ECONOMY OF SCALE

ENERGY STORAGE FOR HEATING AND COOLING

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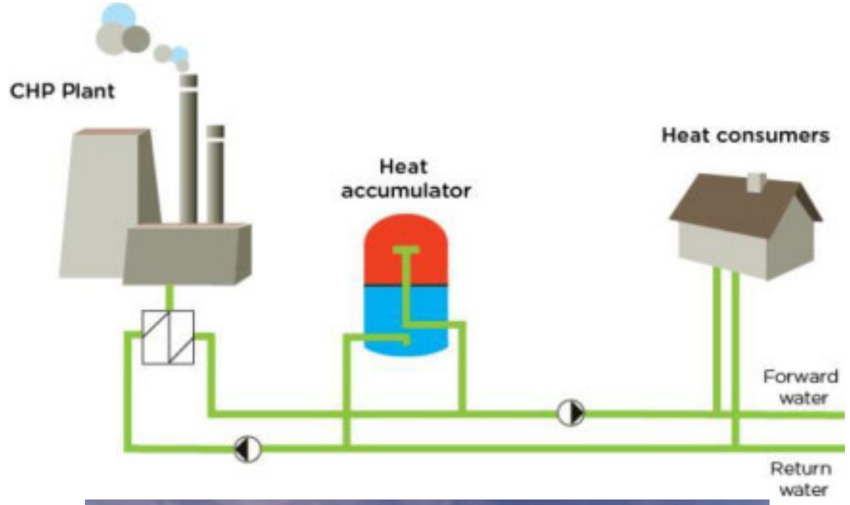
PRESENTATION AND BACK GROUND

- Ramboll
  - Independent Multidisciplinary Consulting Eng. Comp. Owned by the Ramboll Foundation
  - 13.000 Employees 300 offices in 30 countries, mainly Northern Europe
  - World leading within several energy services
- Flemming Ulbjerg
  - Consultant since 1980
  - Building services, new and refurbishing.
  - Energy savings in buildings.
  - District energy.
    - Large scale solar heating.
    - Seasonal hot water / chilled water storage.
    - Heat pumps etc.

ENERGY STORAGE TANKS AND PITS

THE SIMPLE HEAT STORAGE TANKS PRESSURE LESS AND DIRECT CONNECTION

- All CHP plants have heat storage tanks in Denmark
- Optimize operation of the CHP plant > 8 max load hours
- Can integrate surplus heat from waste, solar, wind etc.
- Optimize the operation of the DH system
- Maintain the pressure
- Provide peak capacity the coldest day
- Fynsværket power plant, Odense
  - 75,000 m^3
  - Direct connection
  - Maximum temp 95^{o}C. 90/40
  - Storage capacity, 3,6 GWh, e.g. 300 MW in 12 hours



HEAT STORAGE PITS
PRESSURE LESS AND SECTIONED BY HEAT EXCHANGER

- Heat storage pit, an innovative combination of:
  - Landfills for establishing liners to a water proof pit
  - Heat storage tank with diffuser
  - A floating cover (newly developed)
- Impossible to avoid oxygen in the water, therefore sectioned by heat exchanger
- Maximal temperature 85 ^{o}C
- Storing weekly or monthly fluctuations
- The driver for this development in Denmark has been to increased share of solar heat up to 60% in district heating systems

HEAT STORAGE PITS
PRESSURE LESS AND SECTIONED BY HEAT EXCHANGER

- Test plants with subsidy
  - 10,000 m^3 Test plant in 2010 in Marstal
  - 70,000 m^3 Full-scale test plant 2012 in Marstal
  - 62,000 m^3 Full-scale test plant 2014 in Dronninglund

- Commercially, without subsidy, new floating cover
  - 125,000 m^3 Gram District Heating 2015
  - 200,000 m^3 in Vojens District Heating 2015
  - 70,000 m^3 in Toftlund Histrict Heating 2017

Several more in the pipeline, may be 100 in 2030

ECONOMY OF SCALE
THE MOST IMPORTANT FACTOR

Investment: Euro/MWh storage capacity

• One family house, 0.16 m^3	300,000
• Large building, 4 m^3	40,000
• District heating tank, 160 ^oC	7,000
• District heating tank, <95 ^oC	4,000
• Storage pit total cost, 150,000 m^3	800
• The pit alone, 100,000-200,000 m^3	500
• Marginal extension of the pit	200

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NUMBER OF LOAD CYCLES
THE SECOND IMPORTANT FACTOR

Energy cost of storing heat	Investment and utilization			Energy cost
	€/MWh	Cycles/year	€/MWh/cycle	€/MWh
One family house, 0.16 m³	300.000	300	1.000	**70**
Large building, 4 m³	40.000	150	267	**19**
District heating tank, 160 degr. C	7.000	50	140	**10**
District heating tank, 95 degr. C	4.000	50	80	**6**
Storage pit, 150,000 m³	800	15	53	**4**
The pit alone, 100,000 - 200,000 m³	500	15	33	**2**
Marginal extension of the pit.	200	5	40	**3**

HOW TO INCREASE THE NUMBER OF LOAD CYCLES FOR A 150,000 M³ HEAT STORAGE PIT

Load Cycles per year	€/MWh	Remarks
1,50	**35,56**	Only solar heating
3	**17,78**	Solar and CHP.
5	**10,67**	Solar, CHP and electric boiler
15	**3,56**	Solar, heat pump, CHP and electric boiler
25	**2,13**	Solar, heat pump, CHP, electric boiler and surplus heat
200	**1,07**	Day/night - cooling. (Low deltaT)

GRAM CONSUMER OWNED DISTRICT HEATING
A MIX OF TECHNOLOGIES INTEGRATING RENEWABLES

- Heat production 30 GWh
- 120,000 m^3 heat storage pit
- 44,000 m^2 solar panels (61%)
- A 10 MW electric boiler (15%)
- A 900 kW heat pump (8%)
- Industrial surplus heat (8%) and
- A 5 MWe/6 MWth CHP gas engine (8%)
- Gas boilers for spare capacity (0%)

A VIRTUAL ELECTRICITY STORAGE
A CASE INSPIRED BY GRAM DISTRICT HEATING

Electricity prices 1-21 January 2016: DK east
Strong wind in 10 days followed by 10 days without any wind

Baseline

1,000 individual heat pumps, COP=3 in total	13 MW heat
Average uncontrolled production in January	5 MW heat

District heating, one automatic control centre

District heating annual heat production:	30,000 MWh heat
Average heat production 1-21 January:	5 MW heat
Peak capacity	10 MW heat
Heat pump capacity, COP=3	3 MW heat
Electric boiler capacity	10 MW heat
Gas CHP	4.5 MW elec / 5 MW heat
Volume of large heat storage pit,	125,000 m^3

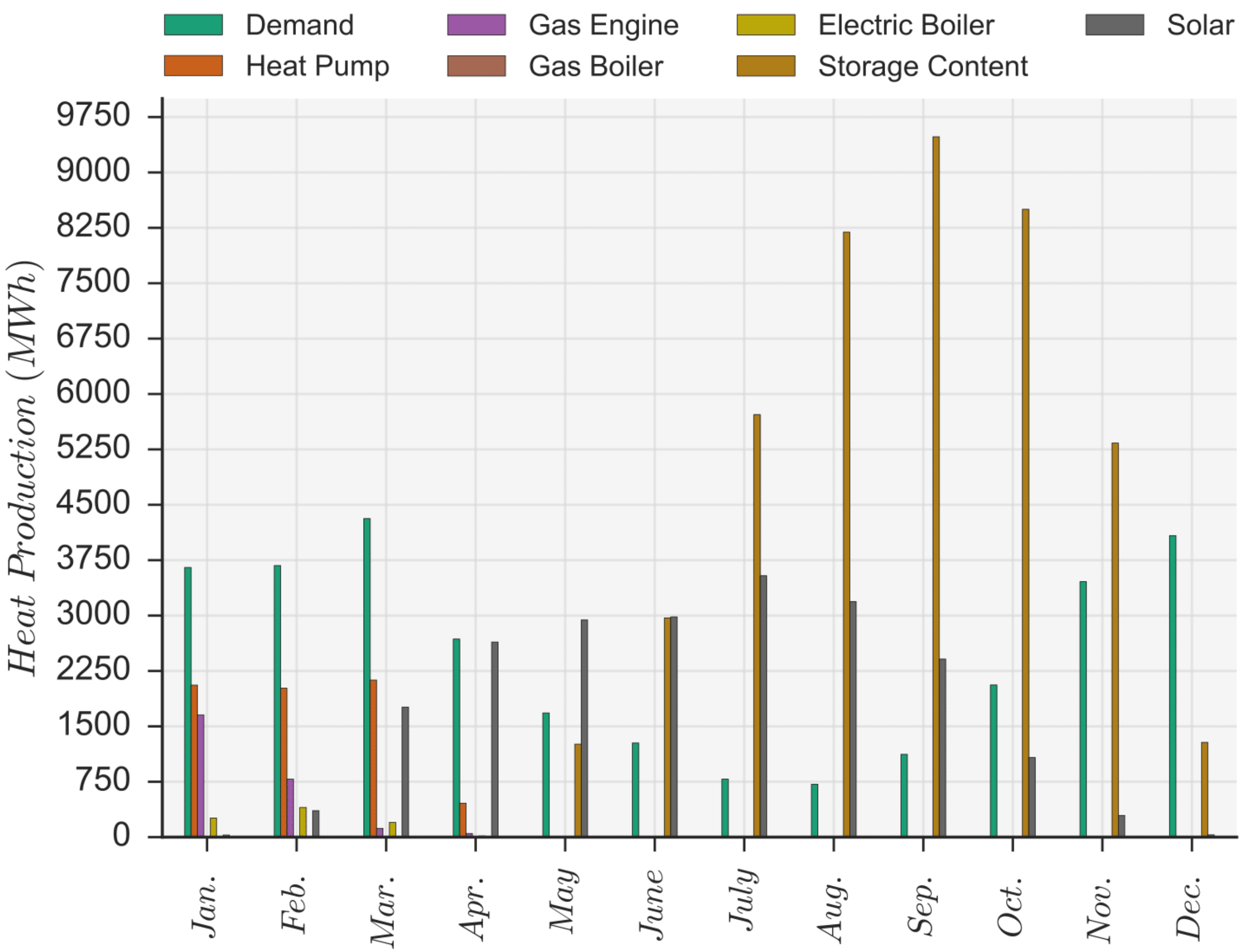
Objective: minimize heat production cost e.g. with Mentor Planner or EnergyPro

More detailed described in Ramboll presentation on “virtual battery”

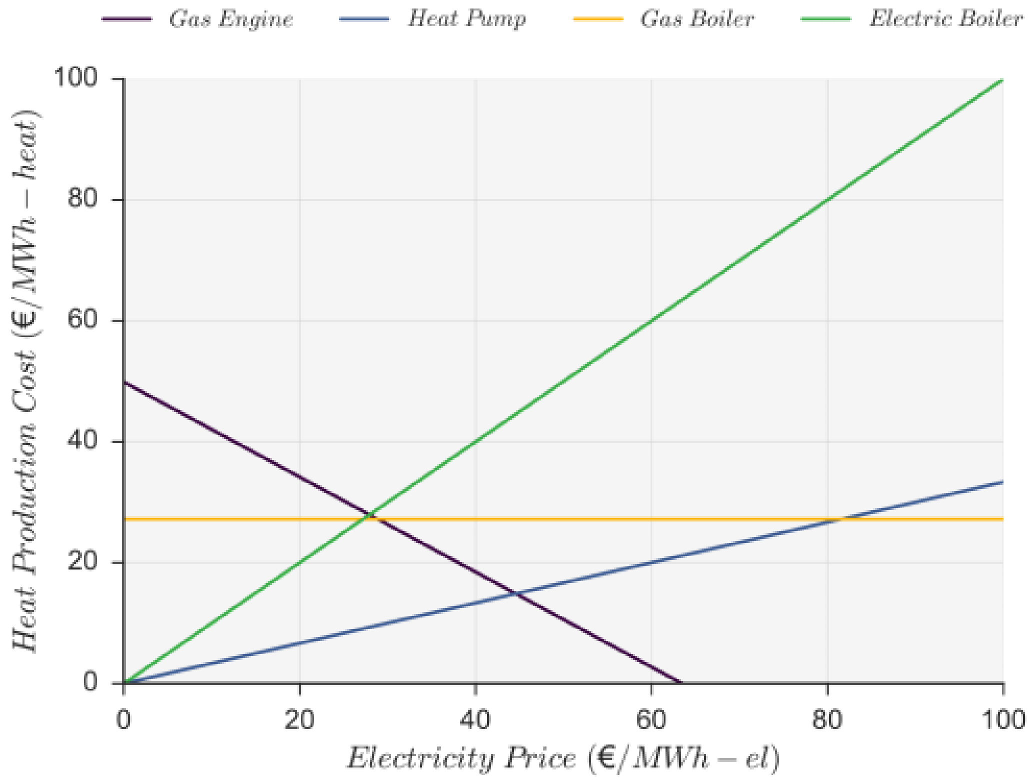
GRAM CONSUMER OWNED DISTRICT HEATING
AN EXAMPLE ON ANNUAL SIMULATION

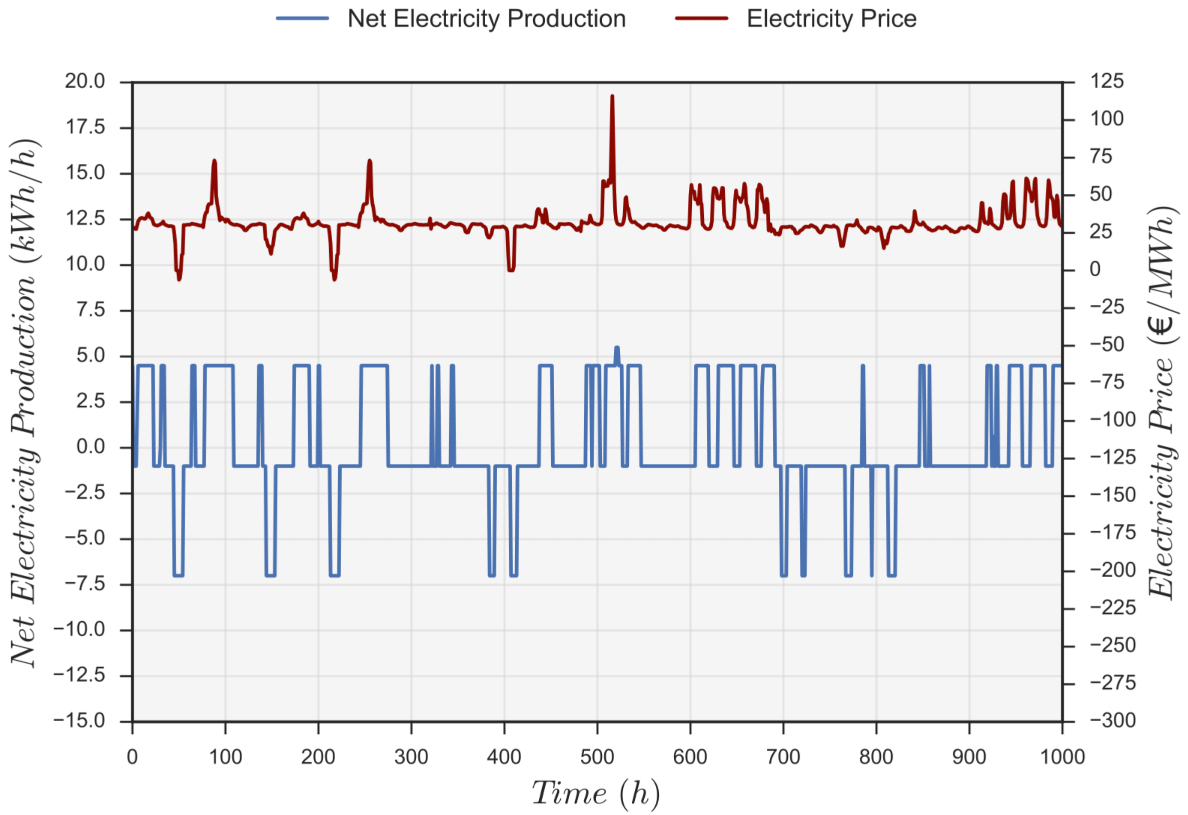
- Large scale solar heating use the storage from April to September
- The rest of the year it is available – free
- Integration wind energy
- Integration of surplus heat from CHP

- A lot more storage capacity available from September to April



GRAM CONSUMER OWNED DISTRICT HEATING SYSTEM RESPONSE ON FLUCTUATING ELECTRICITY PRICES





THANK YOU FOR YOUR ATTENTION
QUESTIONS & ANSWERS

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