Advantages and economical feasibility of combined heat and power production based on biomass with a special focus on ORC technology

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Presentation - overview

- Technologies and constraints for the application of small-scale biomass CHP plants
- The ORC process – technology and application
- Conclusions and recommendations

Definitions and constraints

Decentralised biomass CHP technologies

- Nominal electric capacity: 0.01 – 20 MW_{el}
- Nominal fuel power: 0.02 – 70 MW (based on NCV)

Size of CHP plant limited by

- Low energy density of the biomass fuel (storage, logistics)
- Availability of heat consumers

Constraints for the application of small-scale biomass CHP plants

Nominal electric capacity of small-scale biomass CHP plants: < 2.0 MW(el)

Relatively low electric efficiency → only heat controlled operation economically meaningful

- **Biomass CHP plants in wood manufacturing and wood processing industries (high process heat demand)**
- **Biomass CHP plants for base load coverage in district heating systems**
- **Biomass CHP plants in non-wood and non-agricultural industries with high process heat or process cooling demand**

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Criteria for decentralised biomass CHP technologies (I)

- Biomass should be used locally
- Thermal biomass utilisation for "heat only" production is an exegetically not optimal solution.
- Electricity production increases the plant utilisation rate (in comparison to "heat only" applications).
- The electricity demand of the plant can be covered from the own production (if this is of interest).
- Nearly all electricity production technologies show comparably low electric efficiencies for small-scale applications at present.

Criteria for decentralised biomass CHP technologies (II)

- The specific capital costs (per kW_{el} installed) increase with decreasing plant capacity ("economy of scale").
- Biomass CHP plants only seem to be reasonable if acceptable feed-in rates are secured for long terms.
- A basic requirement for the technologies used is their robustness and their operational safety (especially of relevance for decentralised applications)
- For the operator of a steam boiler or a turbine a higher educational level is affordable than for the operator of a hot water boiler => personal costs increase

Criteria for decentralised biomass CHP technologies (III)

- Ecologically and in most cases also economically seen, decentralised CHP systems should be operated in heat and not in electricity controlled mode.
- In correctly dimensioned plants a minimum of 5,000 full load operating hours per year should be achieved from the CHP unit (target value: >6,000 full load hours per year).
- For the evaluation of the realisability of a biomass CHP project a comprehensive technological and economic assessment should be made (including a heat only application as a reference unit).

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Assessment factors for CHP technologies

plant parameters	$\eta_{el\text{-}plant}$ η_{tot} P_{el} complexity of the plant
operation behaviour	start up partial load operation
process control	demand and education of operation personnel level of automation
maintenance	usual maintenance personnel demand for maintenance frequency of malfunctions
ecology	hazardous operational supplements noise
state of development	maturity of technology short term potential for further development
cost structure	capital costs consumption costs operation costs and maintenance costs other costs

Small-scale biomass CHP technologies - overview

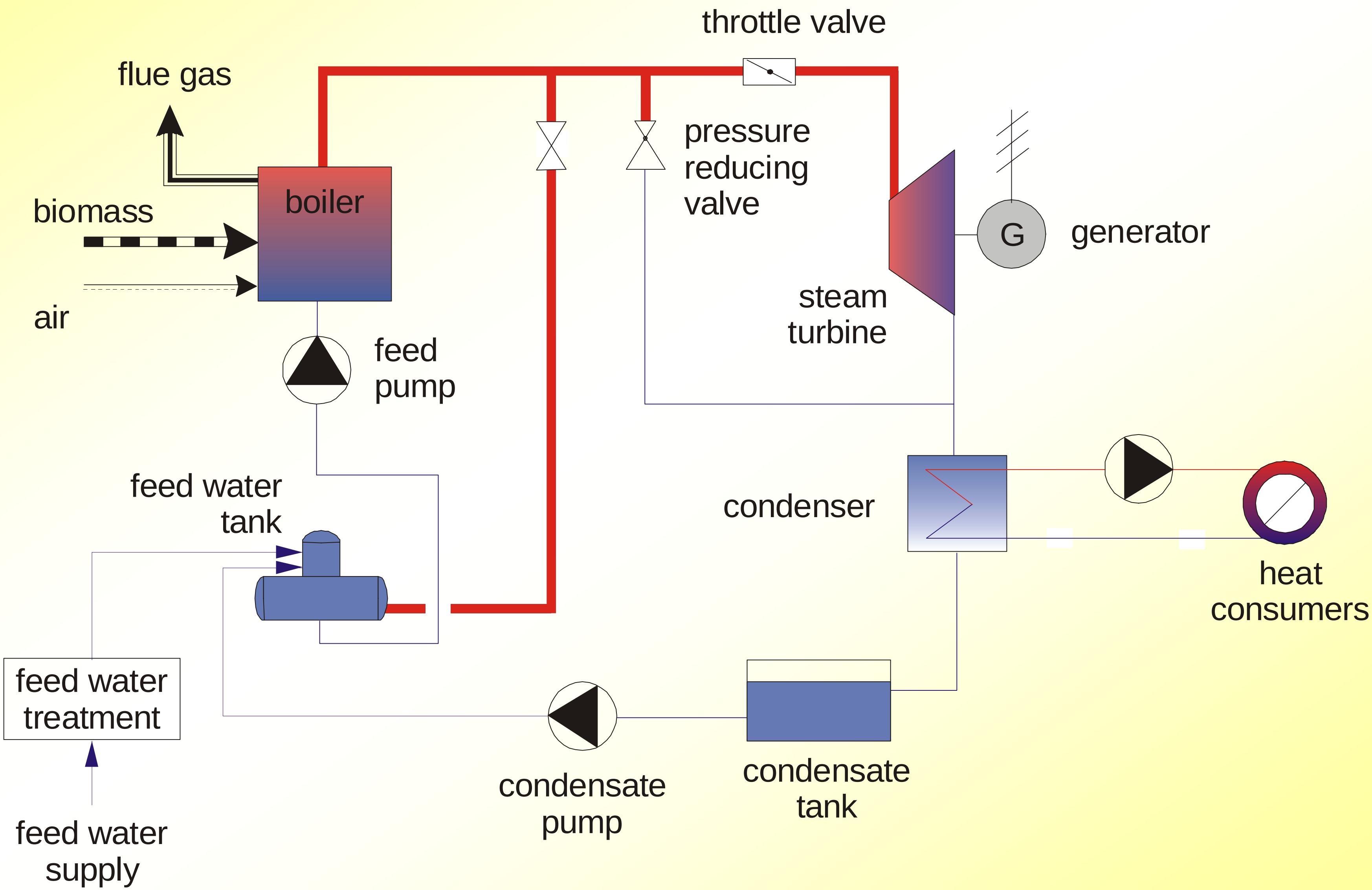
CHP plants based on biomass combustion

- Steam turbine process
- Steam piston engine process
- Screw-type engine process
- ORC process
- Stirling engine process

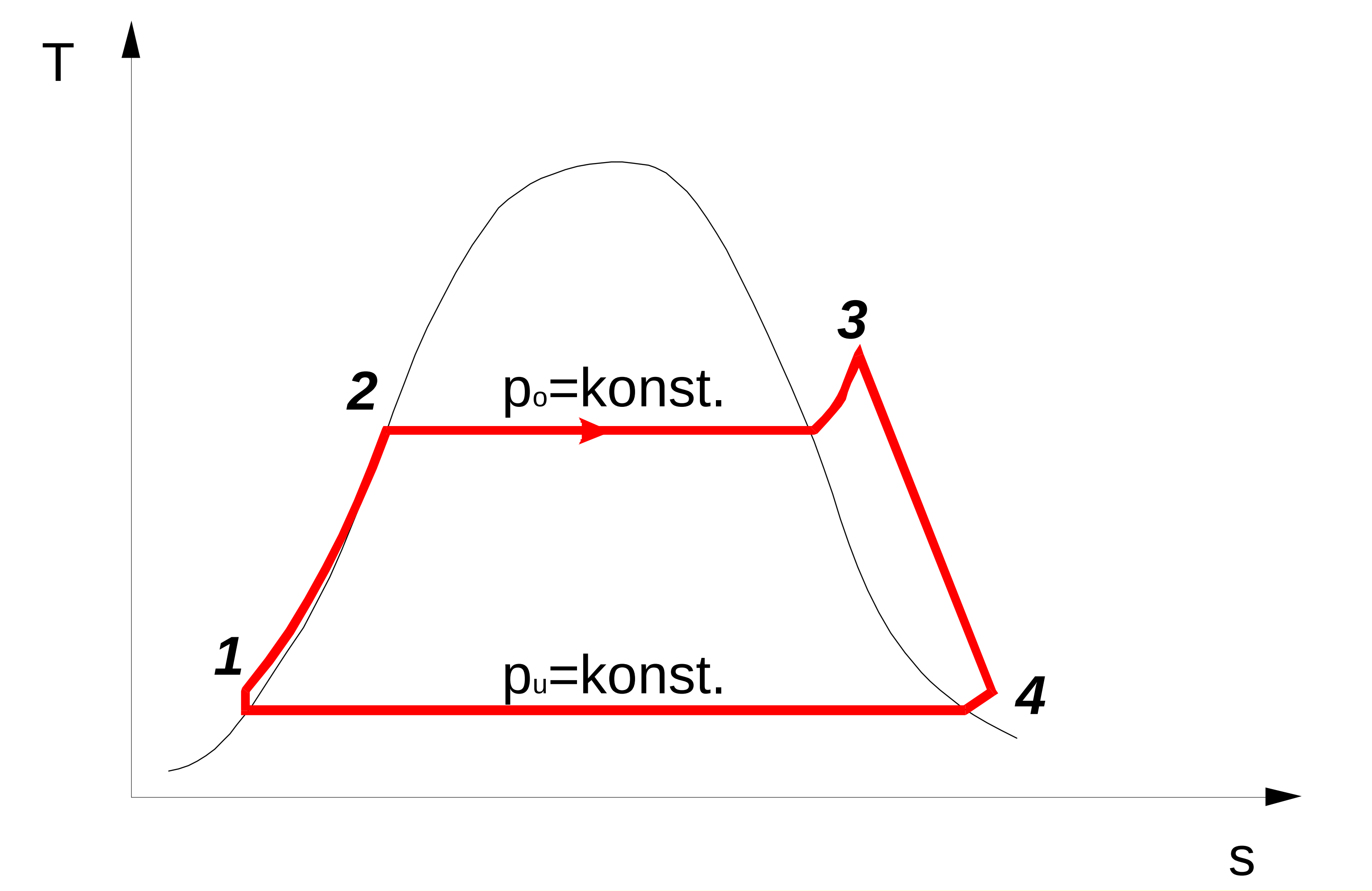
CHP plants based on biomass gasification

- Gasification systems combined with gas engines or turbines

Steam turbine process - scheme



Steam turbine process- thermodynamic cycle



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Steam turbine process - technological evaluation

Advantages

- No upper limit regarding plant size
- Technologically mature
- Low specific investment costs
- Well applicable for large-scale installations (>2 MW_{el})

Weak points

- Low electric plant efficiency for small-scale systems
- Partial load operation requires special control systems
- Educated steam boiler operator necessary
- High operating costs (maintenance, feed water treatment)

ORC process - description of technology

- **Utilisation of an organic working medium instead of water**
  → ***Organic Rankine Cycle*** **(ORC)**

- **The necessary energy is transferred from the biomass boiler to the evaporator of the ORC by a thermal oil cycle under atmospheric conditions**
  → **no pressurised boiler necessary (decreased personal cost)**
  → **no water treatment necessary**

- **An ORC process especially adapted for biomass CHP plants was developed in Italy (working medium: silicon oil)**

- **The implementation of ORC modules in existing biomass combustion plants is relatively easy**

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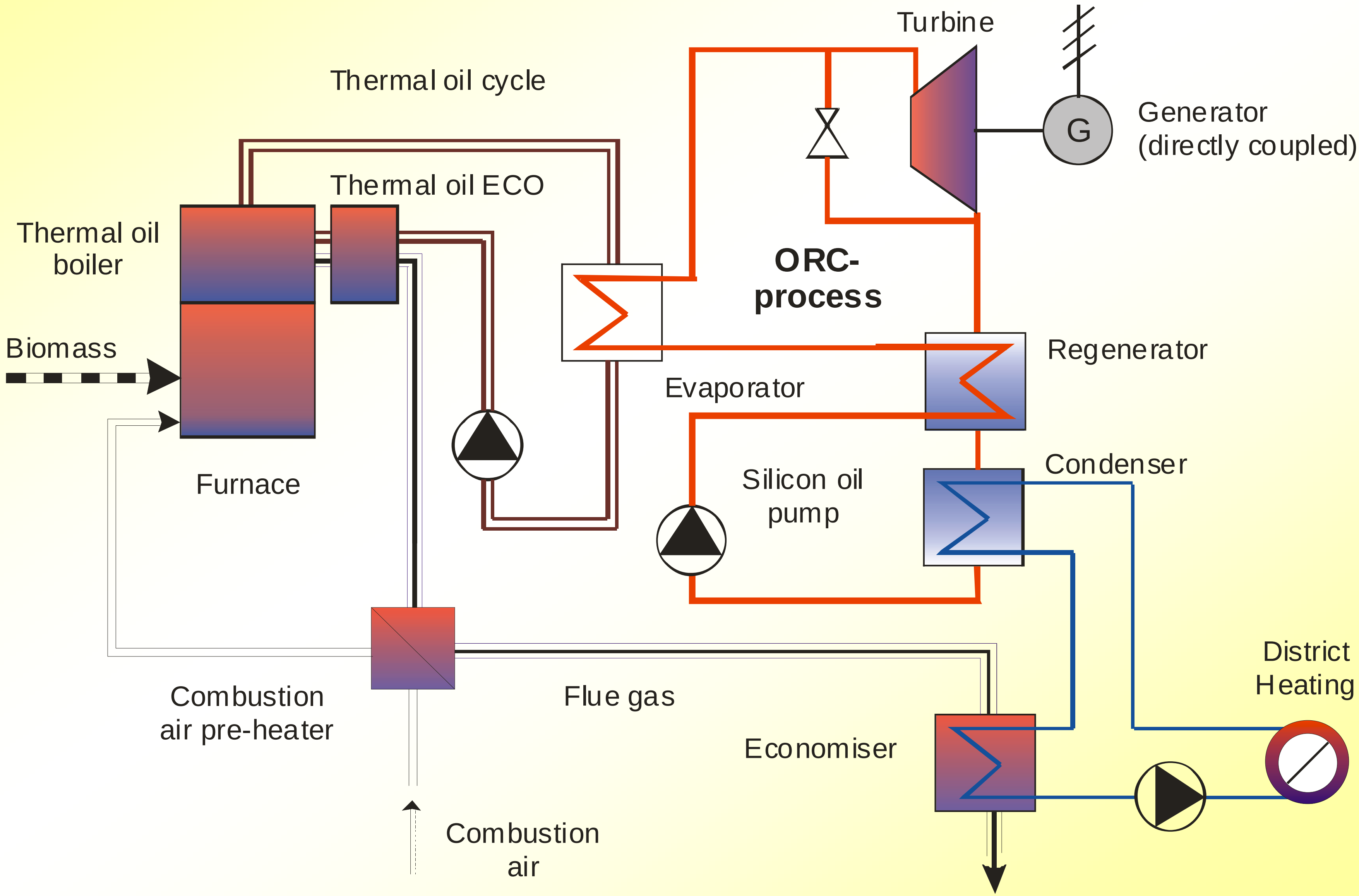
ORC process - optimised scheme



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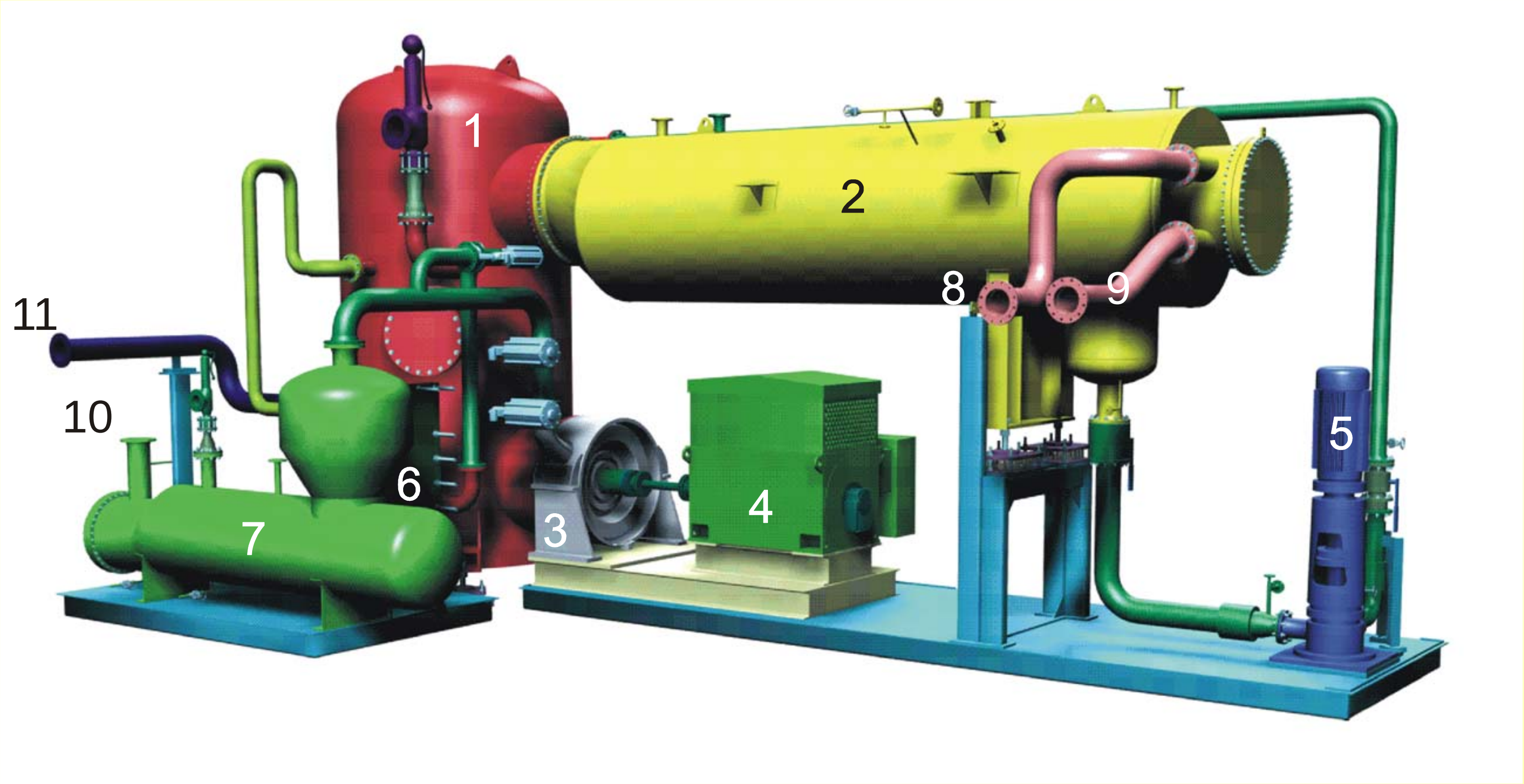
ORC-Process – components



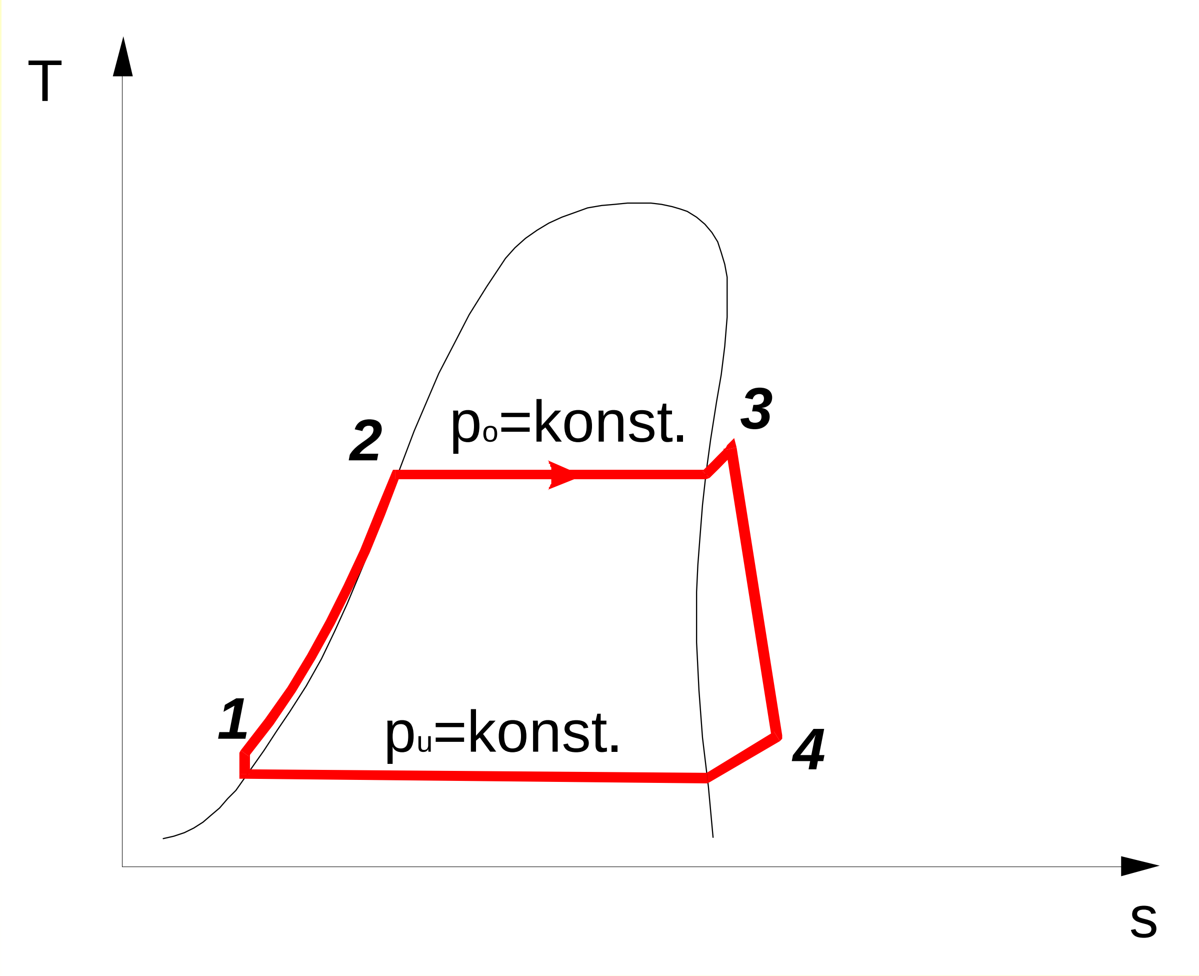
1 Regenerator
2 Condenser
3 Turbine
4 Electric Generator
5 Circulation pump
6 Pre-heater
7 Evaporator
8 Hot water inlet
9 Hot water outlet
10 Thermal oil inlet
11 Thermal oil outlet

EU Demonstration Project Lienz (A) ORC-Process – evaporator, regenerator and turbine

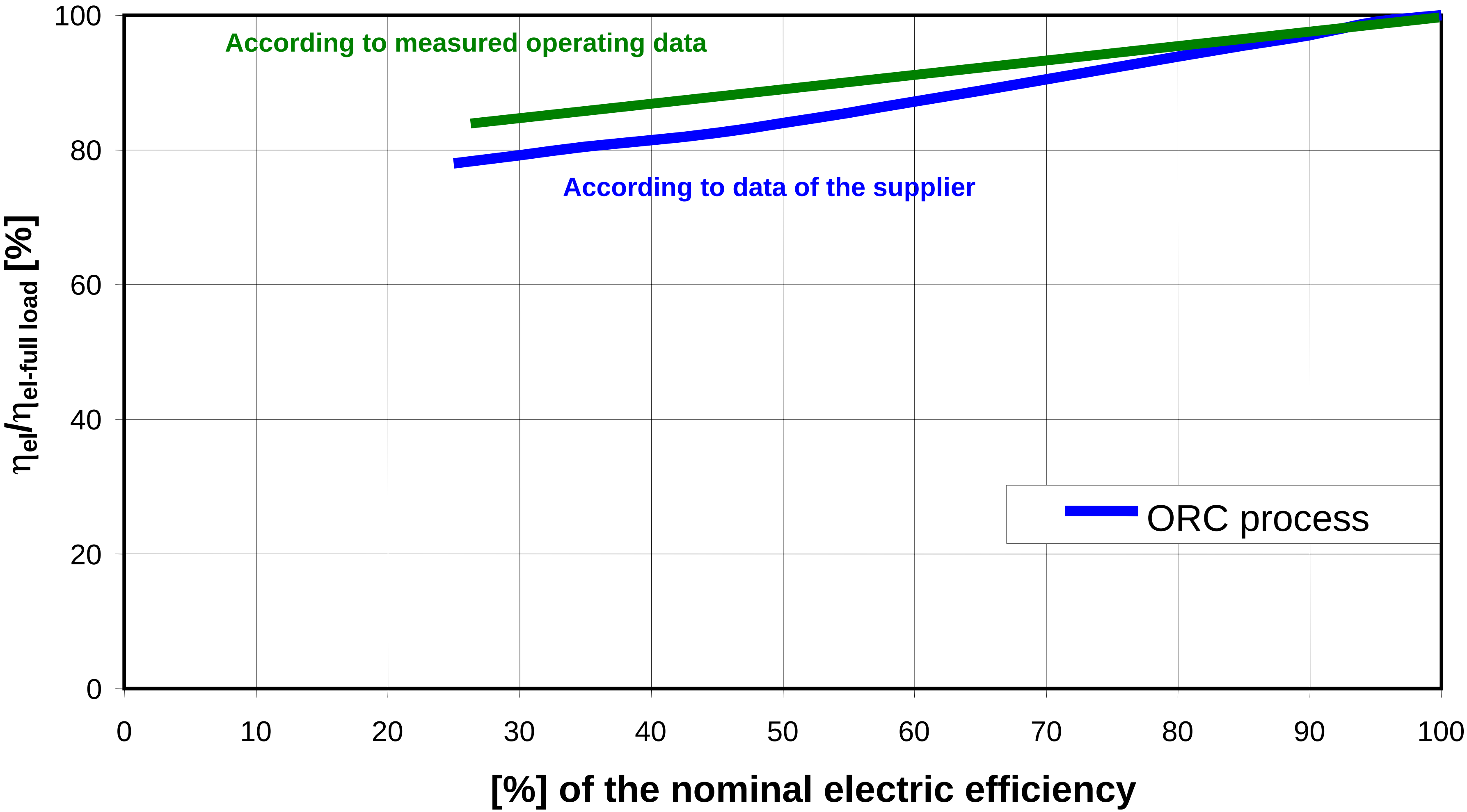
ORC process - description of technology II

- Turbine with high efficiency and low speed of rotation, optimised for small-scale applications
- No danger of droplet erosion on turbine blades due to the favourable thermodynamic properties of the silicon oil
- ORC plants show an excellent partial load behaviour, are suitable for rapid load changes and can be operated between 10% and 100% of their nominal load
- The operation of the ORC plant is fully automatic, no additional personal is required (just some man hours per week for regular checks)

ORC process - thermodynamic cycle



ORC process - partial load behaviour



ORC process - relevant maintenance issues

- **High reliability (long experiences available from geothermal applications)**
- **The working medium does not age and is not corrosive**

ORC process - ecological aspects

- ORC plants are relatively silent
(the highest noise emissions occur at the encapsulated generator and amount to 75 dBA in a distance of 1 m)
- Silicone oil is not toxic, not depleting the ozone layer, not explosive but is flammable with a flame point of 34°C
- The ORC cycle is completely closed
(no losses of the working medium occur)
- The thermal oil cycle demands higher security measures regarding leakage than water or steam cycles

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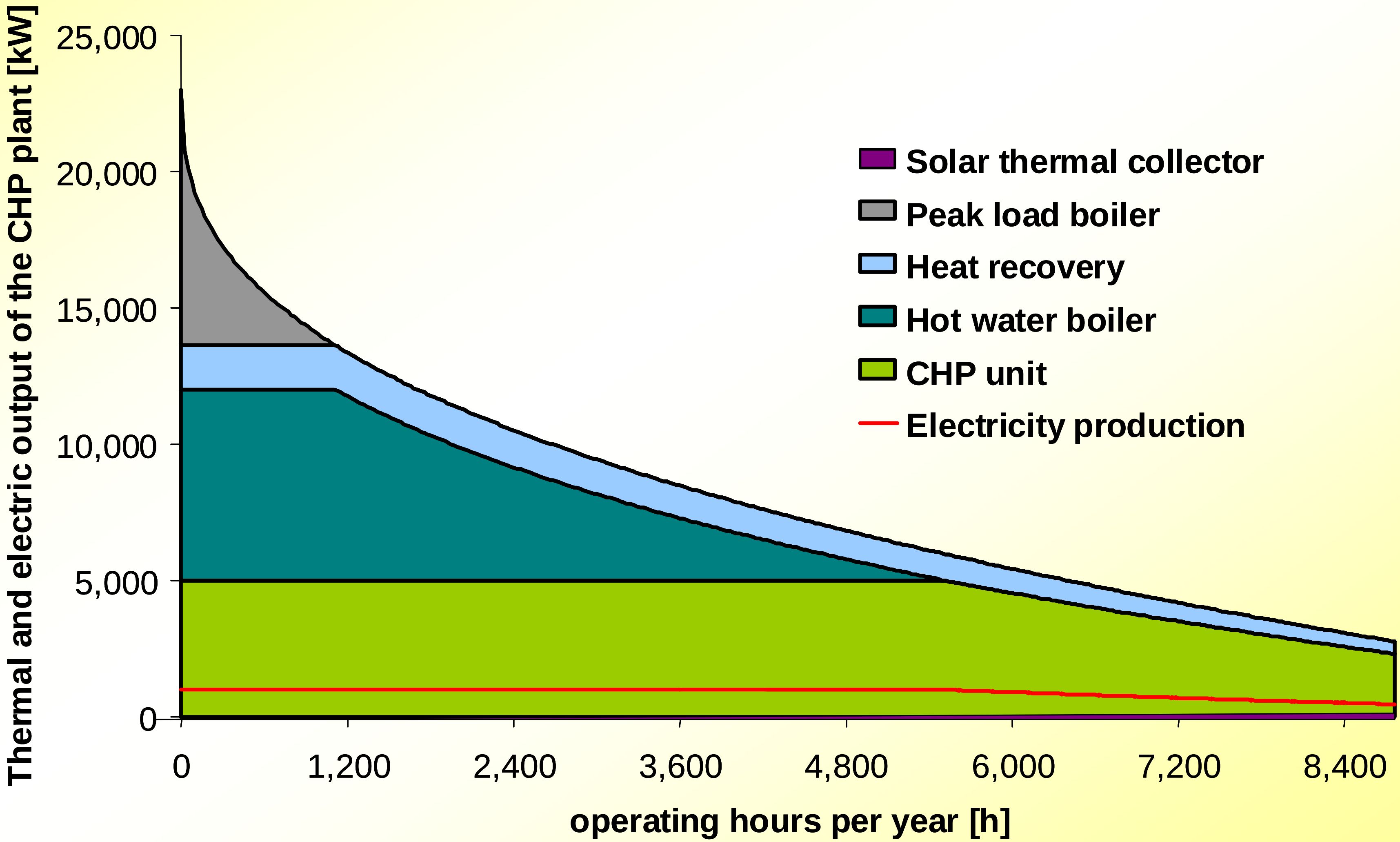
EU Demonstration Project Lienz (A) integration of the ORC process into the overall plant



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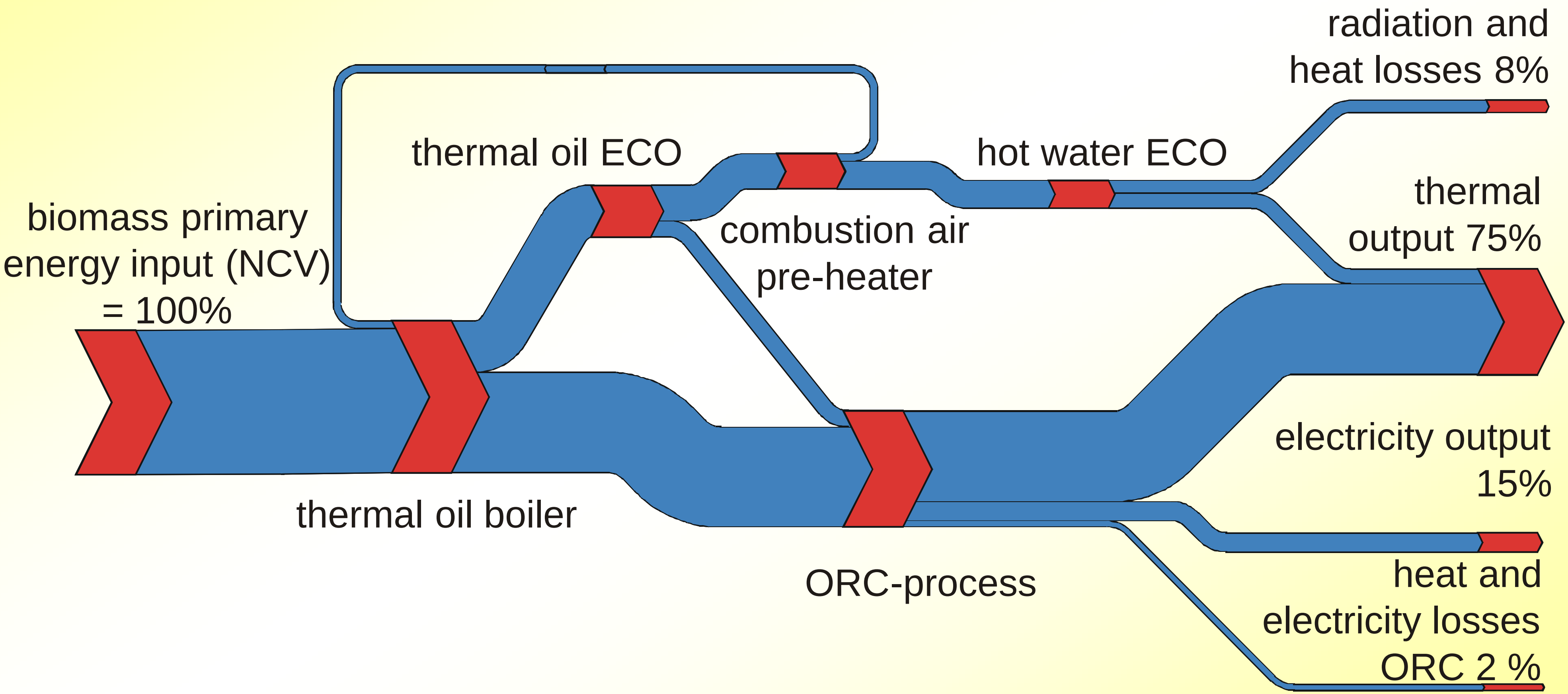
EU Demonstration Project Lienz (A)
ORC process - technical data

Thermal power (thermal oil) input - ORC at nominal load	5.560	kW
Net electric power output - ORC at nominal load	1.000	kW
Thermal power output - ORC at nominal load	4.440	kW
Net electric efficiency - ORC at nominal load	18	%
Thermal efficiency at nominal load	80	%
Electric and thermal losses	2	%
Heating medium	Thermal oil	
Inlet temperature	300	°C
Outlet temperature	250	°C
Working medium	Silicon oil	
Cooling medium	Water	
Inlet temperature	80	°C
Outlet temperature	60	°C

EU Demonstration Project Lienz (A) Energy Flow Sheet



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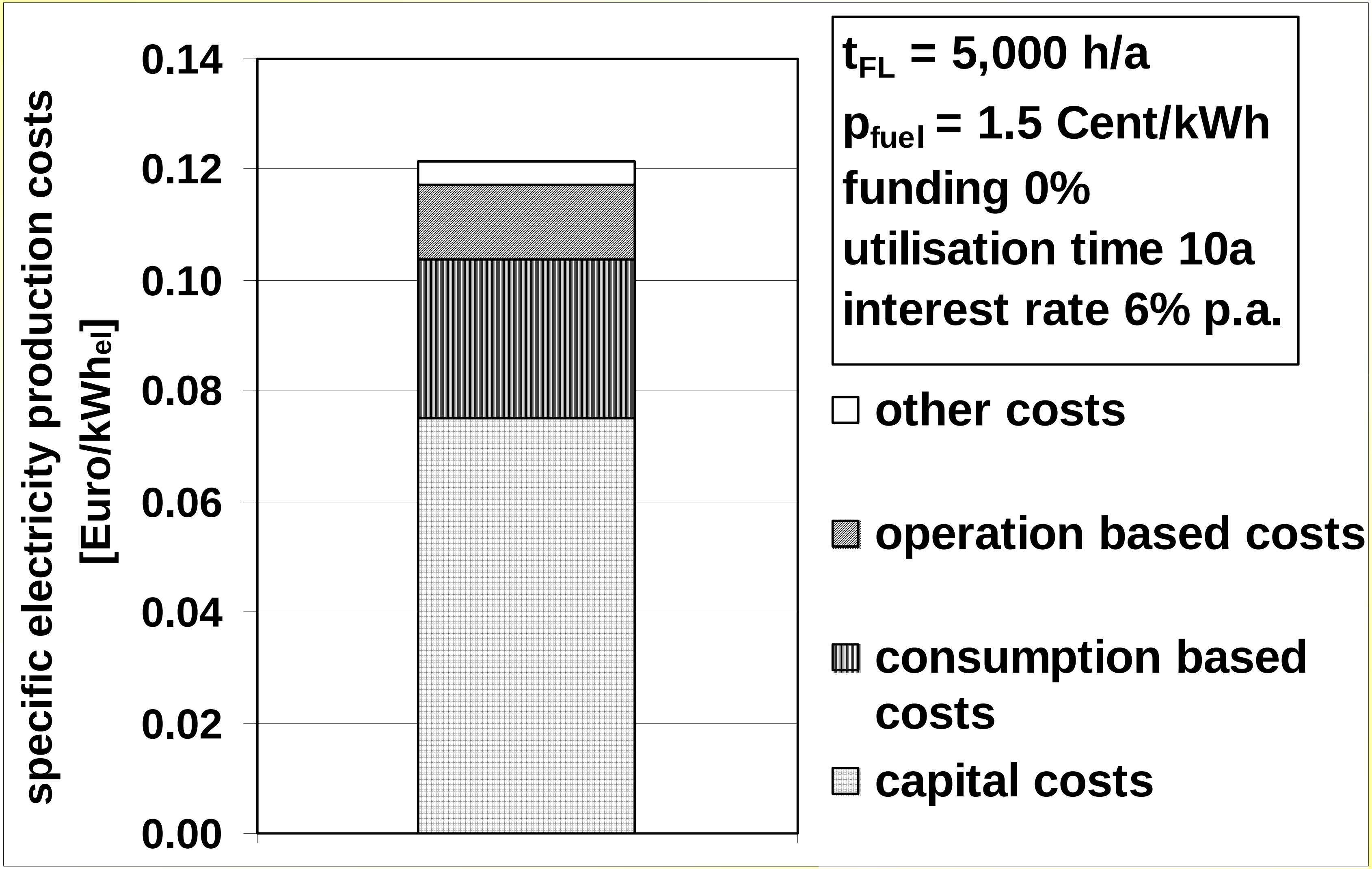
Composition of electricity production costs – ORC process (1,000 kW_{el})



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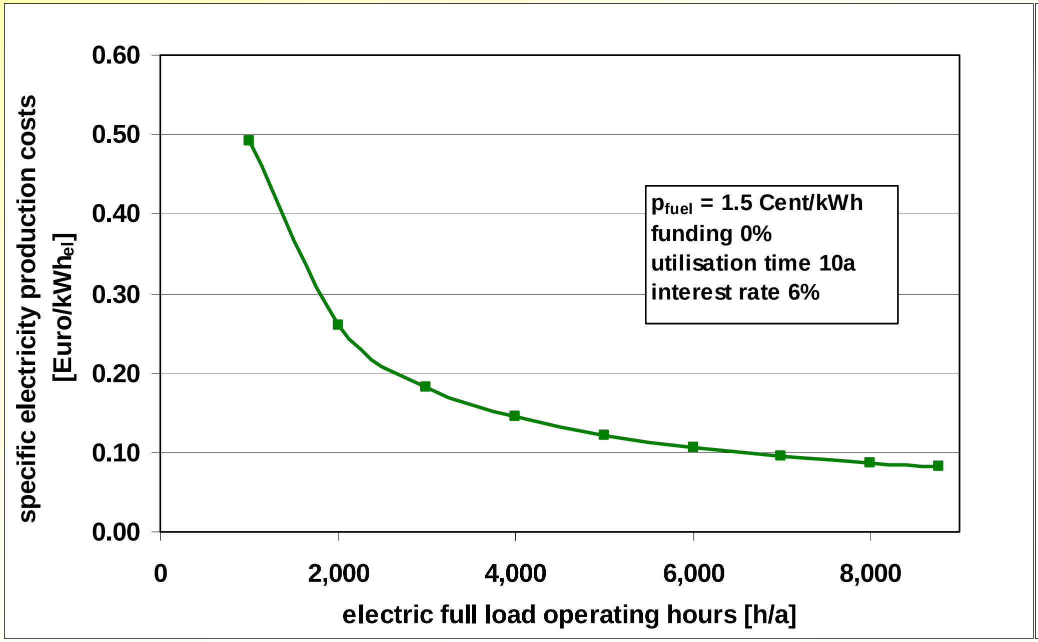
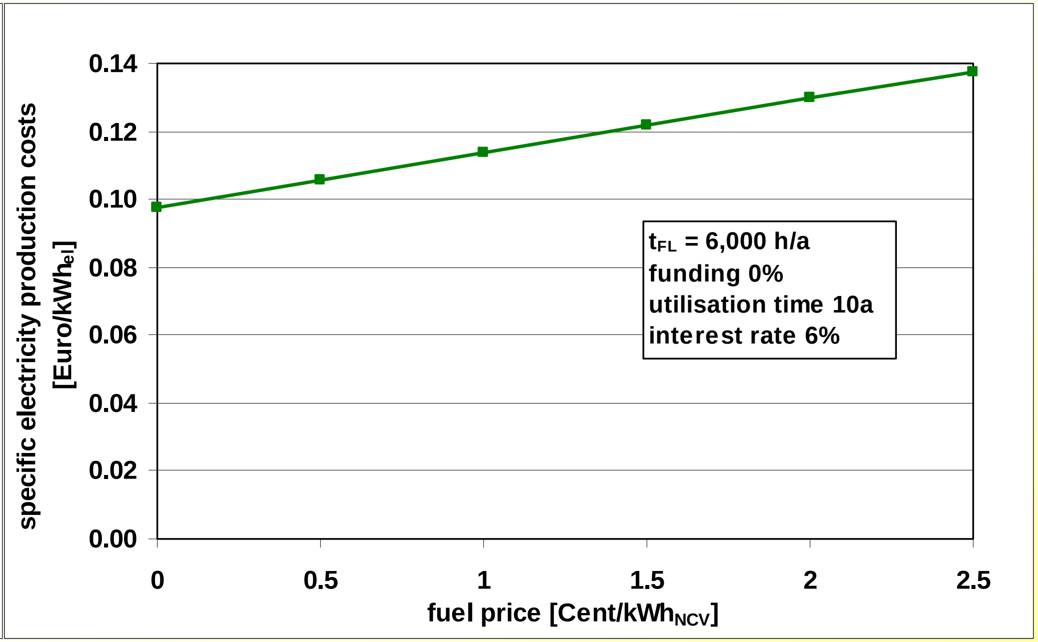
Electricity production costs of a 1,000 kW(el) ORC process vs. full load hours and fuel price





ORC process - state of development

- Thermal oil as well as ORC cycles are applied in industries for many years
- ORC modules for biomass CHP plants with nominal electric capacities between 200 kW_{el} and 1,500 kW_{el} are available
- Biomass CHP plants based on an ORC process are now entering the market
  - → First EU Demo unit: 400 kW(el) (STIA Admont, A), more than 40,000 operating hours
  - → Second EU Demo unit: 1,000 kW(el) (Lienz, A),
  - → Third plant: 1,100 kW(el) (Fussach, A) Combined heat, cold and power production (combination of ORC – absorption chiller)
- About 20 ORC units with nominal electric capacities between 200 and 1,500 kW are in operation in Austria, Italy, Switzerland and Germany

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ORC process - technological evaluation

Advantages

- Excellent partial load behaviour
- Mature technology
- Atmospherically operated boiler reduces personal costs
- High degree of automation
- Low operation and maintenance costs

Weak points

- Relatively high investment costs (no serial production yet)
- Thermal oil cycle necessary

Conclusions and recommendations for small-scale biomass CHP plants (I)

Relevant technical side constraints for small-scale biomass CHP systems (P_{el} < 2.0 MW):

- Highly robust technology (high availability)
- High degree of process control and automation (unmanned operation)
- Good partial load behaviour and suitability for quick load changes
- Overall electric efficiency (=electricity generated / fuel input based on NCV) between 12 and 20%

Conclusions and recommendations for small-scale biomass CHP plants (II)

Relevant economic side constraints for small-scale biomass CHP systems (P_{el} < 2.0 MW):

- High number of full load operation hours (> 5,000 h/a)
- High overall efficiency (heat controlled operation)
- Utilisation of „economy-of-scale“ and „learning curve“ effects regarding a reduction of investment costs
- Appropriate feed-in tariffs for electricity from biomass guaranteed over a time period of at least 10 years
- Typical electricity production costs vary between 70 and 150 Euro / MWh(el) at present

Thank you for your attention

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