Air Liquide

Facing decarbonation with Hydrogen :

from space to aviation

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Air Liquide advanced Technologies

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01

Who are we ?

Air Liquide scientific territory: Essential small molecules

Oxygen, nitrogen and hydrogen are essential small molecules. They embody Air Liquide's scientific territory and have been at the core of the company's activities since its creation in 1902.

Separating the components of **air** to take advantage of their properties

- O_2 — OXYGEN
- N_2 — NITROGEN
- Ar — ARGON AND RARE GASES

Producing molecules from the **natural resources** of the planet

- H_2 — HYDROGEN
- He — HELIUM
- SiH_4 — SILANE
- C_2H_2 — ACETYLENE
- CO — CARBON MONOXIDE

Air Liquide Group : 2021 Key Figures

~66,400
EMPLOYEES

PRESENT IN
75 COUNTRIES

MORE THAN
3.8 MILLION
CUSTOMERS & PATIENTS

REVENUE
€23.3bn

NET PROFIT (GROUP SHARE)
€2.6bn

INVESTMENT DECISIONS
€3.6bn

Who is Air Liquide advanced Technologies (AL-aT)?

The **high technology innovation** subsidiary of the Group

Specialized in **gas engineering and cryogenics**; 60% on **energy transition**

Created in 1962, 1200 employees, 300 m€, CAGR>15% since 9 years

Aeronautics

Cryogenics

Space

New Energies

43 years in space

MELFI (ISS, -80°C)

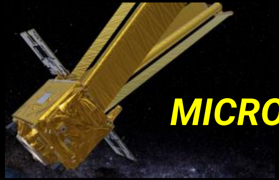
Aboard since 2006

HERSCHEL (-271 °C)

PLANCK (-273 °C)

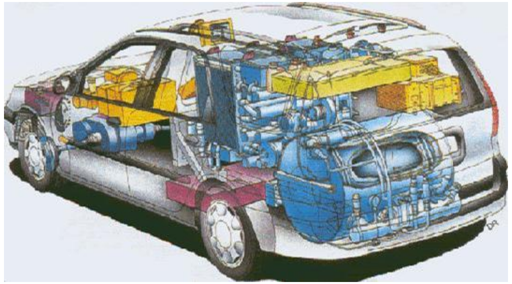
O_2, H_2, He tanks

772 tanks and 8 active machines successfully flown



MICROSCOPE

H2 : from space, through ground mobility, to aerospace



1979

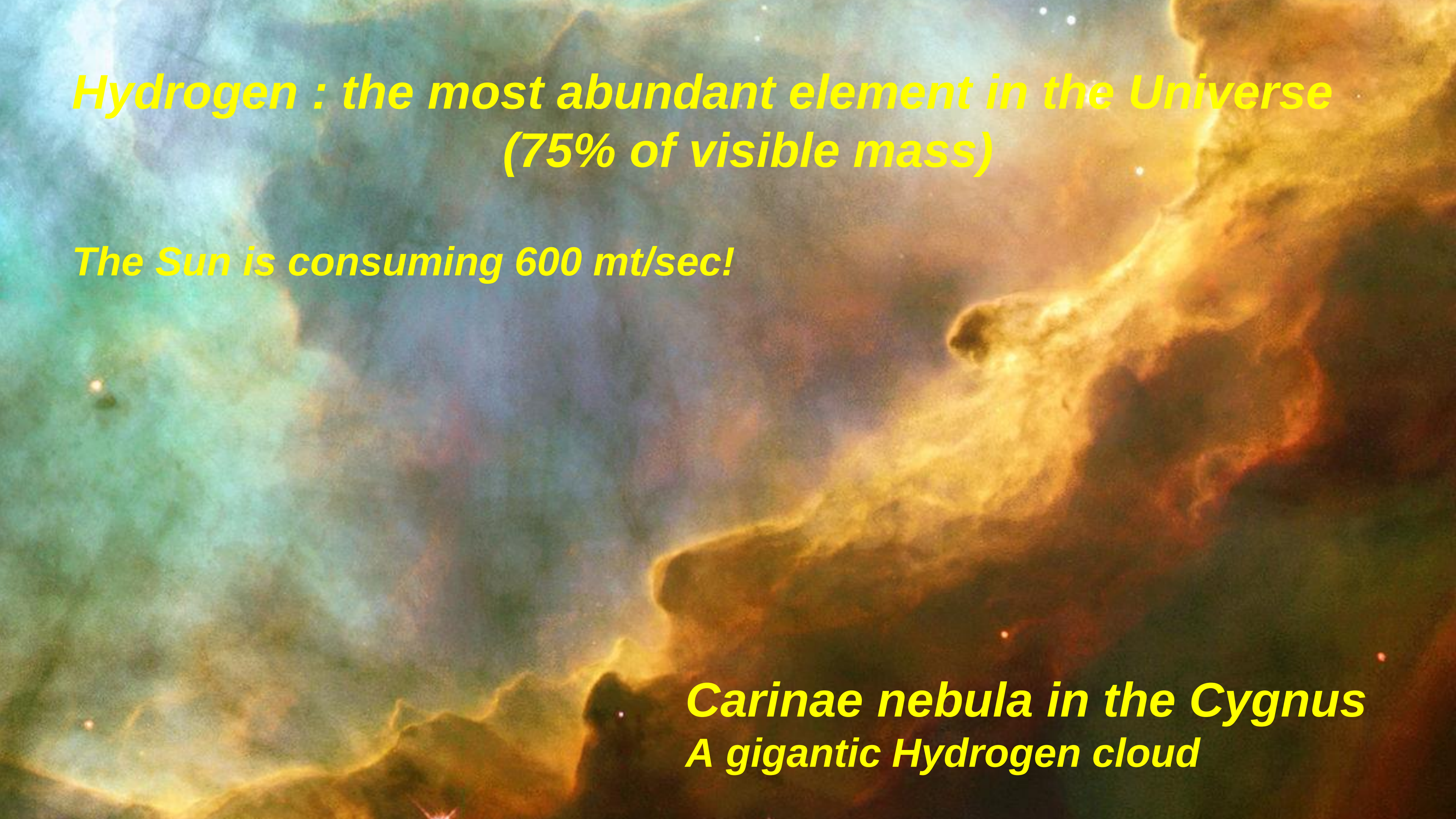
1994

2010

2022

02

What is Hydrogen?


Hydrogen : the most abundant element in the Universe
(75% of visible mass)
The Sun is consuming 600 mt/sec!
Carinae nebula in the Cygnus
A gigantic Hydrogen cloud

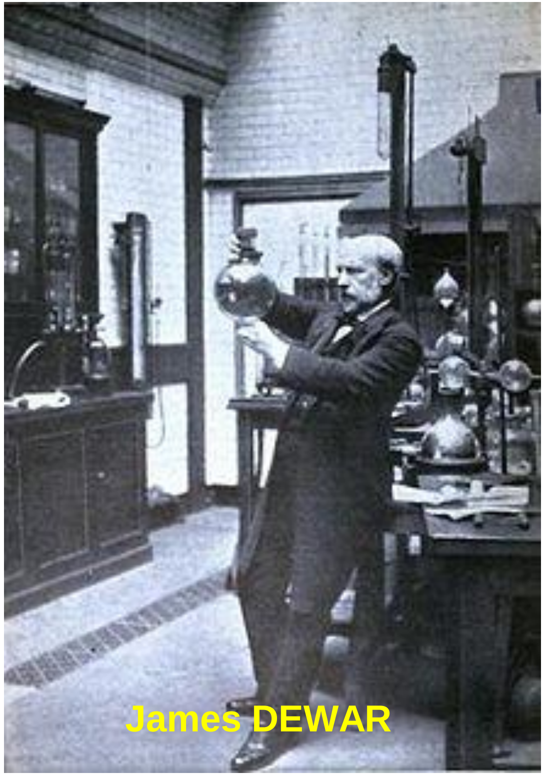
Antoine LAVOISIER

The first chemist who studied Hydrogen
in the XVIII th century
by pouring acid on Iron or Zinc

« flammable air »

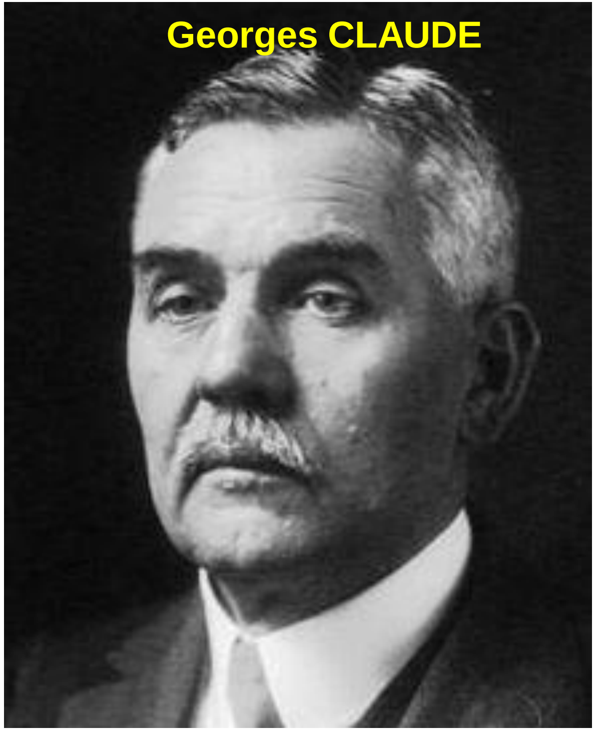
Henry CAVENDISH

1898 : liquefaction of Hydrogen at -253°C by James DEWAR

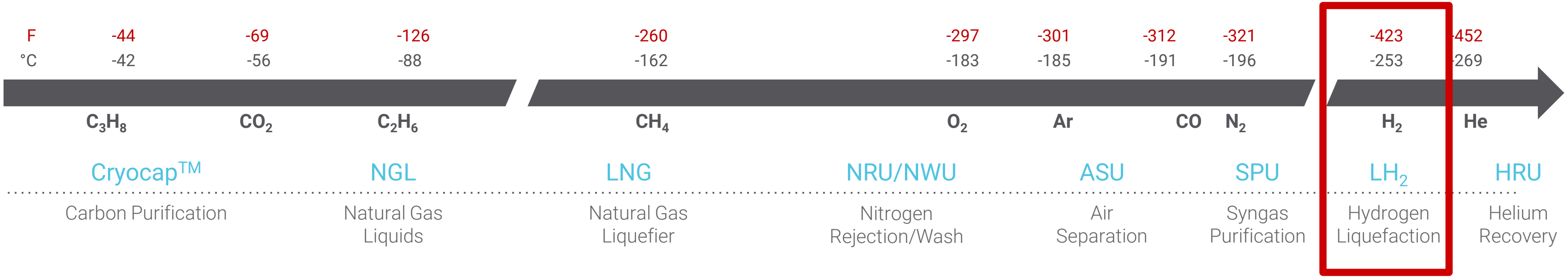


Industrial process by Georges CLAUDE at the beginning of XXth century

The founder of Air Liquide



Cryogenic scale



03

Hydrogen for the Society

Air Liquide : Co-founder of the Hydrogen Council

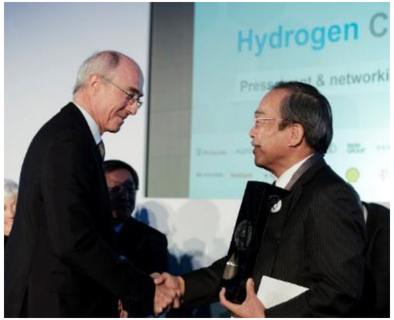
Widening of sector and geographic interest at CEO level

INTERNATIONAL COOPERATION IS KEY TO UNLOCKING THE HYDROGEN ECONOMY

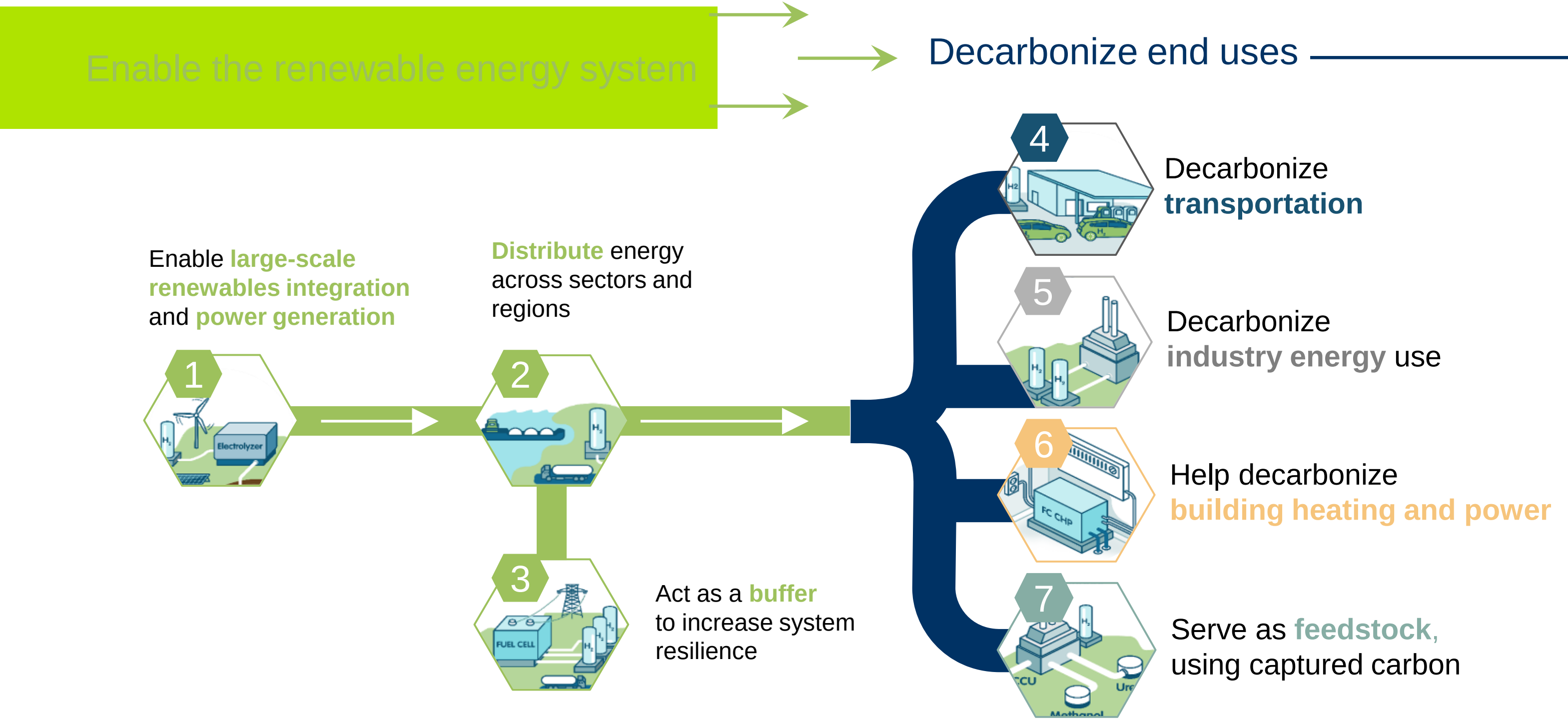
H_2 COUNCIL

covers Europe, Japan, Korea, US, Middle East & China

132 members (April 2022)



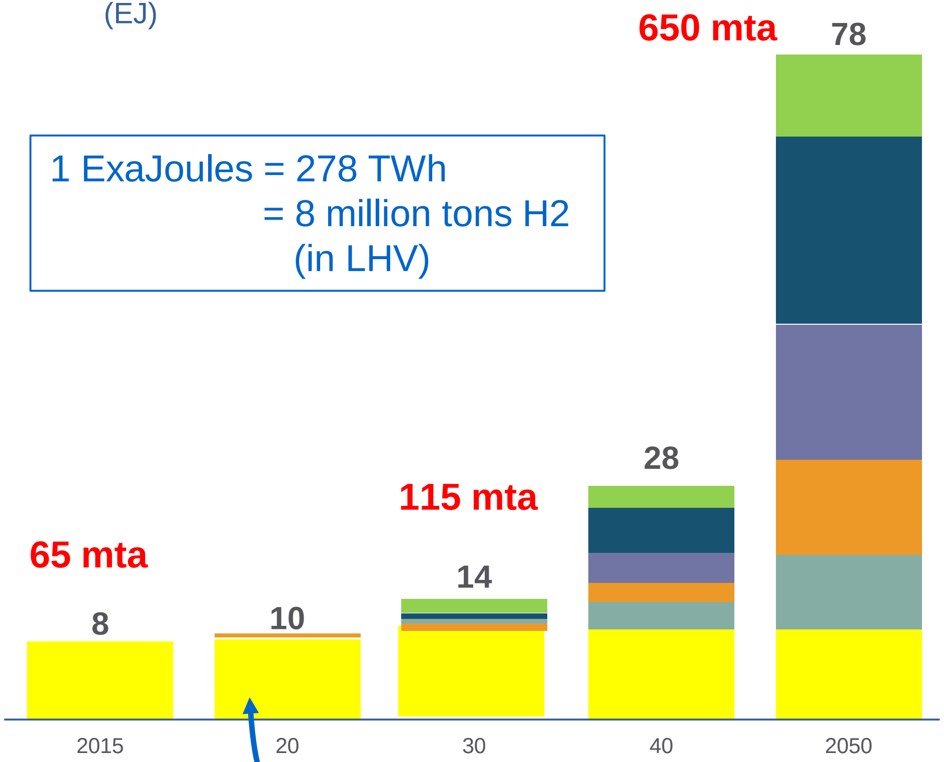
There are seven roles for hydrogen in the energy transition



Source: McKinsey & Hydrogen Council 2017

In a 2-degree-world, hydrogen could contribute ~18% of demand

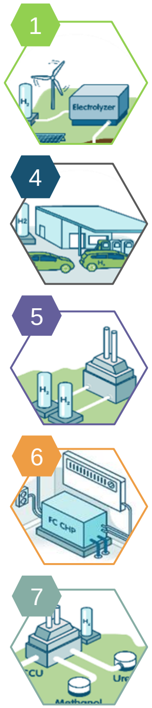
Potential global energy demand supplied with hydrogen, Exajoule (EJ)



SOURCE: Hydrogen Council

1 ExaJoules = 278 TWh
= 8 million tons H2
(in LHV)

Desulfurisation of petrol



Power generation, buffering

Transportation

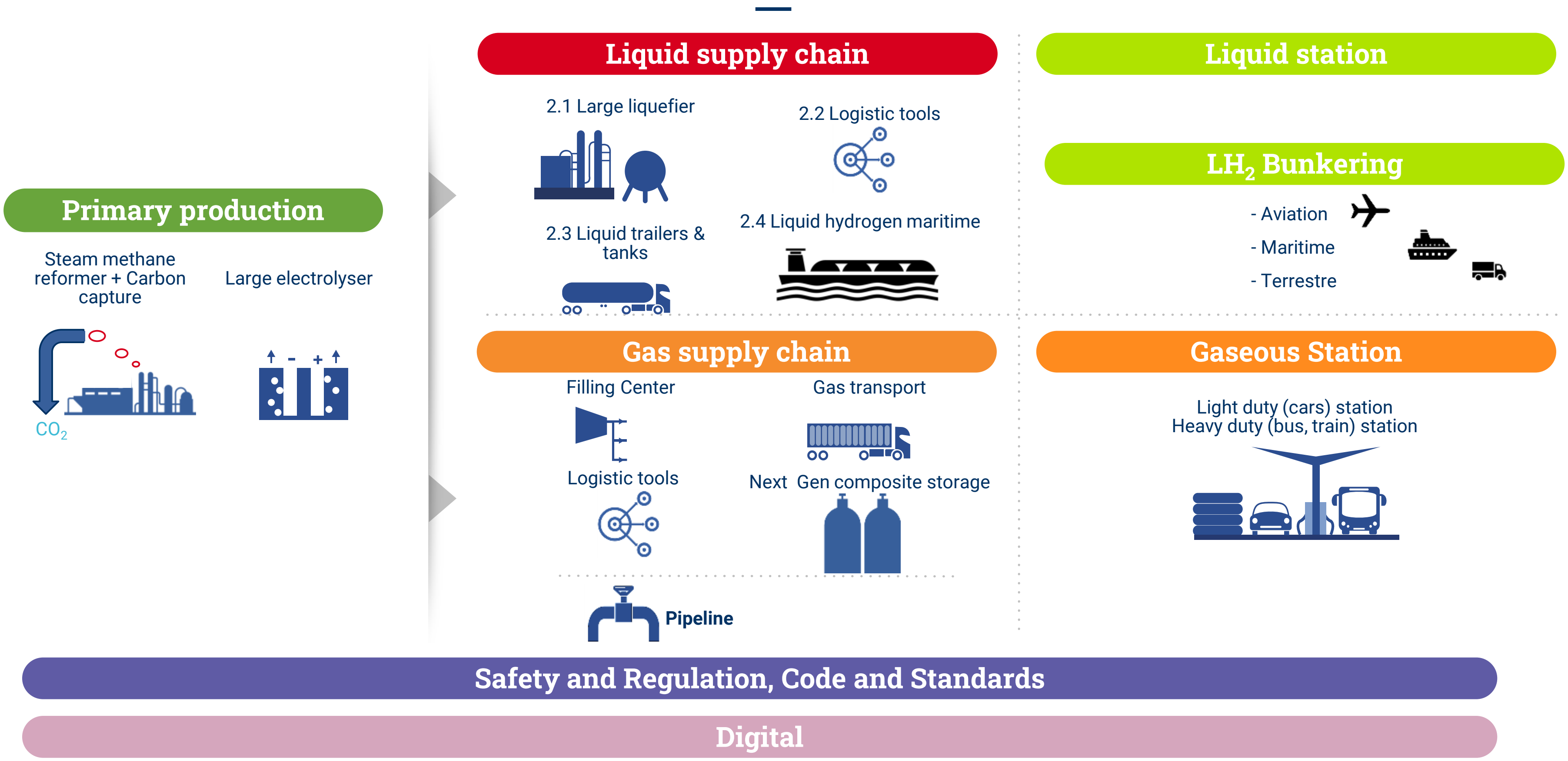
Industrial energy

Building heat and power

New feedstock (CCU, DRI)
Existing feedstock uses

18%
of final energy demand

Key H2 supply chains



Hydrogen mobility markets

ready to scale today

Ferries
1 T/day
LH2

Cruise ships
10 T/day LH2

Material handling vehicles
100 kg/day per site

Trucks
100 kg/day per truck
GH2 or LH2

Individual cars
100-200 kg/day per station

Buses
20 kg/day per bus

Trains
150 kg/day per train

Drones

Airplanes Applications
LH2

Bicycles & scooters


Air Liquide
30 tons of liquid Hydrogen per day (10 000 tons per year)
Already in operation in Nevada to serve fuel cell vehicles in California

Air Liquide's ambitions in hydrogen

Before 2035

Capex

+~€8bn

By 2030(a)

Electrolysis

3GW

(a) Including 1 GW decided still under construction

Walking the talk we are scaling-up

Jan. 2021, Bécancour, Canada: (20MW) .

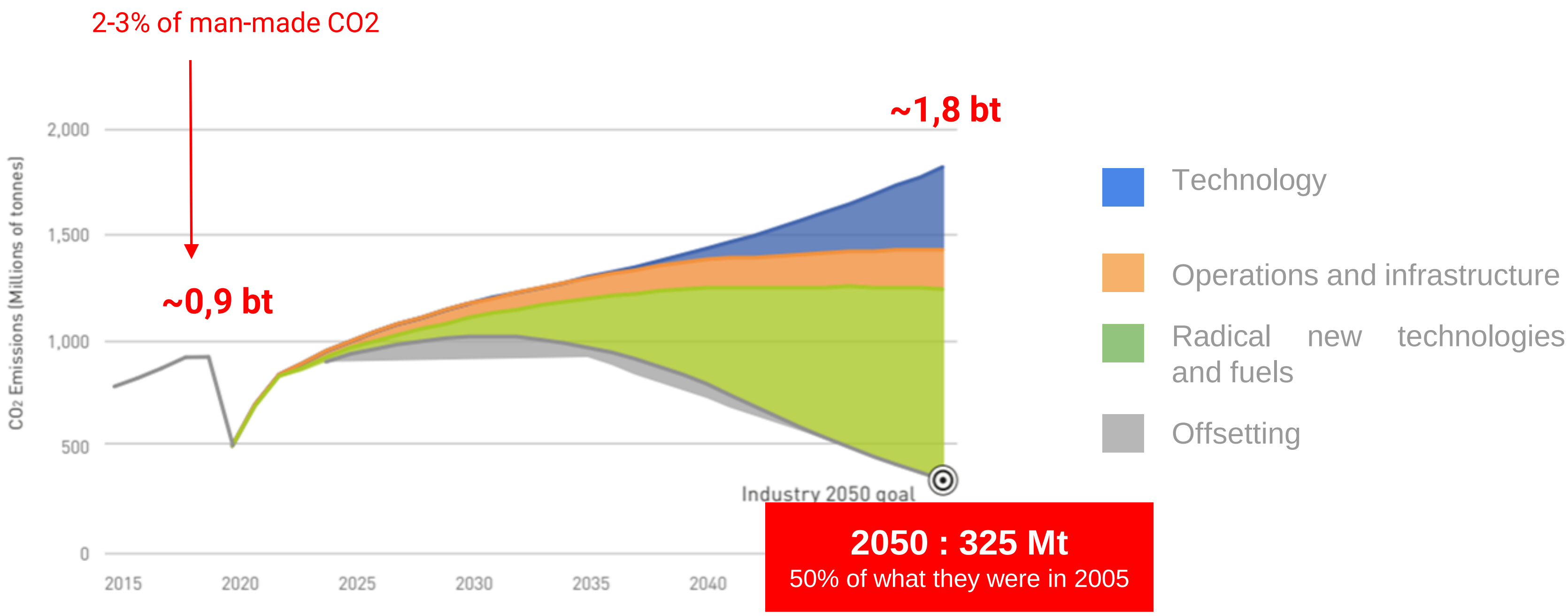
In France, H2V Normandy project

(200 MW)

04

Hydrogen as a fuel for aviation

Aviation facing the decarbonation



Source : ATAG WAYPOINT 2050

SAF : Sustainable Aviation fuels
2 pathways towards a sustainable aviation

Biofuels
& e-Fuels
Starting now

DROP-IN

medium-long range aircraft

H2
Starting 2035

Turbines

Fuel Cells

NON-DROP IN

regional aircraft

H2 for aerospace… they talk about it too

2035 : Entry Into Service - Regional aircraft

Propulsion with H2 : 10 years of R&D in AL

HYCARUS
AIRBORNE FUEL CELLS

2013-2019

350b gaseous H2 tank

HEAVEN
Cryogenic Hydrogen Tech Aircraft

World premiere

2019-2023

LH2 permit to fly

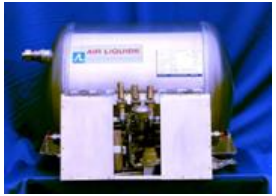
LH2 VS Kerosene

Cryogenic tank competitive in mass
1 kg LH2 ~ 4 kg Kerosene
12 kg of CO_2 saved
BUT **3 X bigger**

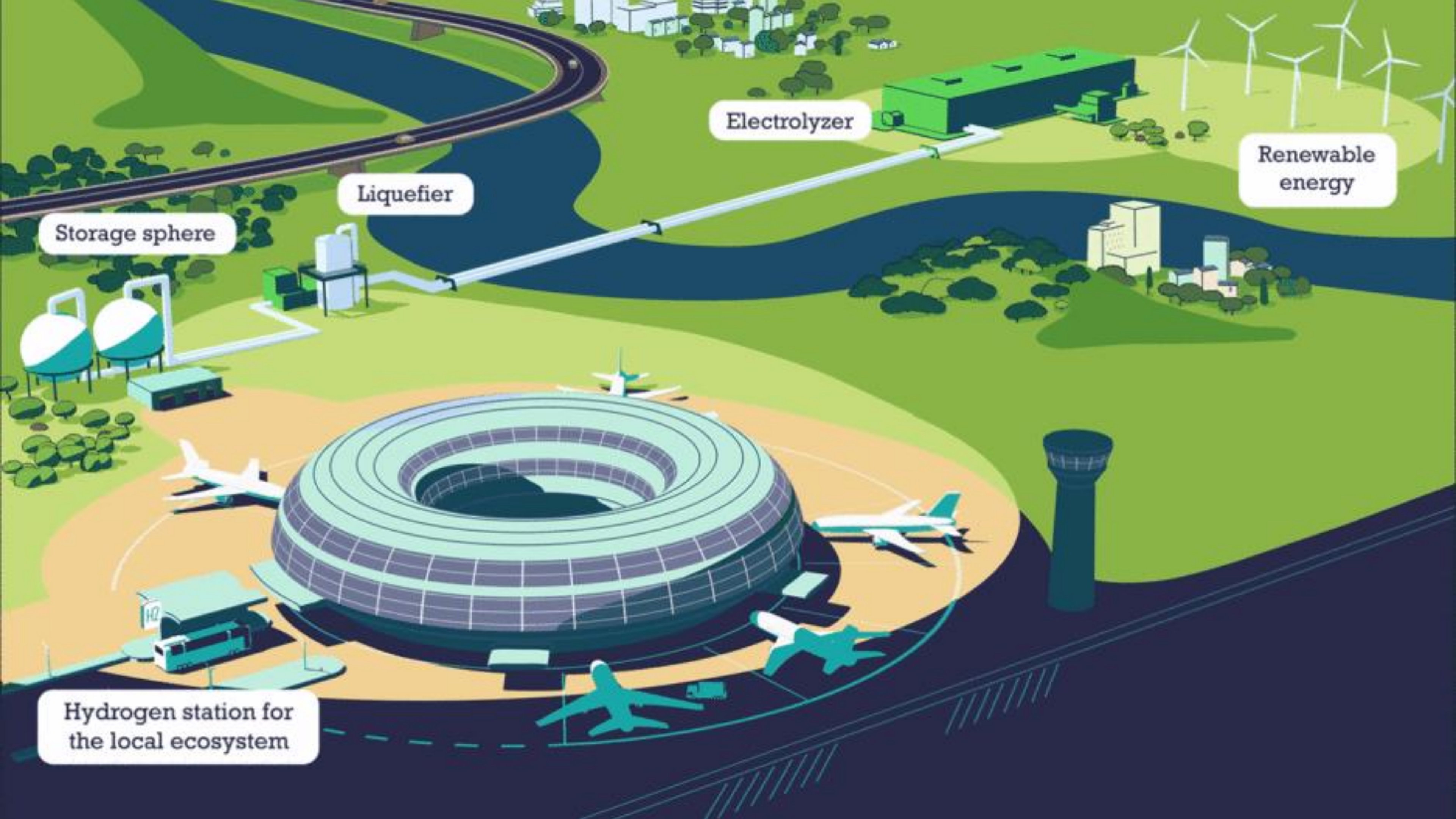
From automobile to aviation :
Specific liquid H2 tank developments

Airborne tank on a vibration bench

Developments in the 2000s for the automotive industry



HEAVEN flight demonstrator
225 l of liquid H2
To fly early 2023


Electrolyzer
Renewable energy
Liquefier
Storage sphere
Hydrogen station for the local ecosystem

Liquid Hydrogen infrastructures on a large airport

10,000 LH_2-powered planes by 2050
100-300 airports to be equipped
5 to 10 million tons LH_2 per year

150 H2-SA-aircraft take-off per day

150t LH_2/day; 400MW

(ex: Francfort)

10 to 20 mobile refuelers

specific LH2 trailer

1 trailer for 10 aircraft

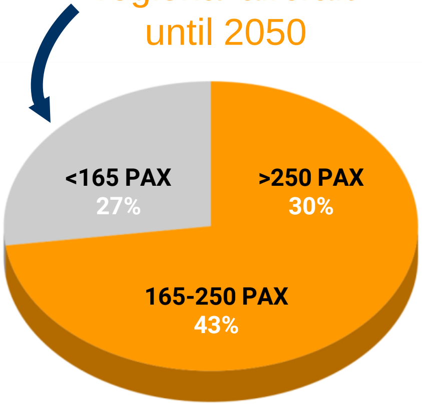
15-20 mn refueling

05

Hydrogen in synthetic aviation fuels

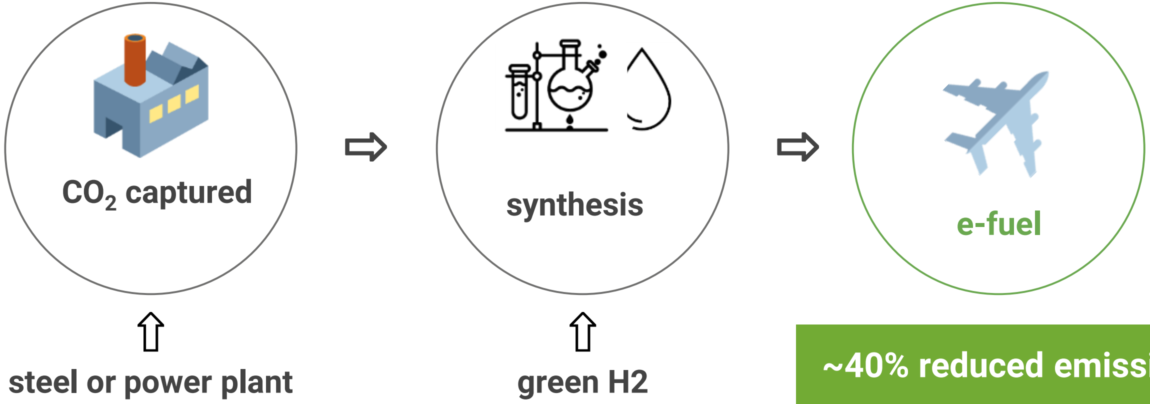
Hydrogen in e-fuel

H_2 will primarily target regional aircraft until 2050



CO2 emissions per aircraft size
PAX = passenger seat
Source : McKinsey study

- Large H2-powered aircraft >> 2050
- **e-fuel : synthetic kerosene**
  - drop-in fuel : low impact on engine and infrastructure



~40% reduced emissions

(0,5 t H2 per ton of e-fuel)

E-kerosene can reduce the global warming due to condensation trails

Global warming impact of condensation trails (contrails) is larger than that of CO2

NASA/DLR: https://www.nature.com/articles/s43247-021-00174-y

Ice crystals form onto soot particles generated by the engines

E-fuels can reduce the soot and hence the contrails

Reducing the global warming potential of aviation :
The key role of H2 as a direct fuel or embedded in synfuels

Change of in-flight emissions and emission related effects[1]

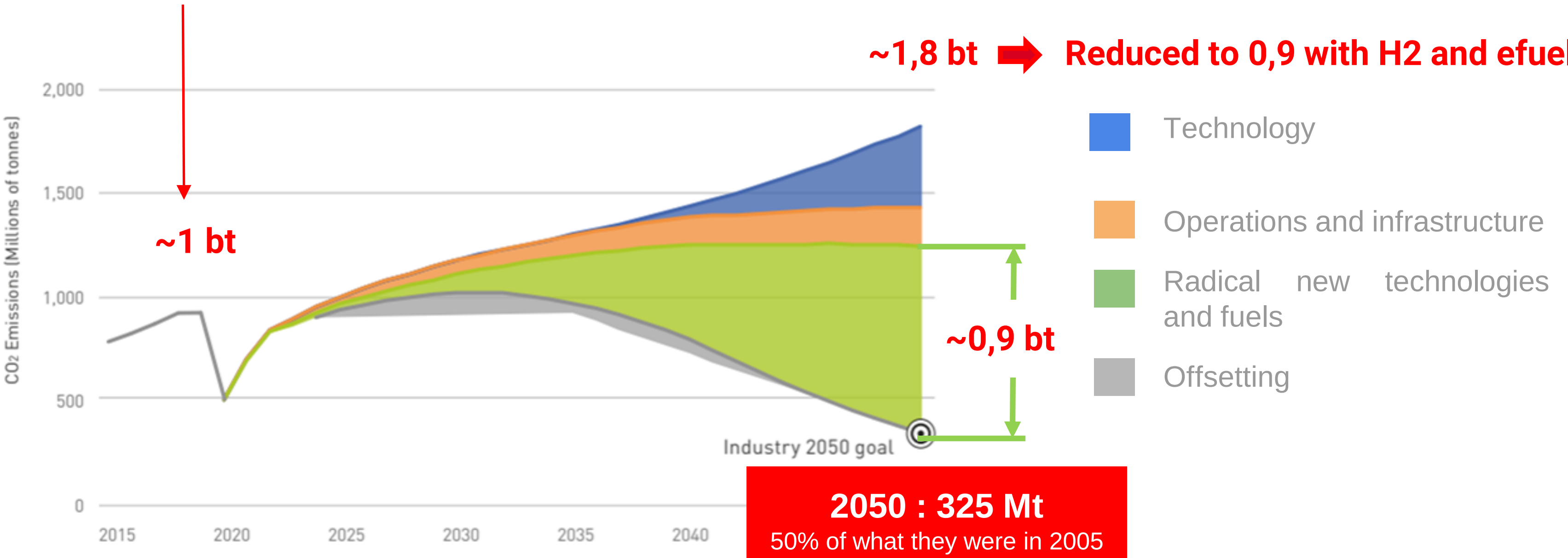
	Direct CO_2	NO_x	Water vapor[2]	Contrails, cirrus	Climate impact reduction potential	
Synfuel	-0% / -100% (Net)[3]	-0%	-0%	-10-40%	-30-60%[3]	← ¾ of fuel burn
Hydrogen turbine	-100%	-50-80%	+150%	-30-50%	-50-75%	50% reduction in total
Hydrogen fuel cell	-100%	-100%	+150%	-60-80%	-75-90%	← 1/4 of fuel burn

Data from McKinsey : Hydrogen-powered aviation, May 2020 report

We can hit our target with Hydrogen and efuels

2-3% of man-made CO2

~1,8 bt ➡ Reduced to 0,9 with H2 and efuels



2050 : 325 Mt
50% of what they were in 2005

Source : ATAG WAYPOINT 2050

Conclusions

After more than 50 years of utilization in space, Hydrogen is now used for mobility

- ❑ Heavy duty/trucks and maritime already ongoing
- ❑ Huge investments in progress on the whole supply chain
- ❑ Strong CO2 neutrality commitment
- ❑ Volume will bring cost down

Liquid H2 for aviation will benefit from synergies with ground mobilities

H2 for regional aircraft and bio/efuels for long range ones can significantly reduce the environmental impact of aviation (by 50%)

- ❑ Several flight demonstrators in progress
- ❑ Regulations and policy needed