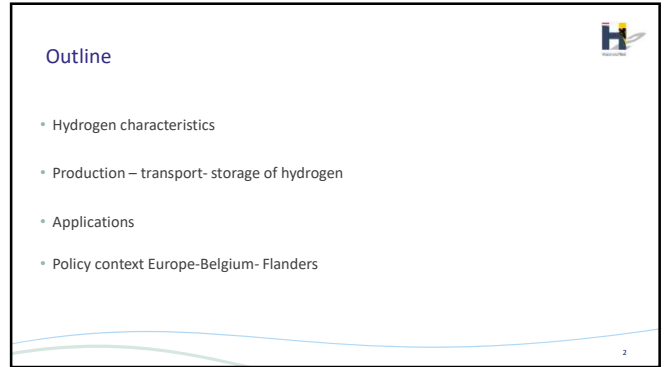
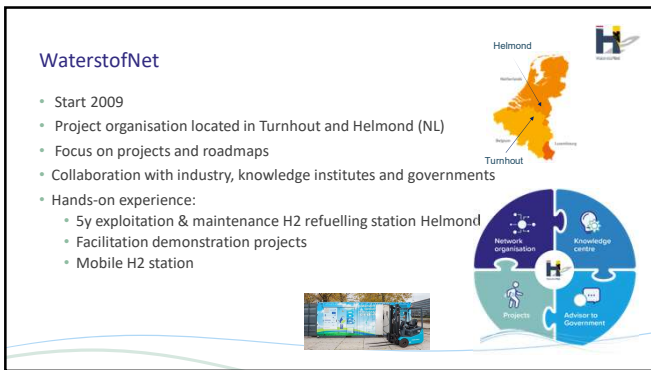




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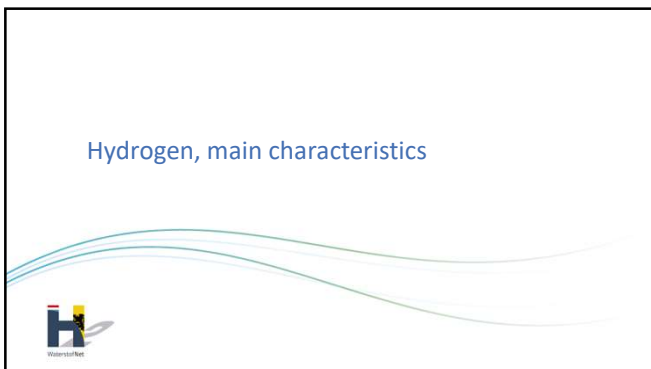
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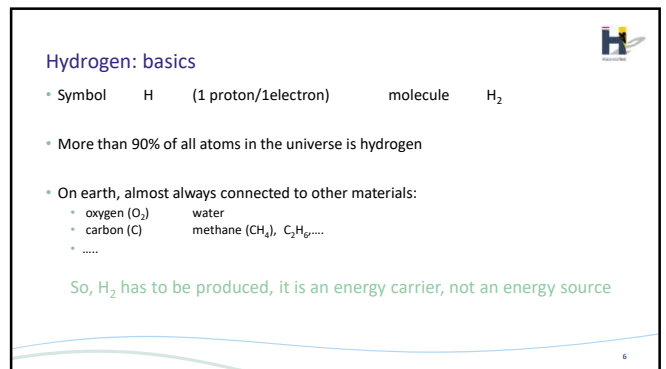
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6

MOU1 Kleur wijzigen of afbeeldingen invoegen?

1. Selecteer op het tabblad Ontwerpen de optie Achtergrond opmaken.
2. Selecteer Afbeelding uit bestand of Vullen met effen kleur.

of

1. Rechtermuisknop
2. Achtergrond opmaken
3. Opvullen met afbeeldingen of Vullen met effen kleur.


Microsoft Office User; 28/09/2020

However....

NEWS
White hydrogen from soil may be inexhaustible source of energy

Source: Change, Inc.
 Copyright Changelinc

We already knew about gray, blue and green hydrogen, but now it turns out there is also such a thing as white or natural hydrogen. That just comes from the ground, just like natural gas. According to preliminary American research, it could provide half of all the world's hydrogen needs until the year 2100 and beyond: hundreds of millions of tons per year. Initial studies have begun in Africa and the Americas.



7

H2 properties: Energy density


ENERGY DENSITY OF FUELS
50 MJ/weight energy density (MJ/L)

High per unit of mass => advantage (for mobile applications) compared to batteries
 Low per unit of volume => store under high pressure (80-350-700bar) or in liquid form (-253°C)

8

Production & transport & storage

Hydrogen 'colours'
 Transport tube trailer & pipelines
 Storage small scale and large scale
 Technologies



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Production methods

- Production method defines the 'colour' of hydrogen: grey, blue, green, turquoise
- Worldwide & Belgium: mostly grey hydrogen via SMR (from fossil fuels)
- Sustainable H2: electrolysis, byproduct H2 or fossile source with CO₂ capture, pyrolysis



Note: CCS = carbon capture, utilization and storage. IEA. All rights reserved.

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Steam Methane Reforming (incl. CCS)

Reforming hydrogen
 = 90-95% of worldwide production

Steam-Methane Reforming Reaction
 $CH_4 + H_2O (+heat) \rightarrow CO + 3H_2$
Water-Gas Shift Reaction
 $CO + H_2O \rightarrow CO_2 + H_2 (+small\ amount\ of\ heat)$

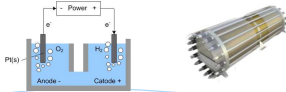




11

Water-electrolysis

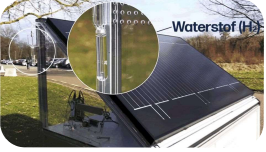
$H_2O \rightarrow \frac{1}{2}O_2 + H_2$ With supply of electricity

- PEM, Alkaline, Solid oxide electrolysis
- Efficiency conversion electricity to H₂:
 - Average 70% (30% energy loss to heat)
 - Recent new technologies up to 85%

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Direct conversion sunlight → hydrogen (e.g. KU-Leuven)

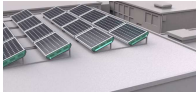


Waterstof (H₂)

- Hydrogen produced in solar panel
- Use of water from the air
- Cheaper material than electrolysis

<http://solhyd.org/nl/>

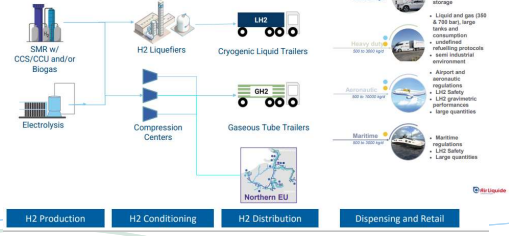
'Photo-electrolysis'



13

Transport of hydrogen

A quick snapshot on the supply chain...



H2 Production | **H2 Conditioning** | **H2 Distribution** | **Dispensing and Retail**

Risks / Opportunities

- Small footprint
- Low risks for urban areas
- Underground storage
- Liquid and gas (LHG) tanks and containers = standardised refuelling protocols = more economical environment
- Airport and aviation regulations
- LHG Safety
- LHG performance
- Large quantities
- Maritime regulations
- LHG Safety
- Large quantities

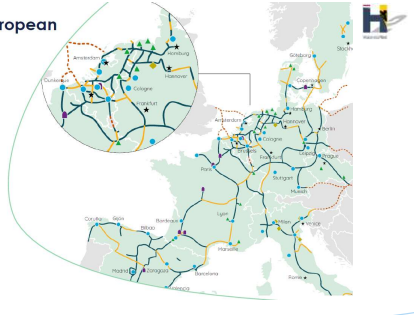
14

Transport in pipelines

- H2NG (Mix H2 and natural gas) in natural gas infrastructure
- Pure H2 in natural gas infrastructure
- Dedicated / New H2 pipelines

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Integrated into the European hydrogen backbone



Logos: ENAGAS, OGE, ENERGINET, ontras, fluxys, GRASURHE, Snam, SWEDEGAS, GRTgaz, TEREGA, ATRIAS

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Small Scale Hydrogen Storage

Hydrogen can be stored in its pure form as

- Compressed gas
- Cold compressed
- Liquid hydrogen

Or it can be stored in compound materials, such as

- Ammonia
- Methanol
-

How is hydrogen stored?

Physical-based

- Compressed Gas
- Cold/Cryo Compressed
- Liquid H₂

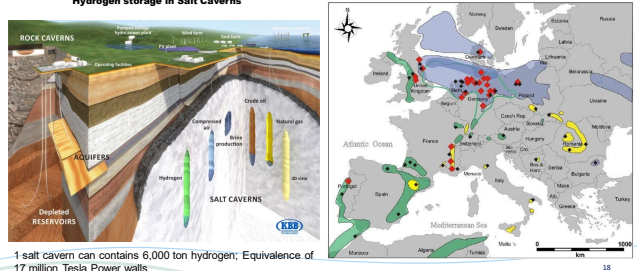
Material-based

- Adsorbent (Ex. MOF-5)
- Liquid organic (Ex. BN-methyl cyclopentane)
- Interstitial hydride (Ex. LaNi₅H₆)
- Complex hydride (Ex. NaAlH₄)
- Chemical hydrogen (Ex. NH₃BH₃)

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Large Scale Hydrogen Storage

Hydrogen storage in Salt Caverns

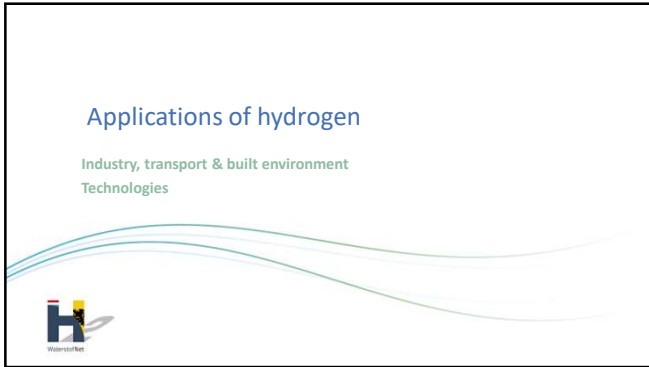


ROCK CAVERNS: Depleted RESERVOIRS, Aquifers, Salt production, Crude oil, Natural gas, Salt caverns, Hydrogen.

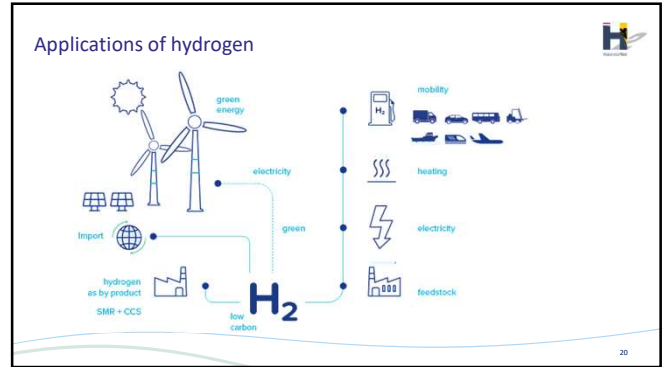
SALT CAVERNS

1 salt cavern can contain 6,000 ton hydrogen; Equivalence of 17 million Tesla Power walls

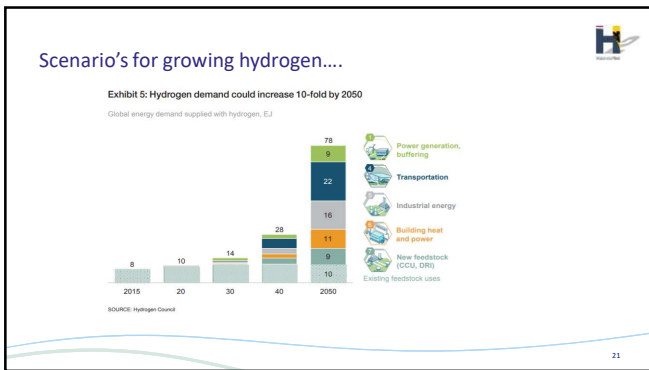
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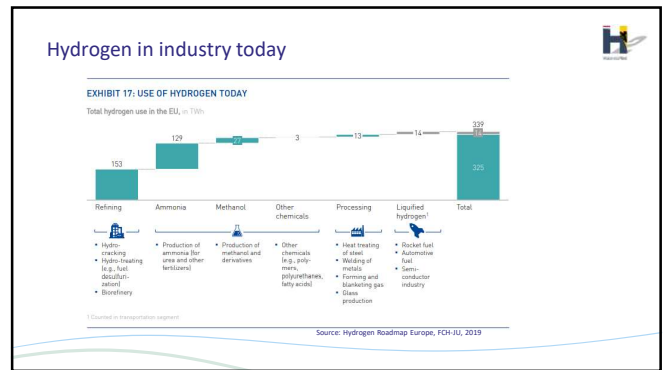
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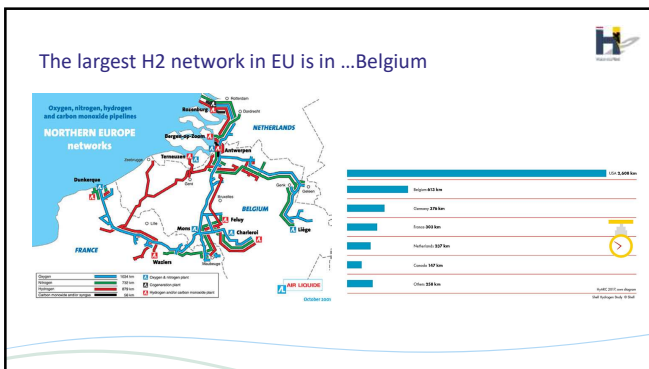
20



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22



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Clean Hydrogen in industry - future

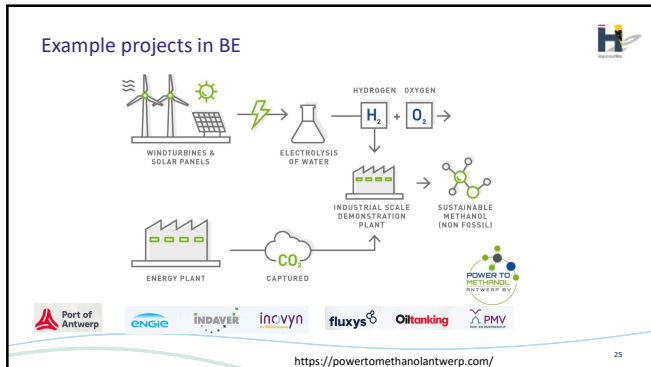
Replacement (drop-in) of (fossil) H2 in existing applications/processes

New applications of H2

- Heat (mid/high grade), replacing natural gas
- Steel production, replacing cokes
- Feedstock for chemicals or synthetic fuels based on H2 and recycled CO2.

Pilot projects in refinery (RefHyne Shell/ITM Germany), steel (H2future Sweden), methanol (CRI Iceland).

24



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Steel production

Blast furnaces: replace **part of cokes** by H₂

DRI process: replace natural gas by **100% H₂**

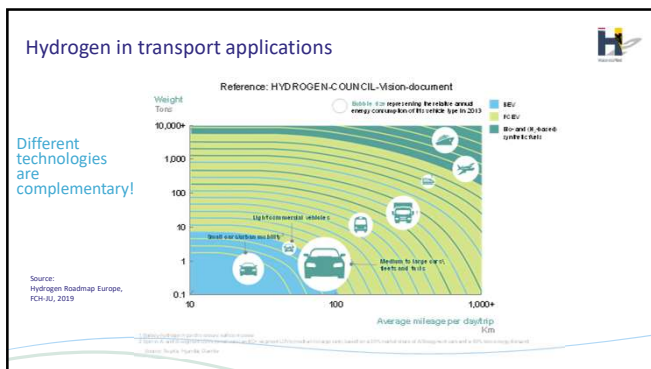
Hydrogen-based steelmaking to begin in Hamburg

by **Stainless Steel World Publisher** - October 7, 2021

ArcelorMittal to build DRI and electric furnaces in Gent

ArcelorMittal announced that it has signed a letter of Intent with the Governments of Belgium and Flanders, supporting a €1.1bn project to build a 2.5 million-tonne direct reduced iron (DRI) plant at its site in Gent, as well as two new electric furnaces.

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Hydrogen in transport applications

ROAD

- Large passenger vehicles with long-ranges (e.g. taxi-fleets)
- Public transport regional buses
 - ✓ Centralised, dedicated infrastructure → high equipment utilization
 - ✓ Fast filling => Operational flexibility
- Heavy-duty trucks
 - ✓ Fast filling => Operational flexibility
 - ✓ Available payload ↔ BEVs: weight and payload penalty

• Status: cars and buses “commercially available”; trucks in development @ major OEM’s (Volvo, Iveco, MAN, Nikola...)

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Hydrogen in transport applications

RAIL

- Zero-emission alternative for Diesel trains

WATER

- Ferry’s/ Inland barges for limited distance
- Seaships: high density fuel needed (loss of payload) → Liquid hydrogen or H₂ carrier (ammonia)

• Status: pilots

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Example projects

<https://www.alstom.com/solutions/rolling-stock/coradia-iiintm-worlds-1st-hydrogen-powered-train>

Hydroville Antwerp (CMB)

Hydrotug Port of Antwerp (2022)

Coradia iLint™ – the world’s 1st hydrogen powered train

Future Proof Shipping


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Hydrogen in transport applications

AIR

- EU flights → H2 combustion in gas turbines / fuel cells / liquid hydrogen tanks
 - Status: R&D phase
- Intercontinental flights → high energy density required
 - Synthetic kerosene → admix in fossil kerosene during transition period

<https://www.airbus.com/innovation/zero-emission/hydrogen/zeroe.html>



Planned 2035
ZEROe
Towards the world's first zero-emission commercial aircraft

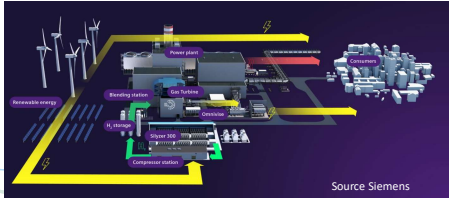
- Synthetic kerosene: recent announcement Synkero in Amsterdam port, production as of 2027

31

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Hydrogen in power & heating

- Turbines/ CHP on hydrogen (combustion)
- Fuel cells
- CCGT - power plants to operate on H2?



Source Siemens


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Hydrogen in built environment

Central production


- Hydrogen imported via gas grid from central source; transport & distribution via gas grid



H21 project in Leeds

Local production

- Hydrogen is produced in/close to the building from onsite produced energy (solar)

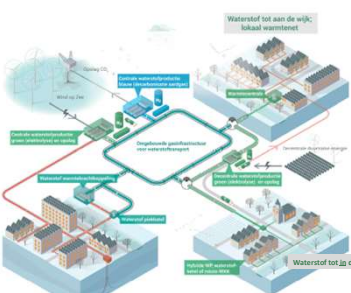


First Dutch hydrogen home

33

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Waterstof aangevoerd via gasnet uit centrale bron



Waterstof tot aan de wijk, lokaal warmtenet

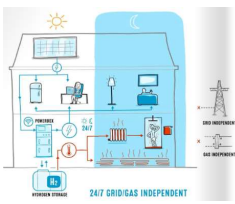
Waterstof tot bij de huizen

34

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Opslag van lokaal geproduceerde elektriciteit

- Opslag van lokaal geproduceerde energie (PV) in waterstof; re-elektrificatie met WKK/brandstofcel



24/7 GRID/GAS INDEPENDENT

Source: Solenco power

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Omzetting waterstof naar stroom en warmte

Gebruik in gebouwen

- Waterstof gas boiler
- WKK gebaseerd op brandstofcel of verbrandingsmotor
- Hybride warmtepomp (elektrische warmtepomp met extra boiler op H2 voor piekvrage)



CHP- PEM fuel cell, CHP- SOFC, CHP- ICE

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µ-WKK op waterstof, verschillende types

- Verbrandingstechnologie**
 - Minder zuivere waterstof nodig
 - Flexibiliteit naar brandstof
 - Lagere elektrische efficiëntie, meer warmte
 - Uitstoot Nox?
 - Levensduur
- PEM-brandstofcel**
 - Zuivere waterstof nodig
 - Lage temperatuur => flexibel aan/uit
 - Lagere elektrische efficiëntie, meer warmte
 - Nul uitstoot
- SOFC (Solid Oxide brandstofcel)**
 - Hoge temperatuur => continue operatie
 - Verschillende brandstoffen mogelijk
 - Hogere elektrische efficiëntie
 - Nul uitstoot

100% H₂

Viessmann Vitocalor PA2
0,75 kW elektriciteit (37%)
1,1 kW warmte

Vandaag werken de brandstofcellen altijd op aardgas.
Lokale SMR nodig om H₂ te onttrekken aan methaan

Elugie 600s elektrische rendement (1,5kW)
30% thermisch (0,75 kW)

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Omzetting elektriciteit → waterstof → stroom en warmte

Gebruik in gebouwen

- Aparte componenten:
 - Elektrolyse van waterstofpanelen
 - + brandstofcel of ICE-WKK
- All-in-one oplossingen
 - Reversibele brandstofcel

SOLENO POWER

The only raw material: WATER

Electricity from Renewable Energy Sources

The reversible process generates H₂ obtained by electrolysis with an efficiency of 90%

The reversible process uses H₂ obtained by production efficiency of 90%

Carbon free

Output

Electricity

Thermal Energy

Domestic Hot Water

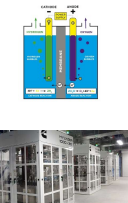
Heating System

38

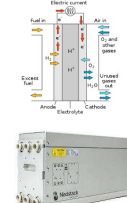
37

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Technologies




Electrolysers



Fuel Cells



Engines



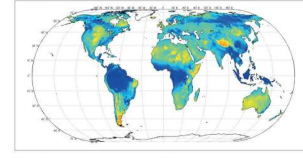
Boilers

39

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
Transport of renewable electricity from regions with ideal conditions

Figure 8. Hybrid solar and wind full load hours adjusted by critical overlap in 2005




Disclaimer: The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the ICA.


Source: Adapted and based on Faeh, Roggman and Bryner (2016), "Techno-Economic Assessment of Power-to-Liquids (PtL) Fuel Production and Global Trading Based on Hybrid PV-Wind Power Plants".




Storage & Liquefaction




Transport



Storage



Pipelines



End use

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H2 Policy context Europe



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Hydrogen developments in Brussels



The EU hydrogen ambition has significantly increased in the last three years

2020	2021	2022
<p>European Hydrogen Strategy</p> <ul style="list-style-type: none"> Ambition of producing 1 Mt by 2024 and 10 Mt of renewable hydrogen by 2030 Ambition of 40 GW_{el} of electrolyzers by 2030 [56-62 GW_{el}] 	<p>Fit for 55 Hydrogen and Decarbonised Gas Package</p> <ul style="list-style-type: none"> Numerous legislative initiatives <ul style="list-style-type: none"> Industry target (50%) General industry demand ~3.3 Mt¹ RFNBOs in transport (2.6%) General transport demand~ 3.4 Mt¹ Others <ul style="list-style-type: none"> Hydrogen and decarbonised gas package Gas regulation Gas directive 	<p>RePowerEU</p> <ul style="list-style-type: none"> Raising the Fit for 55 ambition <ul style="list-style-type: none"> Targets of 10 Mt of domestic renewable H₂ production and 10 Mt of imports Industry target (50%=>75%) General industry demand 3.3->8.3 Mt¹ RFNBOs in transport (2.6%=>5%) General transport demand (3.4->6.4 Mt¹) CCfD Hydrogen Valleys IPCEI acceleration Developing European hydrogen grid (H₂ in TEN-E) 3 import corridors Other support mechanisms

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Renewable Energy Directive (RED III): targets on H2 use 

EU institutions reach agreement on RED III - key implications for hydrogen March 31, 2023

- 42% RFNBO in 2030 in industry, 60% in 2035
- 1 % RFNBO in 2030 in transport,



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WaterstofNet Isabel François
Isabel.Francois@waterstofnet.eu

Open Manufacturing Campus
Scheidtsweg 112 Bus 1
2300 Turnhout
België
T +32 (0)14 40 12 19

Kantoor Nederland
Automotive Campus
Automotive Campus 30
5708 JZ Helmond
Nederland

 WaterstofNet
 WaterstofNet
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Bedankt voor uw aandacht!
Thank you for your attention!



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