

HYDROGEN PRODUCTION & APPLICATIONS

› HYDROGEN – 3 WEBINARS

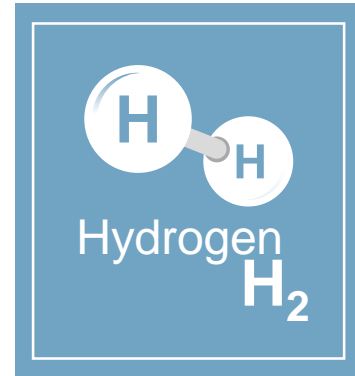
The role
Past

Production,
technologies
and applications
Today

Hydrogen and what
The Netherlands has
to offer
9 December

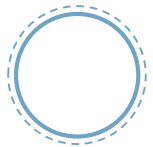
› WEBINARS HYDROGEN: HOW DOES IT WORK?

- › Ask questions by using the button below at right bottom in the video screen
- › Questions that are not answered are answered later.





1. WHAT TECHNOLOGY IS/WILL BE THE MOST PROMINENT



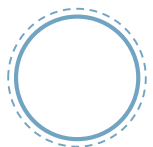
Depends on policy



Depends on research



Depends on context



Depends on belief



› HYDROGEN SPEAKERS

› Rogier Elshout – moderator



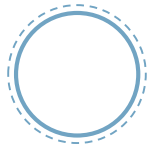
› Lennart van der burg - Business Developer Hydrogen and Synthetic Fuels at TNO



› Roel de Natris - Project Manager/ Consultant Automotive at TNO



1. ANSWER WHAT TECHNOLOGY IS/WILL BE THE MOST PROMINENT



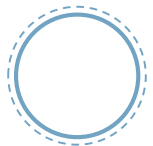
Depends on policy



Depends on research



Depends on context



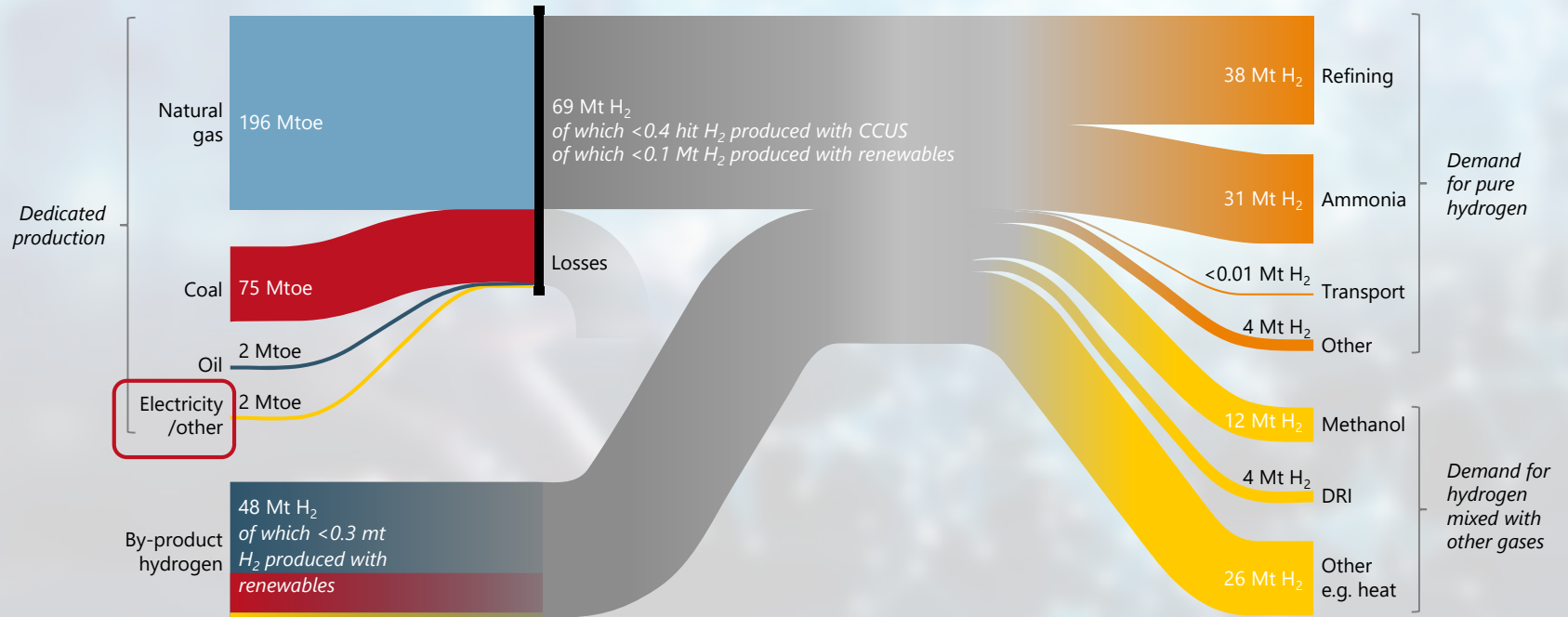
Depends on belief



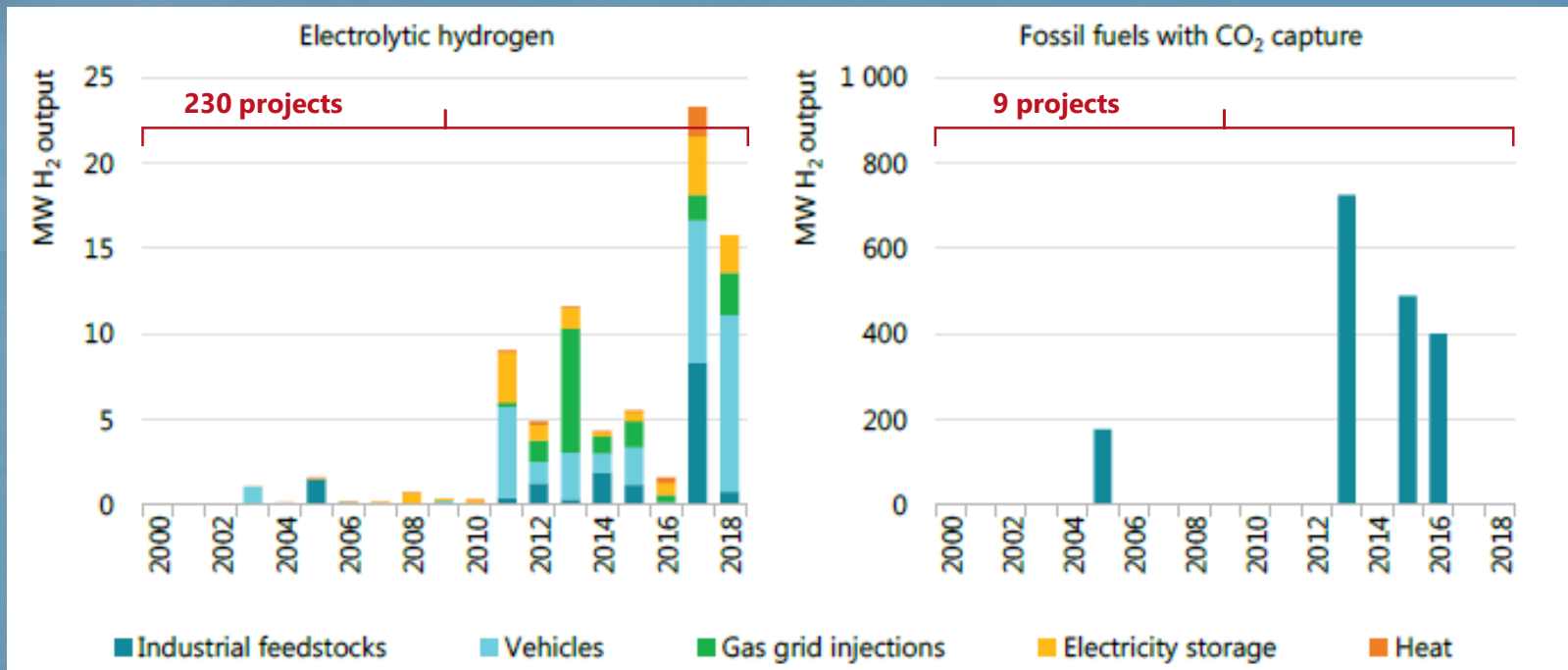


HYDROGEN PRODUCTION

CURRENT PRODUCTION & DEMAND WORLDWIDE



SIZE OF COMPLETED PROJECTS WORLDWIDE



ELECTROLYSER STACK

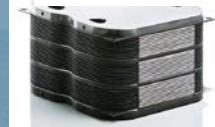
Alkaline



PEM



SOE



AEM



BIGGEST CHALLENGES OF ELECTROLYSIS



Reducing costs



Industrialization



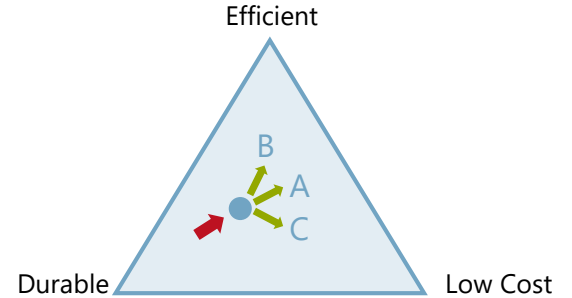
More Renewable electricity



Scarce materials

- A. Decrease membrane thickness
- B. Operate at higher temperature
- C. Use lower catalyst loadings

Key objective of our R&D:
Reduce cost of components
while maintaining durability



PERIODIC TABLE OF THE ELEMENTS

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Legend:
- Alkaline (Orange)
- PEM (Blue)

RESEARCH AND TEST FACILITIES



Faraday lab



Hydrohub



2. WHICH PARTNER IS CRUCIAL FOR UPSCALING ELECTROLYSIS



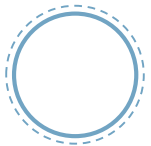
Electrolyser manufacturers



Government



The industry who need hydrogen



All partners in de supply chain

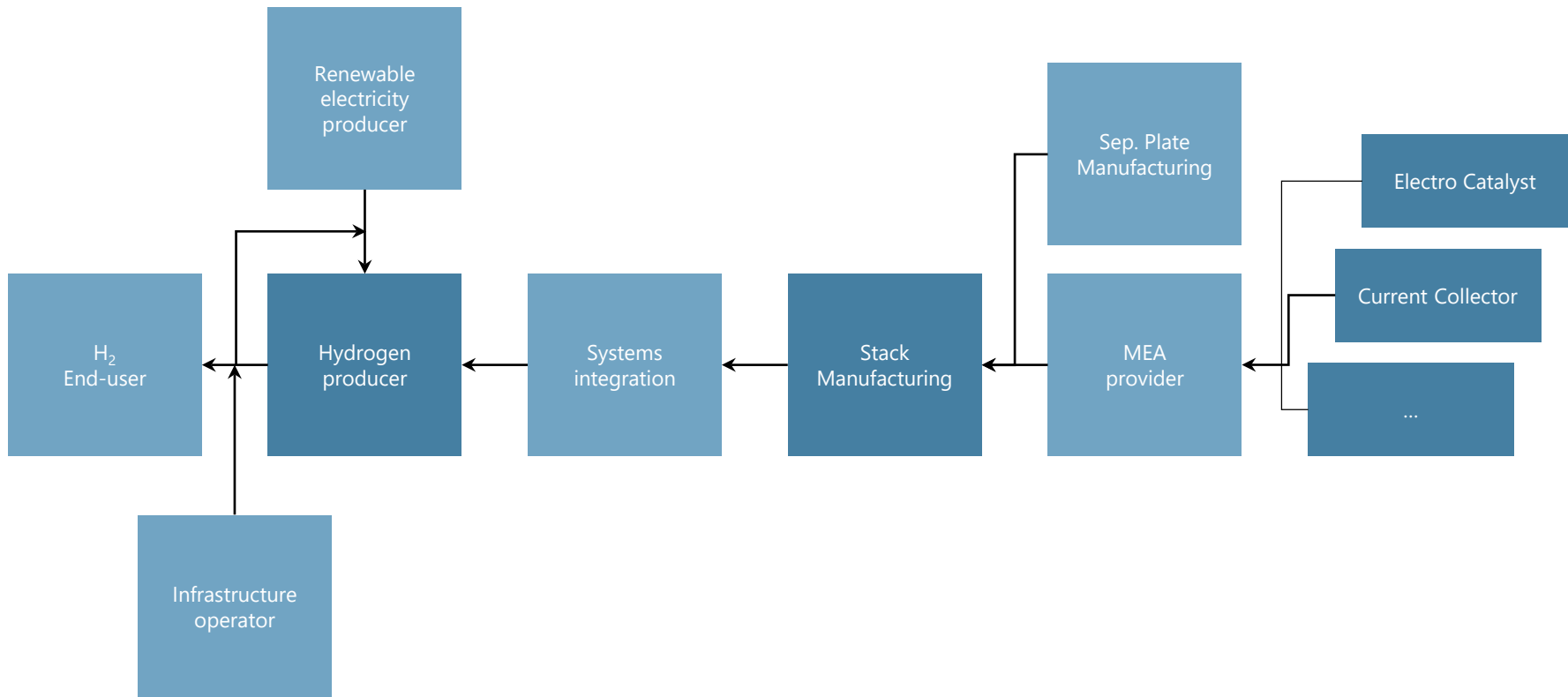


› **VIDEO FARADAY: TNO
RESEARCH FACILITY WITH
JOINT INNOVATION
PARTNERS**





DEVELOPING THE SUPPLY CHAIN



2. ANSWER WHICH PARTNER IS CRUCIAL FOR UPSCALING ELECTROLYSIS



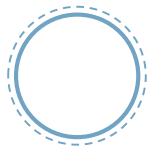
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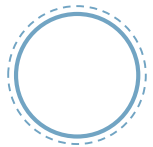


All partners in de supply chain



HYDROGEN IN TRAFFIC, TRANSPORT AND MOBILITY

3. WHEN WILL IT BE SCALED UP IN LOGISTICS



2025



2035



2050

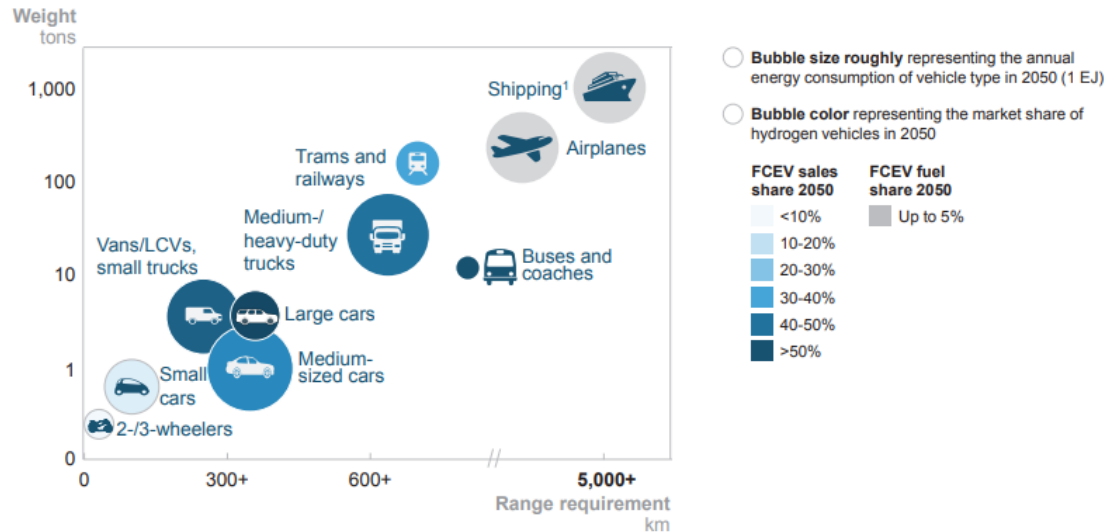


>2050



WHY HYDROGEN VOOR HEAVY TRANSPORT?

Transportation market segmentation





SAFETY

H2 tanks pass extremely demanding testing

Tank designers and inspectors run a multitude of tests in laboratories to ensure safety



Burst test



Bonfire tests



Crush test
150 t force (Power-tech)

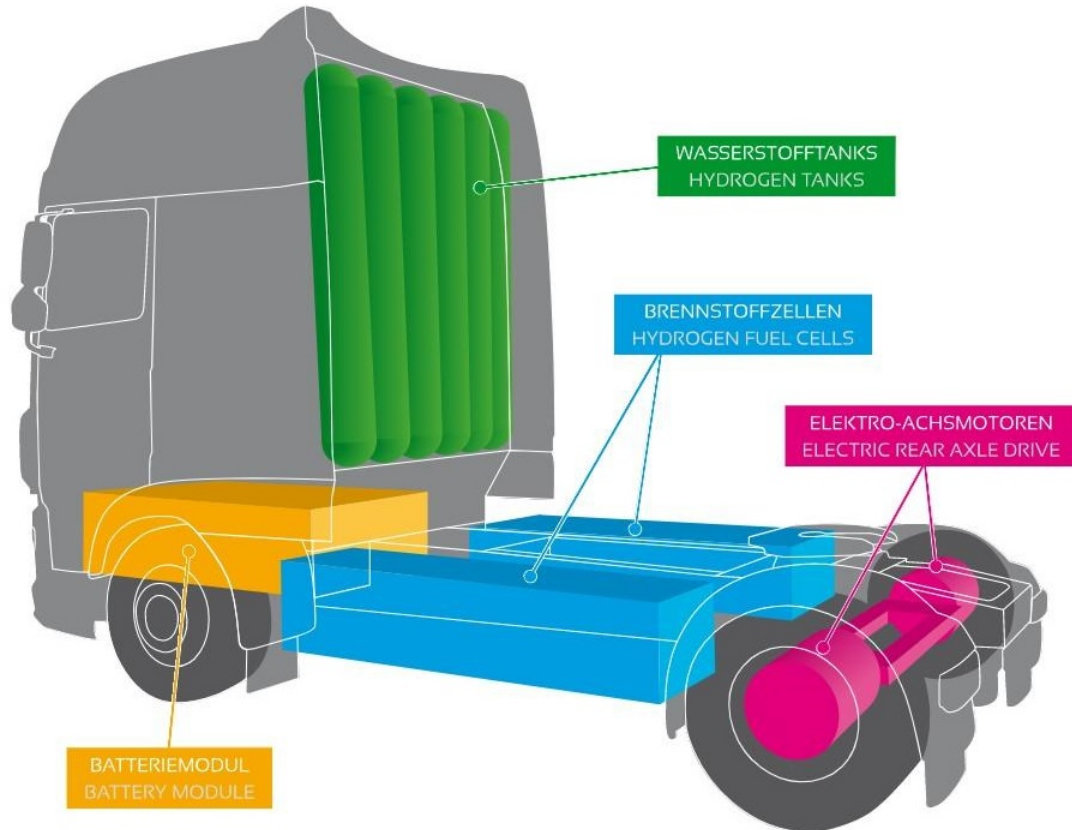


Gunshot test
(tested at Powertech1)

¹Armour-piercing 7mm test according to UN Technical Regulation

Mirai complies with all U.S. and international vehicle safety standards

› CONFIGURATION



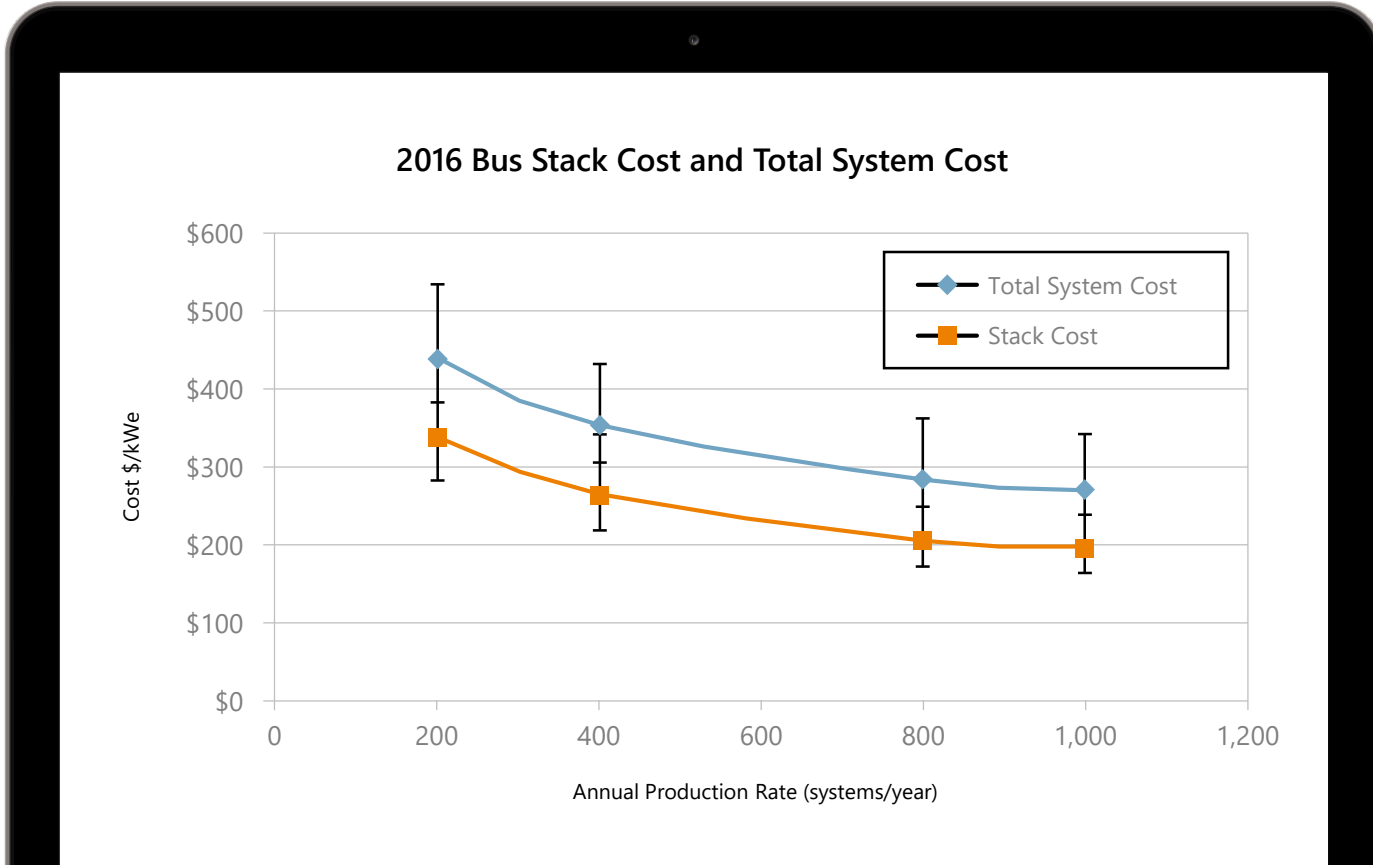
3. ANSWER WHEN WILL IT BE SCALED UP IN LOGISTICS

- 2025
- 2035
- 2050
- >2050





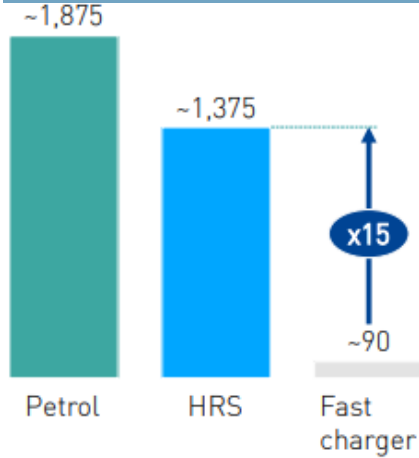
COST



FUEL

Refueling speed

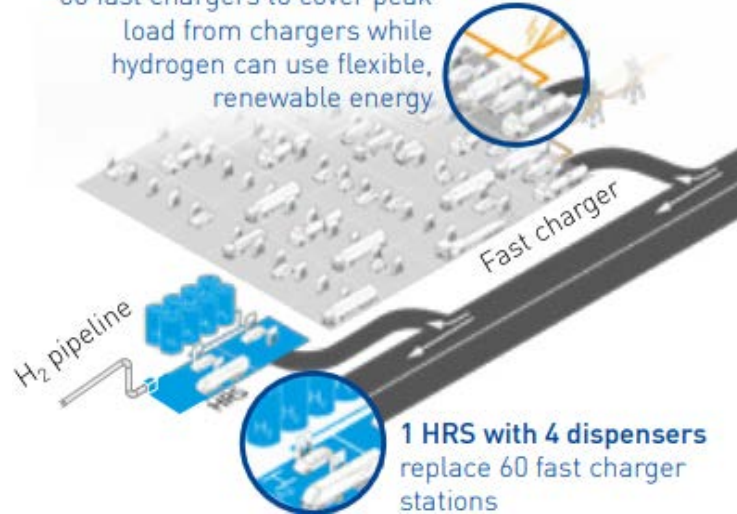
KM/15 minutes of refueling



Hydrogen refueling is **15x faster** than fast charging

Space requirements

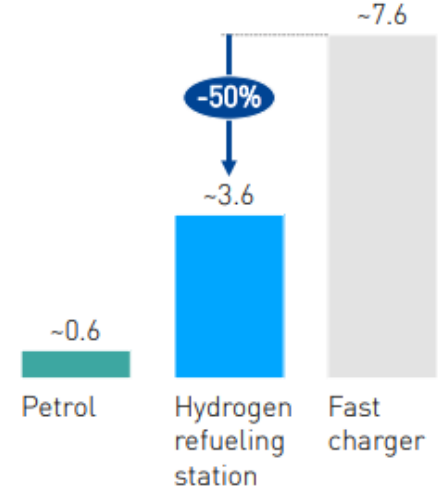
~8 MW powerline required for 60 fast chargers to cover peak load from chargers while hydrogen can use flexible, renewable energy



1 HRS with 4 dispensers replace 60 fast charger stations

Investment costs per refueling

EUR/refueling



Hydrogen refueling is **half as capital-intensive** as fast charging

INFRASTRUCTURE

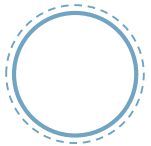


- Operationeel - Openbaar
- Operationeel - Niet openbaar
- In aanbouw
- Gepland / Subsidie ontvangen
- Nieuw initiatief



Versie: 01/10/2019
Voor laatste versie, zie: www.waterstofnet.eu/nl/infrastructuur/overzicht-waterstofstations-benelux

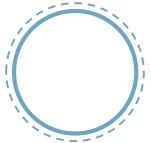
4. WHICH CHALLENGE IS MOST CRITICAL FOR TRANSPORT?



Clarity about depreciation of the hydrogen components



TCO (price)



Unrolled infrastructure

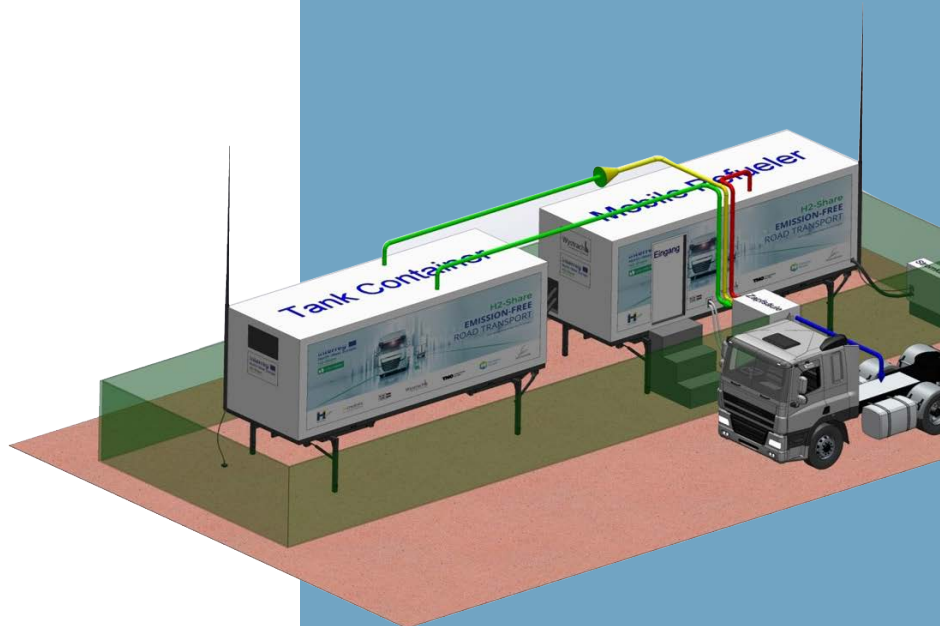


IMPACT PROJECT – H2SHARE

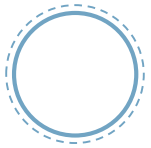
Rigid with H2 Range extender

GVW	27 ton
Power	210 kW
Torque	2.000 Nm
Battery capacity	82 kWh
Battery charging	3C

Range extender	
Charging power	88 kW
Volume	30kg H2
Range	400 km



4. ANSWER WHICH CHALLENGE IS MOST CRITICAL FOR TRANSPORT?



Clarity about depreciation of the hydrogen components



TCO (price)



Unrolled infrastructure



TO REMEMBER



Hydrogen for mobility has the greatest potential in heavy-duty vehicles



Hydrogen safety in vehicles has been extensively investigated

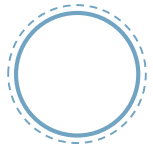


Transition is set in motion by creating supply and demand



FUTURE AVIATION FUELS

5. WHAT IS NEEDED TO KICK START THE FUTURE AVIATION FUELS?



Subsidy



Tax fossil



A mandate

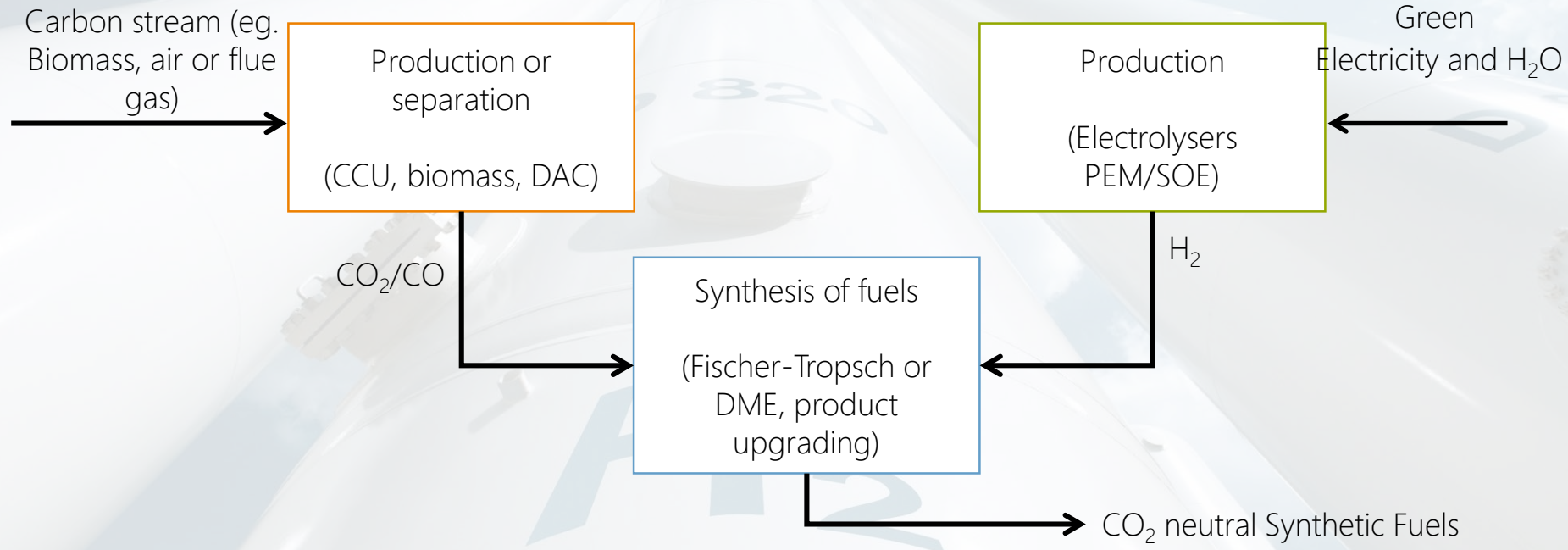


Technology development



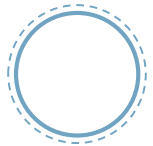
AVIATION

HOW TO PRODUCE SYNTHETIC FUELS?





5. ANSWER WHAT IS NEEDED TO KICK START THE FUTURE AVIATION FUELS?



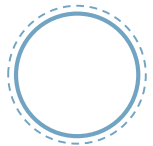
Subsidy



Tax fossil



A mandate



Technology development

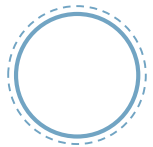




TNO innovation
for life

INDUSTRY PROJECTS

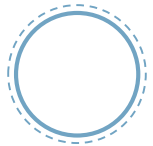
6. HOW TO IMPROVE BUSINESS CASE OF ELECTROLYSIS IN THE INDUSTRY



Lower electricity price



CAPEX reduction



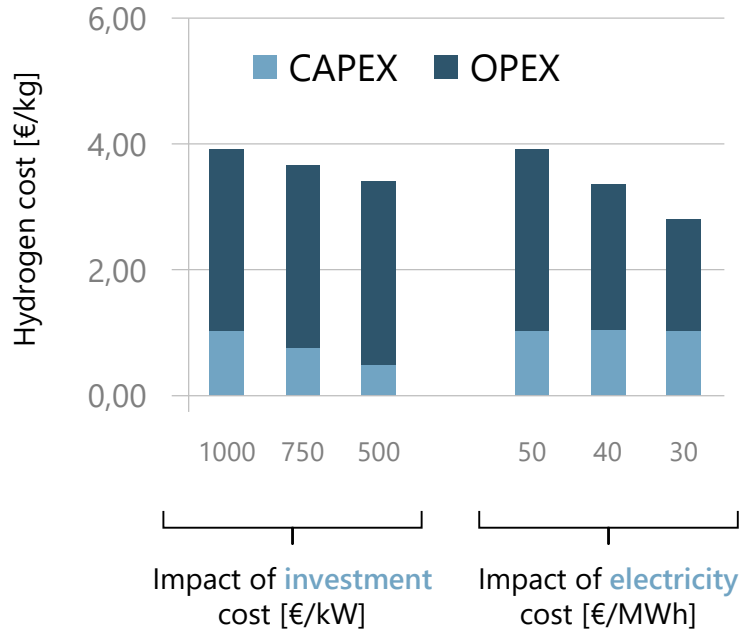
System integration



Higher H₂ selling price



› COSTS (1/2)



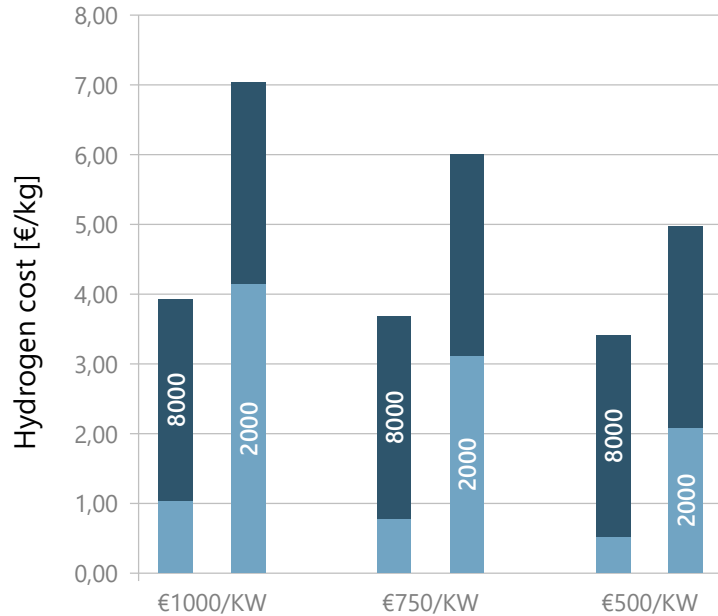
Two major costs:

- › Electrolyser costs (CAPEX)
- › Electricity costs (OPEX)

Base case (BC)

Investment cost	1000 M€/kWh
Depreciation	15% /year
O&M	2% /year
Electricity price	50 Euro/MWh
Operating hours	8000 hours
Efficiency	60%

› COSTS (2/2)



Cost reduction

- › Stack
- › Balance of plant and system
- › Smart contracts with offshore wind

and

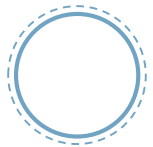
Increase profit

- › Multiple H2 markets
- › Value of flexibility
- › Value of oxygen
- › Value of heat

← Operational hours per year



› 6. ANSWER HOW TO IMPROVE BUSINESS CASE ELECTROLYSIS IN INDUSTRY?



Lower electricity price



CAPEX reduction



System integration



Higher H₂ selling price



H2 IN STEEL INDUSTRY

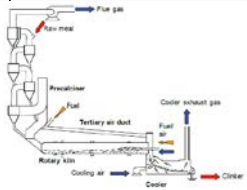
Pathways	Low-carbon smart technologies (+CCS)	Carbon Direct Avoidance (CDA)	
Description	<ul style="list-style-type: none">• Process integration with reduced use of carbon	<ul style="list-style-type: none">• CCU using CO/CO2 from steel mill as raw material	<ul style="list-style-type: none">• Production of H2 to replace carbon
Key projects	<ul style="list-style-type: none">• HISARNA	<ul style="list-style-type: none">• SEWGS, Carbon2Chem, FReSME, Steel2chemicals, SOE,	<ul style="list-style-type: none">• HYBRIT, H2FUTURE

H2 CO-ELECTROLYSE

Steam H₂O

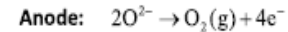
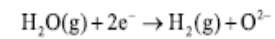
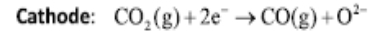
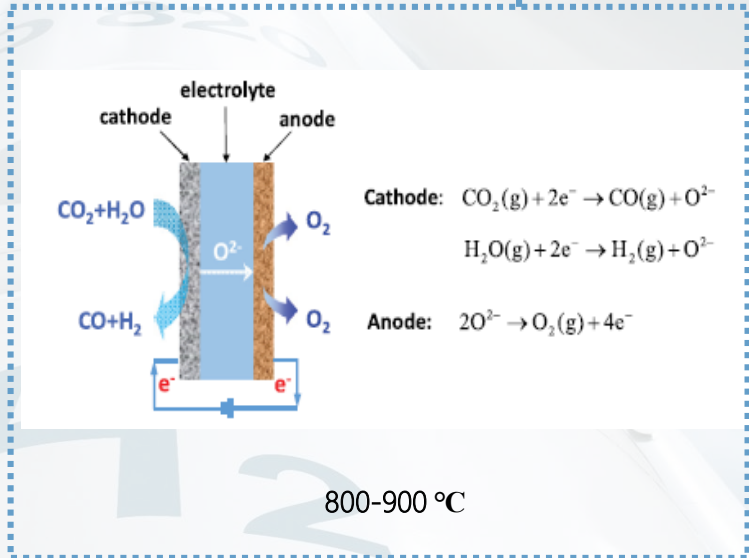


Hisarna TATA Steel



Direct capture / Oxy-combustion Cement clinker plant

Other hot CO₂ processes



O₂:
Useful for oxy-driven processes of steel and cement industry!

Syngas:
Starting ingredient for new chemical products such as fuel

COLLABORATING ON THE ENERGY TRANSITION IS CRUCIAL



› WEBINARS HYDROGEN

- › Please fill in the evaluation visible on your screen
- › View the webinars on demand and sign up for the next webinar: www.tno.nl/hydrogen
- › 9 December 15.00 (English): The Netherlands the international hydrogen hub?
Speakers: Noé van Hulst (National Hydrogen Envoy), René Schutte (Gasunie), René Peters (TNO)
- › Visit and participate in TNO's hydrogen breakout session at het **European Industry and Energy Summit (EIES)** in Amsterdam 11 december 2020

› **THANK YOU FOR
YOUR
ATTENTION**