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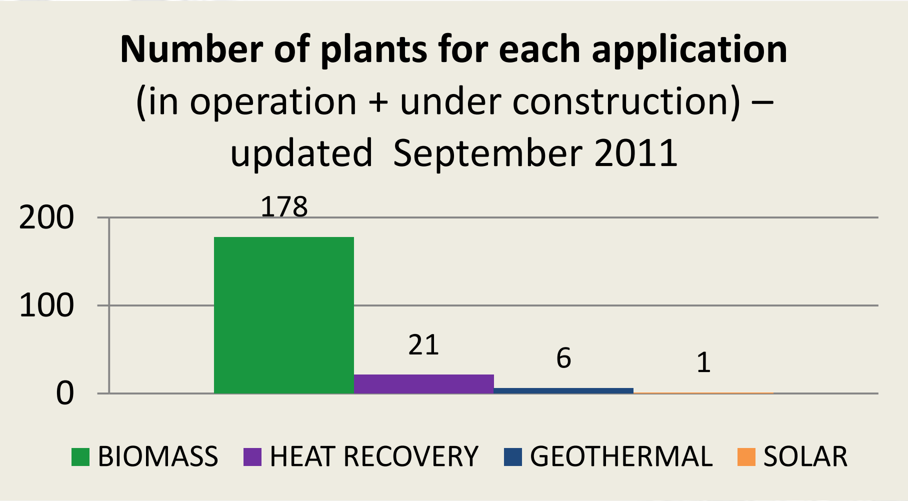
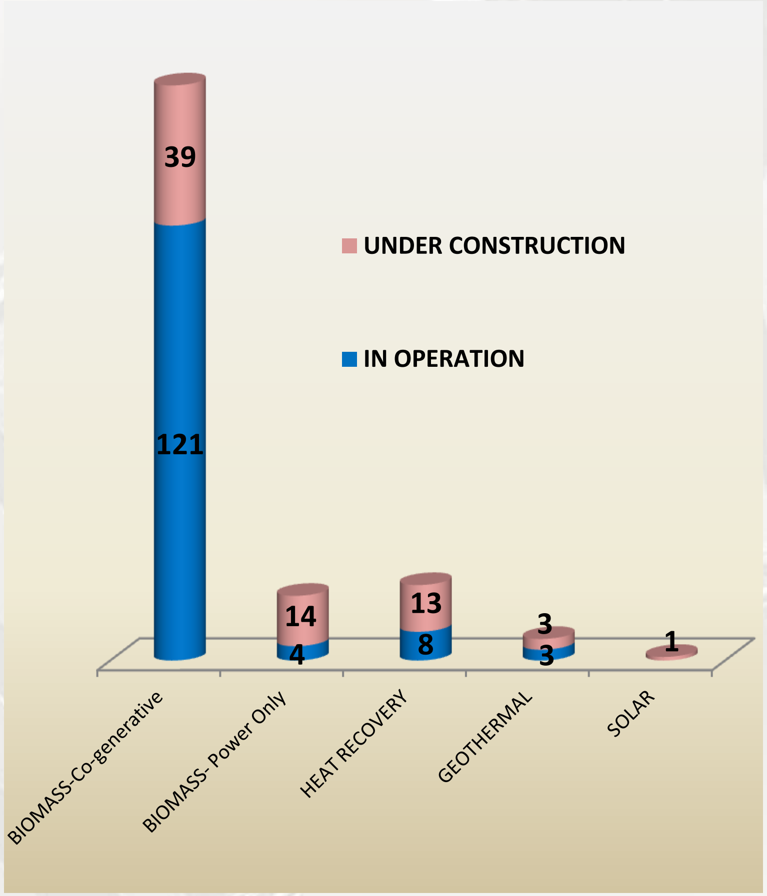
High efficiency (25%) ORC for ‘power only’ generation mode in the range 1-3 MW: an already proven technology also available for partially cogenerative applications

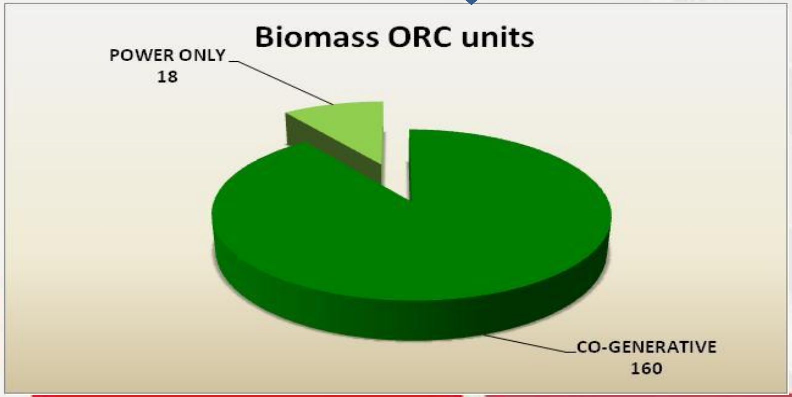
Roberto Bini – Turboden srl – Brescia – I
Fabio Viscuso – Turboden srl – Brescia -I

ORC UE market above 300 kWel

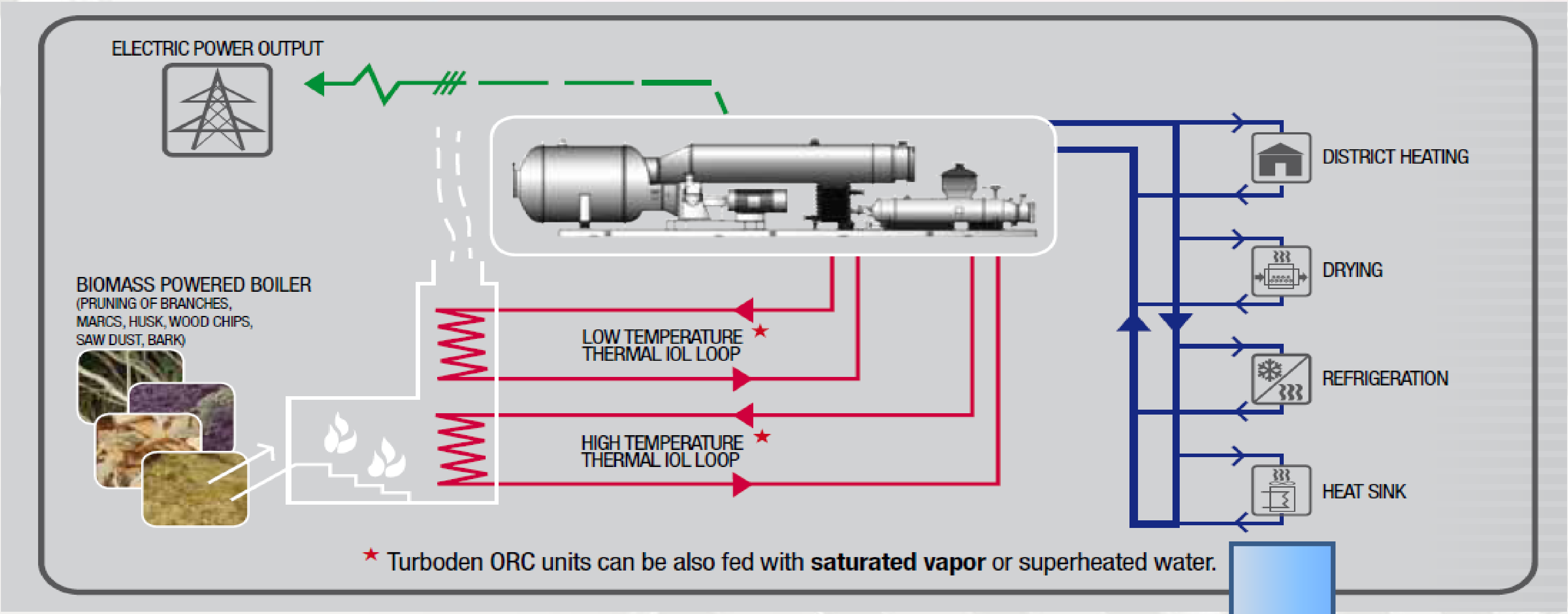
Most frequent application of Turboden ORCs in Europe are for biomass cogeneration







Biomass powered ORCs – cogenerative utilization



In cogeneration systems, water temperature at the condenser output is high enough to satisfy heat consumers, but low enough not to penalize too much ORC efficiency

typically 80-90°C (in some cases up to 120°C)

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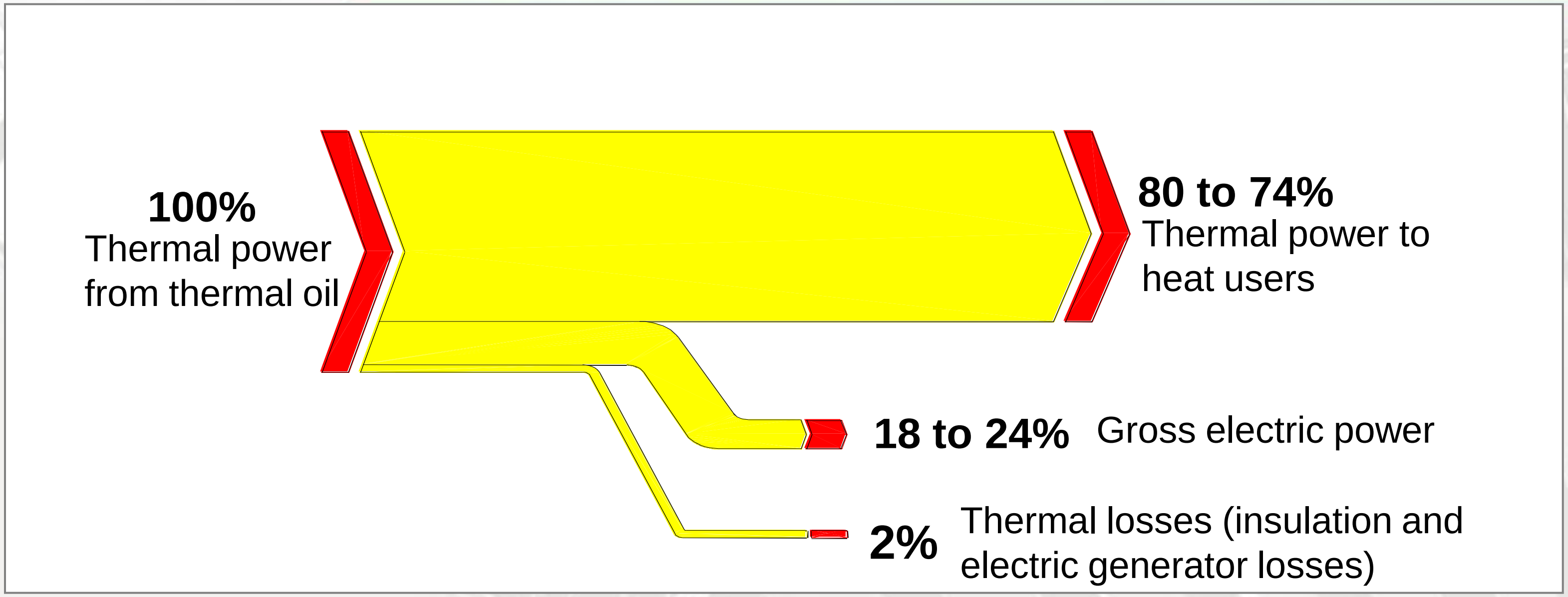
Sankey diagram for cogenerative and 'power only' biomass ORCs



- **Gross electric efficiency: up to 24%**
- **Overall energy efficiency: 98%**

To better exploit the heat source (renewable or not) cogeneration should be strongly preferred as a way to utilize most of fuel/source energy content.
Note: Net efficiency from biomass shall take into account a furnace/boiler efficiency of about 83-88%

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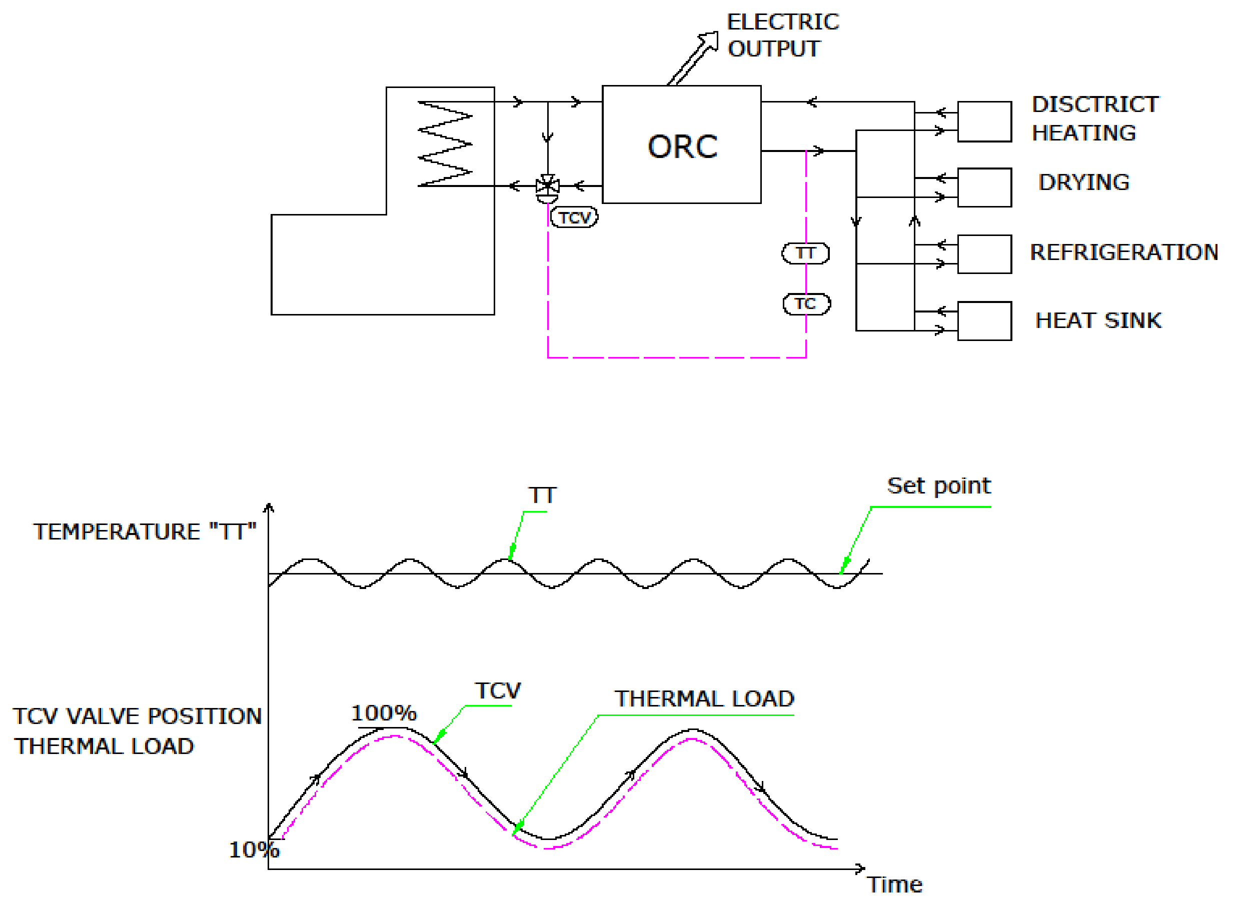
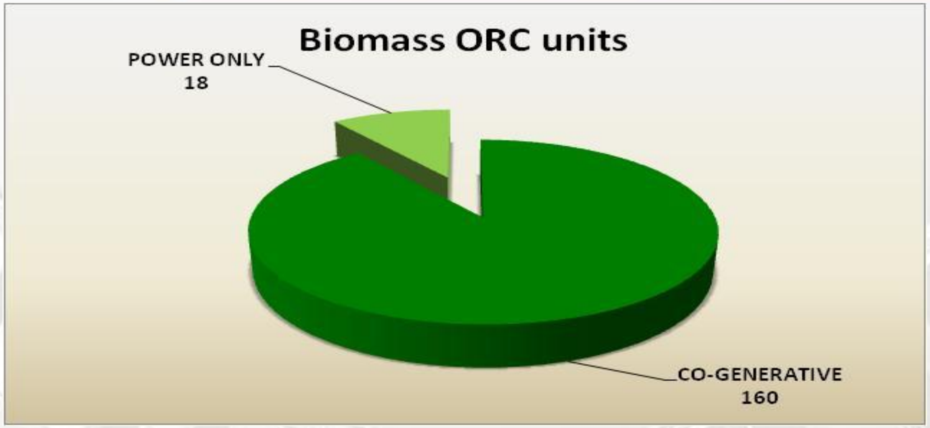
Simple control concept for a biomass powered cogenerative ORC

One of the key point of success of ORC technology is the capability to adapt to load variation easily and quickly



Cogenerative and 'power only' ORCs



Besides cogeneration applications, 'power only' ORCs
are also growing in the biomass market, for a number of reasons, like:

- low heat demand request and/or too high district heating length/cost
- availability of biomass at relatively low price
- presence of a relatively high feed-in tariff

Note: Turboden figures

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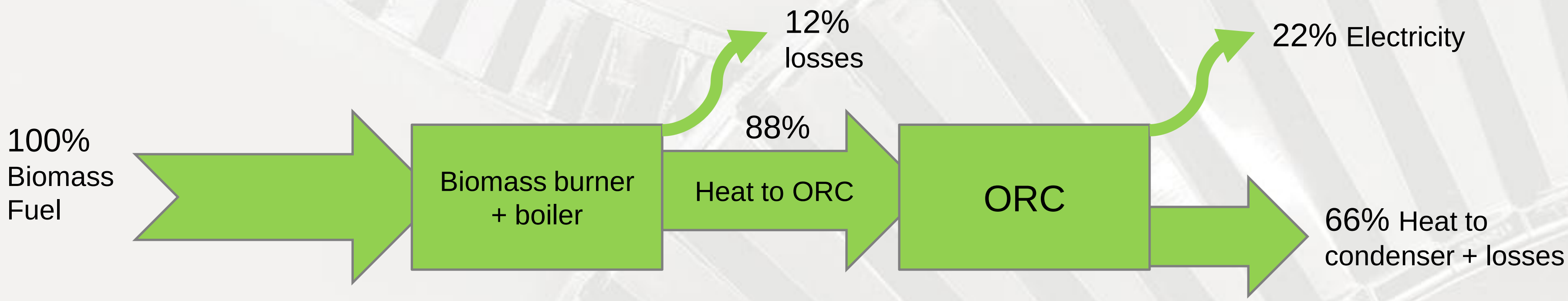
High efficiency ORCs for ‘power only’ production

The high efficiency ORCs available on the market in the range from 1-3 MW allow to obtain a net efficiency (heat-to electricity) of about 25%, i.e. about 22% from biomass-to electricity considering a boiler efficiency of 0.88

Power Only ORCs 1-3MW



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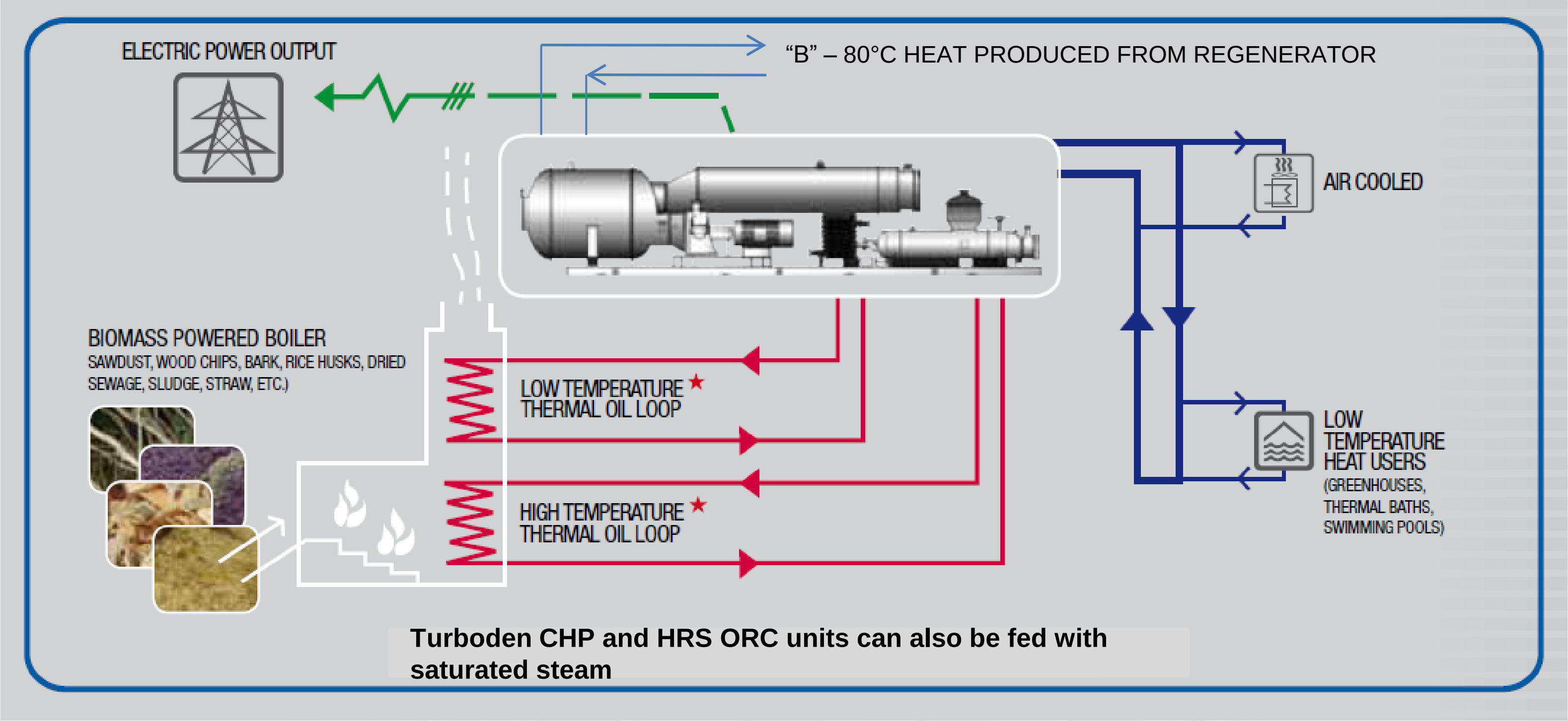
‘Power only’ ORCs

To increase power conversion efficiency water temperature is kept as low as possible using suitable (often very large!) air coolers.
Water temperature is directly related to ambient temperature (normally with 15 C average ambient temperature water is cooled down to 22 C)



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IDEALLY

A more flexible solution would be to have a unit able to move from the cogenerative to the ‘power only’ operation gradually.

This WOULD allow to cover all required operation
From:
-100 % heat to heat consumers at 80-100°C
 (ORC conversion efficiency about 18-19%)
To:
-100% heat discharged to ambient at 25-30°C
 (ORC conversion efficiency about 25%)

with all intermediate cases

BUT…..

From cogenerative to ‘power only’ with the same unit?

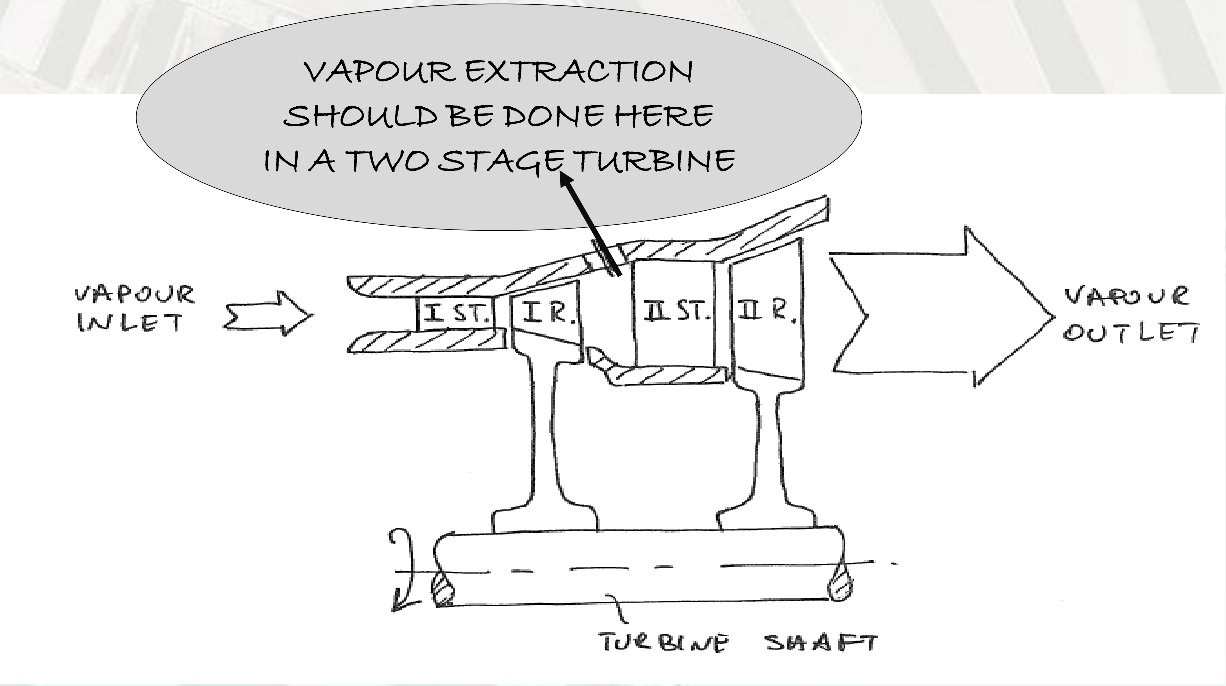
BUT…..

Turbine efficiency would be dramatically decreased by the variation in expansion ratio (and iso-entropic enthalpy drop).

For example, with a typical silicone oil fluid, condenser pressure would increase of by factor 6-7 from 35 C to 100 C condensation temperature

The typical solution (in steam turbines) to extract a fraction of vapour along the turbine expansion to produce heat at temperature level above the condenser temperature is not practically achievable in low pressure ORCs because:

1. ORCs suitable for these applications adopt working fluids featuring a very high volumetric flow rate across the turbine. Hence there is not enough space to realize the ducts to extract large quantity of vapour



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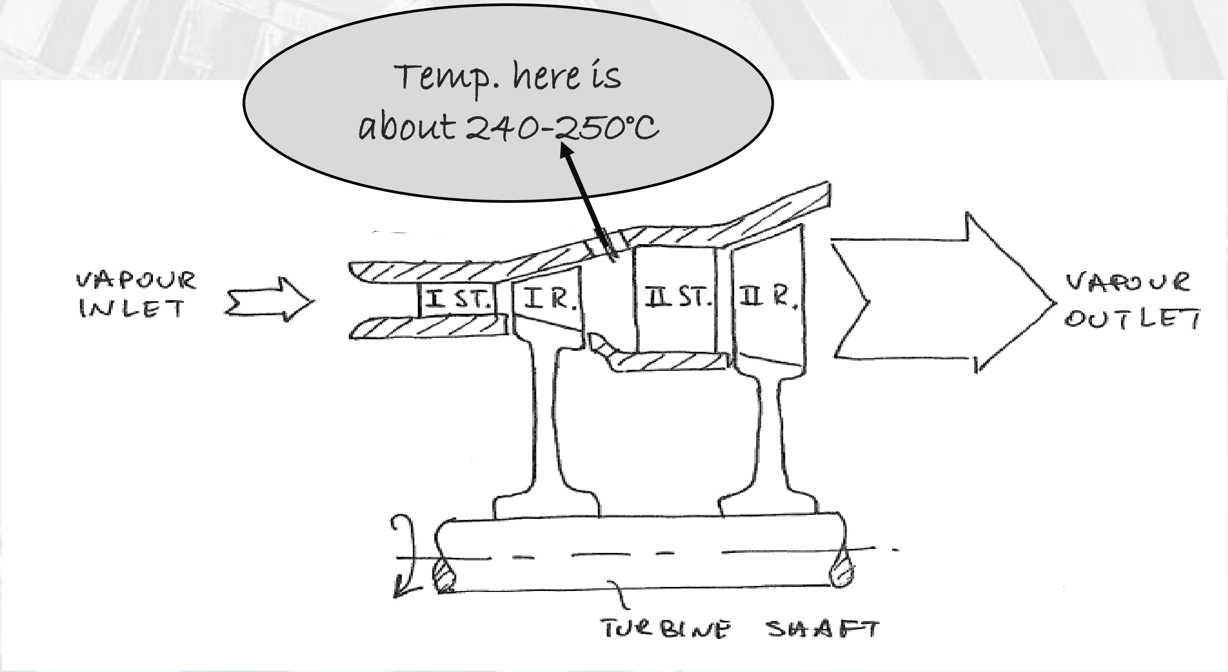
2. A typical characteristic of ORC is to feature very low delta-T during turbine expansion. This means that in a biomass application the vapour extracted during the turbine expansion would be at a very high temperature (about 240°C - 250°C). To use this temperature to produce water at 80-100°C would represent a large thermodynamic loss



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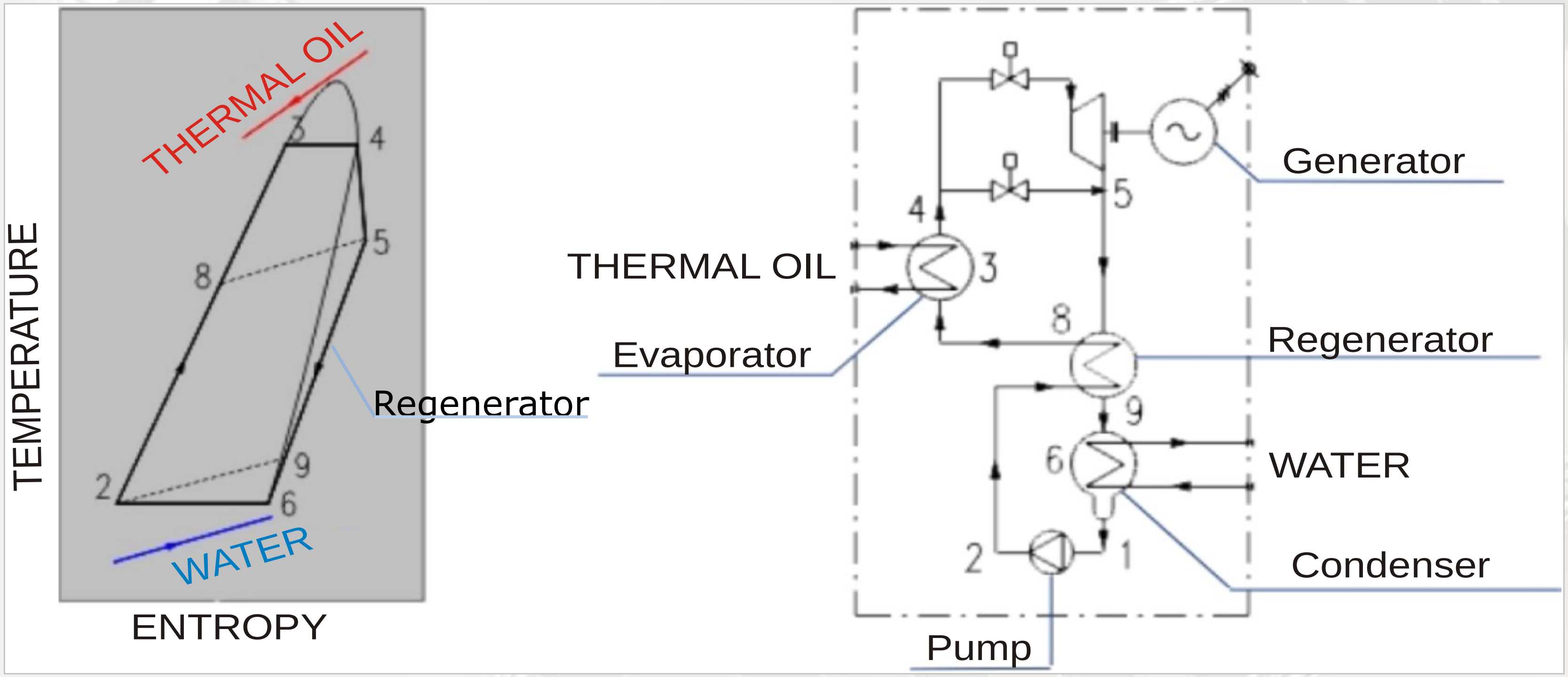
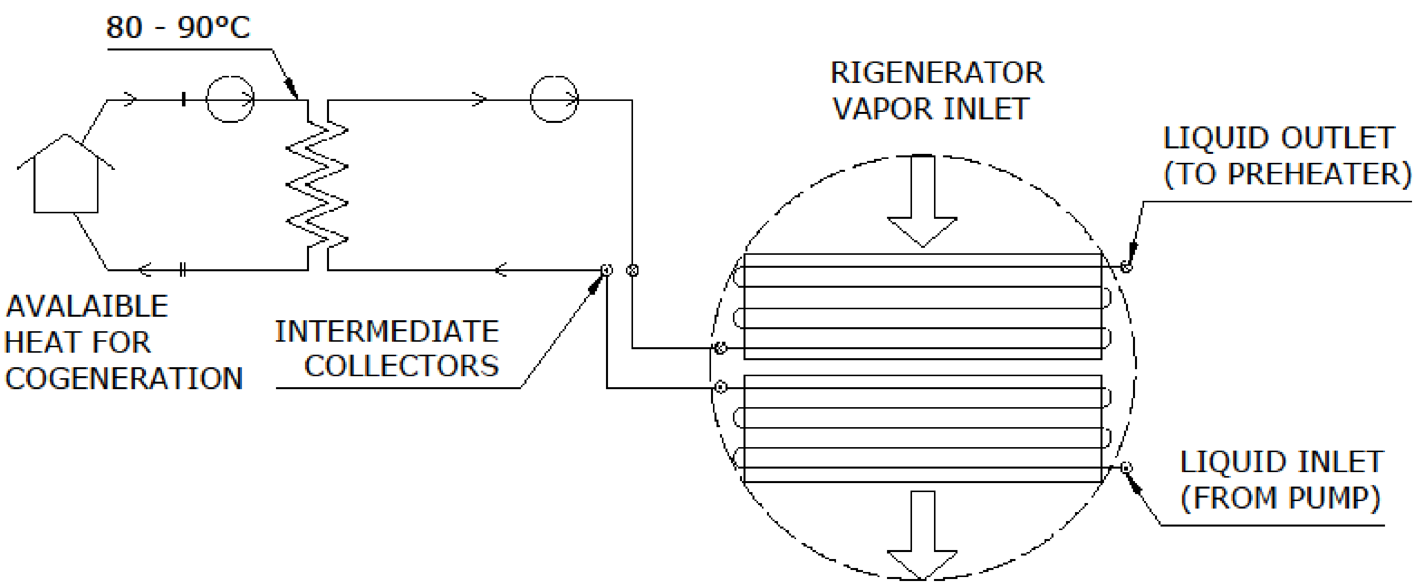
A new solution to obtain partial cogeneration from a 'power only' biomass ORC

The partial cogeneration operation is obtained in the regenerator where vapour is cooled to pre-heat the liquid after the condenser



A solution that has been recently implemented and patented by Turboden is the one indicated below:



⇒The additional circuit allows to utilize a fraction of the heat available in the regenerator to heat up a flow of water at a temperature higher than condenser temperature

Comparison between the proposed and alternative heat production solutions

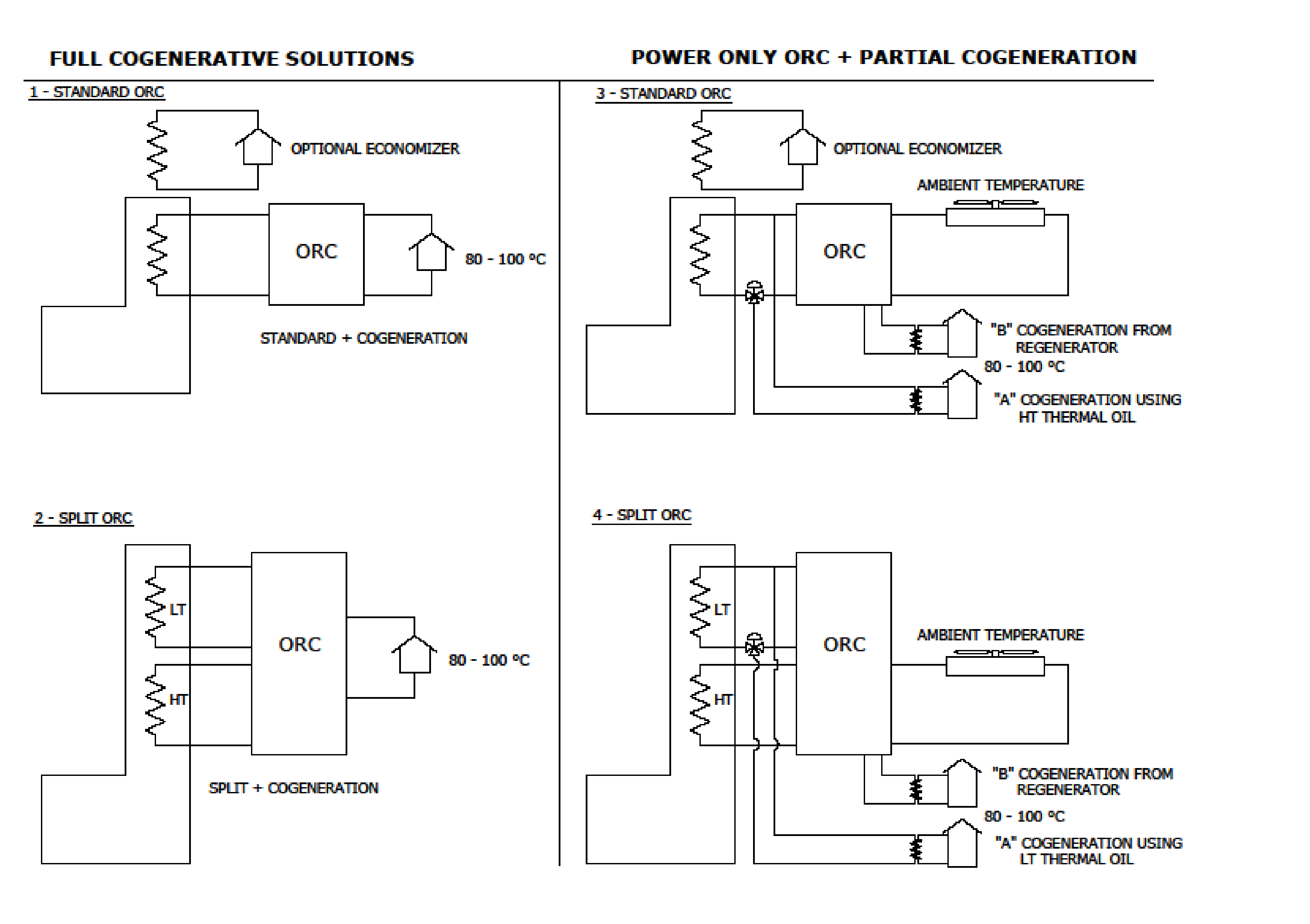
The proposed system offers best results when the heat removed for cogeneration purposes is a small fraction of the condenser heat (0 to 20%)

Alternatively, the required high temperature water flow could be obtained with the non-cogenerative solutions reported in the next slide, i.e.:

-using a water economizer if the split system is not present (cases 1 and 3). This would normally allows to produce about 10-15% additional thermal power (being 100% the power discharged at the ORC condenser)

-using a fraction of the thermal oil feeding the ORC, hence reducing the ORC electric output (from the HT thermal oil loop, case 3_A, or from the LT thermal oil loop, case 4_A). Of course the use of HT oil to obtain low temperature heat is the less efficient (ORC thermal input power is decreased and electric power also, accordingly)

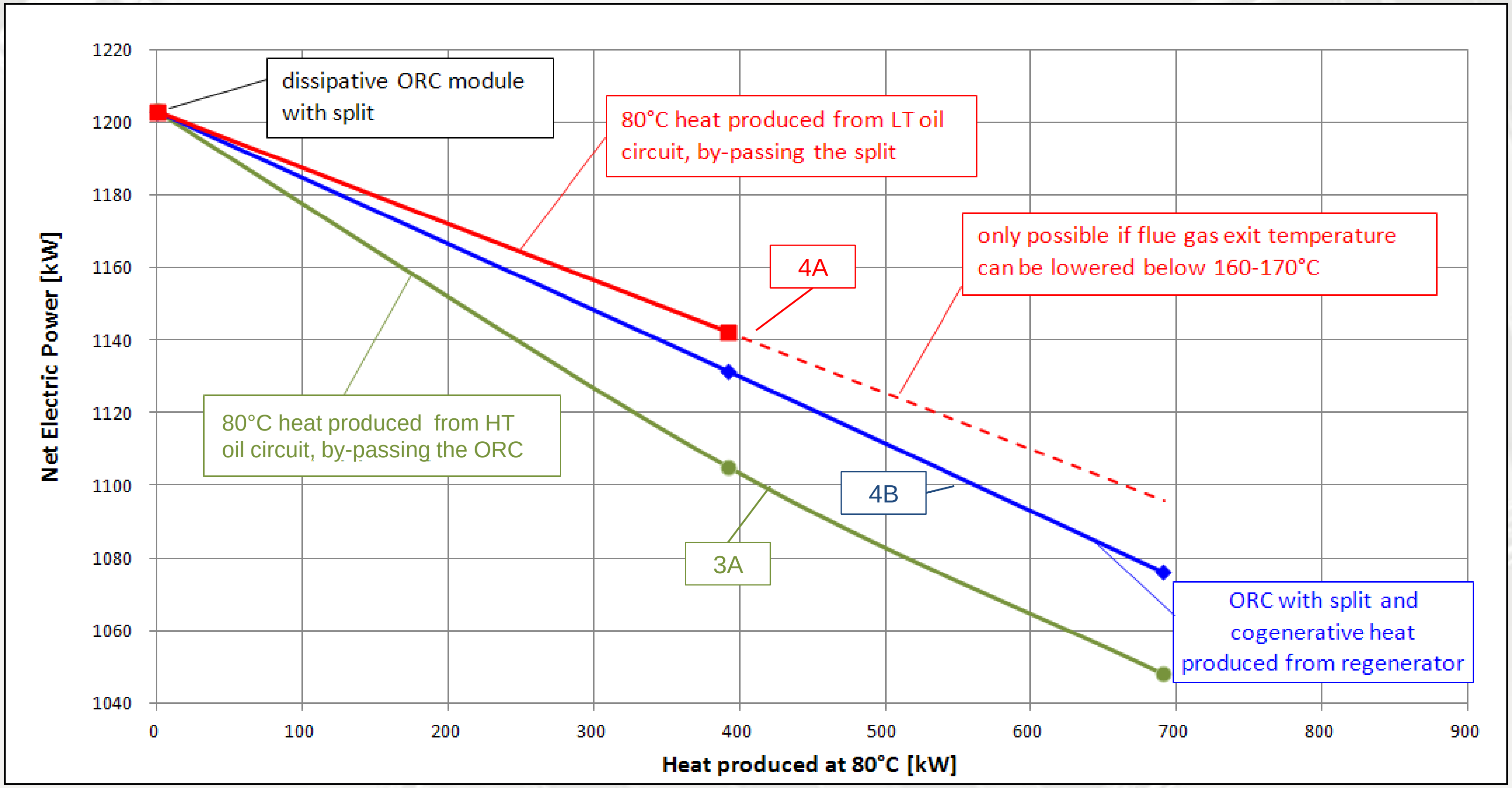
Different schemes for production of 80-100 C heat



Note: the 'house' symbol represents the heat consumers at 80-100°C

A new solution to obtain partial cogeneration from a 'power only' biomass ORC

Comparison between the two solutions "A" and "B" assuming fixed biomass consumption.



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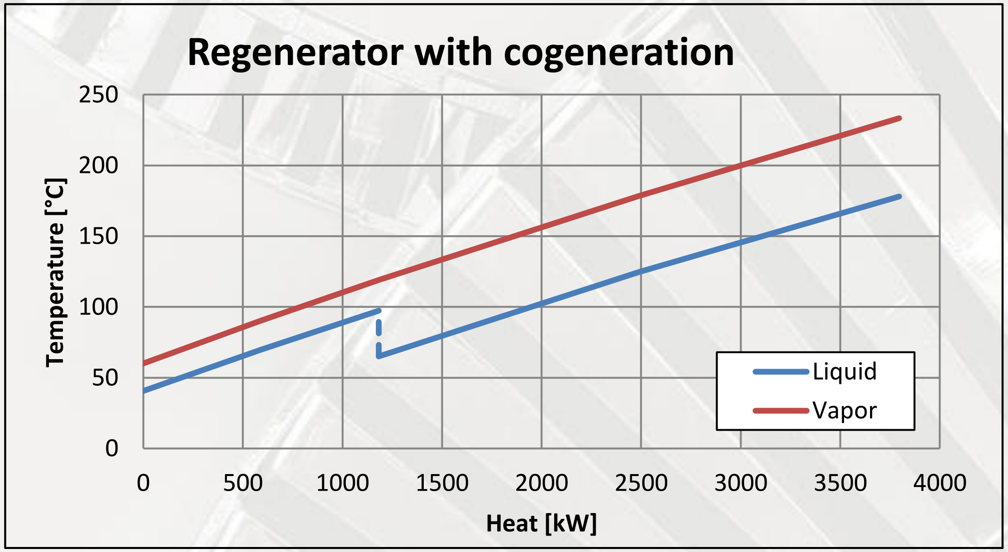
A new solution to obtain partial cogeneration from a ‘power only’ biomass ORC

Heat –temperature diagram of the regenerator with cogeneration



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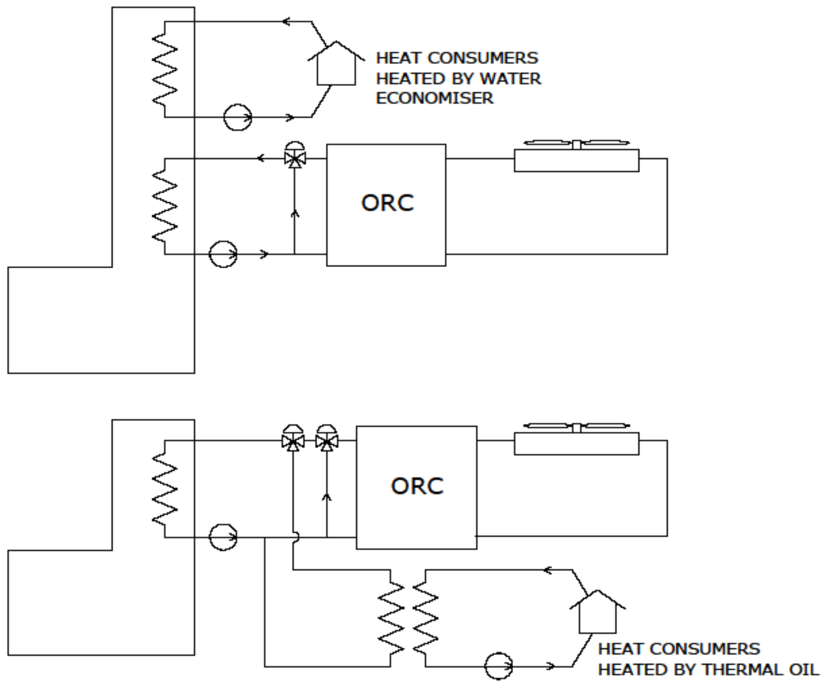
Conclusions

1. High efficiency ORCs for 'power only' production in the range of 1-3 MW are available on market and already in operation in Europe.

2. A net efficiency (heat-to electricity) of about 25% is achieved, about 22% (biomass-to electricity) with a boiler efficiency of 0.88

3. A solution to partly utilize this ORC for cogeneration is also available, the advantages are significant if the alternative solution would be to obtain this heat from the HT thermal oil loop, it decreases if the heat is taken from the LT (split) oil loop

4. In any case, the proposed solution is inherently 'cogenerative', as the heat downstream is obtained thanks to the production of electric power



Roberto Bini – Turboden srl – Brescia – I
Fabio Viscuso – Turboden srl – Brescia -I

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Turboden s.r.l.
Via Cernaia, 10 - 25124 Brescia, Italia
tel +390303552001 - fax +390303552011
info@turboden.it www.turboden.it

C.F./P.I. IT02582620981
capitale sociale €1.800.000 i.v.
R.I.: C.C.I.A.A. di Brescia 02582620981
REA 461817