New Technologies Workshop
Cogen Europe
8 May 2007, Brussels

ORC – Different Applications

Ing Bruno Vanslambrouck,
Laboratory of Industrial Fysics and Applied Mechanics
Hogeschool West-Vlaanderen, dept PIH

Hogeschool West-Vlaanderen:
Founded in 1995 as a fusion of the 5 «non catholic» higher education schools in the province of West-Flanders, also the earlier «Provinciale Industriële Hogeschool (PIH)».
Member of the Associaton University of Ghent

Dept PIH: about 1700 students in various technological professional and academic bachelor en master programs.

Masters (industrial engineer):
- Electromechanics and electrotechnics
- Electronics
- Industrial Design
- Chemistry en biochemistry
- Environmental sciences

Main energy domain activities:

- Research programs, mostly financed by the Flemisch Government, on electrical grid losses, electromechanical drives, power quality, micro CHP, efficient lighting, anareobic digestation of organic waste streams, biogas, energy crops…
- Founding member of « Cogen Vlaanderen vzw »
- Founder and hosting of « Biogas-E vzw »
- Member of the Dutch « Projectgroep biomassa & wkk »

Full didactical CHP unit
288 kWe/478 kWth
20,000 h from 1995

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Departement PIH
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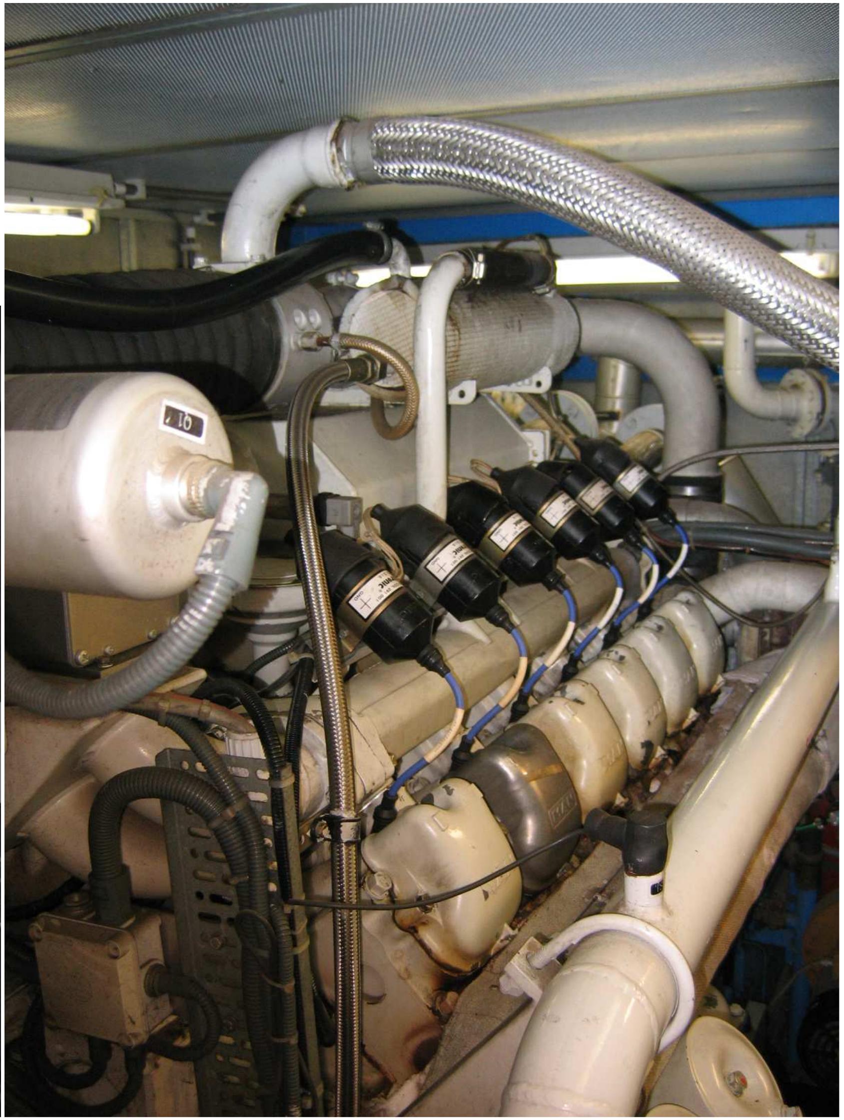
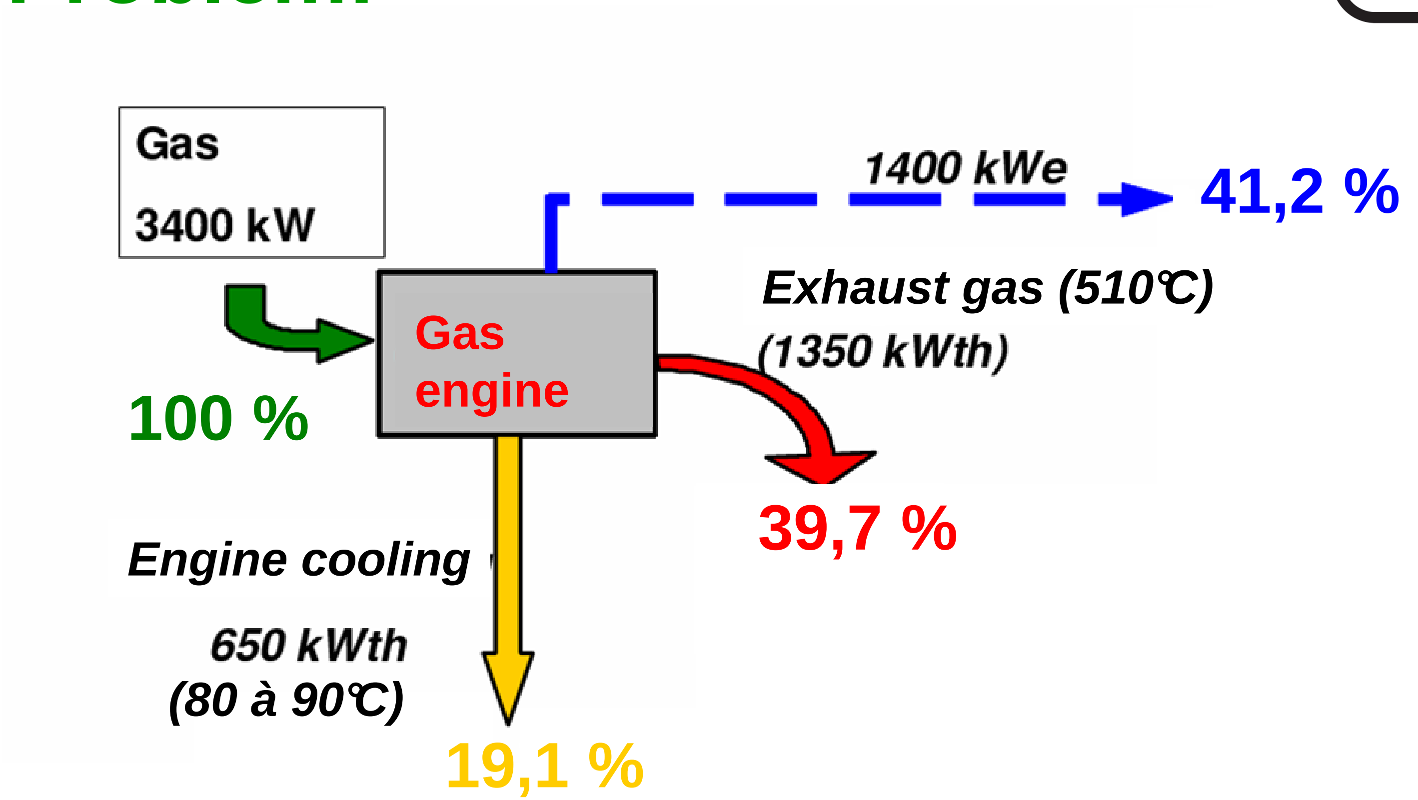
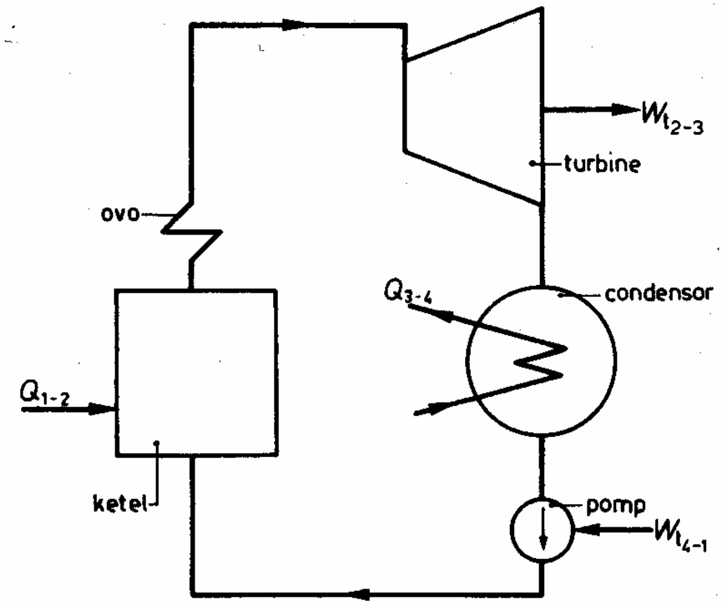


Problem:

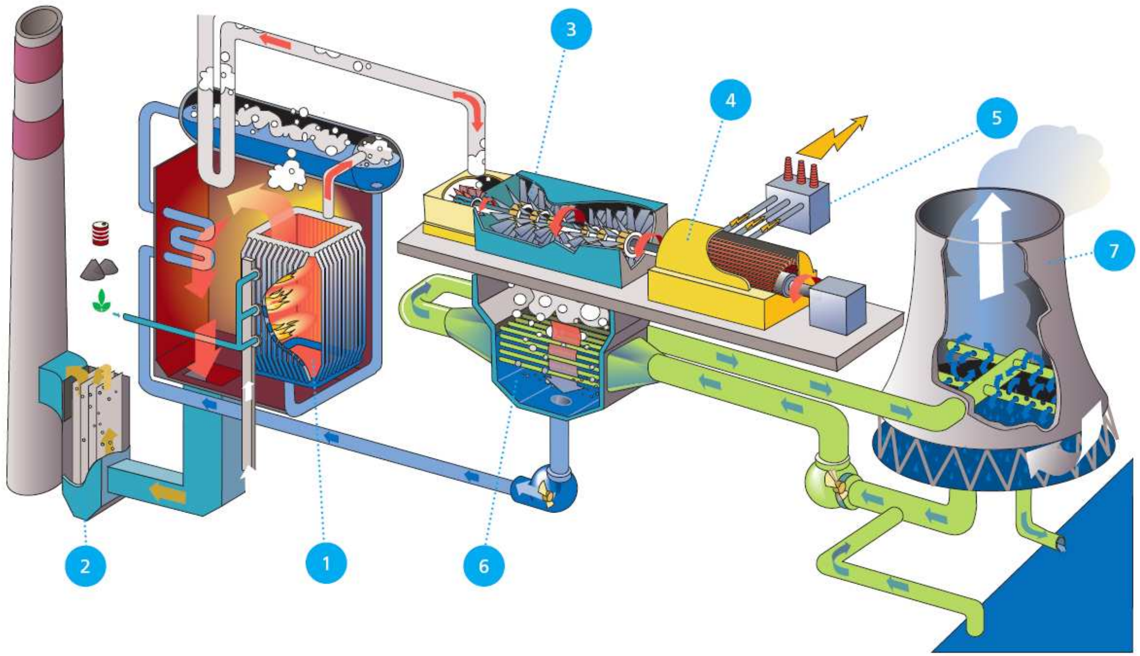


Gas
3400 kW
100 %
Gas engine
1400 kWe
41,2 %
Exhaust gas (510℃)
(1350 kWth)
39,7 %
Engine cooling
650 kWth
(80 à 90℃)
19,1 %

The Rankine Cycle

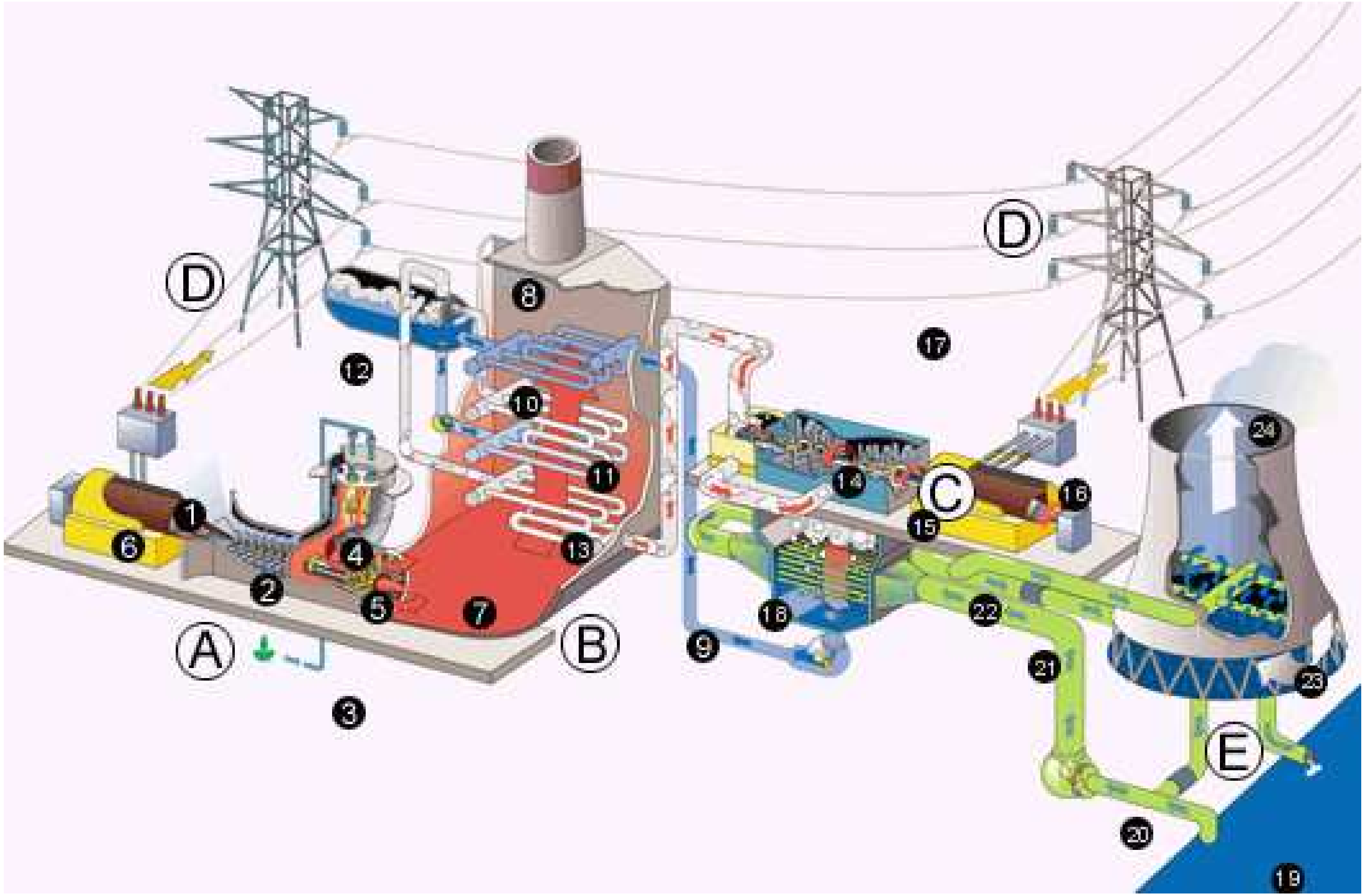


1. Boiler
2. Electrofilter
3. Steam turbine
4. generator
5. Transformer
6. Condensor
7. Cooling tower

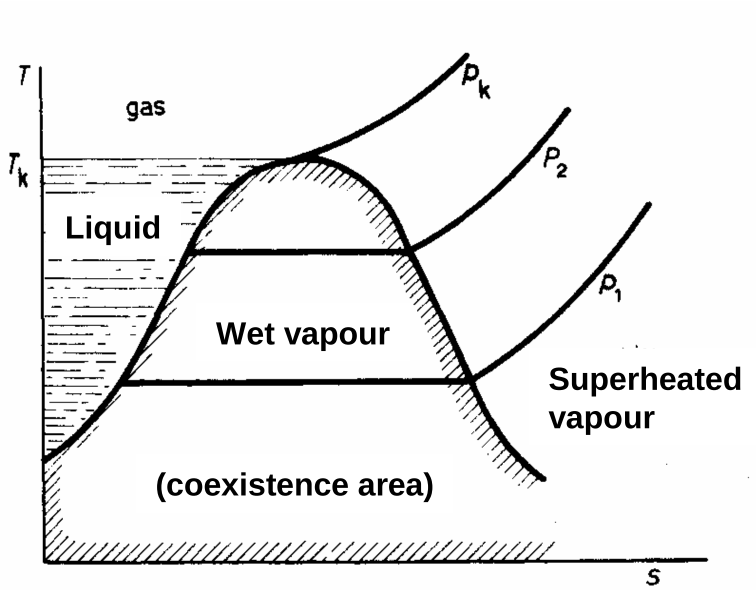


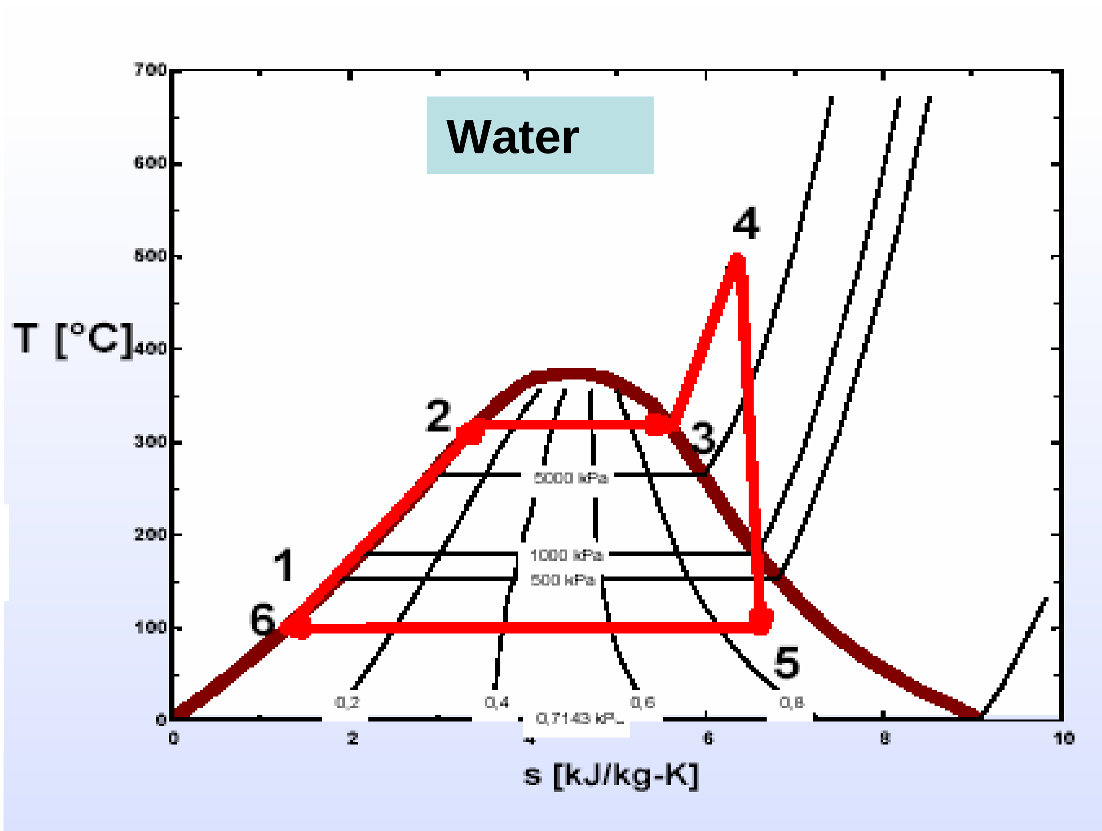
Steam turbine installation in a power station

Combined Cycle:
E-production from recovered heat from the gasturbine exhaust using a Rankine Cycle



Rankine Cycle (cont):





T-s diagram for a working fluid

Rankine cycle with superheated steam

Rankine Cyclus (cont):

Working fluid: usually water

Advantages:

- cheap, widely available
- non toxic
- high heat capacity: excellent medium for heat transport
- chemical stable: less material requirments
- low viscosity: low friction losses

Disadvantages:

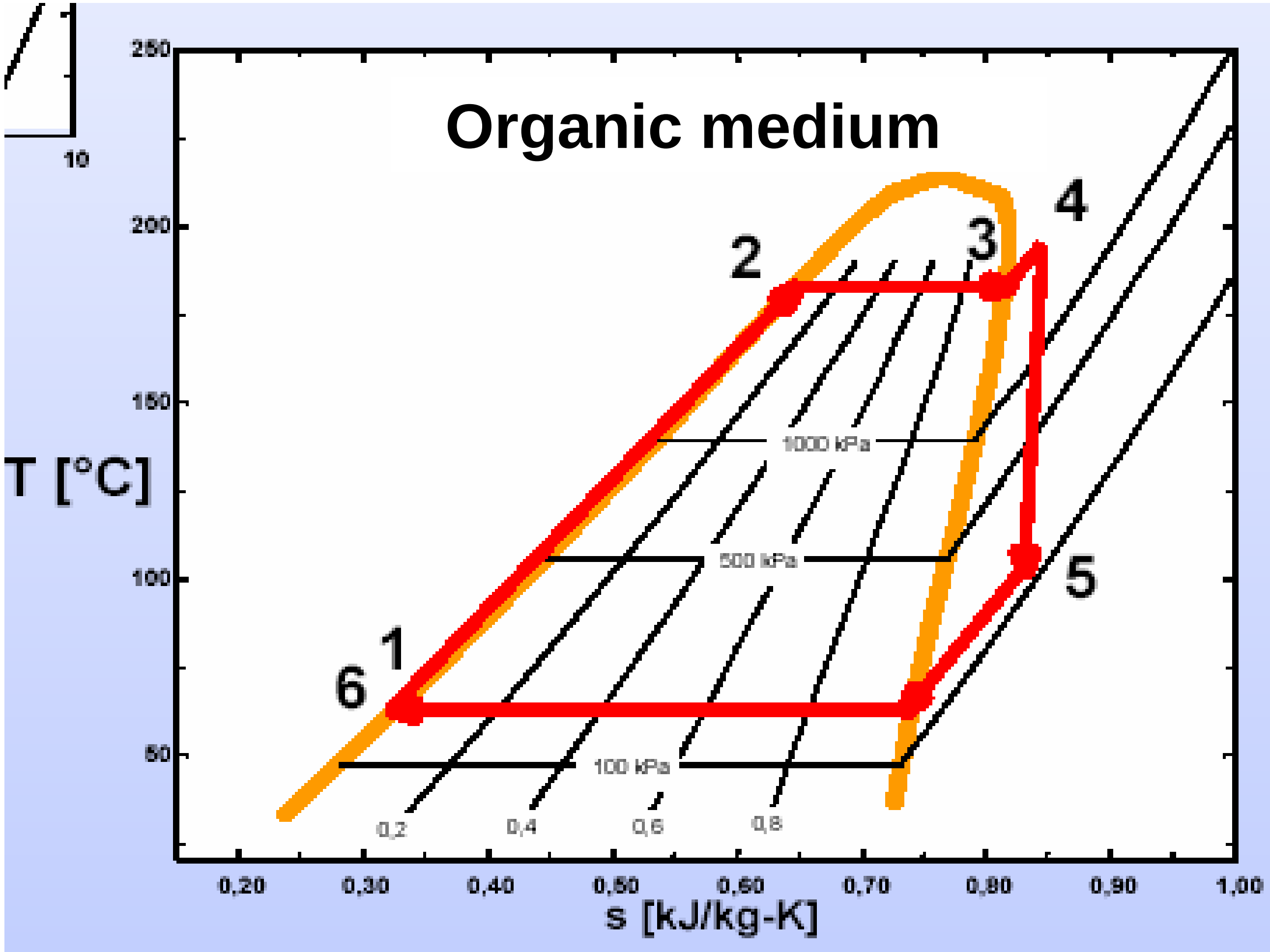
- due to low condensation t°: very low pressure, high sp ecific volume, big installations needed (turbine, condensor…)
- high pressure drop to become a high enthalpy drop: expensive multi stage turbine needed
- expansion has to start in the superheated area to avoid too high moisture content after expansion: need of a high t°- heat source but very partically use.
- because of this: effeciency loss and limited suitability to waste heat recovery

Why ORC ?

Disavantages water probably to correct using other working fluids, mostly of organic origin:

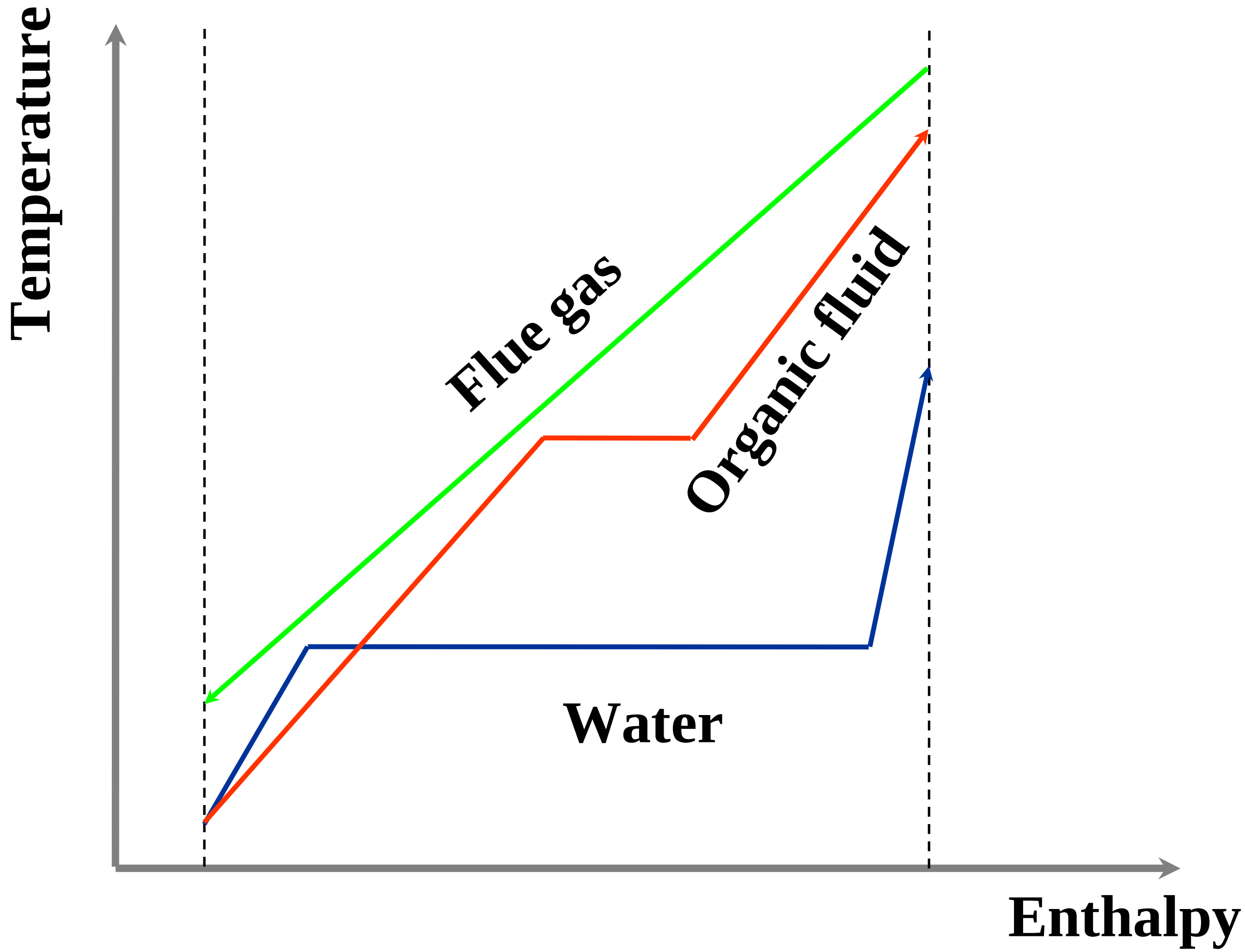
Organic Rankine Cycle (ORC)

Used are:
Toluene, butane, pentane, ammonia, refrigeration fluids…



Organic Rankine Cycle in the T-s diagram

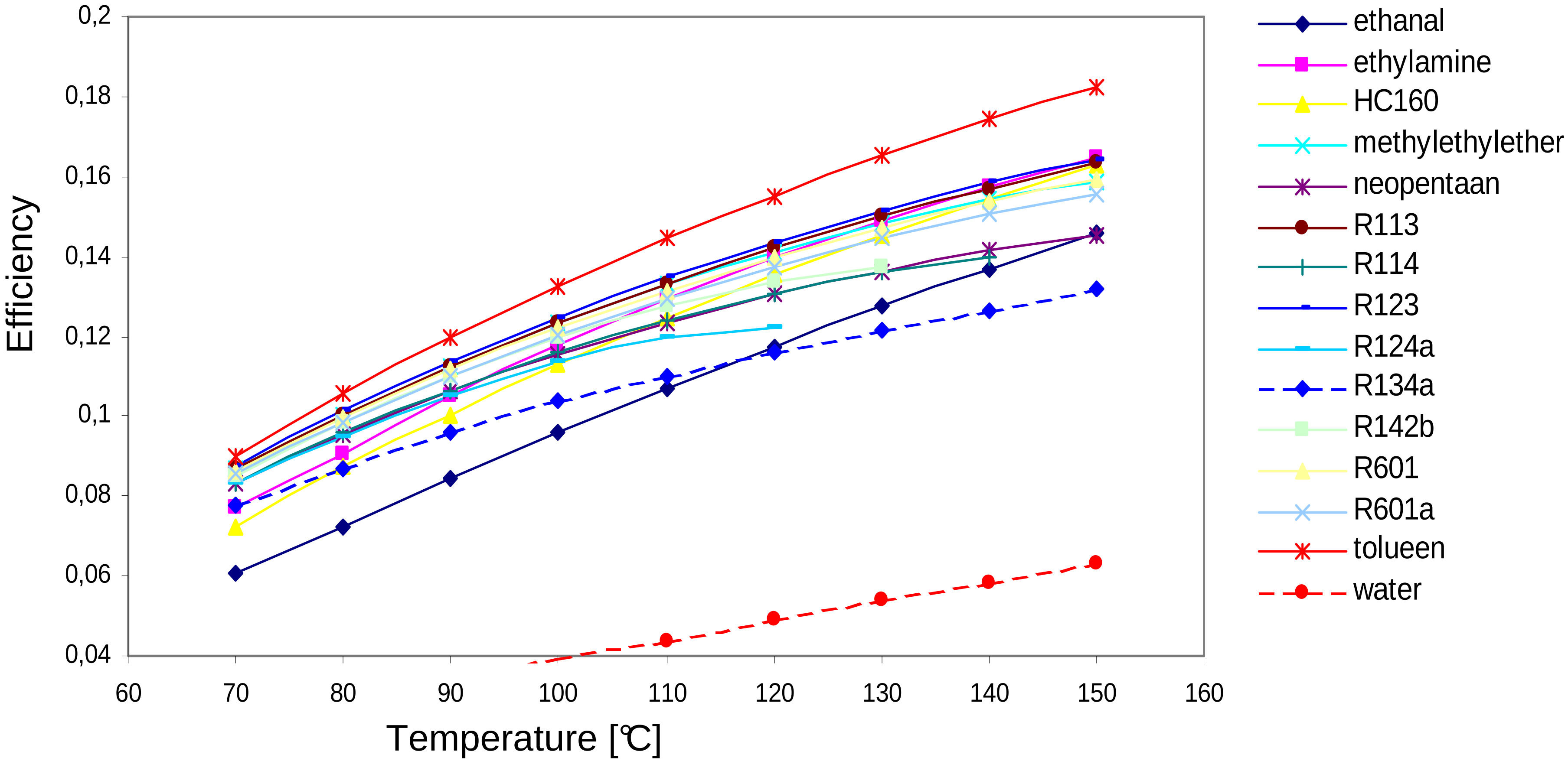
ORC: Organic Fluid vs Water



ORC: Fluid selection

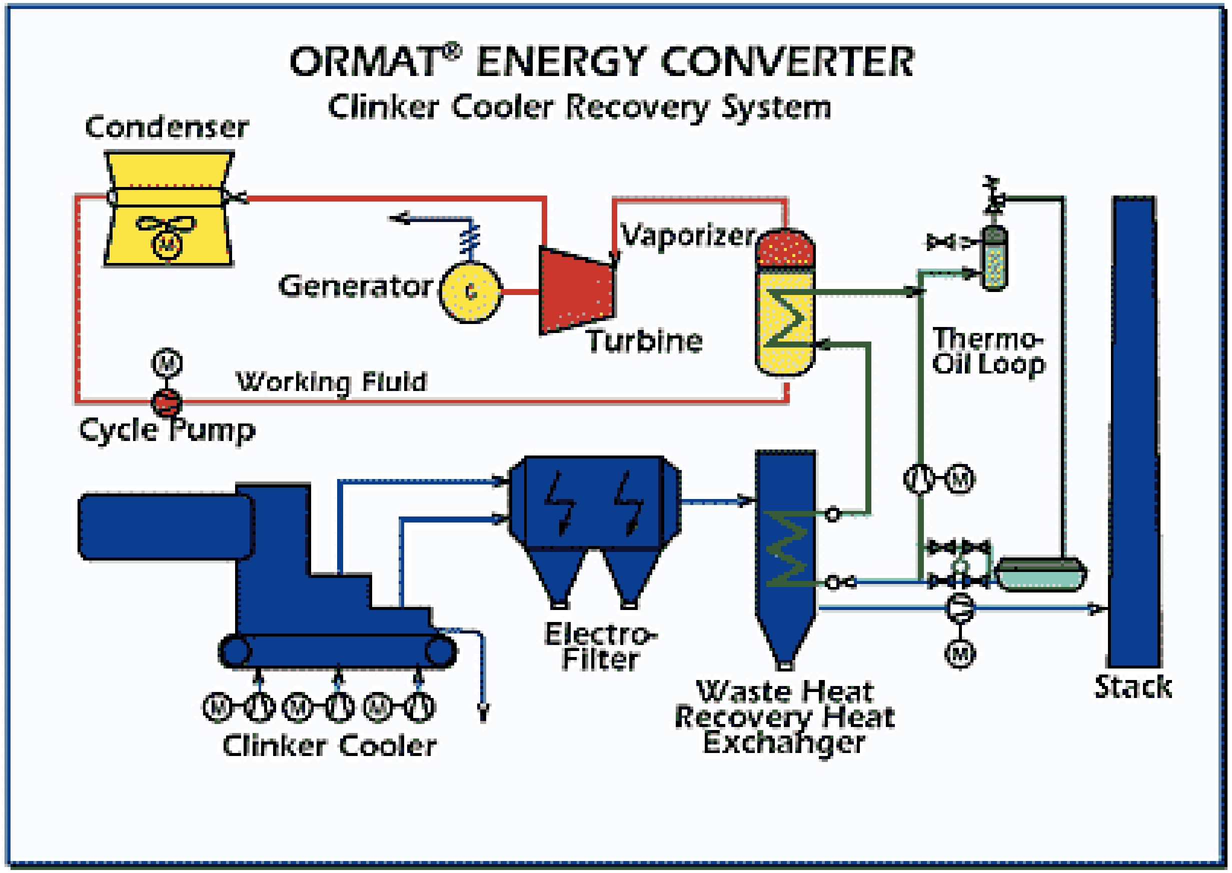
AspenTech simulations (final work PIH 2004)

Cycle efficiency versus temperature @ 75% turbine isentropic efficiency



Applications:

1. Industrial waste heat recovery



Status: commercially available

Applications (cont):

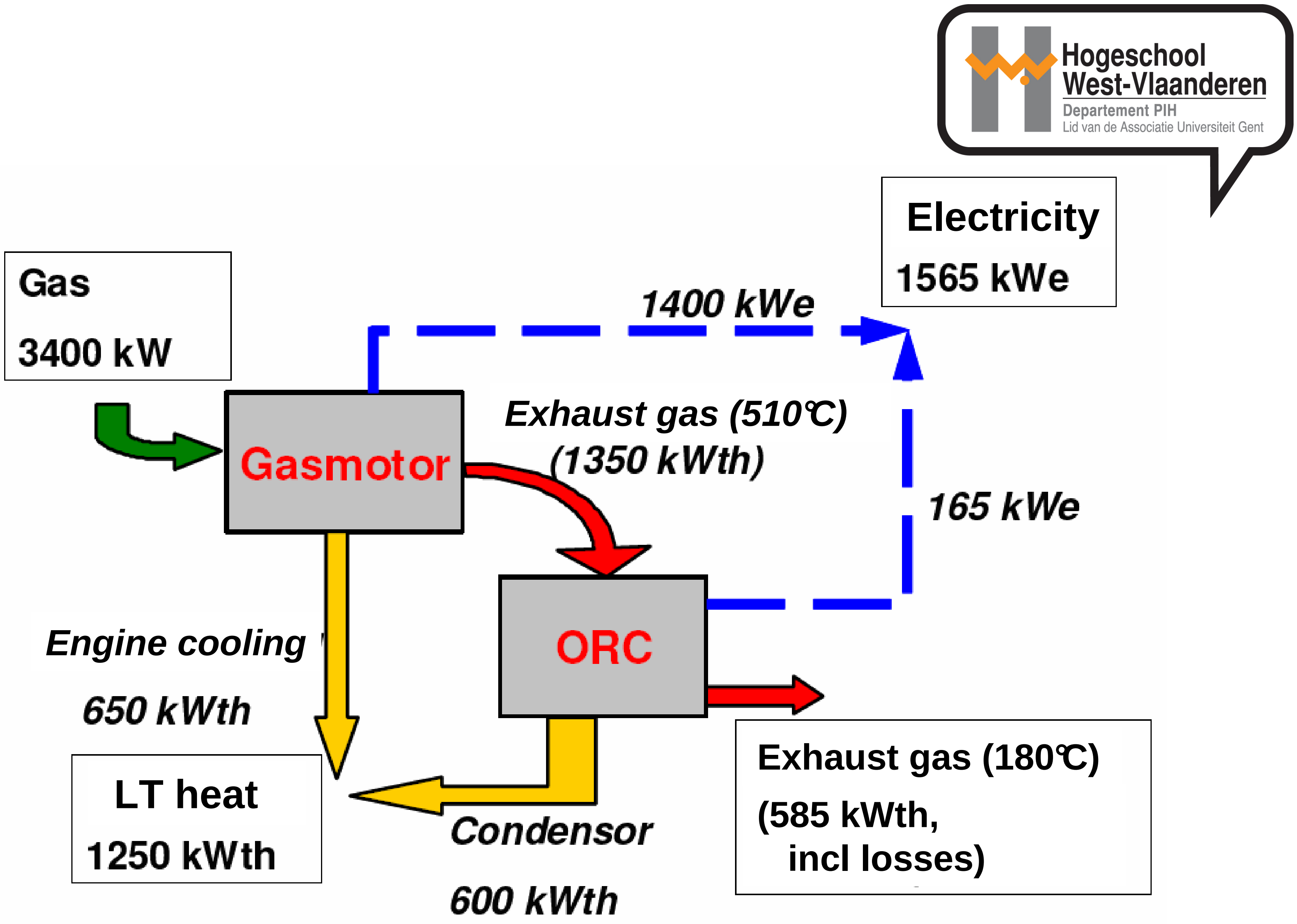
2. Exhaust heat recovery on stationary combustion engines:

- Economical attractive on engines using renewable fuels (sewage gas, biogas, vegatable oils…) because of governmental support (Green Certificates). Simple PBT of 3 years calculated (2 independant sources)
- Flexible power to heat ratio feasable on cogeneration units
- Possibility to upgrade older cogeneration units with respect to CHP certificates by adding a ORC (increase of relative primary energy savings with 5 %)

About 12% of exhaust heat convertable to electricity, rest partially suited for heating purposes (ORC thermal efficiency of 21.5%).

Ex. Gas engine 1,4 MW, η = 41 %
12 % exhaust heat = 0,12 x 1350 = 165 kW
η increases to 46 % !

Status: commercially available but very few references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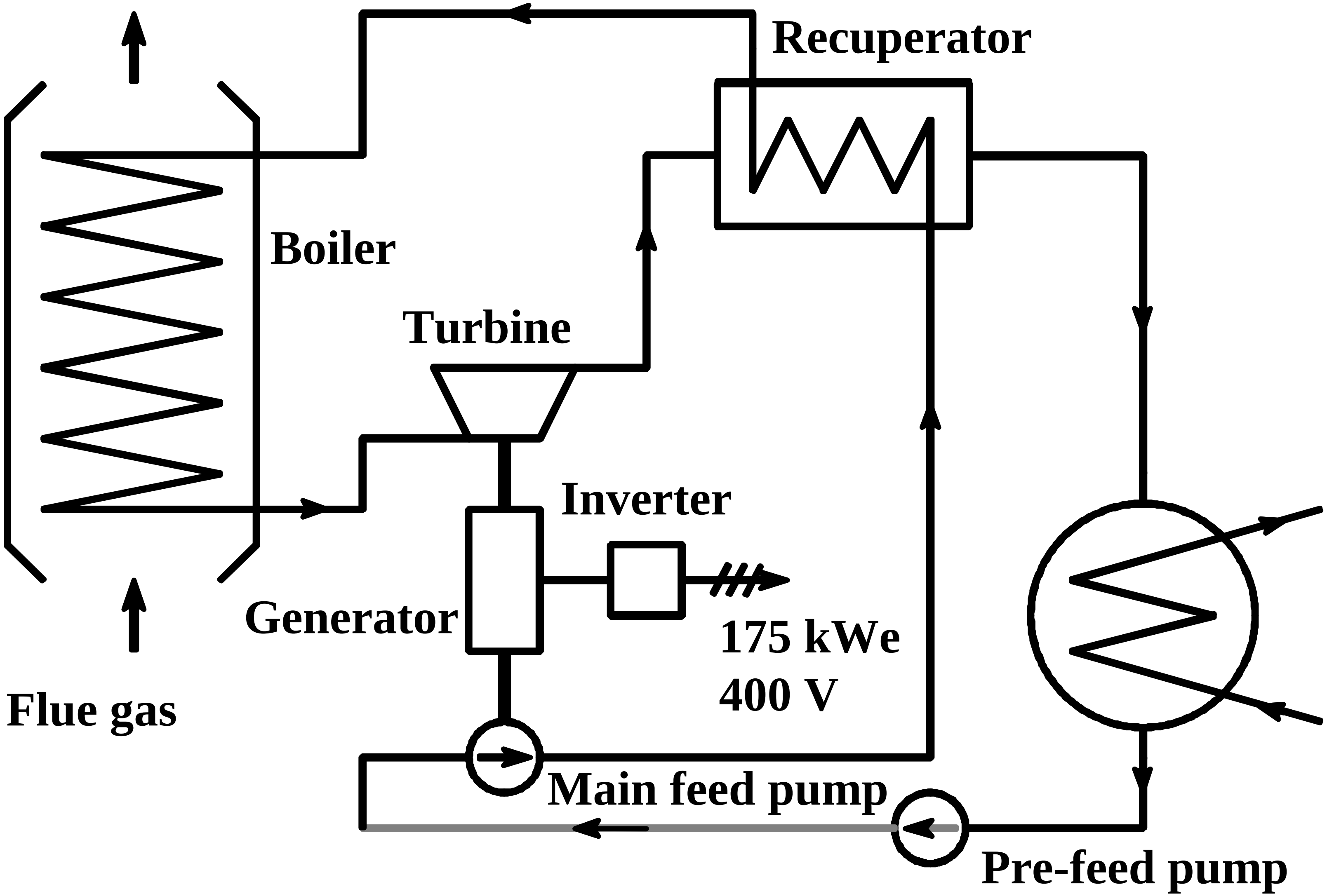
Electricity
1565 kWe
1400 kWe
Gas
3400 kW
Gasmotor
Exhaust gas (510°C)
(1350 kWth)
165 kWe
ORC
Engine cooling
650 kWth
LT heat
1250 kWth
Condensor
600 kWth
Exhaust gas (180°C)
(585 kWth,
incl losses)

Ex: 175 kW ORC by Tri-O-Gen (Nl)



ORC in Danville, IL using exhaust heat from 3 Jenbacher engines

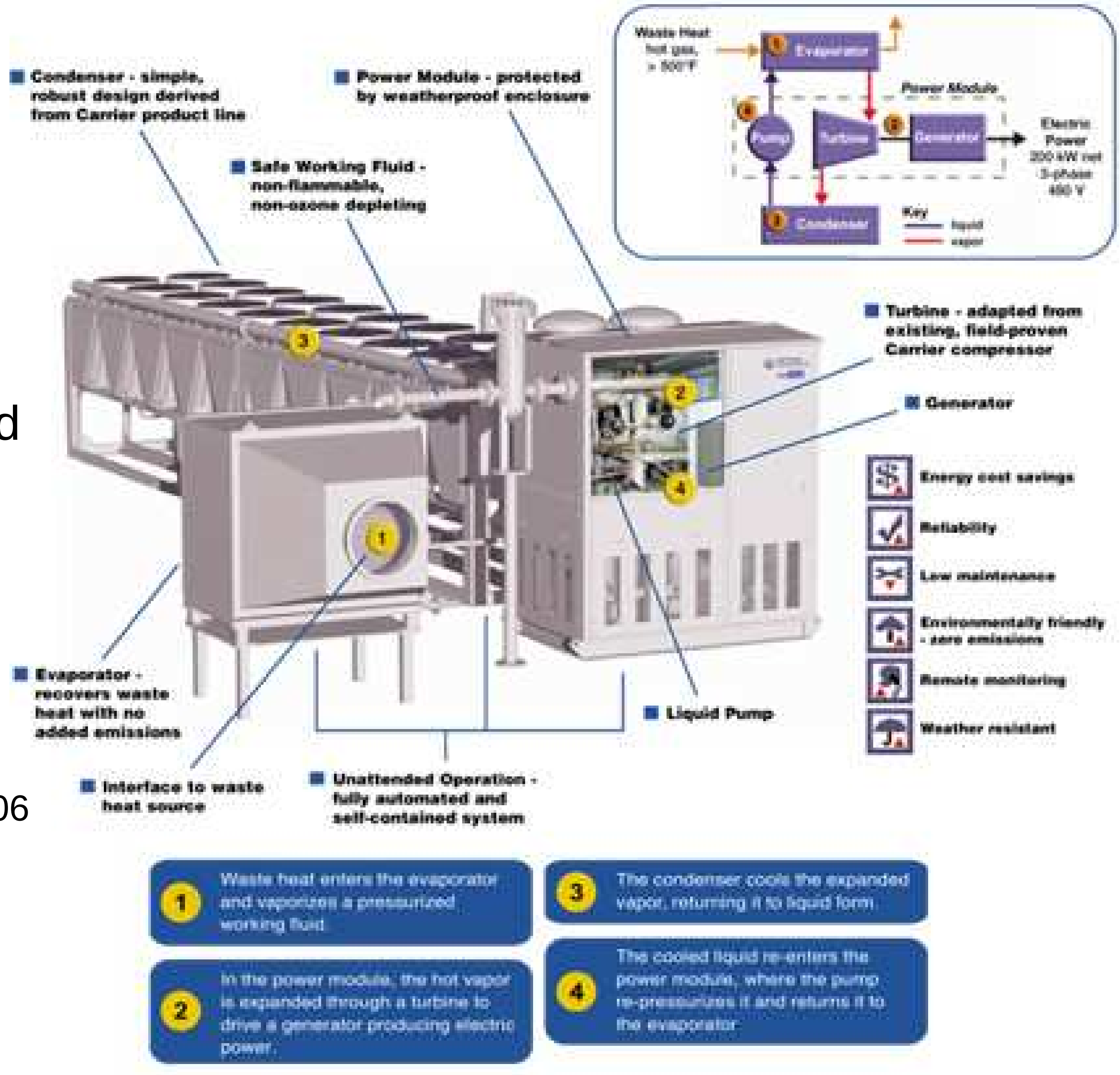
UTC Power (USA) (Carrier)

ORC, derived from airco equipment

200 kWe

First tests: 2004

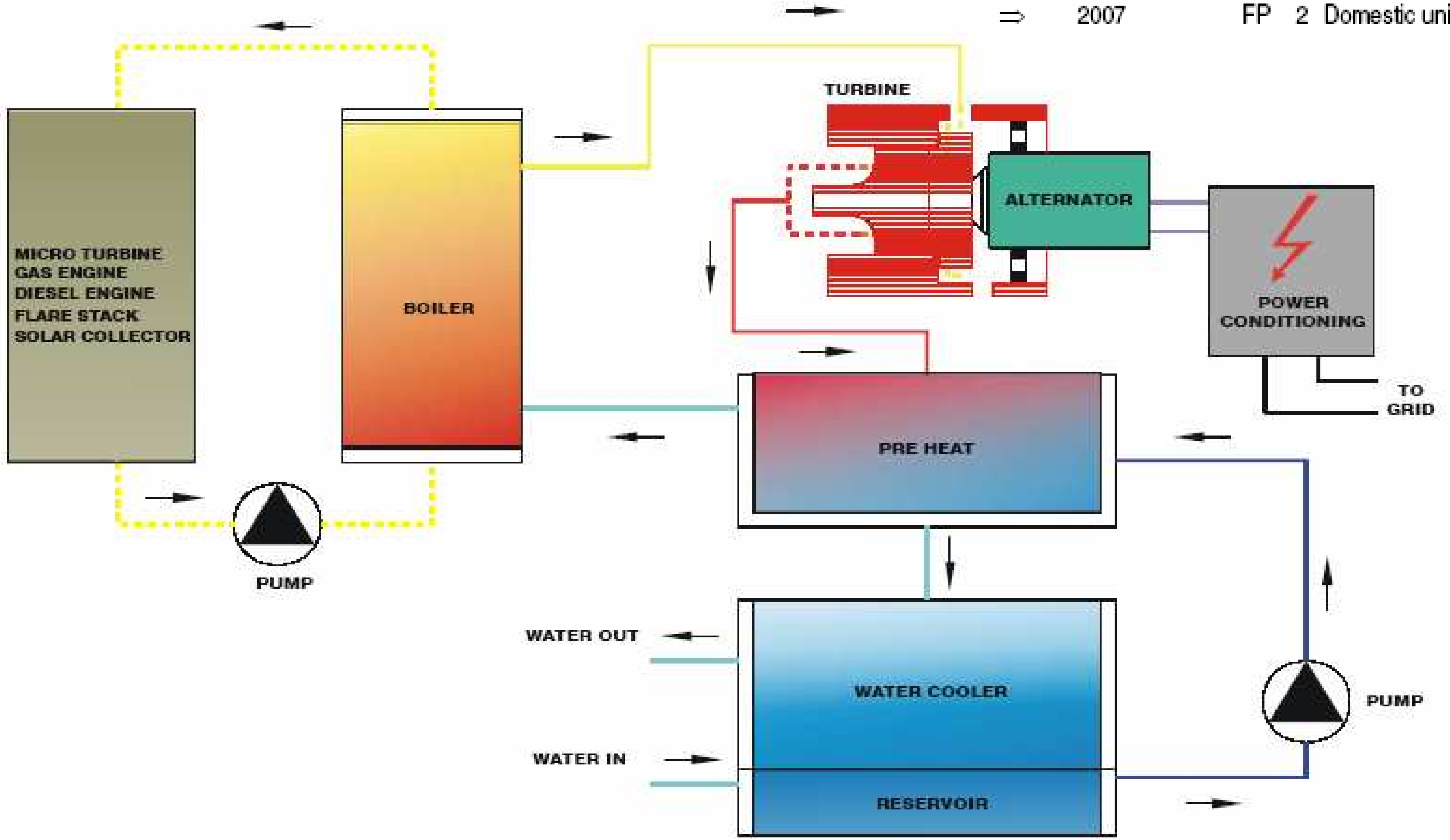
Marked intro: 2006



FUTURE PRODUCT ROLL OUT PROGRAMME

⇒	2004	FP 6
⇒	2005	FP120
⇒		FP 10
⇒	2006	FP 25
⇒		FP 60
⇒		FP250
⇒	2007	FP 2 Domestic unit trials

Freepower Technology : The Practice



Applications (cont):

3. Exhaust heat recovery on transportation vehicles

- powering the airco-compressor ?
- powering refrigeration group on cooling transport (hybrid with oil burner on standstill) instead the nowadays small diesel-compressor group ?
- charge current (ideal on hybrid cars)
- mechanical power coupling to the crankshaft
- …
- status: under development or test by some manufacters

Turbosteamer project BMW: extra 10 kW on 1,8l gasoline engine by heat recovery on cooling water and exhaust (steam and ethanolcycle)

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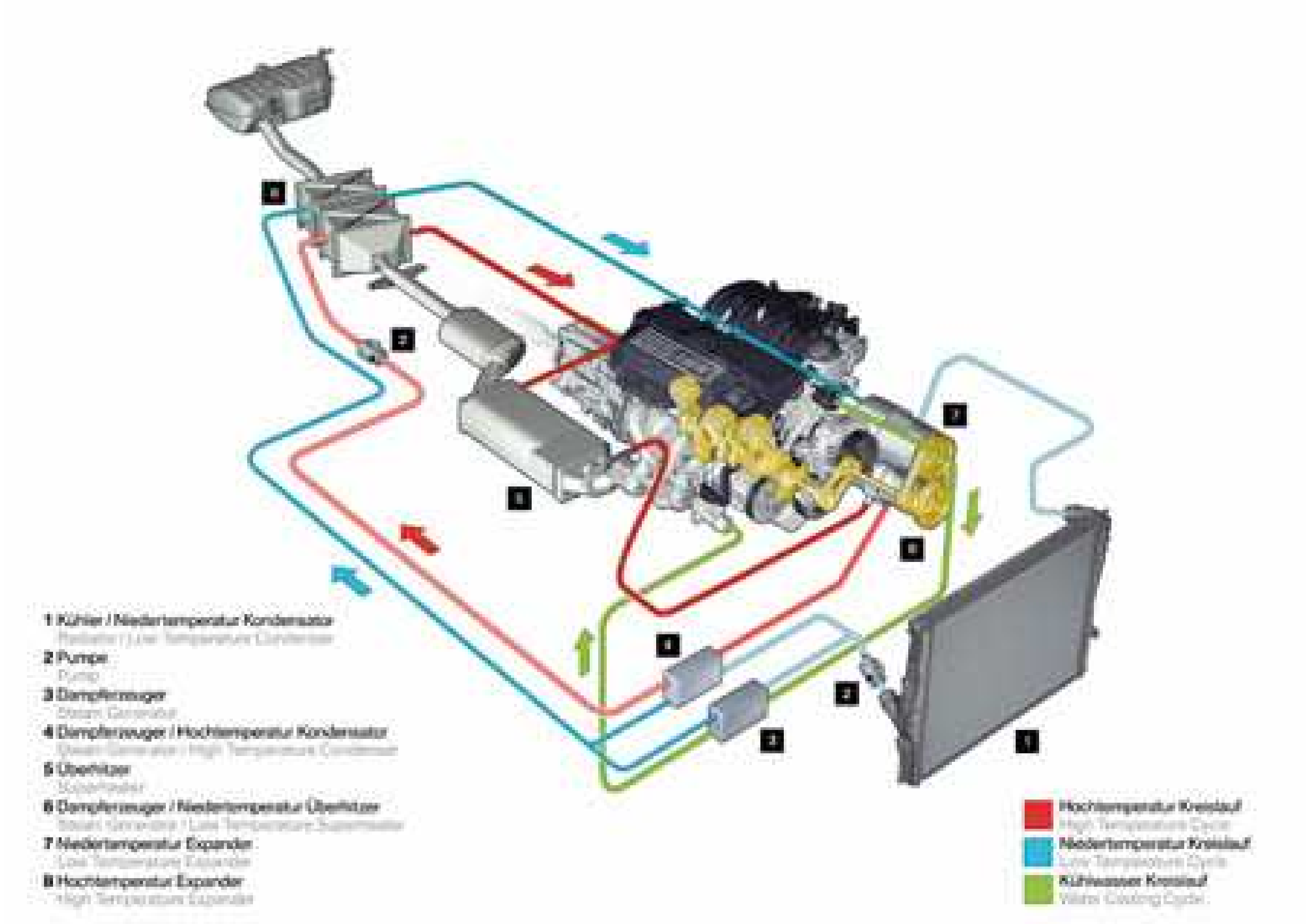
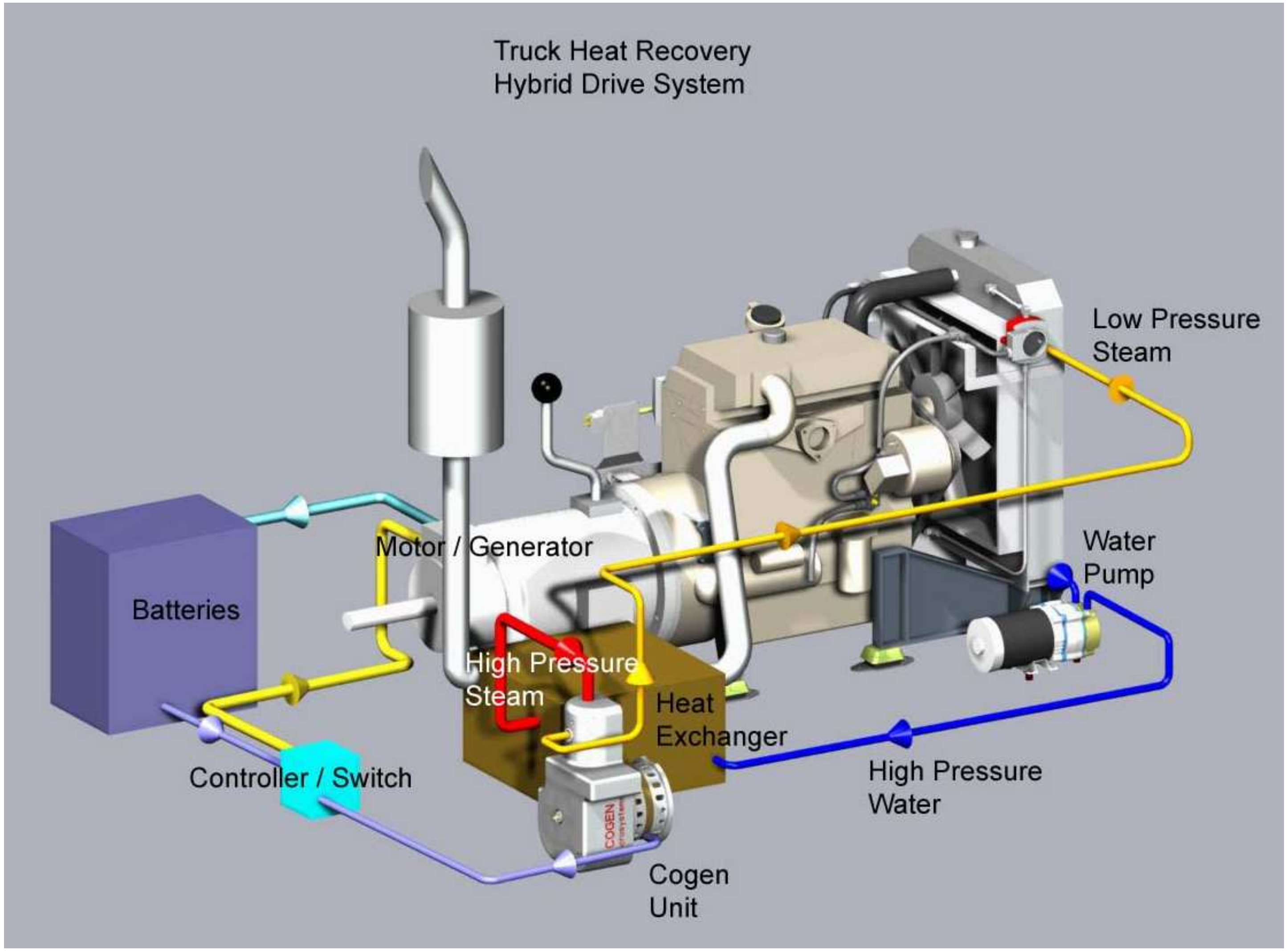


Cogen Microsystems, University of Adelaide
Commerce & Research Precinct
35-37 Stirling Street
THEBARTON, SA 5031 AUSTRALIA



Applications (cont):

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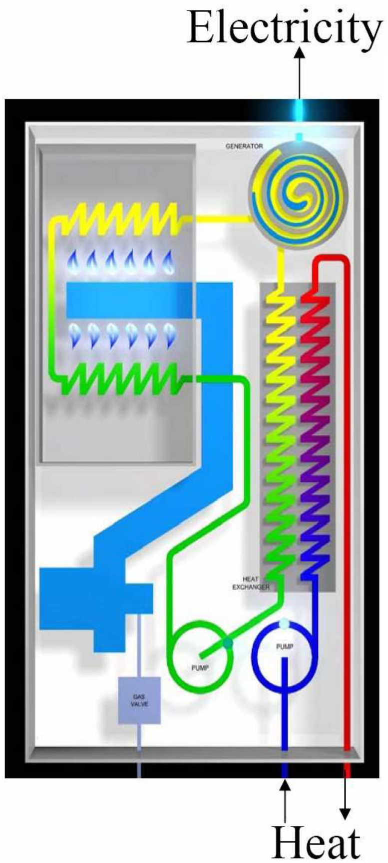
4. ORC-powered domestic micro CHP units

- alternative to gas engines
- in concurrence with other new technologies as stirling engines, fuel cells…
- advantages to other technologies has to been proven
- status: prototyping, maybe available soon

Energetix Group European Headquarters
Capenhurst Technology Park
Capenhurst
Chester
CH1 6EH
UK

ORC/Scroll Expander

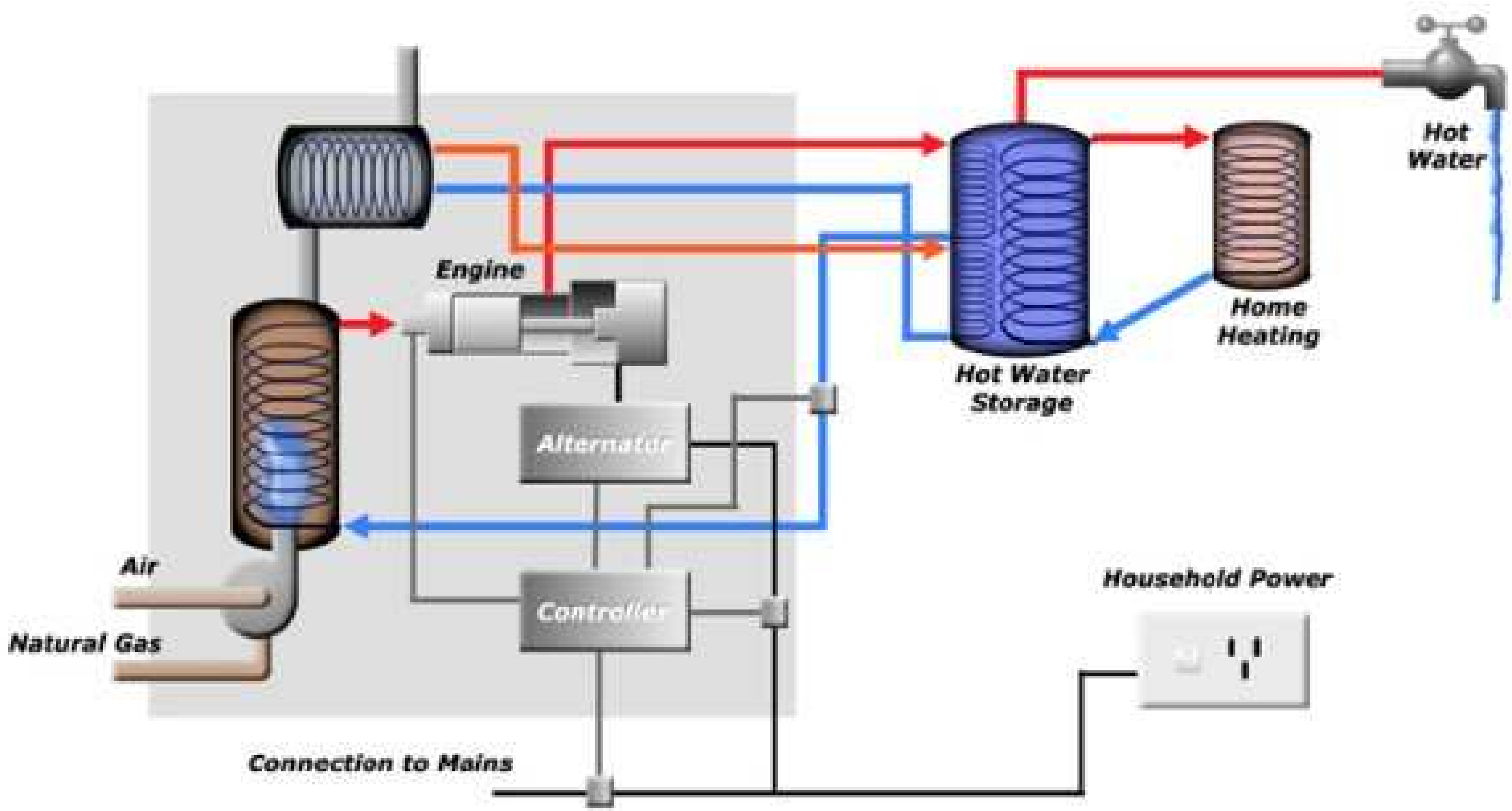
ORC prototype module
Fitted inside boiler casing



Climate Energy
3kWe; 30kWt
Rankine Cycle

Cogen Microsystems
2.5kWe; 11kWt – 22kWt
Rankine Cycle

Cogen Microsystems
(water – steam !)



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AUSTRALIA

OUR PROTOTYPE:

- **2.5kW electrical**
- **11kW heating**
- **90% overall efficiency***
- **17% electrical efficiency***
- **Modulates down to 3kW heat**
- **Integrated boost heating to 22kW possible**
- **Good electrical efficiency at part load**

* based on gross calorific value

THE BENEFITS OF OUR TECHNOLOGY

- **Quiet, low emissions, long life - unlike IC engines**
- **Low manufacturing costs - unlike Stirling cycle engines**
- **Readily scaleable (1 to many kWe) unlike free piston Stirling Engines**
- **No new manufacturing technologies required - unlike fuel cells**
- **Potentially short time to market - unlike fuel cells**

Cogen Microsystems

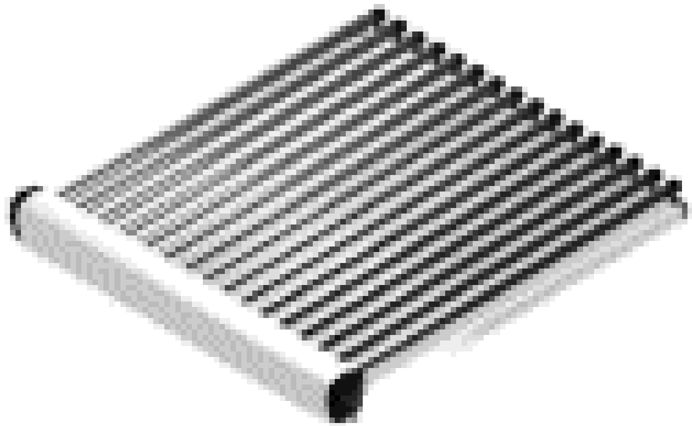
	DOMESTIC (market intro 2007)	SMALL COMMERCIAL
Electrical Output	240V 50Hz, 110V 60Hz	240V 50Hz, 110V 60Hz
Electrical Power, kWe	2.5	10
Heating Power, kW	11 (22 boost mode)	44
Overall Efficiency	90%	90%
Weight, kg	60	175
Dimensions, mm	870h x 600w x 400d	960h x 800w x 600d

Applications (cont):

5. Power generation from thermal solar energy

- probably cheaper than photovoltaic systems
- possible to use condensor heat for sanitary heat water…
- status: technically feasable, no recent commercial references known

Evacuated tube collector fitted to temperatures untill 180-200℃



40 kW solar heat ORC (Turboden, 1984)

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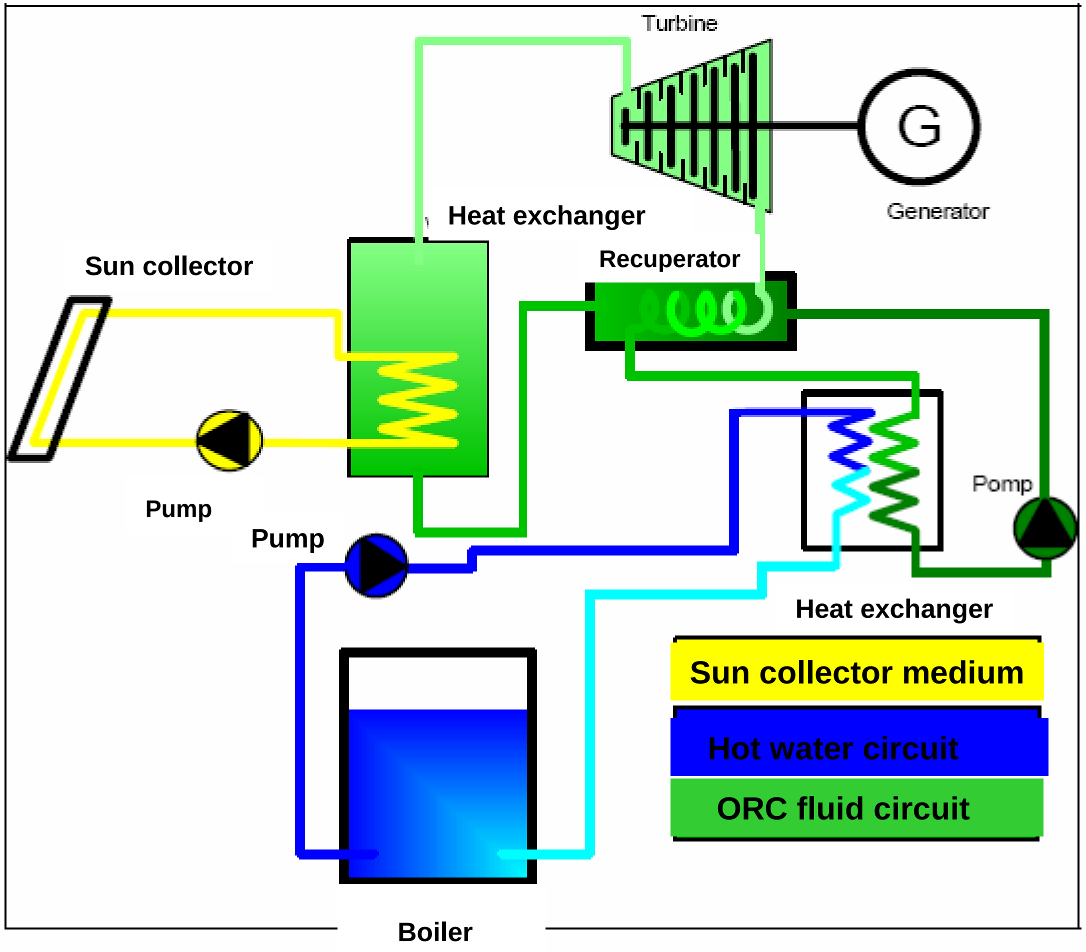
Principle design
(final work dept PIH 2004-2005)



Turbine: tests with scroll expander
(Sanden scroll car airco compressor TRS-090)

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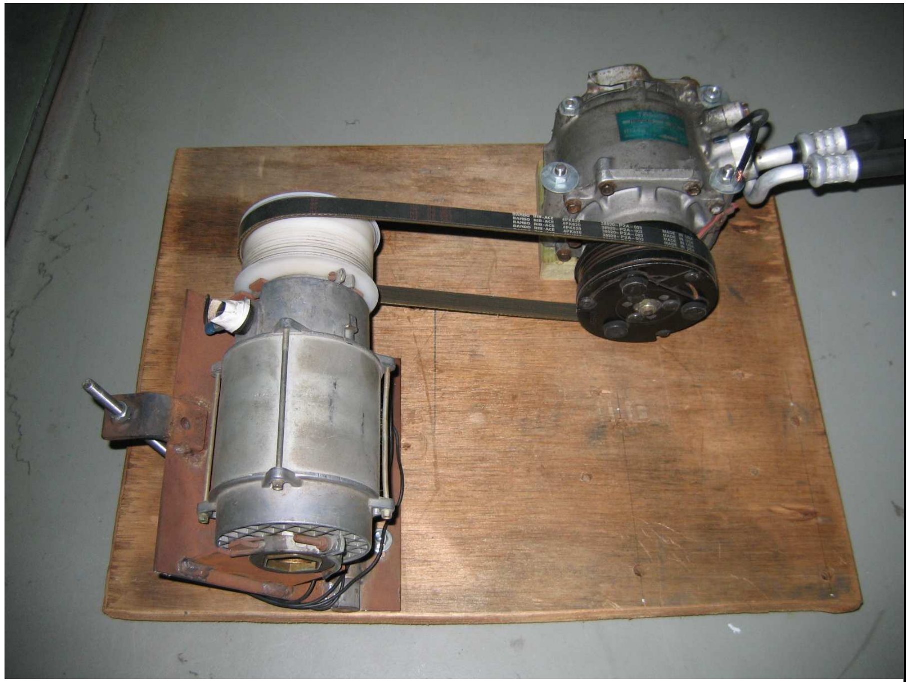
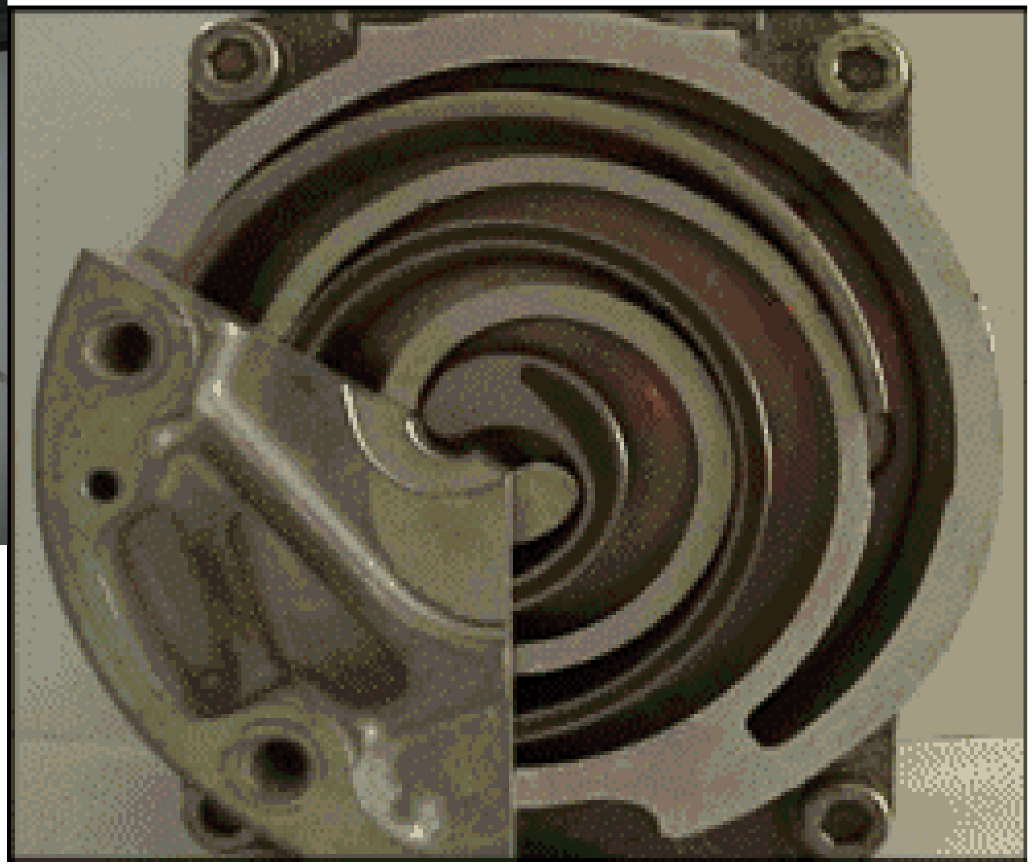




Isentropic efficiency of the scroll expander seemed to be low !

Applications (cont):

6. ORC powered airco on solar heat

Equal to previous, but ORC turbine is direct coupled to the airco compressor (no generator and motor losses)

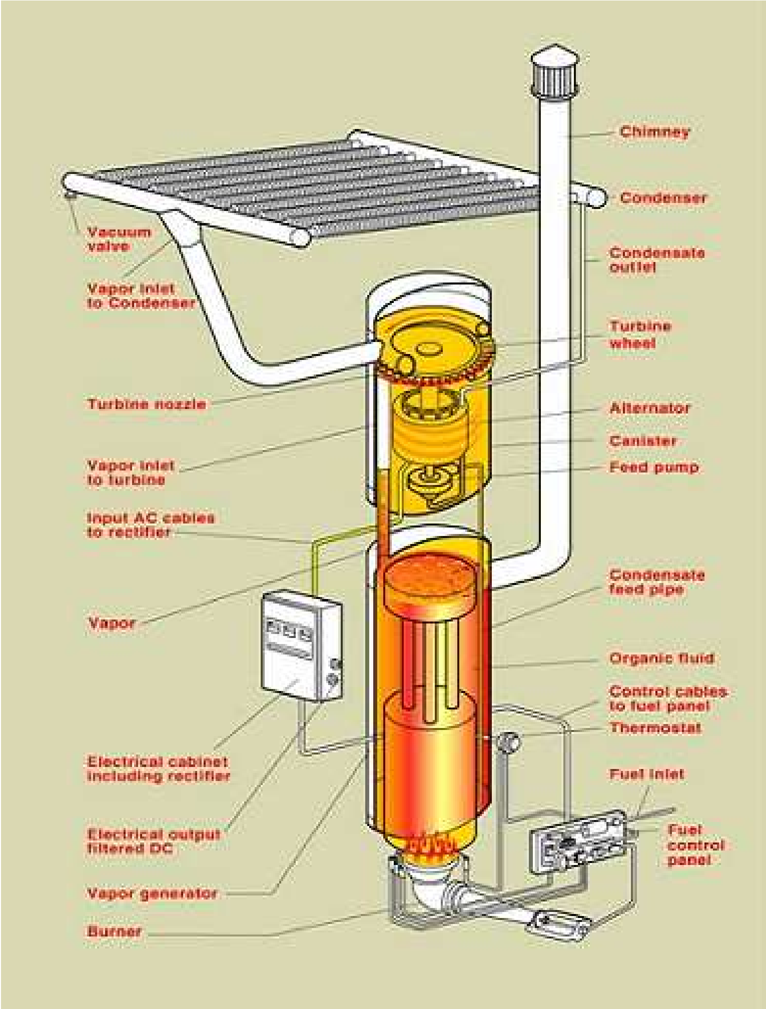
Status: ???

Applications (cont):

7. ORC powered airco (or refrigeration chiller), fed from fuel combustion

Alternative when electrical grid connection big chiller impossible or not allowed.

Been proven having better efficiency (COP) compare to absorption chillers.
(Hybrid with solar heat feasible)
Status: ???



Applications (cont):

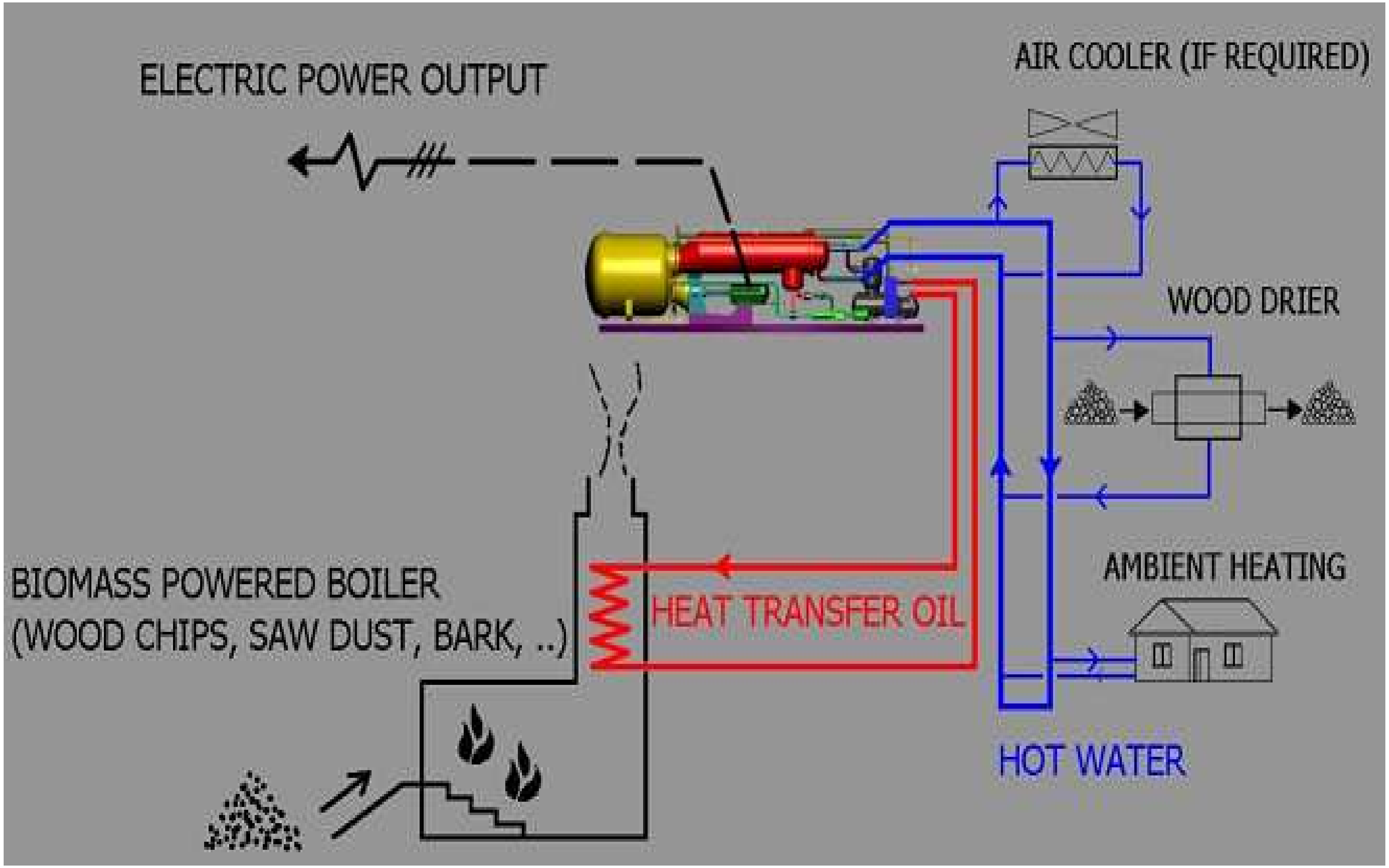
8. ORC, fed by biomass combustion

Many references in CH, A, D, I… (also 1 in NL).
Because of the possibility to reach high temperatures, not convinced of the advantage of ORC compared with a steam cycle.

Can be designed as CHP.

ORC can also use low methane biogas, unadapted to gas engines.

CHP Biomass-ORC (Turboden):



TURBODEN

25122 BRESCIA - I - Viale Stazione, 23 - Tel. 030 377 23 41 / 6 Fax 030 377 23 46
E-MAIL: info@turboden.com - INTERNET: www.turboden.com

Doc.: 05A00143 Subject: Turboden turbogenerators for cogeneration preliminary technical data sheet Page: 1 / 1

	T500-CHP	T600-CHP	T800-CHP	T1100-CHP	T1500-CHP	T2000-CHP
Heat source	thermal oil in a closed loop	thermal oil in a closed loop	thermal oil in a closed loop	thermal oil in a closed loop	thermal oil in a closed loop	thermal oil in a closed loop
Thermal oil nominal temperature (In/Out)	300 / 250 °C	300 / 250 °C	300 / 250 °C	300 / 250 °C	300 / 250 °C	300 / 250 °C
Thermal oil flow (about)	23.6 kg/s	28.3 kg/s	36.3 kg/s	51 kg/s	74 kg/s	98,4 kg/s
Thermal power input from thermal oil	2900 kW	3500 kW	4500 kW	6200 kW	9000 kW	12000 kW
Hot water flow	28.1 kg/s	33.9 kg/s	43.3 kg/s	59.6 kg/s	58,4 kg/s	77,8 kg/s
Hot water temperature (In/Out)	60 / 80 °C	60 / 80 °C	60 / 80 °C	60 / 80 °C	60 / 90 °C	65 / 95 °C
Thermal power to the coling water circuit (about)	2320 kW	2800 kW	3580kW	4930 kW	7350 kW	9800 kW
Net active electric power output	500 kW	600 kW	800 kW	1100 kW	1500 kW	2000 kW
Module dimensions	15 X 3 X 3,1 m Single skid unit	15 X 3 X 3,1 m Single skid unit	15 X 3 X 3,3 m Single skid unit	13 X 6 X 6,2 m Multiple skid unit	15 X 7 X 5 m Multiple skid unit	17 X 7 X 5 m Multiple skid unit
Electric generator	asynch., 3 phase, L.V., 650 kW	asynch., 3 phase, L.V., 750 kW	asynch., 3 phase, L.V., 930 kW	asynch., 3 phase, L.V., 1250 kW	asynch., 3 phase, L.V., 1650 kW	asynch., 3 phase, L.V., 2100 kW

Doubles crew expanders: alternative to turbines

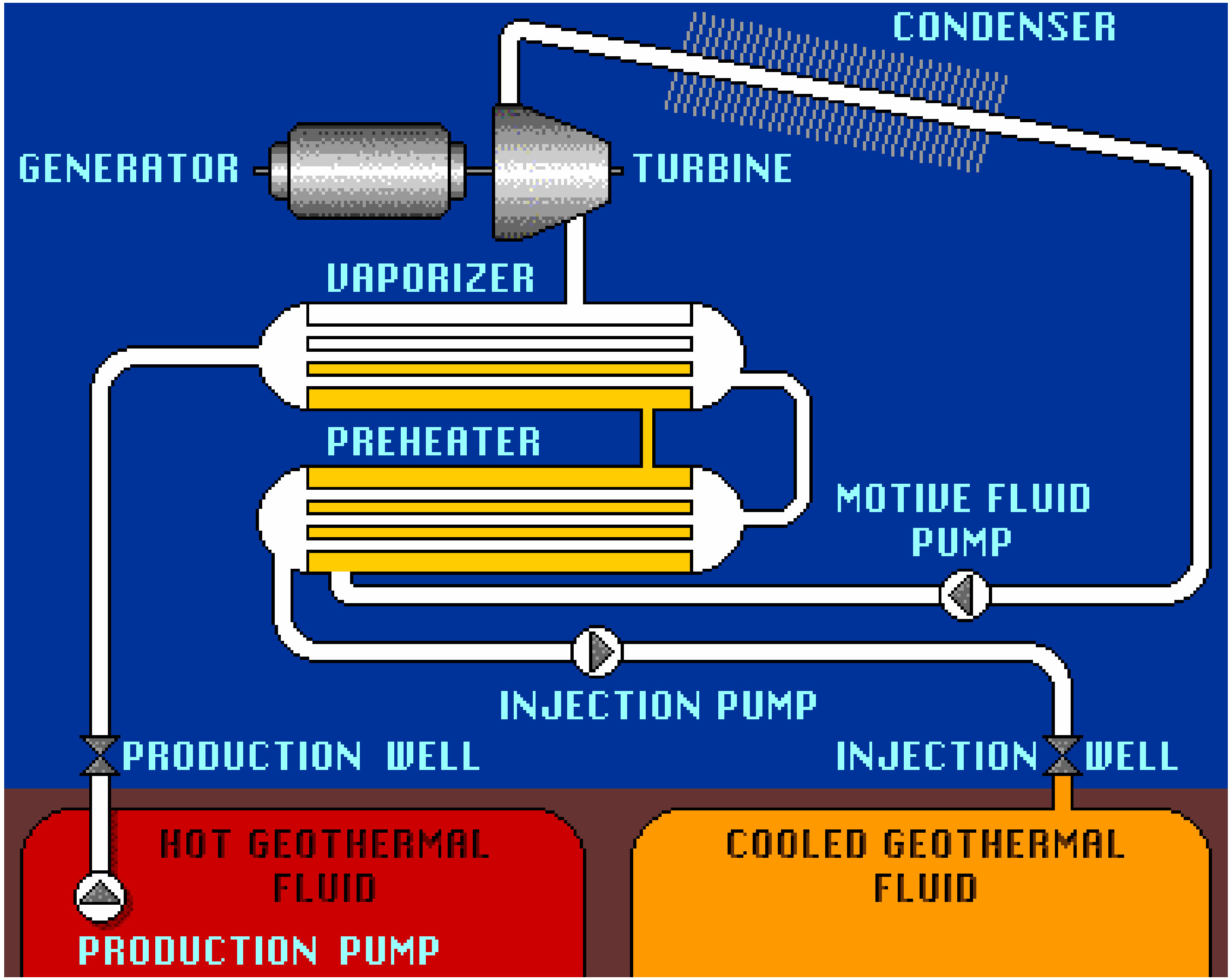
Applications (cont):

9. ORC, fed by geothermal heat sources

Many known references, all > 1 MW (D, USA…)
Source temperature around 100℃.

Good examples to recover waste heat on the same temperature level.

Geothermal ORC (Ormat, Israel)



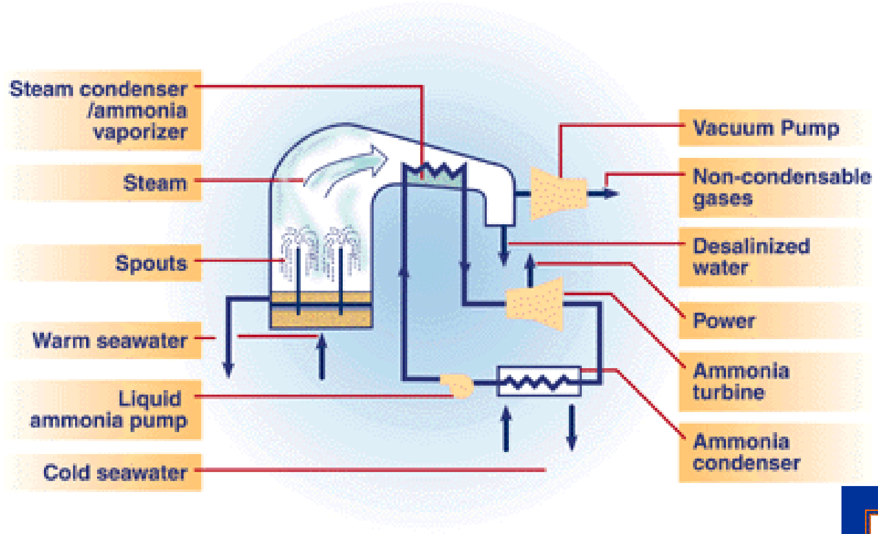
Heber Geothermal Power Station (Californië)
52 MWe

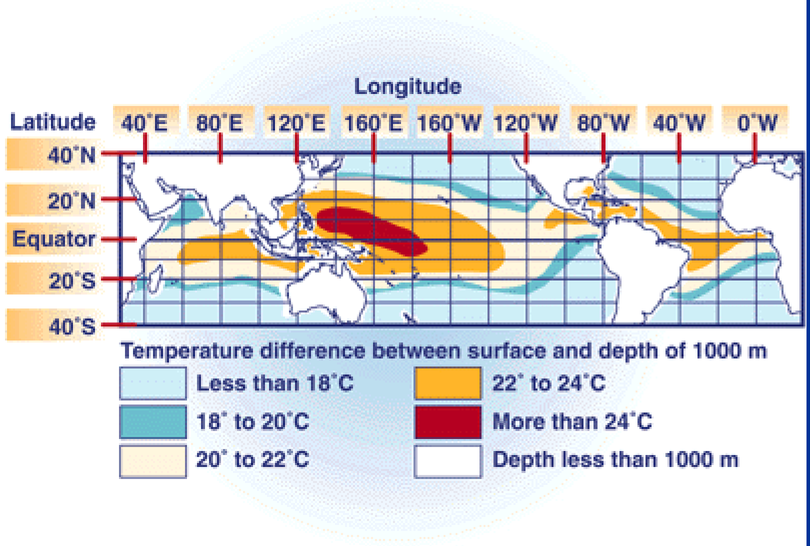
Applications (cont):

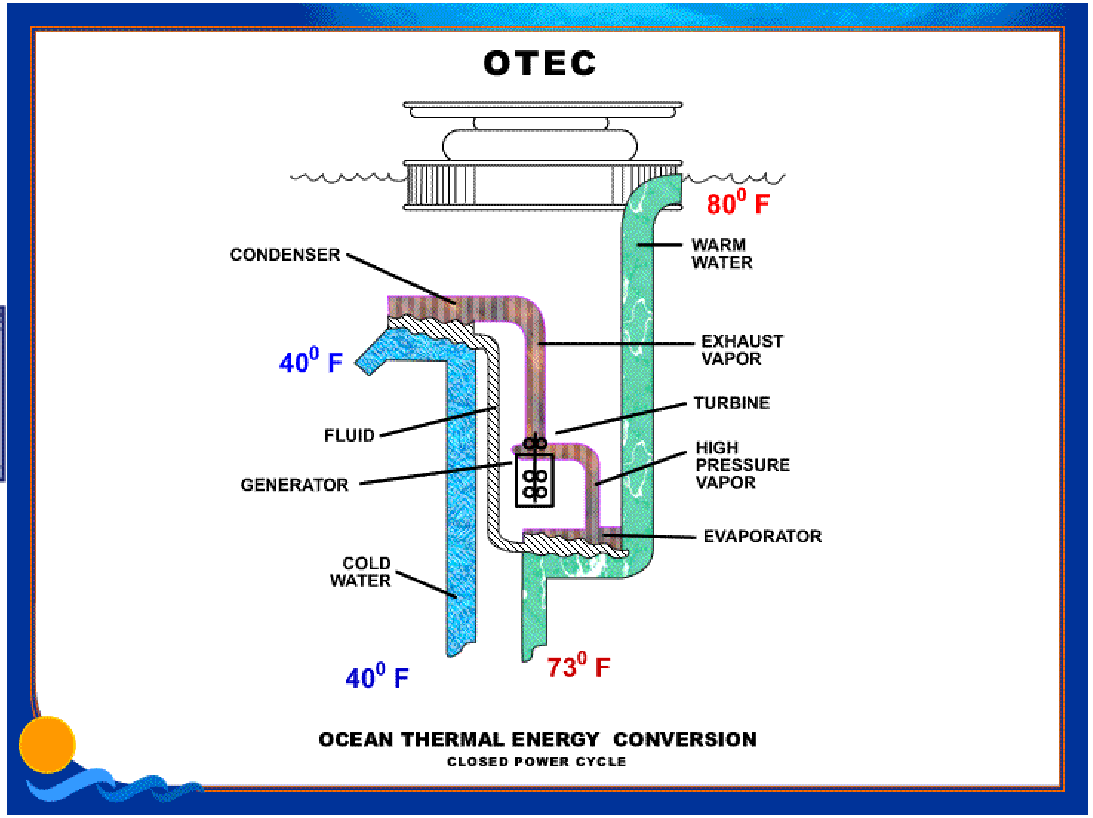
10. ORC, fed by temperature differences in ocean water

Known as “Ocean Thermal Energy Conversion or OTEC”. Uses temperature difference between surface water (about 28℃) and water on great depth (about 6℃) on tropical seas or oceans.
Low thermical efficiency due to the small temperature difference but enormous heat quantities available.

Status: only some demonstration projects known, economical feasibility problematical


Steam condenser /ammonia vaporizer
Steam
Spouts
Warm seawater
Liquid ammonia pump
Cold seawater
Vacuum Pump
Non-condensable gases
Desalinized water
Power
Ammonia turbine
Ammonia condenser


Longitude
Latitude
40˚E
80˚E
120˚E
160˚E
160˚W
120˚W
80˚W
40˚W
0˚W
40˚N
20˚N
Equator
20˚S
40˚S
Temperature difference between surface and depth of 1000 m
Less than 18˚C
18˚ to 20˚C
20˚ to 22˚C
22˚ to 24˚C
More than 24˚C
Depth less than 1000 m


OTEC
80⁰ F
CONDENSER
WARM WATER
40⁰ F
EXHAUST VAPOR
TURBINE
FLUID
HIGH PRESSURE VAPOR
GENERATOR
EVAPORATOR
COLD WATER
40⁰ F
73⁰ F
OCEAN THERMAL ENERGY CONVERSION
CLOSED POWER CYCLE

Conclusions:

- ORC is a proven and commercially available technology for applications such as industrial waste heat recovery, biomass burning, use of geothermal heat sources…
- main advantage compared with a steam cycle is the higher thermal efficiency, in particular when the heat source temperature lowers
- the classical steam cycle should be considered when sufficient temperature levels are reachable (fuel burning) combined with turbine scale sizes from around 500 kWe
- due to the Flemisch Green Certificates System, a 3 year PBT is calculated since ORC investment costs are found from 1,700 to 3,250 €/kWe (all in) corresponding with units sizes from 120 to 1,500 kWe
- small scale ORC applications (transportation, solar heat power, micro CHP) are under investigation, development or prototyping level
- excellent CHP capability since the condensor heat can be used

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Our actions on ORC:

- 2 master thesis 2003-2005
- TETRA project proposal on ORC in 2005. Applications 2, 3, 5 and 6 considered. Technically and scientifically approved but not financed, had to been cancelled.
- New proposal in 2007, focused on renewable energy sources (meanly application 2). Expecting result on end of june 2007 (under review by external experts).

A TETRA project is 92,5 % financed by the Flemisch Government and 7,5% by industrial partners (already found in our case but extra partners are still welcome).

2 scientific researchers can work during 2 years on it (oct 2007- 2009).

Results exclusive reserved to the partners during project time, at the end publical available (by publications, seminars, website…)

Goals of the project:
Introduce ORC in Flanders by:

- state of the art research on both technical and economical feasibility and possibilities
- building a small laboratory test rig, offering the possibility to test different working fluids using different heat sources (simulation of exhaust gases of a gas engine, diesel engine or other heat sources by a air heater and to experiment with the condensation temperature to investigate CHP capabilities.
- case studies on existing installations (sewage gas, vegatable oil and biogas engines, burner grill cooling fluid of biomass furnaces)
- demonstrating and dissipating theoretical and practical knowledge

Thanks for your attention.

Questions ???

Hogeschool West-Vlaanderen, dept PIH
Graaf Karel de Goedelaan 5, B-8500 Kortijk

Bruno Vanslambrouck
Mail: bruno.vanslambrouck@howest.be
Tel: +32 56 241211 or +32 56 241227 (dir)