



# ENERGIE OPSLAG METHODEN

15 dec 2018

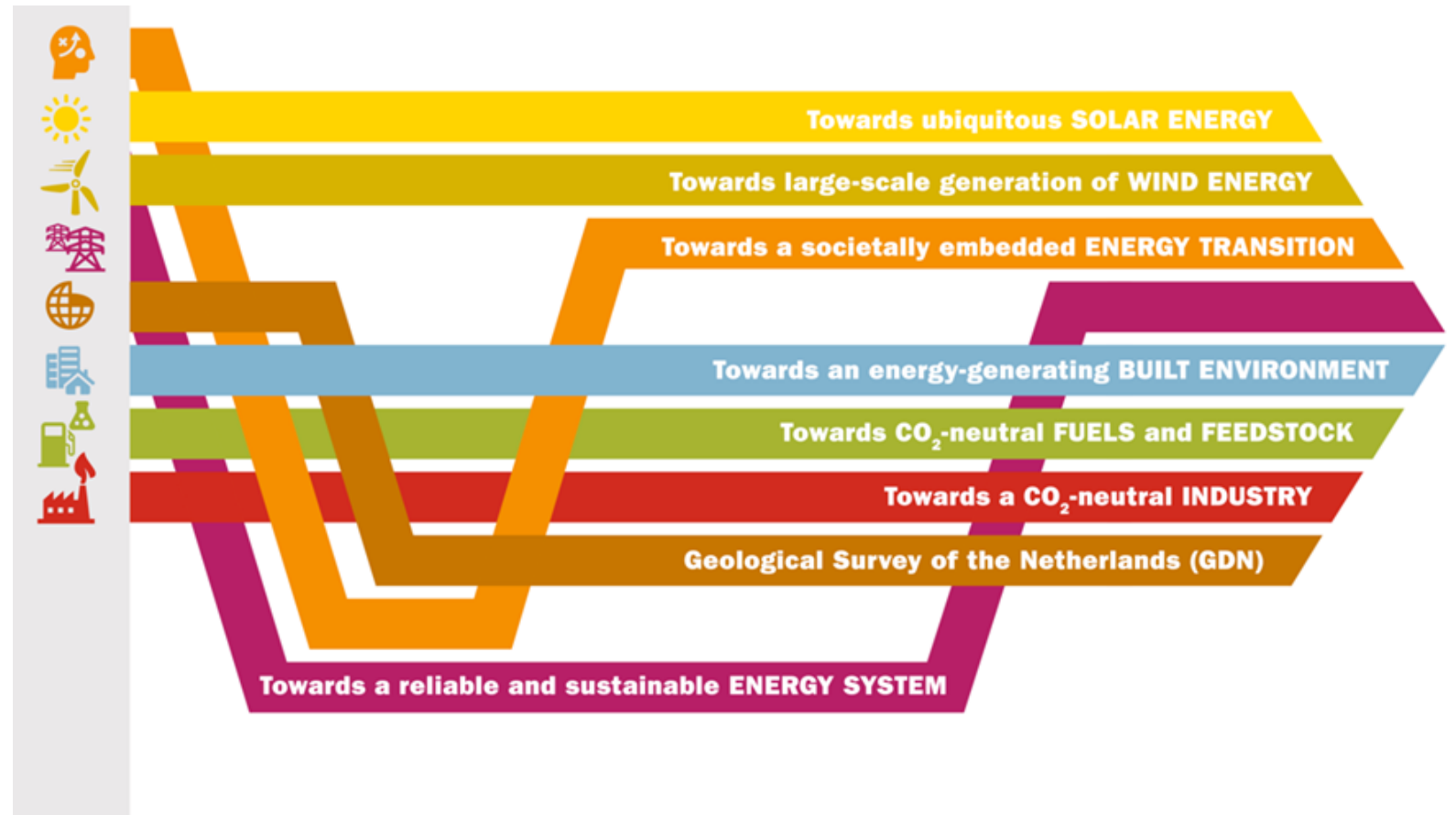
**TNO** innovation  
for life

- **± 700 minds** working on accelerating the energy transition
- **8 roadmaps** shaped by government, industry and research

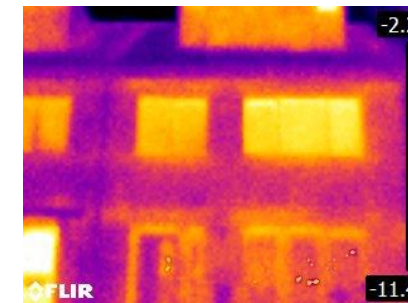
We do:

- **Technology development** for the benefit of society and industry
- **Technology transfer** to the market
- **System analyses** and (market) integration
- **Societal perception**
- **Regulatory framework**
- Independent and applied

## ECN part of TNO



# Energiegroep Bunnik



coöperatie Duurzaam Bunnik

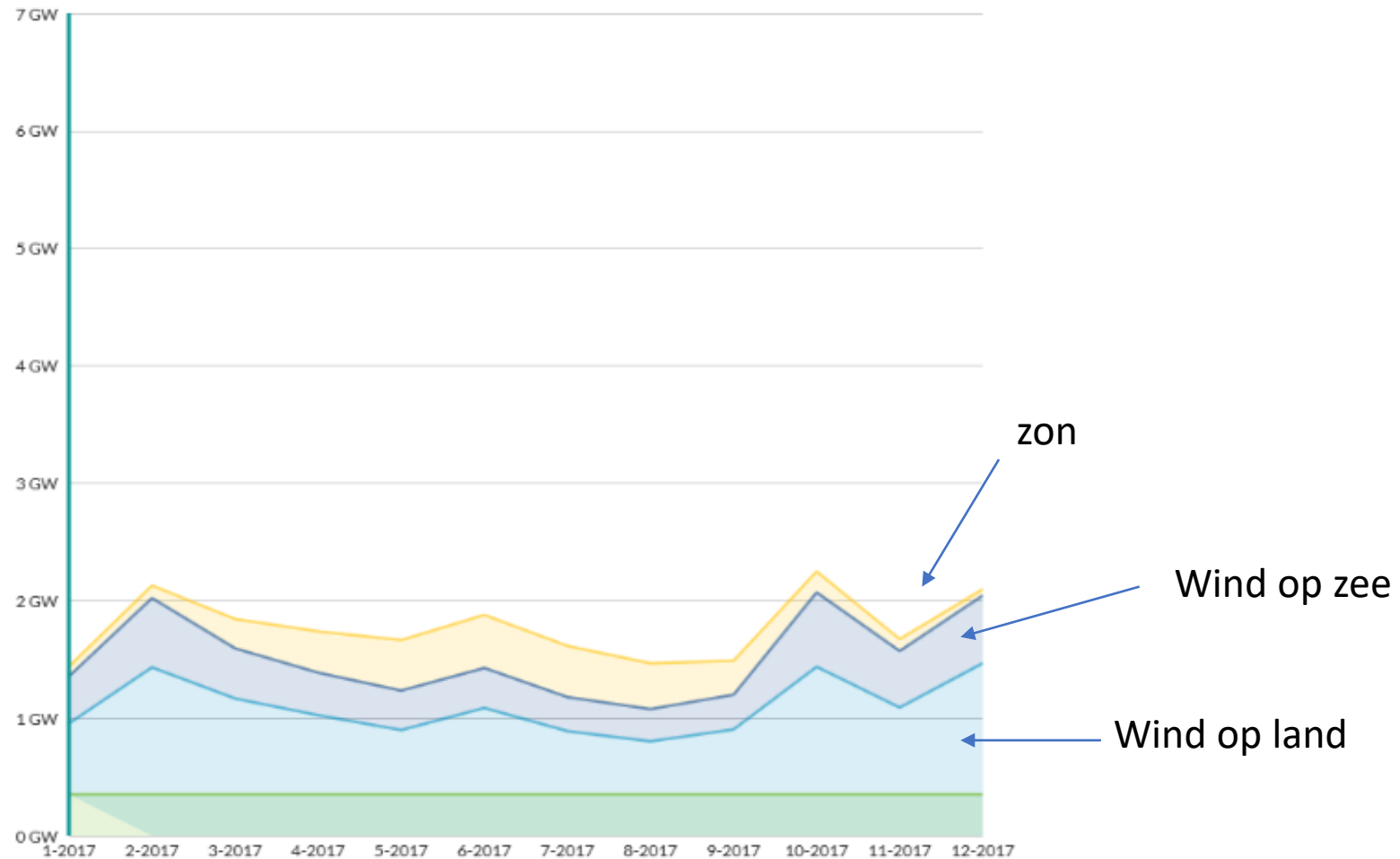
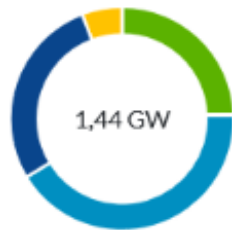
**SAMEN NAAR EEN DUURZAAM BUNNIK,**

**WIJ HOPEN OP UW STEUN!**

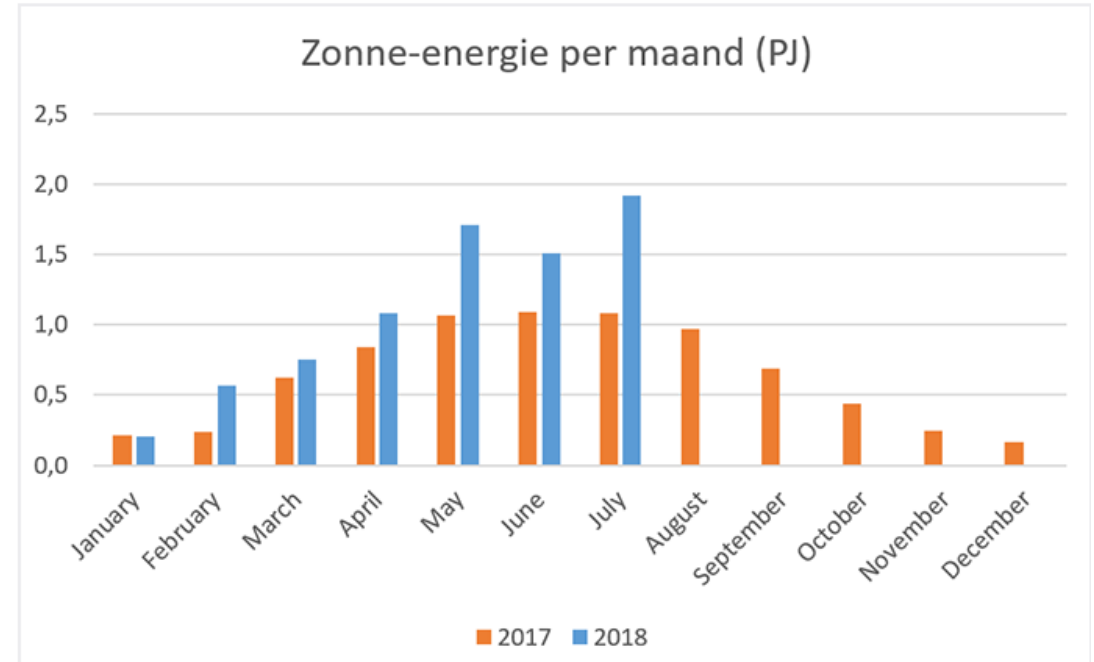
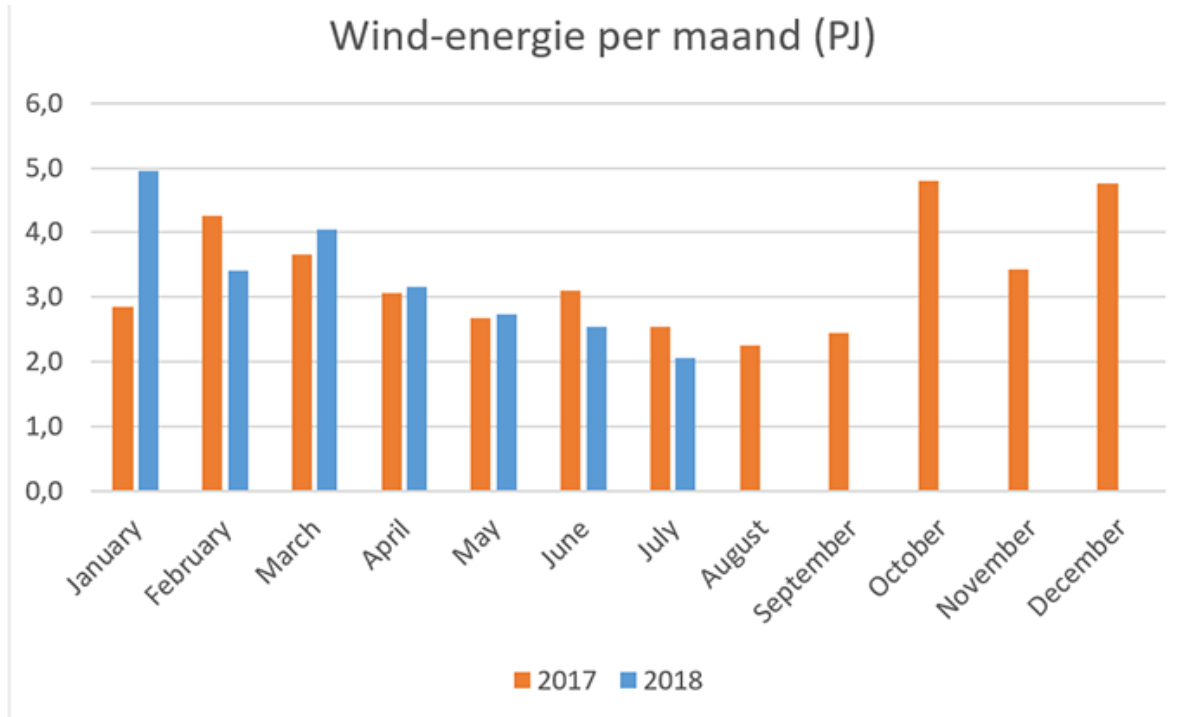


# Duurzame Energie mix NL

Gedurende 2017



# Wind/ZON



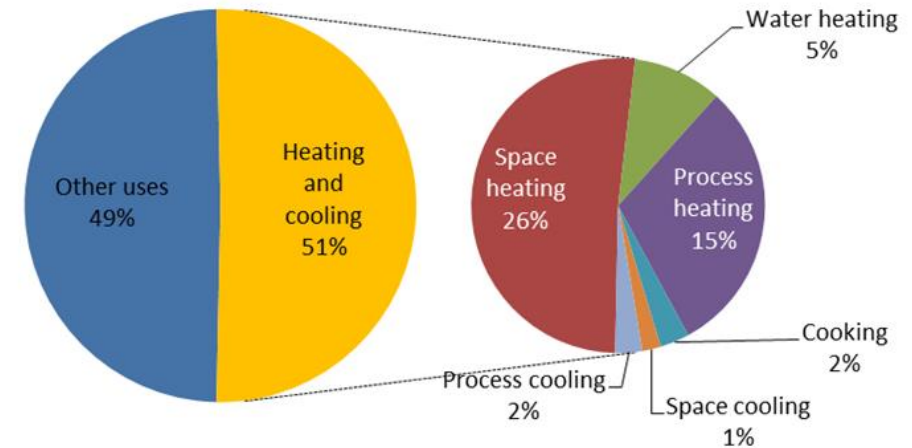
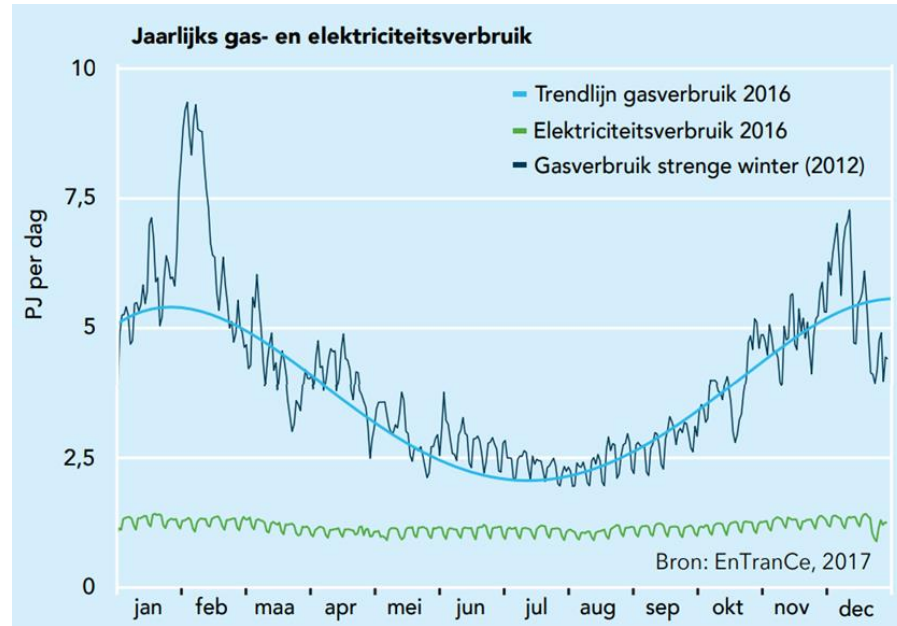
# Dunkelflaute



Geen PV  
Geen wind

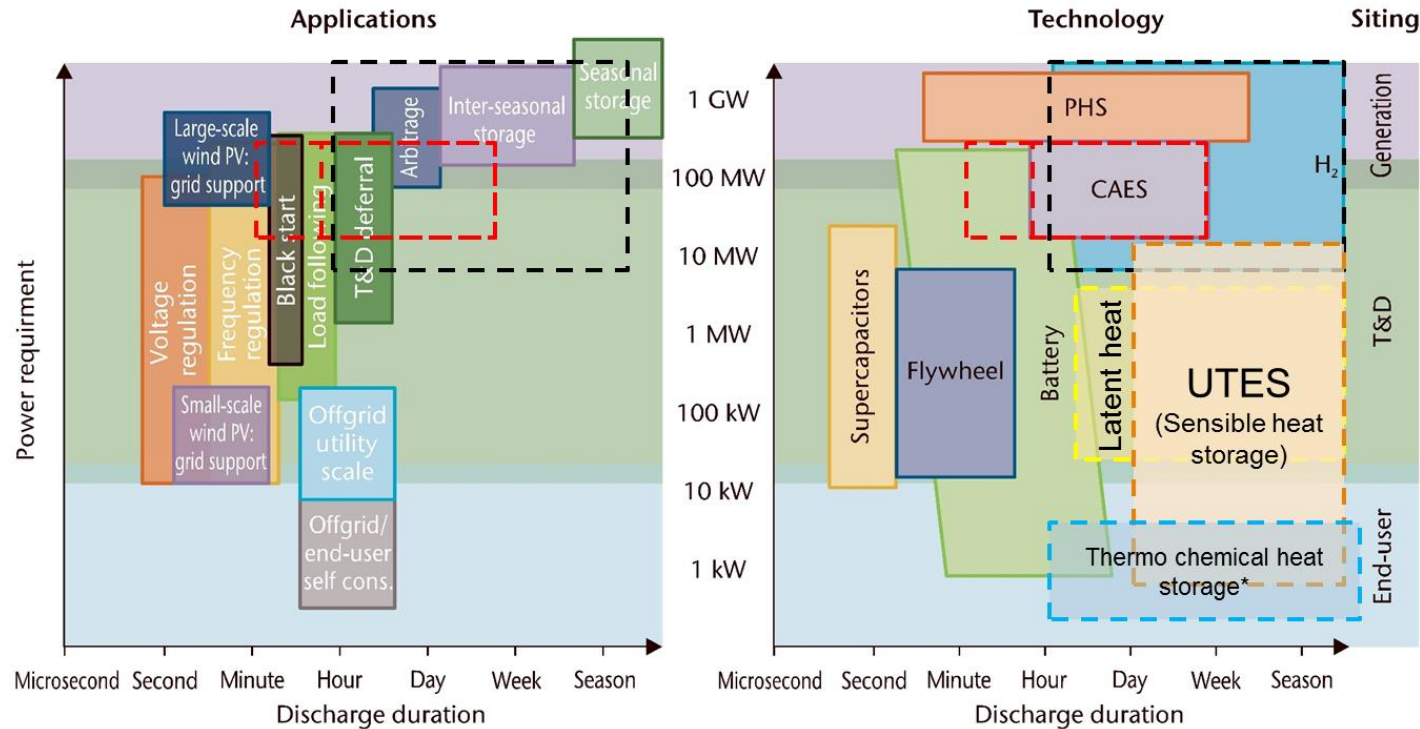
CBS: Bruto finaal energieverbruik (2016) 2090 peta (E15) Joule

# Need for storage



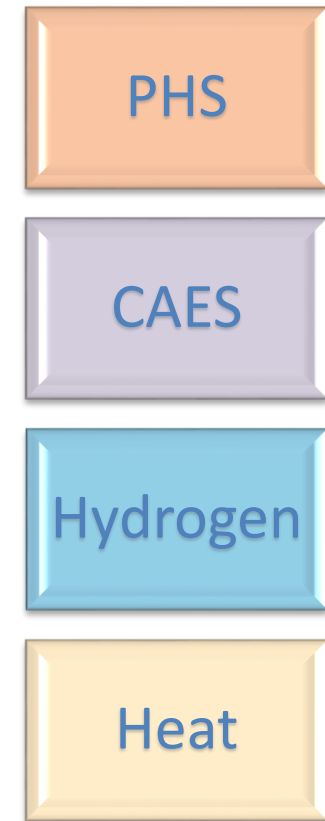
Dutch studies on flexibility	ESTMAP	Work programme EzK 2018 (H <sub>2</sub> 2050)	Work programme EzK 2018 (Heat 2050)	Flexnet (2050)	PBL 2017 (2050)	DNV GL (2030)
Required storage volume in the Netherlands [TWh]	Potential in the EU	510 – 1 600	5 – 10	0.5 – 2	5 – 17	5 – 25

# Need for large scale storage

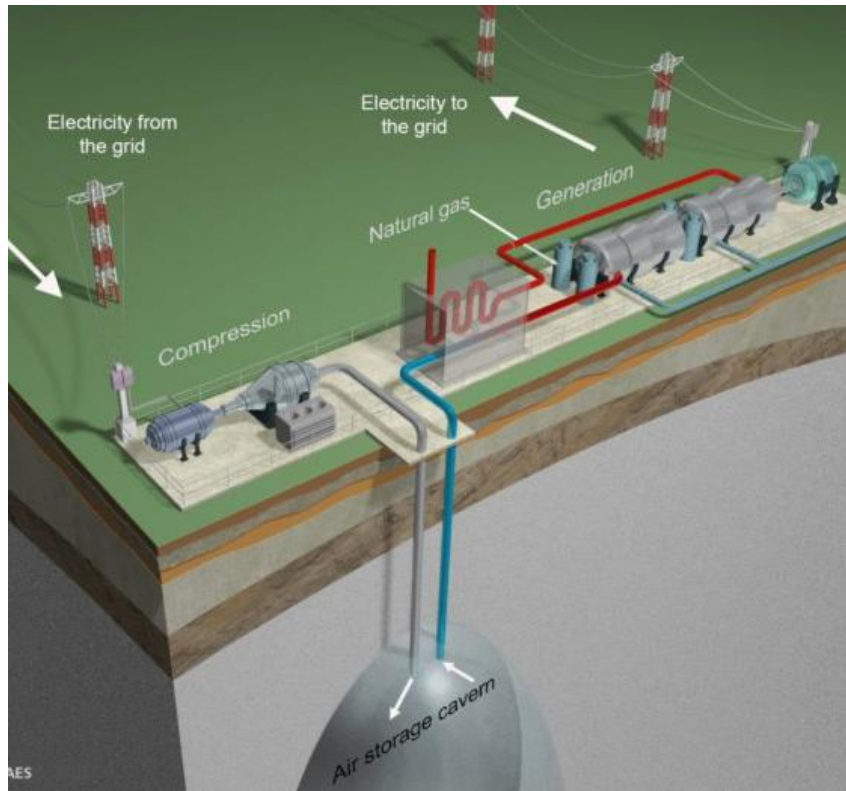


Note: CAES = compressed air energy storage; PHS = pumped hydro energy storage.

	Largest battery	CAES in single cavern	H2 in single cavern
Volume [MWh]	130	2900	120 000
	Jamestown (Aus)	McIntosh (US)	Moss Bluff (US)



# CAES



- Proven technology. Research is location specific
- 2 plants operational (Huntorf, 321 MW, McIntosh, 110 MW)
- New projects planned (Larne, 330 MW, 2GWh and Bethel Energy Center in Texas, 371 MW, 30 GWh)
- Heat from natural gas

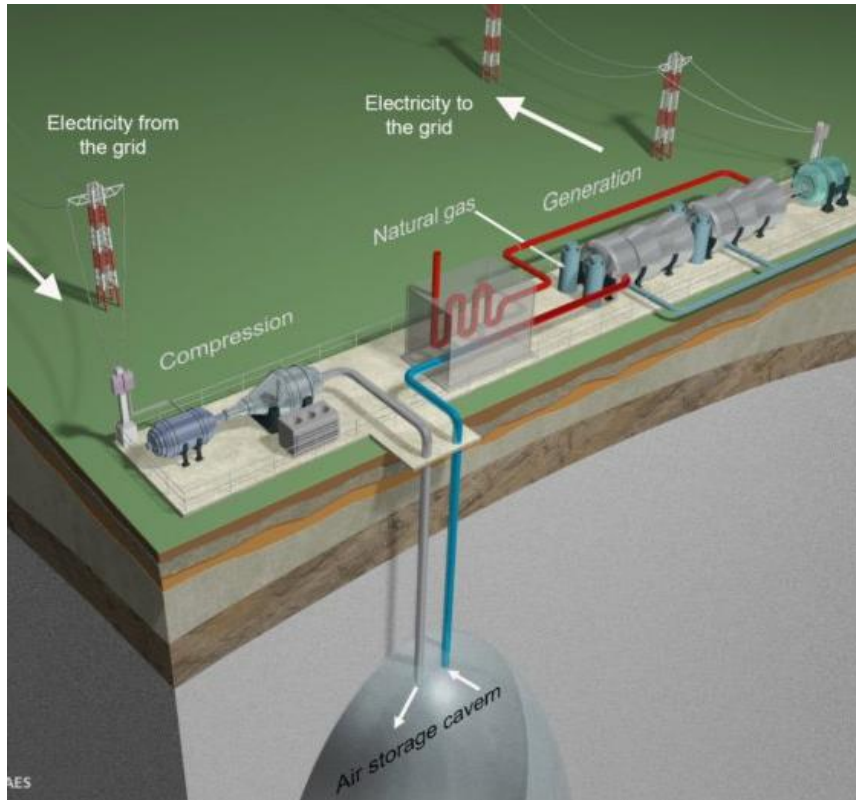
Potential

TRL

Market

Cost

# CAES



Challenge in creating storage space  
Difficult to value the technology

Geographical limitations: salt deposits  
between 500m (due to pressure) and  
1500m (due to temperature)

0.55 TWh Northern Netherlands (306  
caverns)

Fast response system (active frequency  
containment reserves)

Potential

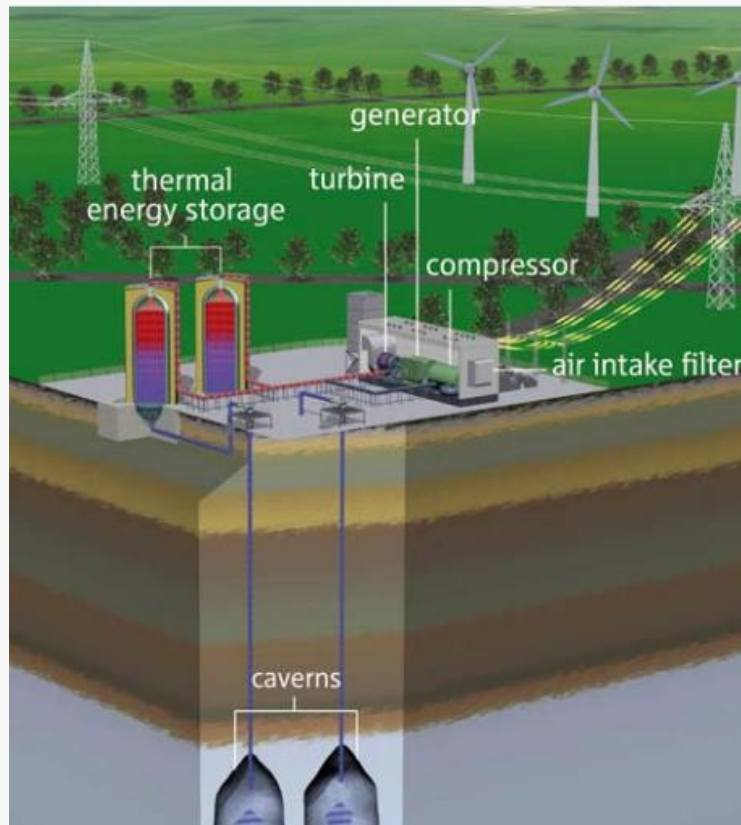
TRL

Market

Cost

# AA-CAES

## Advanced Adiabatic CAES



- Carbon reduction compared to conventional CAES
- 0.55 TWh Northern Netherlands (306 caverns)
- Challenge in creating storage space (i.e. caverns)
- Geographical limitations

Potential

TRL

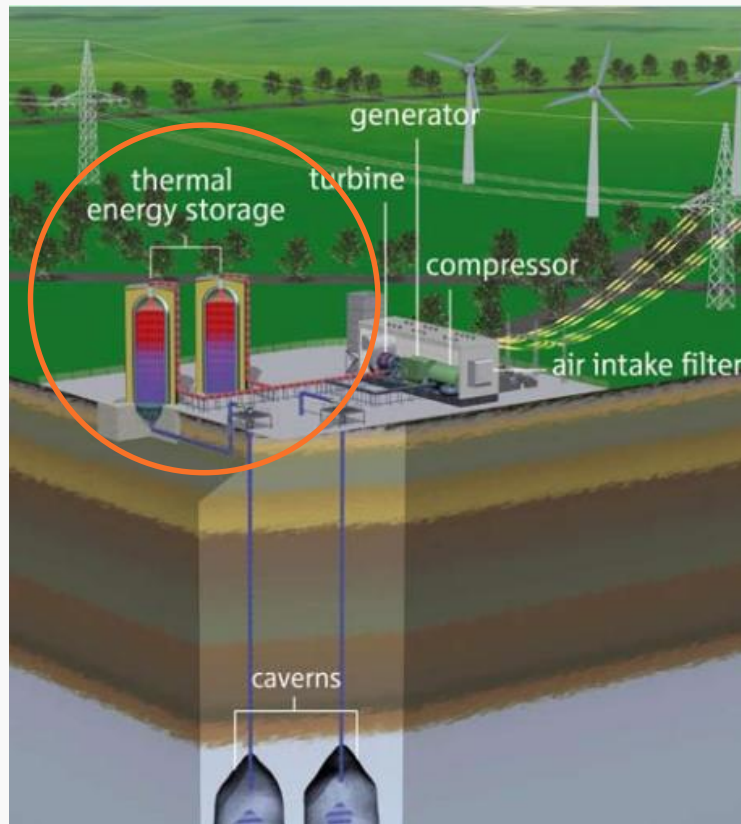
Market

Cost



# AA-CAES

## Advanced Adiabatic CAES



Source: Adele project

- Focus on highly efficient low cost thermal storage tech<sup>1</sup>
- No large demonstration projects in salt caverns
- One 660 kW under water pilot at Toronto Island (Hydrostor)
- Adele (Germany) on hold, reverted to classic CAES
- Hydrostor planned projects in Canada (1.75 MW in 2018) and Australia (5MW in 2019)
- Storelectric no pilot planned

Potential

TRL

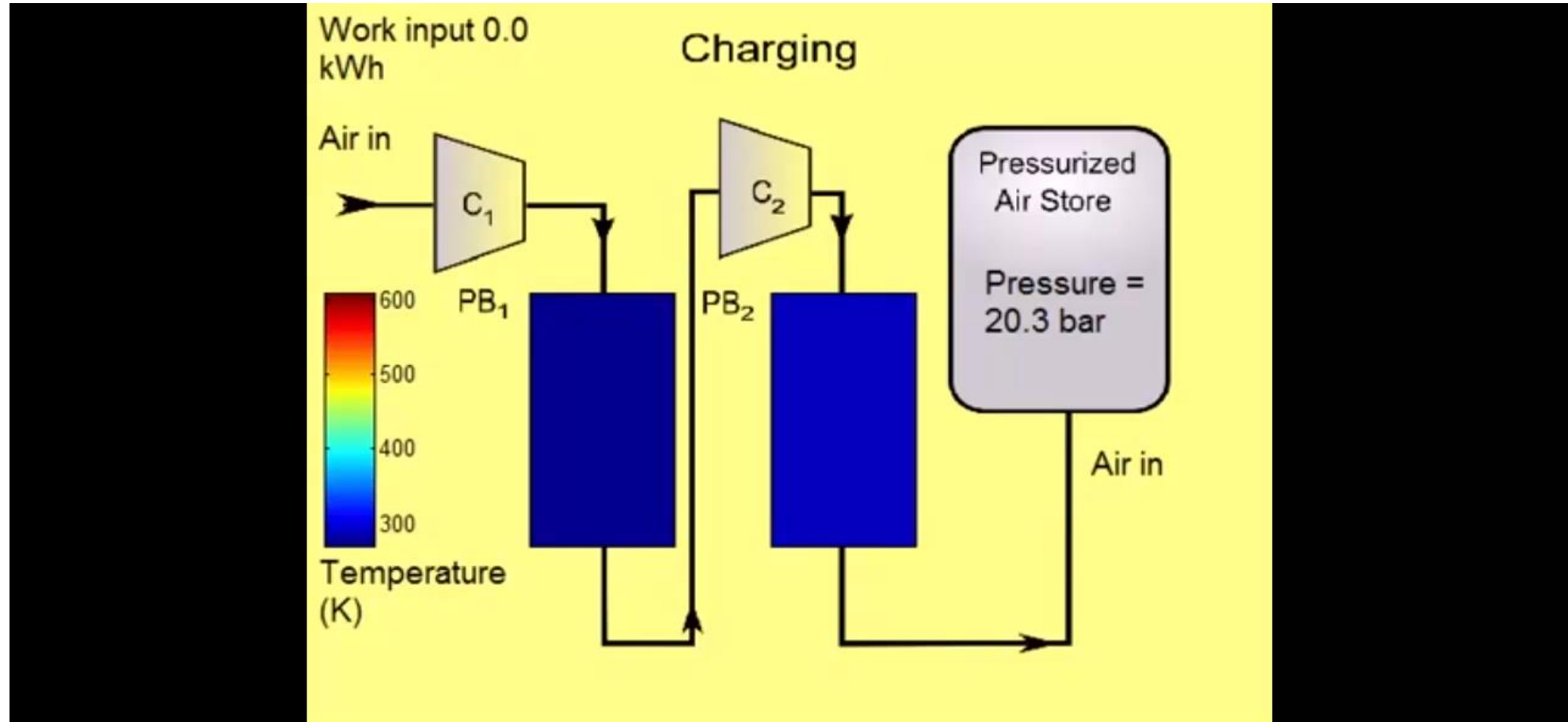
Market

Cost

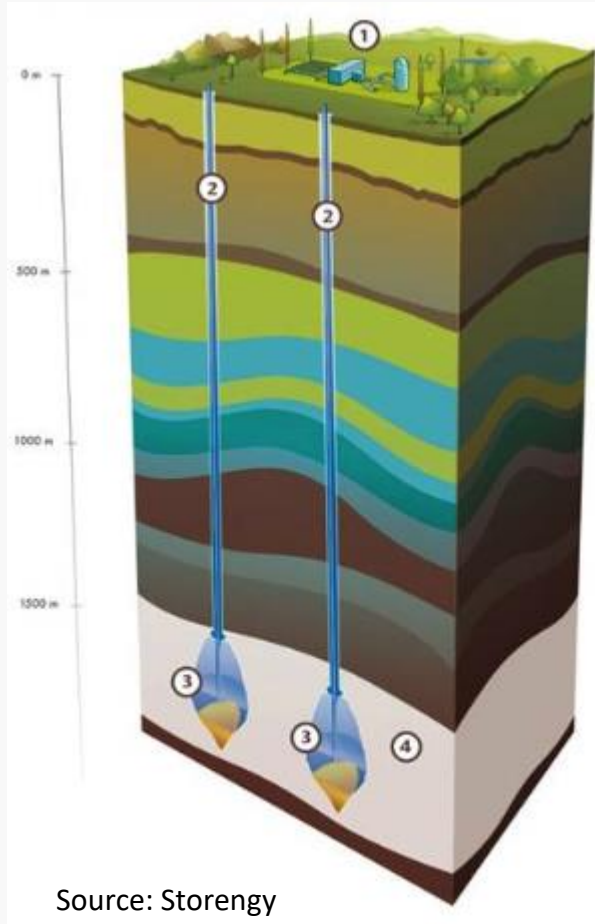
<sup>1</sup>EASE-EERA roadmap



# Adiabatische CAES



# Hydrogen Storage Caverns



Source: Storengy

- Mostly locations specific research questions remain,
- Effect of dense clustering of salt caverns and cyclic operations on the subsurface
- Pure hydrogen salt cavern storage on four locations in the world

Potential

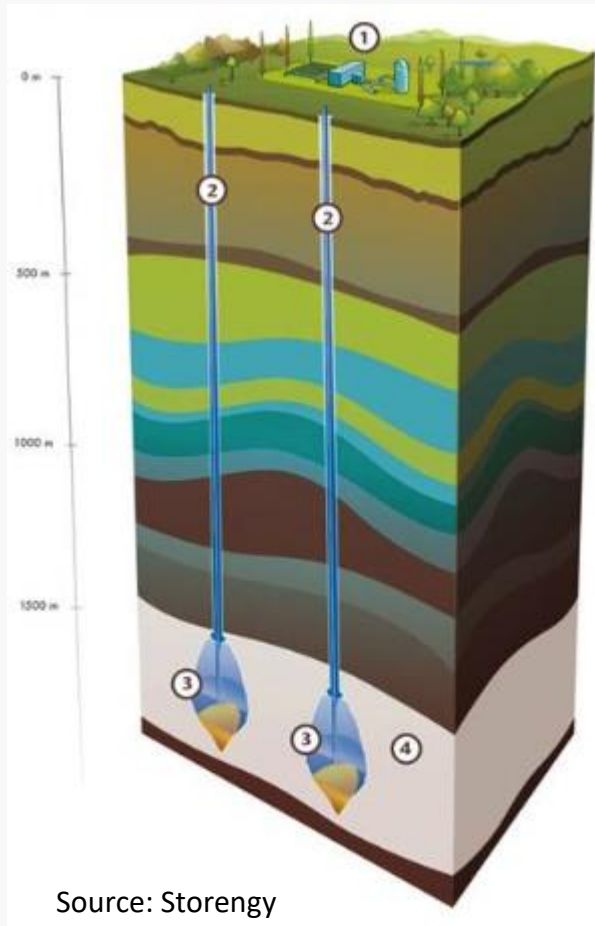
TRL

Market

Cost



# Hydrogen Storage Caverns



Source: Storengy

- Business case of hydrogen storage for electricity market is due to round trip efficiency not feasible yet
- Current hydrogen storages serve as feedstock storages

Potential

TRL

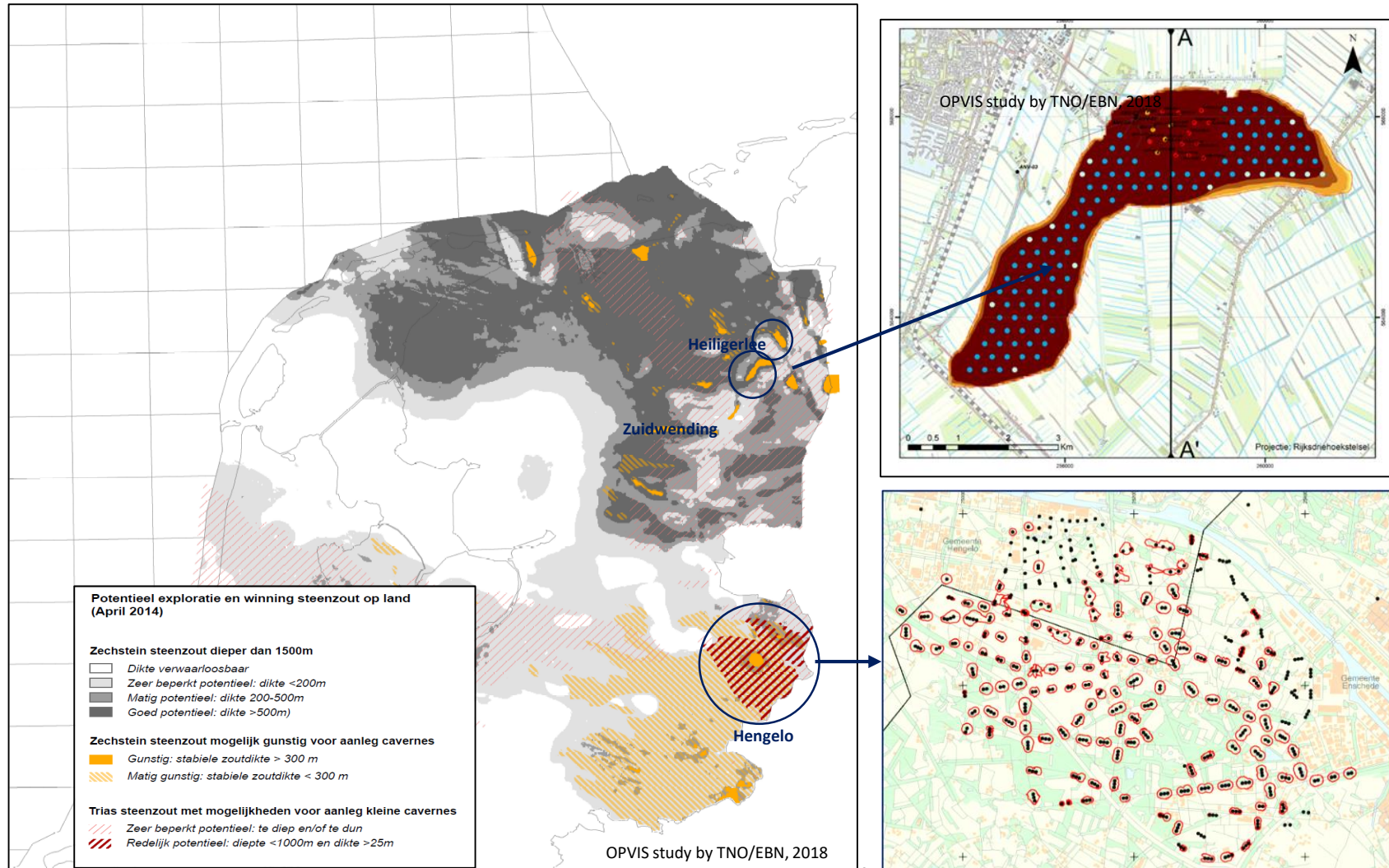
Market

Cost

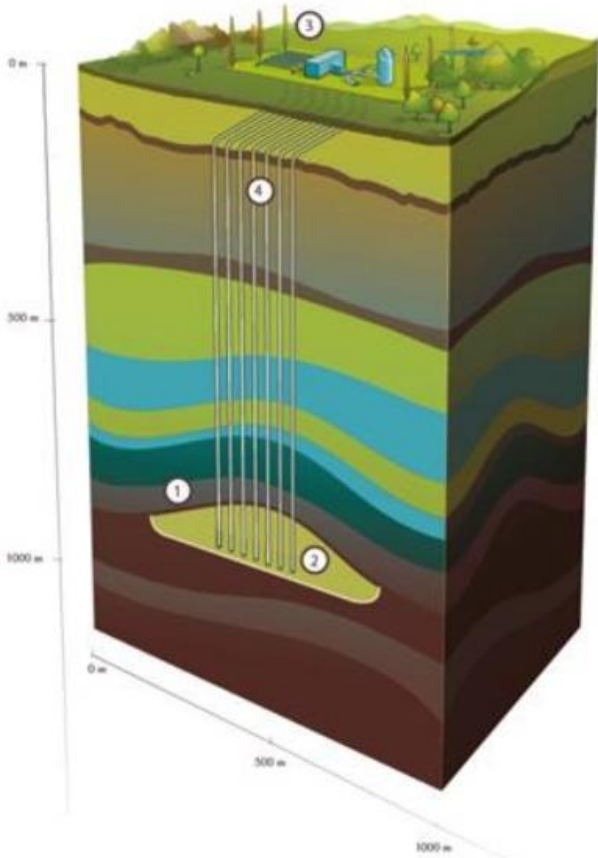


# Zoutcavernes in nederland

Waterstof ook mogelijk



# Hydrogen Storage Gas Fields



- Many questions remain:

- top seal
- Quality at surface
- microbiological and chemical conversions
- mobility and mixing
- material interactions
- cushion gas specifications

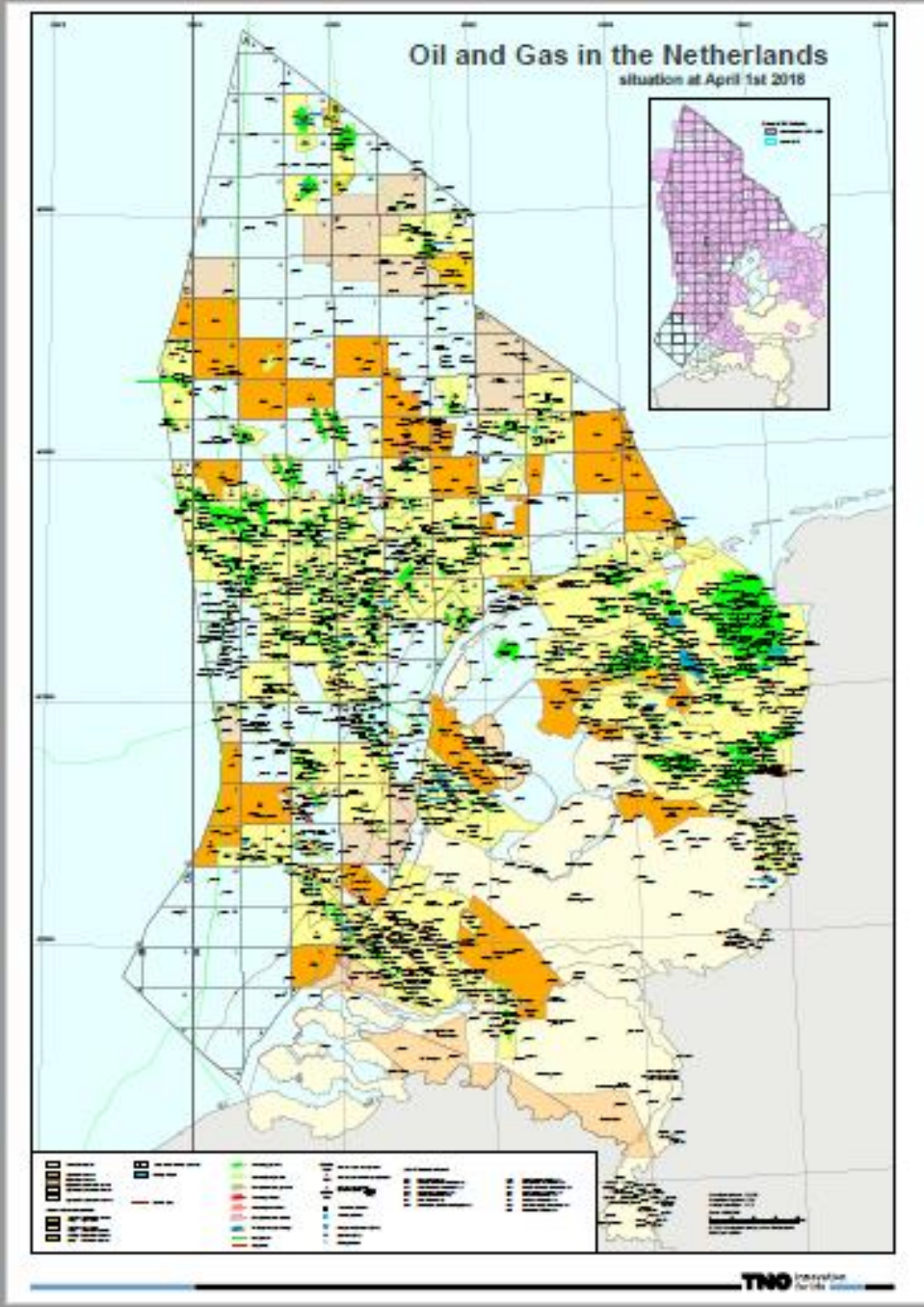
- Pilot in Austria (SunStore, 2015), 10% H<sub>2</sub>
- Pilot in Argentina (Diadema 2009), 10% H<sub>2</sub>
- Methanation occurs, 82% of hydrogen retrieved (SunStore)

Potential

TRL

Market

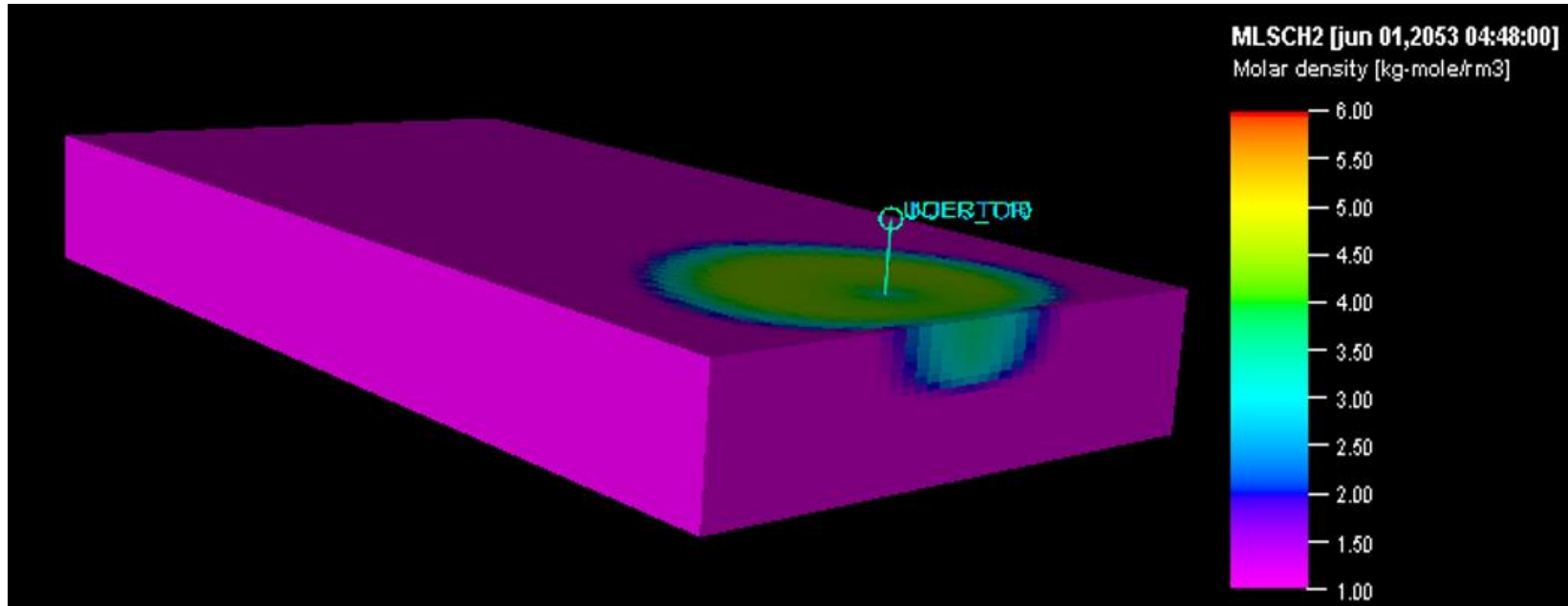
Cost



Nederland zit vol met mogelijkheden

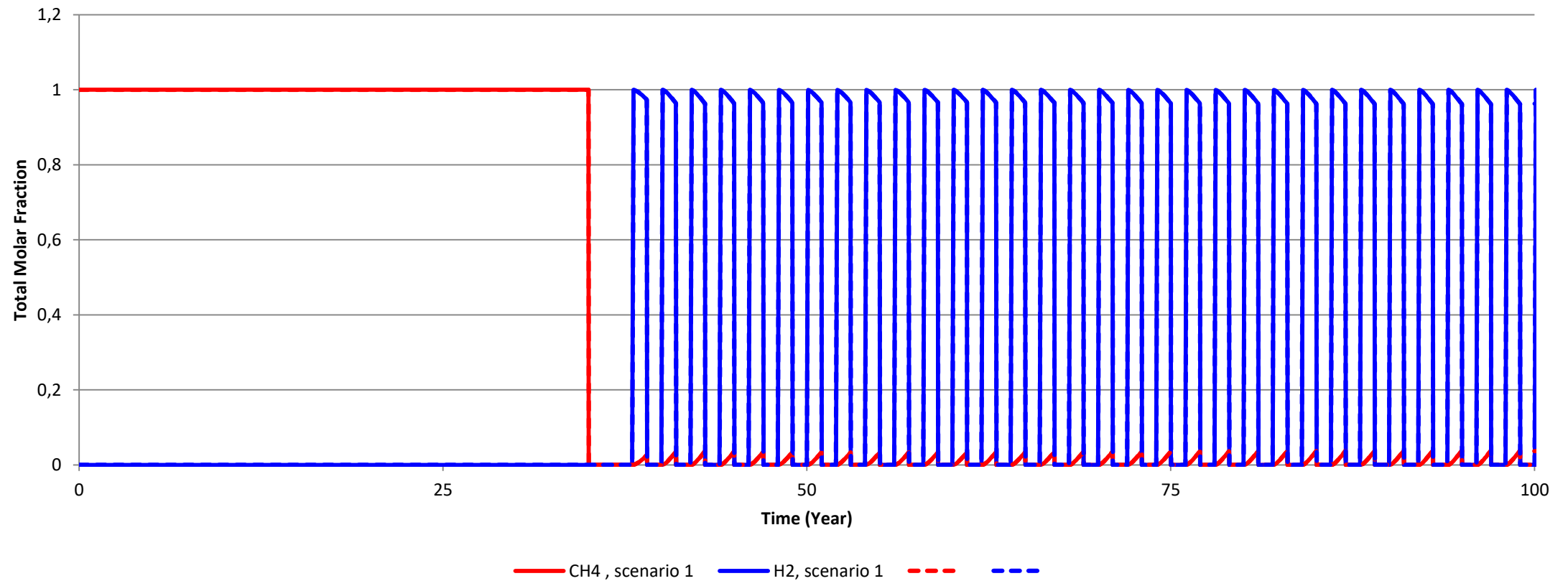
# Opslag in gasvelden

- Sythetische studie

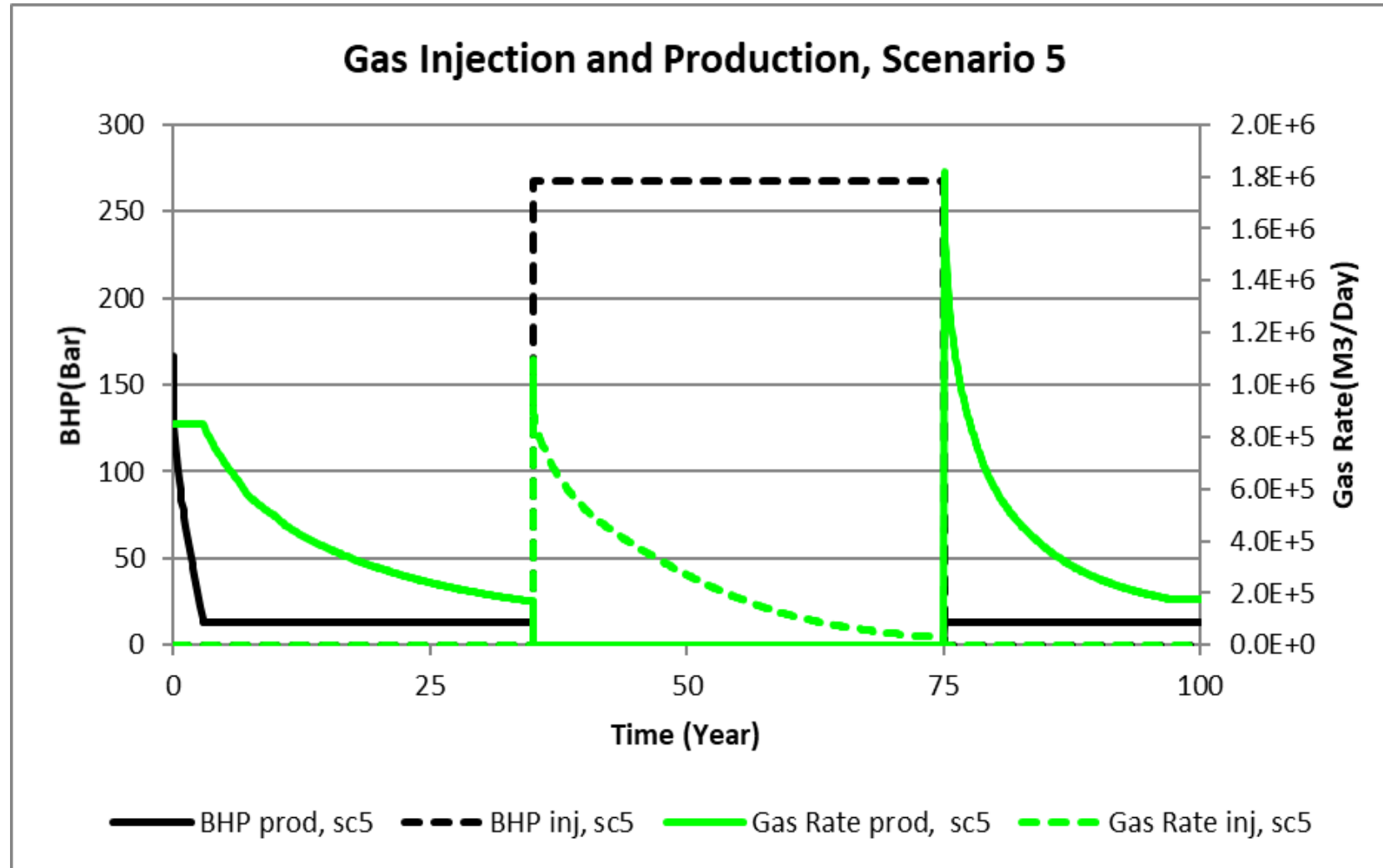


# Productie H2

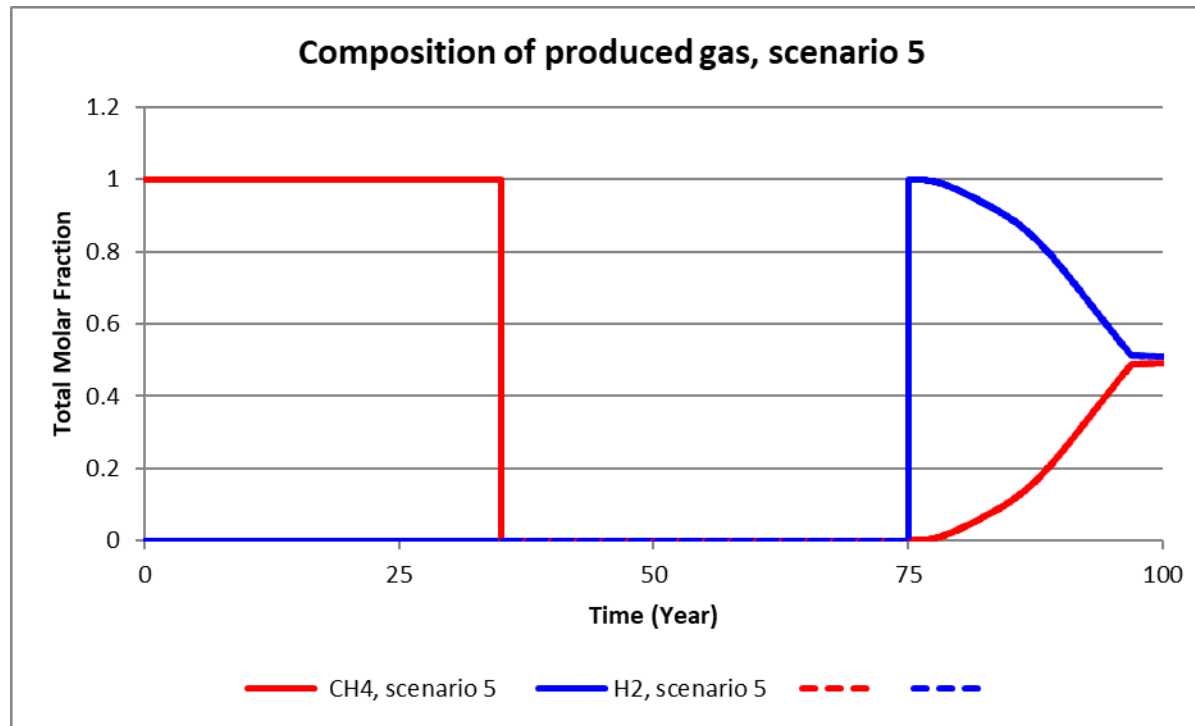
Gas Composition, Scenario 1



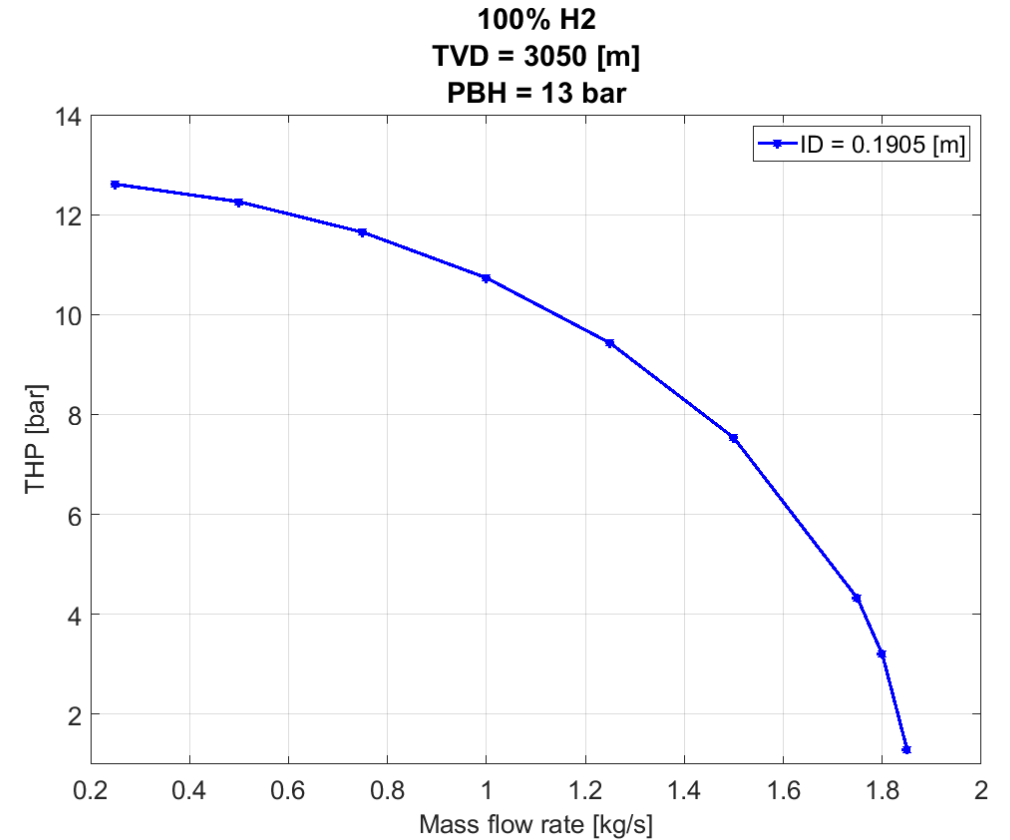
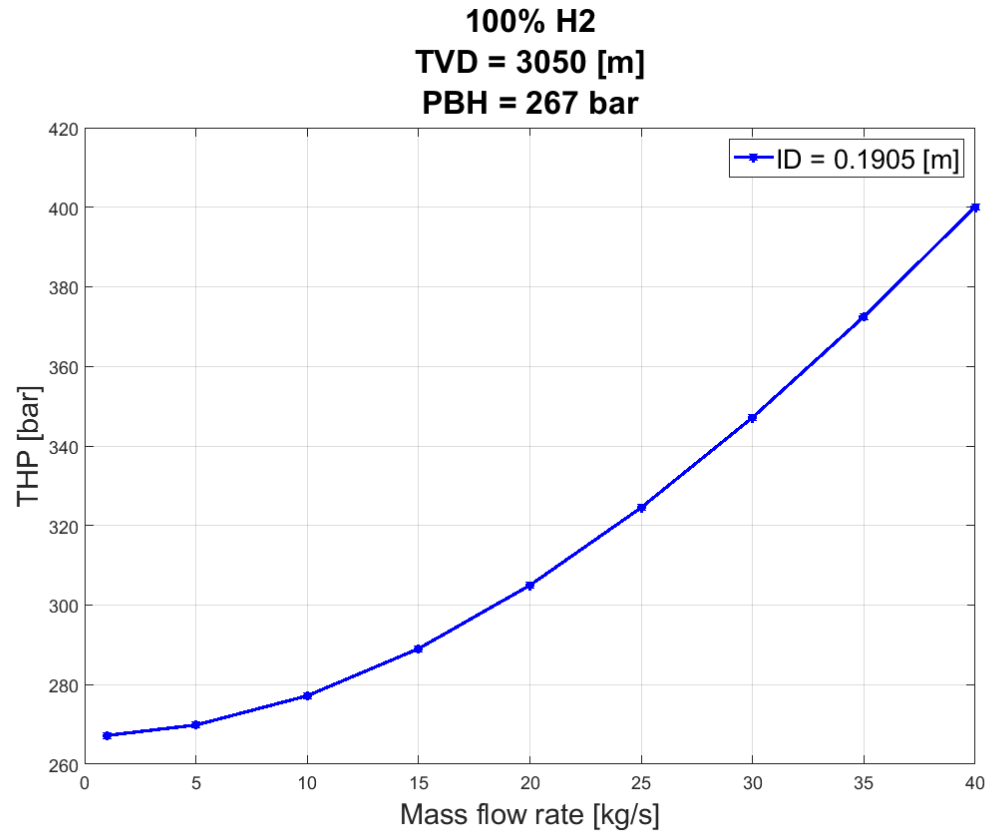
# Ander scenario



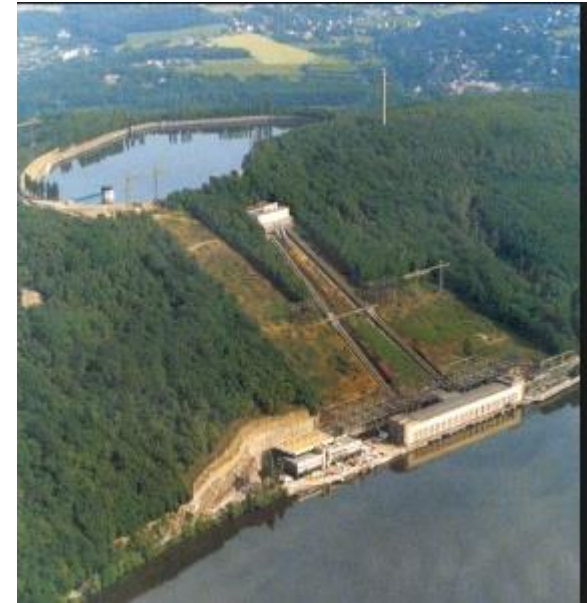
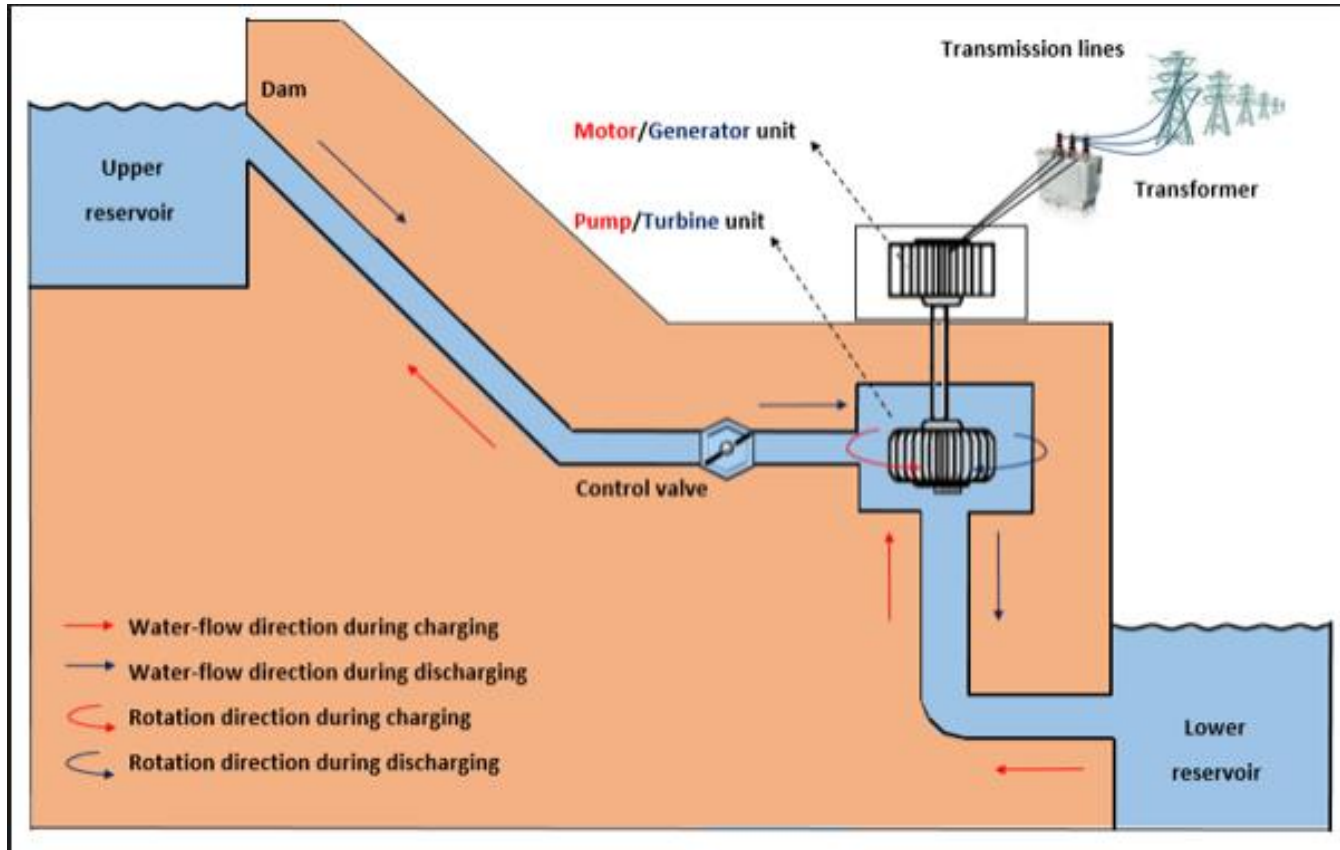
# Ander scenario



# Gedrag van waterstof in put



# Pumped hydro

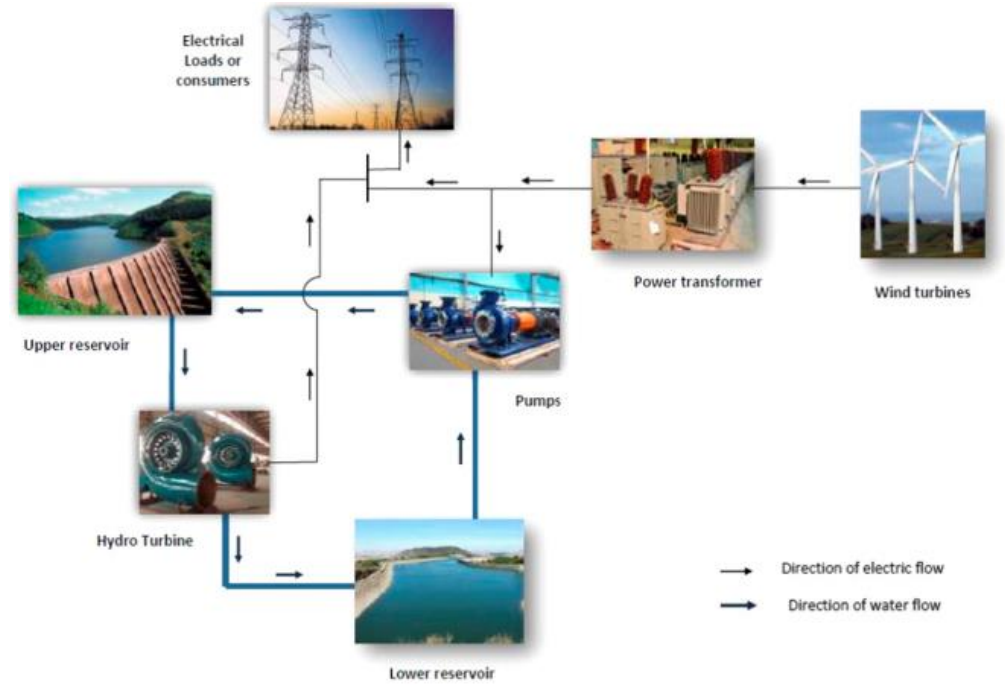




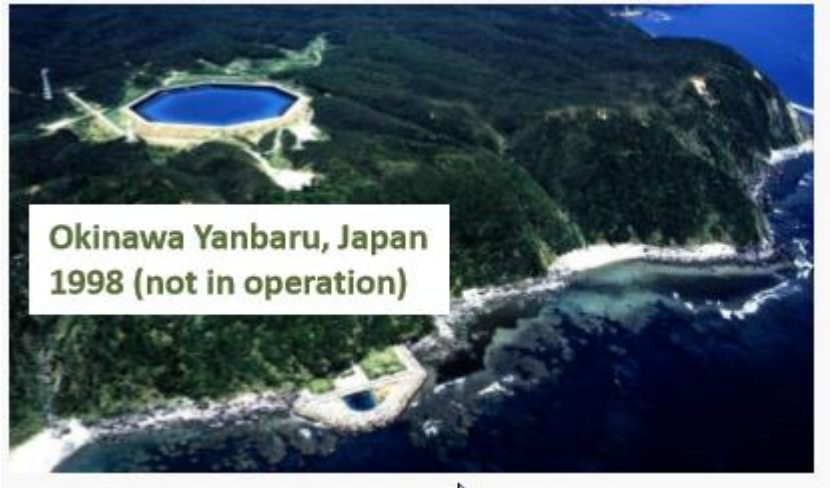
La Muela, Spain 1,516 MW 23 GWh

Iberdrola

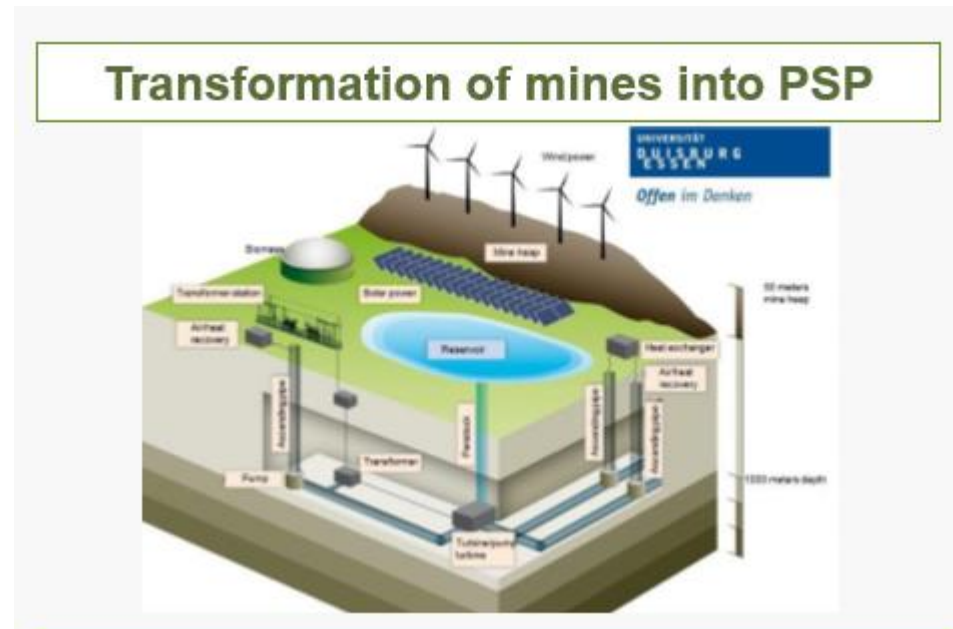
## Stabilisatie Net



# Andere mogelijkheden



Bij zee



Iberdrola

mijnen



# Thermal energy storage



Source: heatstore.eu

- Potential location dependent and very much technology dependent (combination)
- Geology
  - Mines
  - Aquifers
  - Groundwater

Potential

TRL

Market

Cost



# Thermal energy storage



Source: heatstore.eu

- Not proven for high temperatures
- Target efficiency of 75%
- Grid integration requires optimization

Potential

TRL

Market

Cost



# Thermal energy storage



Source: heatstore.eu

- Heating grids seasonal
  - Less peak
  - Less infra
  - Power to heat
- Very good combination with low marginal cost of heat
- Among lowest cost of large scale storage

Potential

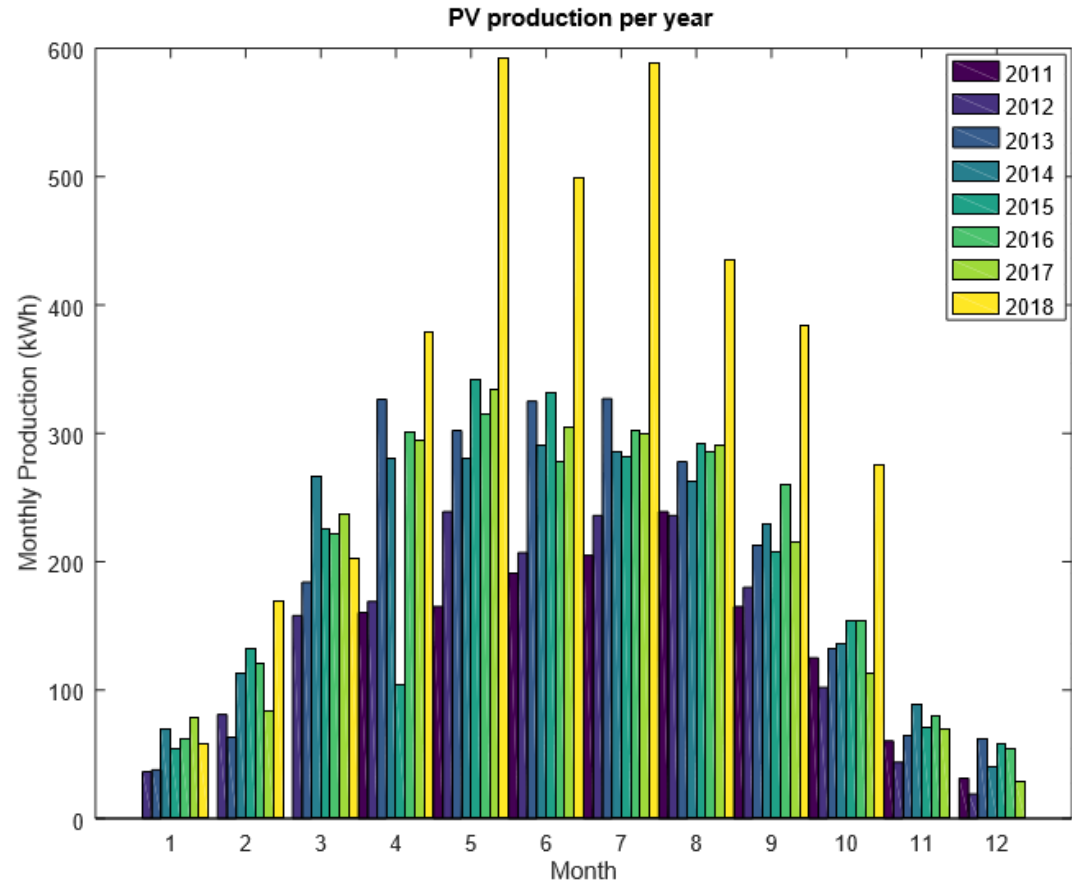
TRL

Market

Cost

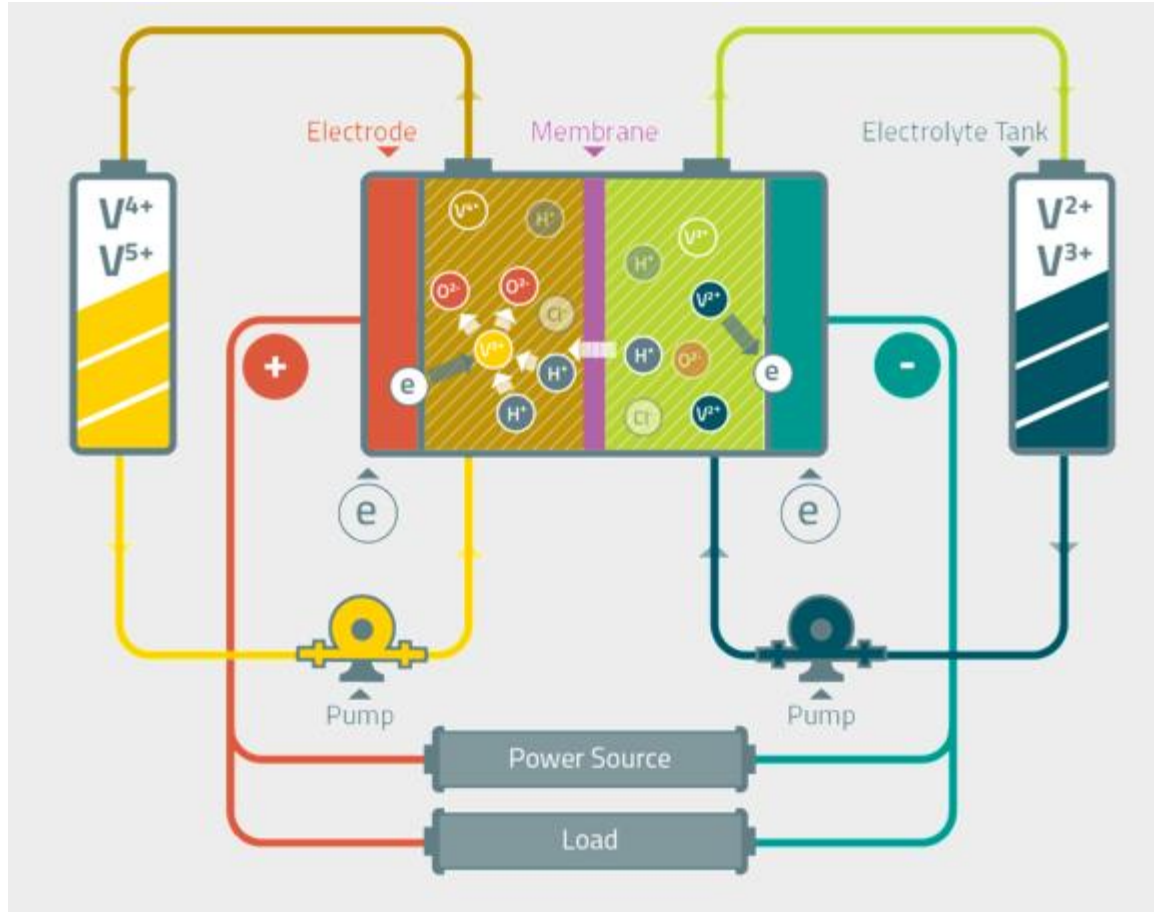


# Opslag thuis



PV gedurende het jaar

# Vanadium Redox Flow



Zwavelzuur

Andere voorbeelden

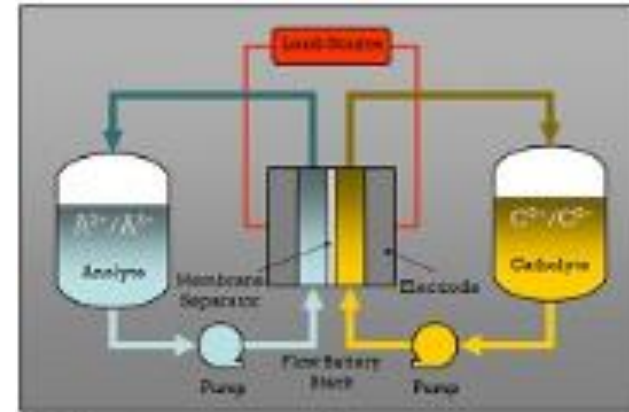
Zink-Broom  
polysulfide-broom



Ontladen  $V^{2+} \rightarrow V^{3+}$   $V^{5+} \rightarrow V^{4+}$

Laden  $V^{3+} \rightarrow V^{2+}$   $V^{4+} \rightarrow V^{5+}$

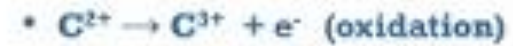
# example



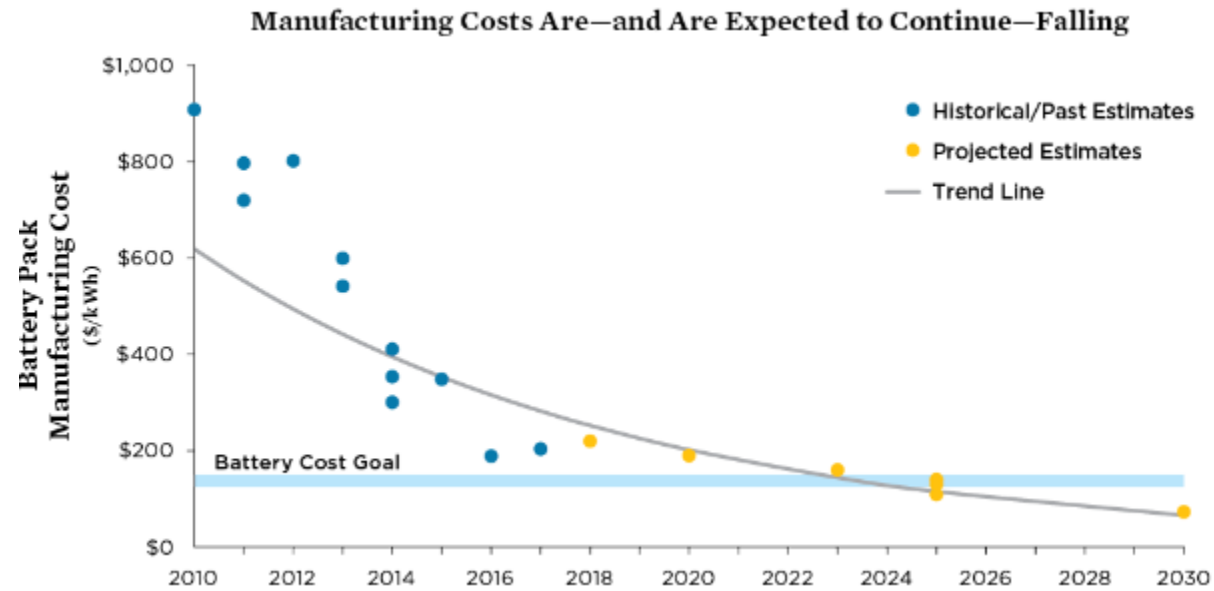
- **Discharge reaction**



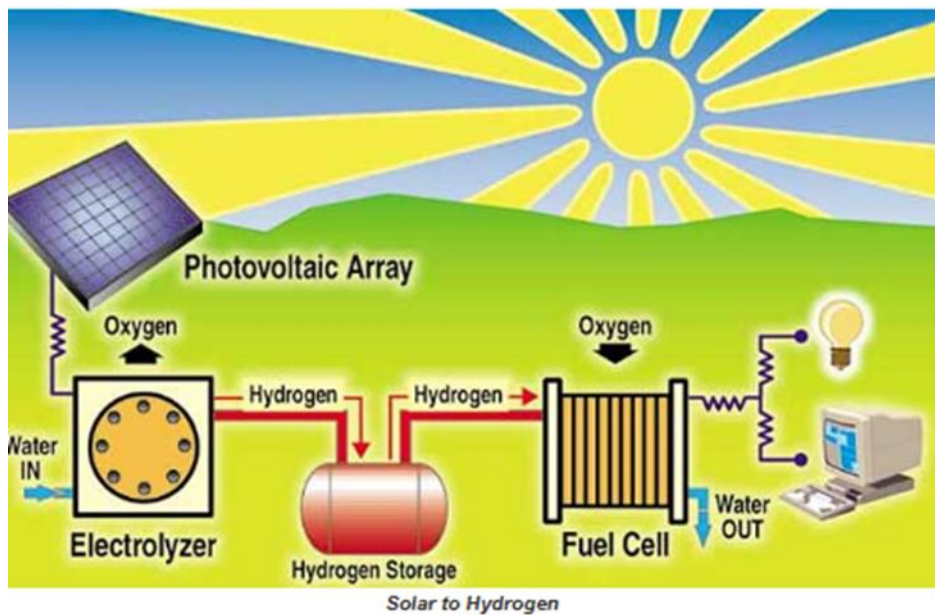
- **Charge reaction**



# Cost prediction battery technology



# Opslag als waterstof



Electrolyse unit bij flatgebouw.

# Warmte Batterij



Zomer:

Zonneboiler/warmtepomp warmte > drogen zouten

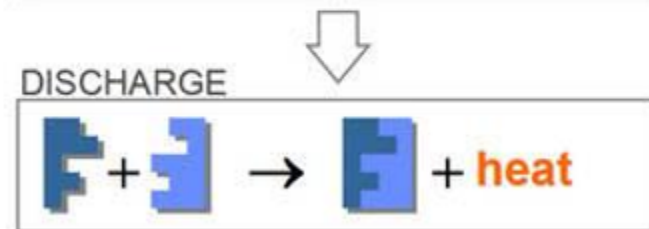
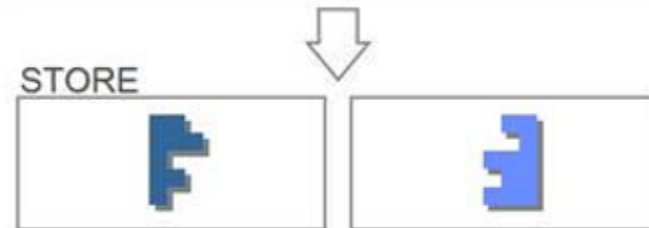
Winter:

Bevochtigen zout > warmte opwekking

Voordelen: geen verlies, seizoen opslag

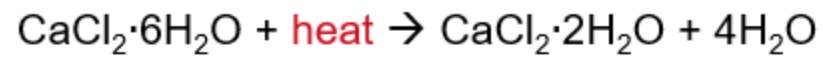
Vervanging CV bij hybride systeem luchtwarmtepomp.

# Principe warmteopslag



Source: ECN, the Netherlands

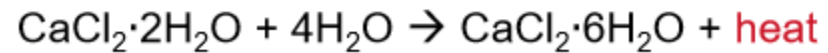
Loading:



Storage:

$\text{CaCl}_2$  separate from  $\text{H}_2\text{O}$

Unloading:

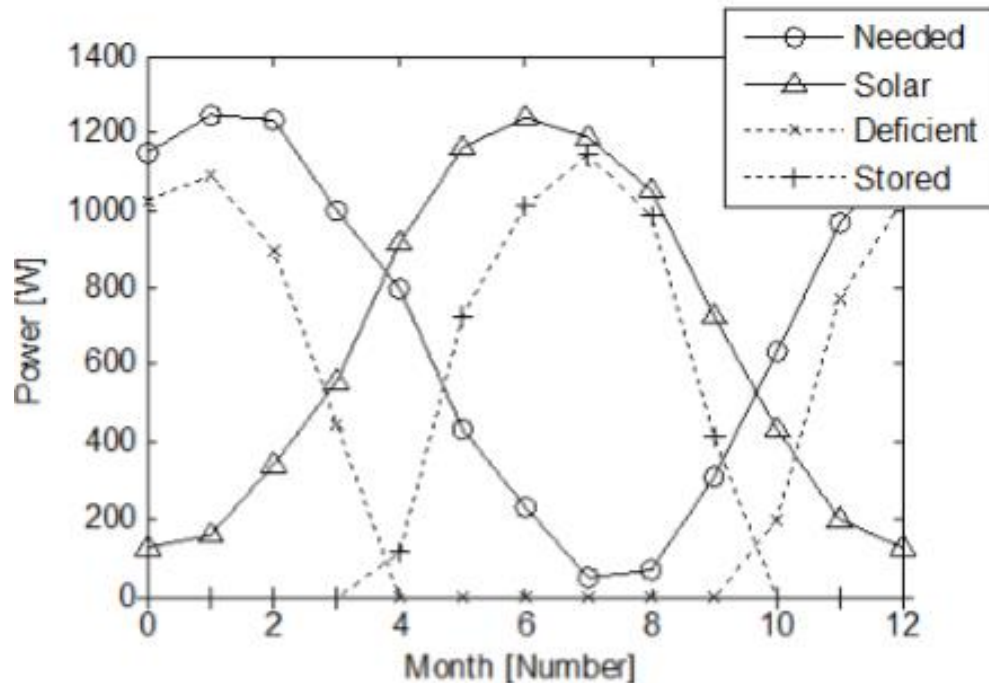


# Case – Thermochemical storage, passive house

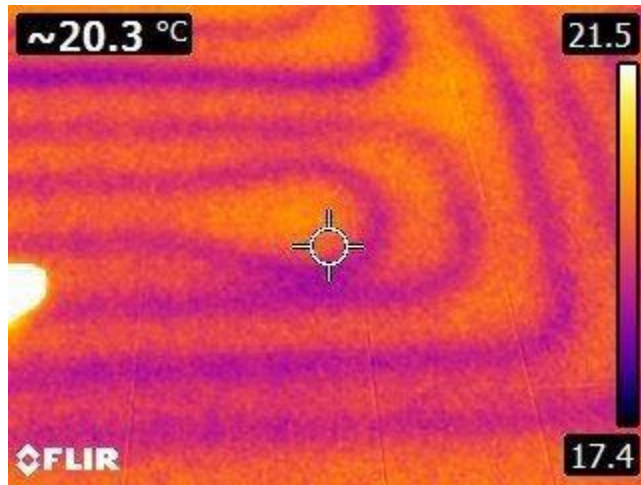
- › Heating demand 2020: 20GJ/year =5555 kwh  
(prognosis continental climate)
- › Storage for cold season 10GJ
- › TCM volume ~10m<sup>3</sup> (~1GJ/m<sup>3</sup>)
- › Solar collectors ~17m<sup>2</sup> (~1.2GJ/m<sup>2</sup>y)
- › Solar boiler for short term storage & delivery



Source: Solarpraxis AG



# Warmteopslag in ondiepe ondergrond



Zomer 2018

Passieve koeling



Warmwater opslag



Ontrekking/opslag  
warmte

# Warmteopslag bij BWW

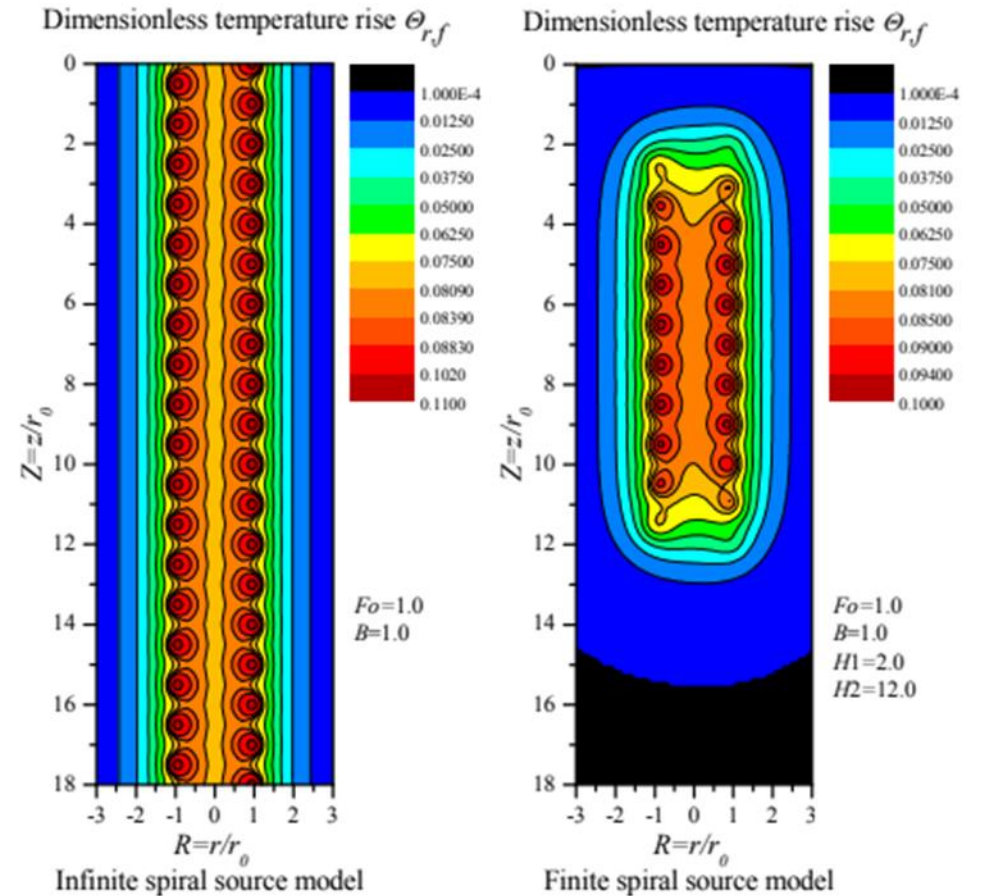
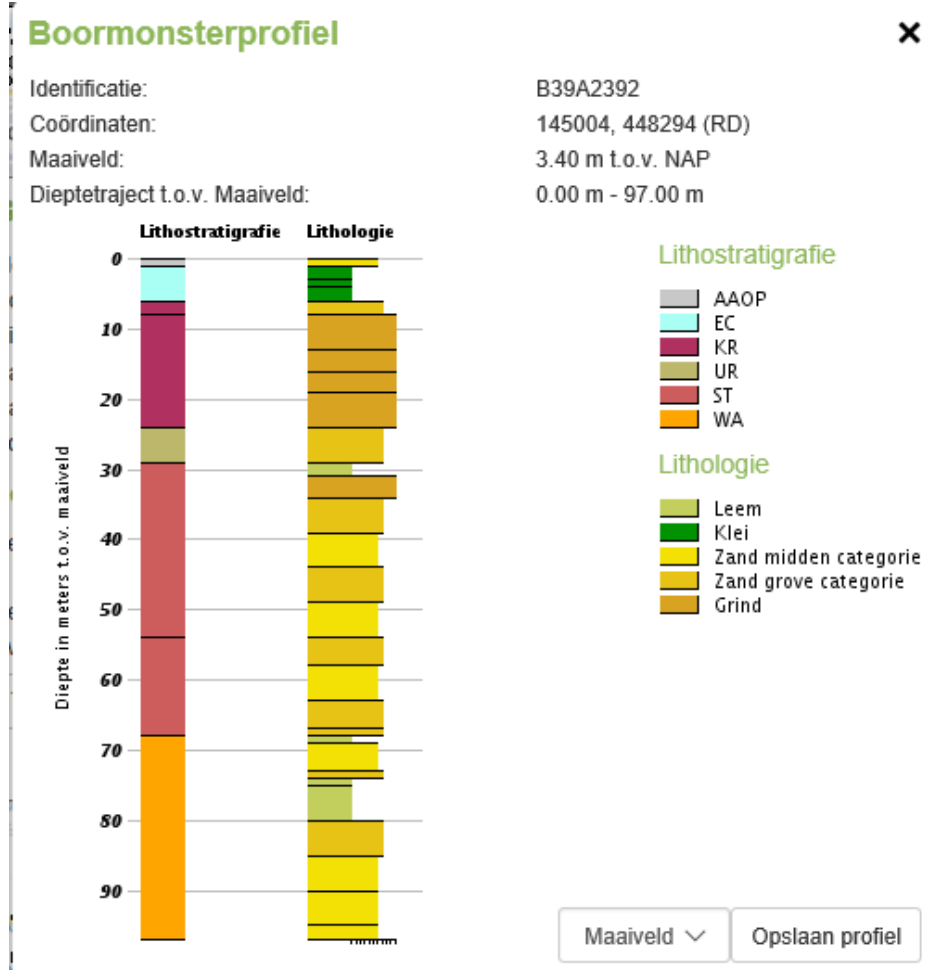
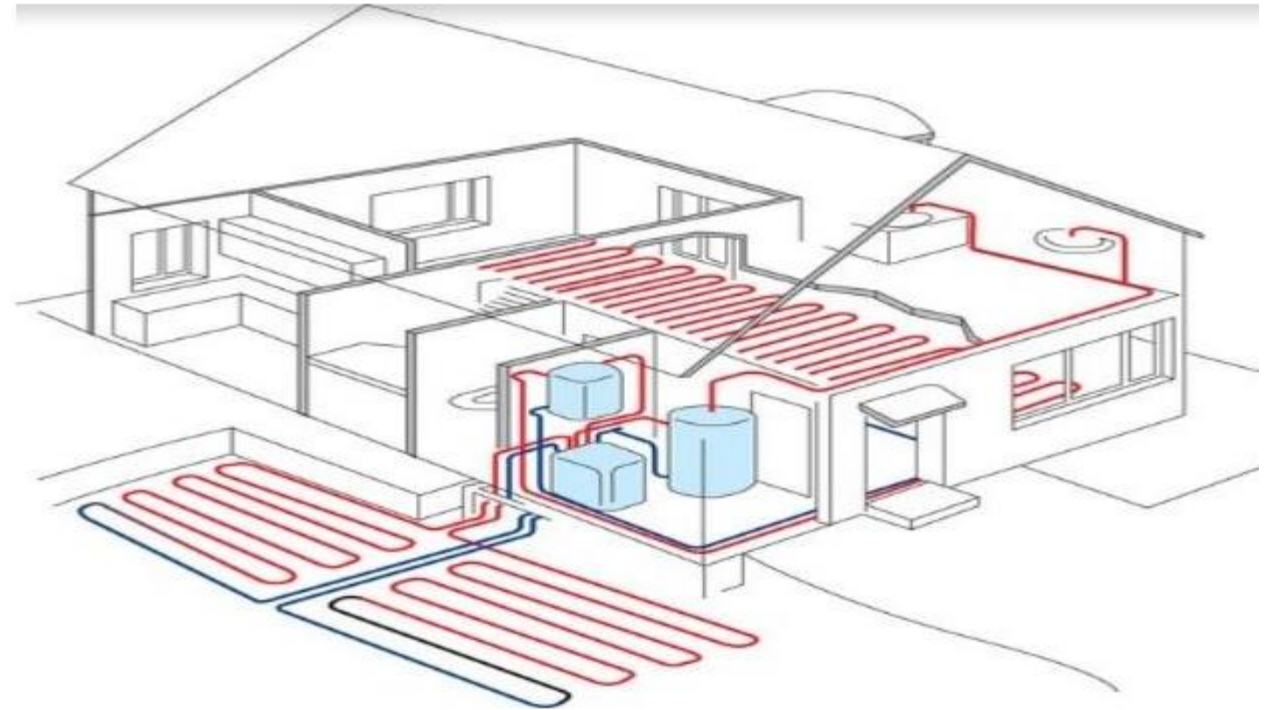
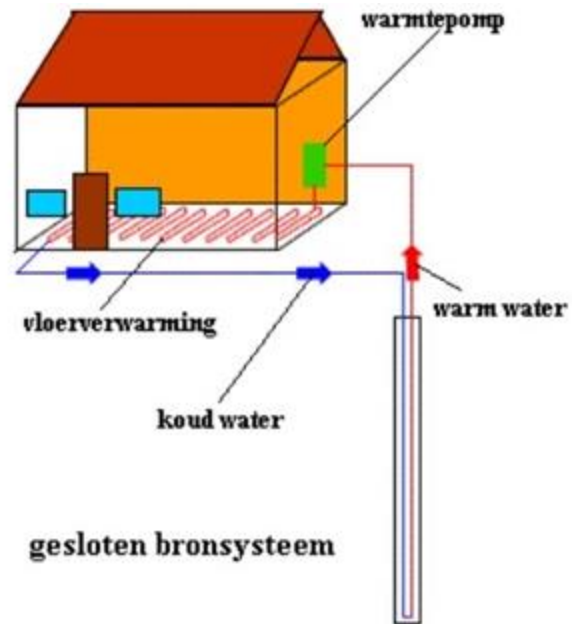


Fig. 10. Temperature response of the infinite and finite spiral source models

(Y Man et al)

# Bodem Warmte Wisselaar



Horizontaal BodemWarmteWisselaar (HBWW)

Ook samen met **Thermische energie uit oppervlaktewater (TEO)**

# Conclusie

- Er zijn veel ontwikkelingen aan de gang rond energie opslag
- Veel is nog onduidelijk, welk scenario waar zal plaatsvinden.
- Er is ook zeker behoefte aan natuurkunde studenten.