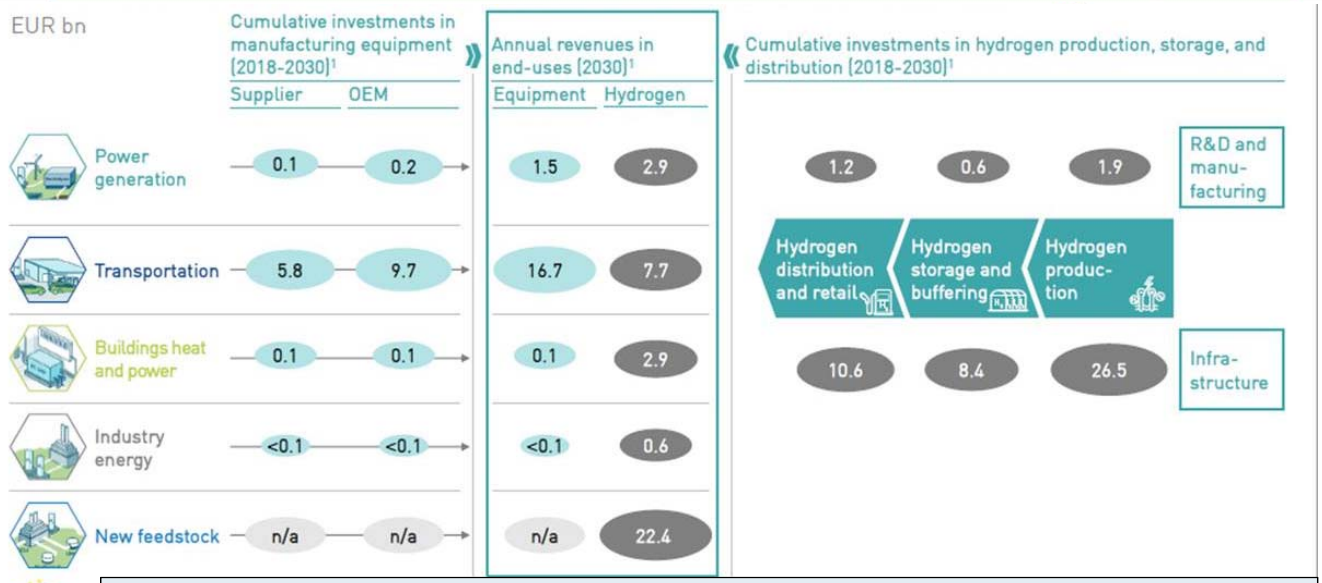
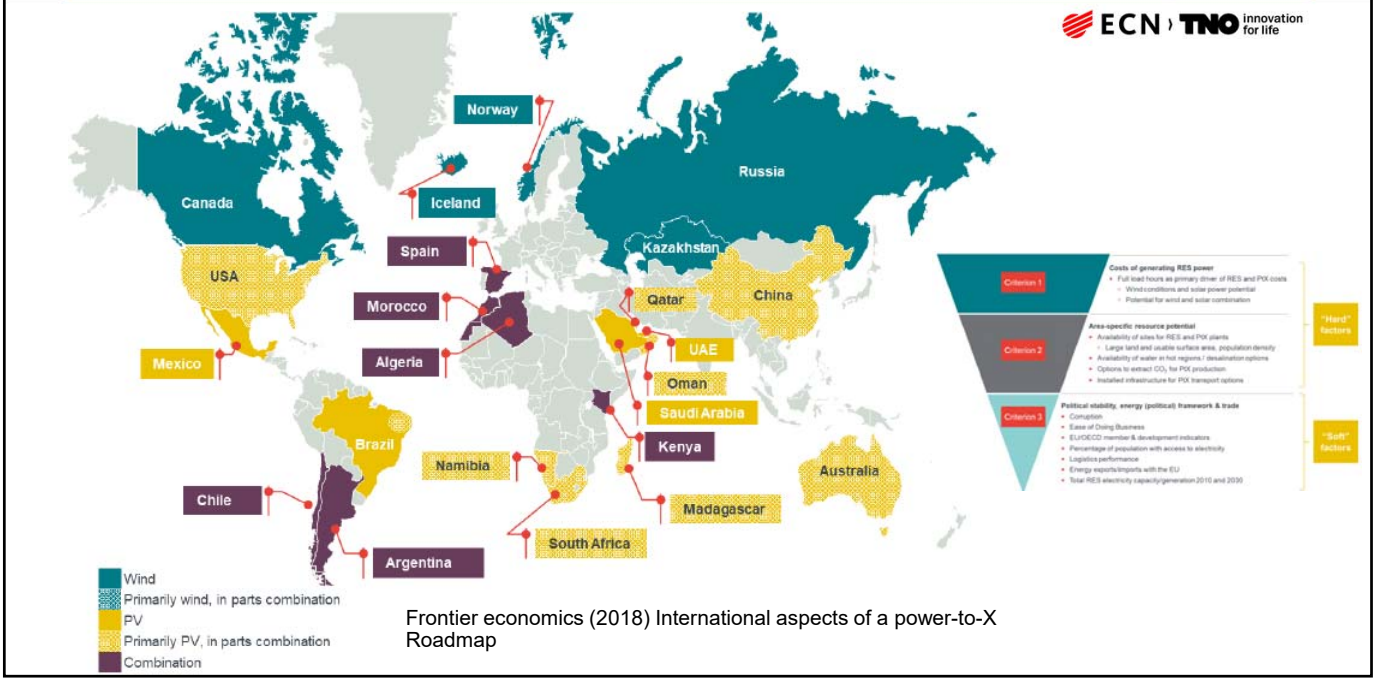
(GREEN) HYDROGEN MARKET POTENTIAL



By 2030, 65 billion cumulative investments and opens a market up to 55 billion annual sales in EU

STRONGEST POTENTIAL P2X PRODUCERS (1/2)



Frontier economics (2018) International aspects of a power-to-X Roadmap

STRONGEST POTENTIAL P2X PRODUCERS (2/2)

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Type	PtX motivation and readiness	Selected example
Frontrunners	▪ PtX already on countries (energy) political radar ▪ Export potential and PtX readiness evident ▪ Uncomplicated international trade partner ➢ Especially favourable in early stages of market penetration	Norway
Hidden Champions	▪ Fundamentally unexplored RES potential ▪ Largely mature, but often underestimated, (energy) political framework with sufficiently strong institutions ➢ PtX could readily become a serious topic if facilitated appropriately	Chile
Giants	▪ Abundant resource availability: massive land areas paired with often extensive RES power ▪ PtX readiness not necessarily precondition, may require facilitation ➢ Provide order of PtX magnitudes demanded in mature market	Australia
Hyped Potentials	▪ At centre of PtX debate in Europe with strong PtX potential ▪ Energy partnerships with Europe foster political support ➢ Potential to lead technology development; may depend strongly on solid political facilitation	Morocco
Converters	▪ Global long term conversion from fossil to green energy sources ▪ PtX to diversify portfolio as alternative long-term growth strategy ➢ Strong motivation for PtX export technology development; may requires political facilitation and partnership with the EU/DE	Saudi Arabia
Uncertain Candidates	▪ Partially unexplored RES potentials, possibly paired with ambitious national climate change policies ▪ PtX export in competition with growing national energy demand ➢ PtX export motivation and potential unclear – may drive PtX technology development, however export uncertain	China

Frontier economics (2018) International aspects of a power-to-X Roadmap

SCENARIO'S HYDROGEN DEMAND NL & GE

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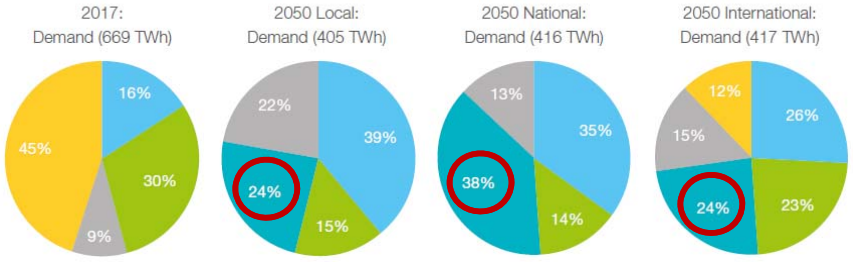
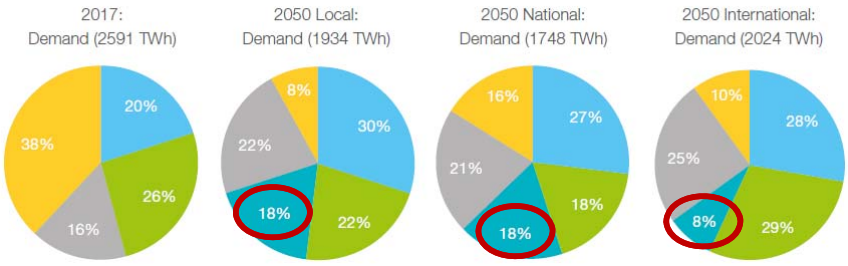
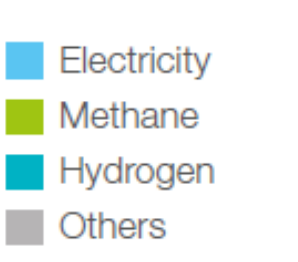
Final energy demand for the Netherlands (2017 and three 2050 scenarios)



Final energy demand for Germany (2017 and three 2050 scenarios)





SCENARIO'S HYDROGEN DEMAND NL

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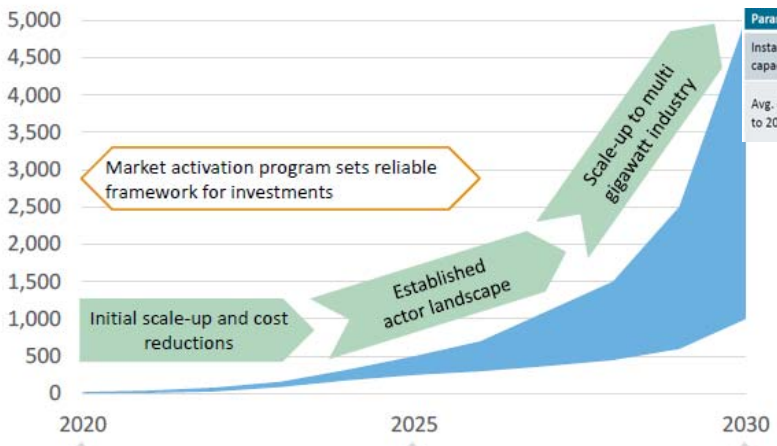
	Local	National	International
Power & Light	25% base-load savings through more efficient appliances. Substantial electrification of industry	25% base-load savings through more efficient appliances. Substantial electrification of industry	25% savings through more efficient appliances
Low-temperature heat	High penetration of heat grids and all-electric (restrictions on green gas, no H_2 distribution) Savings: 23%	High penetration of hybrid heat pumps burning H_2 (and green gas) (restrictions on green gas) Savings: 23%	High penetration of hybrid heat pumps burning H_2 and green gas (mild restrictions on green gas). Savings: 12%
High-temperature & feedstock industry	Circular industry and ambitious process innovation: 60% savings 55% electrification 97% lower CO_2 emissions	Circular industry and ambitious process innovation: 60% savings 55% electrification 97% lower CO_2 emissions	Biomass-based industry: 55% savings 35% biomass 14% electrification 95% lower CO_2 emissions
Passenger transport	100% electric	75% electric 25% hydrogen	50% electric 25% green gas 25% hydrogen
Freight transport	50% green gas 50% hydrogen	50% green gas 50% hydrogen	25% synthetic fuels 25% green gas 50% hydrogen
Renewables generation	84 GW solar 16 GW onshore wind 26 GW offshore wind	34 GW solar 14 GW onshore wind 53 GW offshore wind	16 GW solar 5 GW onshore wind 6 GW offshore wind
Conversion and storage	75 GW electrolysis 60 GW battery storage	60 GW electrolysis 50 GW battery storage	2 GW electrolysis 5 GW battery storage
Hydrogen	100 TWh domestic generation	158 TWh domestic generation	73 TWh import 4 TWh domestic generation
Methane	23 TWh domestic biomethane 35 TWh imported natural gas	46 TWh domestic biomethane 55 TWh imported natural gas	24 TWh domestic biomethane 72 TWh imported natural gas
Biomass			28 TWh import

SCENARIO'S HYDROGEN DEMAND GE

ECN TNO innovation for life

	Local	National	International
Power & Light	25% base-load savings through more efficient appliances	10% savings	25% savings through more efficient appliances
Low-temperature heat	High penetration of efficient electric heat pumps. Savings: 41%	High penetration of heat pumps and gas fired heaters burning methane. Savings: 33%	35% Electric heat pumps. Savings: 41%
High-temperature & feedstock industry	Mix of many energy sources: 15% savings 16% biomass 29% electrification 100% lower CO_2 emissions	Mix of many energy sources: 25% savings 24% biomass 29% electrification 100% lower CO_2 emissions	Growing importance of green gas in industry: 18% savings 4% biomass 36% electrification 86% lower CO_2 emissions
Passenger transport	100% electric	25% electric 25% hydrogen 50% synthetic fuels	25% electric 25% hydrogen 25% methane 25% synthetic fuels
Freight transport	50% hydrogen 50% synthetic fuels	35% hydrogen 65% synthetic fuels	25% electric 25% hydrogen 50% synthetic fuels
Renewables generation	600 GW solar 210 GW onshore wind 64 GW offshore wind	218 GW solar 193 GW onshore wind 191 GW offshore wind	114 GW solar 171 GW onshore wind 26 GW offshore wind
Conversion and storage	281 GW electrolysis 110 GW battery storage	254 GW electrolysis minor effect of battery storage on transmission level	63 GW electrolysis 15 GW battery storage
Hydrogen	365 TWh by domestic P2G *No imports* Demand from industry/transport Fuel for power-plants	323 TWh by domestic P2G *No imports* Demand from industry/transport Fuel for power-plants	164 TWh by domestic P2G *5 TWh imports* Relatively small demand from industry/ transport
Methane	365 TWh by domestic methanation 200 TWh by domestic biomethane *No imports* High demand in all sectors	323 TWh by domestic methanation *No imports* Demand from residential	No domestic methanation *108 TWh imports* High demand in all sectors
Power-fuels	151 TWh by domestic generation *No imports* Demand from transport	No domestic generation *286 TWh imports of green power-fuels* Demand from transport	87 TWh by domestic generation *108 TWh imports of green power-fuels* Demand mainly from transport, but also from industry and residential

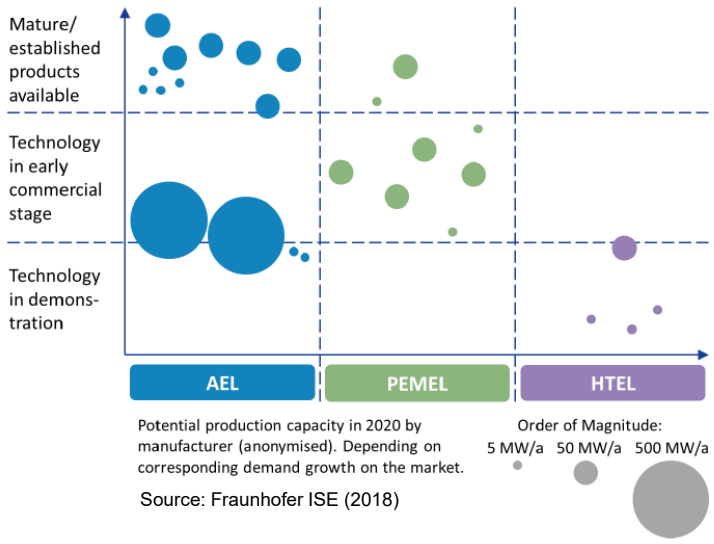
POSSIBLE ROLL OUT SCENARIO GE



Parameter	Unit	2030	2050
Installed electrolysis capacity	[GW]	44 (7 - 71)	213 (137 - 275)
Avg. deployment (relative to 2017)	[GW/a]	3.4 (0.5 - 5.4)	6.4 (4.2 - 8.3)

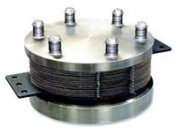
Source: Fraunhofer ISE (2018)

EXPECTED GROWTH PER TECHNOLOGY



Source: Fraunhofer ISE (2018)

PEM short stack (Hydron Energy)



Alkaline short stack (Hydrogenics)

SOFC design

Tapecasting at ECN

OPTIMIZING THE BUSINESSCASE (1/2)

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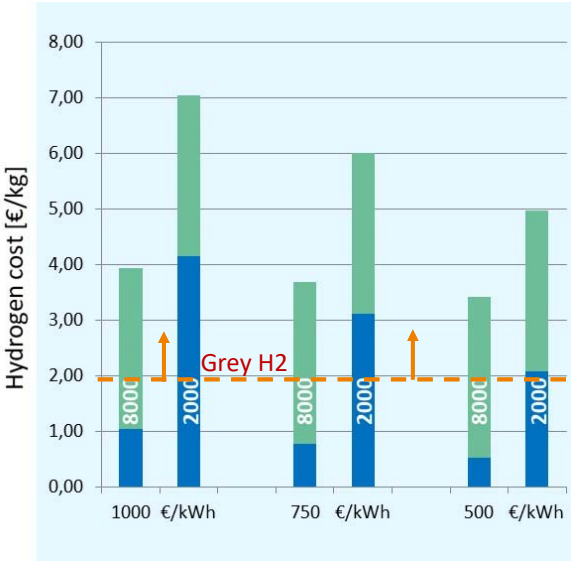


To reduce cost of hydrogen:
- Improve efficiency
- Smart PPA contracts for RES
- Reduce electrolyser cost CAPEX

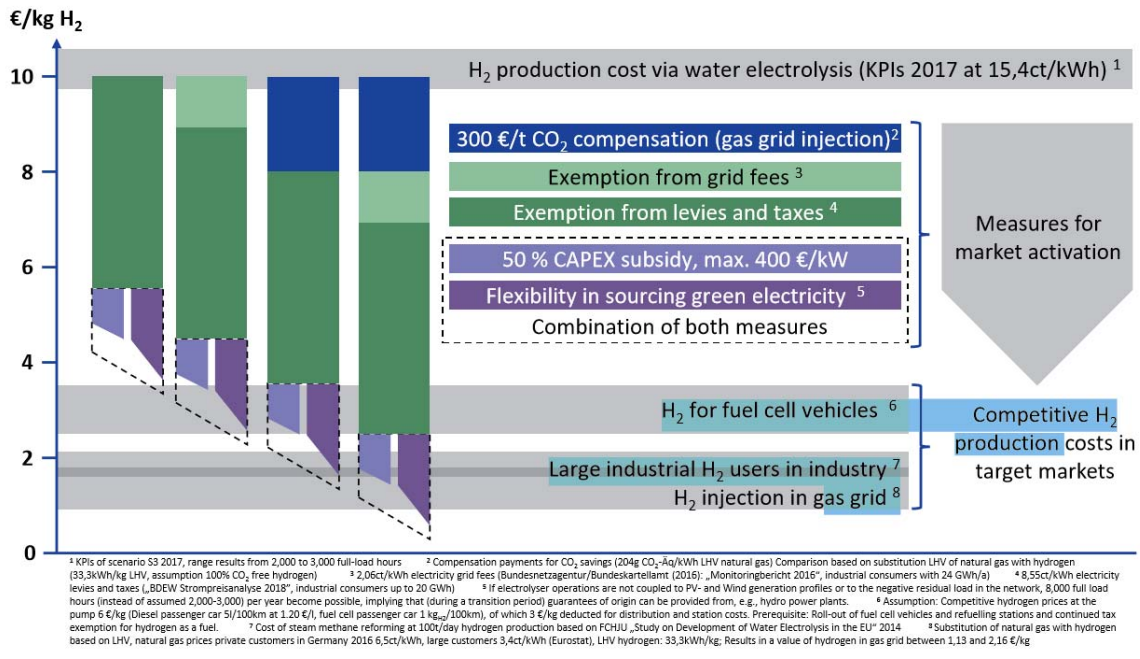
and / or

- Cost of the alternative (reference price gas)
- CO2 ETS / minimum prices
- Value of flexible demand
- Valorise value heat and oxygen
- Increase plant capacity (100+ MW)
- Expected lifetime

⟸ Operating hours per year

OPTIMIZING THE BUSINESSCASE (2/2)

innovation for life



1 KPIs of scenario S3 2017, range results from 2,000 to 3,000 full-load hours 2 Compensation payments for CO_2 savings (204g CO_2-Äq/kWh LHV natural gas) Comparison based on substitution LHV of natural gas with hydrogen (33,3kWh/kg LHV, assumption 100% CO_2 free hydrogen) 3 2,06ct/kWh electricity grid fees (Bundesnetzagentur/Bundeskartellamt (2016): „Monitoringbericht 2016", industrial consumers with 24 GWh/a) 4 8,55ct/kWh electricity levies and taxes („BDEW Strompreisanalyse 2018", industrial consumers up to 20 GWh) 5 If electrolyser operations are not coupled to PV- and Wind generation profiles or to the negative residual load in the network, 8,000 full load hours (instead of assumed 2,000-3,000) per year become possible, implying that (during a transition period) guarantees of origin can be provided from, e.g., hydro power plants. 6 Assumption: Competitive hydrogen prices at the pump 6 €/kg (Diesel passenger car 5l/100km at 1.20 €/l, fuel cell passenger car 1 kg_{H2}/100km), of which 3 €/kg deducted for distribution and station costs. Prerequisite: Roll-out of fuel cell vehicles and refuelling stations and continued tax exemption for hydrogen as a fuel. 7 Cost of steam methane reforming at 100t/day hydrogen production based on FCHJU „Study on Development of Water Electrolysis in the EU" 2014 8 Substitution of natural gas with hydrogen based on LHV, natural gas prices private customers in Germany 2016 6,5ct/kWh, large customers 3,4ct/kWh (Eurostat), LHV hydrogen: 33,3kWh/kg; Results in a value of hydrogen in gas grid between 1,13 and 2,16 €/kg

HOW TO MAKE SURE IT IS GREEN?

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CertifHy

Decision tree presenting the criteria for producing Low-Carbon and CertifHy Green H_2

Average **emissions** of **Non-CertifHy H_2 <91g$CO_{2\,eq}$/MJ** (benchmark)?

- No → **Production unit NOT ELIGIBLE**
- Yes → **Renewable energy** input into batch?
  - No → **100% Non- renew.** batch
    - Batch emissions **< 36,4g$CO_{2\,eq}$/MJ** (40% of benchm.)?
      - No → 100% Grey H_2
      - Yes → 100% Low-carbon H_2
  - Yes → **X% renewable and** and **(1-X%) non-renewable. share**
    - Renewable share emissions **< 36,4g$CO_{2\,eq}$/MJ ?**
      - No → X% Grey H_2
      - Yes → X% Green H_2
    - Non-renewable share emissions **< 36,4g$CO_{2\,eq}$/MJ ?**
      - No → 1-X% Grey H_2
      - Yes → 1-X% Low-carbon H2

Grey H_2 | CertifHy Green H_2 | CertifHy Low Carbon H_2 | Renewable energy | Non renewable energy

WHAT ARE THE INITIATIVES TODAY (1/2)?

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CONVERSIE

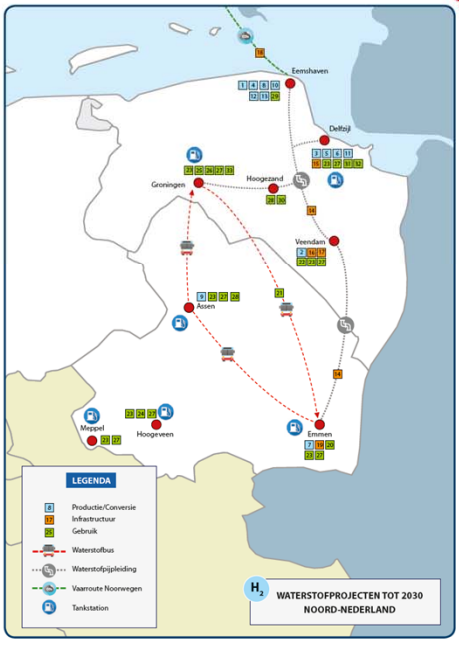
Bedrijf	Plan/Project	Plaats	Datum gereed
1. Equinor/Gasunie	Blauwe waterstof via ATR (H2M)	Eemshaven	2025/2026
2. Gasunie/HyStock	1 MW elektrolyser	Zuidwending	2018
3. Nouryon/Gasunie	20 MW elektrolyser	Delfzijl	2020/2021
4. Engie/Gasunie	100 MW elektrolyser	Eemshaven	2022
5. Lagerwey	2-3 MW waterstofwindmolen	Eemshaven/Delfzijl	2020
6. Lagerwey	4 maal waterstofwindmolen	Eemshaven/Delfzijl	2020/2022
7. Emmen partnership	2-5 MW elektrolyser	Emmen	2020
8. Nouryon	200 MW elektrolyser	Delfzijl	2025
9. Shell & Partners	Blauwe waterstof	N.n.b. (verbonden aan grote keten)	na 2024
10. Engie	Opschalen van 100MW naar 850MW en 1GW elektrolyser	Eemshaven	2026-2030
11. Binnenkort aangekondigd	40 MW elektrolyser	n.t.b.	2020
12. Nuon/Proton Ventures/ BASF/Yara/Orsted/TU Delft	Battolyser (15 kW proefinstallatie)	Eemshaven	2019
13. SCW/Gasunie	300 MW Superkritische watervergassing Eemshaven	Eemshaven	n.t.b.

INFRASTRUCTUUR

Bedrijf	Plan/Project	Plaats	Datum gereed
14. Gasunie	Leiding Eemshaven-Delfzijl-Zuidwending-Emmen	Eemshaven-Delfzijl-Emmen	2022/2023
15. GSP	Waterstofdistributienet Chemiepark Delfzijl	Delfzijl	2019
16. Gasunie/EnergyStock	Waterstofcaverne	Zuidwending	2023
17. Gasunie/EnergyStock	Waterstofcaverne	Zuidwending	2025/2026
18. Shell, NAM & Partners	CO_2-infrastructuur, offloading, shipping en (offshore) opslag	n.t.b.	na 2025
19. NAM & Partners	Kleine keten. hergebruik infra en locaties om duurzame energiebronnen te verbinden.	Emmen en andere clusters in Noord-Nederland	n.t.b.

GEBRUIK

Bedrijf	Plan/Project	Plaats	Datum gereed
20. Emmtec en Klanten	Hogetemperatuurwarmte en elektriciteit uit waterstof	Emmen	2020
21. OV Groningen/Emmen	Bussen op waterstof	Groningen/Emmen	2020
22. Nedmag	Omzetten branders en ovens	Veendam	2023
23. Holthausen/Green Planet/ Pitpoint	8 Tankstations voor mobiliteit	3 noordelijke provincies	2019-2022
24. Hydrogreenn	'Woonwijk op waterstof in Hoogeveen	Hoogeveen	begin jaren '20
25. Gemeente Groningen	Veegwagen en vuilniswagen op waterstof	Groningen	2018
26. Shell & Partners	050Buurtwarmte, 050BW Paddepoel	Groningen	n.t.b.
27. Shell & Partners	Waterstofpompstations	3 noordelijke provincies	n.t.b.
28. Holthausen	Fuel cell component factory	Hoogezand	2020 t/m 2025
29. Nuon	Magnumcentrale op waterstof	Eemshaven	2025/2026
30. Holthausen	Ombouw 5.000 waterstofvoertuigen	Hoogezand	2020 t/m 2025
31. BioMCN	Productie biomethanol uit emissievrije waterstof	Delfzijl	2021
32. Teijin Aramid	Ontwikkeling versterkte kunststoffeiding voor waterstof	Emmen	2018
33. ISPT & Partners	HydroHub. Test- en ontwikkelcentrum waterstof op EnTranCe	Groningen	2019



Example of H2 investment agenda North of the Netherlands

WHAT ARE THE INITIATIVES TODAY (2/2)?

AANBOD EN VRAAG WATERSTOF 2030

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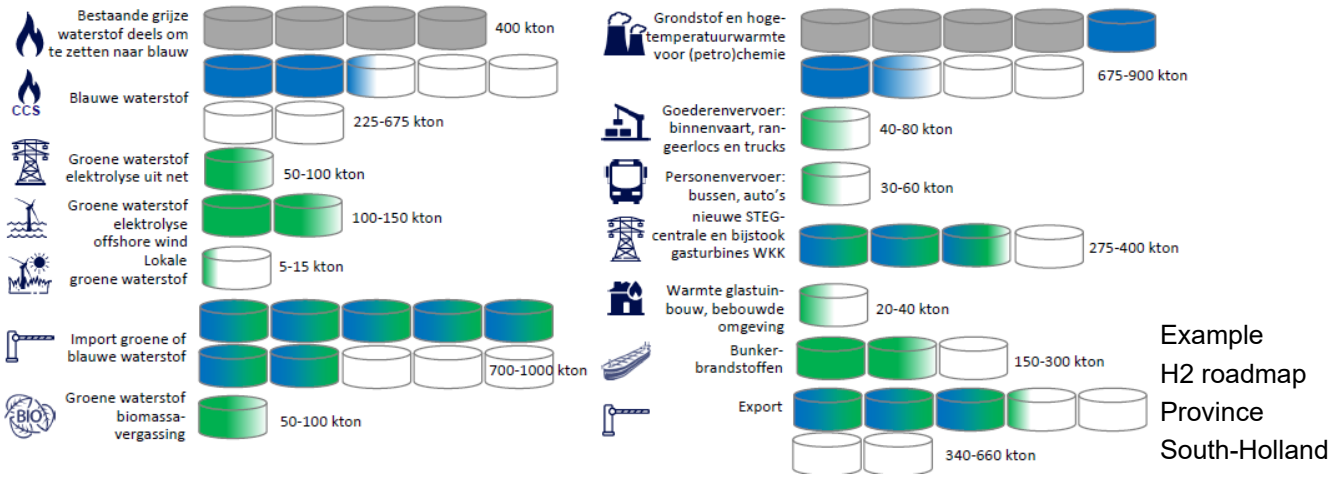


Example
H2 roadmap
Province
South-Holland

H2FUTURE - Hydrogen for the Steel Industry

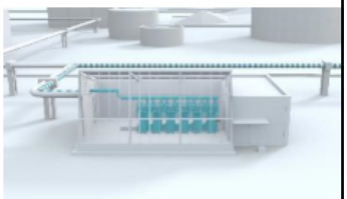
H2FUTURE

- Steel industry accounts for **30% of global industrial CO2 emissions (2 tons of CO2 emissions per ton of steel).**
- Replacing carbon with green hydrogen as the reducing agent is the only realistic way of **fulfilling CO2 reduction targets in 2050**.

Challenges

- Total **replacement of carbon** results in a significant increase in production costs.
- Huge demand for **green electricity 24/7** in the steel industry.

Source: voestalpine



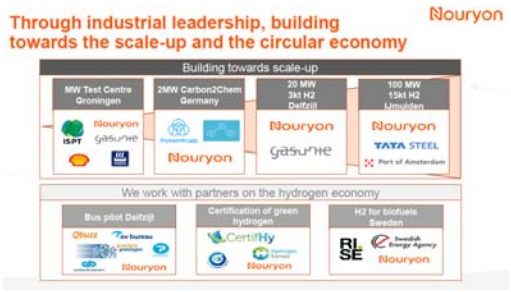
Verbund
voestalpine
SIEMENS
MET
APG
ECN

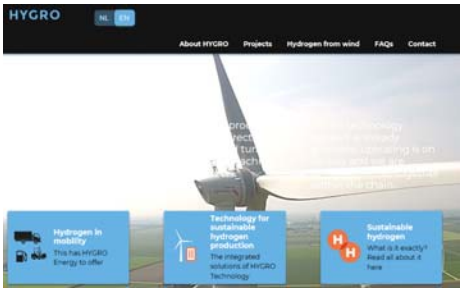
FCH | FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

http://www.h2future-project.eu

4

… AND STRATEGIES?





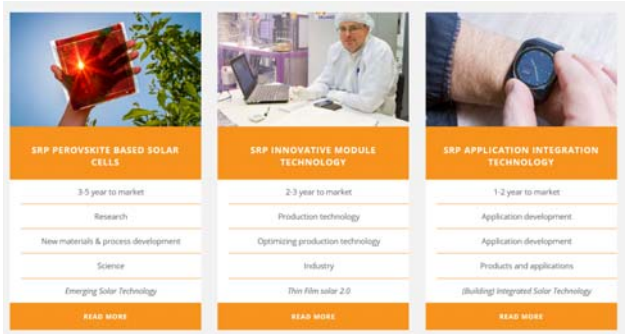
EXAMPLE SOLLIANCE

Can we leverage on 'green H2', the way we did it with the thin-film solar?

- In 8 years became a hotbed of shared, pre-competitive innovation
- 28ME initial investment, created value of 115+ ME, 80+ patents, 30+ industry partners, 150 direct jobs, 4 spin-off companies

Technology partnerships

- Shared and 1on1 research programs



Demo projects

- Involving with industry & knowledge partners

TAKE AWAYS

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- Green hydrogen will take a major roll in the future energy system
- Manny parties are (and will become) active with strategies, programs and projects
- Current market of green hydrogen is now limited → coming year many (demonstration) project
- Still many (innovation) challenges and regulation barriers in order to reach promised upscaling

→ Setting up a H2 supply chain is needed:

1. in order to deliver for projects larger than >XX MW
2. to realize further cost reduction and industrialization
3. to attract new companies to become active in this sector