Development and Operation of a High Temperature High Speed Organic Rankine Cycle System

By
Jos van Buijtenen
Quirijn Eppinga
Stefano Ganassin

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WHAT IS ORC?

- ORC = Organic Rankine Cycle
- A Rankine cycle is a closed thermodynamic process in two phases to convert heat into electricity, usually operating with water / steam
- Organic: organic working fluid, like:
  - Coolants (CFK),
  - Hydro-carbons (pentane, butane, toluene)
  - silicon oils (siloxanes)
  - ammonia

Why ORC?

- **Temperature level of the heat source**
- **Amount of heat to convert**

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RESIDUAL HEAT

Residual or waste heat can be found in:

- **Exhaust gasses from**
  - gas engines
  - Diesel engines
  - gas turbines

Running on fossil fuels or:
Landfill gas, biogas, bio-diesel

- **Various industrial processes**
  - petro-chemical
  - food & dairy
  - base-metal
  - glass, cement, brick manufacturing
- **Combustion of fuels not suitable for use in internal combustion engines and turbines (off-spec fuels)**
  - Residuals and waste
  - Biomass, wood
  - Flare gas (a.o. landfillgas, industrial flares)

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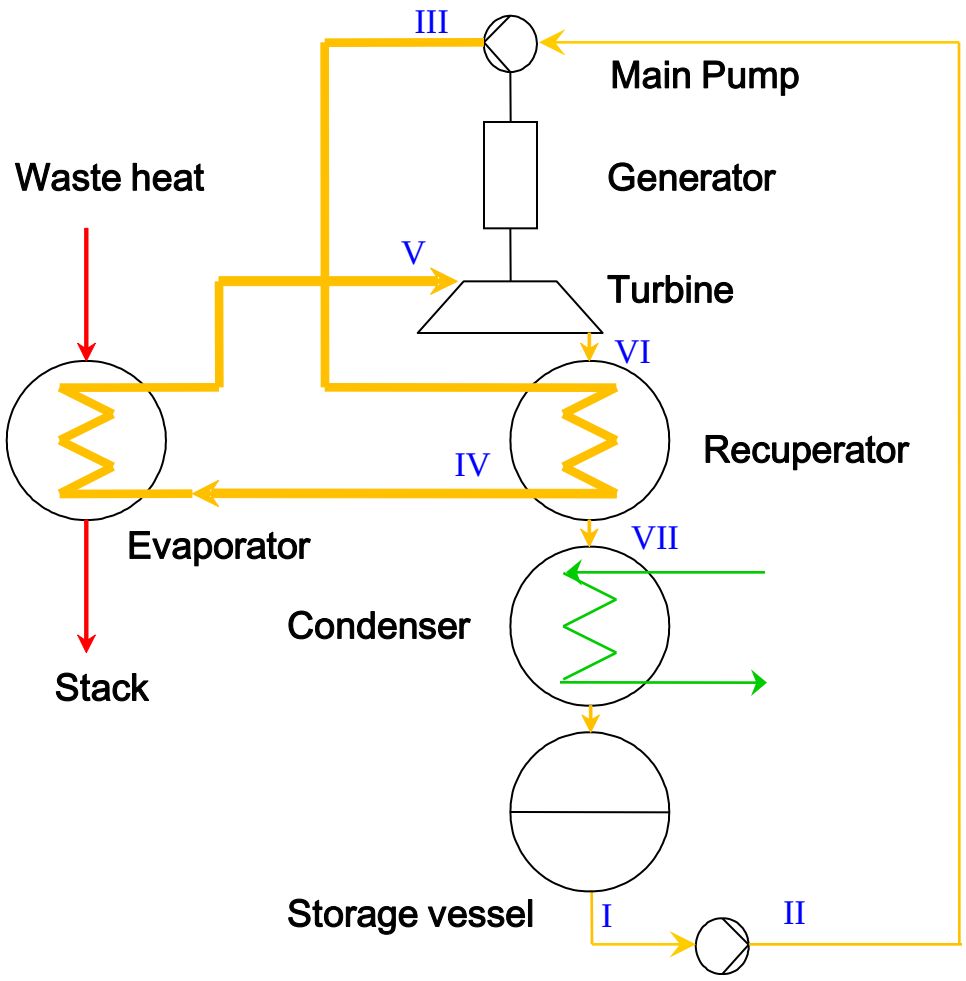
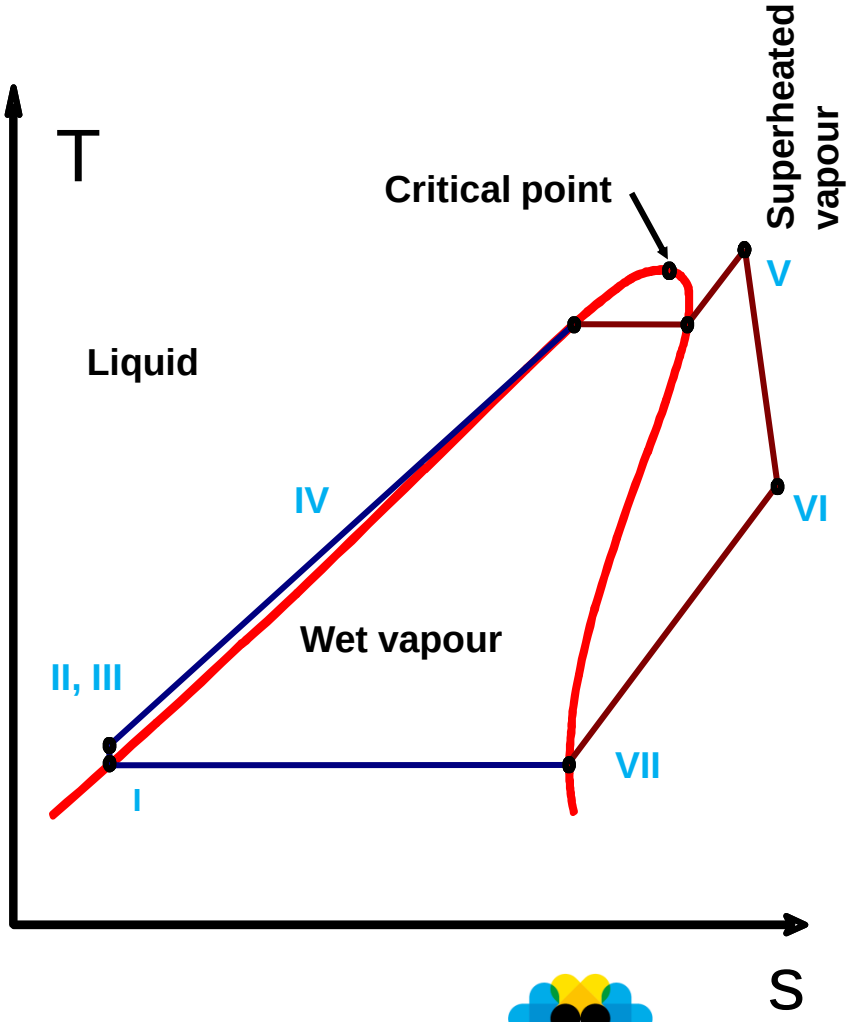
PROCESS CHART ORC TECHNOLOGY





Low pressure system

High pressure system

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HIGH SPEED TURBO GENERATOR (HTG)

- Turbine, high speed generator and main pump on one shaft, no gearbox
- Rugged induction type generator
- 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 (< 1 day)

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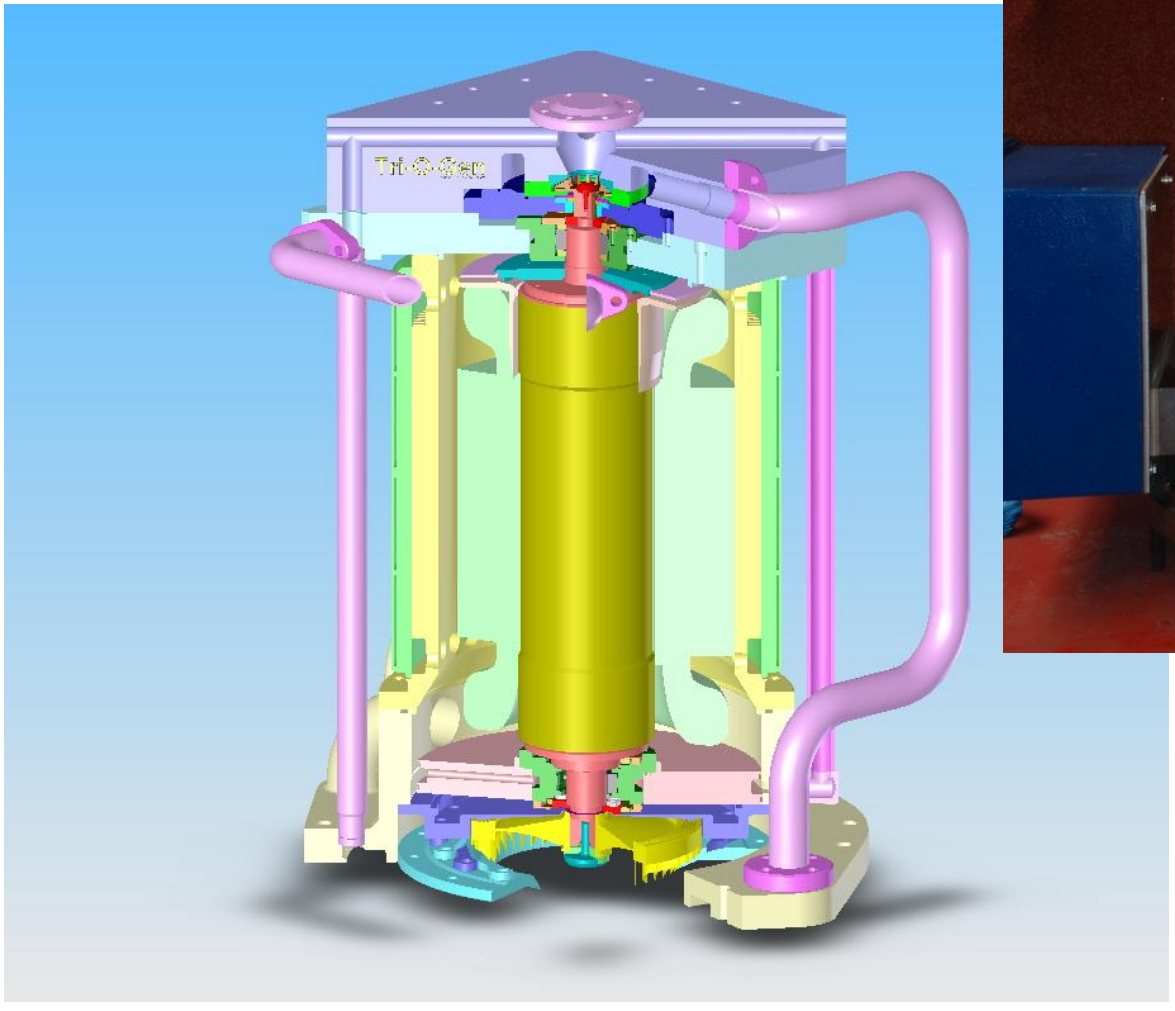
HIGH SPEED TURBO GENERATOR



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PROCESS DATA

- Net output 60 - 170 kW_e , depending heat source and condenser cooling
- Turbine inlet conditions T = 325 °C, p = 32 bar
- Condenser conditions: T = 55 °C, p = 0,175 bar
- Net heat input ~900 kW_{th} @ 180 °C in the ORC exhaust
- Inlet temperature minimal ~ 350 °C
- Exhaust and condenser heat useable for co-generation
- Efficiency:
  - **net power out / net heat input: up to 20 %**
  - **total efficiency in co-generation > 90 % possible**

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APPLICATIONS for IC ENGINES

- IC engines are widely used for distributed and renewable power generation
- Engines inherently produce waste heat in exhaust gas and cooling water
- The energetic value of this heat is a function of temperature
- High temperature exhaust heat can be converted into extra electricity
- Low temperature residual heat is still available for heating and drying purposes

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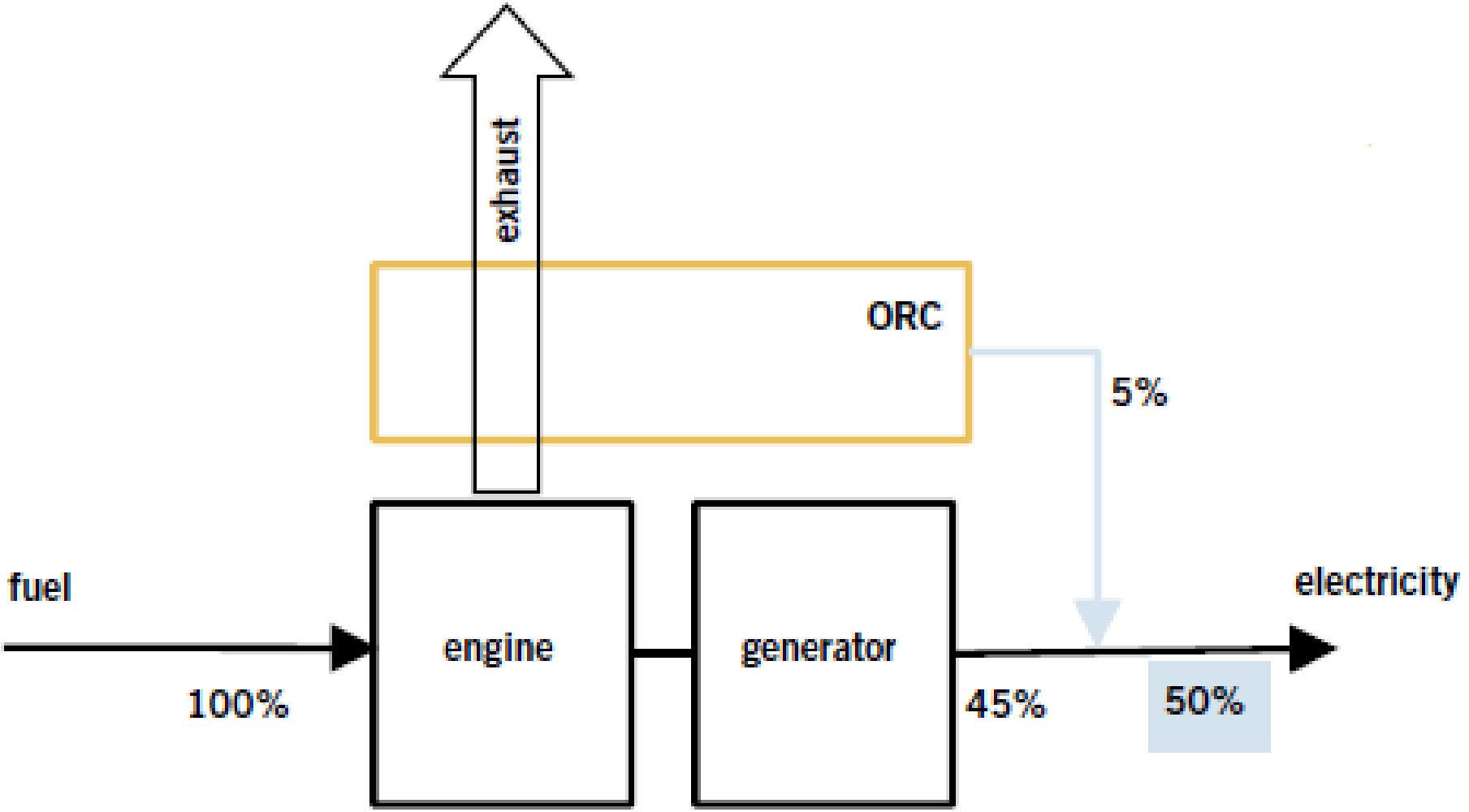
IC ENGINE APPLICATION

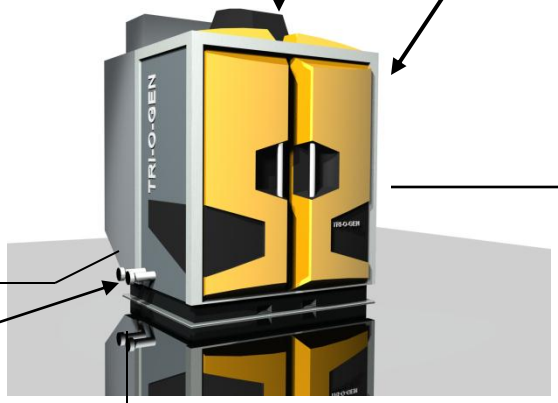


APPLICATION ENVELOPE

Bio-Gas Engines
1 – 2 MW_e

Engine Exhaust Gas
600 – 1200 kW_{heat}
350 – 550 °C

ORC Exhaust Gas
180 – 220 °C



ORC Power
60 – 170 kW_e

T_{in}: 35-60 °C

T_{out}: 55-80 °C

Condesor Cooling Water
400 – 700 kW_{heat}

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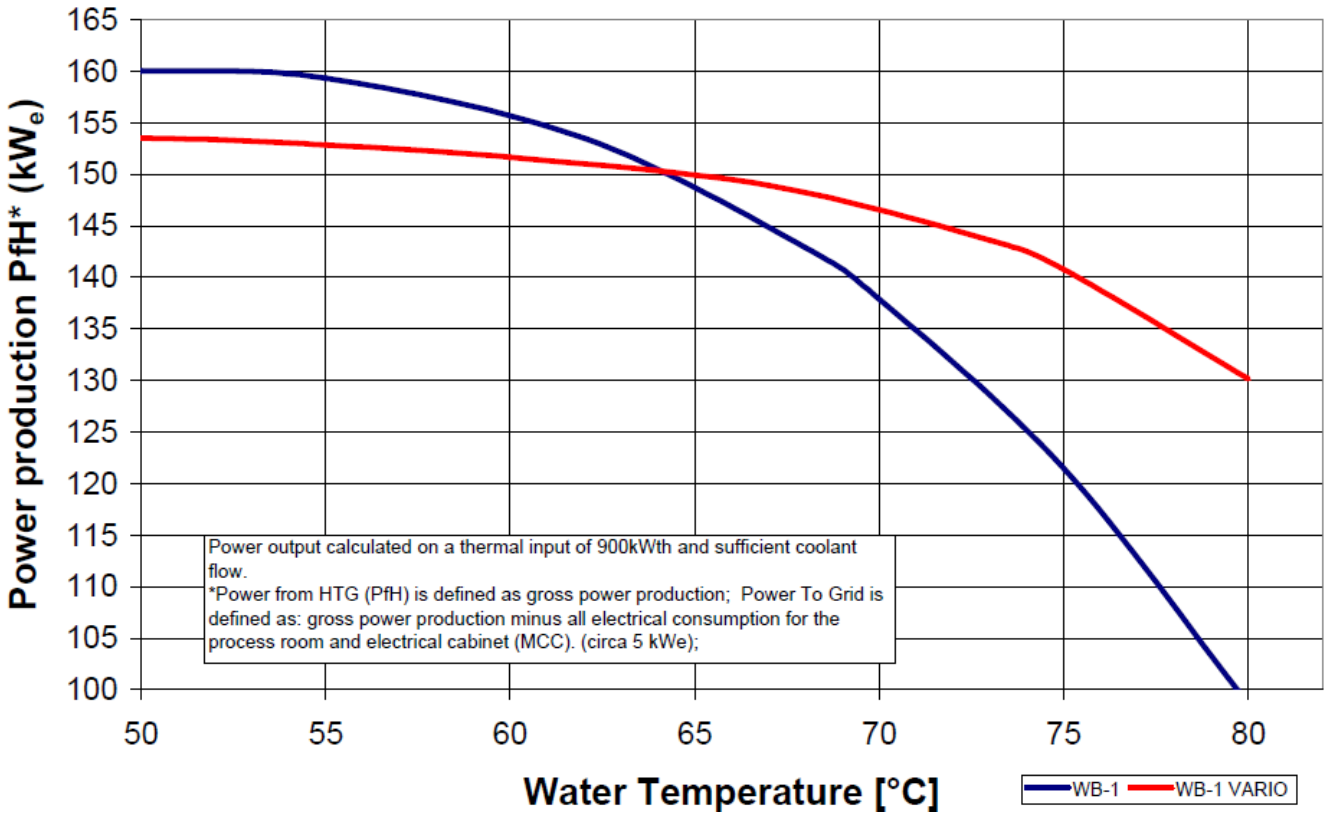
CHP flexibility

Triogen Offers the ORC in 2 diffrent models:

- **The WB1 model**, Ideal to generate the most electrical power from the heat source. The temperature of the condenser load is typically 35-55°C (in/out).
- **The version WB1-VARIO** offers you the flexibility to choose the temperature of the condenser cooling. The temperature can vary between 55°C and 80°C (out), allowing you to get the most out of your heat!



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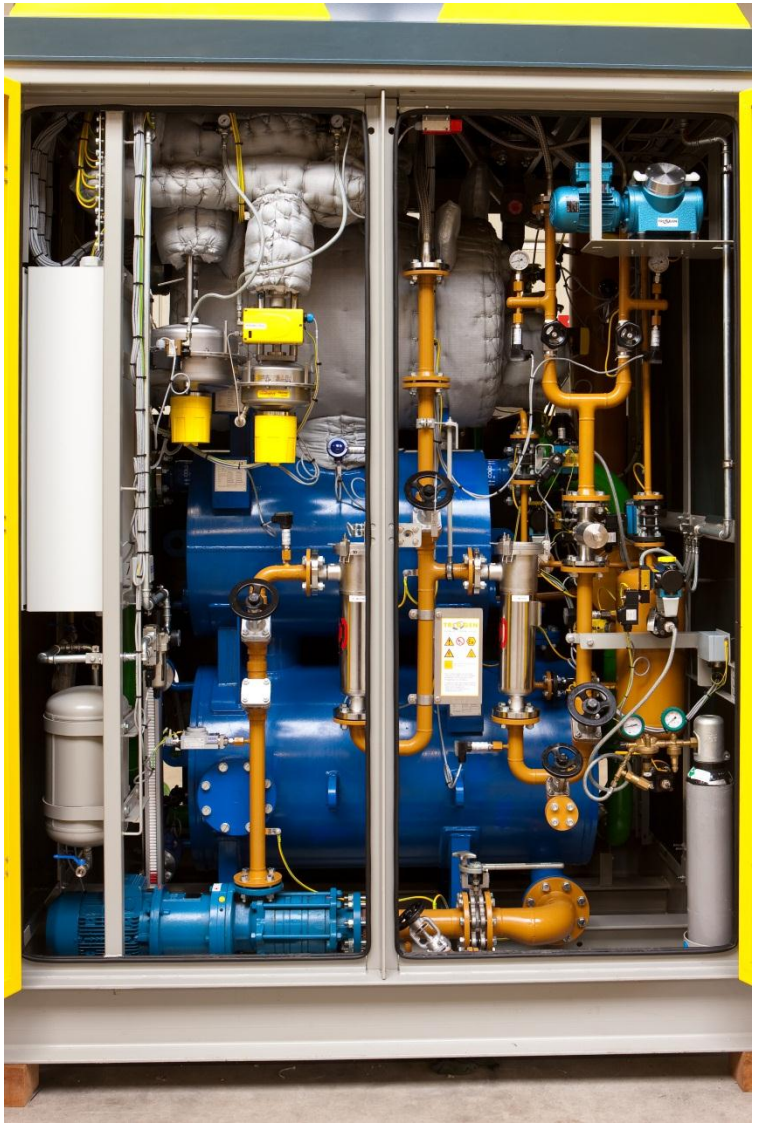
THE TRIOGEN ORC



PACKAGE DATA

- Dimensions within standards for road transport
- Two separated compartments for ORC process and heat supply (evaporator) on one skid
- Gross weight 12 tons, Foot print approx.15 m^2
- Electrical output at 380/400 V, 3 phases, direct grid connection
- Internet connection for remote monitoring and operation
- Operates smoothly under different input heat conditions
- CE marked including FMEA and HAZOP studies under supervision of Lloyds

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MODULARIZED PLANT DESIGN

Four Modules:

1. Standard evaporator, sized to take the available heat-energy
2. Standard Process Module, containing turbogenerator, recuperator, condenser, working fluid inventory, pre-feed pump, valves & piping, instrumentation
3. Standard heat rejection module, to cool the condenser continuously or sized as a back-up for other heat users
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.

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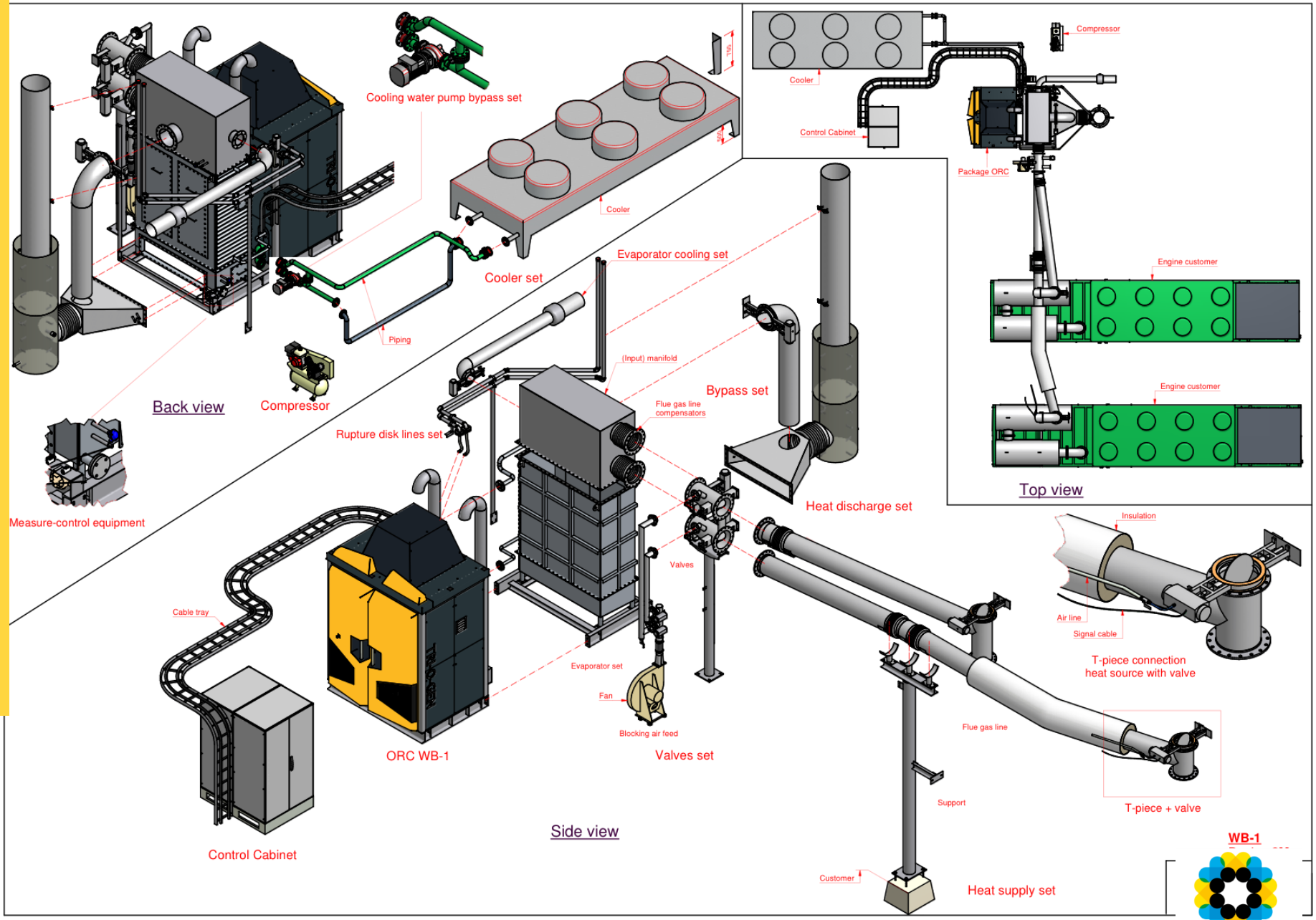
Cooling water pump bypass set
Cooler
Cooler set
Piping
Back view
Compressor
Measure-control equipment
Evaporator cooling set
(Input) manifold
Rupture disk lines set
Flue gas line compensators
Bypass set
Heat discharge set
Valves
Cable tray
Evaporator set
Fan
Blocking air feed
ORC WB-1
Valves set
Control Cabinet
Side view
Compressor
Cooler
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
T-piece + valve
Support
Customer
Heat supply set
WB-1

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APPLICATIONS for Electricity from Biomass

- Solid biomass can not be used directly for generation of electricity
- Biomass can be combusted in furnaces and boilers
- Flue gasses from furnaces can be fed to ORC evaporator
- Triogen system can absorp high temperature (< 600 C) flue gas
- High temperature flue gas heat suitable for conversion into electricity
- Low temperature residual heat is still available for heating and drying purposes
- To plants in operation/commissioning in Italy, three plants on order in Italy, Czech Republic and Slovakia.
- Evaporator with special cleaning device to remove flue gas dust

REFERENCES

- AD Digester gas engines:
  - 7 plants in operation in The Netherlands
- Landfill gas engines:
  - 2 plants in France (Suez)
  - 2 plants in Portugal (AdP)
  - 1 plant in Germany
- Landfill gas direct combustion:
  - Netherlands (prototype)
  - France: supplementary firing next to gas engines
- Natural gas engine:
  - 1 plant for greenhouse co-generation in The Netherlands
- Bio-diesel engine:
  - 1 plant in The Netherlands
- Direct combustion of solid bio-mass:
  - 1 plant operating in Italy
- Order back-log:
  - 10 plants in Belgium, Czech Republic, Slovakia, Latvia, Italy, Finland

- Achievements:
  - Total number of operating hours: > 250.000
  - Total Electricity produced: > 30.000 MWh
  - Demonstrated availability: > 97 %

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KLOOSTERMAN

Corn Fermentation plant

Since 2009, 34.000 hours

Heat source: 2 x 835 kW_e biogas engine

Electric power ORC: 155 kW_e

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EISSEN

Manure Co-Fermentation plant

Since 2009, 25.000 hours

Heat source: 2 x 646 kW_e biogas engine

Electric power ORC: 125 kW_e

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VAR

Fermentation of municipal organic waste

Since 2011, 19.000 hours

Heat source: 2 x 1,1 MW_e biogas engine

Electric power ORC: 155 kW_e

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GERMANY: Landfill site

Landfill Gas Utilization plant

Since October 2011, 14.000 hours

Heat source: 2 gas engines (835 kW_e + 1000 kW_e)

Electric power ORC: 150 kW_e

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FRANCE: 2 Landfill sites (GdF – Suez)

Landfill Gas Utilization plants

Since July 2011, 10.800 + 9.500 hours

Heat sources: 2 gas engines @ 1 MW_e + flaregas burner each

Electric power ORC: 150 kW_e each

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PORTUGAL: 2 Units at Landfill site (AdP)

Landfill Gas Utilization plant

Since September 2011, 15.000 + 14.000 hours

Heat sources: 2 gas engines @ 1 MW_e each

Electric power ORC: 150 kW_e each

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BELGIUM: BiogasTec

Manure Co-Fermentation plant

To be commissioned: August 2013

Heat sources: 2 gas engines @ 1,4 MW_e each

Electric power ORC: 150 kW_e

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Wood burning plant in Italy

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