Ammonia As Hydrogen Carrier to Unlock the Full Potential of Green Renewables

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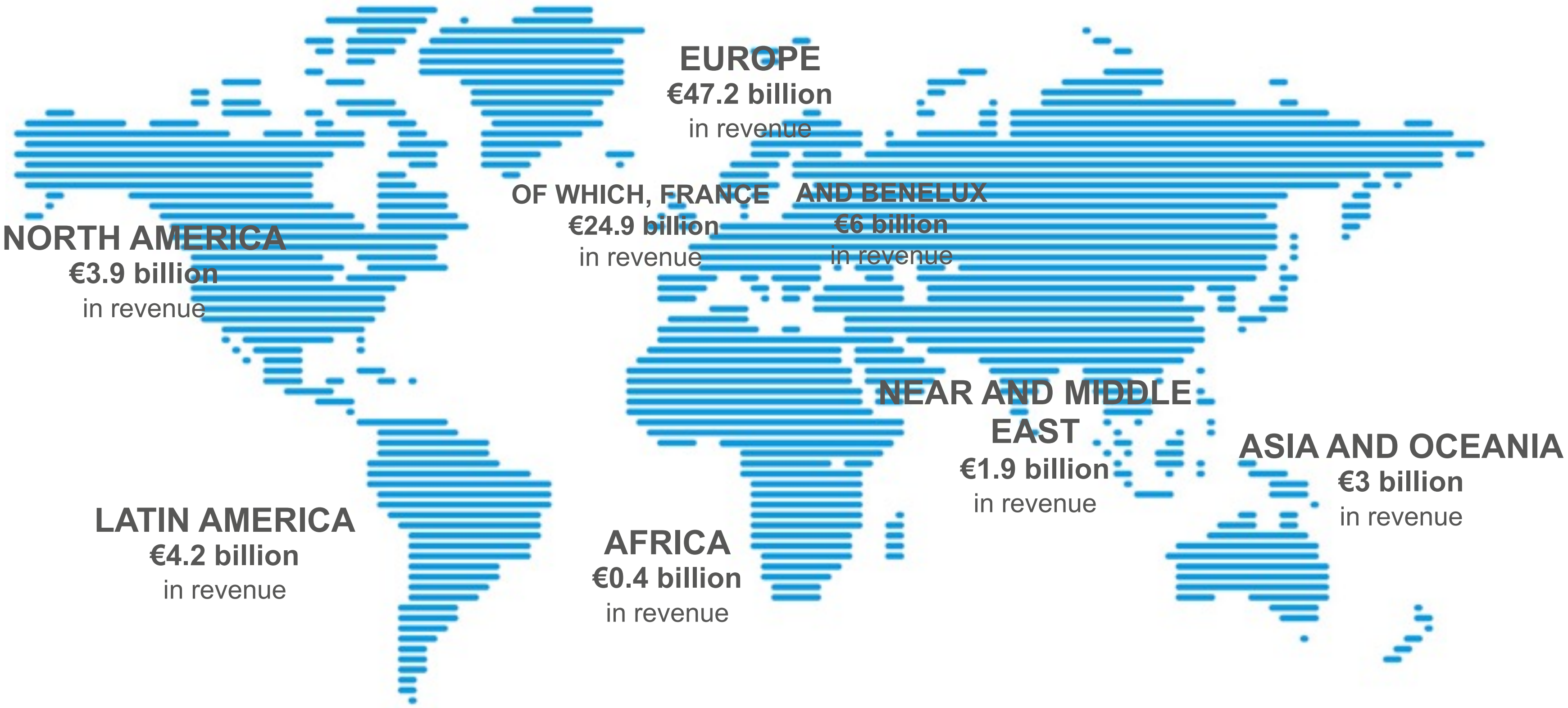
Our worldwide presence*

167,000
employees

€60.6 billion
in revenue

€2.5 billion
recurring profit after tax

€11 billion
of planned investment in growth in 2019-2021



*on 31/12/2018

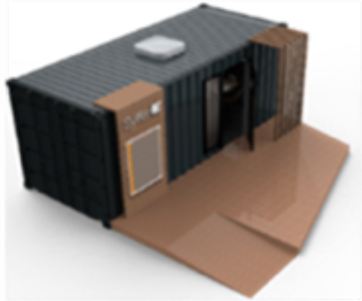
Hydrogen Thematic

We pave together the way for a competitive zero-carbon hydrogen economy

ENGIE Lab CRIGEN – Hydrogen
Ongoing Funded Collaborative projects at Global Scale

NEPTUNE (FCHJU)

REFLEX (FCHJU)

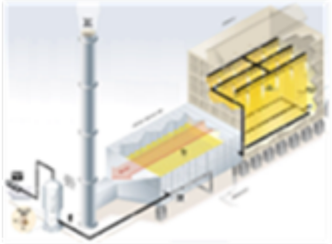


MULTIPLHY (FCHJU)

MACBETH (SPIRE)

HYCARE (FCHJU)

HARWELL (UK BEIS)



C2FUEL (H2020)

GRHYD (ADEME)

HYCAUNAIS (ADEME)

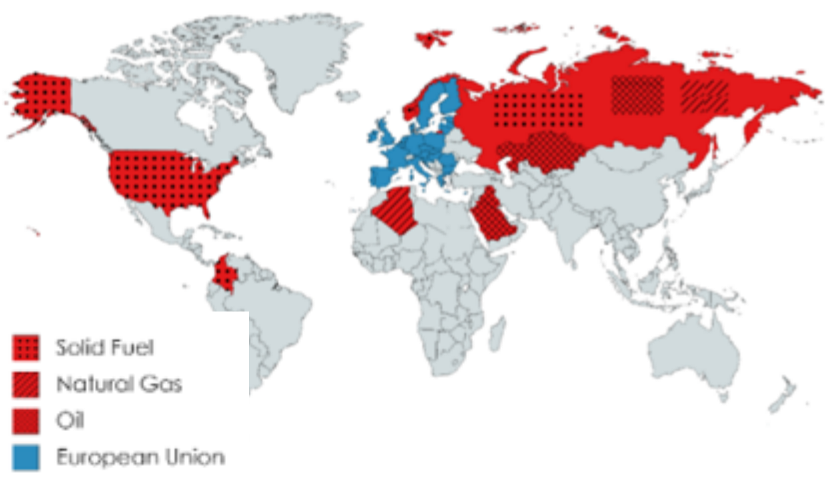
LIVING H_2

Storage & Transport | Production | Usage

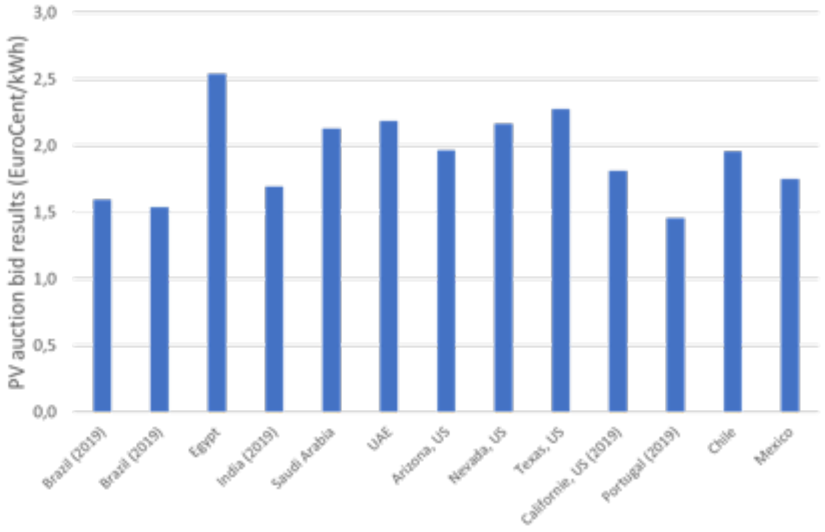
Hydrogen as dispatchable form of energy storage for energy supply diversification

Hydrogen is key for new energy corridors and energy supply diversification through international trading

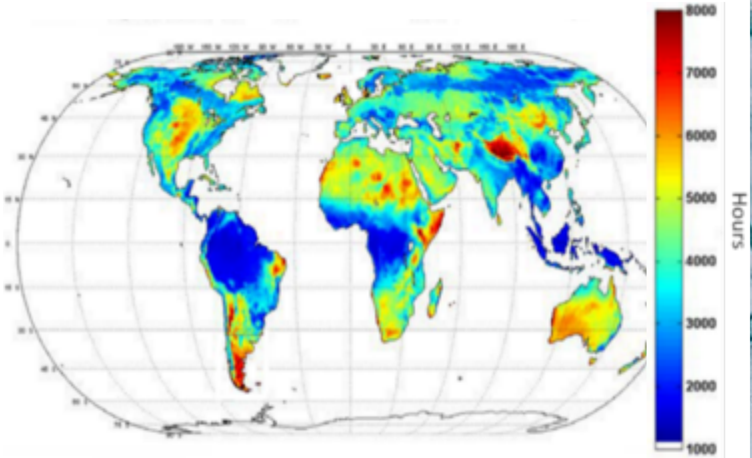
Main fossil fuel exporters to Europe



Lowest PV auction bid worldwide in 2018 and 2019



Hybrid Wind and PV cumulative full load hours – Source VTT

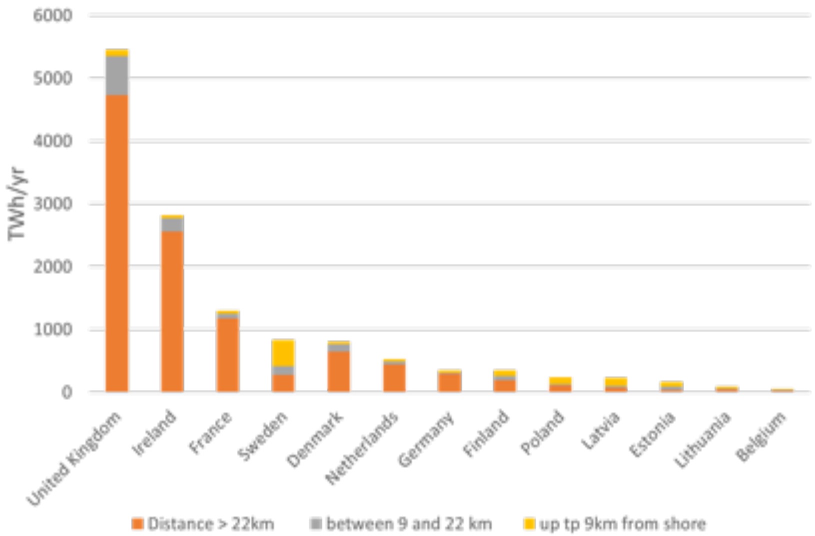


New energy corridor with countries showing electricity economic potential lower than 30€/MWh with cumulative load hours higher than 5000 hours are possible!

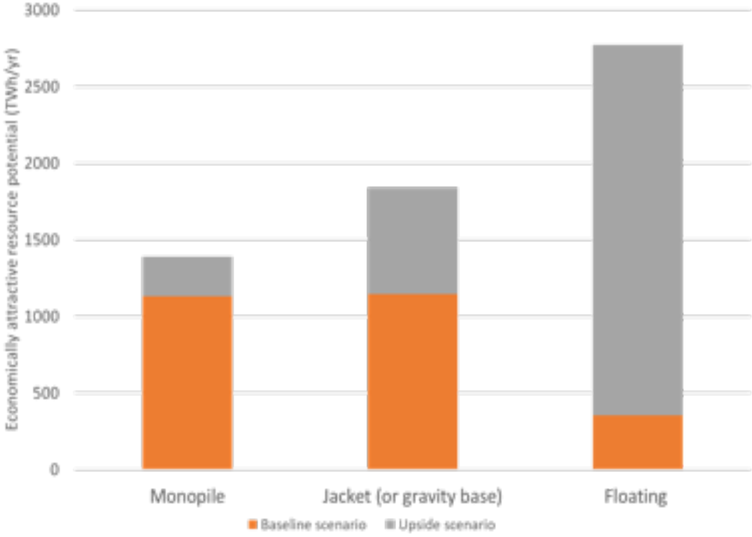
Hydrogen and ammonia will be key to harvest offshore wind energy and reduce curtailement

Technical resource potential at the end of 2030 per 100 km2 WindEurope (2017)

Technical resource potential at the end of 2030 by country (2017)



Economically attractive potential in 2030 by sea basin (WindEurope)-2017

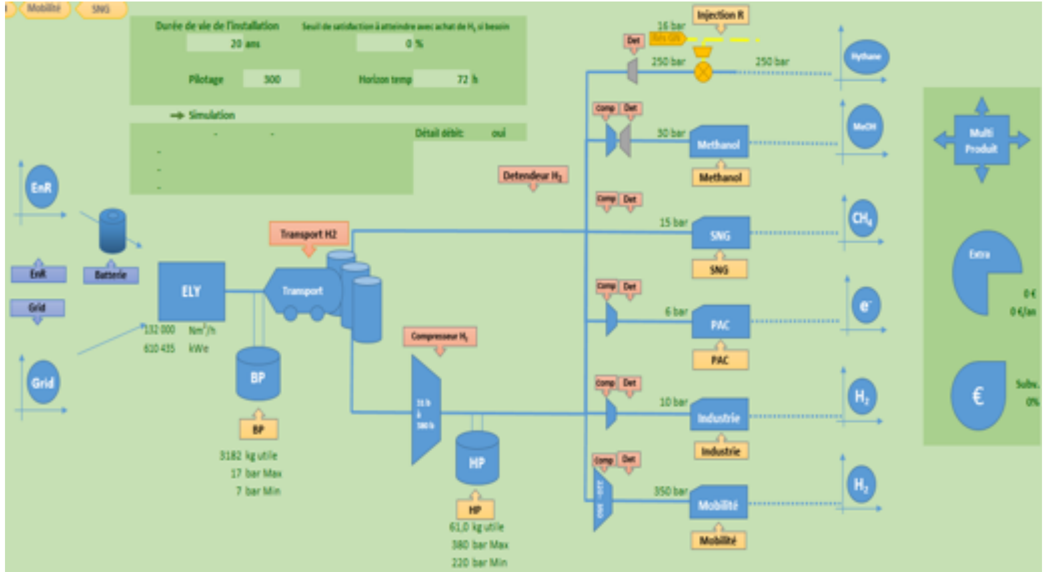


Wind energy potential is huge but implies to make use of far from the shore wind mills in order to be harvested globally. This increases energy transmission cost and reduces thus the economic potential of offshore wind.

Decision-making tools for efficient R&D

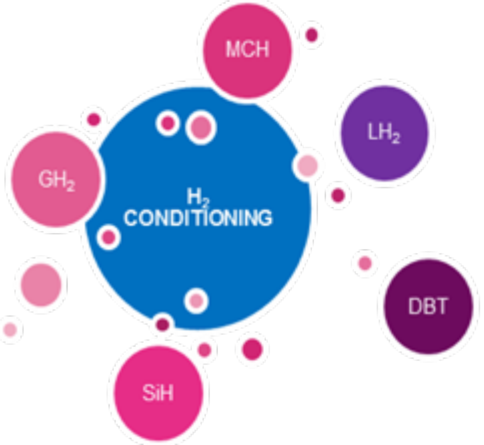
COSTHY is an in-house dynamic decision-making tool which allows :

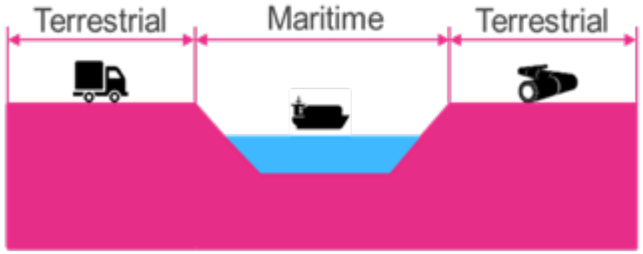
- to self-design the architecture of the process (Electrolysers / Storages / Compressors…)
- to study multi end-use applications (H_2, Gas, Liquid, Power)
- to consider variable electricity sourcing



HYTAC is an in-house add-on linked with COSTHY which allow to determine levelized cost related to multi-segment transportation of hydrogen

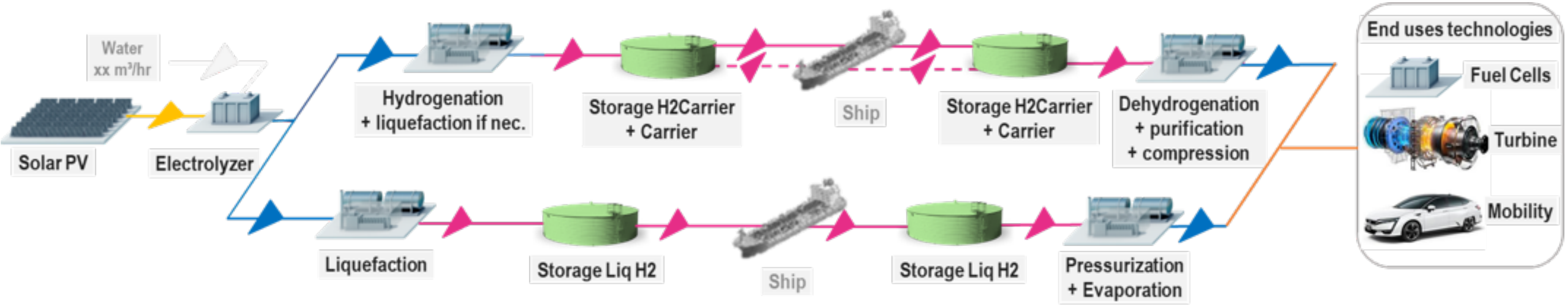
- Consider up to 6 conditioning method
- Up to 3 three segments terrestrial or maritime





Long distance hydrogen transportation : case study in Morocco

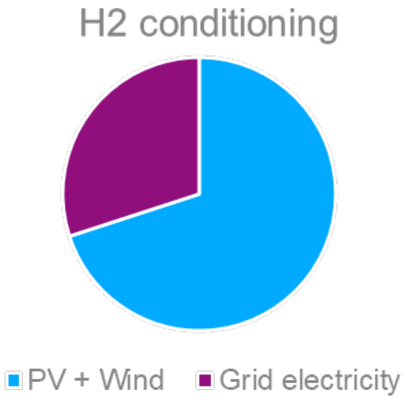
- 4 different hydrogen carrier are considered Liquid hydrogen, DBT, NH_3, SNG : hydrogenated, transported and dehydrogenated except for SNG
- Electricity is produced from PV or from hybrid PV and wind electrical sourcing in three different city in Morocco : Essaouira, Agadir and Tarfaya
- Discharged energy cost are calculated for 3 time frame : 2030,2040 and 2050 respectively for 5, 10 and 20 TWh equivalent

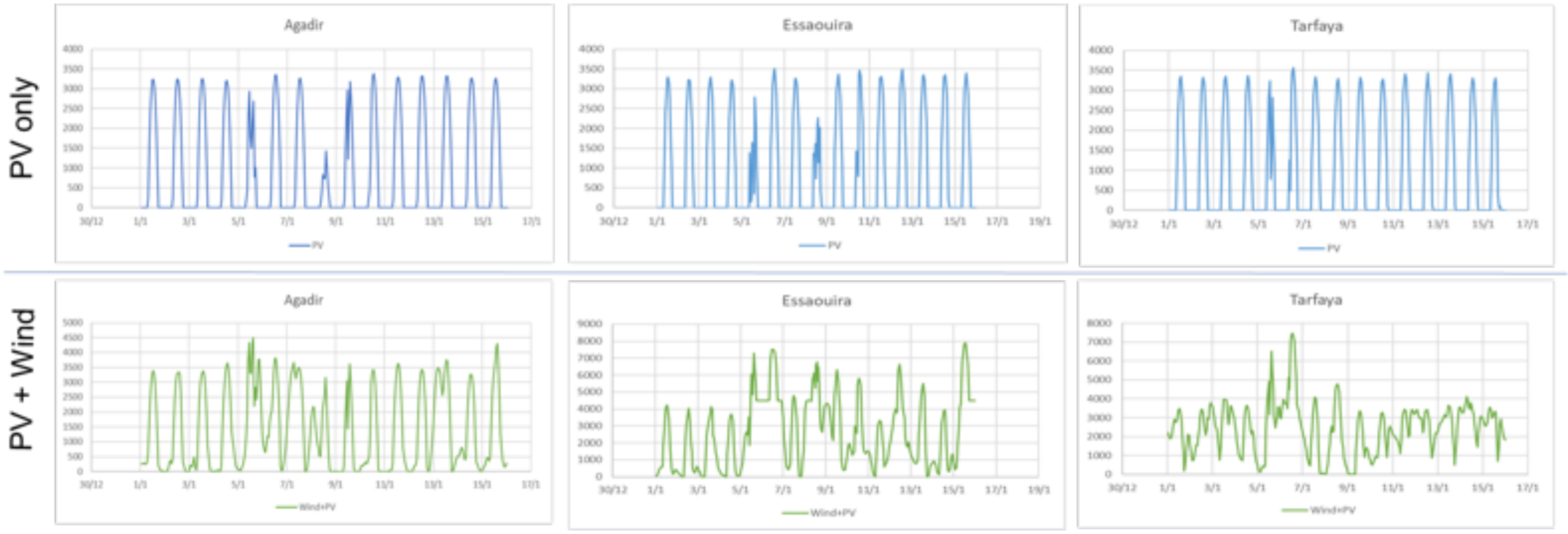


Electricity cost and profile in Morrocco

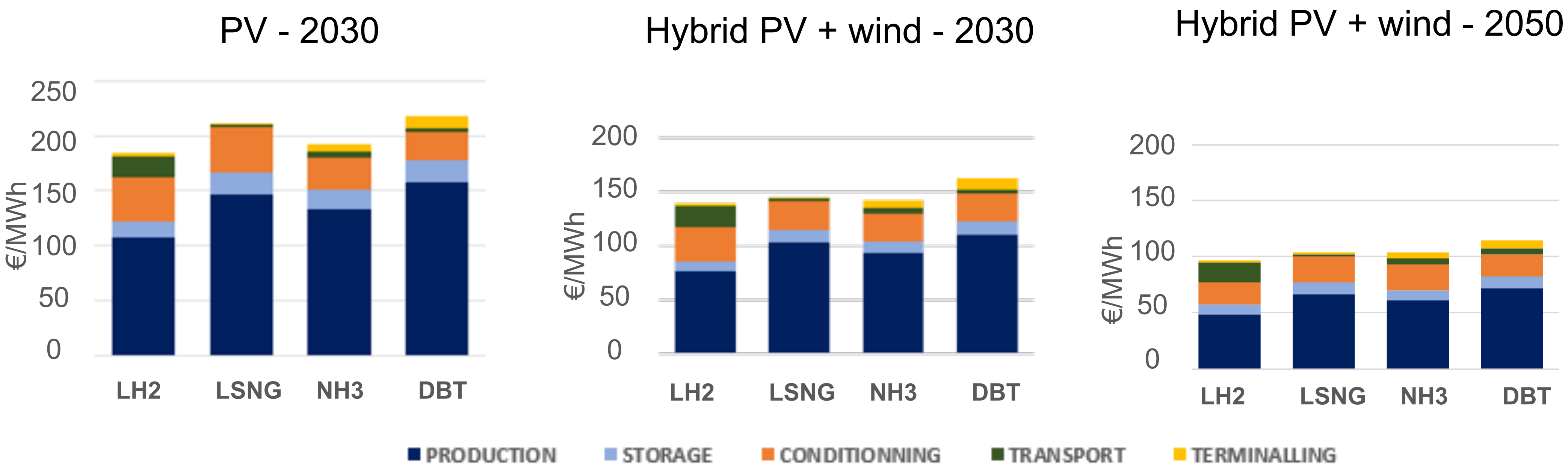
	2030	2040	2050
PV	42 €/MWh	32 €/MWh	23 €/MWh
Wind	42 €/MWh	34/MWh	29/MWh
Grid	>100 €/MWh	>100 €/MWh	>100 €/MWh
ELY	450€/kW	300€/kW	300€/kW

Sources :
- PV : "Current and Future cost of photovoltaics" Fraunhofer ISE
- Eolien : 2009 NREL "Wind LCOE" for IEA, "Forecasting wind energy cost ans cost drivers" IEA Wind + USDoE June 2016
- Grid : Enerdata, internal estimate





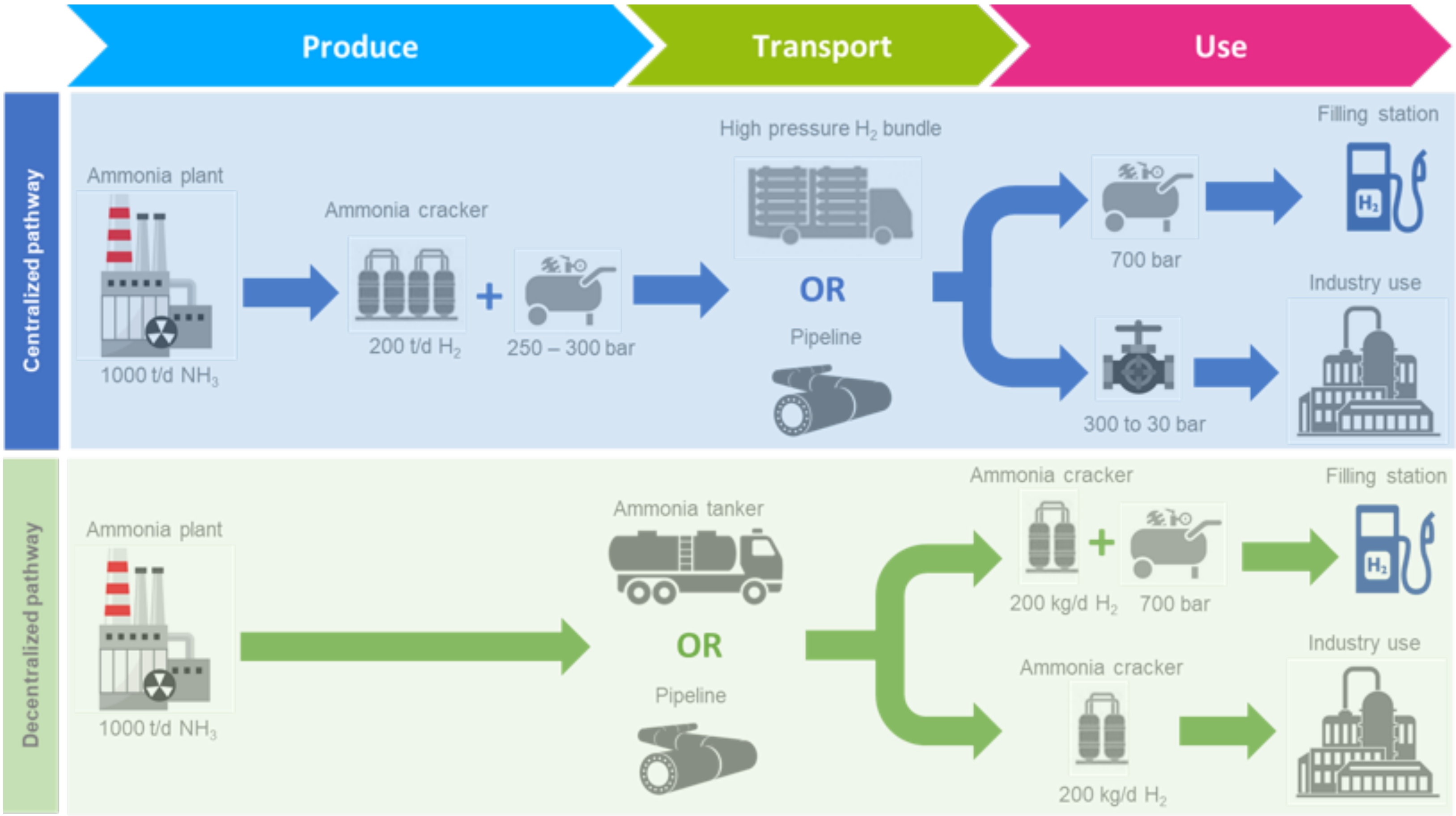
Levelized cost of discharge energy : true, wrong or in between – Case of Agadir



Y. Ishimoto and al. 2015.
D. Teichmann and al., 2012.
M. Eypasch et al.,2017.
M. Reuß, 2017.
M. Appl, 2012

- H_2 production cost is predominant with strong effect of hybridation on levelized cost of discharge energy
- Apparently, LH_2 and NH_3 are the most promising…. But in which extent can we trust these results since maturity levels of each solution are very different
- Ammonia production is particularly mature but pure hydrogen recovery from ammonia cracker is still a question :
  - No large scale cracker exists so far and data are not available in the literature. Decentralized cracker for pure H_2 does not exist!

Ammonia cracking : Centralized versus decentralized

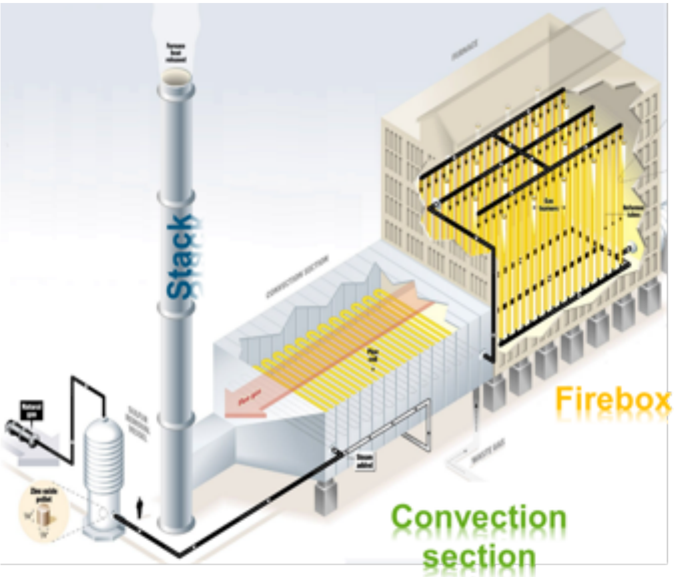


CENTRALIZED AMMONIA CRACKING

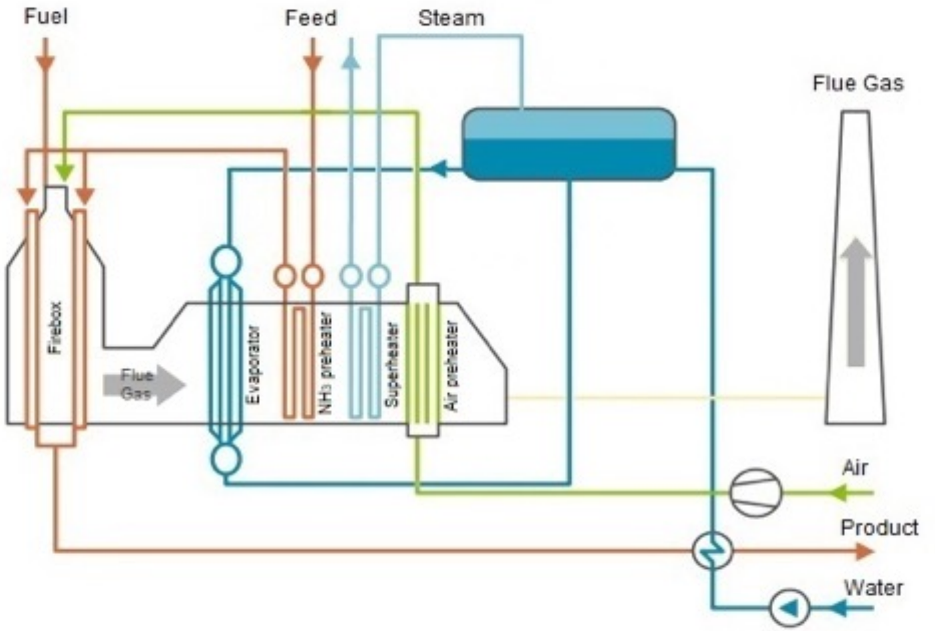
Design of a large scale ammonia cracker based on SMR

Outside Steam methane reformer

Detailed view

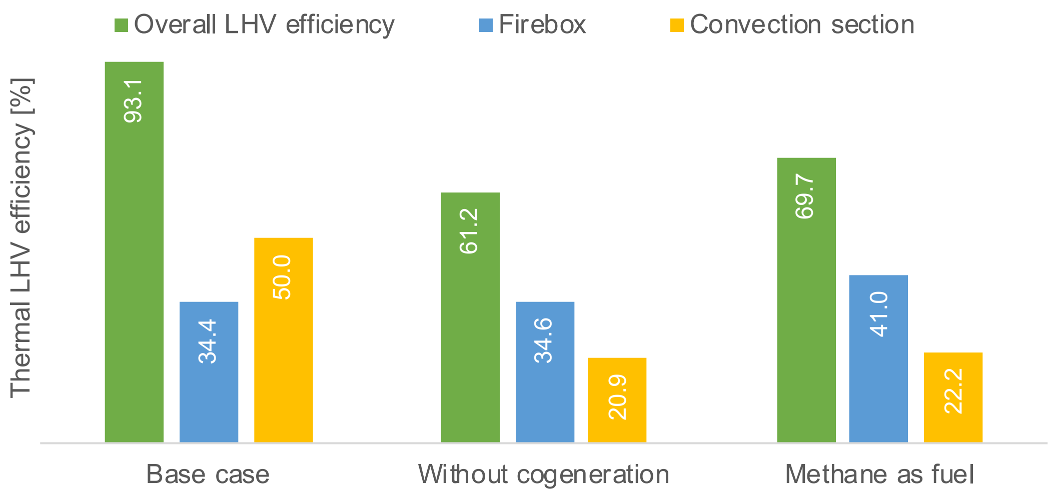


Ammonia cracker modeled under Aspen software

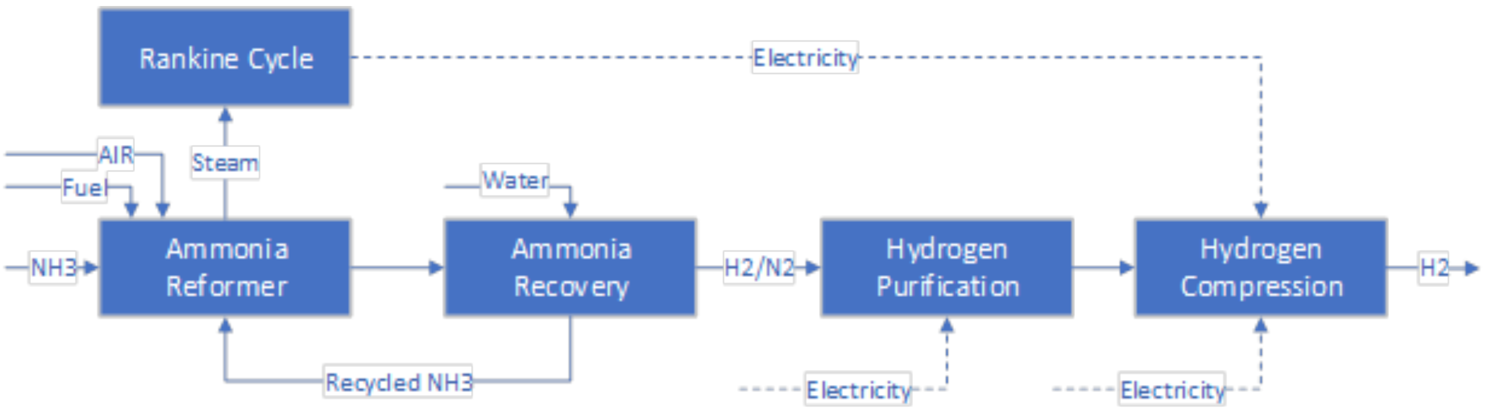


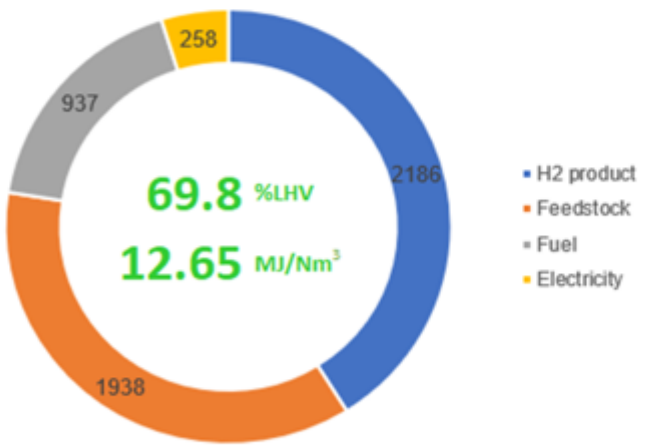
The convection section is subdivided into 4 compartments or banks with different functions each : The first one servers as a feed water evaporator, the second as a process ammonia evaporator, the third as a high pressure steam superheater and the last one as a combustion air preheater.

Centralised Ammonia Reformer : how to get to 0.1 ppm NH_3?



Stream	Composition
Fuel	85% NH_3 15% H_2
Feed	NH_3
Steam	H_2O
Flue gas	67% N_2 31% H_2O <2% O_2, Ar
Product	69% H_2 23% N_2 8% NH_3

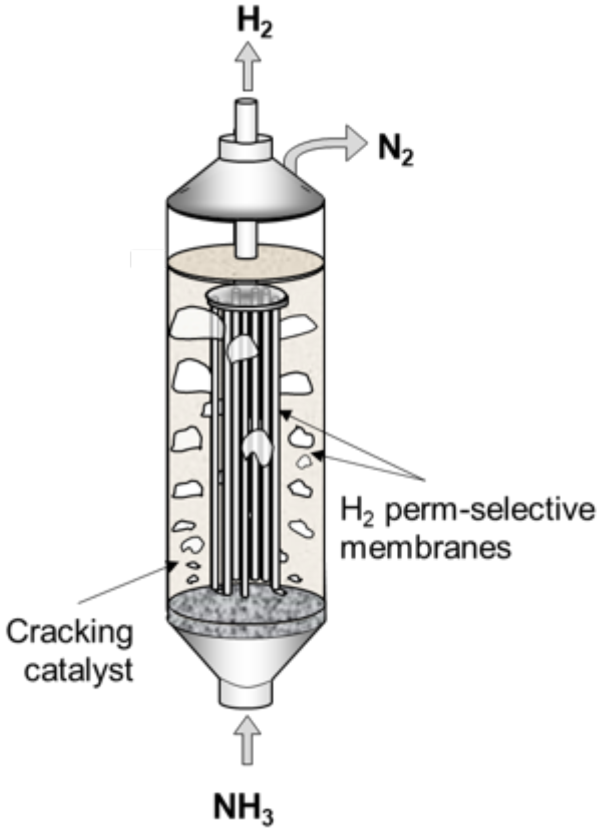




Decentralized ammonia cracking : membrane reactor

Decentralized Ammonia Reformer : Membrane reactors

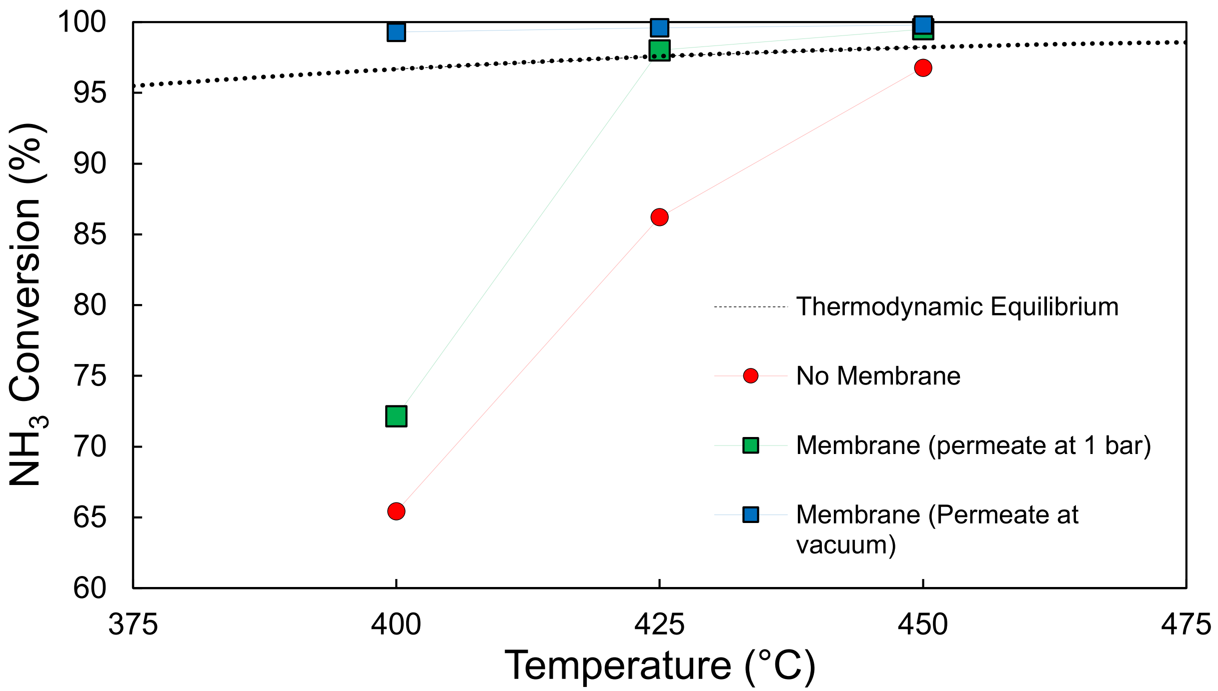
Membrane reactor for NH_3 cracking



1. Reaction and separation simultaneously in one unit
2. Process beyond thermodynamic equilibrium
3. Lower operating temperatures
4. In-situ H_2 recovery.
5. Large decrease in number of operation units and BoP.

Decentralised Ammonia Reformer : Results of NH_3 conversion

Experimental results confirmed by modeling and simulation and extrapolated

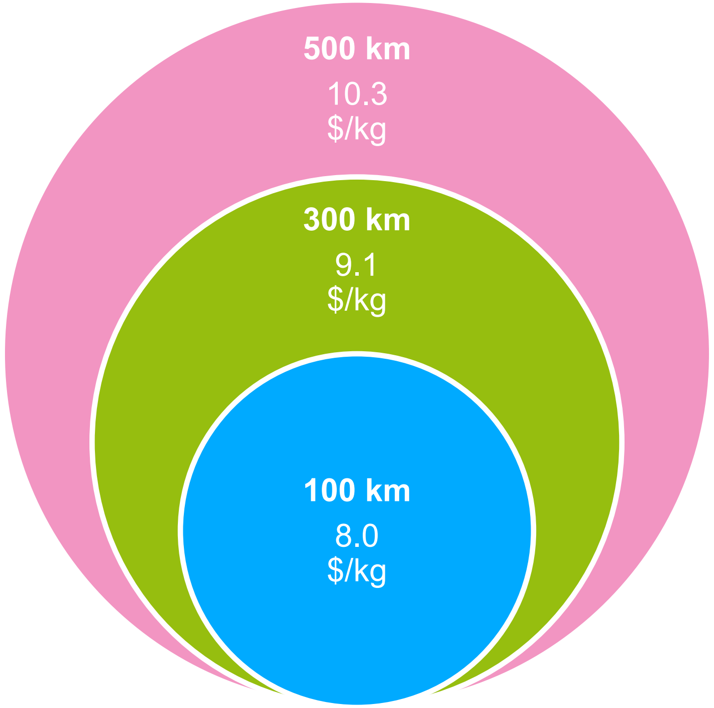


- In a conventional reactor, the NH_3 conversion stays far from the equilibrium at low temperatures.
- In a membrane reactor, the conversion is clearly increased and it can reach equilibrium conditions.
- When vacuum is used in the permeate, virtual full conversion of NH_3 is obtained, even at 400 °C, and in all the cases beyond equilibrium.

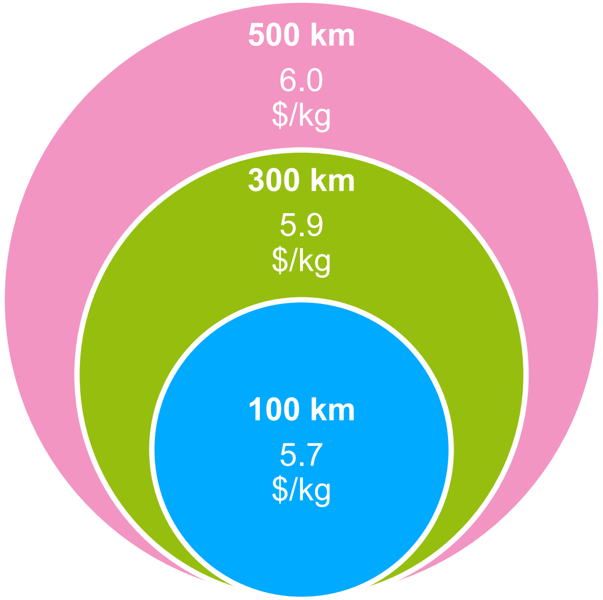
Decentralized ammonia cracking Vs centralized ammonia cracking

Ammonia Cracking : Distance Impact – Preliminary results

Centralized

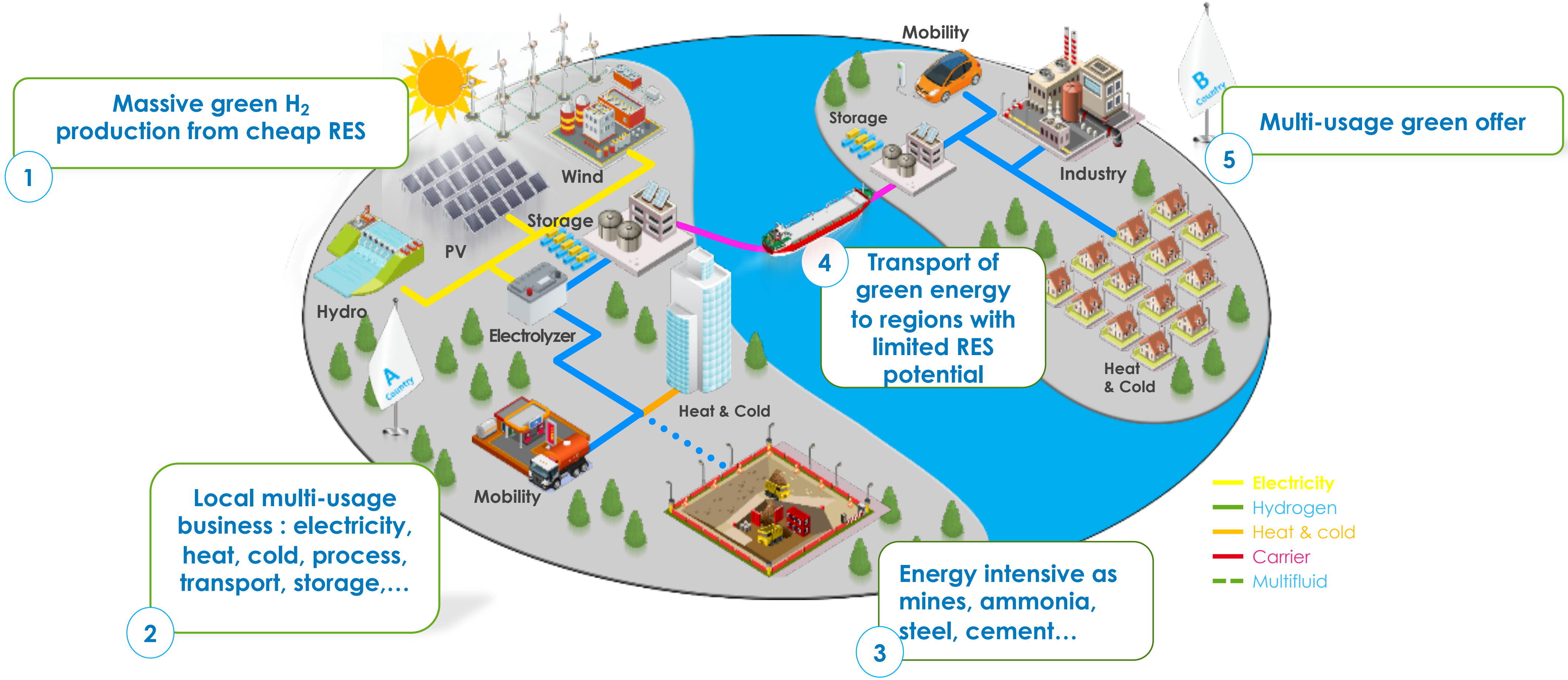


Decentralized



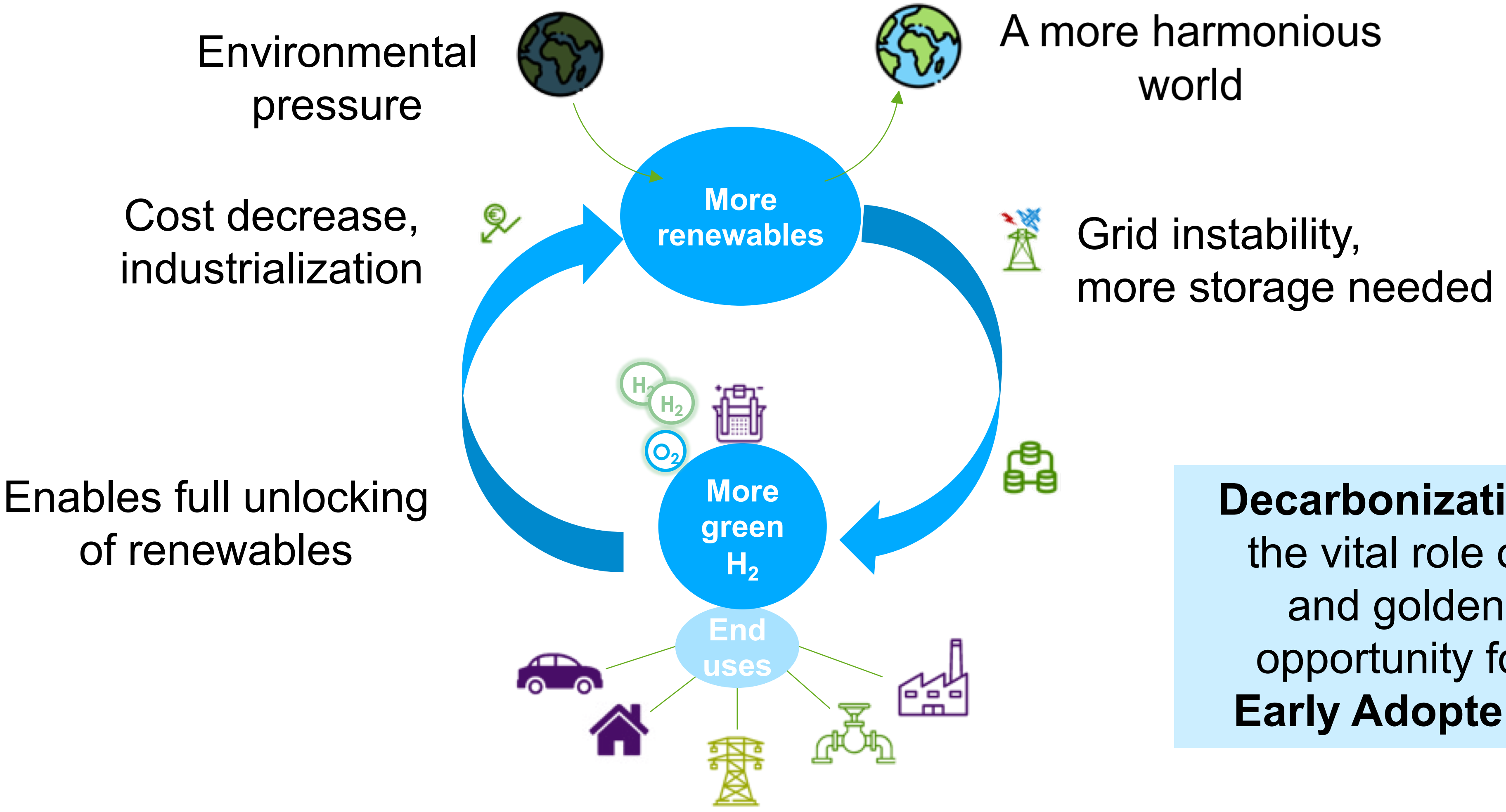

The transition to zero carbon
is under way

What is the end game?



ENGIE **architect, invest, build and operate** large scale hydrogen solutions, across the value chain.

How to get there?
Early Adopters have started the Virtuous Circle



Decarbonization:
the vital role of, and golden opportunity for
Early Adopters!

ENGIE's concrete projects with "early adaptors"

Our commercial development projects span the globe over a range of industries & sectors

Other Hydrogen projects of ENGIE

PpP Pau Porte des Pyrénées Ville de Pau

EffiH2 by ENGIE

HYNOVAR

SMT Syndicat Mixte des Transports Artois-Gohelle

Rungis

CNR

Jupiter 1000

MÉTHYCENTRE

GRHYD

HY PORT

Yara & Engie Project Overview

- Client: **Yara** in Australia.

- Purpose: Design, build, operate a **renewable energy powered green hydrogen** plant.

- H2 usage: **Ammonia** for domestic and international markets – **renewable fertilizers, renewable industrial feedstock, renewable fuel.**

- First milestone: double digit MW, industrial scale.

- End game: GW league.

Enaex & Engie Project Overview

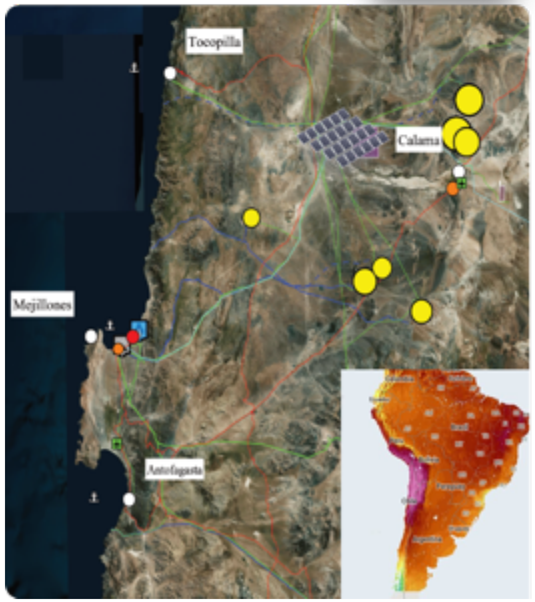
- <u>Client:</u> **ENAEX** in Chile.

- <u>Purpose:</u> Design, build, operate a **renewable energy powered green hydrogen** plant.

- <u>H2 usage:</u> new **ammonia** plant – **green blasting services for the mining industry, a.o.**

- <u>First milestone:</u> double digit MW, industrial scale.

- <u>End game:</u> GW league.



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