Perspective

- POWER Engineers
- 750+ MW of flash and binary geothermal experience
- Spanning OE, IE, and detailed design roles
- Your speaker – Kevin Wallace
Objectives – let’s build up

1. General power plant technologies and relative merits
2. Types of technical challenges and plant configuration options
3. Types of development challenges and lessons learned
4. Need flexibility due to resource uncertainty
The Basic Basics
- Technologies
Our Favorite Fundamental Equation

- Heat engines receive energy at a high temperature, reject it at a low temperature, and produce net work from the difference.
- Results in the (ideal) expression:

\[
\text{Power} \propto \text{Energy in} \times \left(1 - \frac{T_C}{T_H}\right)
\]

Moran & Shapiro, *Fundamentals of Engineering Thermodynamics*
Basic Cycles - Backpressure

1. Suitable for small capacity plant
2. Suitable for large gas quantity
3. Using steam separated by separator
4. Condenser and its auxiliaries are not necessary.
5. Low cost

(MHI, Geothermal Power Generation)

Miravalles PGM-29
(Costa Rica)

San Jacinto 2 x 5 MW
(Nicaragua)
Basic Cycles – Flash/Condensing

1. Suitable for large capacity plant
2. Using steam separated by separator
3. Most popular plant cycle

1. Suitable for large capacity plant
2. Using steam separated by separator and flasher
3. Plant efficiency is 15-20% higher than single flash.

Miravalles III

Mindanao I/II
Basic Cycles - Binary

1. Rankine cycle using a working fluid in low boiling temp. (Freon, Hydrocarbon etc.)
2. Brine in low temperature level is available.
3. Complete package units are suitable for smaller capacity.

TAS unit at Beowawe
The Dizzying Array of Binary Cycle Choices

 Customization is worth it
 Bigger is better, unless it isn’t
 Consider O&M

➢ Combine standardization with flexibility

(Mlcaik, 2002)
(Swandaru and Palsson, 2010)
(Kaplan, 2007)
Specific power output

\[ \text{Power} \propto \text{Energy}_{\text{in}} \left(1 - \frac{T_C}{T_H}\right) \]

Threshold of commercial viability will depend on many factors…

Typical binary output
(MIT, *Future of Geothermal Energy*)
If we understand the basics, we can understand cost and technology selection drivers.
Screening options

Prefeasibility studies might compare plant options on the bases of:

- Resource ‘fit’
- Cost/kW (plant and project)
- Net output
- Land usage
- Water usage
- Equipment marketplace
- Permitting considerations

(Performance comparison by Bombarda and Macchi, 2000)

(Indicative 50 MW plant costs by ESMAP, 2012)
Project capital cost
Significant sensitivities

- Project size
- Resource quality
  - Production
  - NCGs
  - Solids
- Ambient conditions
- Project structure

Sample project cost breakdown (EPRI, 2010)
Let’s explore some major cost/challenge drivers in more detail - starting with:

Resource Production
Uncertainty
Case Study - Geysers

Where are you in your development?

Where will you be?

Sanyal and Enedy (2011)
Strategies for Resource Uncertainty

- Accurate characterization
- Appropriate sizes of development increments
- Coupled resource/plant management
- Makeup well drilling program
- Injection strategies
- Plant design margins for resource decline (P,T, mass)
  - Additional Heat Exchanger Surface Area or Cooling Equipment
  - Multi-configuration NCG Systems
  - Variable Speed Drives for Process Equipment
  - Partial Arc Admission or Variable Guide Inlets Vanes
Solids and Injectivity
## Solids challenges

<table>
<thead>
<tr>
<th>Plant Equipment Scaling</th>
<th>Injection Well Scaling</th>
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<tbody>
<tr>
<td><strong>Binary heat exchanger scaling</strong></td>
<td><strong>Injection well silica scaling</strong></td>
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<tr>
<td>Managed with injection temperature limits</td>
<td>Managed with pH modification</td>
</tr>
<tr>
<td>Managed with O&amp;M procedures</td>
<td>Managed with CRC process</td>
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**Power Engineers, Inc.**

**EnergySource**
Strategies for Solids/Injectivity

- Accurate geochemical assessment
- Binary heat exchanger fouling and cleaning provisions
  - Multiple Trains
- Production well scale inhibitors
- Injection well scaling control
  - Appropriate injection temperature limits
  - pH-mod and scale inhibitors
  - CRC process
- Weigh costs: lost production, chemical, equipment, O&M
Ambient Conditions

\[ \text{Power} \propto \text{Energy}_{\text{in}} \left( 1 - \frac{T_C}{T_H} \right) \]
Strategies for Ambient Condition Uncertainty

- Site monitoring – temperature, humidity
- Wind rose. Beware the hot wind.
- Allowances for climate change
- Reliability of local long-term data
- Design point/PPA considerations
- Cooling system options

- Start early, developers!

ACCs at Steamboat (Google Earth)

Single fan ACCs (TAS/US Geothermal)
Project Management Challenges
## Project Management Challenges

<table>
<thead>
<tr>
<th>Financing exploration and drilling</th>
<th>Cross the ‘Valley of Illiquidity’</th>
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<tbody>
<tr>
<td>Characterizing the reservoir and appropriate development size</td>
<td>Intel, intel, intel</td>
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<tr>
<td>Determining appropriate project structure (EPC, D/B, BOT, BOO, etc)</td>
<td>Make your ‘first cast’ the best</td>
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<tr>
<td>Construction and generating cash flow</td>
<td>Execute with deliberate speed</td>
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<tr>
<td>Managing reservoir and O&amp;M costs</td>
<td>Monitor reservoir and plant performance with diligence</td>
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Summary Considerations

- A wealth of exploration techniques and geothermal plant technologies are available
- Imperative to have accurate resource characterization
- Consider strategies to address technical challenges
- Consider strategies to address project management challenges
Thank you for your attention!

Any questions?
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