Power from Waste - Convert Waste Heat into Power

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Introduction to Waste Heat to Power

Energy Flows in the Global Electricity System, ~65% of total energy input is lost

US Energy in 2013: ~60% rejected/wasted

Waste/lost heat can be converted into useful energy

Rejected and unused Energy continues to be a REALITY
What is Supercritical CO$_2$ Waste Heat to Power?

Supercritical CO$_2$ (sCO$_2$) Waste Heat to Power Technology Solution


Dresser-Rand (DR) & Echogen – Strategic Partnership
## Value Proposition

### Water-Free Option
- Totally dry, water-free, closed-loop process
- Air cooled condenser (water cooled condenser optional)

### Compact
- No exhaust bypass stack required
- 25-40% smaller footprint than steam; minimally invasive retrofit

### Flexible
- Suitable for remote operation; no boiler operator required
- 20-30 minutes to full load

### Efficient
- Simple heat transfer, no boiling process (supercritical)
- Direct in-stack WHX, no intermediate fluid required

### Competitive
- Lower LCOE (Levelized Cost of Electricity)
- Competitive OPEX and long term services contracts

### Clean
- Produces electricity without incremental emissions
- Working fluid is stable, benign and non-flammable
Value Proposition - Footprint

5 ½ Acre Site

4 Acre Site

25% reduction

Gas Turbine / Generator

HRSG

sCO₂ Heat Engine
The EPS100 – Commercialization of Pilot Unit

**Designed for 20-35 MW Gas Turbines (GTs)**

- Siemens SGT-600, SGT-700, SGT-750
- Siemens SGT-A30 RB & SGT-A35 RB [Industrial RB211]
- GE LM2500 / Solar Titan 250 / Combination of smaller GTs
- 8.0 MW gross / 7.3 MW net (ISO)
- Work conducted on further cycle efficiency enhancements toward 9.5 MW gross

**Physical Configuration (see EPS100 flyer)**

- Process skid (right) + Power skid (above)
- Control house + CO₂ storage tank and transfer system
- Cooling system (air or water) + Waste heat exchanger

Accomplished: Factory qualification testing
Final step: Field deployment & operation
Commercially available
EPS100 – Factory Qualification Testing

1. Completed all Phases I-IV of testing
   - I: Validation of components
   - II: Full speed no load
   - III: Durability
   - IV: Partial load endurance test

2. System control & stability fully demonstrated

3. Component performances meet or exceed expectations

4. Turbopump run to max conditions

5. Generator speed control stability demonstrated

6. Power turbine electrical output = 3.1 MWe max to date (limited by available heat on test stand)

7. Run time: 310 hours turbopump / 150 hours power turbine
EPS100 Pilot Project – Compression Station in North America

- Opportunity installation for gas turbine exhausts
- Remote operation
  - Control and isolation of GT exhaust stream
  - No impact on station operation
- Compact arrangement
- Skid-mounted equipment with minimal installation
- Air-cooled condensers
- Option for bypass stack & diverter valve

- Dresser-Rand offering:
  - Turnkey solution
  - Service contracts
  - Power sold to the grid by host
  - Option of project developer
  - FEED under way (commissioning targeted early 2020)
Application in LNG – Value Proposition of EPS100

A NPV type analysis was conducted of the two scenarios:
- Case 1- Traditional power generation
- Case 2- Power generation using sCO2

The following assumptions were used:
- Life 20 years
- Discount Rate 10%
- LNG Cost FOB 8$/MMBTU
- Fuel Cost 3$/MMBTU
- Plant Availability 95%
- CO2 Emission Tax $40/tonne

Acknowledgements: We gratefully acknowledge the assistance of Dresser-Rand and Echogen Power Systems.
Future Applications Offshore

Waste heat recovery for offshore applications

5. A CO₂ cycle was preferred to Organic Rankine cycle (ORC) as an alternative to the standard steam cycle. The main reason for not investigating the ORC option in detail are working fluid stability issues, GWP and/or flammability and toxicity of the fluids, preliminary calculations that showed better compactness of the CO₂ cycle, and other on-going projects focusing on ORC. Hydrocarbons was however considered for a lower temperature power cycle utilizing heat from compressed gas.

8. EFFORT shows that steam and CO₂ bottoming cycles offshore are of similar weight and footprint
   a. CO₂ systems have slightly smaller footprint but potentially larger weight due to the high pressure system requiring larger wall thickness of piping, making piping weight 3 times higher for CO₂ than for steam.
   b. A compact waste heat recovery unit using super-critical CO₂ can be designed with 40% less weight than a unit using steam in a sub-critical once through steam generator.
   c. If distances from the WHRU to the remaining system is long, the weight advantage of a compact CO₂ unit may be offset

EFFORT Consortium in Norway
Tell Us About Your Waste Heat

If you would like more information about how your application can benefit from the Dresser-Rand / Echogen Technology, please complete the “Tell Us About Your Project” form.

Potential waste heat source(s) at the facility:

<table>
<thead>
<tr>
<th>Waste Heat Source</th>
<th>Source 1</th>
<th>Source 2</th>
<th>Source 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Description (if gas turbine exhaust, exact model)</td>
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<tr>
<td>How is heat currently removed (vented, stack, cooling tower, etc.)?</td>
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<tr>
<td>Temperature (indicate unit)</td>
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<tr>
<td>Throughput; Flow rate (indicated unit)</td>
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<tr>
<td>Exhaust gas composition (list or attach)</td>
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<tr>
<td>Minimum allowable reduced temperature (indicate unit) (e.g., temperature of waste heat leaving our exchanger, if available)</td>
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<tr>
<td>Maximum allowable pressure drop in the stack/system, if available</td>
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<tr>
<td>Existing power demand in kW or MW</td>
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<tr>
<td>Preferred voltage output from Echogen system (e.g. 480 volt, 3 phase, 60 hertz)</td>
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<tr>
<td>Average ambient air temperature (indicate unit)</td>
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<tr>
<td>Ambient air temperature range throughout the year, if available (indicate unit)</td>
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<tr>
<td>Heat sink preference:</td>
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<tr>
<td>✔ Air cooling?</td>
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<tr>
<td>✔ Water cooling? If so, average temperature of cooling water as already available (indicate unit)?</td>
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<tr>
<td>✔ No preference</td>
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<tr>
<td>Current or anticipated cost of power @ plant</td>
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<td>Are operational data available (Y/N)</td>
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<tr>
<td>Are site layout drawings available (Y/N)</td>
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</table>
Thank you!

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