Cogeneration with

District Heating and Cooling

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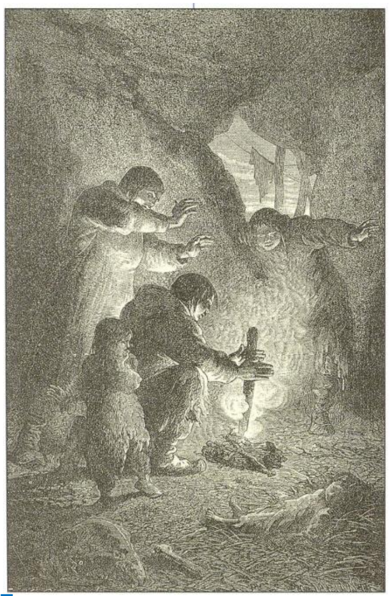
Scientific Direction

Energy and Heat

Heat has always been an issue for mankind



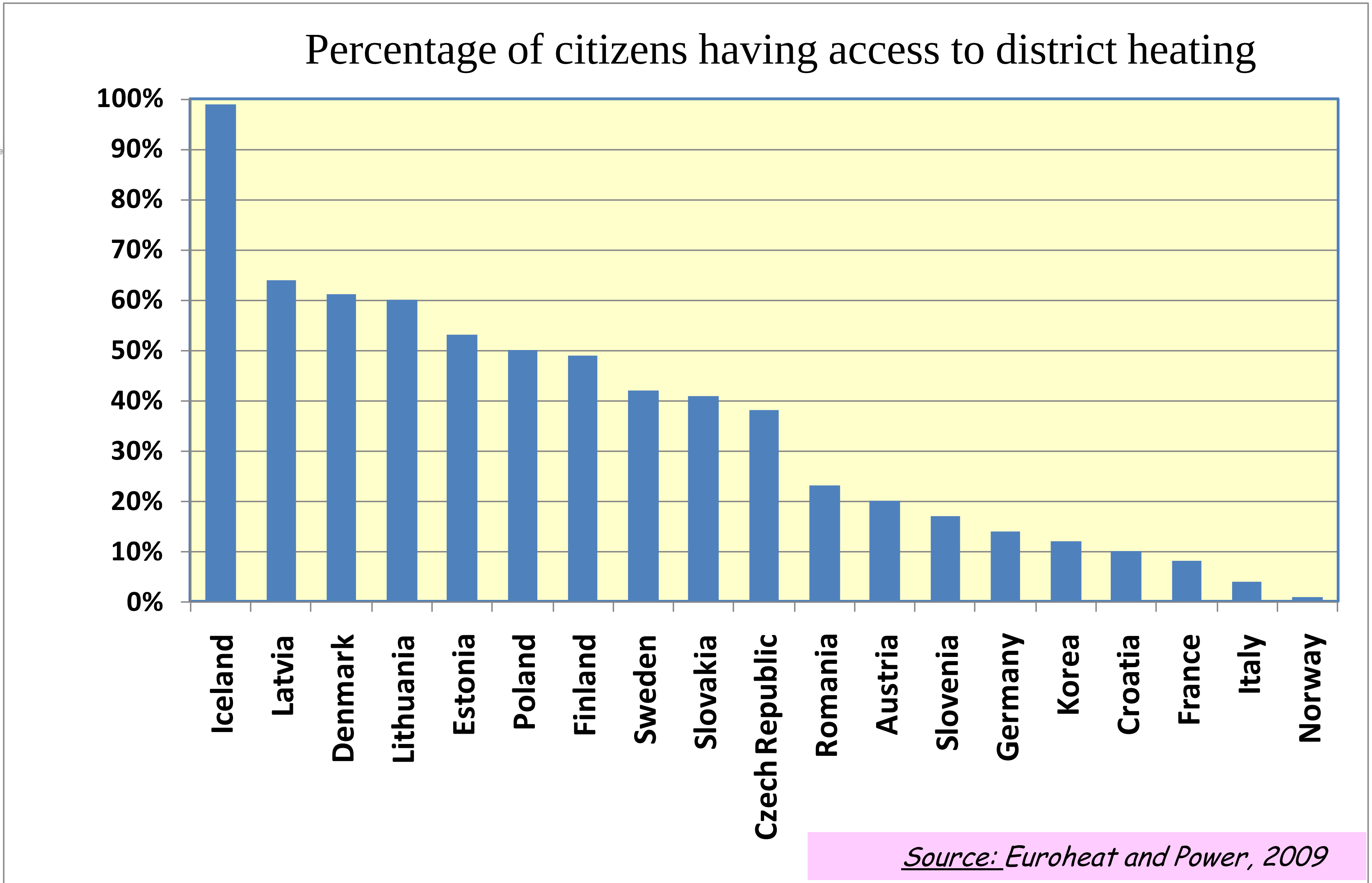
In 2008, the total world energy production amounted to **12000 Mtoe**

Approximately one third of it (4000 Mtoe) was used as **heat.**
50% of this heat was for residential homes, commercial businesses and public services (hospitals, schools, universities, offices)

Total space heating and cooling demand **~ 20000 TWh**
World District Heating and Cooling **~ 2500 TWh**

The potential of DHC increase is very large

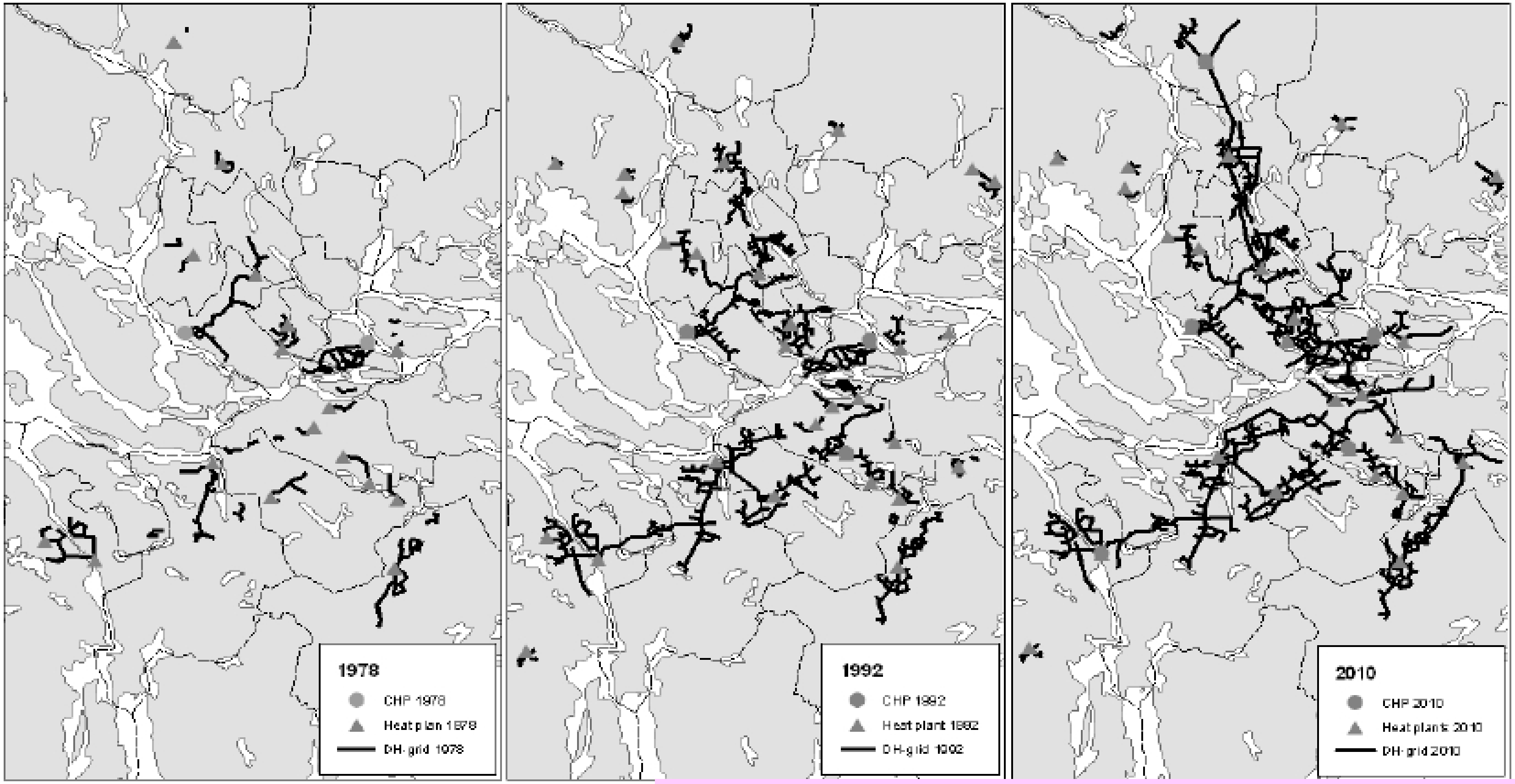
District Heating



District Heating is developed in northern European countries

District Heating

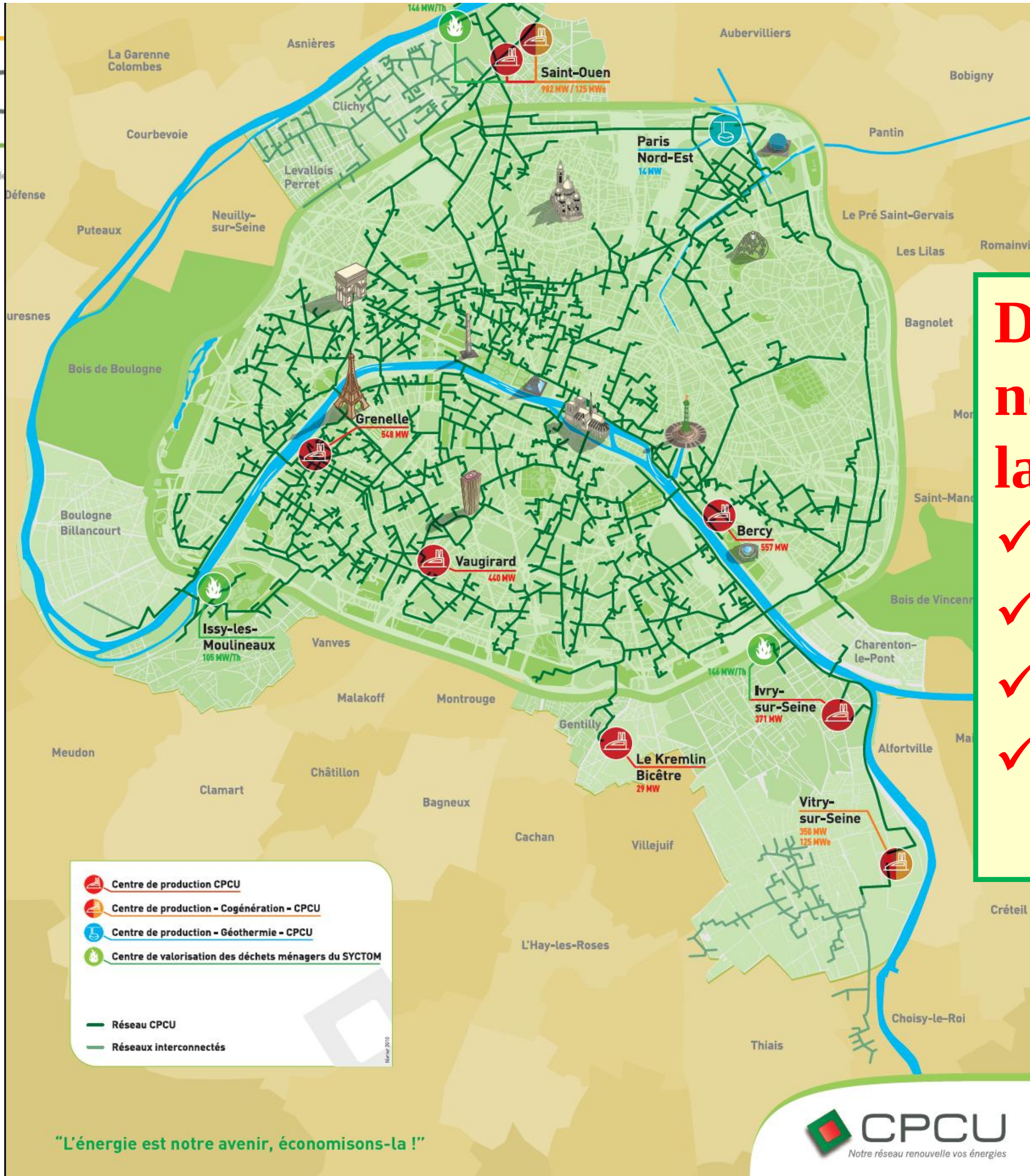
The Development of the District Heating Systems
in Stockholm County - Networks of Heating



Source: D. Magnusson, Linköping University, Sweden

District Heating networks are expanding

District Heating in large cities



District Heating network in Paris is the largest in France:

- ✓ 2 x 440 km
- ✓ 5700 GWh
- ✓ 25% of total heating
- ✓ 8 production sites

Source: CPCU at www.cpcu.fr

District Cooling

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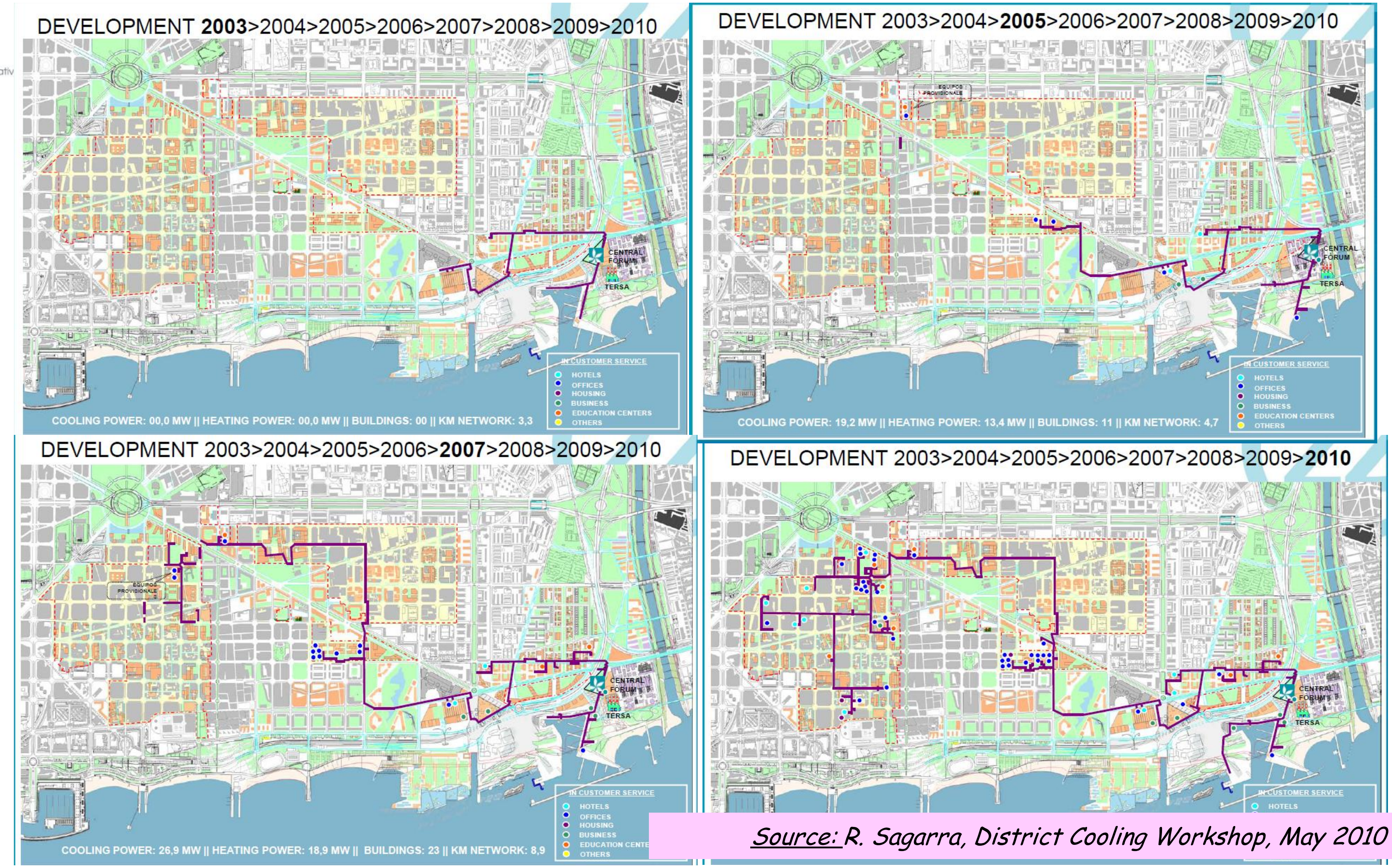
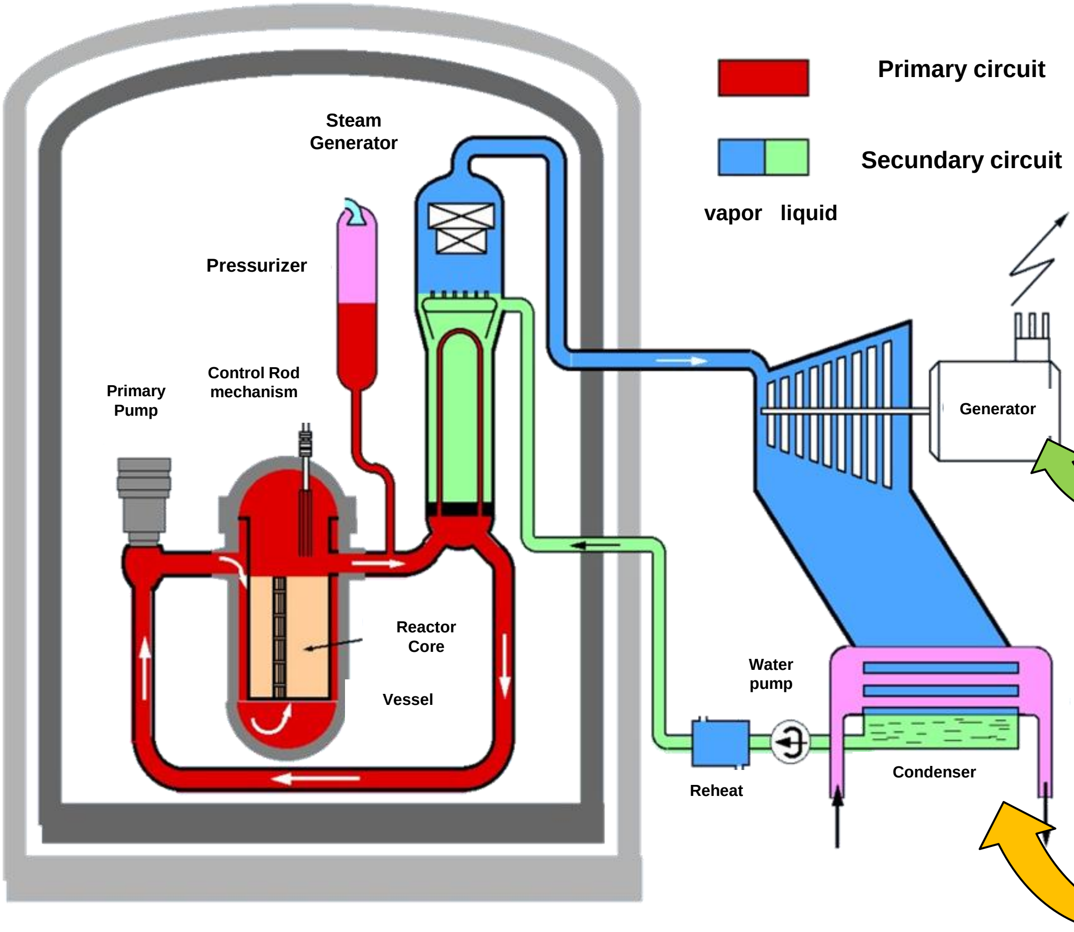
City of Barcelona, Spain



Source: R. Sagarra, District Cooling Workshop, May 2010

District Cooling networks in warm areas

Nuclear Power Plant



1/3 of the fission energy is converted into electricity

2/3 of the fission energy is lost in heat

Exergy

- Ambient temperature heat is of no use
- The **Exergy** concept allows to also valuate the temperature at which the heat is produced.

$$E = H - T_0 . S$$

Exergy of a quantity of heat Q at a temperature T $\longrightarrow$ $E = Q.(1 - \frac{T_0}{T})$

Case of 1300 MWe Nuclear Power Plant

T hot	T cold	Wp	Qi	W_{HP}	W_{BP}	W_{gross}	Qs	η carnot	η
(°C)	(°C)	(MW)	(MW)	(MW)	(MW)	(MWe)	(MW)	(%)	(%)
288	**39**	**9**	**3 920**	**-417**	**-936**	**1 353**	**-2 562**	**44.4%**	**34.3%**

Exergy: Electrical Efficiency

$$\eta = \frac{\left|W_{HP} + W_{BP}\right| - W_P}{Q_i}$$

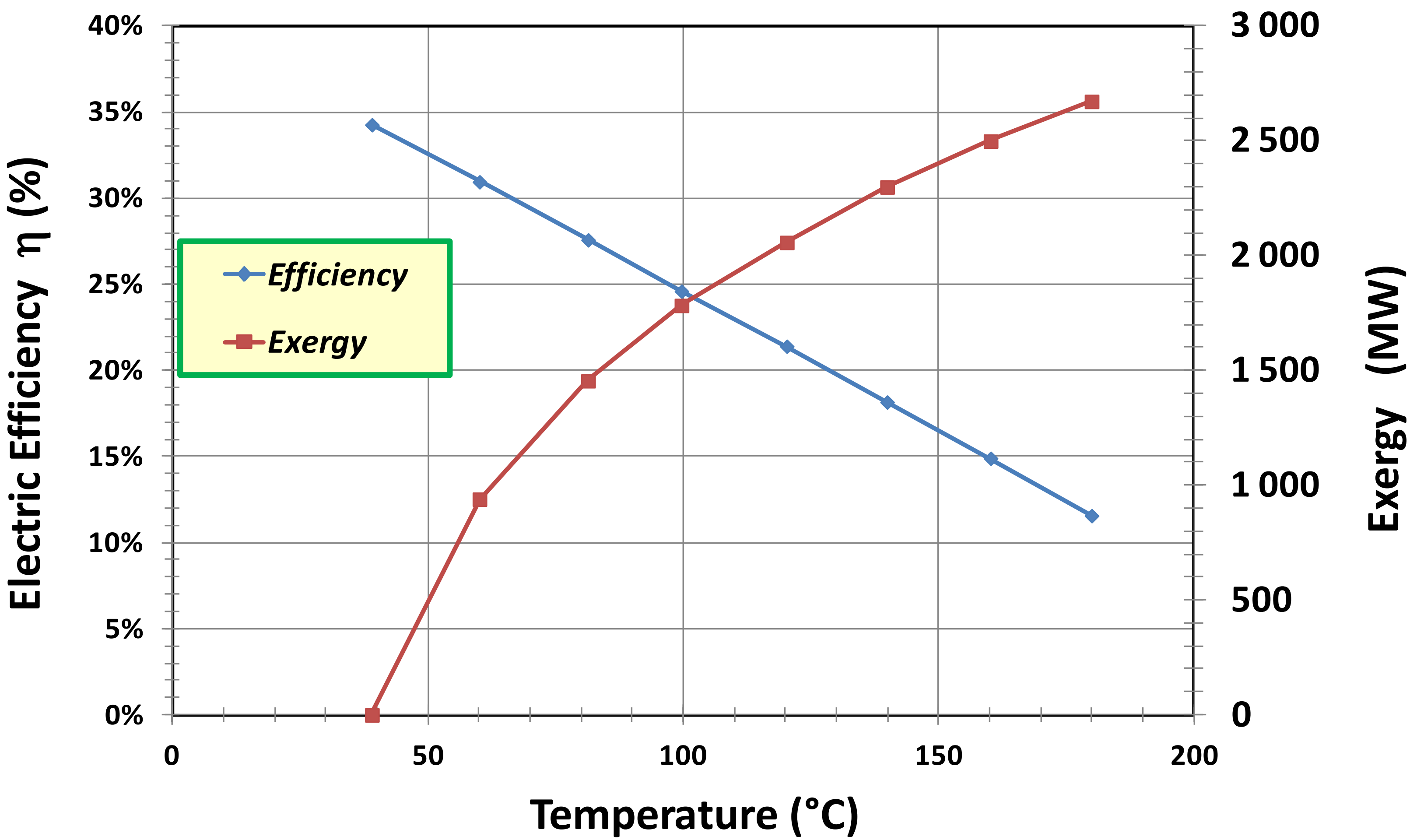
➢ W_{BP} on the Low Pressure Turbine decreases with increasing temperature

$$Q_{out} \approx Q_i - \left|W_{HP} + W_{BP}\right|$$

$$E_{out} = Q_{out} \,.\, (1 - \frac{T_0}{T})$$

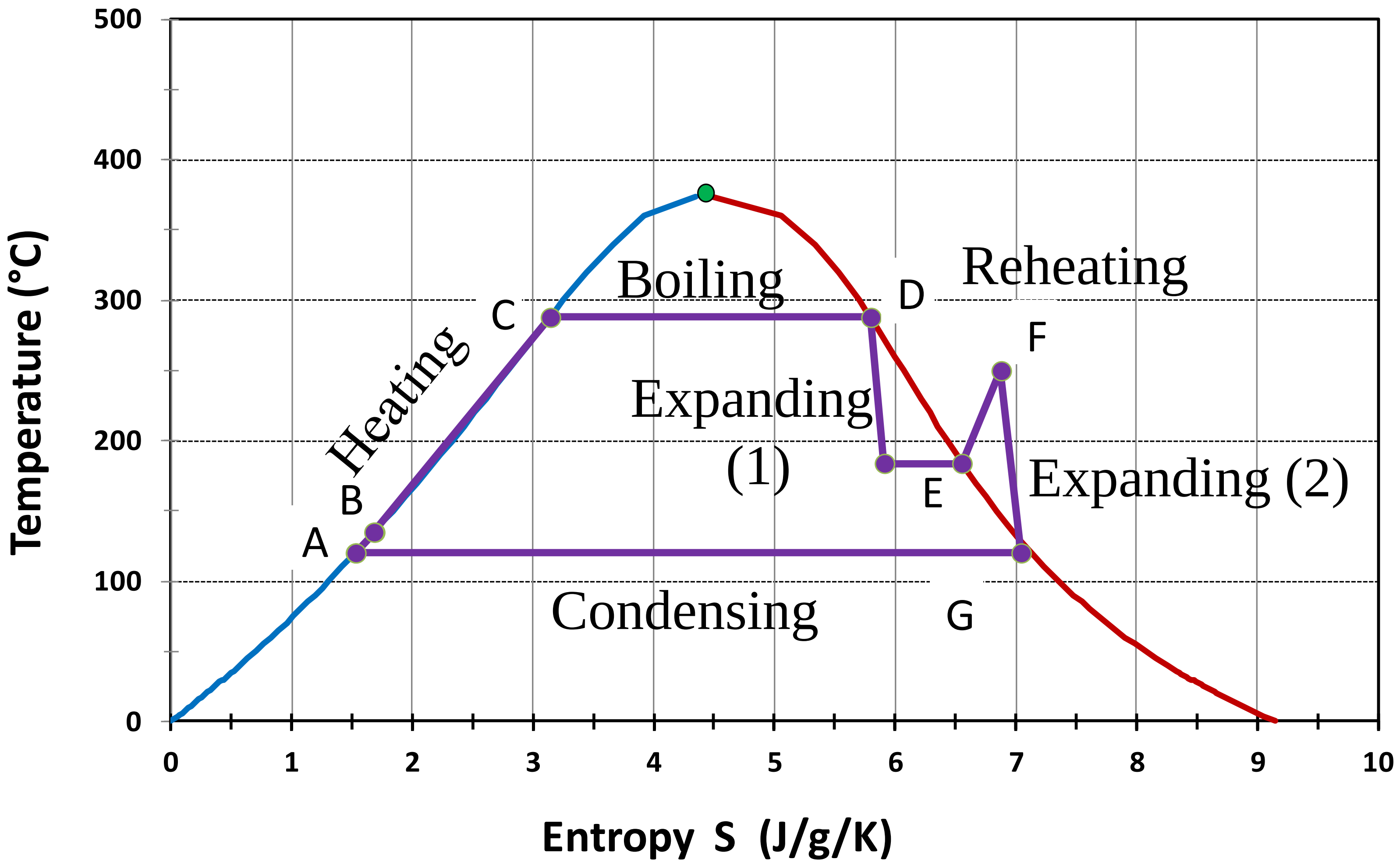
➢ The output exergy increases with increasing temperature

Exergy: Electrical Efficiency



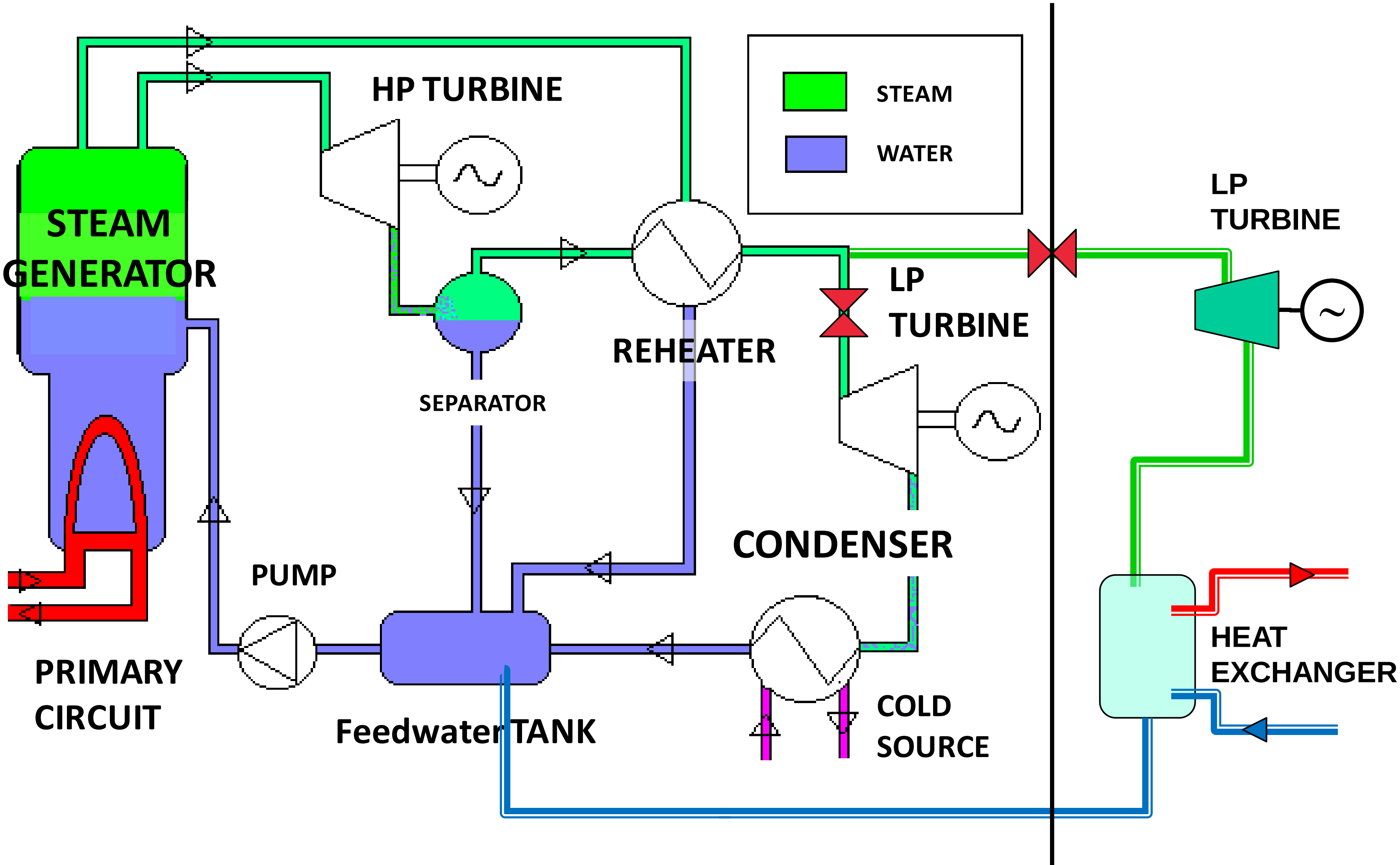
Trade-off between electric output and Exergy

Thermodynamics: The Rankine cycle



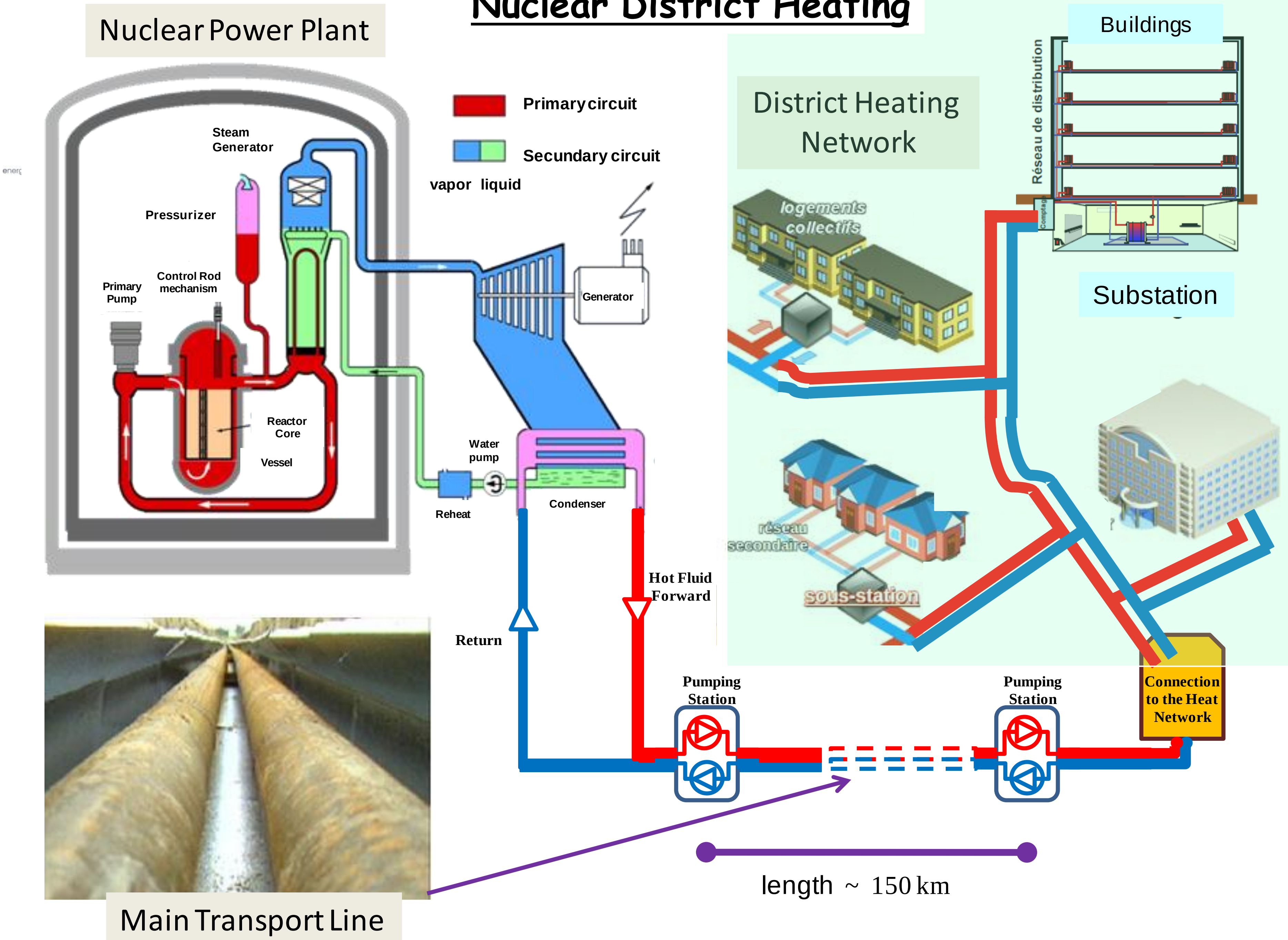
Modify the low pressure turbine: outlet at 2 bars

Thermodynamics: The secondary circuit



Switch between two low pressure turbines

Nuclear District Heating

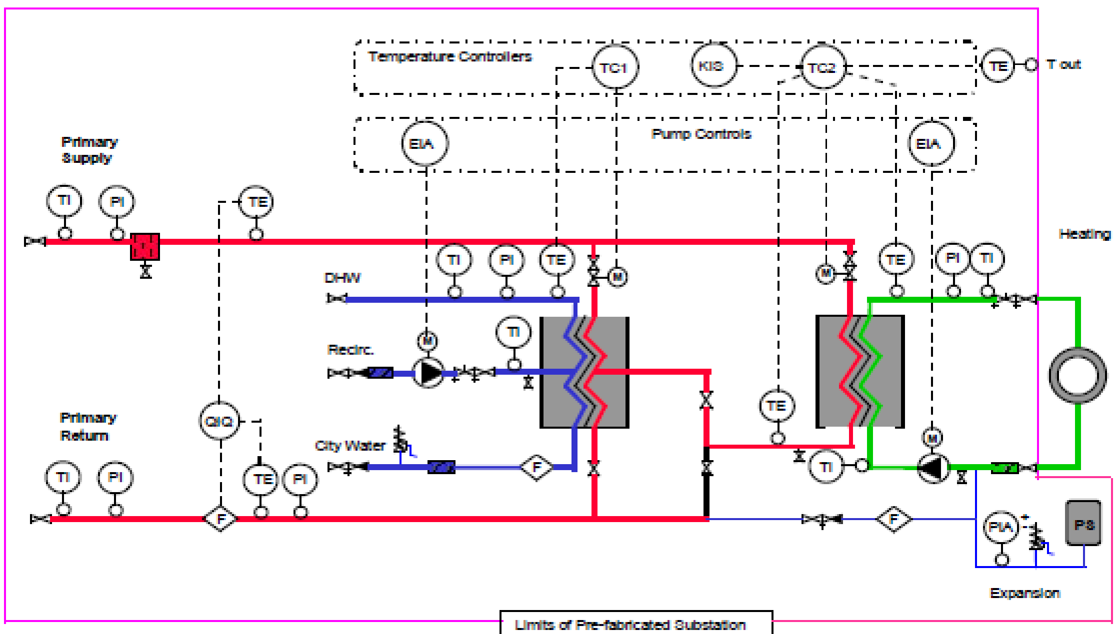


Example of Substations

Prefabricated substations

- The main benefits of prefabricated substations
  - Realiable installation at factory
  - Standardized system solutions
  - Small space requirement
  - Site installation time can be minimized
  - Easy to maintain
  - High degree of automation
  - Easy operation

Source: Janne Lavanti, PÖYRY, Finland Oy Energy, May 2011



The Main Transport Line

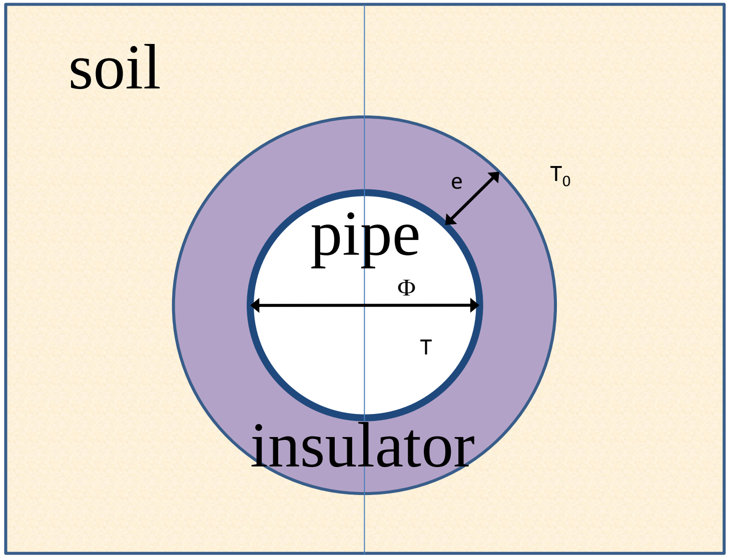
In a Tunnel

(may be used as a common utility)

Copenhagen District Heating Bore Tunnel, 2010

In a Trench

The Main Transport Line: Thermal Losses



- Diameter Φ
- Insulator thickness e
- Insulator conductivity $\lambda < 0.04$ W/m.K

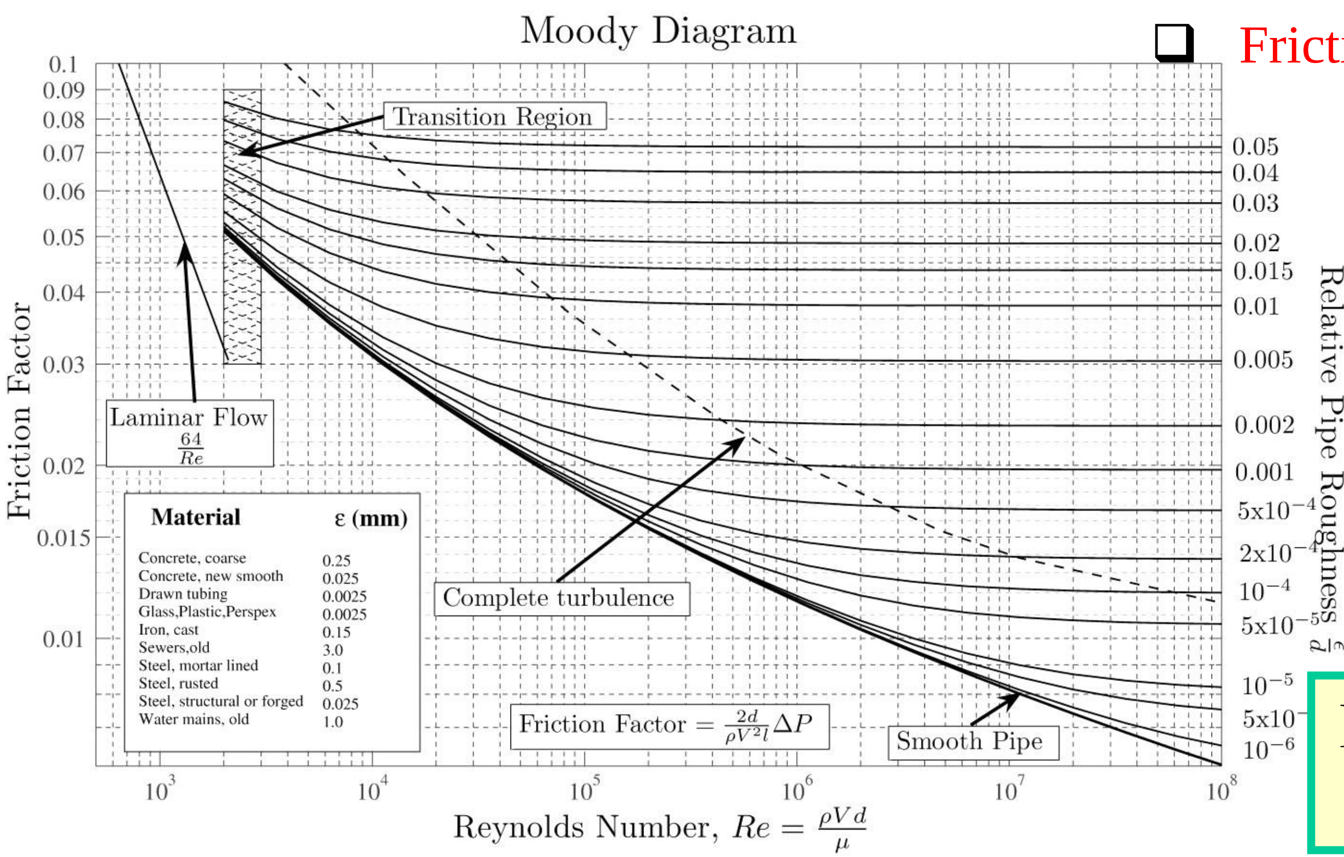
$$\left(\frac{dQ}{dz}\right) = \frac{2\pi\lambda}{\mathrm{Ln}\,(1+\frac{2e}{\Phi})}\,(T - T_0) \quad < 120 \text{ W/m}$$

Total heat loss ~ 2% of the transported power!

The Main Transport Line: Hydraulics

$$\left(\frac{dH}{dz}\right) = C.\ \frac{\rho\, U^2}{2\,\Phi}$$

- ❑ Diameter Φ
- ❑ Water velocity U
- ❑ Water density ρ
- ❑ Friction coefficient C

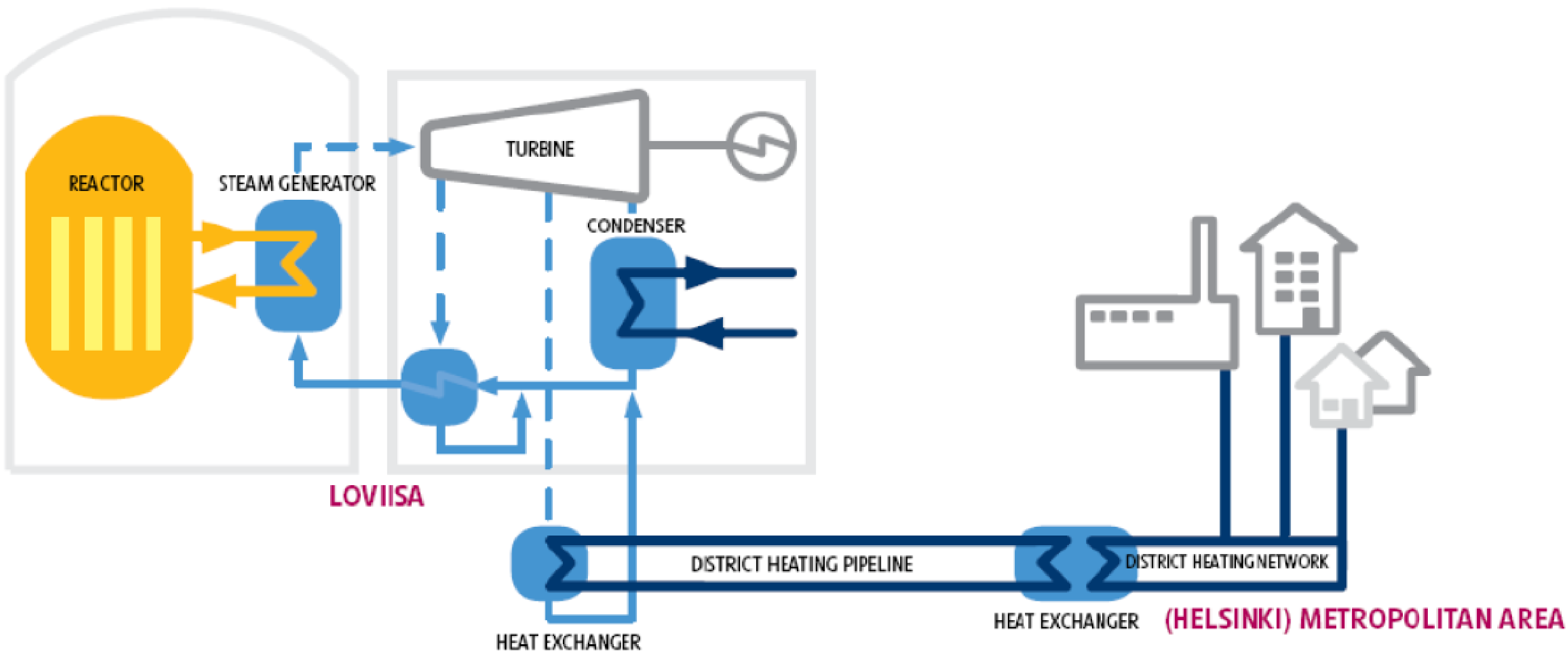


Moody's Diagram for straight pipes

Loviisa 3 Nuclear Power Plant Project in Finland

PWR connection

Heat extraction from a Pressurized Water Reactor



Source: Harri Tuomisto, FORTUM, Finland , October 2010

Loviisa 3 Nuclear Power Plant Project in Finland

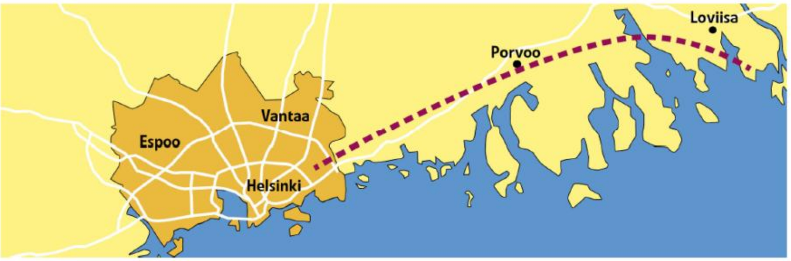
Loviisa 3 CHP – heat transport on a long distance

Heat transport in pipes

– Mounting in a rock tunnel, cross section 30 m^2
  - stable conditions
  - positive maintenance aspects
– Near surface installation
  - lower costs
  - environmentally more challenging

District heat transport system

- Distance over 75 km (Loviisa – eastern Helsinki)
  - 2 x Ø 1200 mm pipes, PN25 bar, Q = 4 - 5 m^3/s
  - 4 - 7 pumping stations
    - total pumping power needed tens of MWs
    - compensates for heat losses
  - Control scheme
    - district heat water temperature or flow rate
  - Heat accumulator needed, heat distribution to the local district heat network via heat exchangers



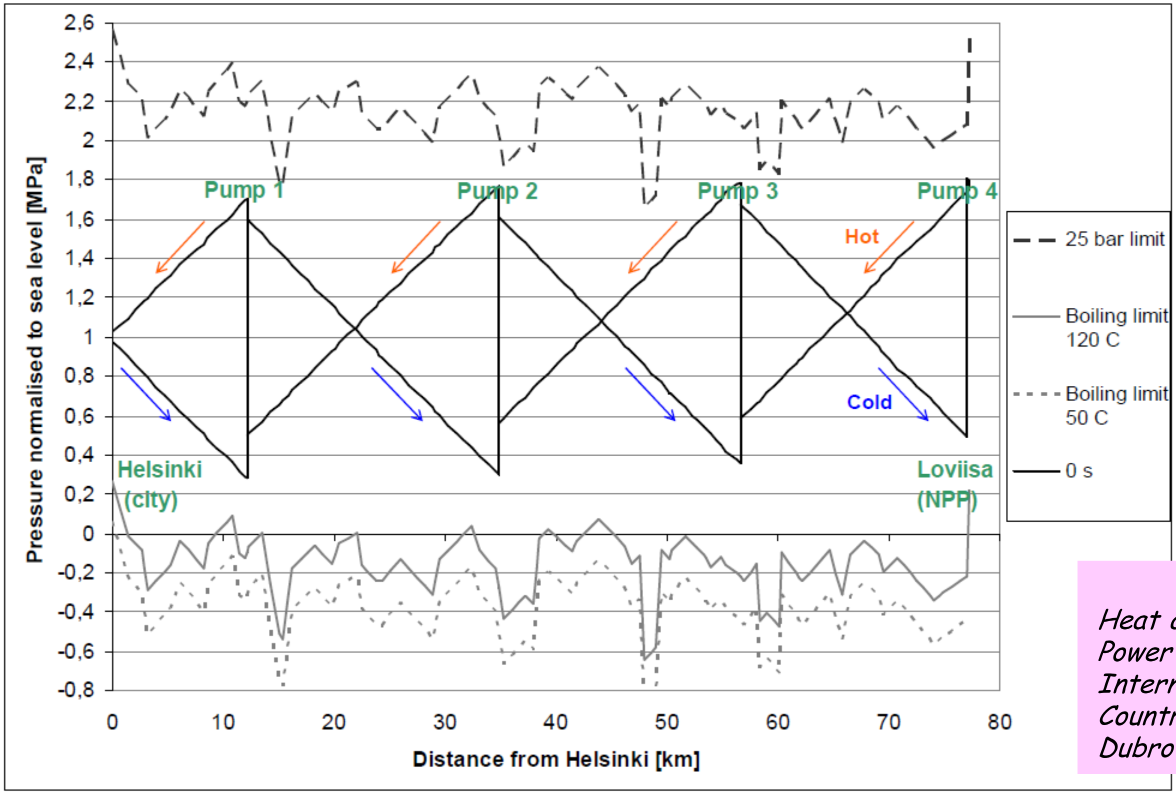
Source: Harri Tuomisto, FORTUM, Finland , October 2010

The Main Transport Line : Pumping Power

Pressure drop along the pipe

$$\left(\frac{dH}{dz}\right) = C. \frac{8\,P^2}{\pi^2\,\rho c_p^2\,\Delta T^2\,\Phi^5}$$

- Diameter Φ
- Heat power P



Loviisa 3 Nuclear Power Plant Project in Finland

Source: N. Bergroth, "Large-Scale Combined Heat and Power (CHP) Generation at Loviisa Nuclear Power Plant Unit 3", Proceedings of the 8th International Conference on Nuclear Option in Countries with Small and Medium Electricity Grids, Dubrovnik, Croatia, (16-20 May 2010)

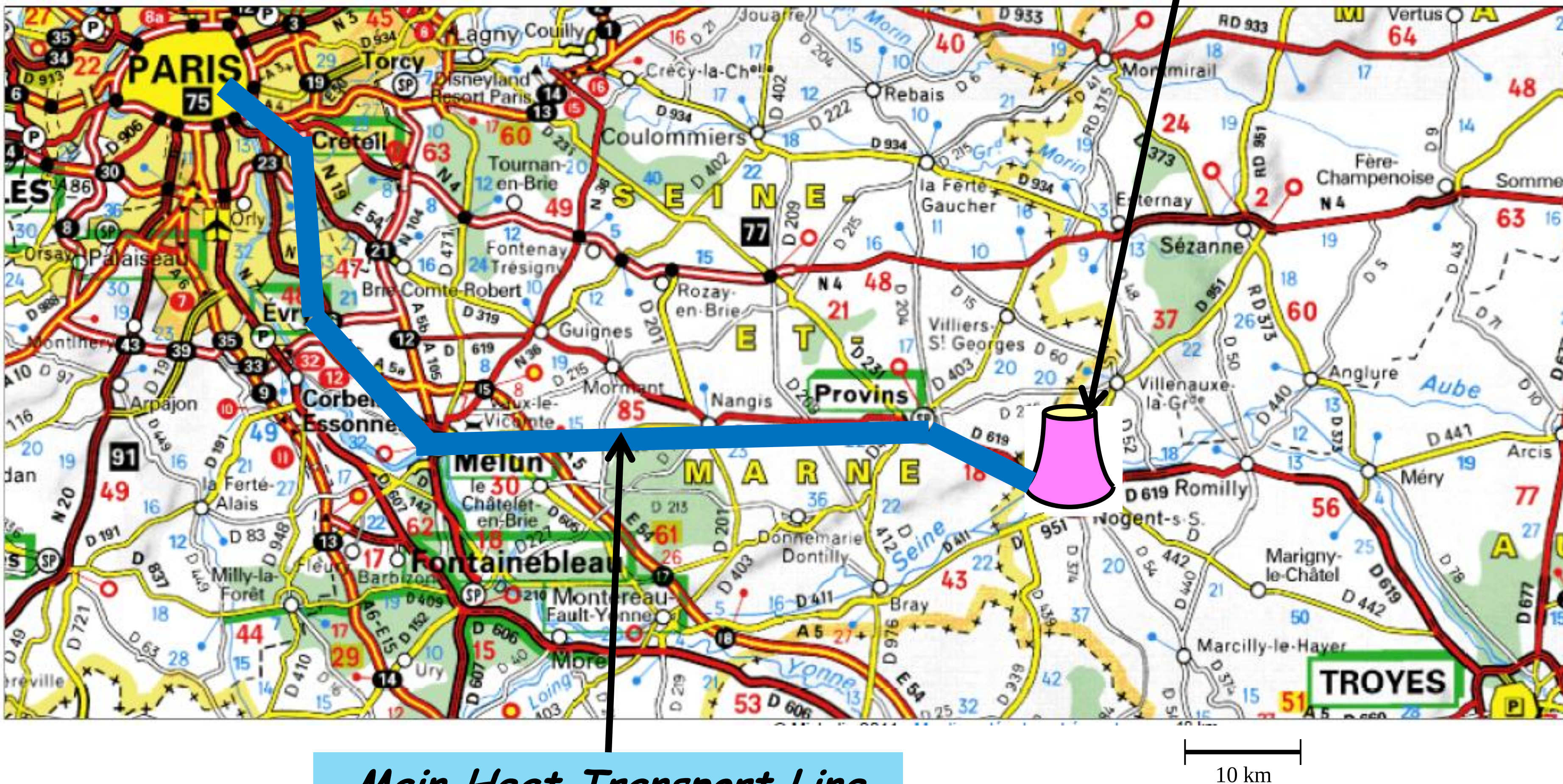
Install pumping stations every ~ 20 km

The Nogent-sur-Seine Power Plant

Two 1300 MWe reactors with cooling towers

The Main Transport Line: An example

Nogent-sur-Seine Nuclear Power Plant



Main Heat Transport Line

Economics

Two main parameters

1. The Temperature T of the fluid

   Electric Efficiency, Heat Losses

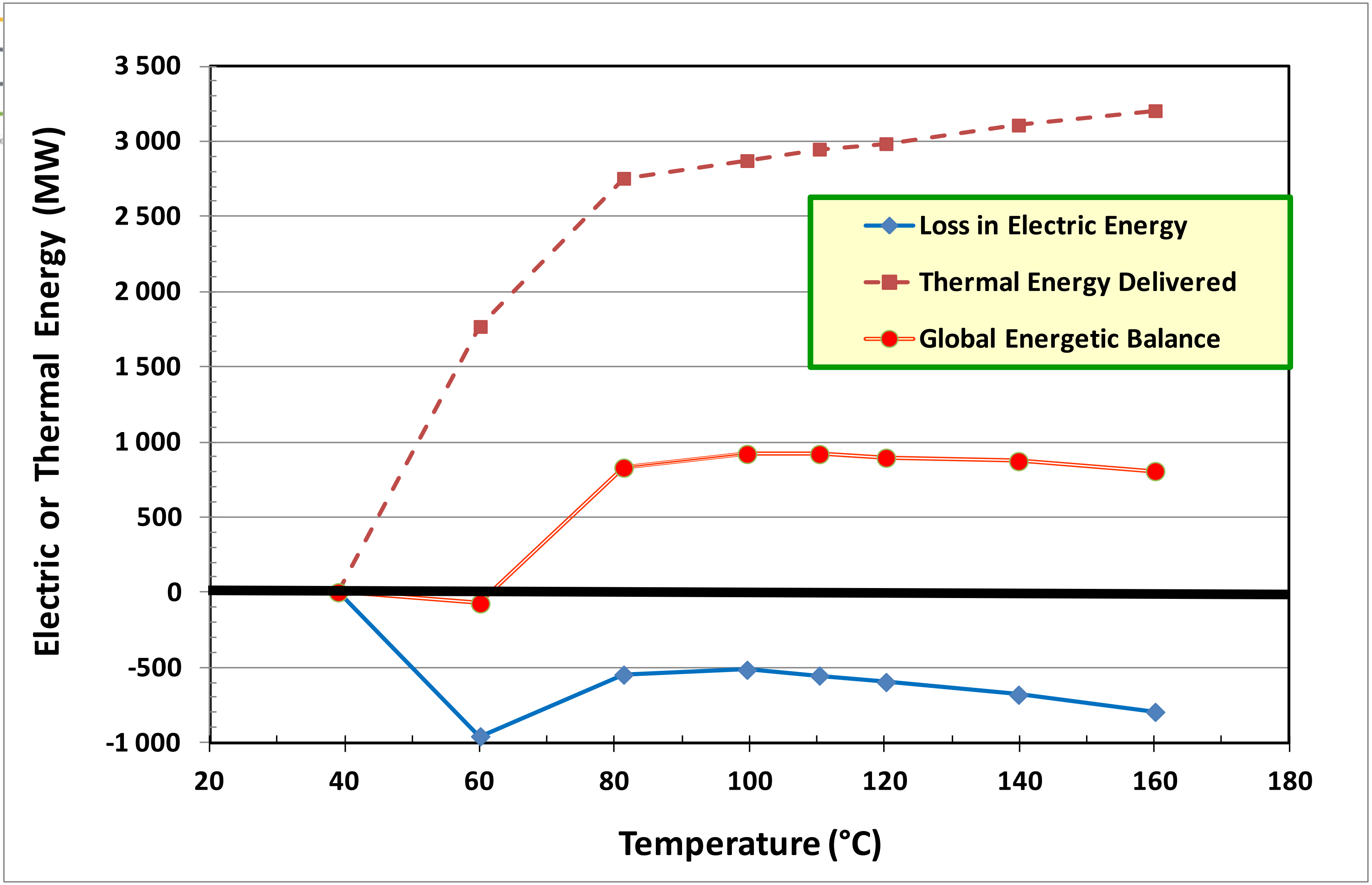
2. The Piping Size Φ

   Pumping Power

<u>Assumptions:</u>

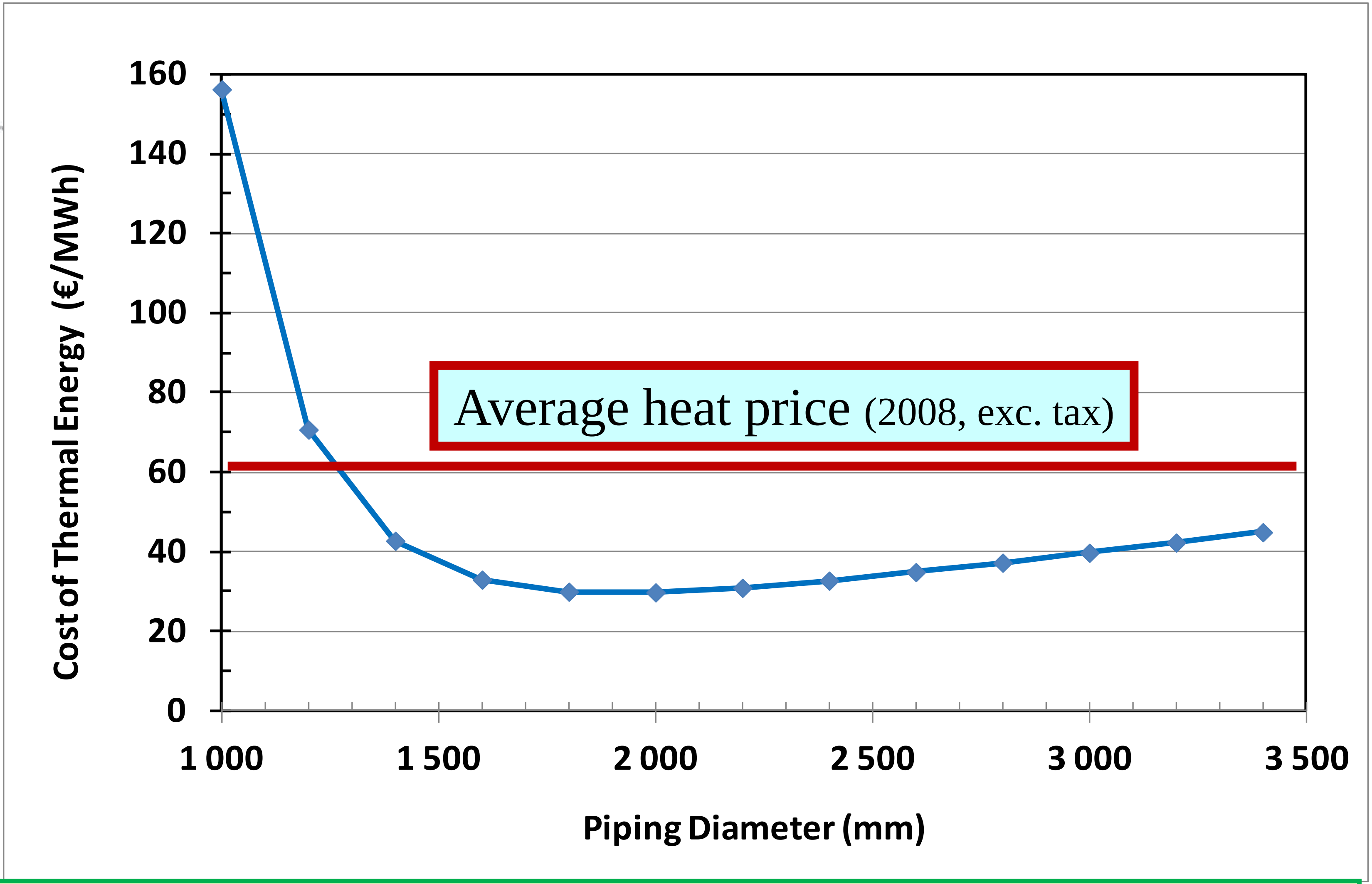
- Operation time: 1/3 cogeneration, 2/3 electric
- Value of 1 MW thermal = 50% of 1 MW electric
- 2 lines of 1500 MW capacity each

Economics: Optimal Temperature



A gain equivalent to 920 MWe (+70%) can be achieved !!

Economics : Optimal Piping Size



A target of ~30 €/MWh can be set for the recovered heat

Main primary line parameters

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Main Transport Line Characteristics		
Transported heat power	1 523	MW
Total line length	150	km
Forward Temperature	120	°C
Return Temperature	60	°C
Insulation Thermal Conductivity	0.05	W/m.K
Insulation thickness	300	mm
Piping size	2 000	mm
Max. pressure	20	bars
Water flow	6.34	m^3/s
Total heat loss	32.3	MW
Hydraulic pressure drop	-0.16	bar/km
Total pumping power	43	MW
Cost of delivered MWh	29.8	€/MWh

Single line should be doubled to get a capacity of 3000 MWth

Economics: Balance

Implementation on Nogent-sur-Seine reactor
(1300 MWe)
150 km long main heat transport line

- Additional heat production of 9 TWh
  Gain of +540 M€/year
- Reduction of electric production -1.8 TWhe
  Loss of -180 M€/year

Total gain of +360 M€/year

CO_2 emissions

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CO_2 emissions from district heating in Paris

60% fossil fuels (gas boilers, coal, oil)
40% waste incineration

Average of 195 gCO_2/kWh

Large reduction in CO_2 emissions

Avoid 1.7 Million tons of CO_2/year

Huge savings in CO_2 emissions

Conclusions

- The recovery of nuclear heat from **present NPP** is **technically feasible**

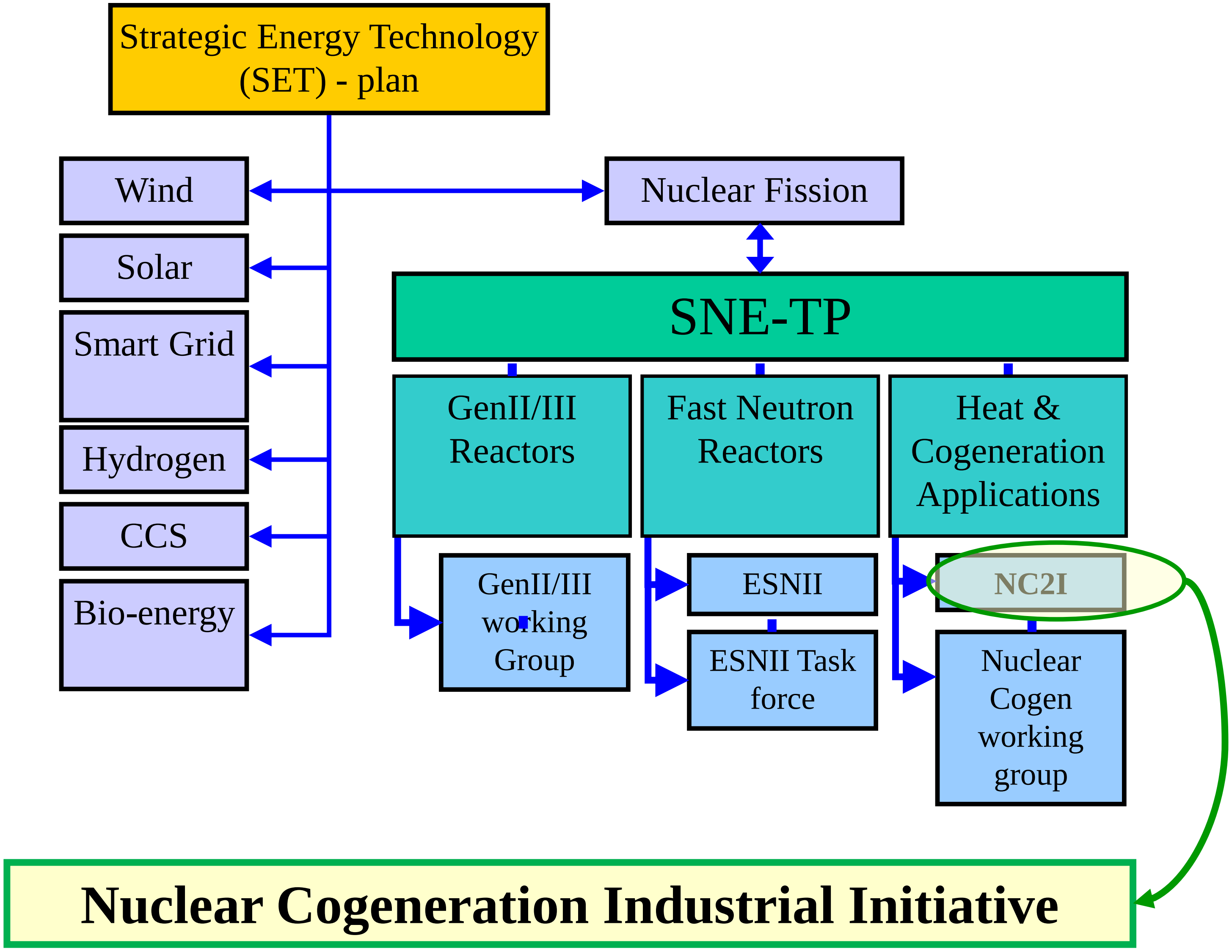
- The **primary heat transport line** can be designed with low thermal losses (a few percents) even for **long distances** (> 100 km)

- Heat recovery enhances the plant efficiency and provides a **high energetic gain** (+70%)

- The recovered heat is **economically** competitive

- Nuclear heat recovery allows large **reduction in CO_2 emissions**

The Sustainable Nuclear Energy Technology Platform



The NC2I Task Force

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Mission:

NC2I TF shall comply with the SNETP mandate and shall launch a Nuclear Cogeneration Industrial Initiative (NC2I) and any other tools required for successful prototype project in the 2020 time frame

Vision:

The NC2I vision is to unlock and use the potential of nuclear cogeneration for considerable savings of fossil resources in the short to medium term

NC2I shall thus develop, demonstrate and stimulate nuclear cogeneration systems compatible with large-scale industry applications and SET Plan targets

- ➔ **Support cogeneration applications for all nuclear systems**
- ➔ **Extend cogeneration potential by accelerated HTR development**
- ➔ **Initiate prototype project(s)**
- ➔ **Possibly prepare/participate in international industrial initiative(s)**

Source: Sander De Groot, NRG, SNETP/NC2I, October 2011