FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

MISSION INNOVATION
accelerating the clean energy revolution

Institute for Sustainable Process Technology

ISPT and the Gigawatt green hydrogen plant

Introduction to ISPT and the Hydrohub Innovation Program

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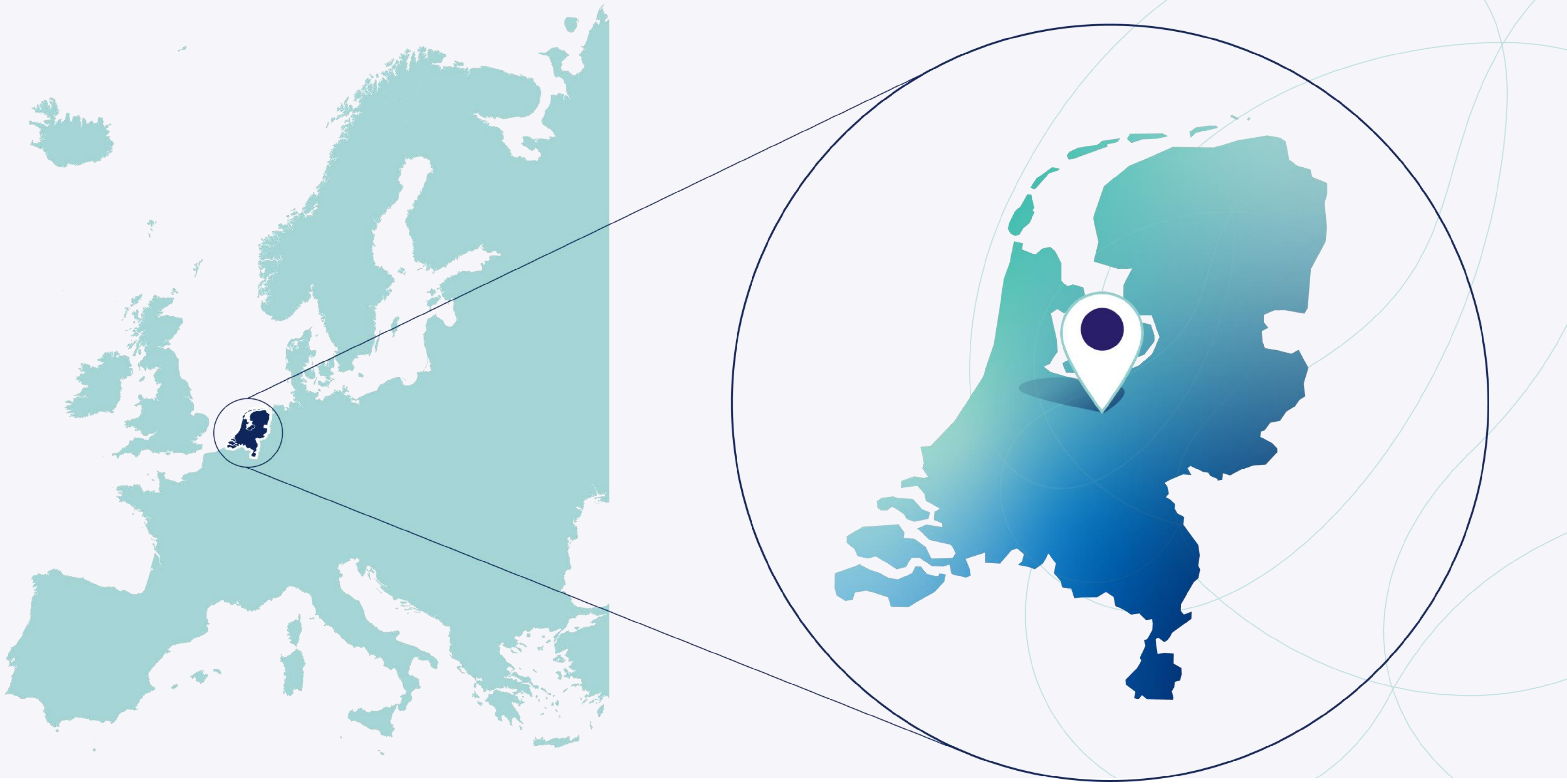
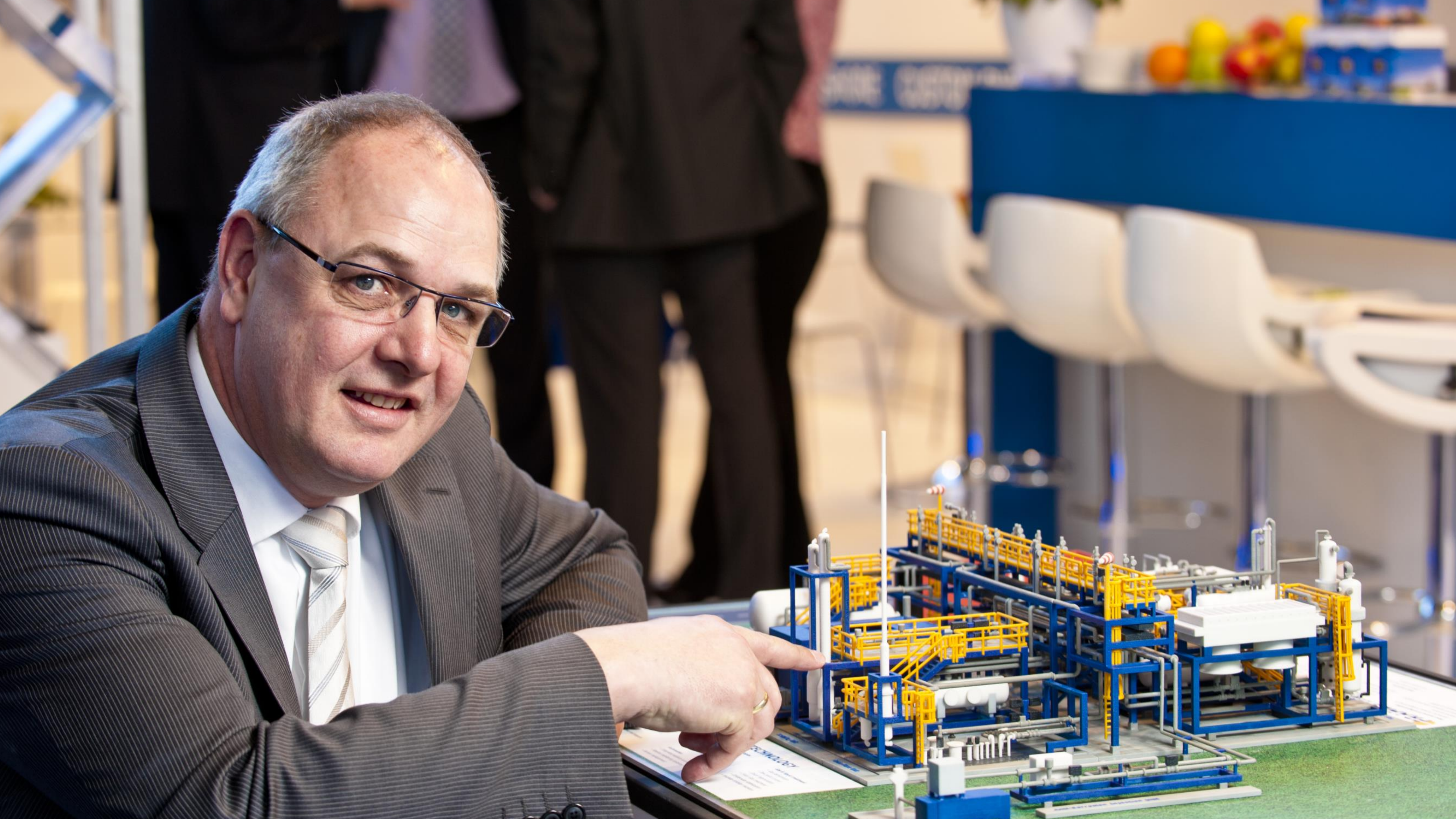
Carol Xiao – Program Manager Hydrohub

Institute for Sustainable Process Technology

Together | Trust-based | Factual | Independent





Some of our partners

Industrial Heat

Deep Eutectic Solvents

Industry 4.0

Mild Fractionation

Circular Plastics

Circular Carbon

Hydrohub

Vopak
provincie Zuid Holland
provincie groningen
Gasunie
Port of Rotterdam
Shell
Royal HaskoningDHV Enhancing Society Together
Tata Steel
Stedin.net
Port of Amsterdam
Nouryon
ECN/TNO Your energy. Our passion.
Cosun
Institute for Sustainable Process Technology
TU Delft
Universiteit Utrecht
Dow
Yara
Frames
Imperial College London
Ørsted
OCI Nitrogen
Hanzehogeschool Groningen University of Applied Sciences
rijksuniversiteit groningen
FrieslandCampina nourishing by nature
TKI Energie & Industrie Topsector Energie
Rijksdienst voor Ondernemend Nederland

Hydrohub Innovation Program

Hydrohub

Matching the scales

~10 GW offshore NL in 2030

NL ~800 kton / yr industrial hydrogen production and use

Hydrohub

Matching the scales

Connect through GW scale water electrolysis

The Hydrohub Innovation Program

Hydrohub

Electrolysis-based production of sustainable, low cost, **hydrogen at scale** as a driver for circular industrial chains

Hydrohub megawatt test center	Gigawatt electrolysis design	HyChain
Open Innovation Technology development on industry-scale water electrolysis	Make design of GW scale system to learn how to drive down costs from 1000 to 350 €/kW or less	Understand the emerging supply chains that shape the hydrogen economy driven by the energy transition

Gigawatt scale water electrolysis conceptual design

Hydrohub

Develop an economically viable GW scale green hydrogen concept for 5 industry clusters

1. Science	2. Business	3. Engineering
Imperial college of London | TNO | Utrecht University	5 Industrial regions	Core consortium partners

1. Science
- Choice of technology
- Stack size
- Learning curves
- Operating model

2. Business
- Infrastructure
- Plot size
- Demand

3. Engineering
- Balance of plant
- CAPEX
- OPEX
- Upscaling versus upnumbering

Two public deliverables so far…

Regional Integration

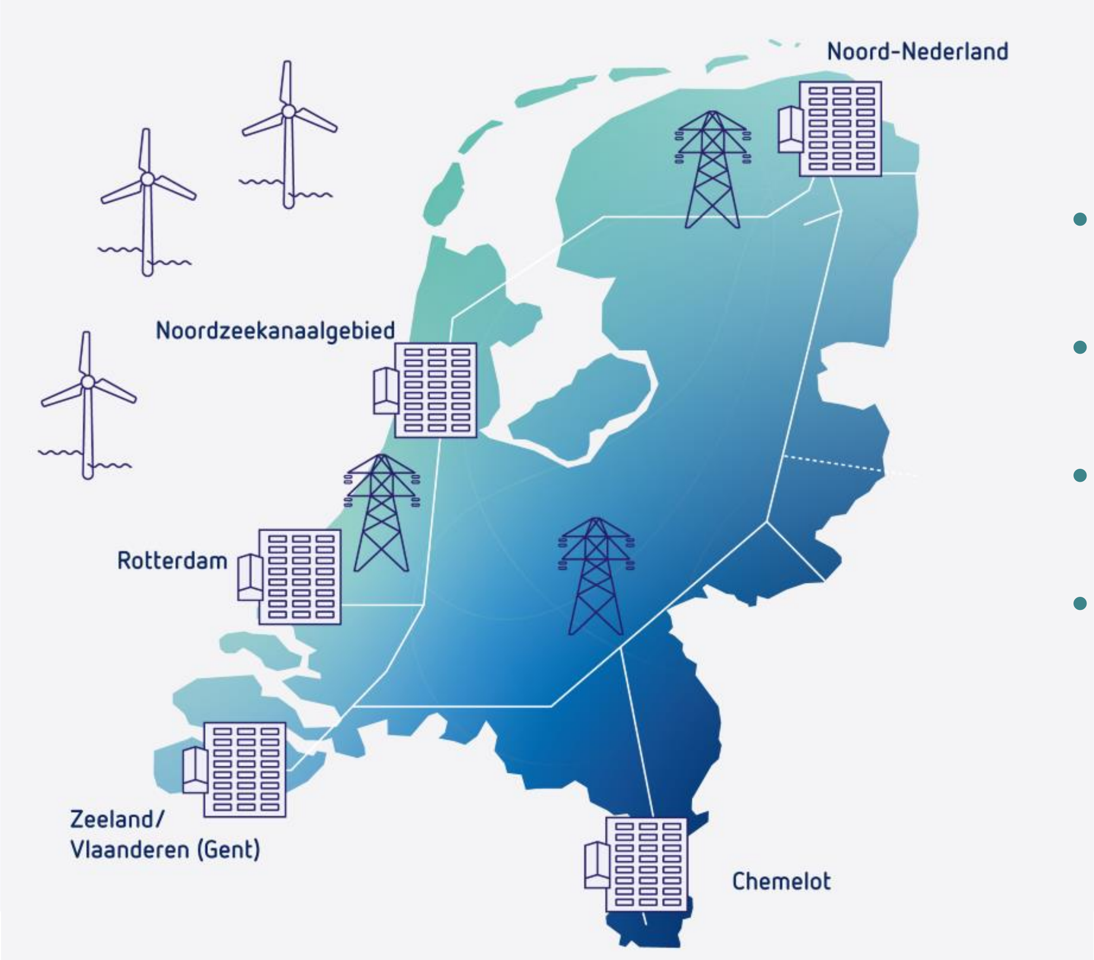
Port region locations for GW scale electrolysis in NL mapped

Published June 18 2020

Baseline design for a GW scale plant

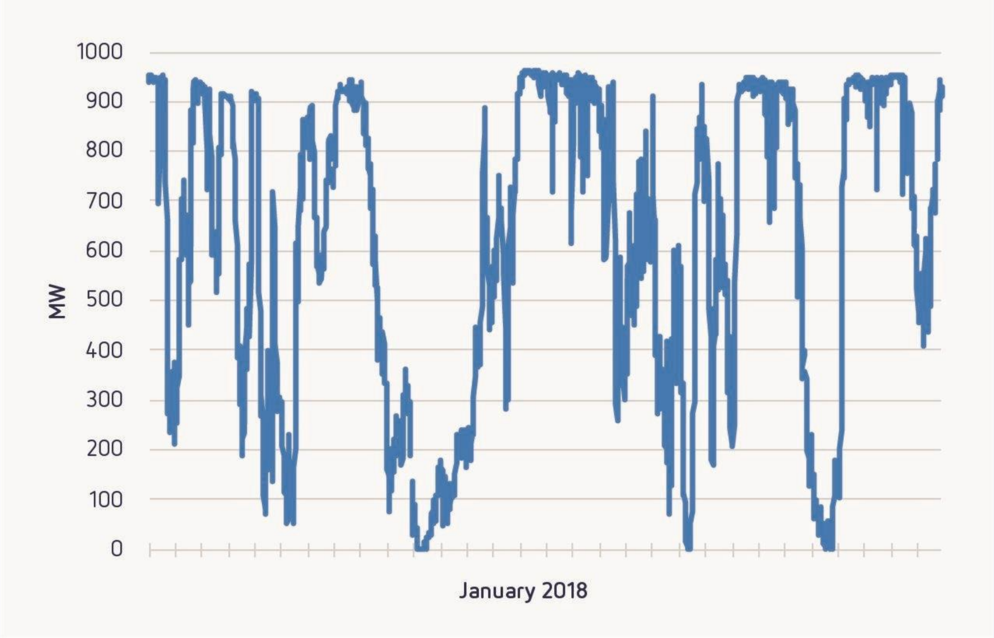
Published October 28 2020

Baseline design starting points – location



- 1 GW Akaline and PEM electrolyser plant
- In the Netherlands
- Greenfield plant
- Industrial zone in port area

Baseline design starting points – power supply



Power supply to a 1 GW green hydrogen plant based on a typical North Sea wind pattern. The graph is based on 2018 data *of a 950MW North Sea wind park, adjusted to gigawatt scale.*

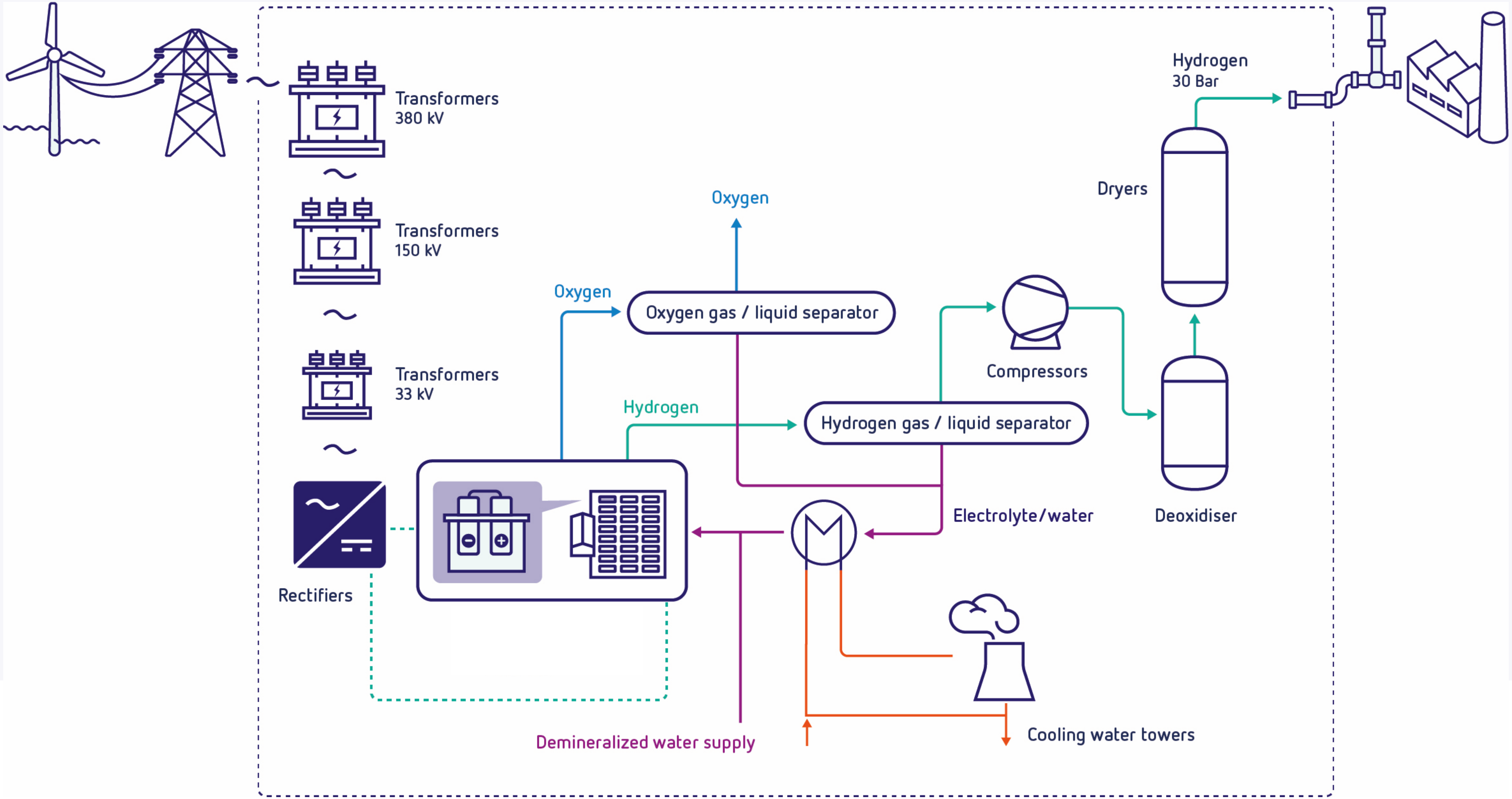
Data provided by **Ørsted**

- Offshore wind power (one year wind profile data)
- 380 kV connection point with 1 GW capacity and amounts to 4000 GWh annually.
- Variation of the wind load results in flexibel power supply.
- Additional back-up electricity needed to ensure minimum load of 15%

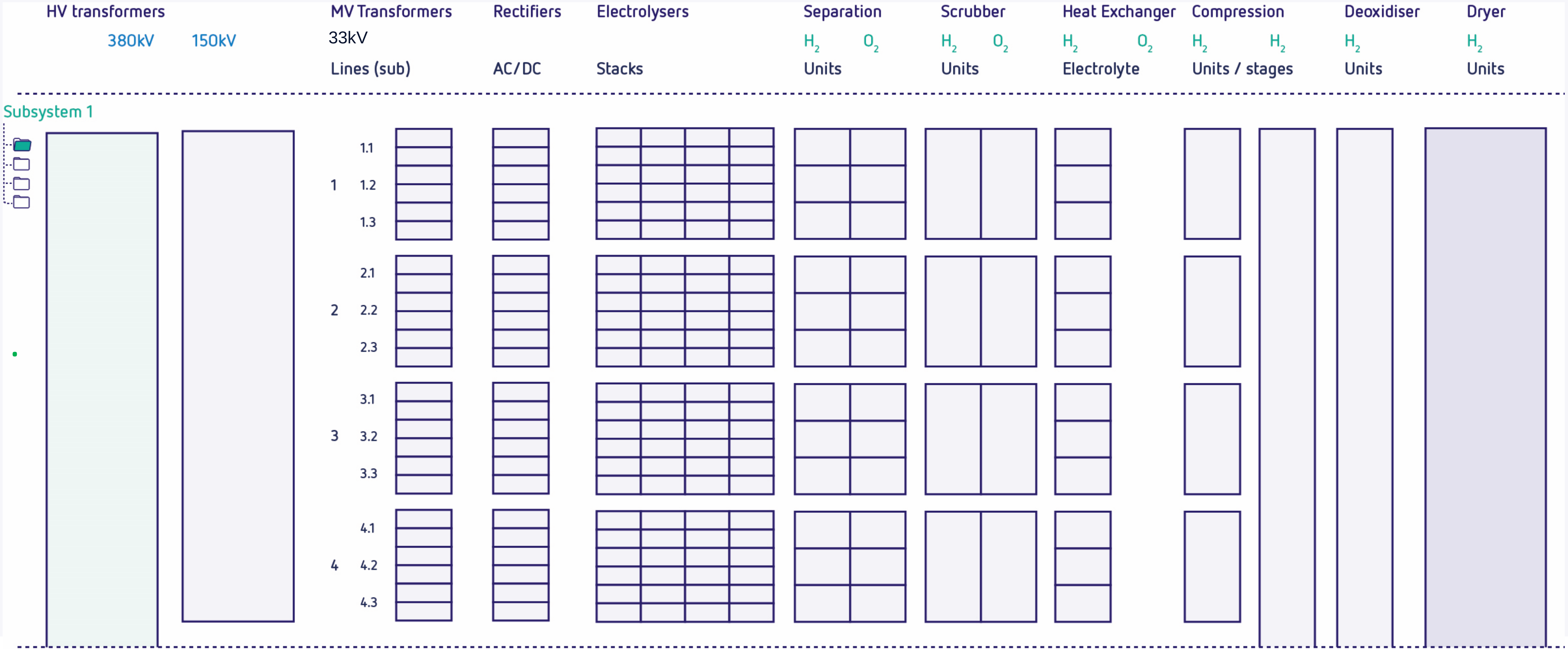
Baseline design starting points – hydrogen production

Production characteristics	Alkaline Electrolyser	PEM Electrolyser
Electricity consumption electrolyser	4.4 kWh per Nm3 hydrogen	4.9 kWh per Nm3 hydrogen
Operational pressure for electrolyser stacks	Atmospheric pressure	Pressurised operation
Electrical losses surrounding electrolyser	8%	5%
Nominal hydrogen output (30 bara, 99,99 % purity, 30ppm (vol) water)	18.8 ton/h	17.1 ton/h

Scope of the GW green hydrogen plant



Modular design of a 1 GW green hydrogen plant



Artists impression of a GW plant

Hydrohub

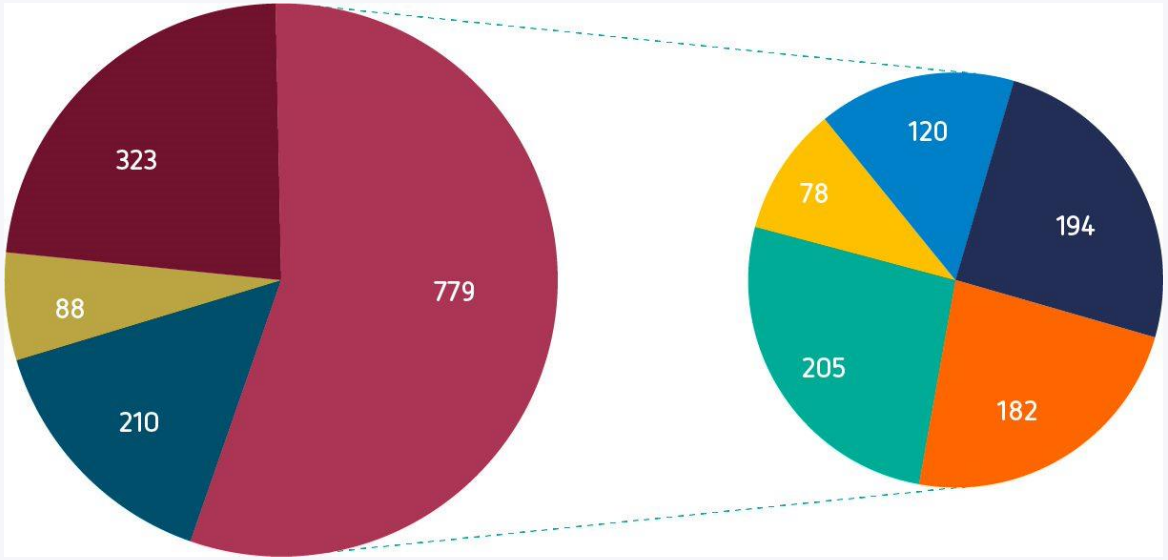
Multidisciplinary team in five main areas

	Areas	Partners	Main equipment
1	**Power supply and electronics**	Ørsted, Yara, Nouryon, MTSA, TUEindhoven, ISPT	380kV, 150kV, 33kV transformers, rectifiers, switch gear, bus bars
2	**Electrolyser stacks**	Nouryon, Ørsted, Yara, TNO, Imperial College London, University Utrecht, ISPT	Alkaline 432 stacks PEM 1485 stacks
3	**Balance of plant (separation, compression and gas treatment)**	Nouryon, Frames, Gasunie, OCI Nitrogen, Yara, ISPT	54 / 99 hydrogen gas-liquid separators (Alkaline/ PEM) 54 / 99 oxygen gas-liquid separators (Alkaline/ PEM)
4	**Utilities and Process Automation**	DOW, Nouryon, Ørsted, Yara, ISPT	cooling water towers demi water treatment DCS (Distributed control system) ESD (Emergency Shut Down)
5	**Civil, structural & Architect**	Nouryon, Ørsted, Yara, ISPT	building, piling, foundation, structural steel

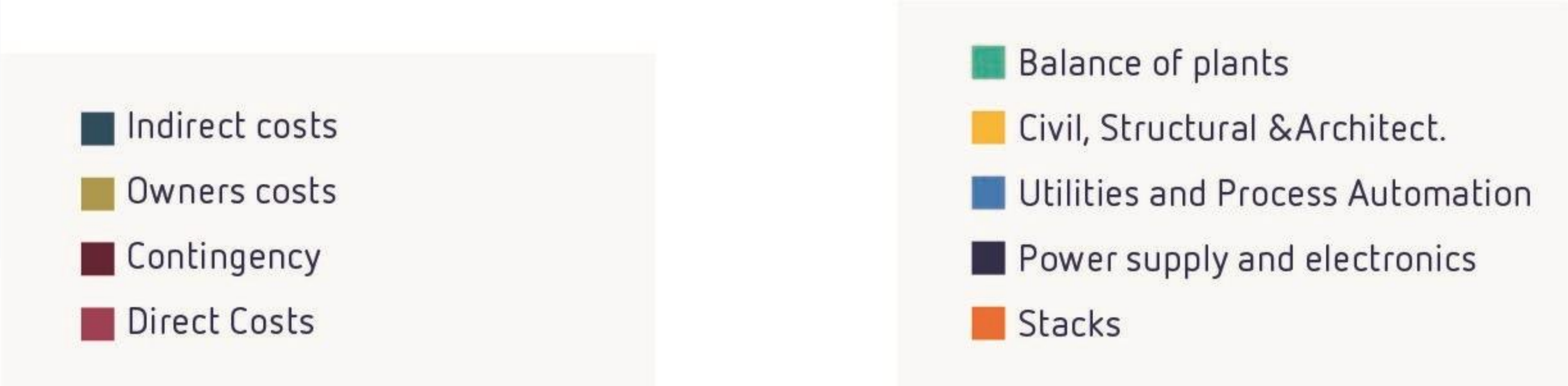
Cost estimating principles

- Total Installed Cost (TIC): cost required to install the plant ready for commercial operation
- Common practice bottom-up cost estimate
- Feasibility study: accuracy within - 25% / + 40% range (class IV level estimate of the Association for the Advancement of Cost Engineering)
- TIC consists of:
  - Direct costs: supply of equipment of the scope
  - Indirect cost: engineering, project management, construction supervision and management, and commissioning costs; fees utilities during start up etc.
  - Indirect Owners costs: project management, site supervision, operator training, insurance, grid fees, electricity consumption during construction etc.
  - Contingency: 30% to cover risks and unknown scope

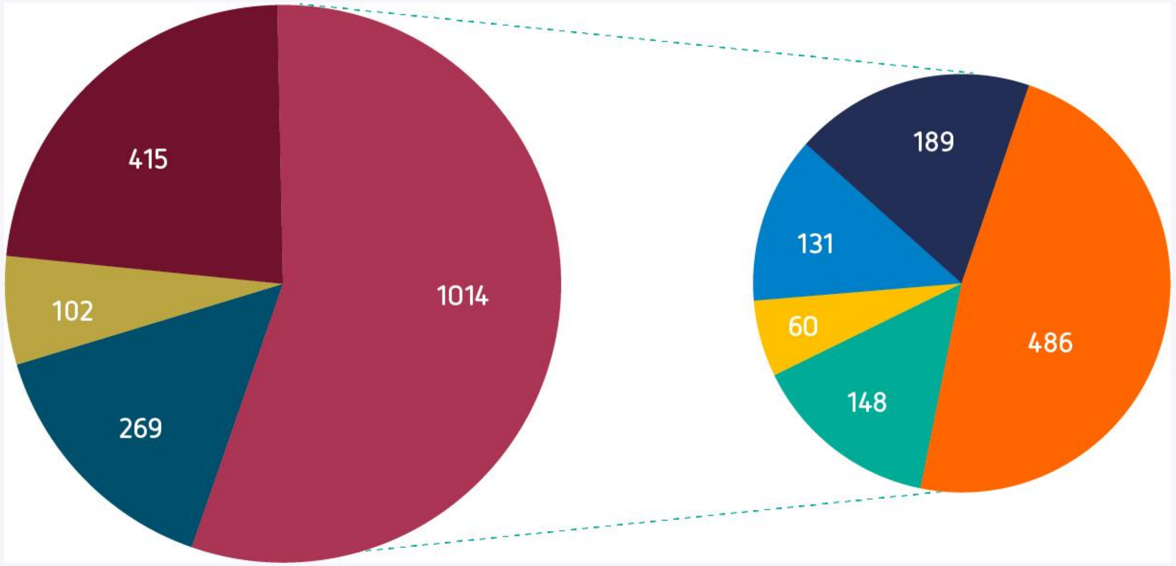
Results Total Installed Cost – Alkaline technology



- Total Installed Costs 1400 Euro/kW
- Direct costs 779 Euro/kW
  - In line with public reported values
  - Stacks cost (~25%) is comparable with the costs of BoP, Power supply and electronics



Results Total Installed Cost – PEM technology



- Total Installed Costs 1800 Euro/kW
- Direct costs 1014 Euro/kW
  - In line with public reported values
  - Stacks cost (~50%) is comparable with the sum of other parts
  - BoP of PEM is lower due to no need for compression

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Conclusion

- ✓ Total Installed Costs (TIC), incorporating indirect costs, owner cost and contingency are the relevant measure for investment in green hydrogen facility
- ✓ For 2020, a TIC of 1400 €/kW for Alkaline and 1800 €/kW for PEM are estimated
- ✓ Next to the Stacks costs, Power supply & Electronics, Balance of Plants, Civil and Utilities contribute significantly to the TIC
- ✓ This baseline design and costs estimate provides the first public reference of the TIC of a GW scale green hydrogen facility. This offers a starting point for exploring cost reductions of CAPEX and Levelised Costs of Hydrogen in the next phase

Consortium partners of the GW project

Institute for Sustainable Process Technology

STEDIN

Port of Rotterdam

provincie groningen

GRONINGEN SEAPORTS

Deltalinqs

Gemeente Rotterdam

provincie Zuid Holland

Nouryon

gasunie crossing borders in energy

Gemeente Amsterdam

Port of Amsterdam

TNO innovation for life

TATA

Provincie Noord-Holland

Imperial College London

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Ørsted

Universiteit Utrecht

FRAMES

YARA

DOW

SDR PLATFORM

North Sea Port Together. Smarter.

OCI NITROGEN

TKI ENERGIE & INDUSTRIE Topsector Energie

MTSA TECHNOPOWER