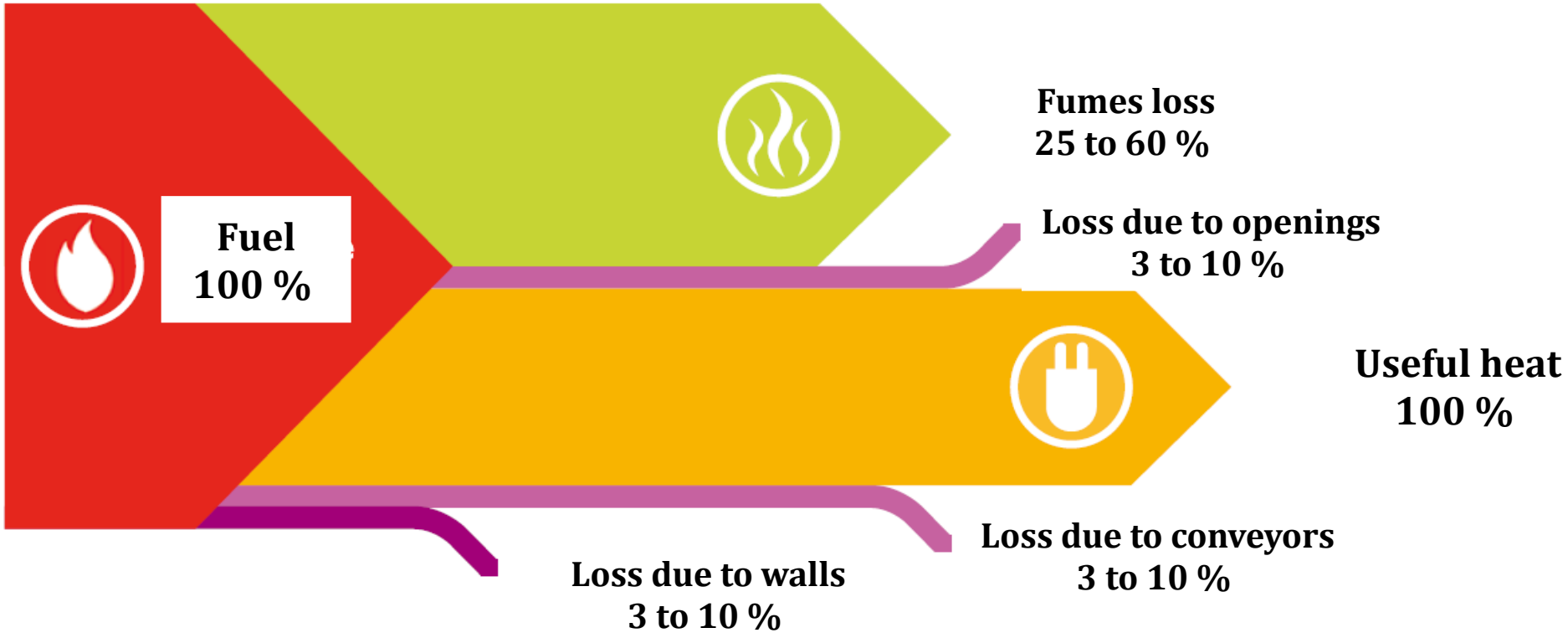
Nicolas Bernier, 5ft June 2018

Waste Heat Recovery using Organic Rankine Cycle turbines

Industrial waste heat : the example of France (1)

Heat balance , fuel furnace, permanent regime

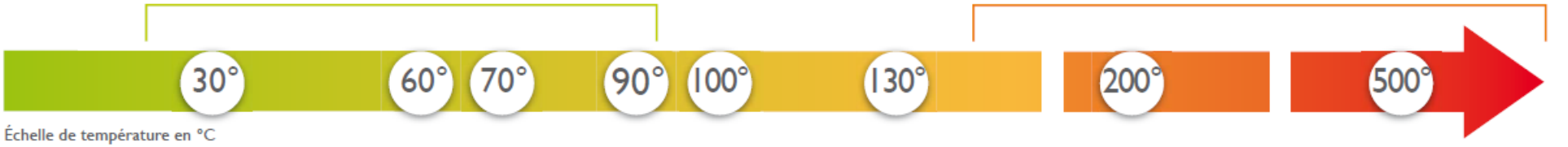


Source : ADEME (2014)

Industrial waste heat : the example of France (2)

Typically : agro, paper, chemical industry

Typically : steel mill, cement & glass factories



Échelle de température en °C

Liquid discharge

Très basses températures :
eaux usées résidentiel - tertiaire

Basse température :
eaux de refroidissement
(compresseurs air et froid,
four à induction, etc.) et lavage

Moyenne température :
eaux de refroidissement
(pièces à haute température,
moule de fonderie, etc.)

Haute température : purges de chaudières,
condensats de vapeur, etc.

Gaseous discharge

Air de conditionnement

Air chaud : de séchage,
de compresseur
(froid et air comprimé),
de refroidissement de pièces

Buées

Vapeur de procédé
ou de flash

Essentiellement gaz de combustion
(four industriel, chaudière, incinérateur, turbine, etc.)

Basse température

Moyenne température

Très haute température

Diffuse discharge

Défauts d'isolation des canalisations,
des parois et ouvertures non fermées (four, séchoir, etc.)

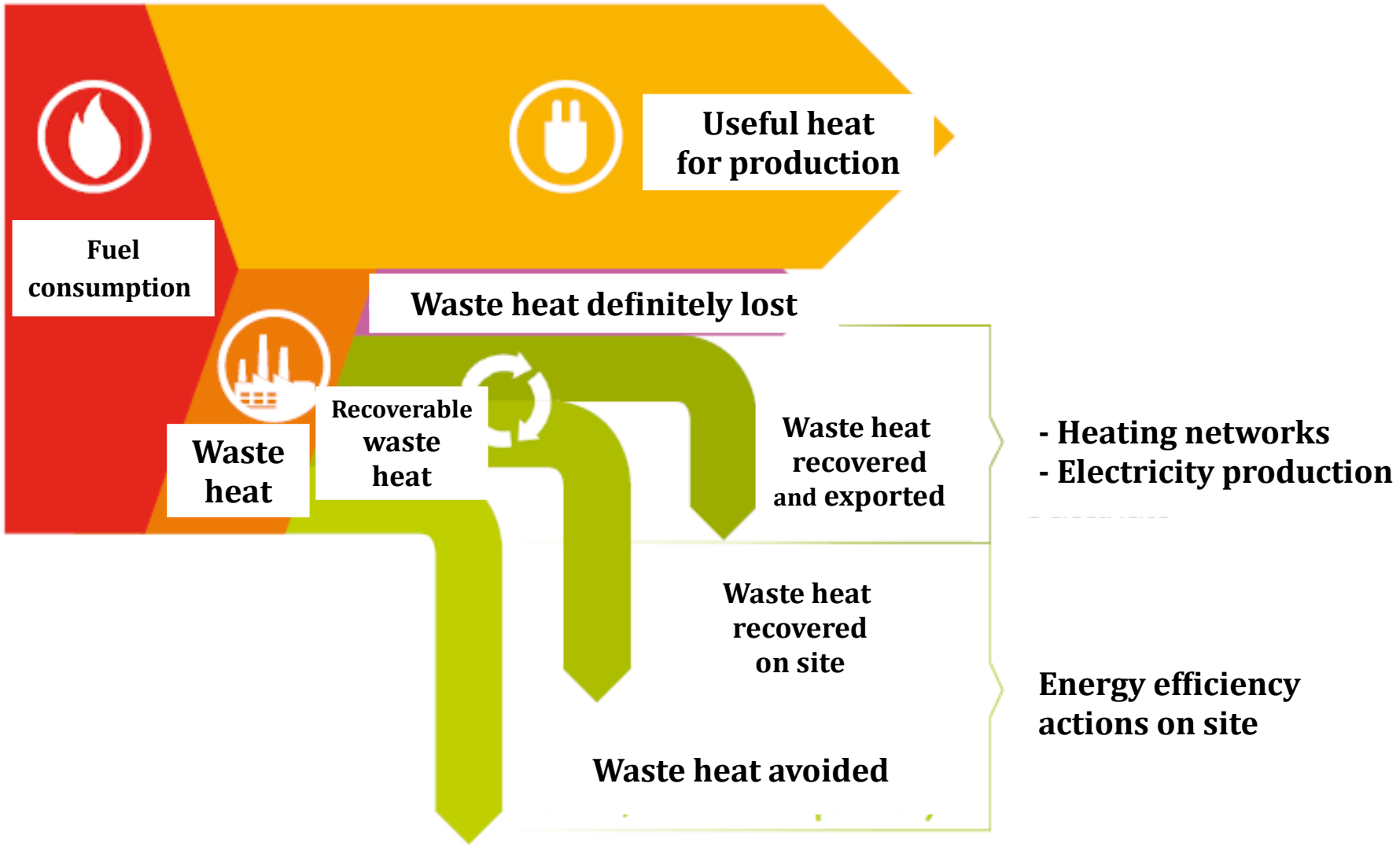
Refroidissement naturel des
produits : métaux, céramique, etc.

Chaleur rayonnée (convoyage brame d'acier, etc.)

Secteurs industriels, origines et caractéristiques des rejets thermiques donnés à titre indicatif.

Source : ADEME (2014)

Industrial waste heat : the example of France (3)



Source : ADEME (2014)

Industrial waste heat : the example of France (4)

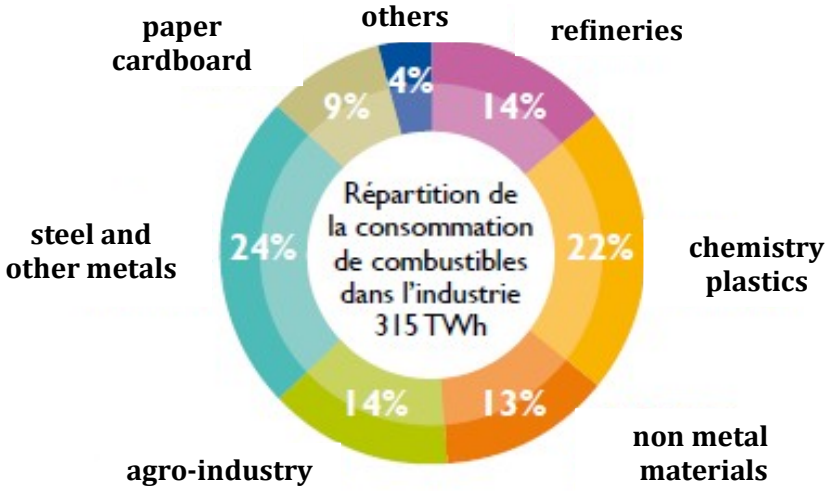
Figures in brief

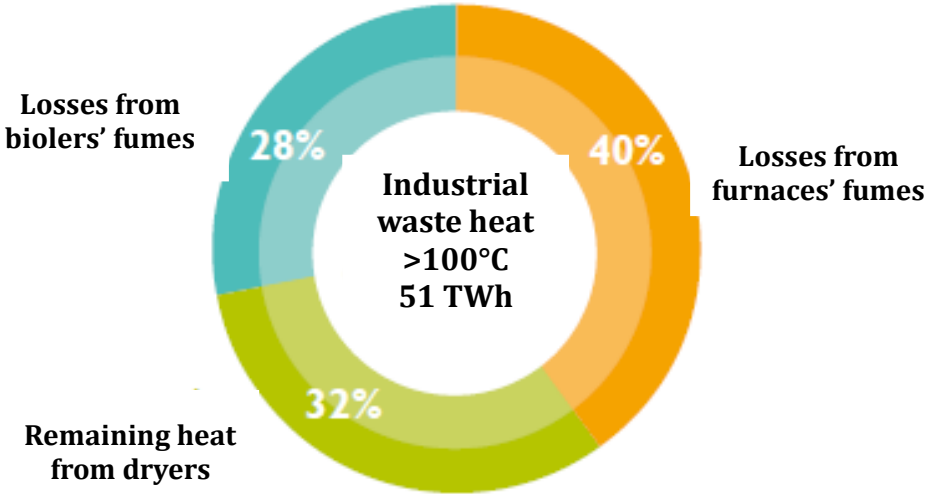
319 TWh : **275 TWh (industry)**
44 TWh (refineries)

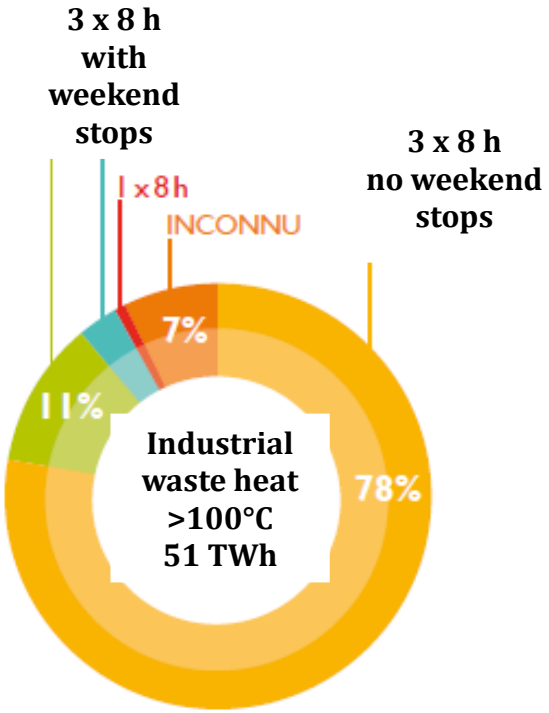
process : furnaces, dryer, boilers

temperature > 100°C

fumes, vaporized fluids



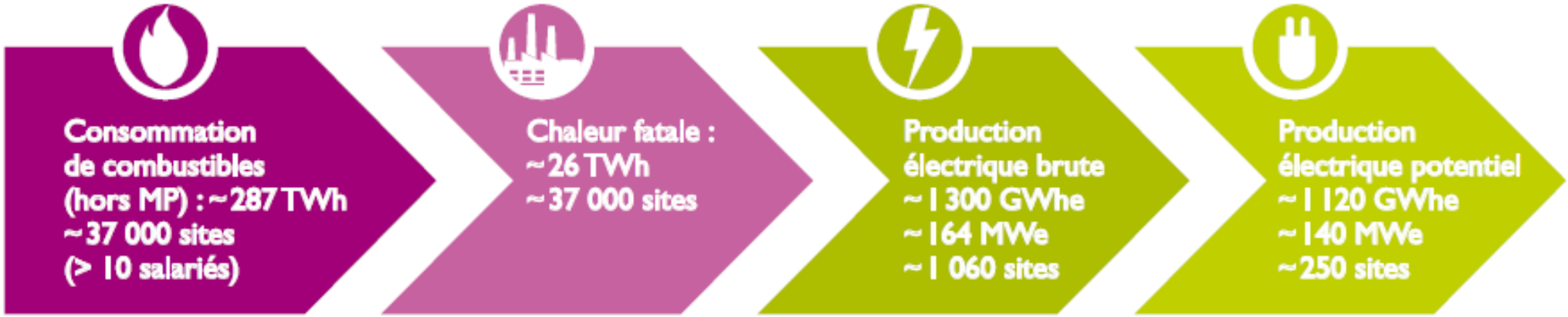




Source : ADEME (2014)

Industrial waste heat : the example of France (5)

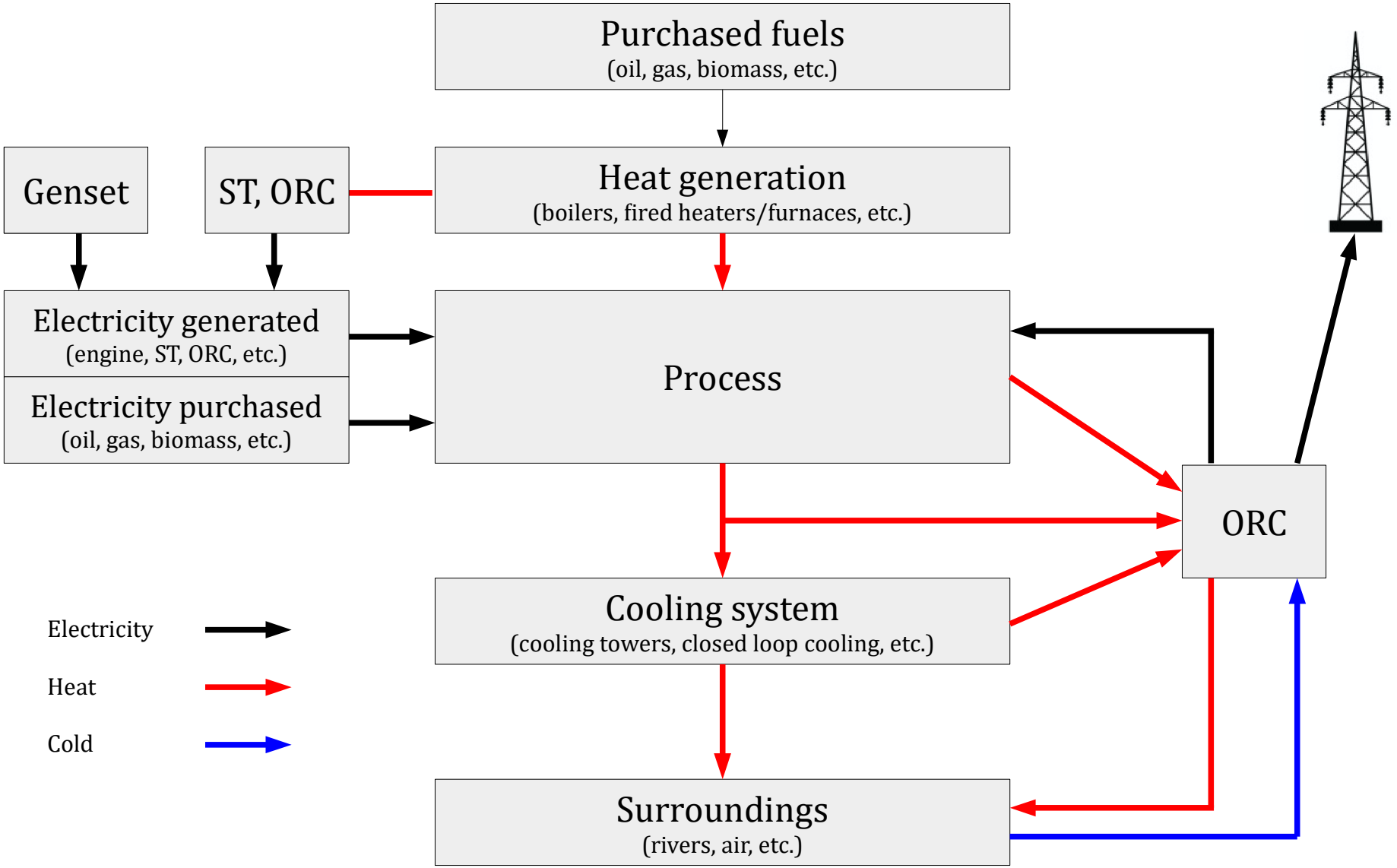
1,1 TWh
250 sites
1,400 MWe potential



Fuel consumption | **Waste heat** | **Gross power production** | **Net power production**

Source : ADEME (2014)

Industrial Waste Heat Recovery



Organic Rankine Cycle

Expanding heat to power scope of possibilities

FLEXIBLE

EFFICIENT

RELIABLE

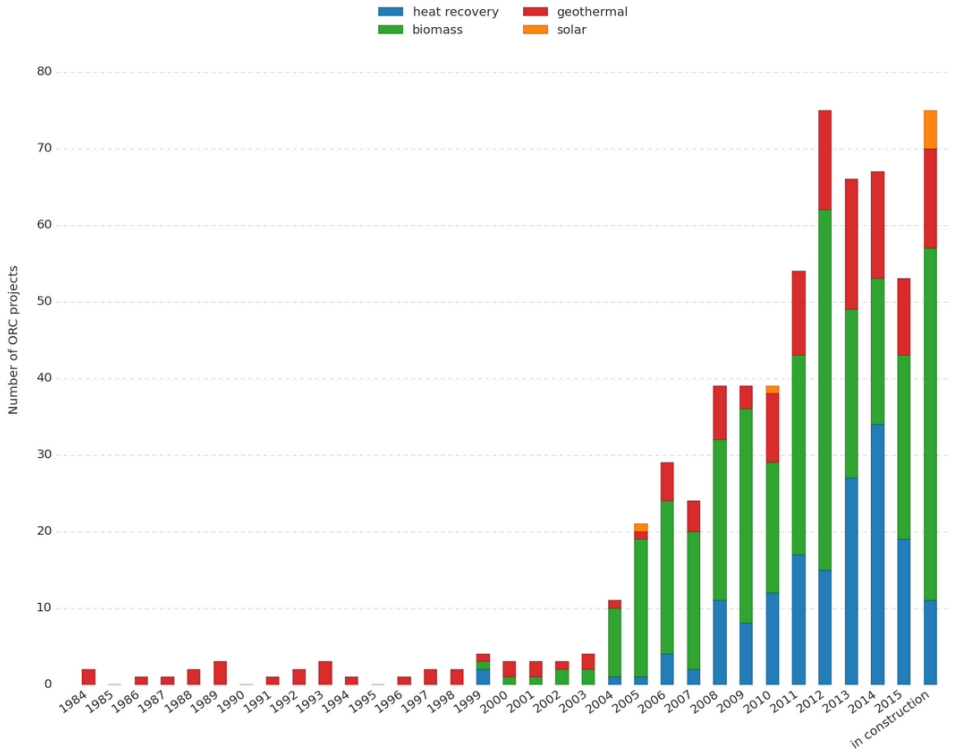
- no fuel
- no combustion
- no emissions
- no chemicals*
- no need for high pressure
- suitable with temperatures as low as 80°C

* hot loop

WHR using ORC technology in the world

In operations for 35 years, producing more than 3,000 MW worldwide!

Source : orc-world-map.org (2015)



More players since the years 2000

ORMAT · TURBODEN · EXERGY · KAISHAN

ENOGIA · AQYLON Smarter Power · enertime · DÜRR

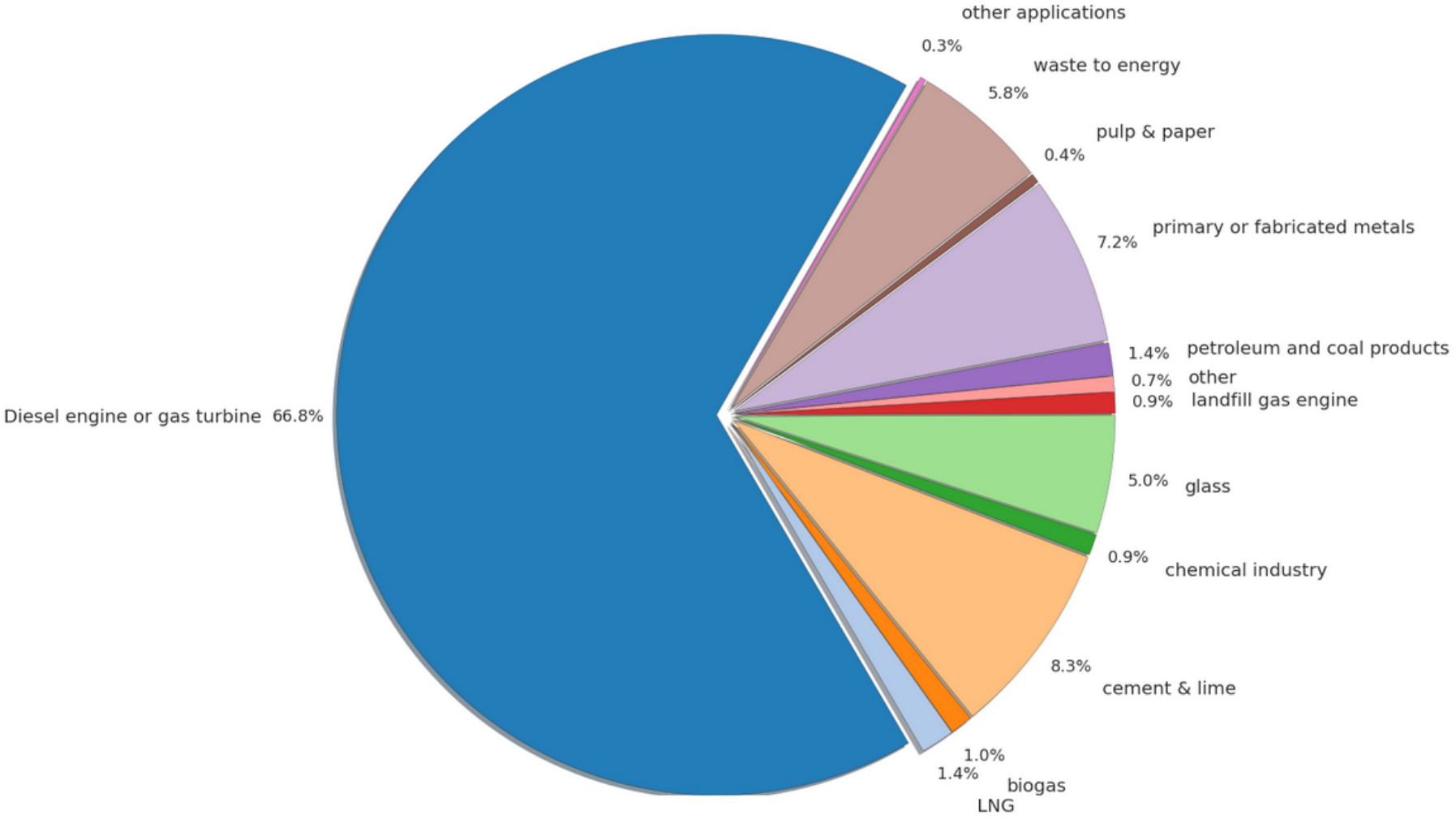
TAS · ELECTRA THERM BY BITZER GROUP · GE Power · CLIMEON

ADORATEC · maxxtec · SIEMENS · ABB

E-RATIONAL VALUE FOR HEAT · CALNETIX TECHNOLOGIES · gT Energy Technologies · Verdicorp

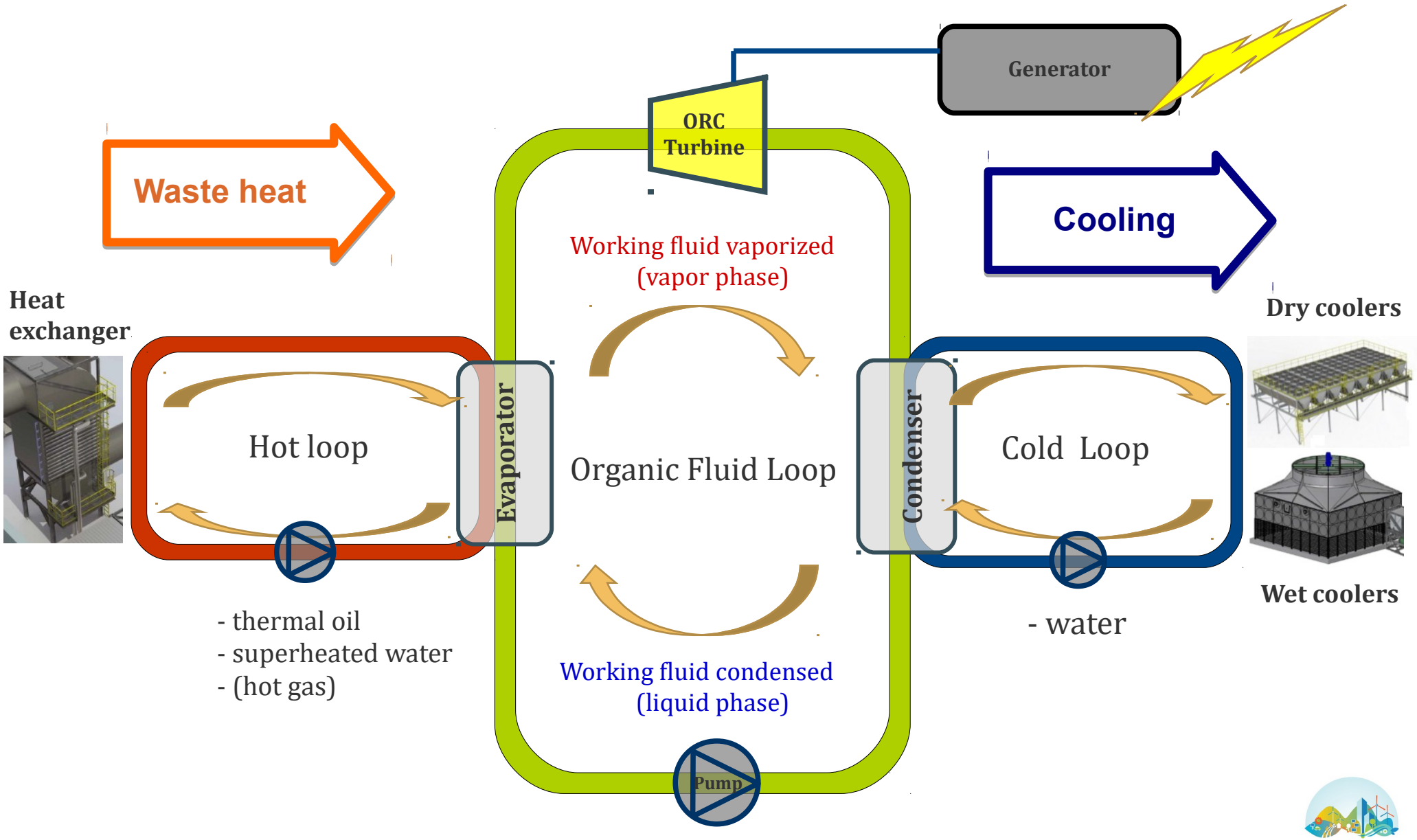
ASIA CLEAN ENERGY FORUM 2018

WHR using ORC technology : types of activities

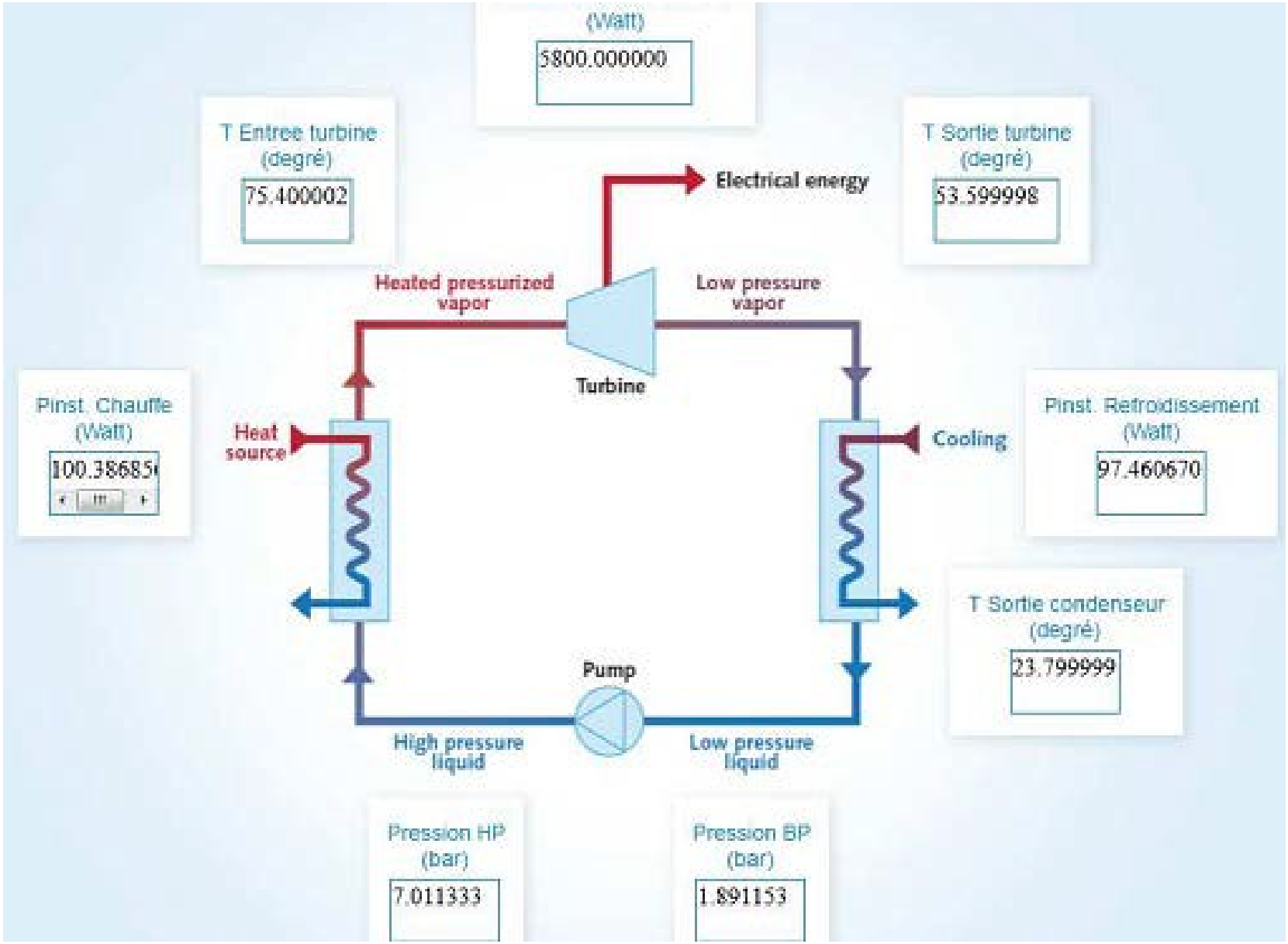


Source : orc-world-map.org (2015)

Reminder of Organic Rankine Cycle (ORC) technology



Figures for a very low enthalpy waste heat recovery



Comparative table between ST and ORC solutions (1)

	Steam turbines	ORC turbines
Hot loop		
fluid	purified water steam	thermal oil or superheated water
pressure	20 to 300 bar	5-20 bar
temperature	250-550°C	80-330°C
chemicals	yes (water purification)	no
reheating device	yes (water purification)	no
Working fluid loop		
fluid	dry purified water steam (HP)	« organic » fluid
	possible droplets at LP stages	
water consumption	yes	no
pressure inlet turbine	20 to 300 bar	5-20 bar
temperature inlet turbine	250-550°C	80-330°C
pressure oulet turbine		< 2 bar
temperature outlet turbines	100-45°C	~60°C
CHP	possible	possible
Turbine		
blades	up to tens of stages	1 to ~15
diameter	up to several meters	10 to 60 cm
rotation speed	1800-3600 rpm	up to 1800 rpm

Comparative table between ST and ORC solutions (2)

ORC *versus* steam turbines technologies

	ST	ORC
Availability	80-90%	98%
Load variation	-5/+5%	-60/+120
Pressure, temperature	High	Low
Corrosion (efficiency decrease)	Yes	No
Lifetime	15	20-25
Water consumption, chemicals	Yes	No
Maintenance, OPEX	High	Low

Financial benefits choosing ORC tech.

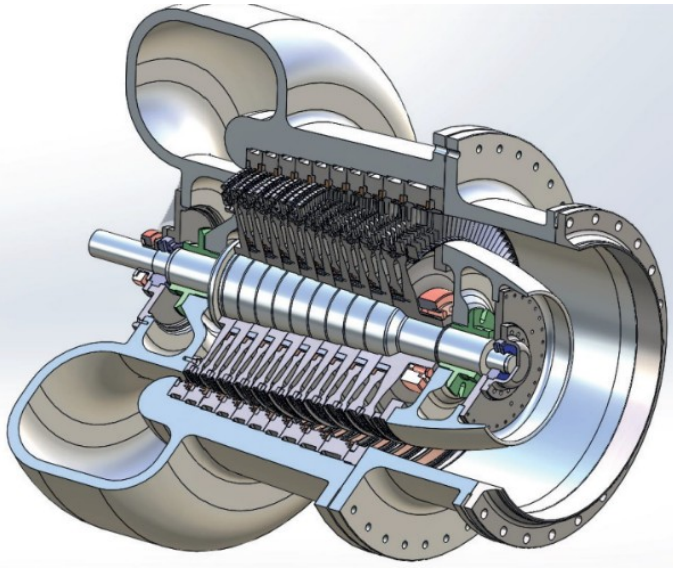
	ST	ORC
CAPEX	+	-
Installation and commissioning	-	+
Exploitation, availability (incomes)	-	+
Maintenance, OPEX	-	+
Value and options at the end of the PPA	-	+
Overall benefits at the end of the PPA	**-**	**+**

Steam and ORC turbines

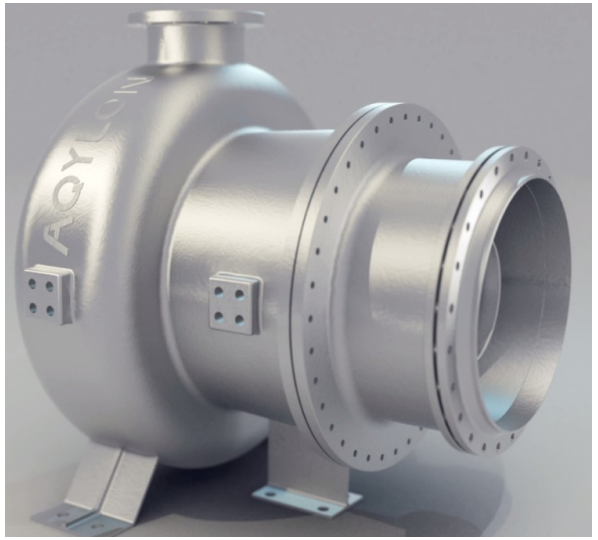
Steam turbine

LP stages

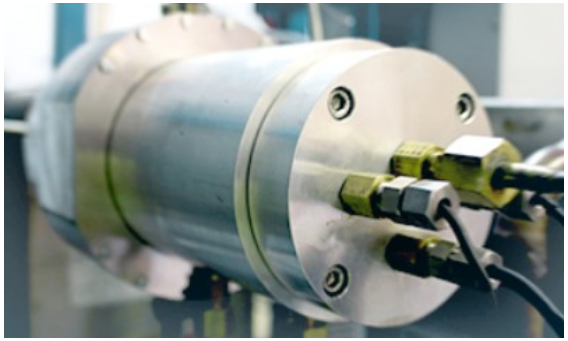
HP stages



ORC turbine



Turbo expander: combination of a micro turbine with an integrated generator



Potential applications are not only ORC but also C02 cycle, natural gas expansion, process gas expansion, hot air energy recovery

Various ORC applications

Biogas, landfill gas

- Enhancement of biogas engine via exhaust, water jacket or both
- Direct biogas to electricity conversion with boiler

Solar

- Solar CHP with CSP field
- Solar CHP with CSP and heat storage

Biomass

- Biomass to electricity
- Biomass CHP
- Isolated site

Geothermal

- Natural hot sources
- Medium temperature wells (from 80°C)

Renewable Energies

Industrial Waste Heat Recovery

- Process Heat
- Exhaust gases
- Waste steam

Diesel and gas gensets

- Efficiency enhancement via exhaust, water jacket or both

Transportation

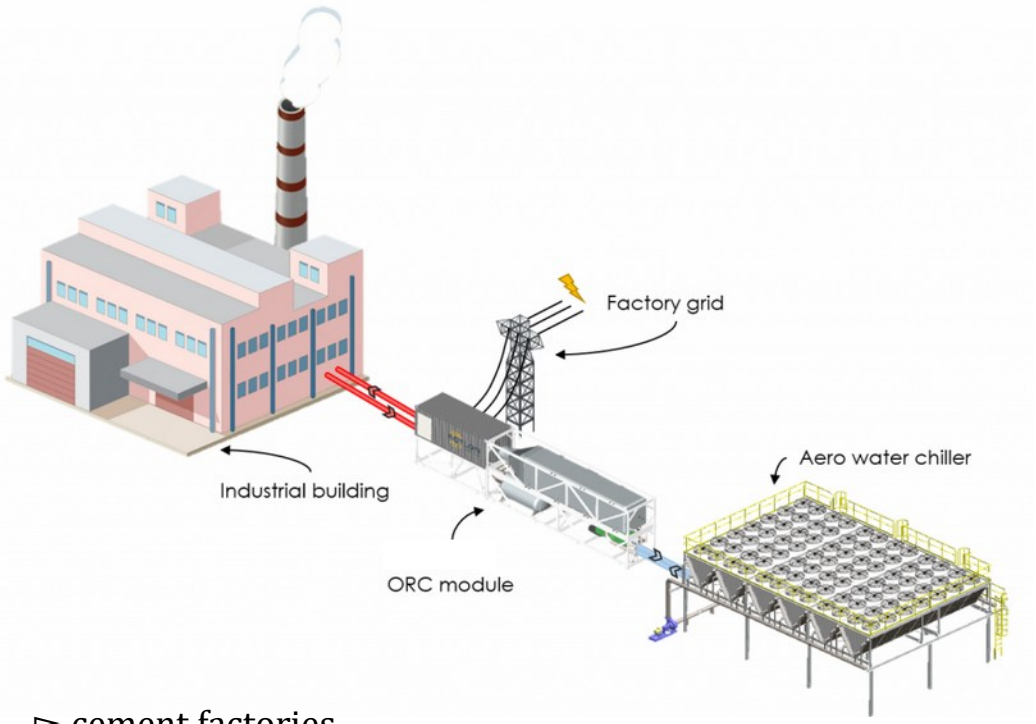
- Vessels
- Railroad
- Heavy Duty Trucks

Education and research

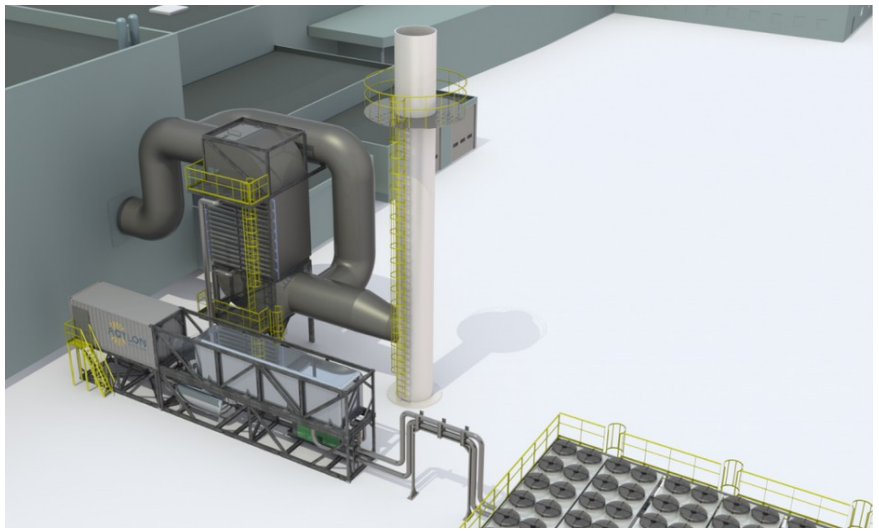
- With boiler simulating heat source

Energy Efficiency

Industrial waste heat recovery



- fumes
- industrial process
- excess steam



- cement factories
- still mills
- foundries
- glass furnaces
- refineries
- aluminium smelters
- incinerators
- plants treating sewage through incineration
- paper factories
- agro-industry
- etc.

Waste Heat Recovery using ORC turbines

Case study : cement factory (1)

- Flue gas outlet temperature from all sources : 180°C

Hot source

Thermal oil loop

Recuperators (Heat exchanger on flue gas)

High temperature loop inlet temperature: 290°C

High temperature loop outlet temperature: 140°C

Thermal oil loop data:
- Thermal oil mass flow : 79.1kg/s
- Thermal power recovered: 26 713 kW
- Electrical consumption : 20 kW

Flue gas data from hot source 1 :
- Mass flow : 25.4 kg/s
- Available temperature : 377°C
- Recovered heat : 5 220 kW
- Flue gas pressure loss in the heat exchanger : <1,5kPa

Flue gas data from hot source 2 :
- Mass flow : 123.2 kg/s
- Available temperature : 339°C
- Recovered heat : 20 315 kW
- Flue gas pressure loss in the heat exchanger : <1,5kPa

Flue gas data from hot source 3 :
- Mass flow : 7.1 kg/s
- Available temperature : 339°C
- Recovered heat : 1 178 kW
- Flue gas pressure loss in the heat exchanger : <1,5kPa

2 X ATM-3000H

6 266 kW gross
(Efficiency: 23,45 %)

5 952 kW net
(Efficiency: 22,28 %)

Net power solution: 5 742 kW
Efficiency: 21.49%

Cold source

Cooling water loop

Outlet temperature: 45°C

Inlet temperature: 35°C

Cold source data:
- Thermal power dissipated: 20 402 kW
- Water mass flow rate: 487.9 kg/s
- Ambient temperature (annual average) : 25 °C
- Electrical consumption of the circulation pump: 58 kW
- Electrical consumption of the dry coolers: 134 kW

Case study : cement factory (2)

Scope / Investment

2x ATM-3000H (2 x ORC 3000 kWe)

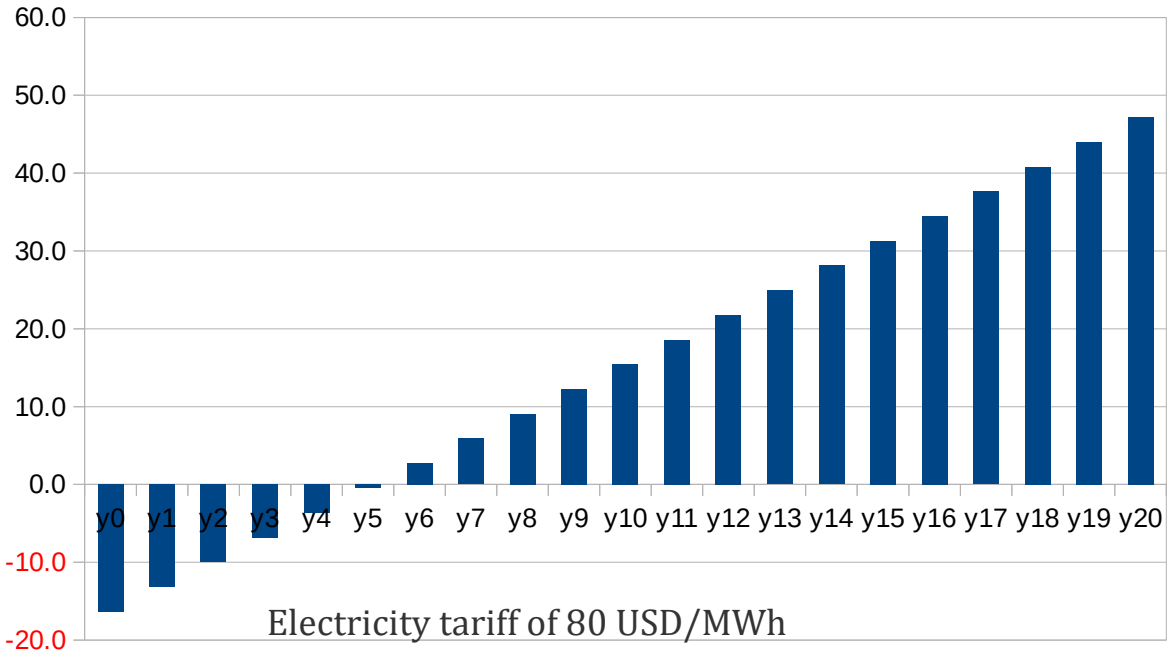
Estimated CAPEX for turnkey PP :	20 MUSD
Incentives :	0
Annual OPEX :	0.5 MUSD

Performance

Net production :	5742 kWe
ORC availability :	8500 h (97 %)
Global availability :	8000 h (91%)
Annual production :	45.936 GWh

Profitability

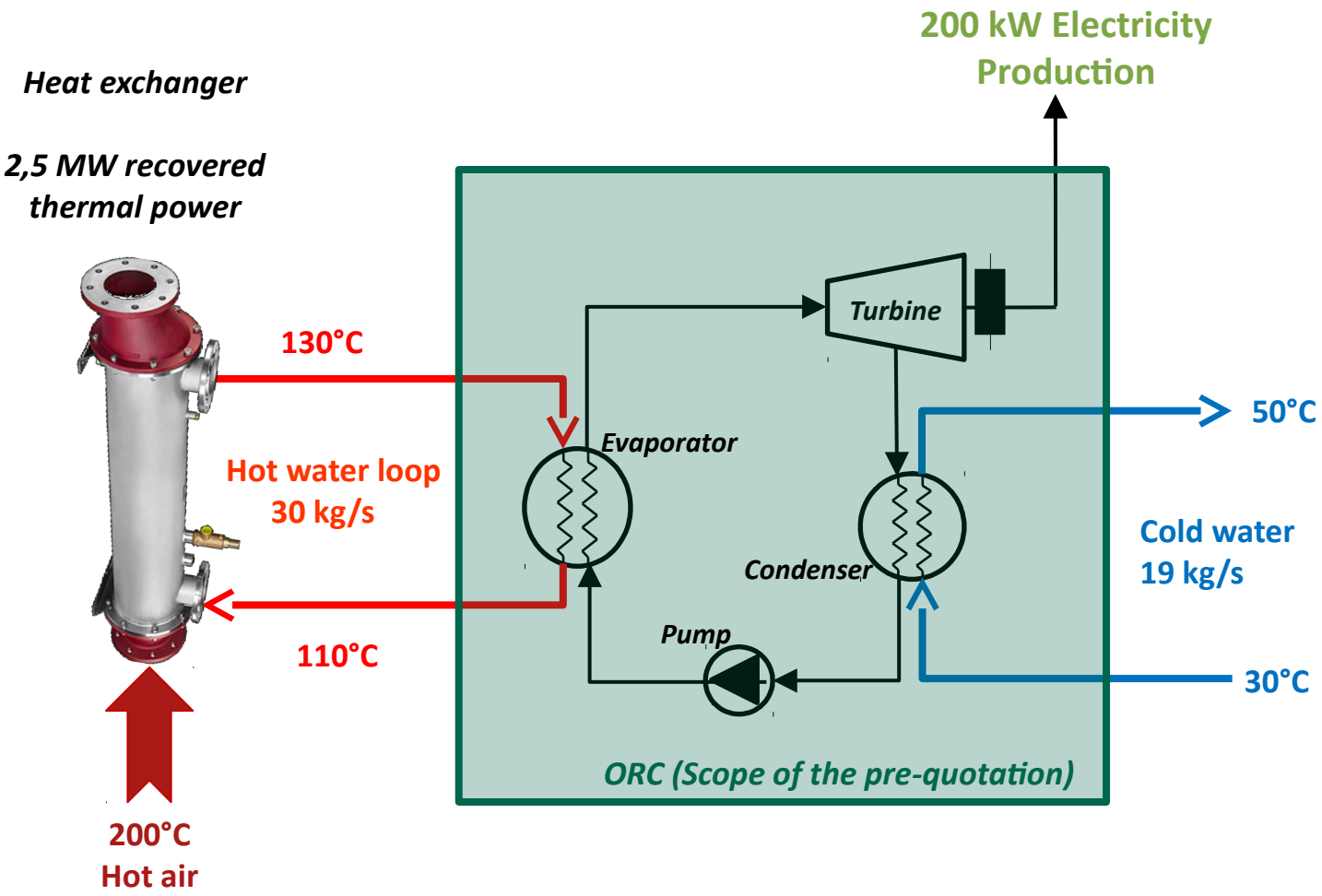
TRI (80 USD/MWh):	**6 years**
TRI (100 USD/MWh):	5 years
LCOE (10 years) :	54 USD/MWh
LCOE (20 years) :	32 USD/MWh

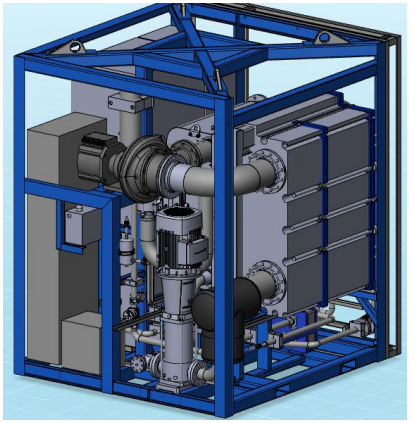


Case study : WHR from biomass dryer (1)

Charcoal and pelets factory:

recovering excess heat from the dryer





Case study : WHR from biomass dryer (1)

Scope / Investment

1x ENO-200LT (ORC 200 kWe)

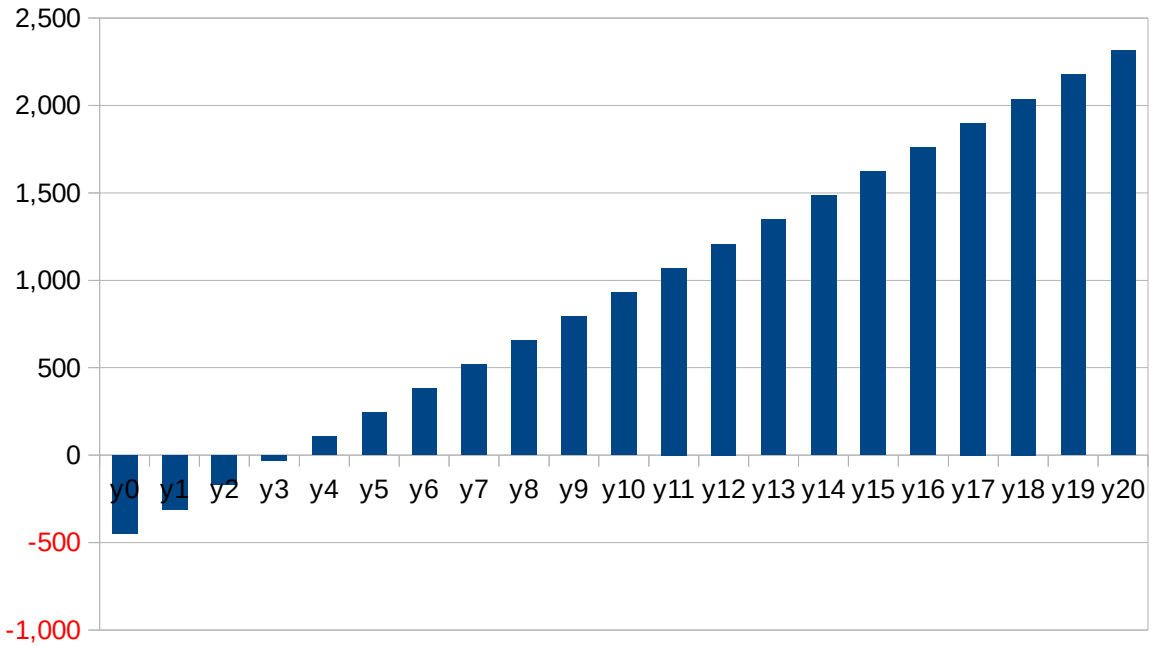
Estimated global CAPEX :	600 kUSD
Incentives :	0
Annual OPEX :	15 kUSD

Performance

Net production :	180 kWe
ORC availability :	8670 h (99 %)
Global availability :	8500 h (97%)
Annual production :	1,530 MWh

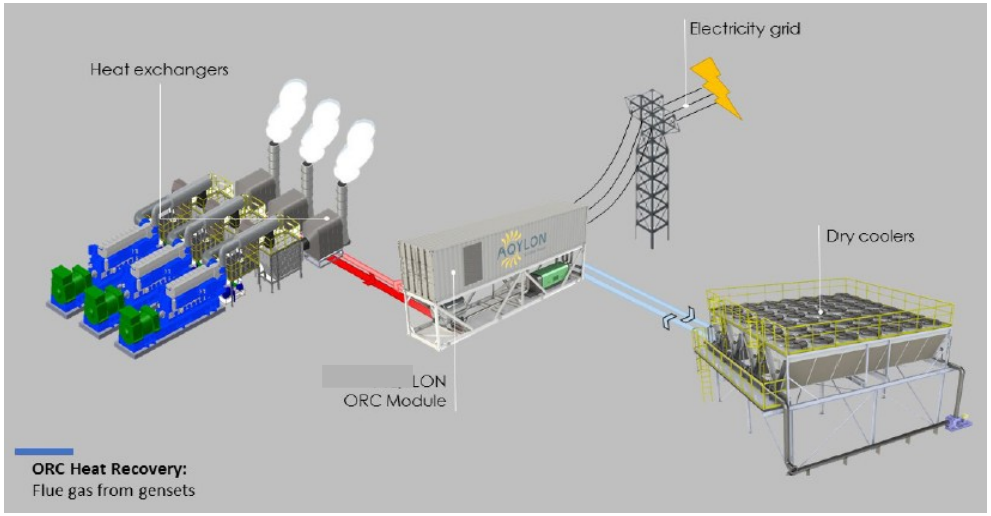
Profitability

TRI (100 USD/MWh):	4- years
LCOE (10 years) :	92,5 USD/MWh

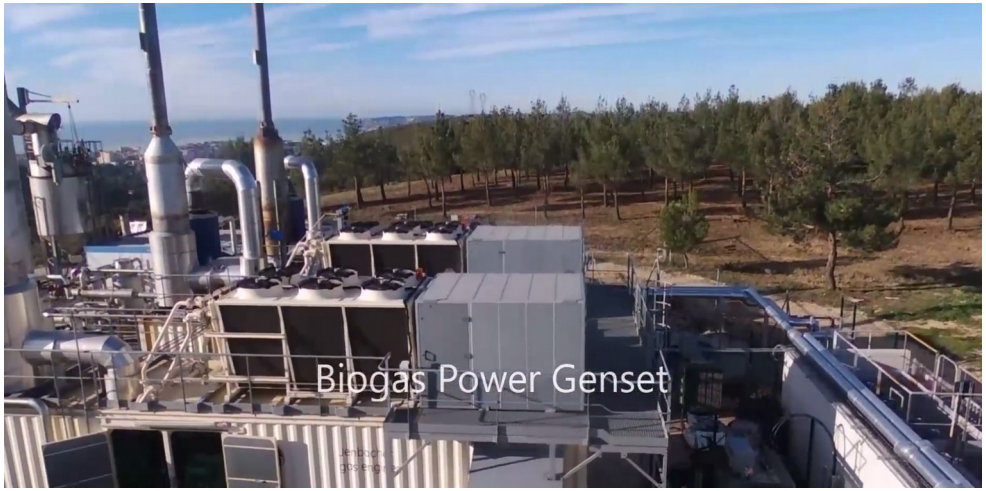


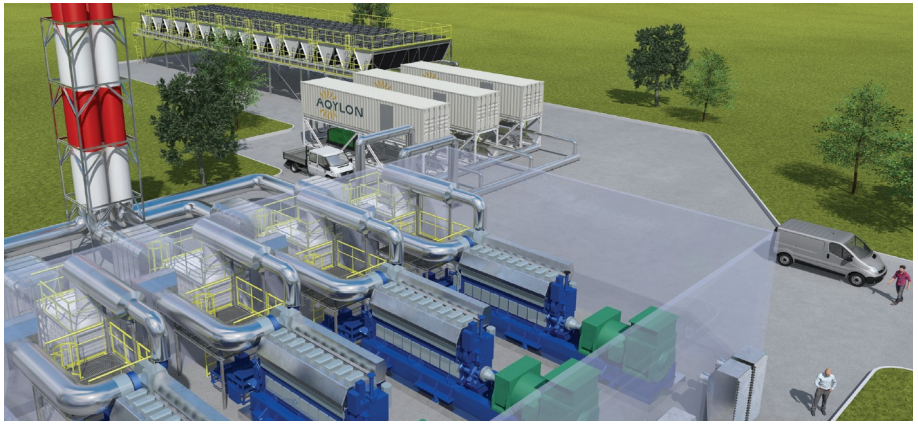
Electricity tariff of 0.1 USD/kWh

Internal Combustion Engines (ICE) heat recovery



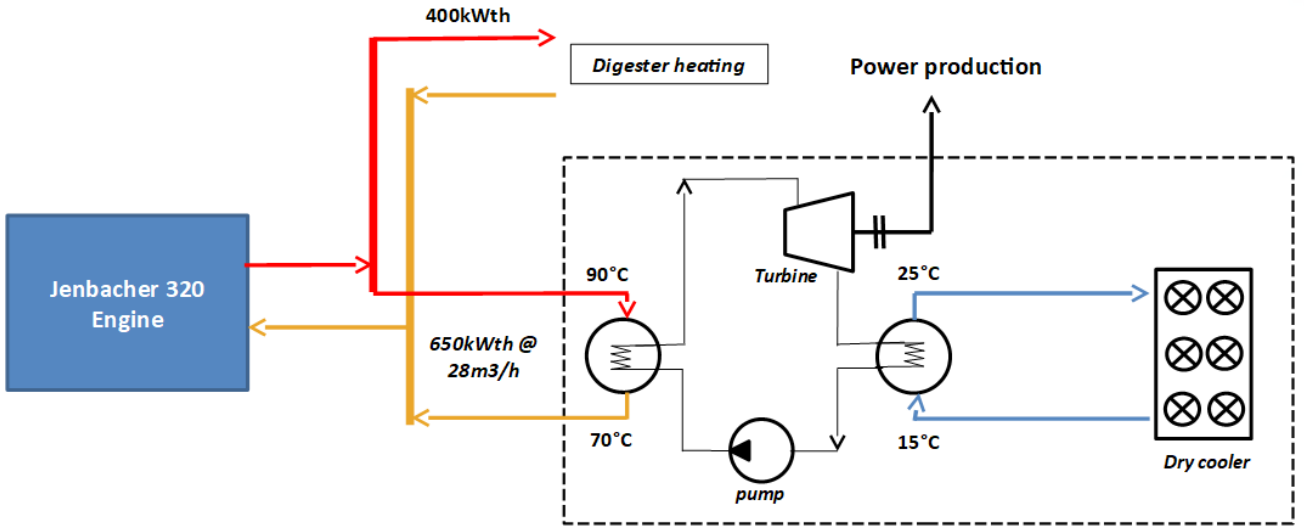
- Diesel, HFO, gas, biogas
- Exhaust gases and possibly jacket water heat the thermal oil with a heat exchanger
- Approximately 10% additional electricity is produced

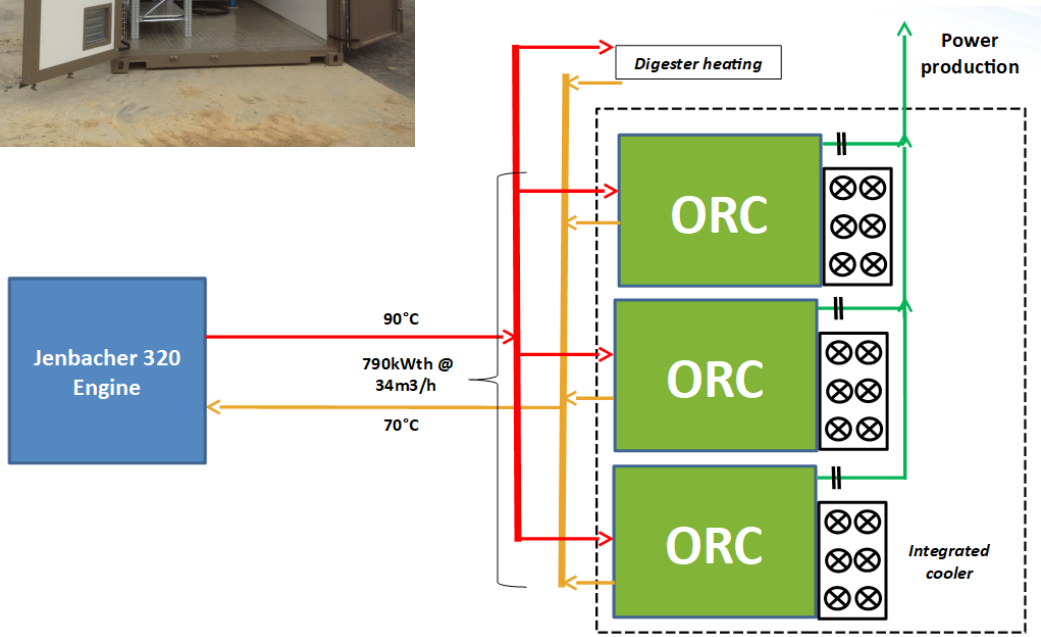




Case study : WHR from a biogas engine

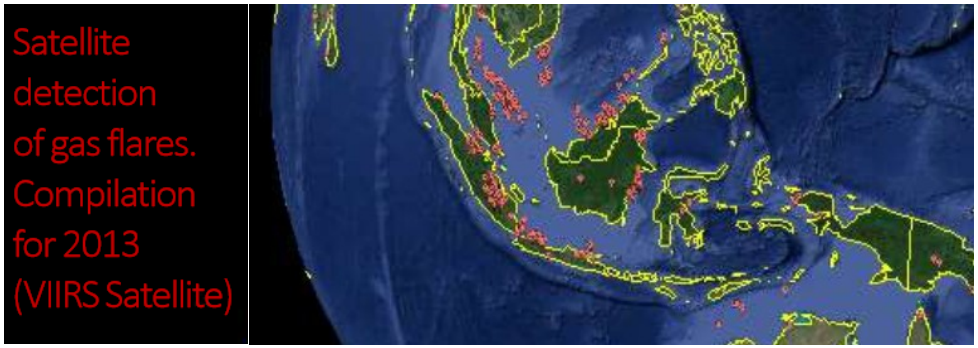
With a Jenbacher biogas eng

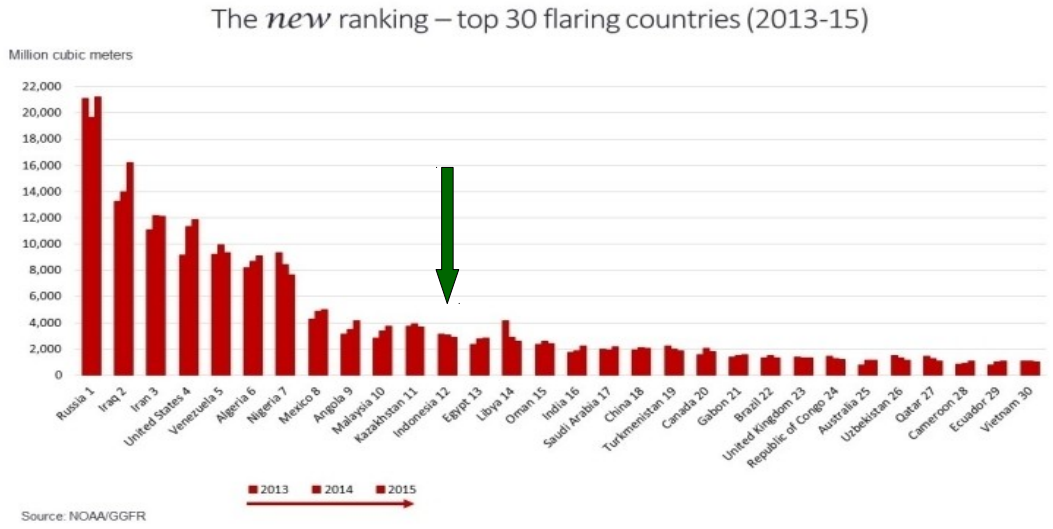


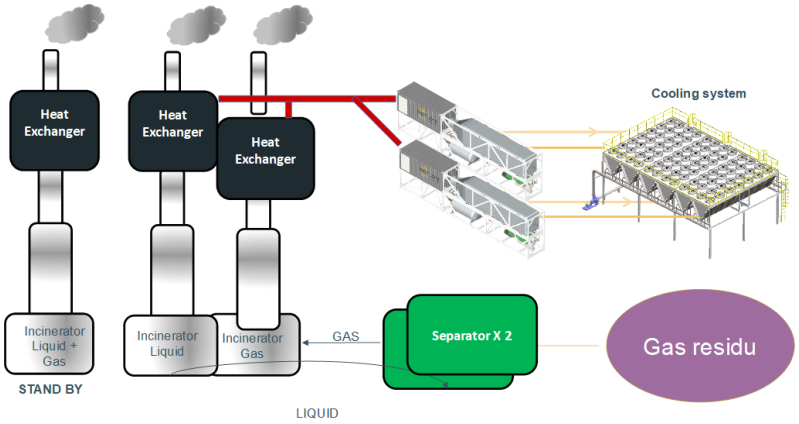


Gas flaring

- ORC technology provides a solution to reduce flaring and venting
- Low quality gases from well are diverted to a boiler (Thermal Oil Heater).



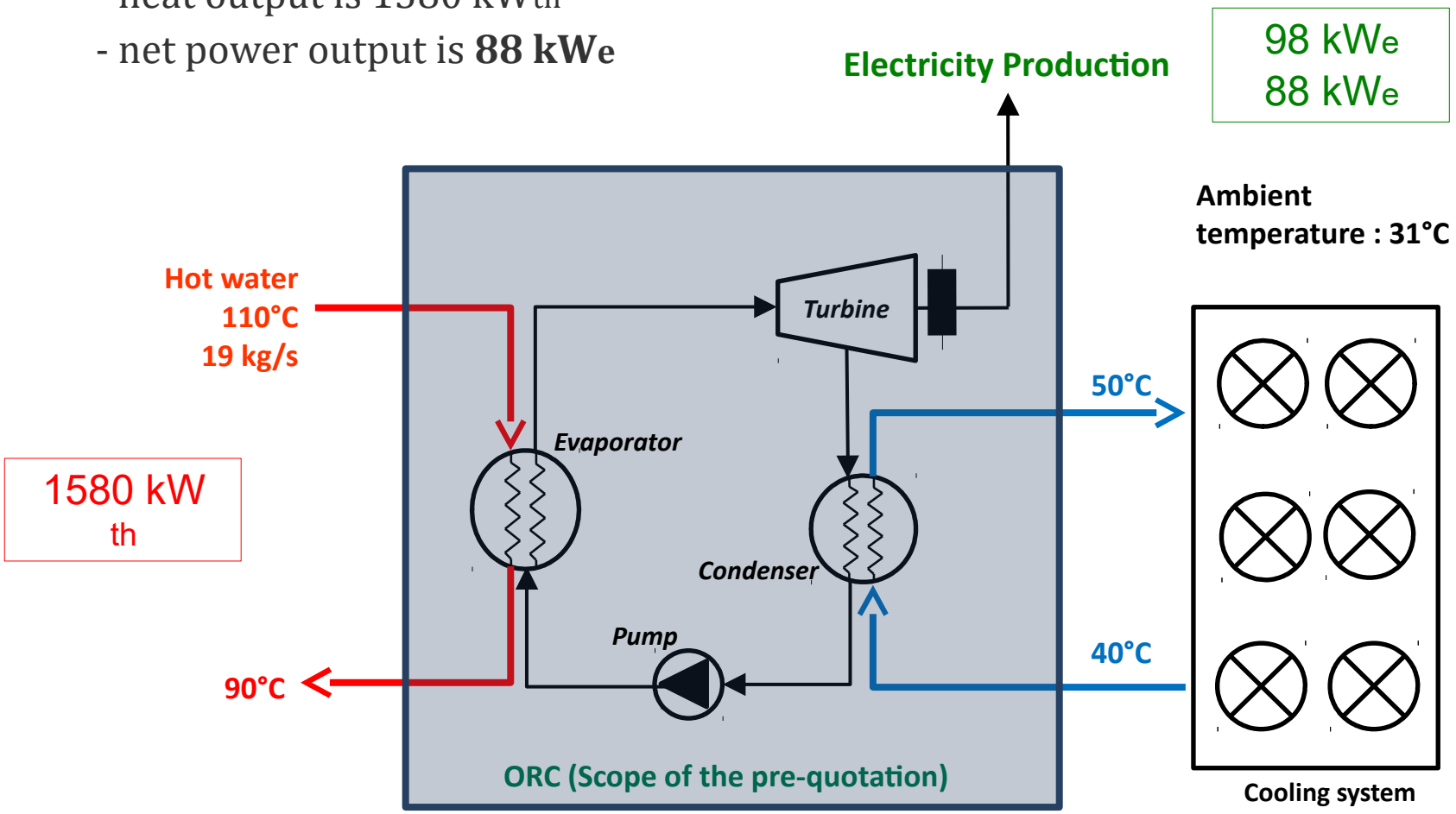




Case study: oil wells conversion –> geothermal (1)

The estimated recoverable :

- heat output is 1580 kWth
- net power output is **88 kWe**



Case study: oil wells conversion –> geothermal (2)

Scope / Investment

ENO-100LT (ORC 100 kWe)

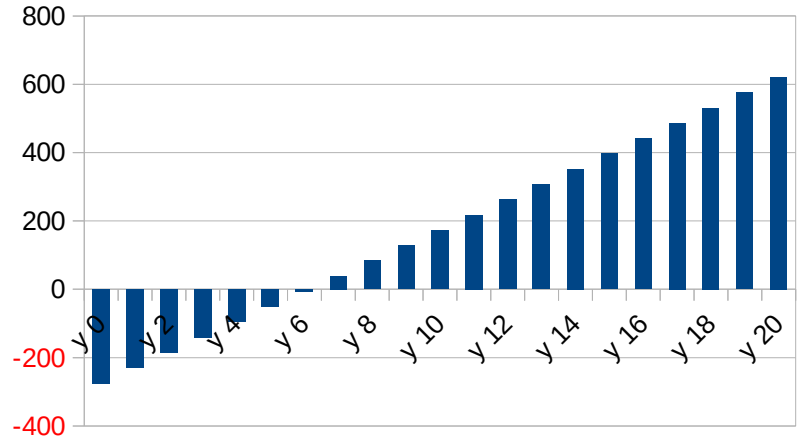
Estimated global CAPEX :	350 kUSD
Incentives :	0
OPEX :	30 kUSD

Performance

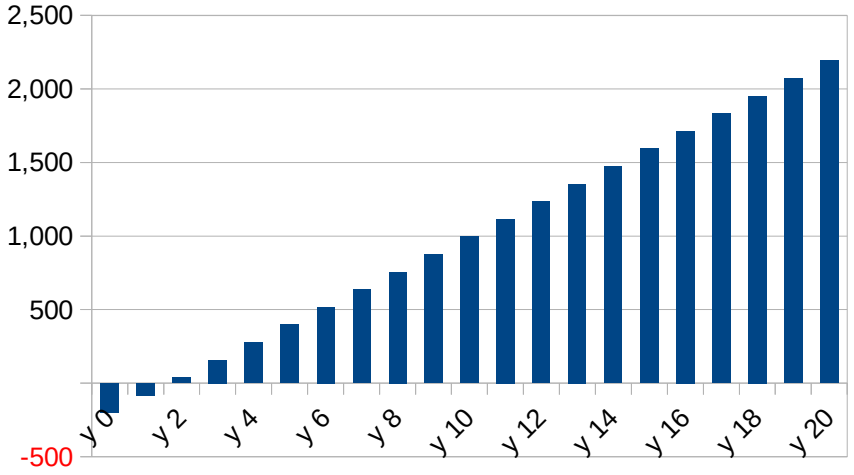
Gross production :	98 kWe
Net production :	88 kWe
ORC availability :	8670 h (99 %)
Global availability :	8500 h (97%)
Annual production :	748 MWh

Profitability

TRI (100 USD/MWh):	6+ years
TRI (200 USD/MWh):	3- years
LCOE (10 years) :	87 USD/MWh
LCOE (20 years) :	63,5 USD/MWh



Electricity tariff of 0.1 USD/kWh

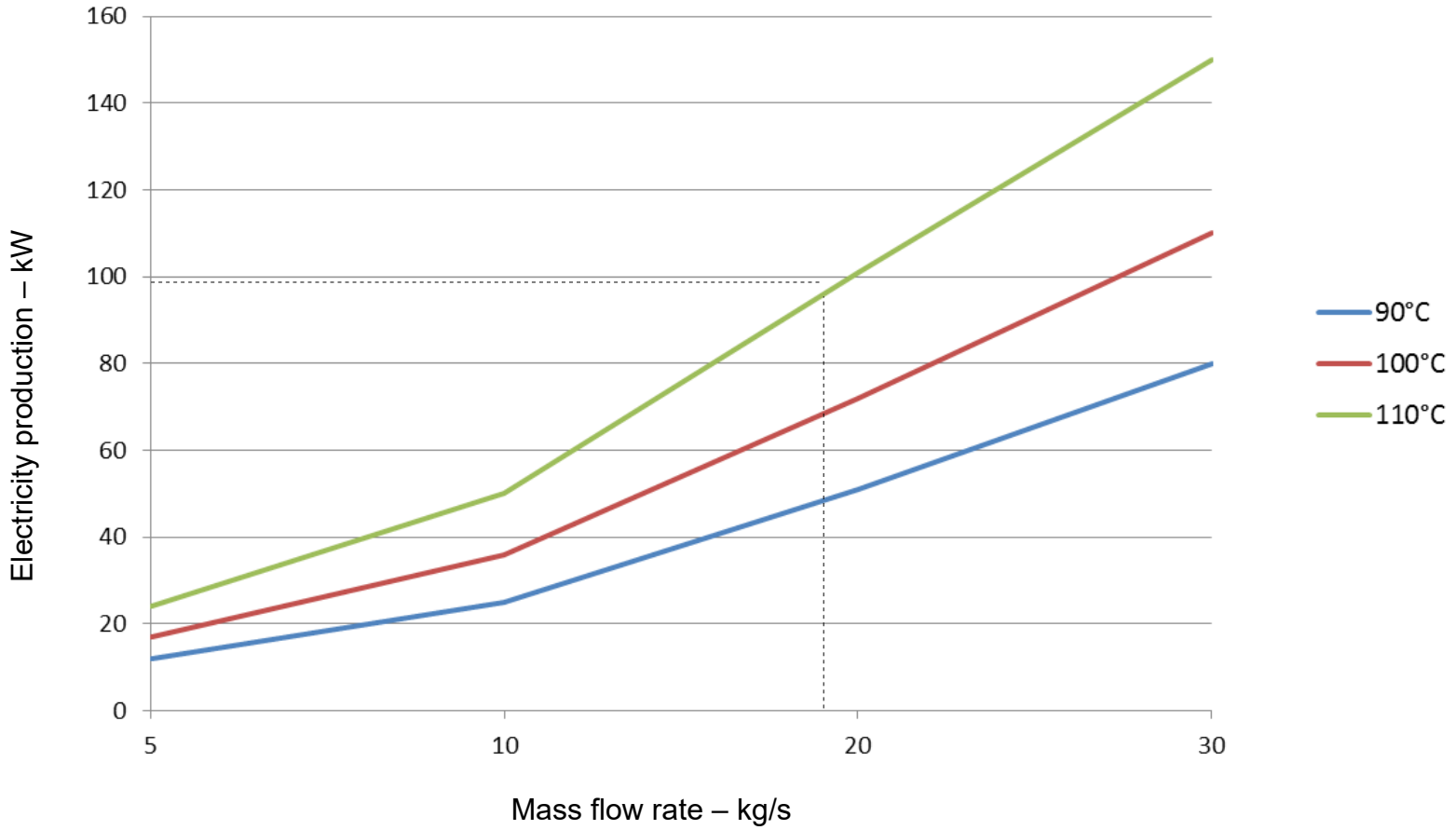


Electricity tariff of 0.2 USD/kWh

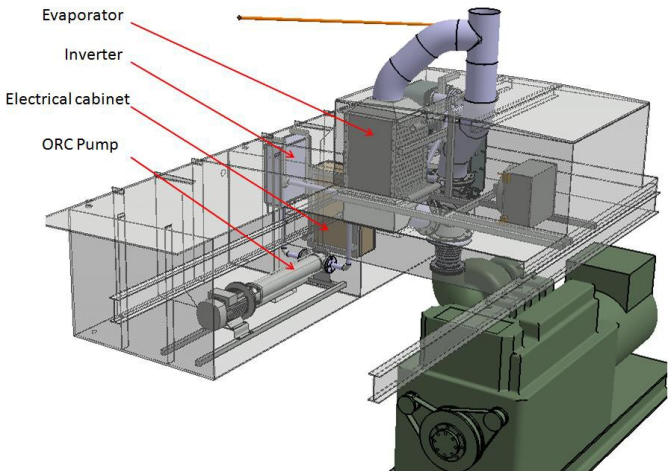
Case study: oil wells conversion – geothermal (3)

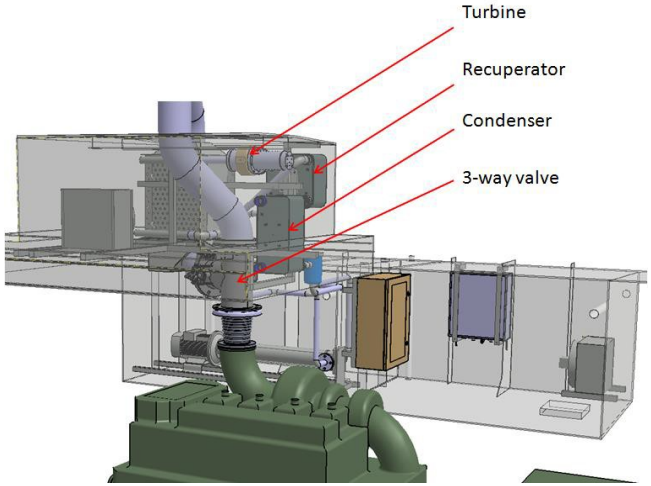
Estimate of electricity production for various flow rates and temperatures of the source

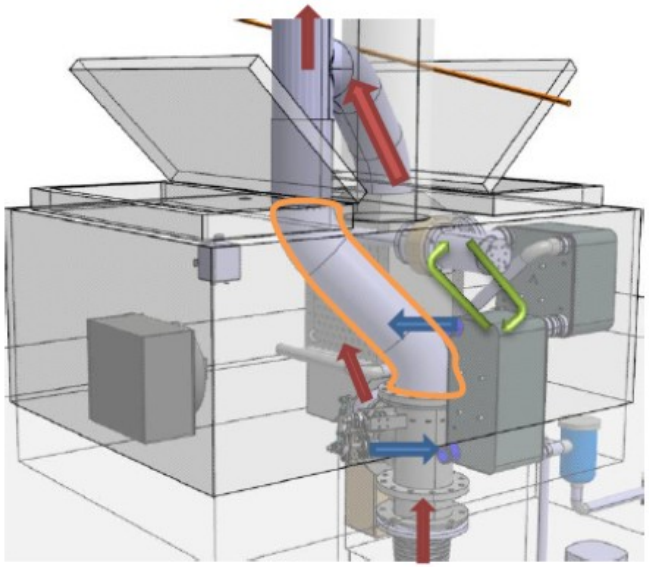
Ambient temperature : 31°C



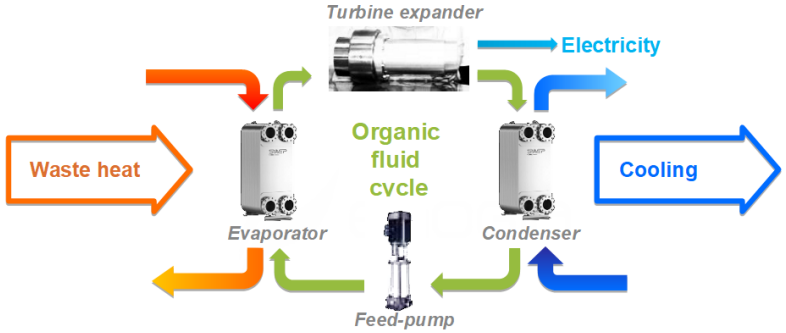
Ship's diesel engine heat recovery (1)

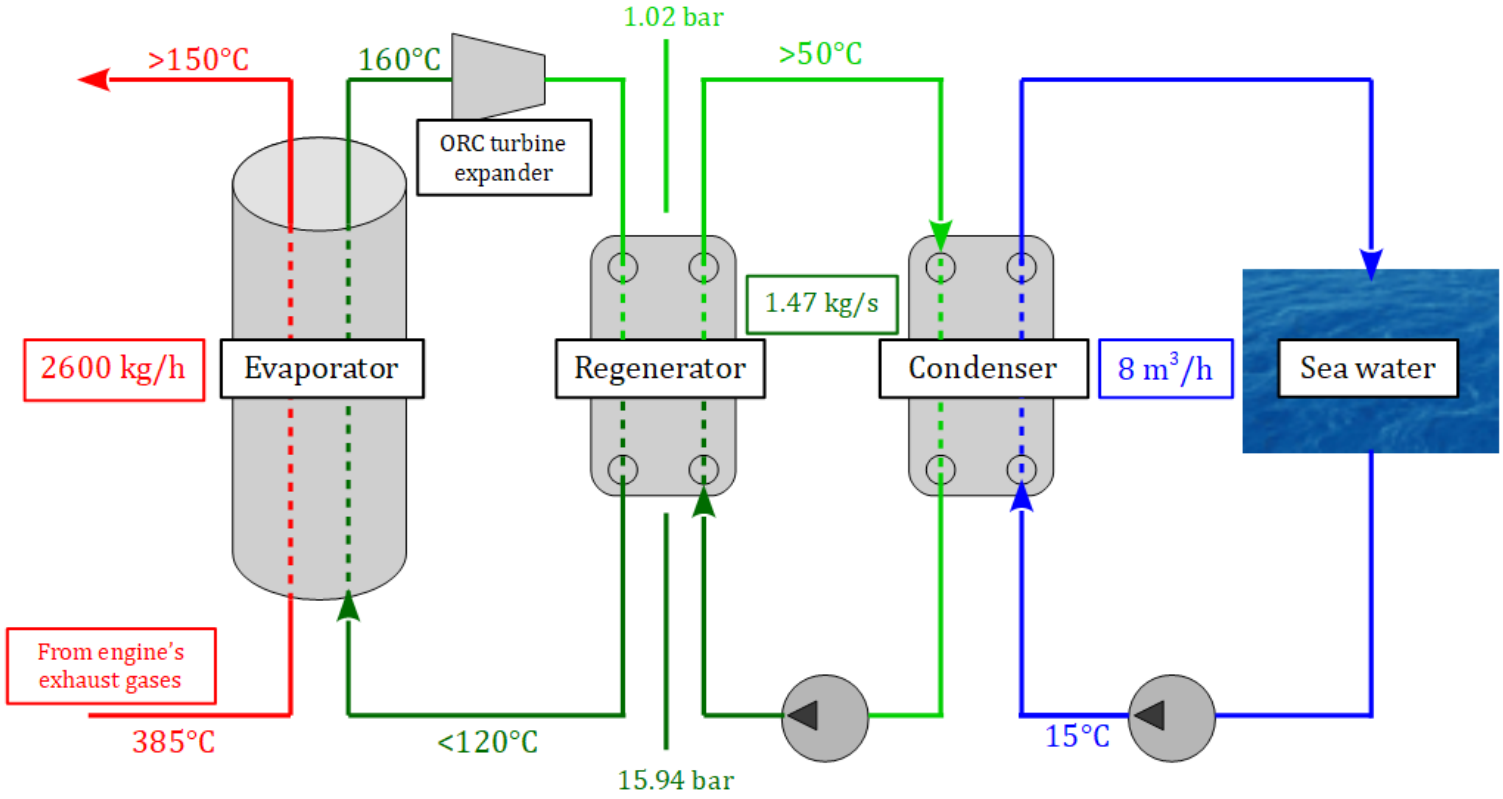




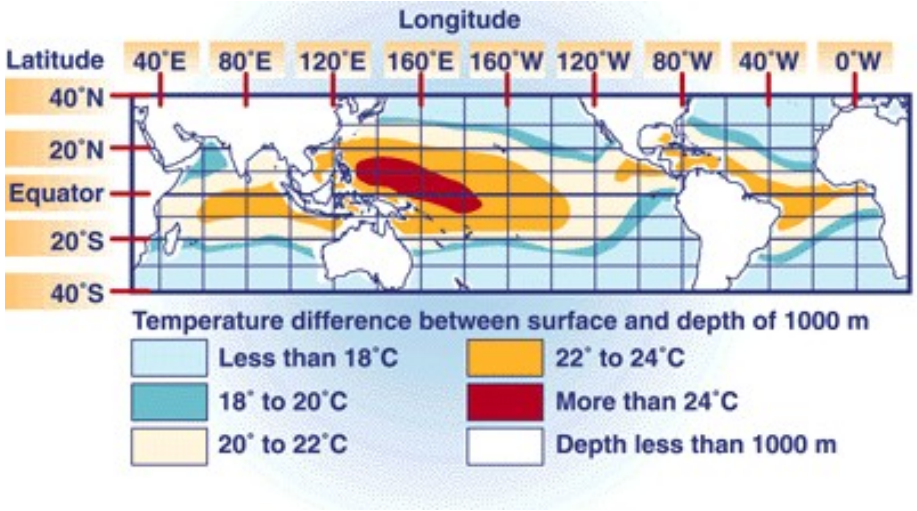


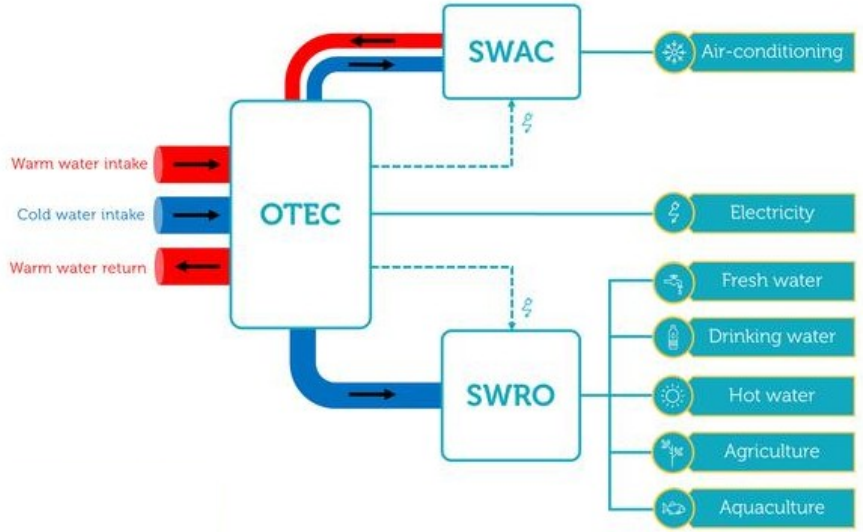
Ship's diesel engine heat recovery (2)

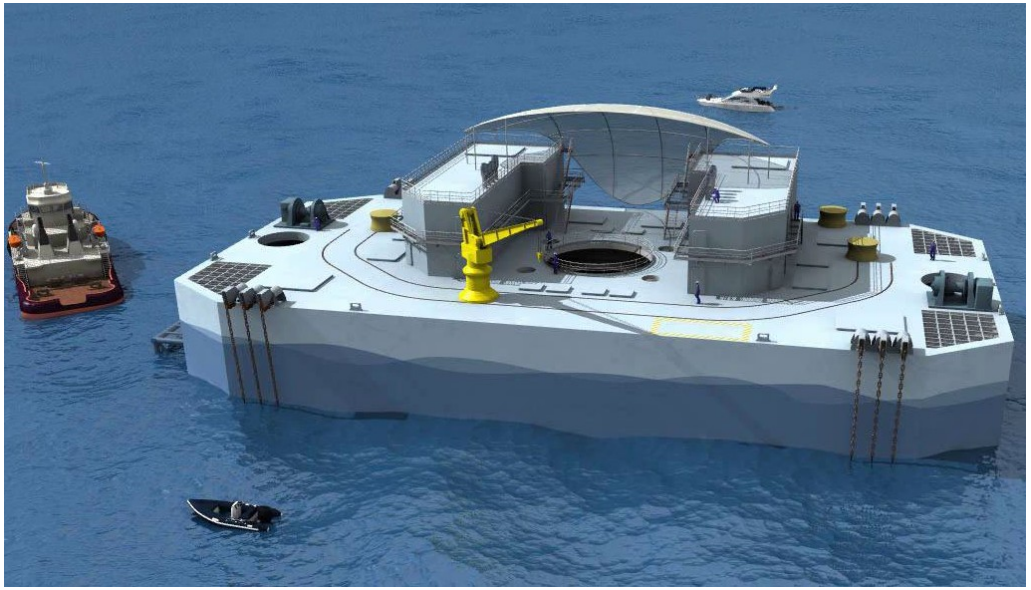




Ocean Thermal Energy Conversion (OTEC)







Contact details

Thank you for your attention!

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