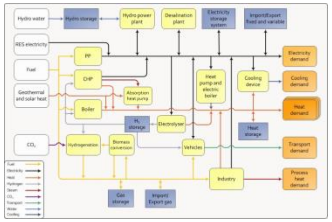
10th Conference on Sustainable Development of Energy, Water and Environment Systems

September 27 - October 2, 2015, Dubrovnik, Croatia



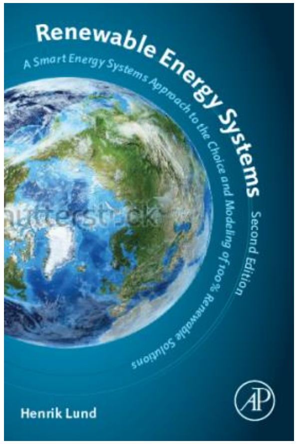
Smart Energy Systems

The Design of 100% Renewable Energy Solutions

Henrik Lund

Professor in Energy Planning

Aalborg University



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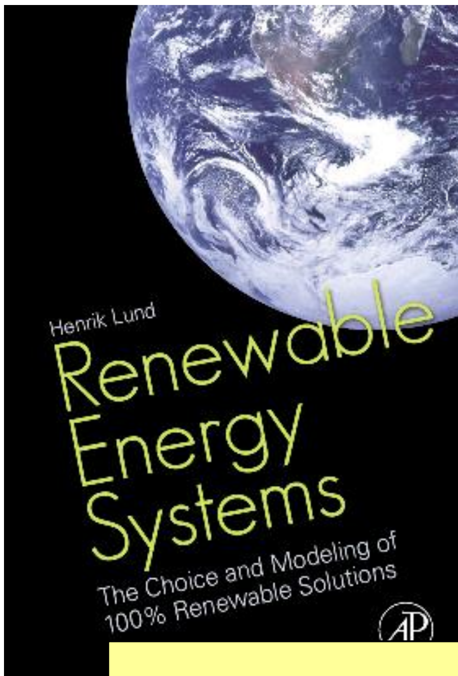
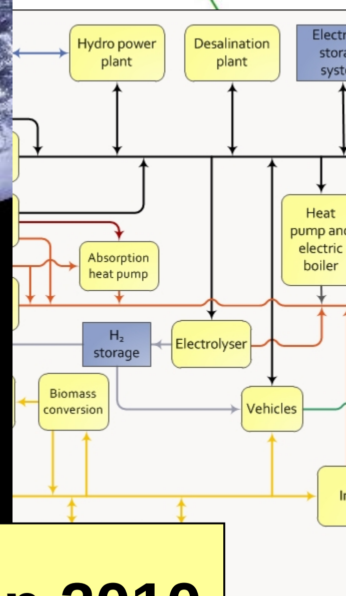
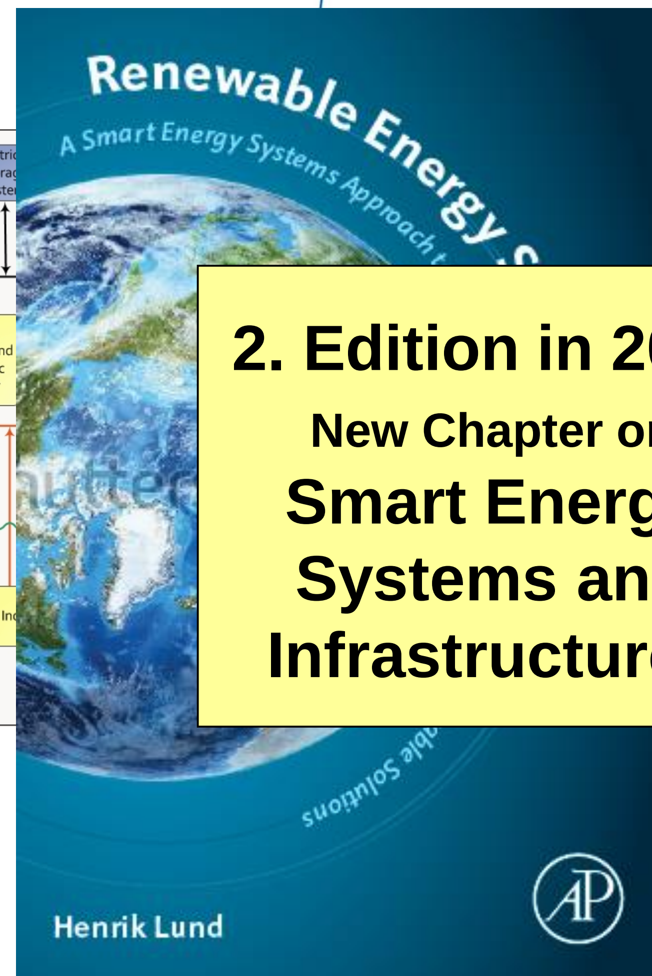
Renewable Energy Systems

A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions





1. Edition in 2010



2. Edition in 2014

New Chapter on

Smart Energy Systems and Infrastructures

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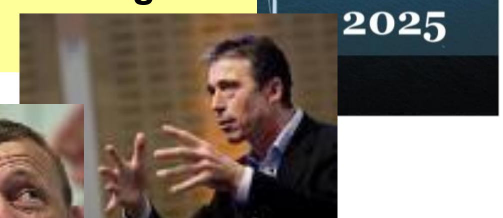
The long-term Objective of Danish Energy Policy

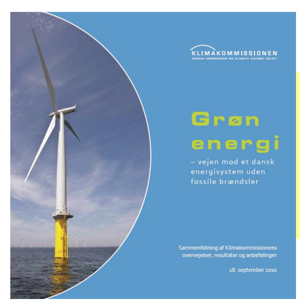
4DH
4th Generation District Heating Technologies and Systems

Expressed by former Prime Minister Anders Fogh Rasmussen in his opening speech to the Parliament in 2006 and in several political agreements since then:

To convert to 100% Renewable Energy

Prime minister 16 November 2008:
”We will free Denmark totally from fossil fuels like oil, coal and gas”





Prime minister 16 November 2008:
”… position Denmark in the heart of green growth”

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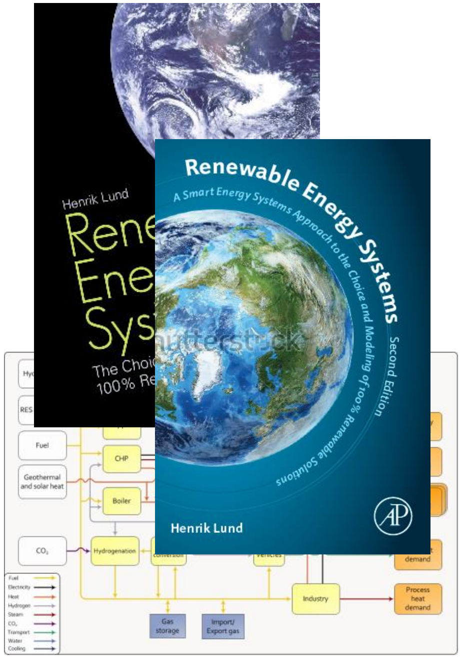
100% Renewable Energy 2050
...... but how…???!!

Smart Energy Systems
The key to cost-efficient 100% Renewable Energy

- A sole focus on renewable **electricity (smart grid)** production leads to electricity storage and flexible demand solutions!
- Looking at renewable electricity as a part **smart energy systems** including heating, industry, gas and transportation opens for cheaper and better solutions…



Power-to-Heat

Power-to-Gas
Power-to-Transport

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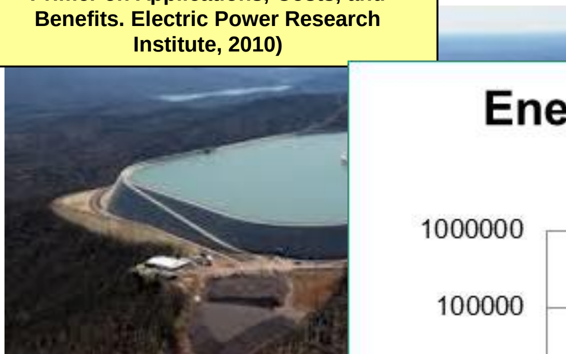
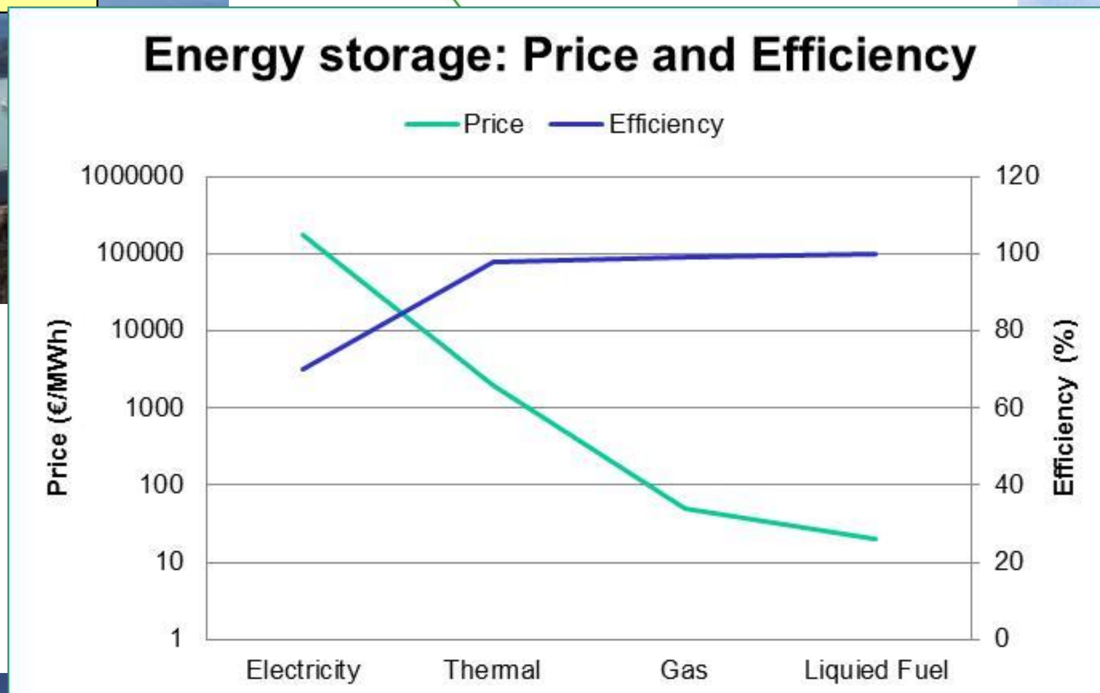
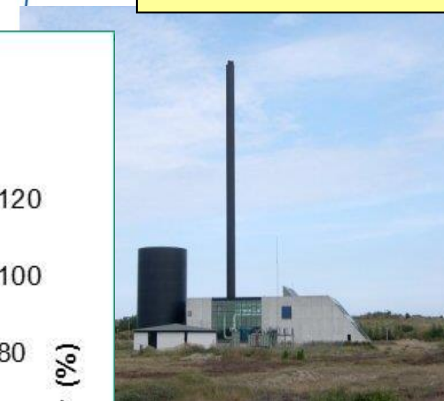
Energy Storage

Pump Hydro Storage
175 €/kWh
(Source: Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits. Electric Power Research Institute, 2010)



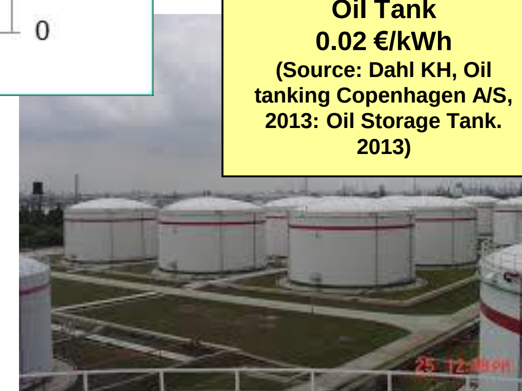


Thermal Storage
1-4 €/kWh
(Source: Danish Technology Catalogue, 2012)



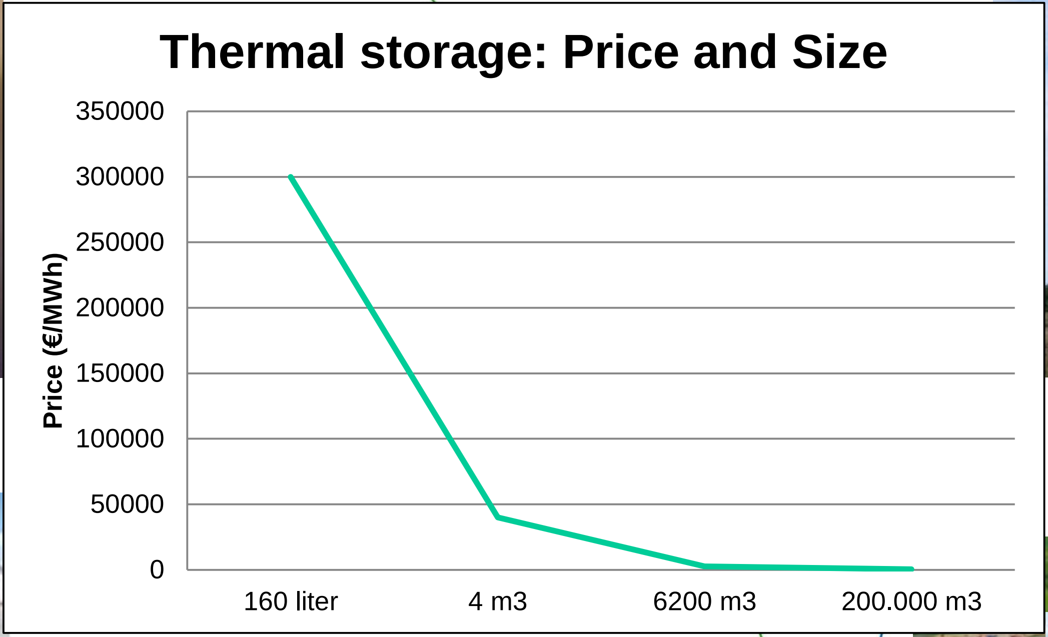
Natural Gas Underground Storage
0.05 €/kWh
(Source: Current State Of and Issues Concerning Underground Natural Gas Storage. Federal Energy Regulatory Commission, 2004)

Oil Tank
0.02 €/kWh
(Source: Dahl KH, Oil tanking Copenhagen A/S, 2013: Oil Storage Tank. 2013)



Thermal Storage

0.16 m3 Thermal Storage
300.000 €/MWh
(Private house: 160 liter for 15000 DKK)



6200 m3 Thermal Storage
2500 €/MWh
(Skagen: 6200 m3 for 5.4 mio. DKK)

4 m3 Thermal Storage
40,000 €/MWh
(Private outdoor: 4000 m3 for 50,000 DKK)

200,000 m3 Thermal Storage
500 €/MWh
(Vojens: 200,000 m3 for 30 mio. DKK)

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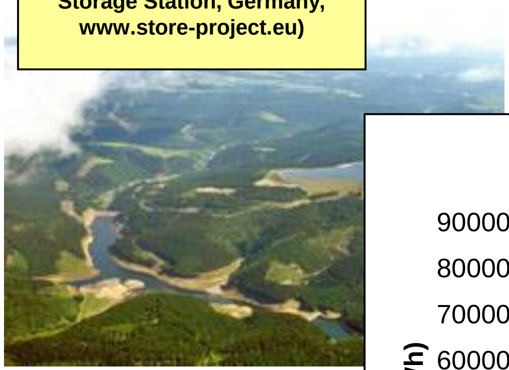
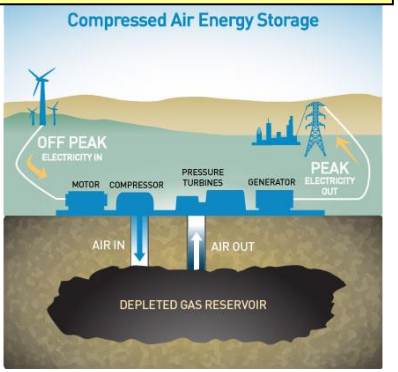
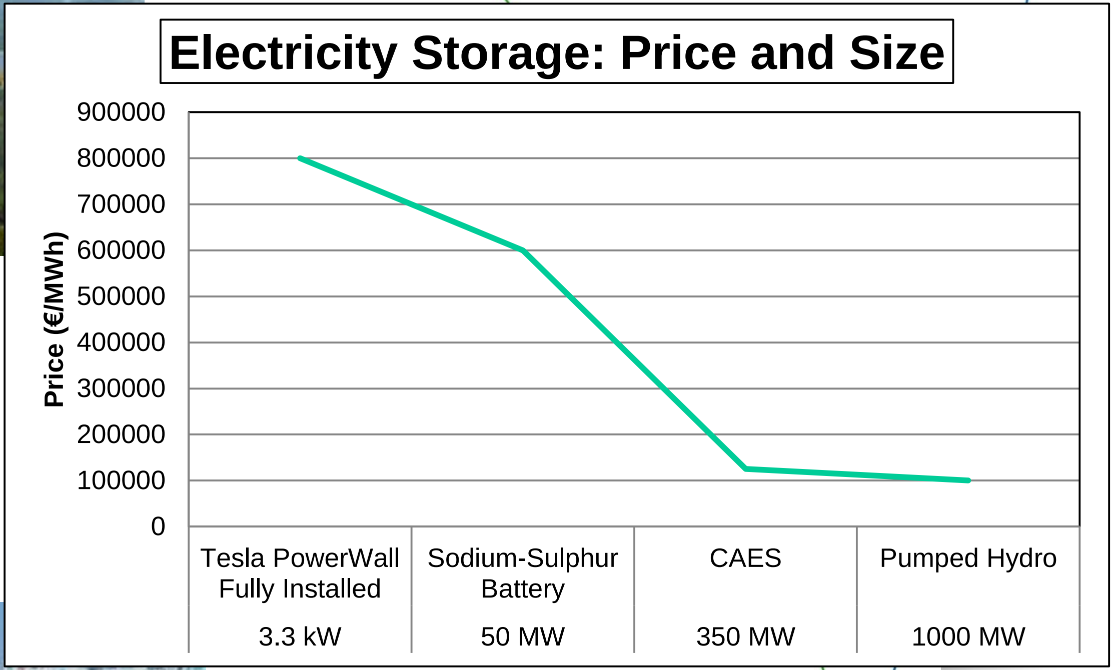
Electricity Storage

Pump Hydro Storage
100 €/kWh
(Source: Goldisthal Pumped Storage Station, Germany, www.store-project.eu)



Compressed Air Energy Storage
125 €/kWh
(Source: http://www.sciencedirect.com/science/article/pii/S0196890409000429)





Sodium-Sulphur Battery
600 €/kWh
(Source: Table 4: http://large.stanford.edu/courses/2012/ph240/doshay1/docs/EPRI.pdf)

Tesla PowerWall
800 €/kWh
(Source: Dahl KH, Oil tanking Copenhagen A/S, 2013: Oil Storage Tank. 2013)

100% Renewable Energy 2050
Power-to-Heat

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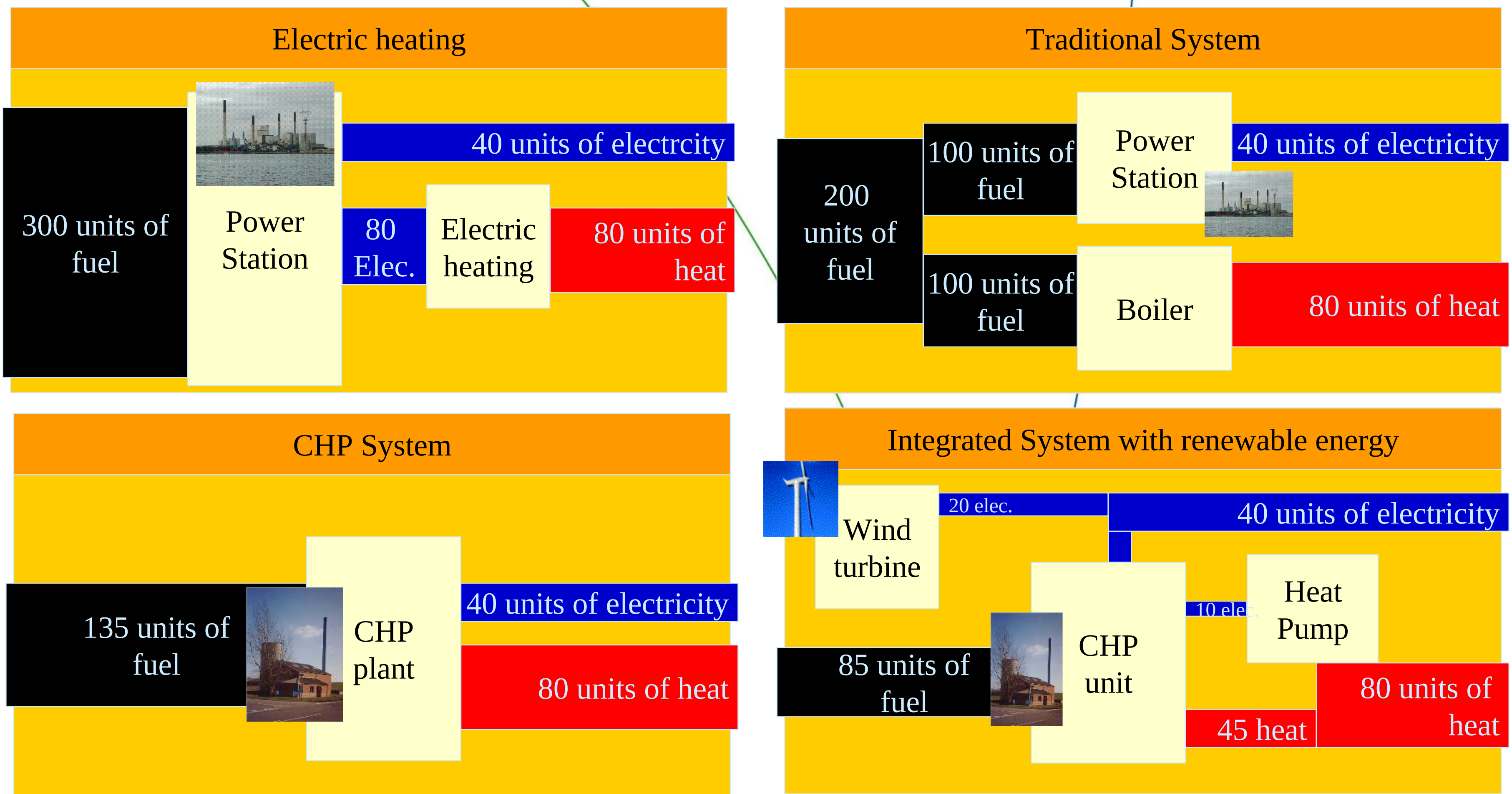
Four different technologies



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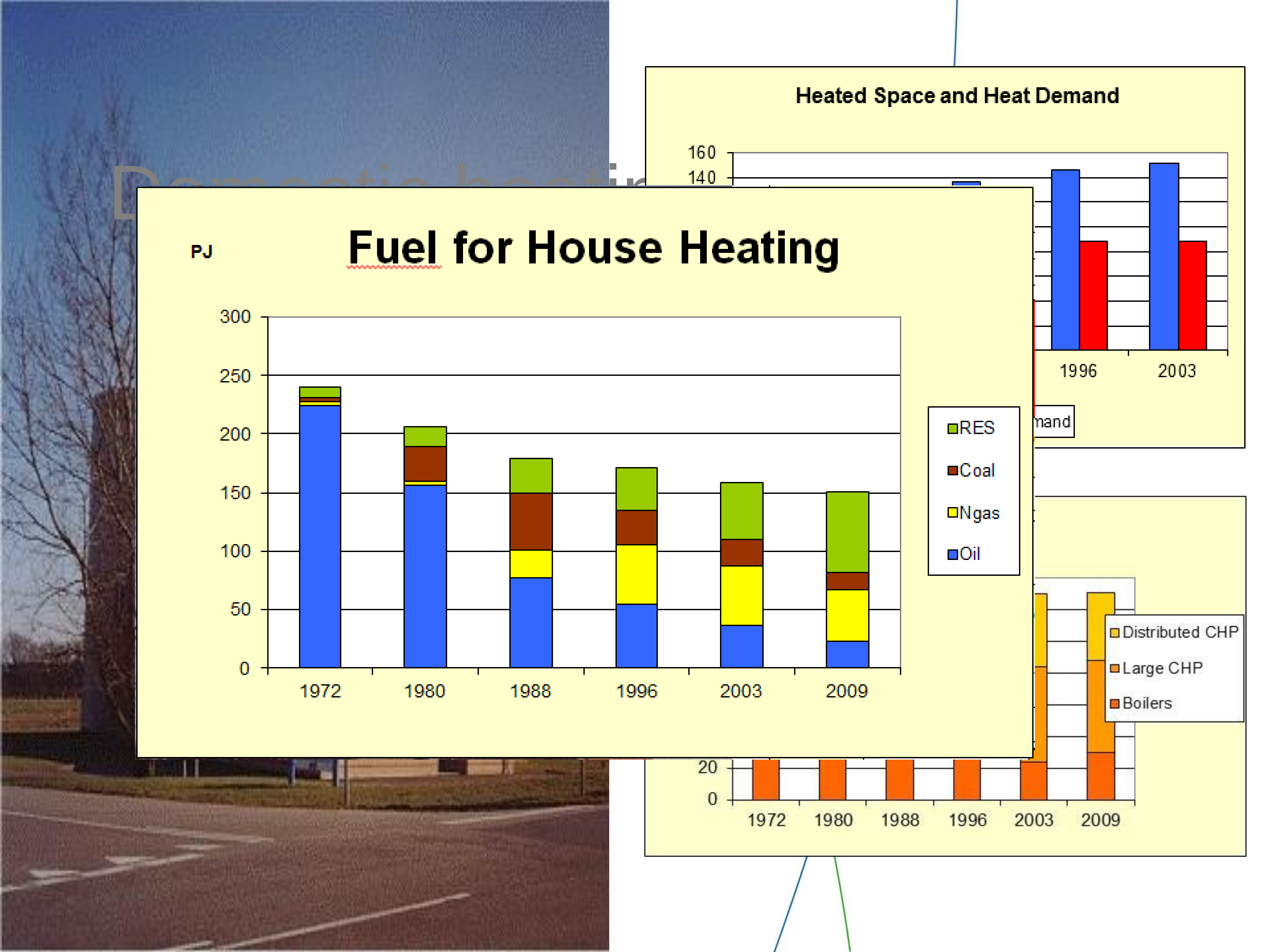
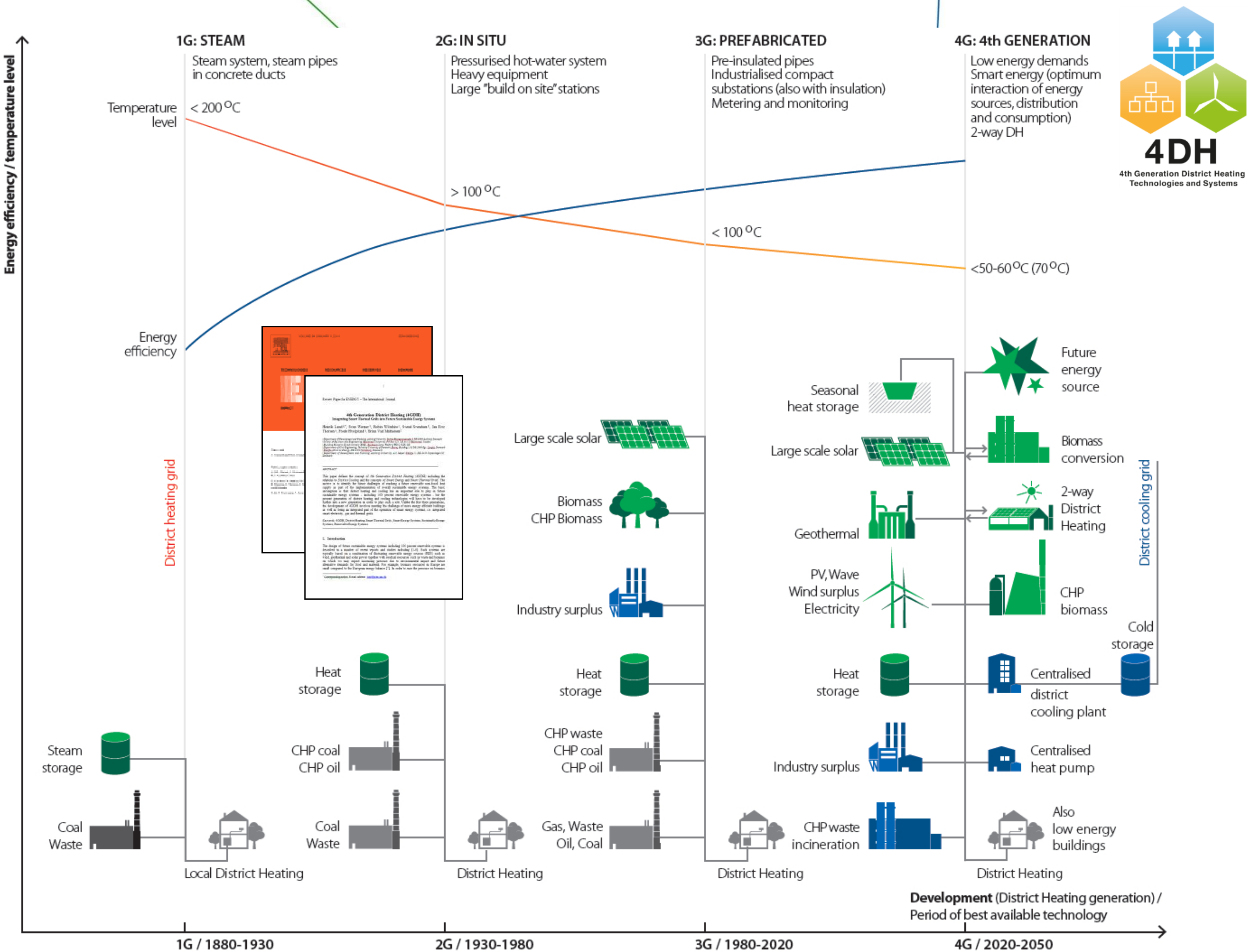
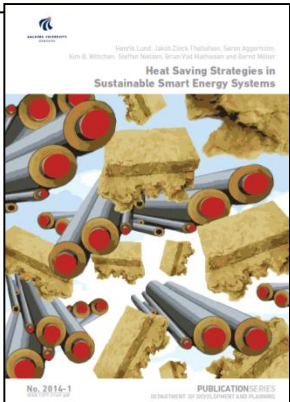

Fuel for House Heating
PJ
300
250
200
150
100
50
0
1972
1980
1988
1996
2003
2009
RES
Coal
Ngas
Oil
Heated Space and Heat Demand
160
140
1996
2003
Distributed CHP
Large CHP
Boilers
20
0
1972
1980
1988
1996
2003
2009

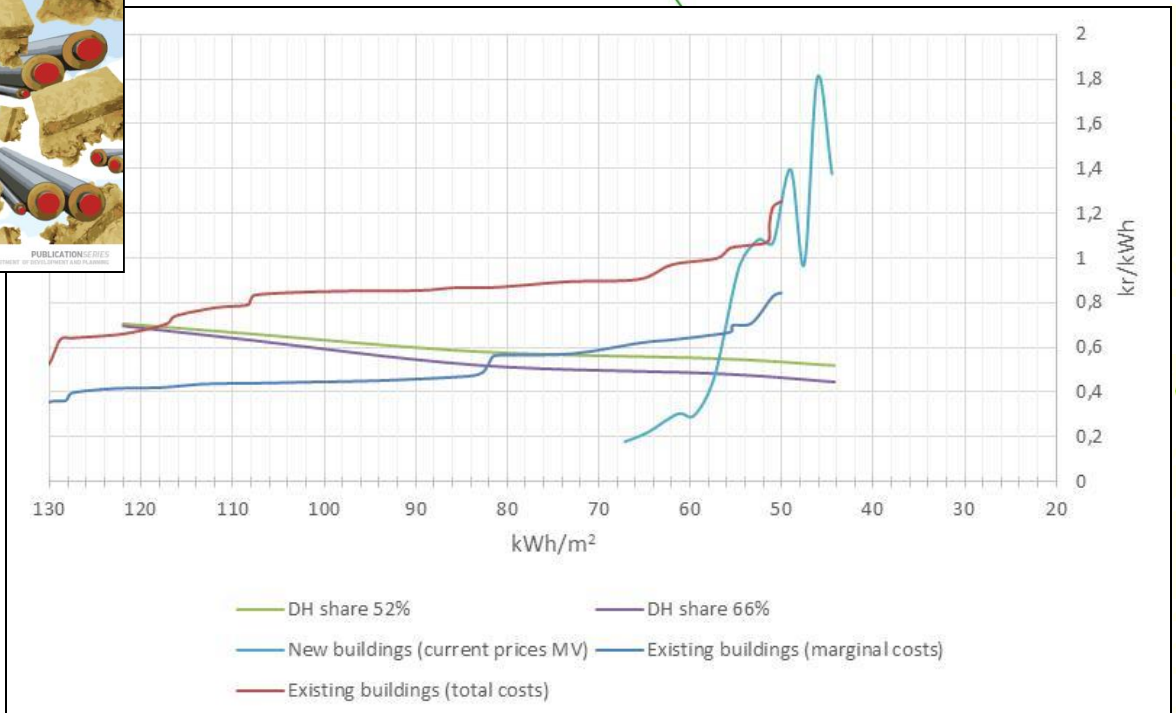
A


Energy efficiency / temperature level
1G: STEAM
Steam system, steam pipes in concrete ducts
2G: IN SITU
Pressurised hot-water system
Heavy equipment
Large "build on site" stations
3G: PREFABRICATED
Pre-insulated pipes
Industrialised compact substations (also with insulation)
Metering and monitoring
4G: 4th GENERATION
Low energy demands
Smart energy (optimum interaction of energy sources, distribution and consumption)
2-way DH
4DH
4th Generation District Heating Technologies and Systems
Temperature level
< 200 °C
> 100 °C
< 100 °C
<50-60 °C (70 °C)
Energy efficiency
District heating grid
District cooling grid
Steam storage
Coal
Waste
Local District Heating
Heat storage
CHP coal
CHP oil
Coal
Waste
District Heating
Large scale solar
Biomass
CHP Biomass
Industry surplus
Heat storage
CHP waste
CHP coal
CHP oil
Gas, Waste
Oil, Coal
District Heating
Seasonal heat storage
Large scale solar
Geothermal
PV, Wave
Wind surplus
Electricity
Heat storage
Industry surplus
CHP waste incineration
District Heating
Future energy source
Biomass conversion
2-way District Heating
CHP biomass
Cold storage
Centralised district cooling plant
Centralised heat pump
Also low energy buildings
District Heating
Development (District Heating generation) / Period of best available technology
1G / 1880-1930
2G / 1930-1980
3G / 1980-2020
4G / 2020-2050

strategic research centre for

ZERO ENERGY BUILDINGS





Industry

- Danfoss A/S
- Saint Gobain Isover A/S
- VKR Holding A/S
- AffaldVarme Århus
- Velux A/S
- Alufacadesektionen, Dansk Byggeri

Research

Aalborg University

- Department of Architecture and Design
- Department of Civil Engineering
- Department of Energy
- Department of Electronic Systems
- Department of Planning and Development
- Danish Building Research Institute, Department of Energy and Environment

Technical University of Denmark

- Department of Civil Engineering

Danish Technological Institute

- Department of Energy Efficiency and Ventilation
- Department of Cooling and Heat Pump Technology
- Department of Renewable Energy

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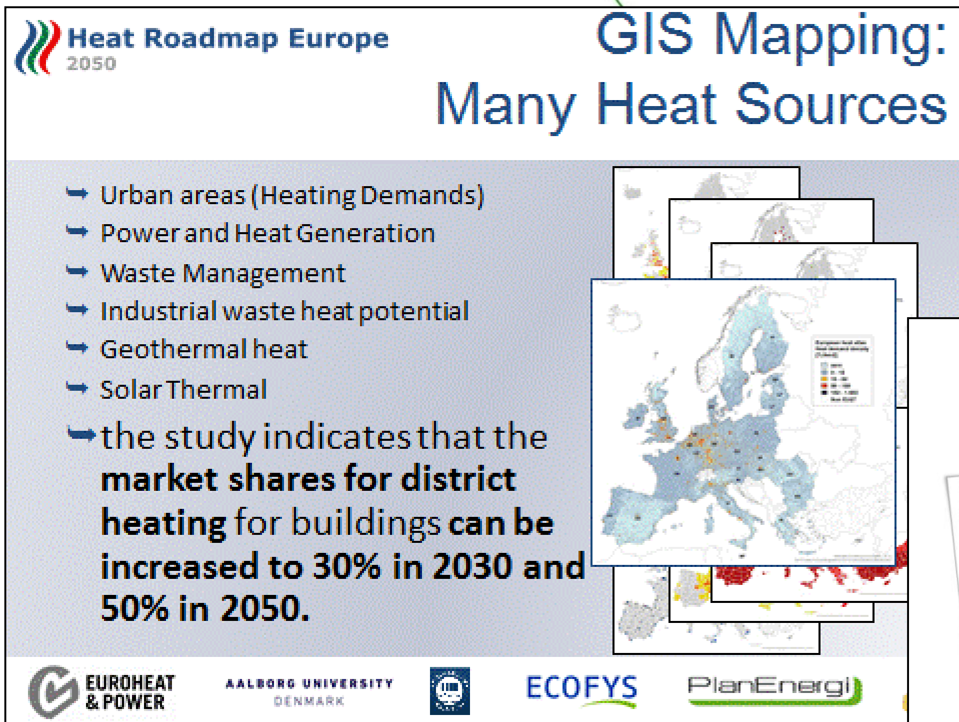
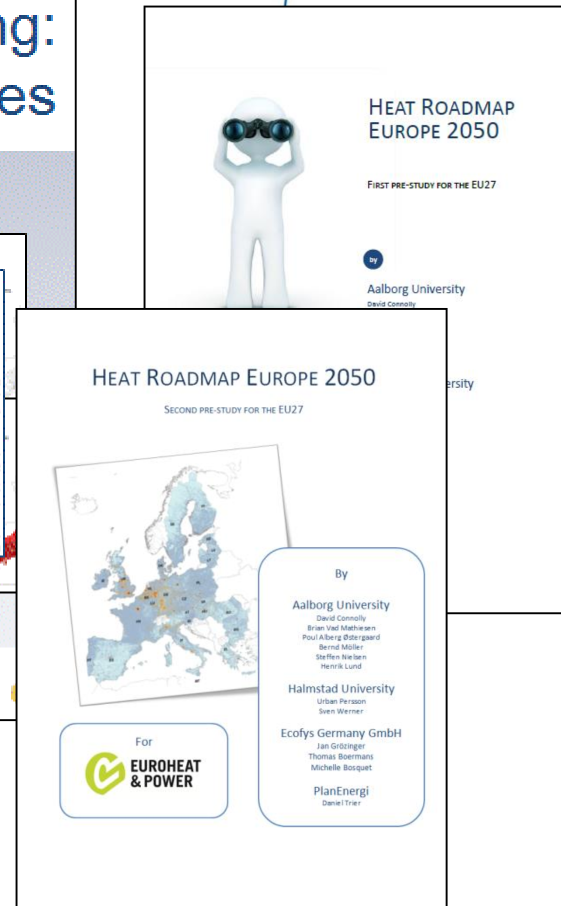
EUROHEAT & POWER

Heat Roadmap Europe

4DH
4th Generation District Heating Technologies and Systems





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ECOFYS
sustainable energy for everyone

PlanEnergi

HÖGSKOLAN HALMSTAD

STRATEGO WP2

Enhanced National Heating and Cooling Strategies

Stratego

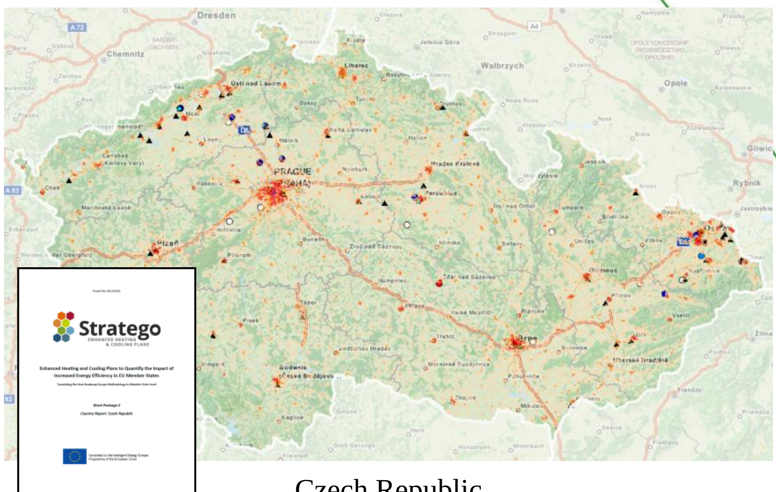
4DH
4th Generation District Heating Technologies and Systems

Co-funded by the Intelligent Energy Europe Programme of the European Union

Heat Roadmap Europe 2050

Stratego

Specific Map & Summary Report Available for Each Country



Czech Republic

Croatia

Heat Demand Classes

1 km2 densities of calculated heat demand.

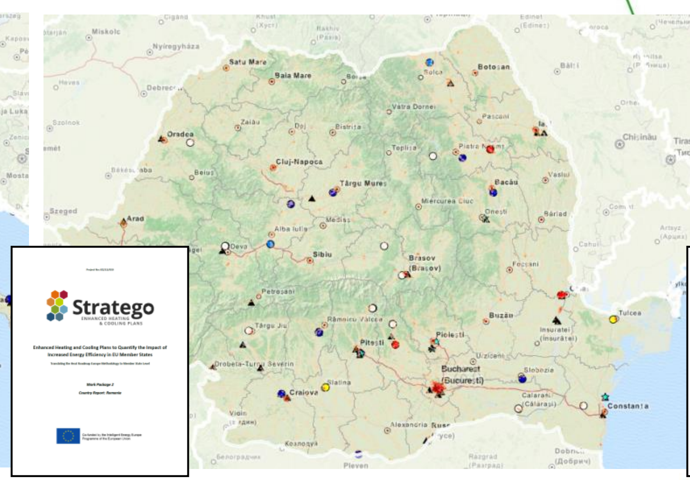
- < 30 TJ/km2
- 30 - 100 TJ/km2
- 100 - 300 TJ/km2
- > 300 TJ/km2

Excess heat facilities

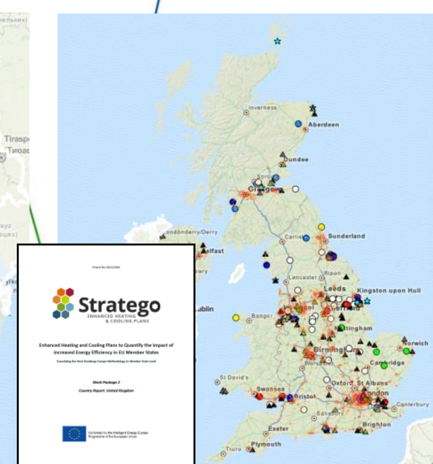
Annual excess heat volumes stated refers to maximal potential, not necessarily reflecting practically recoverable volumes.

- Chemical and petrochemical
- Food and beverage
- Iron and steel
- Non-ferrous metals
- Non-metallic minerals
- Paper, pulp and printing
- Fuel supply and refineries
- Thermal Power Generation - Waste-to-Energy
- Thermal Power Generation - Autoproducer
- Thermal Power Generation - Main activity

Italy



Romania



United Kingdom

100% Renewable Energy 2050
… the overall system..

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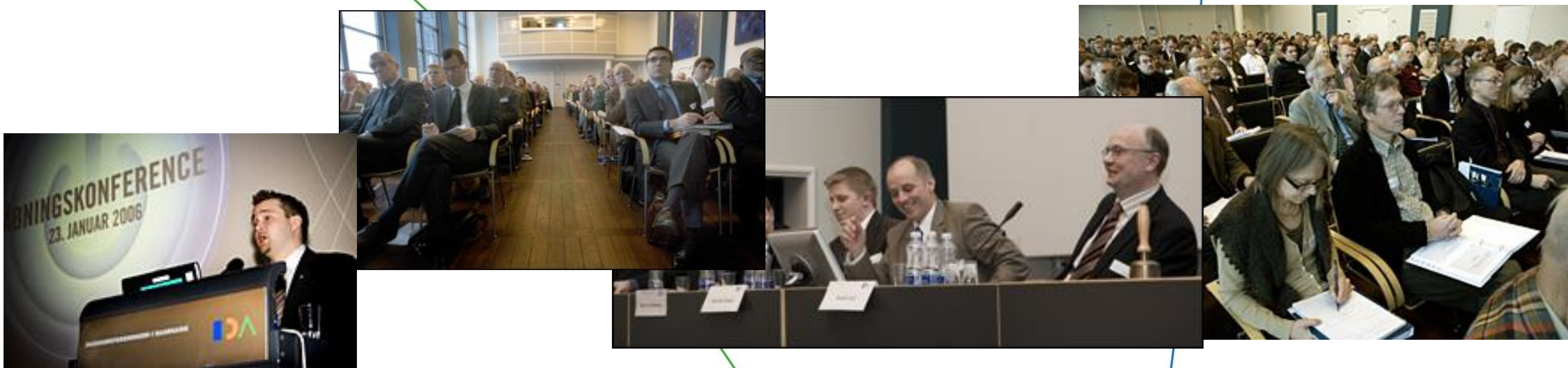
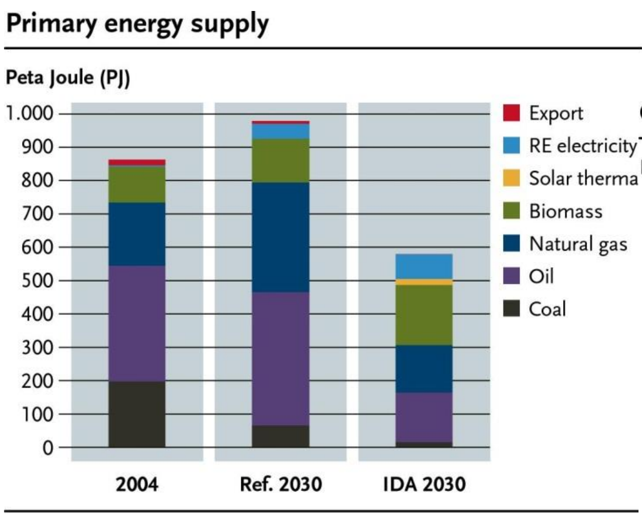
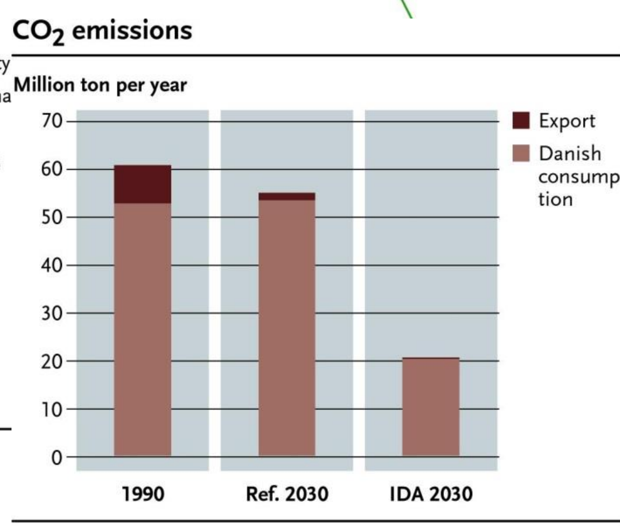
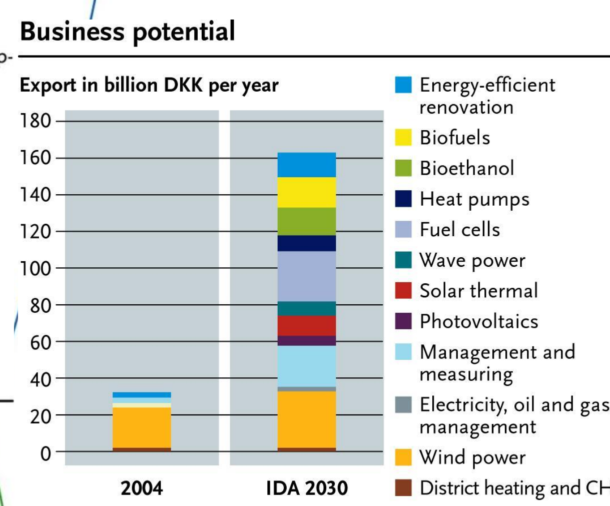


IDA Energiplan 2030







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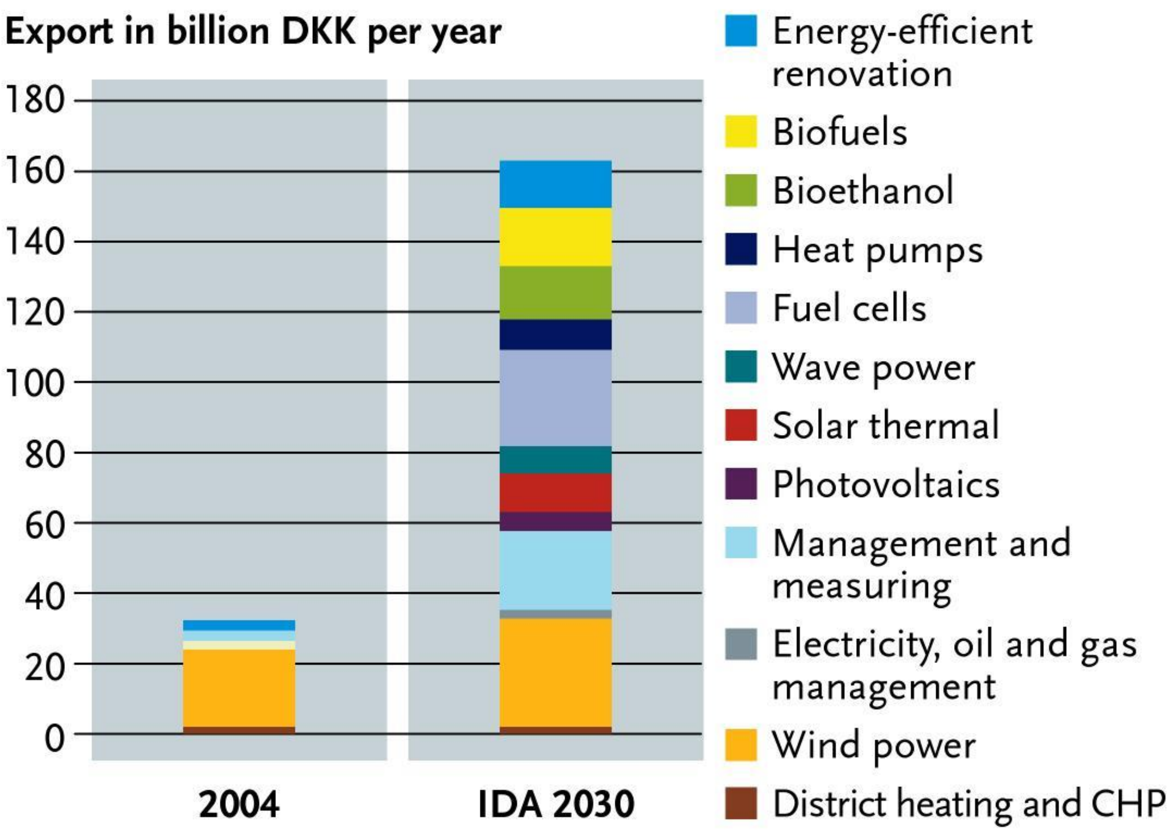
Business potential



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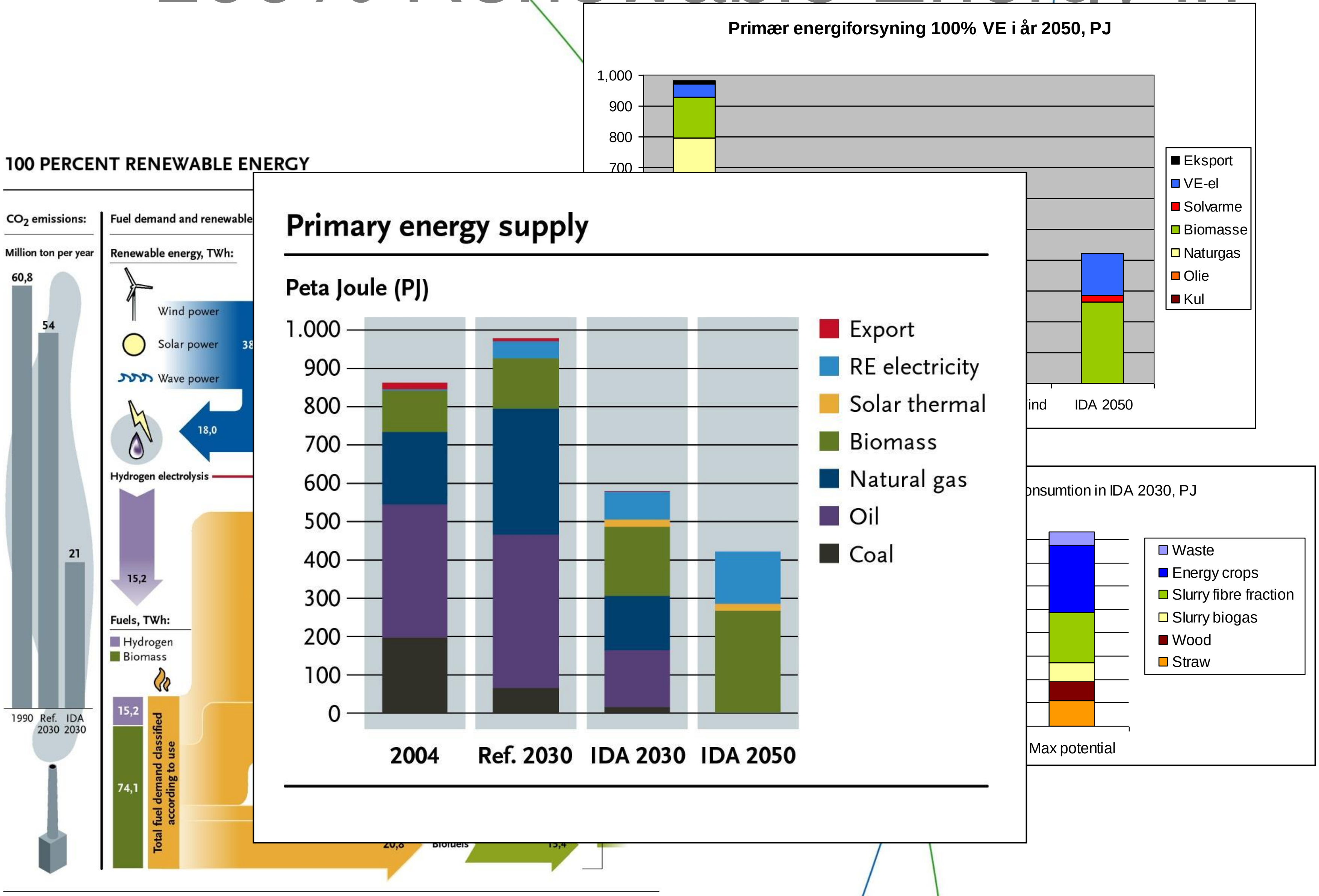
100% Renewable Energy in



DTU Danmarks Tekniske Universitet

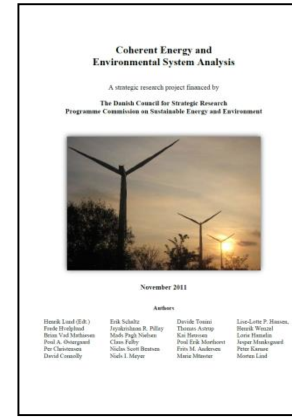
CBS COPENHAGEN BUSINESS SCHOOL HANDELSHØJSKOLEN

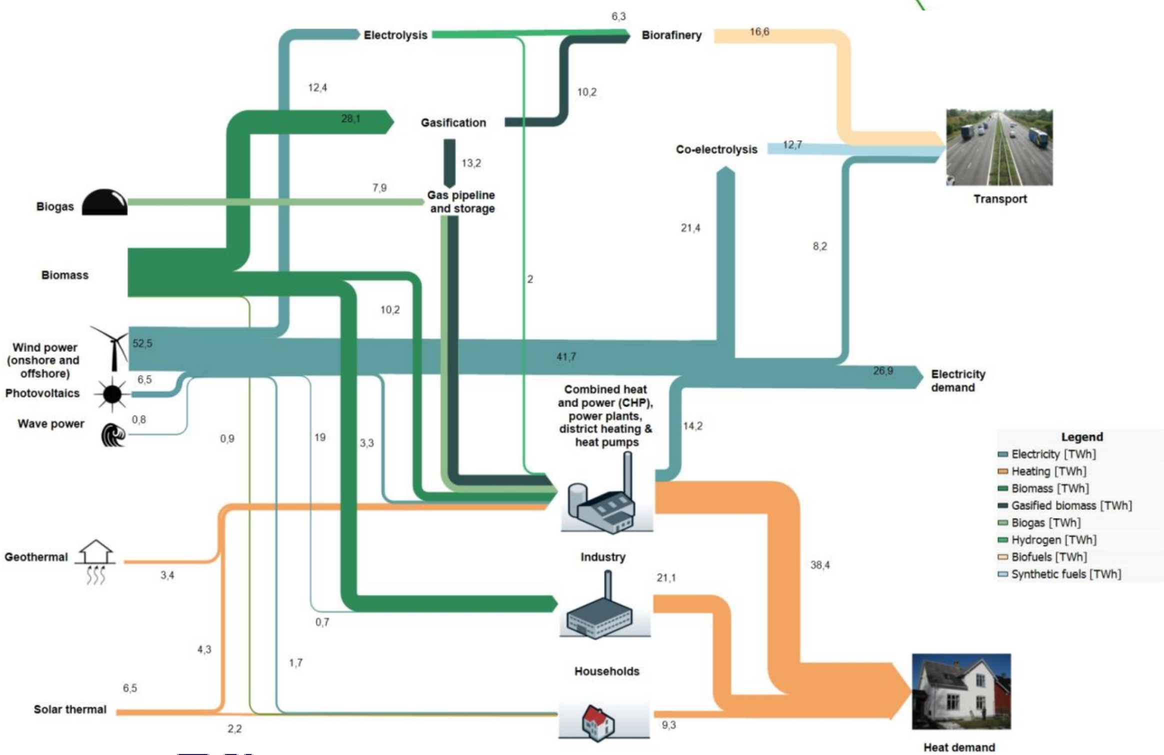
AALBORG UNIVERSITY DENMARK

KØBENHAVNS UNIVERSITET

SYDDANSK UNIVERSITET

CEESA Project 2011/2012





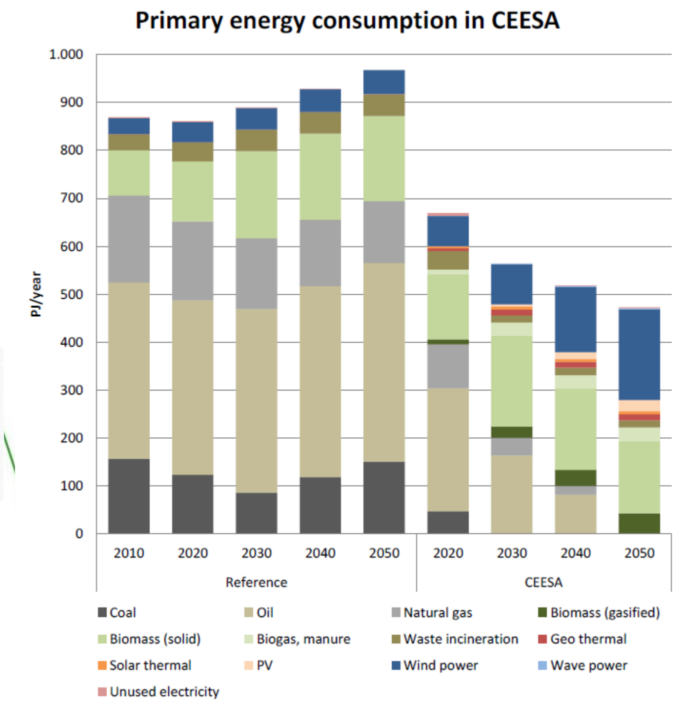
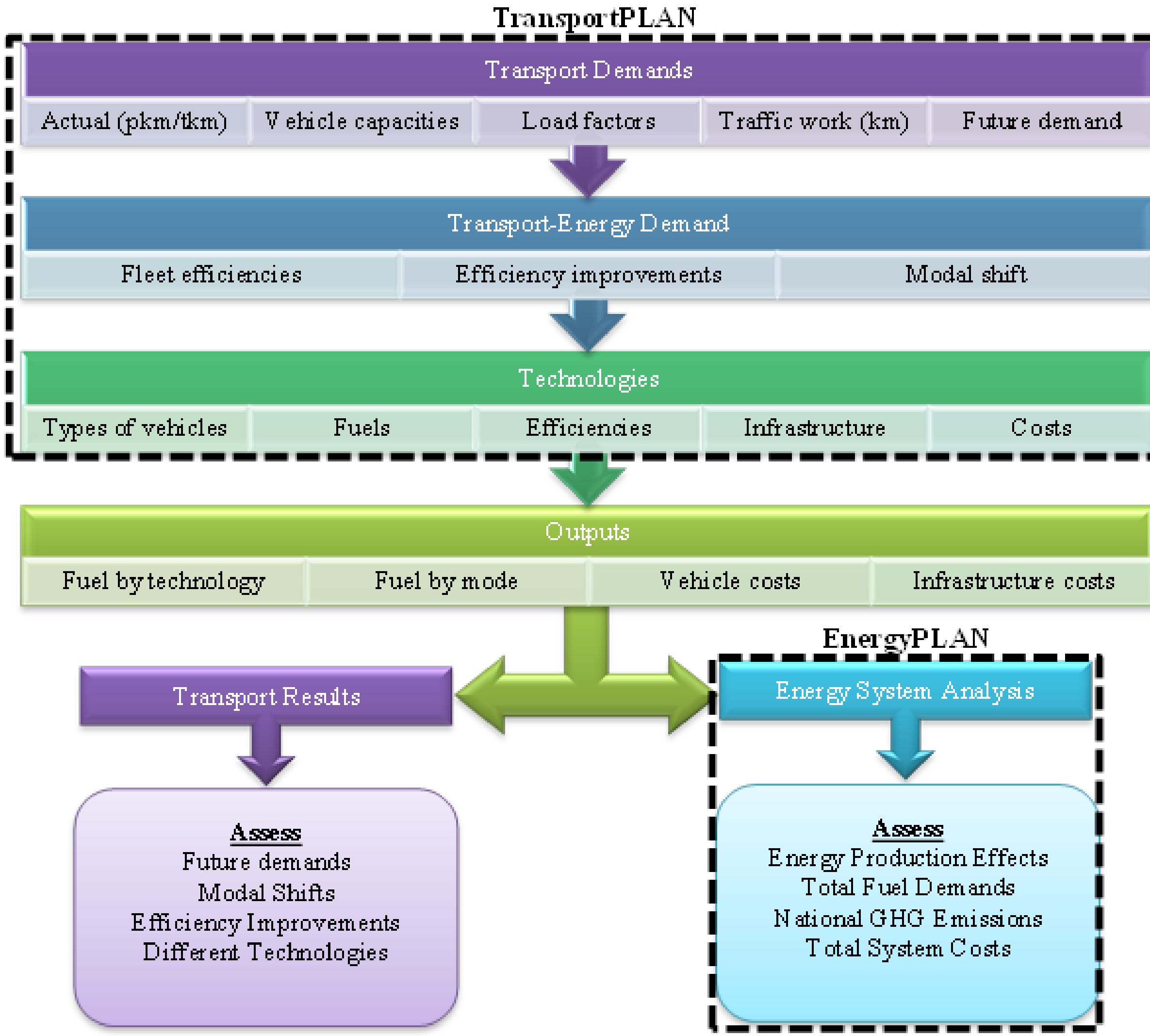


Figure 2: Primary Energy Supply in CEESA.

TransportPLAN modeling and profiling in CEESA

- Particular focus due to large challenges:
  - >95% reliant on oil
  - High increase historically
  - Large potential for electric cars and direct electricity but..
  - Specific challenges in bringing in electricity in sea, aviation and good transport



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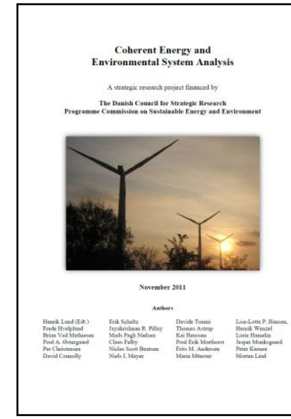
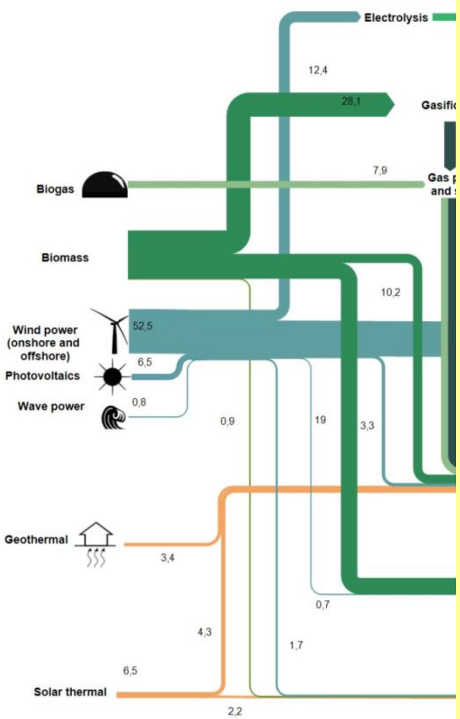


CEESA Project 2011/2012



Transport:
Electric vehicles is best from an energy efficient point of view. But gas and/or liquid fuels is needed to transform to 100%.

Biomass:
.. is a limited resource and can not satisfy all the transportation needs.

Consequence
… Electricity from Wind (and similar resources) needs to be converted to gas and liquied fuels in the long-term perspective…

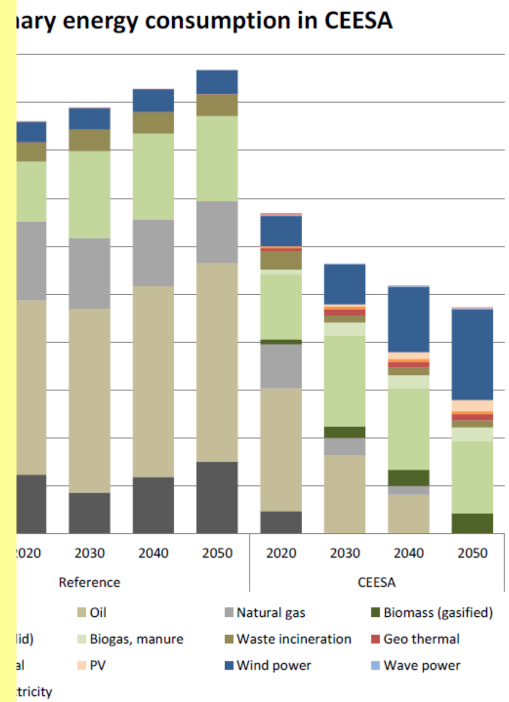


Figure 2: Primary Energy Supply in CEESA.

100% Renewable Energy 2050
Power-to-Transportation

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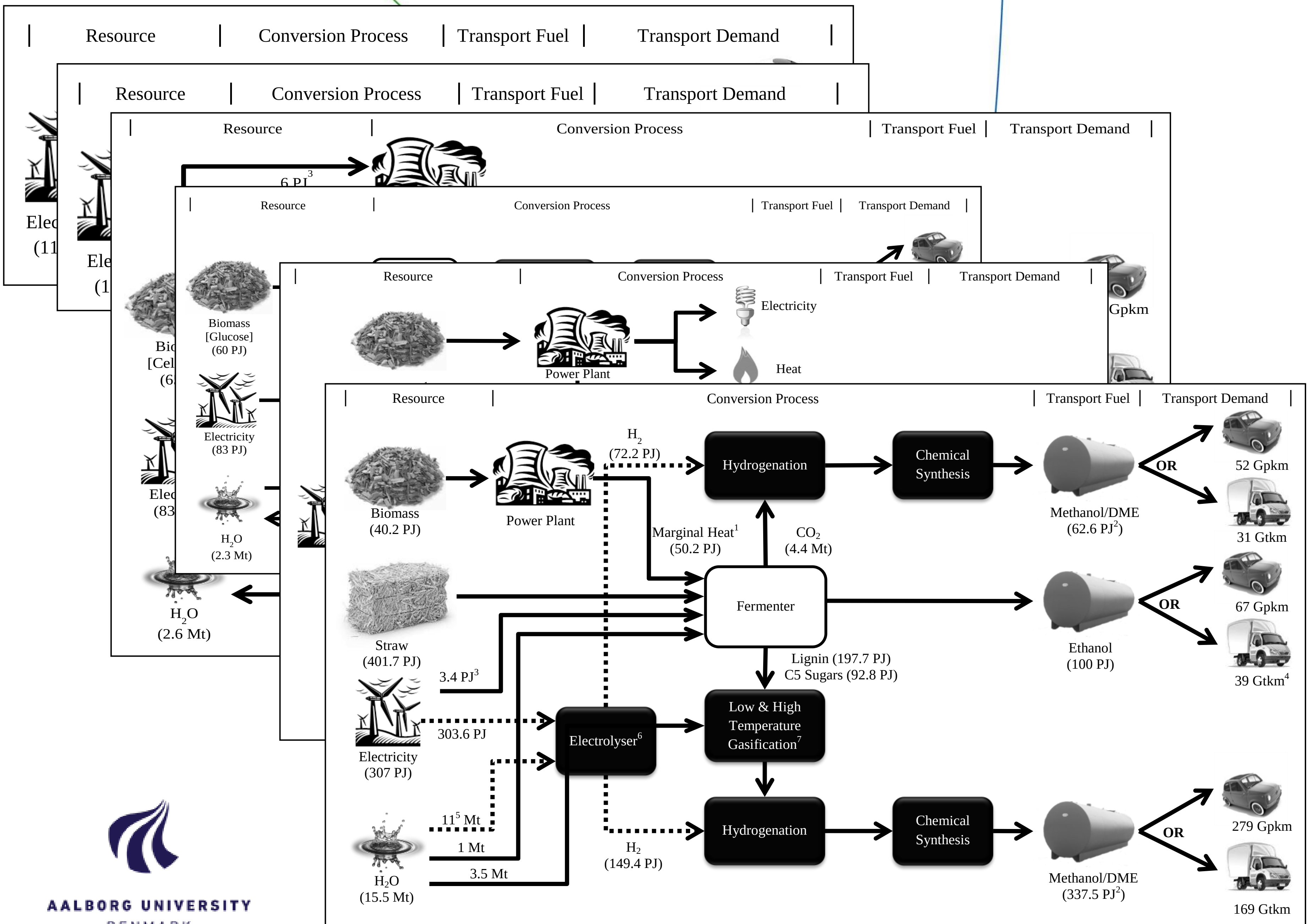

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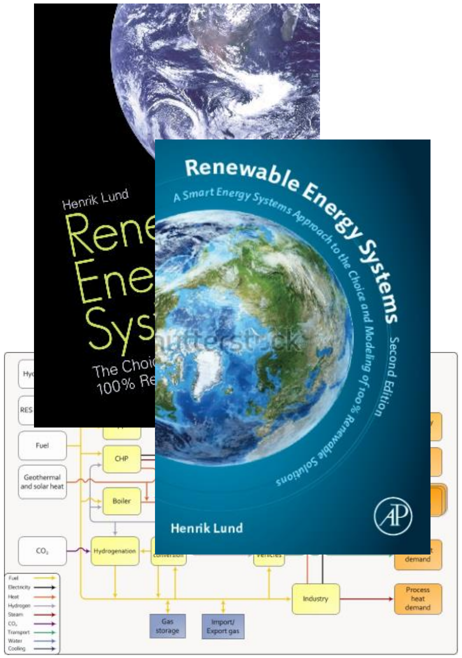
Smart Energy Systems

The key to cost-efficient 100% Renewable Energy

- A sole focus on renewable **electricity (smart grid)** production leads to electricity storage and flexible demand solutions!

- Looking at renewable electricity as a part **smart energy systems** including heating, industry, gas and transportation opens for cheaper and better solutions…



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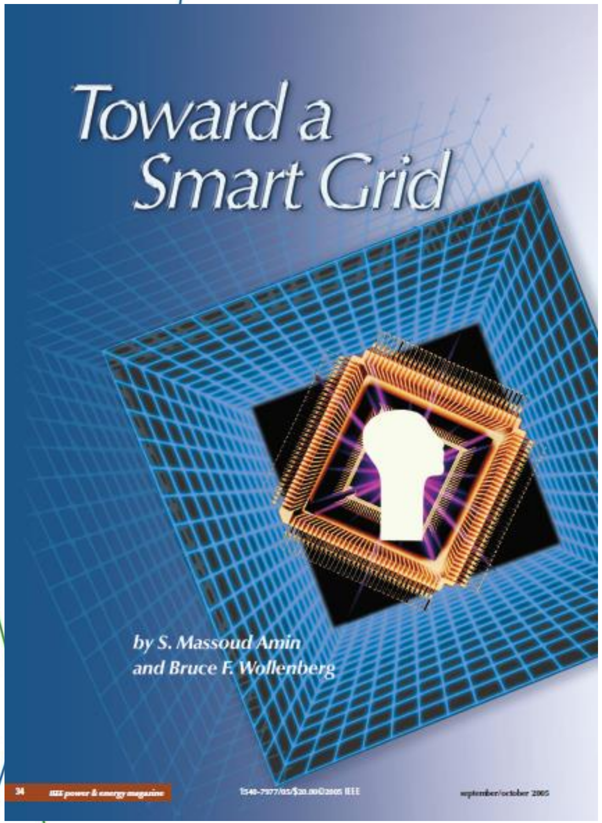
Power-to-Heat

Power-to-Gas
Power-to-Transport

Smart Grid (2005)

No definition.

However it can be understood from the context that a *smart grid* is a power network using modern computer and communication technology to achieve a network which can better deal with potential failures.



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Smart Grid - definitions

"A *smart grid* is an electricity grid that uses information and communications technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity." (U.S. Department of Energy)

"*Smart Grids* … concerns an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies." (SmartGrids European Technology Platform, 2006).

"A *Smart Grid* is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety." (European Commission, 2011)

"*Smart grids* are networks that monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users" …. "The widespread deployment of smart grids is crucial to achieving a more secure and sustainable energy future." (International Energy Agency 2013).

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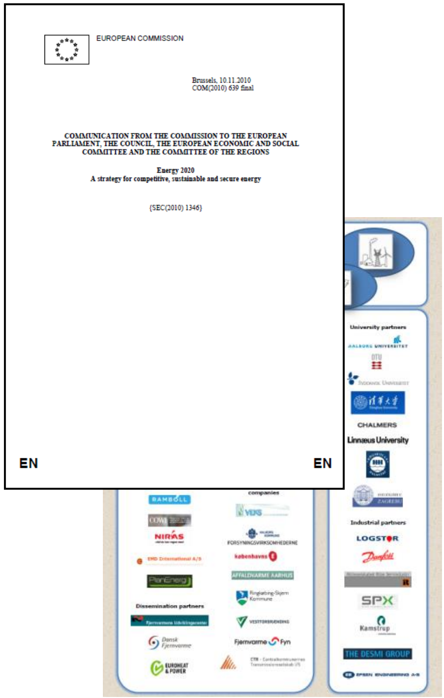
Smart heating and cooling grids

- In the European Commission’s strategy [7] for a competitive, sustainable and secure “Energy 2020“, the need for *“high efficiency cogeneration, district heating and cooling*” is highlighted (page 8). The paper launches projects to promote, among others, *“smart electricity grids*” along with *“smart heating and cooling grids*” (page 16).


EUROPEAN COMMISSION

Brussels, 10.11.2010
COM(2010) 639 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Energy 2020
A strategy for competitive, sustainable and secure energy

{SEC(2010) 1346}

EN EN

4DH
4th Generation District Heating Technologies and Systems

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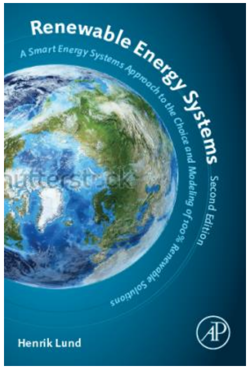
Smart Energy Systems



- *Smart Electricity Grids* are define as electricity infrastructures that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.

Smart Energy Systems is define as an approach in which Smart Electricity, Thermal and Gas Grids are combined and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system.

- *Gas Smart Grids* are defined as gas infrastructures that can intelligent integrate the actions of all users connected to it - supplies, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure gas supplies and storage.

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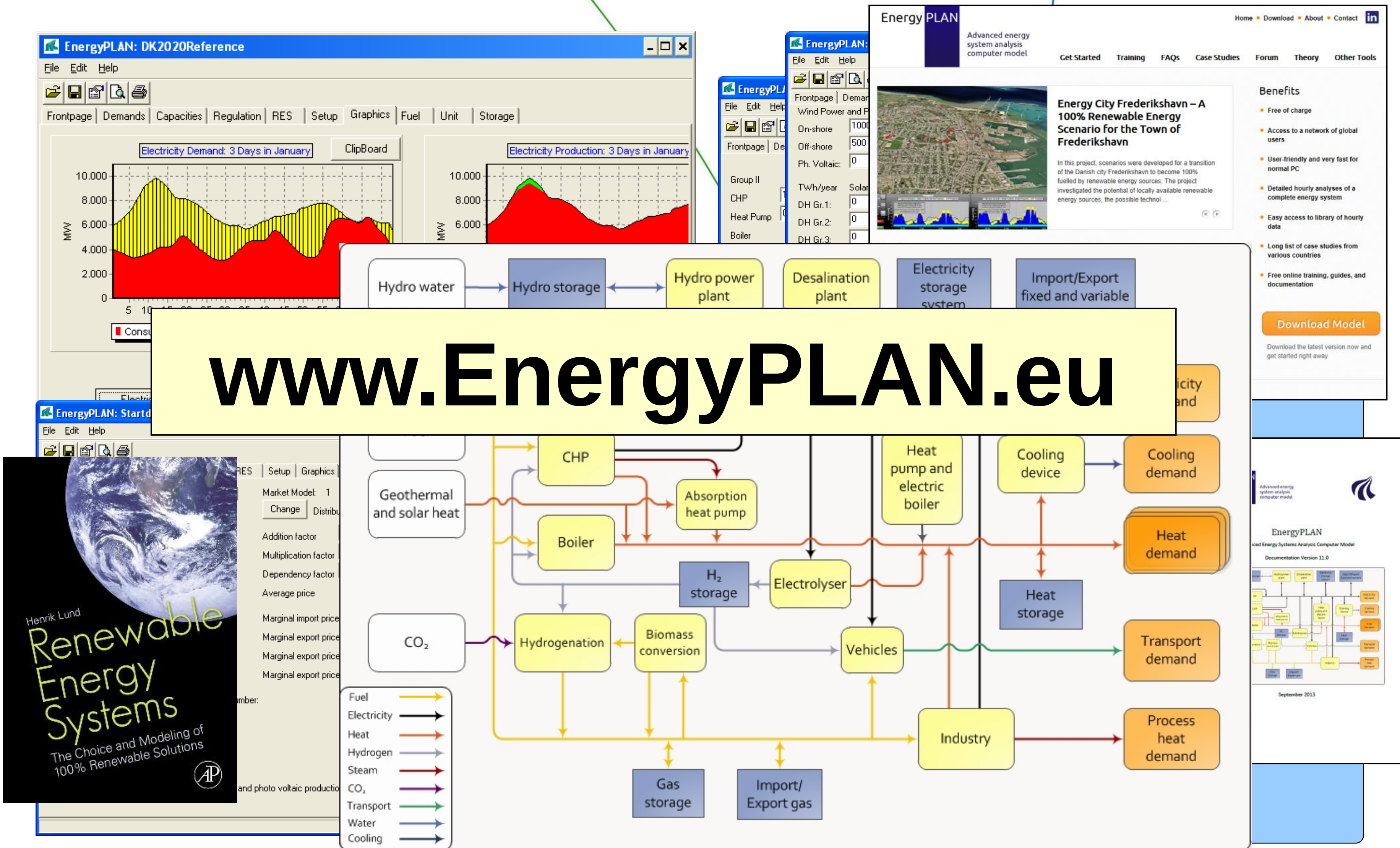
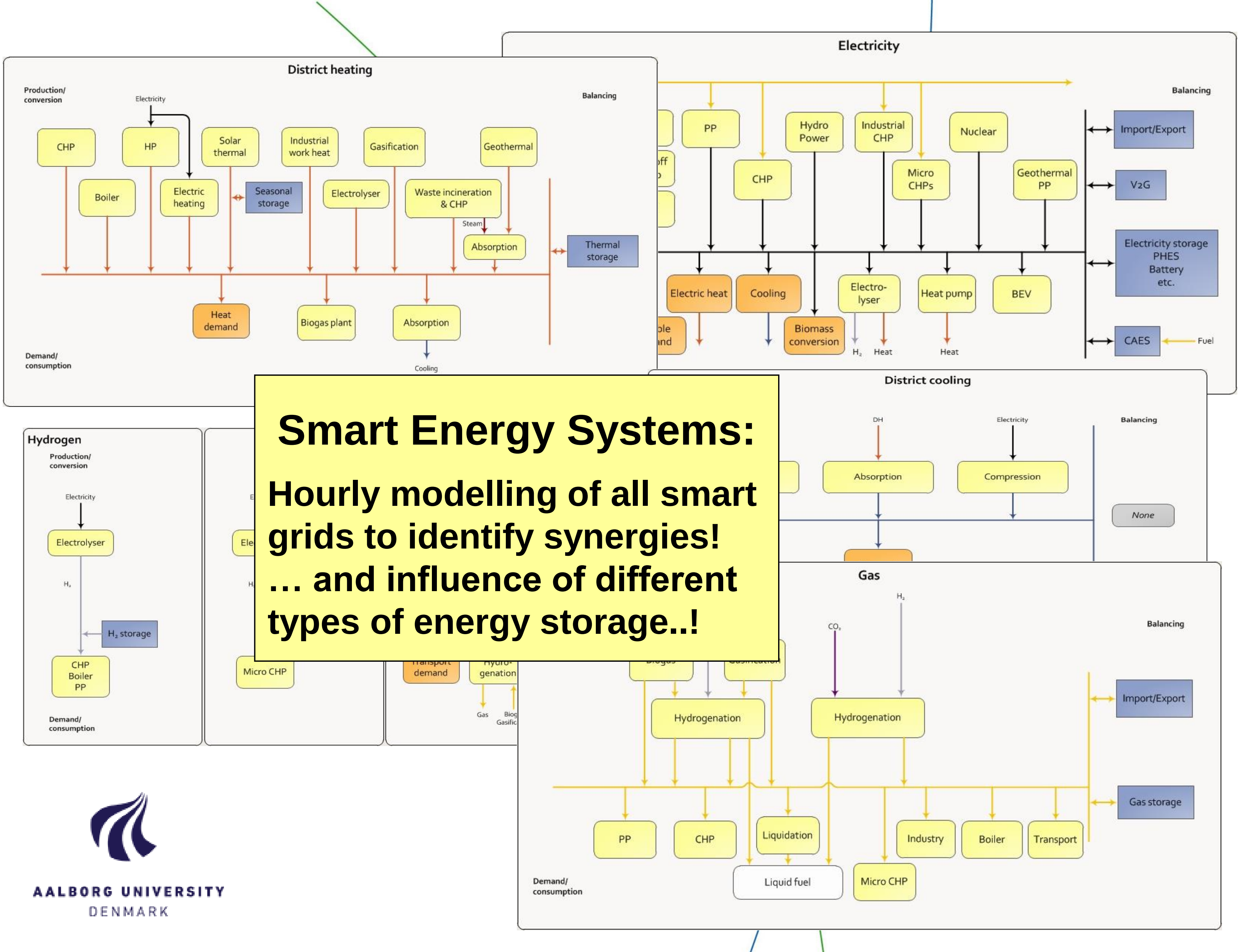
Energi System Analyse Model



www.EnergyPLAN.eu

Smart Energy Systems:

Hourly modelling of all smart grids to identify synergies!
… and influence of different types of energy storage..!



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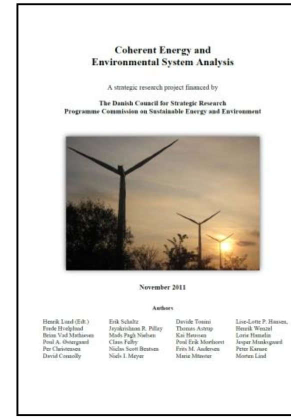
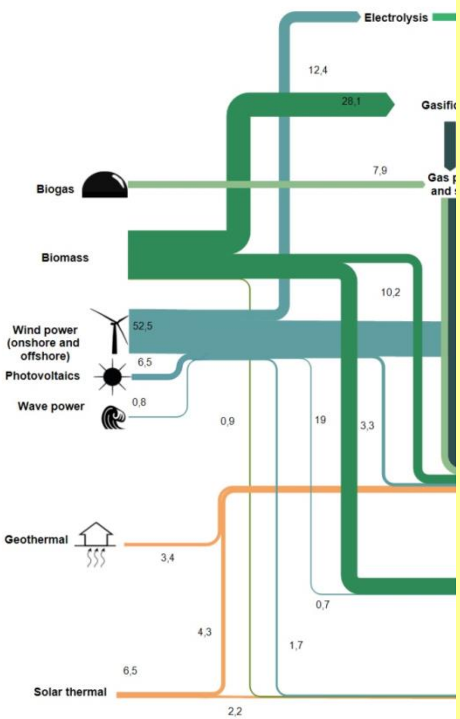




Smart Energy Systems:
Integrated use of Power-To-Heat, Power-To-Transport and Power-To-Gas/Liquid fuel

RES integration:
Hourly balance of wind etc. by use of thermal and gas/fuel storage. (Least-cost solution)

No electricity storage
… except from batteries in cars…

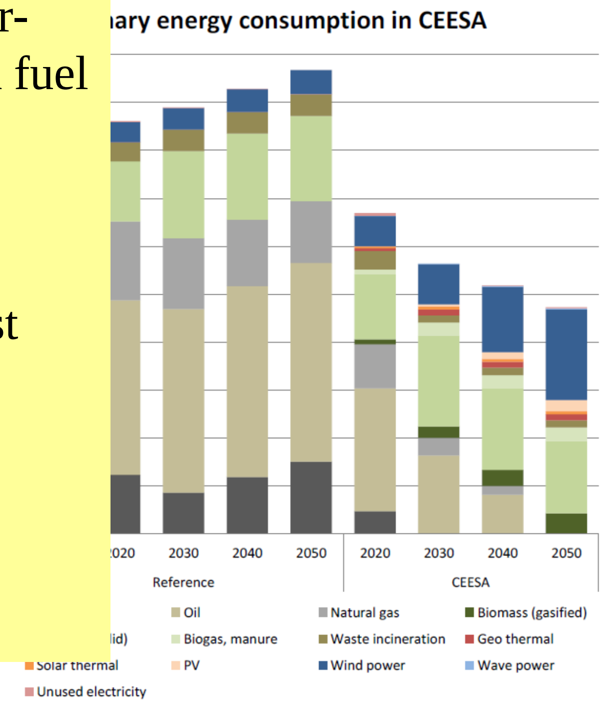
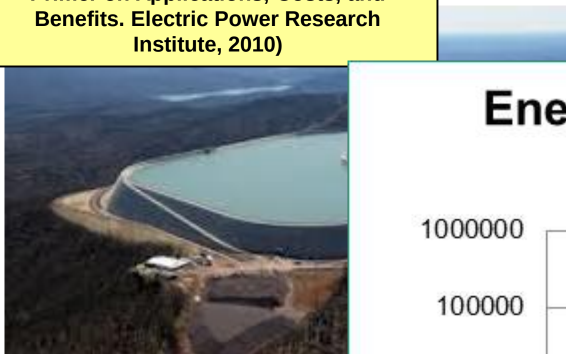
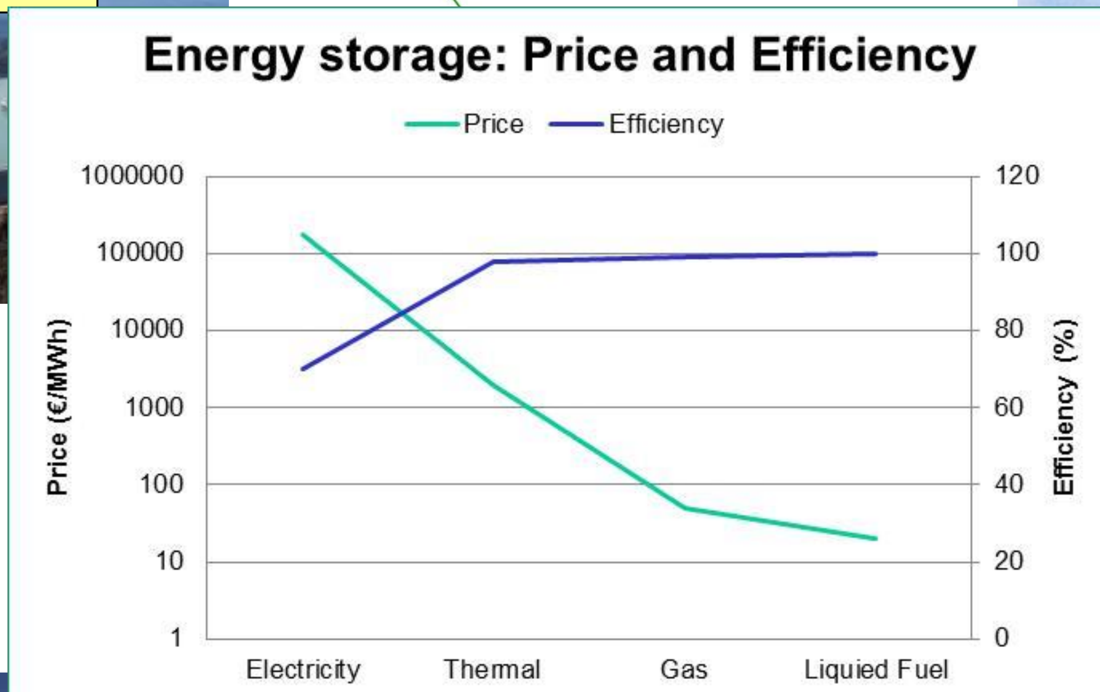


Figure 2: Primary Energy Supply in CEESA.

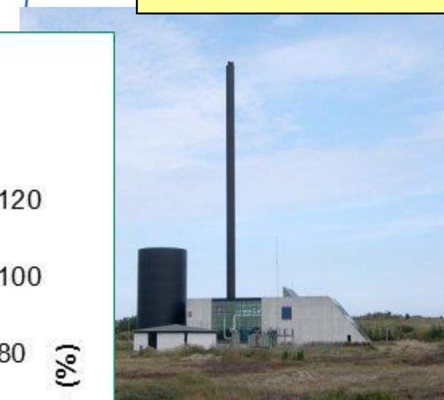
Energy Storage

Pump Hydro Storage
175 €/kWh
(Source: Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits. Electric Power Research Institute, 2010)



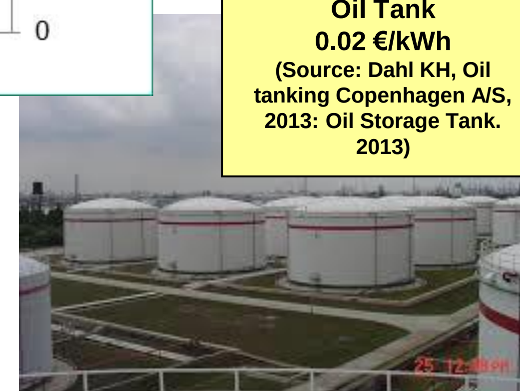


Thermal Storage
1-4 €/kWh
(Source: Danish Technology Catalogue, 2012)



Natural Gas Underground Storage
0.05 €/kWh
(Source: Current State Of and Issues Concerning Underground Natural Gas Storage. Federal Energy Regulatory Commission, 2004)

Oil Tank
0.02 €/kWh
(Source: Dahl KH, Oil tanking Copenhagen A/S, 2013: Oil Storage Tank. 2013)



More information:

http://energy.plan.aau.dk/book.php

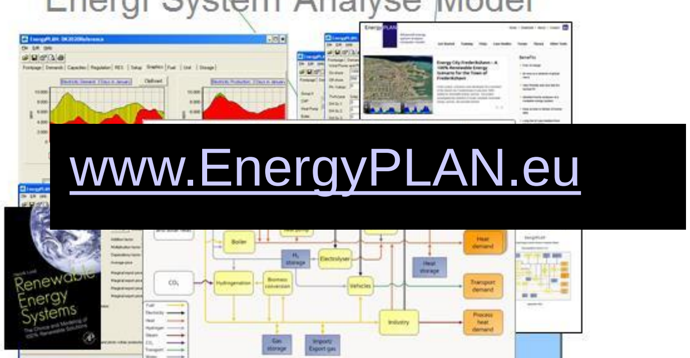
www.4DH.dk

4DH
4th Generation District Heating

Stratego

www.strategto-project.eu

www.heatroadmap.eu



www.EnergyPLAN.eu

- http://www.emd.dk/desire/skagen
- http://www.emd.dk/el

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