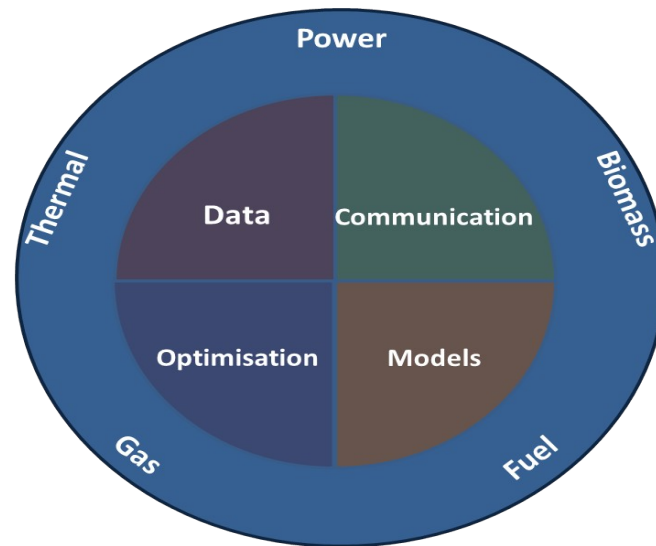


# CITIES

## Center for IT-Intelligent Energy Systems in cities



**Henrik Madsen, DTU Compute**

<http://www.henrikmadsen.org>

<http://www.smart-cities-centre.org>

Quote by B. Obama at the Climate Summit 2014 in New York:

*We are the **first generation** affected by climate changes,  
and we are the **last generation** able to do something about it!*



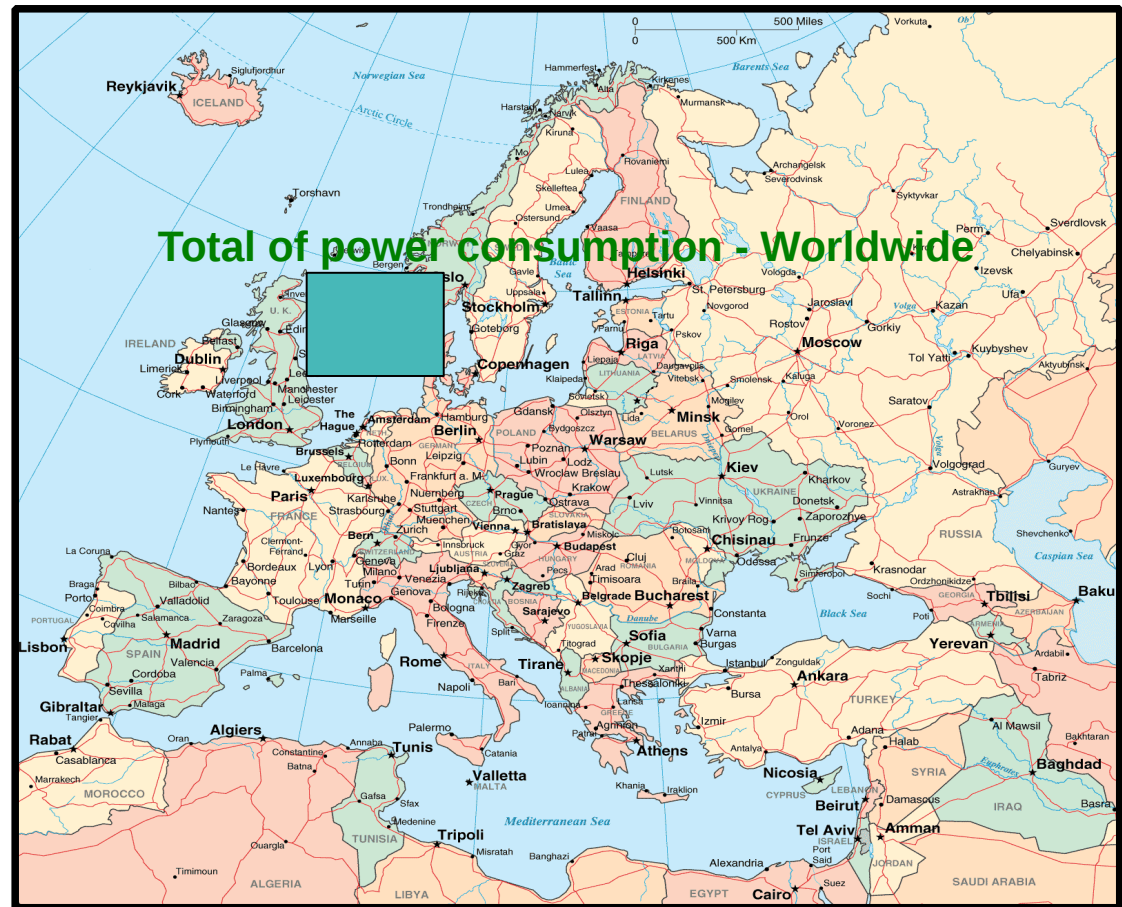
# Potentials and Challenges for renewable energy

- **Scenario:** We want to cover the worlds entire need for power using wind power.
- How large an area should be covered by wind turbines?

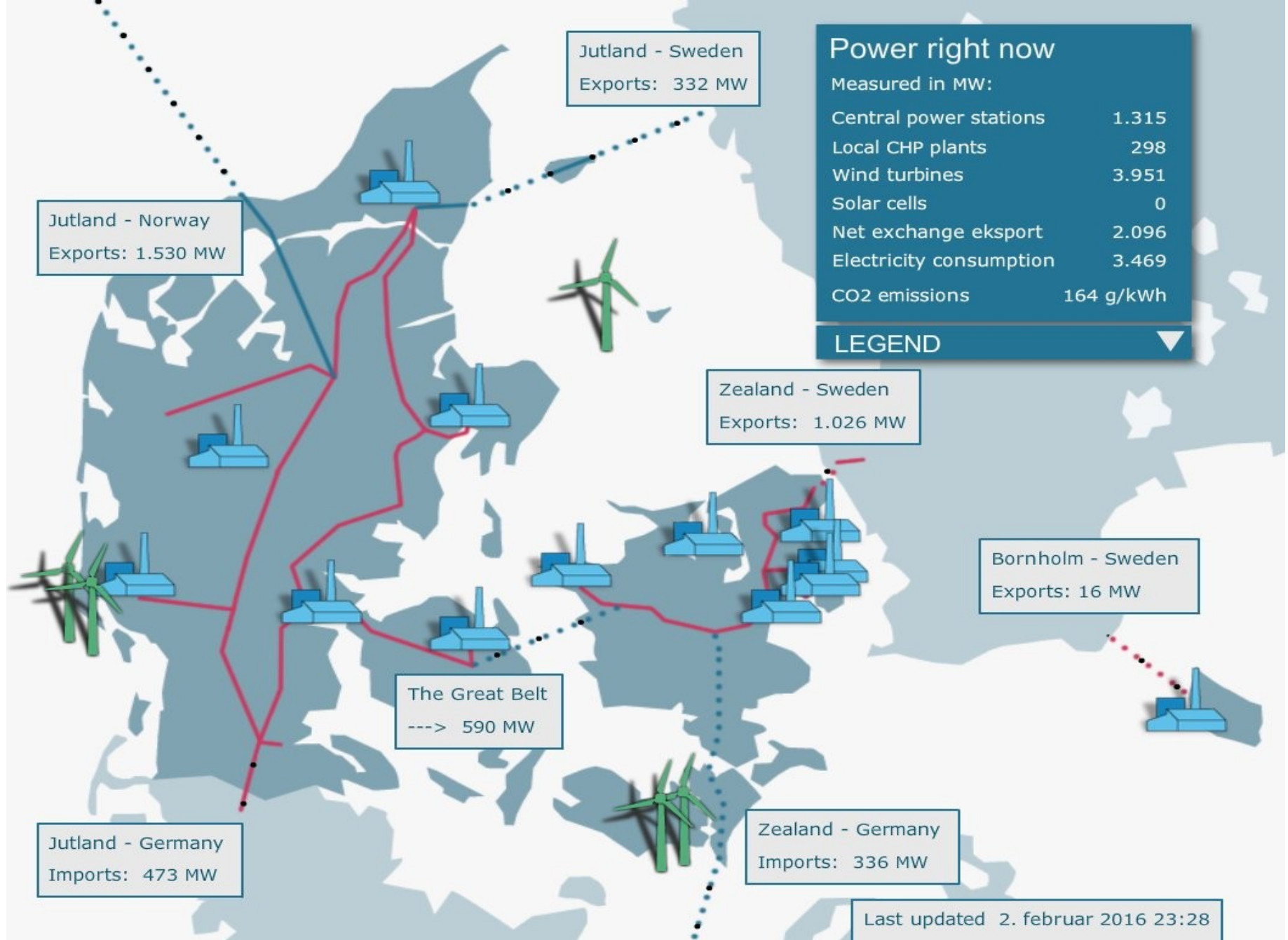


# Potentials and Challenges for renewable energy

- **Scenario:** We want to cover the worlds entire need for power using wind power
- How large an area should be covered by wind turbines?
- **Conclusion:** Use intelligence ....
- Calls for **IT / Big Data / Smart Energy/Cities Solutions/ Energy Systems Integration**







**CITIES**

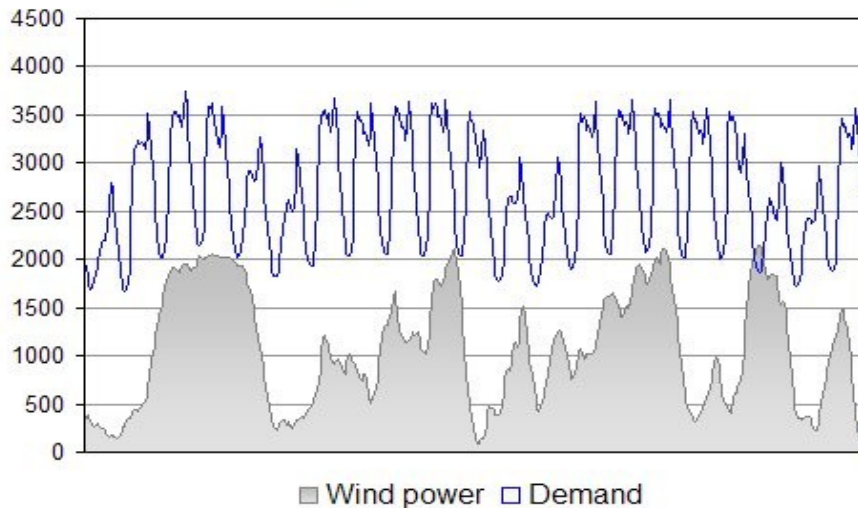
Centre for IT Intelligent Energy Systems

**Boston Climate Bridge – Women Leading Change**

# The Danish Wind Power Case

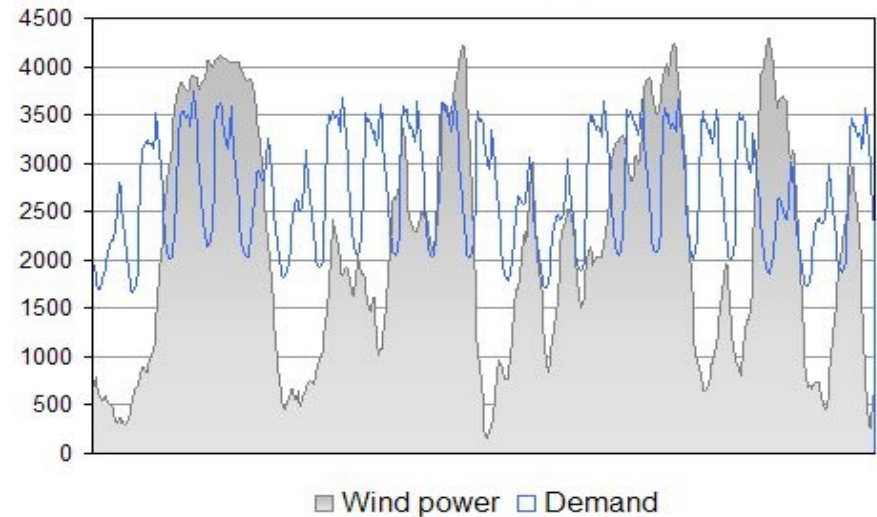
.... balancing of the power system

25 % wind energy (West Denmark January 2008)



In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

50 % wind energy



**In 2015 more than 42 pct of electricity load was covered by wind power.**

For several days the wind power production was more than 100 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power

Latest production data for Tyra: 6.061.111 kWh  
Applicable for 15. februar 2014 11:00-12:00

Lille Torup gas storage facility Entry: 824.732 kWh/h  
Calorific value: 12,150 kWh/m<sup>3</sup>

Nybro Entry: 5.882.672 kWh/h  
Calorific value: 12,197 kWh/m<sup>3</sup>

Egtved Calorific value: 12,213 kWh/m<sup>3</sup>  
CO<sub>2</sub> emissionsfaktor: 56,76 kg/GJ

Ellund Exit: 1.002.678 kWh/h  
Calorific value: 12,228 kWh/m<sup>3</sup>

Stenlille gas storage facility 0 kWh/h  
Calorific value: 12,022 kWh/m<sup>3</sup>

Dragør Exit: 1.405.760 kWh/h  
Calorific value: 12,234 kWh/m<sup>3</sup>

## Natural gas right now

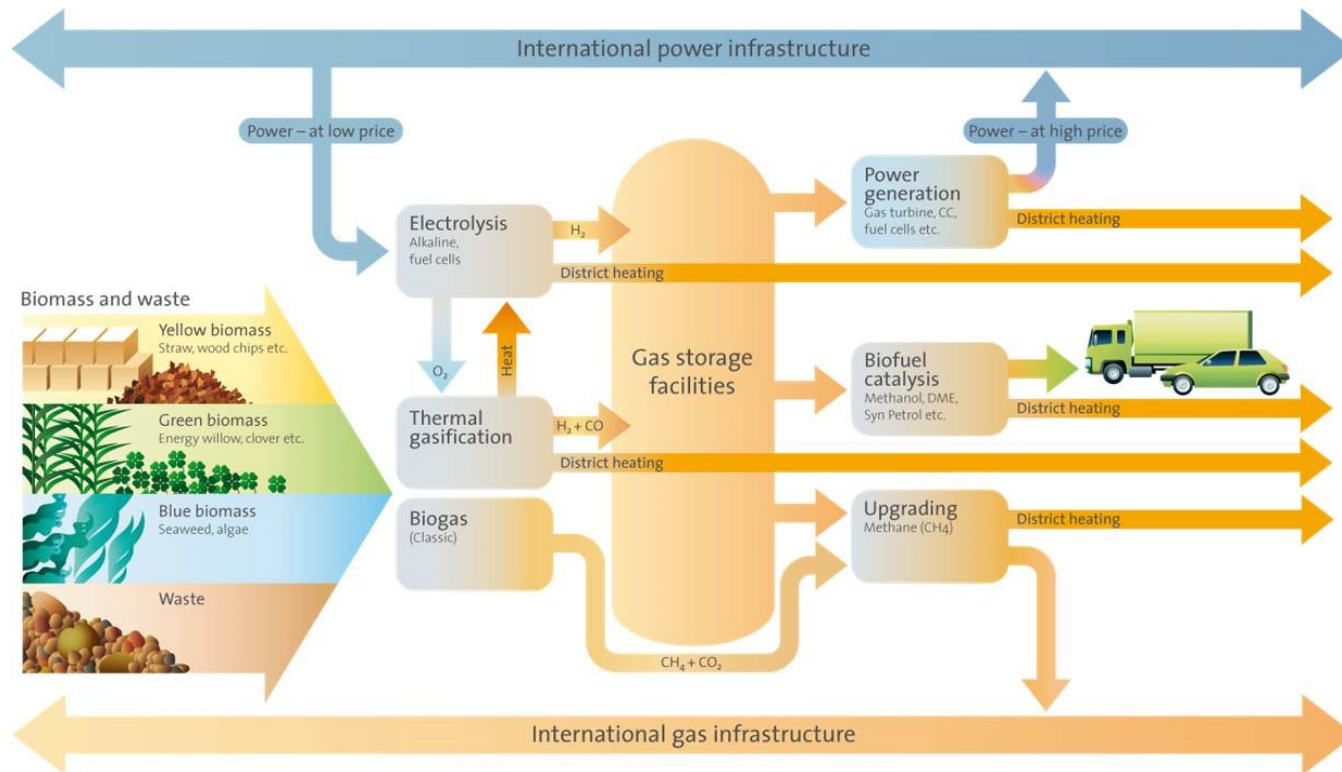
Gas flow – kWh/h:

Nybro entry	5.882.672
Ellund exit	1.002.678
Dragør exit	1.405.760
Energinet.dk Gas Storage	824.732
DONG Storage	0
Exit Zone	4.776.523
CO <sub>2</sub> emission factor	56,76 kg/GJ

## LEGEND



# Gas system is very important ... (Storage capacity approx. 40 Tesla Powerwalls in each house)



Meibom, P.; Hilger, K.B.; Madsen, H.; Vinther, D., "Energy Comes Together in Denmark: The Key to a Future Fossil-Free Danish Power System," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.46-55, Sept. 2013.



# Today



■ Centrale værker  
● Decentrale værker

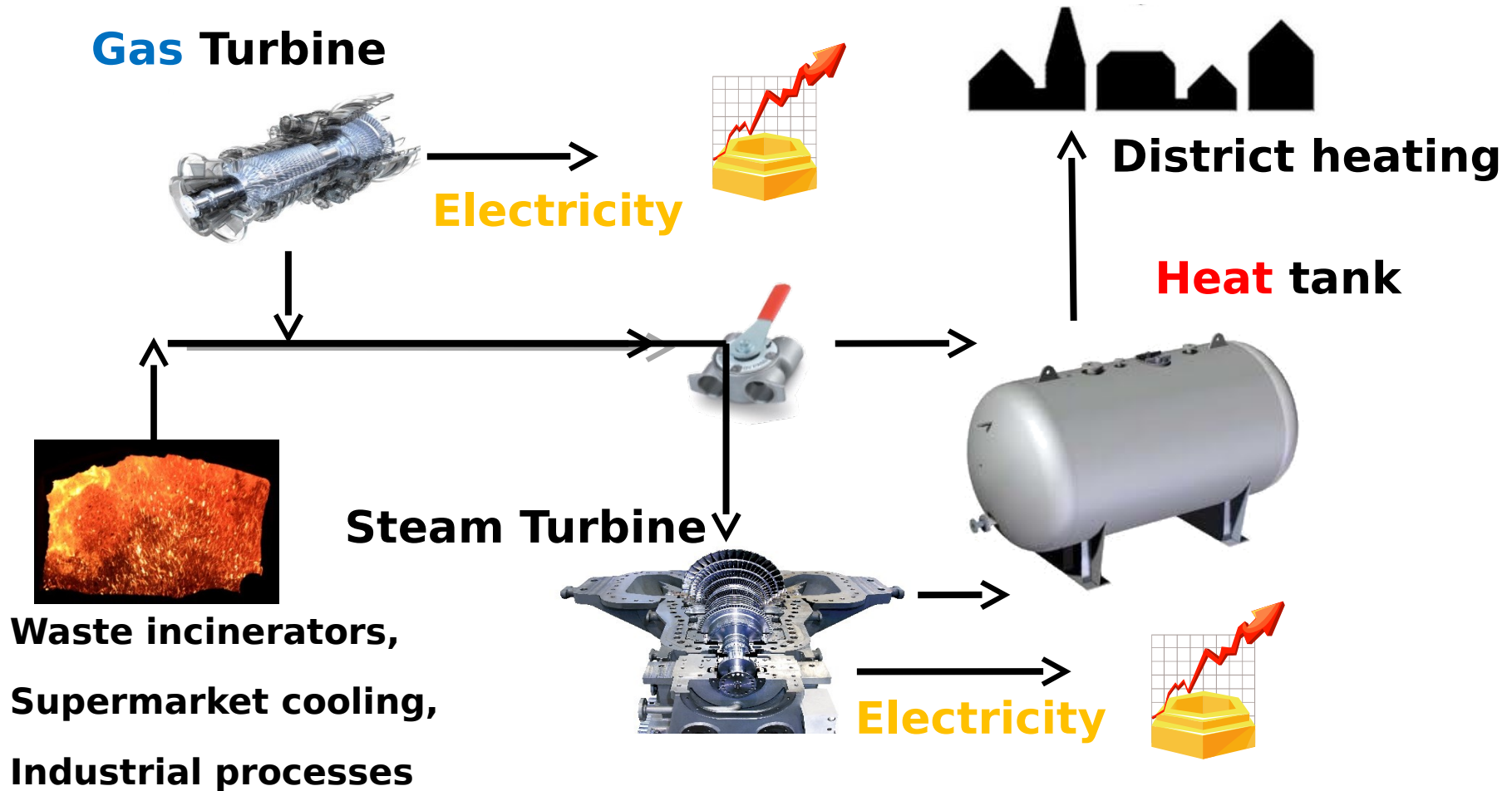
Kilde: Energistyrelsen, Energiproducenttællingen

DK has enough excess heat to cover the entire need for heating .... but ...

## Boston Climate Bridge – Women Leading Change

# CHP and Integrated Energy Systems

(Paradigmatic example - Denmark)



# Flexibility – Ringkøbing CHP

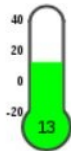


Sold Electricity: 0.0 MW

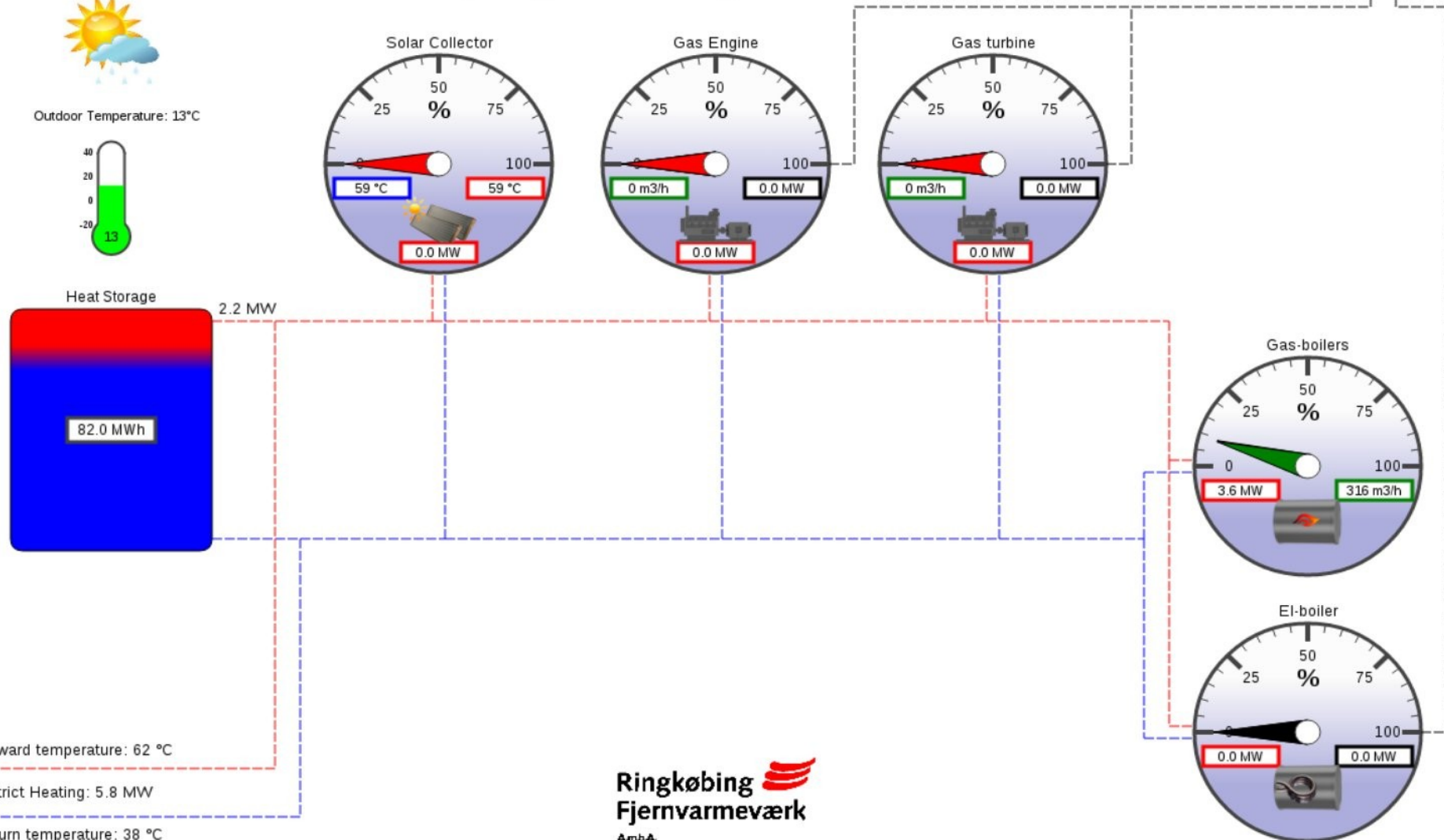
Solar Radiation: 2 W/m<sup>2</sup>



Outdoor Temperature: 13°C



Ringkøbing District Heating - 28-05-2016 23:36:00



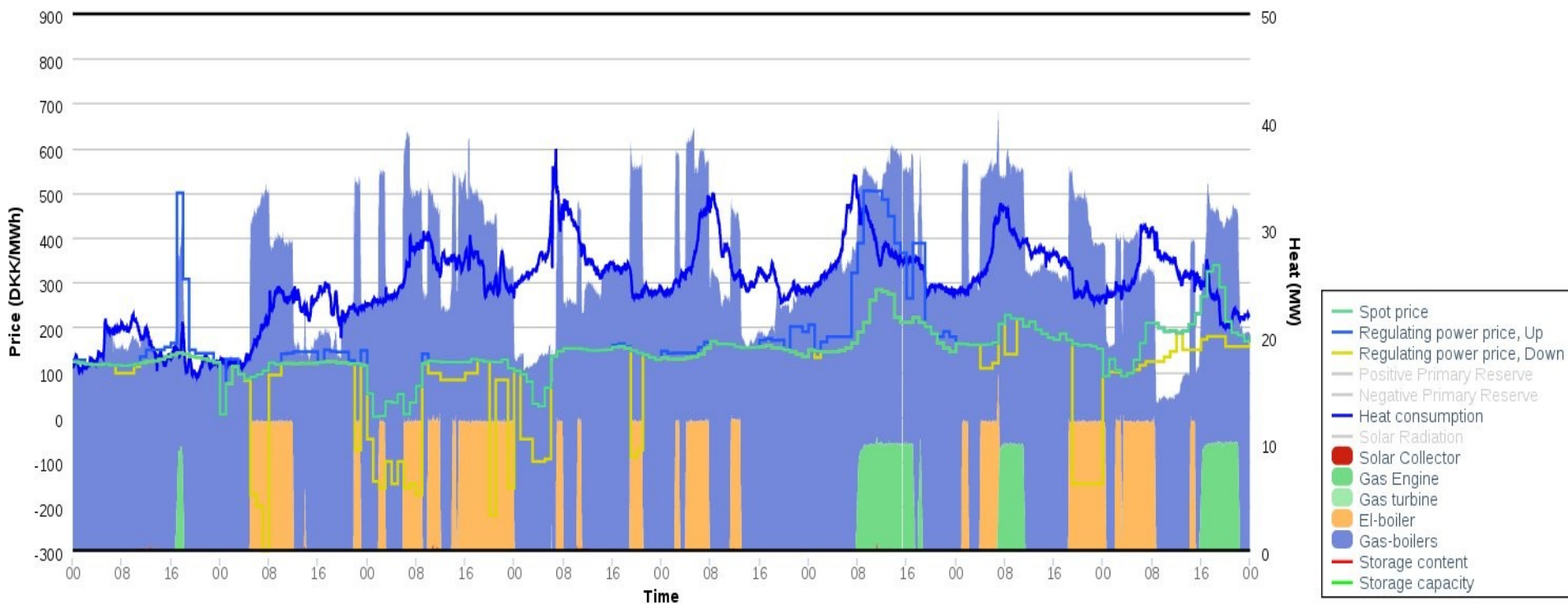
CITIES

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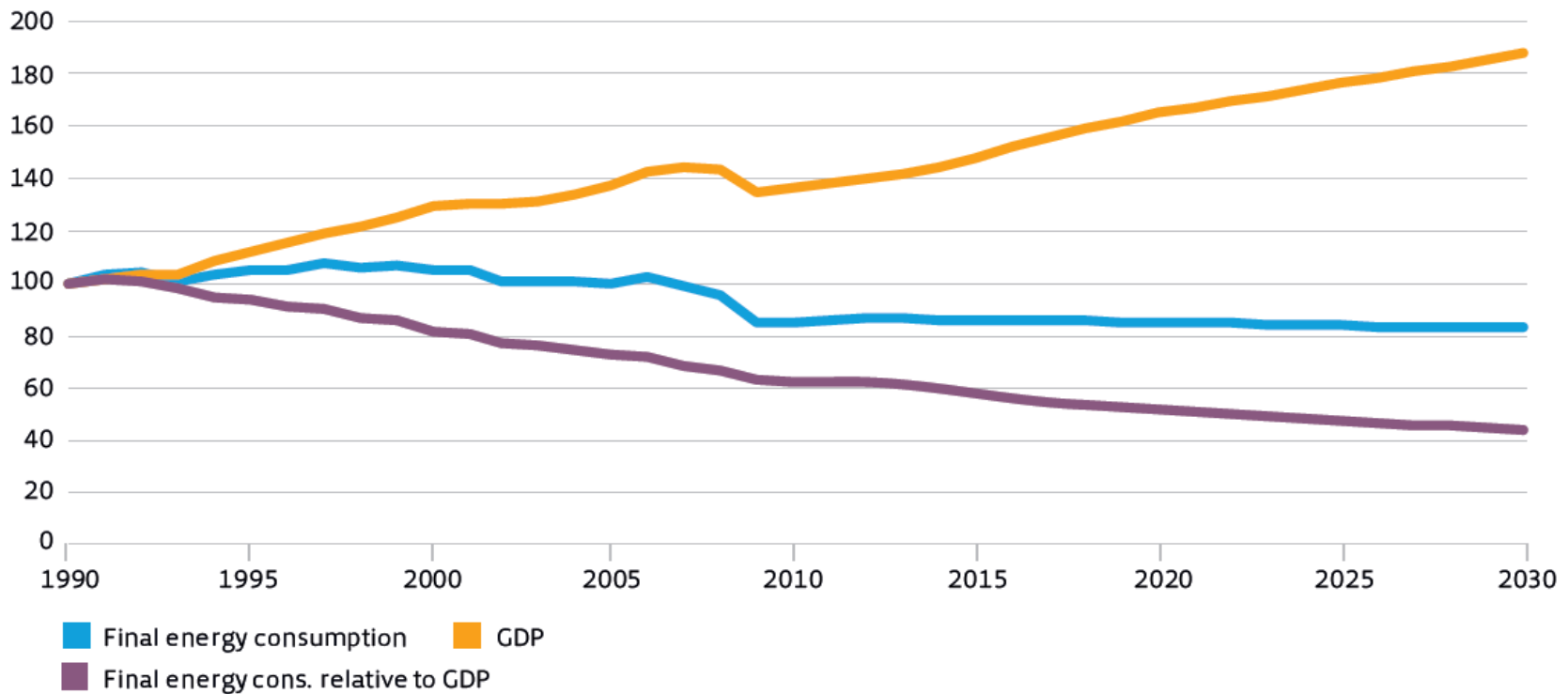
# Flexibility – Ringkøbing CHP

Ringkøbing District Heating, Friday, 2016-01-01 to Friday, 2016-01-08





# What has since been achieved: De-coupling of consumption and GDP growth



Source: Energy Policy in Denmark. Danish Energy Agency. December 2012

# Danish Climate and Energy Policy / Goals



- **2020:** 50 pct of electricity from wind power, and 35 pct of total energy consumption from renewable sources
- **2035:** 100 pct of electricity and heating from renewable sources
- **2050:** 100 pct of all (electricity, heating, transport, industry) from renewable sources



# CITIES

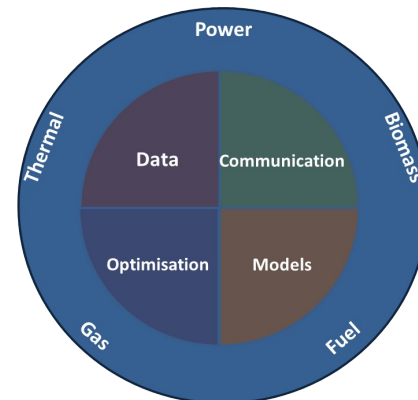
## Assumptions, Goals and Methods



# CITIES – Hypothesis

The **central hypothesis of ESI** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in we can enable very large shares of renewables, and consequently obtain substantial reductions in CO<sub>2</sub> emissions.

**Intelligent integration** will (for instance) enable lossless ‘virtual’ storage on a number of different time scales.





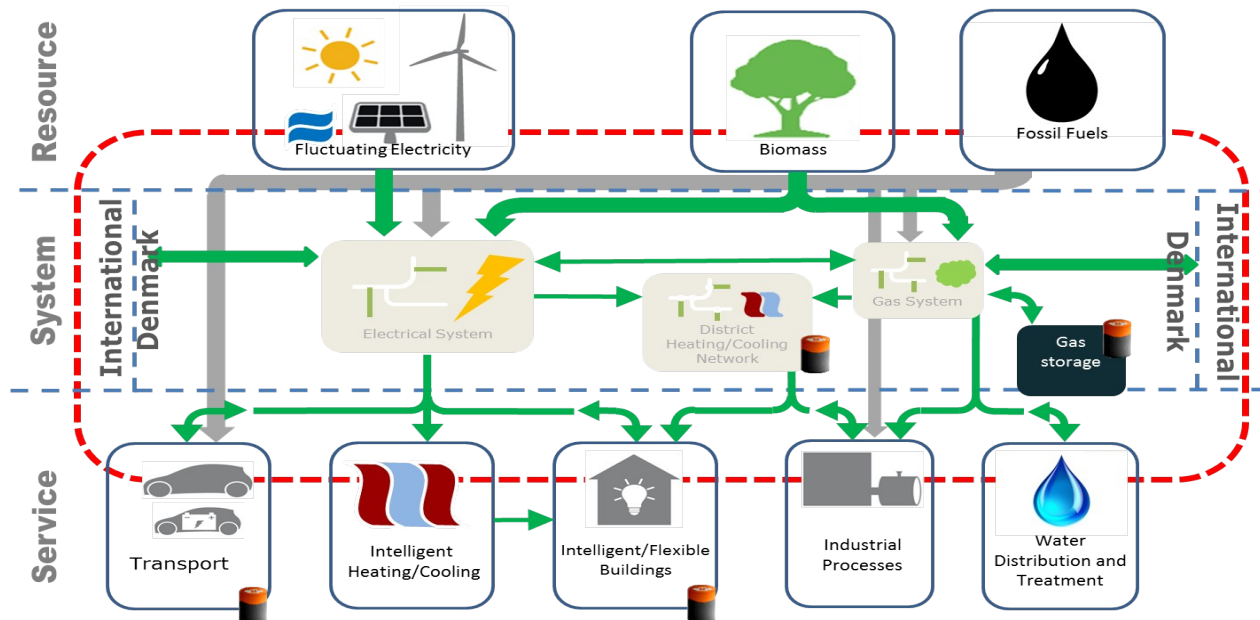
# CITIES – Research Challenges

To establish methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales

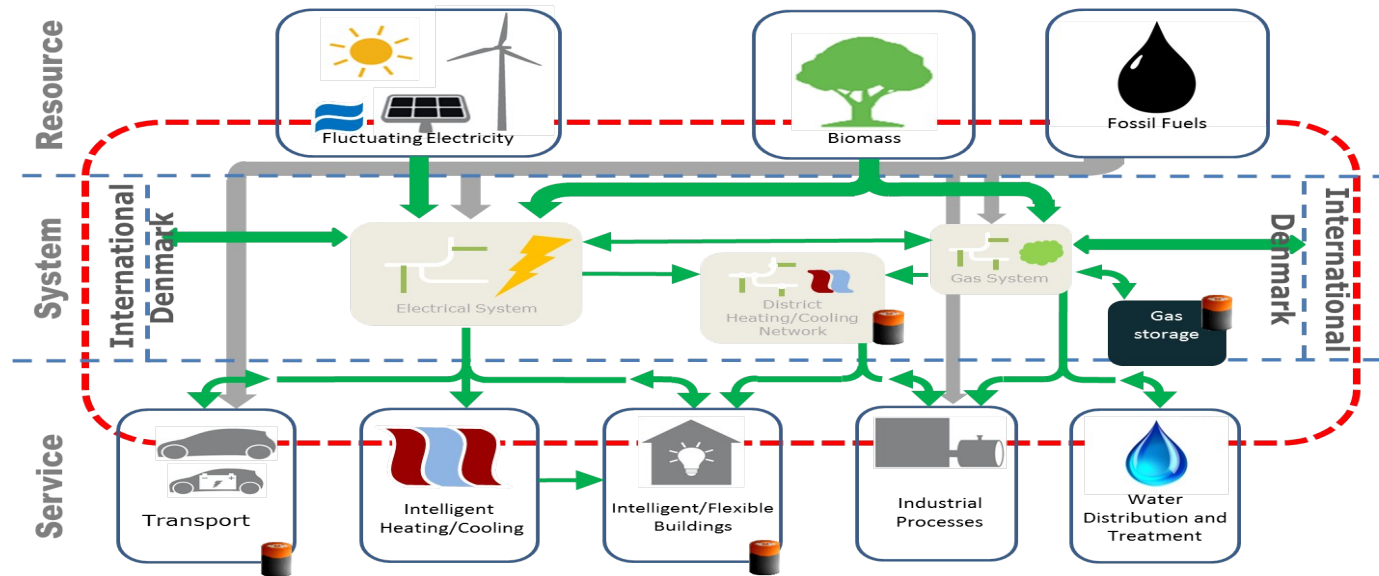


# CITIES – Concept Challenges

**Energy Systems Integration** using data and IT solutions leading to **models and methods** for **planning and operation** of future electric energy systems.

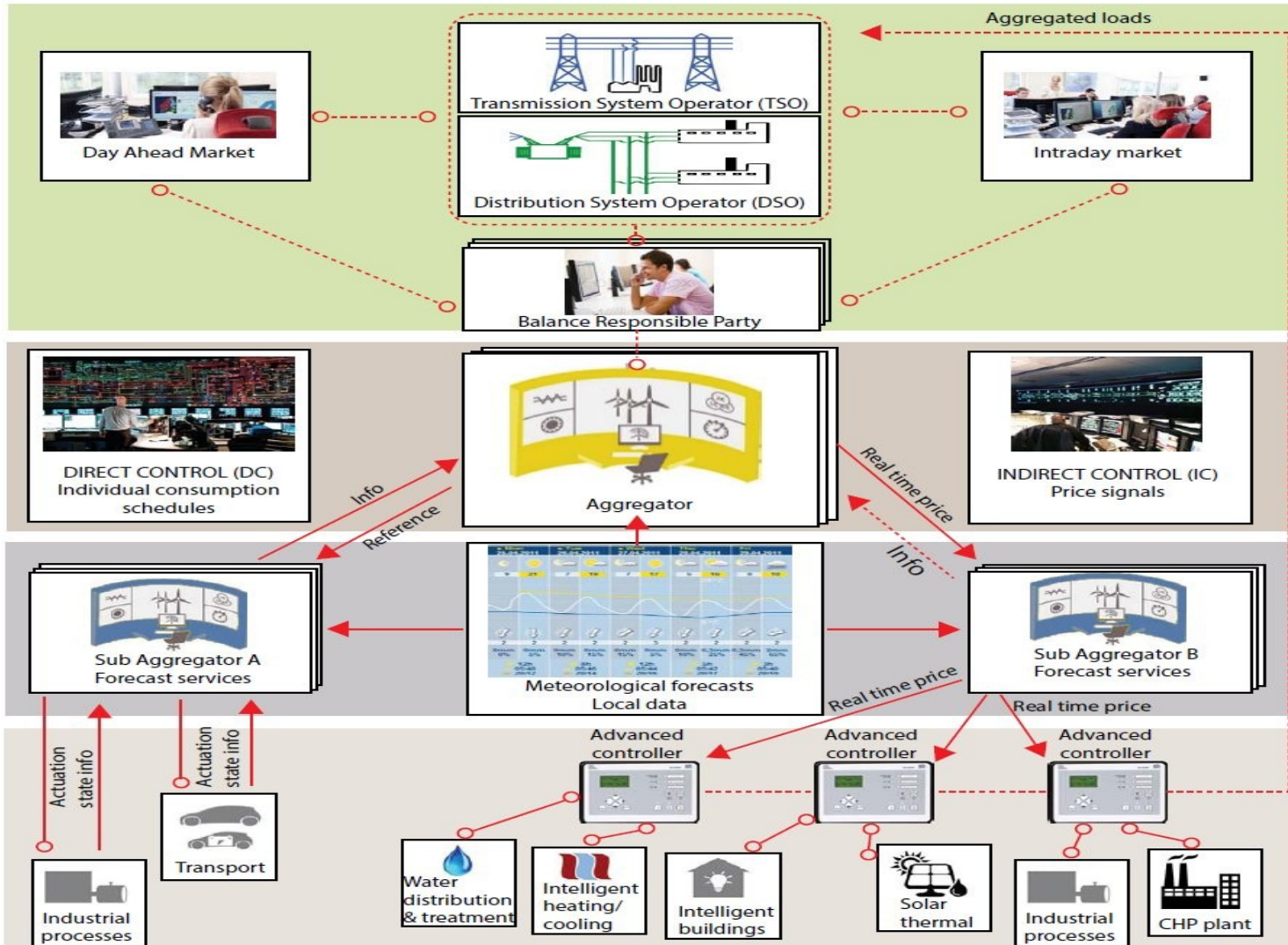


# Example: Storage by Energy Systems Integration



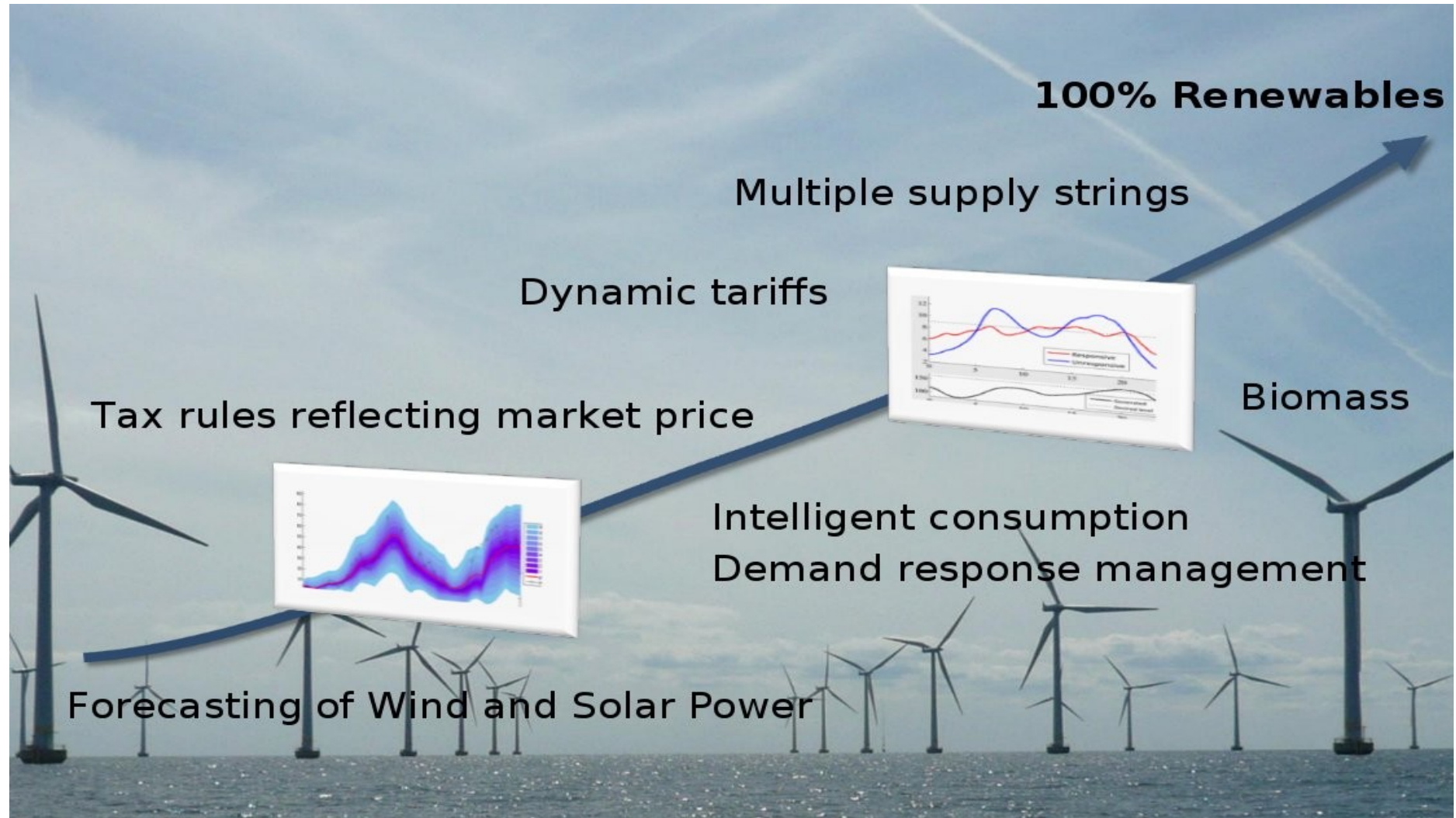
- **Denmark (2014) : Approx 42 pct of power load by renewables (> 100 pct at some days in January)**
- **(Virtual) storage principles:**
  - Buildings can provide storage up to, say, 5-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - Gas systems can provide seasonal storage

# Smart-Energy OS





# How to reach a fossil-free society



## Case study

# Control of Wastewater Treatment Plants

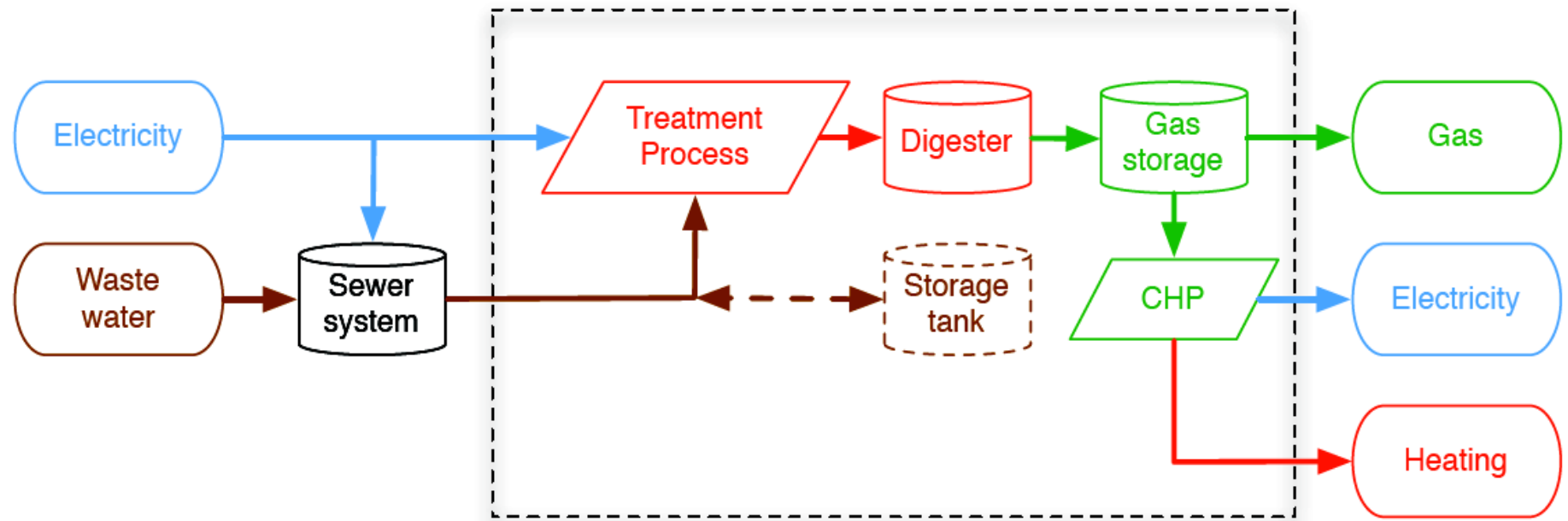


# Waste-2-Energy

Resources

WWTP Energy Hub

Energy service



# Energy Flexibility in Wastewater Treatment

- **Sludge -> Biogas -> Gas turbine -> Electricity**
- **Power management of the aeration process**
- **Pumps and storage in sewer system**

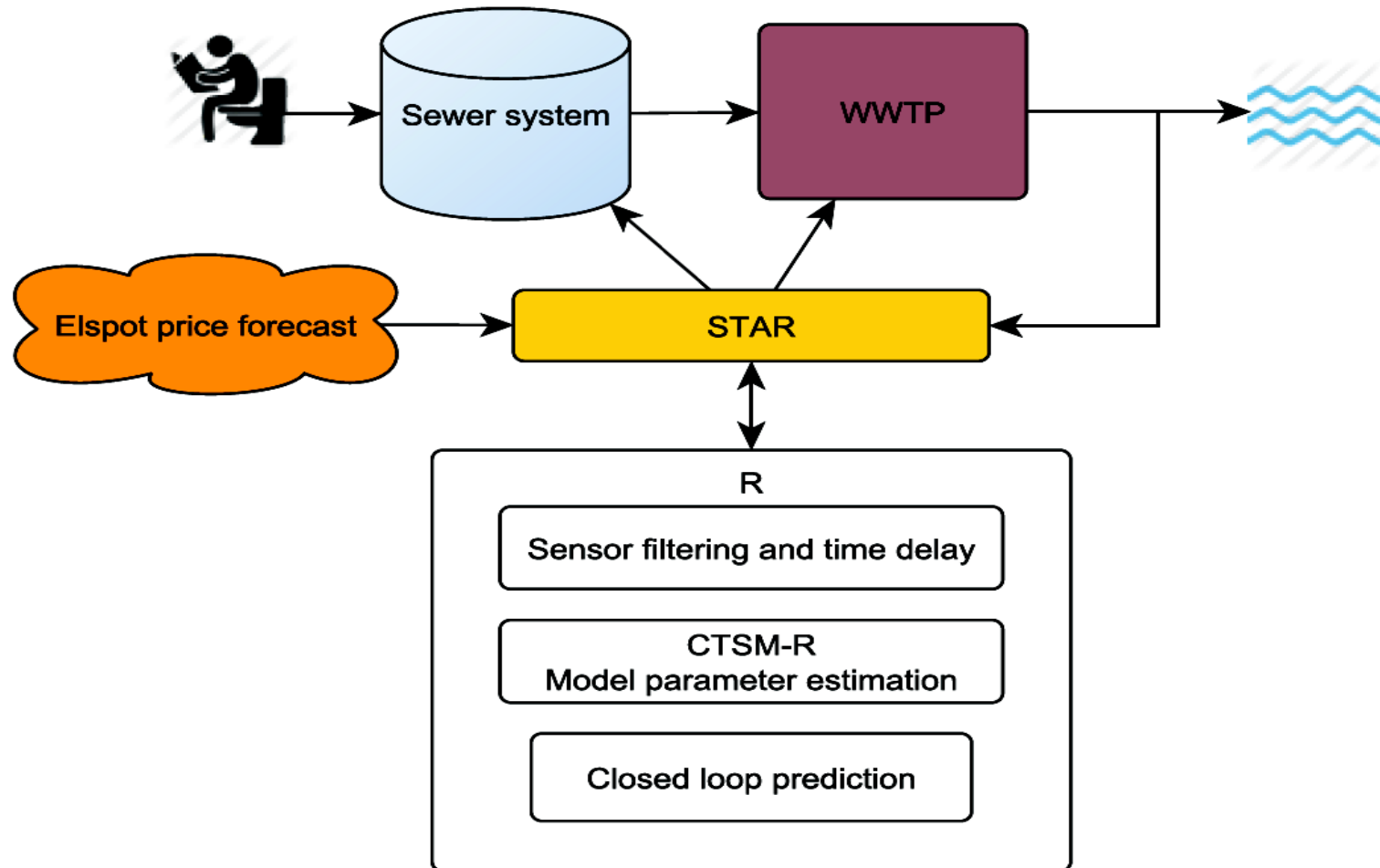
## **Overall goals:**

**Cost reduction**

**Minimize effluent concentration**

**Minimize overflow risk**

# Energy Flexibility in Wastewater Treatment



[Demo projects](#)[Software solutions](#)[Work Packages](#)[Partners](#)[Events](#)[Communications](#)[Publications](#)[Vacant positions](#)[Contacts](#)

## Software solutions

### Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at [CTSM.info](#).

### Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available on [GitHub](#).

MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R. The software is available on [GitHub](#).

#### Latest news

Summer School at DTU, Lyngby, Denmark – July 4th-8th 2016

Summer School – Granada, Spain, June 19th-24th 2016

Third general consortium meeting – DTU, May 24th-25th 2016

Smart City Challenge in Copenhagen – April 20th 2016

Guest lecture by Pierluigi Mancarella at DTU, April 6th 2016



# Case study

## Use of Heat from Supermarket Cooling in DH Systems



# Using Heat from Supermarket Cooling in the District Heating System

## SuperBrugsen in Høruphav

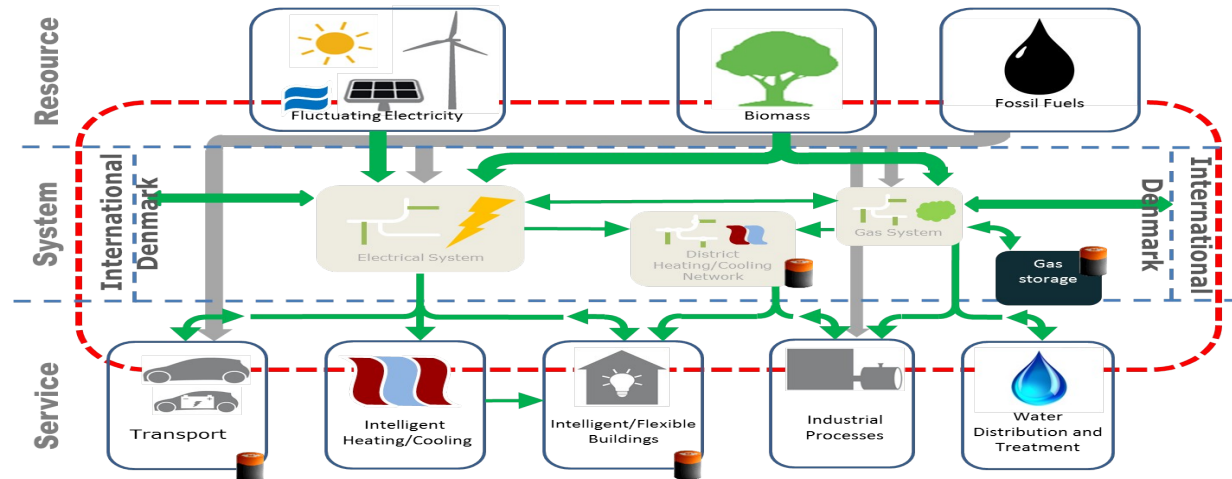


- Area: 1000 m<sup>2</sup> from 2010
- Compressors: 5 MT (1 VS), 4 LT
- Cooling Capacity: 160 kW
- Heating :
  - Sanitary water (1800 l tank (65 °C )
  - Floor heating/low temp coils (35 °C )
  - District heating production

# Using Heat from Supermarket Cooling in the District Heating System

- SuperBrugsen gets paid for energy they would have otherwise have paid for to get removed
- Corresponds to the total consumption of 15-20 households
- Payback time for SuperBrugsen is 1-2 years
- Payback time for DH system is 3-4 years
- This is a small supermarket. Business case even better for large supermarkets

# Virtual Storage or Flexibility Characteristics



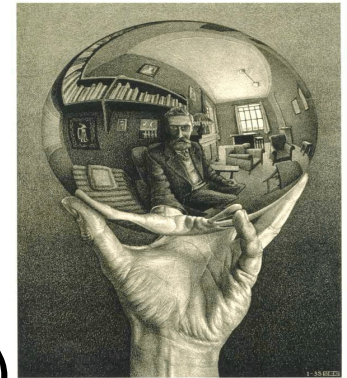
## ● Flexibility (or virtual storage) characteristics:

- Supermarket refrigeration can provide storage 0.5-2 hours ahead
- Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
- Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
- District heating/cooling systems can provide storage up to 1-3 days ahead
- Gas systems can provide seasonal storage

# Energy Flexibility

## Some Demo Projects in CITIES

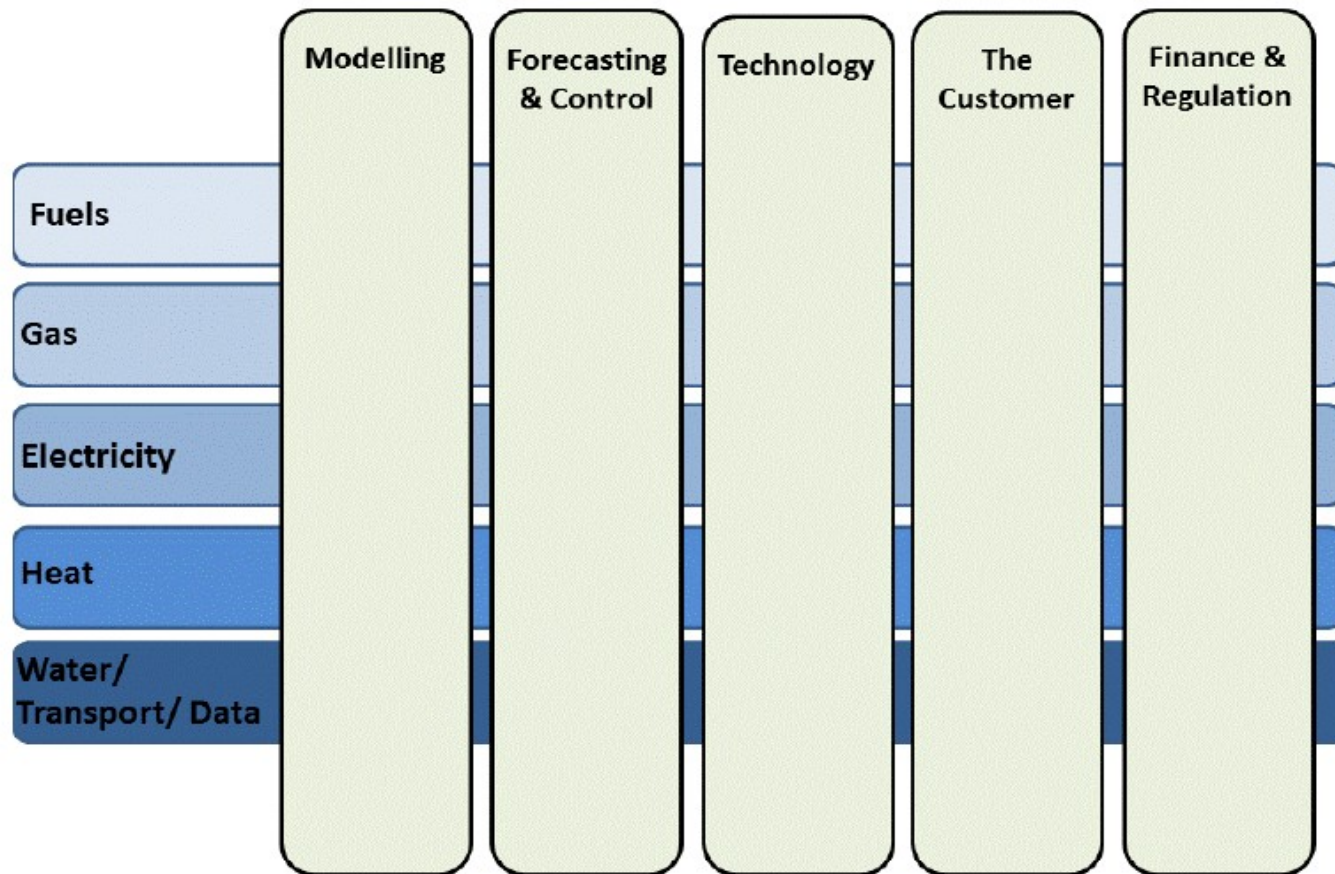
- Control of WWTP (ED, Krüger, ..)
- Heat pumps (Grundfos, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, SE, Energinet.dk, ..)
- Green Houses (NeoGrid, Danfoss, F.Fyn, ....)
- CHP (Dong Energy, FjernvarmeFyn, HOFOR, NEAS, ...)
- Industrial production (DI, ...)
- VE (charging) (Eurisco, ED, ...)





UCD, DTU, KU:

# ESI Joint Program ESI European Research (EERA)



**CITIES**

Centre for IT Intelligent Energy Systems

**Boston Climate Bridge – Women Leading Change**



International Institute  
for Energy Systems  
Integration

## Addressing energy challenges through global collaboration



**Vision:** A global community of scholars and practitioners from leading institutes engaged in efforts to enable highly integrated, flexible, clean, and efficient energy systems

**Objectives:** Share ESI knowledge and Experience:  
Coordination of R&D activities:  
Education and Training  
Resources

### Activities 2014

- Feb 18-19 Workshop (Washington)
- May 28-29 Workshop (Copenhagen)
- July 21 – 25, ESI 101 (Denver)
- Nov 17th Workshop (Kyoto)

### Activities 2015

- Dublin, Denver, Brussels, Seoul



# Discussion

- **Intelligent Energy Systems Integration can provide virtual storage solutions (... less need for physical storage)**
- **District heating (or cooling) systems can provide flexibility on the essential time scale (up to a few days)**
- **We have enough waste heat to cover the entire need for heating (but ... !)**
- **Gas systems can provide seasonal virtual storage solutions (but ... !)**
- **We see a large potential in Demand Response. Automatic solutions, price based control, and end-user focus are important**
- **We see large problems with the tax and tariff structures. Coupling to prices for carbon capture could be advantageous.**
- **Markets and pricing principles need to be reconsidered; we see an advantage of having a physical link to the mechanism (eg. nodal pricing, capacity markets)**

# Discussion (2)

- Smart Cities is a part of a Smart Society
- Within CITIES a number of solutions have been developed
- A huge potential in the use of smart meter data
- It is our impression that by intelligent energy systems integration we could rather easily obtain a fossil-free society, however ....
- We need stronger decision makers ...

Thanks for  
your attention !



# Use of Meter Data

- Reliable Energy Signature.
- Energy Labelling
- Time Constants (eg for night set-back)
- Proposals for Energy Savings:
  - Replace the windows?
  - Put more insulation on the roof?
  - Is the house too untight?
  - .....
- Optimized Control
- Integration of Solar and Wind Power using DSM

