The Rankine Cycle is a thermodynamic cycle which converts heat into work. The heat is supplied externally to a closed loop, which usually uses water as working fluid. The Rankine Cycle based on water provides approximately 85% of worldwide electricity production.

Organic Rankine Cycle (ORC) is a well-known and widely used form of energy production, mostly in biomass and geothermal applications, but solar and heat recovery applications are increasing. Environmental concerns over climate change and unstable fossil fuel prices are driving the explosive growth of this efficient, clean and reliable technology.

The Organic Rankine Cycle uses other working fluids instead of water: Hydrocarbons like Isopentane, Isooctane, Toluene, Silicon oil etc. The working fluid properties dictates the heat source temperature requirements.
Organic Rankine Cycle

Advantages

✓ Combined Heat & Power
✓ Highly Efficient
✓ Commercially Proven Technology
✓ Low Temperatures and Pressures
✓ Low Operating & Maintenance Costs
✓ Wide Operating Range (10 - 100% of capacity)
✓ Fuel Diversity
✓ Unattended Operation is Possible

ORC CHP Process
Steam Cycle for Power Generation

1. Furnace
2. Steam Boiler
3. Steam Drum
4. Super Heater
5. Economizer
6. Air Pre-Heater
7. HP Distributor
8. Pressure Red.
9. LP Distributor
10. Feed Water Tank
11. Turbine
12. Generator
13. Steam Bypass
14. Consumer
15. Air Condenser
16. Condensate Tank
17. Condensate Pump
18. Feed Pump
19. Water Treatment

A. Comb. Air
B. to Flue Gas Treatment

Organic Rankine Cycle

1. Furnace
2. Thermal Oil Heater
3. Economizer I
4. Economizer II
5. ORC Evaporator
6. Primary Pump
7. Additional ORC Heat Exchanger
8. Turbine
9. Alternator
10. Regenerator
11. Condenser
12. ORC Feed Pump
13. Bypass-Heat Exchanger

A. Combustion Air
B. to Flue Gas Filter
85% Total Efficiency

Energy In vs. Energy Out
(Thermal & Electrical)

ORC Energy Flow Diagram
(Fuel Input to Energy Output)
Proven European Technology

> 120 Plants in Operation
1st Plant - 20+ Years Old

Power Generation by Biomass

- Burning $\lambda > 1$
  - Steam Turbine
  - Organic Rankine Cycle
  - Steam Motor
  - Stirling Motor
  - Kalina Cycle
  - Hot Air Turbine
  - Direct Gas Turbine
  - Inverse Gas Turbine

- Gasification $\lambda < 1$
  - Gas Motor
  - Diesel-Ott Motor (Pyrolysis)
  - Gas Turbine
  - IGCC-Plant
  - Cheng Cycle (STC)
  - Fuel Cell
Electrical Efficiency of Biomass Power Generation

- Fuel Cell with Gas or Steam Turbine
- Fuel Cell
- Gas Turbine
- Combined Cycle
- Gas Motor
- Steam Turbine
- Steam Motor
- IGCC
- In Addition to Coal

Combined Heat & Power (CHP)

- Efficient Hot Water
- Renewable Electric Generation
Advanced European System Designs are 98.8% Efficient.
- Designed for fuels up to 60% Moisture Content
- Hydraulic Grate designed for Dirty & Low Energy Fuels
- Water-Cooled Grate – Improves System Efficiency
- Flue Gas Recirculation
- Complete Combustion via Robust Computer Controls
- Post Combustion Chamber
- Automatic Ash Removal
Fuel Diversity

- Woody Biomass
- Agriculture Waste
- Forest Debris
- Food Waste
- Energy Crops
- Municipal Solid Waste (MSW)
Modern firing systems allow long-term operation without interruption. Increasing demands on cost-efficiency increase the demands on heating surface cleaning systems.

Robot with laser-based control for exact positioning of the access ports for the AirMaxx4 cleaning system.
ORC Plant Sizes

ORC – Biomasse Fernheizwerk Schluderns Glurns
District heating and electricity supply

ORC – Module AD 270 TF-plus
Generator output 270 kW\textsubscript{el}
Heating water capacity 1,250 kW\textsubscript{th}

ORC – Biomasse Heizkraftwerk EPC-Torgau
Heat and electricity supply for pellet production

2 ORC – Modules AD 1600 TF-plus
Total Generator output 3,100 kW\textsubscript{el}
Total heating water capacity 15,180 kW\textsubscript{th}

Skid-Mounted ORC Module
Applications

✔ District Heating/Cooling
✔ Process Heat (176 - 248°F)
✔ Pre-Heating Steam Condensate
✔ Desalination

Pre-Heating Steam Condensate

✔ Steam Turbine Condensate @ 120°F
✔ Steam Boiler Heating System Condensate @ 180°F
✔ Biomass Use With Easy Integration
✔ Improved Overall System Efficiency
✔ Plus Renewable Electric Generation
Low Cost Biomass Energy Output

- **50% MC Biomass @ $40/Ton**
  - $5.47/MMBTU of Thermal and Electrical Energy at 85% Efficiency

- **Natural Gas @ $4.50/MMBTU**
  - $5.63/MMBTU at 80% Thermal Efficiency

- **Coal @ $70/Ton in Large Steam Plant**
  - $6.93/MMBTU at 33% Electrical Efficiency

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### Renewable Energy Combined Heat & Power (CHP) Facility

**AD-2400 Biomass ORC** – 10,570 kW Thermal & 2,400 kW Electrical Output

#### Budgetary Economic Evaluation

**FACILITY CHARACTERISTICS**

- **Generator (Hydrocycle):** 2,400 kWe (Gross) ($1700)
- **Thermal Output (194°F Hot Water):** 10,570 kWe (1078 BHP) (36.07 MMBTU/hr)
- **Overall Efficiency:** 84.8% (Fuel Energy Input vs. Total Energy Output)
- **Total ORC Plant Load:** 552 kWe (23.00% of Electric Output)
- **Biomass Fuel Cost (Est.):** $40.00 per ton ($4.65 Million Btu)
- **Biomass Fuel Energy Content:** 4,300 Btu/lb (8.60 MMBtu/Ton)
- **Biomass Fuel Annual Consumption:** 48,451 tons/year (71,841 Barrels of Crude Oil)
- **Biomass Fuel Hourly Consumption:** 6.06 tons/hour (8.980 Barrels of Crude Oil)
- **Operating Availability @ Full Power:** 36.015 hours (322 days or 97%)
- **Planned & Unplanned Outages:** 760 hours (32 days or 9%)

- **Project Cost Excluding Land (Est.):** $11,637,300
- **Initial Equity & Grants (Est.):** $11,637,300
- **Loan:** $0 for 10-Year Term
- **Interest Rate:** 8.00%

**ANNUAL OPERATING EXPENSES** (91% Availability - 8,000 Hours per year)

- **Breakout of Generation Costs**
  - **Cost of Capital (on $0.00 M Loan):** $0.000000 / kWe ($0.00%)
  - **O&M (Includes wages, insurance, & spare parts):** $0.003631 / kWe (16.27%)
  - **Biomass Fuel:** $0.018678 / kWe (83.73%)

**TOTAL GENERATION COSTS:** $0.022309 / kWe (100.00%) $2,314,761

**FINANCIAL PROJECTIONS** (91% Availability or 8,000 Hours per year at 100% capacity)

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Gross Revenue</td>
<td>$4,156,350</td>
</tr>
<tr>
<td>Annual Operating Expenses</td>
<td>$2,314,761</td>
</tr>
<tr>
<td>Annual Net Income (EBITDA)</td>
<td>$1,841,589</td>
</tr>
<tr>
<td>Eligible for Government Grant</td>
<td>Time sensitive application required.</td>
</tr>
<tr>
<td>Project IRR (Operation Year 3):</td>
<td>15.28%</td>
</tr>
<tr>
<td>Value of Electric Energy:</td>
<td>$80.00 (Sale Price) and $60.00 (Current Rate) / MWh</td>
</tr>
<tr>
<td>Value of Thermal Energy:</td>
<td>$10.00 (Sale Price) and $0.00 (Current Rate) / MMBtu</td>
</tr>
<tr>
<td>Payback:</td>
<td>6.9 Years</td>
</tr>
<tr>
<td>Breakdown of Generation Costs (91% Availability - 8,000 Hours per year at 100% capacity)</td>
<td></td>
</tr>
</tbody>
</table>
ORC Plants

Thank You!

The End!