Decarbonization through Waste Heat to Power

WIEG Annual Meeting June 2022
Heat Wasted at Industrial Facilities

42% of energy we actually use ends up as “work”

58% of energy ends as rejected energy, including waste heat
Industrial Decarbonization

Challenge Meets Opportunity

Industry represents quarter of emissions

Industrial decarbonization represents a massive opportunity to impact climate change

290,000 petajoules of waste heat is released from heavy industrial operations every year

Source: US EPA, 2019
Heat Recovery as a Service

**The Business Model**

Partners Don’t Pay, Develop or Operate the Project

**Status Quo**

Industrial Facility → Waste Heat → Atmosphere

**The Kanin Approach**


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**How it Works**

### Waste Heat to Power Process

- Convert your waste gas into clean power
- Temperatures above 150°C / 300°F
- Use off-the-shelf proven tech
- Tech Agnostic

![Diagram of Waste Heat to Power Process]

### Organic Rankine Cycle Conversion Process

- Convert your waste gas into clean power
- Temperatures above 150°C / 300°F
- Use off-the-shelf proven tech
- Tech Agnostic

![Image of Organic Rankine Cycle Conversion Process]

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Proprietary & Confidential
## Industrial Waste Heat Opportunities

<table>
<thead>
<tr>
<th></th>
<th>Steel Facility</th>
<th>Foundry Facility</th>
<th>Paper Mill</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project Size (kW electric)</strong></td>
<td>~500-10,000 kWe</td>
<td>~1,000-4,000 kWe</td>
<td>~100-500 kWe</td>
</tr>
<tr>
<td><strong>Heat Sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Reheat Furnace</td>
<td></td>
<td></td>
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<tr>
<td>• Blast Furnace</td>
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<td></td>
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<tr>
<td>• Electric Arc Furnace</td>
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<tr>
<td>• Furnace Combustion Gases (300C-600C)</td>
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<tr>
<td>• Hardening Ovens</td>
<td></td>
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<tr>
<td>• Casting Process</td>
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<tr>
<td>• Dust Collectors/Baghouses</td>
<td></td>
<td></td>
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<tr>
<td>• Cooling/Thermal Oil System</td>
<td></td>
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<tr>
<td>• Pulp Processing: recovery boilers, biomass boilers, heaters (~250-350C)</td>
<td></td>
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<tr>
<td>• Sludge Incineration (~150-250C)</td>
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<tr>
<td>• Pulp Drying (might be too low)</td>
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</table>
Case Studies

Natural Gas Compressor Station

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Heat Source</strong></td>
<td>Gas Turbine Flue Gas</td>
</tr>
<tr>
<td><strong>WHP Power</strong></td>
<td>11.2 MW</td>
</tr>
<tr>
<td><strong>WHP Production</strong></td>
<td>92,000 MWh per year</td>
</tr>
<tr>
<td><strong>CO2 Avoided</strong></td>
<td>+51,000 tonnes per year</td>
</tr>
<tr>
<td><strong>CAPEX</strong></td>
<td>$34M ($USD)</td>
</tr>
<tr>
<td><strong>Payback</strong></td>
<td>7 years</td>
</tr>
</tbody>
</table>

Steel Manufacturing

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat Source</strong></td>
<td>Reheat Furnace</td>
</tr>
<tr>
<td><strong>WHP Power</strong></td>
<td>0.56 MW</td>
</tr>
<tr>
<td><strong>WHP Production</strong></td>
<td>3,400 MWh per year</td>
</tr>
<tr>
<td><strong>CO2 Avoided</strong></td>
<td>+1,900 tonnes per year</td>
</tr>
<tr>
<td><strong>CAPEX</strong></td>
<td>$2.5M ($USD)</td>
</tr>
<tr>
<td><strong>Payback</strong></td>
<td>4 – 10 years*</td>
</tr>
</tbody>
</table>

* Grant Funding Support

Source: Heat is Power

Source: Kanin Energy
WHP Supporting a Decarbonized Grid

WHP can support the development of intermittent renewable generation
Comparing by Capacity

Emissions Impact

Comparing WHP to Solar & Wind

Annual Carbon Emissions Impact by Technology for 1 MW of Generation Capacity

- WHP
- Solar PV
- Wind
- Gas-fired CHP

Avoided Grid Emissions
On-Site Emissions

Carbon Emissions (tons/MW-year)

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Emissions Impact

Comparing WHP to Solar & Wind

Comparing by MWh

Carbon Emissions Impact by Technology per MWh of Energy Generation

- WHP
- Solar PV
- Wind
- Gas-fired CHP

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Existing and Future 24/7 Carbon Free Energy

- Most 24/7 carbon free options are very expensive, and Geothermal and Hydro-electric deployments are geography constrained and have their own environmental issues.
Benefits

- Hedge against fluctuating energy prices
- Reduce Scope 2 Emissions
- On-site energy resiliency & reliability
- Non-intrusive and low maintenance
- Support decarbonization of products

Barriers

- Waste Heat to Power awareness
- Techno-Economic feasibility assessments

Key Economic Considerations

- ITC 26% for 2022
  - Dropping to 2023
  - Build Back Better could bump to 30%
- Environmental Credits
  - Compliance Markets (Ohio)
  - Voluntary Markets (MRETS)
- On-Site Power / Net-Metering
  - ‘Behind the Fence’ power generation can deliver cost savings as compared to grid utility power
TURBODEN IS A GROUP COMPANY OF MHI

MHI BUSINESS DOMAINS

- POWER SYSTEMS
- INDUSTRY & INFRASTRUCTURE
- AIRCRAFT, DEFENSE & SPACE

One of the world’s leading heavy machinery manufacturers, with consolidated sales of around $38 billion (in fiscal 2021).
Foundation July 7, 1884

$12.9 B NET SALES
$15.6 B NET SALES
$6.3 B NET SALES
MILESTONES

Prof. Mario Gaia makes experience in the field of ORC within his research group at Politecnico di Milano.

1976

Prof. Mario Gaia founds Turboden.

1980

Turboden enters geothermal, waste heat recovery and solar markets.

1998

1st ORC prototype.

1st ORC biomass plant.

‘90-2000

Turboden becomes leader in Europe with its biomass plants.

2000-2009

2013

MHI acquires the majority of Turboden.

2019

Turboden launches new products, LHP and EXP

2020

1990

ORC SIZES AVAILABLE
300 kW
1

ORC PLANTS INSTALLED

2000

1 - 2 - 4 MW
100

2010

5 - 8 - 10 MW
220

2020

20 MW
400+
ABOUT TURBODEN

SINCE 1980

Turboden is an Italian firm and a global leader in the design, manufacture, and maintenance of Organic Rankine Cycle (ORC) systems, highly suitable for distributed generation.

ORC systems can generate electric and thermal power exploiting multiple sources. Thanks to its long experience in the energy efficiency sector, today Turboden expands its solutions offering with gas expanders and large heat pumps.

Since 2013 part of

MITSUBISHI
HEAVY INDUSTRIES

RANGE SIZE

up to
20 MWe
per single shaft
THE ORC CYCLE – HOW IT WORKS

The ORC turbogenerator uses medium-to-high temperature thermal oil to preheat and vaporize a suitable organic working fluid in the evaporator (4>5).

The organic fluid vapor rotates the turbine (5>6), which is directly coupled to the electric generator, resulting in clean, reliable electric power.

The exhaust vapor flows through the regenerator (6>7), where it heats the organic liquid (2>3) and is then condensed in the condenser and cooled by the cooling circuit (7>8>1).

The organic working fluid is then pumped (1>2) into the regenerator and evaporator, thus completing the closed-cycle operation.

The waste heat from production process is transferred to the ORC working fluid by means of an intermediate circuit or directly via the exhaust gases in direct exchange systems. The media used in the intermediate circuits are thermal oil, saturated steam or superheated water.
ORC SYSTEM FEATURES

Simplicity
- Remote monitoring and automatic operation
- No water use and treatment required
- Minimal maintenance activities

Flexibility
- Ease of integration
- Excellent part load capability down to 10% load
- Different primary energy sources

Dependability
- High availability
- Long life (> 25 years)
- 40+ years in the design and production of turbomachinery

Sustainability
- Core system for renewable energy and energy efficiency
- Clean generation of power and heat
- Reduction of CO₂ emissions
- The Waste Heat Recovery Unit is ZERO EMISSION.
GLOBAL AND PROVEN EXPERIENCE

Biomass
- 327 units, 476.6 MWe

Waste Heat
- 37 units, 89.7 MWe

Oil & Gas
- 5 units, 37.3 MWe

Gas Expander
- 2 units, 1.3 MWe

Waste to Energy
- 25 units, 66.2 MWe

High Temperature Cogeneration
- 2 units, 2.1 MWe

Large Heat Pump
- 1 unit, 5.7 MWth

Geothermal
- 16 units, 119.1 MWe

Biomas
- 327 units, 476.6 MWe

Experience in over 50 countries

With 400+ installations

Power generated 25 thousand GWh

Cumulative operation time 19 million hours

Last update: April 2022

* including two hybrid power plants

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TURBODEN REFERENCES IN STEEL & METAL

<table>
<thead>
<tr>
<th>PLANT</th>
<th>START UP</th>
<th>MAIN PROCESS EQUIPMENT</th>
<th>HEAT CARRIER</th>
<th>ORC</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>type</td>
<td>charge</td>
<td>capacity</td>
</tr>
<tr>
<td>NATSTEEL Singapore</td>
<td>2013</td>
<td>steel rolling mill billet reheating furnace</td>
<td>billet</td>
<td>125 ton/h</td>
</tr>
<tr>
<td>ELBE STAHLWERKE FERALPI</td>
<td>2013</td>
<td>steel electric arc furnace</td>
<td>scrap</td>
<td>100 ton</td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORI MARTIN Italy</td>
<td>2016</td>
<td>steel electric arc furnace</td>
<td>scrap - consteel</td>
<td>85 ton</td>
</tr>
<tr>
<td>FONDERIA DI TORBOLE Italy</td>
<td>2016</td>
<td>iron cupola furnace</td>
<td>scrap, pigs</td>
<td>30 ton/h</td>
</tr>
<tr>
<td>ARVEDI Italy</td>
<td>2018</td>
<td>steel electric arc furnace</td>
<td>scrap</td>
<td>250 ton</td>
</tr>
<tr>
<td>POSCO ICT South Korea</td>
<td>2019</td>
<td>Fe-Mn submerged arc furnace</td>
<td>raw materials</td>
<td>150 ton/d</td>
</tr>
<tr>
<td>SACAL Italy</td>
<td>2019</td>
<td>aluminum rotative furnaces</td>
<td>scrap</td>
<td>n.a.</td>
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</tbody>
</table>
DEDICATED AFTER-SALES SERVICE

Qualified staff is exclusively dedicated to the customer assistance, both from remote and on-site, with the aim of optimizing the management of the plants. The customer can choose the most suitable service package thanks to the wide range of services offered.

Customer request or Turboden planned checks → Trend analysis with local operator support → Focused teamwork and technical decisions → Reaction plan: remote or on-site → Satisfied customer

COVERAGE
2 service subsidiaries and 5 international service partner companies.

ASSISTANCE
Turboden 24/7, the call center service h24, 7 days per week.

CUSTOMISED SERVICES
- single contact for requests for support
- staff dedicated to on-site and remote technical support
- assistance of an international network of companies able to provide technical support
- wide range of services provided
- prompt assistance and customized after-sales services
- remote technical support using innovative tools (TOS – Turboden Online Service)
- dedicated spare parts warehouse
TURBODEN – A SOLUTIONS PROVIDER

• Turboden is not just an equipment supplier. Turboden is able to provide the following services:
  
  o Project development  
  o Economic modelling  
  o Financing solutions  
  o EPC solutions  
  o Operations & Maintenance