2. PLANNING OF CHP SYSTEMS

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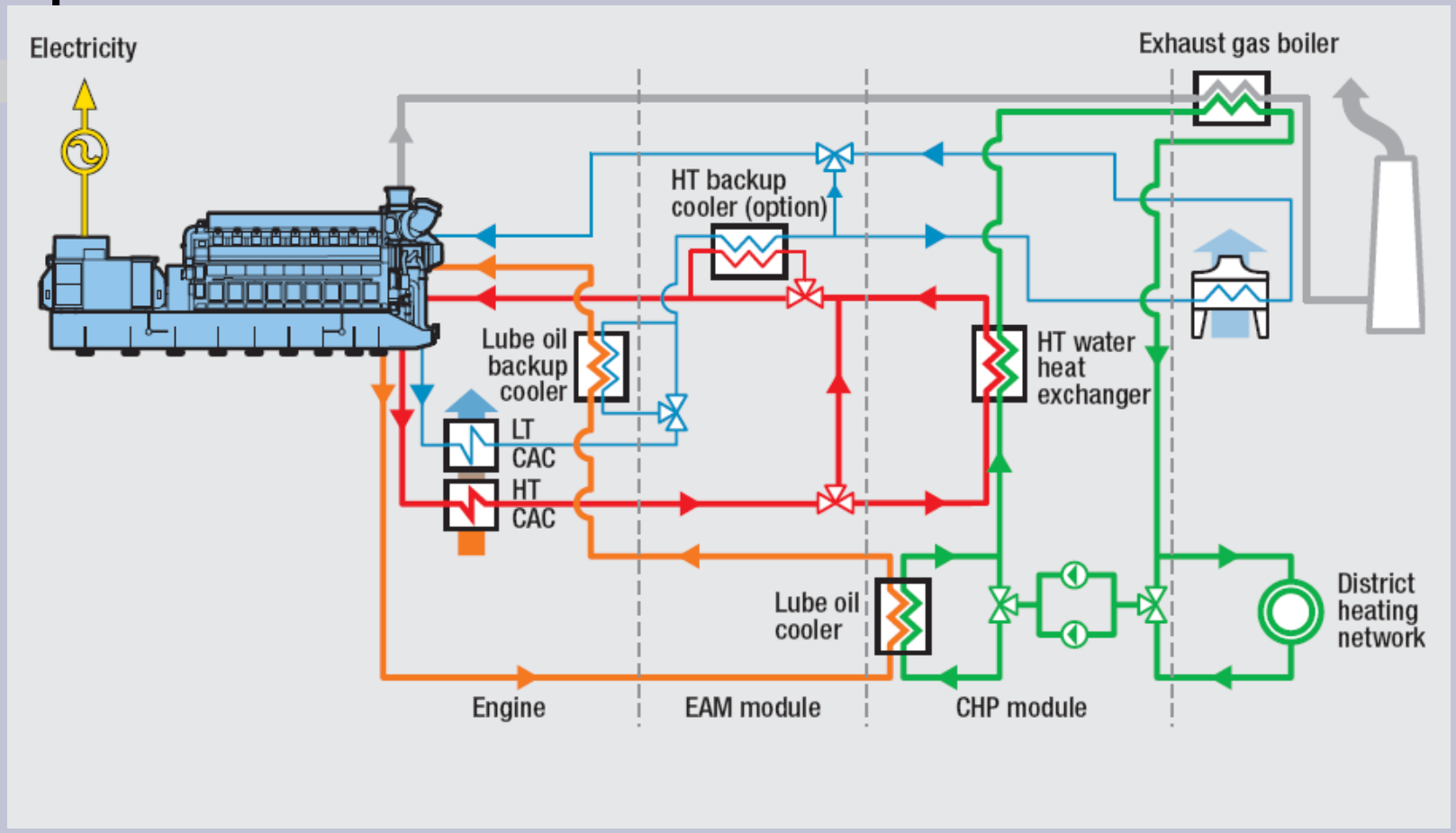
Saving by Combined Heat and Power (CHP) generation

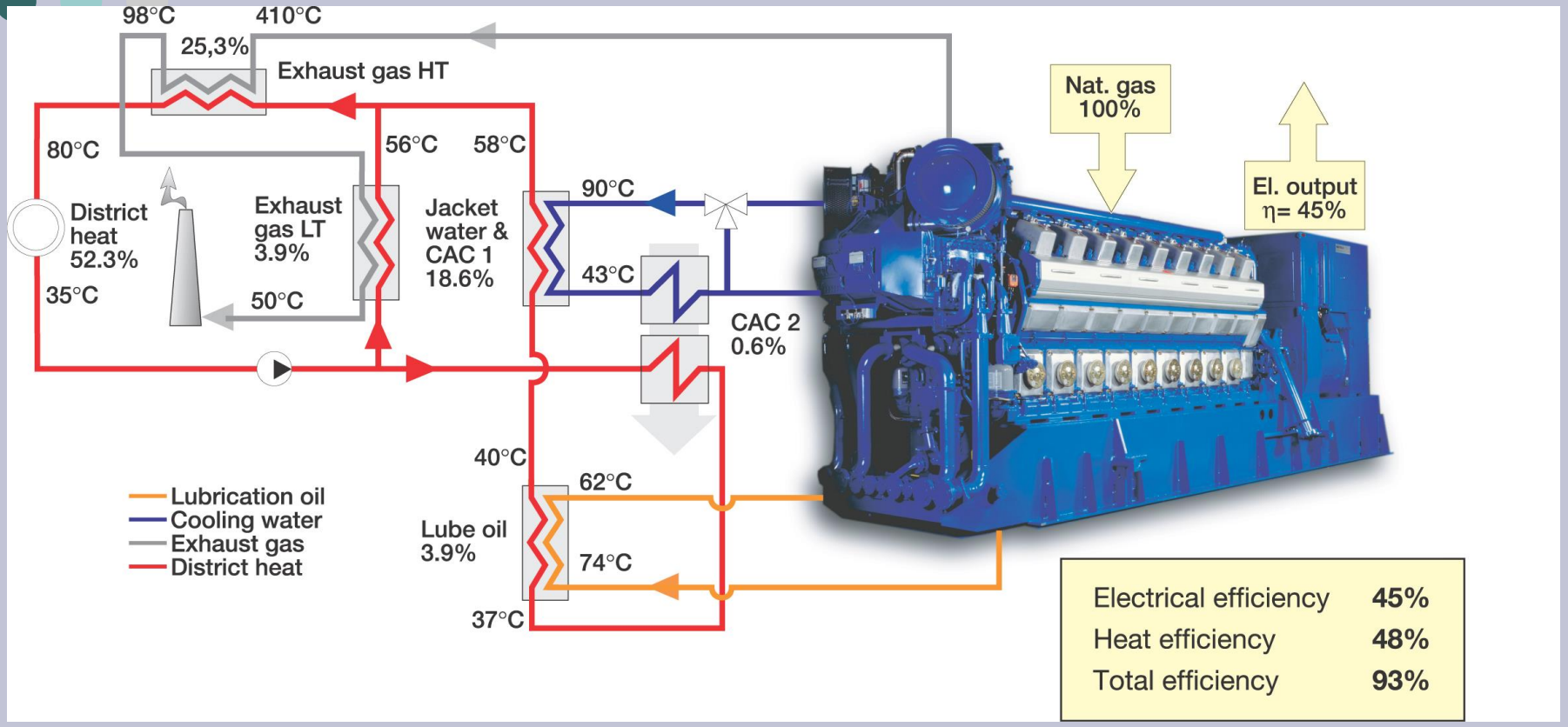
Separate generation		Fuel	
- power plant	40 MW	100 MW	
- hot water boiler	50 MW	60 MW	
		160 MW	100 %
CHP			
- power	40 MW		
- Heat	50 MW	100 MW	62 %
Saving		60 MW	38 %

Heat recovery systems

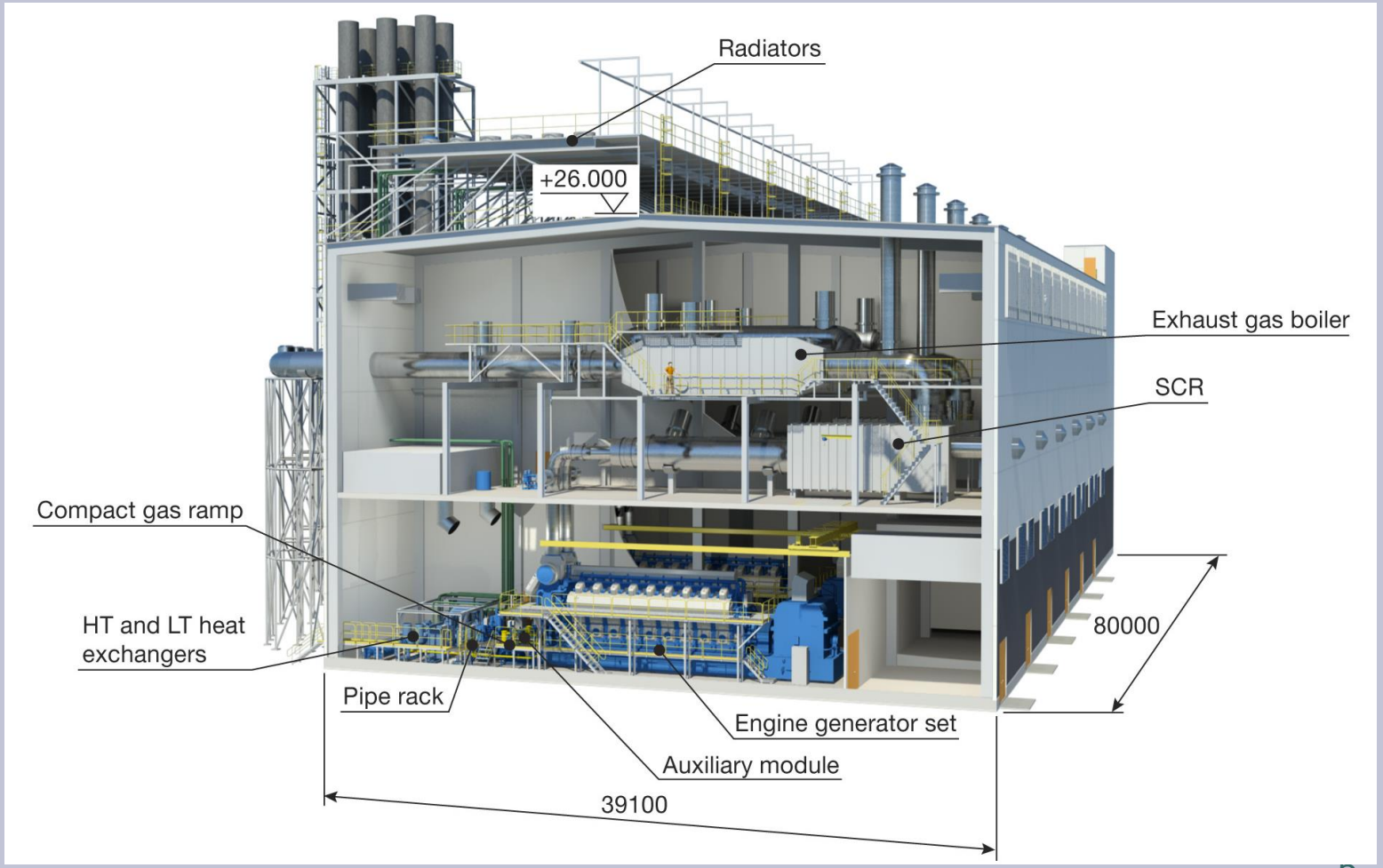
Wärtsilä 34 SG-engine: Electricity 8,7 MW, Heat 8,0 MW, Efficiency 85 %



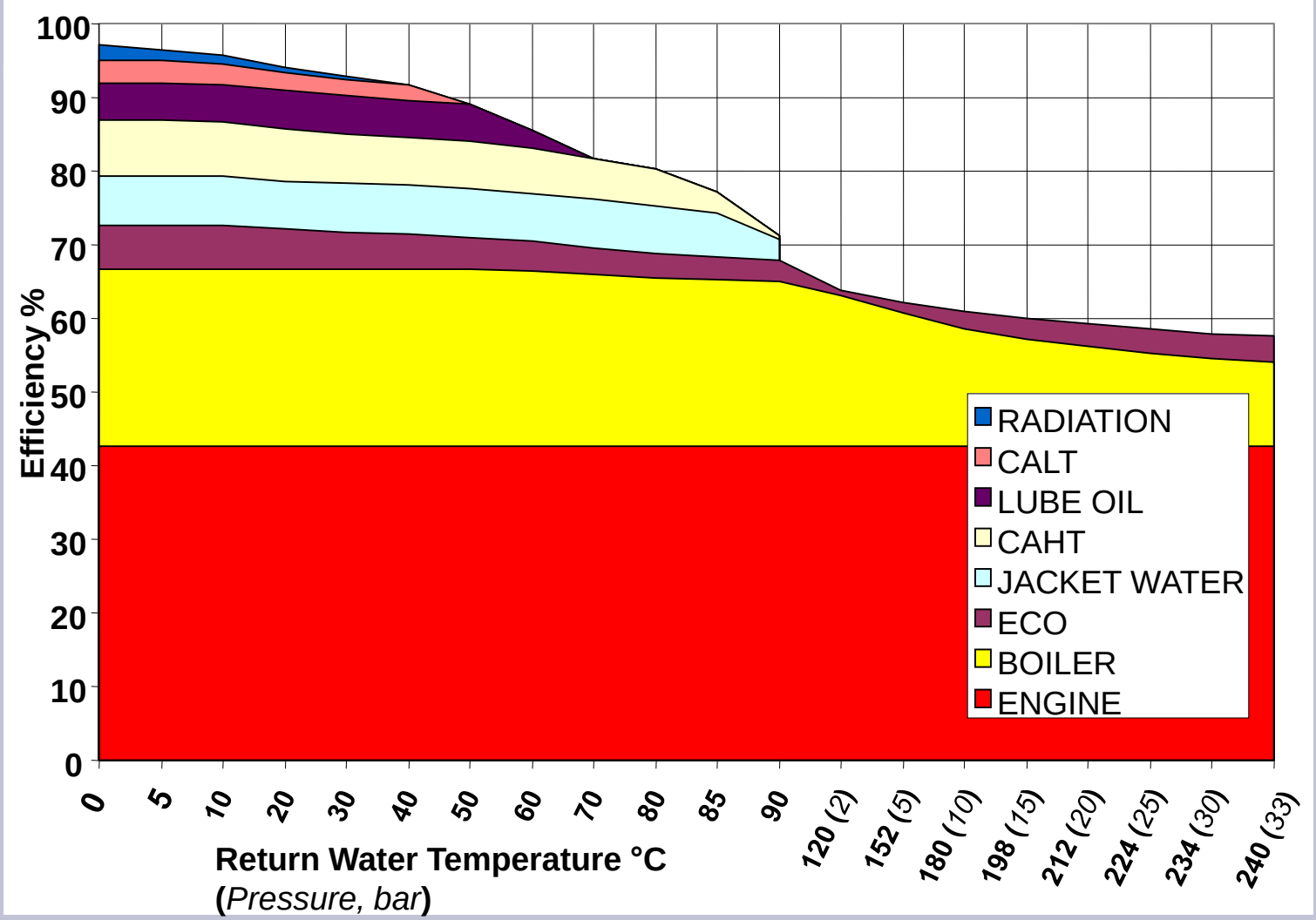
Danish case 93 % efficiency



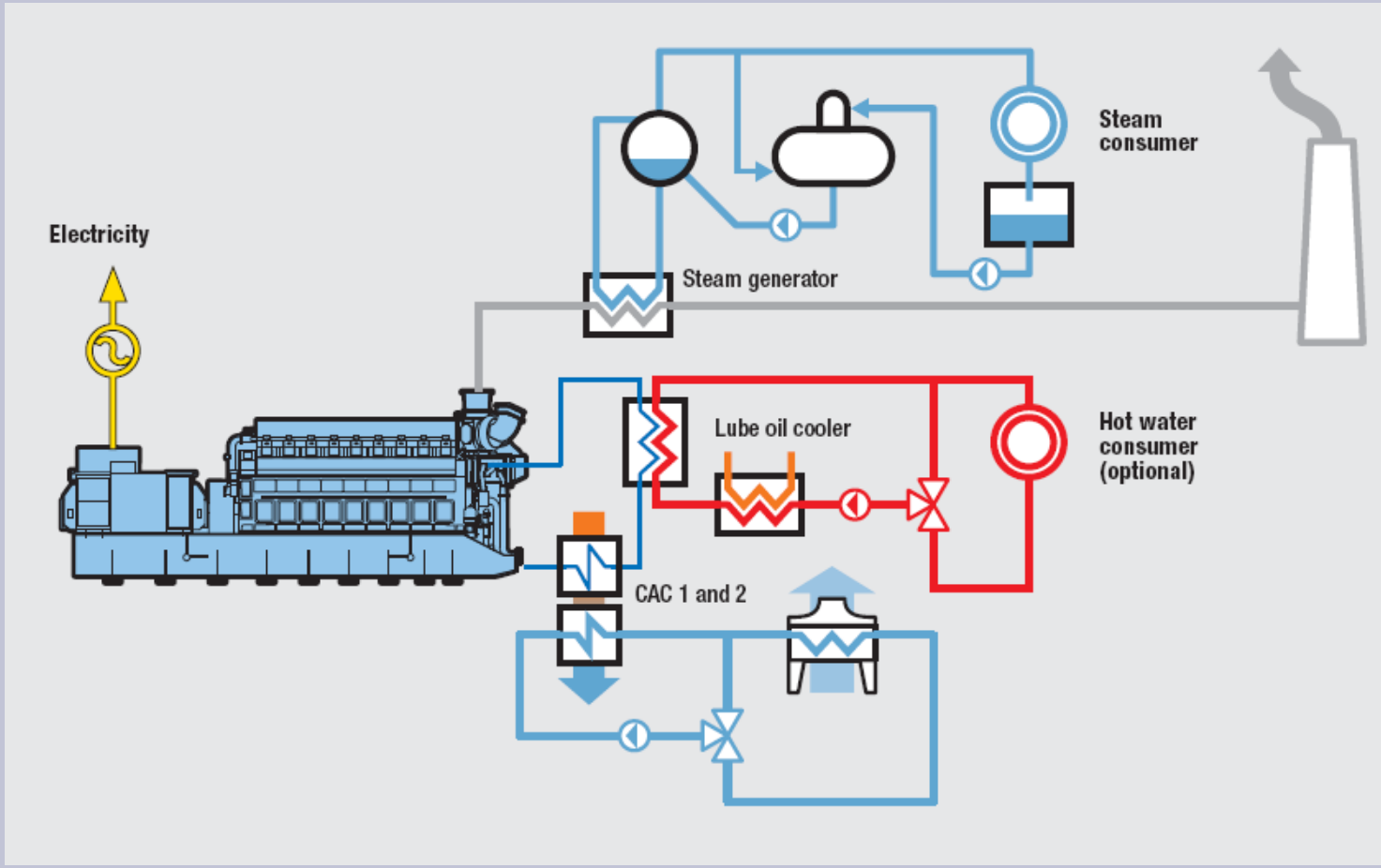
100 MW CHP Plant
6 x Wärtsilä 50 SG



Energy balance (Wärtsilä)



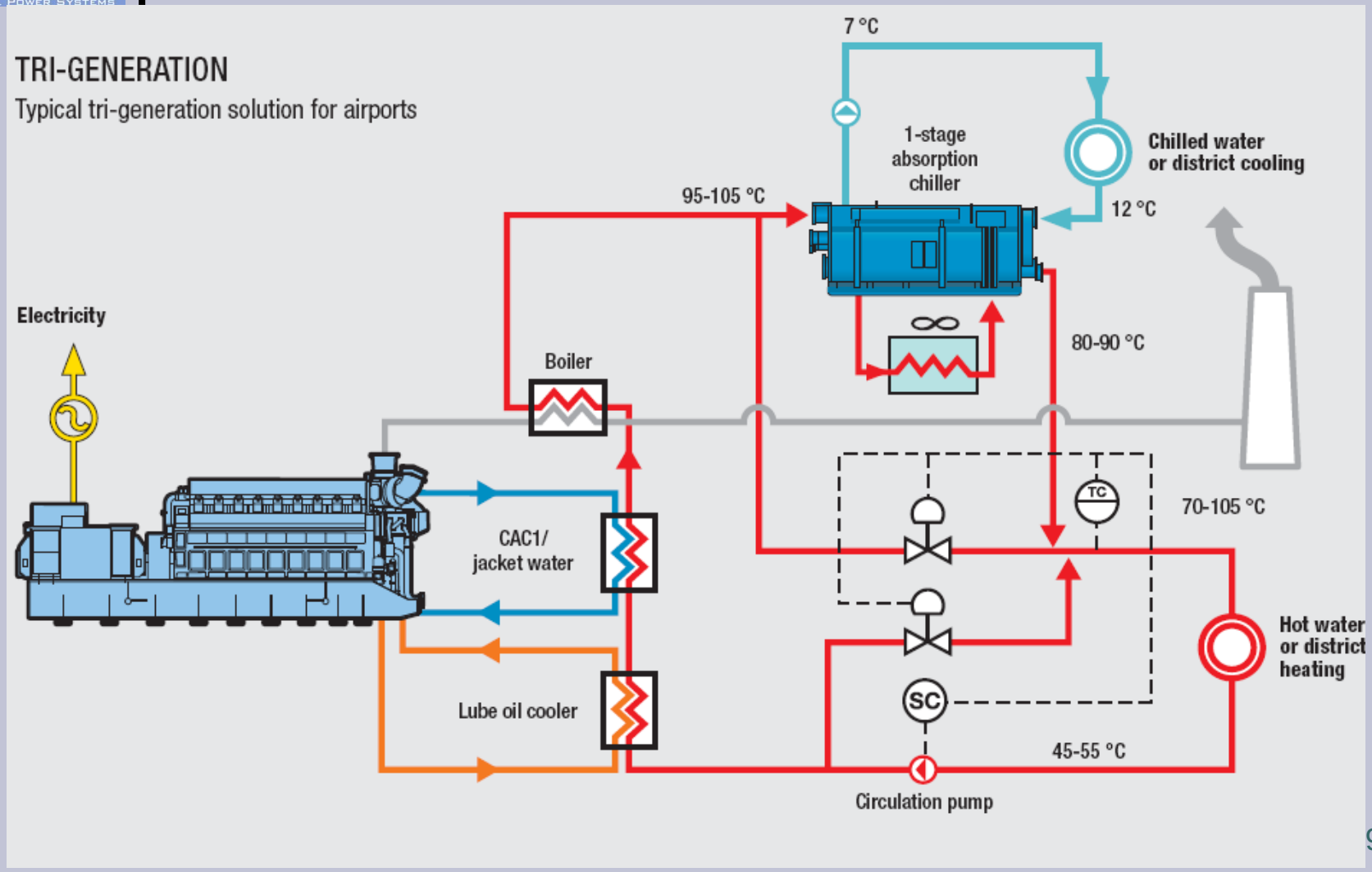
Steam and hot water



Steam and hot water

W20V34SG Engine
Generator output: 8730 kWe
Electrical efficiency: 44.3%
Saturated steam, 8 bar: 4.8 t/h
Electricity + steam efficiency: 60.5%
Hot water 90/50°C: 3350 kWth
Total efficiency: 77%

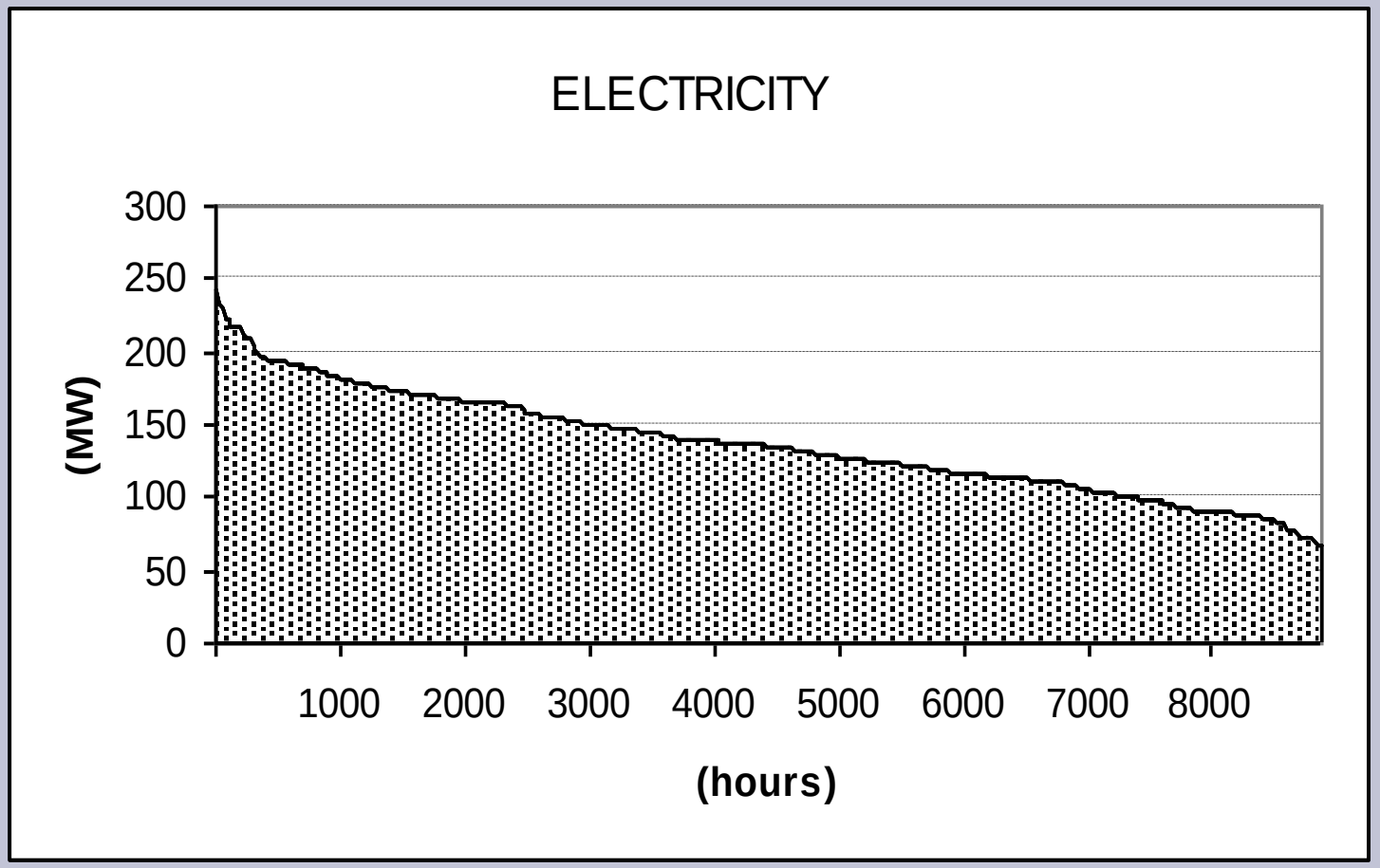
Hot and cold water and electricity



System conditions

- City in North-Europe
- 100 000 inhabitants
- Peak electricity load 250 MW
- Electricity consumption 1200 GWh/a
- Full power hours 4800 h/a

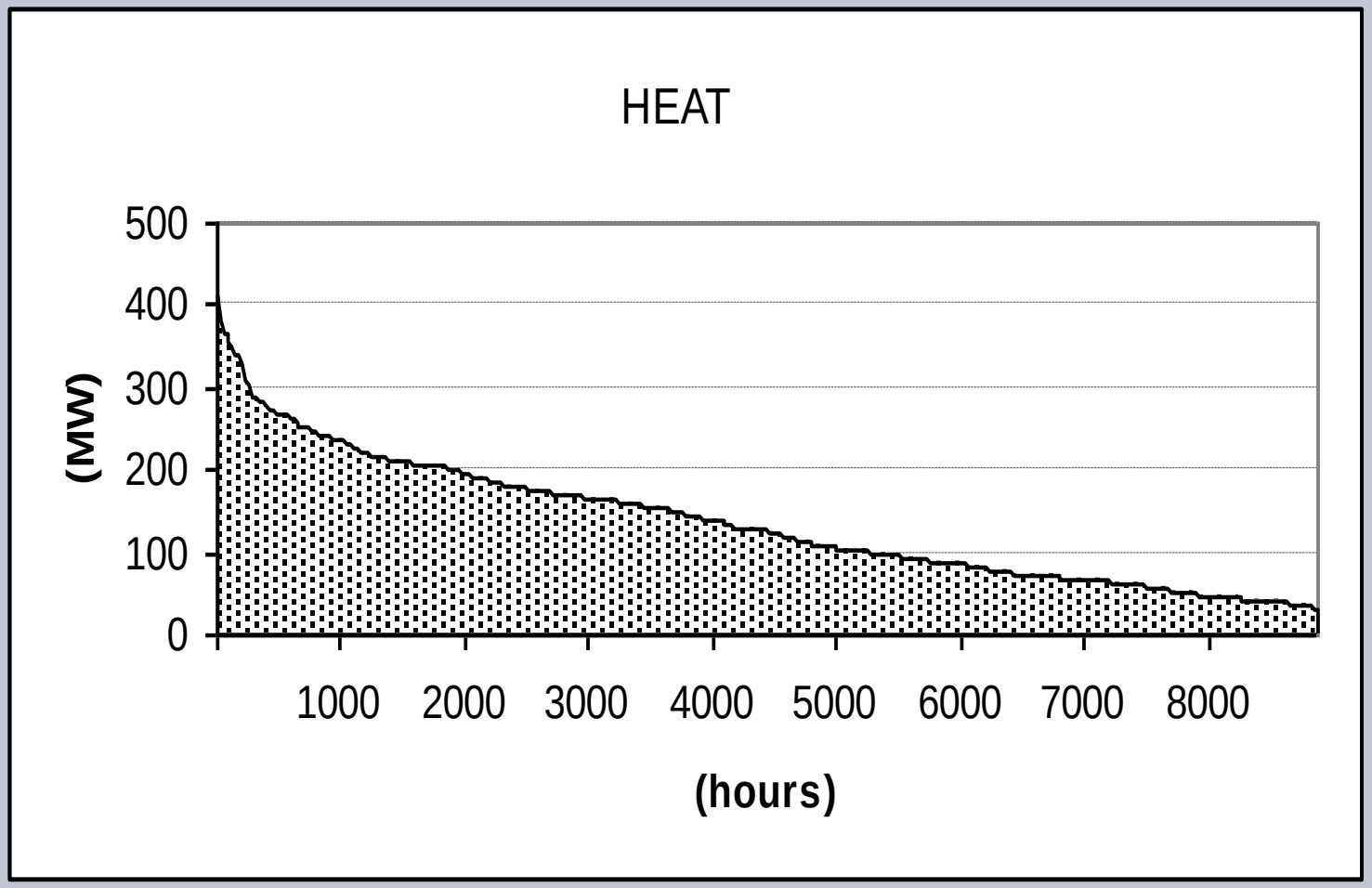
Electrical load duration curve



Heat load in district heating network

- Peak heat load 400 MW
- Heat consumption 1200 GWh/a
- Full power hours 3000 h/a
- Number of people living in district heated houses 80 000 (80 %)

Heat load duration curve



Power plant alternatives gas fired CHP plants

		GE*	DFCC**
Electricity	MW	32	67
Heat	MW	32	61
P/Q		1.0	1.1
Electrical efficiency		43 %	45 %
Total efficiency		86 %	86 %

* Gas engine plant (4 x 8 MW)

** Dual-fuel combined cycle plant with 4 x 16 MW dual-fuel engines and 3 MW steam turbine or alternatively with 1 x 50 MW gas turbine and a 17 MW steam turbine

Power plant alternatives
Other plants

		Coal/bio*	HW boiler**
Electricity	MW	60	-
Heat	MW	120	30
P/Q		0.5	-
Electrical efficiency		28 %	-
Total efficiency		85 %	85 %

* Steam plant with back-pressure steam turbine using coal or woodchips

** Hot water boiler without electricity generation

What is the optimal size of a gas engine CHP plant?

- Specific investment costs become lower with larger size
- Full power hours in chp operation will become lower with larger size
- Optimal size is the one, which gives the best profitability of investment

Assumptions

- Power plants will operate in full CHP mode and generate always heat and power at the same time*
- Ancillary services and reserve power needs are not taken into account**
- All the investments will be made at the same time***

* The CHP plant can also designed to generate only electricity

** If the plant can start up in ten minutes, it can generate also non-spinning and regulation reserves and increase profits

*** Stepwise investments according to the growth of consumption are many times more profitable

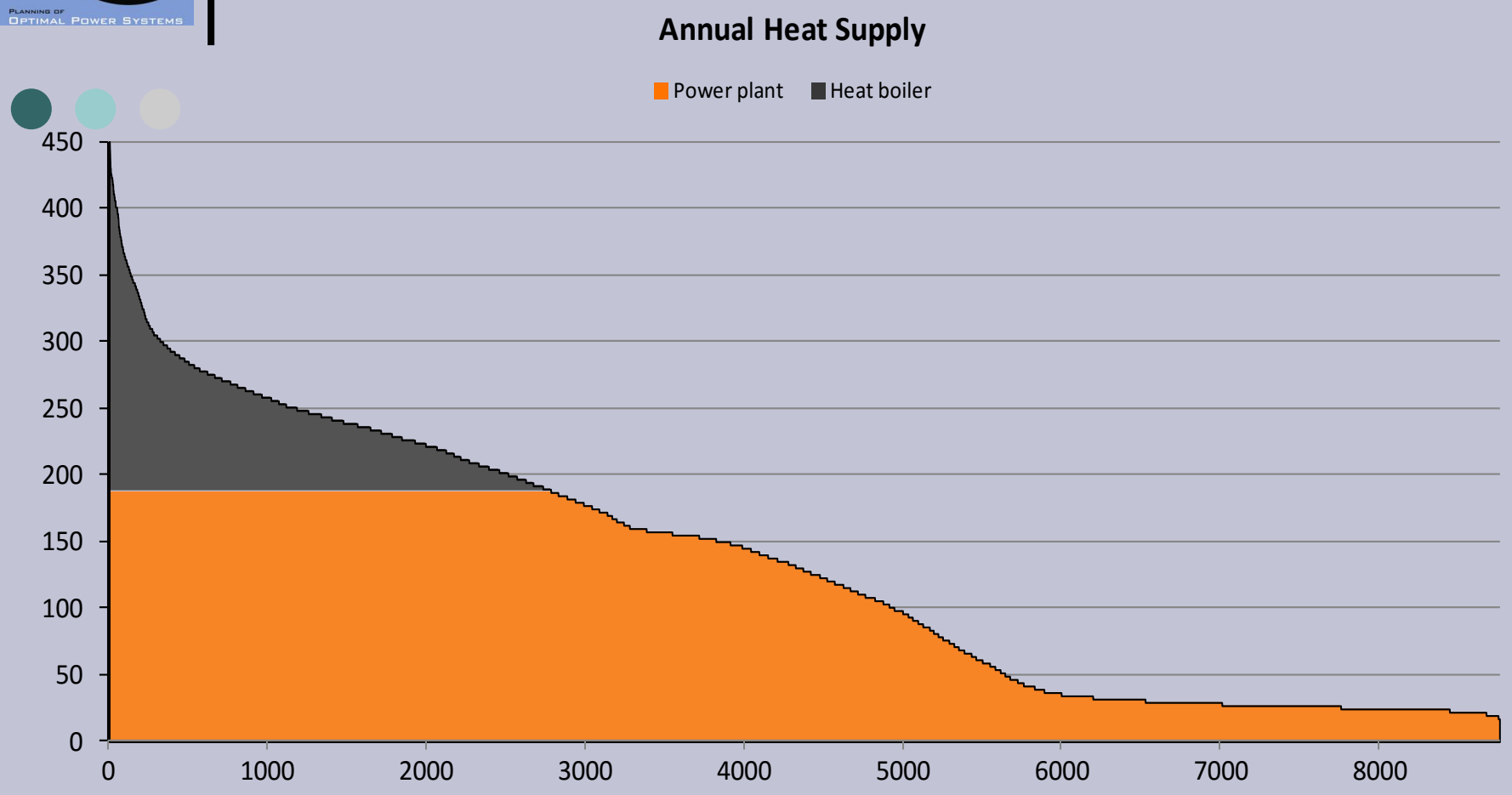
Levelised energy prices*

Electricity	
- internal sales	70 €/MWh
- external sales	60 €/MWh
Heat	40 €/MWh
Natural gas	26.5 €/MWh
CO_2-allowance	15 €/t

- Levelised prices have been defined in presentation ”Planning of national power systems”

Optimal size of a gas engine CHP plant

Heat balance



Elecitricity balance gas engine CHP plant

Output MWe/MWt	Generation GWh	Purchases GWh	Ext. sales GWh
0/0	0	1200	0
96/96	732	468	0
128/128	875	328	4
160/160	1005	219	24
192/192	1088	175	63
224/224	1140	166	105
256/256	1168	166	133

Heat balance, gas engine CHP plant

Output MWe/MWt	CHP plant GWh	HW boiler GWh	CHP share
0/0	0	1200	0 %
96/96	732	468	61%
128/128	875	325	73 %
160/160	1005	195	84 %
192/192	1088	112	91 %
224/224	1139	61	95 %
256/256	1168	32	97 %

Investment cost estimates gas engine CHP plant

$$I(P) = I(P_0) \times (P/P_0)^{y} \times K_i$$

where

I(P) = investment costs at output P

$I(P_0)$ = investment costs at output P_0 (22.5 M€)

P_0 = base output of gas engine plant (32 MW)

y = exponent (0.9)

Ki = coefficient for infrastructures (1.1)

Investment cost estimates gas engine CHP plant

CHP plant MWe/MWt	CHP plant M€	HW boiler M€	Total M€
0/0	-	33.2	33.2
96/96	69.5	26.5	96.0
128/128	90.1	24.1	114.2
160/160	110.1	21.8	132.0
192/192	129.8	19.5	149.3
224/224	149.5	17.1	166.2
256/256	168.1	14.7	182.8

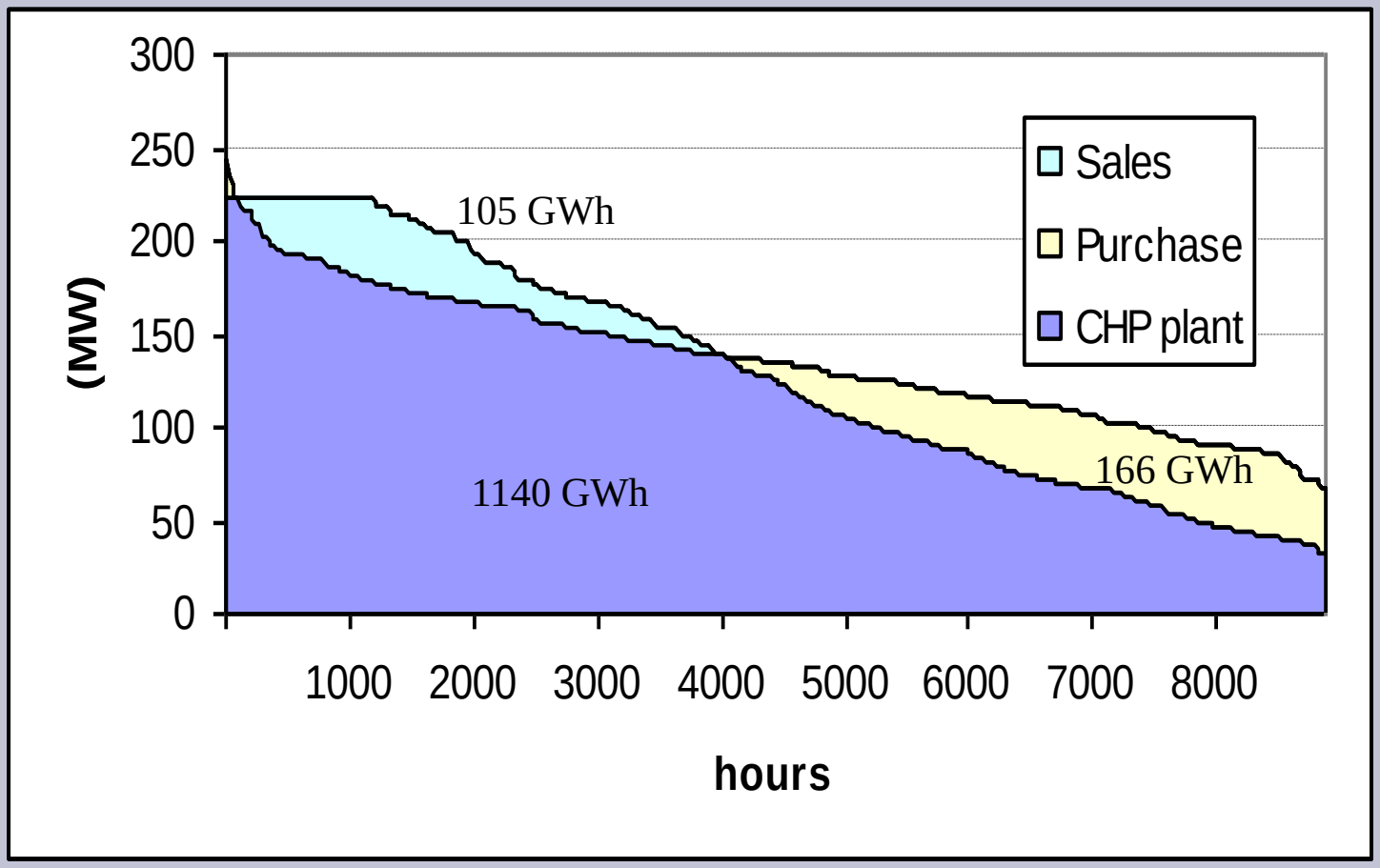
Profitability of gas engine CHP plant investment

Output MWe/MWt	Investment M€	Profit M€	Inv./ profit
0/0	32	9.7	3.3
96/96	96	26.7	3,6
128/128	114	30.5	3,7
160/160	132	34.3	3,8
192/192	**149**	**37.4**	**4,0**
224/224	166	40.0	4,2
256/256	182	41.6	4,4

Profitability of marginal gas engine CHP plant investment

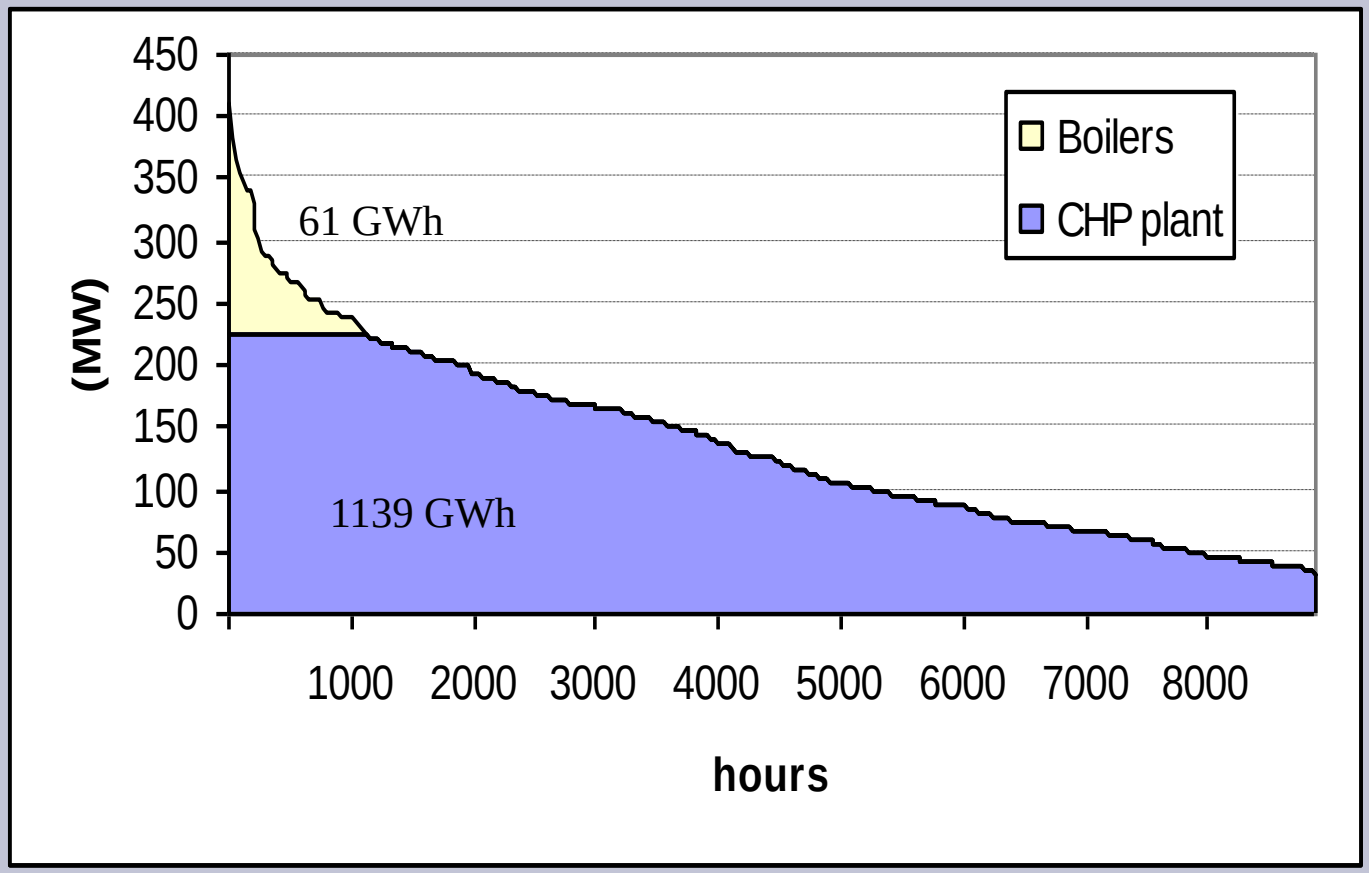
Output MWe/MWt	Marg.Inv. M€	Marg.Profit M€	M.Inv./ M.profit
0/0	32	9.7	3.3
96/96	63	17	3.7
128/128	18	3.8	4.8
160/160	18	3.7	4.9
192/192	17	3.1	5.5
224/224	**17**	**2.6**	**6.6**
256/256	17	1.6	10.5

Optimal electricity balance of a gas engine chp system



CHP share = 95 % of electricity

Optimal heat balance of a gas engine CHP system



CHP share = 95 % of heat

Design parameters of the optimal gas engine plant

Gas Engines	28 x 8 MW
Electrical output	224 MWe
Heat output	224 MWt
Electricity gener.	1139 GWh
Heat generation	1139 GWh
Full power hours	5085 h/a

Optimal size of a coal of woodchip fired CHP plant

Heat balance coal or woodchip fired CHP plant

CHP plant MWe/MWt	CHP plant GWh	HW boiler GWh	CHP share
60/120	837	363	70 %
90/180	995	205	83 %
120/240	1006	194	84 %
150/300	952*	248	79 %

* Generation becomes lower because of mimimum output of the plant is 30 % of the nominal output

Electricity balance coal or woodchip fired CHP plant

CHP plant MWe/MWt	Generation GWh	Purchase GWh	Ext. sales GWh
60/120	419	781	0
90/180	498	702	0
120/240	503	697	0
150/300	476*	724	0

* Generation becomes lower because of mimimum output of the plant is 30 % of the nominal output

Investment costs coal or woodchip fired CHP plant

Investment (P) = $(P/32)^{0.9}$ x 32 M€

CHP plant MWe/MWt	CHP plant M€	HW boiler M€	Total M€
60/120	57.5	24.7	82.2
90/180	82.8	20.4	103
120/240	107	15.9	123
150/300	131	11.3	142

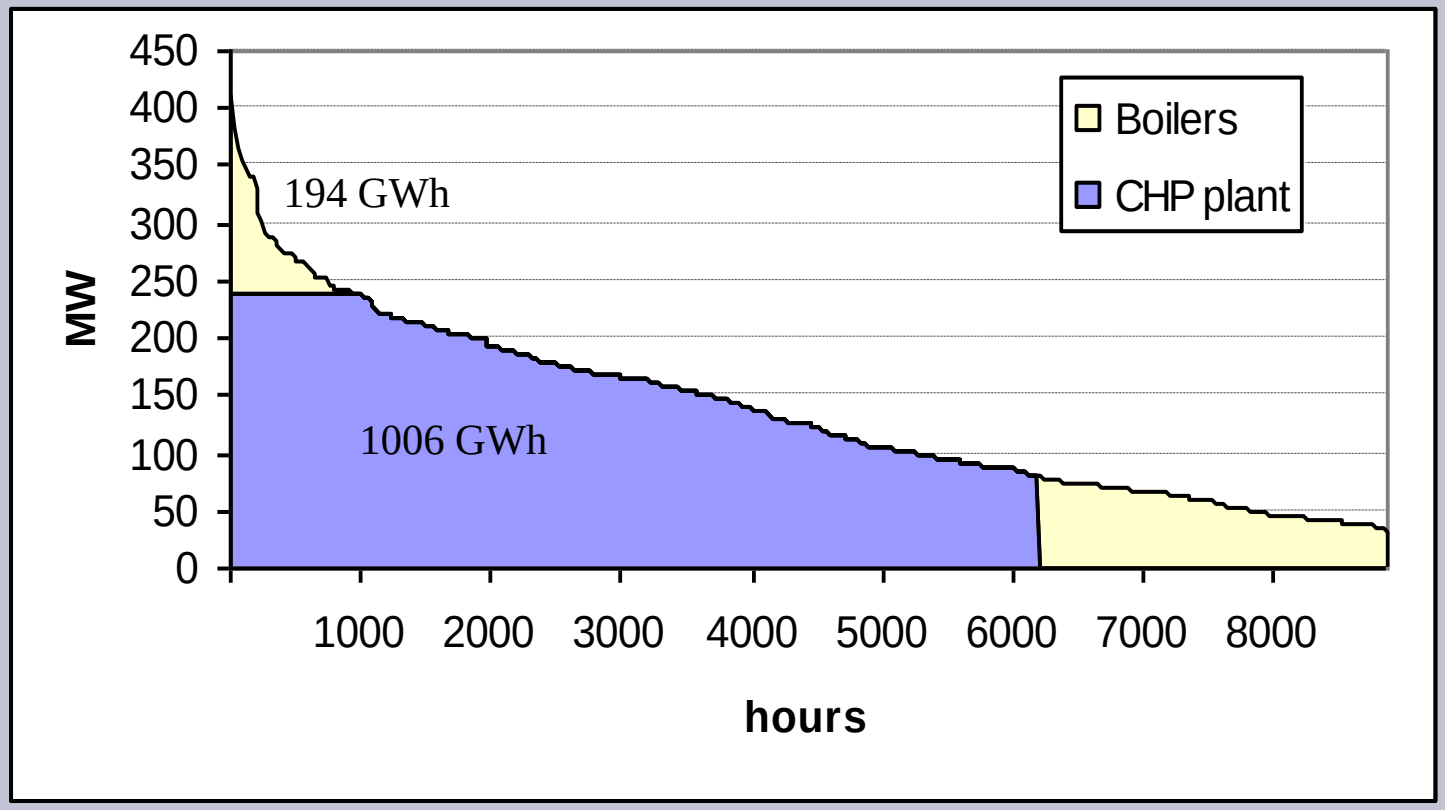
Profitability of coal fired CHP plant

CHP plant MWe/MWt	Investment M€	Profit M€	Inv./ profit
60/120	82.2	41.5	2.0
90/180	103	48.6	2.1
120/240	123	50.7	2.4
150/300	143	50.6	2.8

Marginal profitability coal fired CHP plant

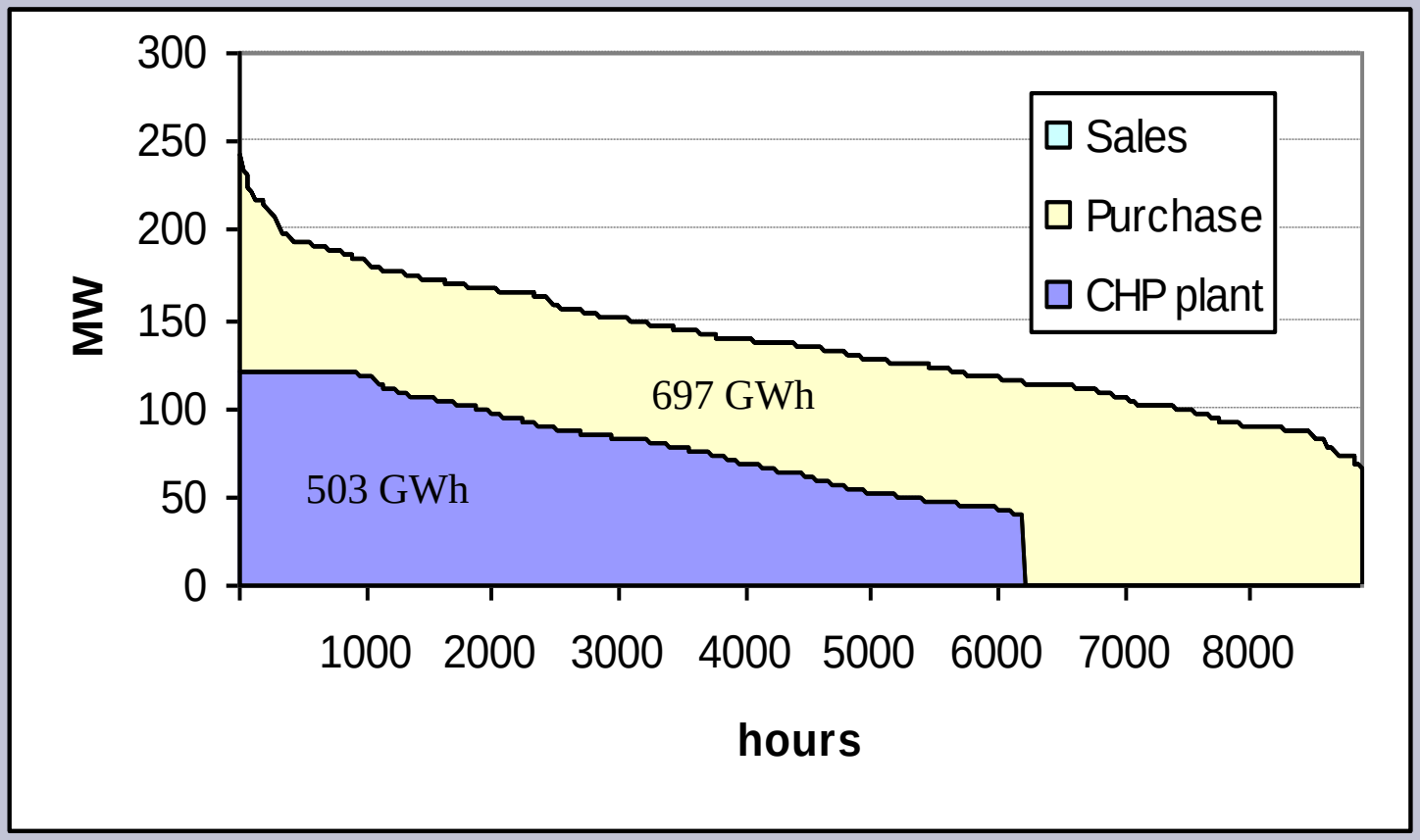
Output CHP plant MWe/MWt	Marginal Investment M€	Marginal Profit M€	Marginal inv./ mar. profit
60/120	82.2	41.5	2.0
90/180	21	7.1	3.0
120/240	**20**	**2.1**	**9.5**
150/300	19	-0.1	neg

Optimal heat balance of a coal fired CHP plant



CHP share = 84 % of heat

Optimal electricity balance of coal or wood fired CHP plant



SHP share = 42 % of electricity

Design parameters of the optimal coal or woodchip fired CHP plant

Steam turbine	1 x 120 MW
Electrical output	120 MWe
Heat output	240 MWt
Electricity gener.	696 GWh
Heat generation	1006 GWh
Full power hours	4190 h/a

Comparison of systems

Comparison of systems

System	Electrical output (MW)	(kW/capita)	CHP-share
GE-224/224	224	2.2	95 %
Coal/Wood-120/240	120	1.2*	84 %

* With coal/wood fired plant the potential capacity of CHP system is only 55 % of the capacity of a gas engine (GE) or dual-fuel combined cycle systems

Evaluating the potential CHP capacity in Finland

Potential CHP capacity of cities (kWe/capita)

Area	Natural gas available	
	Yes	No
Large cities	2.3	1.2
Small cities	2.2	1.0

Population living in district heated houses in Finland (thousands)

Area	Natural gas available		
	Yes	No	Total
Large cities	1364	358	1722
Other areas	450	283	733
Total	1814	641	2455*

* 47 % of people live in district heated houses

Potential CHP capacity in Finland (MWe)

Area	Natural gas available		
	Yes	No	Total
Large cities	3270	430	3700
Other areas	855	255	1110
Total	4125	685	4810

Potential new municipal CHP capacity in Finland

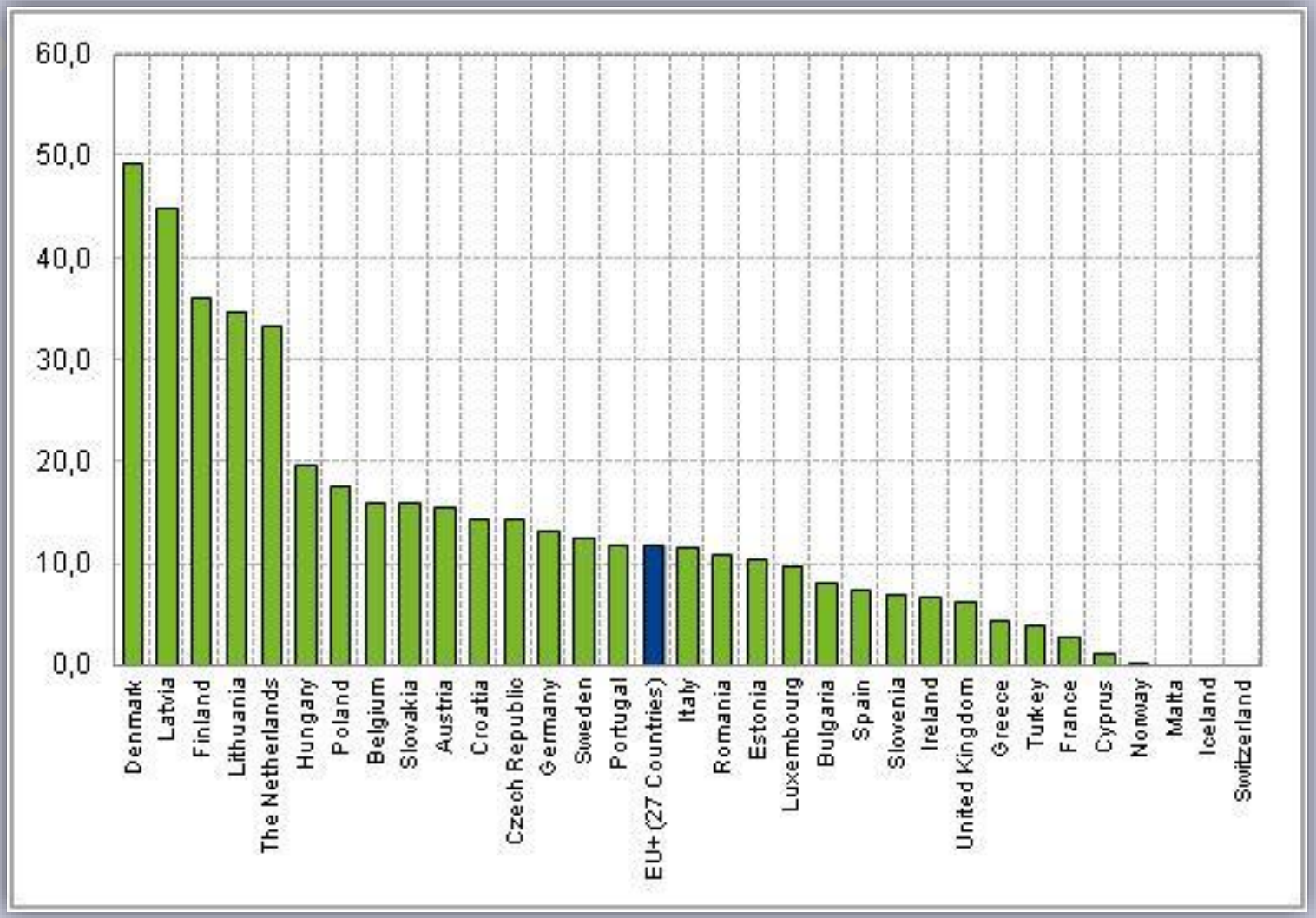
Total potential	4810 MW*
Capacity today	-4420 MW
Potential new capacity	**490 MW**

*Total potential = 0.9 kWe/capita
(Finnish total population is 5.4 Million)

CHP capacity of the eight largest cities in Finland

City	CHP capacity (MWe)	Population in DH (number)	Capacity per capita (kW/capita)
Helsinki	1017	595 000	1.71
Espoo	365	252 000	1.45
Tampere	336	203 000	1.65
Turku	261	195 000	1.34
Vantaa	250	169 000	1.48
Oulu	188	141 000	1.33
Jyväskylä	328	92 000	3.57
Lahti	249	90 000	2.77
Total	2994	1737 000	1.72

CHP share of electricity in EU 2010



Summary

The potential CHP capacity is about 2 kWe/capita in cities with gas network and 1 kWe/capita in other cities in the Nordic countries

The cities can planned to be independent of outside electricity by building gas fired CHP plants

For details see reference text book ”**Planning of Optimal Power Systems**”

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