Working Fluid Developments for HT Heat Pumps and ORC Systems

Renewable Energy, Heating and Cooling Applications
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Waste Heat Recovery Drivers

- **Increased focus on economic benefits of energy & fuel conservation**
  - need to remain competitive drives focus on energy costs
  - Converting waste energy to usable energy / power has a high value
- **Availability of distributed energy and the need for more energy**
  - need for less reliance on grid power / distributed energy
  - adoption of more self generated / sustaining sources of energy
- **Climate change & environmental legislation**
  - energy efficiency and reduction targets
  - emissions legislation, including CO_2 emissions
  - More power output for a given environmental impact

Generating Usable Energy from Waste Heat Reduces Energy Consumption and Reduces CO_2 Emissions

Opportunity for Low Temperature Waste Heat Recovery

- **Recovery of high temperature waste heat (>300℃) is common**
  - **Low temperature (50-250℃) waste heat recovery is less common**
  - **Perception that it is un-recoverable / un-economic to recover**
- **Huge opportunity for low vs. high temperature waste heat recovery**
  - **Estimated >2 x 10^{13} mega joules industrial waste heat**
  - **>$20BN low temp heat recovery opportunity in large industrial space**
  - **High value of recovered energy - higher temperature heat and electricity**
- **Perceptions changing**
  - **Low Temp heat recovery technologies proving performance**
  - **Improving technologies & Improving economics – KEY TO GROWTH**

Converting Waste Heat to Energy is Good Business and Good for the Environment

Heat Pump and ORC – Low Temperature Waste Heat Recovery

High Temperature Heat Pumps

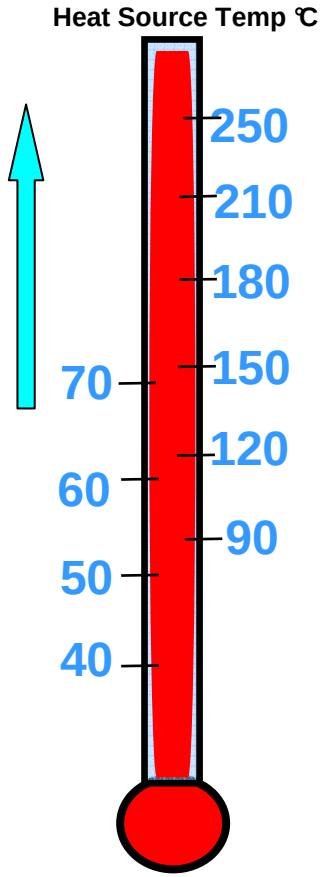
Waste Heat to Thermal Power

Applications (90-140℃)

- Industrial Process Heat
- District Heating
- Onsite / localized heating

Sources (40-70℃)

- Geothermal
- Waste Hot Water
- Low Temp Steam



ORC

Waste Heat to Electricity

Sources (80-250℃)

- Geothermal
- Waste Hot Water / Steam
- Solar Thermal
- Waste streams from boilers, generators, power plants, industrial processes

Applications

- Prime power generation
- Industrial plants
- Homes & Buildings

What is ORC?

Waste Heat Sources

- Waste streams from boilers, generators, power plants, industrial processes
- Geothermal
- Waste Hot Water / Steam
- Solar Thermal

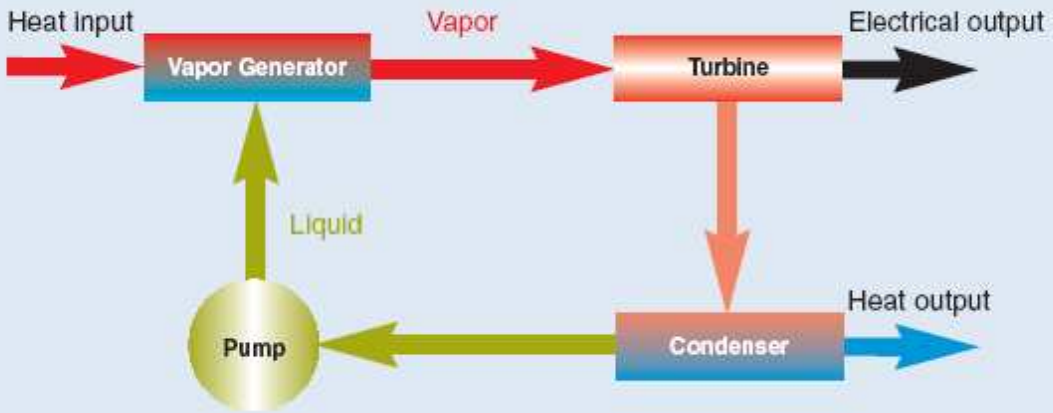
Applications

- Prime power generation
- Industrial plants
- Buildings
- Homes

Key benefits

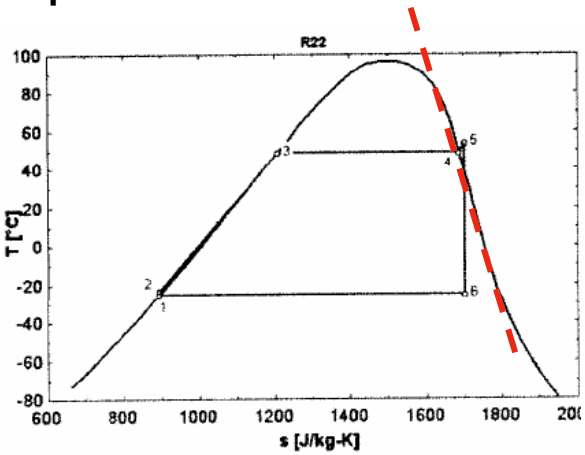
- Power from waste heat and renewable heat sources
  - Reduces specific fuel consumption
  - Increases the extent of renewable energy / offset grid consumption
  - Reduce per unit emissions (CO_2, NO_x, So_x)
- Are built to last > 20 years
- Are leak tight – elimination of working fluid emissions

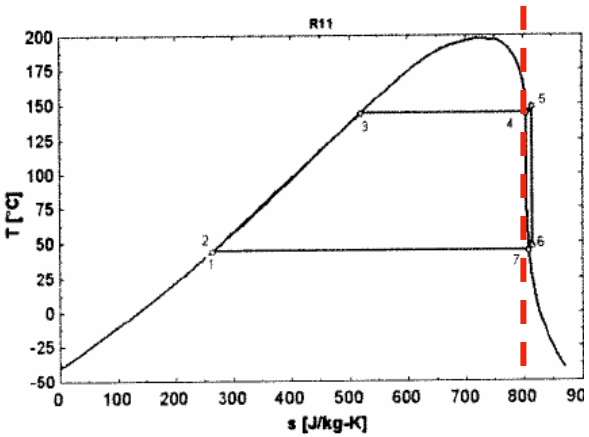
Schematic of a typical ORC Configuration

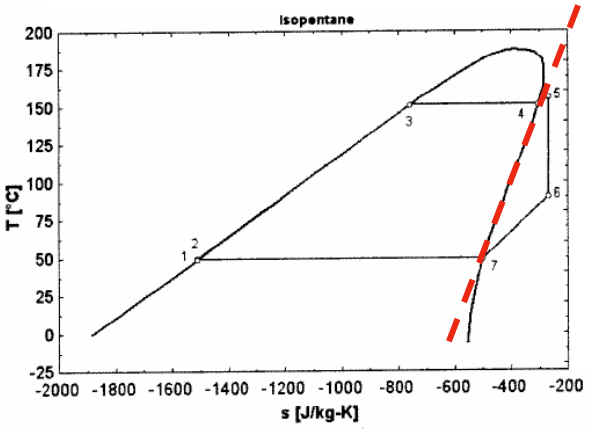


Refrigerants Comparison

The shape of the saturation curves, hence the choice of the working fluid will impact cycle performance







Negative Slope Saturation curve

Wet fluid at exit from turbine
Risk of damage to turbine blades

Example:
Water
R22
R134a

Isentropic Saturation curve

Preferred characteristic
Heat addition at constant temperature
Expansion parallel to saturation curve

Example:
R11
R123
R245fa

Positive Slope Saturation curve

Superheated turbine exit conditions
Possibility to use a regenerator

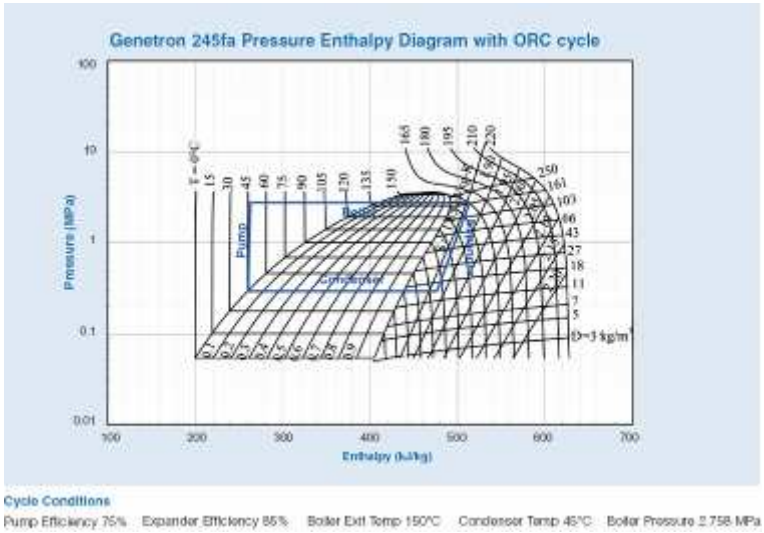
Example:
R113
n-pentene
Toluene

Genetron 245fa Properties

Genetron 245fa is an HFC specifically designed as a working fluid for 'green' energy systems

- Thermodynamic properties that maximize low temperature waste heat recovery cycle performance
  - Very suitable for low temperature heat recovery (source heat of 80-250℃)
  - Maximizes system efficiency / performance economics
- Non-flammable / Non-Corrosive
- Favorable toxicological profile

Chemical Name	1,1,1,3,3,-pentafluoropropane
Molecular Formula	$CF_3CH_2CHF_2$
Flash Point	None by ASTM
Flammability range in air	None
Boiling point ℃ at 1.01 bar	15.3 ℃ / 59.5 ℉
Critical Temperature *NIST Refprop v 6.01*	154 ℃ / 309 ℉
Liquid Heat Capacity kJ/kg K	1.36
Vapor Heat Capacity at constant pressure 1.01 bar kJ/kg K	0.8931

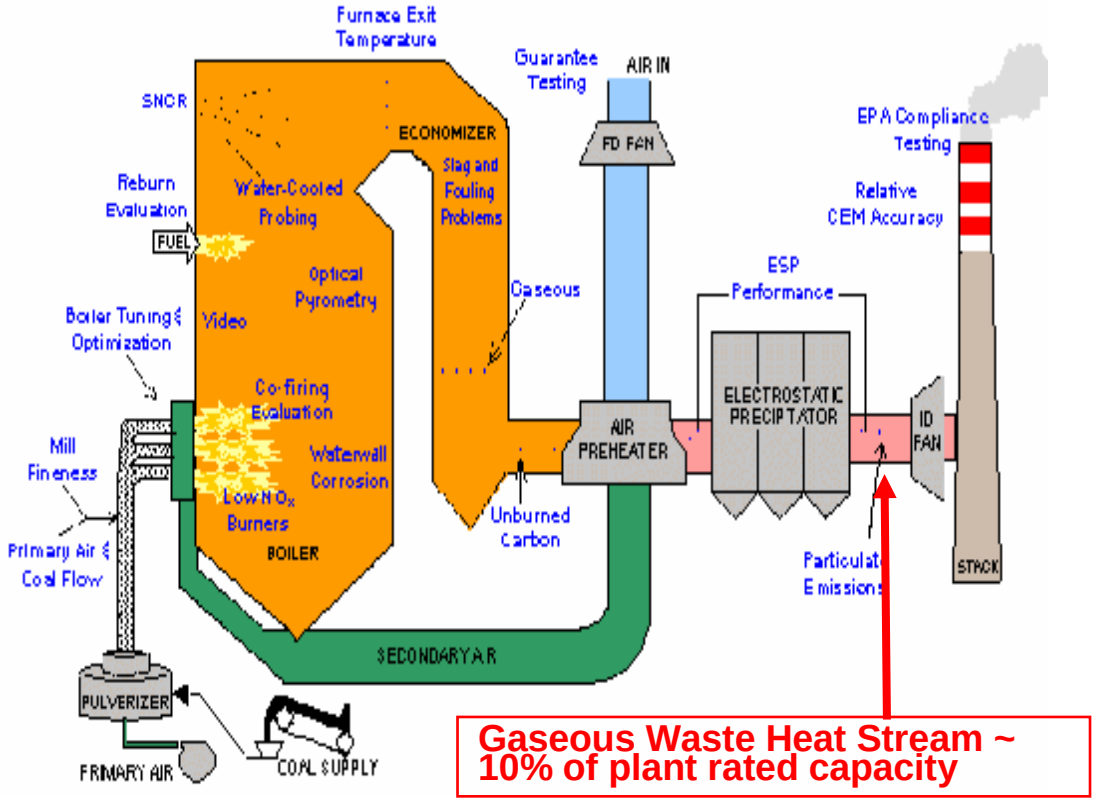


Comparative assessment of potential working Fluids

	Environmental			Performance				Safety
Refrigerant	Atmospheric lifetime	ODP	GWP	Slope of saturation vapour line	Critical point	Heat of Vaporazation at 100°C	Boiling temp. at 1 atm.	Flammability
Water		0		Wet	374°C - 220 bar	2256.4	100	Non-Flammable
R-11	45	1	3660	Isentropic	198°C - 44.1 bar	147.1	23.5	Non-Flammable
R-22	12	0.034	1710	Wet	96.1°C - 49.9 bar	~	-41.1	Non-Flammable
R113	85	0.9	5330	Dry	214°C - 34.4 bar	125.4	47.8	Non-Flammable
R123	1.3	0.012	53	Isentropic	184°C - 36.7 bar	134	27.7	Non-Flammable
R134a	14	0	1320	Wet	101°C - 40.6 bar	34.4	-26.4	Non-Flammable
R245fa	7.6	0	1020	Isentropic	154°C - 36.4 bar	135.5j/gm	15.3	Non-Flammable
R365mfc	10.2	0	910	Isentropic	195°C -27.5 bar	149j/gm	40.2	Flammable
R4310mee	17.1	0	1700	Dry	181°C - 22.9 bar	108.7j/gm	54	Non-Flammable
R7100	4.1	0	320	Dry	195°C - 22.3 bar	99.9j/gm	60	Non-Flammable
n-pentane		0	20	Dry	196°C - 33.6 bar	296.4	35.5	Flammable
isopentane		0	20	Dry	187°C - 33.7 bar	275	27.5	Flammable
Benzene	8-10	0		Dry	289°C - 49 bar	379.7	79.8	Flammable
Toluene	2	0		Dry	319°C - 41 bar	368.4	110.4	Flammable
p-xylene	<1	0		Dry	343°C - 35 bar	360.3	138.4	Flammable

Low Temperature ORC Heat Recovery Opportunity in Thermal Power in India

- Several opportunities to recover low temp heat
  - Bottoming of steam cycle
  - Flue gas from boiler exhaust
  - Exhaust gas from Flue Gas Pre-heater
- In Thermal Plants in India recovery of flue gas waste heat is a potentially attractive opportunity
  - Accessible
  - Suitable Temperature (150-250℃)
  - High uptime



Recovery of Gaseous Waste Heat Potentially Attractive Opportunity

Benefits of ORC in Thermal Power Plants

- Improve efficiency of power generation in existing coal power plants
  - ORC typically converts 10-15% of waste heat stream to electrical power
  - Estimated ~2.5 MW of electrical power recovery possible just from post-ESP gaseous heat stream of 210 MW unit before ID fan
  - No fuel or water consumption for this additional power
- Reduce environment impact per unit output
  - Lower per unit generation of fly ash and consumption of water and fuel
  - Reduction of CO_2 emissions - possibility of carbon credits
- Defer capital investment in additional power generation plant
- Typically modular systems: minimize process interruption for installation and commissioning

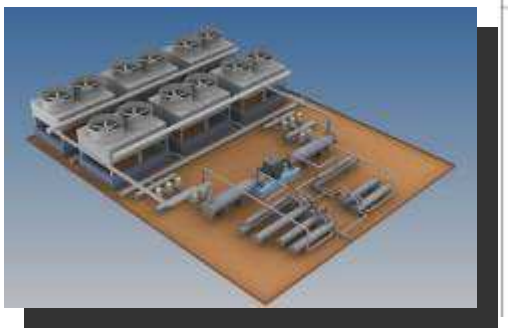
Geothermal Power Plant – Sauerlach, Germany

- **Plant type:** Geothermal ORC turbogenerator unit
- **Total electric power:** 5+ MWel plus thermal decoupling for district heating
- **Working Fluid:** 245fa
- **ORC Unit to be supplied by:**

Turboden S.r.l.

- **End Customer:** SWM - StadtWerke München (public utilities company)
- **Location:** Bavaria, Germany
- **Commissioning expected:** end 2011
- **Heat source:** geothermal fluid at 140°C
- **Cooling device:** air condensers

New 5MW plant under construction



Heat Recovery from Biomass Boiler – Trevisio, Slovenia

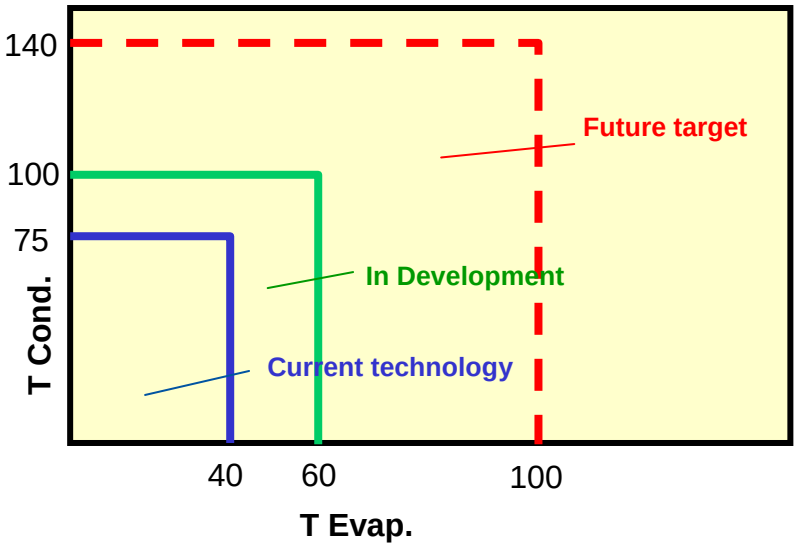
- ORC system manufactured & supplied by

Calnetix Power Solutions (CPS)

- Working Fluid Genetron 245fa
- 125KW electrical power output
- Running on steam from a sawdust fired boiler
- Indirect condensing using cooling tower
- Commissioned Q1, 2010

EDF Industrial Heat Pump Development

- Project at **EDF R&D**, France
- Working Fluid Genetron 245fa
- Pilot size unit running
- 400KW energy output at condenser
- 100℃ water temperature at condenser exhaust
- Potential applications in industrial waste heat recovery



Genetron 245fa in High Temperature Heat Pumps

- Thermal energy from low temperature sources can be recovered and boosted to a more valuable temperature
  - Process usage, pre-heating, site usage
  - Offset existing thermal energy / fuel consumption
- Genetron 245fa critical temperature enables 120ºC output / sink temperature
- Higher source temperatures greatly improve Efficiency (COP)

High Temperature Heat Pump developed for Dairy Industry.

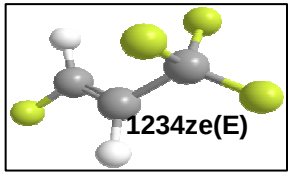
Further Working Fluid Developments

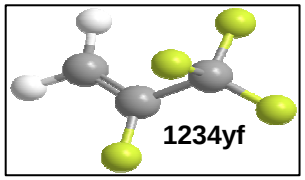
Auto Exhaust Gas WHR

- Heavy duty trucks
- ORC – exhaust gas heat to power
- Safe, efficient working fluid solutions

New Molecules

HBA-2





- Lower GWP
- Excellent performance

Genetron
245fa
(134a)
(410A)

Low Enthalpy Geothermal

- Large developing application
- ORC technology evolving
- Fluids to meet needs / performance improvement

Tailored fluids

- Evolving needs of ORC / HTHP
- Specific high growth applications
- Solutions of commercially available / new molecules

Honeywell is working with industry to meet heat recovery needs

Commercial Status / The Future

- **ORC**
  - **Genetron 245fa has been selected by numerous ORC OEM's as a preferred working fluid**
  - **ORC moving from Feasibility to Commercial (3KW to 10MW)**
  - **40 ORC systems using Genetron 245fa in 2010**
  - **Substantial market growth over 2010-2015 period**

- **Heat Pumps**
  - **Recovery of low temperature industrial waste heat in development phase**
  - **Several development projects running with Genetron 245fa**
  - **Piloting and commercial implementation over next 2-3 years**

Thank you

Questions

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