Flexible Power Generation ETN Webinar Series

3rd Episode – 1/12/2020

HYFLEXPOWER

Power-H_2-Power Pilot CO_2-Free Green Energy with H_2 GT

Dr. Ertan Yilmaz
Project Coordinator & H2 Portfolio Manager
Siemens Energy

HYFLEXPOWER Power-H_2-Power Project

Overview

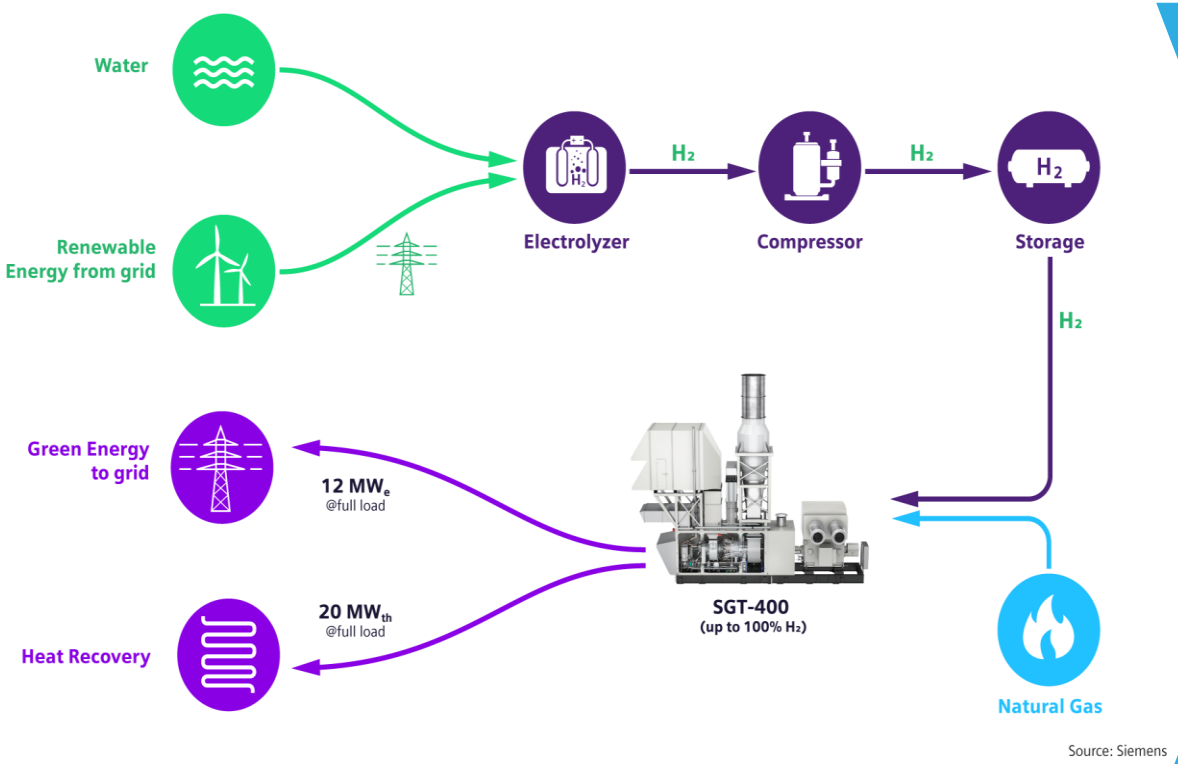
World-first demonstration of a **power-to-H_2-to-power path for CO_2-free** power generation pilot including an advanced **H_2 gas turbine**

- Decarbonizing papermill by modernizing combined heat and power plant in Saillat-sur-Vienne, France.
- Siemens Energy led consortium with project volume of 15.2 M€
- Project Start: May 1st, 2020 - Duration: 4 years
- Partners include: Engie Solutions, Centrax, Arttic, German Aerospace Center, Universities: Duisburg-Essen, Lund-Sweden, University College London, National Technical University of Athens

Customer, academia and OEM formed strong consortium demonstrating CO2-free power generation

EU Framework Horizon 2020: HYFLEXPOWER

Project Concept



Smurfit Kappa plant in Saillat-sur-Vienne, France: Pilot Cogeneration SGT-400 Plant

- **Engie:** Develop advanced plant concept with H_2 storage and supply
- **Siemens**: Development H_2 SGT-400; Electrolyser
- **Centrax**: H_2 gas turbine package upgrade
- **Academia:** DLR, Universities UCL, Duisburg-Essen and Lund to support H2 GT technology development
- **NTUA:** Economic, environmental social assessments
- **Arttic:** Support in PM and communication activities
- **EU:** Significant funding ~70% from EU Framework H2020

Significant EU funding for world-first power-H_2-power pilot with advanced H_2 GT

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Key Milestones - Expected Results & Impact

2021

- Installation of the **H_2 production, storage** & supply facility at site

2022

- Initial demonstration of **advanced plant concept** with NG/ H_2 mixtures

2023

- Pilot up to **100% H_2 for carbon-free energy production** from stored excess renewable energy (CO2 saving 65,000t/yr.)

Expected Results & Impacts

- Industrial scale power- H_2 -power solution pilot
  - Importance of H_2 as long-term energy storage technology on high renewable grid
  - Decoupling renewable energy generation from electricity demand and enabling additional revenue stream
  - Utilization of existing assets to produce green energy & heat
- Validation of SGT-400 dry low emissions (DLE) high-H_2 technology with up to 100% H_2
- Economic, environmental & social assessments for business case evaluation, carbon footprint, & policy recommendations

HYFLEXPOWER has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 884229

Thank you!

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ENGIE SOLUTIONS HYDROGEN STRATEGY

Marie-Perrine DUROT
Innovation Director

ENGIE Solutions

ENGIE: leader in the energy transition

57.8 GW of natural gas capacities

24.8 GW of installed renewable capacities

10,7 B€ in revenues on customers solutions

39 400km natural gas transmission network

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

160,000
employees

€61 Bn
in revenue

€4 Bn to €5 Bn
investment
in customer solutions
between 2019 and 2021

ENGIE Solutions for Industries

22 000
employees

€3.8 bn
in revenue

ADDRESSING YOUR CHALLENGES TO MAKE FACTORIES GREENER, MORE EFFICIENT, SMARTER AND SAFER

CONSUMING **LOW-CARBON RESOURCES AND ENERGIES**

OPTIMIZING ENERGY USE BY COMBINING **PERFORMANCE, ENERGY TRANSITION AND RESPONSIBLE GROWTH**

DEVELOPING **THE INDUSTRY OF THE FUTURE**

ENGIE Solutions H2 strategy

Electrolyze (Green H2)

≠

Methane reforming (Grey H2)

$CH_4 + H_20 \rightarrow CO + 3H_2$

$CO + H_20 \rightarrow CO_2 + H_2$

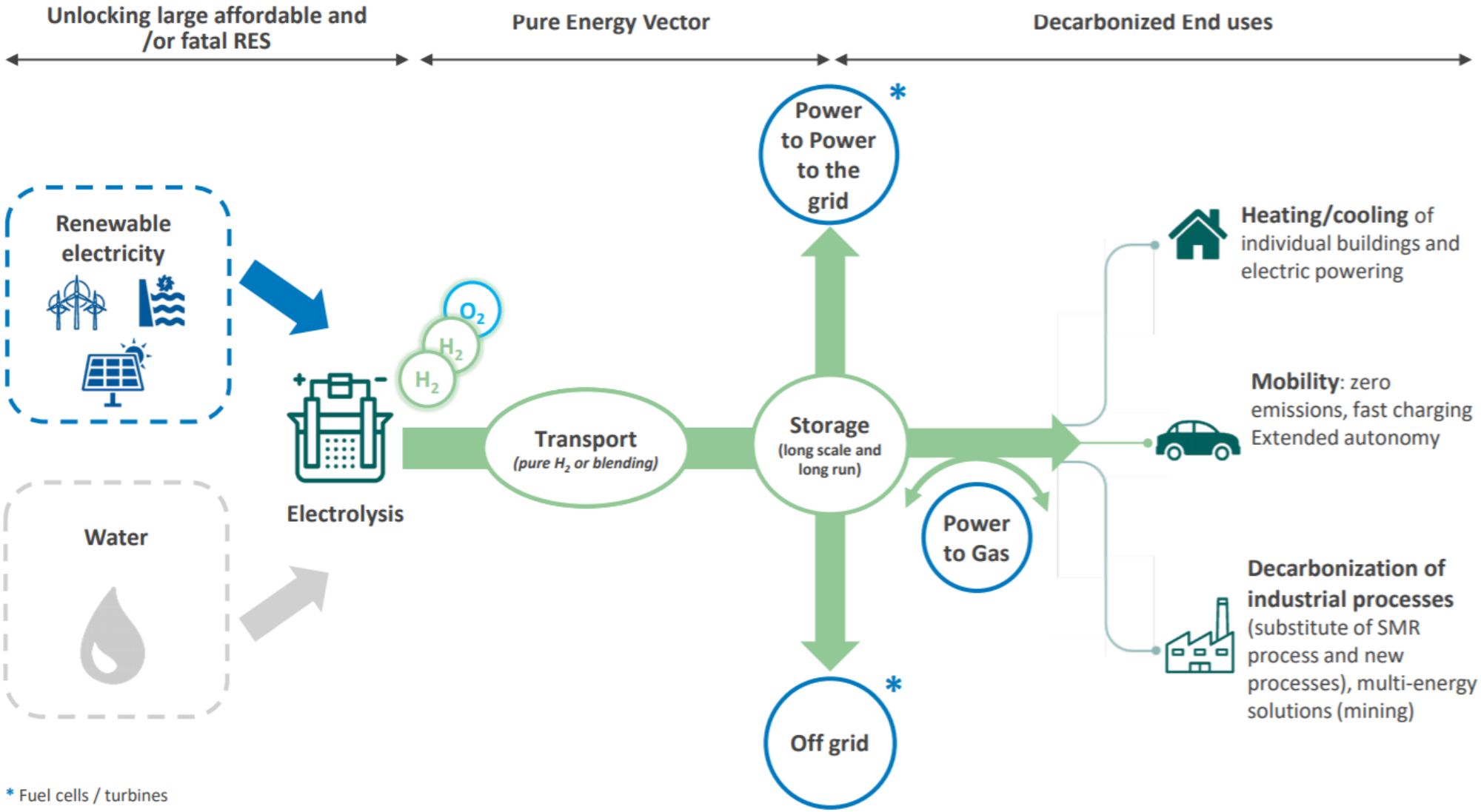
1kg H2 = 10kg eq CO2

Hydrogen Council

Since January 2017, ENGIE has been one of the founding members of the "Hydrogen Council" with 12 other major energy and mobility groups with the main objectives:

- Accelerate investments in the hydrogen and the fuel cell sectors
- Encourage key players to strengthen their support for hydrogen through policies and appropriate support systems

Green H2: a multi-purpose energy vector



Our H2 integrated offers

- **H2 for industrial processes**

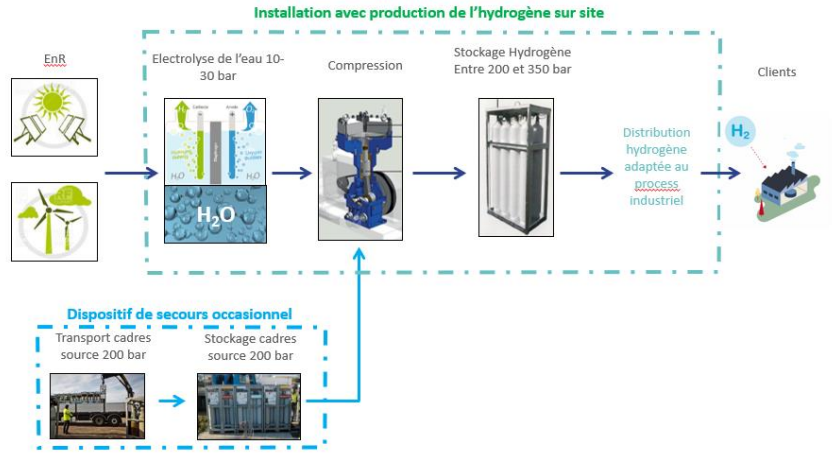
Design, invest in, build, operate a renewable energy-powered renewable H2 plant

- **H2 for mobility**

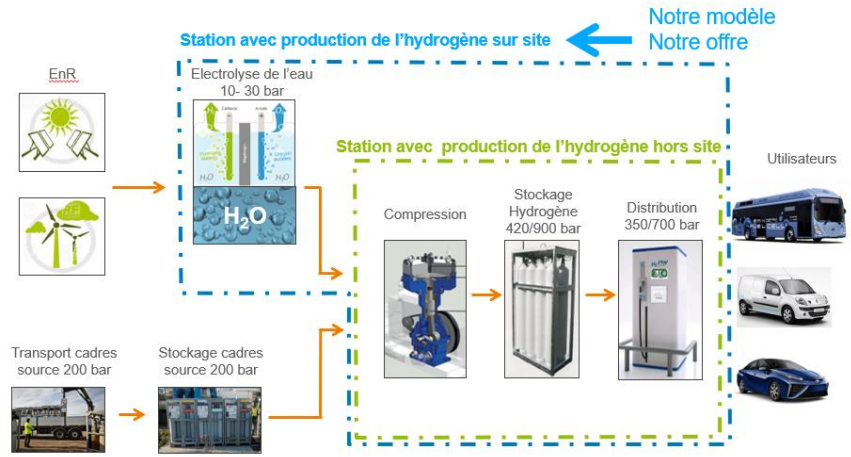
Design, invest in, build, operate hydrogen refueling stations

=> Towards H2 territorial Hubs combining industrial and mobility uses

Installation hydrogène industrielle



Station Hydrogène pour la Mobilité



ENGIE H2 References

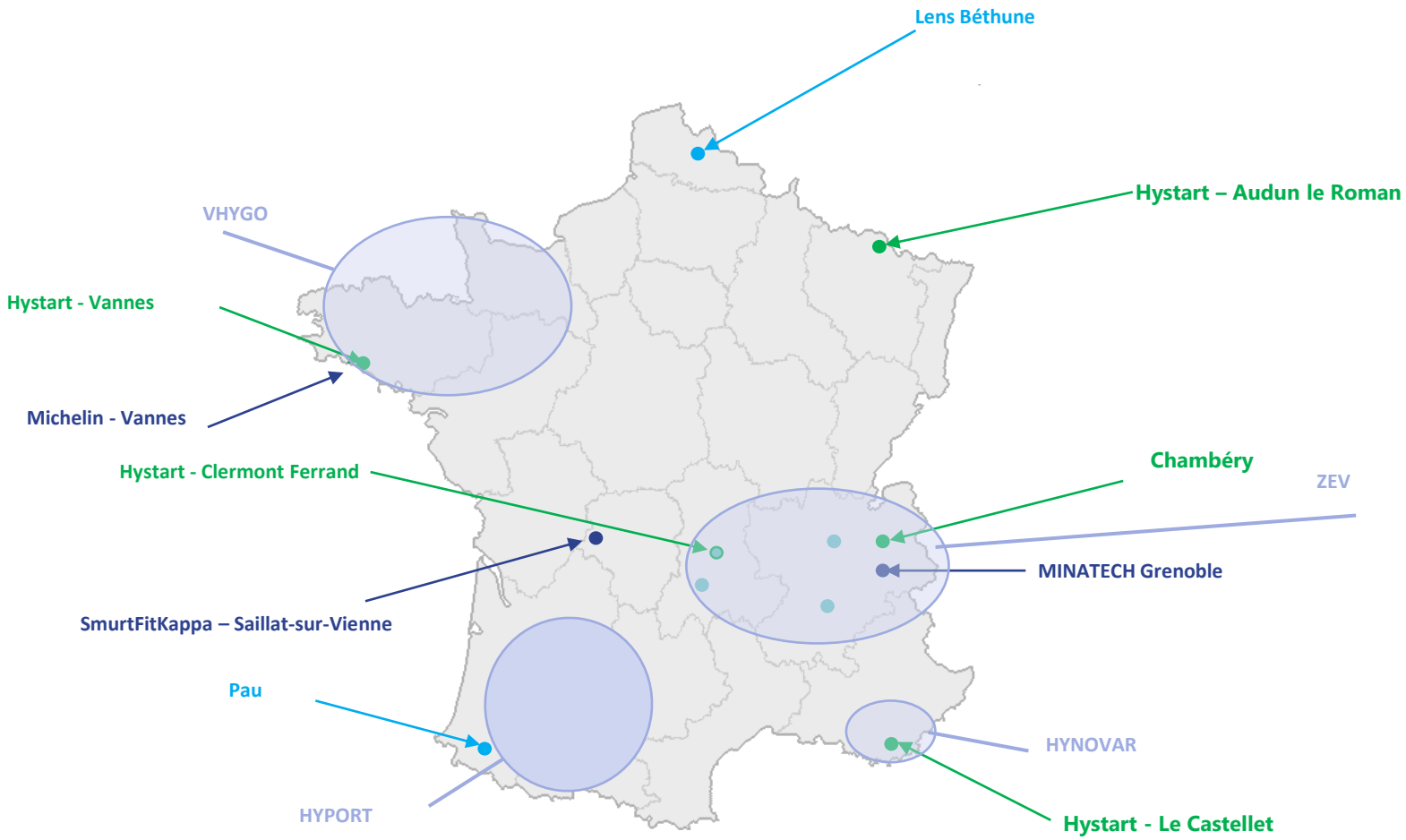
Industrial-Scale Projects

Project	Sector
HyNetherlands	Chemical feedstock, industrial fuel, and transport
HyGreen Provence	Mobility and industry
Zev	Mobility
Yuri	Green ammonia
HyEx	Ammonia nitrate
Multiplhy	Bio refinery
Rhyno	Mining
Liquid H2	Maritime and more
H2@Rail	Trains

Demonstrator Projects

H2 references in France

- Industrial H2
- Hy Start
- H2 Bus
- Territorial hubs



H2 innovations

HyFlexPower

Semi-industrial platform to study the decarbonation of high temperature furnaces

Hydrogen Liquefaction

ENGIE Solutions in HyFlexPower

- **First 100%H2 DLE gas turbine demonstrator** proposed at power plant operated by ENGIE Solutions at SMURFIT KAPPA's site in Saillat sur Vienne (South-West of France)
- **Engie Solutions will install the H2 value chain**, up to the natural gas / hydrogen mixture for injection into the turbine
- **Engineering** carried out in partnership by ERAS, subsidiary of ENGIE Solutions and ENGIE Lab CRIGEN
- **Commissioning** in Q1 2022
- **First Tests (30% H2)** in April 2022
- **Second tests (100% H2)** in April 2023

Thank You

Smurfit Kappa: sustainable use of energy

Steven Stoffer
Group VP Sustainable Development

ETN webinar series, 1 December 2020

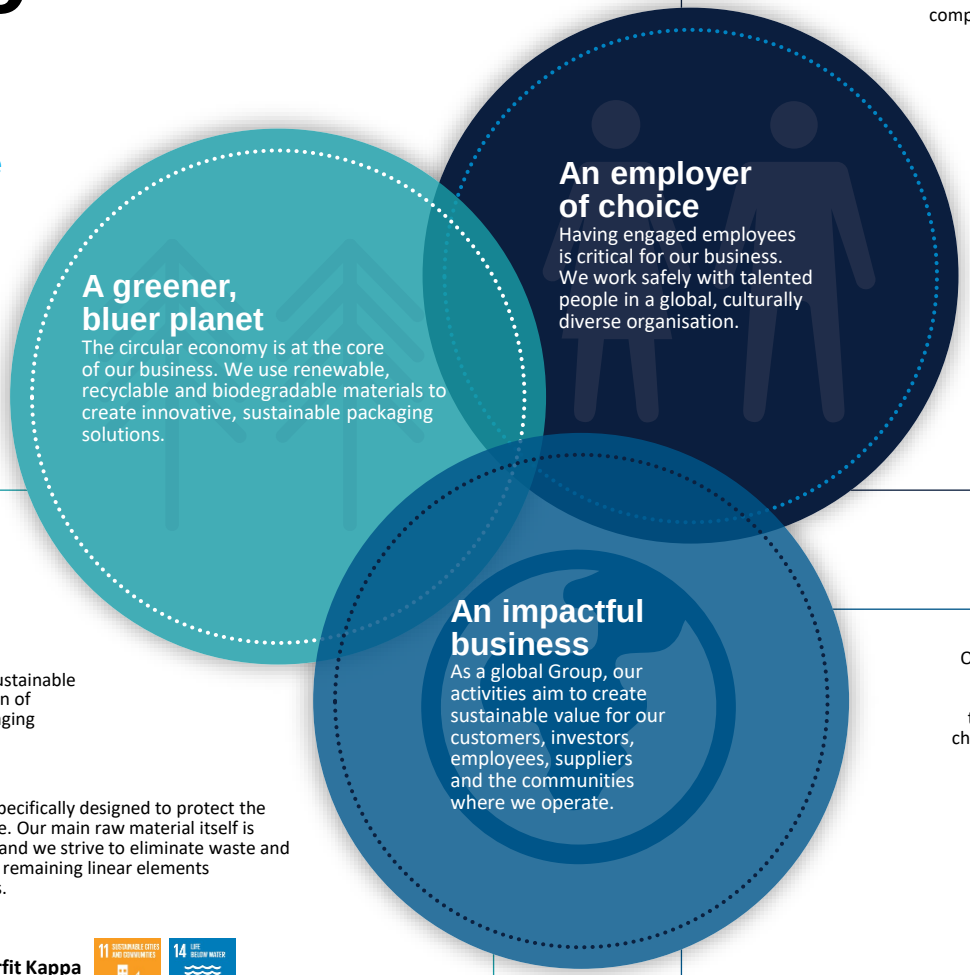
Smurfit Kappa

The world needs packaging and paper-based packaging is the most sustainable of all materials

Our Approach to Sustainable Business

As a leading company in sustainability, we base our ambition of sustainable growth on three pillars: Planet, People and Impactful Business.

This means: continually striving to minimise our environmental impact and practising responsible governance; treating our stakeholders with respect; and creating an impactful business through our products and their production.



A greener, bluer planet

Climate change
We are stepping up our ambition with low-carbon and energy-efficient production systems, and increasing our use of renewable fuels. We also offer our customers optimised packaging solutions that help them to reduce CO2 emissions in their value chain.

Forest
We balance the use of virgin and recycled fibres to maintain a positive and sustainable balance of renewable raw materials. We have committed to a complete Chain of Custody certified sourcing and manufacturing chain, from fibres to the packaging solutions.

Water
We are committed to responsible water stewardship. We focus our efforts on continually improving the quality of water we discharge and understanding the risks associated with water availability in the areas where we operate.

Waste
Our products are specifically designed to protect the goods they package. Our main raw material itself is circular by nature, and we strive to eliminate waste and keep removing the remaining linear elements from our processes.

Smurfit Kappa Impacts

Smurfit Kappa Supports

An employer of choice

People values
We endorse the principles of respect for human rights, freedom of association, fair compensation and diversity, regardless of age, gender, sexual orientation, ethnic origin, disability or nationality.

People strategy
Employees who find meaning at work are happier, more productive and more engaged. This is why we are constantly evolving and improving our people strategy. We believe our employees are the beating heart of our business and they need to feel how much they are valued by the organisation.

Health and Well-being
The safety of our people is a core value to the organisation. Our Safety for Life initiative was launched to increase the level of safety awareness among our entire workforce, to reach our zero-accident goal.

Communities
We are proud to participate where we can in the communities, where we are privileged to operate. In 2019, Smurfit Kappa made approximately €3.5 million in social investments, across many projects in the areas in which it is located.

Smurfit Kappa Contributes

Smurfit Kappa Impacts

Smurfit Kappa Supports

An impactful business

Innovation
Offering tailored fit-for-purpose packaging is the core of our eco-design. We link data, engineering and creative thinking throughout the packaged products' value chain, from packaging solutions back to our supply chain and processes.

Governance and Human Rights
Smurfit Kappa supports the UN Global compact and I s committed to promoting the United Nations Global Compact (UNGC) 10 principles of human rights, labour, environment and anti-corruption. As part of this, Smurfit Kappa reports transparently on its activities and performance in these areas.

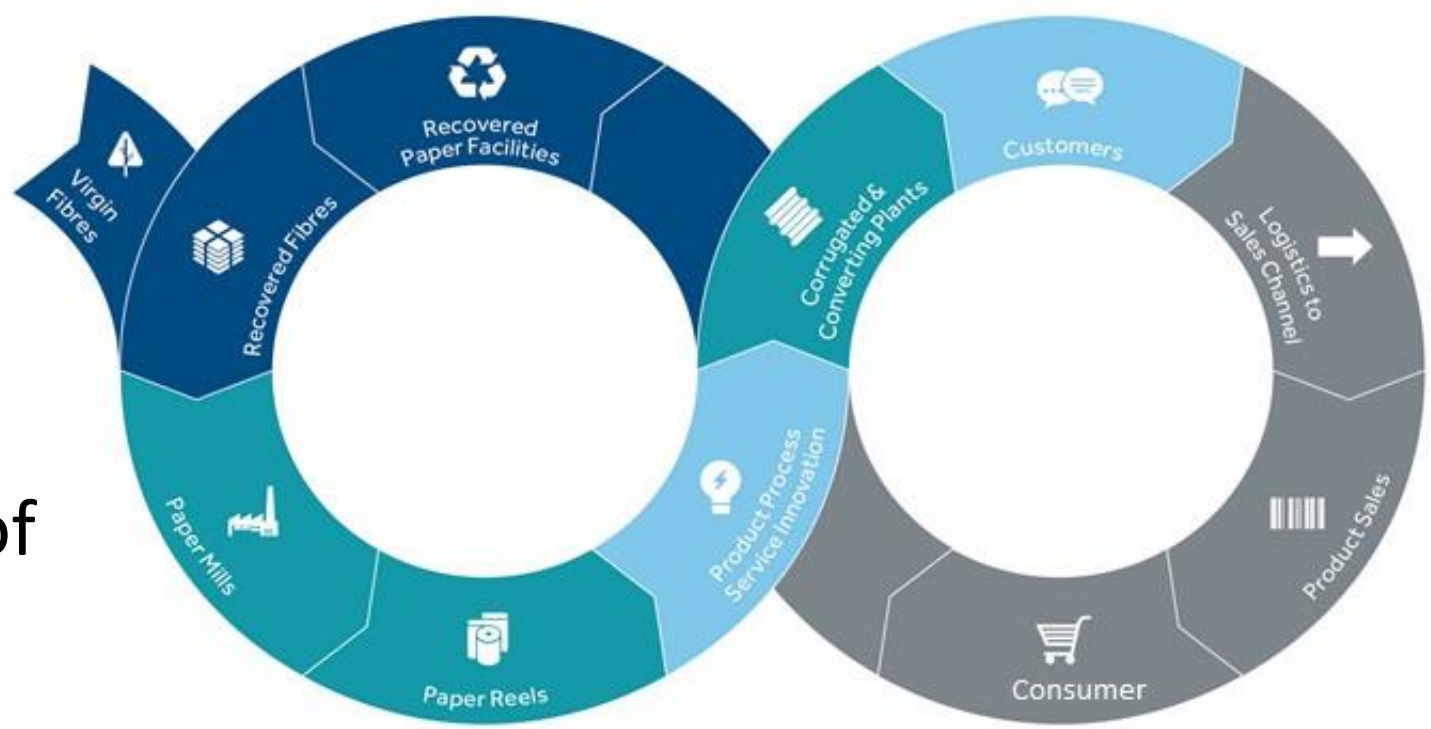
Sustainable sourcing
Sharing our sustainability knowledge, experience and expertise with our suppliers increases the sustainability of our whole value chain. To be able to sustainably grow our business, our materials, goods and services, must have the right quality and cost, but also be securely and responsibly sourced.

Kappa Contributes

Smurfit Kappa Supports

Our circular business model

Understanding our business environment enables us to increasingly integrate in the circular economy and drive sustainability in all areas of our value chain.



Setting ambitious goals helps us keep focus on priority issues

CLIMATE CHANGE

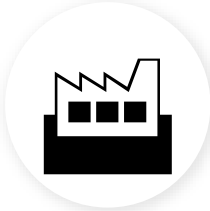
55% reduction in fossil fuel emissions intensity by 2030 compared to 2005 and at least net zero by 2050

FOREST

>90% packaging solutions sold as Chain of Custody certified to customers

WATER

60% reduction in Chemical Oxygen Demand intensity by 2025 compared to 2005



WASTE

30% less waste to landfill by 2025 compared to 2013

PEOPLE

5% reduction in Total Recordable Injury Rate annually

Three pathways to lower fossil CO_2 emissions

And a customer perspective

1. Efficient energy generation
2. Efficient energy use
3. Switch to renewable energy

Using our suite of tools, including Paper to Box and Pack Expert, we work with customers to lower the carbon footprint of their packaging and products

Where does Hydrogen fit in for Smurfit Kappa

>80% fossil emissions occurs in our paper mills

- Kraftliner mills: close to zero fossil CO_2 (biomass)
- Recycled paper mills: depend on fossil fuels
- Efficient energy generation and efficient usage, but not enough to reach net zero
- Non-fossil alternatives all have issues
  - Biomass: availability
  - Geothermal: not everywhere possible
  - Green electricity: grid capacity, connectivity and availability
- How can Hydrogen help?

Green electricity is preferred over Hydrogen

SK will/should only use green Hydrogen when green electricity options are exhausted

- For the paper industry, Hydrogen applications seem limited
  - Hydrogen is not the most efficient application for low temperatures heat (150-200 ℃) as used in our industry
  - Using green electricity directly is preferred as it eliminates conversion losses from electricity to hydrogen)

Hydrogen production on-site or off-site compared

Via CHP on-site or via power plant (grid)

- Hydrogen from grid or green electricity from grid?
  - Efficiency of electrolysis is 70%, so only excess green electricity should be used to produce Hydrogen
- Energy production by Hydrogen at power plant has efficiency of +/-45% (70% * 65%)
- Energy production by Hydrogen on-site with a CHP has efficiency of +/-60% (70% * 85%

One hour of efficient on-site Hydrogen conversion at a medium sized paper mill into electricity saves annual e-use of 8 households compared to conversion at a power plant

Many questions still unanswered for the use of Hydrogen

- Conversion cost turbines and boilers?
- Extra maintenance needed?
- Will higher NOx emissions impact electricity production
- Other....
- Many questions for management still unanswered

And

- Are there addition barriers for on site Hydrogen production such as safety?

Delivering
Together.

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SIEMENS energy

Hydrogen Integration into existing Gas Turbine plants

Ian Amos, Product Family Owner
Siemens Industrial Turbomachinery Ltd
Dec 2020

Siemens Hydrogen Gas Turbines for our sustainable future
The mission is to burn 100% hydrogen

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Gas turbine model	Power Output[1]	H_2 capabilities in vol. %
SGT5-9000HL	593 MW	30
SGT5-8000H	450 MW	30
SGT5-4000F	329 MW	30
SGT5-2000E	187 MW	30
SGT6-9000HL	405 MW	30
SGT6-8000H	310 MW	30
SGT6-5000F	215 to 260 MW	30
SGT6-2000E	117 MW	30
SGT-A65	60 to 71/58 to 62 MW	15 – 100
SGT-800	48 to 62 MW	50
SGT-A45	41 to 44 MW	100
SGT-750	40/34 to 41 MW	40
SGT-700	33/34 MW	55
SGT-A35	27 to 37/28 to 38 MW	15 – 100
SGT-600	24/25 MW	60
SGT-400	10 to 14/11 to 15 MW	10 – 65
SGT-300	8/8 to 9 MW	30
SGT-100	5/6 MW	30 – 65
SGT-A05	4 to 6 MW	2 – 15

DLE burner WLE burner Diffusion burner with unabated NOx emissions

Heavy-duty gas turbines Industrial gas turbines Aeroderivative gas turbines

1 ISO, Base Load, Natural Gas; Version 3.4, July 2020

DLE : Dry Low Emissions
WLE : Wet Low Emissions

Values shown are indicative for new unit applications and depend on local conditions and requirements. Some operating restrictions/special hardware and package modifications may apply.

Technology Gap exists in providing 100% H2 fuel capability with a Dry Low Emissions combustion system

Zero Emissions via Hydrogen Combustion
Some physics to be handled in the system

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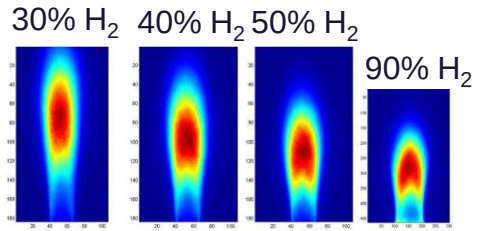
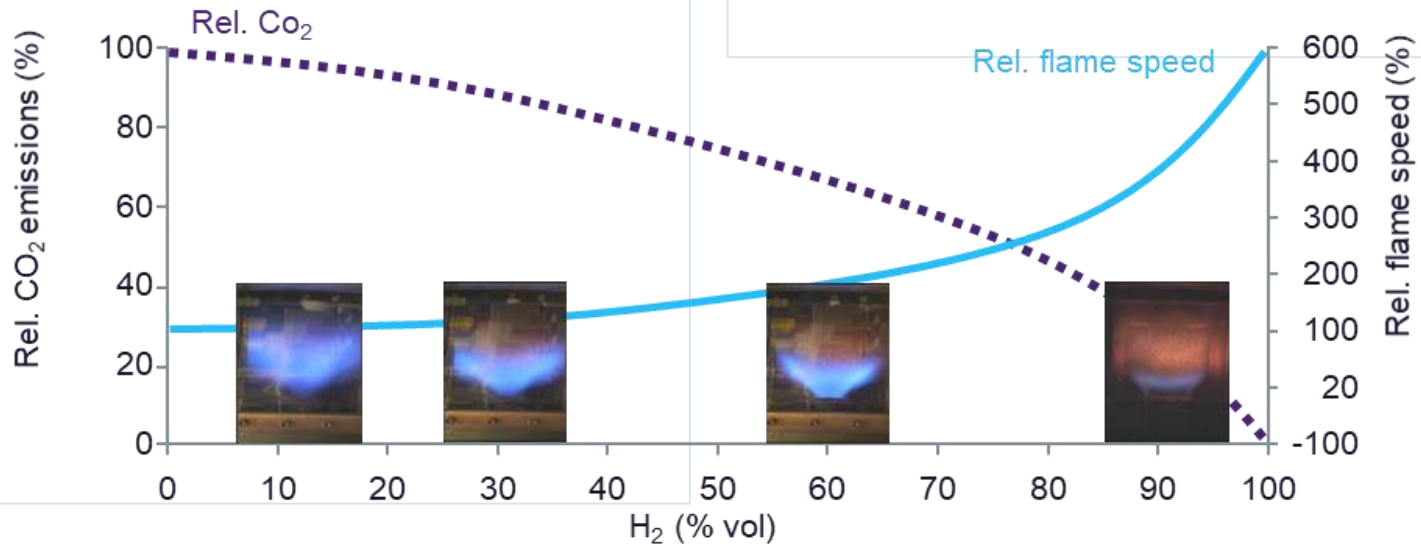
Differences of hydrogen and natural gas as a fuel in gas turbines

Physics of hydrogen

- 3x energy content per kg than Natural Gas … but 1/8th the density
- Flame location closer to the burner …increases risk of flashback

Hydrogen flame





Values shown are relative to natural gas (indicative only)

Challenges

- **Higher diffusivity** requires re-certification of sealing. Upgrade to stainless steel materials …
- **Lower volumetric energy content** requires larger flows to be handled by fuel system
- **Higher reactivity** pushes flame towards burner and increases risk of explosion or flashback
- **Higher flame temperature** can lead to local hotspots if imperfectly mixed and thus increased NOx emissions

Siemens Solution for different H_2 levels
Expected changes

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Differences in Design between “standard” and H_2-Gasturbines:

System/Procedures	H_2 Volume Impact on Package		
	0% – 10% – 30%[1]	10% – 30%[1] – 50% – 70%[1]	50% – 70%[1] – 100%
Burners and combustion chamber	No change	Modified burner may be required	New burner design
Combustion monitoring system	n.a.	n.a.	n.a.
Fuel supply system	No change	Ensure all components Stainless Steel	Pipe diameter increase
Control/protection systems	No change	Additional gas detection	All hazardous area electrical equipment to Gas Group IIC
O&M Procedures	No change	Leak check of gas fuel system after maintenance inspections	Start-up/shutdown on conventional fuel
	No modifications needed	**Smaller modifications may be required**	**Modifications needed**

1 Percentage varies from GT model to model and emission limit requirements

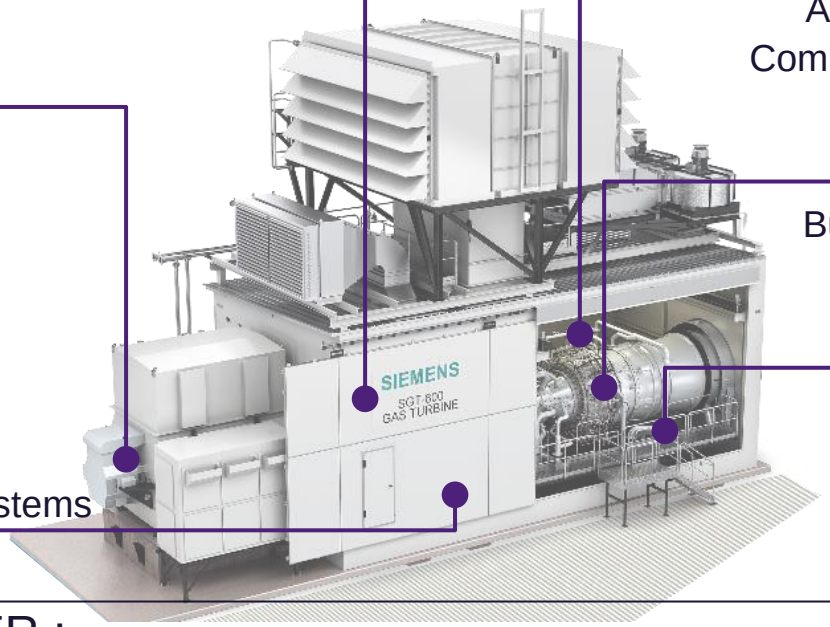
High Hydrogen Modifications for Industrial Gas Turbines

Main systems requiring modification when upgrading to higher H_2 content

Fire Protection System

Gas Group IIC electrical equipment

H_2 compatibility of plant auxiliary and peripheral systems



Additional Flame Control and Combustion Monitoring Systems

Burner Adjustment/Exchange

Fuel Gas System material and set-up

Consequences and solution

- Project specific evaluation and decision on required modifications
- Power output control to ensure compliant NOx emission levels
- Conventional/non-H_2 fuels may be required for start-up and shutdown
- Re-certification with respective authorities might be required

In HYFLEXPOWER ;

Centrax will modify the package of the installed unit

Siemens Energy will develop the new combustor technology and controls for retrofit.

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Environmental Assessment of Power-to-H_2-to-Power Technologies

Prof. Sotirios Karellas

Laboratory of Steam Boilers and Thermal Plants
National Technical University of Athens, Greece

Laboratory of Steam Boilers and Thermal Plants

- 30 years Experience in Thermochemical processes and power plants
- Collaborations with international universities and major industrial partners
- More than 40 Research Projects with total funding> 5 Million Euro (Last 10y)
- Bilateral collaborations with Greek industry for technology development and evaluation, technical studies, measurements, licensing/ financial studies

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Taks in HYFLEXPOWER
a) Modelling and cycle optimization
b) Technoeconomic assessment of the developed solutions
c) Environmental assessment
d) Socioeconomic evaluation and policy recommendations

Cooperation with large industries (indicative list)

SIEMENS, ENGIE, CENTRAX GAS TURBINES, Air Liquide, ARKEMA INNOVATIVE CHEMISTRY, ArcelorMittal, RWE, ELVALHALCOR, ΔΕΗ, MOTOR OIL, ΟΜΙΛΟΣ ΕΛΛΑΚΤΩΡ, MYTILINEOS, ΗΡΩΝ, ΓΕΚ ΤΕΡΝΑ ΟΜΙΛΟΣ ΕΤΑΙΡΕΙΩΝ

Projects (indicative list)

- HYFLEXPOWER
- BIOTRIC
- EXP-HEAT
- CO2freeSNG2.0
- CO2freeSNG
- CO2TRACCS
- CAPSOL
- CACHET
- CACHET2
- CESAR
- CO2 GLASS

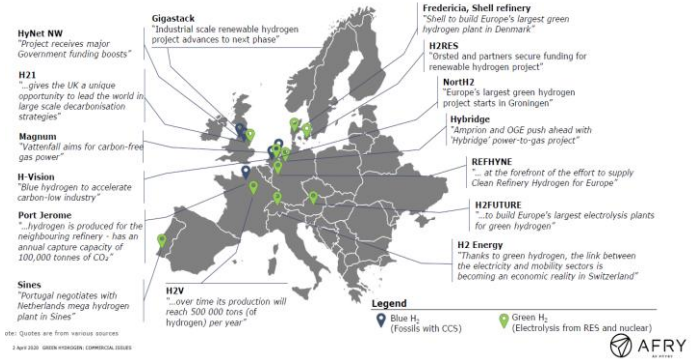
Infrastructure (indicative list)

- Certification Unit for Heat Systems (CUHS)
- Measurement Environmental Unit (MEU)- Certified EN ISO/IEC 17025 & CEN TS 15675
- Two fluidized beds for combustion & gasification
- 1 Fuel Cell 100% H2 ready
- 2 Thermal Power plants
- 2 ORC Units
- Boiler testing unit

Why Hydrogen? Why H_2-to-Power?

Hydrogen Today

- EU: "more than 1 GW of electrolyser projects are in the pipeline, the total European production capacity for electrolysers is currently below 1 GW per year EC, COM(2020) 301 final
- Germany Hydrogen strategy (status 6.2020): 5GWe electrolyser is targeted for 2030
- 2 x 40 GW Initiative by Hydrogen Europe



European Hydrogen Strategy
(EC, COM(2020)301 final)

1st Phase 2020-2024
6 GWe electrolysers

2nd Phase 2025-2030
>40 GWe Electrolysers

3rd Phase 2030-2050
1/3 of electricity generation is used for H_2 production

2030

2050

Milestone:
-Competitive Green H2
-Open EU H2 trade market

Milestone:
-H2 used in all sectors
-Full maturity and deployment of market and technologies

1. Hydrogen when combusted leads to zero carbon emissions in all systems (water as end product)
2. Thermal power generation is required for security of supply (especially with Coal exit). Hydrogen use in thermal power generation allows the decarbonisation of both power and heat sector
3. Green Hydrogen allows the efficient use of otherwise "wasted"/curtailed RES electricity as well as flexibility during charging and discharging time

Power-to-H_2-to-power technologies

Stages:

- Hydrogen **production**: mainly electrolysis (AEL, PEM, SOEC), using **renewable energy**!
- Hydrogen **storage**: compression (gas or liquid form – depending on cost!), in pressure tanks or underground (e.g. depleted oil wells, salt caverns etc.)
- Hydrogen **re-electrification**: fuel cells, hydrogen – ready combustors, gas turbines / IC engines (availability of scalable technologies)

Source: https://www.petroleum-economist.com/ (2020)

Scales:

- Large scale Power to Hydrogen to Power:
  - Use in CCGTs and GTs , substitution of NG
  - Use in Boilers and Heat Recovery Boilers
- Medium scale Power to Hydrogen to Power:
  - Use in GTs, fuel cell complexes and motors
- Small scale Power to Hydrogen to Power:
  - Use in fuell cells, decarbonisation of residential sector

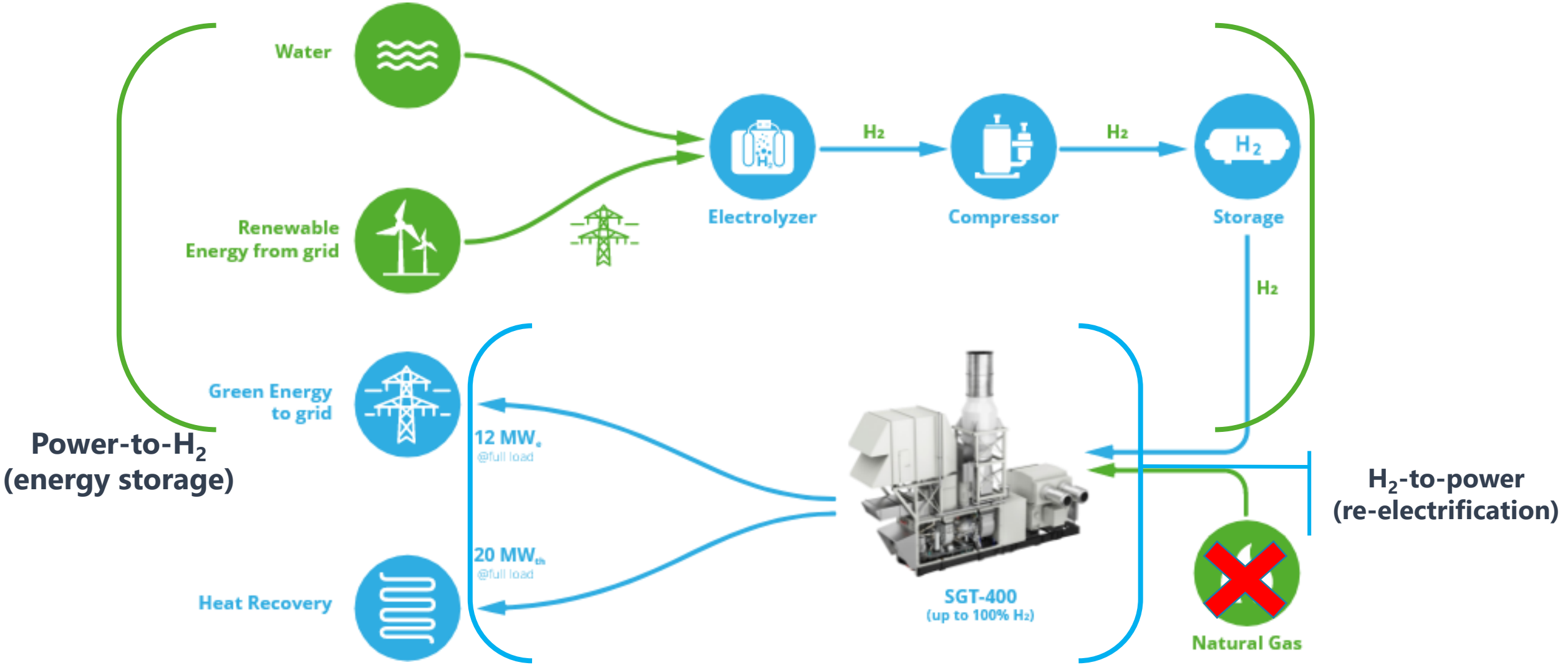
Hydrogen Production: Environmental aspects

Hydrogen when combusted leads to zero carbon emissions in all systems (water as end product)

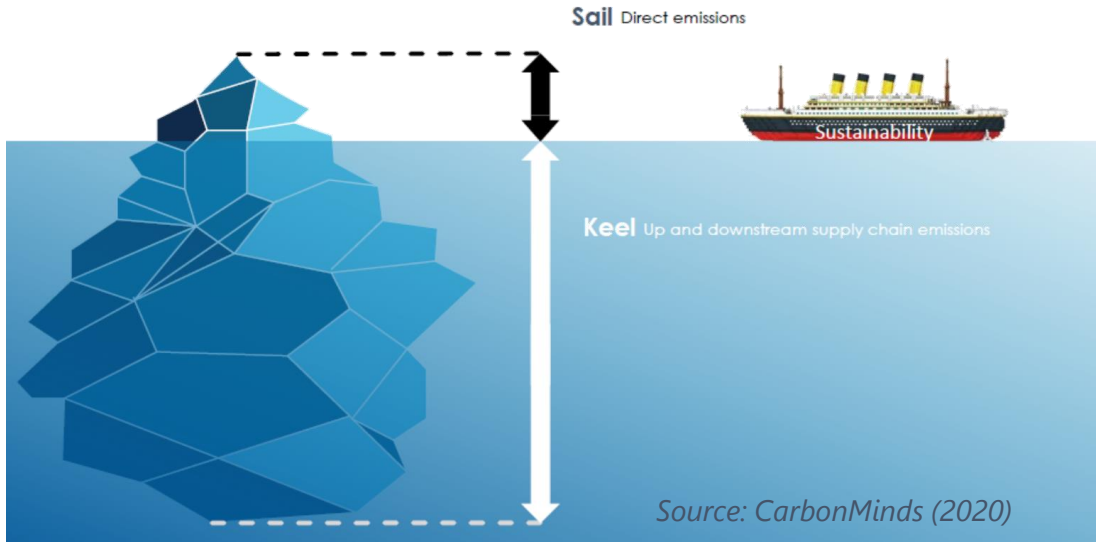
…..However when produced the carbon emission intensity changes according to the technology and feedstock used

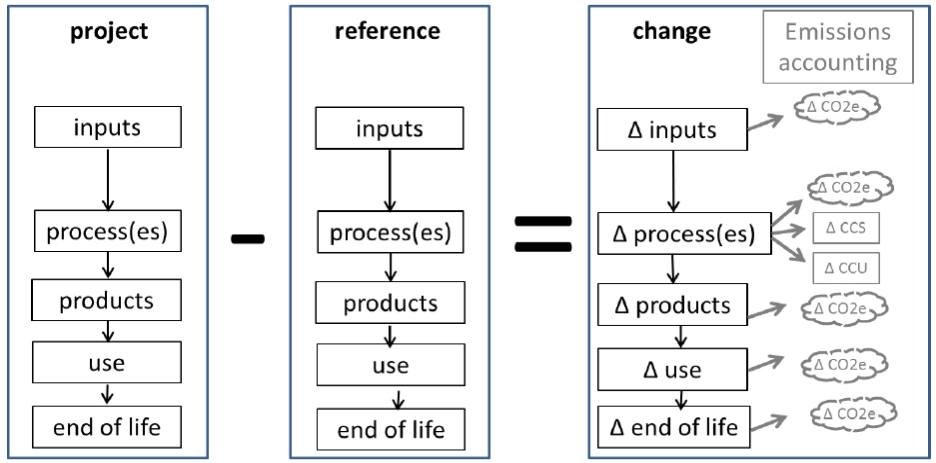
Type	Primary energy/feedstock	Technology	TRL	Direct CO_2 emissions	Environmental characterisation
Grey Hydrogen	Mainly NG, fossil	Reforming	9	~10 t CO_2/t H_2	Fossil derived fuel
Blue Hydrogen	Mainly NG, fossil	Reforming +CCS	9	~1 t CO_2/t H_2	Low carbon Hydrogen
Turquoise hydrogen	Mainly NG, fossil	Thermal cracking- Kværner process	5	~ solid and gaseous carbon capture and use?	Low carbon Hydrogen
Green Hydrogen	Water & Power	Electrolysis	9	ZERO	Carbon free

Large scale Decarbonisation: Power-to-H_2-to-power components



Why we use LCA thinking to assess the environmental performance of technologies





Source: EC, Draft Methodology for Calculation of GHG emission avoidance, First Call for proposals under the Innovation Fund, 2020

Influencing factors of Environmental performance of PtH_2tP configurations

- Selected study parameters (system boundaries, modelling tools, assumptions etc.)
- **Energy source(s) used!!!**
- Hydrogen compression / transport requirements, storage specifications & maximum achievable storage duration
- Energy efficiency, heat integration potential
- Oxygen utilisation options (co-product from water electrolysis)
- Recyclability & disassembly / waste management options of construction materials
- Operational lifetime of components
- Potential for synergies with nearby facilities – formation of industrial symbiosis hubs

Example: 30% vol H_2 use in CCGT enables a 10% reduction of direct emissions in g CO_2/kWh_e basis.
But what about the carbon footprint of the electricity produced?

Thank you!

Prof. Dr.-Ing. Sotirios Karellas
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