Design, Development & Operation of the TRI-O-GEN ORC Power Unit

by

Jos van Buijtenen

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TRI-O-GEN
POWER FROM HEAT


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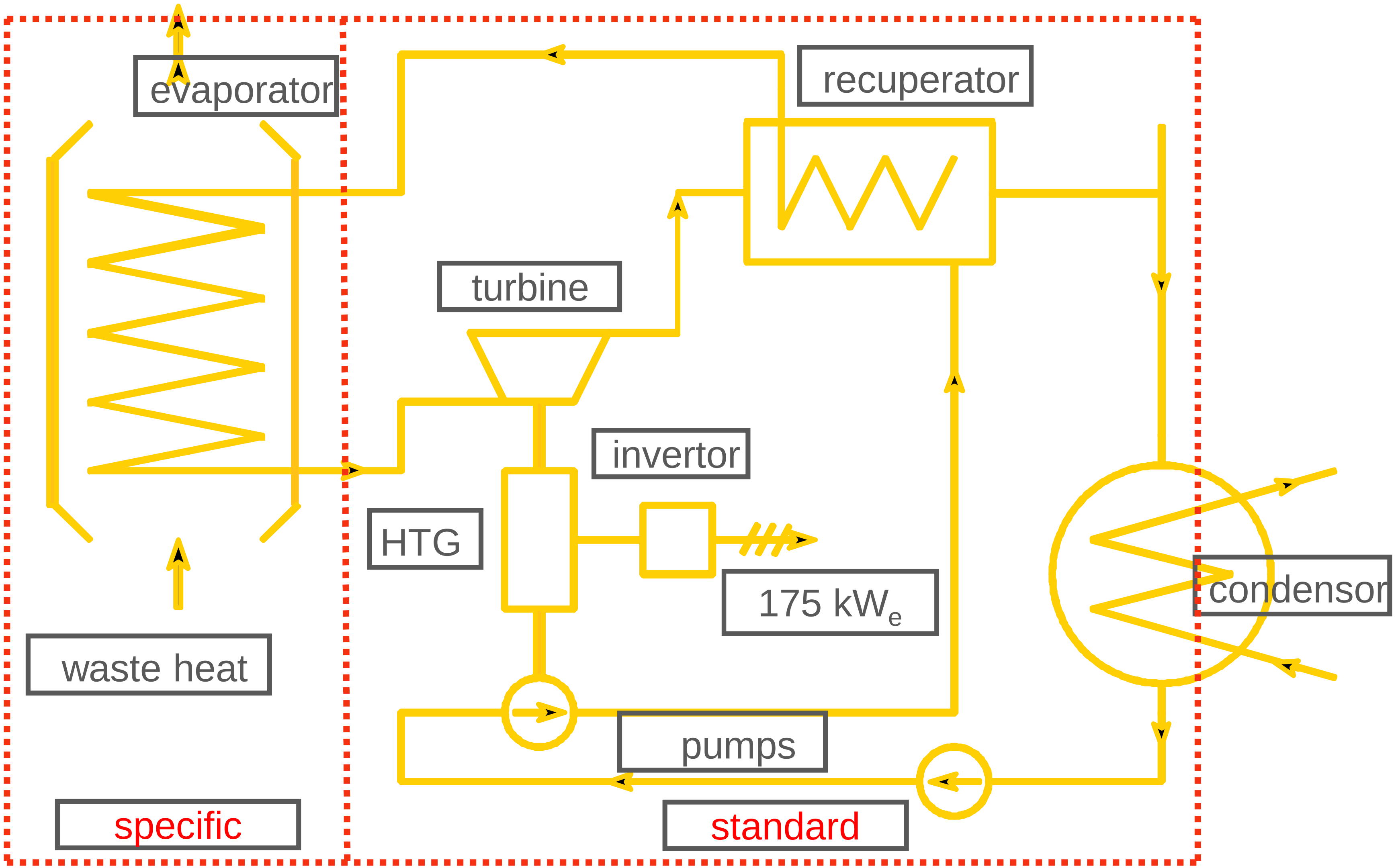
INTRODUCTION

- Tri-O-Gen was established in 2001, to develop and market ORC technology, conceived by the Lappeenranta University of Technology, Finland.
- The technology implies a high temperature, high speed, hermetically closed, turn-key packaged system in the 150 kWe class.
- Commercial operation is realized since 2007 through 4 ß-units, and subsequent 10 production units, which clocked more than 60.000 hours in total.

CHARACTERISTICS

- Working Fluid is a thermally stable hydro-carbon
  - Direct heat transfer from heat source to working fluid
- System suitable for heat sources of relatively high temperture > 350 ℃
  - High ΔT heat-exchange and high Carnot efficiency
- High-speed generator, on single shaft with turbine and pump
  - High component efficiencies
- Working fluid lubrication and cooling
  - hermetic and seal-less turbo-generator
- Modularized plant design
  - Standard process and power modules, customized heat addition and rejection

PROCESS CHART ORC TECHNOLOGY



ORGANIC WORKING FLUIDS

- Low heat of evaporation at moderate pressure, because of critical point and the shape of the co-existence area
- High volume flow at low enthalpy drop

Single stage turbine (radial)
can be applied with high efficiency

- Fluids with good lubrication properties
- Low electric conductivity (0!), so electrical components might be subjected to it

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REQUIREMENTS FOR WORKING FLUIDS

- Thermodynamic:
  - Position critical point
  - Shape of T-s and log p-h diagram
  - Pressure / Temperature at condensation
- Environmental Effects:
  - At release into the atmosphere
  - After combustion
- Safety Aspects:
  - Toxicity
  - Flammability
- Operational:
  - Chemical stability at high temperature
  - Effects on lub-oil
  - Electrical conductivity
  - Lubrication properties
  - Cost

ORC WORKING FLUIDS

	Toluene	n-pentane	Typical Siloxane (MDM)	R245fa	Water / steam
Critical temperature [^oC]	321	196	292	155	374
Critical pressure [bar]	42	34	14,4	37	221
Boiling point @ 1 bar [^oC]	110	36	151	15	100
Auto-ignition temperature [^oC]	480	309	482	412	–

TRI-O-GEN ORC: TOLUENE

- Chemically stable to >> 400 ^{o}C
- Suitable for “higher temperature” segment: heat-sources from ~ 350 ℃
- Limited toxicity: comparable to transport-fuels, however non carcinogenic (in use as solvent)
- Little atmospheric emission allowed
- No toxic emissions from combustion: pure hydrocarbon
- Flammability controllable through proper safety measurements
  - System inherently hermetic
  - 60 ppm: shutdown; 120 ppm: grid disconnected (LEL: 12000 ppm)
- Liquid to be used for lubrication of bearings
- Vapor to be used as coolant for generator

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HIGH SPEED TURBO GENERATOR (HTG)

Turbine, high speed generator and main pump on one shaft, no gearbox

Patented generator, in use as motor in 1000's of units worldwide

High speed (~25.000 rpm), for optimum turbine and pump efficiency

Hermetically closed system: no leakage of working fluid

No external shaft connections, so no shaft seals

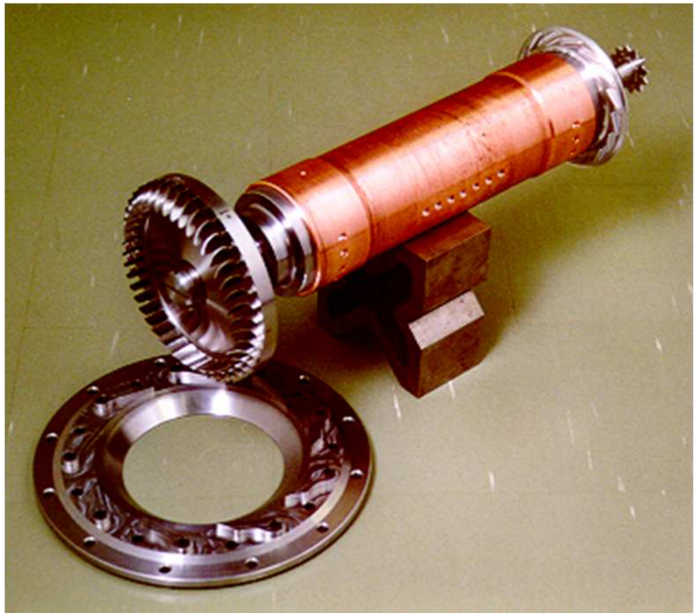
Lubrication of hydrodynamic bearings by working fluid, so no lubricants

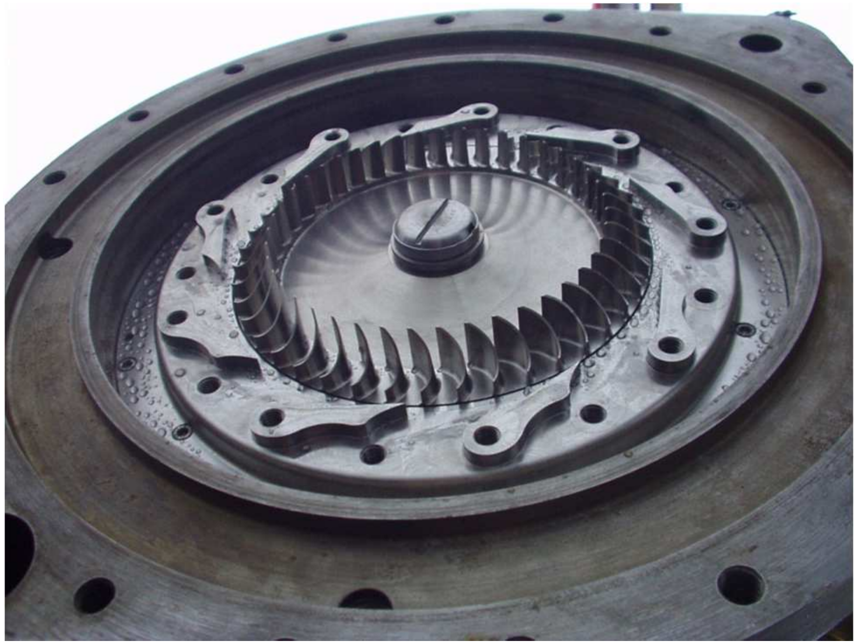
Generator internal cooling through working fluid

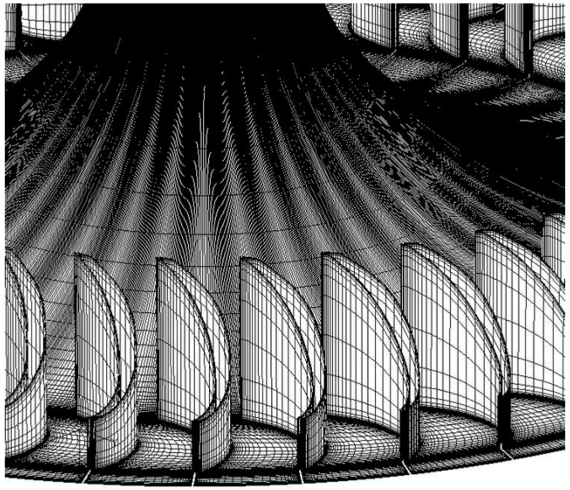
HTG exchangeable as a module.

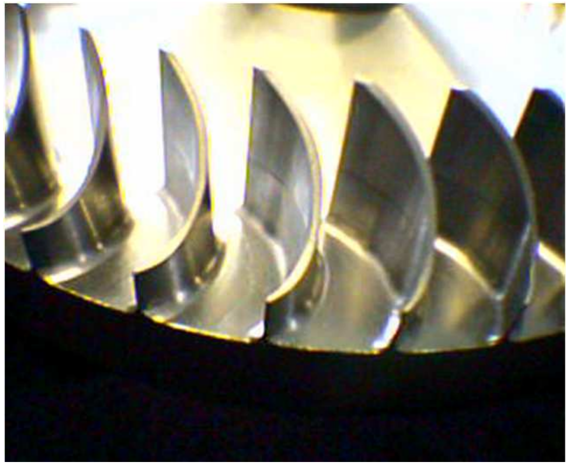
HIGH SPEED TURBO GENERATOR

HTG ROTOR & STATOR









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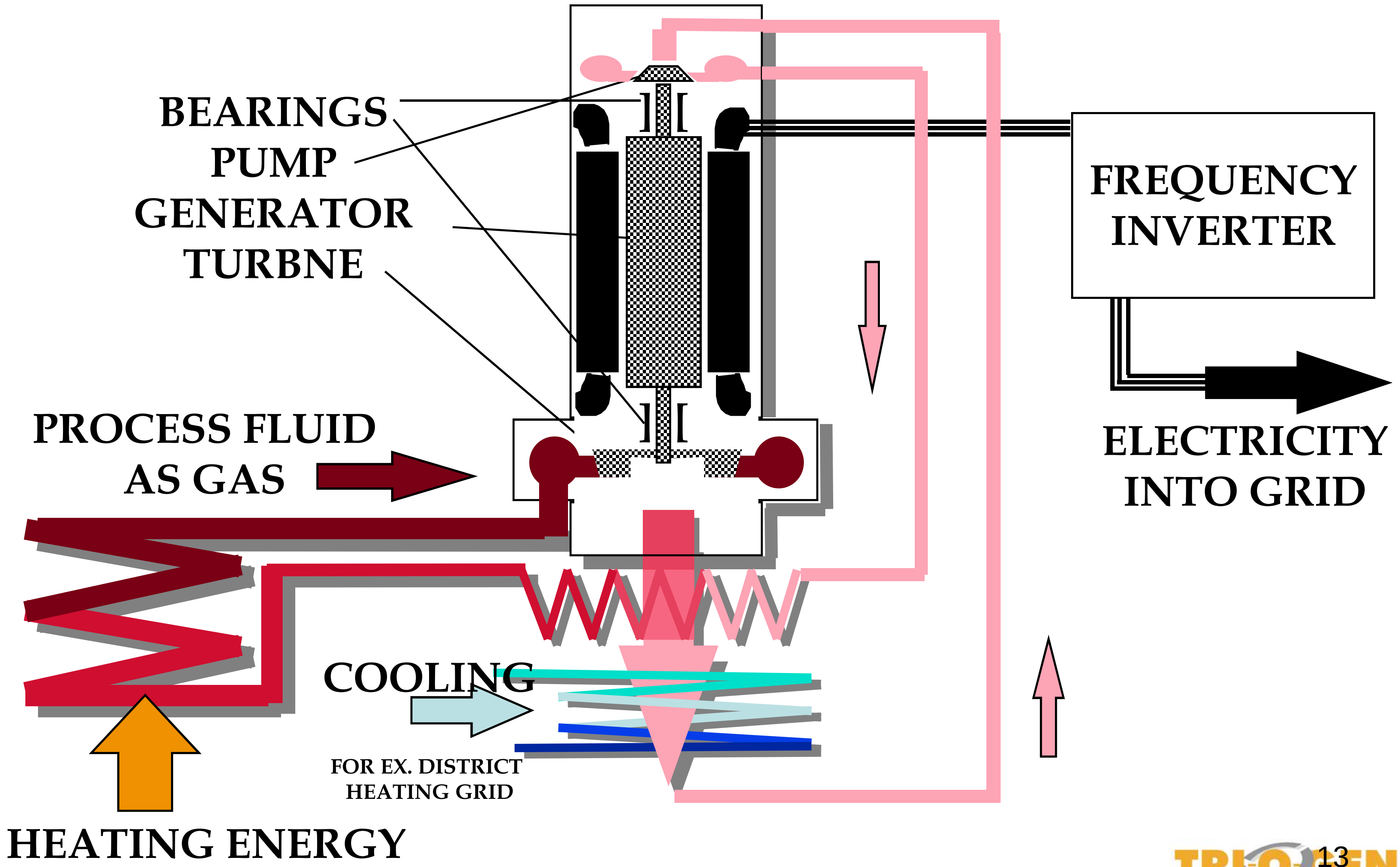
HIGH-SPEED TURBO-GENERATOR: HTG IN ORC PROCESS



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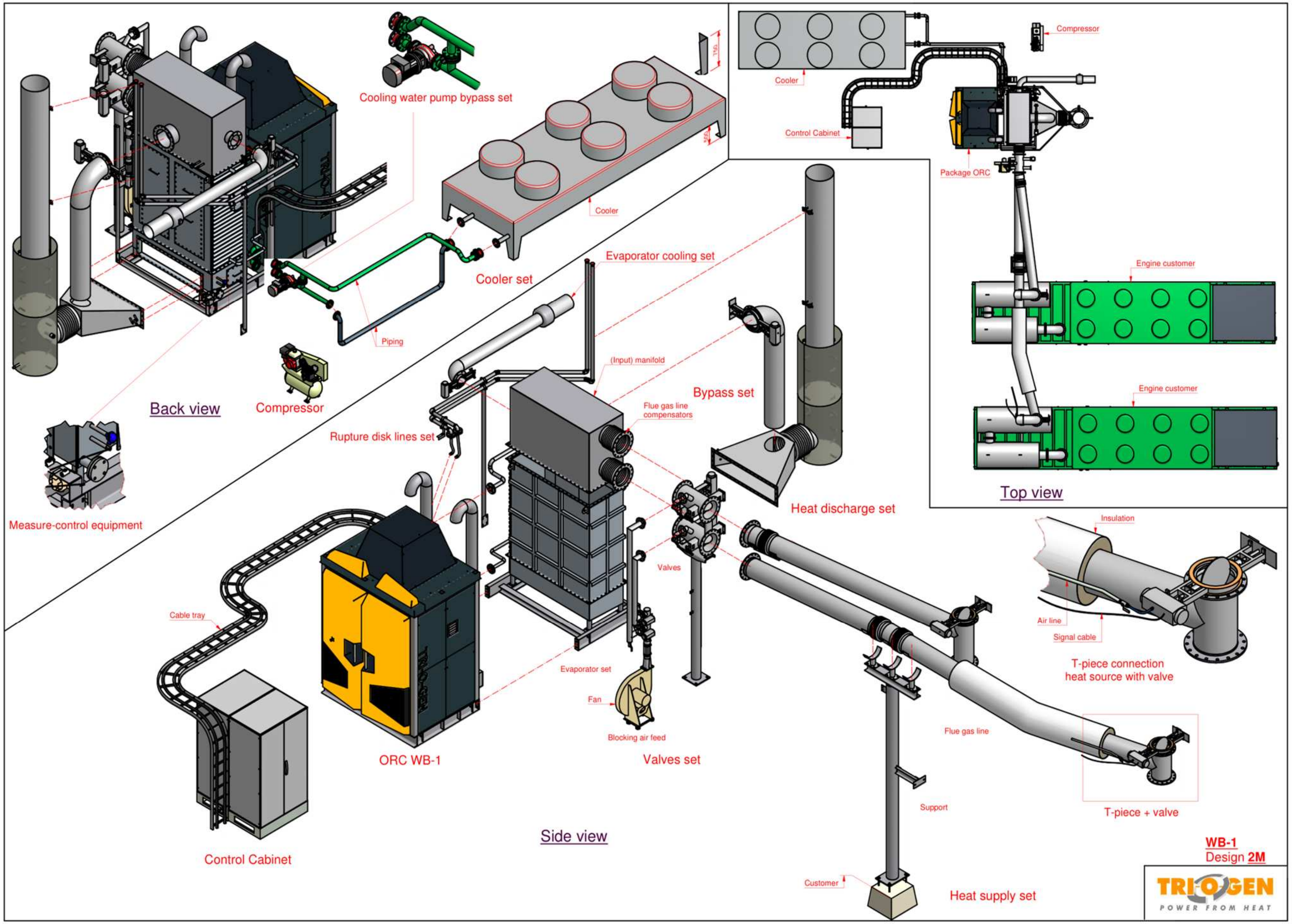
MODULARIZED PLANT DESIGN

Four Modules:

1. Customized evaporator to take the heat-energy
2. Standard Process Module, containing turbogenerator, recuperator, condenser, working fluid inventory, pre-feed pump, valves & piping, instrumentation.
3. Customized heat rejection module, to cool the condenser
4. Electrical power module, for grid connection (inverter) and unit control

Turn key delivery also contains flue gas ducts and valves, electrical connections and flue gas ducting.


Cooling water pump bypass set
Cooler
Cooler set
Piping
Back view
Compressor
Measure-control equipment
Evaporator cooling set
(Input) manifold
Rupture disk lines set
Bypass set
Flue gas line compensators
Heat discharge set
Valves
Cable tray
Evaporator set
Fan
Blocking air feed
ORC WB-1
Valves set
Control Cabinet
Side view
Cooler
Compressor
Control Cabinet
Package ORC
Engine customer
Engine customer
Top view
Insulation
Air line
Signal cable
T-piece connection heat source with valve
Flue gas line
Support
T-piece + valve
Customer
Heat supply set
WB-1
Design 2M
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THE ORC INSTALLATION

NET electricity production ~ 60 to165 $kW_{e.}$

Very low operational cost

Operates smoothly under different input heat input conditions

Dimensions within standards for road transport

Fully compliant with CE (Pressure Equipment Directive)

FMEA and HAZOP studies completed, under supervision of Lloyds

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DEVELOPMENT HISTORY

- 2002 – 2003: Design, Engineering and Commissioning of prototype
- December 2002: prototype mechanical complete
- October 2003: first successful test (45 kWe)
- May 2005: 145 kWe
- June 2005: first endurance test: 8 hours at full power
- January 2006: second endurance test : 36 hours
- September 2006: > 3000 hours at landfill site
- November 2006: first commercial unit sold
- January 2008: first commercial unit commissioned
- May 2009: 2nd commercial unit: 155 kWe
- February 2010: 165 kWe
- Now:
  - 14 units in operation in 4 EU countries; 10 on order
  - More than 60.000 operating hours
  - Availability of over 97 % demonstrated

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FIELDS OF APPLICATION

Co-generation units.

Gas engines: using

- Natural gas
- Mine gas
- Biogas
- Landfill gas

(Bio) diesel engines

Gasturbines

Industrial waste heat

Land fill gas flares.

Industrial flares.

Biomass combustors

Furnaces

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REFERENCES

- Greenhouse cogeneration, using exhaust heat from a 2 MW Deutz natural gas engine (from 2007)
- Waste heat from 2 Jenbacher engines, running on corn digester gas (from December 2008)
- Waste heat from 2 Jenbacher engines, running on manure digester gas (from July 2009)
- Exhaust heat from an ABC bio-oil fired Diesel engine serving as cogenerator for a swimming pool (2010)
- Waste heat from 2 Jenbacher engines, running on bio-waste digester gas (from December 2010)
- Two units using exhaust gas from two landfill gas engines each (Portugal, since June 2011)
- Two units using exhaust gas from two landfill gas engines each, or flue gas from landfill gas burner (France, since September 2011)
- Three units running on exhaust gas from digester gas engines in The Netherlands (since August 2011)
- One unit using exhaust gas from a landfill gas engine (Germany, September 2011)

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PERSPECTIVES

- Currently several new units in production
- Product development continues on product improvement in terms of:
  - Efficiency
  - Operability
  - (see presentations in other sessions of this conference)
- Expansion towards non-engine applications:
  - Industrial waste heat
  - Wood burning
  - Waste incineration

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THE TRI-O-GEN ORC

FLARE GAS STAINKOELN GRONINGEN

First installation (Jan. 2006).

Fluctuating gas quantity and quality.

Very few technical problems.

12.000 hrs of operation.

Very valuable in terms of knowledge and experience build-up.

FLARE GAS STAINKOELN GRONINGEN

OLIJ ROZEN

Heat source: 2 MW Deutz natural gas engine

Parallel linked to flue gas cooler for greenhouse warming

(flexible power / heat ratio)

Cyclic day / night operation

Recent inspection showed no wear or degradation

OLIJ ROZEN

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KLOOSTERMAN

Corn Fermentation unit

Heat source: 2 x 835 kWe Jenbacher biogas engine

Continuous operation (> 8.500 h/a)

Electricity production 150 kWe

KLOOSTERMAN

EISSEN

Manure Fermentation unit.

Heat source: 2 x 646 kWe Jenbacher biogas engine.

Continuous operation (> 8.500 h/a).

Electricity production 125 kW_e.

EISSEN

EINDHOVEN SWIMMING POOL

Bio oil cogeneration.

Heat source: 2.1 MW_e bio-oil Diesel engine.

Electricity production 150 kW_e.

TONGELREEP EINDHOVEN

VAR

Domestic Biomass Fermentation unit

Heat source: 2 x 1.065 kWe Jenbacher biogas engine

Continuous operation (> 8.500 h/a)

Electricity production 150 kWe

VAR

STEEGRO Netherlands

POWER FROM HEAT

GERMANY – LANDFILL

SUEZ - FRANCE

ADP PORTUGAL

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