KIVI bijeenkomst

16-oktober-2019

Stay tuned. Safety first!

Voor uw en onze veiligheid vragen we uw aandacht voor de volgende veiligheidsmaatregelen.

In geval van een ontruiming van het pand:

- Volg de vluchtroute zoals aangegeven.

- Gebruik de trap in plaats van de lift.

- Ga naar het verzamelpunt.
- Volg de aanwijzingen van de bedrijfshulpverlener. Deze is in geval van een ontruiming aanwezig.

Inhoud

1. Introductie TenneT
2. Introductie Gasunie
3. Huidige energiestromen
4. Infrastructure Outlook 2050:

   “Hoeveel systeemintegratie is er nodig voor een klimaat-neutrale energiehuishouding?”

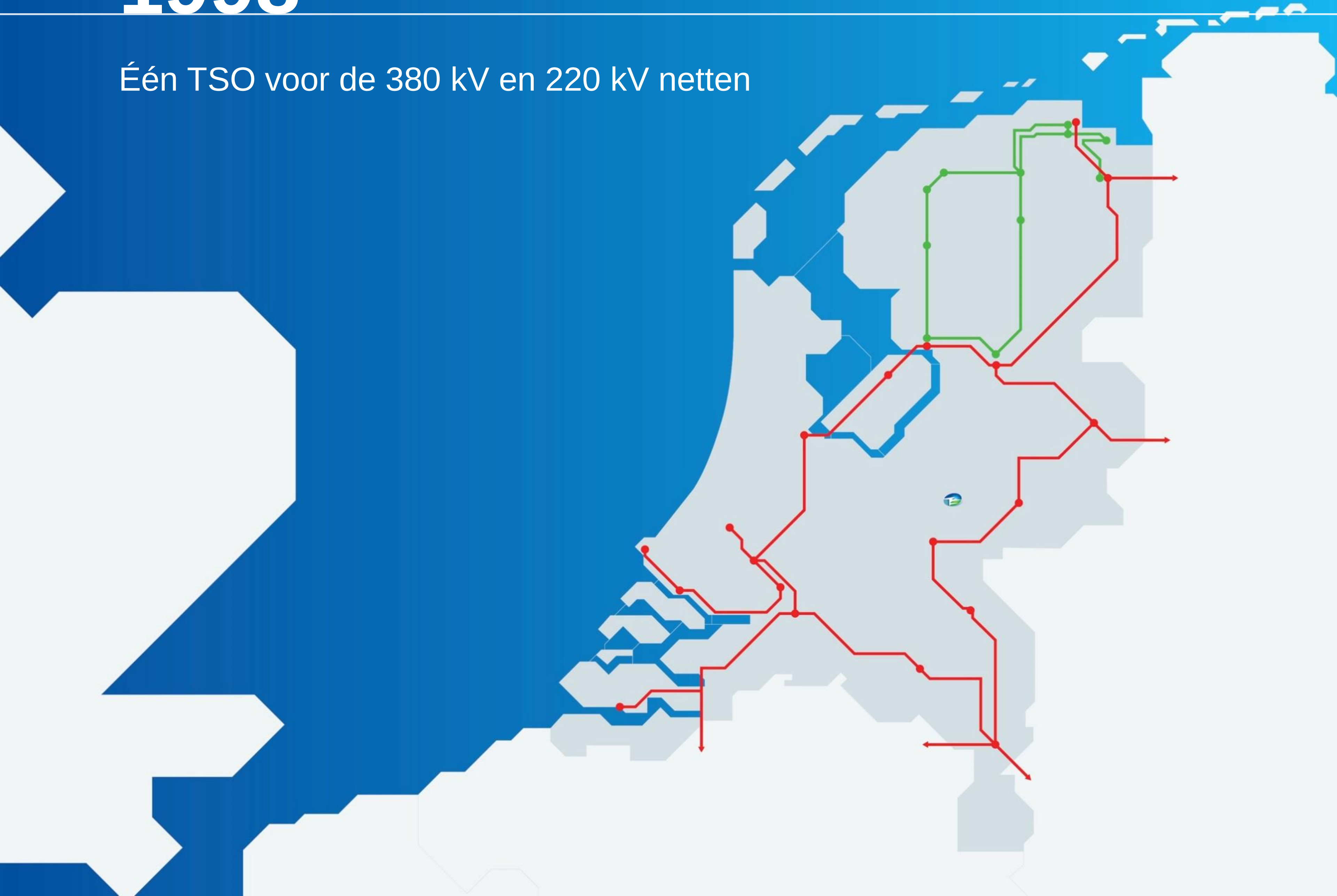
De TenneT organisatie

Het ontstaan van TenneT

1880-1900	Gemeentelijke energiebedrijven.
1949	Regionale energiebedrijven verenigen zich voor productie en netbeheer in Sep N.V.(Samenwerkende elektriciteitsproductiebedrijven).
1998	TenneT Transmission System Operator B.V. opgericht. De nieuwe Elektriciteitswet (1998) wijst TenneT aan als de onafhankelijke beheerder van het landelijk transportnet voor kwalitatief en betrouwbaar elektriciteitsverkeer in Nederland.
2003	TenneT neemt de regionale netbeheerder B.V. Transportnet Zuid-Holland (TZH) over.
2008	TenneT neemt het beheer van de 110 kV en 150 kV-netten over van de regionale netbedrijven.
2010	Overname van het Duitse hoogspanningsnetwerkbedrijf transpower Stromübertragungs GmbH (voorheen onderdeel van E.ON AG).

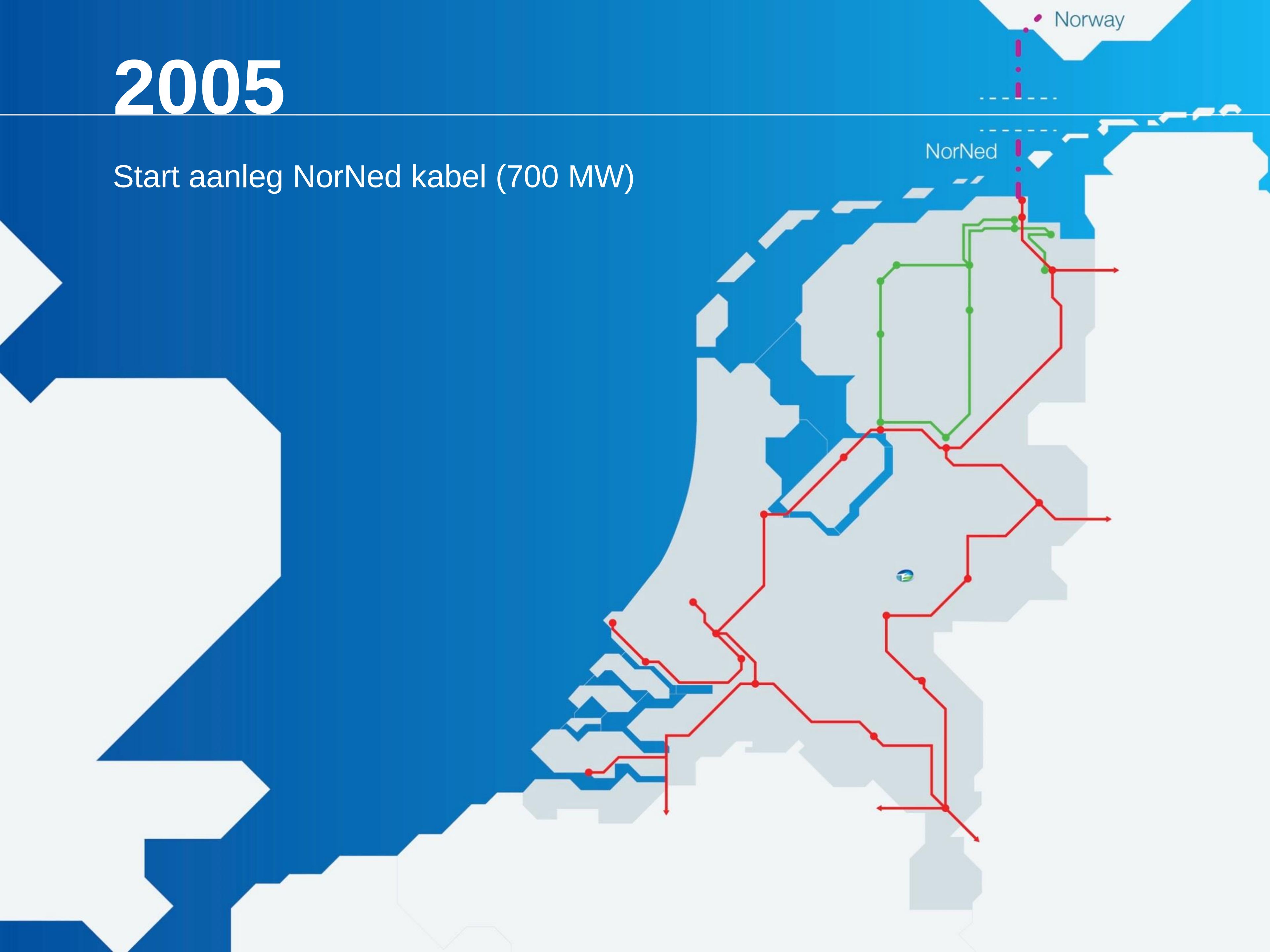
1998

Één TSO voor de 380 kV en 220 kV netten



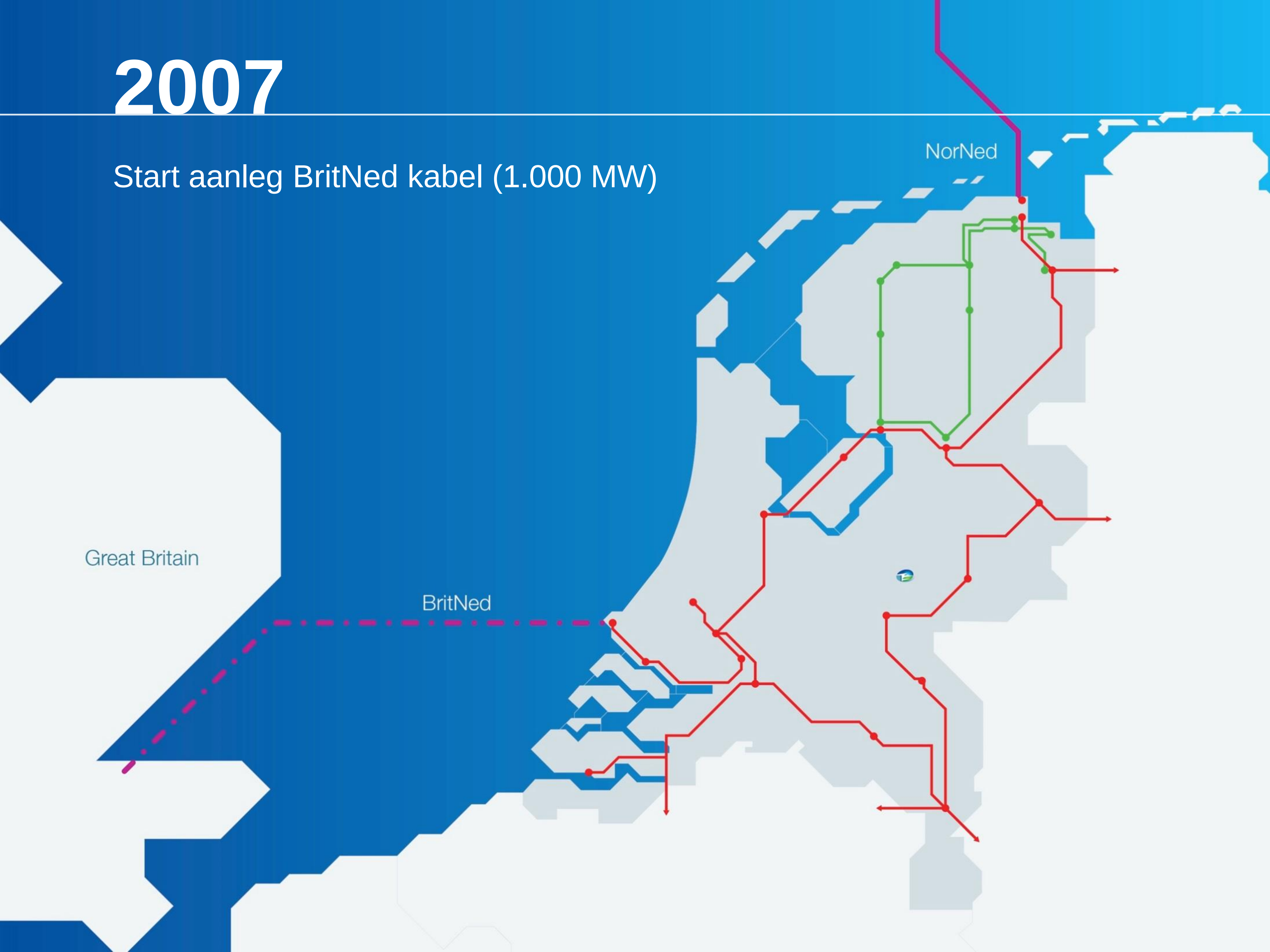
2005

Start aanleg NorNed kabel (700 MW)



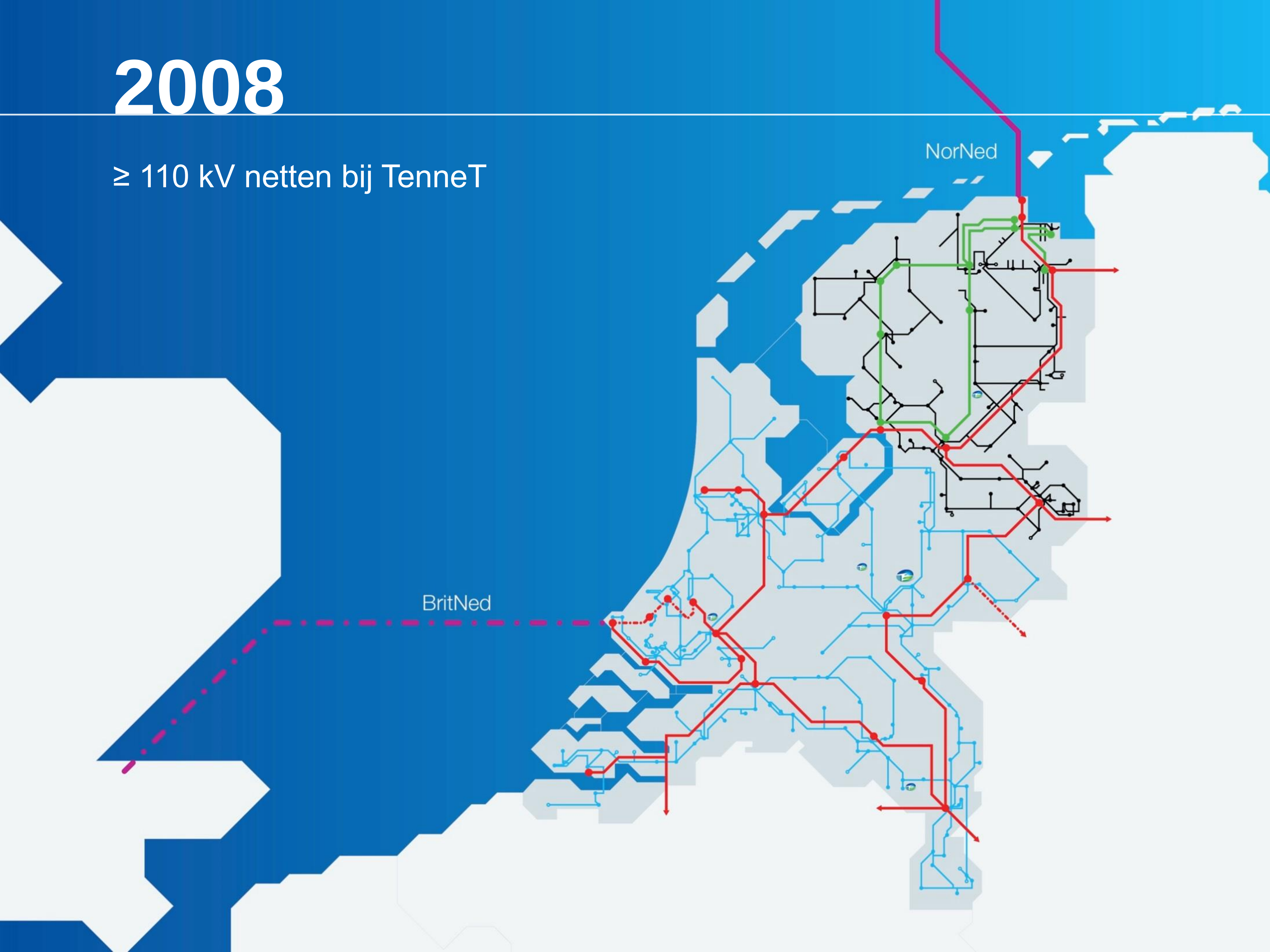
2007

Start aanleg BritNed kabel (1.000 MW)



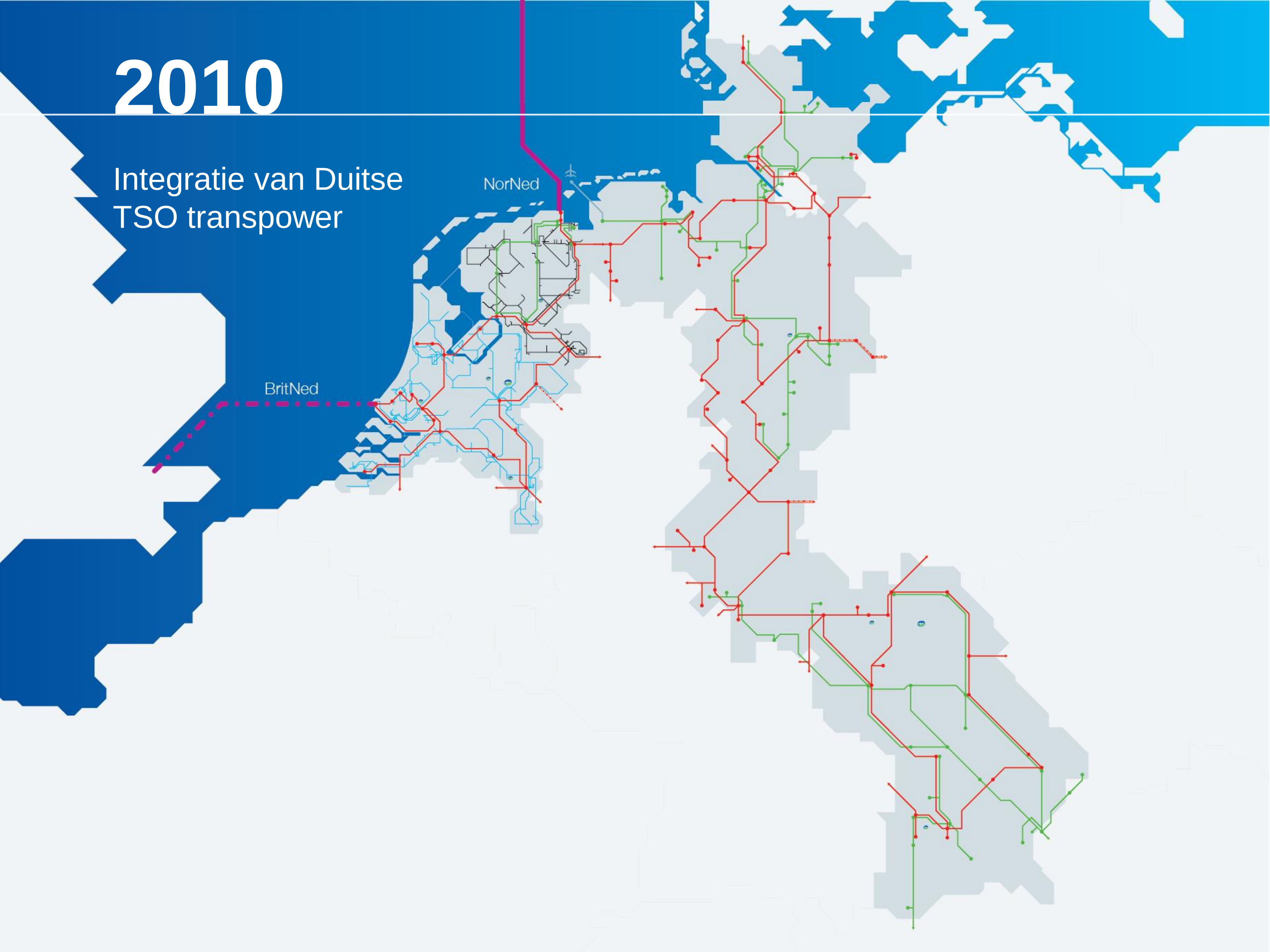
2008

≥ 110 kV netten bij TenneT



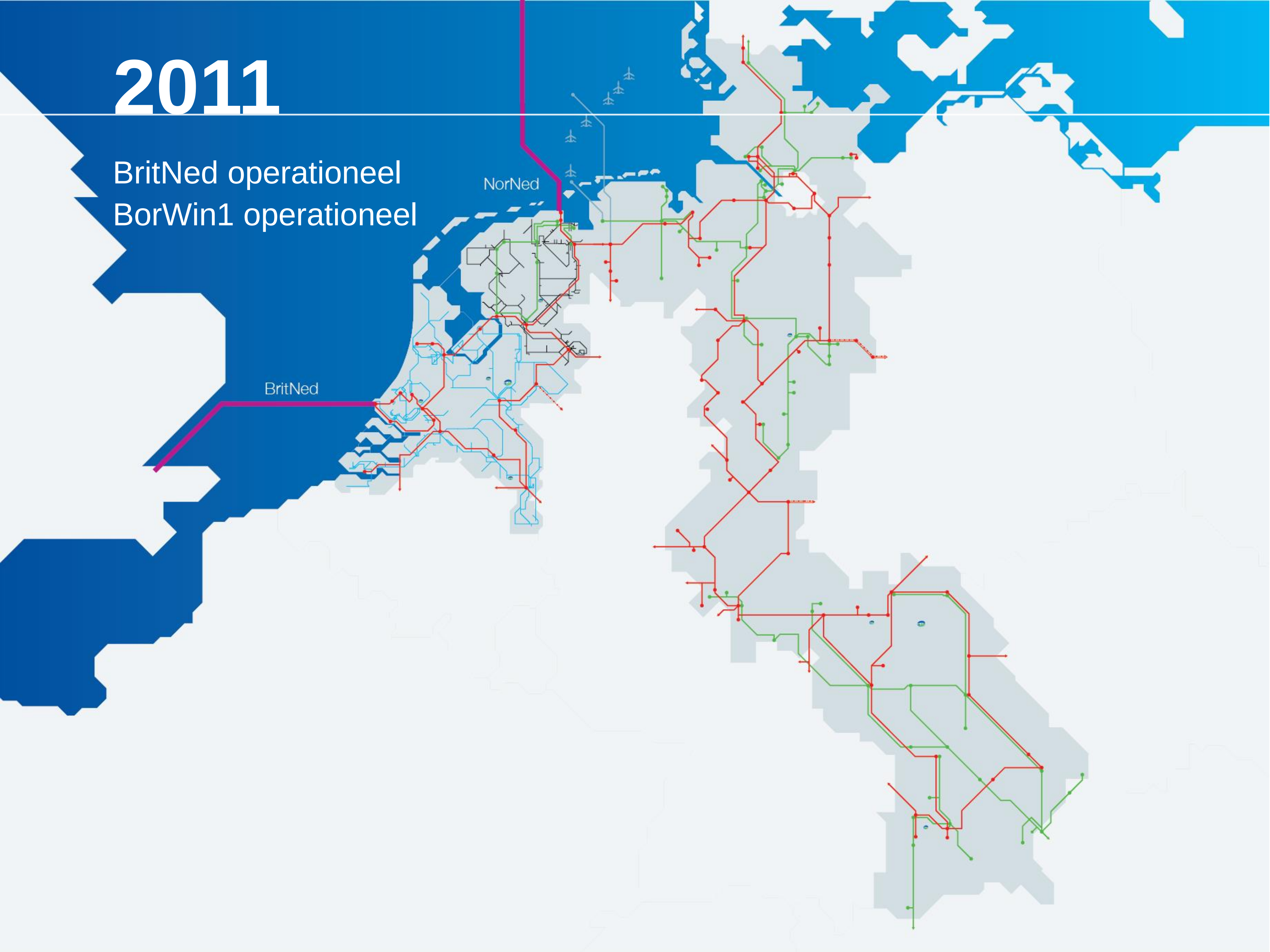
2010

Integratie van Duitse
TSO transpower



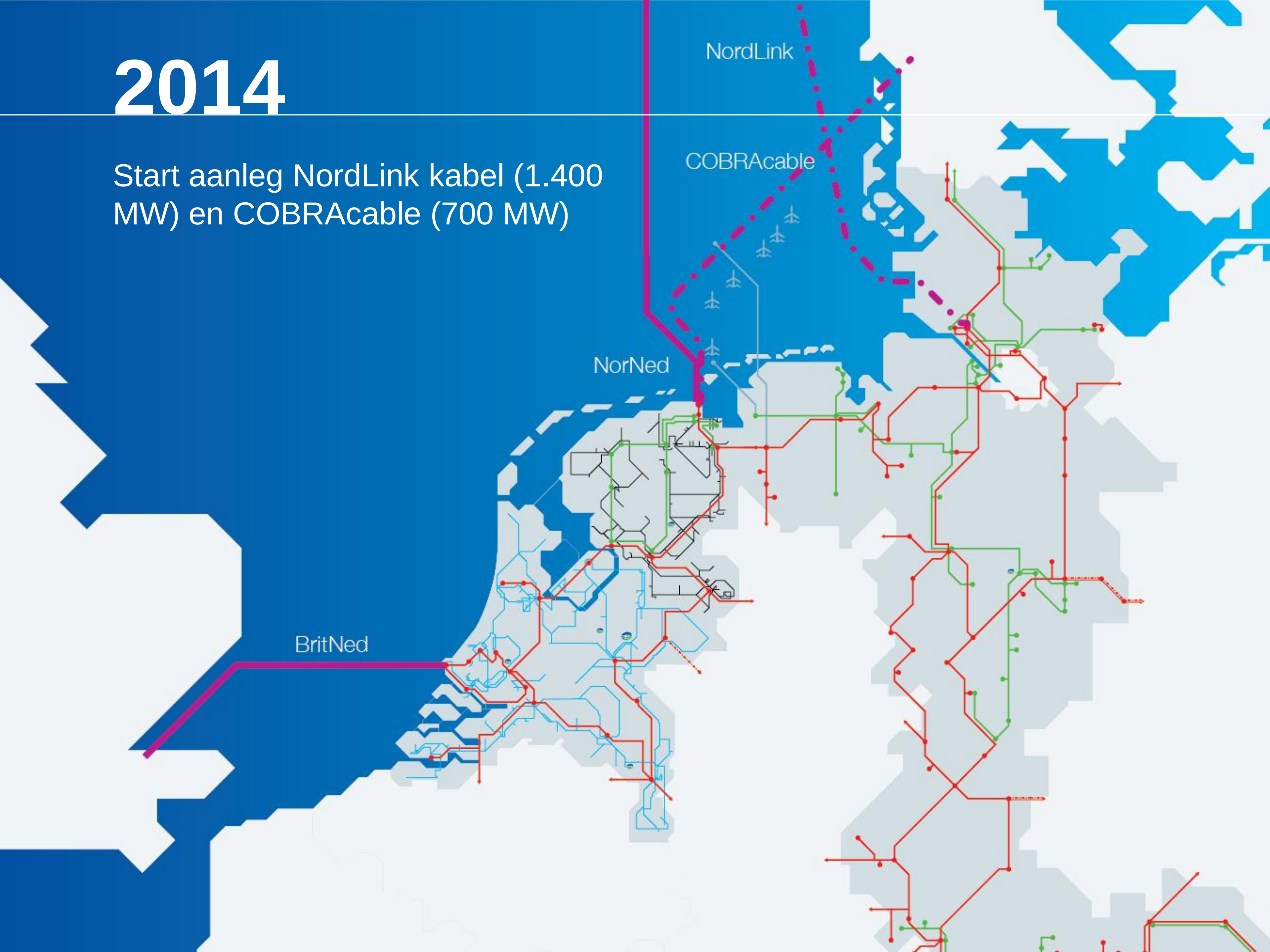
2011

BritNed operationeel
BorWin1 operationeel



2014

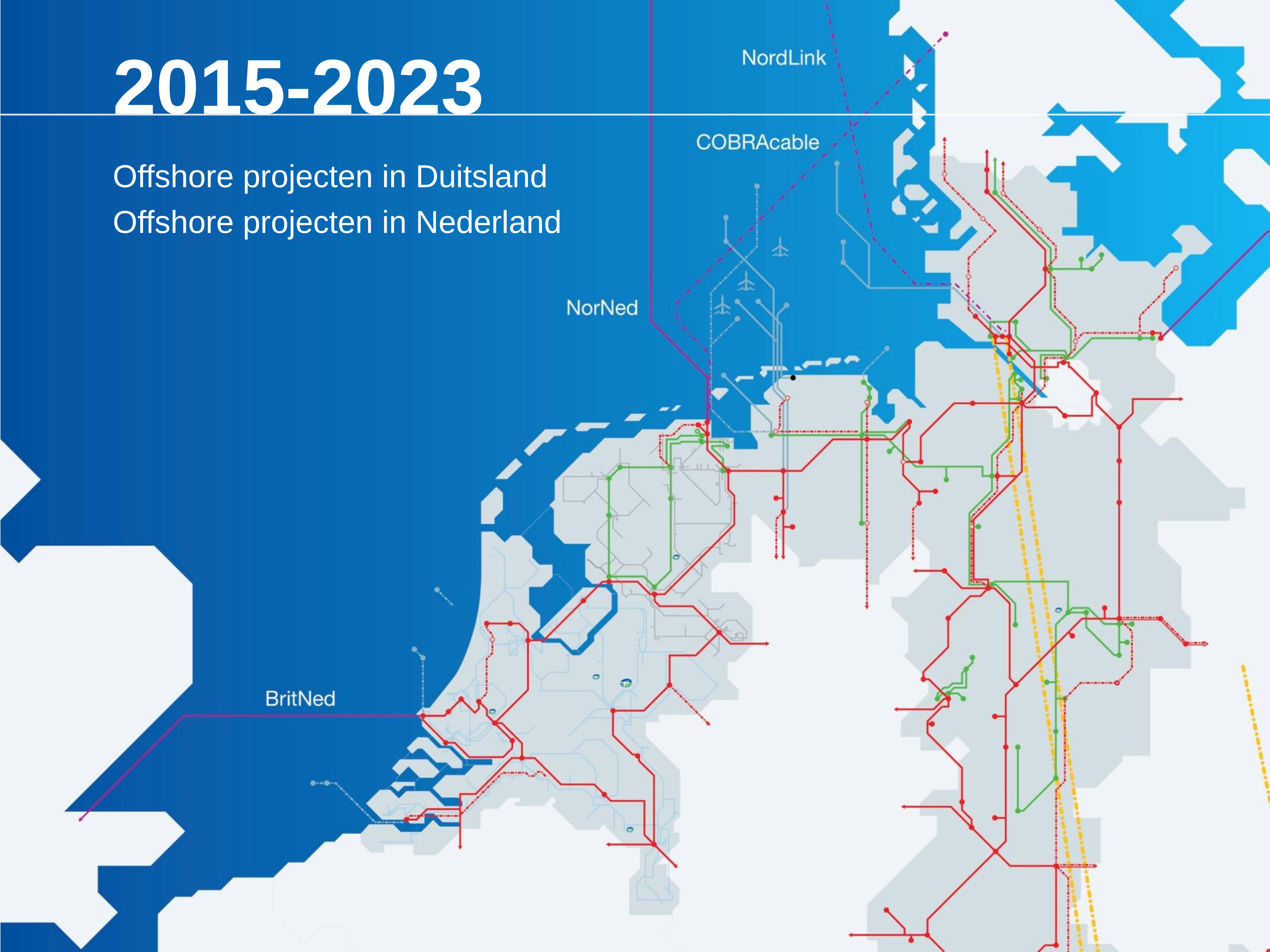
Start aanleg NordLink kabel (1.400 MW) en COBRAcable (700 MW)



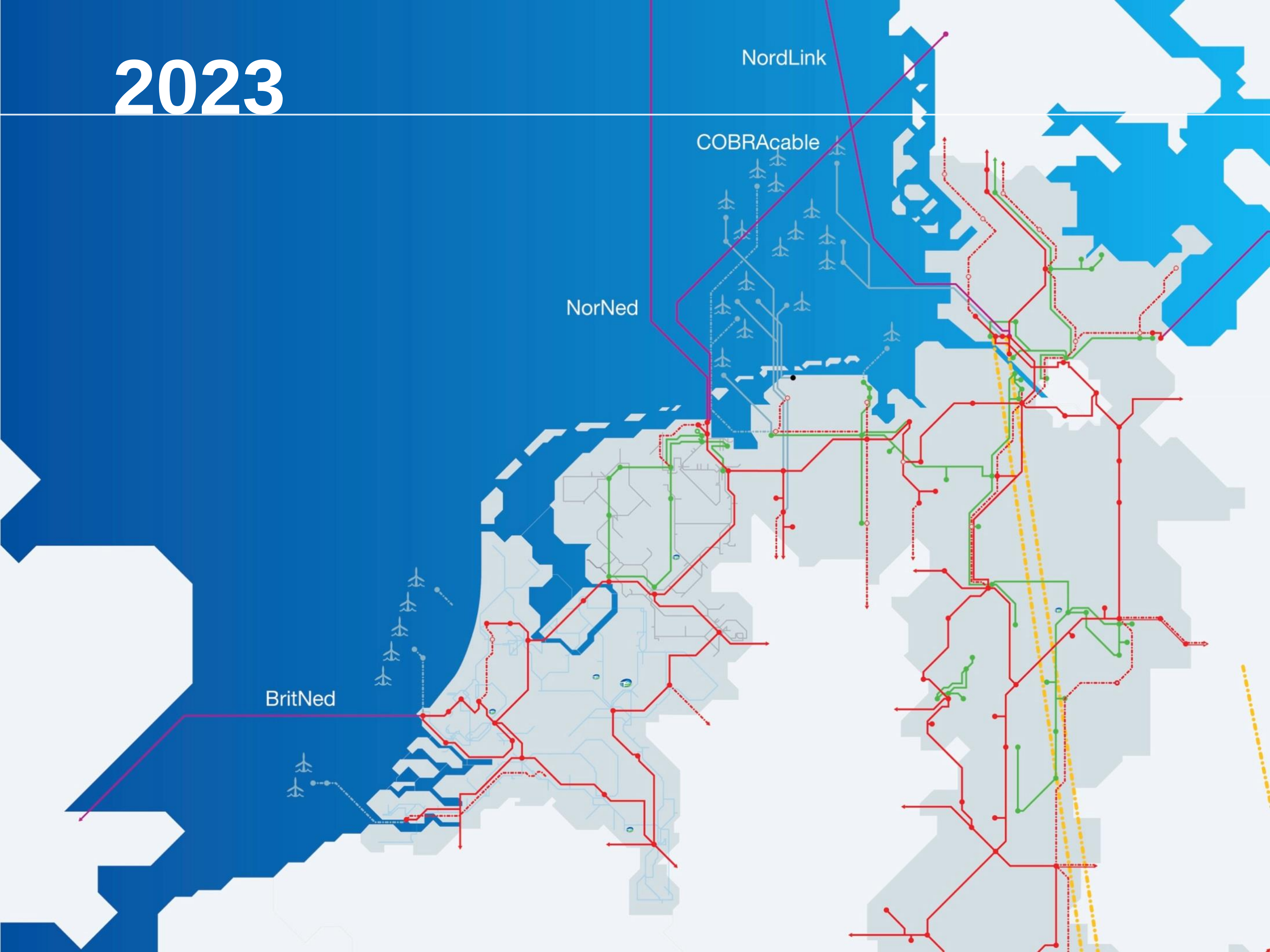
2015-2023

Offshore projecten in Duitsland

Offshore projecten in Nederland



2023



TenneT in één oogopslag

De eerste grensoverschrijdende netbeheerder in Europa

4,538
Medewerkers

EBIT
806
(EUR miljoen)

Activa
21,8
(EUR miljard)

Investeringen
2019-2029
35
(EUR miljard)

Aantal aangesloten offshore windparken
17

Totale lengte net
23.000 km

Aantal eindgebruikers
41
miljoen

Aantal transformator-stations
462

Aantal HVDC stations
18

Netbeschikbaarheid
99,99%

TenneT in één oogopslag

Nederland

Facts & figures

Medewerkers (intern+extern)	2.148
Activa	EUR 6,165 miljard
Import	24.735 GWh
Export	18.730 GWh
Totale lengte net	10.168 km
Aantal transformatorstations	333
Aantal eindgebruikers	17 miljoen

TenneT in één oogopslag

Duitsland

Facts & figures

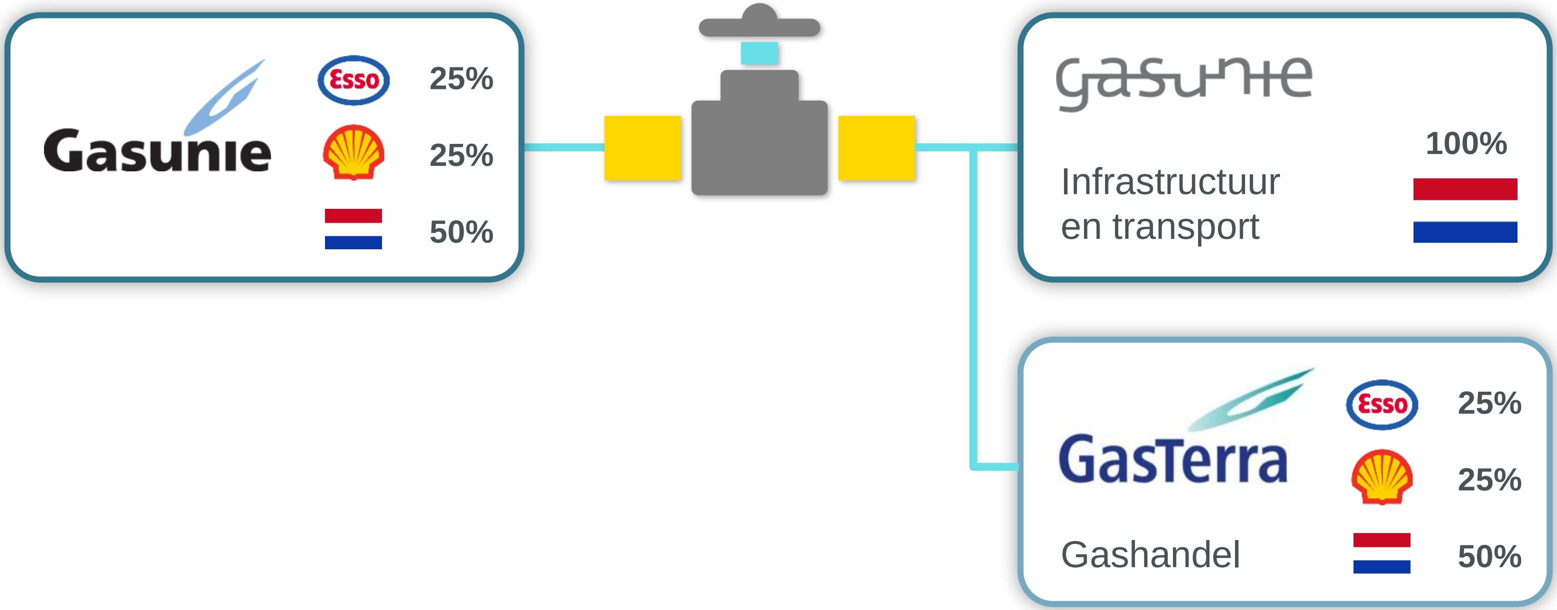
Medewerkers (intern+extern)	2.390
Activa	EUR 16,067 miljard
Import	65.593 GWh
Export	67.411 GWh
Totale lengte net	12.606 km
Aantal transformatorstations	129
Aantal eindgebruikers	24,3 miljoen

NB TenneT is één van de vier TSO's in Duitsland

Gasunie Transport Services

Juli 2005: Gasunie gesplitst

Eén onderneming ⟵ **1 juli 2005** ⟶ Twee ondernemingen



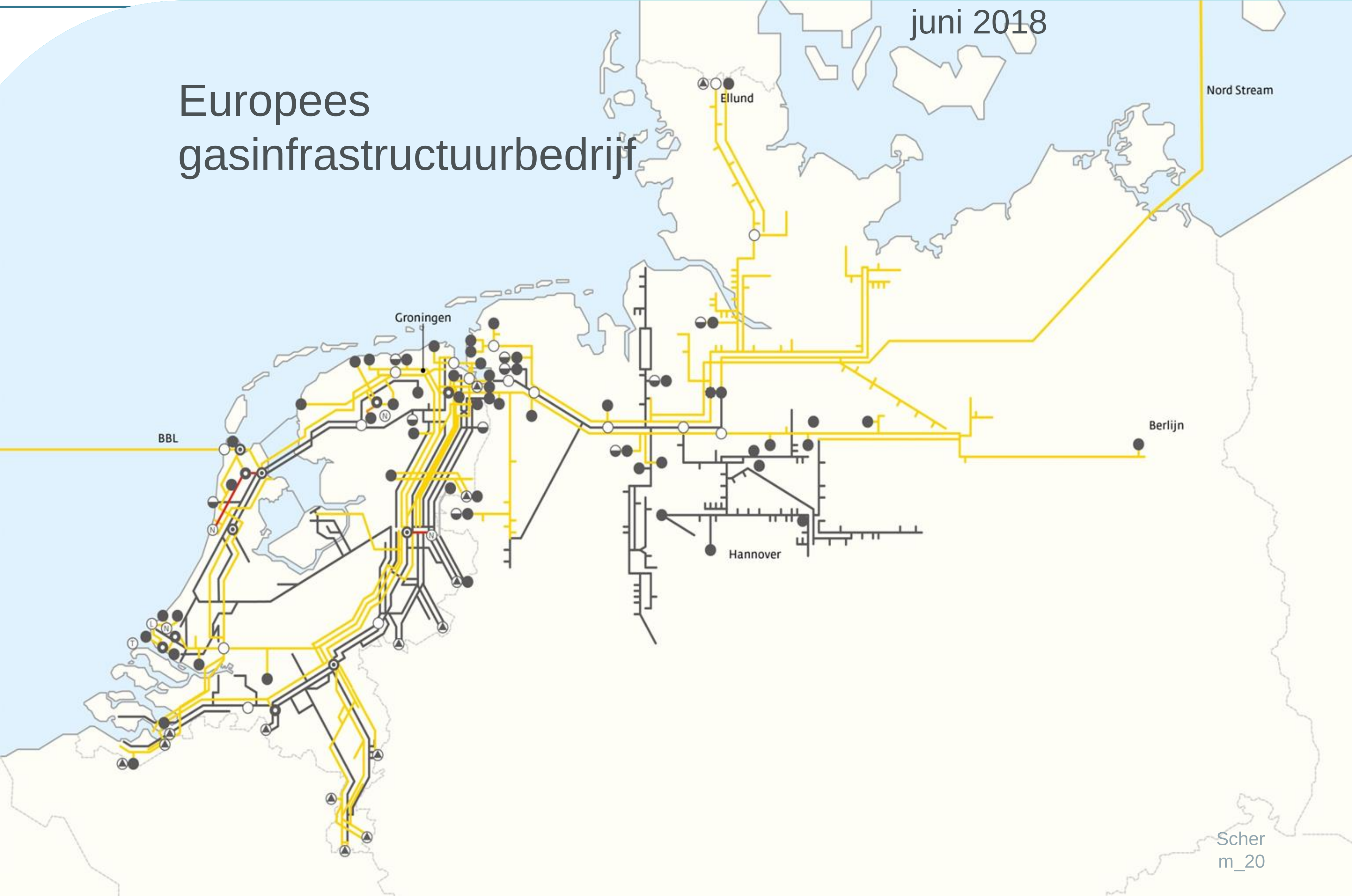
Gasunie
Esso 25%
Shell 25%
🇳🇱 50%

Gasunie
Infrastructuur en transport
🇳🇱 100%

GasTerra
Gashandel
Esso 25%
Shell 25%
🇳🇱 50%

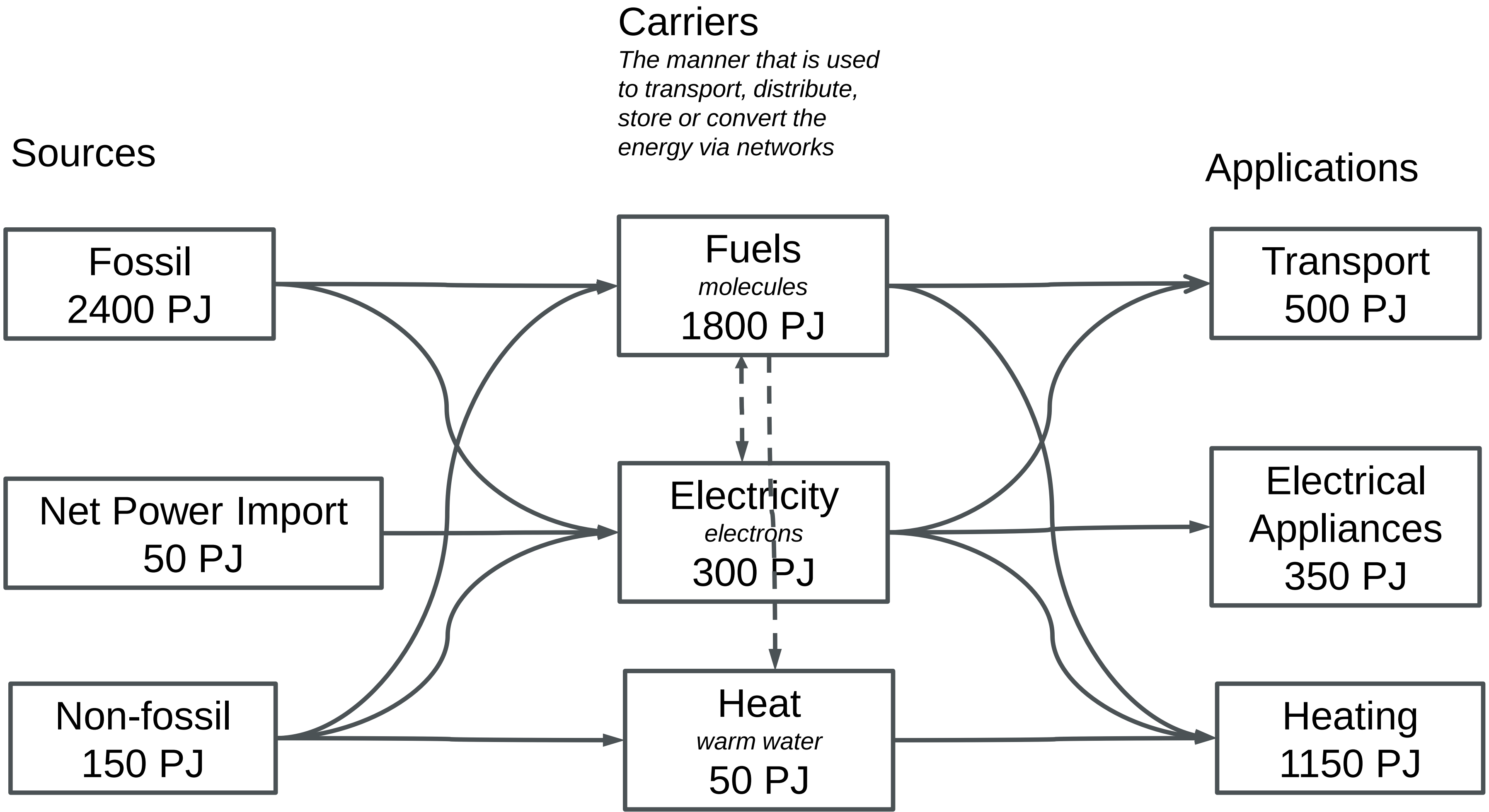
Groningen,
juni 2018

Europees gasinfrastructuurbedrijf



De huidige energiebalans

Energy balance in the Netherlands (2015)



Carriers

The manner that is used to transport, distribute, store or convert the energy via networks

Sources

Applications

Fossil
2400 PJ

Net Power Import
50 PJ

Non-fossil
150 PJ

Fuels
molecules
1800 PJ

Electricity
electrons
300 PJ

Heat
warm water
50 PJ

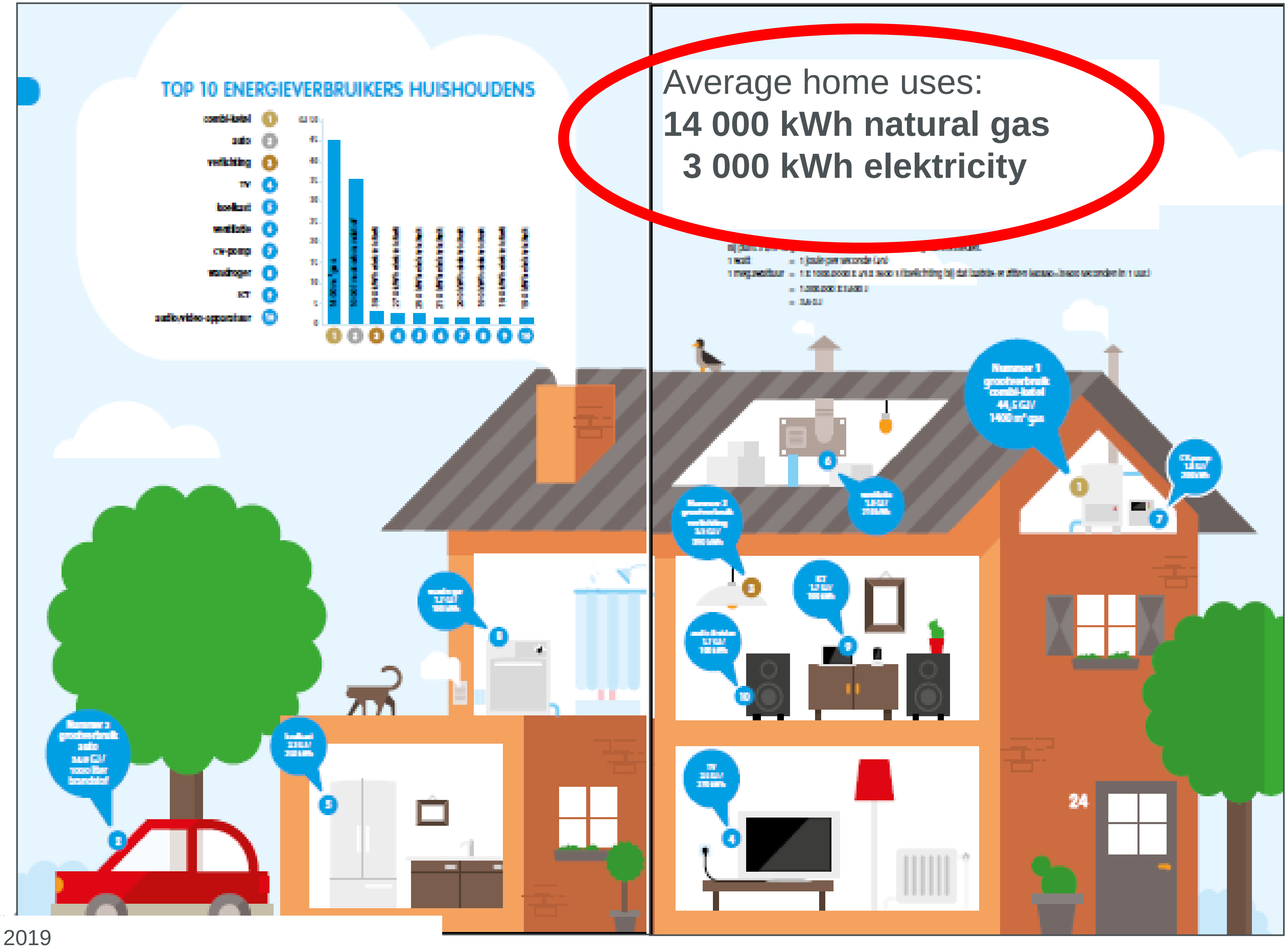
Transport
500 PJ

Electrical Appliances
350 PJ

Heating
1150 PJ

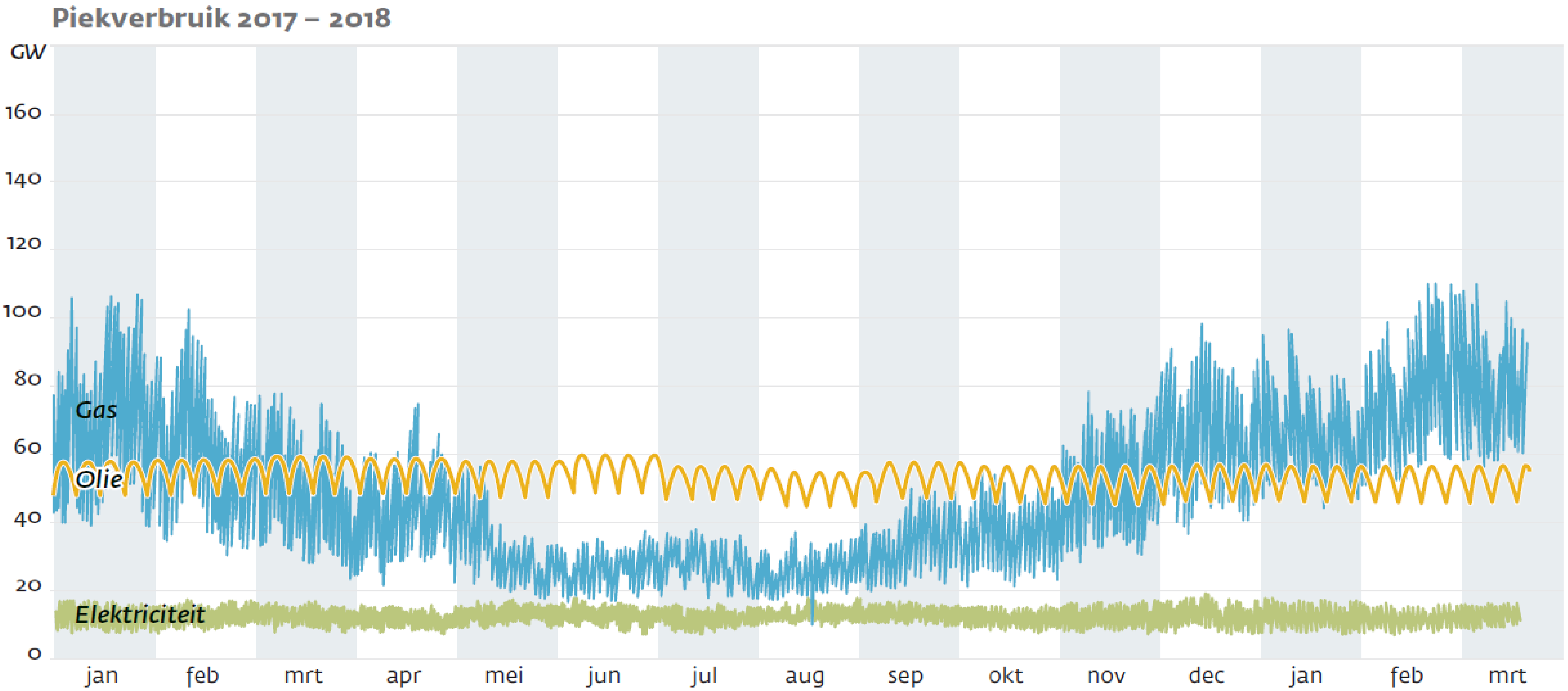
Source: NEV 2016

Consumption average home



Average home uses:
14 000 kWh natural gas
3 000 kWh elektricity

Comparison of energy consumption profiles of electricity, gas and oil



Infrastructure Outlook 2050

A joint study by Gasunie and TenneT on integrated energy infrastructure in the Netherlands and Germany

Source: www.tennet.eu, www.gasunie.nl and www.gasunie.de

gasunie crossing borders in energy

TenneT Taking power further

Opdracht

Tijdlijn

201	
Begi	
Med	zijn
Med	ttelijke
201	2030-
201	ericht op schaal.
201	
202	t name icaties
(Vanaf) 2020	Verbrede monitor leveringszekerheid
Eind 2021	Transitievisies warmte


21 december 2018

Ontwerp van het Klimaatakkoord

Opzet

De transitie naar een duurzame energievoorziening vereist een andere benadering van de netplanning

Beschouwen van het integrale energiesysteem aan de hand van scenario’s.

Bepalen van consequenties voor gas- en elektriciteitstransportnet met geïntegreerd infrastructuurmodel.

Netwerken

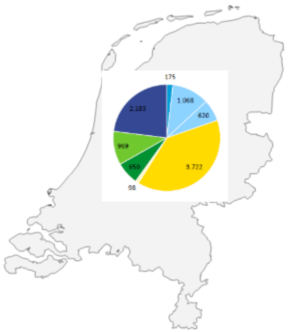
Tennet high-voltage net

Gasunie high-pressure net

Capacity: 20 GW

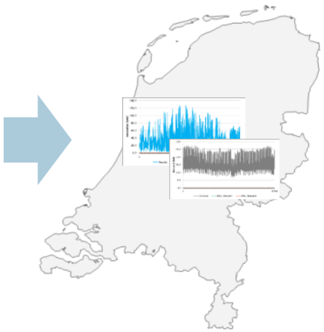
Capacity: 350 GW

Aanpak



Scenario's
"Net voor de
Toekomst" **CE Delft**

Regionaal
Nationaal
Internationaal

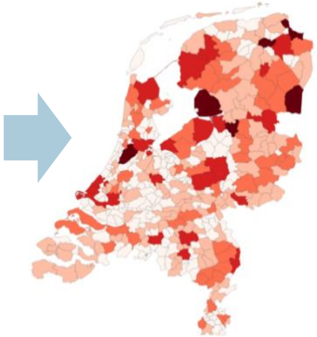


Genereer
tijdreeksen
met
ETM van Quintel

ENERGY TRANSITION MODEL
Independent, Comprehensive and Fact-based

8760 uur

temperatuur en wind:
jaar 2015



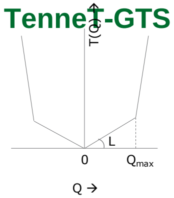
Regionaliseer data
per markt

Zon-PV
Wind op land
Wind op zee
Groen gas

Industrie
Huishoudens
Mobiliteit

Etc.

Bereken
energietransport
met geïntegreerd
model
TenneT-GTS



Visualiseer
stromingspatronen
en knelpunten

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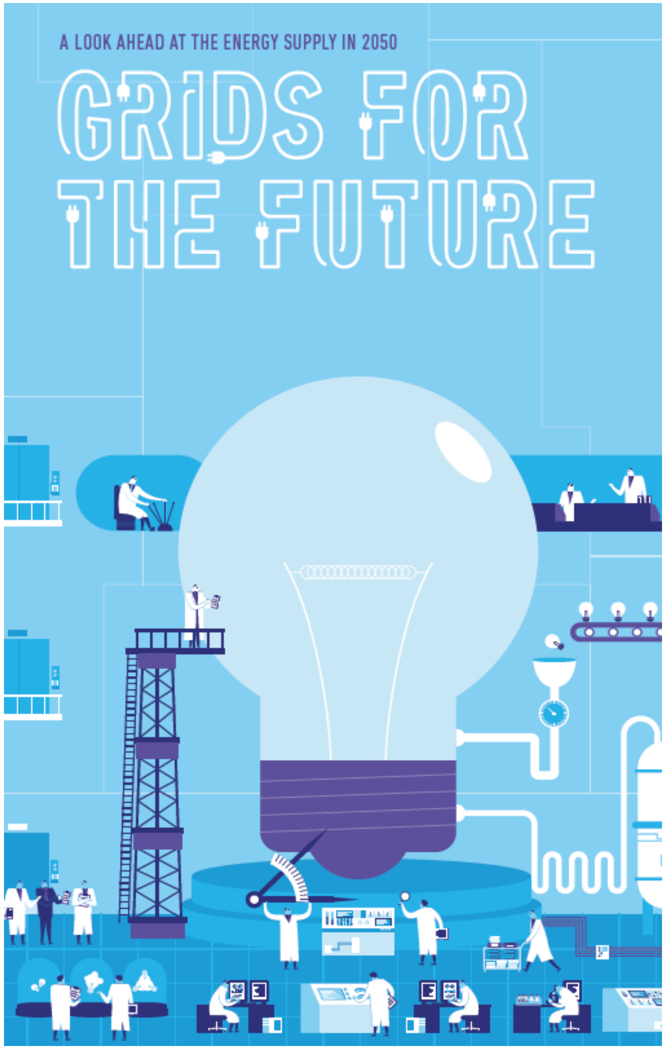
🟨 High
🟥 Overloaded

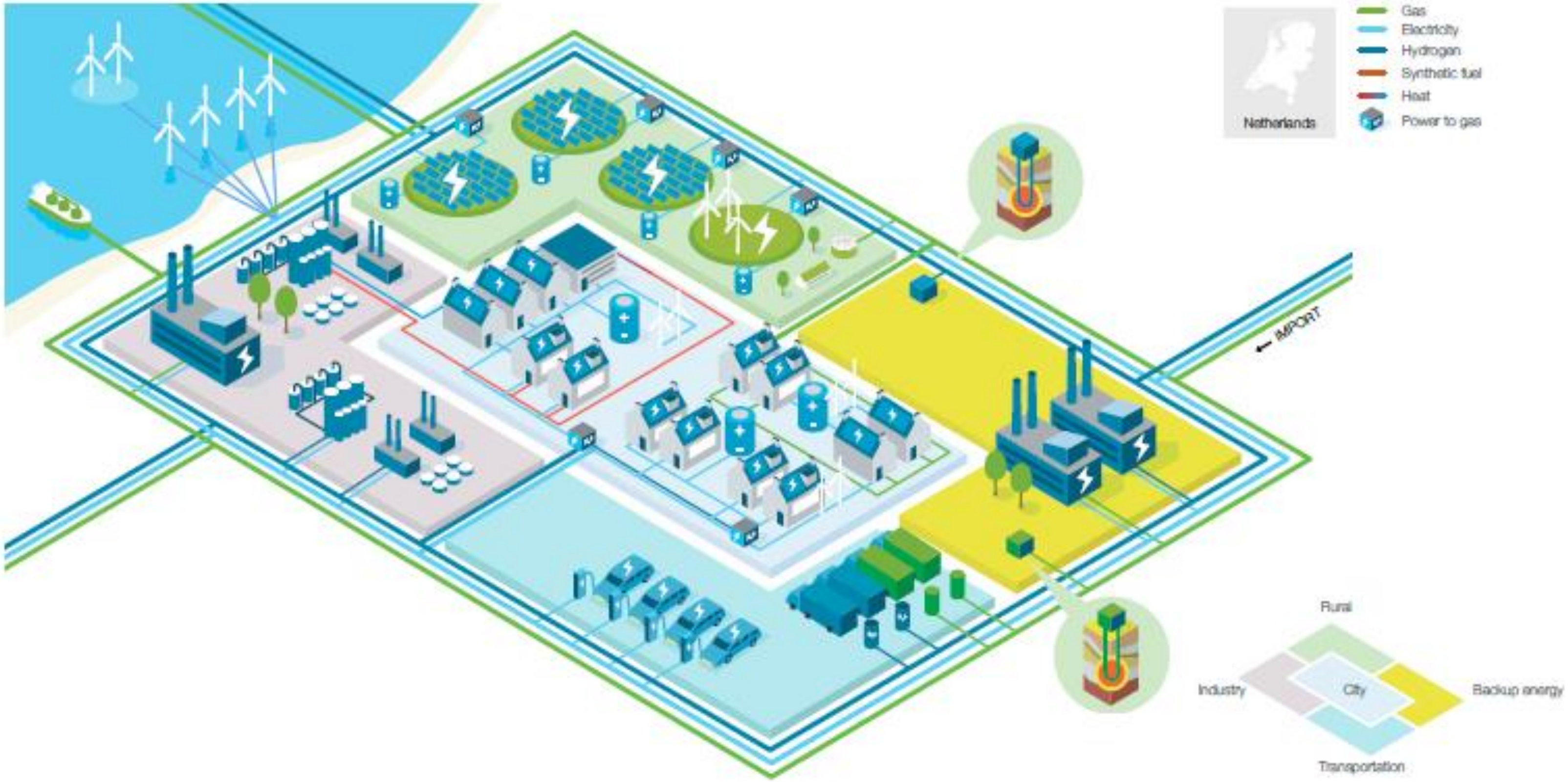
De Scenario's



A LOOK AHEAD AT THE ENERGY SUPPLY IN 2050

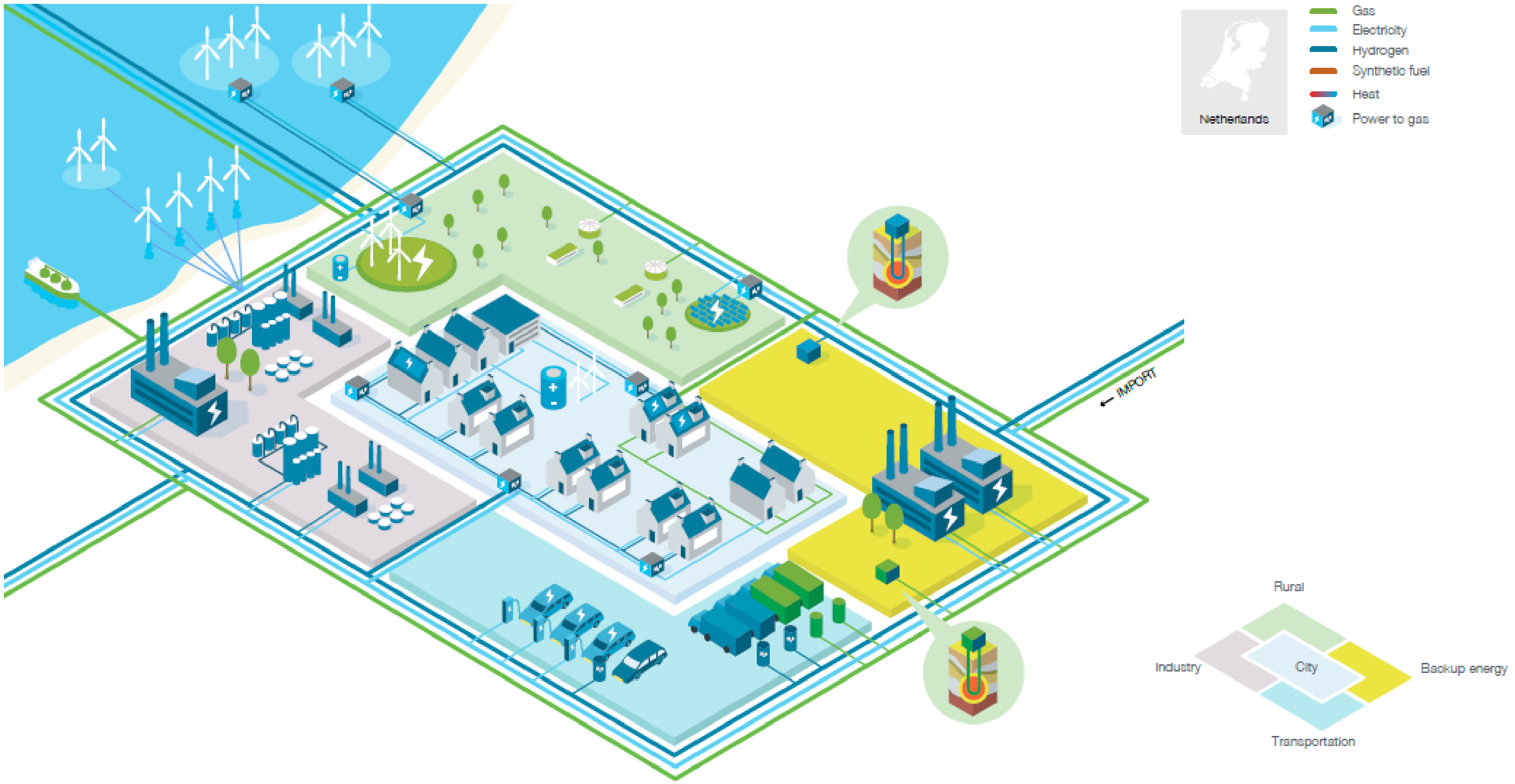
GRIDS FOR THE FUTURE

Local scenario (the Netherlands)



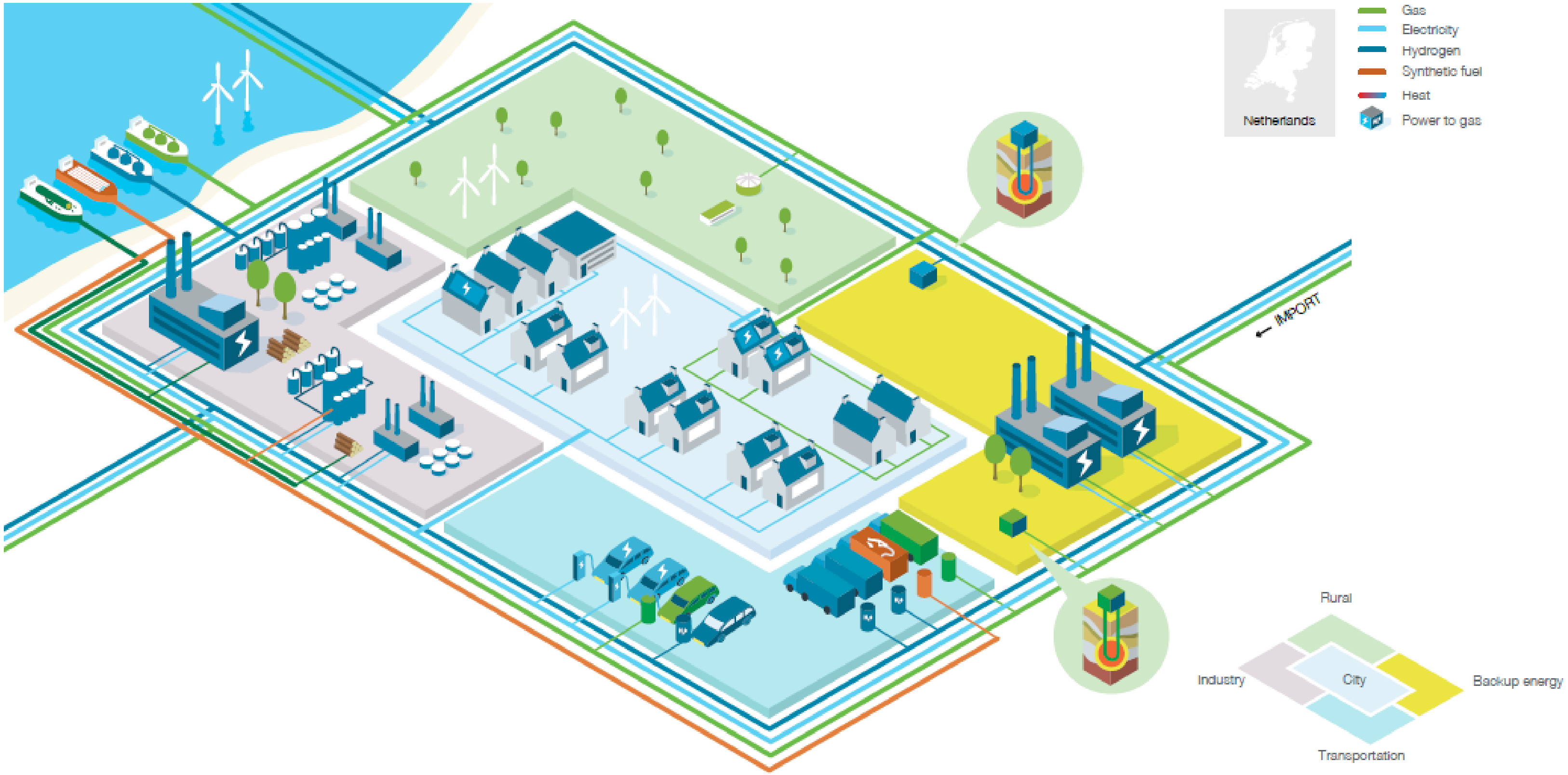
Supply: Large volume solar PV and limited wind power. Some biogas production and import of natural gas
Demand: Spatial heating: district heating (geothermal, residual heat), electric heat pumps and hybrid green gas boilers.
Industry: feedstock: plastic waste and hydrogen, heat: hydrogen and electricity
Transport: passenger cars: 100 % electric, trucks: 50% hydrogen and 50% green gas
Flexibility: Power to gas and batteries

National scenario the Netherlands



Supply: Large volume offshore wind and limited solar PV. Some biogas production and import of natural gas.
Demand: Spatial heating: hybrid and conventional hydrogen and methane gas boilers.
Industry: feedstock: plastic waste and hydrogen, heat: hydrogen and electricity
Transport: passenger cars 75 % electric, 25% hydrogen, trucks: 50% hydrogen and 50% green gas
Flexibility: Power to gas and batteries

International scenario the Netherlands



Supply: Import of biomass, synthetic liquid fuels, hydrogen and methane. Some biogas production

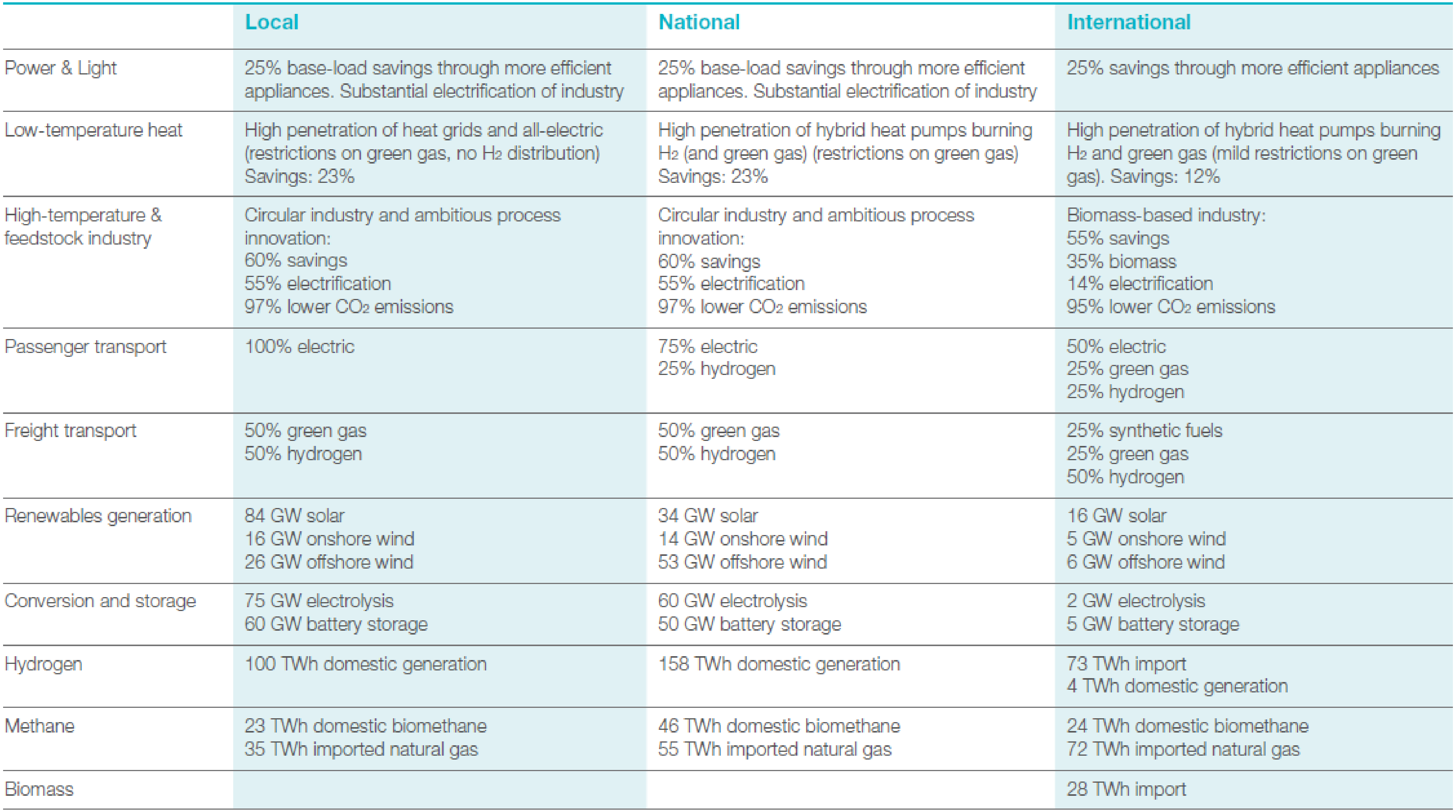
Demand: Spatial heating: Hybrid and conventional hydrogen boilers and hybrid biogas boilers

Industry: feedstock: biomass and hydrogen, heat: hydrogen, biomass, green gas and synthetic fuel

Transport: passenger cars 50 % electric, 25% hydrogen and 25% biogas, trucks: 50% hydrogen, 25% green gas and 25% synthetic fuels

Flexibility:

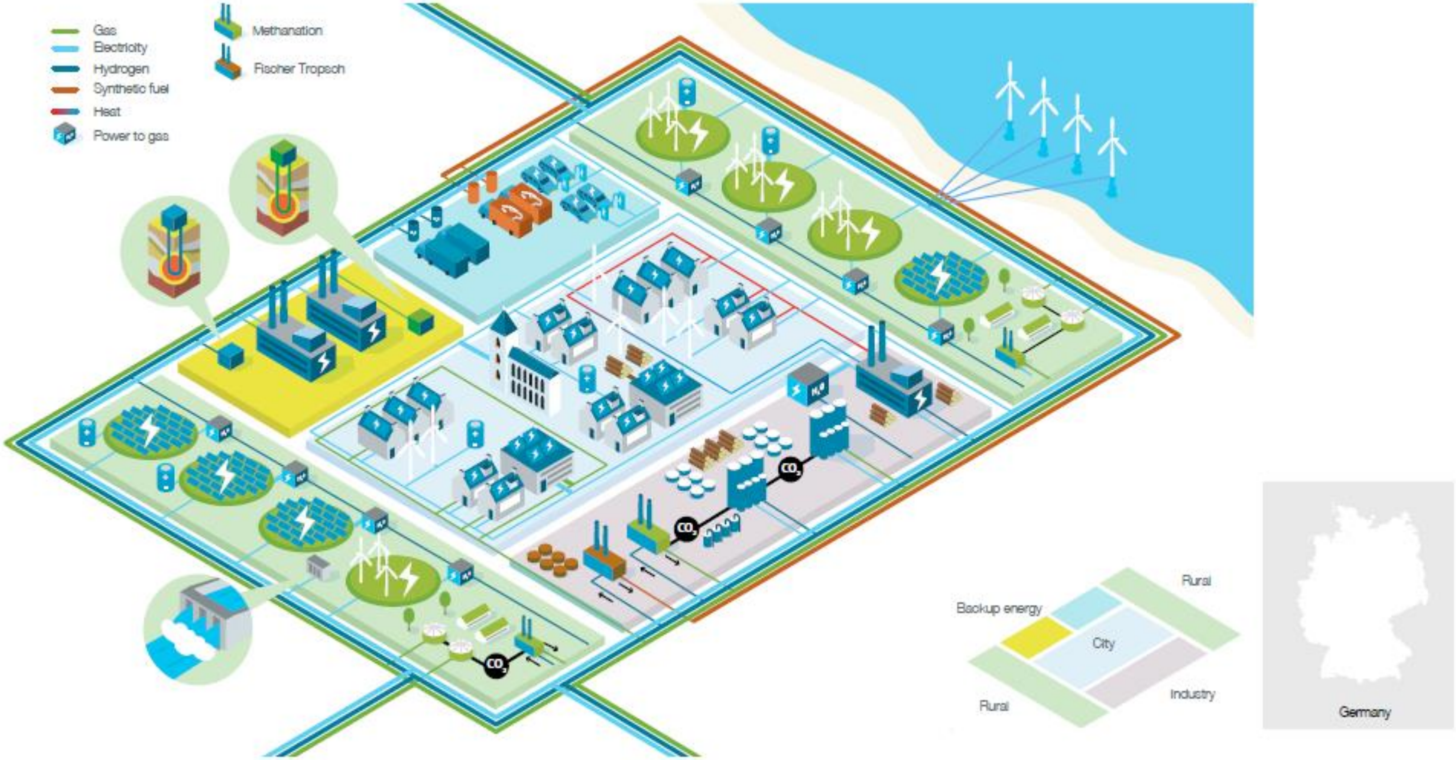
Scenarios (NL)



	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

Table 2: Main characteristics of the Dutch scenarios

Local scenario Germany



Supply: Large volume of installed solar PV and considerable amount of wind power. Biogas production

Demand: Spatial heating: district heating, electric heat pumps and green gas boilers.

Industry: feedstock: methane, heat: biomass, electricity, hydrogen and methane

Transport: passenger cars: 100 % electric, trucks 45% hydrogen, 50% synthetic fuel, 5% electric

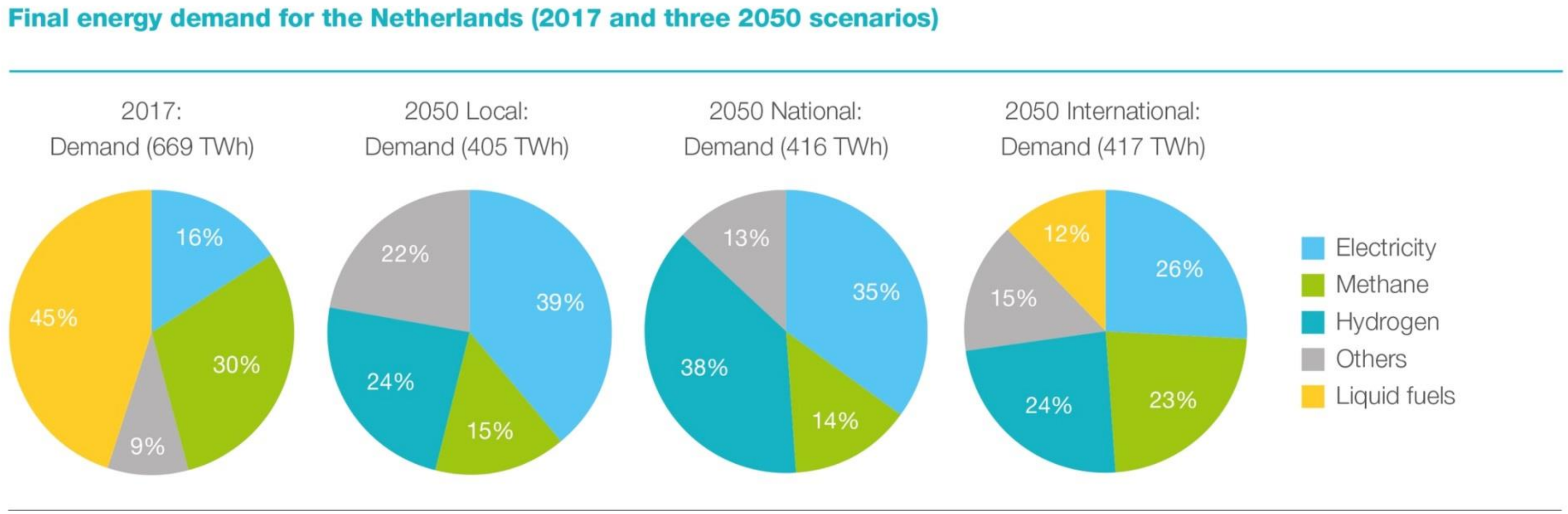
Flexibility: Power to gas and batteries

Hoofdbeelden (1)

De rol van aardolie zal richting 2050 grotendeels overgenomen zijn door elektriciteit en (duurzame) gasvormige energiedragers.

Eindverbruik van elektriciteit zal toenemen door elektrificatie warmtevraag en vervoer.

(Duurzame) gassen, zoals groene waterstof en biogas, krijgen belangrijke rol als feedstock voor de industrie en brandstof voor vervoer en verwarming.


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

Hoofdbeelden (2)

Piekaanbod van elektriciteit kan vervijfvoudigen

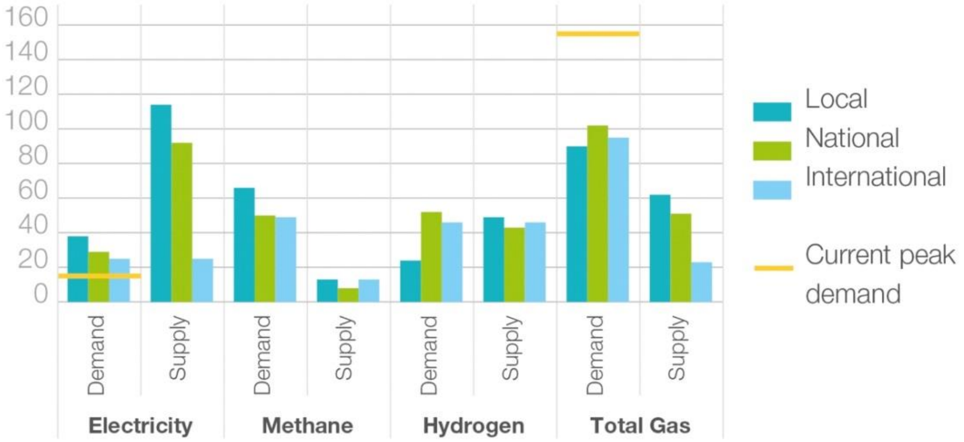


Figure 7: Dutch national peak demand and supply (GW) for the three scenarios[18].

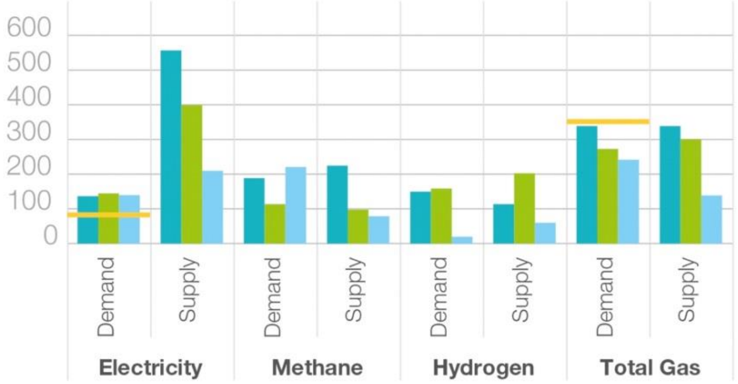
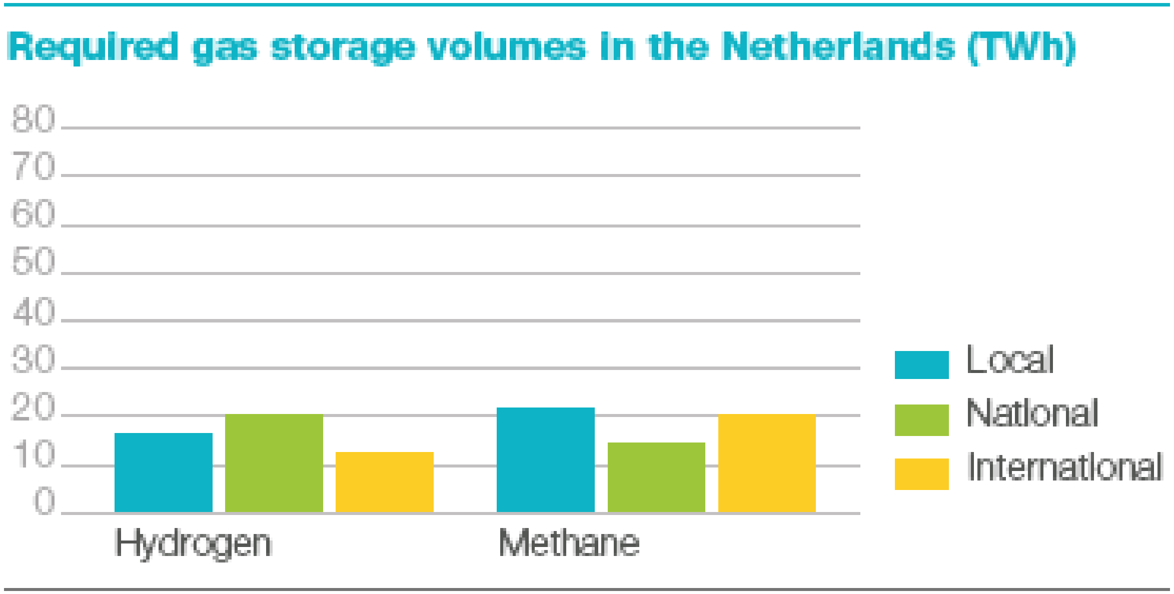


Figure 8: German national peak demand and supply (GW) for the three scenarios[19].

Het is onmogelijk het elektriciteitsnet hiervoor uit te breiden.

Hoofdbeelden (3)

Totale behoefte seizoensopslag bedraagt in alle scenario’s ongeveer 35 TWh.



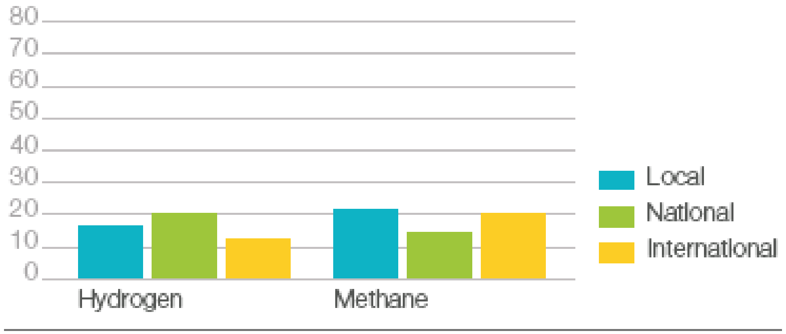
Required gas storage volumes in the Netherlands (TWh)

Het is onmogelijk dit met elektrische opslag te realiseren

Hoofdbeelden (4)

De behoefte aan seizoensopslag bedraagt in alle scenario's 35 TWh
Deze kan niet worden beleverd met opslag in batterijen

Required gas storage volumes in the Netherlands (TWh)



Waarom?

Tesla auto batterij heeft een capaciteit van ongeveer 60 kWh
Tesla PowerWall heft ongeveer 6 kWh.

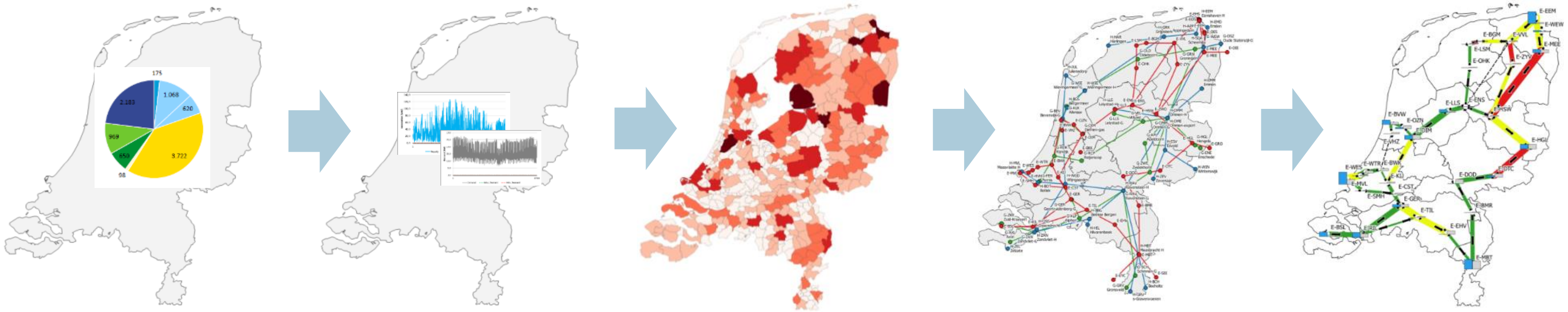
35 TWh is dus equivalent met:

- 600 mln Tesla auto batterijen (=33 Tesla auto's per Nederlander)
- of
- 6 mrd Tesla PowerWalls.

Een PowerWall kost ongeveer € 3000,-

Uitgedrukt in PowerWalls kost opslag van 35 TWh dus zo'n € 18000 mrd (!)

Aanpak



Scenario's
"Net voor de
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Regionaal
Nationaal
Internationaal

Genereer
tijdreeksen
met
ETM van Quintel

8760 uur

temperatuur en wind:
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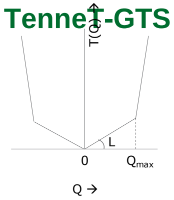

Visualiseer
stromingspatronen
en knelpunten

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Snapshots

Situation A:

- High wind and/or solar supply
- High final demand

HIGH
RES

Flex options:
Demand management
Battery
Conversion
Export
Curtailment

GW

High demand
conventional

Situation B:

- High wind and/or solar supply
- Low final demand
- *NOTE: The need for flexibility options could be larger compared to situation 1*

HIGH
RES

Flex options:
Demand management
Battery
Conversion p-2-h2
Export
Curtailment

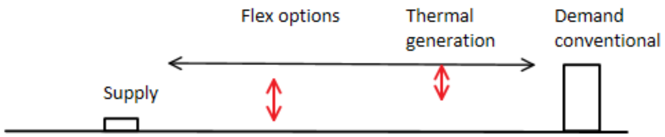
># GW

Low demand
conventional

Case: High RES WIND and low conventional demand

Situation C:

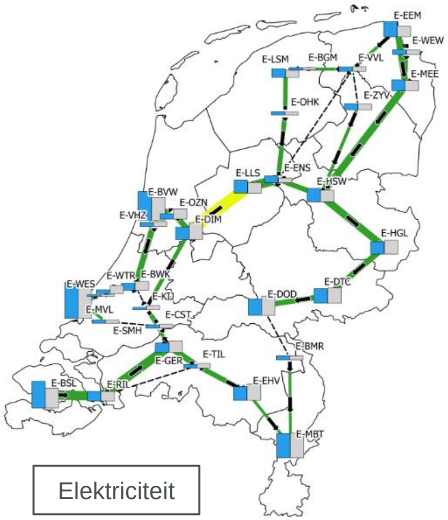
- Low wind and/or solar supply
- High final demand
- *NOTE: this could result in a need for back-up power plants*



→ Selection of suitable „snapshot hours“ that fullfill the defined criteria

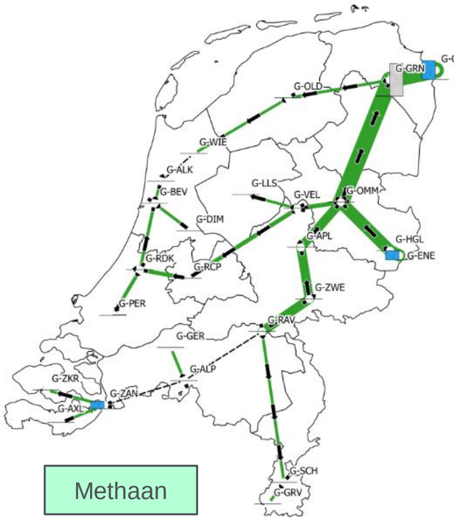
Voorbeeld 1

zonnige zomerdag, veel wind, lage vraag



Elektriciteit

Waterstof



Methaan

Regionaal scenario: zonnepanelen + wind op land

Juni 2050, 12:00 ‘s middags

Elektrolyse bij stroomproductie

🟦 Supply

⬜ Demand

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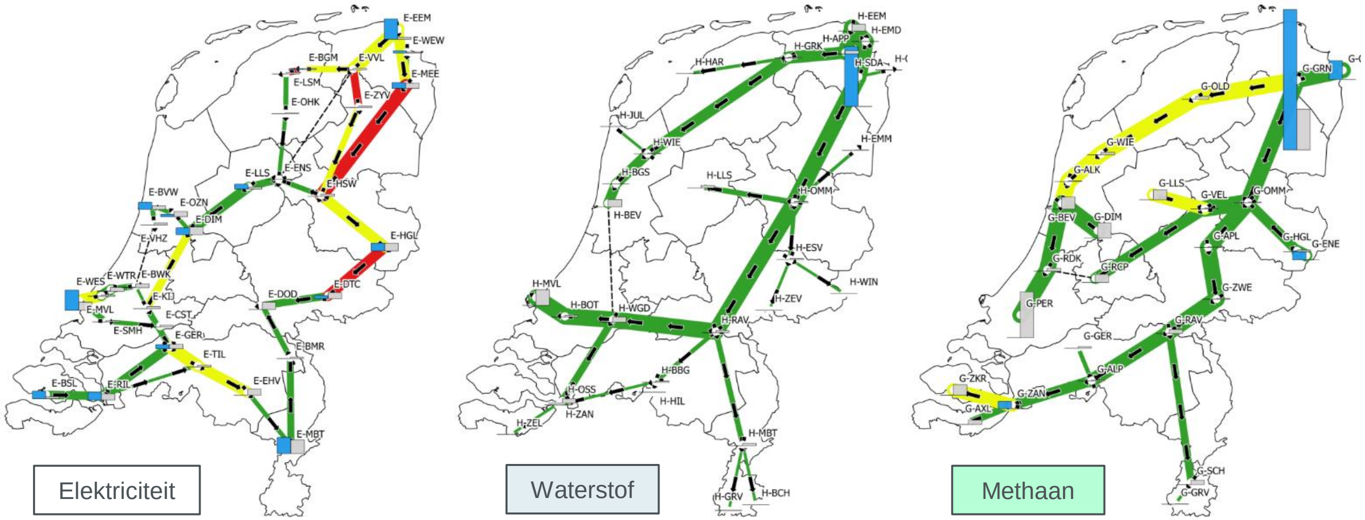
Normal
High
Overloaded

Voorbeeld 2

winteravond, weinig wind, hoge vraag



Elektriciteit

Waterstof

Methaan

Regionaal scenario: zonnepanelen + wind op land

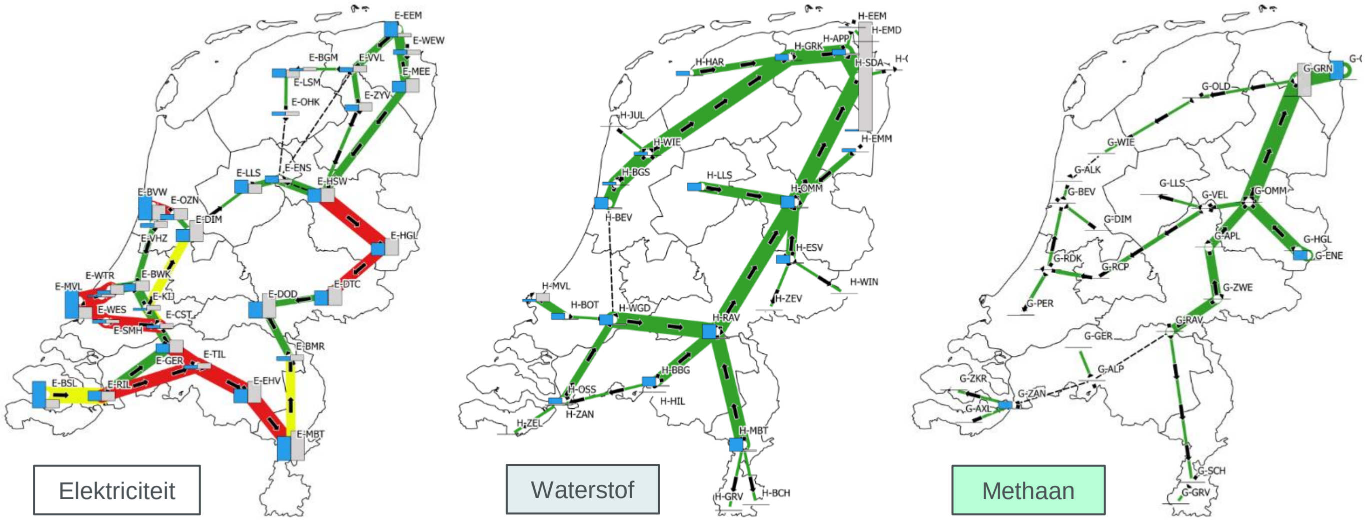
Februari 2050, 18:00 ‘s avonds
Elektrolyse bij stroomproductie

🟦 Supply
⬜ Demand

Loading
---None---
Normal
High
Overloaded

Voorbeeld 3

zomerdag, lage vraag, P2H2 bij de markt



Regionaal scenario: zonnepanelen + wind op land

Juni 2050, 12:00 ‘s middags

Elektrolyse bij de markt

🟦 Supply

⬜ Demand

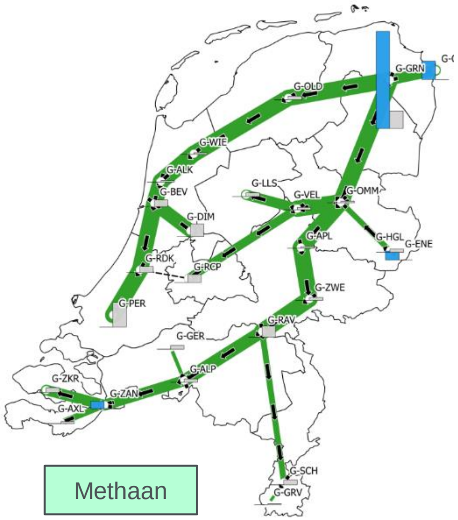
Loading
---None---
Normal
High
Overloaded

Voorbeeld 4

winteravond, hoge warmtevraag

Elektriciteit

Waterstof



Methaan

Internationaal scenario: import en export

Februari 2050, 's avonds

Import van energie; maximale productie bergingen

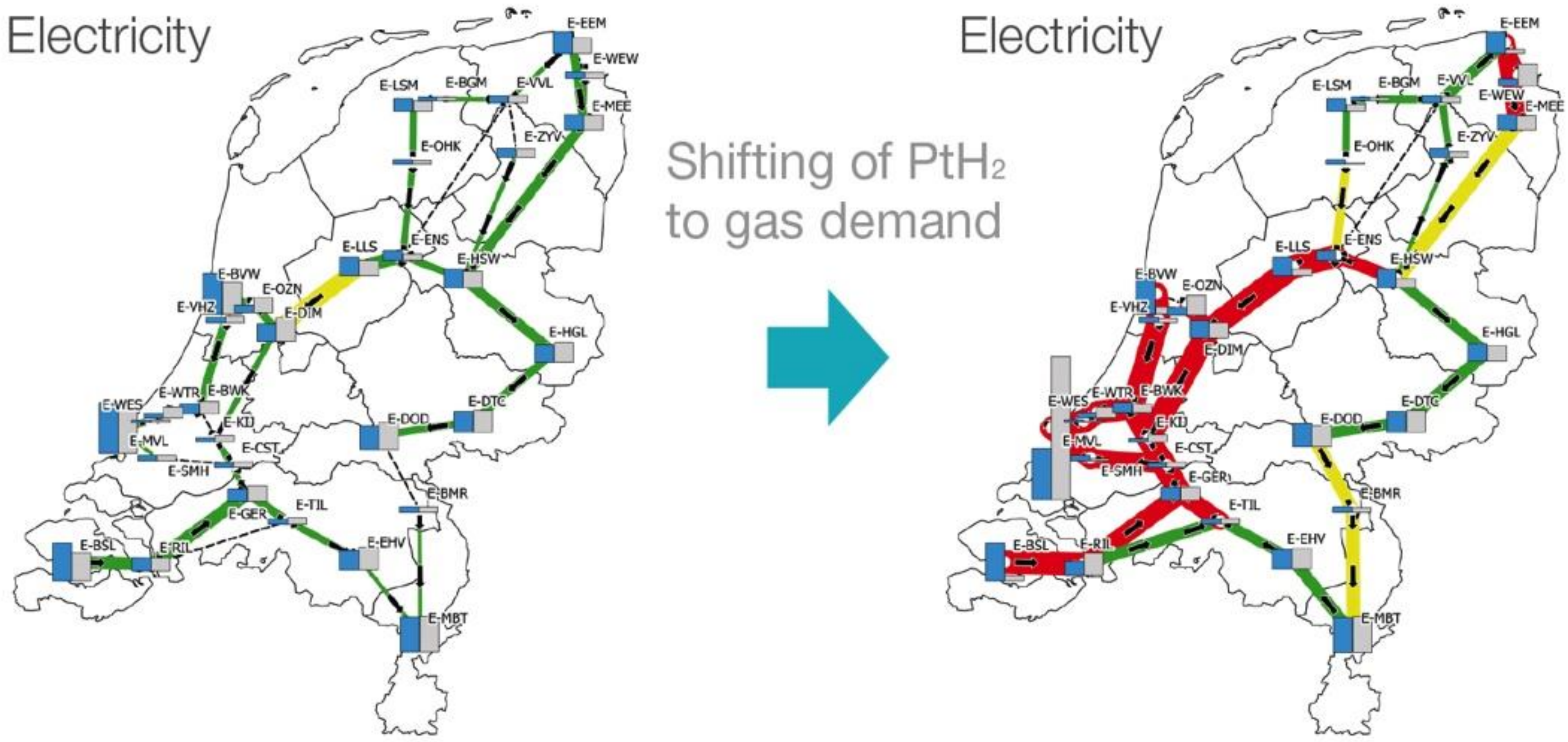
🟦 Supply

⬜ Demand

Loading
---None---
Normal
High
Overloaded

Plaatsing P2G

Plaatsing van P2G-installaties dichtbij duurzame elektriciteitsproductie is daarom een conditio sine qua non om grootschalig zon- en windvermogen te integreren!



Conclusies

- Alle scenario’s laten zien dat **zowel de elektriciteits- als de gasinfrastructuur een cruciale** rol spelen in het toekomstige energiesysteem.

- De energienetwerken (elektriciteit, waterstof en methaan) moeten verder worden **geïntegreerd**. Het **bestaande gasnetwerk** kan gesplitst worden in een netwerk voor waterstof en voor methaan en heeft **voldoende capaciteit**.

- Er is een grote behoefte aan **energieopslag in de vorm van gas** om seizoenen te kunnen overbruggen, o.a. voor situaties als “Dunkelflaute” en “Elfstedentocht”. Dit leidt tot een grote behoefte om **zoutcavernes** in te richten voor opslag van waterstof.

- Hoewel elektriciteitsopslag breed beschikbaar zal zijn in 2050 zal alleen **gasopslag** een oplossing zijn voor **seizoensopslag** in een energiesysteem gebaseerd op zon en wind.

Conclusies

- De **locatie**, capaciteit en inzet van P2G installaties zijn bepalend voor investeringen in elektriciteitsnetten en moeten worden afgestemd met zowel electriciteits- en gas TSO's

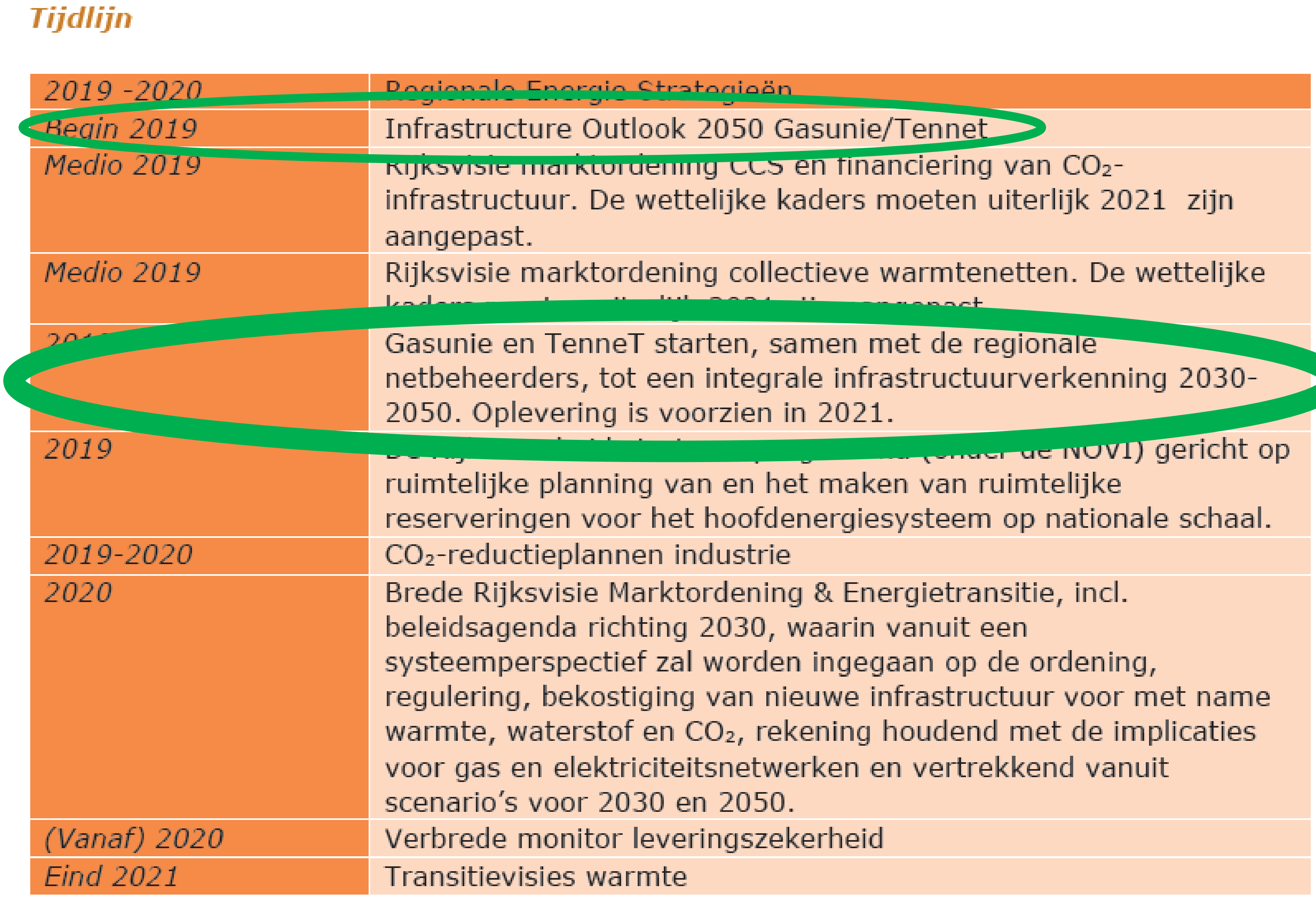
- Ook **na 2030** zullen elektriciteitsnetwerken verder moeten worden uitgebreid om te kunnen voldoen aan de toenemende vraag naar elektriciteit.

- **Import** van hernieuwbare energie (groene moleculen) kan de noodzaak aan uitbreiding van elektriciteitsnetwerken **beperken**

Aanbevelingen

- In toekomstig beleid in het kader van de energietransitie zal aandacht moeten zijn voor een **P2G implementatiestrategie** waarin aandacht is voor de consequenties voor de elektriciteits- en gasinfrastructuur
- Deze strategie zal ook een **routekaart** moeten bevatten naar volwassen grootschalige P2G technologie.
- Om te komen tot efficiënte investeringen in netwerken zullen **elektriciteits- en gas TSO's betrokken** moeten worden in het opzetten van een gedetailleerde P2G integratie-strategie.
- Voor een efficiënte energietransitie zullen ook **ontwikkelpaden richting 2050** moeten worden beschreven.
- De conclusies uit deze studie kunnen dienen als **richtinggevend in de investeringsplannen** (NEP in Duitsland en IP/NOP in Nederland).
- De scenario's die in deze studie zijn gebruikt zijn gebaseerd op nationale emissie-eisen. In een follow up studie zal ook de energiebehoefte van de **internationale lucht- en scheepvaart** moeten worden meegenomen.

Vervolg



Tijdlijn

2019 -2020	Regionale Energie Strategieën
Begin 2019	Infrastructure Outlook 2050 Gasunie/Tennet
Medio 2019	Rijksvisie marktordening CCS en financiering van CO_2-infrastructuur. De wettelijke kaders moeten uiterlijk 2021 zijn aangepast.
Medio 2019	Rijksvisie marktordening collectieve warmtenetten. De wettelijke kaders moeten uiterlijk 2021 zijn aangepast.
2019	Gasunie en TenneT starten, samen met de regionale netbeheerders, tot een integrale infrastructuurverkenning 2030-2050. Oplevering is voorzien in 2021.
2019	De Rij[illegible] (onder de NOVI) gericht op ruimtelijke planning van en het maken van ruimtelijke reserveringen voor het hoofdenergiesysteem op nationale schaal.
2019-2020	CO_2-reductieplannen industrie
2020	Brede Rijksvisie Marktordening & Energietransitie, incl. beleidsagenda richting 2030, waarin vanuit een systeemperspectief zal worden ingegaan op de ordening, regulering, bekostiging van nieuwe infrastructuur voor met name warmte, waterstof en CO_2, rekening houdend met de implicaties voor gas en elektriciteitsnetwerken en vertrekkend vanuit scenario's voor 2030 en 2050.
(Vanaf) 2020	Verbrede monitor leveringszekerheid
Eind 2021	Transitievisies warmte

Aanvullende verkenningen

CO_2-free/poor production routes

The main options

CO_2-free/poor production routes

Hydrogen can be produced with four types of CO_2–free/poor processes:

1. Thermochemical with CCS (Blue hydrogen)

   In these processes heat is used to release hydrogen from the various resources, such as natural gas, coal, or biomass. In a subsequent step is CO_2- removed from the product gas stream and stored in e.g. empty gas fields (CCS)

   Steam methane reforming and coal gasification are the two most common processes commercially used. (see further)

2. Electrolytic water processes (Green hydrogen)

   Electrolysers use electricity to split water into hydrogen and oxygen.

   Technology is available for small scale production. Upscaling including cost reduction is currently main focus area (see further)

CO_2-free/poor production routes

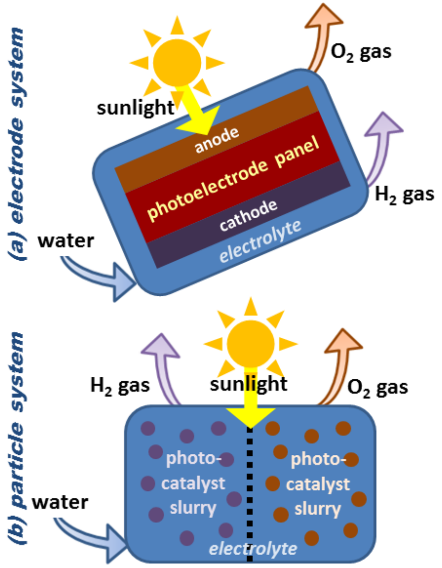
Hydrogen can be produced with four types of different CO_2–free/poor processes (continued):

3. Direct solar water splitting. (Green hydrogen)

   These processes use special semiconductor materials that convert solar energy directly to chemical energy in the form of hydrogen.

   Application in panels, identical to PV-panels, is main development route.

   All processes are currently in the early stages of research but offer long-term potential for sustainable hydrogen production



4. Biological. (Green hydrogen)

   Fermentation of biomass (waste), using bacteria and microalgae, is a biochemical process that can produce green hydrogen.

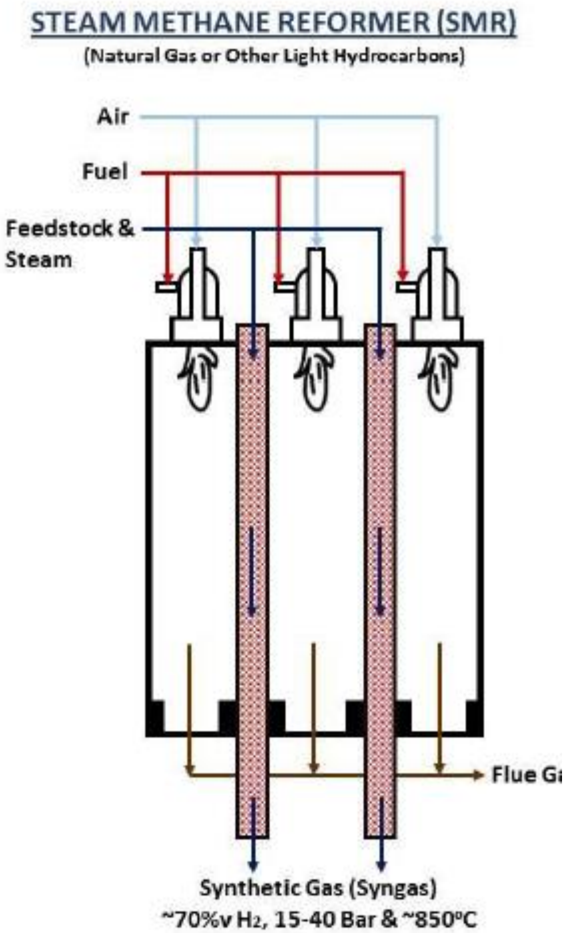
   All processes are currently still in the early stages of research.

CO_2-free/poor production routes

Blue Hydrogen

CO$_2$-free/poor production routes

Production of blue hydrogen from natural gas . (1/3)



With the current SMR technology natural gas is not only used as a reactant, but also as a fuel for steam production and for external heating of the reactor.

The burning of natural gas generates an exhaust gas with relatively low concentrations of carbon dioxide.

Complete carbon capture is therefore difficult for the SMR process, resulting also in a lowering of the process efficiency with seven percent points.

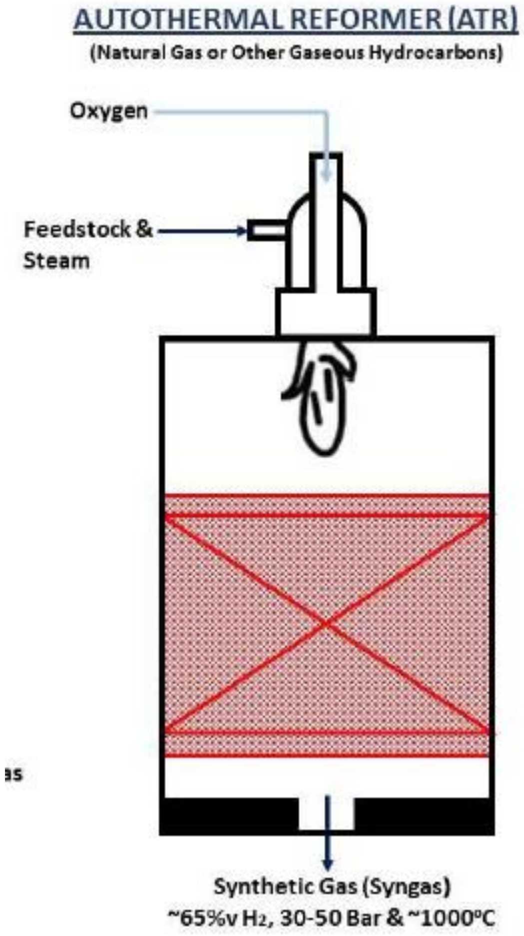
In practice a removal efficiency between 50 and 60% is considered possible.

CO_2-free/poor production routes

Production of blue hydrogen from natural gas . (2/3)

Autothermal steam reforming, where the reaction heat is generated within the reforming reactor by burning of methane with pure hydrogen, is a better technology for production of blue hydrogen.

CO_2-removal efficiencies of around 90 % are possible with this route.



CE-Delft, waterstofroutes Nederland, Publicatienummer: 18.3K37.075, juni 2018

CO_2-free/poor production routes

Production of blue hydrogen from natural gas . (3/3)

Production of one kg hydrogen from methane will generate 9 kg of carbon dioxide.

With an estimated cost price for CCS in 2030 of about 50 €/ton as determined by the World Energy Council* production of blue hydrogen will increase the production cost of hydrogen from natural gas with 0,45 € per kg hydrogen.

Rule of thumb for determination cost price of 1 kg blue hydrogen:

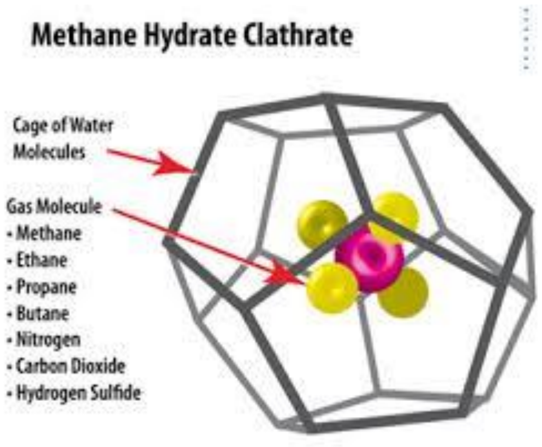
$$\text{€/kg } H_2 = 4{,}8 \text{* price of natural gas (€/m}^3\text{) + 0,85 €}$$

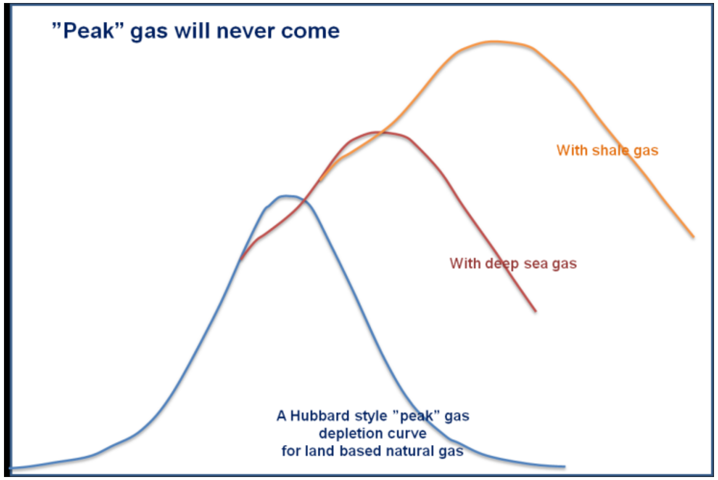
http://www.wereldenergieraad.nl/wp-content/uploads/2019/02/190207-WEC-brochure-2019-A4.pdf

CO_2-free/poor production routes

Blue hydrogen: available resources

- According to IEA proven global natural gas reserves are still sufficient to cover about 50 years of current demand.
- But possibly much longer, because other large resources such as natural gas clathrates still not exploited





CO$_2$-free/poor production routes

Blue hydrogen: available resources

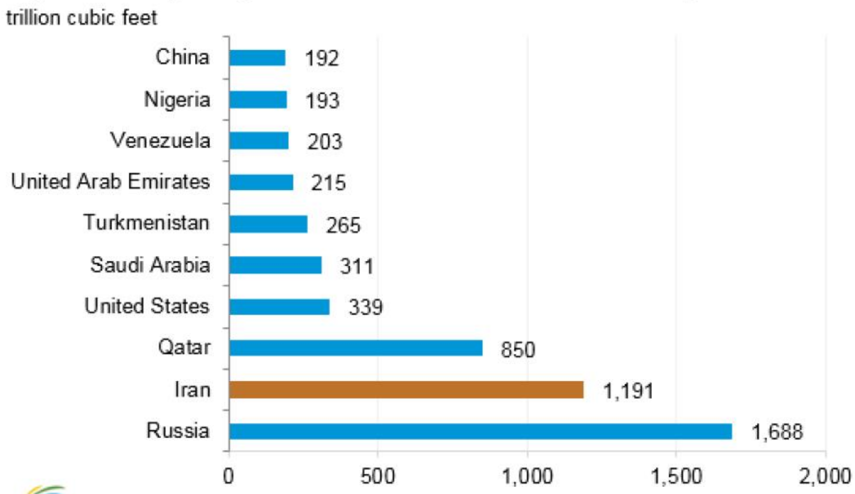
- Largest proven natural gas reserves are however located in not the most political stable countries.

- Most of these countries want/need to continue the capitalization of their natural gas resources to support their economy on the long term.

- According to Coby van der Linde (CIEP) has Russia already determined that the reservoir characteristics of their gas fields are well suited for carbon dioxide storage.

- Based on the existing natural gas pipelines between Russia and Europe, import of blue hydrogen from Russia can become an option.

Figure 8. Largest proved reserve holders of natural gas, 2017



Source: *Oil & Gas Journal*, December 2017

CO_2-free/poor production routes

Green Hydrogen

CO_2-free/poor production routes

Production of green hydrogen:

There are three main categories of electrolysers:

1. Alkaline Electrolysis (AEL)

   Most mature technique, commercial available for industrial processes since the 1920’s

2. Proton Exchange Membrane or Polymer Exchange Membrane (PEM)

   Technology developed in the 1990’s for fuel cells in passenger cars and buses. Technology still not available at large scale

3. Solid Oxide Electrolysis (SOE)

   Technology based on high temperature steam electrolysis (700 to 900^{o}C). Development still at the stage of basic research. Material stability still an important issue.

CO_2-free/poor production routes

Production of green hydrogen:

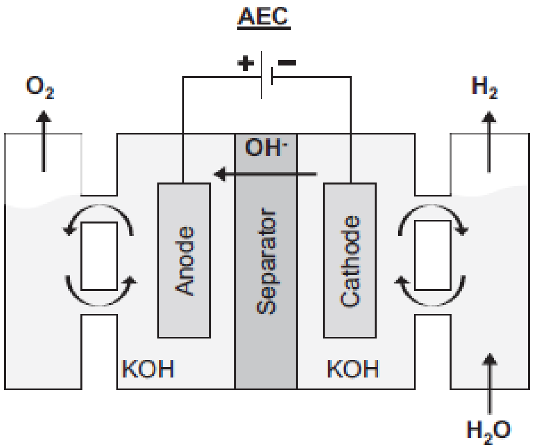
Alkaline Electrolysis (AEL)

Key advantages of this technology are its maturity and durability.

The use of rather cheap steel and nickel plated steel electrodes is also seen as and advantage of the AEL

Disadvantages of the process are its low current density and operating pressure which increases the size of the system size and the production costs.

Dynamic operation (frequent start-ups and varying power input) of AEL is limited and as a consequence will limit operation with intermittent renewable sources



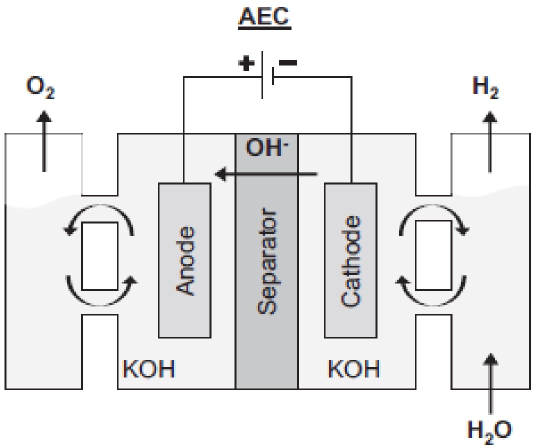
CO_2-free/poor production routes

Production of green hydrogen:

Alkaline Electrolysis (AEL)

Although identified as less suitable for the integration of variable renewable energy is Nouryon considering to build in the coming decade a 100 MW and 250 MW electrolysis demo plant in respectively Amsterdam and Rotterdam based on the alkaline technology.

One of the Nouryon experts mentioned that the choice for alkaline was based on the fact that Nouryon has large experience with this technology in chlorine production and that based on this experience they have come to the conclusion that the other two electrolysis technologies are still not mature enough for demonstration plants.



CO_2-free/poor production routes

Production of green hydrogen:

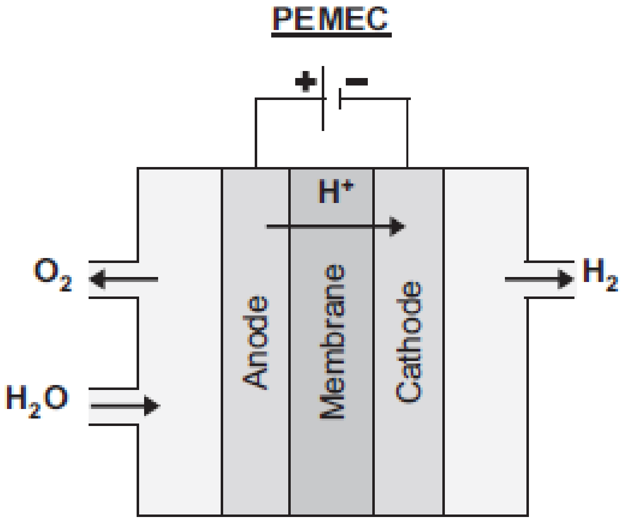
Proton Exchange Membrane electrolysis (PEM)

Key advantages of the PEM technology are:

- Its high power density and cell efficiency;
- The ability to operate at high pressure;
- The production of hydrogen at high purity over the whole operating window;
- Its flexible operation, which makes its suitable for op

The main disadvantages are:

- High costs due to the use of platinum (cathode) and iridium (anode) catalysts.
- Use of expensive membranes with restricted lifetime
- High system complexity due to high operating pressure and water purity requirements



CO_2-free/poor production routes

Production of green hydrogen:

Proton Exchange Membrane electrolysis (PEM)

Its potential in system integration has created a lot of interest in the PEM-technology;

Main focus is now on the upscaling or upnumbering of the process to reduce investment costs.

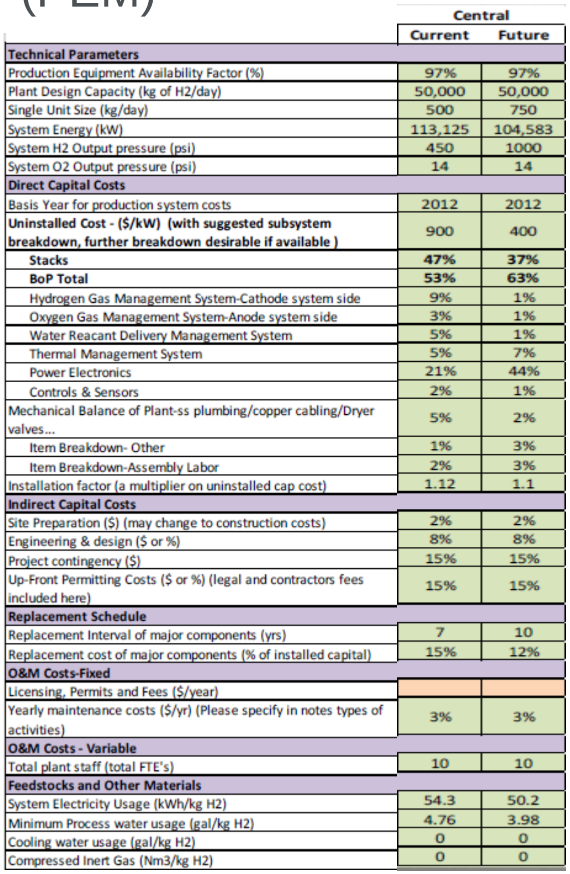
The InStitute for Sustainable Process technology has started a research programme to develop a basic design for a 1000 MW electrolyser at an investment cost of 350 €/kW (350 million in total)

A quick and dirty internet survey showed that this is a very ambitious target (see next slides).

CO_2-free/poor production routes

Production of green hydrogen:

Proton Exchange Membrane electrolysis (PEM)

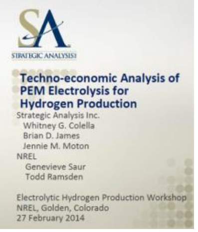


	Central	
	Current	Future
Technical Parameters		
Production Equipment Availability Factor (%)	97%	97%
Plant Design Capacity (kg of H2/day)	50,000	50,000
Single Unit Size (kg/day)	500	750
System Energy (kW)	113,125	104,583
System H2 Output pressure (psi)	450	1000
System O2 Output pressure (psi)	14	14
Direct Capital Costs		
Basis Year for production system costs	2012	2012
Uninstalled Cost - ($/kW) (with suggested subsystem breakdown, further breakdown desirable if available)	900	400
Stacks	**47%**	**37%**
BoP Total	**53%**	**63%**
Hydrogen Gas Management System-Cathode system side	9%	1%
Oxygen Gas Management System-Anode system side	3%	1%
Water Reacant Delivery Management System	5%	1%
Thermal Management System	5%	7%
Power Electronics	21%	44%
Controls & Sensors	2%	1%
Mechanical Balance of Plant-ss plumbing/copper cabling/Dryer valves...	5%	2%
Item Breakdown- Other	1%	3%
Item Breakdown-Assembly Labor	2%	3%
Installation factor (a multiplier on uninstalled cap cost)	1.12	1.1
Indirect Capital Costs		
Site Preparation ($) (may change to construction costs)	2%	2%
Engineering & design ($ or %)	8%	8%
Project contingency ($)	15%	15%
Up-Front Permitting Costs ($ or %) (legal and contractors fees included here)	15%	15%
Replacement Schedule		
Replacement Interval of major components (yrs)	7	10
Replacement cost of major components (% of installed capital)	15%	12%
O&M Costs-Fixed		
Licensing, Permits and Fees ($/year)		
Yearly maintenance costs ($/yr) (Please specify in notes types of activities)	3%	3%
O&M Costs - Variable		
Total plant staff (total FTE's)	10	10
Feedstocks and Other Materials		
System Electricity Usage (kWh/kg H2)	54.3	50.2
Minimum Process water usage (gal/kg H2)	4.76	3.98
Cooling water usage (gal/kg H2)	0	0
Compressed Inert Gas (Nm3/kg H2)	0	0

The most positive results regarding cot price development were found in a Techno-Economic analysis by Strategic Analysis

This analysis was based on interviews with producers of electrolysis systems.

Based on these interviews SA have found that investment cost of large scale PEM electrolysers can go down from 1360 $/kW to 560 $/kW



STRATEGIC ANALYSIS

Techno-economic Analysis of PEM Electrolysis for Hydrogen Production

Strategic Analysis Inc.
Whitney G. Colella
Brian D. James
Jennie M. Moton
NREL
Genevieve Saur
Todd Ramsden

Electrolytic Hydrogen Production Workshop
NREL, Golden, Colorado
27 February 2014

CO_2-free/poor production routes

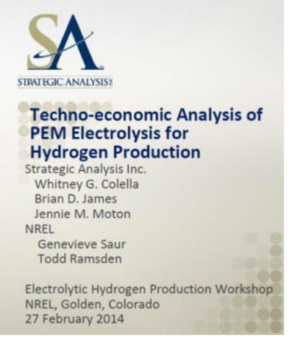
Production of green hydrogen:

Proton Exchange Membrane electrolysis (PEM)

According to a study by Strategic Analysis the O&M and capital cost of a future one gigawatt electrolyser, built at a cost price of 560 $/kW or 500 €/kg, will be around 0,7 $/kg H_2 or 0,6 €/kg H_2

Based on this the rule of thumb for cost price of 1 kg green hydrogen will be in the future:

€/kg H_2 = 50* price of electricity (€/kWh) + 0,6 €/kg



SA
STRATEGIC ANALYSIS

Techno-economic Analysis of PEM Electrolysis for Hydrogen Production

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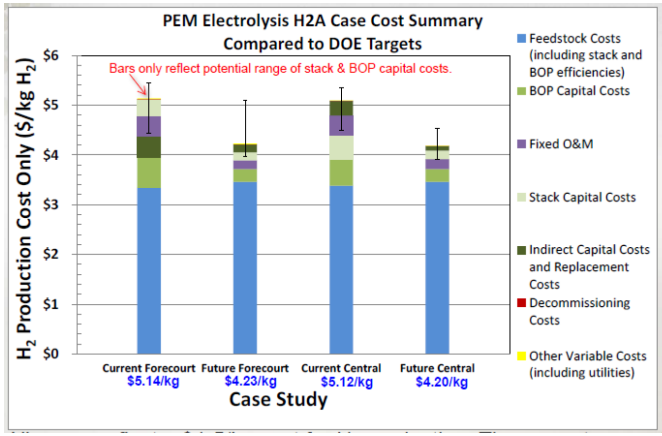


CO$_2$-free/poor production routes

Production of green hydrogen:

Proton Exchange Membrane electrolysis (PEM)

According to professor Richard van de Sanden (DIFFER) , expert in the field of electrolysis at TuE, will the decrease in cost price be a long-lasting repeating process, where:

- First of all upscaling an automation of the electrolyzer stack production process is needed, since currently the PEM stacks are manually assembled.

- A number of improvement cycles of the production process, including the use of cheaper parts and materials as a result of research efforts, will be needed to decrease production cost.

One of the critical items for cost reduction is the lifetime of the proton exchange membrane. Currently the lifetime of the membrane is of the order of 60.000 hours (seven years) and replacement costs for a 1000 MW electrolyzer are estimated at around 100 million euro.

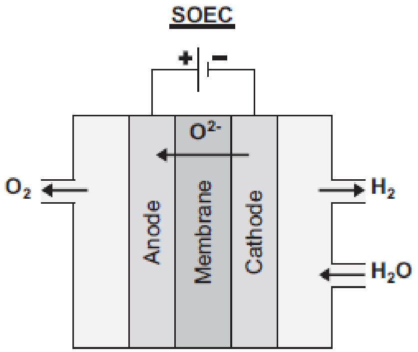
CO_2-free/poor production routes

Production of green hydrogen:

Solid Oxide Electrolysis

Potential advantages of the SOE technology are:
- Lower electricity use due to high operating temperature (700 to 1000°C)
- Low material cost.
- The option to operate in reverse mode as a fuel cell.

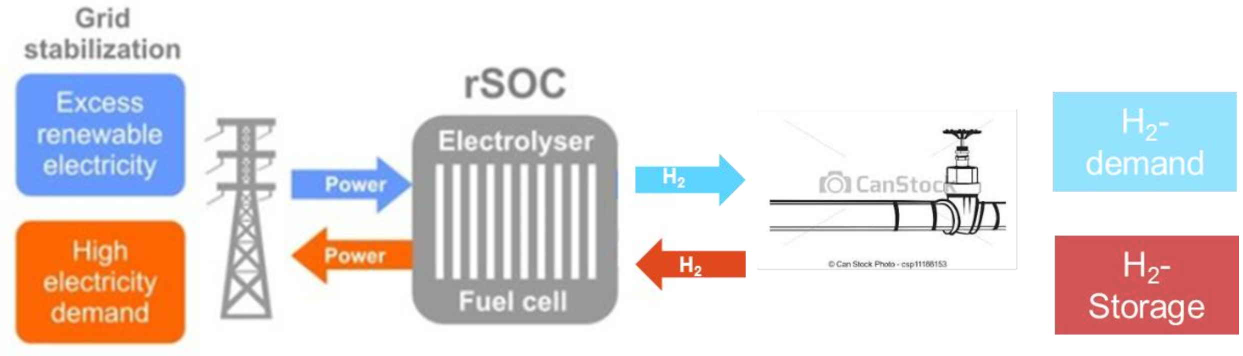
Potential disadvantage:
- Severe material degradation as a result of the high operating temperatures.



CO_2-free/poor production routes

Production of green hydrogen:

Solid Oxide Electrolysis



The option to operate the Solid Oxide electrolyser also in reverse mode as a fuel cell makes the technology interesting option for TenneT

Location of this type of units near demand opens a way to net concepts with lower redundancy in parent networks without compromising on security of supply.

It is recommended for TenneT to create awareness of this option and support studies by third parties on the development.

DANK VOOR DE AANDACHT

VRAGEN?