September 19, 2014 – DTU, Kgs. Lyngby – Michael Weinhold & Jacob Østergaard

Energy Future and Impact of New Technologies

The Innovation Waves in Electricity Systems

3-phase generator from Siemens & Halske

Begin of electrification

~ 1830 – 1920

HVAC transmission lines

Synchronous AC Systems

1920 – 1950

HVDC with Power Electronics

Interconnected grids

1970

CCPP-efficiency >60%

Clean & efficient fossil age

2010

Wind turbine > 6 MW

Multiple Stakeholders

2012

Digitalization

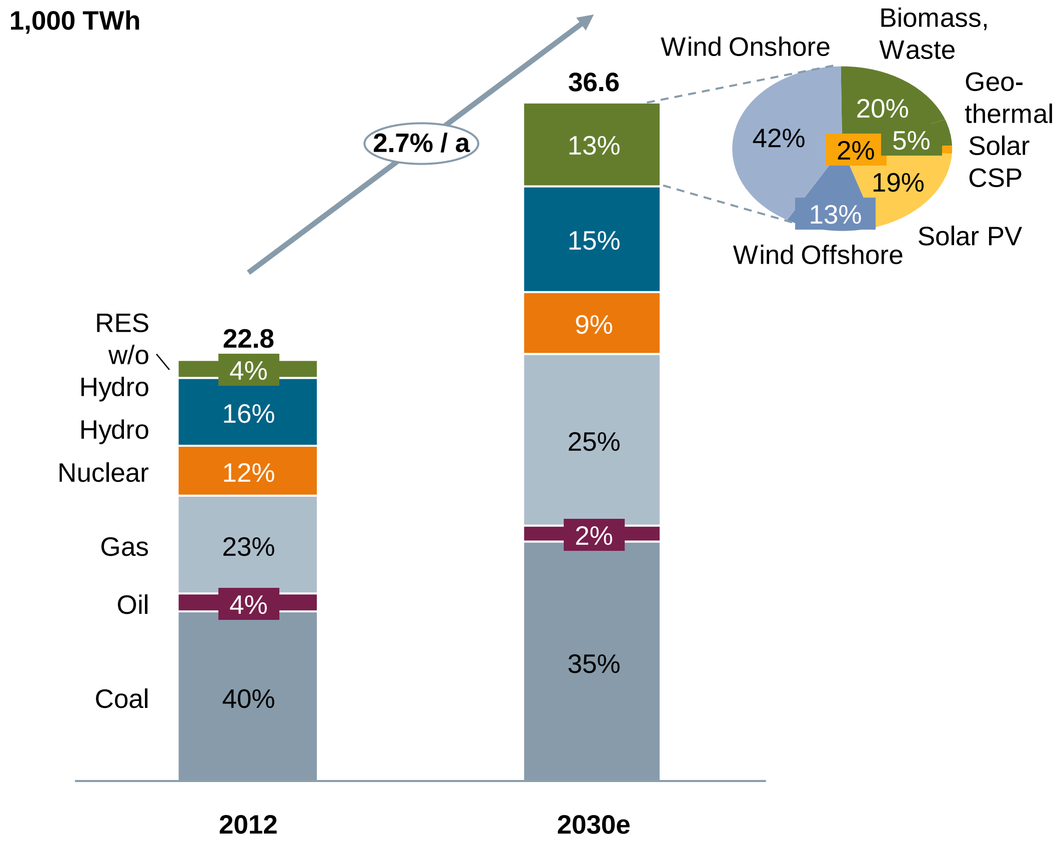
Energy Cells

2010 – 20xx

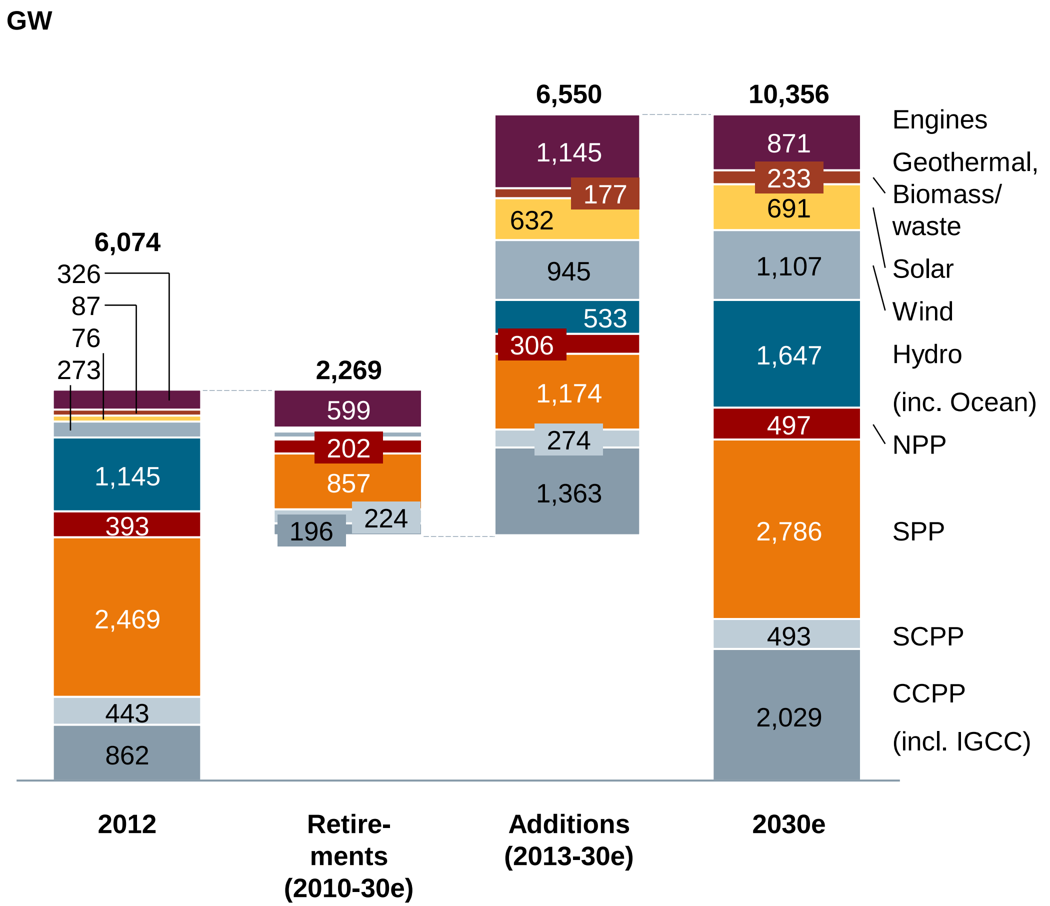
Power generation expected to grow 2.7% p.a., with more additions by 2030 than today's capacity

SIEMENS

World power generation

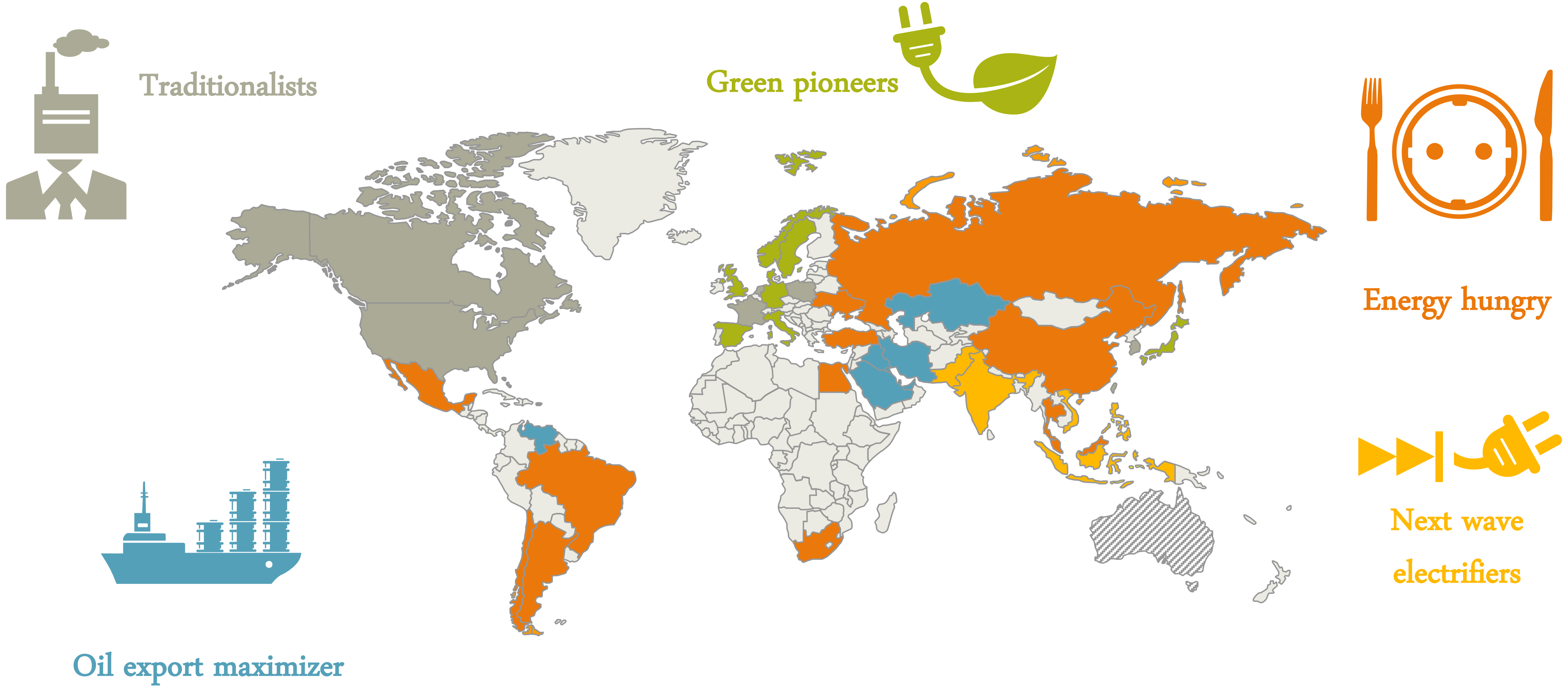


Installed world power plant capacity



Source: Siemens

Five archetypal energy developments

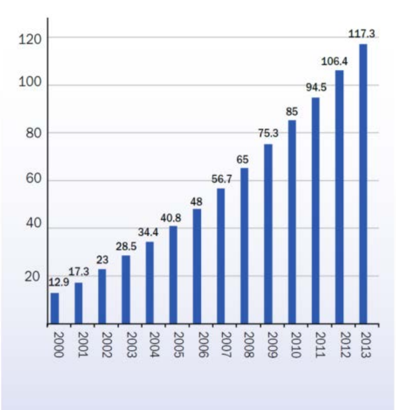


Transformation of the Energy System to a Renewable-based Infrastructure

EU "20-20-20" targets in 2020:

- 20% reduction in GHG emissions
- 20% renewable energy resources
- 20% improvement in energy efficiency

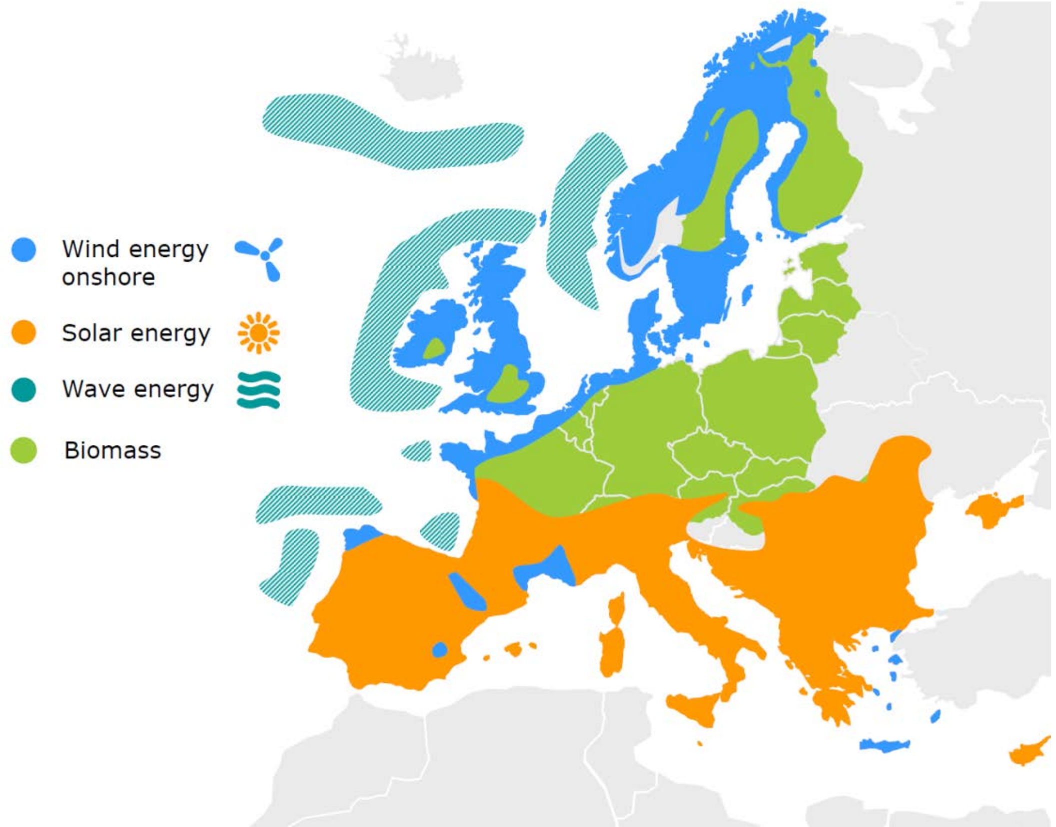
Cummulative wind power installations in the EU (GW)



Source: EWEA

PV generation in Germany

Source: re.jrc.ec.europa.eu/pvgis

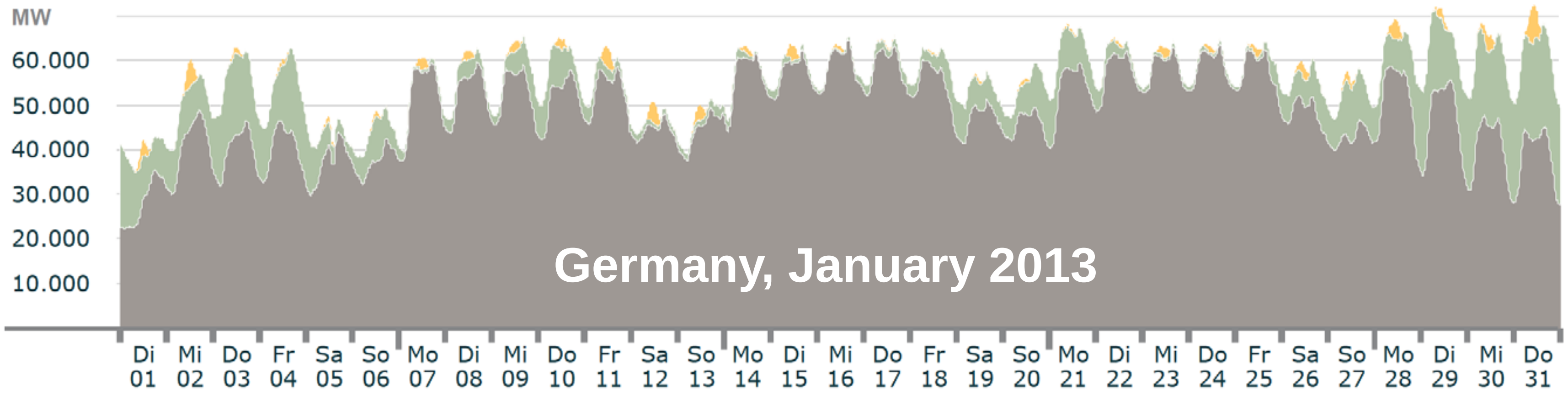


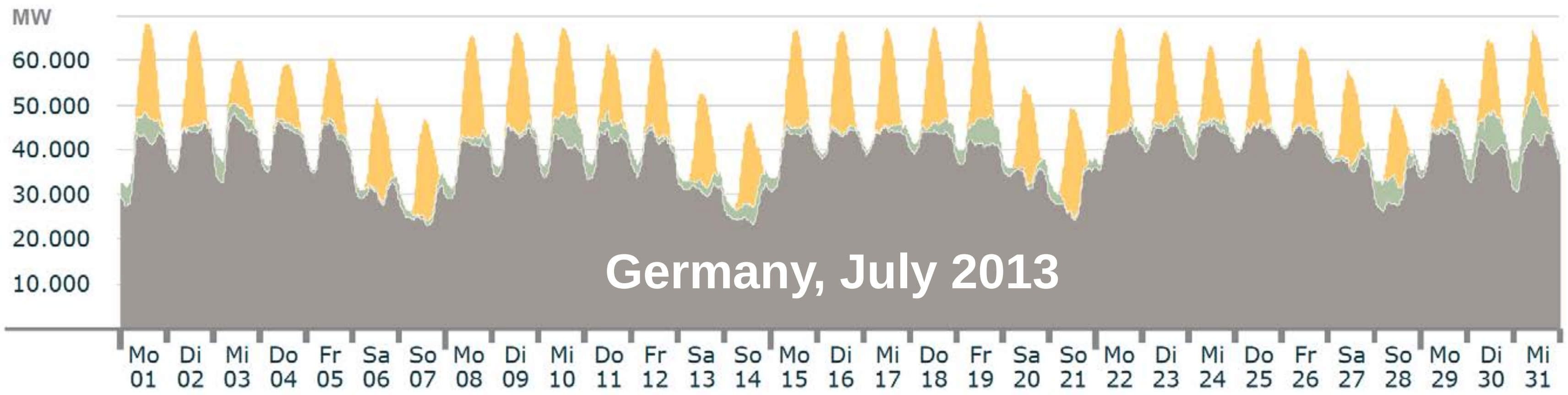
Source: The EU commission

Reliable power generation from wind and solar only on long-term average basis

Power generation capacity of wind, PV and conventional power plants 2014

>180GW





Source: http://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/stromproduktion-aus-solar-und-windenergie-2013.pdf

Wind Power Generation in Denmark

Year 2013

Danish wind power covered 33.2 % of the electricity consumption

January 2014

Danish wind power covered 63.3 % of the electricity consumption

December 21th 2014

Danish wind power covered 102 % of the electricity consumption

March 11th 2014

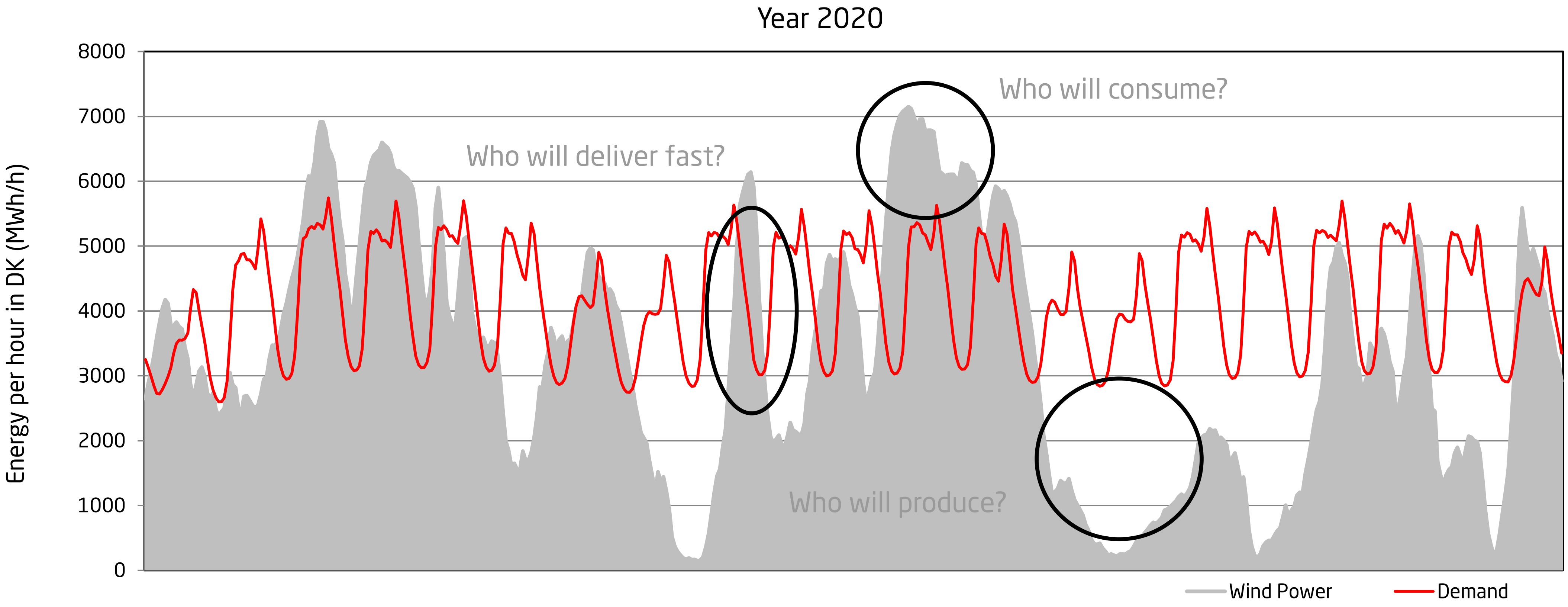
only 9 MW wind power generated out of installed 4,900 MW

but 480 MW out of 580 MW solar units supplied the grid

Source: Energinet.dk

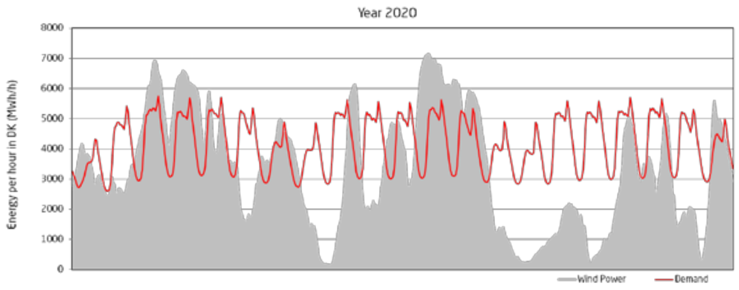
Challenge #1 of a RE-based Energy System

Energy and Power Balancing



Instruments to effectively integrate large amounts of fluctuating renewable energy in the power system

Increasing renewable generation



Instruments

Strong transmission grid and interconnections - and well functioning energy markets

+

Flexibility in production and consumption. Close integration with the heat, gas and transportation sector

+

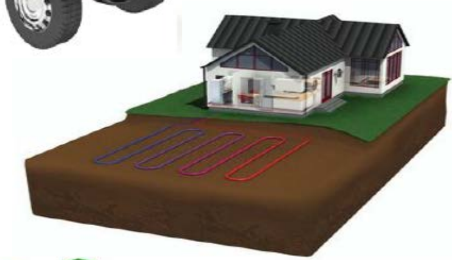
Smart Grid to implement intelligence in the power system

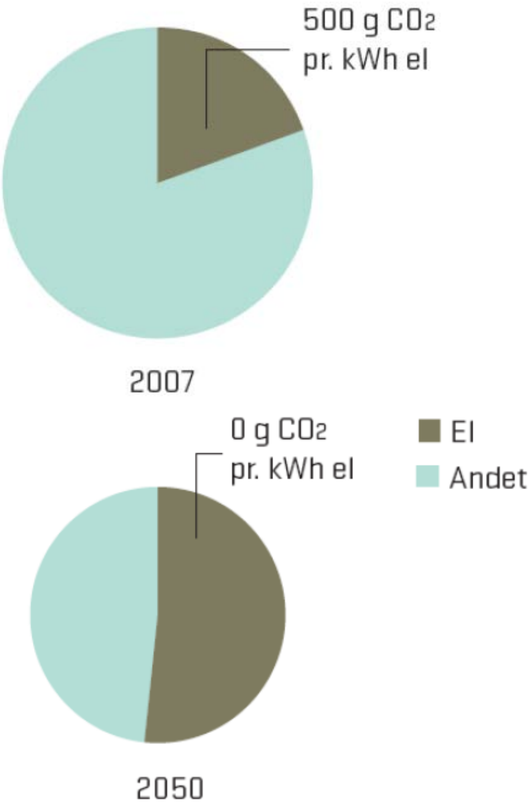
Source: Energinet.dk

The Future Energy System

Development of a reliable, cost-efficient and sustainable energy system based on renewable energy

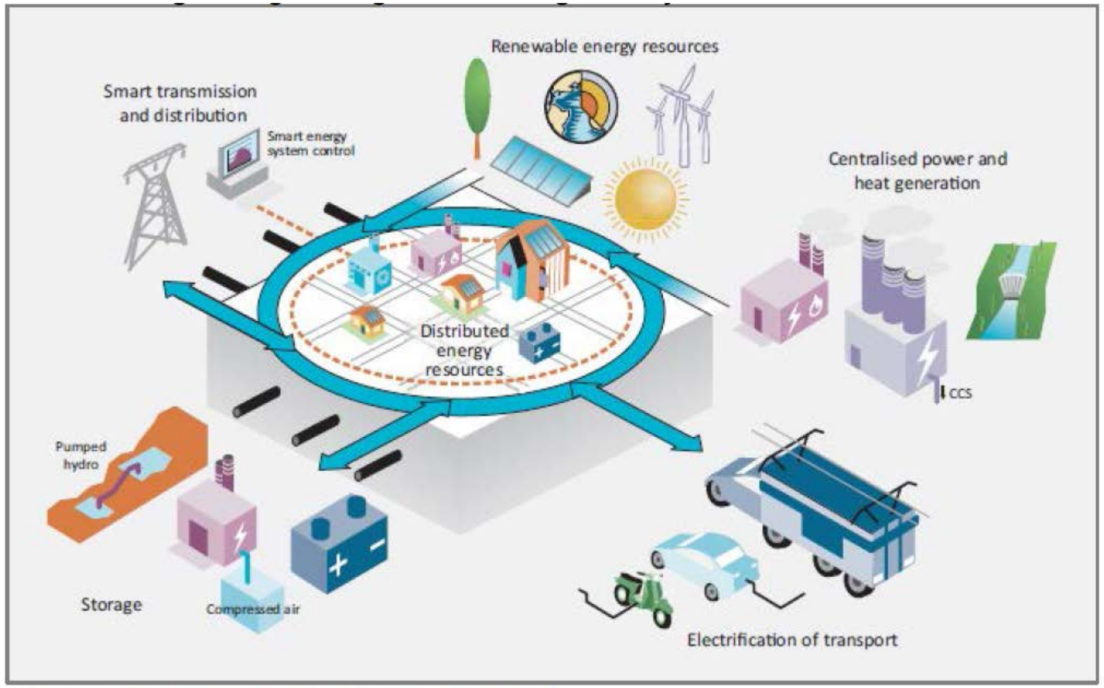
Electrification





Source: Dansk Energi

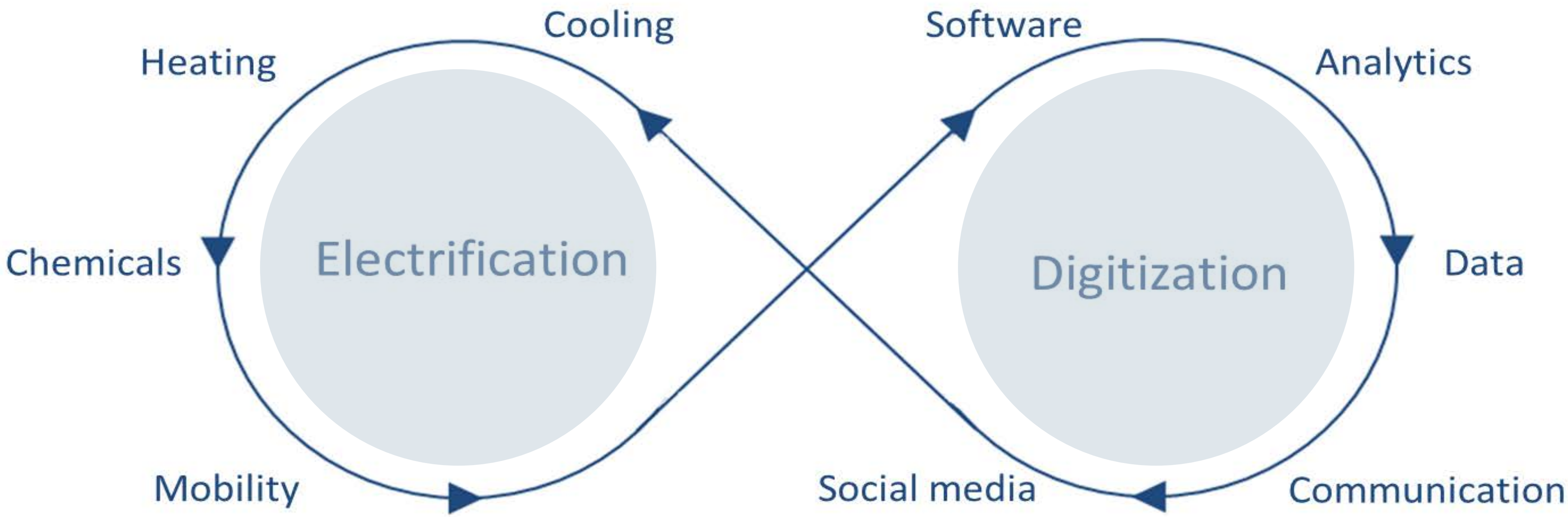
A more integrated and intelligent energy system



Kilde: IEAs scenario for 2050 (IEA – ETP 2014)

Two major trends aiding one another: Electrification & Digitization

SIEMENS

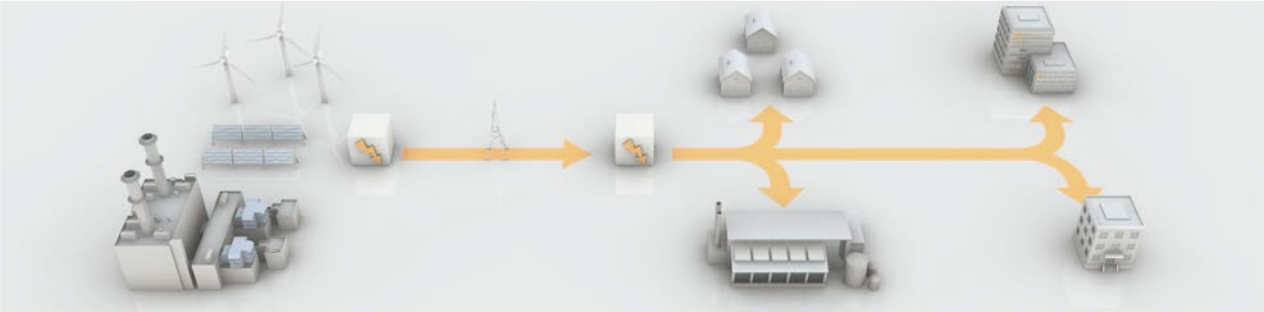


Requirements of the society:

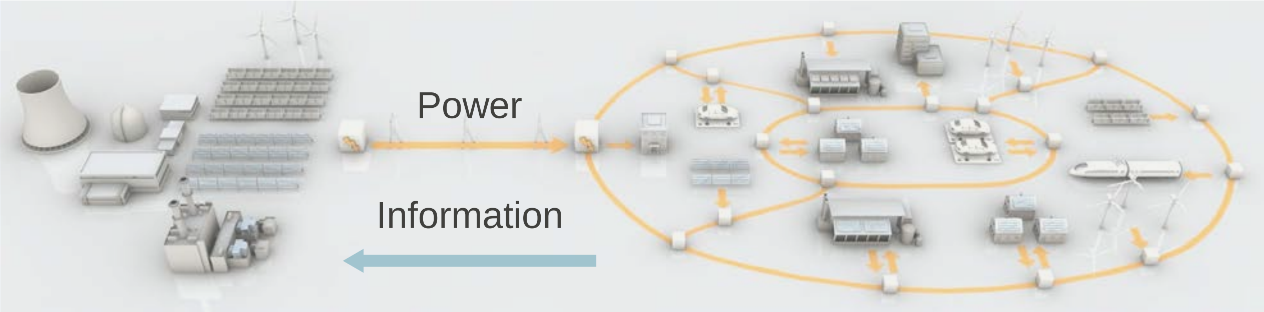
Climate Change – CO_2 reduction / Resource Efficiency / Affordability / Acceptance & CO_2-determination

Whereto?

Yesterday



Today

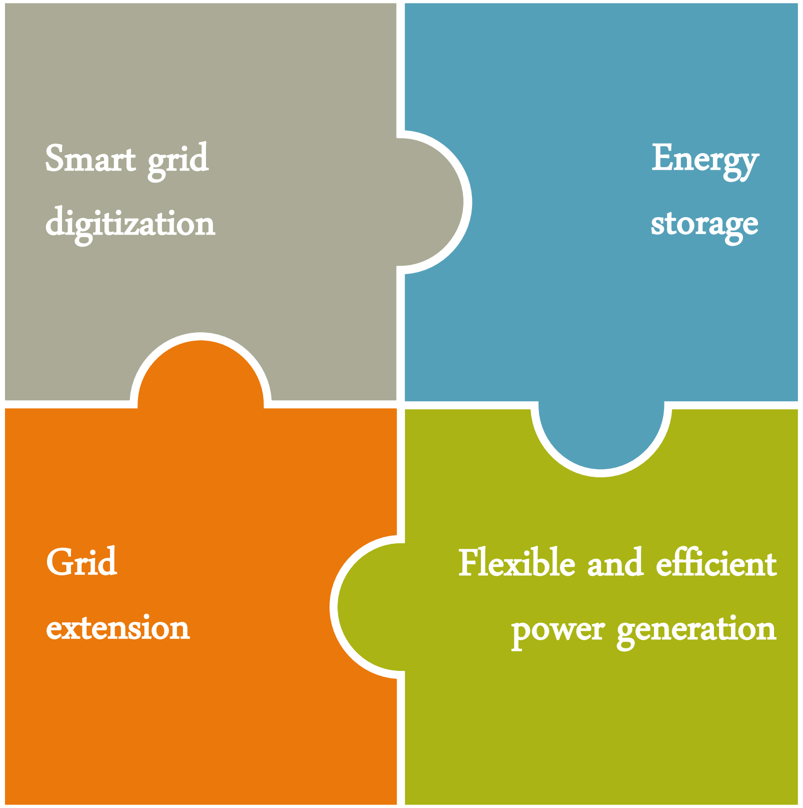


Tomorrow

Components and tasks for a future energy system

Managing increasingly complex energy systems

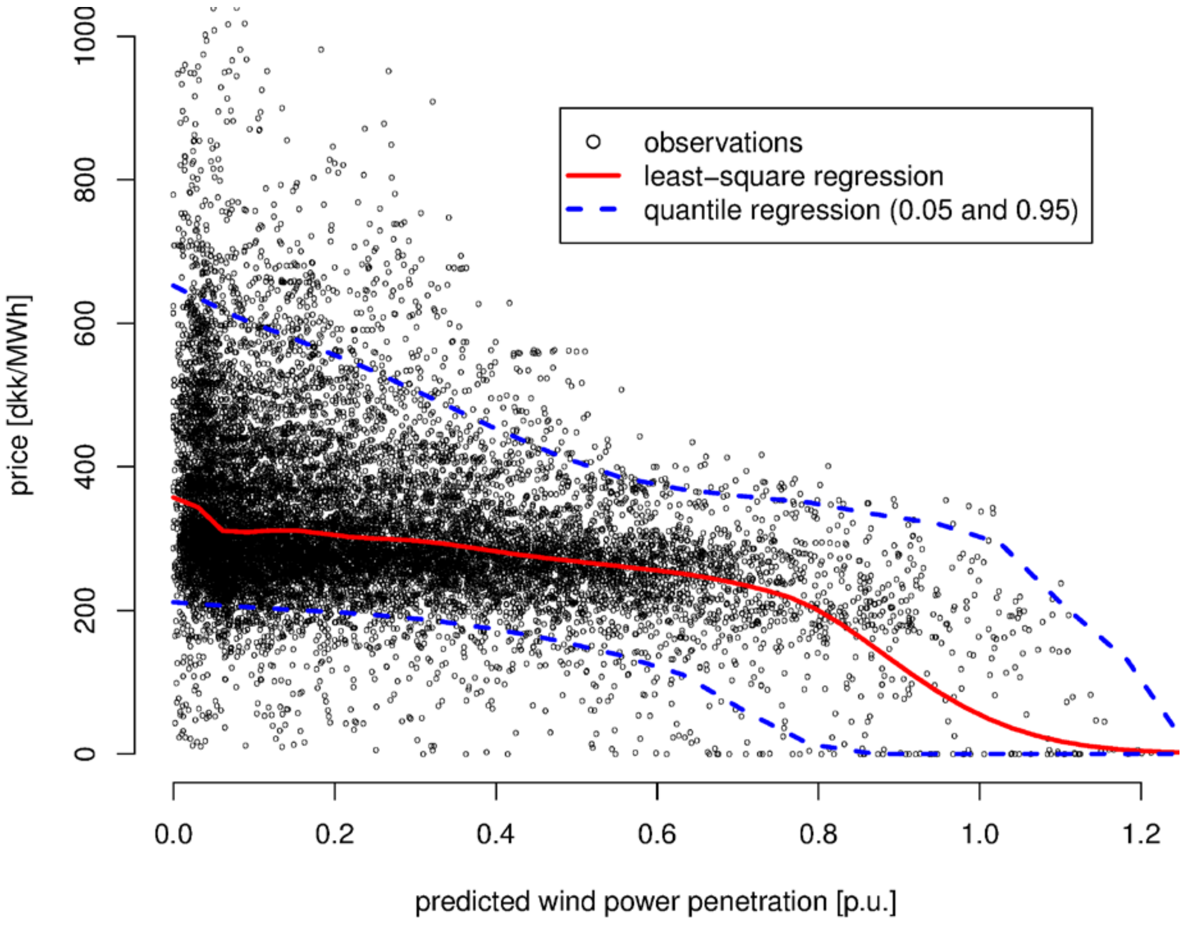
Cross-regional electricity transfer and integration of distributed generation



Grid stability and system efficiency

Cost-efficient use of conventional and renewable energy

Need for New Market Designs
Impact of Wind Power on the Nordic Electricity Market



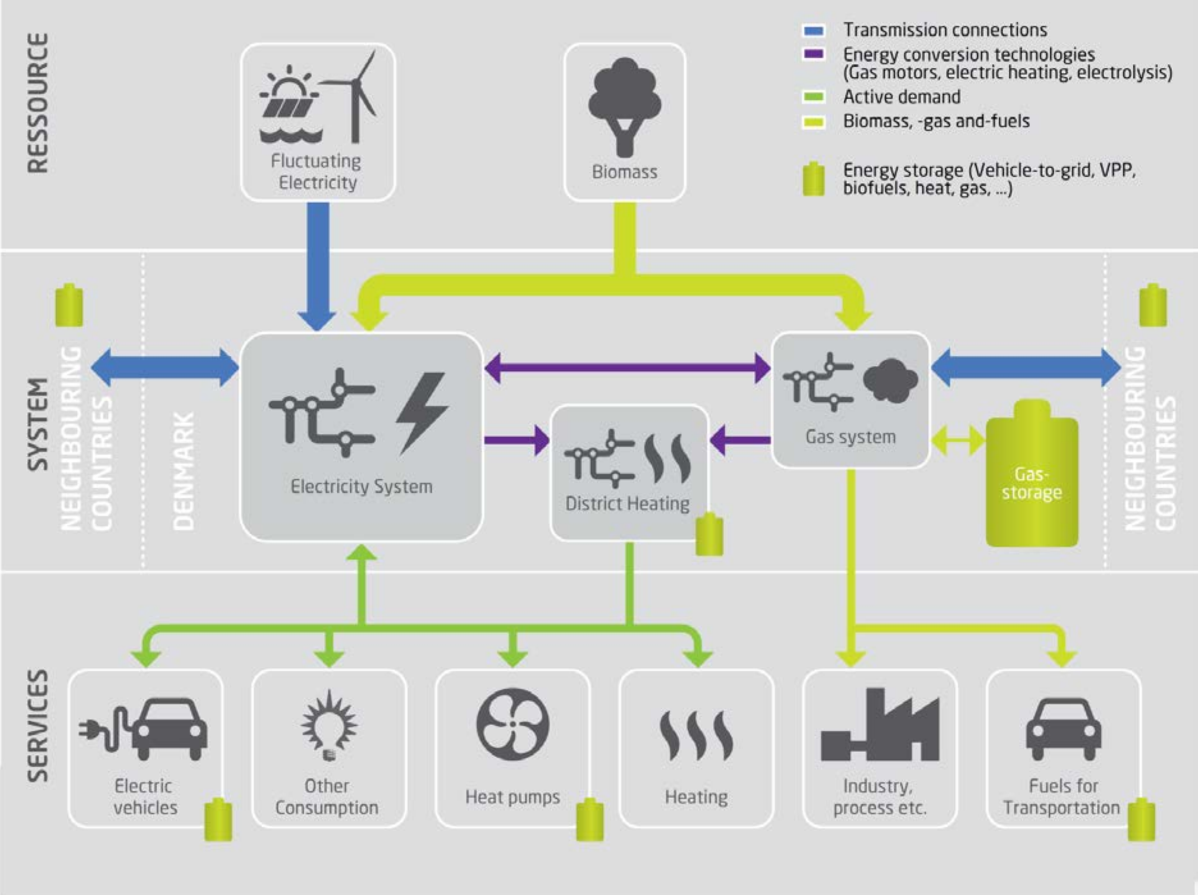
Source: Pinson et. al (2012). IEEE Power & Energy Society General Meeting 2012, San Diego, California, US.

Challenge #2 of a RE-based Energy System

Integrated Multi-Carrier Energy System (Electricity, Heating, Cooling, Gas)

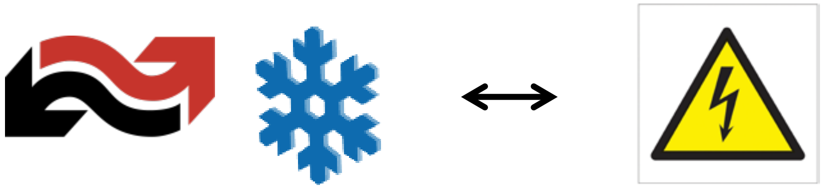
Figure 42

Interactions between the various energy infrastructures help to provide the flexibility required in a fully renewable energy system [2].



Source: Jacob Østergaard et. al (2013)

Flexibility through a more Integrated Energy System

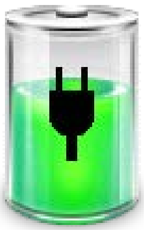


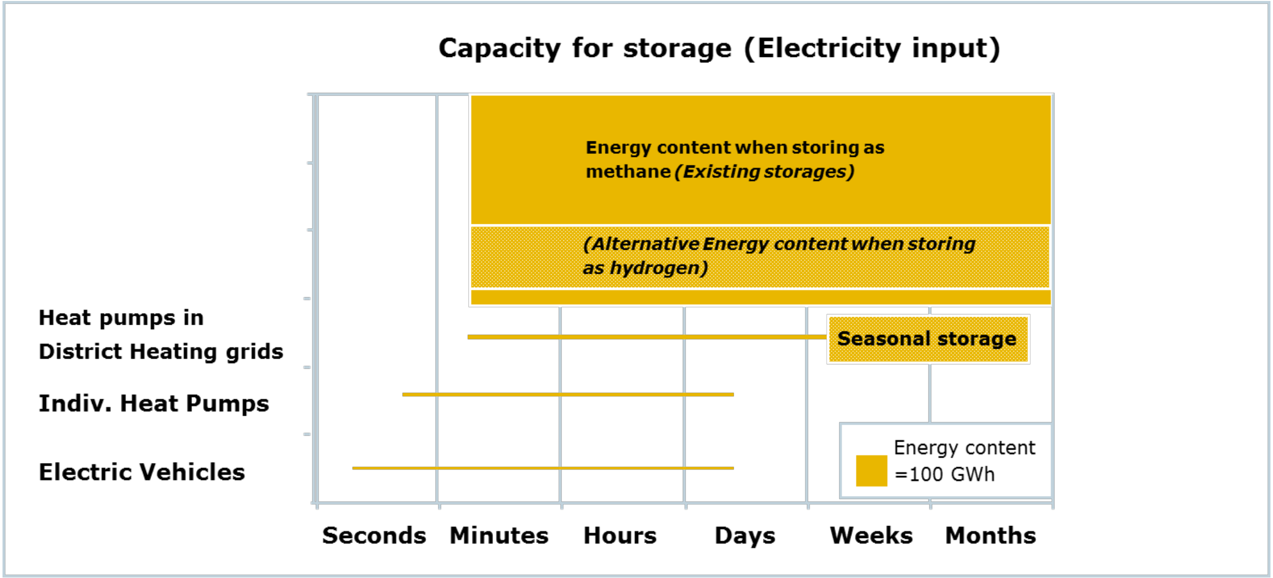
- Heating and cooling systems providing storage

- Fuel-shift technologies

- Smart buildings w. intelligent grid interaction

- Energy conversion technology
- Energy storage technology





Source: Energinet.dk

SIEMENS

Pushing the integration of infrastructures

Application cases by location of storage

Central	**Decentral**
Large Utilities	Small utilities, municipalities, industry – prosumer

Pumped storage

Electricity

Grid balancing and stability

H2

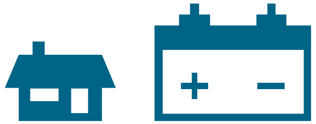
Electricity

H2/ Methane (gas grid)

H2 Fuel for car

Power-to-gas
Power to value

Battery



Electricity

Grid stability and self-supply

Thermal

Heat (power)

Power-to-heat

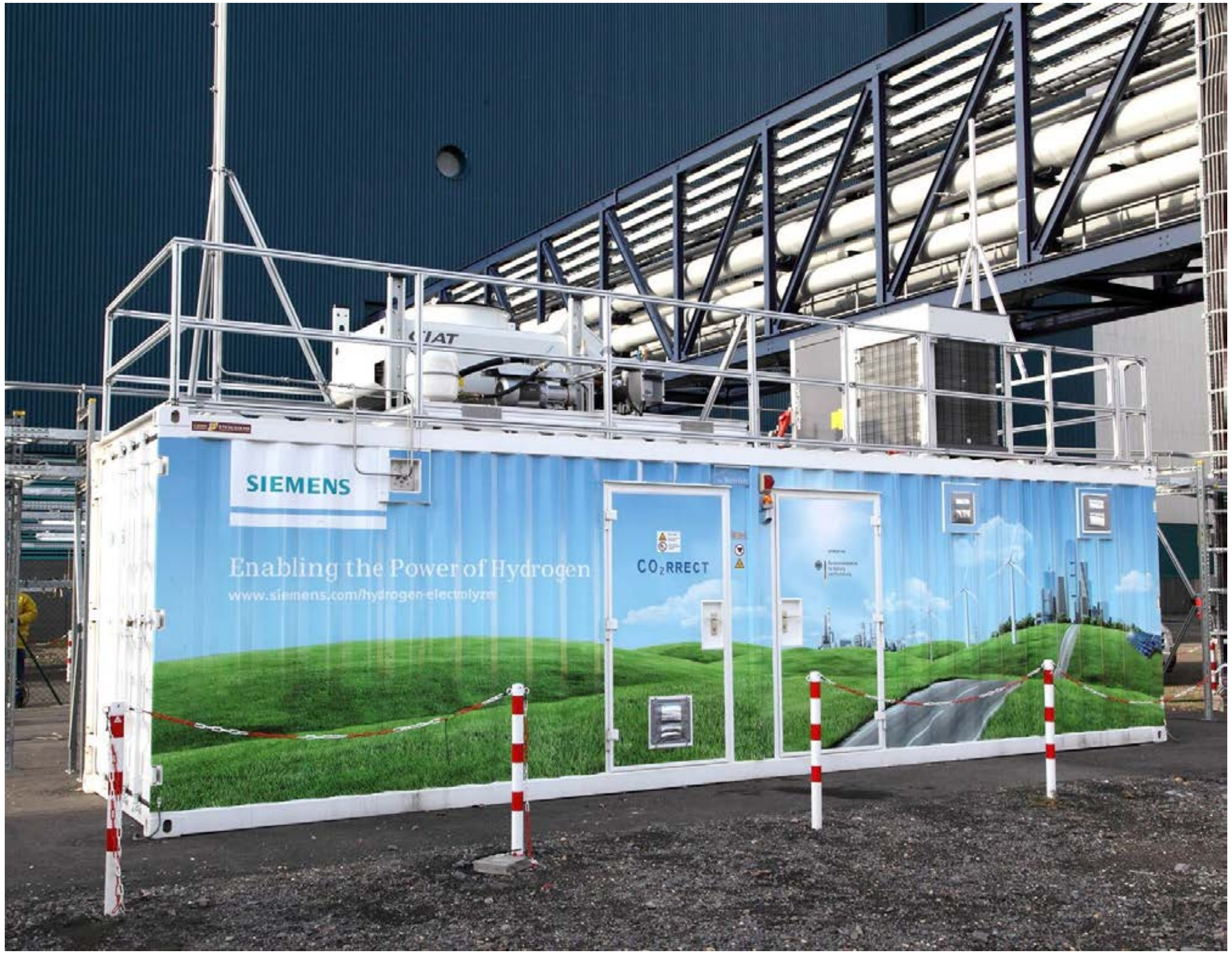
1 MVA, 500 kWh

Application:

- Frequency regulation
- Integration of photovoltaic power plants and for an e-vehicle charging station
- Black start capability

SIEMENS

Hydrogen PEM-Electrolyzer



High dynamic Siemens electrolyzer

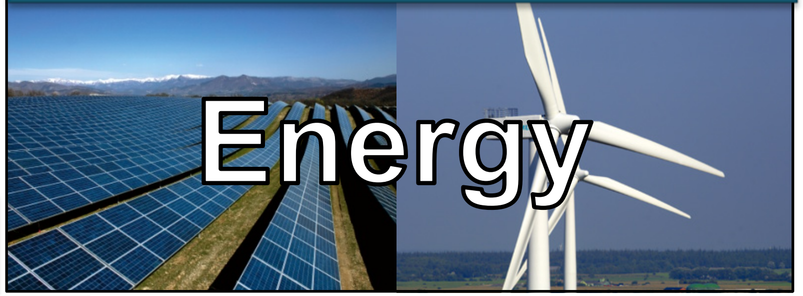
- Delivery Dec 2012
- Rated power 100 kW
- Peak power 300 kW
- H_2 and O_2 pressure 50 bar
- Power supply and water purification onboard → “self-sustaining”

Looking ahead: Power-to-value

CO_2 from fossil-fired power plants

+

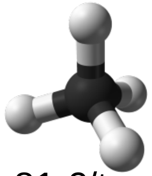
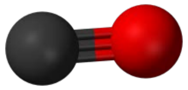
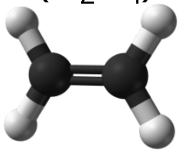
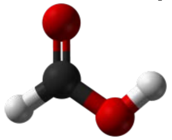
Electricity



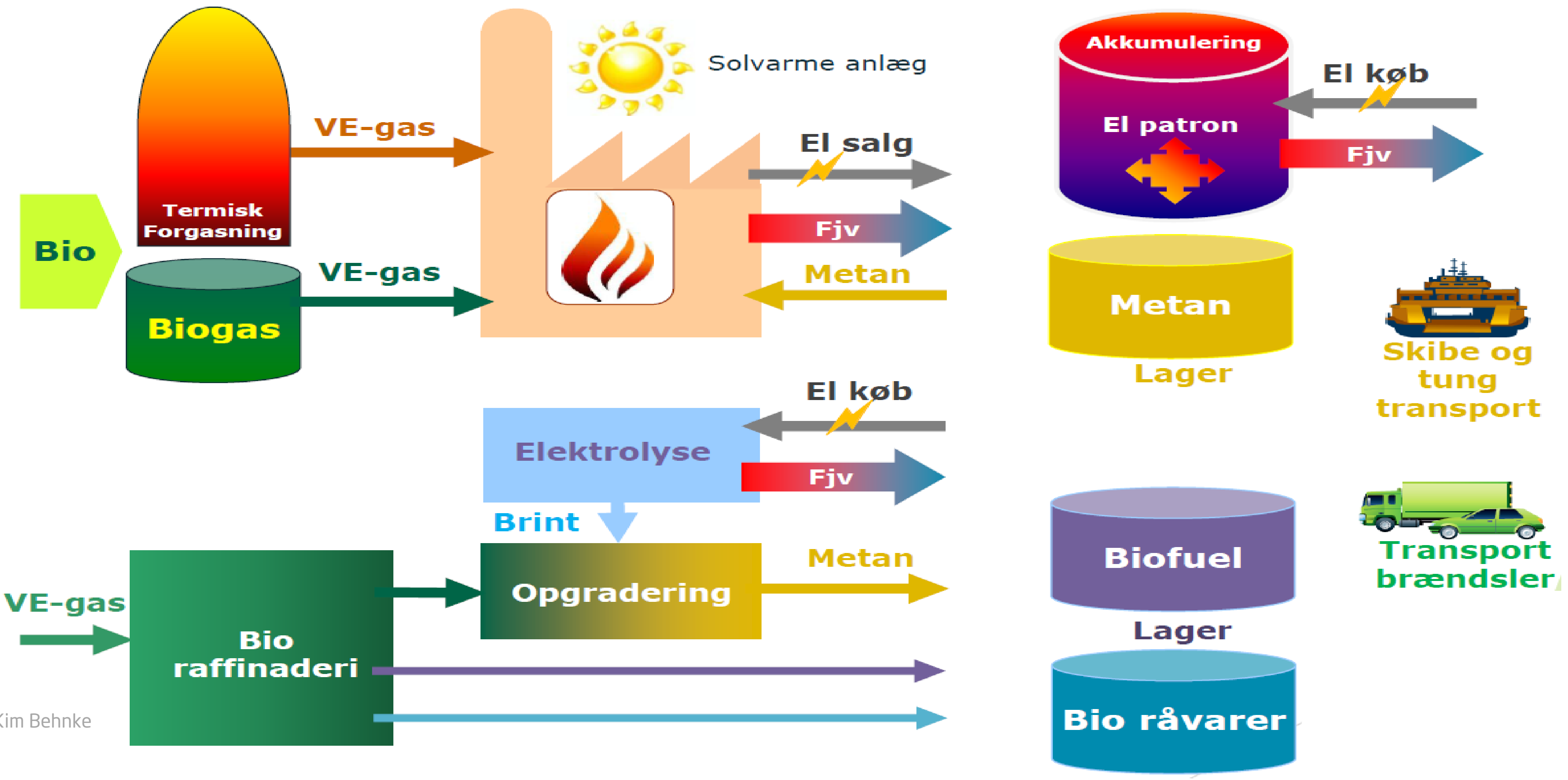
TO

Synthetic fuels or chemical feedstock

Valuable products

	Methane (CH_4)	Carbon monoxide (CO)	Ethylene (C_2H_4)	Formic acid (HCOOH)
				
Market Price	81 €/t	650 €/t (Naphtha)	1000 €/t	
Market Volume	>2400 Mt/y	> 210000 Mt/y	141 Mt/y	0.7 Mt/y

Poly-generation – from Vision to Application



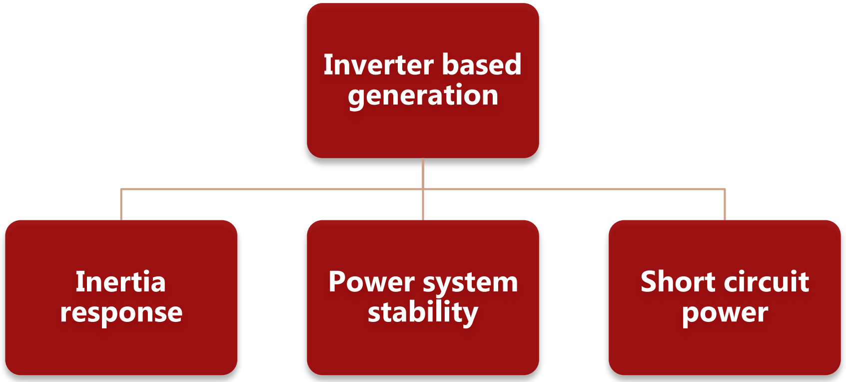
Source: Kim Behnke

Challenge #3 of a RE-based Energy System

Stability and Reliability

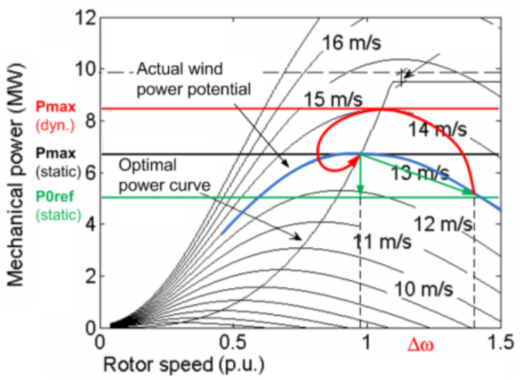
More Converter-based Generation

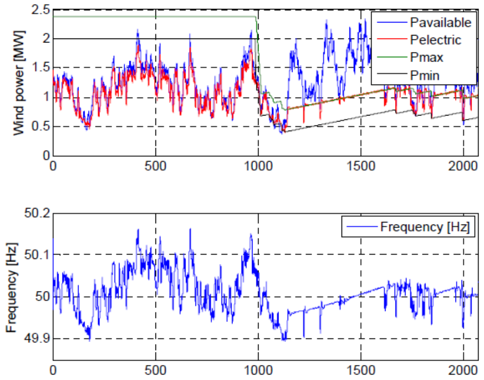
Challenges: Stabilizing synchronous generators are displaced by power electronic based generation



Posibilities: The power electronics can provide new controlability

Examples:
Transient inertia and frequency control from wind turbines.





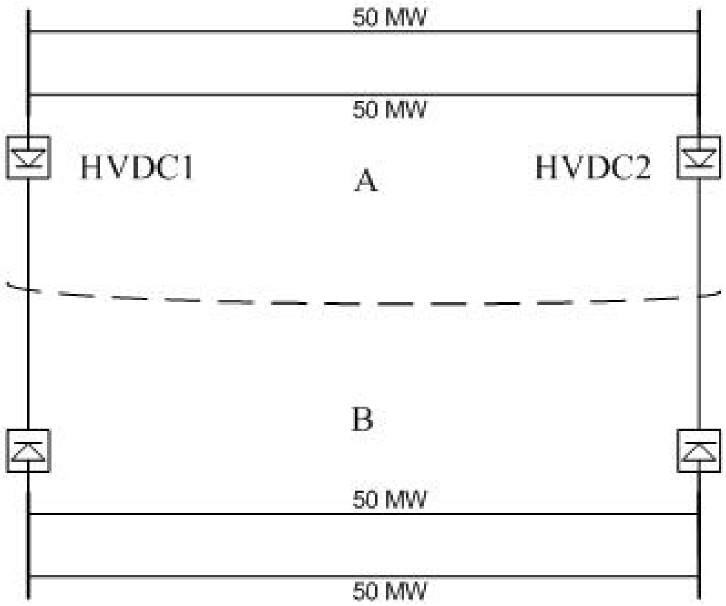
Source: *9th International Workshop on Large-Scale Integration of Wind Power*, 2011
Patent No. US20120161444, 2011

More Intelligent use of Existing Infrastructures

Coordinated Operation of Multiple DC connections

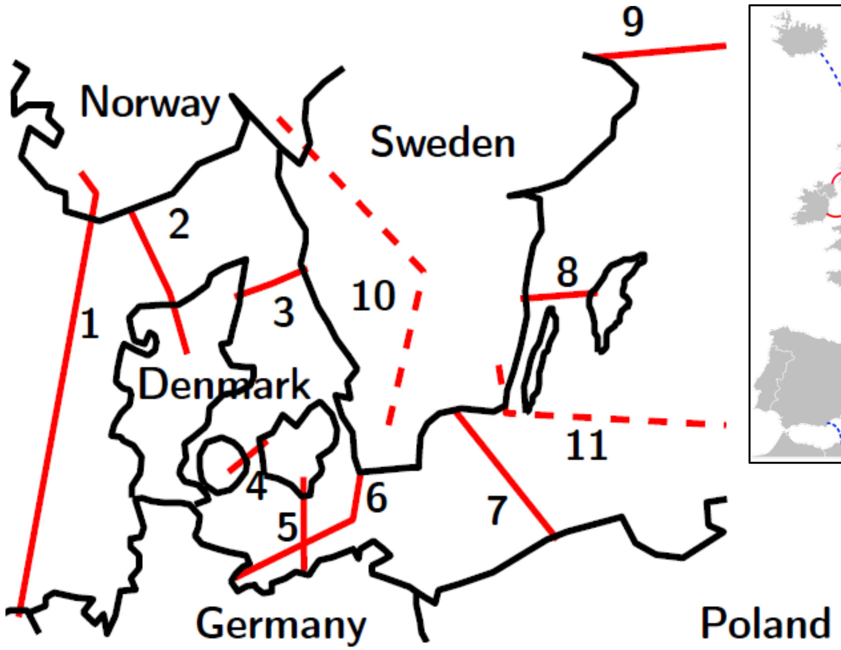
Optimal coordination of multiple controllable HVDC links can create a lot of added value.

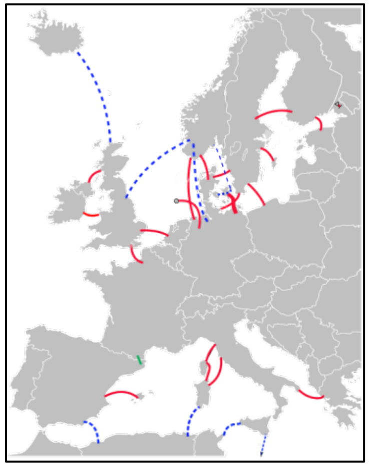
The Nordic region has world-record penetration of HVDC connections.



Example: Basic coordination allows 75 MW per line, total 150 MW, i.e. increase transfer limit by 50%.

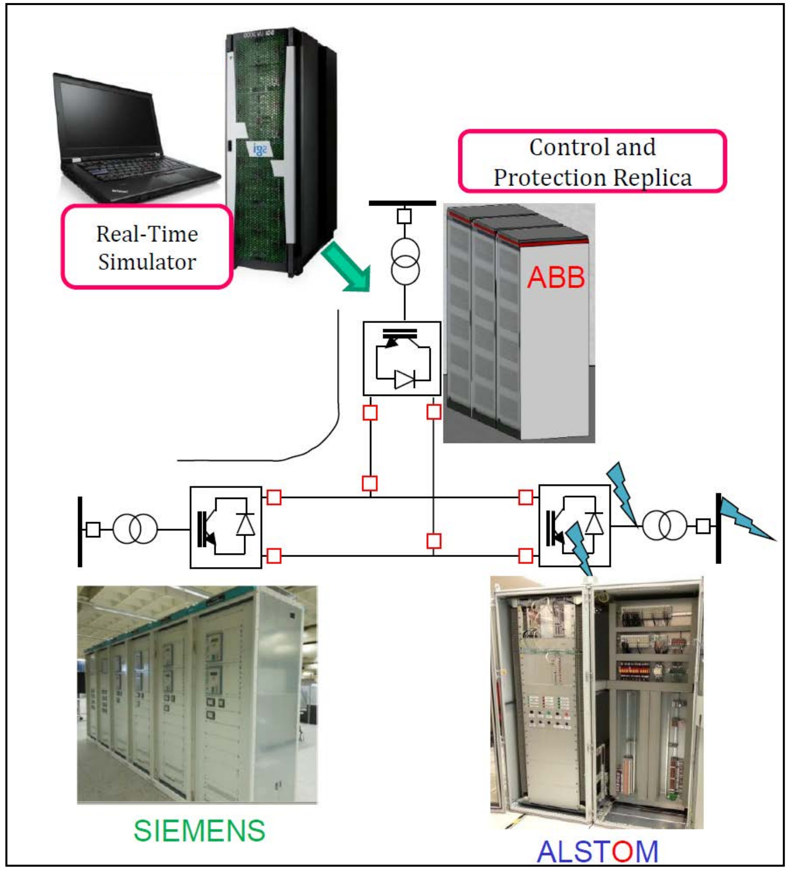
Source: Robert Eriksson, CEE.





Interoperability of Multi Vendor DC solutions

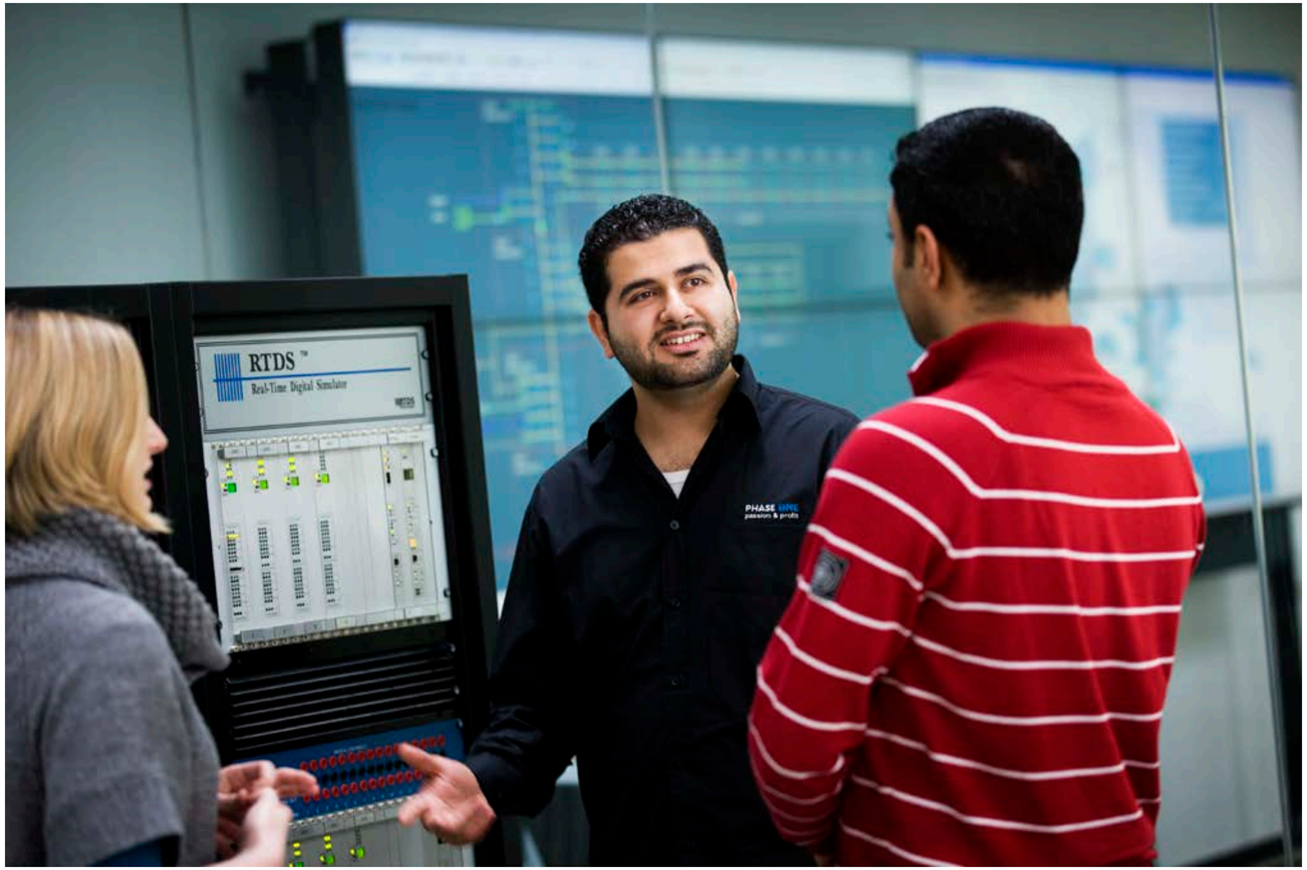
Validation methods for multi-vender solutions needed



Source: RTE

Europe's most powerful real-time simulator installation in the lab at DTU (no. 2 in the world)

PowerLabDK



Trans Bay cable project, USA 2010

Trans Bay Cable Project

Pittsburg, CA
San Francisco, CA

400 MW

85 km HV DC PLUS
Submarine Cable

± 200 kV DC
230 kV/138 kV AC, 60 Hz

IGBT

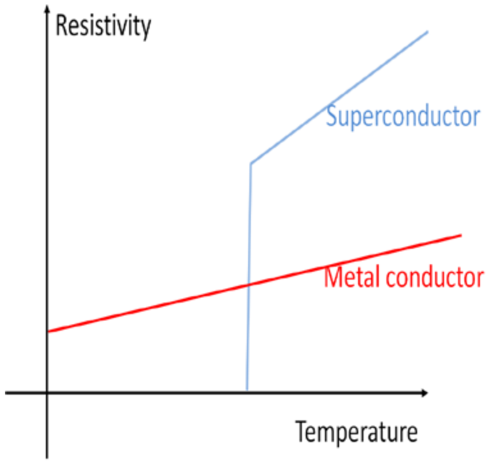
Siemens H-Class Gas Turbine

Challenge #4 of a RE-based Energy System

Lower the Costs of Renewable Energy Technology

Novel Designs of Wind Power Plants and their Components

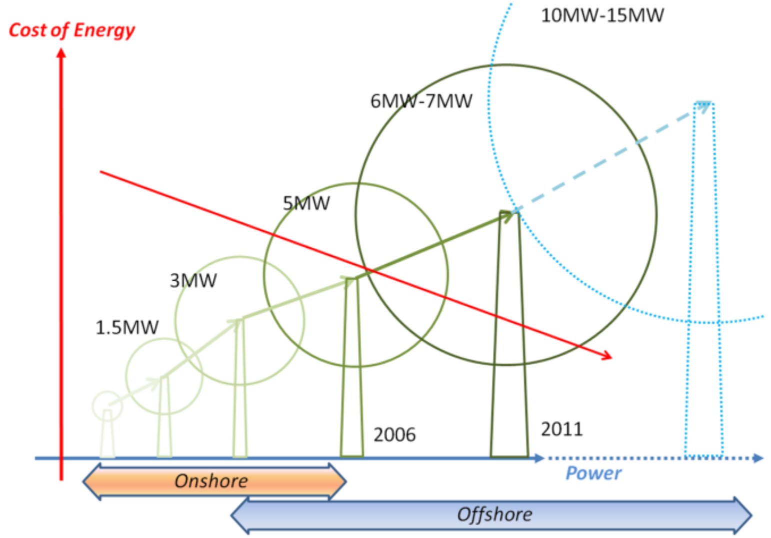
Wind Turbine Generator Technology

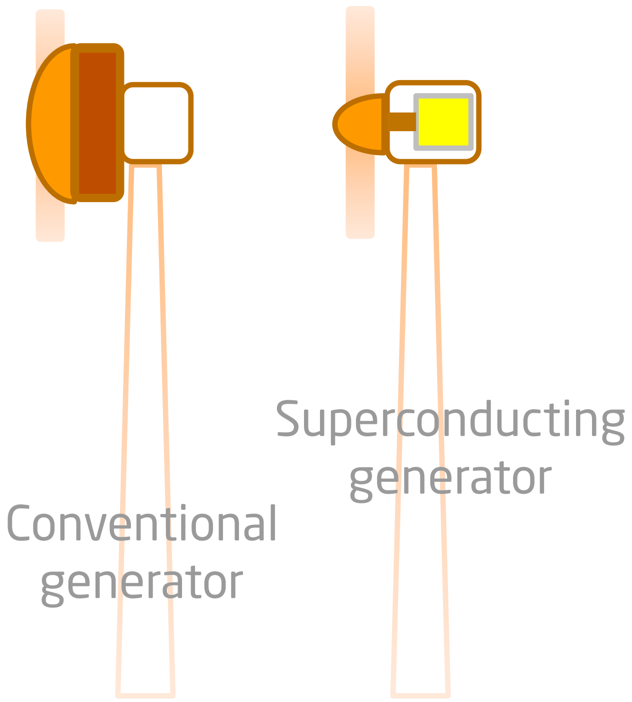


- Zero resistance
- Low operating T

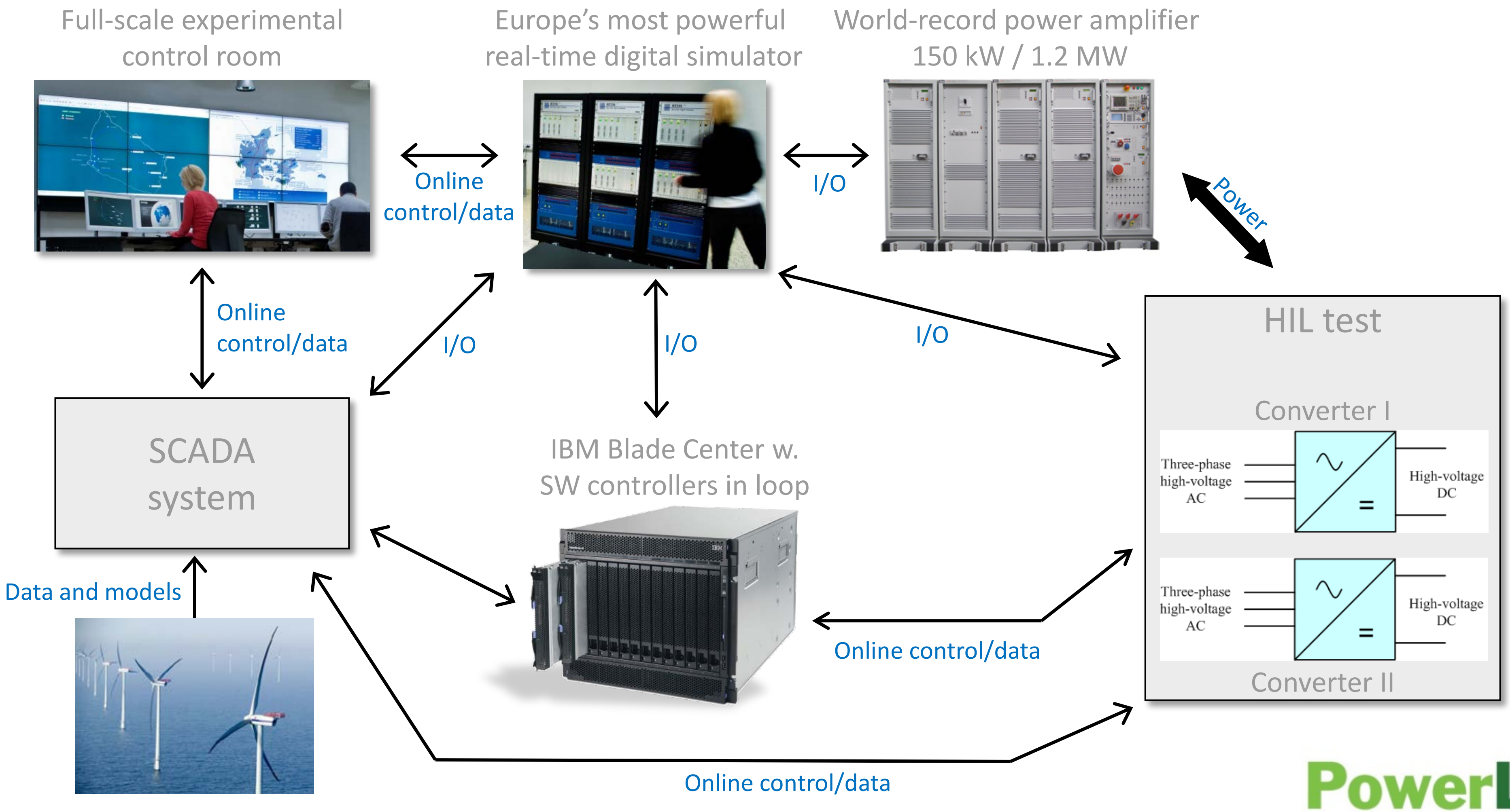
$$P = \omega_m T$$

$$T = \sqrt{2} A \hat{B}_g V$$





Test and Validation before Going Off-shore



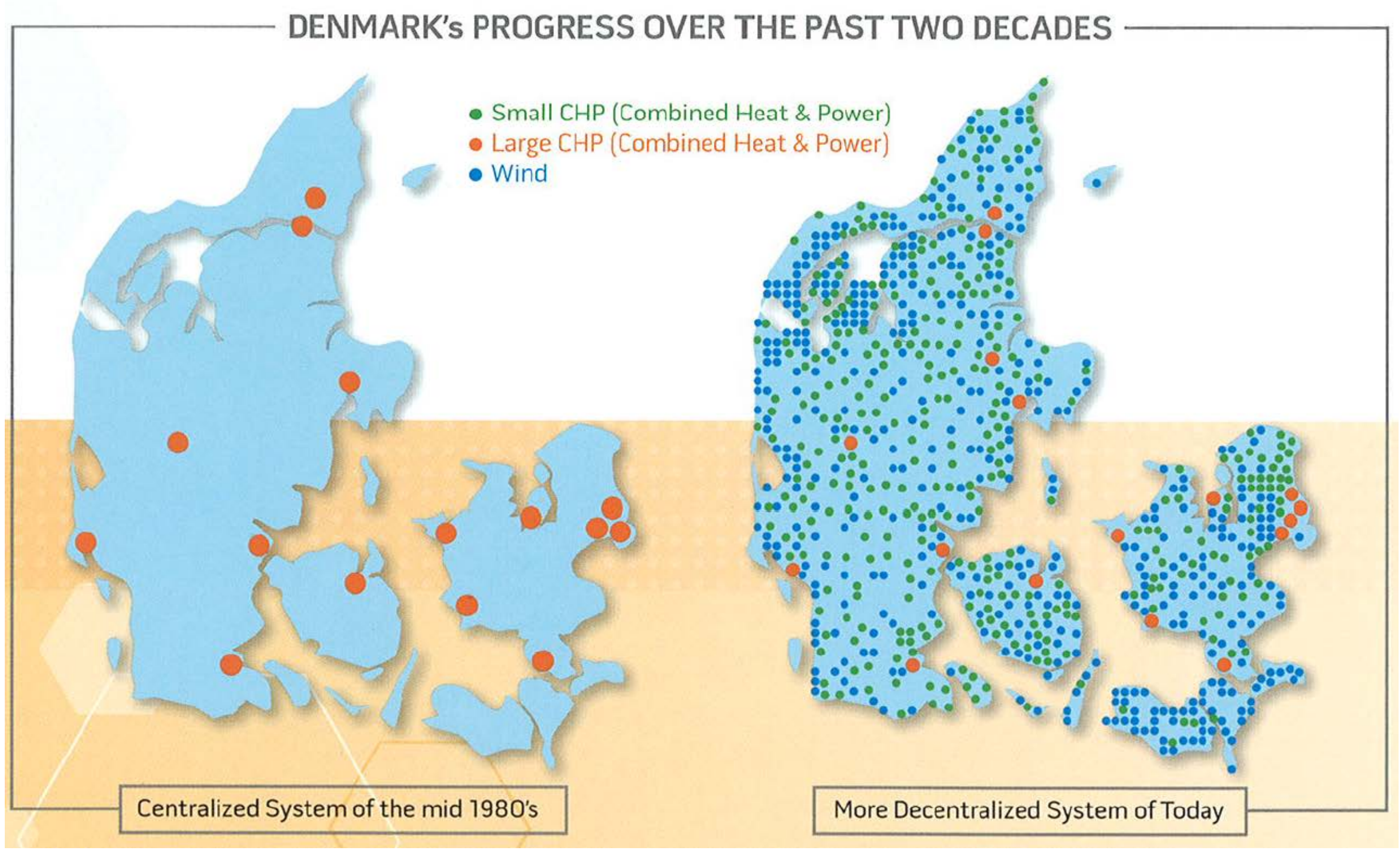
PowerLabDK

The world’s largest wind turbine

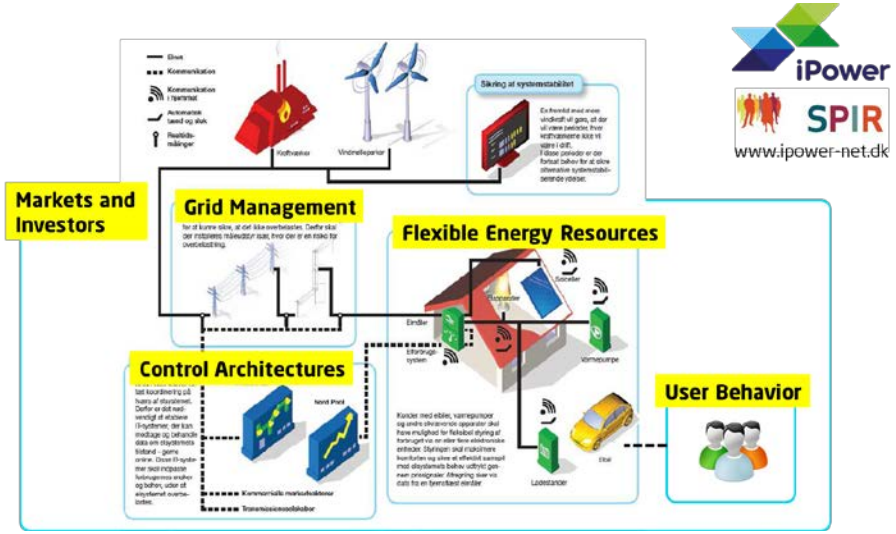
6.0-154 prototype
in operation

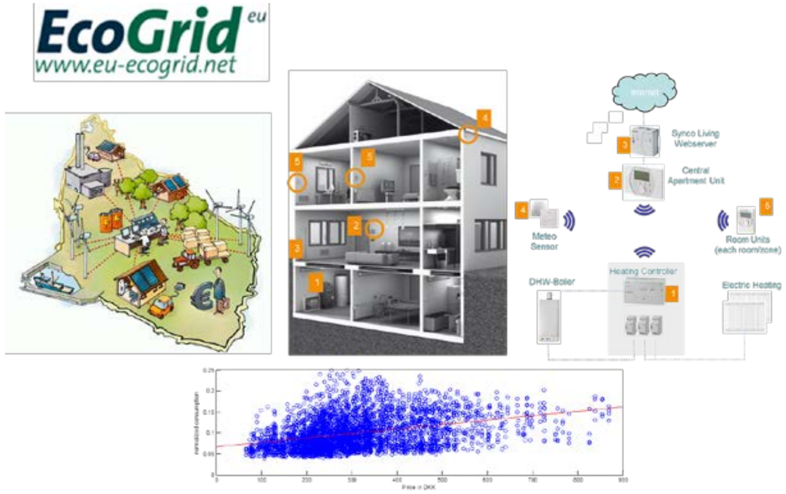
Challenge #5 of a RE-based Energy System

Decentralisation of the Energy Resources



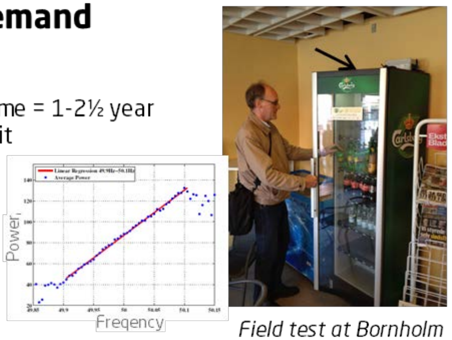
Cost-effective Activation of the Decentralised Resources





Frequency control services from demand

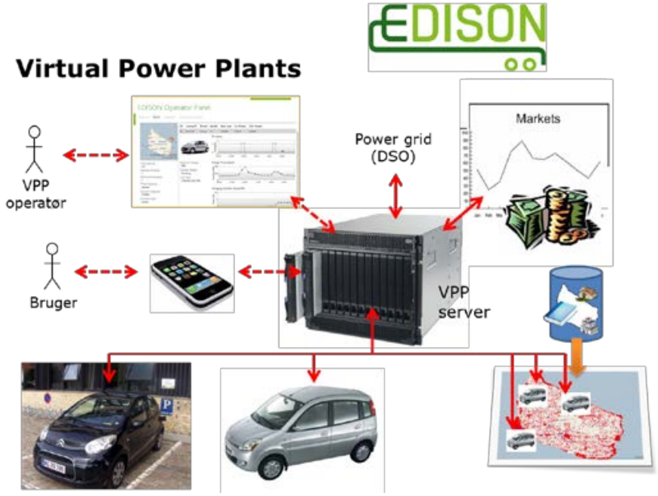
Pay pack time = 1-2½ year
w/ 1 kW unit



Field test at Bornholm

Refs: *IEEE Transactions on Power Systems*, August 2011.
IET Generation Transmission and Distribution, August 2009.

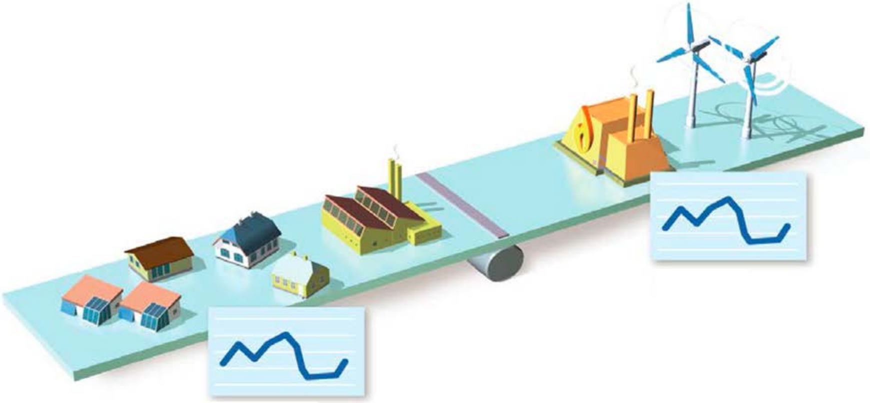
Virtual Power Plants



Different Objectives of TSO’s and DSO’s

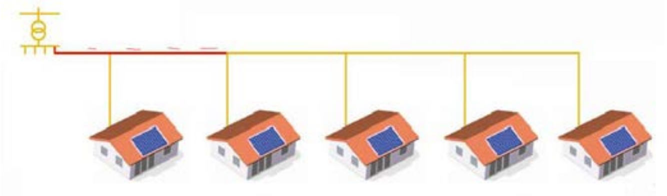
TSO

Balancing (f ≈ 50 Hz)

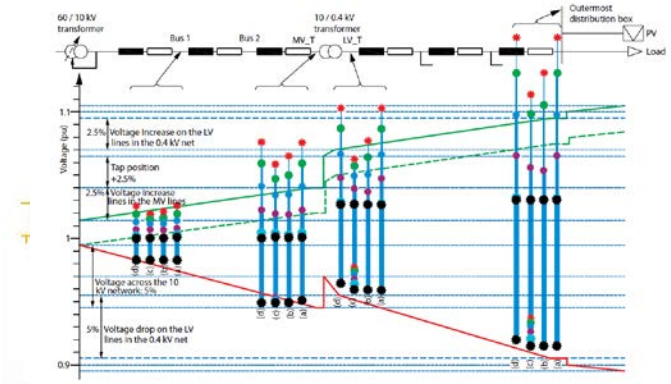


DSO

Overload

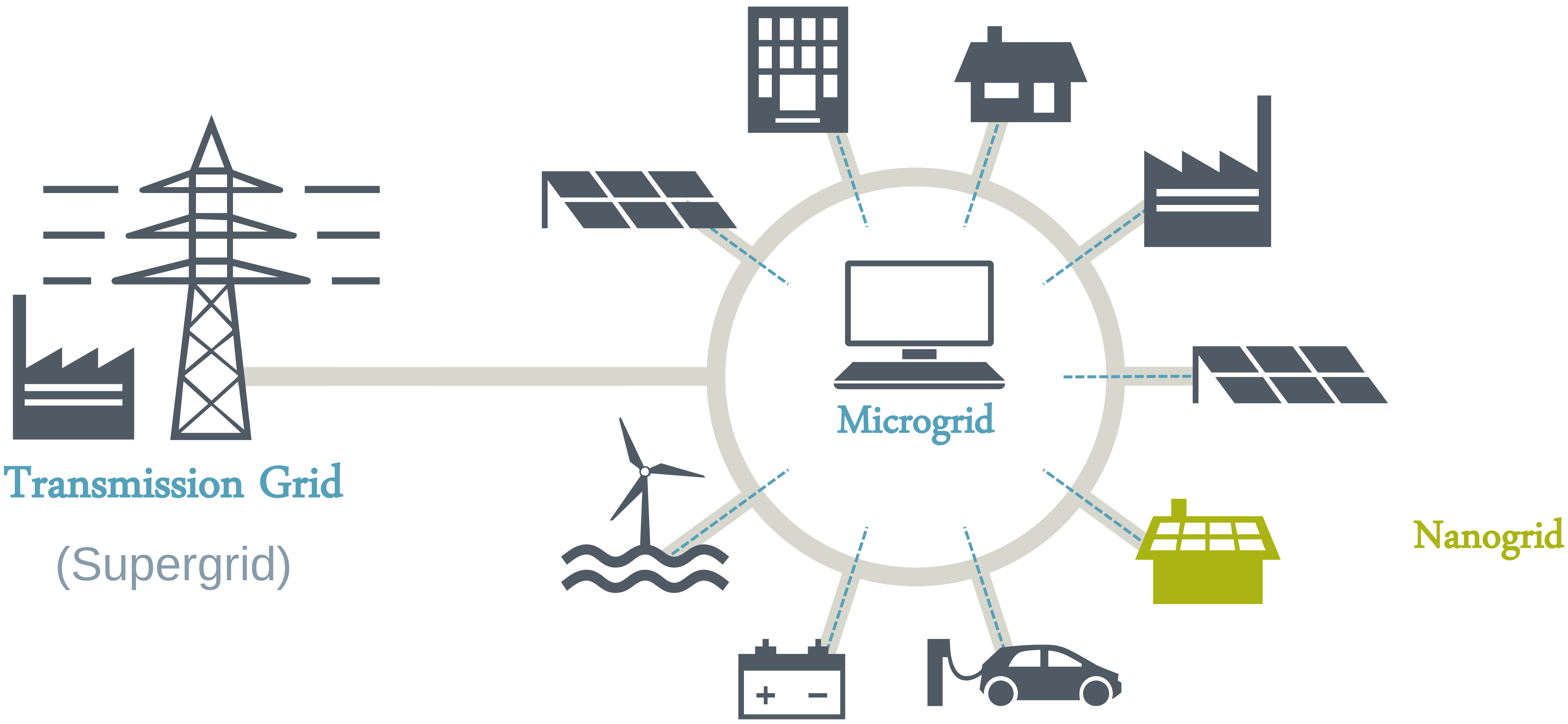


Voltage profiles (±10%)

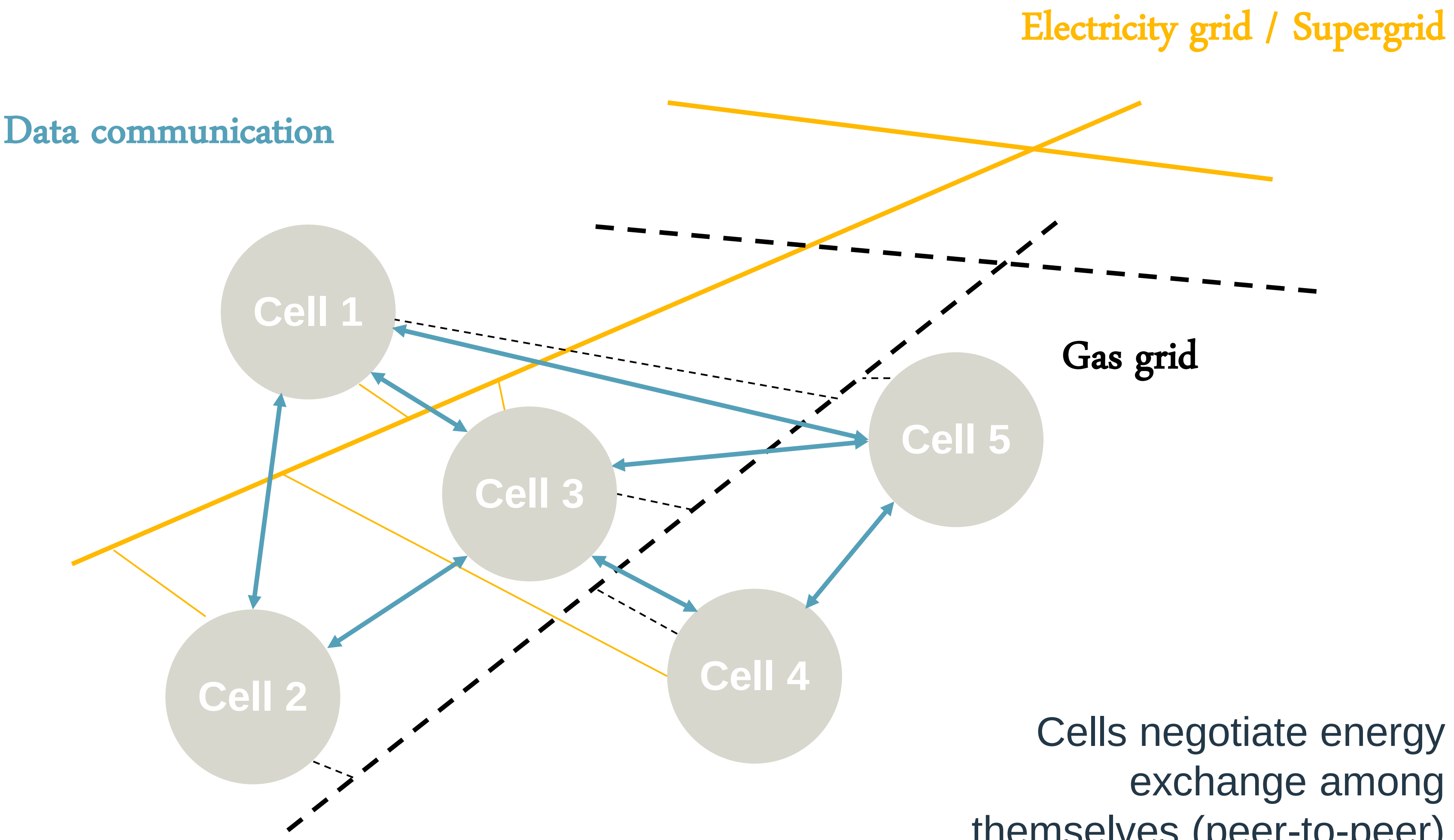


Supergrid, Microgrid und Nanogrids: more sensors (data), more electronics, more resilience

SIEMENS



The energy cell concept



Cells negotiate energy exchange among themselves (peer-to-peer)

Energy cell can be

- Community
- Factory
- Power plant
- Dedicated storage Facility

Energy cell contains

- Power generation
- Energy storage
- Thermal grids
- Loads
- ICT


H2

The development of the Power Matrix

- Growing share of distributed power generation and Renewables
- Multiple Stakeholders – multiple usage of electricity
- Energy Cells develop – Grids remain essential
- Digitalization drives change of technology and business models

Challenges for engineering companies

- Deep understanding in integration of Renewables and distributed generation required (technology and regulation)
- Expansion of competence from single energy carrier to overall energy system
- Increased sensitivity for society aspects (people acceptance and behavior)
- Understanding of business model innovations

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