**

K Potassium 39.098

Cs Cesium 132.91

Na Sodium 22.989

...

Sources [34], [35]

Future catalyst will have to be based on earth-abundant materials and will require to work at moderate pressure and temperature ultimately

The biocatalytic approach could allow the convergence of both approaches

ADVANTAGES

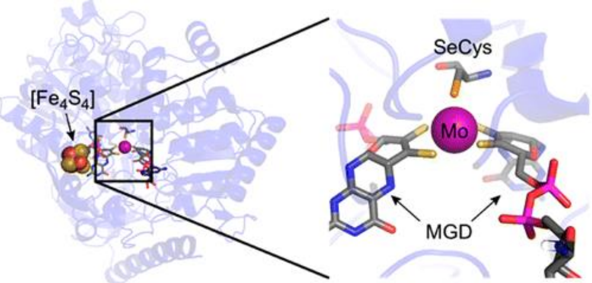
Mimicking the reactions taking place in living organisms, biocatalysis has many attractive features in the context of green and sustainable chemistry:

- Mild reaction conditions: ambient temperature and pressure
- High flexibility
- Efficient
- Highly selective
- Sustainable : biodegradable catalyst (enzyme)

CHALLENGES

- Recycling biocatalysts
- Development of more stable biocatalysts according to two different approaches:

- Keep wild type organisms / enzymes and select organisms that live in extreme environments as these will be naturally more stable.
- Engineer it using genetic tools



Formate dehydrogenase with focus on the active site of Mo for the CO_2 reduction into formate

Over the last few years, an increasing number of pilot and demonstration emerges.

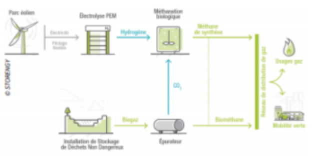
North-C-Methanol
Methanol
Thermocatalytic hydrogenation
45 000 t/y

PMV
PRO MAN
MITSUBISHI POWER
North Sea Port
POM
Oiltanking
fluxys
ENGIE
ArcelorMittal
ALCOBIOFUEL

Power-to-Methanol
Methanol
Thermocatalytic hydrogenation
8 000 t/y

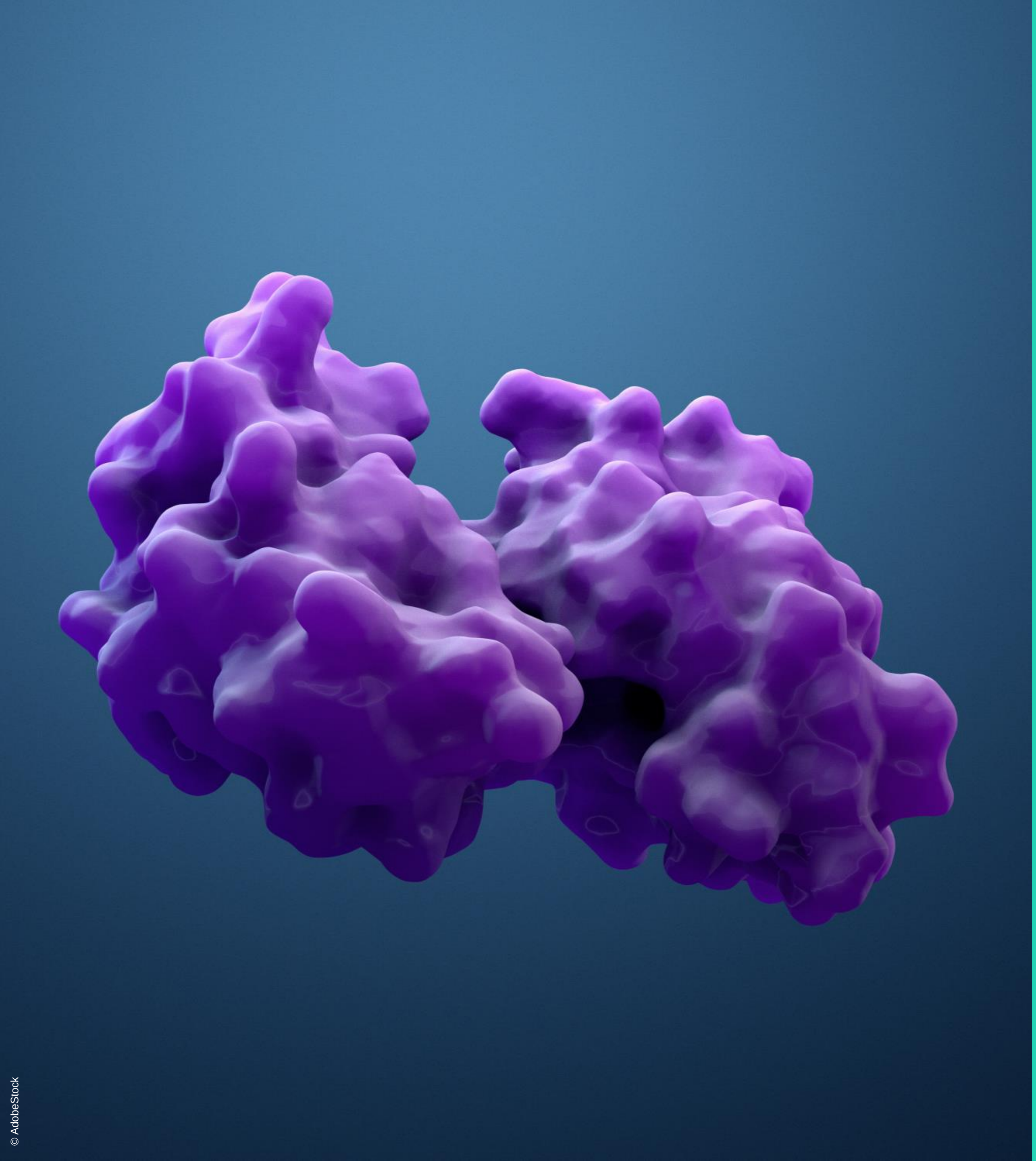
Port of Antwerp
ENGIE
fluxys
inovyn
PMV
Oiltanking
INDAVER

Power-to-gas Hycaunais
E- methane
Bioconversion
H_2 electrolyser @ 1MWe



storengy
ENGIE Green
ENGIE Lab
FC LAB
AREVA H_2Gen
sdey
Yonne énergie
Electrochaea

Source [36]



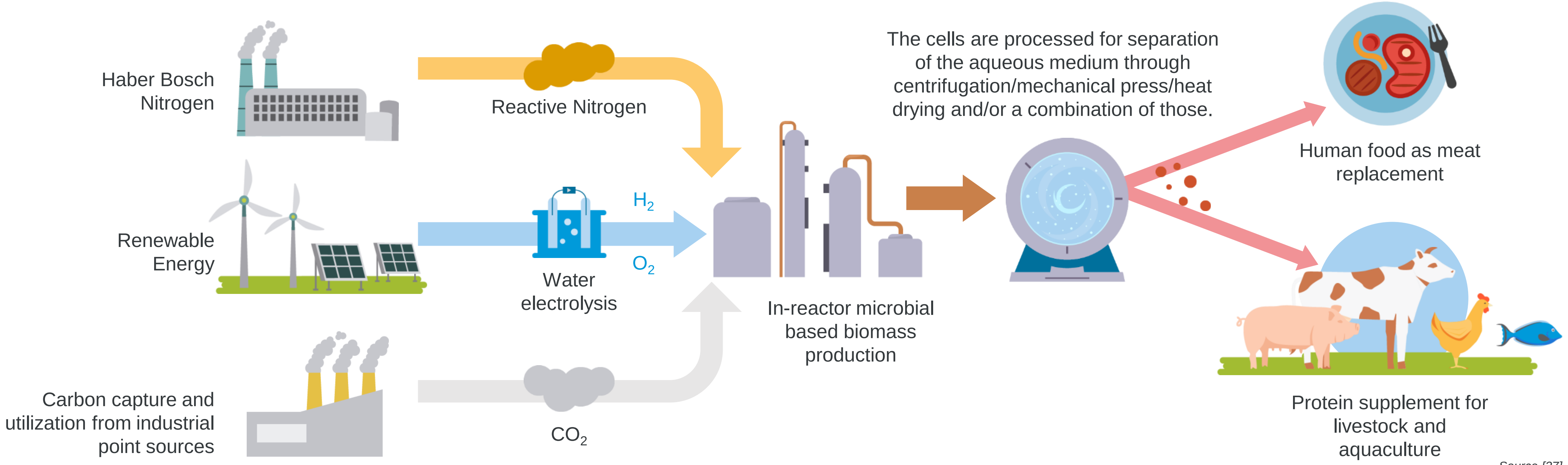
6

Power-to-proteins

Power-to-proteins approach consists in the production of a protein-rich material by bacterial cultures using electrolytic H_2 as energy source

- Commonly used microorganisms are **hydrogenotrophs** like *Cupravidius necator*, *Rhodococcus opacus* or *Hydrogenobacter thermophiles*. These bacteria **oxidize hydrogen** in anaerobic conditions **to power their metabolism** and **accumulate proteic biomass** at high rates (kg/m³.h scale)

Power-to-protein concept for food/feed production: a process that decompartmentalize energy, biology and agriculture sectors.

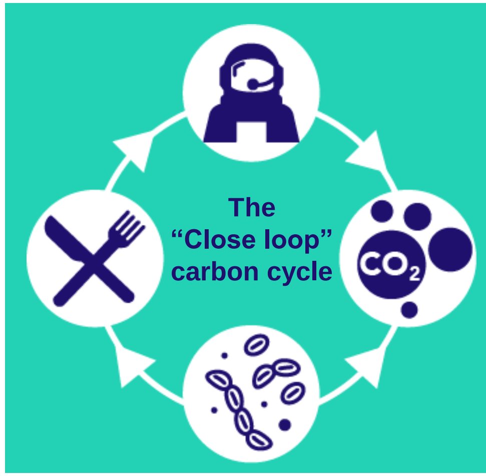


Source [37]

This no-brainer protein production pathway remains to be demonstrated economically at scale and socially accepted

Parameter	Animal based	Vegetable based	Microbial
Land footprint	High and only arable	Medium and only arable	Low and can be barren
Water use	High	High	Low
Greenhouse gases footprint	High	Medium	Low
Production time	Days to years, non seasonal	Months, seasonal	Days, non seasonal
Proteic efficiency	Low	Low	High
Nutrients environment spillover	Large, linked to vegetal feed needs	Large, through N emissions when fertilisers are applied	Close to 0
Resilience towards climate change	Low due to ecosystems change		High as it is decoupled from the environment
Pesticide and antibiotics use	Yes		No
Sterile environment	No	No	Yes

Comparison of animal, vegetable and bioconversion protein production pathways.



Food for astronauts?

Food cargo is a large expenditure when it comes to space exploration. Producing it autonomously is thus a huge opportunity. Power-to-proteins was actually initially developed for that application by NASA and still viewed as a long-distance space exploration enabler.

CHALLENGES:

- **Foremost challenge is to make it renewable and economical as hydrogen is the main cost**
- **Social** acceptance of eating a microbe or eating meat produced on microbes.

Sources [38], [39]

A dynamic portfolio of start-ups developing the subject at different stages and with different focuses. Oil and gas as well as electricity utilities are partnering

Start-ups

novonutrients
feed from CO_2

Deep Branch
BIOTECHNOLOGY

Avecom
Bioproducts & Apps

Kiverdi

SOLAR FOODS

In partnerships with

Chevron

Shell

fortum

drax

esa

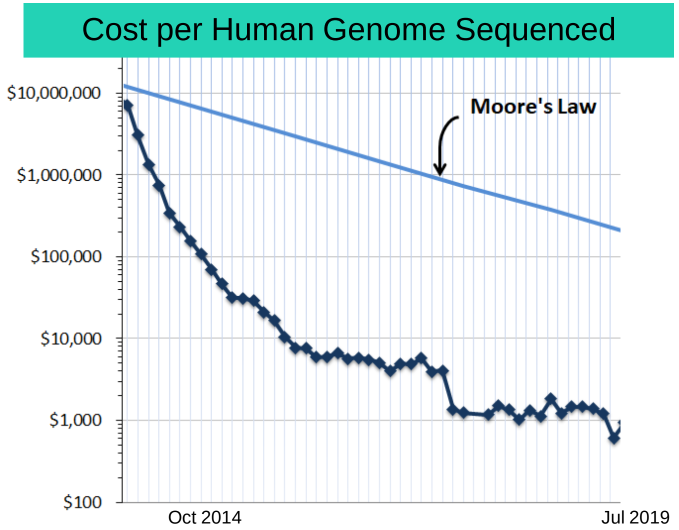
ENGIE

The steadily growing biotech economy is experiencing an ever growing momentum pulled by key enabling technologies to harness biology without wasting resources

Biotechnologies have been ever rising since a couple of decades through 3 main different sectors: **Industrial**, **pharmaceutical** and **agricultural applications**. Today, pharma sector is leading but the grow is cross sectorial.

Currently, an **even stronger development** of the sector is observed due to several factors:

- **Dropping DNA sequencing costs to access massive information**
- **Artificial intelligence** (especially machine learning) developments to **manage the massive amount of data**
- **CRISPR/Cas9** development, a genetic editing tool to **screen large number of precisely edited mutants**
- Laboratory increasing **automatization** capacity

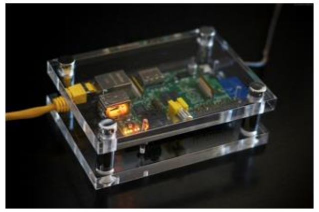


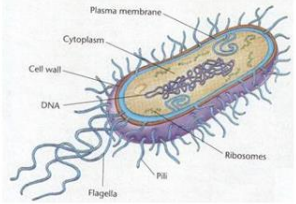
Nobel Price in Chemistry 2020: Emmanuelle Charpentier and Jennifer Doudna.


© Alexander Heinl/Picture Alliance/DPA

Similarities with the informatics wave?

Actors in the field sometimes compare this evolution to the computer and IT revolution that occurred the past decades as both show **impressive growth and several similar concepts**





"Blank" chassis	"Evolutionary" based chassis
Constructed by modules (parts)	
Behavior code based	
Non self replicative	Self coding and self replicative
Possible contamination by external code	
Similarities with IT exists but fundamental differences	

Sources [40], [41], [42]

7

Hydrothermal gasification of biomass and waste

Hydrothermal Gasification converts liquid organic waste into green gases in contrast to pyrogasification processes which valorize dry organic waste

What is a liquid organic waste?

- Biomass or waste having a dry matter range of 5-50 wt%
- Organic fraction in the dry matter is higher than 50 wt%
- Liquid organic waste must be pumpable to reach high pressure required by the process

Inputs=
Waste or residues difficult to valorize

Digestates from anaerobic digestion

Sewage sludge from industrial or municipal wastewater treatment plant

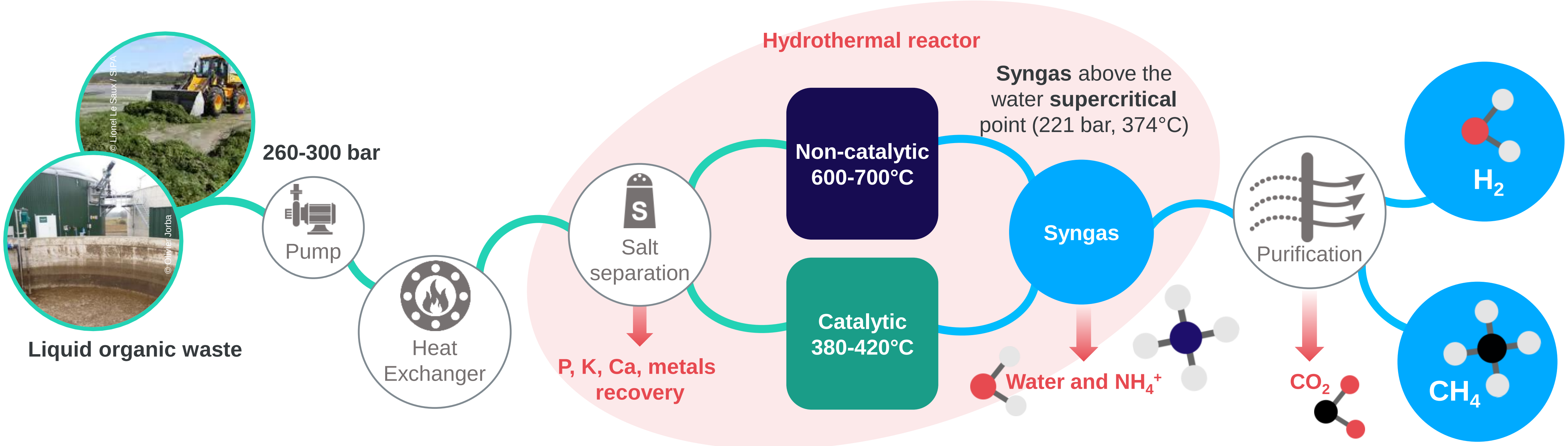
Food industry residues and by-products

Macro and micro-algae

Liquid industry, effluents

Liquid and solid farming waste

Hydrothermal Gasification is gasification in hot compressed water which uses water in a supercritical state



Production of syngas, CH_4, H_2, or chemicals

- Raw syngas can be valorized either directly for heat and/or electricity production, or purified to clean CH_4 or H_2, or converted into **chemicals.**
- CH_4 content reaches 50-60% in catalytic conversion, and up to 90% when H_2 is co-injected in the gasifier
- H_2 concentration can achieve 50-75% in syngas

Sources [43], [44], [45]

Hydrothermal Gasification is either a complementary or competitive alternative pathway for green gas production from organic waste

ADVANTAGES

- Complementary to **pyrogasification process** which valorizes dry organic waste and to **anaerobic digestion (AD)** by valorizing liquid digestates in saturated spreading zones
- Efficient production of **CH_4 or H_2** depending on the operating conditions and process chain (CH_4 production is doubled compared to **AD**)
- Fast conversion (<10min) ➔ **compact units** (10 times more compact than AD)
- Co-production of minerals (P, K, Ca) and NH_4+ possibly valorized as fertilizer ➔ **extra-revenues**
- Low quantity of **final solid residue** generated
- No problem by using only one type of feedstock contrary to AD

CHALLENGES

- Operating with high pressure and high temperature
- **Optimisation of minerals separatio**n to avoid plugging of the gasification reactor
- Preventing from catalysts **deactivation by poisoning** (sulfur compounds) and **plugging** (minerals precipitation)
- Scaling-up and simplifying the installation operation
- Potentially in competition with anaerobic digestion since both sectors valorize **liquid organic fuels**
- Uncertainty on profitability due to costly alloys for reactor and equipment to withstand operating conditions and **corrosion**

Sources [45], [46], [47], [48], [49], [50], [51], [52]

Gas companies and transport infrastructures are involved in the development of the sector by providing support to technology developers and to initiate pilot or demonstration projects

GRTgaz

FROM RESEARCH TO INDUSTRY
cea tech

PAUL SCHERRER INSTITUT
PSI

KIT
Karlsruhe Institute of Technology

SCW Systems
clean energy technology
&
gasunie
crossing borders in energy

PAUL SCHERRER INSTITUT
PSI
&
TreaTech

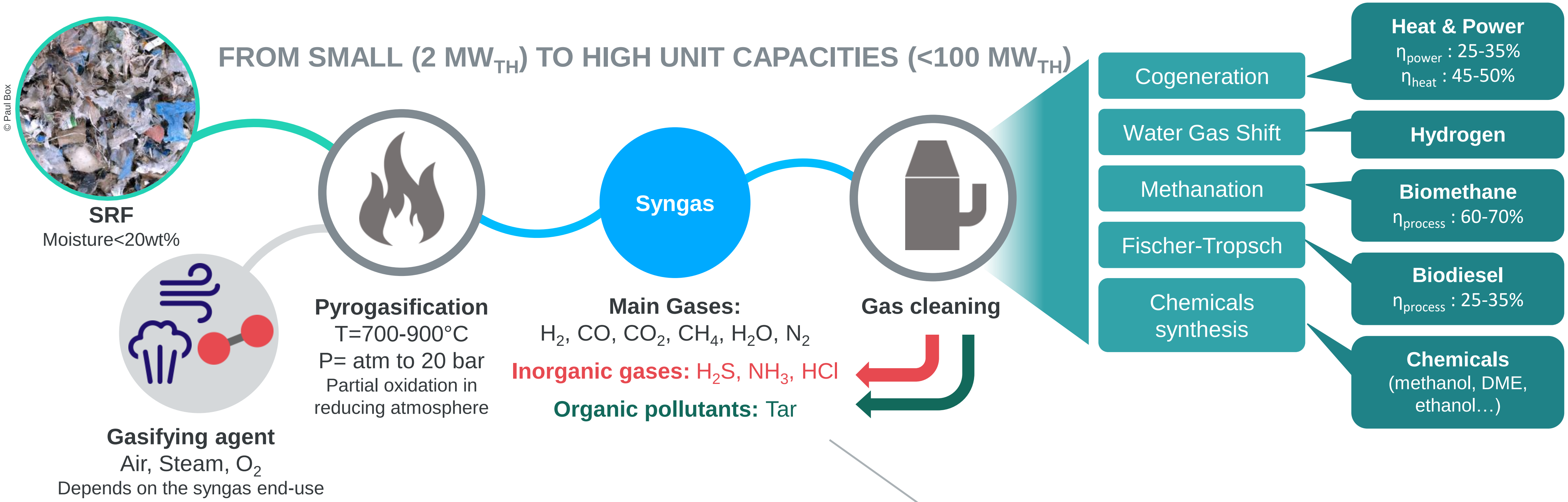
Bright
Circular


© Paul Box

8

Pyrogasification of waste (Solid Recovered Fuel)

Pyrogasification of Solid Recovered Fuel (SRF) is an efficient way to convert dry waste into several energy carriers



FROM SMALL (2 MW_{TH}) TO HIGH UNIT CAPACITIES (<100 MW_{TH})

© Paul Box

SRF
Moisture<20wt%

Gasifying agent
Air, Steam, O_2
Depends on the syngas end-use

Pyrogasification
T=700-900°C
P= atm to 20 bar
Partial oxidation in reducing atmosphere

Main Gases:
H_2, CO, CO_2, CH_4, H_2O, N_2

Inorganic gases: H_2S, NH_3, HCl

Organic pollutants: Tar

Gas cleaning

- Cogeneration
- Water Gas Shift
- Methanation
- Fischer-Tropsch
- Chemicals synthesis

Heat & Power
η_{power} : 25-35%
η_{heat} : 45-50%

Hydrogen

Biomethane
$\eta_{process}$: 60-70%

Biodiesel
$\eta_{process}$: 25-35%

Chemicals
(methanol, DME, ethanol…)

SRF are complex and **heterogeneous** materials, strongly dependant on initial waste, production method, and season

Solid Recovered Fuels (SRF) are a mixture of:

- Plastics
- Waste wood
- Paper/carton
- Textiles…
- Carpet/matress
- Rocks
- Glass
- …

Syngas from SRF contains much more **pollutants** than syngas from clean biomass.
Conventional **inorganic gases** removal processes must be adapted before valorising syngas.

Pyrogasification of dry wood is a mature technology also flexible to turn various waste into valuable end-products in the future

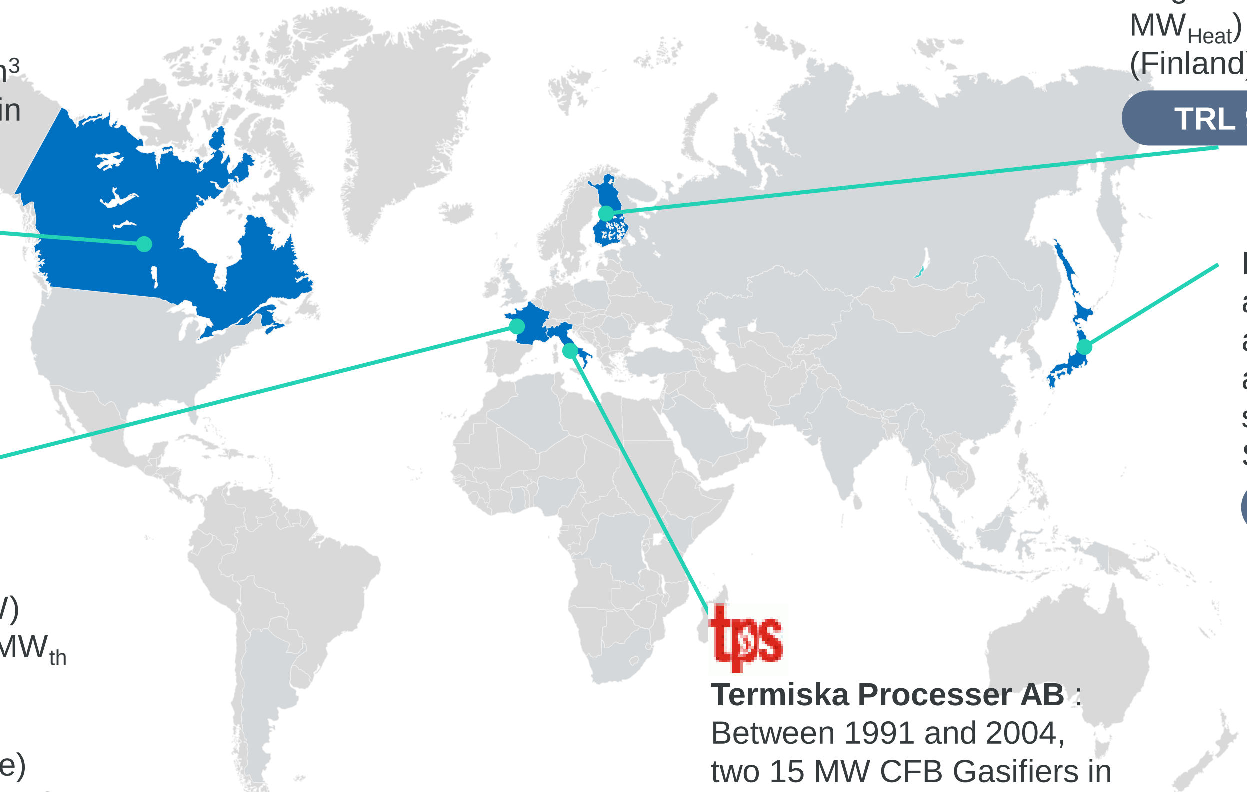
ADVANTAGES

- It reduces waste dumping and its impact on **Health & Environment**
- SRF are **low cost** materials: from -20 to + 90 €/ton depending on the country and the quality
- SRF represents a **large, increasing**, and **available resource** → Lowering the stress on biomass supply
- Mix of **SRF** with **conventional biomass** can be valorized in pyrogasification plants
- Small (2 MW_{th}) to high (<100 MW_{th}) unit capacities can be addressed by pyrogasification

CHALLENGES

- Costly p**retreatments** due to heterogeneity of waste
- Higher content of heteroatoms in SRF than in biomass, resulting in **higher pollutants content** in syngas and/or in fluegas (H_2S, HCl, NH_3)
  - **Corrosion issues**
  - **Syngas cleaning** process to adapt
- **Higher ash content** than in biomass: **15-35%** for SRF from Municipal Solid Waste, **2-20%** for SRF from Ordinary Industrial Waste.
  - Large quantity of **solid residues** to landfill in Hazardous Waste centers if no other valorization way is developed
- **Fouling** of apparatus (such as heat exchangers) due to **high alkaline and particle contents**
- Emerging market → competition for quality and quantity of SRF

While biomass pyrogasification has been widely proven, only few examples of waste pyrogasification are available



Enerkem

Enerkem inaugurated in 2014 an industrial-scale unit producing 38000 m^3 of ethanol from Municipal Solid Waste in Edmonton (Canada)

TRL 9

Valmet

Cogeneration unit of (50 $MW_{electricity}$, 90 MW_{Heat}) from 160 MW of SRF in Lahti (Finland) since 2012

TRL 9

In **Japan**, many technologies are operated to produce Heat and/or electricity from waste and immobilizing minerals in a slag phase (Ebara, Nippon Steel, JFE, Hitachi)

TRL 9

LLT
LEROUX & LOTZ TECHNOLOGIES

Industrial unit (Bonnefoy, France) gasifying RDF and waste wood (25 MW) and producing by ICGC 7 Mw_e and 12 MW_{th}

TRL 8-9

2 MW_{th} pilot plant (Innov'Energy, France) dedicated to biomethane production from SRF

TRL 6-7

tps

Termiska Processer AB : Between 1991 and 2004, two 15 MW CFB Gasifiers in Grève in Chianti (Italy)

TRL 8-9

9

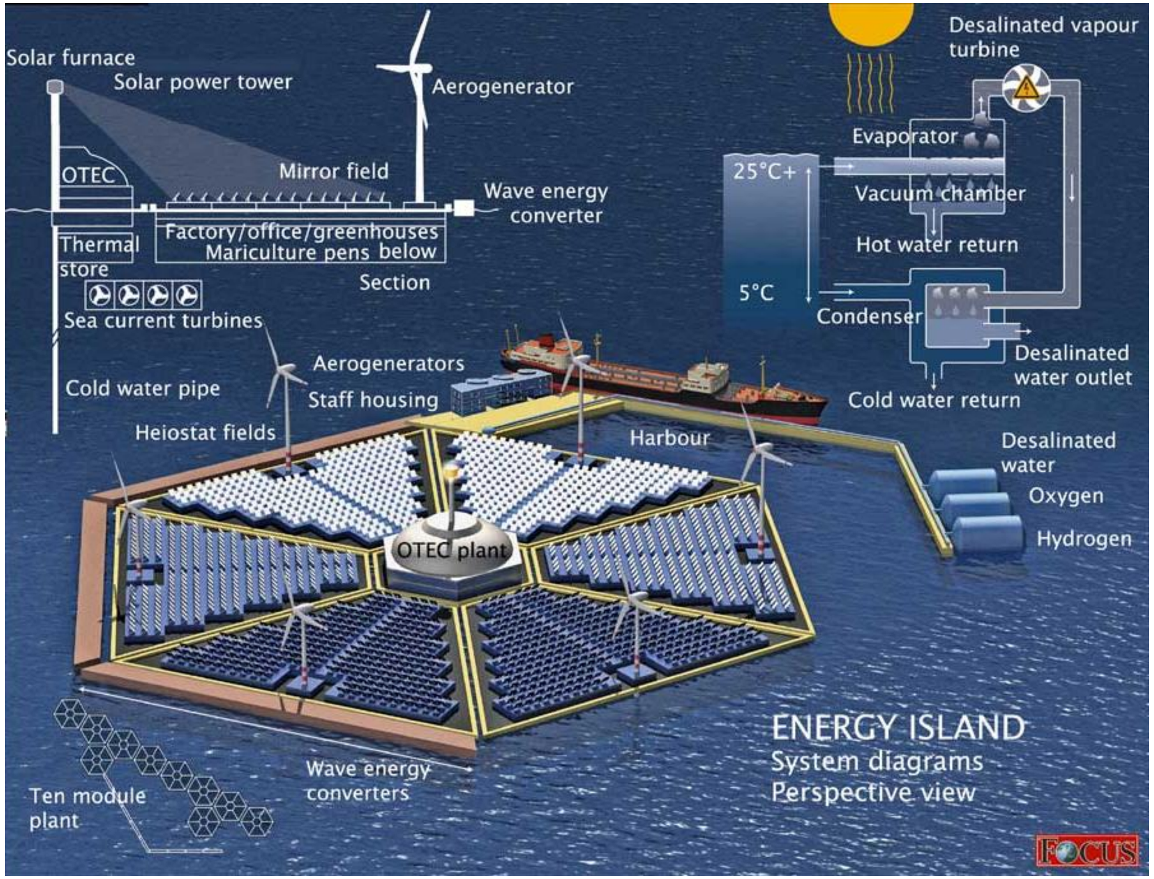
Multi-purpose offshore platforms

Multi-purpose offshore platform is an oppportunity of exploiting synergies for activating (far-)offshore economic activities

What it is? a constellation of various offshore industrial and other activities, like **renewable energy generation** (wind, solar, wave,...), **energy storage, aquaculture, desalination, marine research, security**, etc.

The classification is often based on connectivity among activities, distinguishing:

- **co-located systems** – share the **same location** (not the platform) and possibly common infrastructure
- **combined structures** - share the **same platform facility** providing multiple technical and economical benefits to different combinations of **production and/or service** activities.
- **island structures** – envisage to integrate four main industrial sectors: transport, energy, aquaculture and leisure.



© Energy Island

Sources [53], [54], [55]

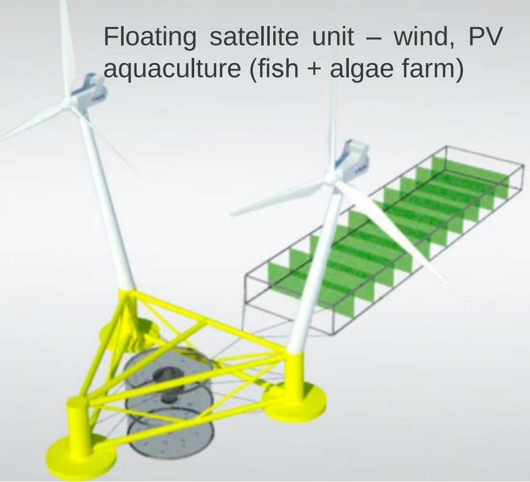
Compared to several single-use platforms, multi-purpose platforms reduce environmental pressure on the oceans but governance, public acceptance and still present technical issues make their implementation challenging

ADVANTAGES

- Shared **infrastructure, resources** and **services** for lowering the costs of offshore industrial activities
- Better reliability, increased energy yields and smooth output power due to combination of different power generation technologies
- Optimization of spatial planning and minimization of the impact on the environment

CHALLENGES

- Implementation of technologies with different maturity level
- Governance
- Environmental impact of large industrial offshore activities
- Safety and high technical risks for system integrity and reliability due to the dynamic mechanical loads, corrosion, biofouling, complex mooring needs, harsh weather conditions, etc.
- Manage the offshore local power grid, energy storage and electricity transport
- Public acceptance



Floating satellite unit – wind, PV aquaculture (fish + algae farm)

Configuration of the industrial complex – energy, storage, transport, aquaculture, leisure

Sources [56], [57], [58], [59]

Their development is mainly supported by different European Commission research programs

SEVENTH FRAMEWORK PROGRAMME

Ocean of Tomorrow within the FP7, with around 31 projects including:

- **MERMAID**: offshore wind farms, marine aquaculture and wave energy.
- **TROPOS**: deep Water Offshore Platform Harnessing and Servicing Mediterranean, Subtropical and Tropical Marine and Maritime Resources.
- **H2OCEAN**: harvesting wind and wave power and using it for aquaculture and hydrogen production

HORIZON 2020
LE PROGRAMME DE RECHERCHE ET D'INNOVATION DE L'UNION EUROPÉENNE

Horizon 2020 - Until now 7 projects have been accepted and 3 are finishing between 2021- 2024.

- MUSICA: providing blue growth solution for islands (renewable energy, desalination, aquaculture,…)

Regional projects such as **Dolphyn** or joint-industry projects like **PosHYdon**, both focusing on the challenges related to the offshore production of hydrogen as an energy vector.

GOAL

Increase **TRL from 5 to 7**, ensuring their demonstration in the real environment.

Sources [56], [60], [61], [62], [63]


© AdobeStock

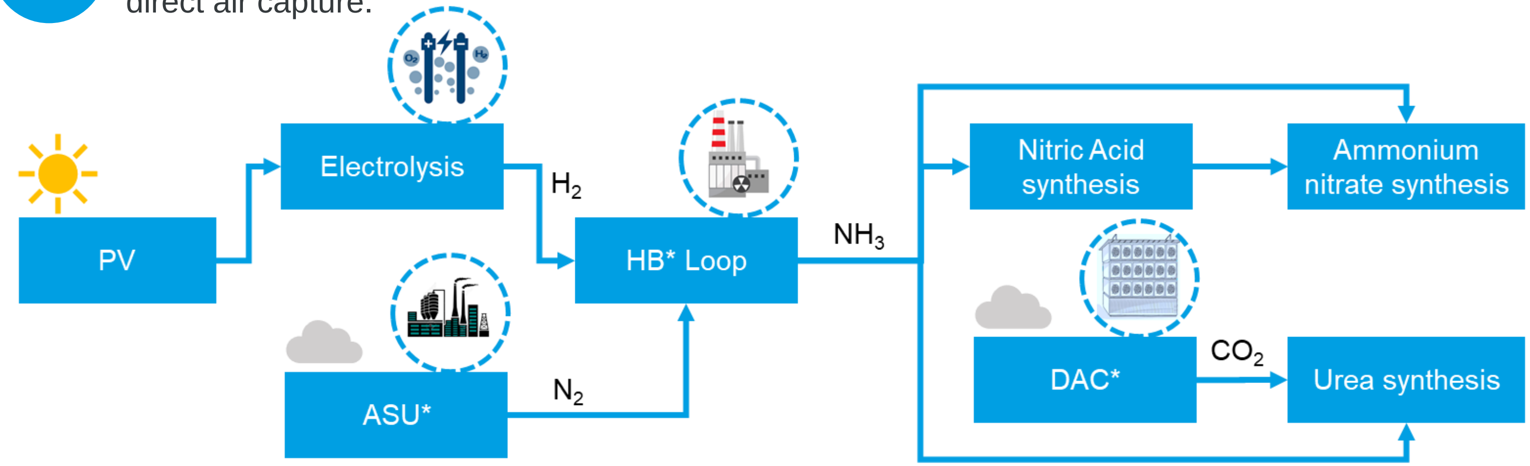
10

Green Ammonia and Smart Fertilizers

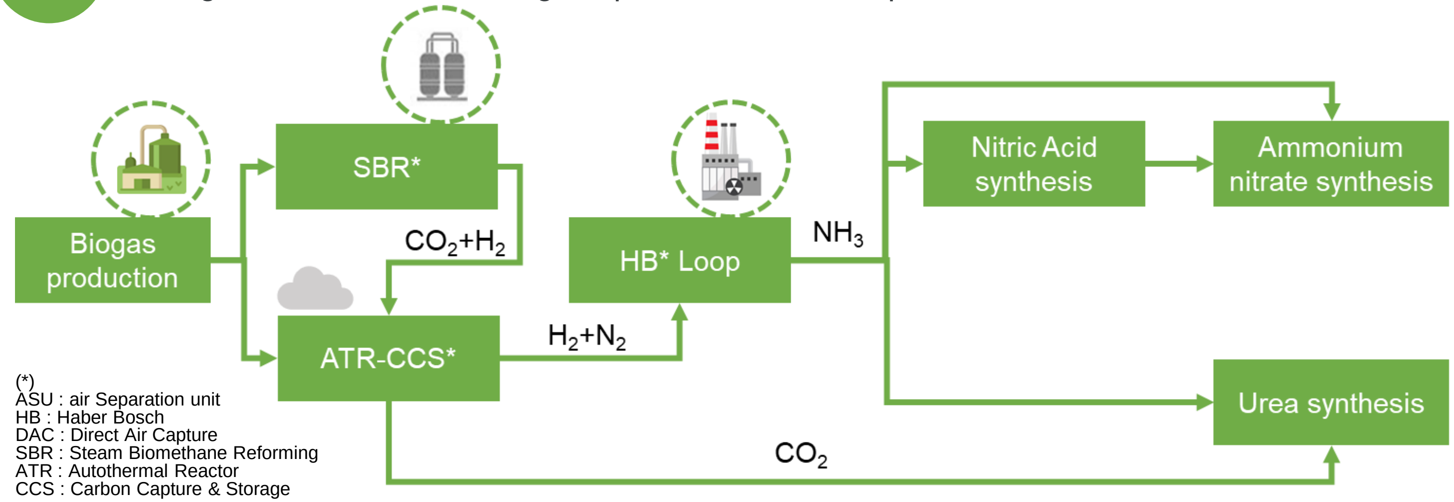
Tomorrow's green fertilizer production could be based on renewable Energie sources

- ✓ **A practical and short-term solution** to produce sustainable nitrogen-based fertilizers is to integrate renewable feedstock in the conventional process.
- ✓ Besides, **more compact and low elevation** plants allow for lower construction and O&M costs.

1 The combination of the production of green ammonia form **renewable electricity** derived from wind, PV or hydro, while using carbon dioxide from conventional power plants, industry or through direct air capture.

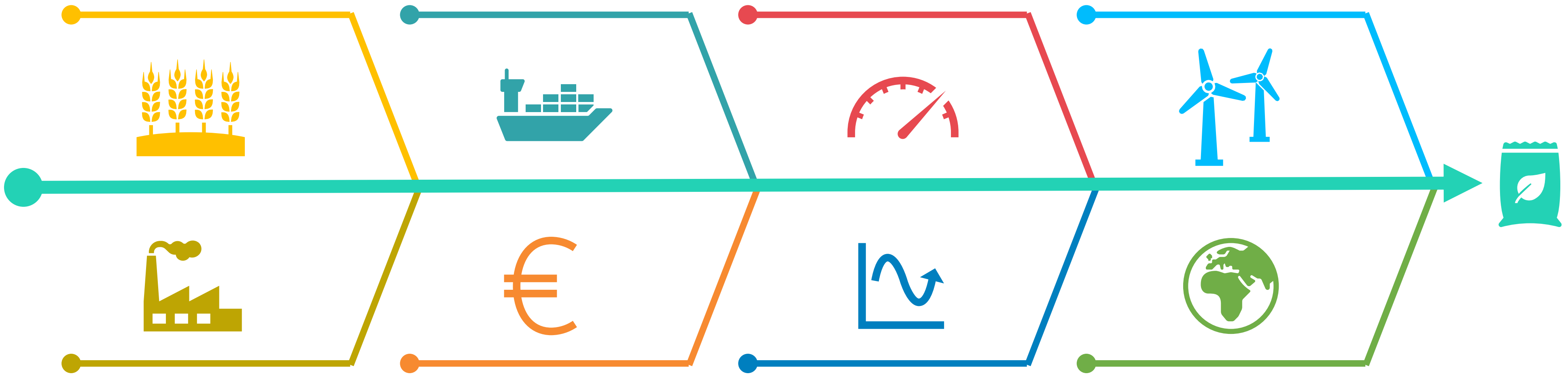


2 The use of **bio-based feedstock** originating form gasification units which produces syngas, or through biomethane reforming coupled with carbon capture units.



(*)
ASU : air Separation unit
HB : Haber Bosch
DAC : Direct Air Capture
SBR : Steam Biomethane Reforming
ATR : Autothermal Reactor
CCS : Carbon Capture & Storage

Drivers of sustainable small-scale fertilizer production



INCREASING DEMAND in the food/agriculture market. How to reliably feed 10 billion people by 2050?

LONG-RANGE TRANSPORT to isolated areas adds a substantial cost burden to farmers up to 40% of the final product cost.

PROCESS CONSTRAINTS
Intermittency effect on synthesis process which operates at very high temperature and pressure.

GEOGRAPHICAL DISPERSION
Renewable energies are produced in a geographically dispatched mode.

CAPEX INTENSIVE INDUSTRY
Fertilizer industry relies on CapEx heavy plants with large production capacities.

OPEX INTENSIVE INDUSTRY
The cost of natural gas accounts for at least 80% of the cost of ammonia and by extent, the cost of nitrogen-based fertilizers.

PRICE FLUCTUATION
Highly volatile prices of natural gas lead to increase in fertilizer imports and decrease of domestic production.

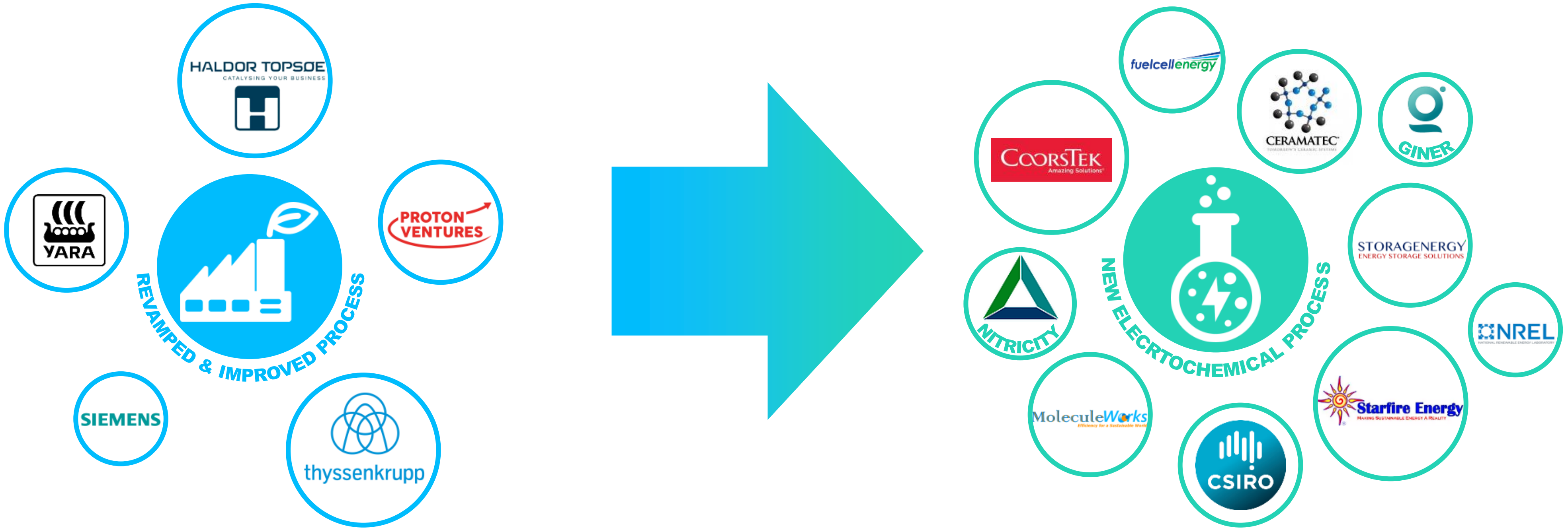
ENVIRONMENTAL COST
Around 1% of global emissions, 100kg of nitrogen-based fertilizer is equivalent to the average annual emission of 72 million cars.

DISTRIBUTED-SCALE PRODUCTION
✓ More efficient
✓ Scalable production
✓ Flexible operation
✓ No carbon emissions
✓ Less transport costs
✓ Self-sufficient supply

Green fertilizer production is an active sector of innovation

Short to Mid-term solutions

Long-term solutions



TARGETS:

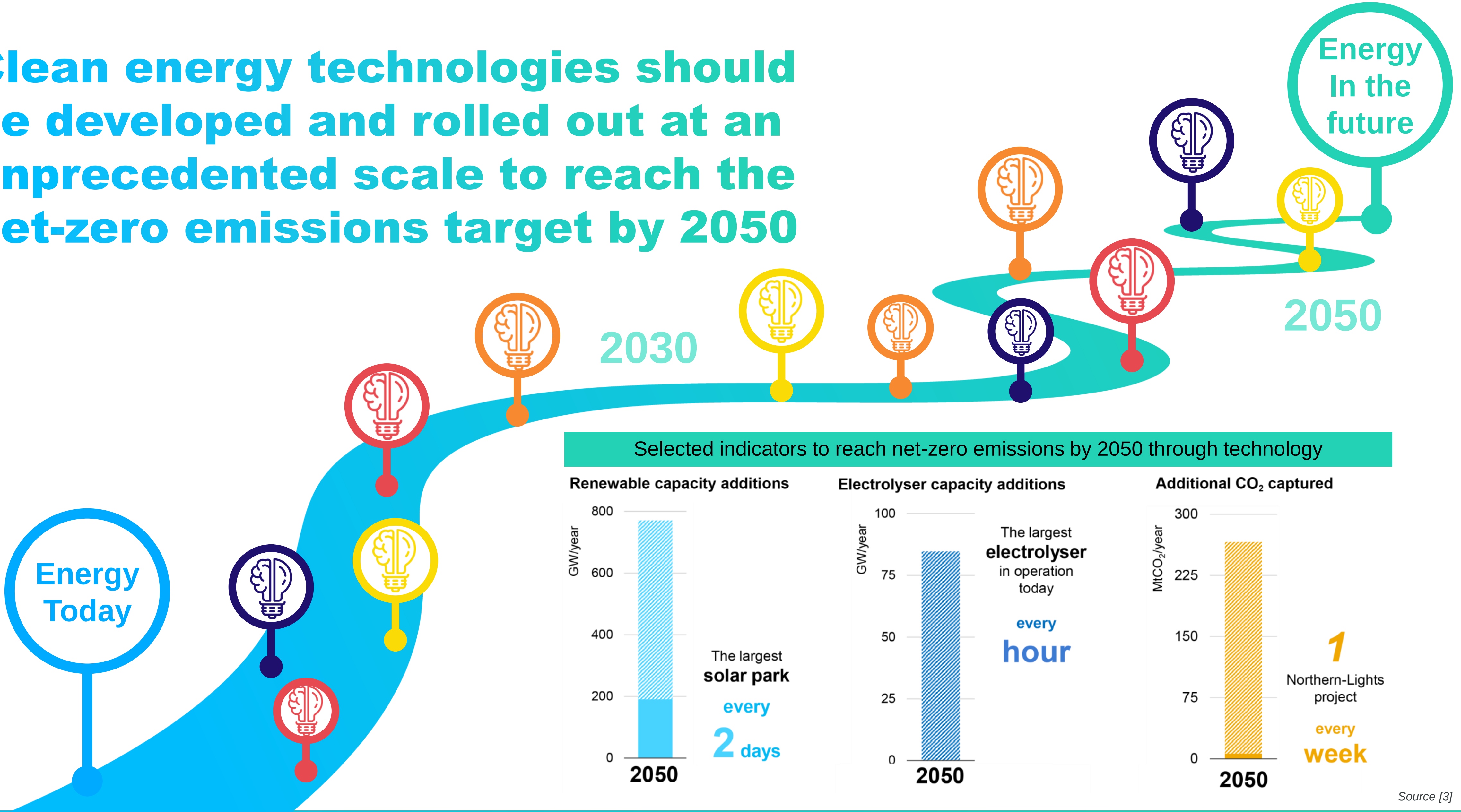
- Higher catalyst activity at low temperature
- Lower synthesis loop pressure
- More efficient ammonia separation
- Higher turndown ratio for more plant flexibility

TARGETS:

- Higher faradaic efficiency
- Higher current density
- Higher catalyst selectivity
- Improved material durability

Conclusions

Clean energy technologies should be developed and rolled out at an unprecedented scale to reach the net-zero emissions target by 2050



Selected indicators to reach net-zero emissions by 2050 through technology

Source [3]

Research

Discussion / Questions

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