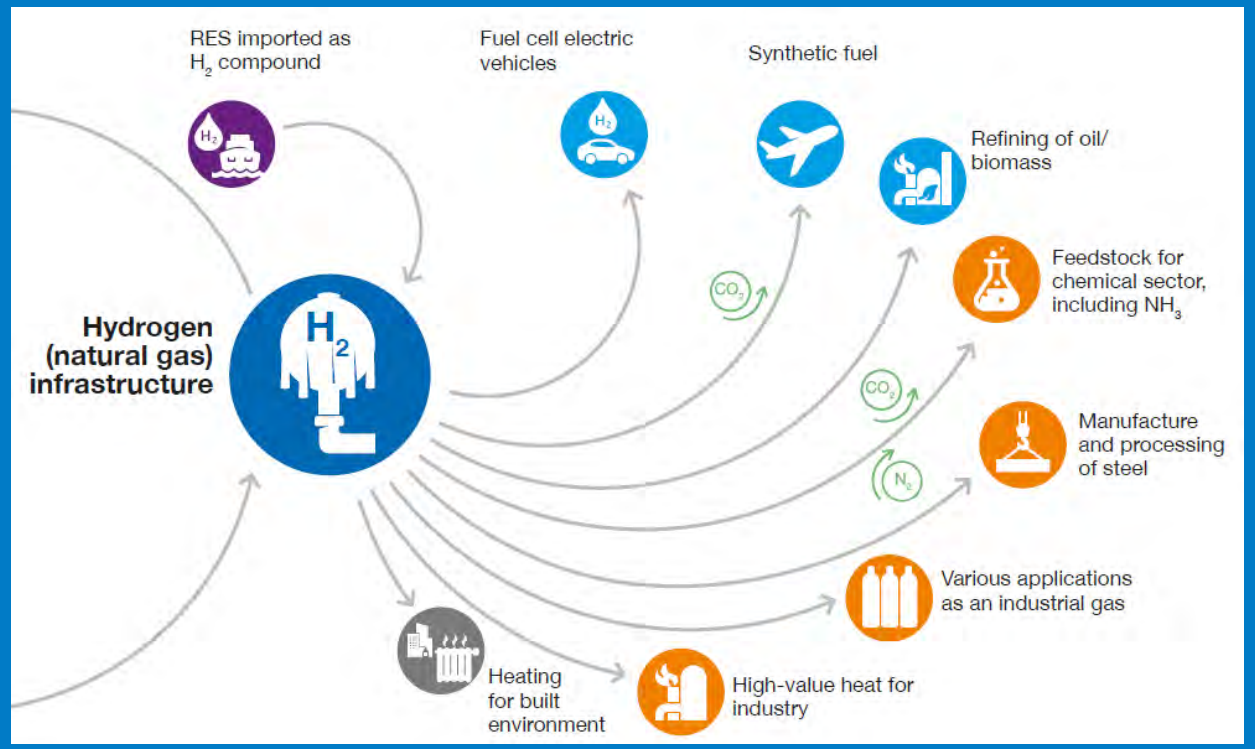
Ministry of Economic Affairs
and Climate Policy



Hydrogen Production with CCS

A National Perspective

Marten Hamelink MSc.

Ministry of Economic Affairs and Climate Policy

Industry
14.3 Mt

Mission National Climate Agreement Industry

59% CO_2 reduction by 2030 while safeguarding competitiveness and preventing leakage effects with the use of a proper mix of instruments.

55Mton - Heavily concentrated in clusters and strongly integrated

CO2-emissions industry

12 companies are responsible for 75% of total industrial CO2 emissions

1. Shell Refinery (14%)
2. Tata Steel (13%)
3. Dow Chemicals (8%)
4. Yara (8%)
5. Sabic (6%)
6. ExxonMobil Refinery (5%)
7. BP Refinery (4%)
8. Air Liquide (4%)
9. OCI (4%)
10. Total Refinery (3%)
11. Nouryon (2%)
12. Air Products (2%)

North NL | *Emissions: 1.2 Mton*
(Eemsdelta 0.7 Mton, Emmen 0.5 Mton)
Chemical industry: AkzoNobel, Dow Chemicals en OCI.

Noordzeekanaal Area (IJmuiden-Amsterdam) |
Emissions: 12 Mton
Tata Steel

Rotterdam-Moerdijk | *Emissions: 16.9 Mton*
Refineries and chemical industry: AkzoNobel, Shell, BP, ExxonMobil, Air Liquide, Air Products

Southwest NL | *Emissions: 7.9 Mton*
Chemical industry and refiner: Dow Chemicals, Yara, Total en Sabic.

Chemelot (Sittard-Geleen) | *Emissions: 4.5 Mton*
Strongly integrated chemical cluster

Balanced mix of carrots and sticks

- Subsidies to accelerate innovation, pilots and demo's to drive down costs
- CO_2 levy – not a tax
- Regional and industrial cluster approach
- European policies

"By starting now, we give ourselves the time to develop and scale up new technologies (solutions of the future). Make the transition an economic opportunity."

Climate agreement industry goal: emission reduction
Circular economy program: also resource security and value creation

Policy Instruments

Regional approach 5 major industrial clusters:
Coördination mechanism for systemic transitions,
includes Taskforce infrastructure and support for (re)training of technical personel

National Carbon Tax (+ ETS)
Obligatory Norms (IRR < 5 year: for rest of industry):
Market creation for emission reducing technologies (market-pull)

Innovation programs industry + Pilots en demo's:
Bringing emission reducing technnologies to pre-commercial TRLs (tech-push)

SDE++ (feed-in subsidy) + EIA (tax bonus on investment)
Bringing down costs of technologies by scaling-up and learning-by-doing

Thematic mission driven innovation programs:
CO_2-free industrial heat system, Electrification and radically novel processes

Thematic mission driven innovation programs:
Circular Economy + Closing the industrial resource loop

Technologies needed to reach our goals

Inventory of technological options	
Technology	**Estimated reduction in 2030 (Mton)**
Process efficiency, energy saving	6
Electrification and green hydrogen	4
Recycling, CCU and biobased	1
N_2O	1
CCS	7
F Gases	1
Total -including current policies	**20**

Hydrogen Roadmap

- **Commissioned by Min. Economic Affairs and Climate Policy:**
  - Potential role hydrogen in a sustainable energy system in 2050?
  - Projects, developments and actors in the Netherlands?
  - Identify promising next steps and actions

English version available

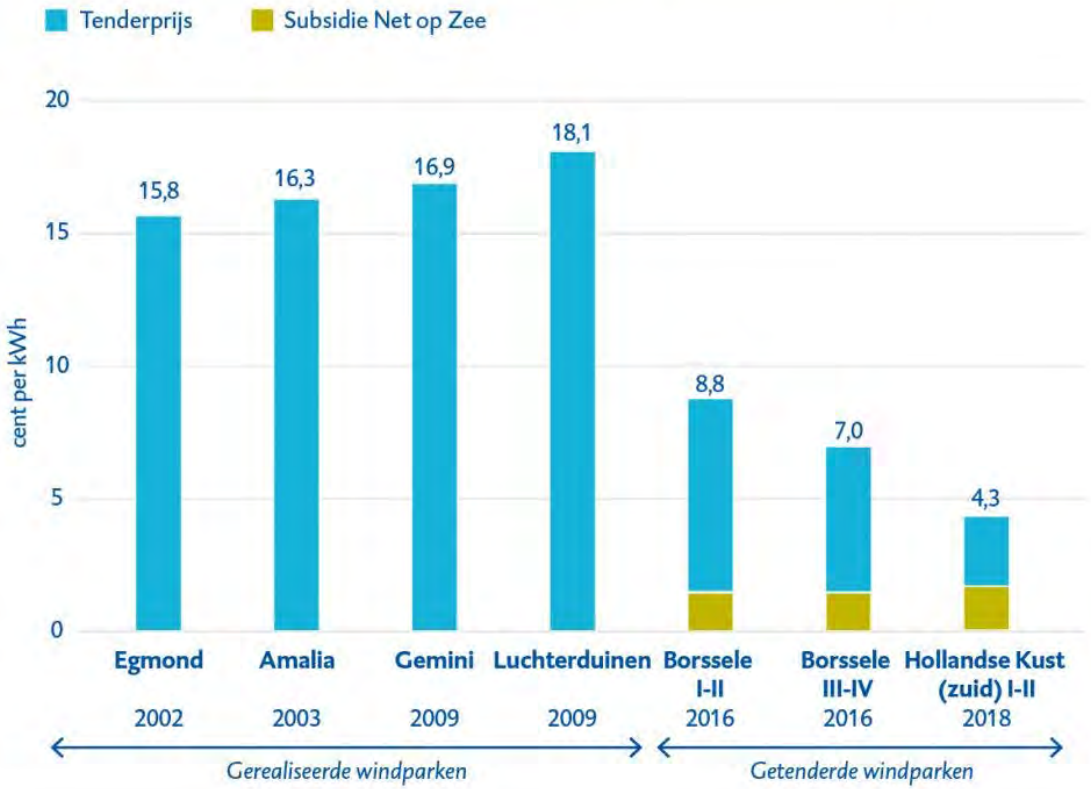
Other two reports only available in Dutch

Spectacular decrease of offshore wind prices

Pionierparken	Routekaart t/m 2023		Routekaart t/m 2030
Status Operationeel	Status Gegund	Status Gepland	Status Gepland
2007	2020	2025	2030

Nr.	Windparken	Vermogen (MW)
1	Egmond aan Zee 2007	108
2	Amalia 2008	120
3	Luchterduinen 2015	129
4	Gemini 2017	600
5	Borssele I-II 2020	752
6	Borssele III-IV 2021	732
7	Hollandse Kust (zuid) I-II 2022	740
8	Hollandse Kust (zuid) III-IV 2023	740
9	Hollandse Kust (noord) 2023	700
10	Hollandse Kust (west) 2024 t/m 2025	1400
11	Ten noorden van de Waddeneilanden 2026	700
12	IJmuiden Ver 2027 t/m 2030	4000

Prijzen windenergie op zee: lichte stijging, gevolgd door spectaculaire daling



Renewable Electricity goal 2030

- 35 TWh Offshore
- 49 TWh Land

- Potential offshore wind 2050: +/- 284 TWh
- (TKI Energy)

Table 5 | Overview of the indicative estimates of possible demand for hydrogen in the Netherlands in a climate-neutral energy supply system with an indicative translation into amounts of offshore wind energy or natural gas with CO_2 storage required for the production of that hydrogen.

Functionality	Hydrogen demand		Offshore wind energy Electrolysis		Natural gas/ CCS Reforming	
	PJ/j	Mton/j	TWh/j	GW	PJ/j	Mton CO_2/j
High-Temperature Heat:						
- Non-energy use	50	0,4	21	4,8	67	3,8
- Process heat	100	0,8	42	9,6	133	7,5
- Sustainable chemistry	480	4,0	202	46,1	640	46,2
- Sustainable fuels	700	5,8	295	67,3	933	52,8
- Steel production	20	0,2	8	1,9	27	1,5
Mobility and Transport	125	1,0	53	12,0	167	9,4
Power and Light	115	1,0	48	11,1	153	8,7
Low-Temperature Heat	100	0,8	42	9,6	133	7,5
	1690	**14,1**	**711**	**161**	**2253**	**128**

Assumptions: The energy value of hydrogen is 120 MJ/kg or 33.3 kWh/kg (LHV); the power consumption for electrolysis is 50 kWhe/kg H_2; offshore wind energy 50% full-load hours per year (4380 hours); reforming 75% efficiency (LHV); emission factor for natural gas is 56.6 Mt CO_2/PJ.

Figure 10 | Comparison of the CO_2 emission factor of hydrogen from electrolysis and that of hydrogen from natural gas through SMR.

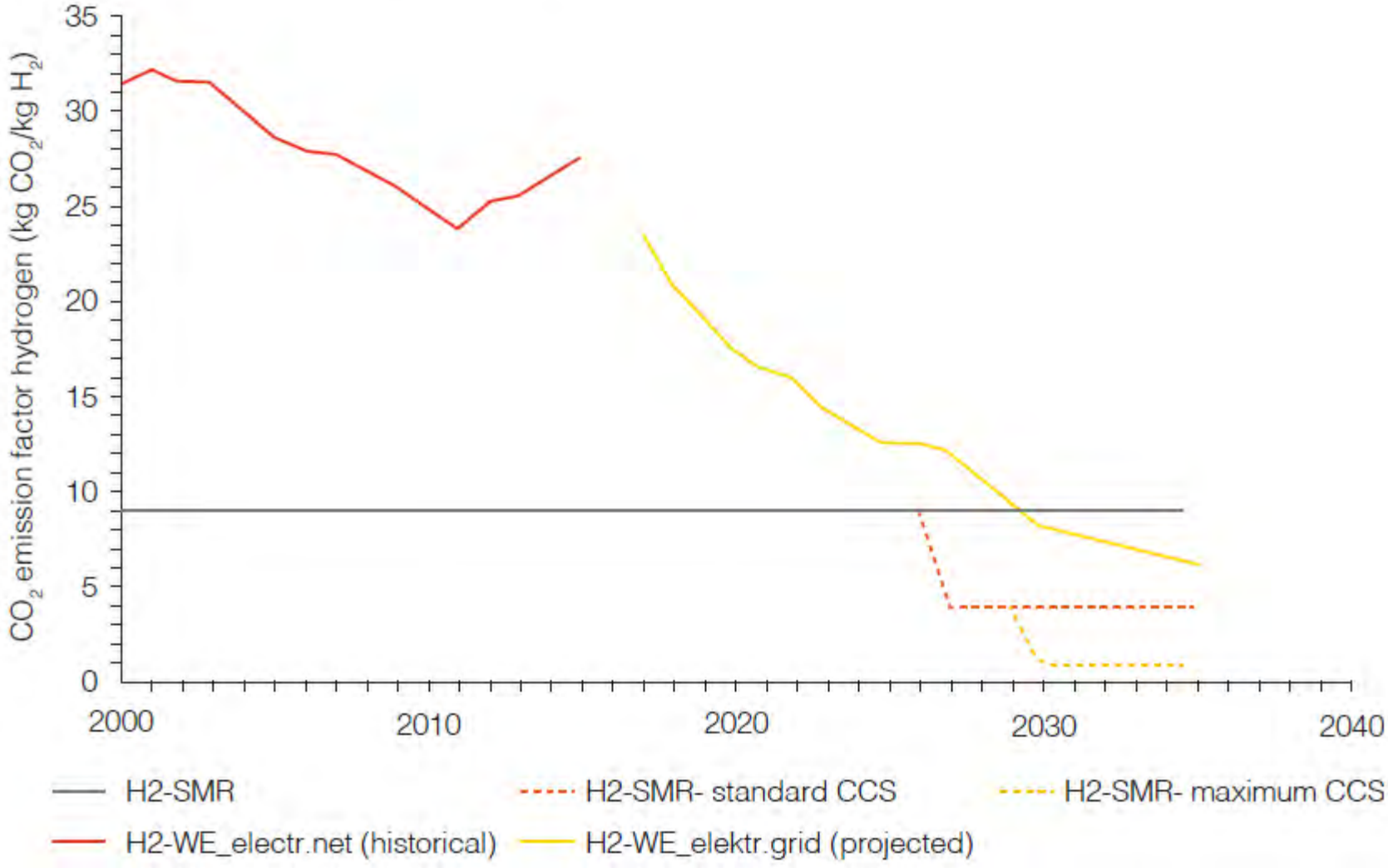
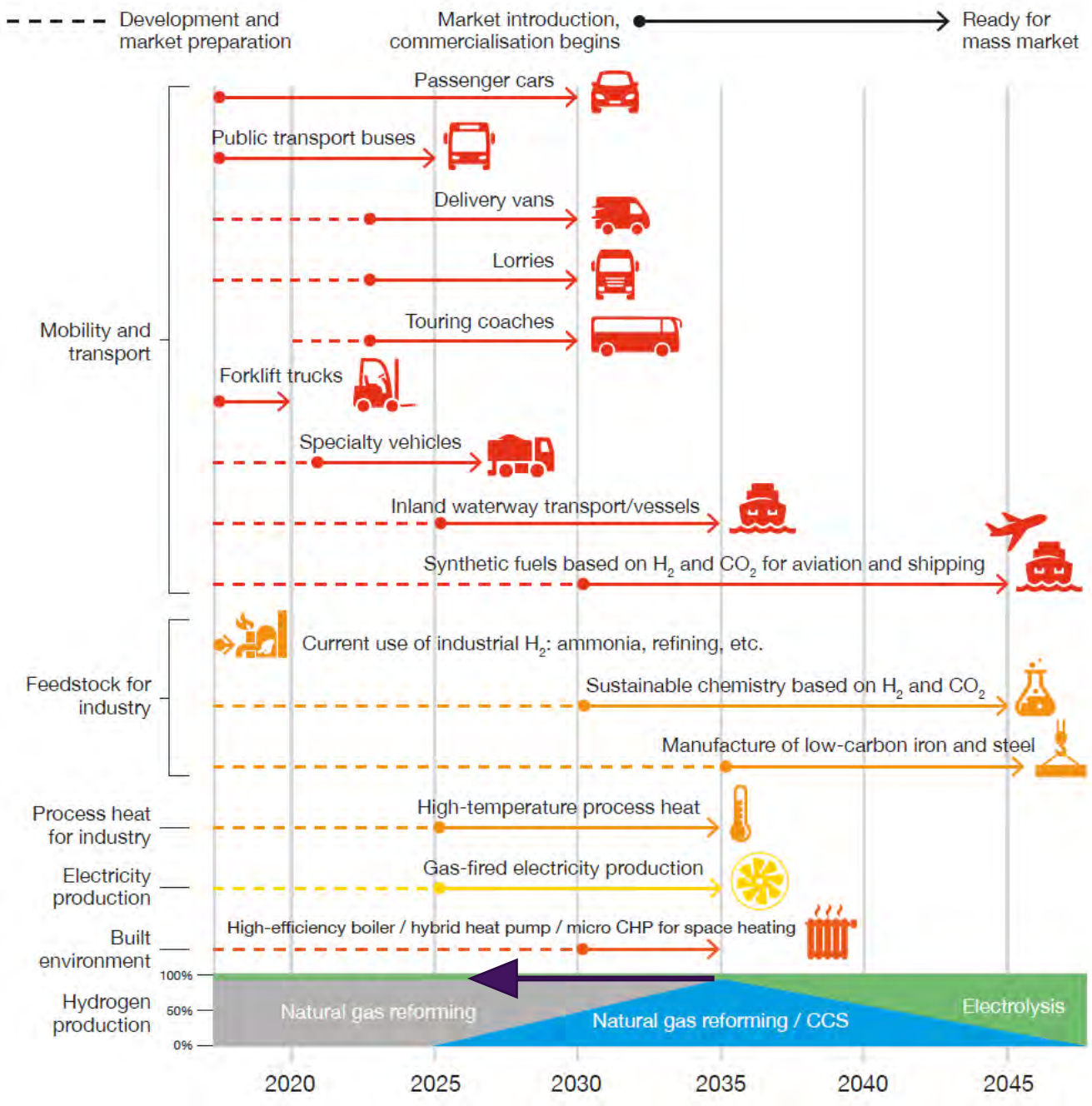


Figure 4 | Outline schedule of implementation processes for a range of hydrogen applications.



Hydrogen, natural gas and CCS

- CCS necessary to meet reduction targets in 2030
- Investments in infrastructure
- Scaling up production of low-emission hydrogen

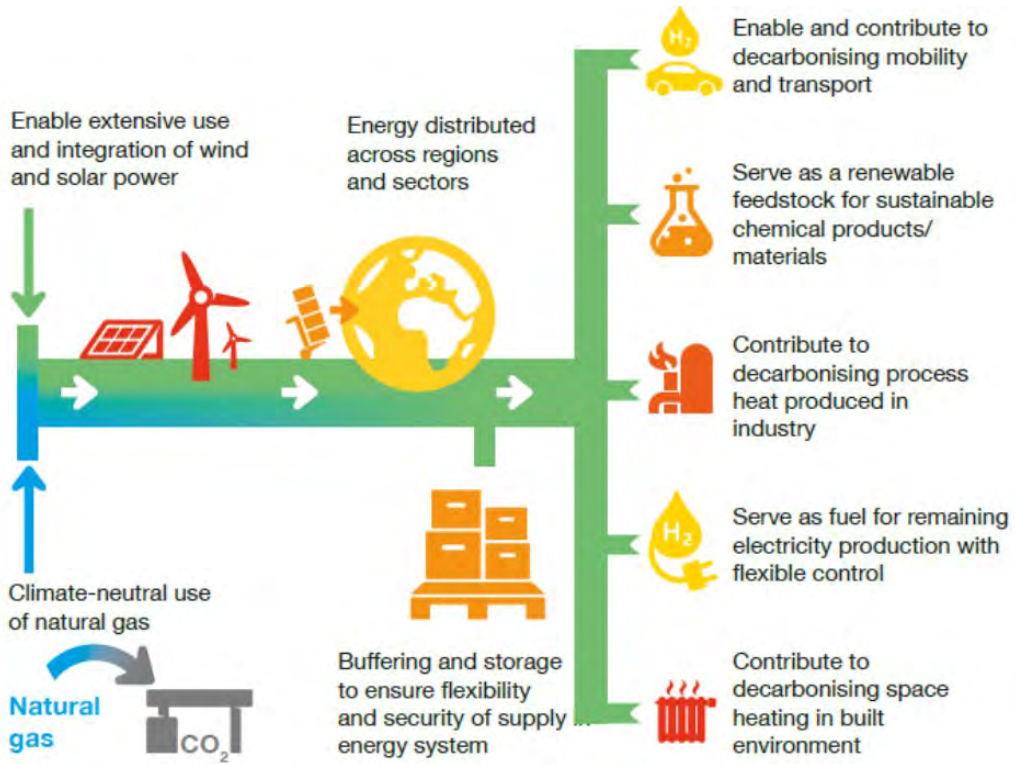
- Role of TSO and DSO’s, re-using gasinfrastructure
  Explorative studies on partial conversion of natural gas grid to hydrogen backbone, e.g. to connect main industrial regions.

Hydrogen in the Netherlands

National Climate Agreement of the Netherlands (June 2019):
- General target to meet 'Paris Agreement': minus 49% CO_2-emission by 2030;
- Hydrogen is seen as a robust element in the CO2-free energy and feedstock system.

- Built Environment
- Mobility
- Industry
- Electricity
- (Agriculture & Land use)

<u>Hydrogen:</u>
=> Several (renewable) sources
=> Many applications



Highlights in issues and discussions in NL

- ## Blue and green hydrogen
  Focus on green hydrogen as much as possible (based on electrolysis using renewable electricity).

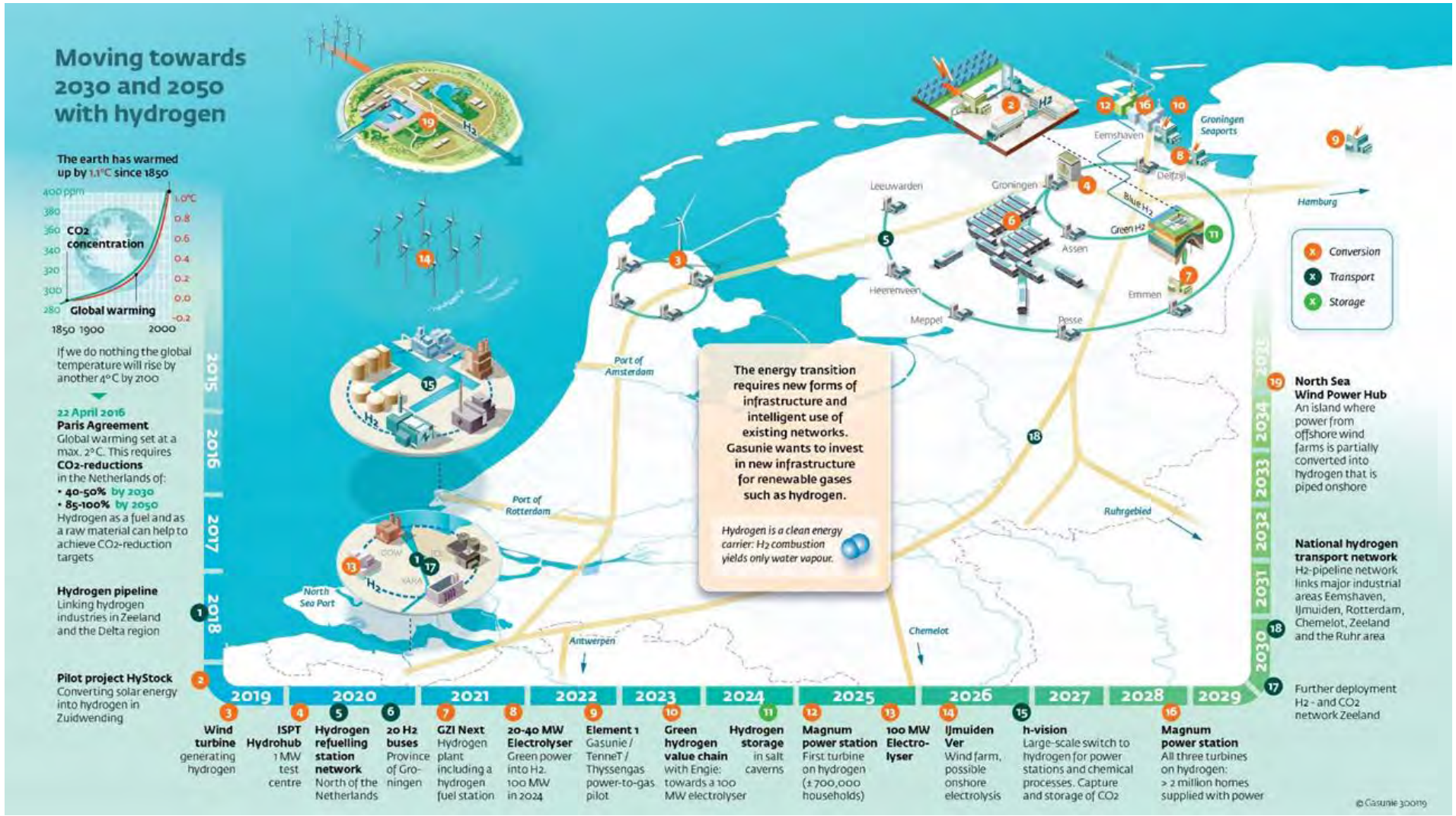
- An optimal contribution to the development of a broader hydrogen system through the use of blue hydrogen (CCS) must be ensured, without impeding the growth of green hydrogen.

A national approach towards 3 GW

A substantial hydrogen programme is to be initiated.
And scaling up in three fases.
Target 2030: 3 – 4 GW of established electrolysis capacity, connection to storage sites and expansion of infrastructure, on the condition of additional growth of renewable electricity, among other things.

Hydrogen Symbioses: use of section of natural gas transmission pipeline for transport of hydrogen

A lot is going on, especially in the North and Rotterdam Harbour

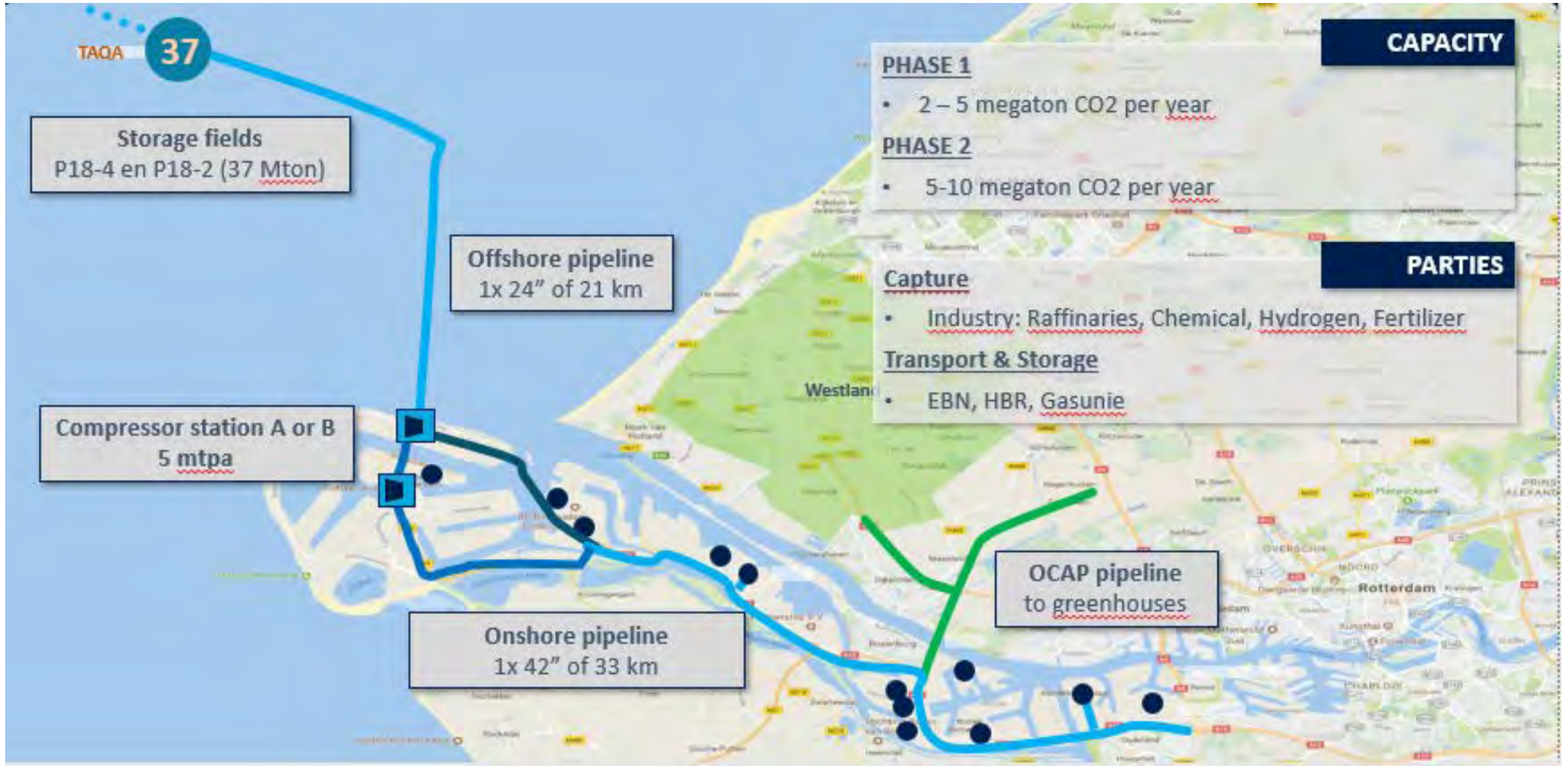


Examples of NL Hydrogen projects and initiatives

- **Hydrogen-to-Magnum**
  - TSO2020-project joint project electricity and natural gas TSO to test PEM-electrolysis: grid services and future incorporation offshore wind
  - Expansion and scale-up deployment of electrolysis; first step 20 MW

Magnum Power Plant; Photo Vattenfall

Rotterdam CCUS Project Porthos



H-vision

- Feasibility study 2019
- https://www.deltalinqs.nl/document/h-vision-eindrapport-blue-hydrogen-as-accelerator

Figure 6.10: Reference scope case overview of the blue hydrogen production and transport infrastructure for the Rotterdam port, including both RFG and NG heating demand from end users. 'J#' are identifiers for junction points where the transmission pipeline splits into smaller lines going directly towards the plants.

H-vision

Air Liquide bp Deltalinqs ebn ENGIE equinor GasTerra gasunie

Linde OCI NITROGEN Port of Rotterdam Shell TAQA TNO uniper Vopak

H-vison feasibility study 2019

- The CO2 avoidance cost: €86 to €146 per tonne.
- Unit costs for compression, transport and storage: €17 - €30 per tonne.
- CO2-reduction from 2.2 in 2026 to 4.3 Mt per year in 2031 for the reference scope.
- two 1460 MW production trains , 700 kt.
- €1.3 - €2.0 billion investment

KEY UNCERTAINTIES [1]	
TECHNICAL	Hydrogen national backbone capacity (GW)
	Hydrogen external storage availability
	Electrification industry (PJ)
COMMERCIAL ECONOMICS	CO_2 market price (€/ton) [3] 2020-2045
	Gas market price (€/MWh) [3] 2020-2045
	CO_2 tariff (€/ton) [4]
	CAPEX
POLITICAL	Political/societal support Porthos

Key Elements of EU Hydrogen Strategy

- EU Hydrogen strategy in 2020 (priority new European Commission)
- Ambitious targets for clean hydrogen market: blending in gas grids/industry, transport
- Common standards, guarantees of origin (CertifyHY), flexible and hybrid market regulation
- Build strong EU presence in clean hydrogen value chain
- Boost EU clean hydrogen R&D

Government of the Netherlands

Questions?

m.hamelink@minezk.nl