The Future of Energy

KIS lecture 08-11-2023

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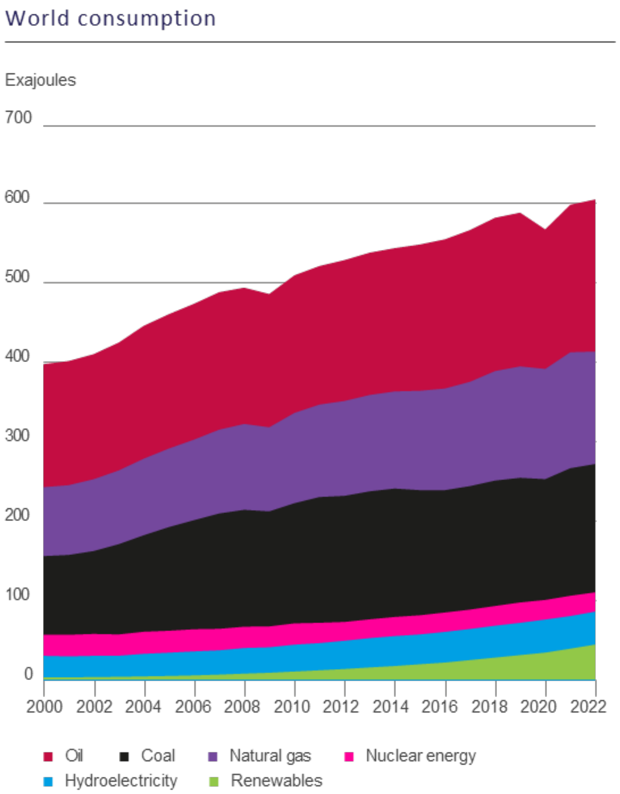
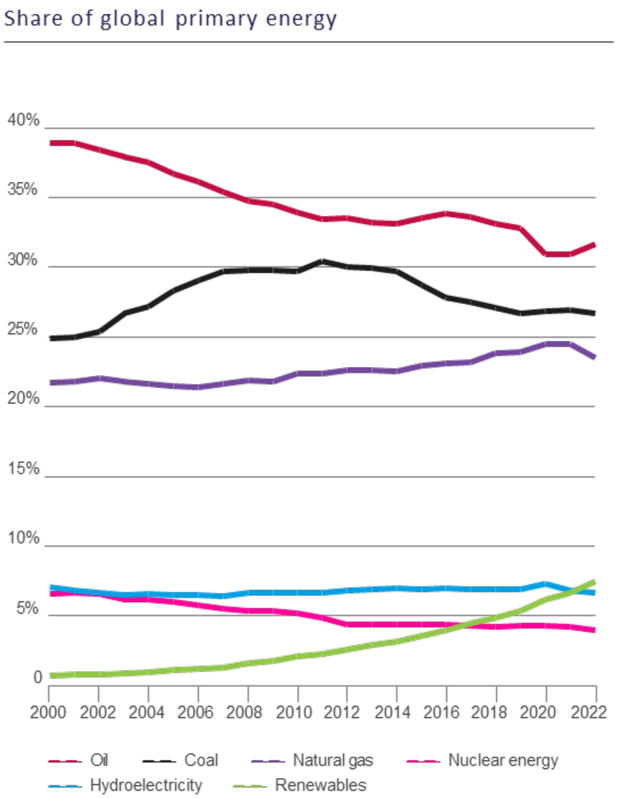
Overview of this lecture

- The energy transition: where do we stand?
- Towards a future energy system: dot on the horizon
- EIRES: renewable energy research at TU/e
- Deep dive on 3 topics
  - Hydrogen
  - Metal fuels
  - Heat
- Wrap up & conclusions

The energy transition: where do we stand?

The energy transition: where do we stand?

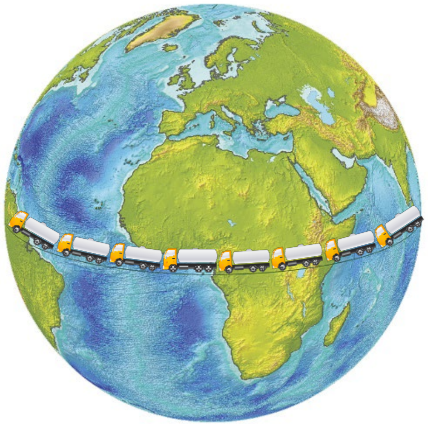
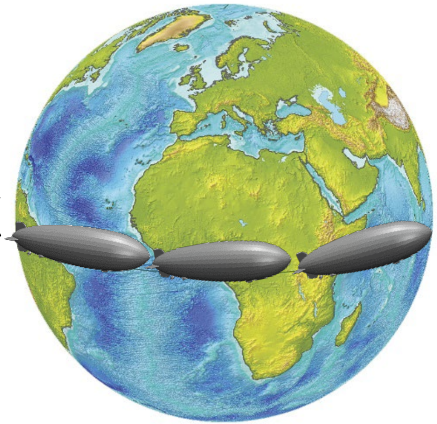
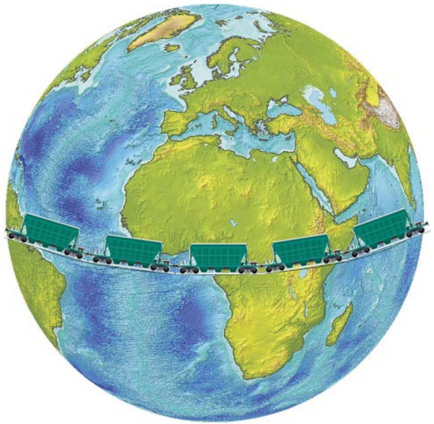




Energy Institute Statistical Review of World Energy 2023

1 exajoule = 278 TWh = 163 Mboe = 26.5 Gm^3 NG

Energy consumption visualized

50x  + 125x  + 24x 

Or closer to home: personal energy consumption

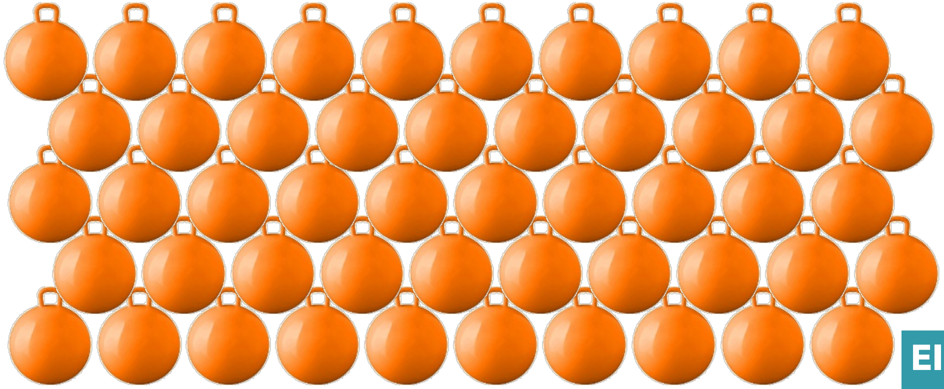
1,25 kg coal

Per person in NL per day*

* Excluding the 2.5l oil pp for international marine and air transport

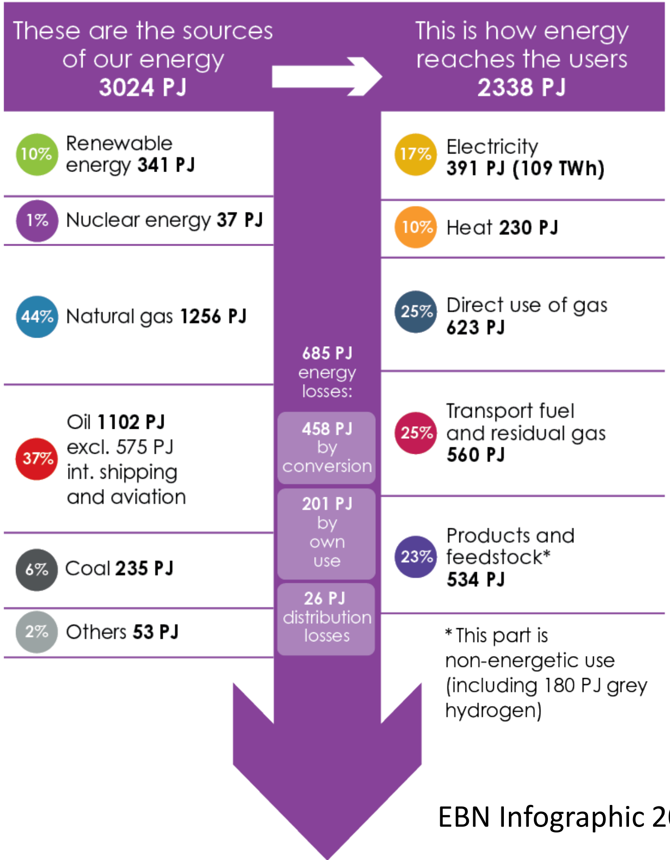
4,5 l oil

5,5 m^3 nat. gas



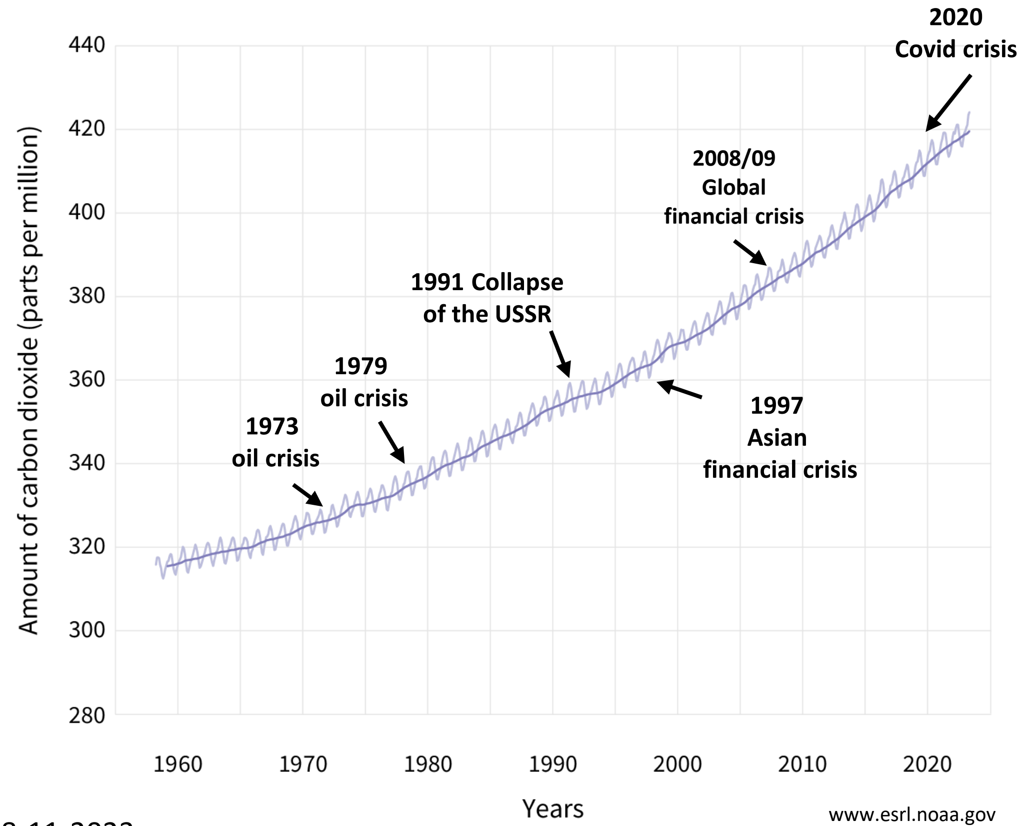
What do we use the energy for?

THE DUTCH ENERGY SYSTEM:
FROM PRIMARY DEMAND TO FINAL DEMAND



EBN Infographic 2023

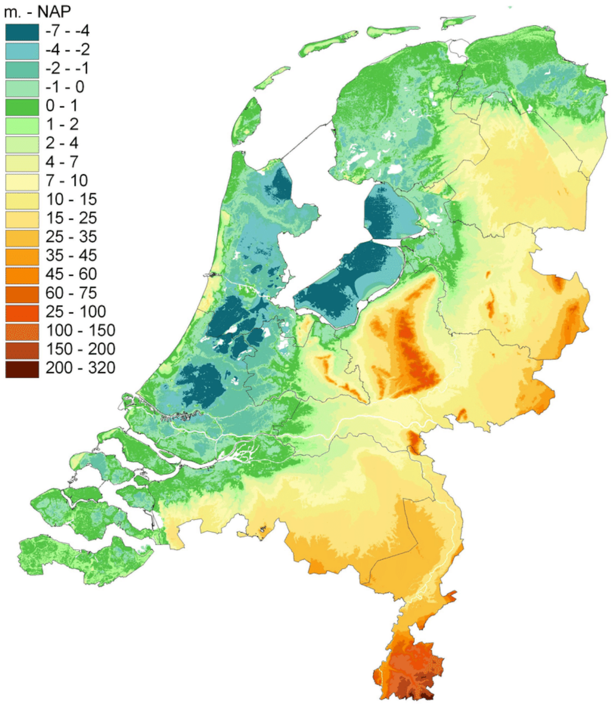
The consequence



www.esrl.noaa.gov

Why we should care

Google earth



M. Blom-Zandstra et al., doi:10.1088/1755-1315/8/1/012018

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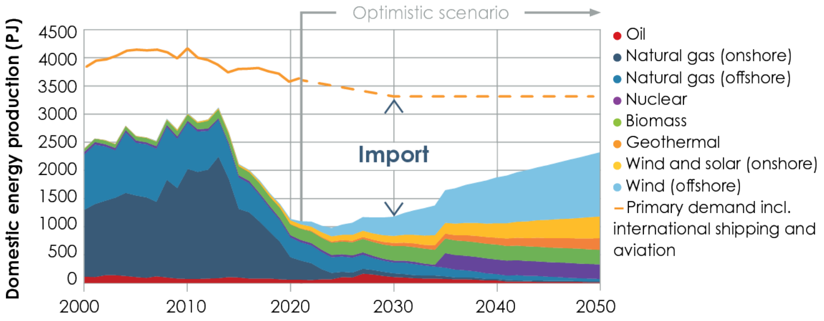
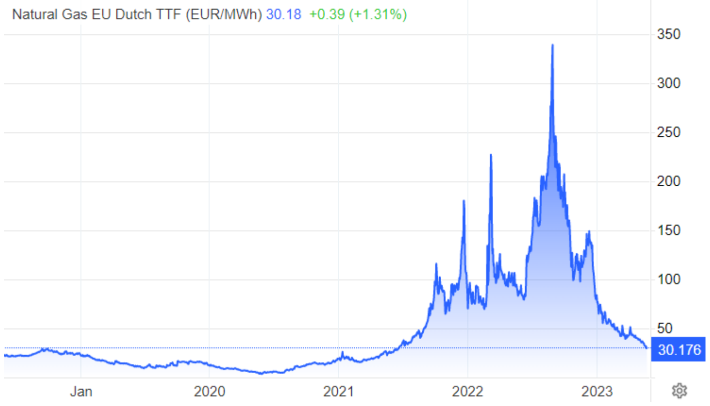
Russian invasion as terrible wake-up call

- EU and NL dependance on energy import

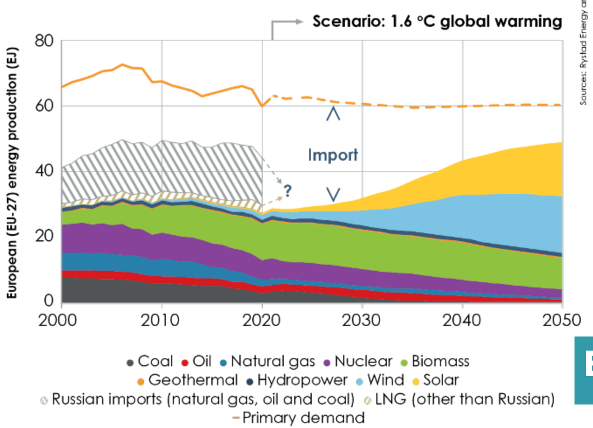
THE IMPORT GAP OF THE NETHERLANDS



EBN 2023



THE IMPORT GAP OF EUROPE



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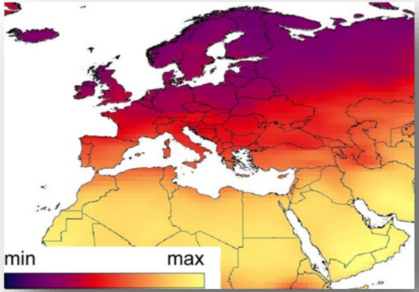
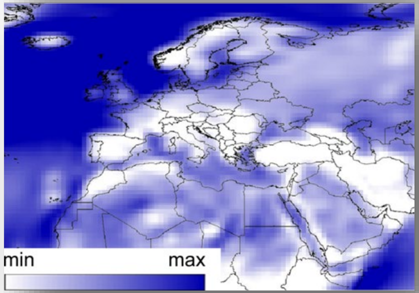
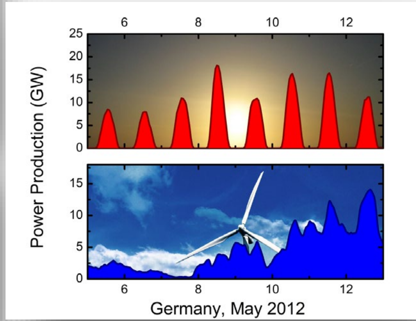
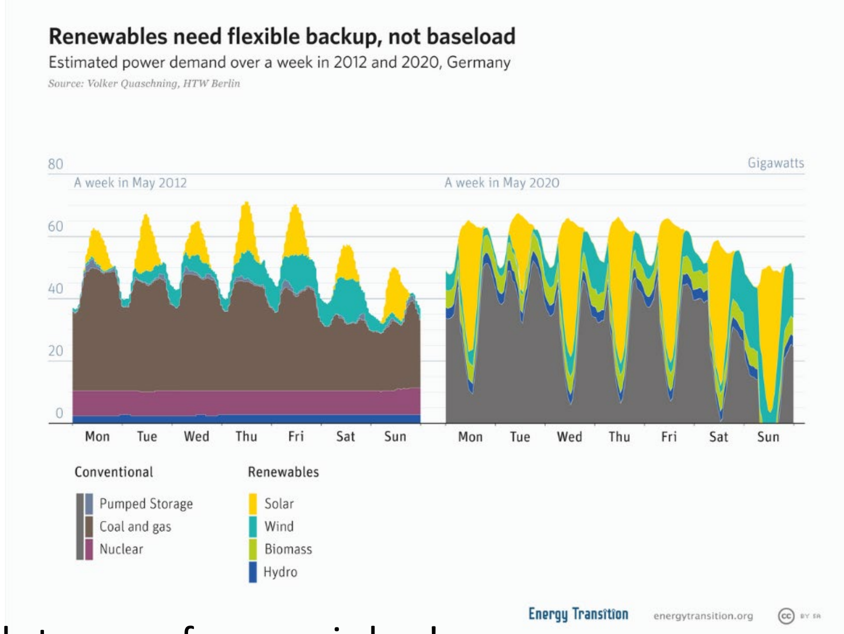
Renewable energy brings its own challenges

Supply and demand: mismatch in time and place





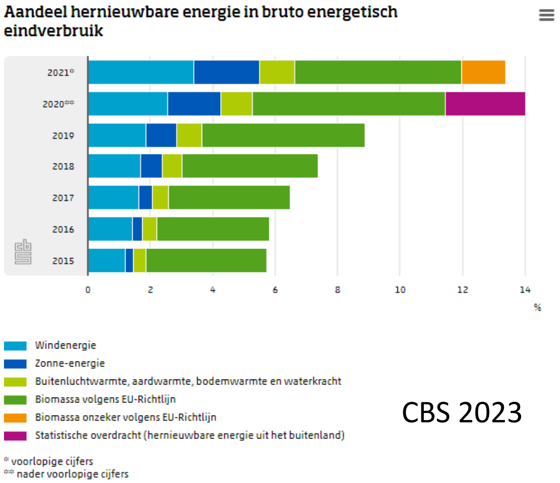




Transport, conversion, and storage of energy is key!

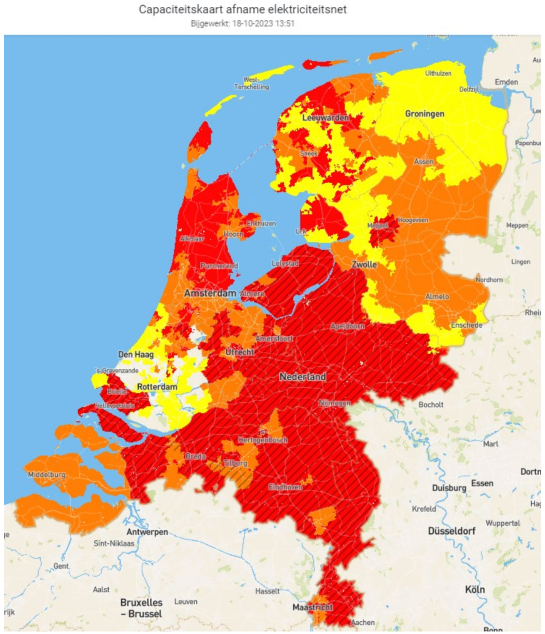
Current infrastructure is not prepared

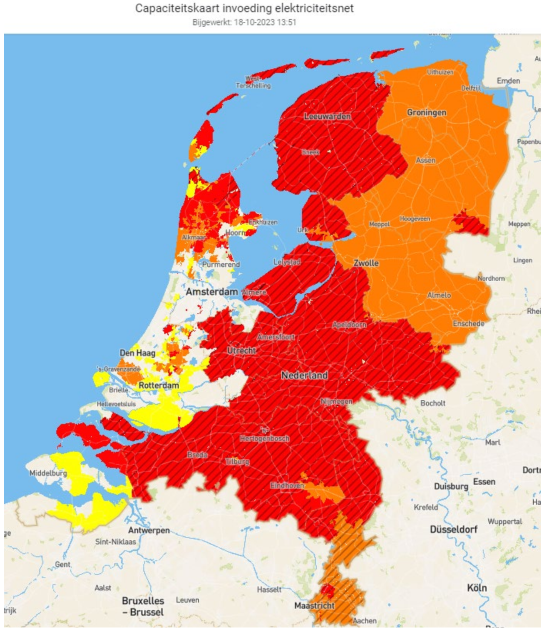
- NL as testcase for the world
- Rapid increase solar and wind



CBS 2023

- transport capacity available
- limited transport capacity
- no transport capacity, congestion mgmt. res. pending
- no transport capacity, no congestion mgmt. possible
- congestion mgmt. actions taken, limited possibilities
- congestion mgmt. actions taken, limit reached





Netbeheer Nederland 2023

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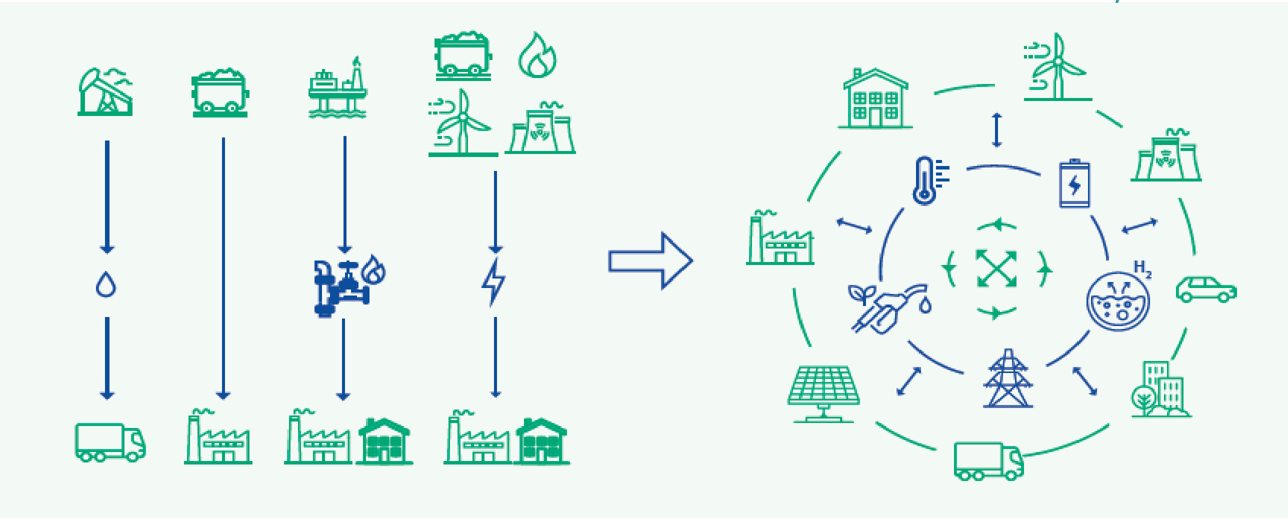
Towards a future energy system: dot on the horizon

The future energy system: dynamic and complex

The energy system today: linear and wasteful flow of energy, in one direction only

The future integrated energy system: energy flows between user and producers, reducing wasted resources and money



- A more **efficient and decentralized system**, where waste energy is captured and re-used
- A **cleaner power system**, with more direct electrification of end-use sectors such as industry, heating of buildings and transport
- A cleaner fuel system, for hard-to-electrify sectors such as heavy industry or transport (aviation and marine)

https://ec.europa.eu/commission/presscorner/detail/en/FS_20_1295

Speeding up technology development by granularity

C Wilson *et al.*, Science **368**, 6486 (2020)

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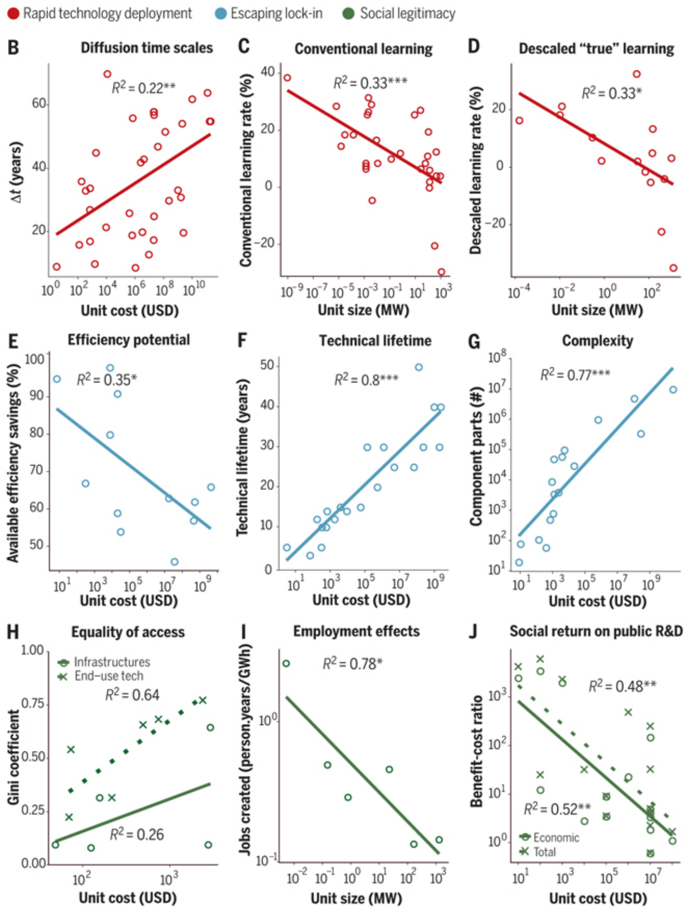
The role of granularity

Benefits of modular technologies:

- Rapid market penetration, steep learning curves
- More efficient, less complex, less risk of lock-in
- Broader accessible, more jobs per installed capacity, higher social return on public R&D

→ Our USP – modular scaling is Brainport DNA



C Wilson *et al.*, Science **368**, 6486 (2020)

The role of gra

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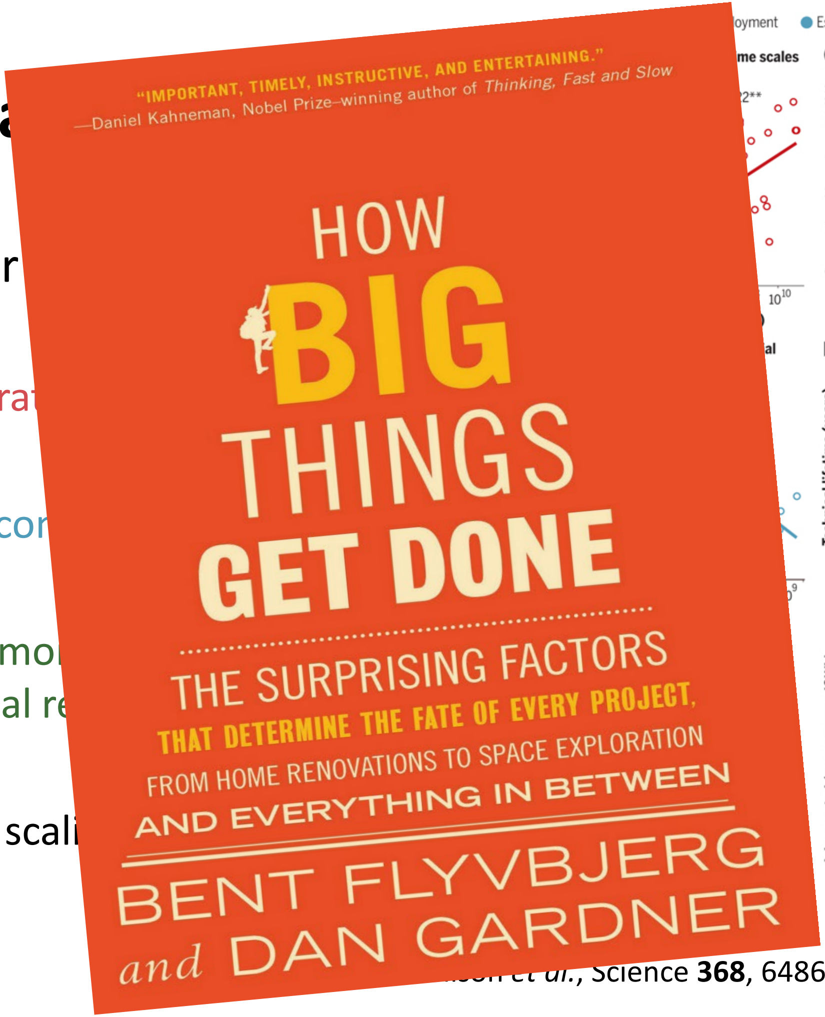
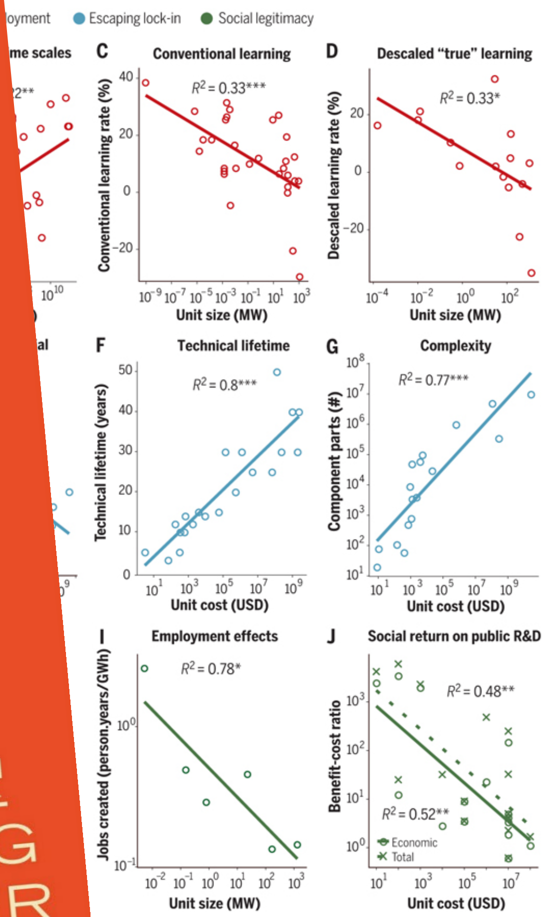
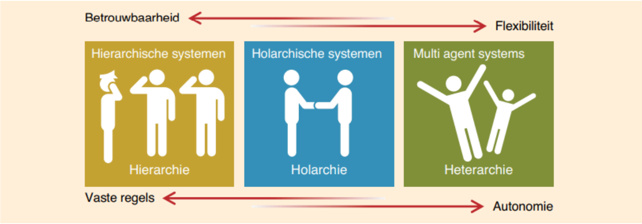
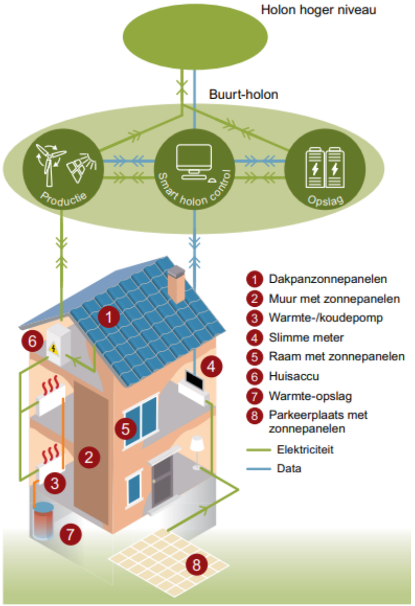


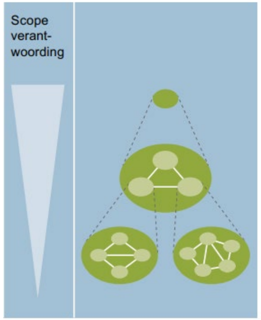


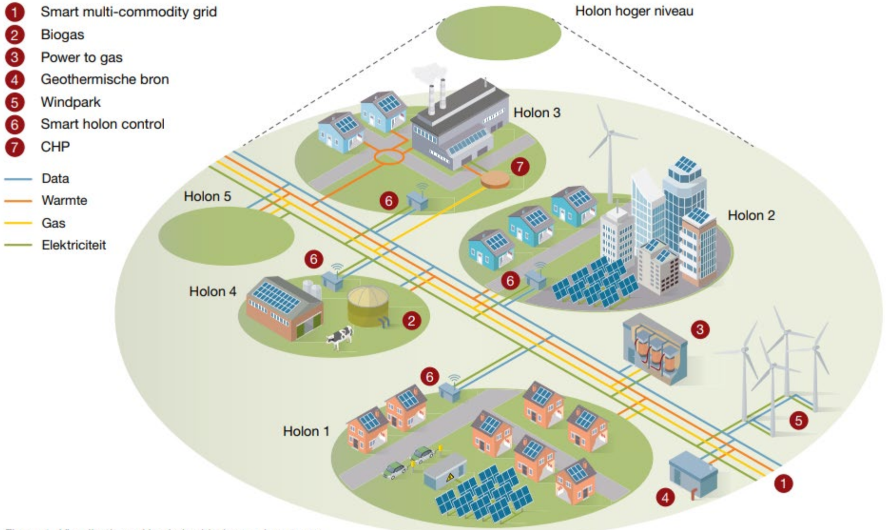
al., Science **368**, 6486 (2020)

Organizing our future energy system in a granular way









Figuur 4. Visualisatie werking holarchisch energiesysteem.

Topsector Energie, Systeemintegratie

EIRES: renewable energy research at TU/e

EIRES

Origin

- Opened 31/08/2020 by Secretary of State I&W
- Signing of MoU with VDL

Tasks

- Bring together TU/e researchers from various disciplines and departments on *renewable energy systems*
- Forster excellence in (team) research on the Energy Transition with the aim to accelerate it
- Develop challenge-based programs – both bottom & top down, in strong connection with industry and society

EIRES EINDHOVEN INSTITUTE FOR RENEWABLE ENERGY SYSTEMS TU/e

Key numbers

Semi virtual

140 researchers + 400 PhD students

EIRES building on campus for collaboration & meetings

Incubator for student teams & startups

M€ 2,5/y funding by TU/e

Talent, infrastructure, seed money

Total contract value of ~M€ 35/y

>2 startups per year

Some startup successes last year

- Carbyon winner of XPRIZE milestone award
- RIFT selected as Breakthrough Energy Fellow
- Cellcius received Breakthrough Energy Explorer Grant

Organization of EIRES

Organization via four focus areas:

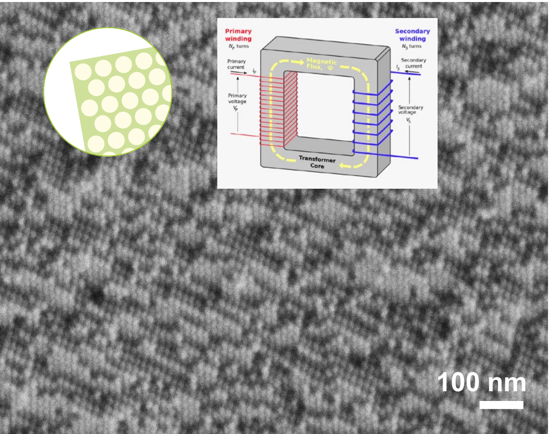
- Proven scientific excellence
- Unique research infrastructure
- Iconic projects with societal partners

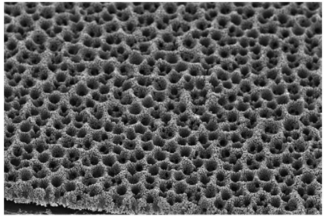
Energy Generation & Storage	Greening the Process Industry	Energy Transition in the Built Environment	System Transition & Scenarios

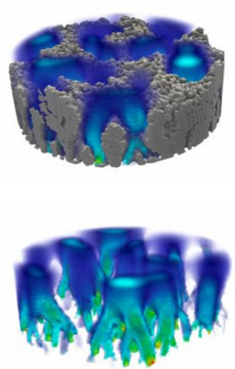
Energy Generation & Storage

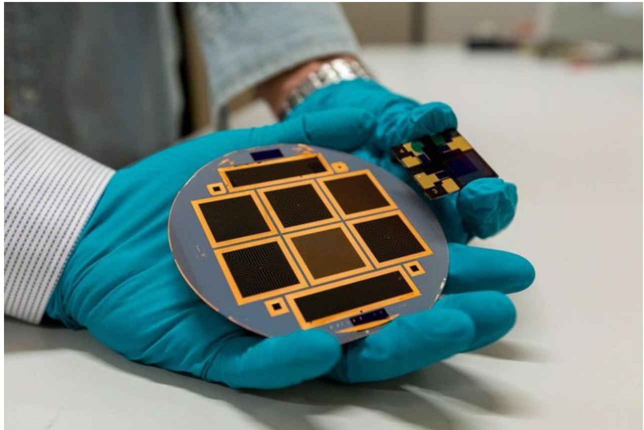
- Focus on materials and interfaces for energy generation, conversion, and storage
- Examples: PV, batteries, metal fuels, fuel cells, fusion
- Typical partners:

DENS Dutch Energy Solutions, LeydenJar Energising Technologies, TNO innovation for life, veco, Solliance Solar Research, vonk, LionVolt, [cellcius], ZIGZAGSOLAR, solarge, nyrstar, DEMCON, elestor, Battery Competence Center




500 µm

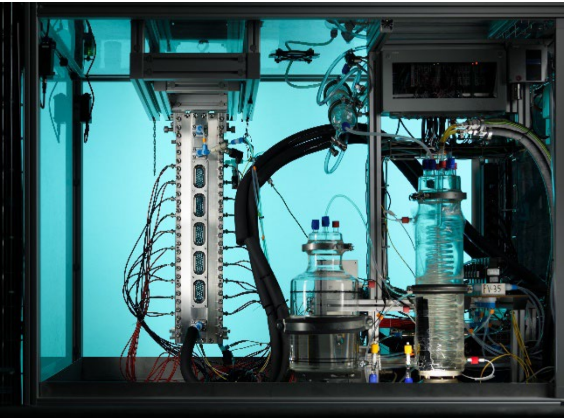




Greening the Process Industry

- Focus on processes for energy conversion
- Examples: (electro)catalysis, electrification of industrial heat, small-scale chemical reactors
- Typical partners:

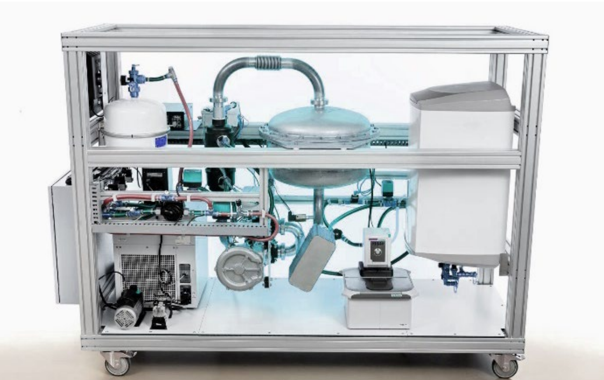
Shell, TNO innovation for life, VDL, metalot, Institute for Sustainable Process Technology, Nouryon, carbyon Closing the CO_2 cycle., DIFFER, syngaschem BV synthesis gas chemistry fundamental research projects, TEAM SOLID, FLOWID



Energy Transition in the Built Environment

- Focus on devices and systems needed for the energy transition in the built environment
- Examples: district heat networks, heat pumps, insulation & renovation, net congestion
- Typical partners:

heijmans
BOUW & TECHNIEK
Q box
Witteveen + Bos
STEDIN.NET
alliander
TRUDO
ENEXIS
ENERGIE IN GOEDE BANEN
EINDHOVEN
Provincie Noord-Brabant
wooninc.
ennatuurlijk



System Transition & Scenarios

- Focus on system-of-systems modelling of our future energy system
- Examples: dynamic models, digital twins, transition scenarios, just transition
- Typical partners:

TOPSECTOR ENERGIE
Innovatie voor een duurzame toekomst

alliander

OVER MORGEN

DNV

ZEnMo simulations

TIBO energy

Fontys

SUMMA College

Provincie Noord-Brabant

STEDIN.NET

ENEXIS
ENERGIE IN GOEDE BANEN

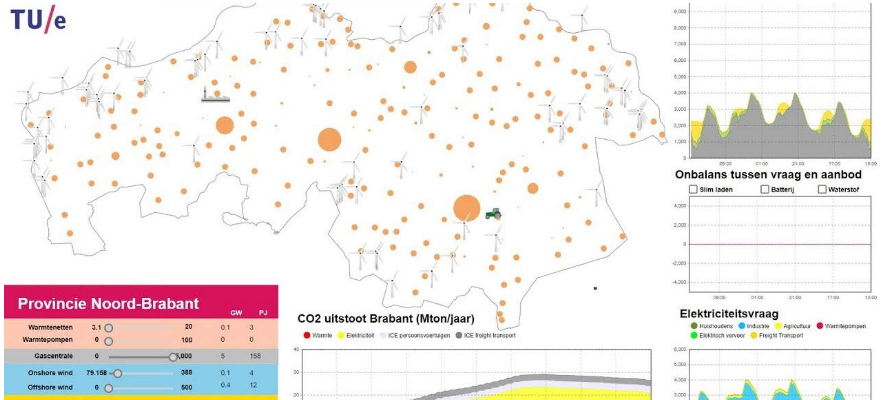
TenneT

RWE

avans hogeschool

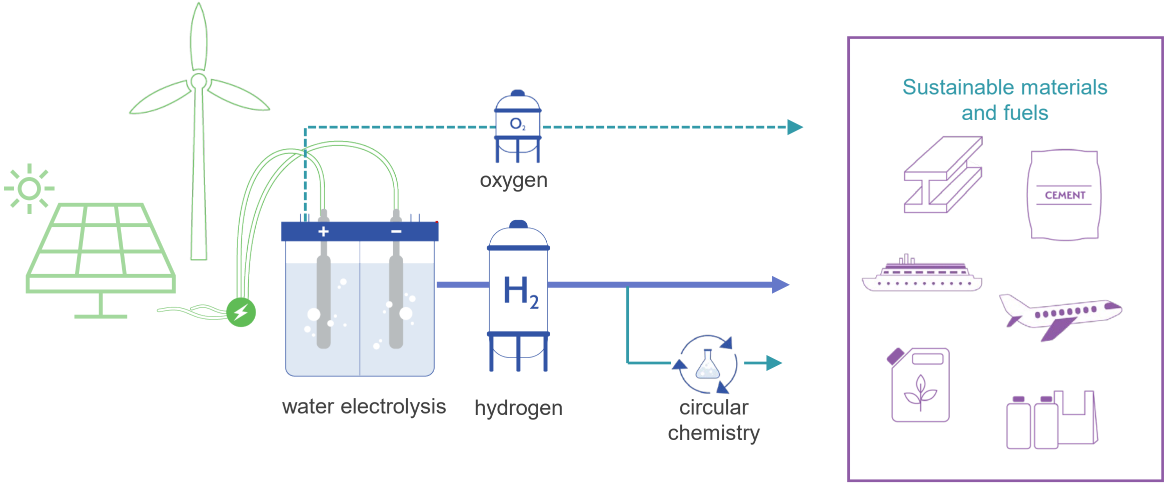
simpl.energy

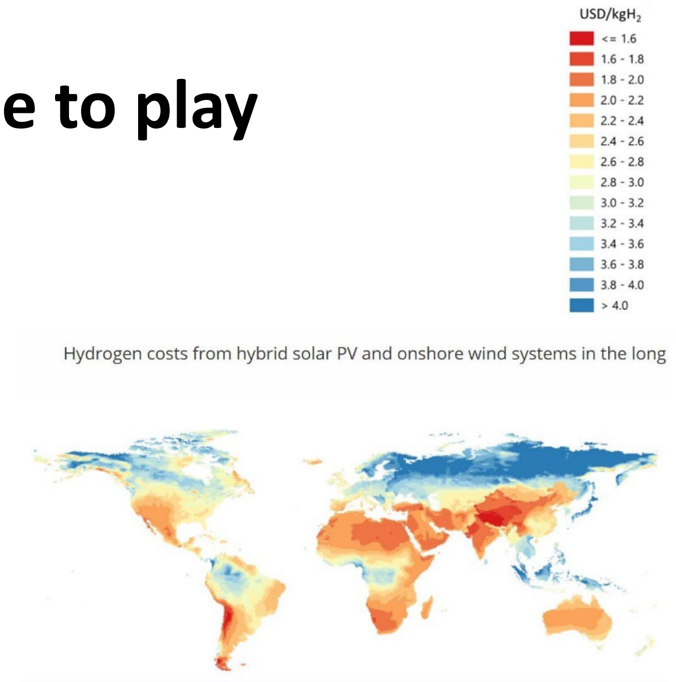
TU/e



Deep dive: Hydrogen

Green hydrogen has an important role to play





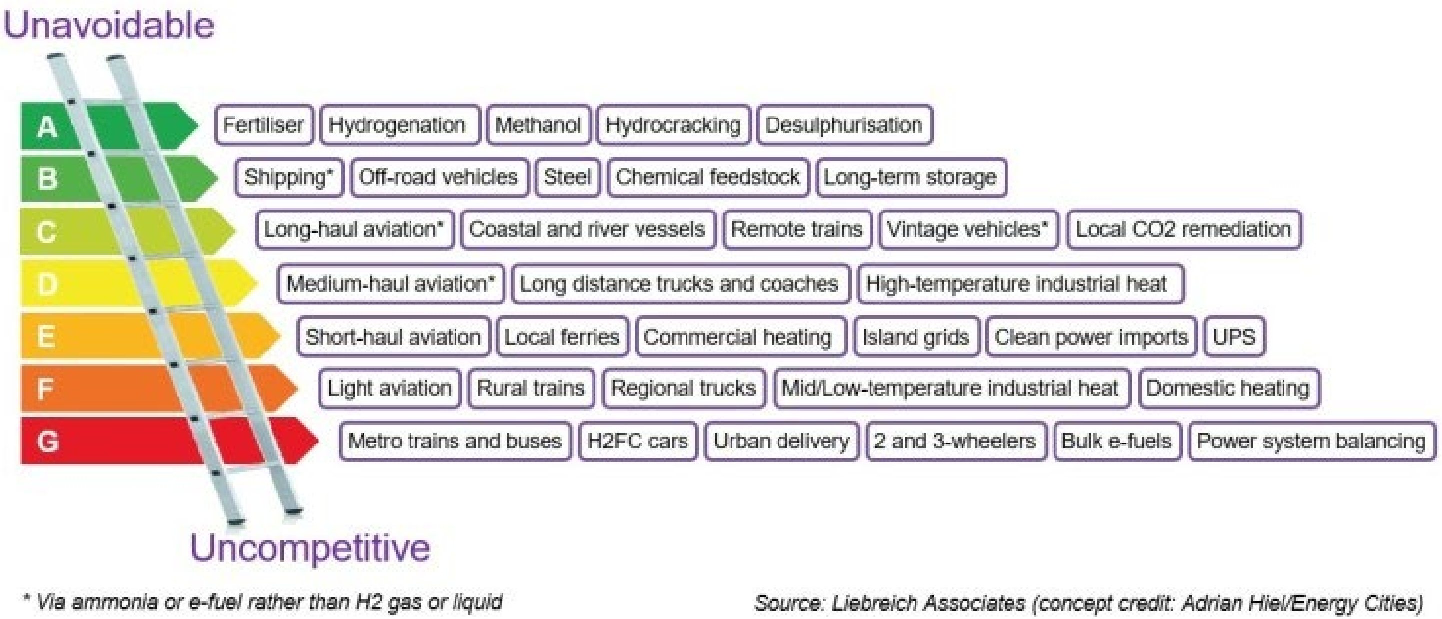
→ Storage, conversion and transport of RE is key: H_2 in most cases first step

→ Boundary conditions: the availability of green electricity & electrolyzer development

Electrolyzers development: current status

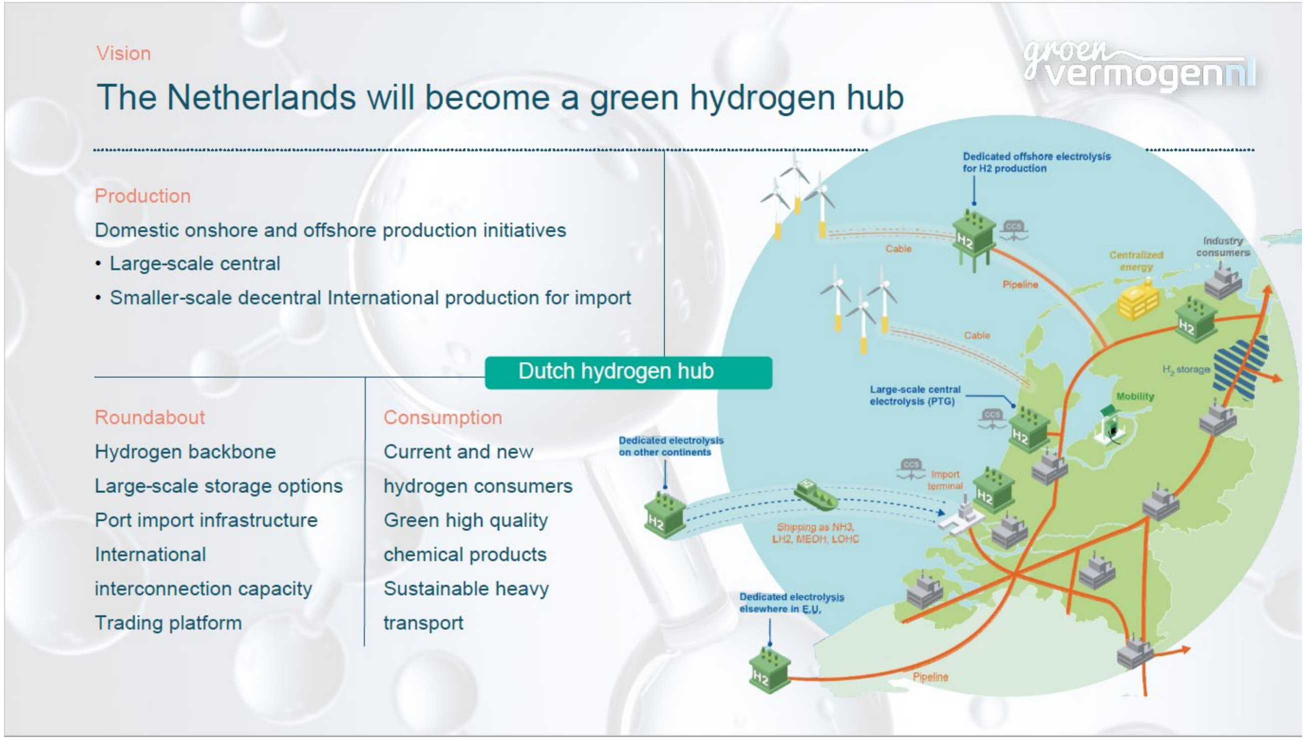
	Alkaline	PEM	Solid oxide	AEM
				
Stack size (MW)	1 – 6	0.5 – 2.5	0.01	0.0025
Largest operational factory (MW)	150 Ningxia (China)	20 Bécancour (Canada)	0.72 Salzgitter (Duitsland)	0.02 Rozenburg (Netherlands)
# suppliers	9	4	2	1
Strengths	Cheap material and proven technology	Compact and flexible	Efficient	Combines strengths of Alkaline and PEM
Weaknesses	Less efficient (<70%)	Requires Iridium	Thermo-mechanical challenging	Early phase

Thus, H2 usage needs to be prioritized



→ Chemical reagent >> long-distance transport >> local fuels/short term use

The Netherlands is taking a frontrunner role on H2



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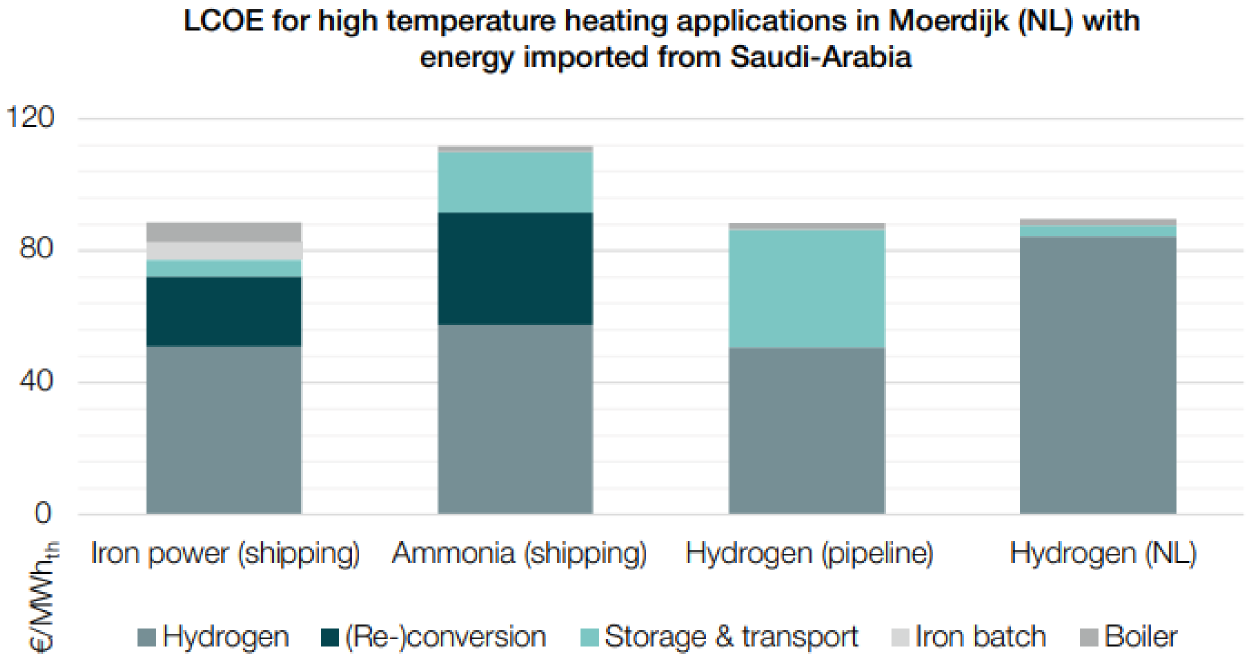
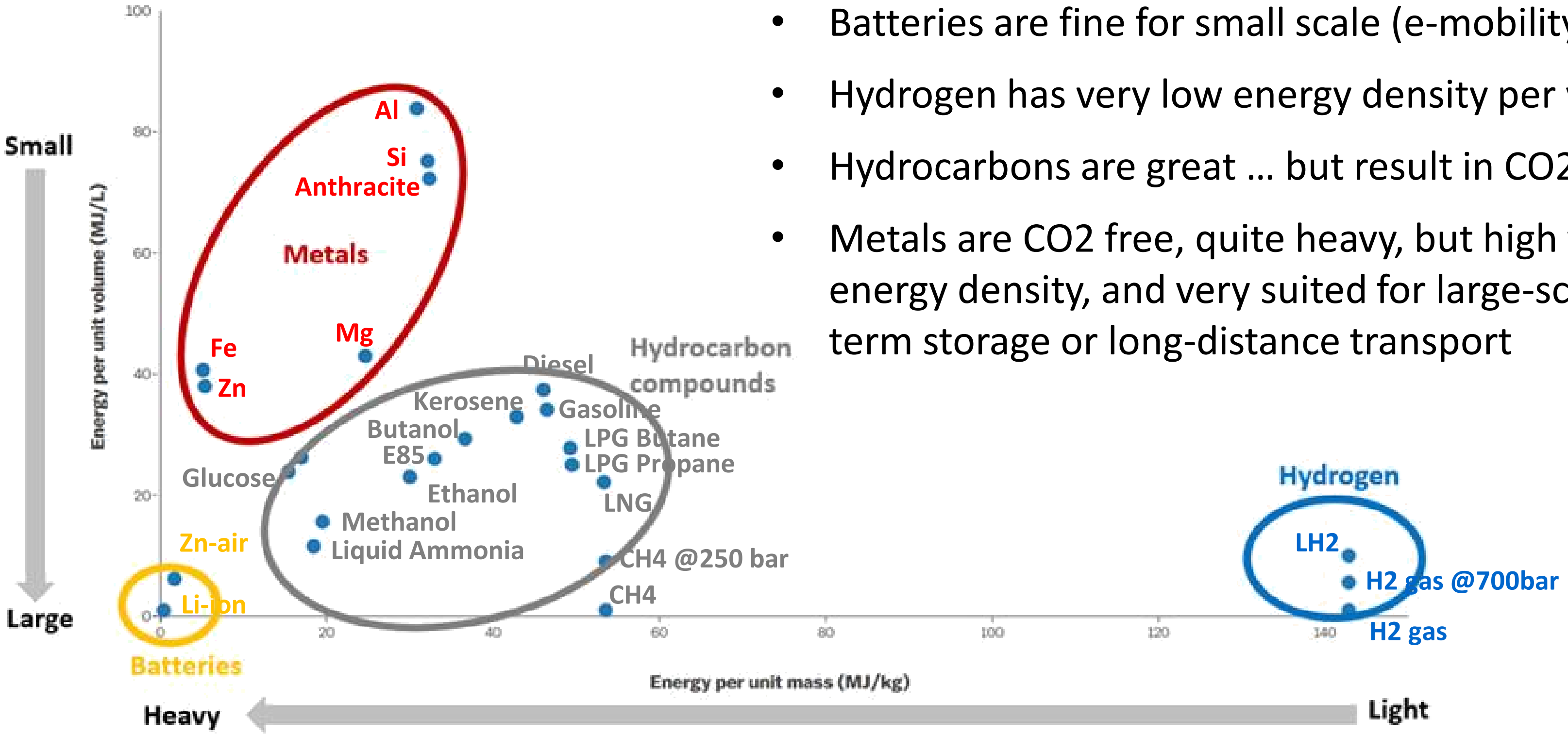
But whether H_2 will be a long-distance energy *carrier* is still to be decided



Vision document Iron Power ecosystem, courtesy metalot

Deep dive: Metal fuels

The quest for the ideal energy carrier/storage medium



- Batteries are fine for small scale (e-mobility)
- Hydrogen has very low energy density per volume
- Hydrocarbons are great … but result in CO_2 emissions
- Metals are CO_2 free, quite heavy, but high volumetric energy density, and very suited for large-scale long-term storage or long-distance transport

Courtesy: Philip de Goey

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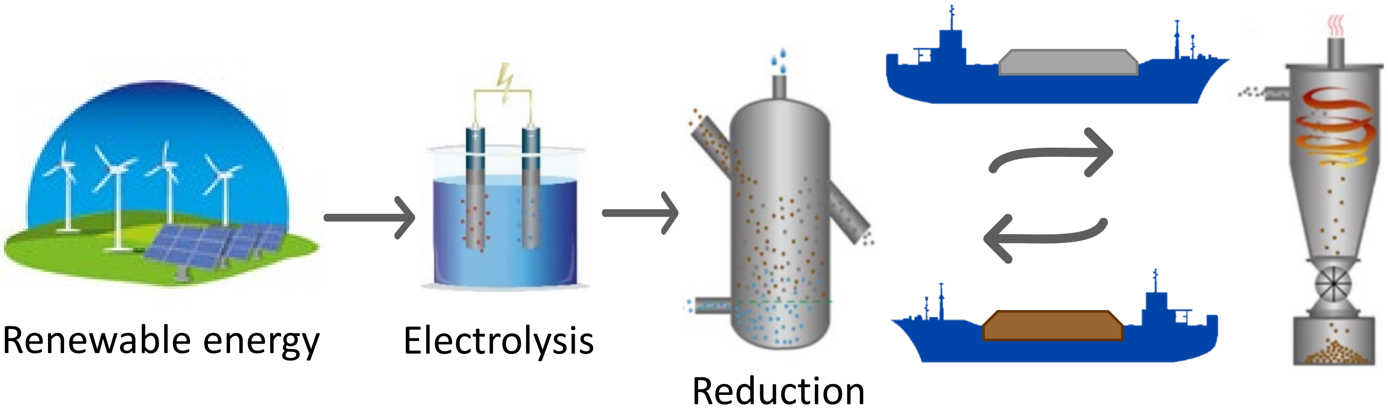
Focus on Iron Fuel

- Iron has temperature & time scales similar to fossil fuels
- Potential for retrofitting solid fuel systems like coal fired power plants

Methane	Iron	Aluminum	Boron + Al	Zirconium
1963 °C	1955 °C	3268 °C	2587 °C	3587 °C

Courtesy: Philip de Goey

Iron fuel as energy carrier for high T process heat

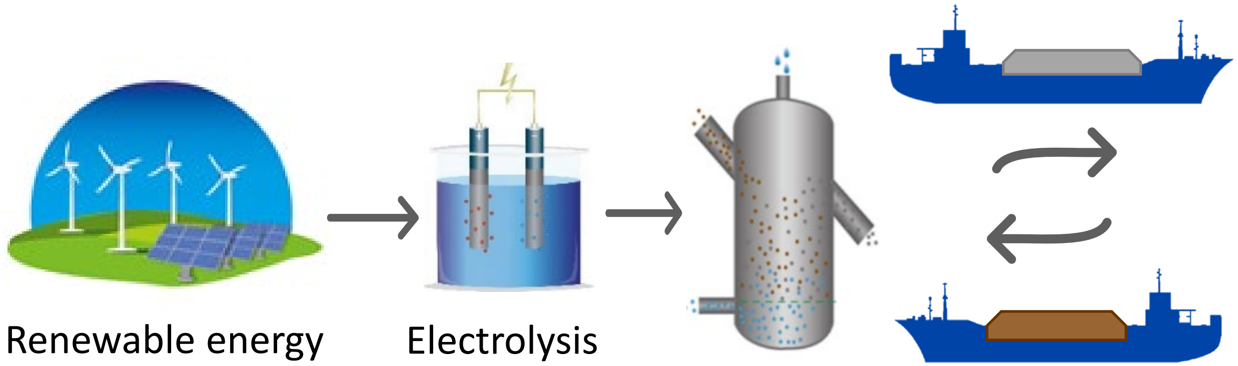


$$Fe_2O_3 + 3\ H_2 \rightarrow 2\ Fe + 3\ H_2O$$

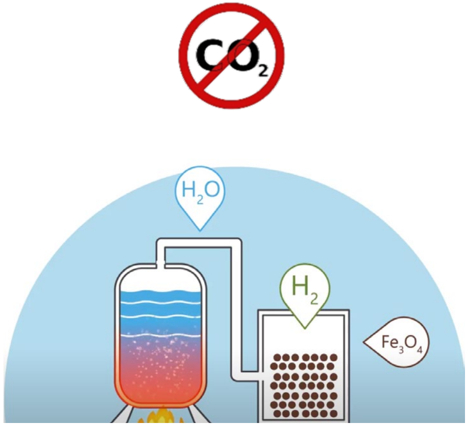
$$4\ Fe + 3\ O_2 \rightarrow 2\ Fe_2O_3$$

Courtesy: Philip de Goey

Iron fuel as energy carrier for on site H2 production



$$Fe_2O_3 + 3\ H_2 \rightarrow 2\ Fe + 3\ H_2O$$



Iron-based hydrogen storage (IRHYS)

$$3\ Fe + 4\ H_2O \rightarrow Fe_3O_4 + 4\ H_2$$

Courtesy: TEAM SOLID

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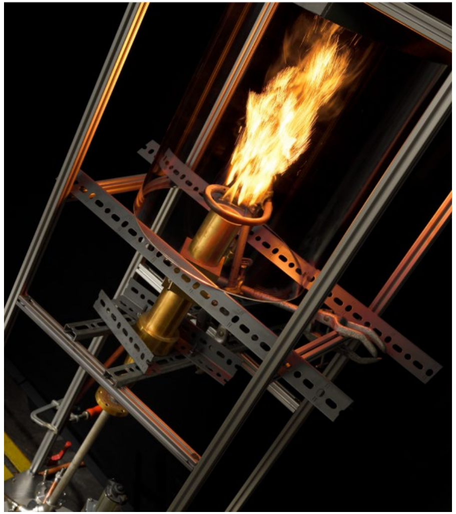
Status of the technology: combustion

- Demonstrations at 100 kW scale at Bavaria, at 200 kW scale in Metalot, at 1 MW scale in Helmond at Ennatuurlijk



Courtesy: Philip de Goey, Metalot, Krols Media, RIFT

Status of the technology: reduction

- Regeneration in fluidized bed and rotating drum setups up till 50 kW scale

Courtesy: Philip de Goey, Metalot, RIFT

metalot

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Status of the technology: IRHYS

- Proof of concept, storage up to 1 kg H_2 (eq to 33 kWh energy)

Courtesy: TEAM SOLID

Photo: Bart van Overbeeke Photography

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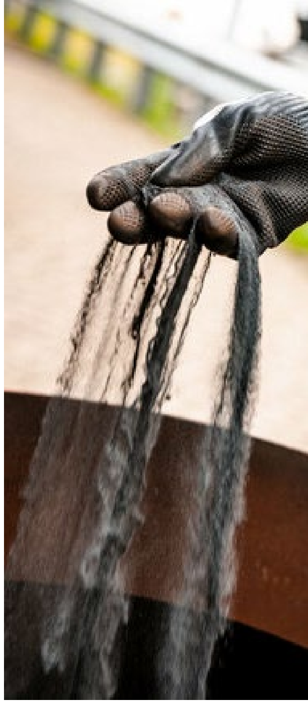
Key challenges in moving forward

- Hydrogen price for regeneration (!)
- Combustion technology: recovery rate and conversion efficiency
- Reduction technology: conversion efficiency and throughput (from batch to continuous processes)
- IRHYS: technology development in general, early stage
- Iron fuel itself: powder quality over multiple oxidation/reduction stages
- Market penetration: development of ecosystems, interdependence oxidation & reduction demand, transport infrastructure



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Deep dive: Heat

Heat – *the* ET challenge in the built environment

- Heat demand in the built environment is responsible for >50% of direct gas use in NL.

- Geothermal heat as potential solution is not new: was used in Roman times (Aquae Sulis → Bath, UK). And since last century for power as well.

Roman baths in Bath, Sommerset.
Photo by David Iliff

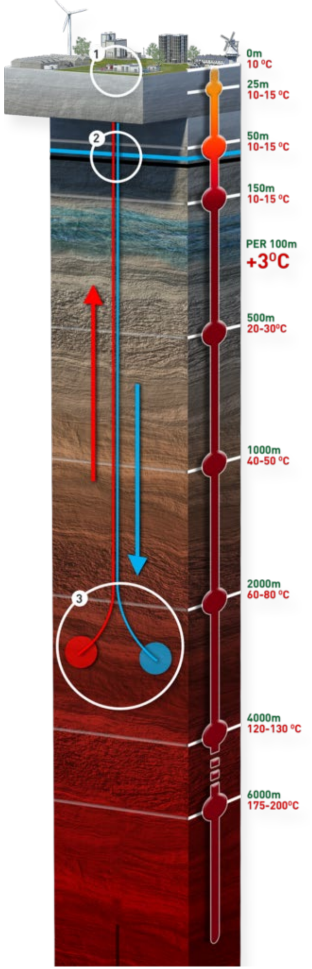
The Imperial Valley Geothermal Project near the Salton Sea, California.
Photo by Jack Catalano

Potential and challenges of geothermal energy

- Potential of geothermal energy is to supply ~25% of NL heat demand and ~50% of heat demand of our greenhouses.

- With the current net congestion and public ban of biomass many RES regions are looking towards geothermal as a potential heating source.

- However, there are challenges related to
  - Economics: high capex, difficult to fund survey and equipment, failure rate
  - Sustainability: risk of depletion, emissions of CO_2, H_2S, CH_4, NH_3
  - Seismic activity: next to (limited) real risks also risks in public perception



Courtesy of www.geothermie.nl

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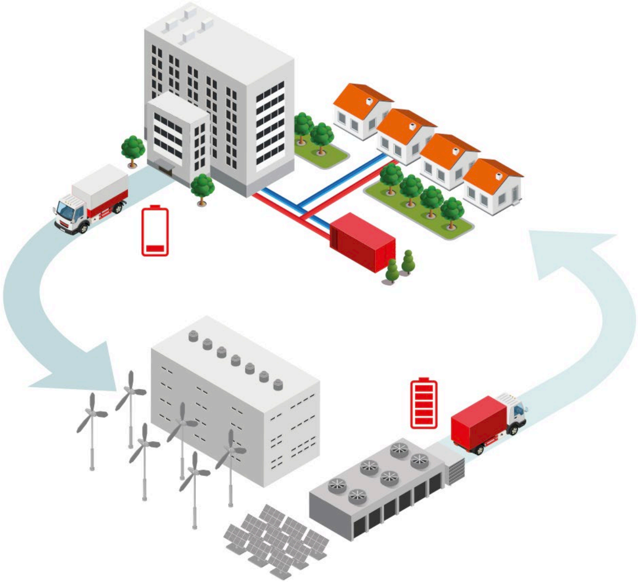
Potential and challenges of using waste heat

- At the same time we cool away 125 PJ industrial waste heat of >100 ^{o}C (eq. 4 Gm^3 NG, or heating for >3 million houses).
- But feeding in waste heat in district heat networks requires large infrastructural investments, and security of supply may be an issue in this transition.
- Unless you can provide heat-as-a-service (HaaS)…



Courtesy of [cellcius]

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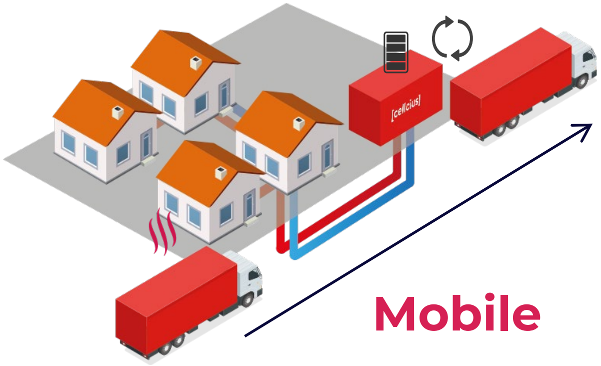
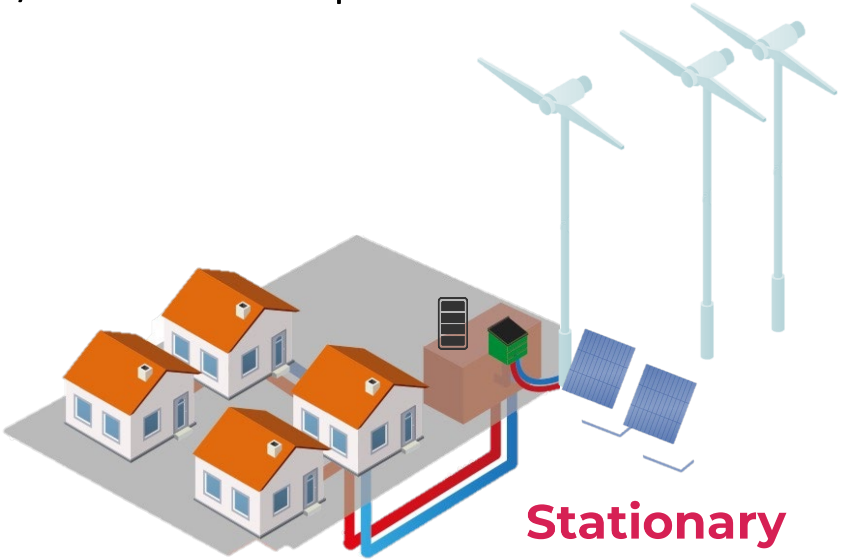
Requirements for HaaS

- Low cost solution: heat is a commodity
- High energy density for small footprint and/or low-cost transport
- Low loss storage (during transport)

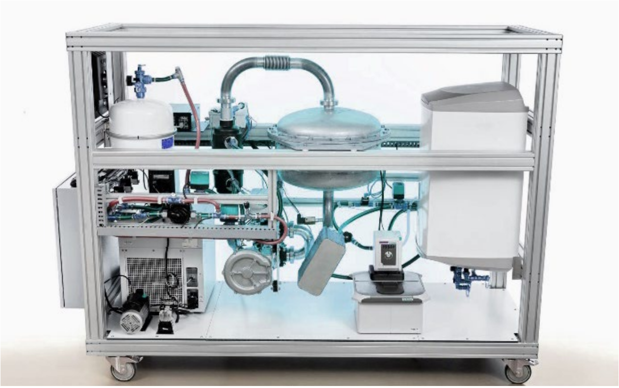


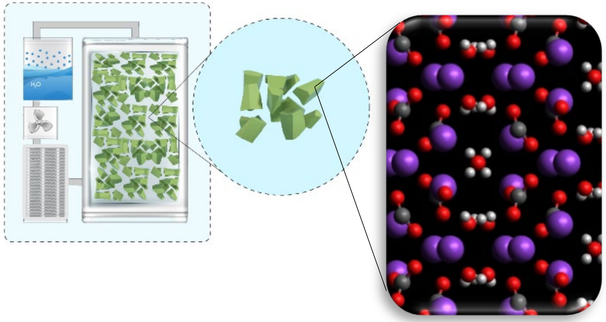


Courtesy of [cellcius]

Technology challenges

- Power – high capacity but low power
- Cyclic stability of the composite
- Upscaling industrial production





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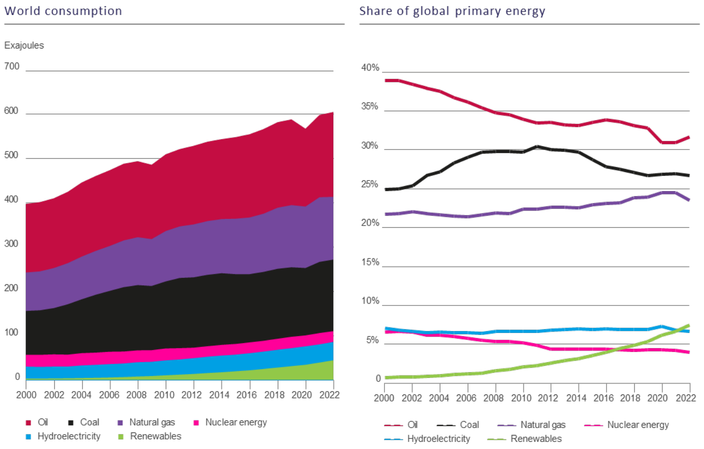
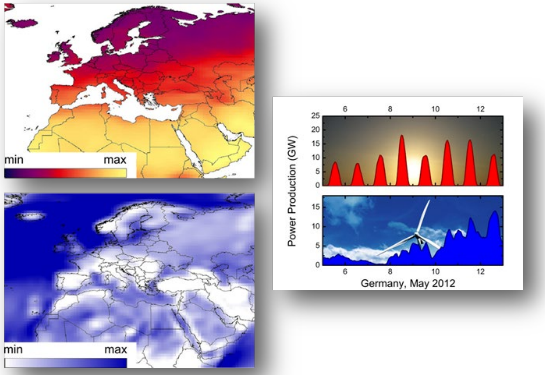
Wrap up & conclusions

Conclusion (1/4)

- Energy transition requires rapid acceleration and radical system change

- Key challenge is the transport, conversion, and storage of energy





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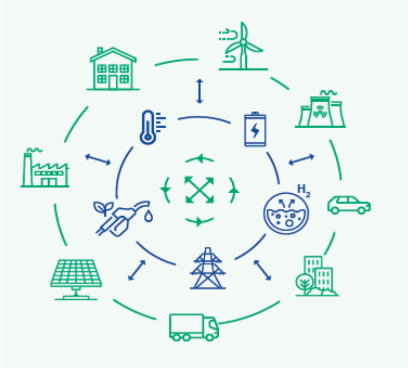
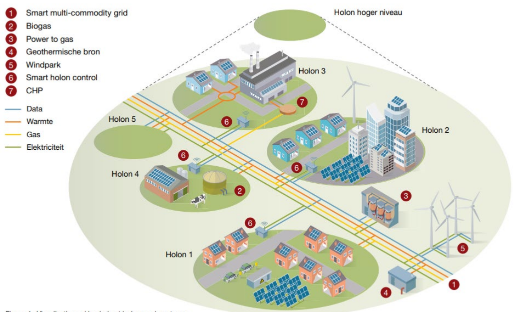
Conclusion (2/4)

- Modular scaling and a holarchic lay out of the energy system provide acceleration pathways
- EIRES organizes TU/e energy research on this philosophy and on key research strengths





Figuur 4. Visualisatie werking holarchisch energiesysteem.

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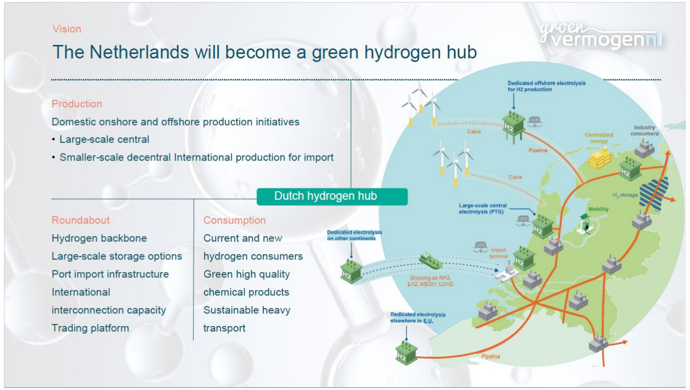
Conclusion (3/4)

- Hydrogen will play a large role in the transition, but will remain scarce in the foreseeable future
- Iron pow(d)er provides an interesting alternative route for long-duration storage and long-distance transport



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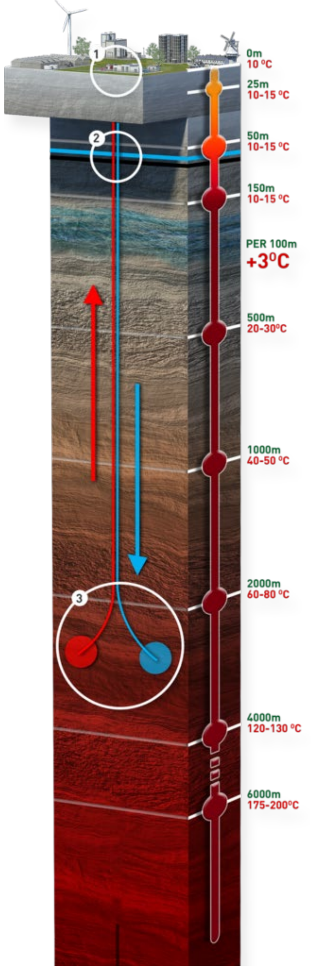
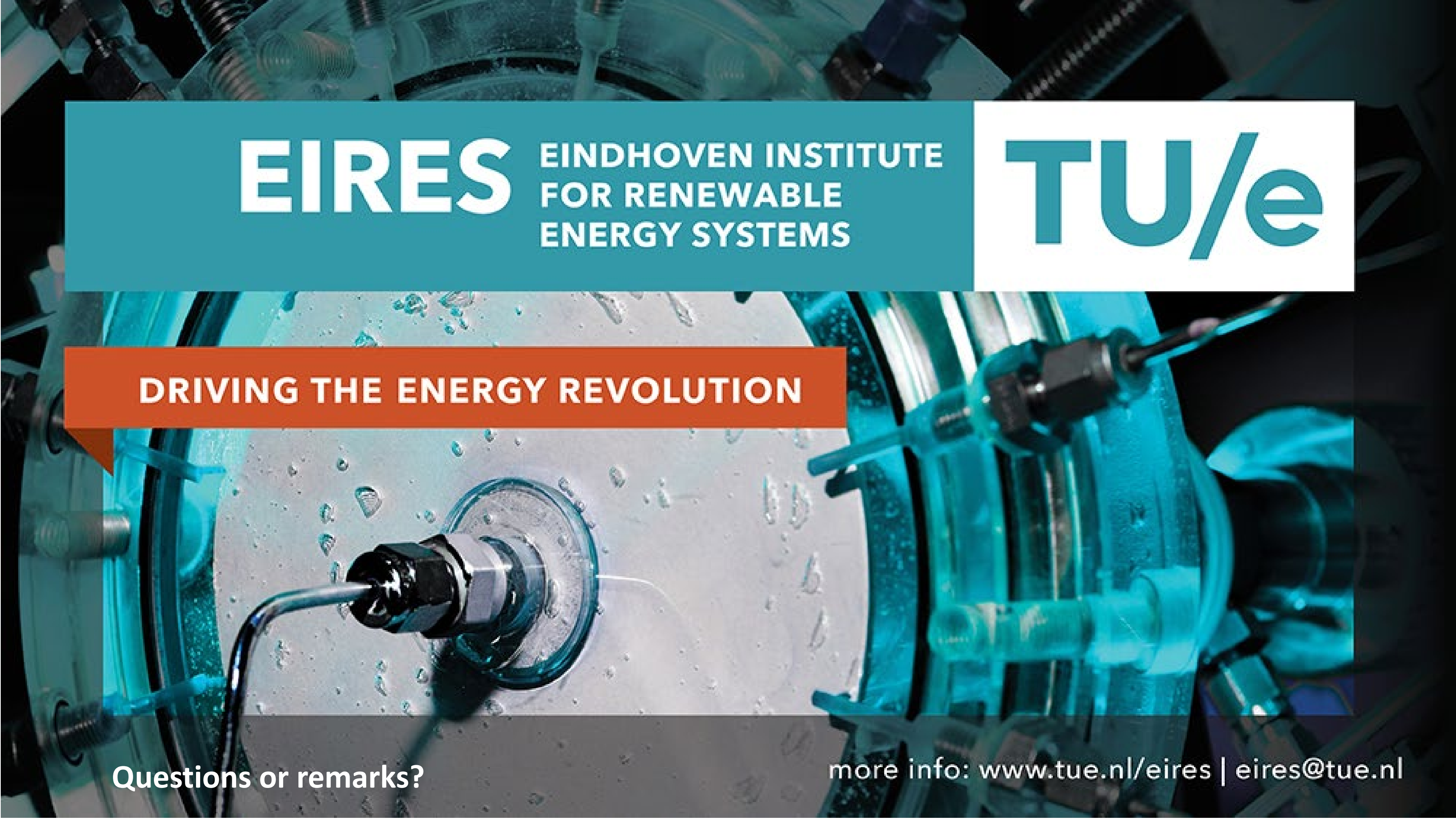
Conclusion (4/4)

- Heat has long been the overlooked factor in the ET but is gaining increasing attention

- Geothermal heat has a lot of potential given the net congestion problems and public ban on biomass

- Thermochemical heat storage is a promising new technology for heat-as-a-service





Questions or remarks?