4TH GENERATION DISTRICT ENERGY

THE BACK BONE OF LIVEABLE AND RESILIENT CAMPUSES AND CITIES

Anders Dyrelund, Senior Market Manager, Ramboll Energy

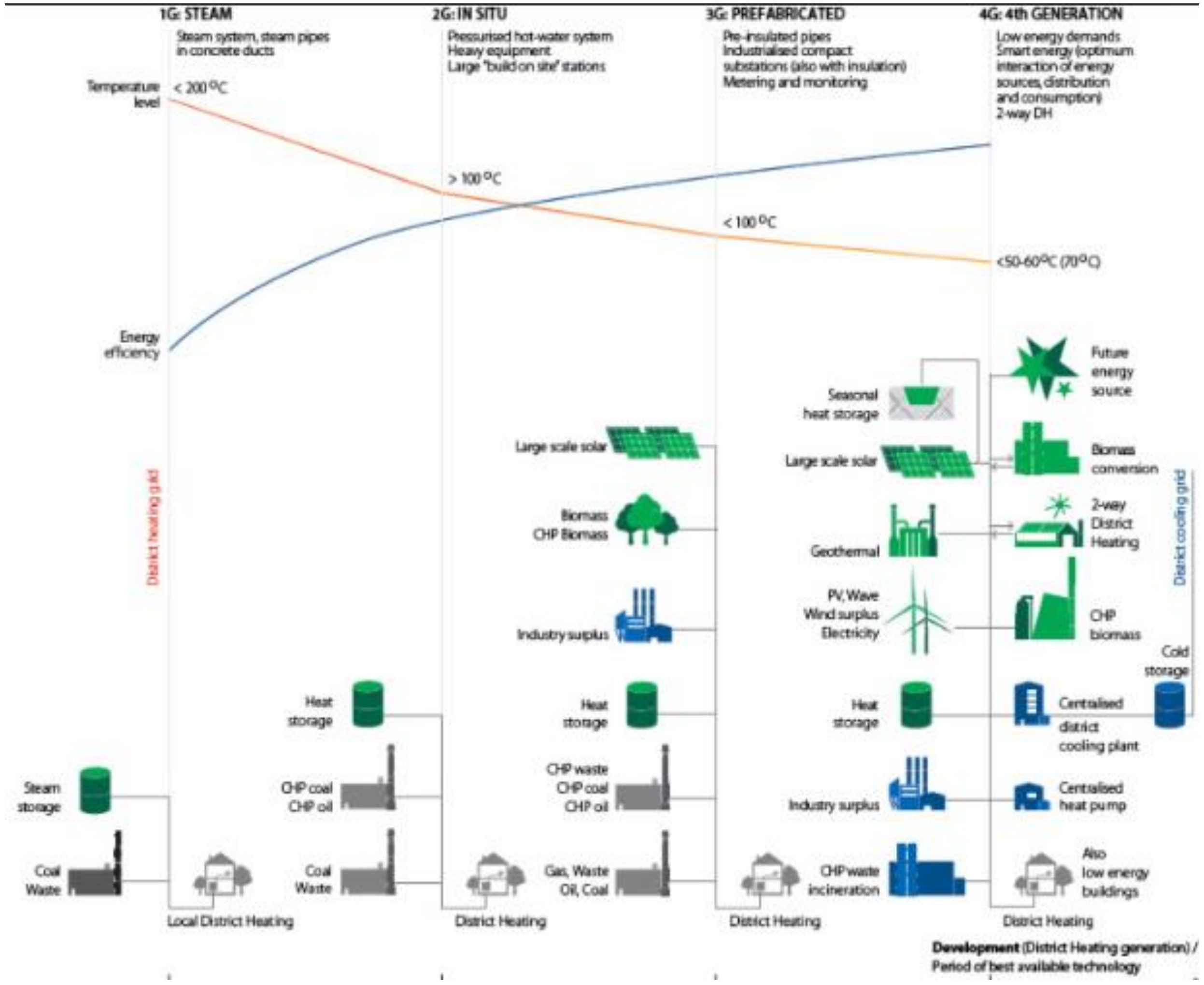
RAMBOLL

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
- Anders Dyrelund
  - Civ.Eng. in buildings, Graduate diploma in Economics
  - 1975-81 Ramboll (BHR)
  - 1981-86 Danish Energy Authority
  - 1986- Ramboll
  - 1980 The First Heat Plan in Denmark for Aarhus, PM
  - 1981- Copenhagen Regional DH, task manager/consultant
  - 1990- Consultancy services to more than 20 countries

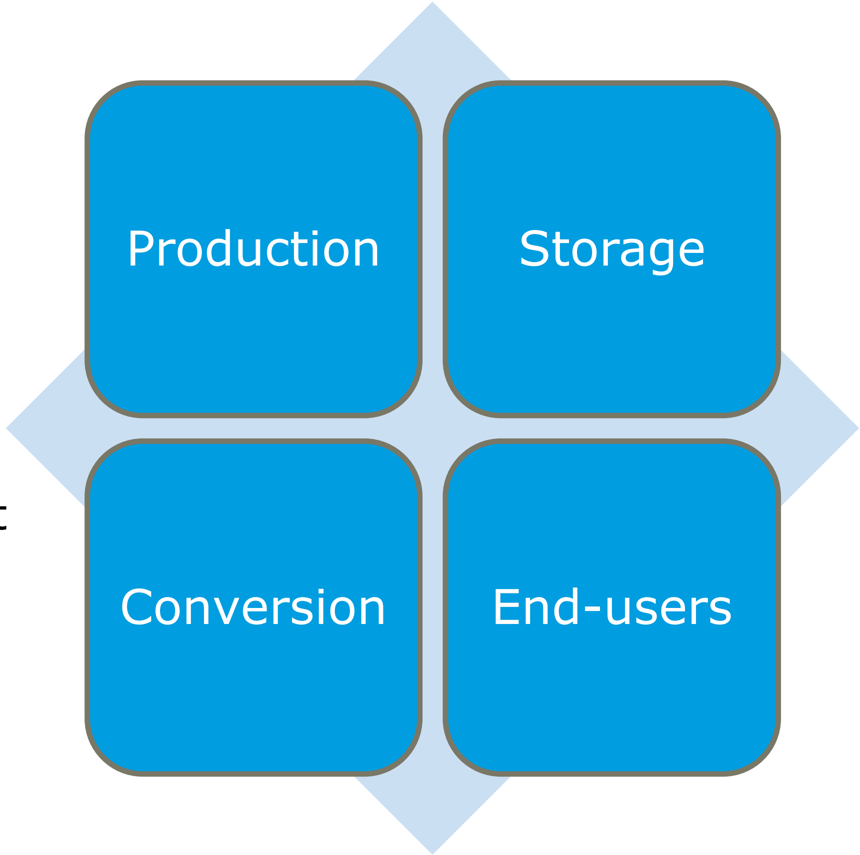
CHARACTERISTIC OF THE 4TH GENERATION ENERGY SYSTEM

- The 4 energy carriers are fully integrated with conversion technologies
- The HVAC systems in buildings are integrated with the district heating and cooling infrastructure
- Larger energy storages
- Low-temperature heating and high-temperature for cooling in buildings
- Integrate low quality and fluctuating low-carbon energy production
- More efficient conversion technologies for heating and cooling with CHP and heat pumps



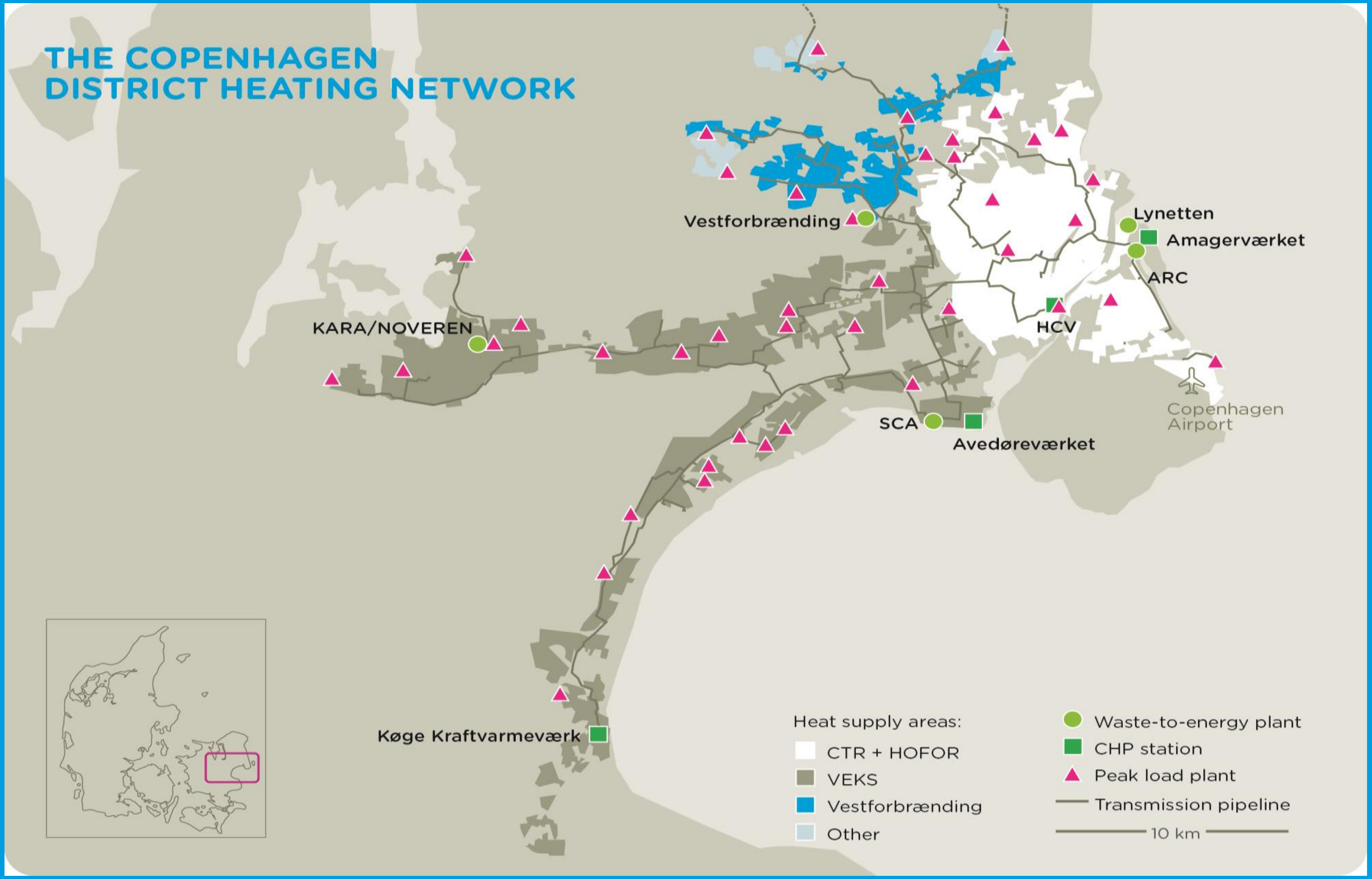
THE SMART ENERGY SYSTEM
INTERCONNECTING THE 4 ENERGY CARRIERS

- International power grid
  - Hydro power, but limited storage capacity
- International gas grid for natural gas (and biogas)
  - Large storages, CHP, industry
- City district heating grids
  - Storage for CHP, electric boilers, heat pumps and RES
- City district cooling grids
  - Storage for and optimal cooling in symbiosis with heat
- Buildings - end-users the basis for 4th GDH
  - Optimized building envelope
  - **Low temperature heating**
  - **High temperature cooling**
  - Adjust consumption to dynamic prices



OUR VISION IS TO CREATE LIVEABLE CITIES
SMART SOLUTIONS FOR THE CITIZENS

THE DISTRICT HEATING AND COOLING GRIDS



DEVELOPMENT OF DH&C PIPE CONSTRUCTIONS IN BRIEF IN 5 DECADES

- 1970 Concrete ducts, expensive, long life-time, but some failures, first preinsulated pipes in Løgstør, but poor quality
- 1980 Danish standard for DH pipes in the ground, Better quality of preinsulated pipes of various principles and competition
- 1990 Preinsulated pipes of good quality almost 100% market share, bonded system, welded muffs, no expansion joints, surveillance system
- 2000 Curved pipes, twin pipes <DN200, no-dig methods etc.
- 2010 Preinsuated pipes all over the world for DH&C
- Two options for DC systems in competition:
  - Preinsulated pipes: DH technology, no oxygen, Copenhagen DK
  - PE-pipes: Water supply technology, Frederiksberg DK

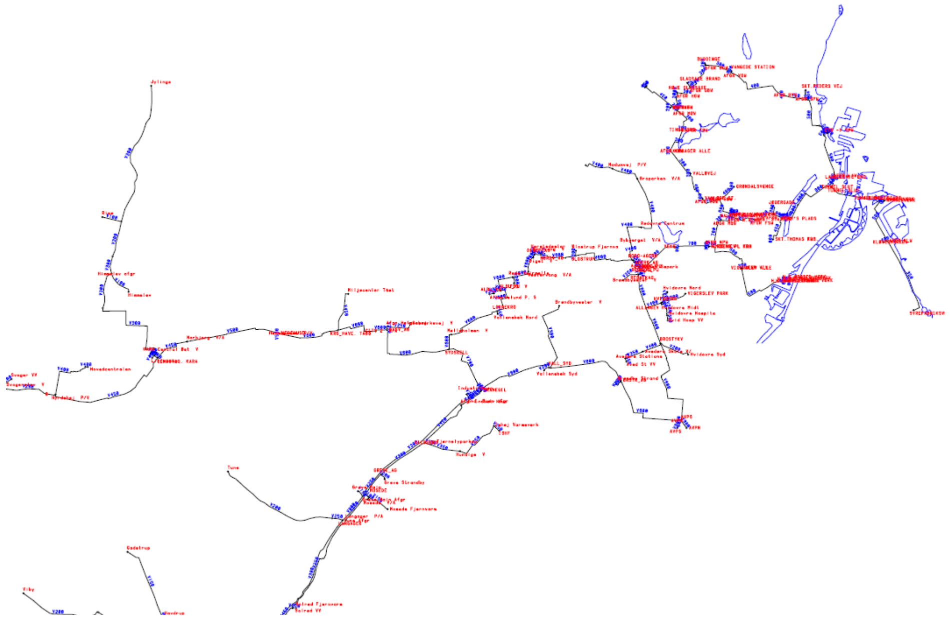
STANDARDS FOR DH PIPE SYSTEMS AND PIPES FREEDOM TO GOOD DESIGN LOWER COSTS

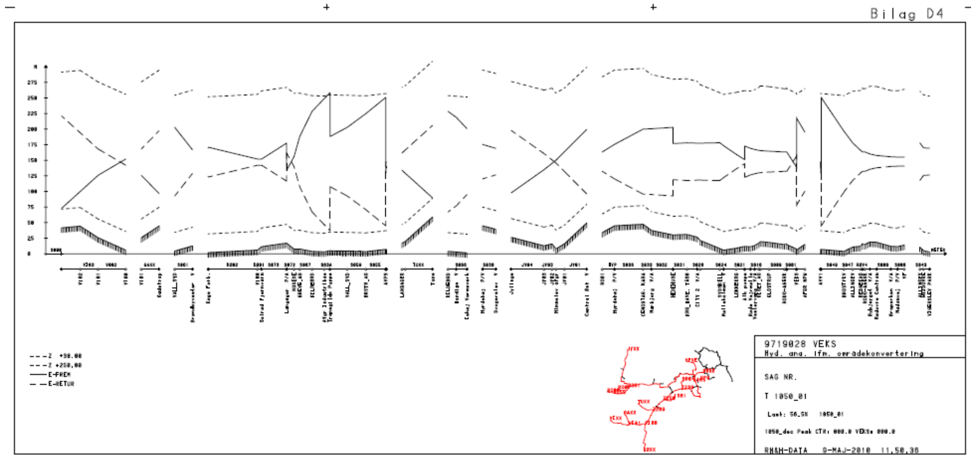
- Standards for use of preinsulated pipes
- Standards for the preinsulated pipes
- Safety regulations and classification, e.g. pressure and temperature
- Standards for specific components, boilers etc.
- Environmental requirements

- Guidelines for infrastructure in the ground in roads – "the guest principle"
- Way of right, same importance as roads for public use
- Declaration in land-owners register

TYPICAL DESIGN PARAMETERS

- Pressure level: 6, 10, 16 or 25 bar max. pressure
- Maximal temperature: <**85 ^{o}C** < 95 ^{o}C <110 ^{o}C or <160 ^{o}C
- Normal off peak operation temperature: **65 ^{o}C**
- Return temp.: as low as possible: **< 40** ^{o}C < 50 ^{o}C
- Hydraulic design: Optimize based on life-cycle cost, use available pressure, but **max 3,5 m/s**, typical 10 mm/m for new networks, as much as possible in old networks
- Bonded without expansion joints for temp. < 110 ^{o}C
- Twin pipes < DN200 if regular flat trench
- Long trench, ”gas pipe” technology





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DISTRICT HEATING TRANSMISSION AND DISTRIBUTION SYSTEMS – ECONOMY OF SCALE

- Interconnect
  - New waste CHP
  - New gas CCGT CHP
  - Heat accumulators
  - DH&C stations

- Economy of scale
  - Larger heat market
  - Larger dimension
  - Lower unit costs and
  - Lower unit heat loss

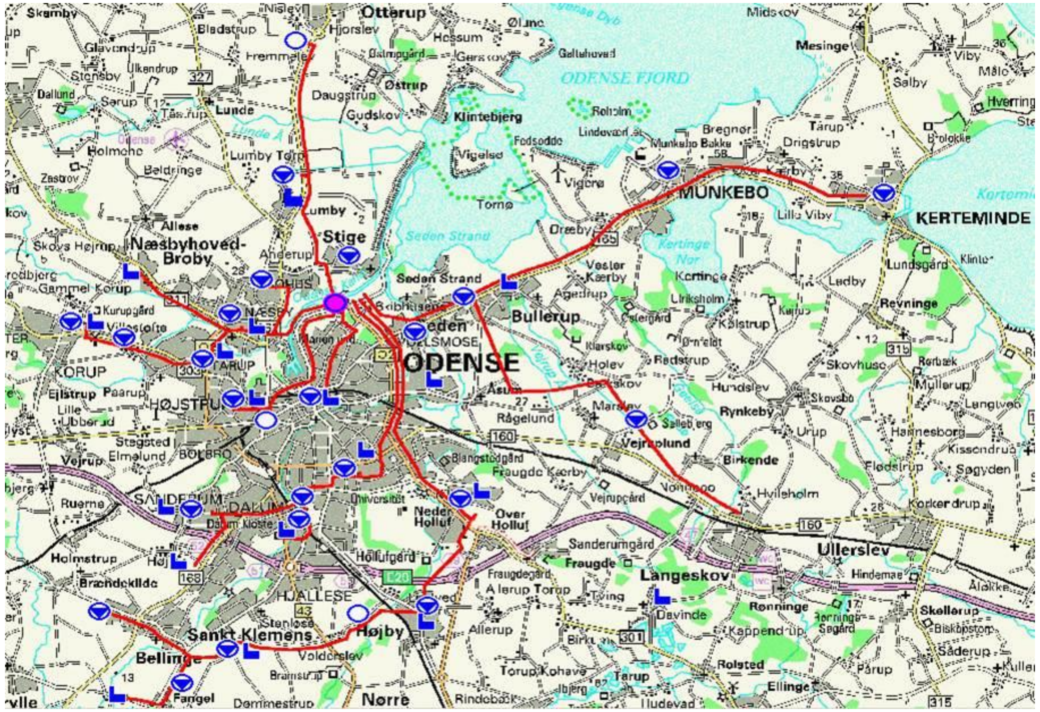
DN	Flow	Capacity	Price pr km trench	Price pr. km pr. capacity	Price pr. km pr. annual sale	Heat loss pr. km
mm	m/s	MW	mio.Euro/km	Euro/km/MW	Euro/km/MWh/a	%/km
100	1,0	2	0,6	265.775	66	2,96%
200	1,5	13	1,0	75.726	19	1,08%
300	2,0	38	1,6	43.488	11	0,50%
400	2,3	69	2,1	30.197	8	0,28%
500	2,6	125	2,7	21.622	5	0,15%
600	2,9	203	3,3	16.110	4	0,11%
700	3,2	301	3,7	12.222	3	0,09%
800	3,5	431	4,1	9.632	2	0,07%
900	3,5	551	4,8	8.711	2	0,06%
1000	3,5	681	5,4	7.949	2	0,05%
Preinsulated pipes			Supply temperature		120	°C
max design app. 130 °C			Return temperature		60	°C
Variable flow pumps			Pressure loss		10	mm/m
Transmits base load			Max load hours		**4.000**	hours

A case based on Danish data

- 300 MW heat capacity 10 km from city
- Annual heat transmission 1,200 GWh/a
- 10 km DN700: 37 mio. Euro
- Annual heat loss 2%
- Pressure loss 2 x 10 Bar
- Transmission cost: 2,5 Euro/MWh

PRESSURE SECTIONING AND SHUNTS
AN ALTERNATIVE TO HEAT EXCHANGERS

- Remove heat exchangers from transmission to distribution
- No heat exchangers from distribution to building system
- Only heat exchanger og tank for hot tap water preparation
- Pressure and temperature control + reduction
- Transient analysis to design pressure vessels to secure against water hammering
- Leak detection valves to close in case of leaking water



Fjernvarme Fyn Denmark:

- 70,000 consumers
- **No heat exchangers**
- High and low pressure
- Two large pressure vessels

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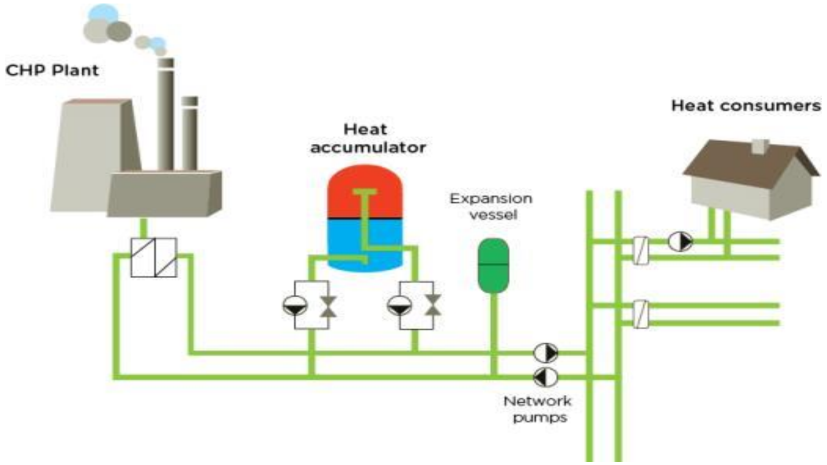
THERMAL ENERGY STORAGES

ADVANCED HIGH TEMPERATURE HEAT STORAGE TANKS PRESSURIZED AND PRESSURE SECTIONED

- Temperature **above 100 °C** can be necessary due to consumer needs (poor heating installations),
- But - the larger temperature - the larger investment.
- Pressure sectioning can be necessary due to the pressure level in the DH grid and due to necessary pressure variations at the location
- Pressure sectioning increase costs, but is cheaper and more efficient than a heat exchanger connection
- Avedøre CHP plant, Copenhagen
  - 2 x 24,000 m^3
  - Maximal temp **120 °C**   actual temp. 105/50
  - Pressure diff: 10 Bar
  - Storage capacity 2,400 MWh, e.g. 300 MW in 8 hours



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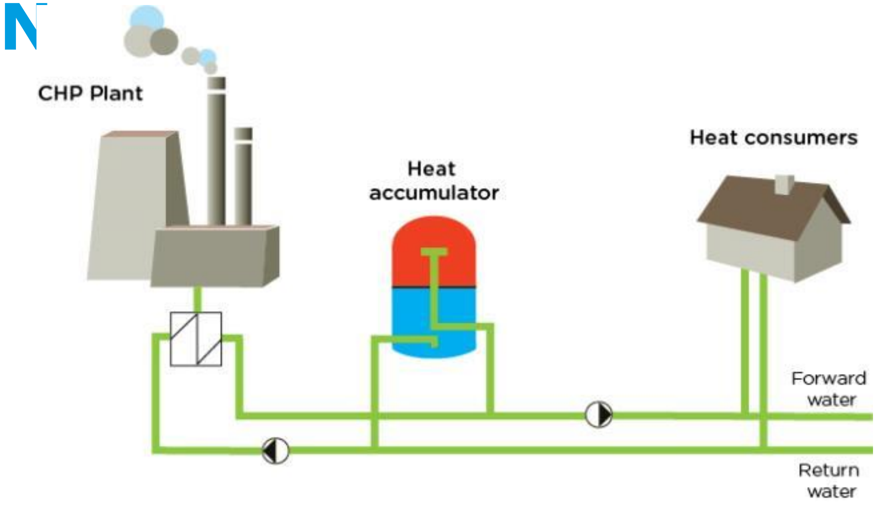
THE SIMPLE HEAT STORAGE TANKS PRESSURELESS AND DIRECT CONNECTION



- 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
- Fjernvarme Fyn at 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
PRESSURELESS AND SECTIONED BY HEAT EXCHANGER

- Heat storage pit, an innovative combination of:
  - Landfills for establishing liners to a water proof pit
  - Heat storage tank for diffusers
  - Off shore technology for diffusers and pipes
  - A floating cover (newly developed)
- Impossible to avoid oxygen in the water, therefore sectioned by heat exchanger
- Maximal temp **85 °C up to 90** °C
- Storing weekly or monthly fluctuations
- The driver for this development in Denmark has been to increase share of solar heat up to 60%

HEAT STORAGE PITS
PRESSURE-LESS AND SECTIONED BY HEAT EXCHANGER

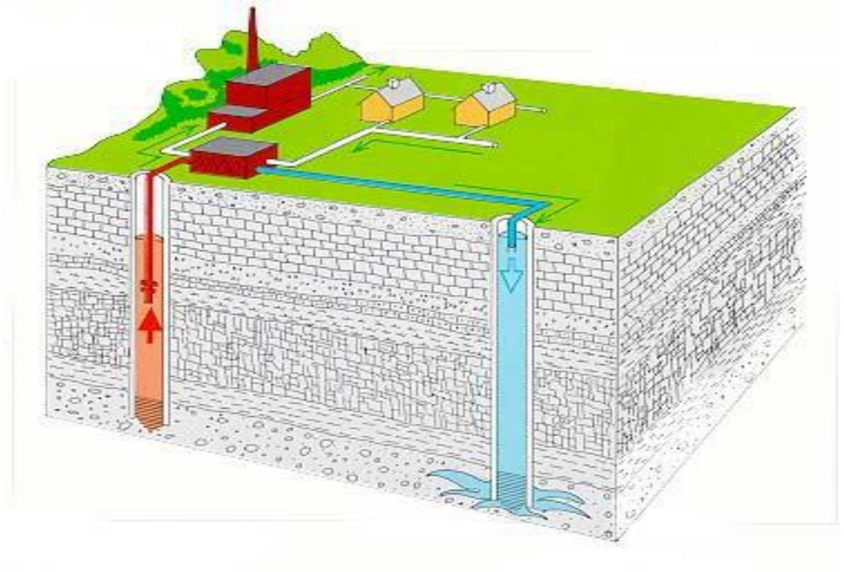
- Test plants with subsidy
  - 10,000 m³ Test plant in 2010 in Marstal
  - 70,000 m³ Full-scale test plant 2012 in Marstal
  - 62,000 m³ Full-scale test plant 2014 in Dronninglund

- Commercially, without subsidy, new floating cover
  - 125,000 m³ Gram district heating 2015
  - 200,000 m³ in Vojens district heating 2015
  - **70,000 m³ in Toftlund district heating 2017**
  - 150,000 m³ in Løgumkloster district heating 2017/18

Several more in the pipeline, may be 100 in 2025

CHILLED WATER STORAGES, REDUCING THE DAILY COOLING PEAKS

- Steel tank, district heating technology, Halmstad
- Concrete chamber, water supply technology, e.g. under new road in Carlsberg city
- Cold water storage, heat storage pit technology
- Ground source cooling (ATES)

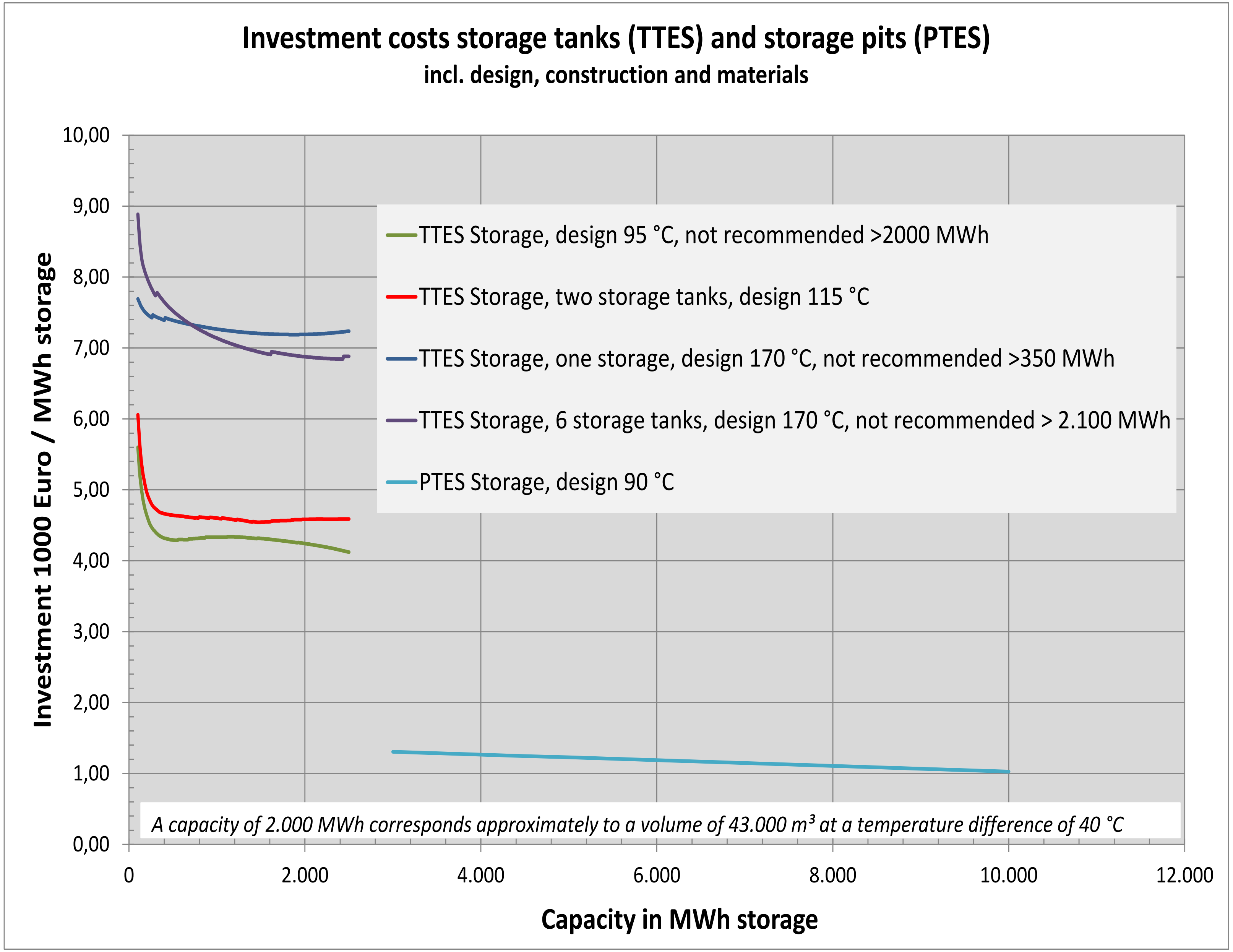


ECONOMY OF SCALE FOR HOT WATER STORAGES EUR/MWH HEAT STORAGE CAPACITY

• One family house, 0.16 m³	300,000
• Large building, 4 m³	40,000
• DH tank, 160° C	7,000
• DH tank, < 95° C	4,000
• Storage pit, 150,000 m³	800
• Pit alone, 100,000-200,000 m³	500
• Marginal extension of the pit	200

- Sources: Henrik Lund and Ramboll

ECONOMY OF SCALE



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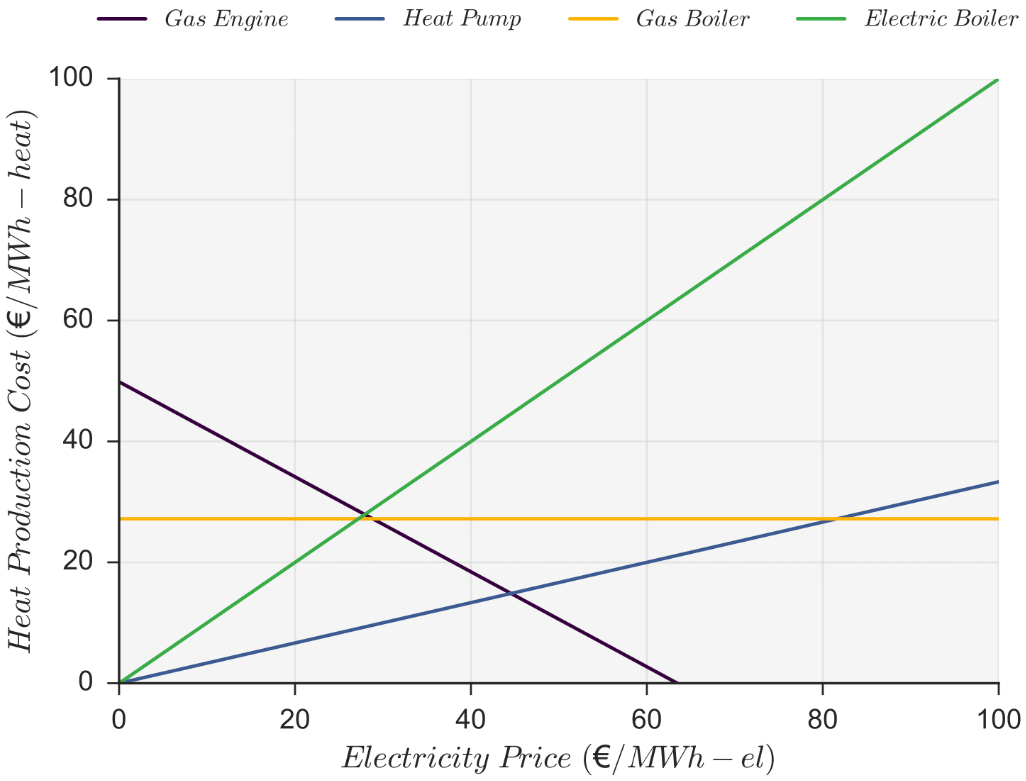
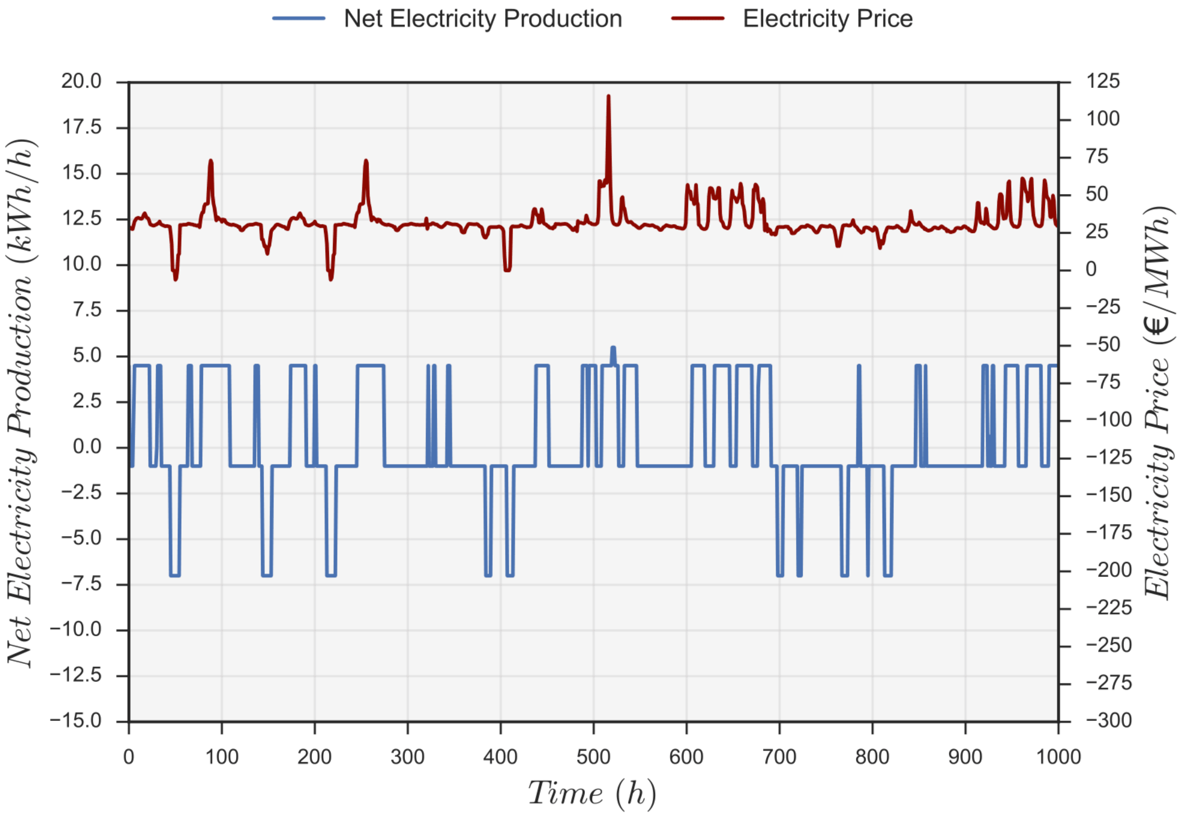
GRAM CONSUMER OWNED DISTRICT HEATING
A MIX OF TECHNOLOGIES FOR INTEGRATION OF RES

- Heat production 30 GWh
- 120,000 m3 heat storage pit
- 44,000 m2 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%)

SYSTEM RESPONSE ON FLUCTUATING ELECTRICITY PRICES
A COST EFFECTIVE "VIRTUAL" ELECTRICITY STORAGE





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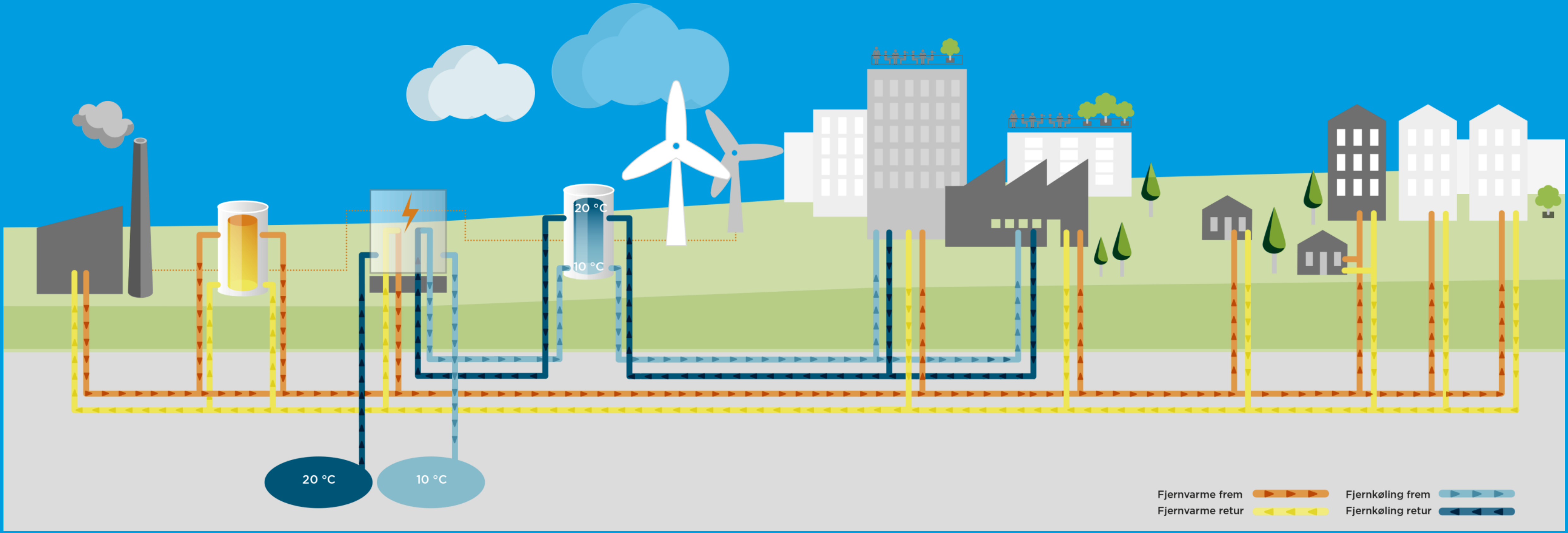
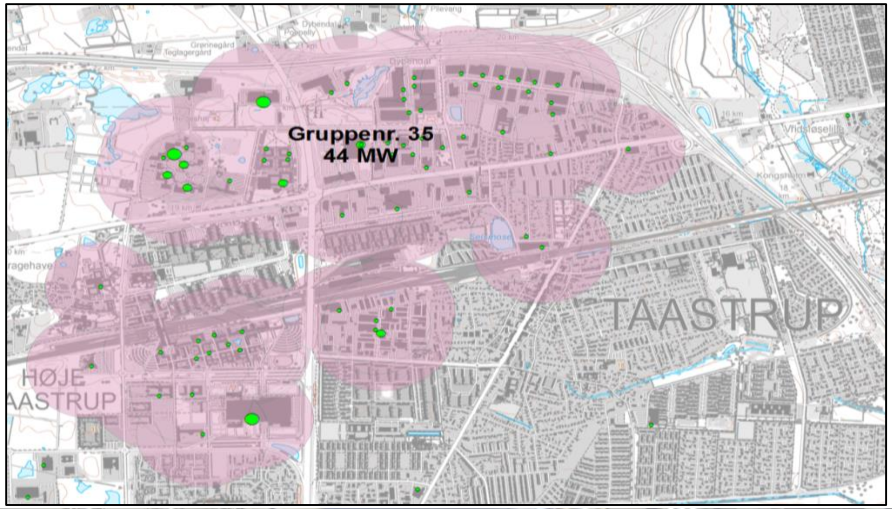
COMBINED HEATING AND COOLING WITH HEAT PUMPS
THE SECRETS OF DISTRICT COOLING



THE SECRET OF DC A KEY TO SCREENING THE DC POTENTIAL

- Save investment, which can justify the network
  - Simultaneity factor and flexibility of capacity
  - Storage levels daily fluctuation and reduce peak
  - Economy of scale for chillers and heat pumps
- Optimize electricity consumption with storage
- Heat pump has 3 modes of operation:
  - Cogeneration of heat and cold COP=5-7
  - Produce heat / waste the cooling, COP= 3-4
  - Produce cooling / waste the heat, COP= 7-8
- Better use of ground source cooling, ATES
- Høje Taastrup district heating, Copenhagen



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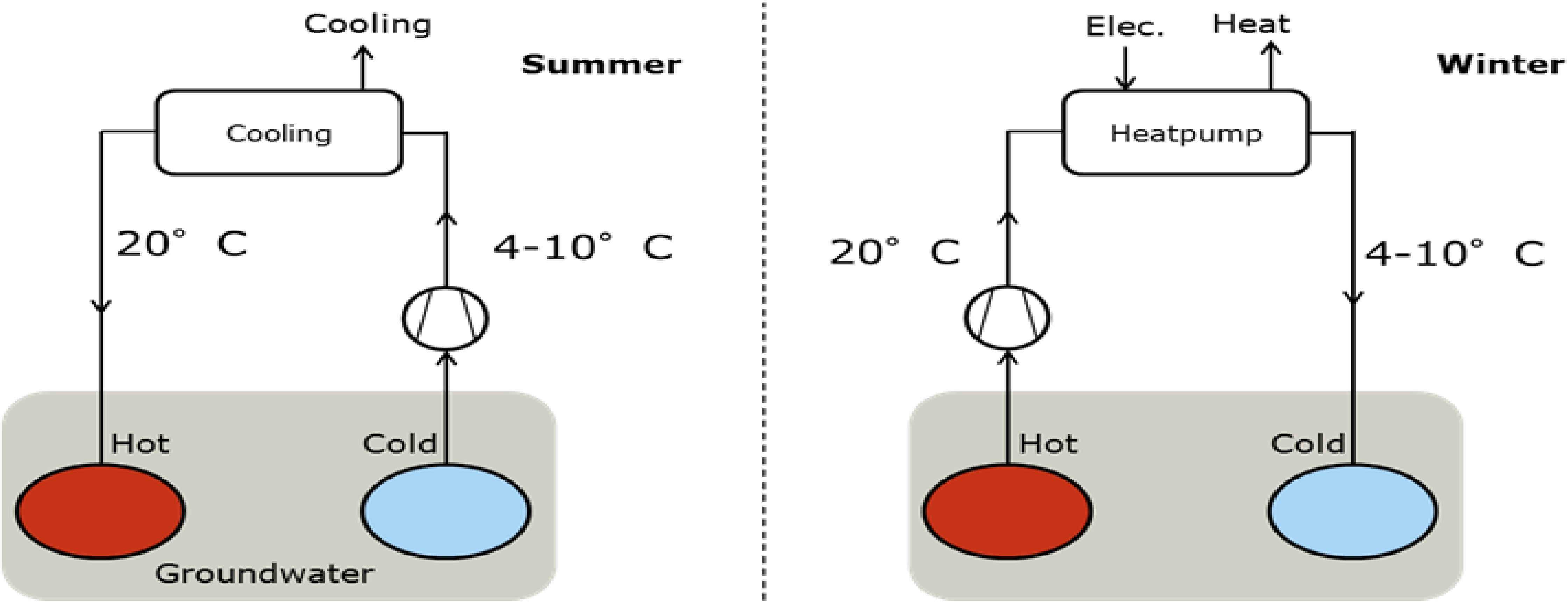
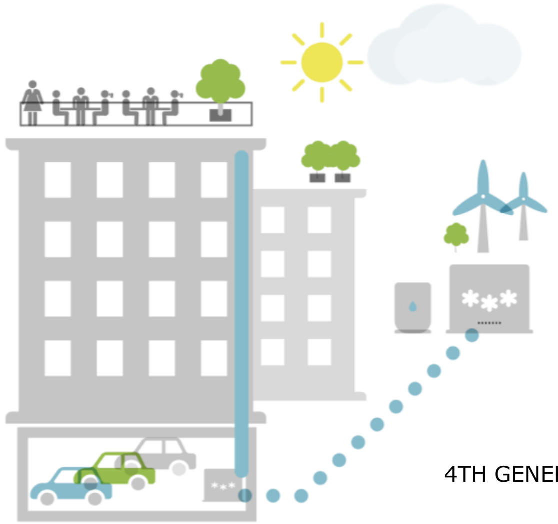
PRINCIPLE OF GROUND SOURCE COOLING (ATES)



ON NOISY CHILLERS ON THE ROOF TOOP



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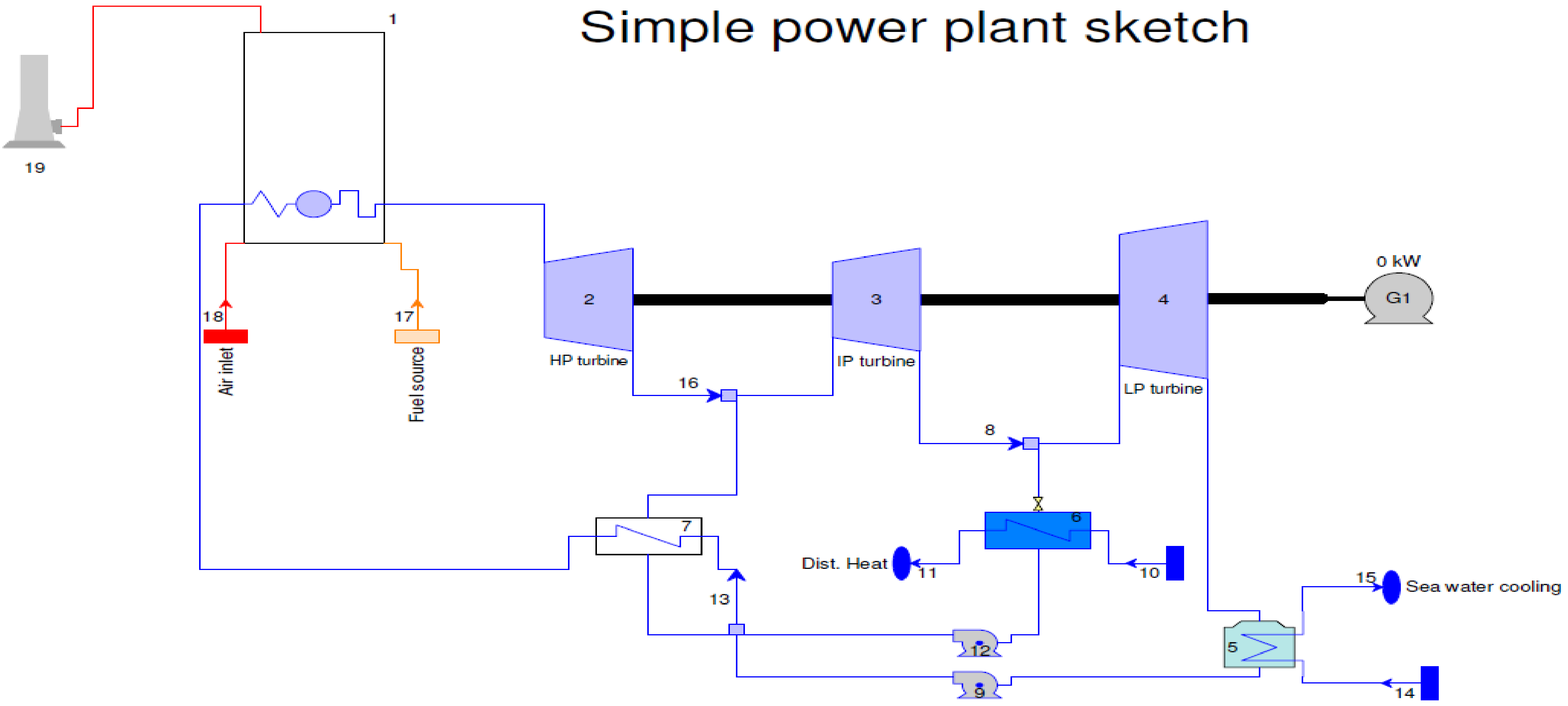
COMBINED HEAT AND POWER, CHP

CHP, FYNSVÆRKET DK
EXTRACTION PLANT – SIMPLE DIAGRAM



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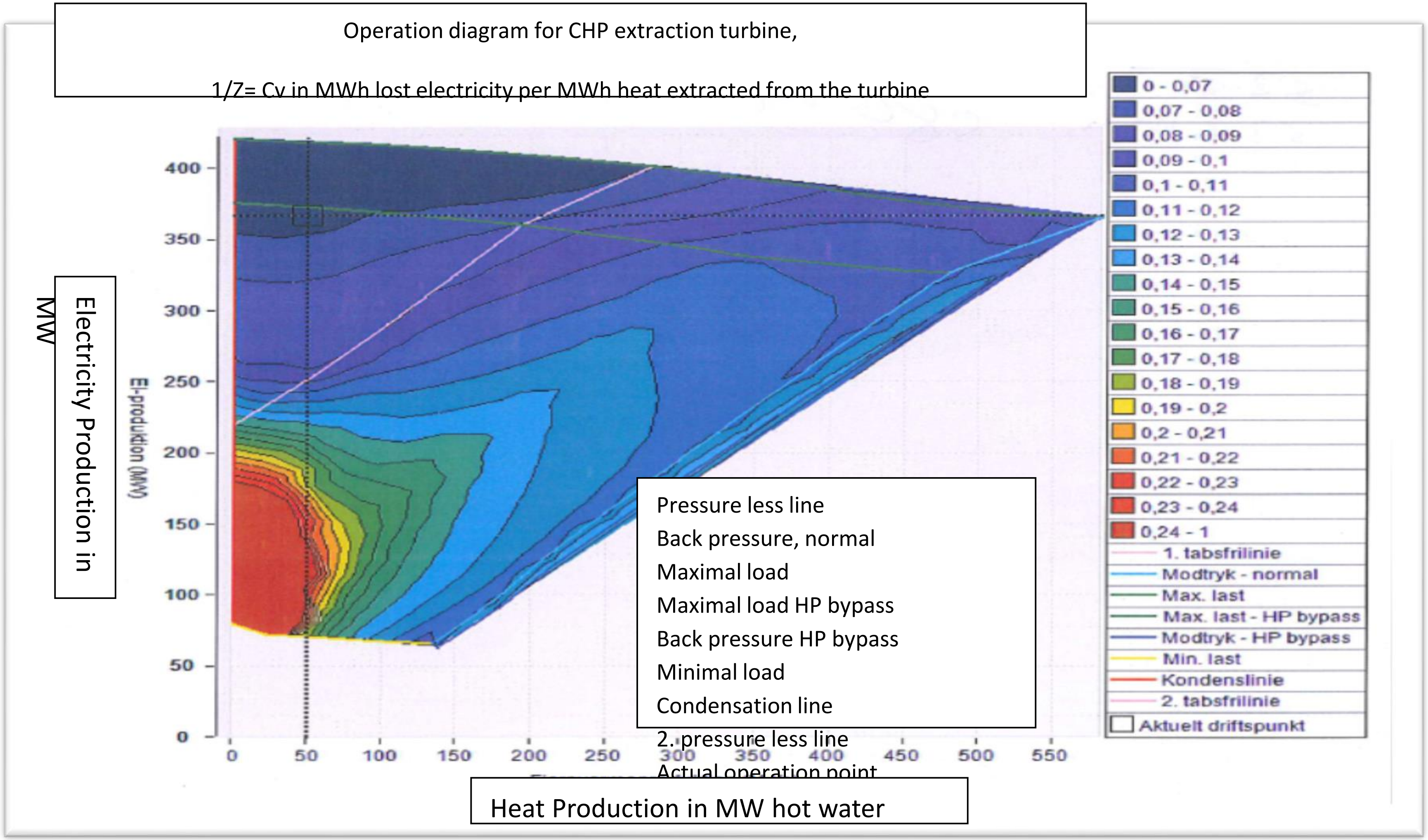
CHP EXTRACTION PLANT – MIX OF HEAT AND POWER FYNSVÆRKET DK



CHP POTENTIAL FOR NEW POWER GENERATION COMPARED TO NEW POWER ONLY PLANT

- Assuming that **a good 300 MW CCGT condensing plant** is the baseline (on the margin), corresponding to the new CHP plants
- Calculation of the fuel consumption for production of heat by various sources with the same fuel (small but never zero)

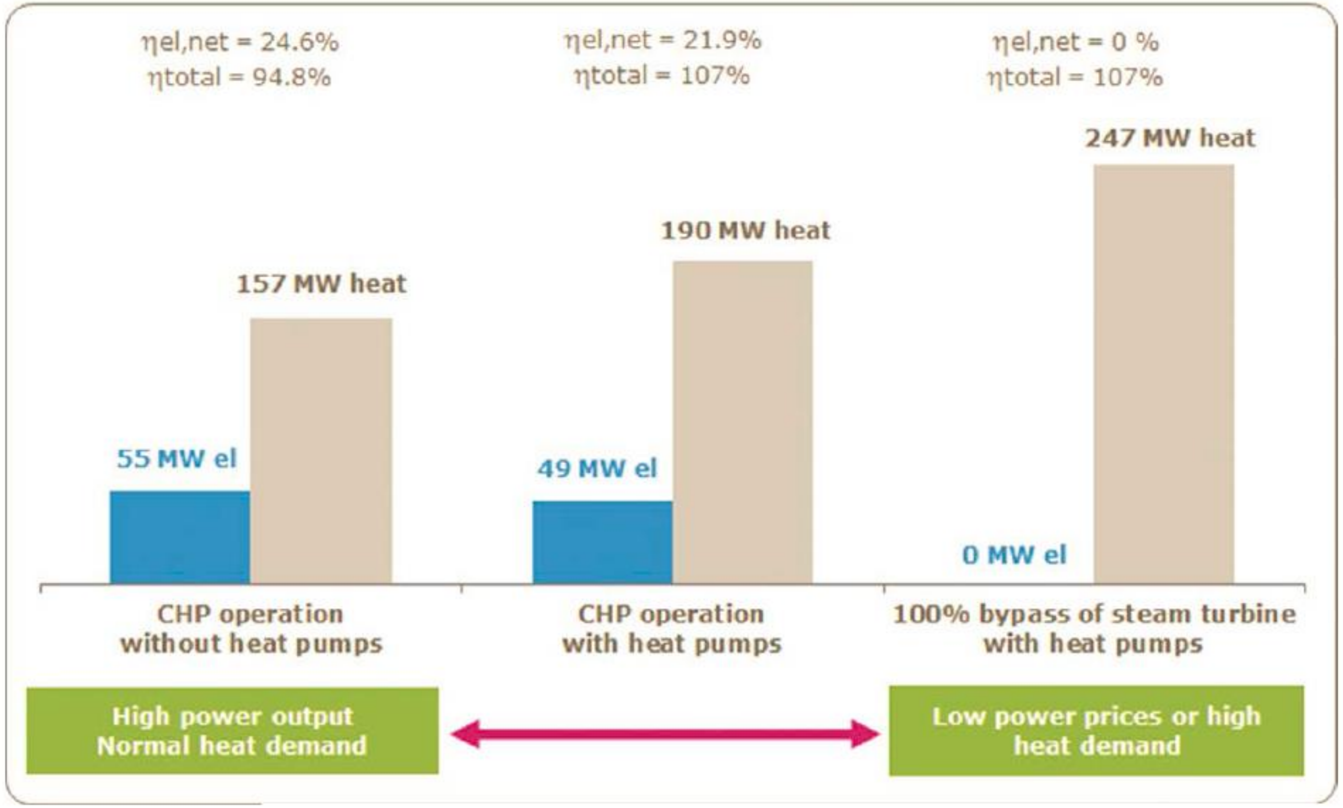
Cases	**Reference plants**			**Today**		**DK today**			
Poor Reference power condensing plant gas fuelled CCGT on the margin	Heat only boiler	300MW CCGT elec.heat	300MW CCGT HP	1,5-5 MW Gas eng.	1,5-5 MW Gas turb.	3 MW Gas eng.	60MW CCGT Backpres.	300MW CCGT extraction	300MW CCGT extraction
Maximal temperature, °C				160	160	120	120	120	90
Heat efficiency Backpressure	90%			40%	50%	52%	46%	40%	37%
Power efficiency Backpressure				35%	30%	38%	45%	51%	54%
Total efficiency of plant, LHV	**90%**			**75%**	**80%**	**90%**	**91%**	**91%**	**91%**
Power to heat ratio				**0,88**	**0,60**	**0,73**	**0,98**	**1,28**	**1,46**
Power efficiency of Ref plant, LHV		**58%**	**58%**	**58%**	**58%**	**58%**	**58%**	**58%**	**58%**
Estimated marginal loss from central plant		6%	6%	6%	6%	4%	2%	0%	0%
Ref power eff. local grid		55%	55%	55%	55%	56%	57%	58%	58%
Extraction Z-factor or COP			**3,0**					**5,7**	**9,3**
Extraction of hea MWh fuel/MWh heat								0,30	0,19
Heat productior MWh fuel/MWh heat	**1,11**	**1,83**	**0,61**	**0,90**	**0,90**	**0,61**	**0,45**	**0,30**	**0,19**
Heat loss in district heating grid	0%	0%	0%	5%	5%	5%	10%	10%	10%
Heat supply MWh fuel/MWh heat	**1,11**	**1,83**	**0,61**	**0,94**	**0,95**	**0,64**	**0,50**	**0,34**	**0,21**
Savings compared to a boiler	**0%**	**-65%**	**45%**	**15%**	**15%**	**42%**	**55%**	**70%**	**81%**
EE directive, total saving of heat and power: good CHP > 10%				*5%*	*7%*	*19%*	*22%*	*24%*	*25%*

GAS FUELLED CC CHP, ABSORPTION HEAT PUMP AND LARGE-SCALE SOLAR HEATING IN SILKEBORG

- Gas fuelled CC plant 106 MW elec./120 MW heat
- Total efficiency of the plant 102%
- Heat storage tanks 4 x 16.000 m^3 = 64.000 m^3
- Large-scale solar heating 156.000 m^2
- Absorption heat pumps 25 MW cooling
- Heat production solar 70 GWh
- Heat pump from solar 10 GWh
- Heat production CHP (market) 210 GWh
- Heat pump condensation 30 GWh
- Heat production boilers 80 GWh

WASTE INCINERATION AND BIOGAS

ARC COPENHILL – NO WASTE TO BE DUMPED AT LANDFILLS ENERGY PRODUCTION - FLEXIBILITY - AND LIVEABILITY



Credit: BIG

FROM SLUDGE AND WET WASTE TO BIOGAS
FROM LOW COST ELECTRICITY TO H2 TO NATURAL GAS

- Biofoss, Lynetten, Copenhagen
  - Sludge to biogas
  - Biogas to city-gas for cooking and process energy
  - Sludge incineration to district heating
- Biofoss, Avedøre Holme, Copenhagen
  - Sludge to biogas
  - Biogas to natural gas and CO_2
  - Sludge incineration to district heating
  - Power to H_2 (test)
  - H_2 and CO_2 to natural gas (test)
- **Nymindegab MOD DK**
  - Wet waste to biogas to CHP to heat and power

LARGE-SCALE SOLAR WATER HEATING

LARGE-SCALE SOLAR HEATING DEVELOPED IN 10 YEARS IN DK

- Marstal DH, 18,000 m2 with subsidy
- Danish manufacturer ArconSunmark
- Status 2017, installed without subsidy
  - 100 plants in DK
  - Total panel area 1,100,000 m2 in DK
  - +10,000 m2 in Norway
  - +39,000 m2 in Chile
  - +xx m2 in USA
  - 155,000 m2 in Silkeborg, so far the largest
- Heat Plan Denmark in 2035
  - 8 mio.m2 estimated in DK

COST OF LARGE SCALE SOLAR
FACTOR 3 FROM HOT TO MILD CLIMATE

Production from 10.000 m^2 DH solar heating plant, field							
Temperatures in panels		**Low DH temperature**			**High DH temperature**		
Climate zone		Mild	Warm	Hot	Mild	Warm	Hot
Annual solar radiation	kWh/m^2 panel	1.150	1.350	2.300	1.150	1.350	2.300
Average out door temperature	°C	9	13	16	9	13	16
Supplytemperature	°C	60	60	60	90	90	90
Return temperature	°C	40	40	40	70	70	70
Expected production	kWh/m^2 panel	550	850	1.500	450	700	1.300
Investment in plant 10.000 m2	€/m^2 panel	200	200	200	200	200	200
Annual O&M cost 10.000 m2	€/m^2 panel	2	2	2	2	2	2
Investment in plant 10.000 m2	€/MWh/a	364	235	133	444	286	154
Capital costs, 30 year 3%	€/MWh	19	12	7	23	15	8
Annual operation costs	€/MWh	4	2	1	4	3	2
Average production cost	**€/MWh**	**22**	**14**	**8**	**27**	**17**	**9**

ECONOMY OF SCALE FOR SOLAR HEATING FACTOR 3-6 FROM FIELD TO BUILDING ROOF-TOP

Economy of scale for solar heating, warm climate zone, low DH temperature							
Typical heat consumer		Building, roof top			District heating, field		
Size of consumer		Small	Medium	Large	Small	Medium	Large
Solar panel area	m^2	5	200	2.000	2.000	10.000	20.000
Expected production	kWh/m^2 panel	750	800	850	850	850	850
Total annual investment	€/m^2 panel	1.000	450	400	380	200	190
Annual O&M cost	€/m^2 panel	9	7	5	4	2	2
Investment in plant	€/MWh/a	1.333	563	471	447	235	224
Capital costs, 30 year 3%	€/MWh	68	29	24	23	12	11
Annual operation costs	€/MWh	12	9	6	5	2	2
Average production cost	**€/MWh**	**80**	**37**	**30**	**28**	**14**	**13**

THANK YOU FOR YOUR ATTENTION
QUESTIONS & ANSWERS

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