Global Value Chain and Manufacturing Analysis on Geothermal Power Plant Turbines

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Highlights

- Overview of global geothermal power market
- Methodology for manufacturing analysis
- Minimum sustainable Price (MSP) Analysis
- Manufacturing analysis: case studies
  - 1 MWe geothermal ORC turboexpander, manufacturing volumes from 1 to 50
  - 5 MWe geothermal ORC turboexpander, manufacturing volumes from 1 to 50
  - 20 MWe geothermal steam turbine, manufacturing volumes from 1 to 5
- Sensitivity analysis
- Discussion on custom vs standard design turbines
- Conclusions
- Next Steps & Future work
Global Geothermal Energy Market
The global geothermal power market has significantly grown over the last decade and is expected to reach a total installed capacity of 18.4 GWe in 2021 (GEA, 2016).

The developing projects are expected to create an annual average demand of 1 GW for a diverse mix of geothermal turbine types (BNEF, 2016; GEA, 2016).
Overview of Global Geothermal Power Market

The United States Geothermal Market:
- Geothermal market had a challenging year in 2016 and did not grow significantly.
- However, there are potential opportunities on the horizon that could help the sector grow and expand.
- 784 MWe is expected to come online by 2020 and an additional 856 MWe could come online in the next 5 years if existing barriers could be removed to expedite project development (Wall and Young, 2016).

Fast Growing Geothermal Markets:
- Indonesia;
  - Indonesia’s current installed capacity is 1,600 MWe but the government is targeting 6,500 MWe by 2025.
  - Indonesia has a high feed-in-tariff (FIT) policy which ranges from 12.6 to 26.2 ¢/kWh.
- Kenya;
  - 681 MWe of installed capacity in 2016
  - An additional 680 MWe of capacity is expected to come online by 2018.
- Turkey;
  - 1 GW installed capacity in 2017 and has additional 900 MW projects in pipeline.
  - New renewable energy law in 2010,
  - 10.5 ¢/kWh FIT for geothermal power plants for the 10 years with bonus FIT for locally manufactured
    - Turbines: 1.3 ¢/kWh
    - Generators: 0.7 ¢/kWh
    - Pumps and compressors: 0.7 ¢/kWh (IEA, 2011)
  - Total geothermal FIT could reach up to 13.2 ¢/kWh
Global trade flow of geothermal turbines between 2005 and 2015
Organic Rankine Cycle (ORC) Power Plant Market

- ORC technology has been used for Geothermal Energy, Waste Heat Recovery (WHR), Biomass (biogas and landfill gas), and Concentrating Solar Power (CSP) over the last decade.

Data source: Tartiere, 2016.
Methodology for Manufacturing Analysis
Methodology

- **Identify turbine materials, manufacturing steps and required manufacturing equipment**
  - Literature search
  - Industry interviews

- **Develop Machining Process Model**
  - Identify required machining processes
  - Identify Parts to machine (impellers, shaft/rotor, inlet guide lanes, casing...etc.)
  - Identify inventory of machine
  - Define annual maximum allowable working hours (MAWH)

- **Develop Manufacturing Cost Model**
  - Machining times
  - Work load on machinery
  - DFMA® software was used for some of the key, high value components such as impellers and shafts for the manufacturing cost analysis of turbines

- **Develop Financial Model**
  - Determine Minimum Sustainable Price (MSP) for turbine
  - Apply discounted cash flow (DCF) analysis
Materials & Process Steps

Materials

- Iron
- Carbon
- Chromium
- Nickel, Molybdenum
- Titanium
- Aluminum
- Epoxy-Based Plastics
- Refined Plastics
- Oils & Lubricants

Processing

- Cast Iron
- Carbon Steel
- Stainless Steel
- Inconel Alloys
- Titanium

Manufacturing

Outsourced/Purchased Parts

- Bearings
- Seals and Rings
- Bolts and Joints

In-House Machining

- Casting/Forging
- Rough Milling
- Drilling
- Rough Grinding
- Precision
- Precision Grinding
- Finishing
- Quality Control

Assembly

- Assembly, Lubrication, Testing
- Turboexpander
- Steam Turbine
- Impellers/Blades
- Inlet Guide Lanes
- Fixing and Cover Rings
- Shaft/Rotor
- Casings
- Nozzles and Flanges
- Exhaust Diffuser
MACHINING EQUIPMENT

<table>
<thead>
<tr>
<th>#Units</th>
<th>5 Axis CNC Machine</th>
<th>3 Axis CNC Machine</th>
<th>CNC Horizontal Lathe</th>
<th>CNC Grinding Machine</th>
<th>CMM</th>
<th>OSTB</th>
<th>Assembly Line</th>
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<td>5</td>
<td>7</td>
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<td>3</td>
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</table>

MAWH is set as 3,400 hours (250 annual labor days, 8 working hours, 2 shifts, and 85% production-up-times)
Machining Cost (Example: Impeller)

- Machining cost savings of 25-30% can be achieved by increasing the volume of manufacturing.
- These savings are mostly due to the machining setup times.
Discounted Cash Flow (DCF) and Minimum Sustainable Price (MSP)

- MSP is the minimum price that a company would have to charge for a good or service to cover all variable and fixed costs and make sufficient profit to pay back investors at their minimum required internal rates of return (IRR).

- The MSP is computed by setting the net present value (NPV) of an investment equal to zero with the IRR equal to the weighted average cost of capital (WACC).

- U.S. capital assets pricing model is used to derive debt and equity ratios, and weight them by their relative contribution to the overall capital structure of the firm to estimate WACC values.

<table>
<thead>
<tr>
<th>Inputs for DCF Calculations</th>
<th>Values</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Inflation on cost of goods sold (COGS)</td>
<td>3</td>
<td>%</td>
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<tr>
<td>Corporate interest rate</td>
<td>3.3</td>
<td>%</td>
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<td>Initial Loan (or bond) maturity</td>
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<td>years</td>
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<td>Corporate tax rate</td>
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<td>%</td>
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<td>Dividend payout rate</td>
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<td>%</td>
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<td>Cost of equity</td>
<td>10.6</td>
<td>%</td>
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<tr>
<td>Cash flow analysis period</td>
<td>20</td>
<td>years</td>
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<td>Working capital collection period</td>
<td>10</td>
<td>years</td>
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<tr>
<td>Calculated WACC</td>
<td>5.3</td>
<td>%</td>
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<tr>
<td>Working capital inventory turnover</td>
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<td>years</td>
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<tr>
<td>Working capital payable period</td>
<td>10</td>
<td>years</td>
</tr>
<tr>
<td>CAPEX Initial target capital structure, % of debt in (debt + equity)</td>
<td>64</td>
<td>%</td>
</tr>
<tr>
<td>Replacement equip. target capital structure, % of debt in (debt + equity)</td>
<td>50</td>
<td>%</td>
</tr>
<tr>
<td>Depreciable life for plant</td>
<td>25</td>
<td>years</td>
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<tr>
<td>Capital replacement loan maturity</td>
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<td>years</td>
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<tr>
<td>Equipment depreciation type</td>
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<tr>
<td>Tooling depreciation type</td>
<td>3 Year Straight-line</td>
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<tr>
<td>Building depreciation type</td>
<td>15 Year Straight-line</td>
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</table>
Manufacturing Analysis: Case Studies
Case Studies

Three Case Studies:
1. 1 MW ORC Turboexpander
2. 5 MW ORC Turboexpander
3. 20 MW Steam Turbine

→ Compared MSP of custom design turbine to standard turbine as a function of manufacturing volume
A single custom design 1 MWe turboexpander was found to be 893 $/kW whereas a standard-design 1 MWe turboexpander has an MSP of 226 $/kW at a manufacturing volume of 5.
Case Study-1: 1 MW ORC Turboexpander

**Sensitivity Analysis**

- Design & Engineering (D&E) is the most important cost factor at a custom design unit due to time spent on tailor made design for each custom unit.

- D&E is assumed to take 9 months and 2 full time employees (FTE).

- Manufacturing labor is the second most important factor at a custom design unit due to setup times.

- Selling, General and Administration (SG&A), capital (equipment and facilities), and materials are the other important factors which have a moderate effect on manufacturing cost for a custom design unit.
Case Study-1: 1 MW ORC Turboexpander

Manufacturing cost savings by switching to standard design turbines
Case Study-2: 5 MW ORC Turboexpander

A single custom design 5 MWe turboexpander was found to be 216 $/kW whereas a standard-design 1 MWe turboexpander has an MSP of 66 $/kW at a manufacturing volume of 5
Case Study-2: 5 MW ORC Turboexpander

**Sensitivity Analysis**

- Material becomes the most important cost factor at the standard size unit with a manufacturing volume of 10 units/year.

- Manufacturing labor is the second most important factor at the standard size unit with a manufacturing volume of 10 units/year.

![Custom Design](chart1.png)

![Standard Design](chart2.png)
Case Study-2: 5 MW ORC Turboexpander

Manufacturing cost savings by switching to standard design turbines

Bar chart showing manufacturing cost per unit for different categories and comparing Custom Design to Standard Design.
Case Study-3: 20 MW Geothermal Steam Turbine

A single custom design 20 MWe geothermal steam turbine is found to be 361 $/kW, whereas the MSP of a standard-design 20 MW steam turbine is calculated as 135 $/kW at an annual production rate of 5 unit

However...
1. Because of geofluid composition and corrosion issues, steam turbines have to be custom designed for a given geothermal resource.
2. Interviews revealed that in steam turbine industry, all steam turbines are custom design anyway.
Sensitivity Analysis

• Labor is the most important factor at a custom design unit due to setup times and high labor requirements during assembly.

• Capital is the second most important cost factor at a custom design.

• D&E is assumed to take 12 months and 4 FTEs unit due to time spent on tailor made parts for each unit.

• SG&A, capital (equipment and facilities), and materials are the other important factors which have a moderate effect on manufacturing cost for a custom design unit.
Case Study-3: 20 MW Geothermal Steam Turbine

Manufacturing cost savings by switching to standard design turbines
Discussions & Conclusions
Discussion on custom vs standard design turbines

- Currently, the geothermal turbine market is driven by developer`s demand for plant efficiency and custom turbines designed specifically for geothermal areas.

- **Custom Design Turbines:**
  - Designed and sized to optimize efficiency and resource utilization for electricity production,
  - Design & engineering stage is one of the most important factor affecting manufacturing cost
  - Custom design manufacturing processes result higher manufacturing setup costs, longer lead-times, and higher capital costs

- **Standard Design Turbines:**
  - The MSP`s could have a significant drop at increased volume of manufacturing
  - Can have lower total lead time (i.e. 18 months to 8 months including shipping and installation)
  - One size standard turbines can operate at off-design conditions proving different output capacities

<table>
<thead>
<tr>
<th>MSP</th>
<th>Custom Design Single Unit</th>
<th>Standard Design Volume of 5 Units</th>
<th>Standard Design Volume of 50 Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MW Turboexpander</td>
<td>893,000 $</td>
<td>893 $/kW</td>
<td>226,000 $</td>
</tr>
<tr>
<td>5 MW Turboexpander</td>
<td>1,080,000 $</td>
<td>216 $/kW</td>
<td>332,000 $</td>
</tr>
<tr>
<td>20 MW Steam Turbine</td>
<td>6,350,000 $</td>
<td>361 $/kW</td>
<td>2,790,000 $</td>
</tr>
</tbody>
</table>
Conclusions

• CEMAC developed model which assumes;
  o Facility cost based on minimum required working area per machine;
  o Equipment cost based on annual straight line depreciation,
  o Labor cost based on operational hours with setup time.
  o The model does not include storage and shipping costs

• This may result in differences between the MSP`s calculated in this study and actual industry costs. However, the concept of standard design and manufacturing cost saving would be similar.

• Sensitivity analysis indicated these savings come largely from reduced labor costs for design & engineering and manufacturing setup.

• Standard size geothermal turbines manufactured at high volumes can lower down manufacturing costs.

• A significant barrier to implementing this strategy is the demand for these technologies at high volumes.

• However, as the global geothermal market continues to grow, opportunities in new markets will continue to increase which may be an opportunity for reducing plant capital costs by standardized turbines.
Next Steps & Future Work:

- Off-Design turbine performance analysis for standard size turboexpanders
- Balance of Plant (BOP) analysis including heat exchangers, and cooling tower /Air cooled condenser (ACC) effectiveness with respect to off design operating conditions.
- DCF analysis of project economics to see if standard design makes sense – do lower turbine costs (capital costs) compensate for lower efficiency/lost revenue?
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Thank You

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