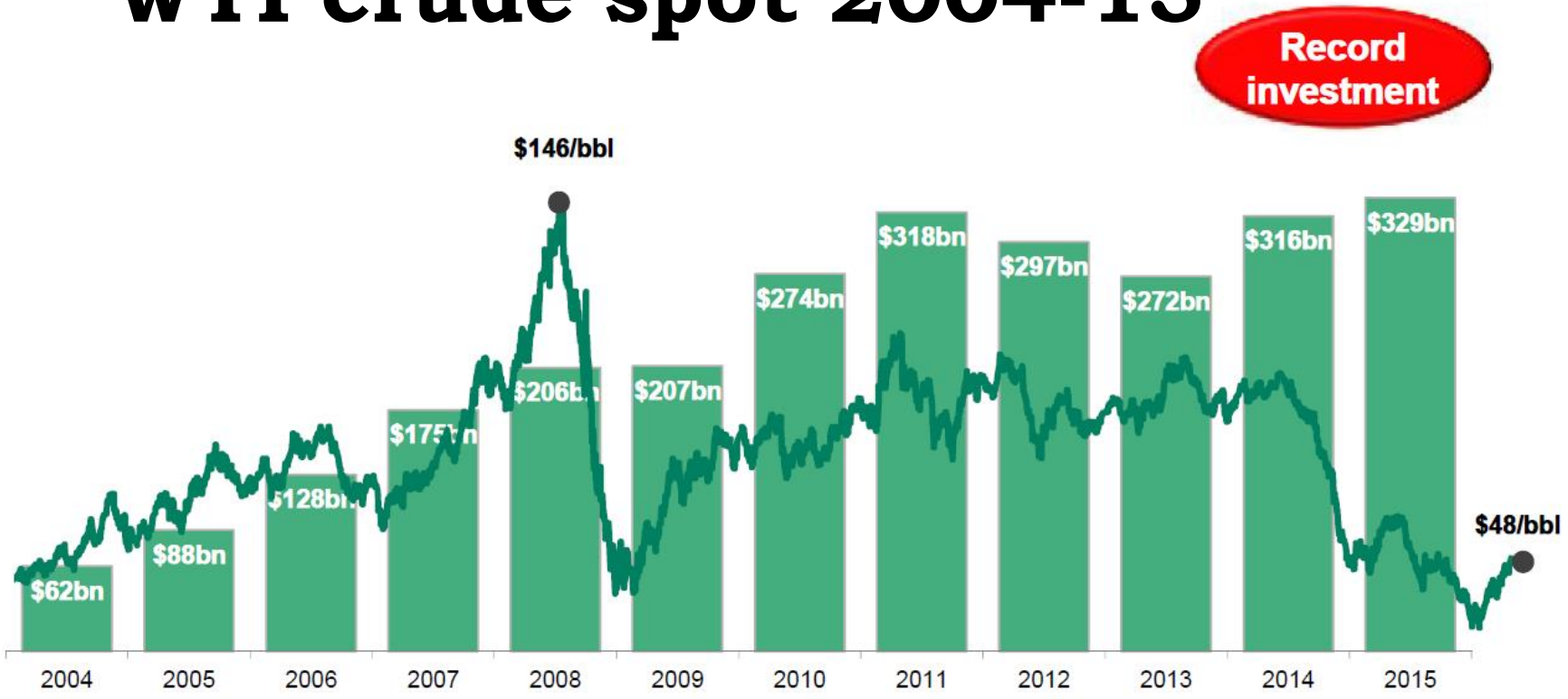
Green Hydrogen Economy

Prof. Dr. Ad van Wijk

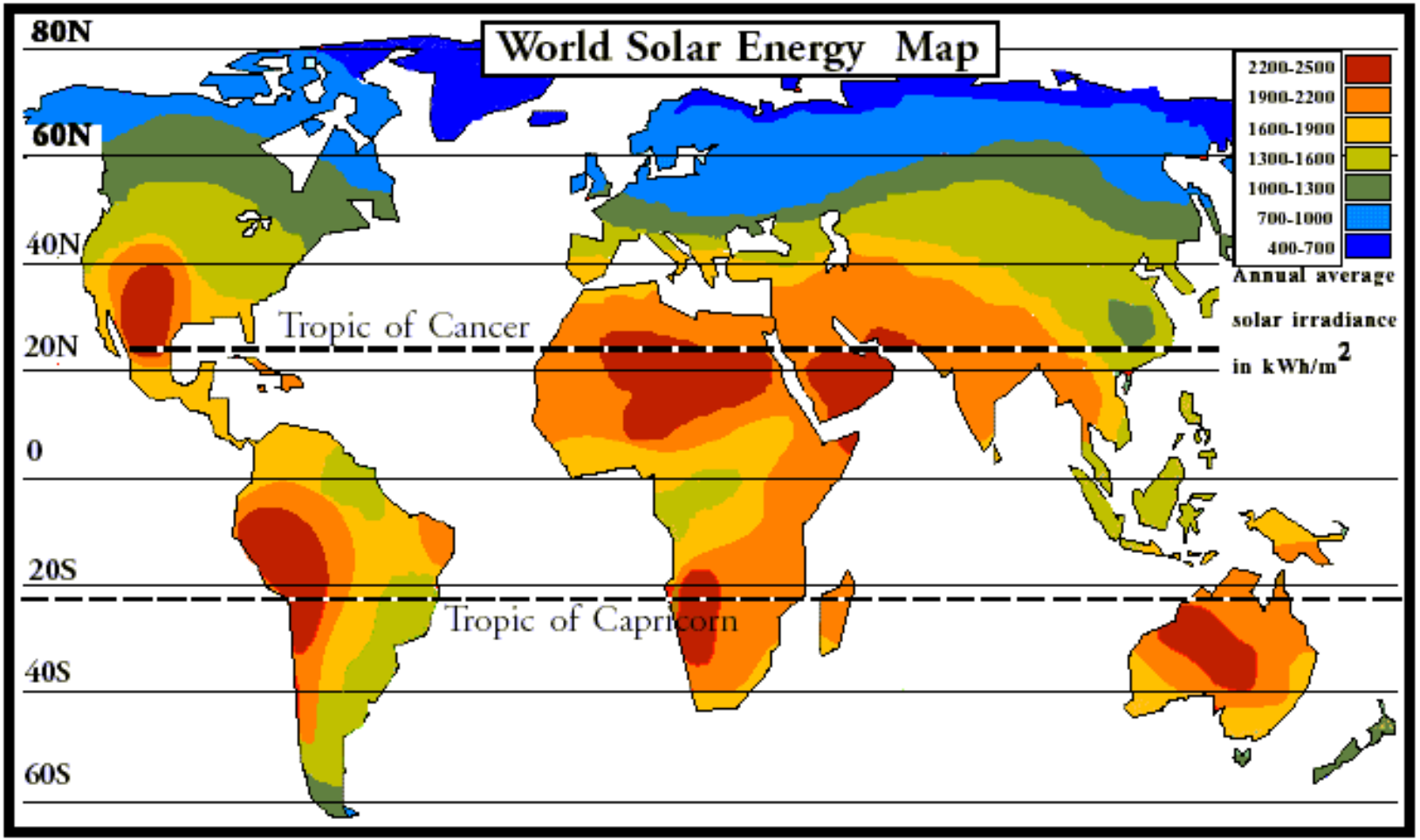
17-5-2017

Global clean energy investment vs WTI crude spot 2004-15

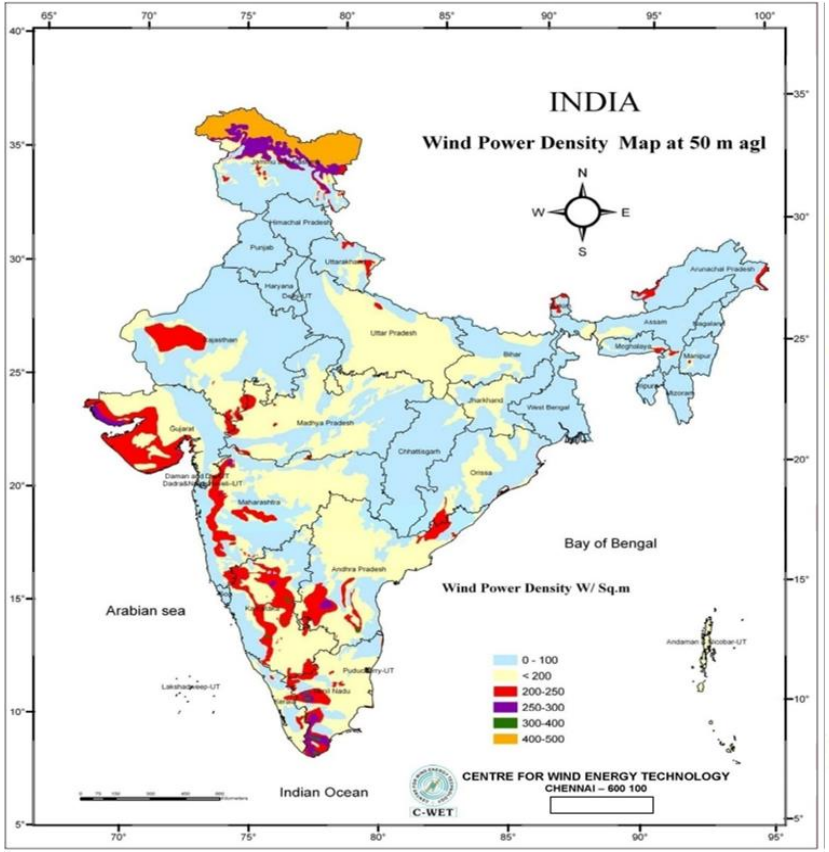


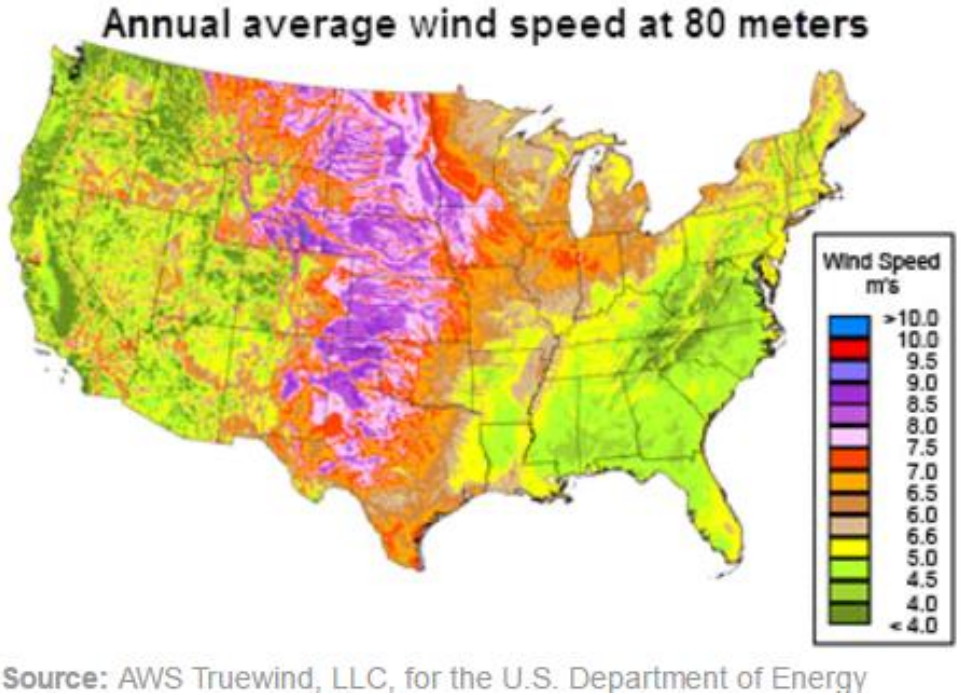
2016 unsubsidised clean energy world records

ONSHORE WIND	SOLAR PV
	
Location: Morocco	Location: Dubai
Bidder: Enel Green Power	Bidder: Masdar Consortium
Signed: January 2016	Signed: May 2016
Construction: 2018	Construction: 2019
Price: US$ 3.0 c/kWh	Price: **US$ 2.99 c/kWh**


World Solar Energy Map
80N
60N
40N
20N
0
20S
40S
60S
Tropic of Cancer
Tropic of Capricorn
2200-2500
1900-2200
1600-1900
1300-1600
1000-1300
700-1000
400-700
Annual average
solar irradiance
in kWh/m2

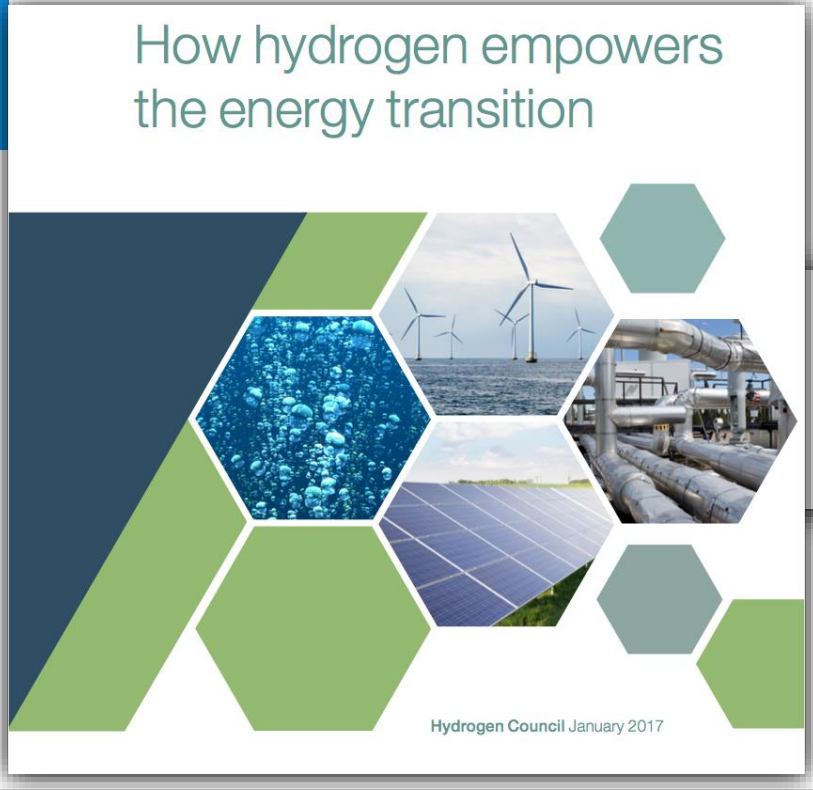
Wind Energy





Source: AWS Truewind, LLC, for the U.S. Department of Energy

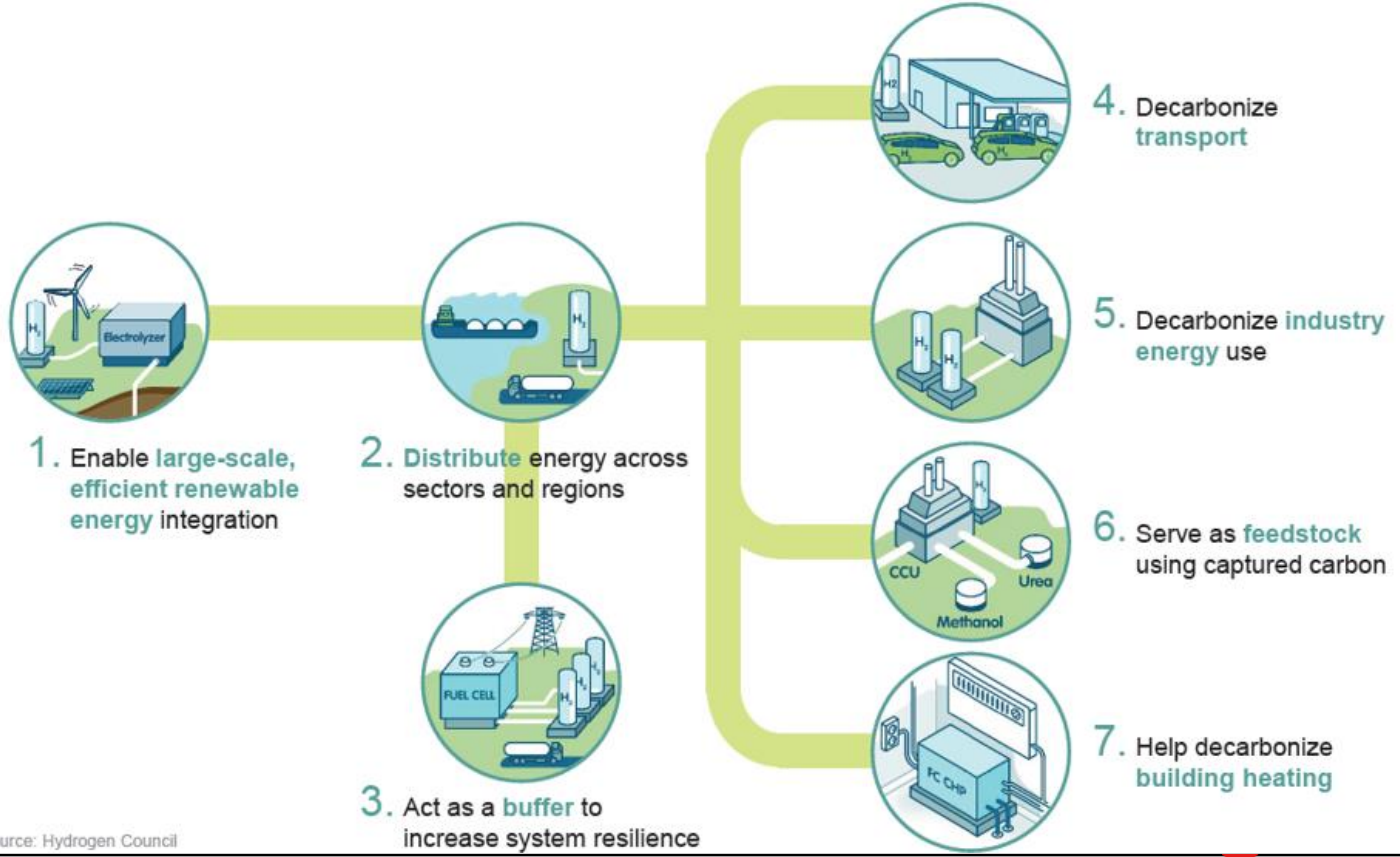
World Hydrogen Council



AIR LIQUIDE Creative Oxygen · ALSTOM · AngloAmerican · BMW GROUP · DAIMLER · ENGIE by people for people

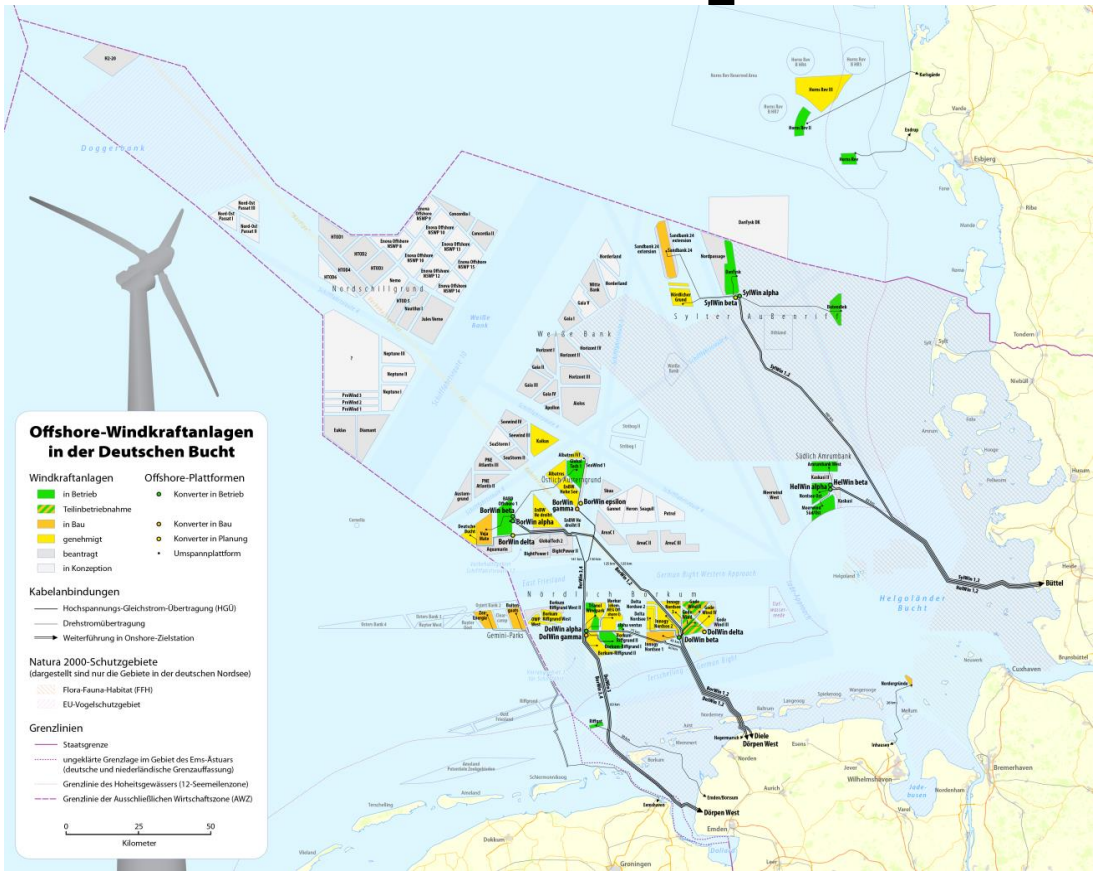
HONDA · HYUNDAI · Kawasaki · THE LINDE GROUP · TOTAL · TOYOTA

Why Green Hydrogen?

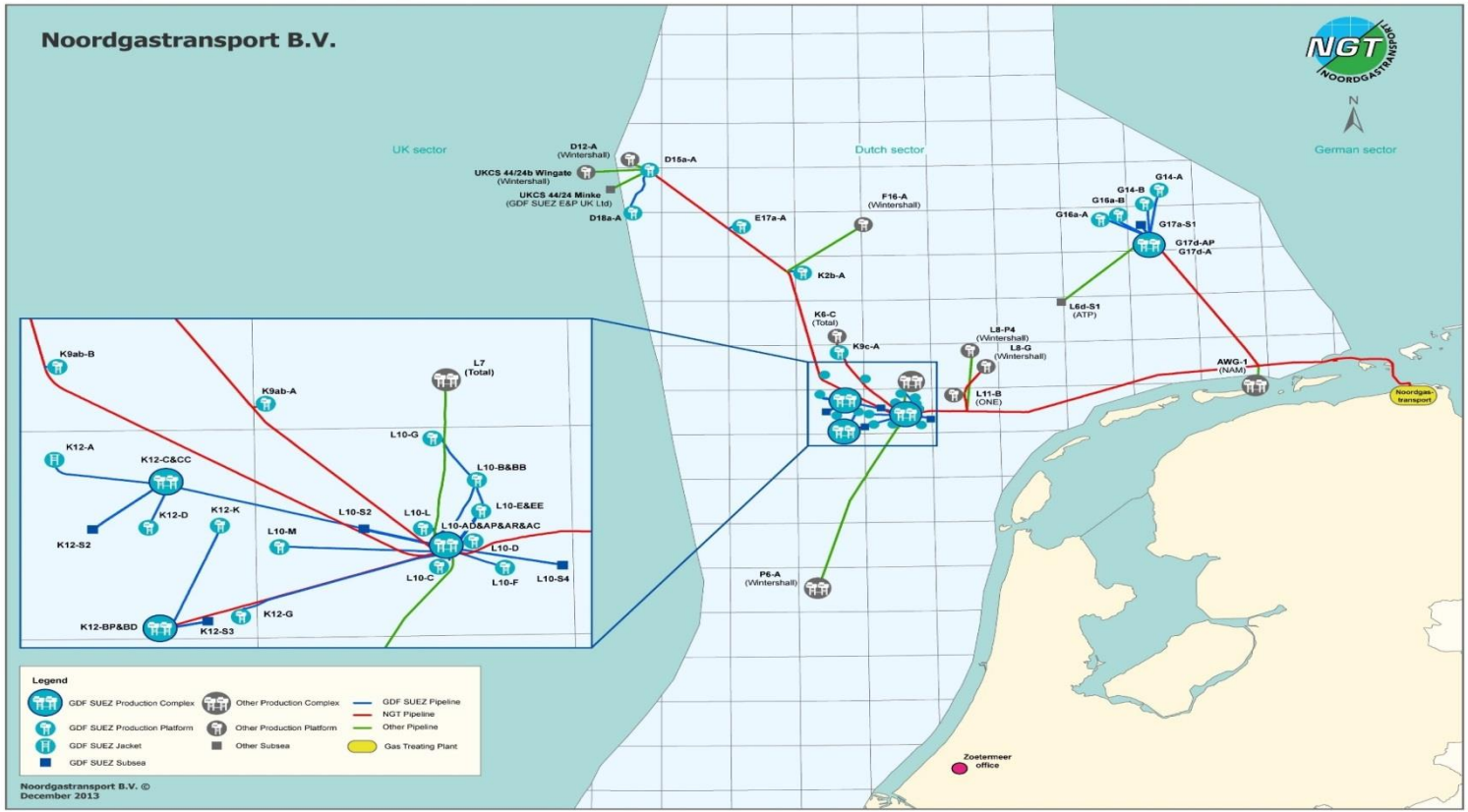


Source: Hydrogen Council

Offshore Wind Development Germany



Offshore Hydrogen Production

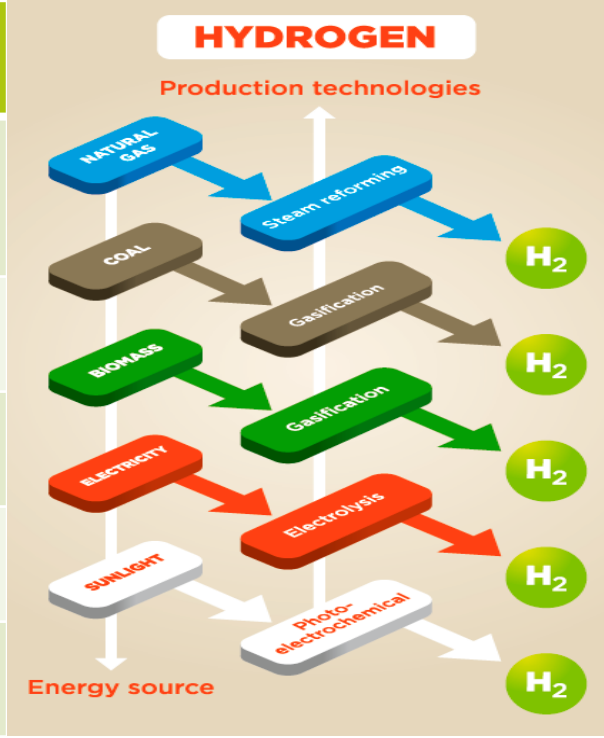


Electricity and Gas Transport Grid

Eemshaven; The Energy Harbor

Hydrogen production

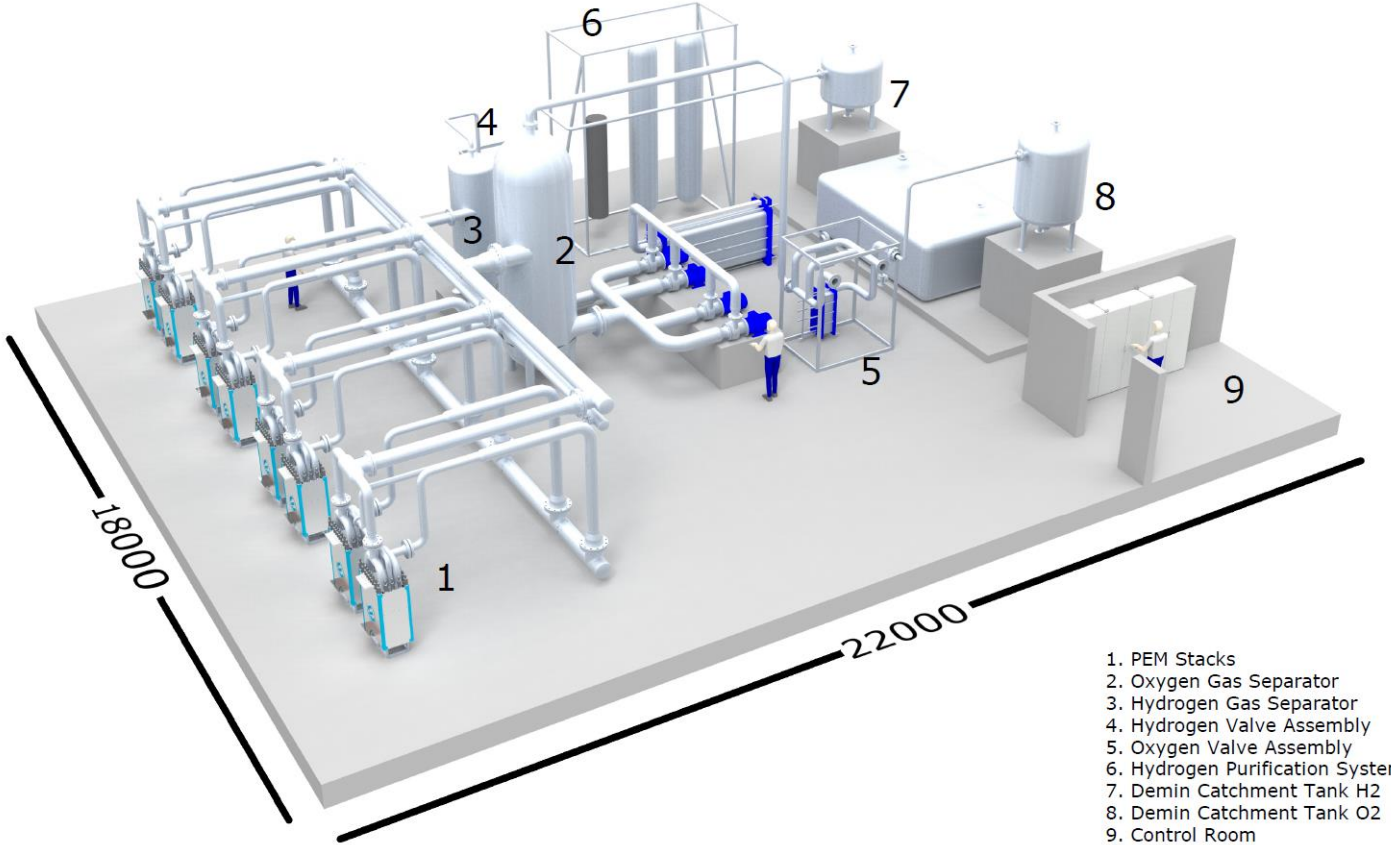
Energy source	Process	Efficiency Today
Natural gas **Bio Gas**	Steam reforming Solid Oxide Fuel Cell	72% 80% (40-40)
Coal/Oil	Gasification	56%+ (=syngas)
Biomass	Gasification	44%+ (=syngas)
Electricity	Electrolysis	67% (90% exp.)
Sunlight	Photoelectrochemical	14% (lab)



Siemens Silyzer 200

SILYZER 200 basic system *Technical data*
Electrolysis type/principle: PEM (Proton Exchange Membrane)
Rated stack capacity: 1.25 MW
Skid dimensions: 6.30 m x 3.10 m x 3.00 m
Startup time: < 10 sec
Output pressure: Up to 35 bar
Hydrogen purity (dep. on operating point): 99.5% – 99.9%
Hydrogen quality 5.0: Optional DeOxo dryer
Hydrogen production under nominal load: 225 Nm^3/h
Life cycle design: > 80,000 h
Weight: 17 t
CE conformity: Yes
Fresh water demand: 1.5 l / Nm^3 H_2

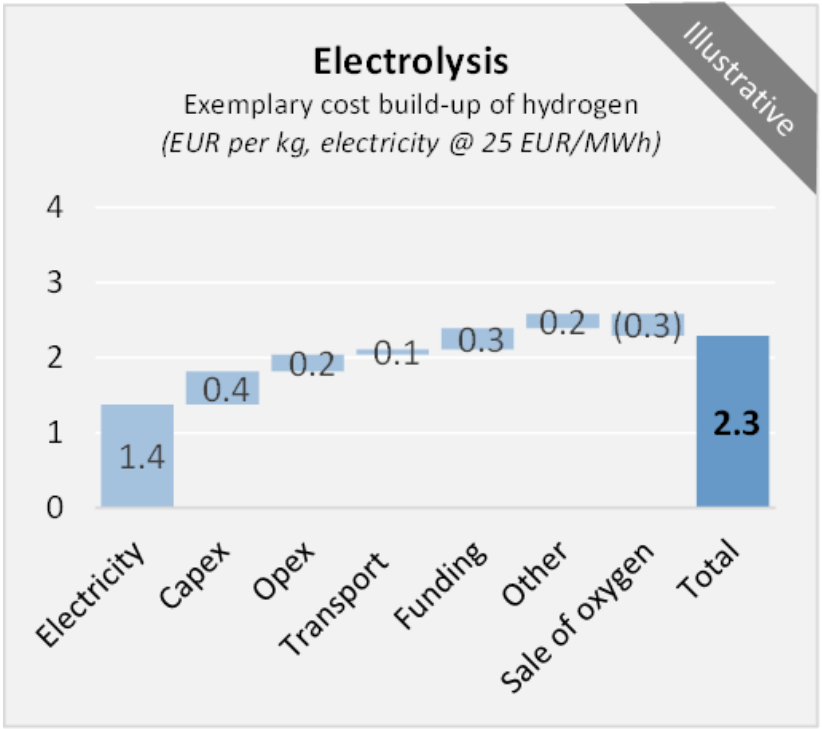
Hydrogenics 20 MW PEM electrolysis

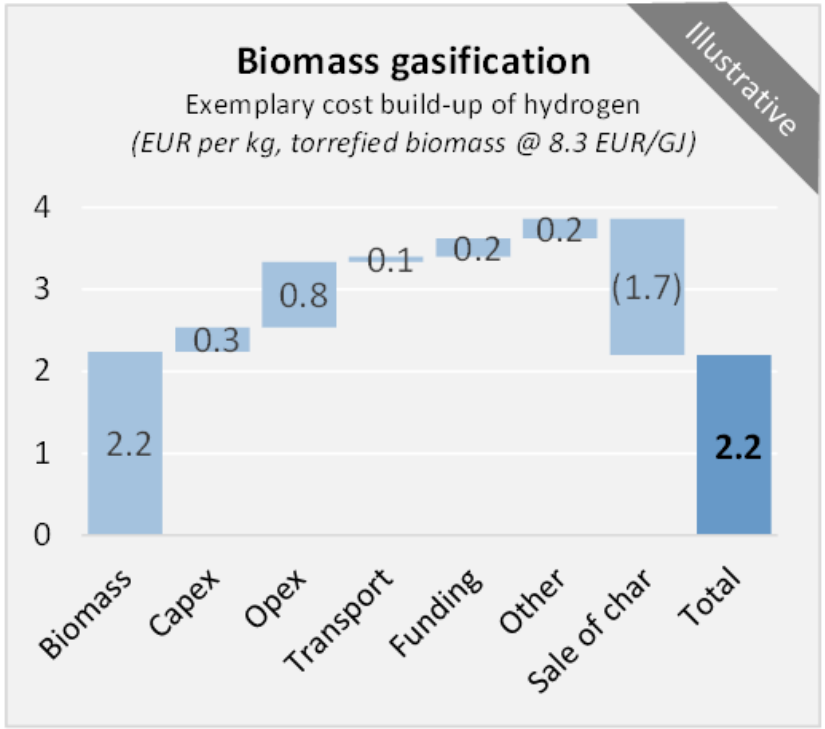


1. PEM Stacks
2. Oxygen Gas Separator
3. Hydrogen Gas Separator
4. Hydrogen Valve Assembly
5. Oxygen Valve Assembly
6. Hydrogen Purification System
7. Demin Catchment Tank H2
8. Demin Catchment Tank O2
9. Control Room

Torrgas biomass gasification

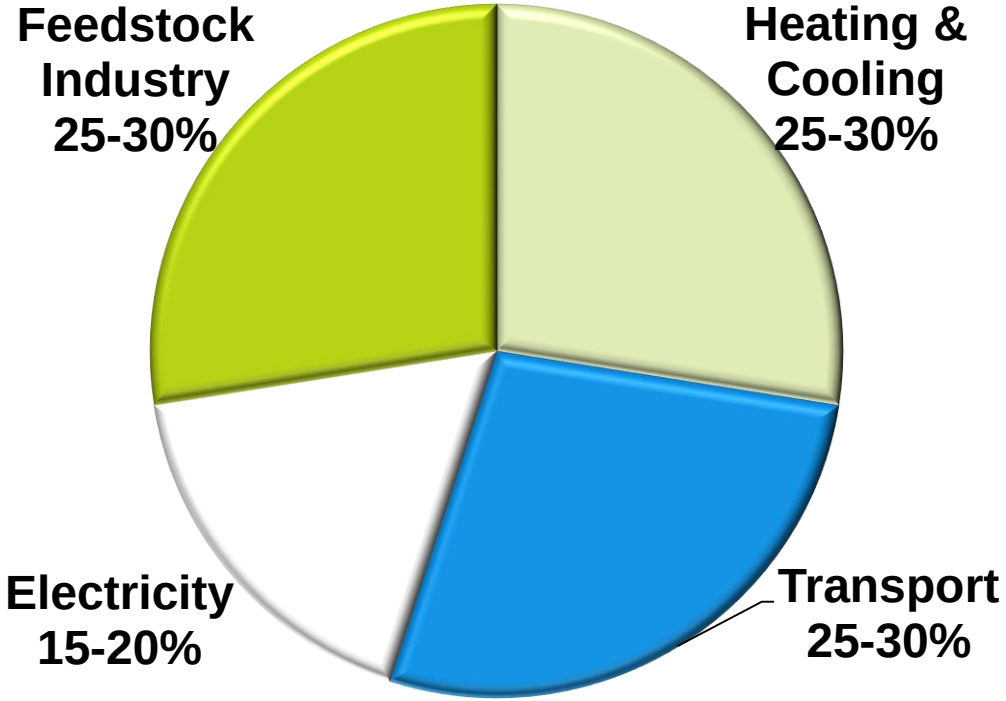
Hydrogen production cost 2-3 Euro/kg



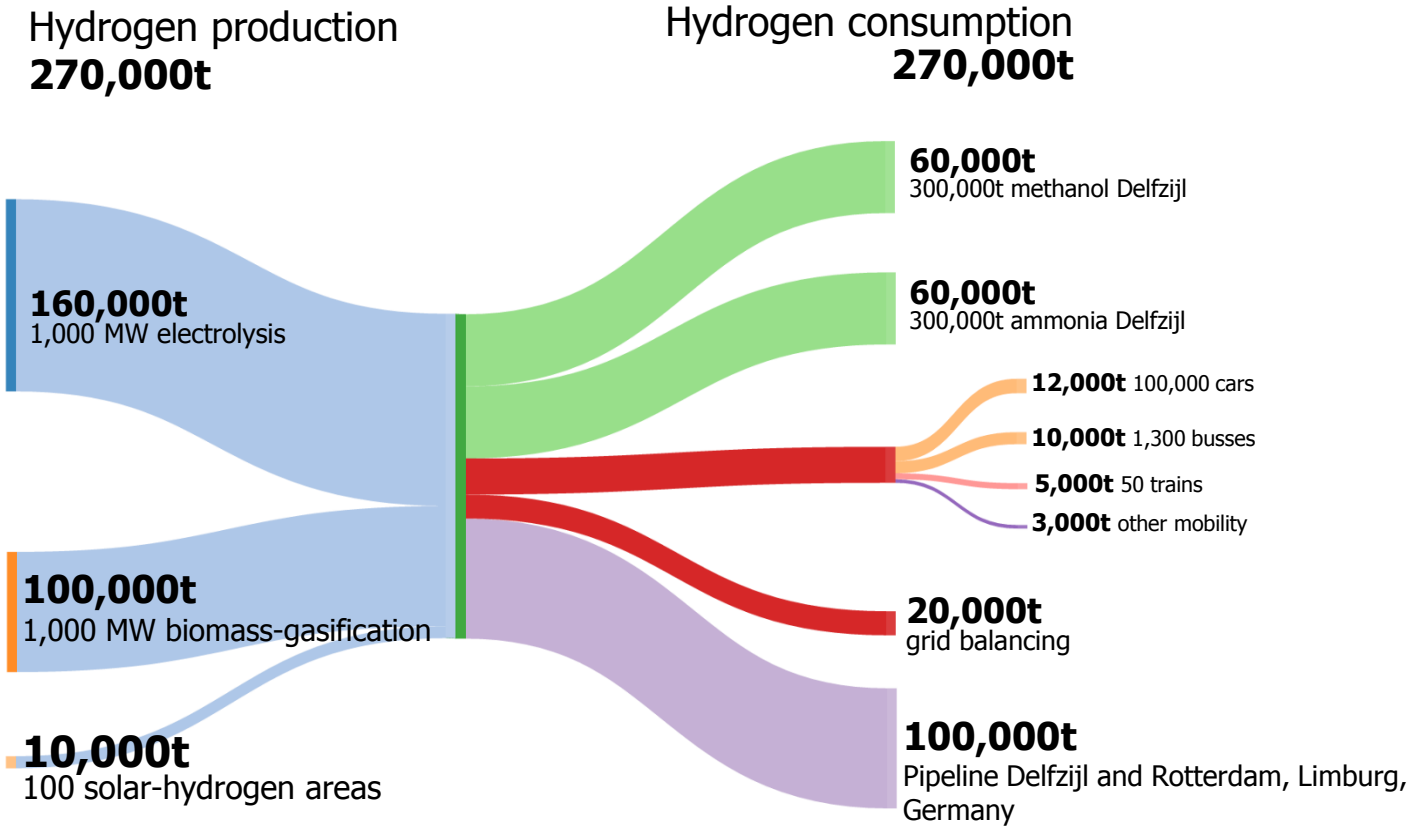


Source: RABO bank

Worldwide energy system use



Green Hydrogen Economy Northern Netherlands 2030



Delfzijl chemical site
Ammonia and Methanol production

Hydrogen Pipeline network

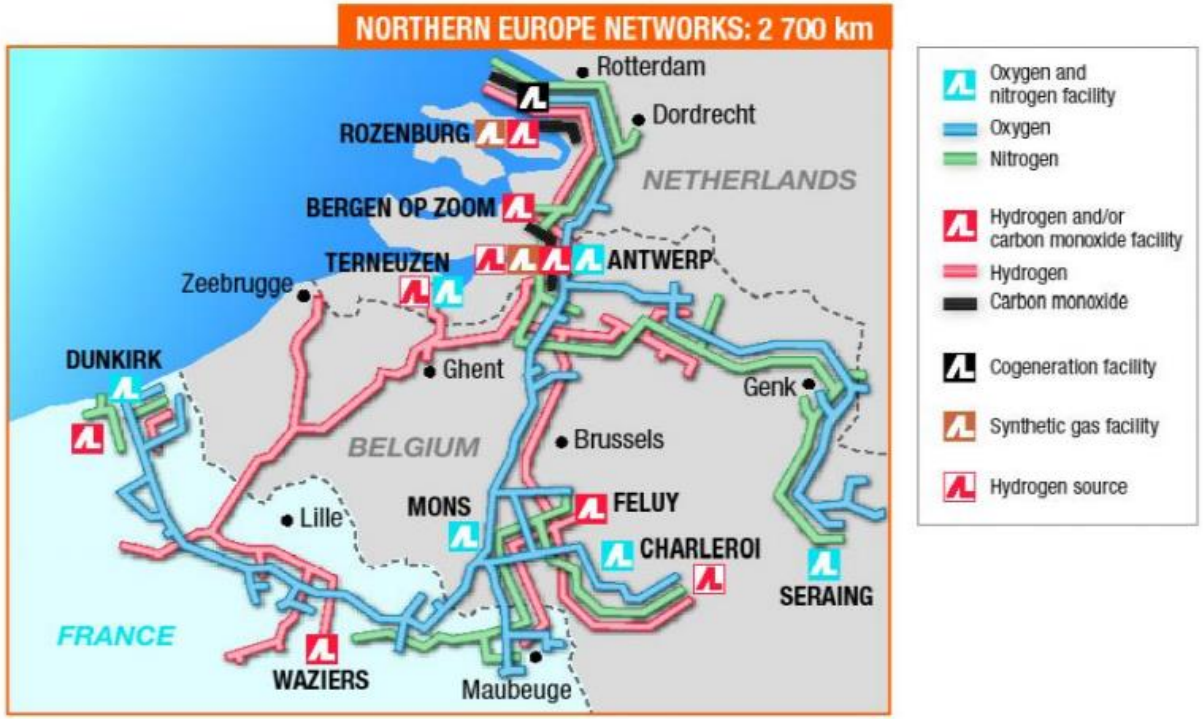
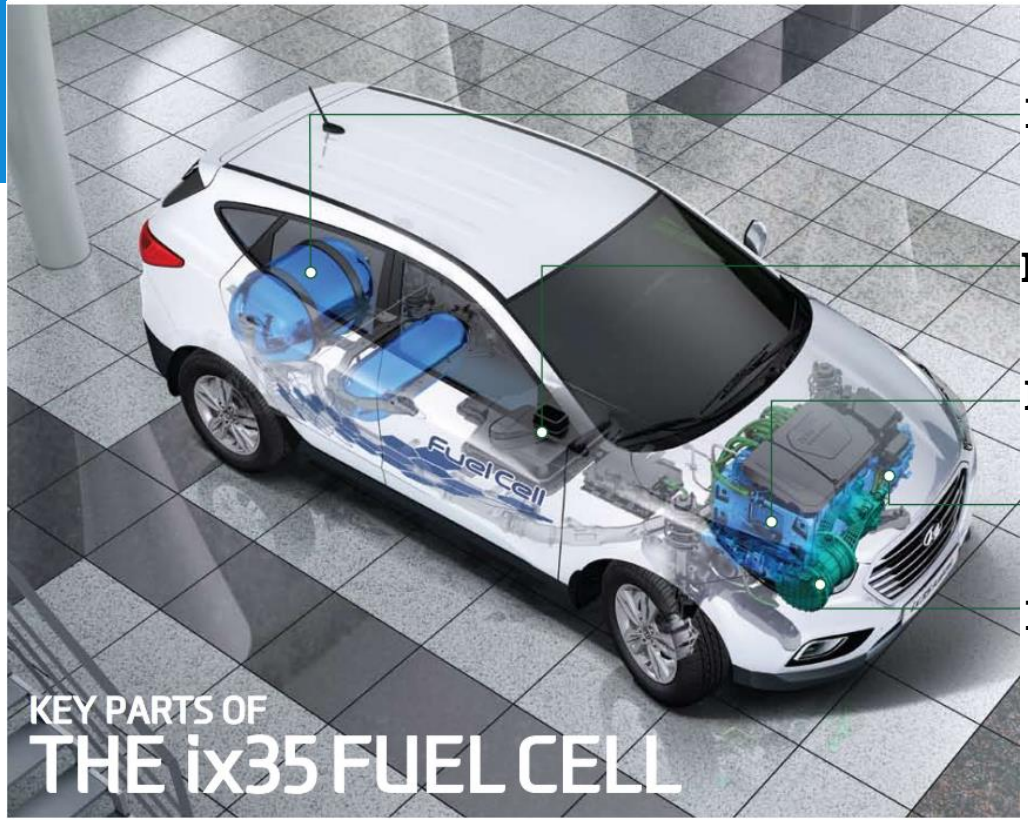


Fig.6 - Industrial Gas Pipelines in the Benelux Region (Source: Air Liquide, 2006)

Hyundai ix35



Hydrogen storage tanks (700 bar)

High voltage battery

Fuel cell stack

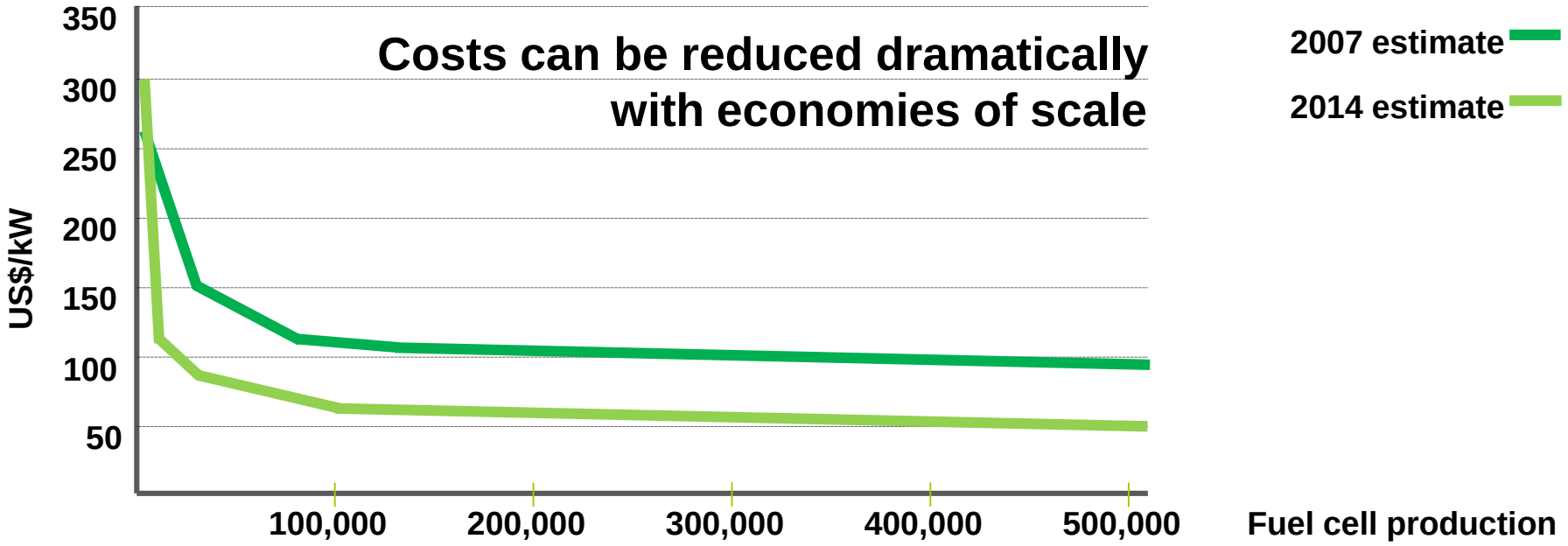
Inverter

Electric drive motor

Fuel cell car characteristics

Fuel cell type	Proton Exchange Membrane
Capacity	80-120 kW
Electrical efficiency	60% at full load
Hydrogen tank capacity	4-6 kg
Hydrogen energy content (HHV)	39 kWh per kg
Water production	9 Liter per kg Hydrogen
Driving distance	100 km per kg Hydrogen

Fuel cell costs



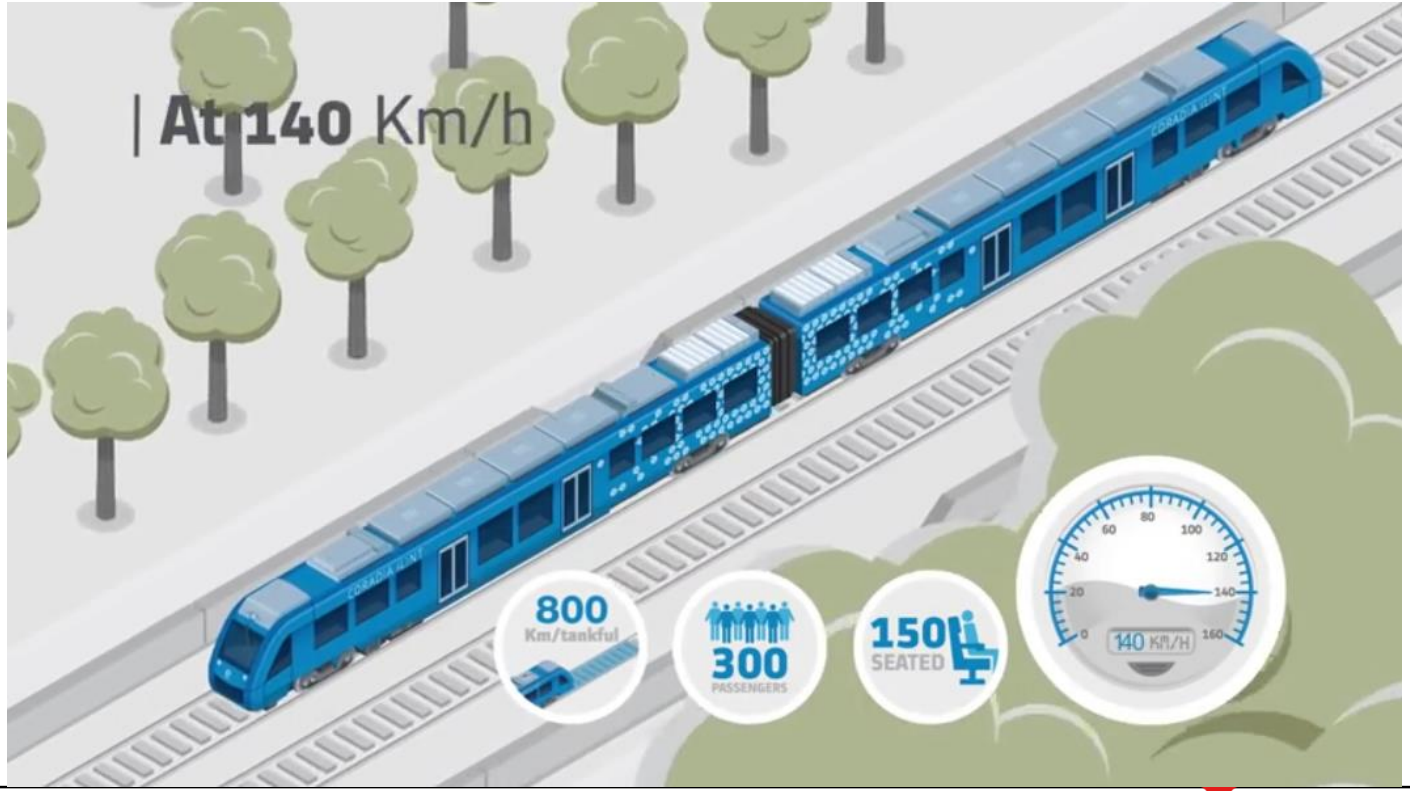
Source: U.S. DOE/IEA

Hydrogen fuelling stations

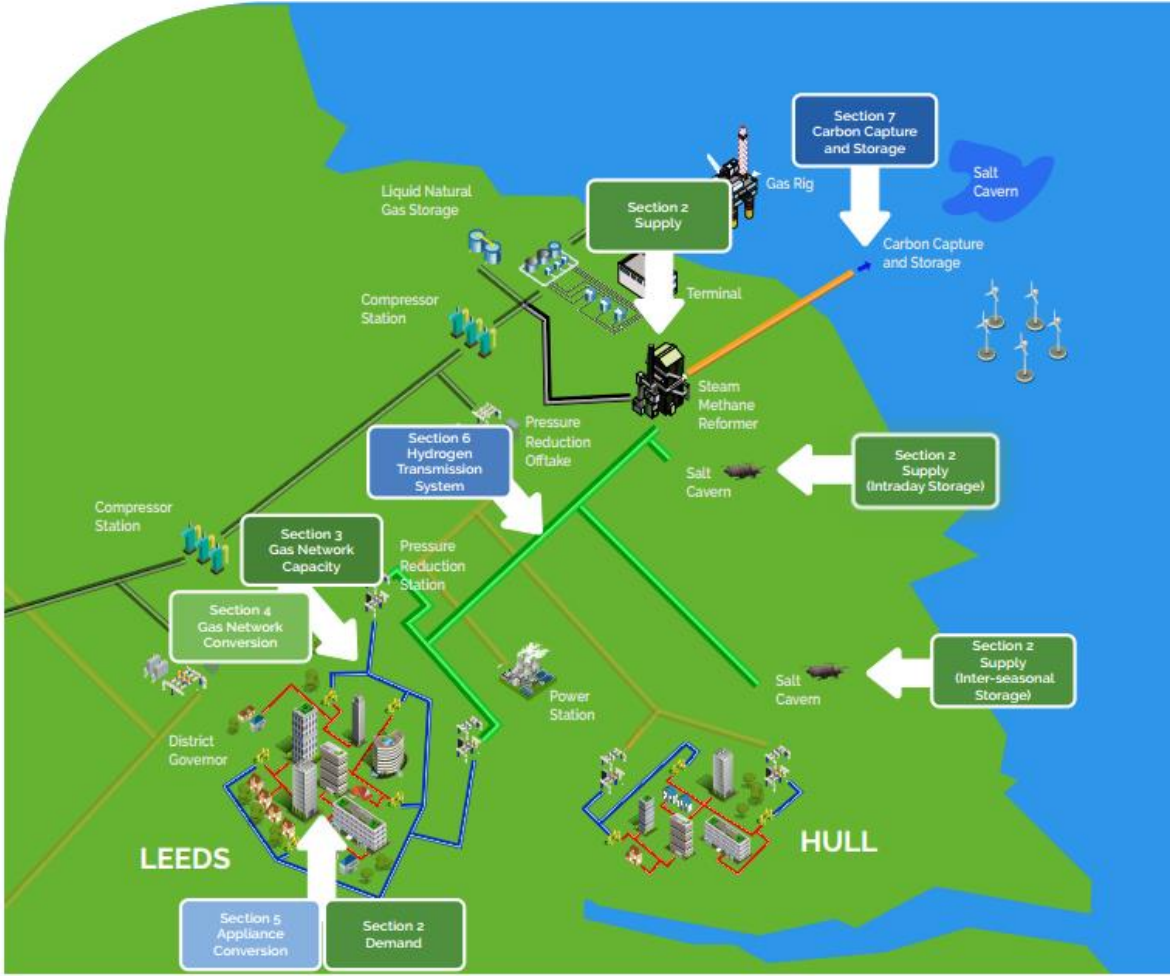
Rhoon

Hamburg

Fuel Cell Hydrogen Train



Leeds City Gate Project



The Northern Netherlands uniquely positioned for green hydrogen

- Large scale green electricity production
- Large scale green electricity import
- Existing gas knowledge infrastructure
- Existing chemical clusters; Delfzijl and Emmen

- **Existing gas infrastructure which can be retrofitted easily and cheaply to transport hydrogen**

Green Hydrogen Economy Northern Netherlands 2030

Production

- 4,000 MW offshore wind
- 1,000 MW electrolysis hydrogen production
- 1,000 MW biomass gasification
- 100 solar-hydrogen smart areas
- Future far offshore wind-hydrogen

Infrastructure

- H_2 pipeline to Rotterdam/Limburg and Germany
- Hydrogen trading platform
- Hydrogen harbor facilities Eemshaven
- 5 hydrogen distribution centers

Markets

- 300,000 tons green methanol and
- 300,000 tons green ammonia
- Ammonia-hydrogen Magnum power plant
- 100 H_2 fueling stations in Northern NL
- 5 hydrogen fuel cell balanced data centers
- 3 hydrogen innovation/startup centers

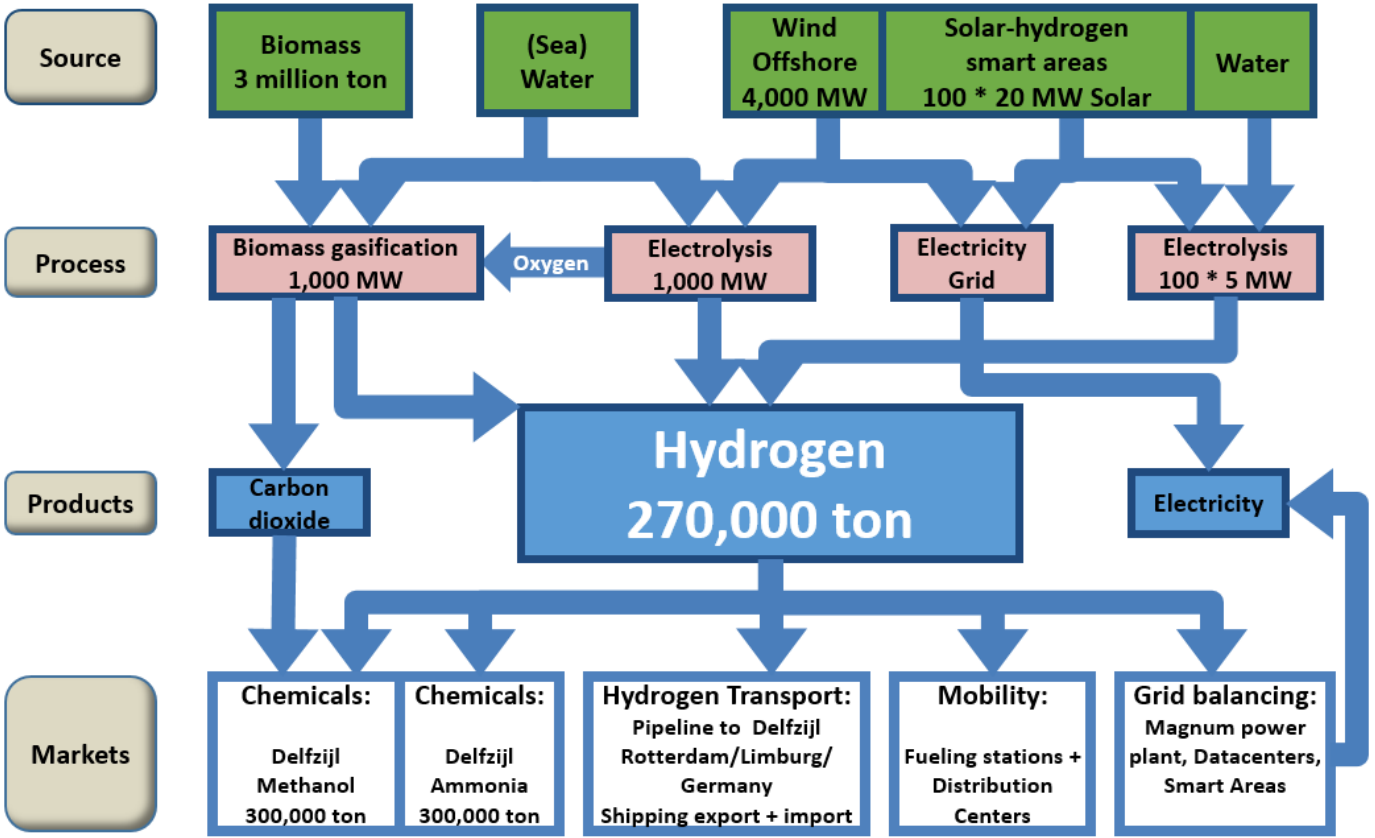
Society

- Zero emission public transportation (busses, trucks, trains, ferries)
- Hydrogen trade fair and exhibition
- Hydrogen regulatory framework
- Green hydrogen certificates

Investments 2018-2030
Green Hydrogen Economy

Northern Netherlands	Investment (million Euro)
Production	3,000-5,000
Markets	1,000-1,800
Infrastructure	700-2,000
Society	800-1,200
Total Hydrogen Related	5,500-10,000

Green Hydrogen Economy



High level Roadmap for the green hydrogen economy in the Northern Netherlands up to 2030

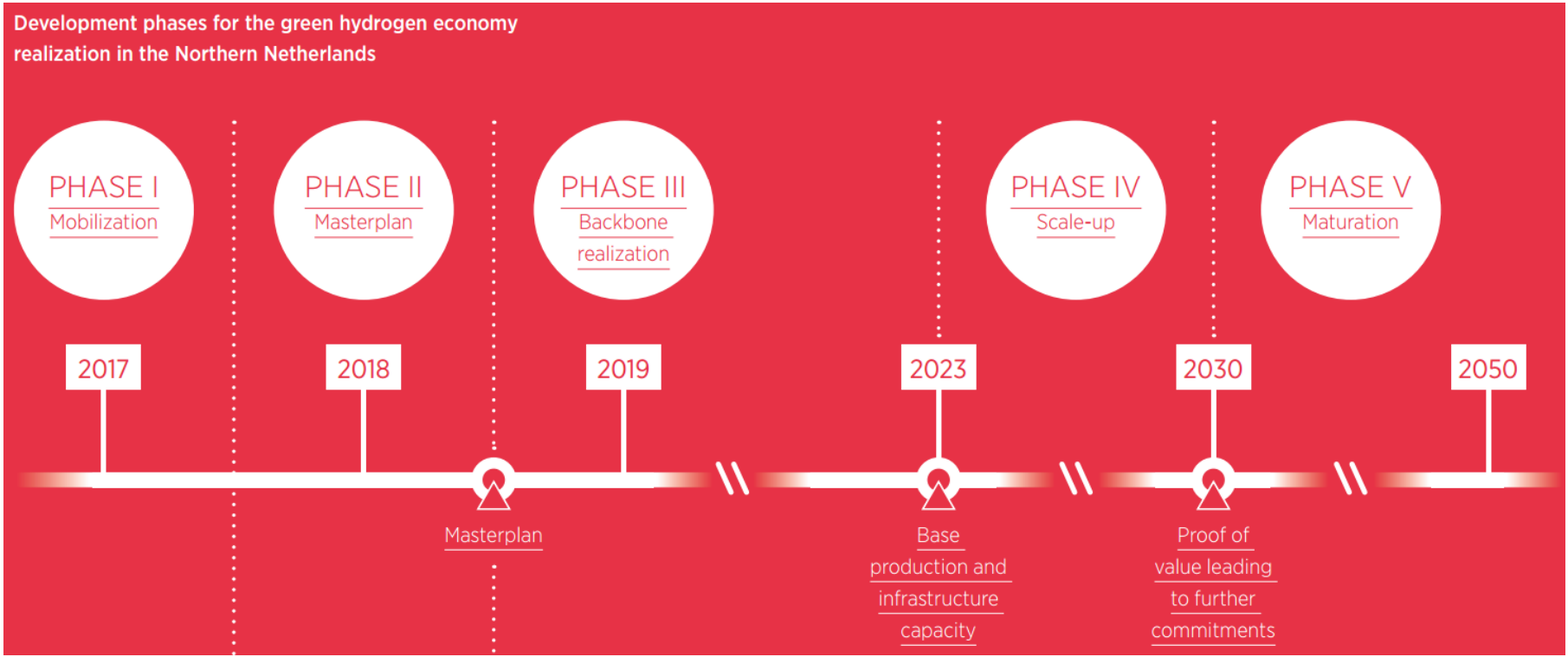
Under construction | *A* | **A** | Priority to realize

Included in investments | A | **A** | (A) | Not included in investments

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Wind offshore	*600 MW Gemini*				1,000 MW		1,000 MW		1,000 MW		1,000 MW		(Far offshore wind)
Electrolysis			20 MW		480 MW		500 MW			(1,000 MW)			(1,000 MW)
Biomass gasification					20 MW		480 MW		500 MW				
Solar-hydro areas		Ameland	1 icon area	1 icon area		5 areas	5 areas	10 areas	10 areas	15 areas	15 areas	15 areas	20 areas
Offshore cable	*600 MW Gemini*		*700 MW Cobra*		1,000 MW wind		1,000 MW wind		1,000 MW wind		1,000 MW wind		(1,000 MW NorNed 2)
Ammonia					(Magnum Nuon First import)	Delfzijl 150,000 tons production		Delfzijl 150,000 tons production		(Magnum Nuon 1.3 million tons import)			
Methanol								Delfzijl 150,000 tons		Delfzijl 150,000 tons			
Pipeline					Delfzijl, Rotterdam, Limburg		Ruhr area, Harlingen, Emmen				Bremen-Hamburg		(Offshore gas/ hydrogen pipeline)
Fueling stations	Delfzijl	2	4	6	8	10	10	10	10	10	10	10	10
Distribution centers					Harlingen i.e. trains	Groningen i.e. trains	Emmen	Leeuwarden		Hoogeveen		Harlingen electrolysis	Emmen electrolysis
Fuel cell balancing									100 MW	100 MW	100 MW	100 MW	100 MW
Harbor facilities			Truck loading		Ammonia import		Biomass import						(Hydrogen shipping)
Busses	2	6	20	20	20	20	50	50	50	50	50	50	50
Trains			Groningen-Leeuwarden		10	20	20						
Trucks	2	6	10	20	30	50	50	50	50	100	100	100	100
Cars		20	100	500	1,000	3,000	6,000	10,000	10,000	15,000	15,000	20,000	20,000
Boats			Ecolution	Sail boats	Sail boats	First ferry	First yacht	First fishing boat	First freight ship				
Others		Forklifts	Drones	Robots	Mobile								
Research, innovation centers	Energy Academy Europe, research universities, universities of applied sciences, EnTranCe (Groningen), Wetsus (Leeuwarden), Emmtec (Emmen)						Energy Academy Europe, research universities, universities of applied sciences, EnTranCe (Groningen), Wetsus (Leeuwarden), Emmtec (Emmen)						
Trading platform													Established
Trade fair		Shows	Shows	First time	1	1	1	1	1	1	1	1	1
Green certificates					Established NL	Established Germany			Established Europe				
Regulations		Provisionally established			Fully implemented								
Education	MBO, HBO, universities, high schools, primary schools, etc.						MBO, HBO, universities, high schools, primary schools, etc.						
Training	Automotive, fire department, police, installation technicians, builders, technicians, regulators, etc.						Automotive, fire department, police, installation technicians, builders, technicians, regulators, etc.						

	2017	2018	2019	2020	2021	2022	2023
Wind offshore	*600 MW Gemini*				1,000 MW		1,000 MW
Electrolysis			**20 MW**		**480 MW**		**500 MW**
Biomass gasification					**20 MW**		**480 MW**
Solar-hydro areas		**Ameland**	**1 icon area**	**1 icon area**		5 areas	5 areas
Offshore cable	*600 MW Gemini*		*700 MW Cobra*		1,000 MW wind		1,000 MW wind
Ammonia					(Magnum Nuon First import)	**Delfzijl 150,000 tons production**	
Methanol							
Pipeline					**Delfzijl, Rotterdam, Limburg**		Ruhr area, Harlingen, Emmen
Fueling stations	**Delfzijl**	**2**	**4**	**6**	**8**	**10**	10
Distribution centers					**Harlingen i.e. trains**	Groningen i.e. trains	Emmen
Fuel cell balancing							
Harbor facilities			**Truck loading**		Ammonia import		Biomass import

Green Hydrogen Economy in Northern Netherlands



Green Hydrogen Economy Northern Netherlands 2030