COMBINED HEAT AND POWER (CHP)
Smart Power Generation
- District Heating Solutions

Edward Nagelhout, WÄRTSILÄ POWER PLANTS

May 2012

Timer

Agenda

- District Heating
- Opportunities and Challenges
- CHP Technologies in DH Applications
- Economic Comparison
- Other Benefits

WÄRTSILÄ

Timer

Agenda

- District Heating
- Opportunities and Challenges
- CHP Technologies in DH Applications
- Economic Comparison
- Other Benefits

WÄRTSILÄ

District Heating

Heat

Next to electricity, modern society requires much heat for

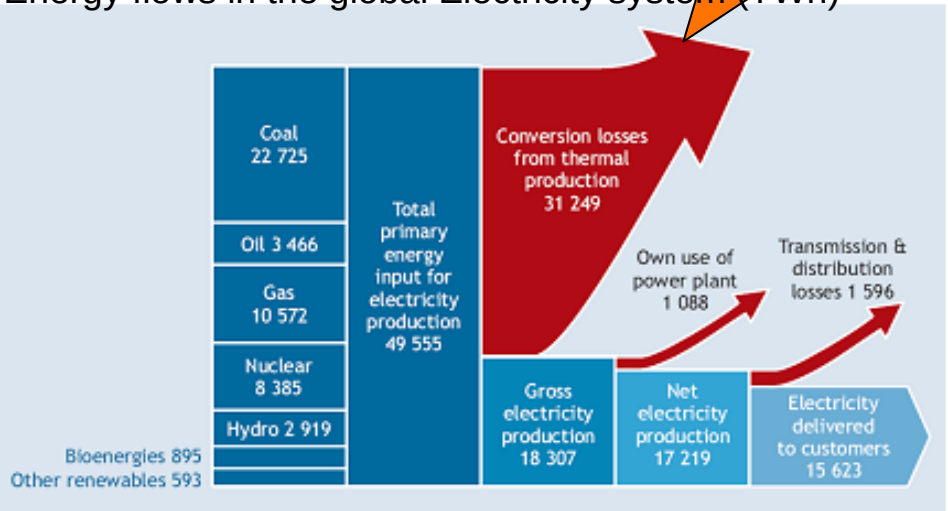
- industrial processes
- space heating
- hot water

Heat can be generated by

- Solar (Radiation (glass) or solar boilers)
- Heat pumps
- Fuel-based boilers
- CHP (combined heat and power)
  - This is especially the case if the electricity generators are installed at the site where the heat is needed.
  - Examples: Hospitals, chemical industries, refineries, large greenhouse facilities and district heating

Possible cogeneration, needs ofc heat demand

Energy flows in the global Electricity system (TWh)



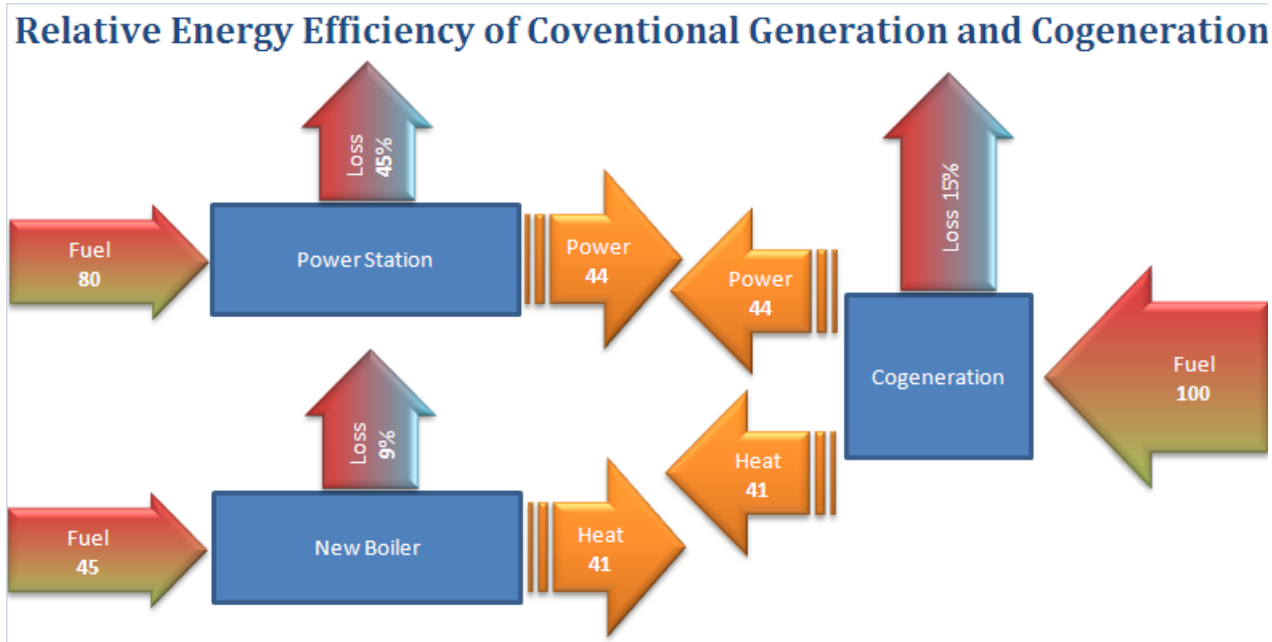
Source: IEA, *CHP, Evaluation the benefits of greater global investment, 2008*

District Heating

Cogeneration

Combined Heat and Power (CHP), also known as cogeneration, generates electricity while using **residual(excess)** heat for residential heating, hot water or steam

- CHP currently accounts for 9-11%* of global power generation
- CHP plants can use various fuels ranging from natural coal, gas, to even bio-mass



Total Fuel Needed:	
Conventional Generation	125
Hot Water Cogeneration	100

Efficiency Gain: 25%

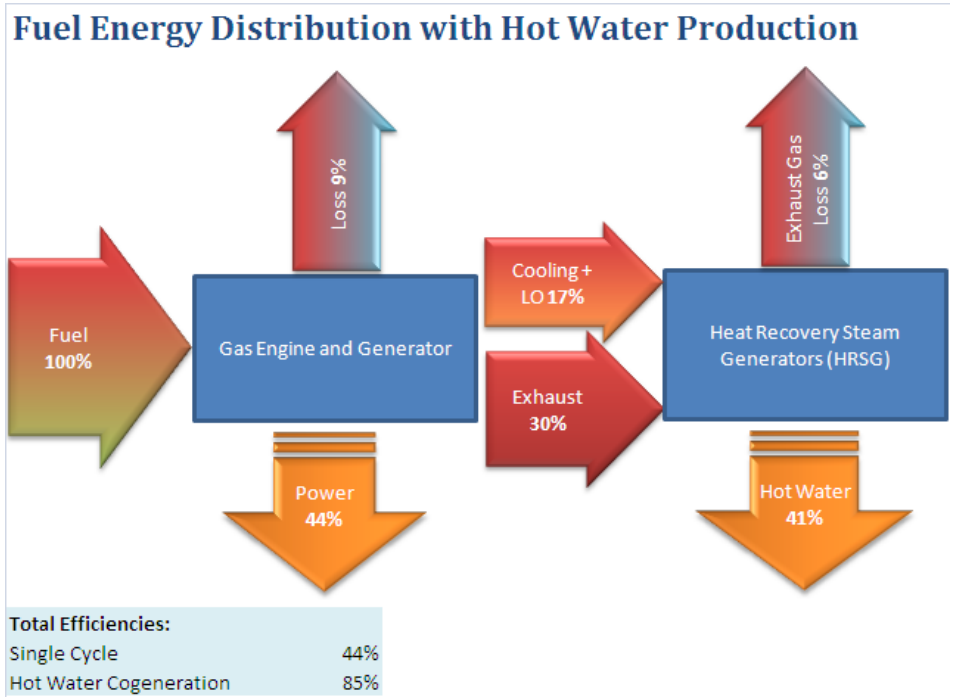
Source: IEA ETSAP Technology Brief E04, May 2010
Source: Cogen Europe

District Heating

Cogeneration

CHP Plant technologies

- Gas turbines (OCGT) with heat recovery steam generators (HRSG)
- Combined-cycle gas turbines (CCGT) consisting of a gas turbine with HRSG, which drives a steam turbine with a back pressure or a steam extraction system
- Internal combustion engines with electrical generators and heat extraction systems



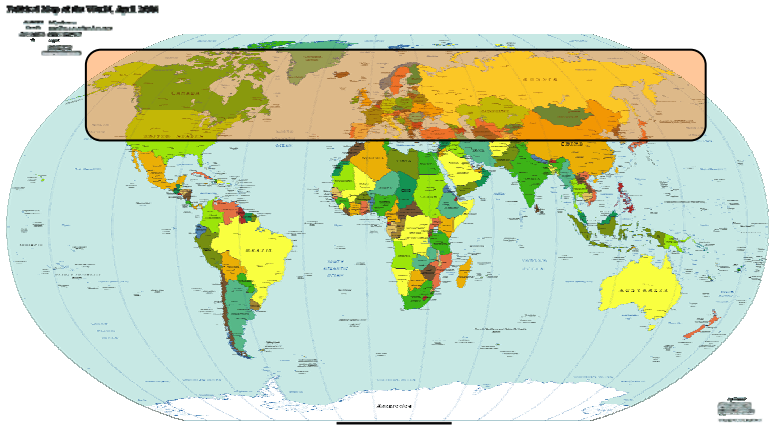
Source: IEA ETSAP Technology Brief E04, May 2010
Source: Cogen Europe

District Heating (DH)

DH systems

Heat Networks are a global happening

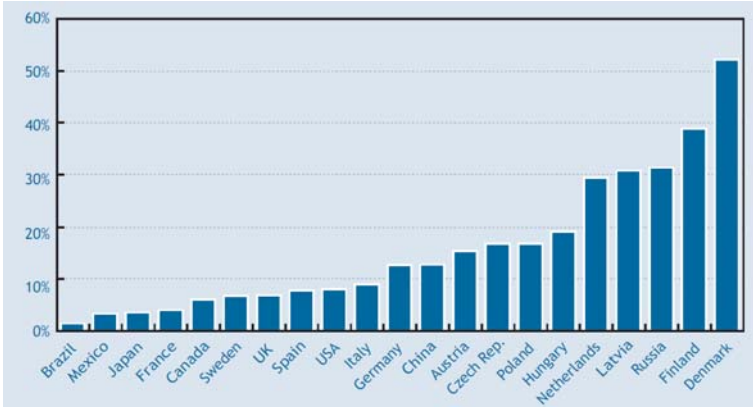
- North America (USA, Canada)
- North and Eastern Europe
- Russia
- Northern China and Japan
- South Korea



Built in Cities and Urban Areas

- Dense accumulation of buildings
- One common system covers one city
- System designs are country specific
- Most systems are based on
  - 110-170 °C Hot water
  - 90-100 °C Warm water
- Traditionally heated by centralised coal or oil fired thermal plants, which have been replaced by gas fired CHP

CHP share of total national power production



Source: IEA, *CHP, Evaluation the benefits of greater global investment, 2008*

District Heating (DH)

DH systems

Most CHP based DH systems are operated according to heat demand

- Electricity production is seen as a by-product to be sold to grid
- Typically only operated during cold seasons
- Summer heat load is lower than minimum requirements (So boilers take over)
- Summer E-prices are lower than winter prices (Less income)

Politically desirable

- Energy efficient (85-90%)
- Environmentally friendly (CO_2 reduction)

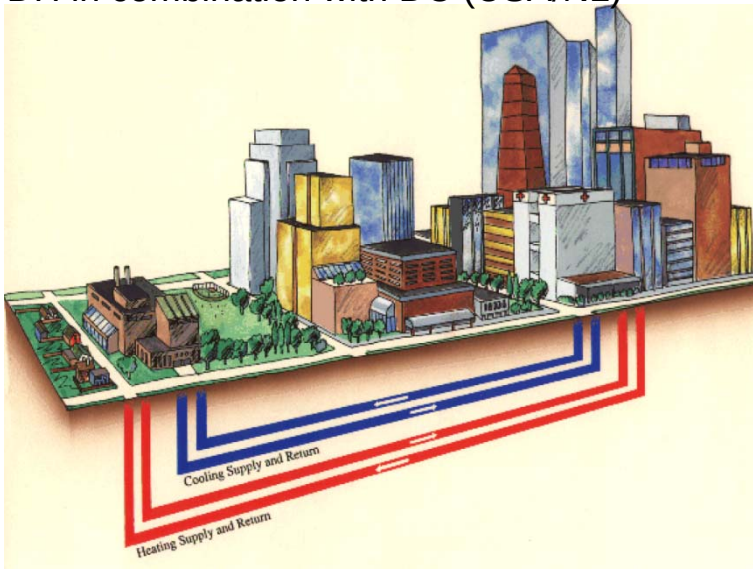
Feasibility is at question

- Large investments

Opportunities

- Product combination (DC, Heatpumps, RE)
- Maximise Earnings by increasing flexibility

DH in combination with DC (USA/NL)



Source: IEA, *CHP, Evaluation the benefits of greater global investment, 2008*

District Heating

DH systems

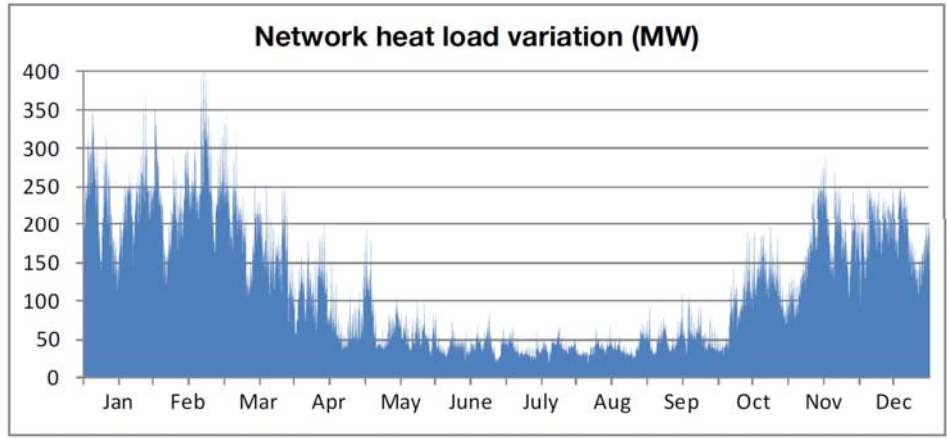
To make CHP more flexible

- DH systems need to make electricity and heat generation partially independent by
  - Heat storage (thermal/electrical)
  - Backup generation

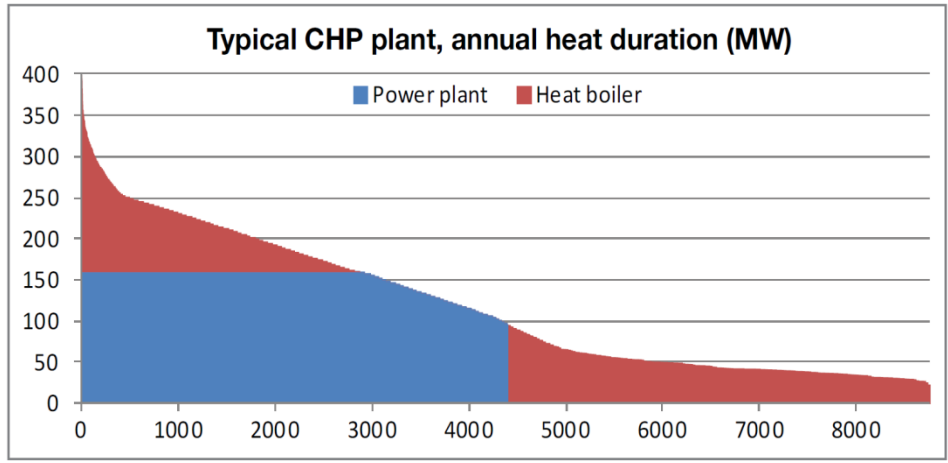
DH load

- DH load is generally scattered over a wide area with many smaller load points
  - Optimisation is challenging
  - CHP plant is economically viable at 40-50% of the annual peak load

Load variation curve of a typical 400 MW_{th} DH system



Corresponding load duration curve



Source: Heating data from a Central European City with a population of ~300,000

Timer

Agenda

- District Heating
- Opportunities and Challenges
- CHP Technologies in DH Applications
- Economic Comparison
- Other Benefits

WÄRTSILÄ

Timer

Opportunities and Challenges

Efficient use of primary fuels

Following EU Energy Strategy 20-20-20

- CHP and DH systems have a important role in increasing efficient use of fuels
- Replacement of coal, oil and gas-fired boilers plants with CHP

New investment in CHP and DH systems have requirements

- Need accurate and reliable forecasts of heat loads and prices
- Potential income from electricity
- Stable regulatory frameworks, due to long lifespan (20-40 years)

Heat load

- Typically heat loads are low in summer, while during other seasons loads varies heavily. Winter has very short term heat demand peaks with a higher base load
- Also notable annual heat load variations which makes optimisation challenging
- Improvement in insulation, such as housing, leads also to annual decrease in heat demand.
  - Estimations range from 1-3% per year
  - Growth of connections and increase in consumer comfort will alleviate this partially

WÄRTSILÄ

Timer

Opportunities and Challenges

Feasibility

Electricity

- Competitive markets
  - Leads to more price volatility
- Dispatch according to market price signals
- Higher shares of renewable plant (Wind and Solar)
  - Increase in electricity price variations, due to intermittency

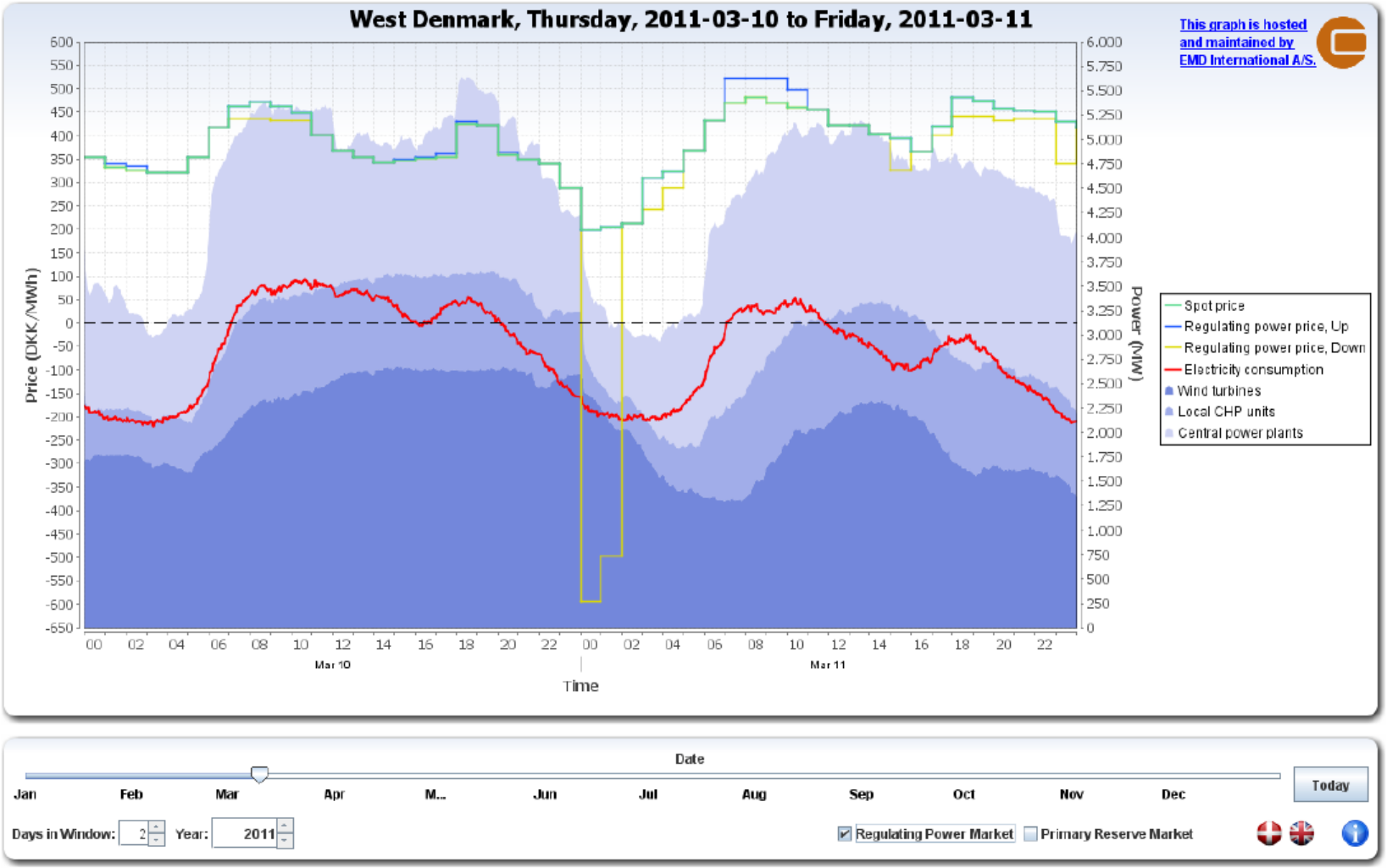
CHP

- Heat load and electricity prices do not always correlate (match)
- Making CHP heat and electricity production (partially) independent will increase its profitability
- Some markets promote merit order of CHP plant, improving feasibility
- CHP bonus is also known, bonus electricity tariffs, based on annual total efficiency

WÄRTSILÄ

Opportunities and Challenges

Spot Market Denmark



Opportunities and Challenges

Improved flexibility with DH storage

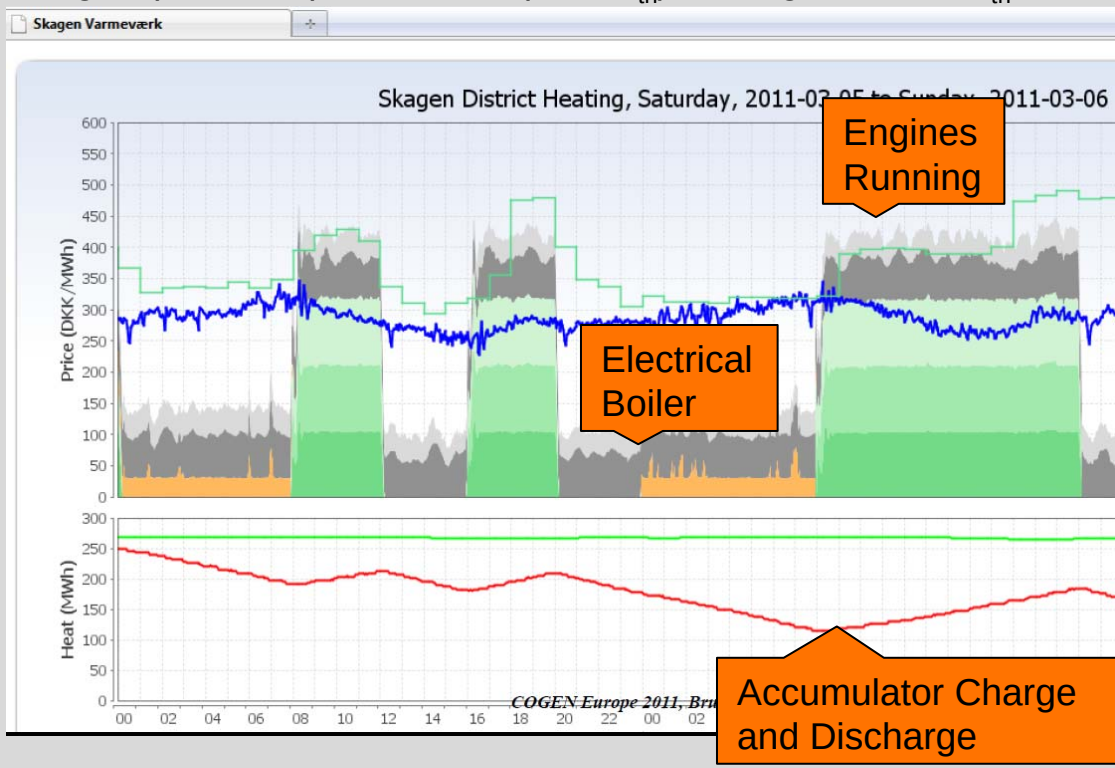
A heat storage system enables

- Efficient use CHP
- CHP flexibility

Utilisation of an accumulator

- High E-prices, CHP runs full load
  - Charges accumulator
- Low E-prices, storage discharges
  - CHP doesn't need to run
  - E-boiler practical when in markets with high share of intermittent plant
- Fast dispatching CHP
  - Possible balancing services
  - Tertiary income (ancillary markets, ETS)

Skagen (Denmark) CHP Plant (18MW$_{th}$), Storage 250 MWh$_{th}$



Source: www.emd.dk/desire/skagen

Timer

Agenda

- District Heating
- Opportunities and Challenges
- CHP Technologies in DH Applications
- Economic Comparison
- Other Benefits

WÄRTSILÄ

CHP Technologies in DH Applications

In mid segment (50-300MW) choices

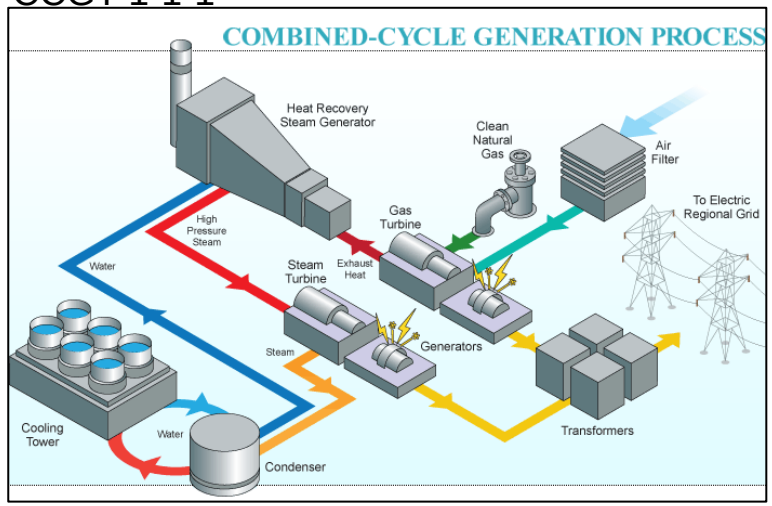
CCGT

- High electrical efficiency (48-58%)[1]
- Consists of a gas turbine with HRSG
  - driving a steam turbine with a back pressure
  - or a steam extraction system
- High gas pressure, High temperatures
- High quality materials and operators needed
- Gas turbine start 25 mins, CCGT 45 mins
- Minimum load 50% E, 60% Heat
- Once per year full maintenance with 50-100% capacity loss

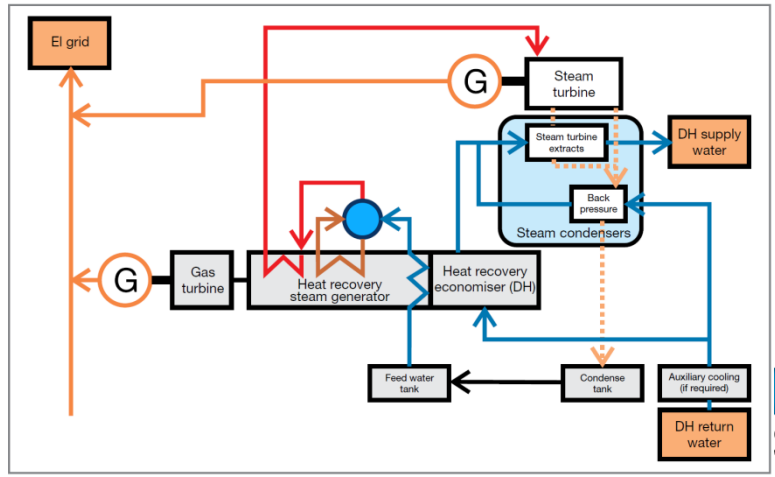
CCGT Configuration for DH

- Possible 1-1-1 or 2-2-1 setup
- The larger, the better the price per KW_e
  - Higher efficiency with larger turbines

CCGT 1-1-1



CCGT Back pressure plant with HRSG and DH



Source: GTPro, Thermoflow software

CHP Technologies in DH Applications

In mid segment (50-300MW) choices

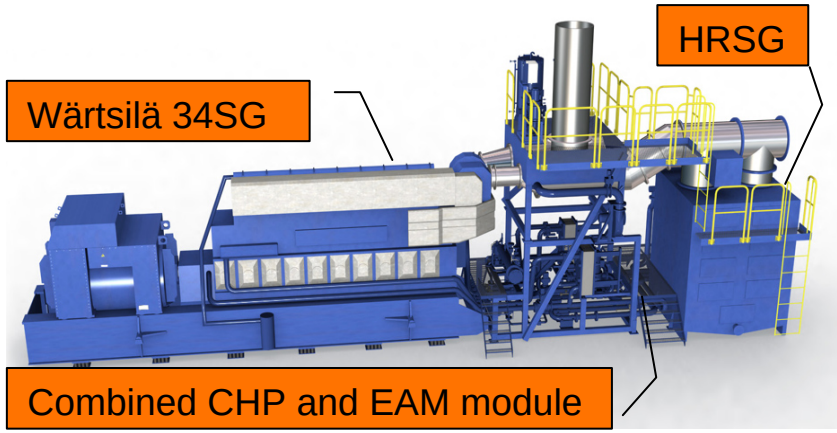
Reciprocating combustion engines

- Electrical efficiency (44-48%)[1]
- Multiple generation sets in parallel
  - HRSG and Engine cooling system
  - Jacket water, lube oil, charge air
- Gas pressure 5 bar, temperatures 400°C
- Modular design, enabling short start up times
- Start 5 mins
- Maintenance can be run with minimal loss of capacity 5 engines 20%, 10 engines 10%
- Wide load range 5%-100% for both E and heat

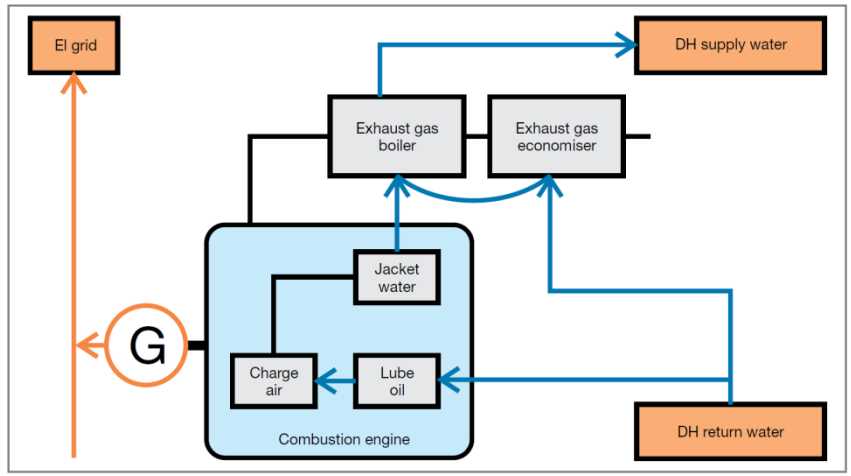
Configuration for DH

- Easy to optimise due to multiple engines

Wärtsilä 34SG CHP Modular Unit



Combustion Engine Heat Recovery



Also biomass fired plants

Source: Wärtsilä

WÄRTSILÄ

CHP Technologies in DH Applications

Comparisons

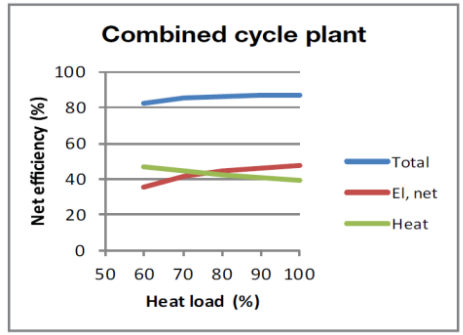
Efficiencies

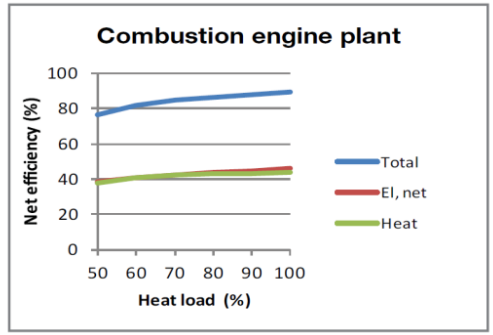
- Gas turbines
  - E-efficiency decreases at part load
  - Heat efficiency increases at part load
- Combustion engines
  - High part load E-efficiency
  - Constant power-to-heat ratio at any load
- Minimum electrical load in the graphs is assumed at 50% for both technologies

Power-to-heat ratios

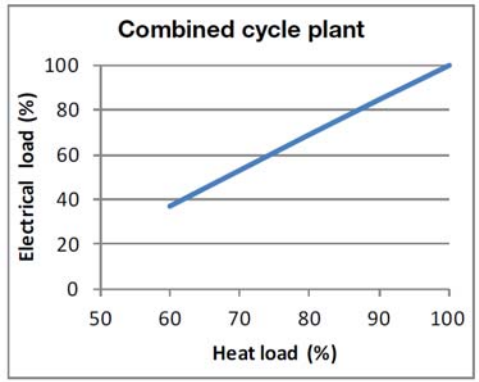
- As seen the CCGT can operate between a heat load range
  - 60-100% in 1-1-1 and
  - 30-100% in 2-2-1 configuration
  - 2-2-1 running in 1-1-1 can increase its power-to heat ratio to 100% at 50% load
- Combustion engines can run at 5-100% heat load (10 units)

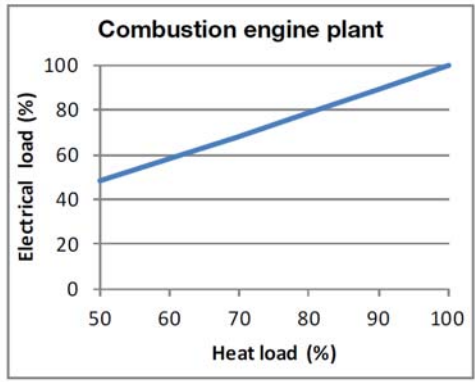
Typical part load performance curves





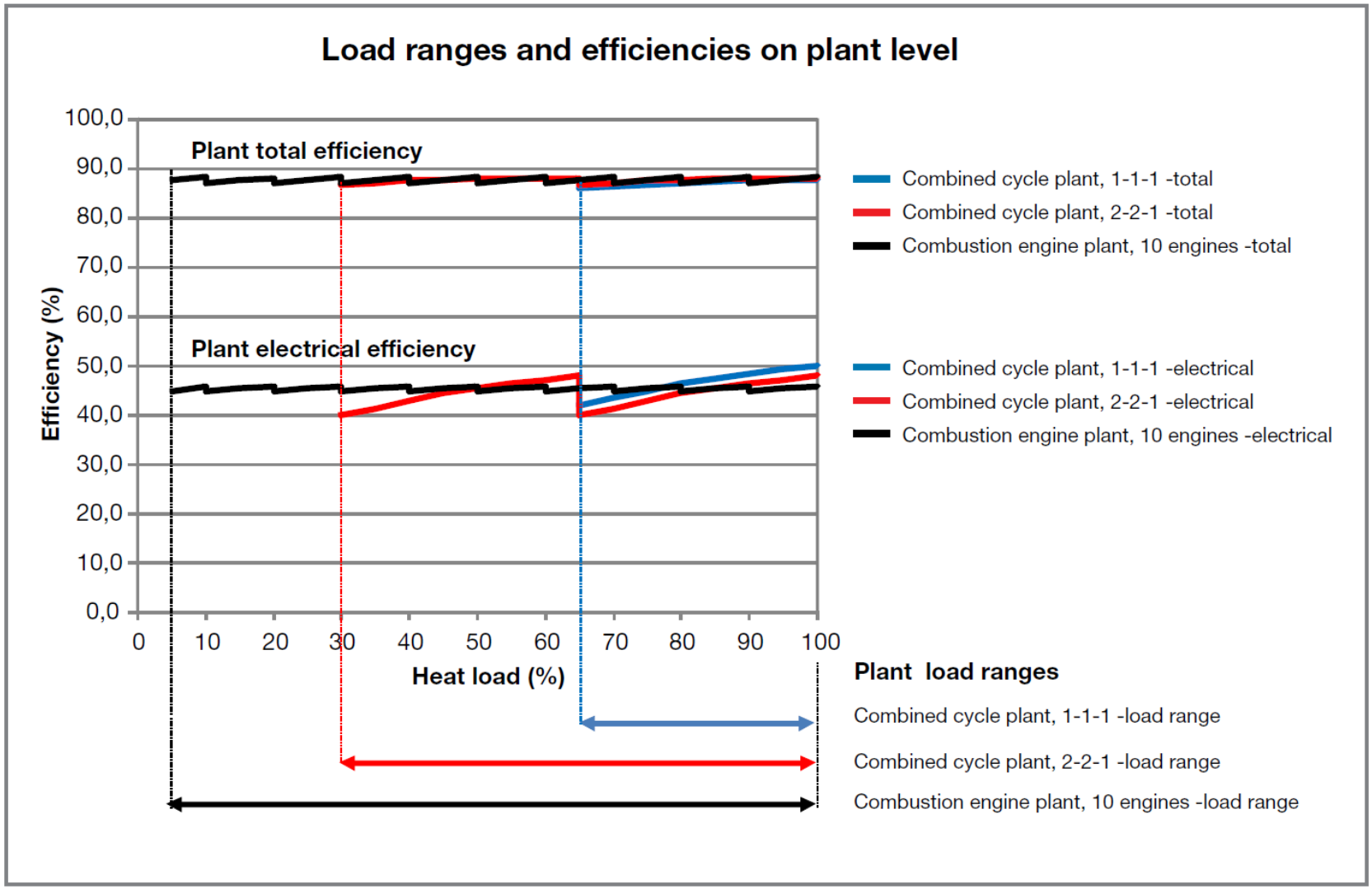
Typical power-to-heat ratio performance curves





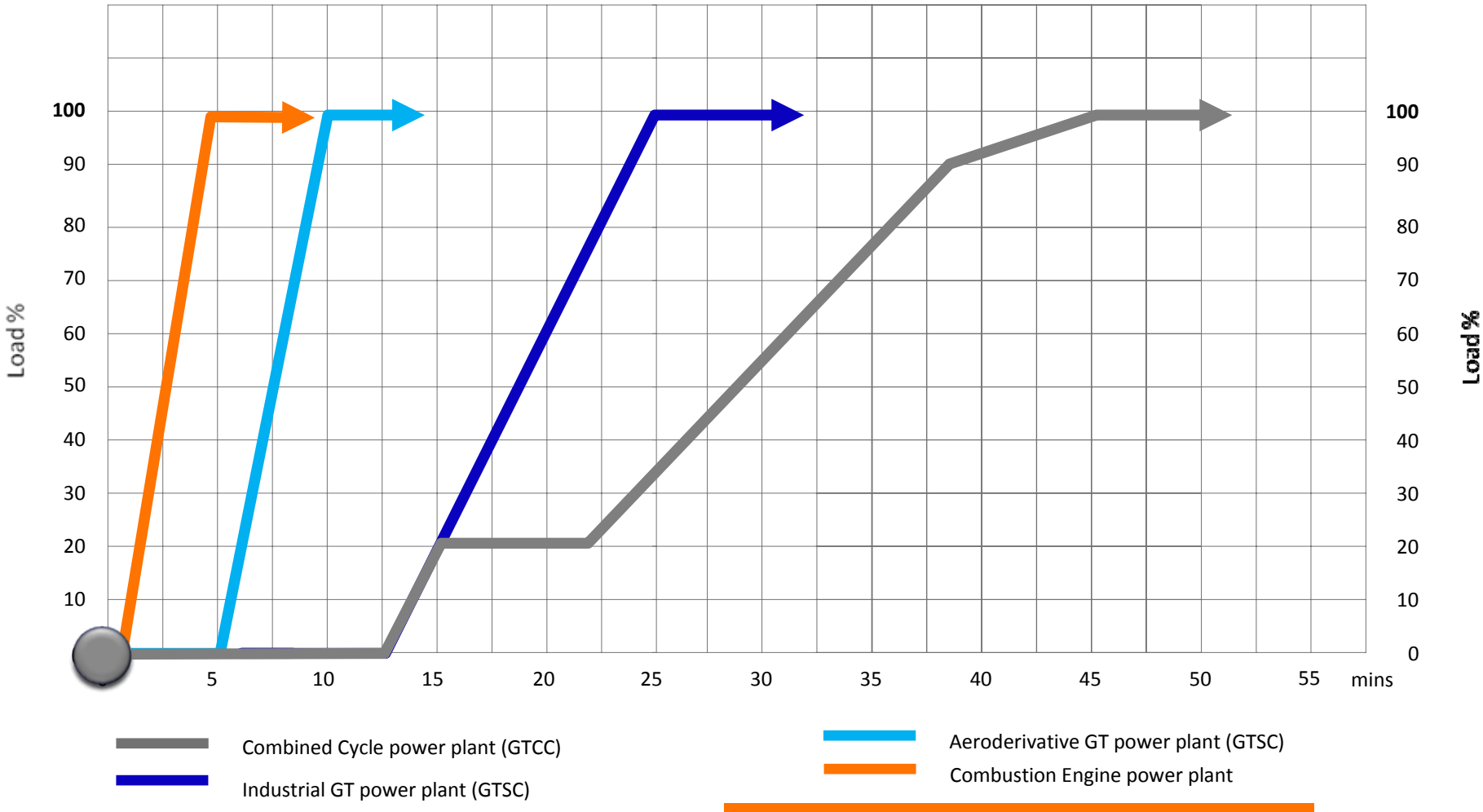
CHP Technologies in DH Applications

Comparisons



CHP Technologies in DH Applications

Dynamic features



Note: Start up times from warm stand-by!

Timer

Agenda

- District Heating
- Opportunities and Challenges
- CHP Technologies in DH Applications
- Economic Comparison
- Other Benefits

WÄRTSILÄ

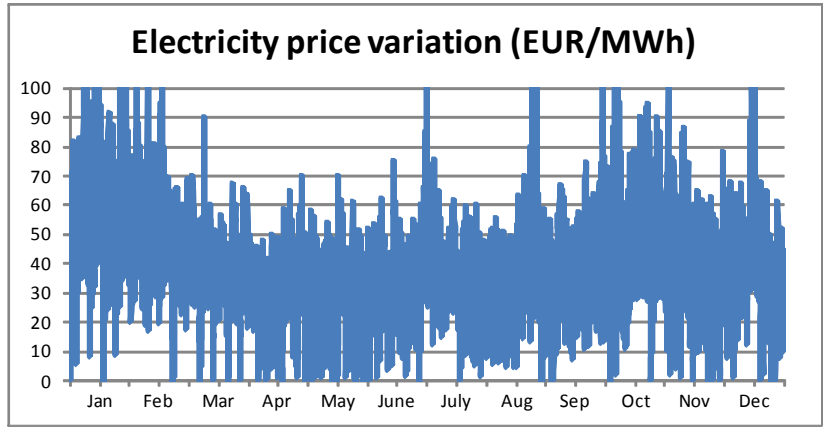
Economic Comparison

Input data for model

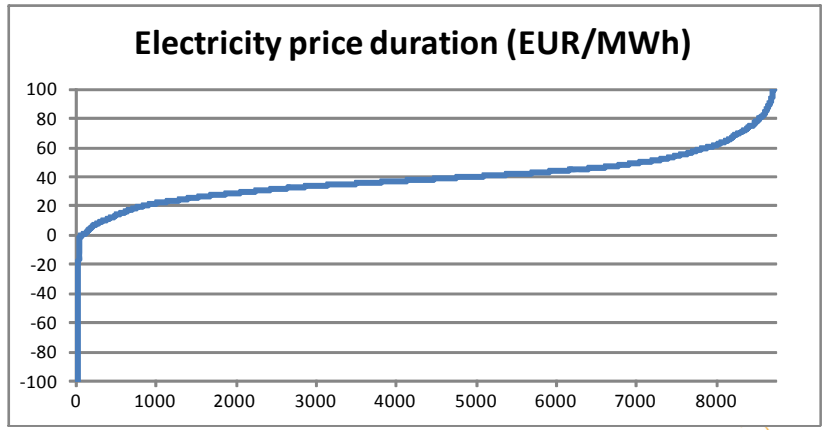
Model data

- Electricity market
  - E produced sold to German National Grid (EEX)
  - E-prices 2009[1], CHP get bonus of €15/MWh_{el}[2]
- Gas market
  - € 25/MWh[3] (€ 6.9/GJ) fuel cost
  - Corresponding heat price at 91% efficiency is € 27.5/MWh_{th}
- Economic variables
  - Lifespan is 20 years, with 6% WACC
  - Hourly evaluation for 1 operational year
  - 400 MW_{th} DH network, optimal 40% load setup
- Compared solutions [3]
  - 1-1-1 CCGT, 220 MW_{el}, 50% efficiency
  - 2-2-1 CCGT, 2x100 MW_{el}, 48% eff.
  - Combustion engine plant, 10x18MW_{el}, 46% eff.
  - All: 88% efficiency total, 165 MW_{th} full load

E-Market price variation



E-Market price duration



Timer

Economic Comparison

Performance Values

Data

- Sources: Wärtsilä and GTPro, thermoflow software
  - Project and development costs are assumed at 25-30% of total investment
  - These also contain the investment for storage/accumulators
  - O&M are estimates based on data from multiple sites, calculating costs related to start/stop use

Performance values of the compared solutions

Plant name		Combined cycle plant, 1-1-1	Combined cycle plant, 2-2-1	Combustion engine plant 10 engines
Plant size	MW_{el} / MW_{th}	220 / 167	200 / 167	180 / 164
Plant net efficiency				
Electricity	%	50	48	46
Heat	%	38	40	42
Total	%	88	88	88
Plant load range				
Electricity	%	50–100	25–100	5–100
Heat	%	68–100	34–100	5–100
Prices and costs				
Power plant (EPC)	EUR/kW_{el} net	900	1000	700
Project development / administration	EUR/kW_{el} net	300	300	300
Total investment	EUR/kW_{el} net	1200	1300	1000
O&M costs including consumables	EUR/MWh_{el}	4	4	6

WÄRTSILÄ

Economic Comparison

Optimal plant operating modes

Model output

- CCGT shut down during summer months, due to narrow load range + long start-up times
  - 1-1-1 configuration produces more E, because of size and higher efficiency
  - 2-2-1 configuration gets more operation hours due to its boarder range
  - Combustion engines produce more heat and electricity because it can operate during summer
  - Combustion engines reach higher annual running hours due to its wide load range (multiple units)

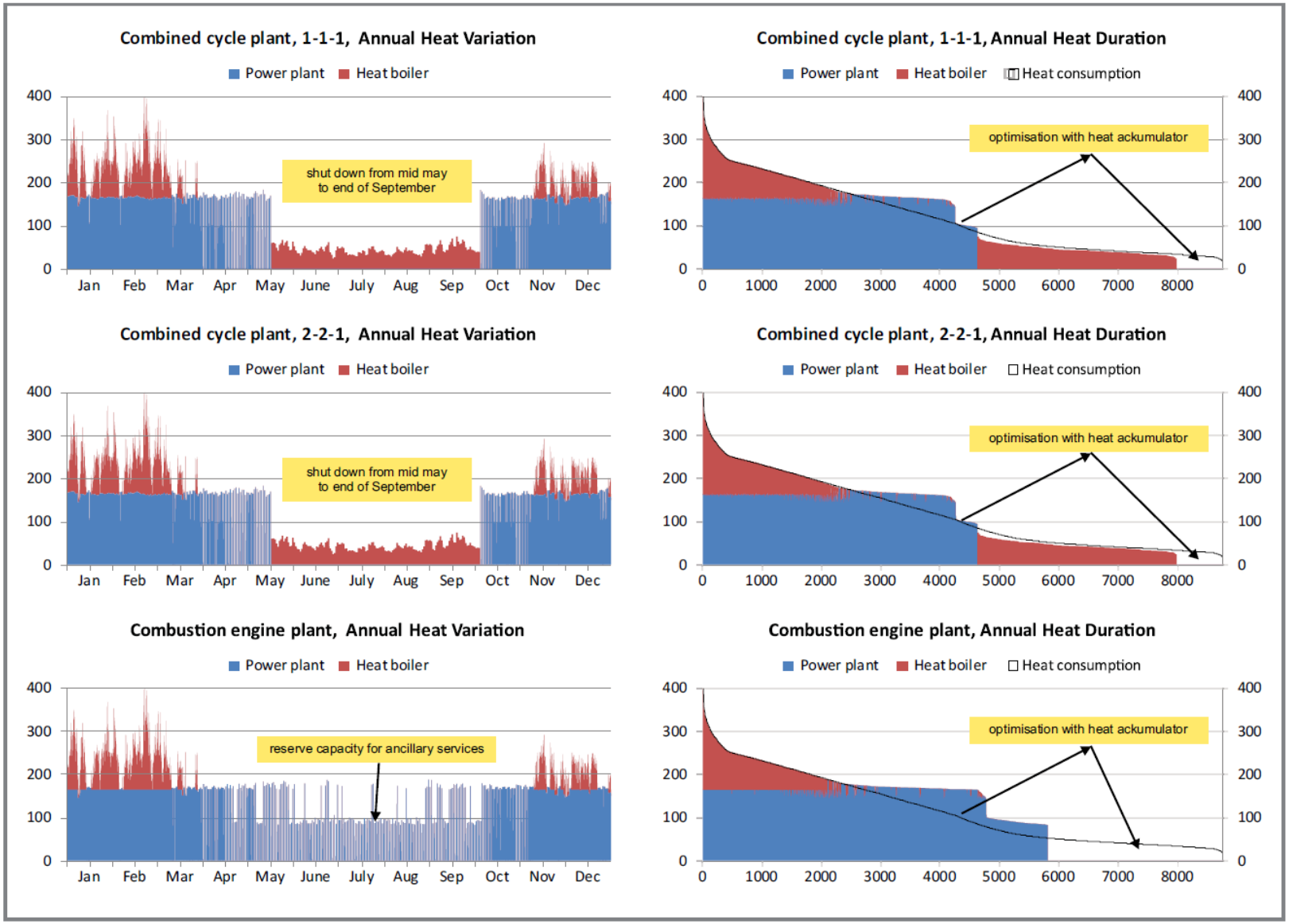
Performance values of the compared solutions

Plant name		Combined cycle plant, 1-1-1	Combined cycle plant, 2-2-1	Combustion engine plant 10 engines
Plant size	MW_{el} / MW_{th}	220 / 167	200 / 167	180 / 164
Electricity production balance				
Electricity production	GWh_{el}	869	840	940
Fuel consumption	GWh_{fuel}	1 746	1 777	2 045
Annual running hours	h	4 192	4 698	5 820
Heat production balance				
Power plant	GWh_{th}	668	716	862
Heat boiler	GWh_{th}	375	328	181
Total	GWh_{th}	1 044	1 044	1 044
Annual efficiencies				
Electricity	%	50	47	46
Heat	%	38	40	42
Total	%	88	88	88

Source: Wärtsilä, moduled via Plexos

Economic Comparison

Annual variation and duration curves for the compared solutions



Source: Wärtsilä, moduled via Plexos

Economic Comparison

Economic Results

CCGT <-> Combustion engines

- Feasibility Model
  - Annual operating profits of all 3 solutions are similar
  - Lower E-efficiency of combustion engine is compensated by its flexibility in summer
  - The relative low CAPEX costs gives the combustion plant healthier cash flow
    - This in return shortens the pay-back time, IRR and NPV is higher

Economic values of the compared solutions

Plant name		Combined cycle plant, 1-1-1	Combined cycle plant, 2-2-1	Combustion engine plant 10 engines
Plant size	MW_{el} / MW_{th}	220 / 167	200 / 167	180 / 164
Revenues and cost division				
Revenues from sales of electricity	MEUR / year	39	37	41
CHP bonus	MEUR / year	13	13	14
Total revenues	MEUR / year	52	49	55
Operating costs	MEUR / year	29	28	33
Operating profit	MEUR / year	23	21	22
Capital Costs	MEUR / year	23	23	16
Net cash flow	MEUR / year	0	-1	7
Feasibility of the investment				
Pay-Back Time	years	21	23	11
Internal Rate Of Return	%	6	5	11
Net present value	MEUR	0	-16	76
Total Investment	MEUR	264	260	180

Source: Wärtsilä, moduled via Plexos

WÄRTSILÄ

Economic Comparison

Economic Results

CCGT <-> Combustion engines

- Feasibility Model
  - Combustion engine has higher production costs, due to its higher running hours
  - On the other side it has a lower annual generation cost
    - High electrical output
    - Lower capital cost

Economic values of the compared solutions

Plant name		Combined cycle plant, 1-1-1	Combined cycle plant, 2-2-1	Combustion engine plant 10 engines
Plant size	MW_{el}/MW_{th}	220 / 167	200 / 167	180 / 164
Production costs				
Fuel	MEUR	44	44	51
Variable O&M	MEUR	3	3	6
- Fuel savings from heat recovery	MEUR	-18	-20	-24
Total	MEUR	29	28	33
Generating costs				
Electricity production costs	EUR/MWh_{el}	33	33	35
Capital costs	EUR/MWh_{el}	26	27	17
Total	EUR/MWh_{el}	60	60	52
- CHP bonus	EUR/MWh_{el}	-15	-15	-15
Net generating costs	EUR/MWh_{el}	45	45	37

Source: Wärtsilä, moduled via Plexos

WÄRTSILÄ

Summary

The study showed, future CHP and DH systems should:

- Fulfil environmental norms
- Utilise heat storage
- Have high efficiency
- Have a high power-to heat ratio
- Have good dynamic capabilities
  - fast start to full production, fast stop and good ramping possibilities
- Have a wide plant heat load range

Timer

Summary

The key findings from the comparison are:

- A wide heat load range enables flexible operation during variable heat demands
- Heat storage improves the system's flexibility with optimal electricity and heat production
- A efficient plant with high power-to heat ratio enables more electricity production
- Multiple units with fast starts/stops enable dynamic operation in low heat demand seasons
- Good dynamic capabilities (multiple units) enable opportunities in ancillary services markets due to increasing shares of intermittent renewable generation. Is also therefore more profitable

WÄRTSILÄ

Timer

Agenda

- District Heating
- Opportunities and Challenges
- CHP Technologies in DH Applications
- Economic Comparison
- Other Benefits

WÄRTSILÄ

Other Benefits

Additional earning potential

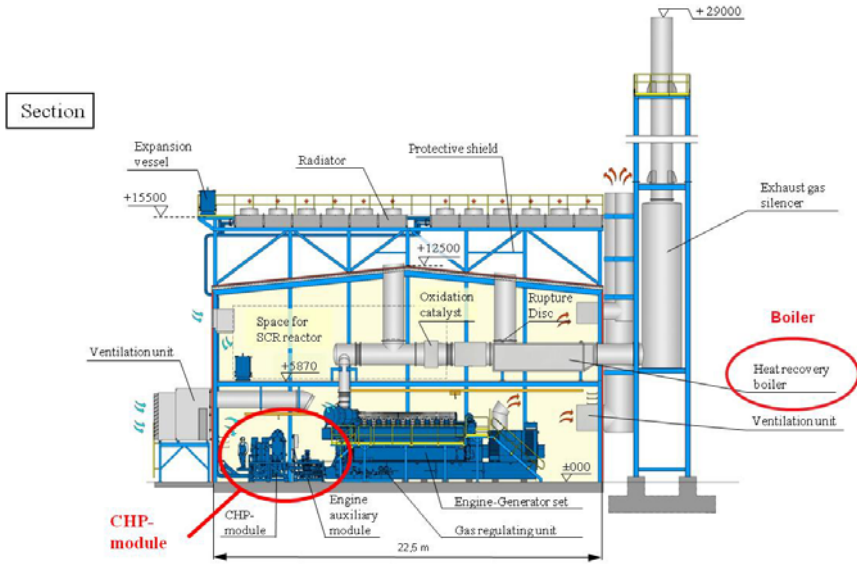
CHP can earn extra income on dynamic markets

- Electricity market
  - Sell capacity (reserve) in summer mostly
  - Sell ancillary services, balancing and frequency balancing

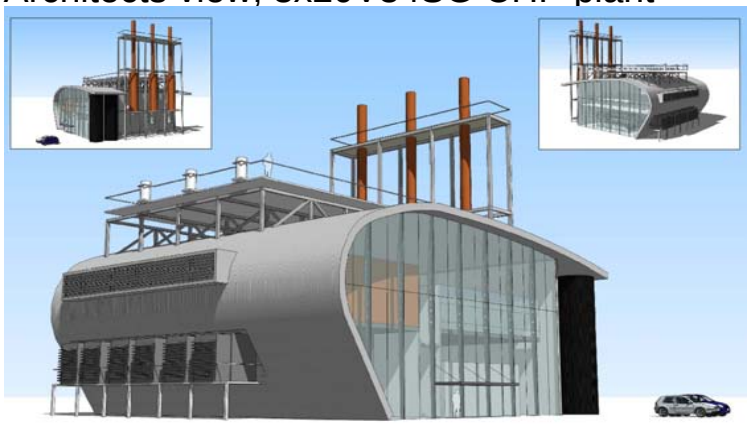
- Decentralised plant locations
  - Multi unit combustion engine plants offer the same efficiencies and cost level regardless of the number of units
  - Improves reliability and efficiency of energy supply
  - Reduces electrical and heat transmission losses
  - Saves pumping energy in the DH system
  - May be connected directly to medium voltage systems, reducing connection fees to high voltage national grid

- Permit allowance (easier to get building permits)

"Town" concept, 2x20V34SG CHP plant



Architects view, 3x20V34SG CHP plant

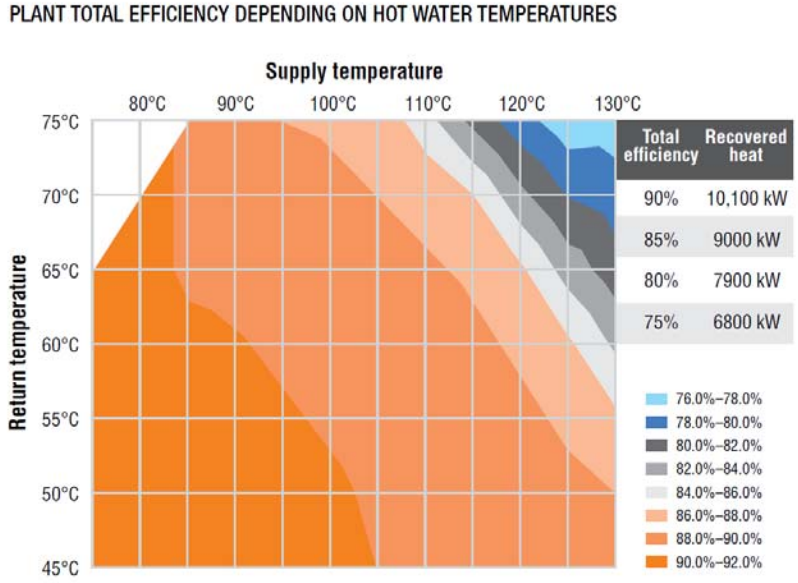


WÄRTSILÄ

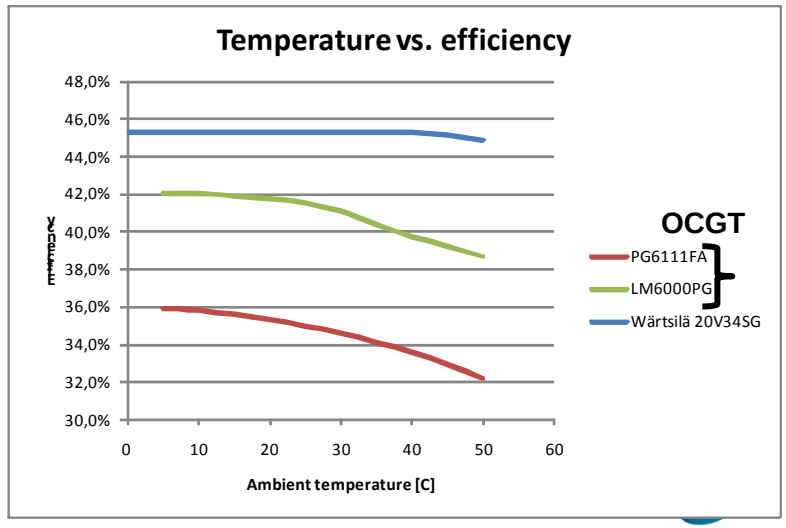
Optimise CHP

- Combustion plant efficiency is dependant on DH system
  - The lower the return temperature, the higher the total efficiency possible
- Plant efficiency is dependant on ambient temperatures
  - When running in the summer combustion plants don't suffer efficiency losses as much as GT's

Efficiency dependant on return temperature



Efficiency dependant on ambient temperature



WÄRTSILÄ

THANK YOU FOR YOUR ATTENTION!

Edward.Nagelhout@wartsila.com

Smart Power Generation

www.smartpowergeneration.com