Saving Fuel Using a Stirling Engine

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Introduction and Overview

Exciting Market Opportunity

Technology and Innovation

Unique Market Positioning

Path to Market
Diesel Generation is a Big Problem

5%
world energy production – 1,000 GWh

95%
off-grid power generation – 30 GW

Sources: International Energy Agency, Alliance for Rural Electrification, McKinsey
Extremely High Diesel Costs for Military

Fully burdened cost of diesel, forward deployed bases

$100 / L

Ratio of per capita fuel use, US military vs. civilian:

4 to 1

1 in 8 Soldiers Killed or Wounded in Iraq Between 2003-2007 Were Protecting Fuel Convoys

Stirling Engine 101

- Heat
  - Waste heat
  - Solar heat
  - Biomass
  - Fossil fuels

- Hot Heat Exchanger
- Ambient

- Electricity
Diesel Genset Augmentation is a Clear Application

Drop-in technology for improving diesel efficiency with a short pay-back period
Technology Advantages and Disadvantages

**Advantage**
- Flexible fuel: only requires heat
- Theoretically more efficient

**Disadvantage**
- Other cycles are cheaper at larger sizes
- Expensive heat exchangers required
- Poor reliability

**Our Tech**

**Best of Stirlings**
- Flexible fuel intake
- High efficiency

**Reduced Disadvantages**
- Designed for low cost
- Highly efficient, low-cost heat exchanger
- Increased reliability
Innovative Ultra-efficient Heat Exchanger

- **Heater**
  - From 40 °C wasted

- **Regenerator**
  - 1st half-cycle
  - 2nd half-cycle
  - ...to 4 °C

- **Cooler**

Ultra-efficient heat exchanger

Order-of-magnitude less temperature loss

Less heat wasted

Higher Efficiency
## Low-Cost Advantages

<table>
<thead>
<tr>
<th>Materials</th>
<th>Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Primarily off-the-shelf components</td>
<td>• Simple design limits fabrication complexity</td>
</tr>
<tr>
<td>• Low-cost heat exchanger</td>
<td>• Very few parts require machining</td>
</tr>
</tbody>
</table>

![Image of materials](image1.png)  ![Image of manufacturing](image2.png)
Filling a Gap Versus the Competition

- **Our Stirling**
- **Existing Stirling**
- **Thermoelectrics**
- **Diesel genset waste heat**
- **Brayton**
- **Rankine**
Ideal Use Case: Increasing Diesel Genset Efficiency

- Optimized for Diesel’s Power Range
- Efficiency and Cost Advantage
- Technology Complements Heat Source
- Medium Temp. Means Higher Reliability
Efficiency Yields Payback under 2 Years in Base Case

Simple Payback Period in Months by Cost of Device and Cost of Diesel

<table>
<thead>
<tr>
<th>Cost of Diesel ($ / L)</th>
<th>Months</th>
<th>LCOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 / L (US)</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>$2 / L (Tanzania)</td>
<td>9</td>
<td>7.2¢</td>
</tr>
<tr>
<td>$5 / L (Military)</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Note: LCOE of Stirling capex and maintenance only, does not include diesel cost
Efficiency Yields Payback under 2 Years in Base Case

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<td>$1 / L (US)</td>
<td>12</td>
</tr>
<tr>
<td>$2 / L (Tanzania)</td>
<td>6</td>
</tr>
<tr>
<td>$5 / L (Military)</td>
<td>3</td>
</tr>
<tr>
<td>$2</td>
<td>4.8¢</td>
</tr>
<tr>
<td>$3</td>
<td>7.2¢</td>
</tr>
<tr>
<td>$6</td>
<td>14.4¢</td>
</tr>
</tbody>
</table>

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Prioritization of Diesel Generation Market Segments

- US military
- Off-grid telecom
- Off-grid micro grid
- Commercial micro grids
- Municipal
- Medical facilities
- Grid peak shaving

Barrier to Entry:
- High
- Low

Cost of Diesel:
- Low
- High

Relative market size for diesel generation:
- $2.5Bn

Opportunity
Sales Channels

US Military
$800M

Telecom
$1.5Bn

Micro-grid
>$200M

Telecoms
Manufacturers

DARPA
GSMA
CAT

LOCKHEED MARTIN

The World Bank
KenGen

vodafone

Lighting Africa

Department of Commerce
Department of Energy
US Army

Telecom Manufacturers

Energy for the nation
Roadmap to Market

0-6 months

• Finalize design
• File IP

6-18 months

• Finalize prototype and test

Long-term

• Develop sales channels and manufacturing partnerships
• Reduce cost
• Revisit other applications (CHP, solar)
Summary

• 20% Efficiency Increase
• Payback Period Less than 2 Years
• Large potential market
## Competitive Advantage Improves On Status Quo

<table>
<thead>
<tr>
<th>Customer Need</th>
<th>Our Technology</th>
<th>Other Stirling Engine</th>
<th>Rankine Cycle</th>
<th>Status Quo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td><img src="#" alt="Yellow" /></td>
<td><img src="#" alt="Red" /></td>
<td><img src="#" alt="Yellow" /></td>
<td><img src="#" alt="Green" /></td>
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<tr>
<td>Operating Costs</td>
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<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Yellow" /></td>
<td><img src="#" alt="Red" /></td>
</tr>
<tr>
<td>Efficiency at Low Power</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Yellow" /></td>
<td><img src="#" alt="Yellow" /></td>
<td><img src="#" alt="Red" /></td>
</tr>
<tr>
<td>Reliability</td>
<td><img src="#" alt="Green" /></td>
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Risks and Mitigation Tactics

**IP**
- Lack of IP protection relative to competition

**Market Conservatism**
- Customers seek products with proven track record

**Cost**
- Cost not competitive relative to other technologies (e.g. PV)

**Market Trends / Competition**
- Competition will continue to improve

**Mitigation**
- File provisional patents on key innovations
- Conduct initial testing with customers willing to take on risk
- Diesel augmentation as first market; lower cost via continued refinement
- Utilize advantages of technology: flexible fuel source, storage
Secondary Application: Solar Thermal with Diesel Waste Heat Extraction

Seamless all-day solution for energy needs with even greater return in areas with expensive diesel and a good sun source.
Combining solar thermal with diesel augmentation could make sense in locations with very high diesel cost (e.g. military)
Filtering Criteria and Narrowing of Market Applications

Technical Factors
- Temperature
- Required Power Output
- Form Factor

Commercial Factors
- Customer Use Case / Cost
- Market Factors
- Barriers to Entry

Household solar thermal
- Re-heat cycle
- Dairies / manure
- Sewage treatment
- Solar thermal, utility scale
- Steam regeneration
- Backup Generation
- Triple bottoming cycle

Oil and gas extraction
- Geothermal
- Boiler Waste Heat
- Household natural gas / CHP
- Remote power / micro-grid solar thermal

Diesel Augmentation