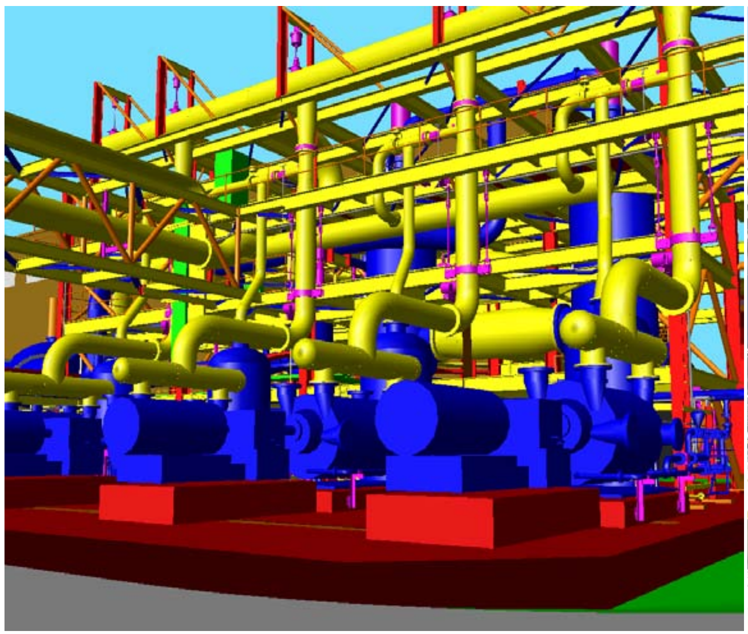
2013 APEC Geothermal Conference

Geothermal Power Plant Development

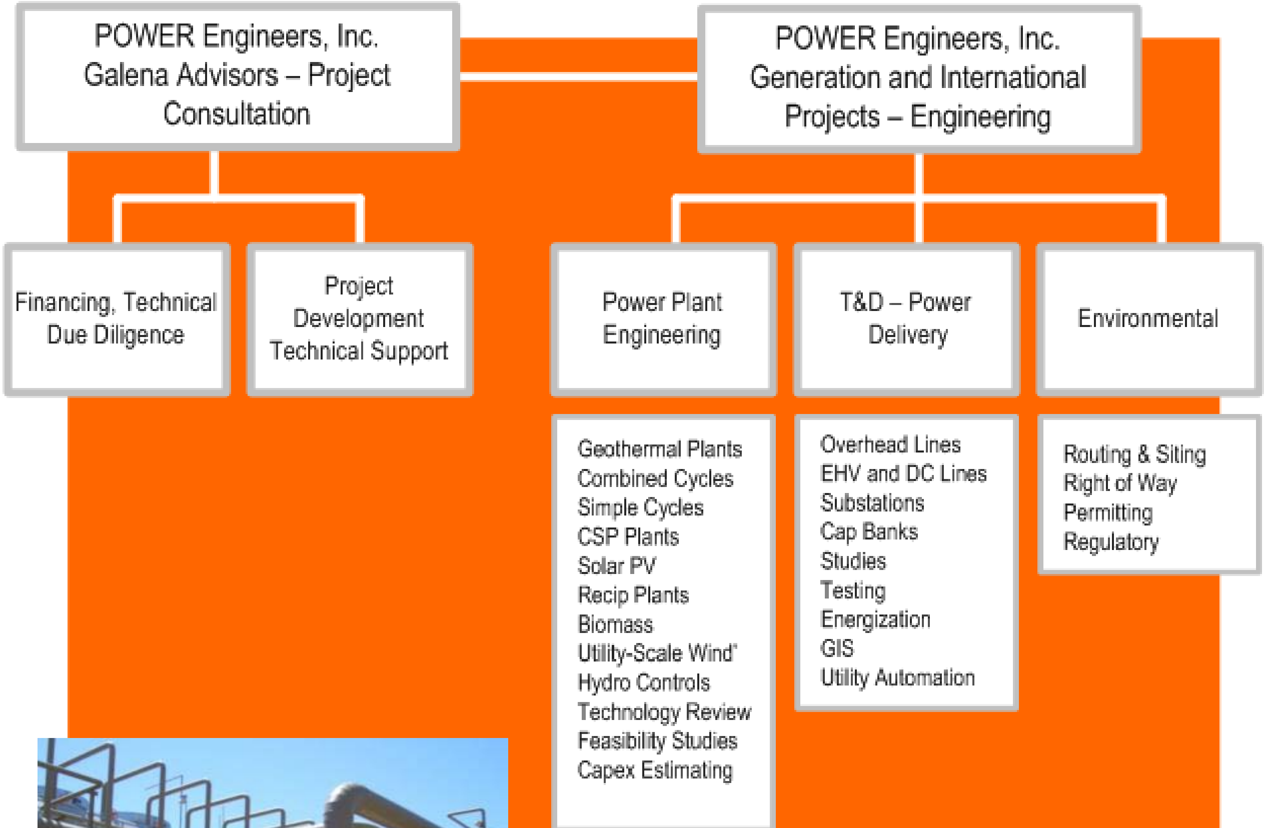
Basic technology, technical challenges, and lessons for developers



POWER ENGINEERS

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

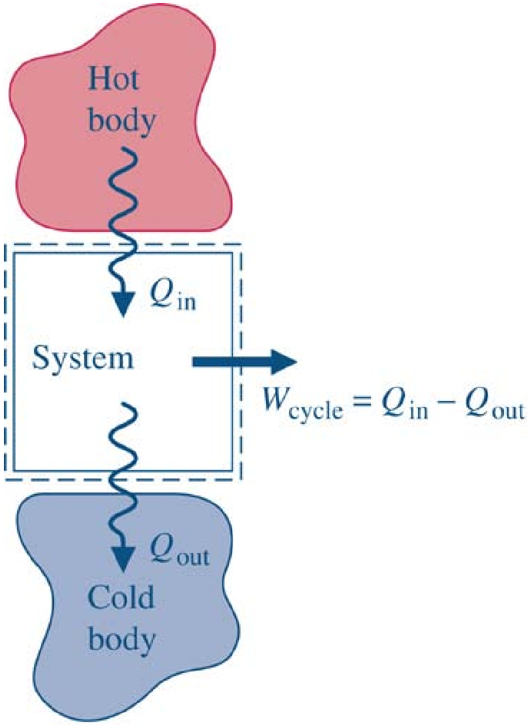
1. General power plant technologies and relative merits
2. Types of technical challenges and plant configuration options
3. Types of development challenges and lessons learned
4. Need flexibility due to resource uncertainty

The Basic Basics
- Technologies

Our Favorite Fundamental Equation

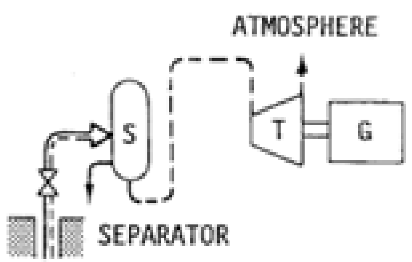
- Heat engines receive energy at a high temperature, reject it at a low temperature, and produce net work from the difference
- Results in the (ideal) expression:

$$Power \propto Energy\_in * \left(1 - \frac{T_C}{T_H}\right)$$



Moran & Shapiro, *Fundamentals of Engineering Thermodynamics*

Basic Cycles - Backpressure

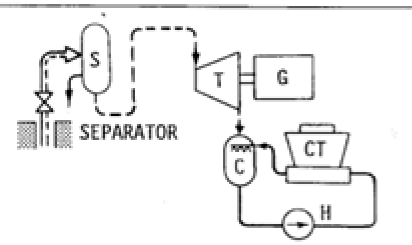
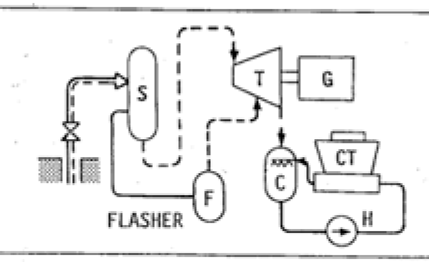
BACK PRESSURE	 	1. Suitable for small capacity plant 2. Suitable for large gas quantity 3. Using steam separated by separator 4. Condenser and its auxiliaries are not necessary. 5. Low cost

(MHI, Geothermal Power Generation)

Miravalles PGM-29
(Costa Rica)

San Jacinto 2 x 5 MW
(Nicaragua)

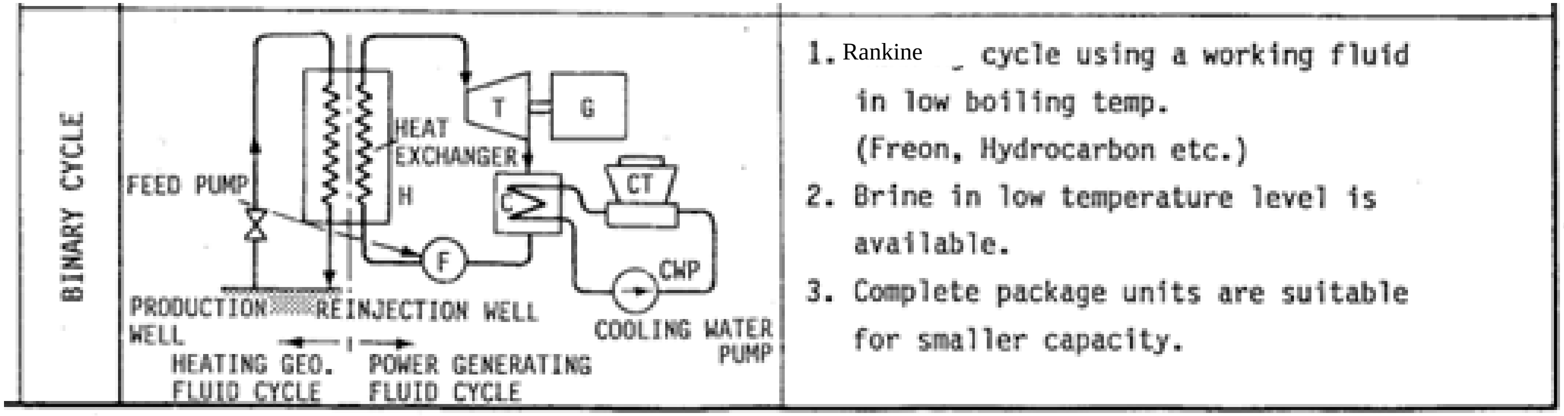
Basic Cycles – Flash/Condensing

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

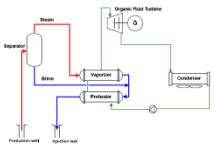


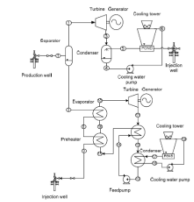
1. Rankine cycle using a working fluid in low boiling temp. (Freon, Hydrocarbon etc.)
2. Brine in low temperature level is available.
3. Complete package units are suitable for smaller capacity.

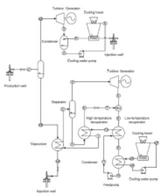
TAS unit at Beowawe

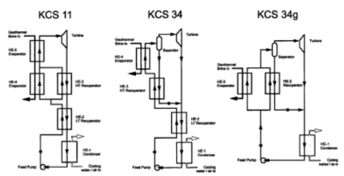
The Dizzying Array of Binary Cycle Choices

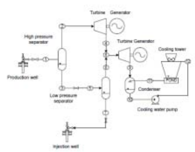
- Customization is worth it
- Bigger is better, unless it isn't
- Consider O&M

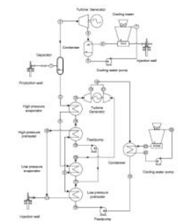


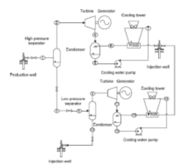




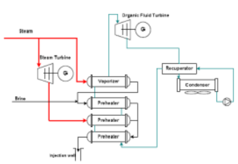


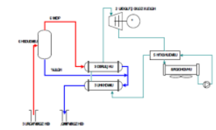






- ➢ Combine standardization with flexibility

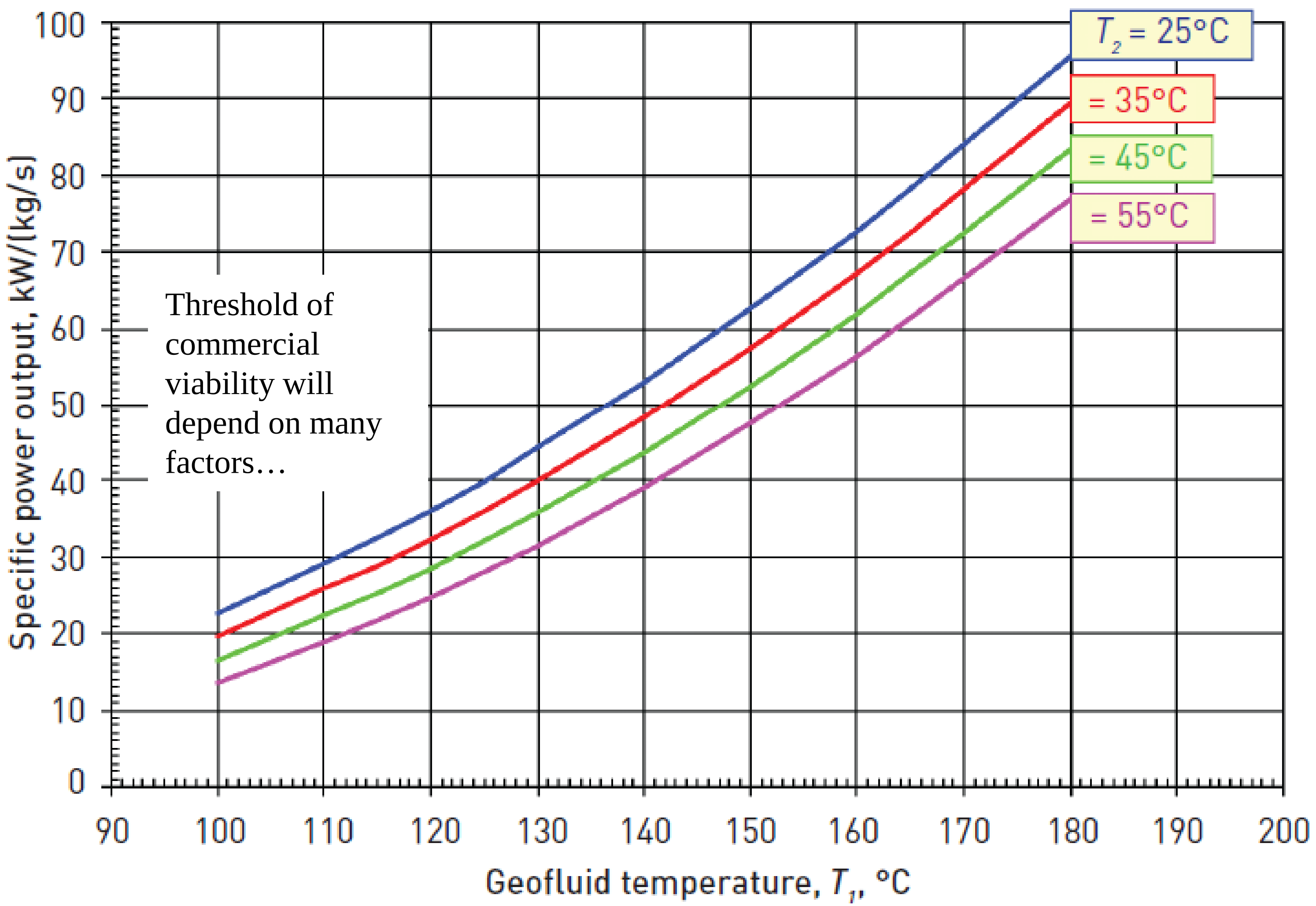




(Mlcak, 2002)
(Swandaru and Palsson, 2010)
(Kaplan, 2007)

Specific power output

$$Power \propto Energy\_in * \left(1 - \frac{T_C}{T_H}\right)$$



Typical binary output (MIT, *Future of Geothermal Energy*)

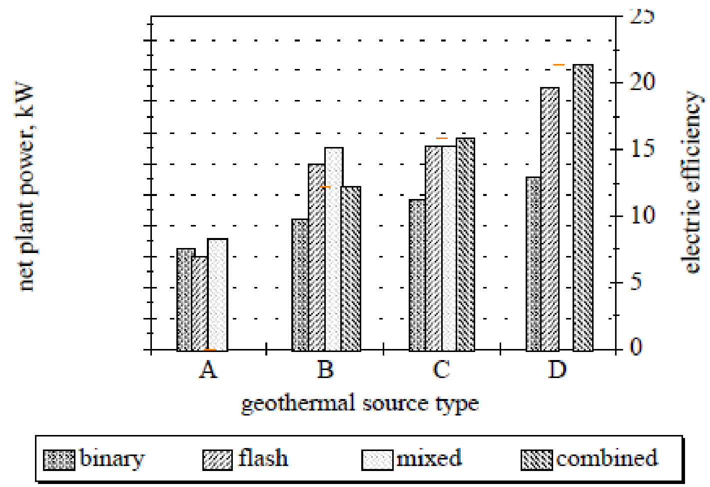
If we understand the basics,

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



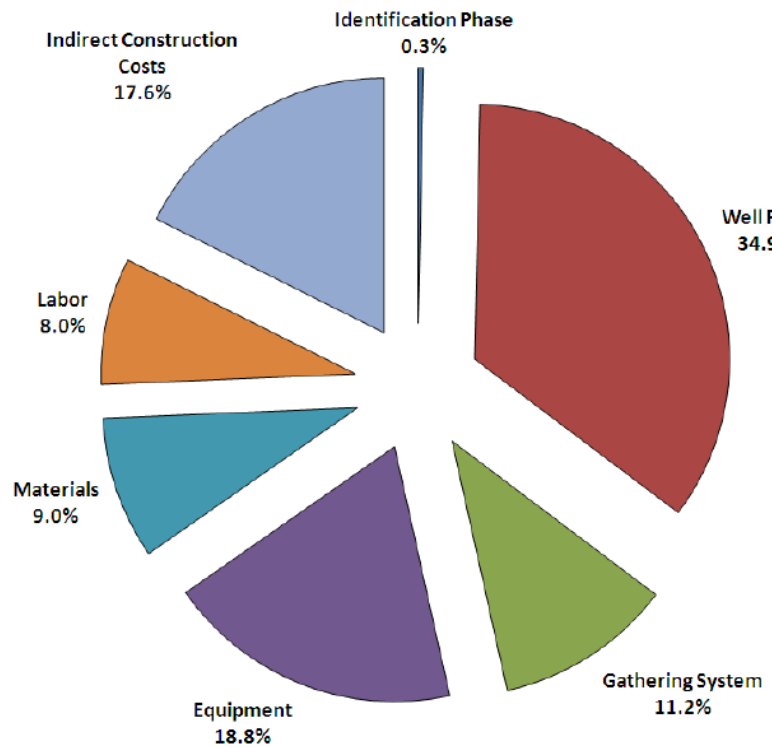
(Performance comparison by Bombarda and Macchi, 2000)

(Indicative 50 MW plant costs by ESMAP, 2012)

	PHASE / ACTIVITY	LOW ESTIMATE	MEDIUM ESTIMATE	HIGH ESTIMATE
1	Preliminary Survey, Permits, Market Analysis[16]	1	2	5
2	Exploration[17]	2	3	4
3	Test Drillings, Well Testing, Reservoir Evaluation[18]	11	18	30
4	Feasibility Study, Project Planning, Funding, Contracts, Insurances, etc.[19]	5	7	10
5	Drillings (20 boreholes)[20]	45	70	100
6	Construction (power plant, cooling, infrastructure, etc.)[21]	65	75	95
	Steam Gathering System and Substation, Connection to Grid (transmission)[22]	10	16	22
7	Start-up and Commissioning[23]	3	5	8
	TOTAL	**142**	**196**	**274**
	In US$ Million per MW Installed	2.8	3.9	5.5

Project capital cost
Significant sensitivities

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

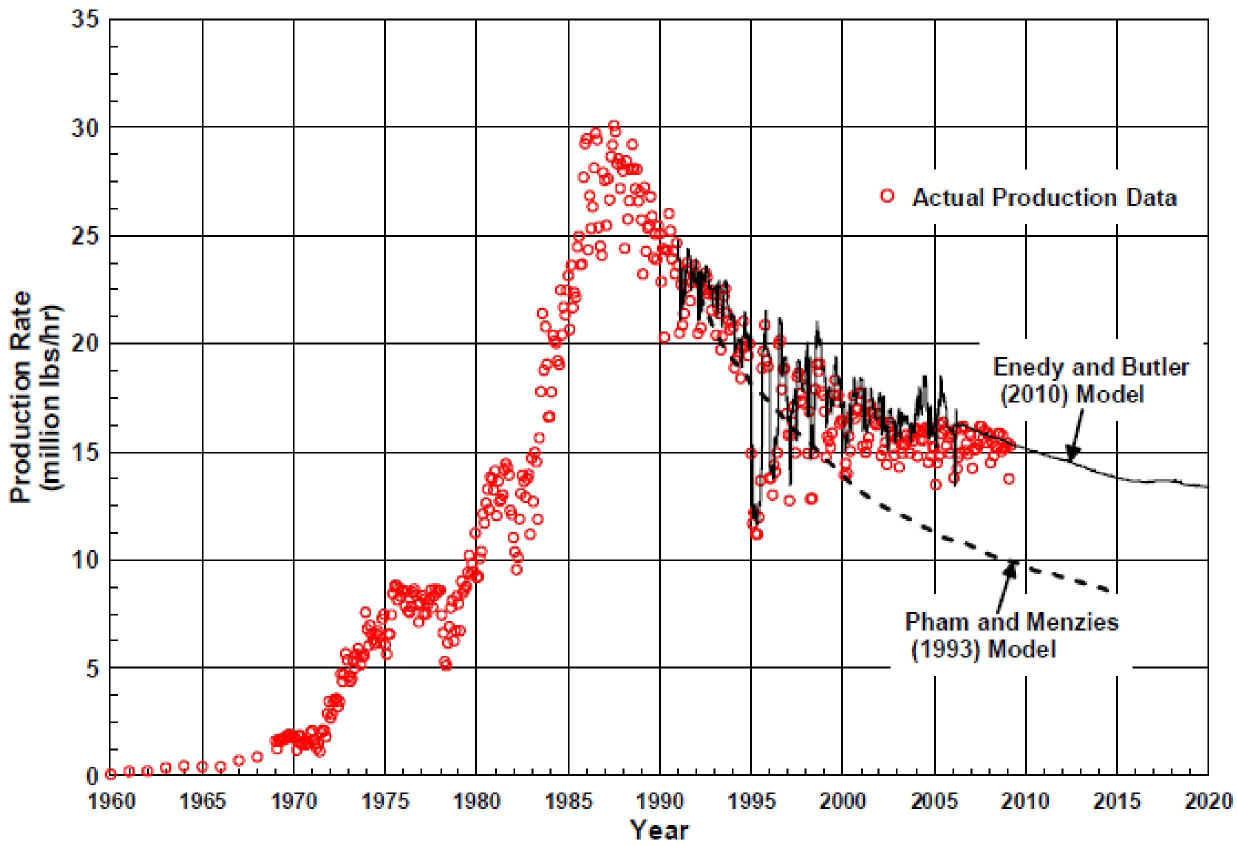


Sample project cost breakdown
(EPRI, 2010)

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

Plant Equipment Scaling	Injection Well Scaling
	 EnergySource
Binary heat exchanger scaling Managed with injection temperature limits Managed with O&M procedures	Injection well silica scaling Managed with pH modification Managed with CRC process

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

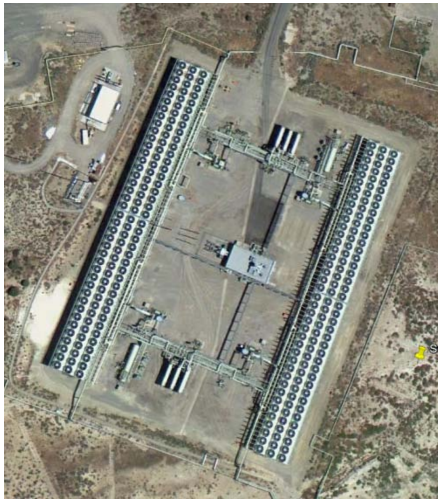
Ambient Conditions

$$Power \propto Energy\_in * \left(1 - \frac{T_C}{T_H}\right)$$

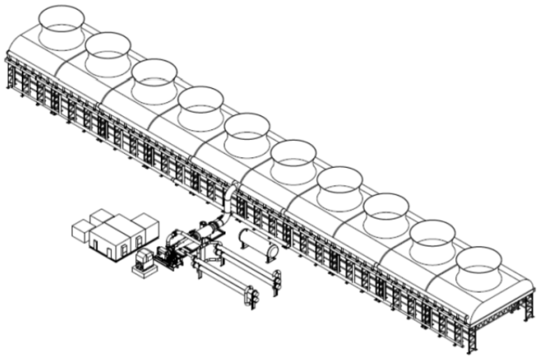
Strategies for Ambient Condition Uncertainty

- 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

Financing exploration and drilling	Cross the 'Valley of Illiquidity'
Characterizing the reservoir and appropriate development size	Intel, intel, intel
Determining appropriate project structure (EPC, D/B, BOT, BOO, etc)	Make your 'first cast' the best
Construction and generating cash flow	Execute with deliberate speed
Managing reservoir and O&M costs	Monitor reservoir and plant performance with diligence

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?
Please contact:

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Stillwater (ENEL)