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Operational Flexibility of Geothermal Power

Geysers Power Company, LLC

January 28, 2016

Investigating Flexible Generating Capabilities at The Geysers

California Energy Commission (Grant # EPC-14-002)

CLEAN MODERN EFFICIENT FLEXIBLE POWER GENERATION

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The Geysers Overview
Calpine Corporation 2014 Facts

Calpine Geothermal Operations

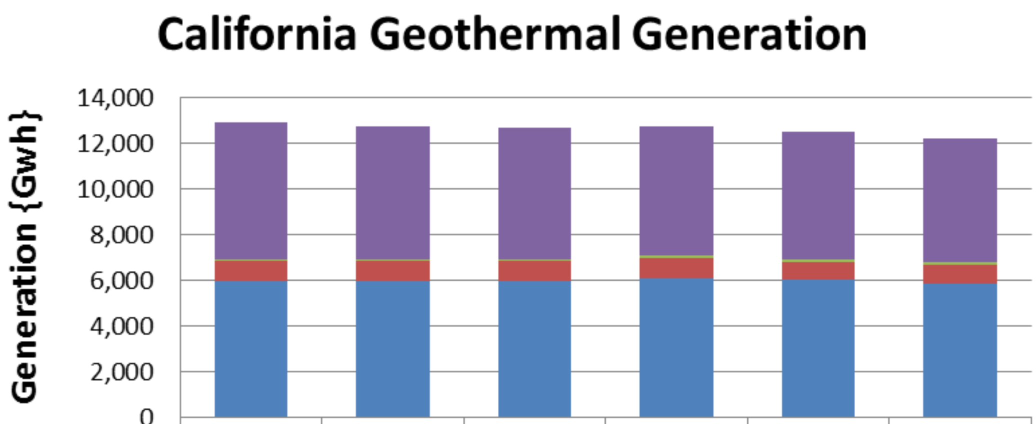
- 29000 acres (45 square miles – 120 square kilometers)
- 14 geothermal power plants

Calpine Power Generation

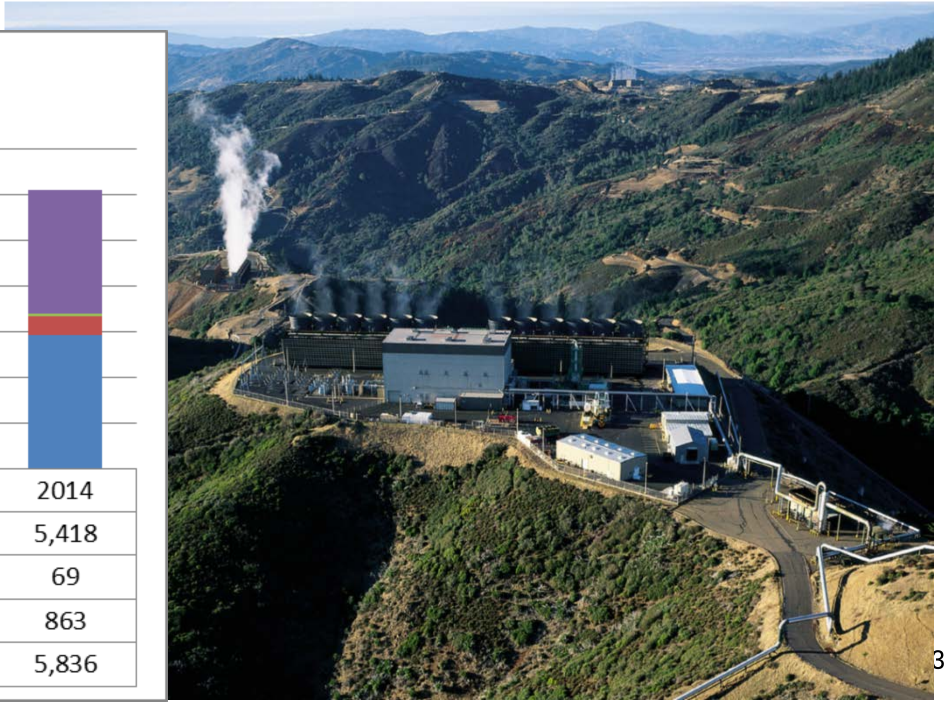
- 2014 average load: 666.2 megawatts net
- 2014 generation: 5,836,316 net megawatt hours
- 2014 average unit availability: 96.0%

13% of California's renewable energy generation (15.3% in 2013)

36.8% of United States geothermal energy generation



	2009	2010	2011	2012	2013	2014
Other	5,967	5,846	5,756	5,671	5,586	5,418
Bottle Rock	88	68	88	72	73	69
NCPA	903	846	858	875	817	863
Calpine	5,949	5,981	5,981	6,115	6,003	5,836



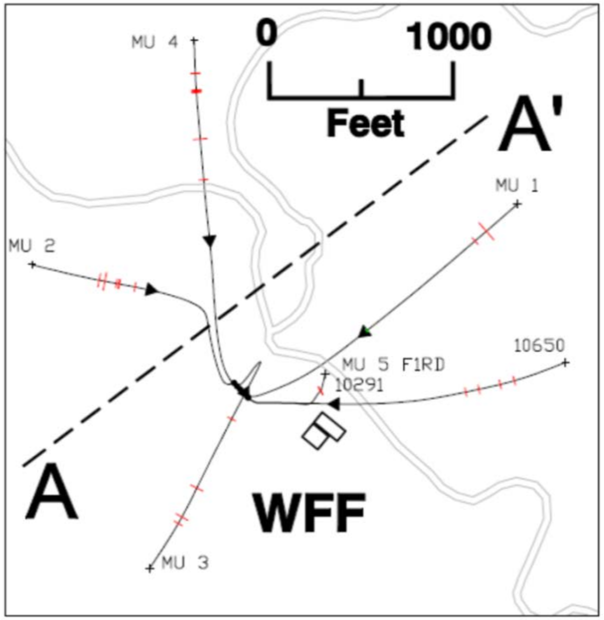
The Geysers
Calpine Corporation 2014 Facts

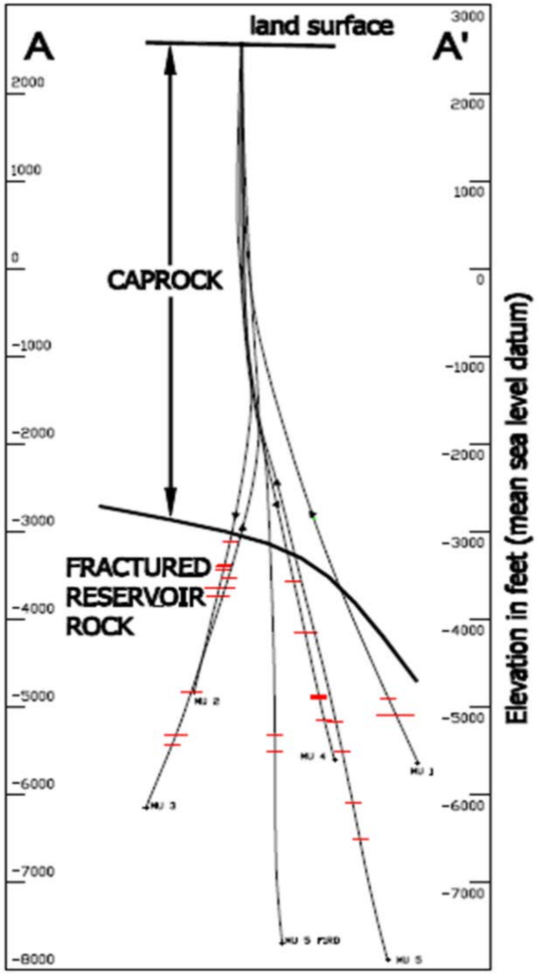
Calpine Geothermal Wells

- 333 steam production wells - 60 water injection wells
- Average well depth: 8,500 feet (~ 2590 m)
- 2014 average steam production per well: 36,200 lb/hr
- Flow weighted average wellhead pressure: 79.2 psig
- Flow weighted average wellhead temperature: 362º F
- Flow weighted average wellhead enthalpy: 1216 Btu/lb
- Average reservoir rock temperature: 465º F

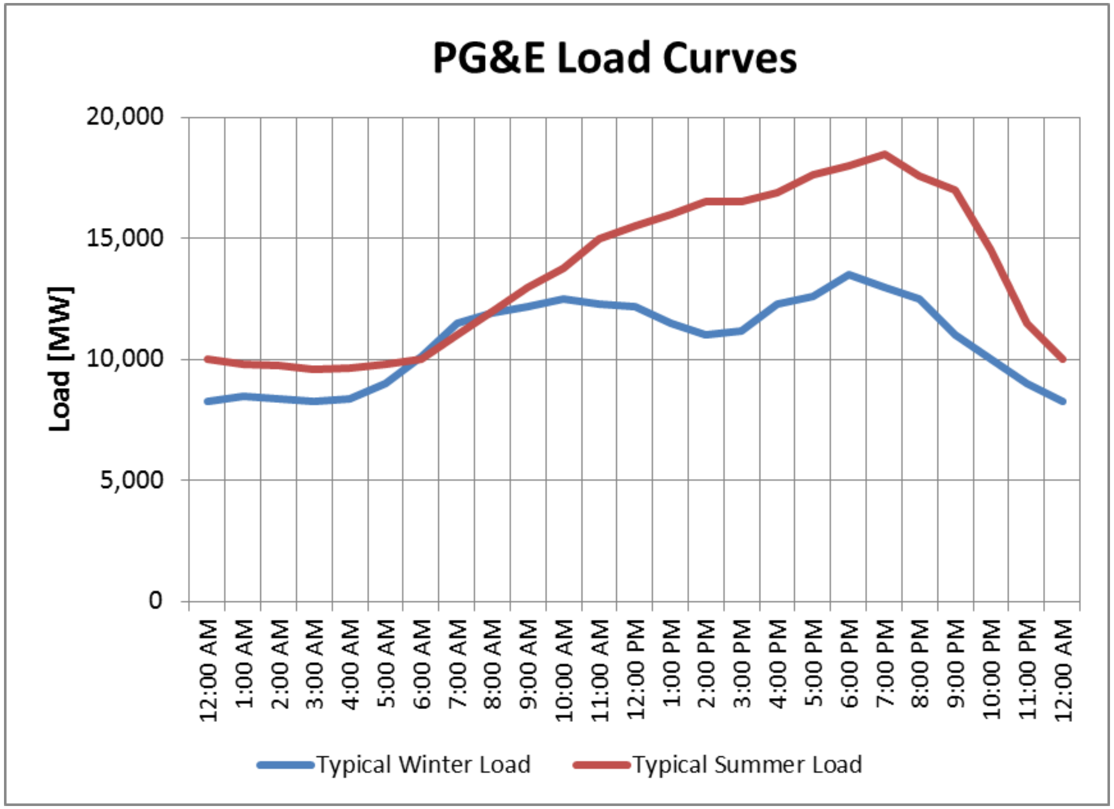
Calpine Steam Gathering System

- Approximately 70 miles of steam pipelines feeding 14 power plants from 400 wells (approx. 5000 nodes)





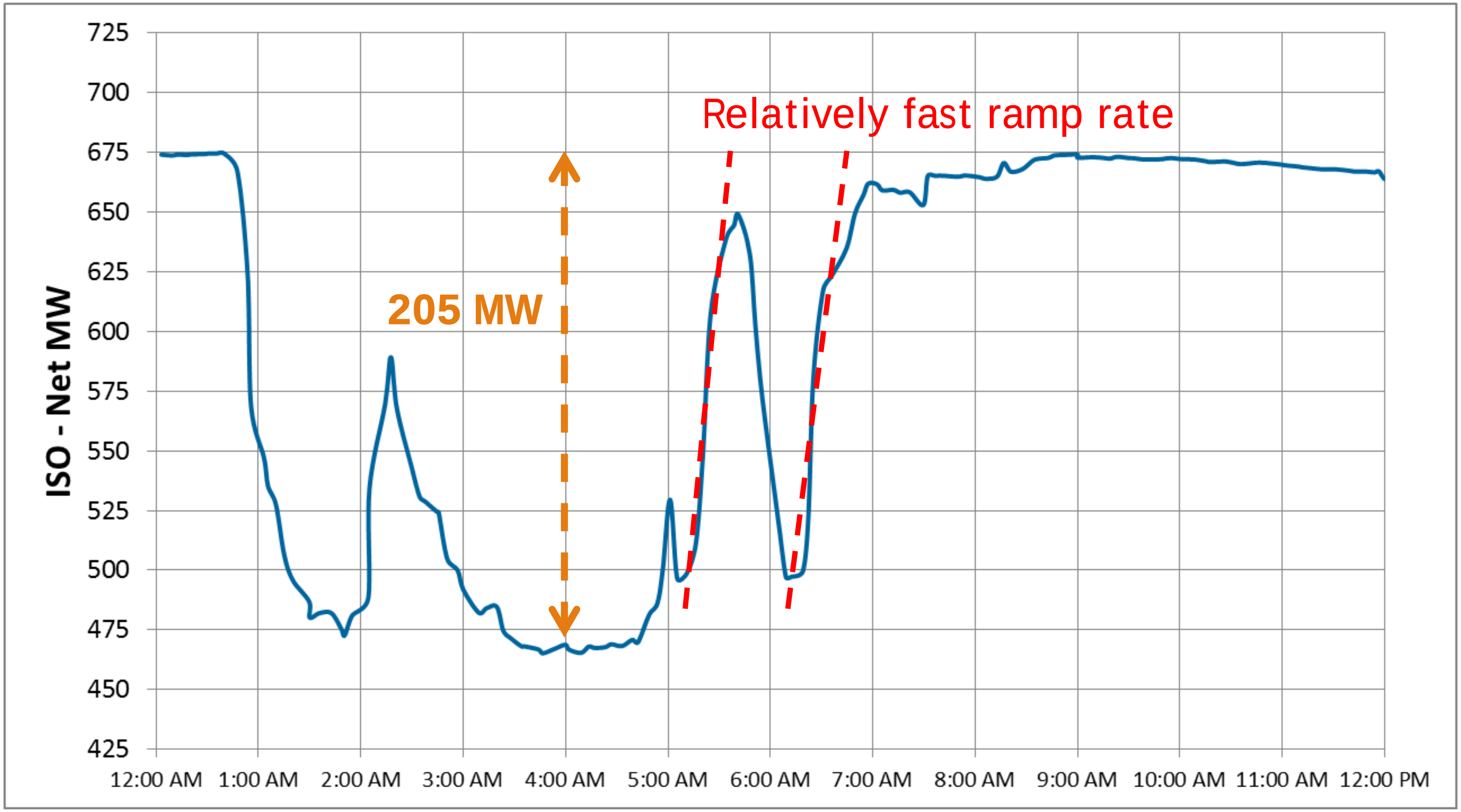
Load Following in the 1990's



- In August of 1994 PG&E executed new steam sales agreements for 12 power plants with provisions for cycling operations up to:
  - 25% capacity factor monthly basis
  - 40% CF annual basis
- Fall '94 and spring '96 Night and Weekends curtailments
- 1995 month-duration curtailment due to high hydro generation.

- Daily cycles of approximately 200 MW
- <u>Benefits</u>: "keep utility bills low", reduced reservoir decline rates, short term increase generation "puff"
- <u>Disadvantages</u>: Deferred revenues, damages due to thermal cycling of wells, corrosion, increased pipeline operation and maintenance problems, increased NCGs.

Load Cycling - Today {May 23rd, 2014}



05-23-2014 00:47PDT	Jerry Stasik Sr.	Dispatch	ADS instructions : at 0052 go to 469 mw ISO, SO-3 to 30, MC-5/6 to 60. RL-7/6 to 35. ER-11 to 49, CC-12 to 33, BG-13 to 32 mw, SS-14 to 34, QK-16 to 27, SC-18 to 25, CA-19 to 31, GT-20 to 22. PCO's notified.
05-23-2014 02:16PDT	Jerry Stasik Sr.	Dispatch	ADS instructions : at 0222 go to 618 mw ISO, SO-3 to 30,, CC-12 to 52, BG-13 to 40 mw, SS-14 to 52, SC-18 to 31, GT-20 to 29. PCO's notified
05-23-2014 02:31PDT	Jerry Stasik Sr.	Dispatch	ADS instructions : at 0237 go to 495 mw ISO, RL-7/8 to 45 CC-12 to 31, BG-13 to 22 mw, SS-14 to 28 QK-16 to 27. PCO's notified.
05-23-2014 06:26PDT	Steven Wilson	Dispatch	ADS Instructions: go to 650.6 mw's, Operators notified

Towards a more flexible Geysers generation

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725 MW

X
- Plant operations
- Steam field configuration

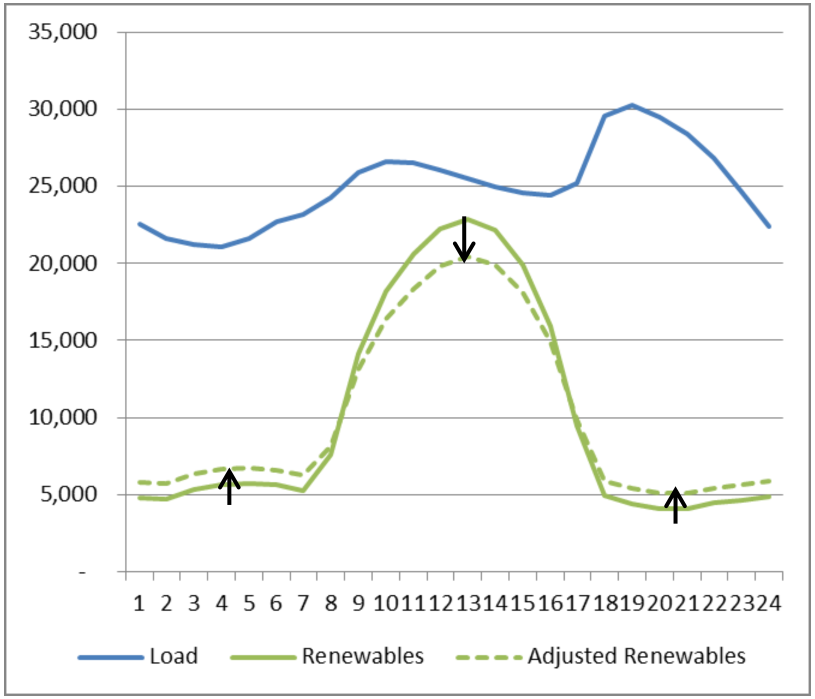
Y
- Turbine bypass

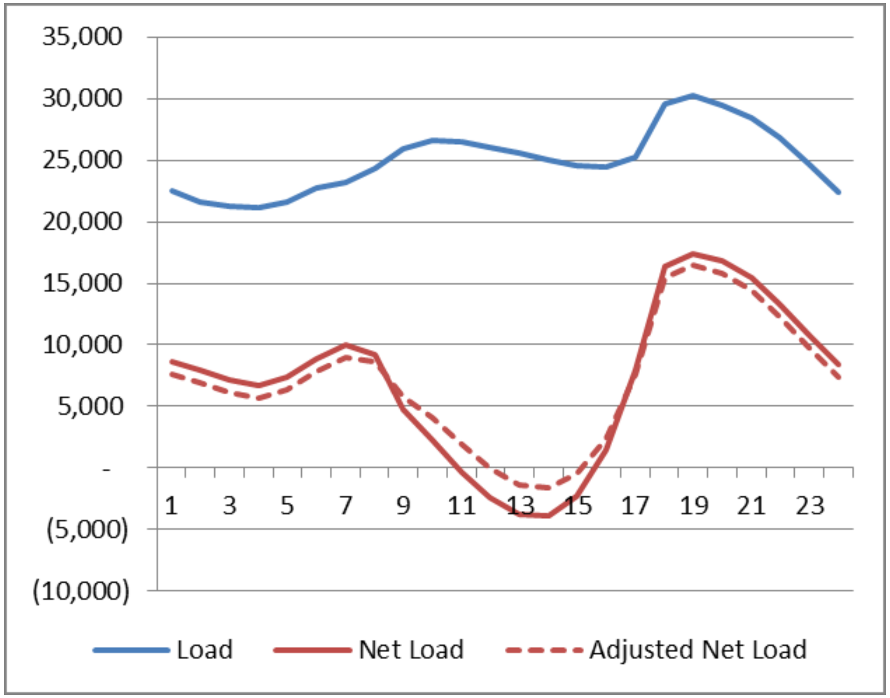
Z
- Steam field configuration
- Individual well curtailments

P - min

Steamed duck and geothermal contribution tomorrow (2022)

Effect of substituting 1,000 MW of geothermal for equivalent amount of solar
40% renewable portfolio in 2022





- Substituting geothermal flattens renewable generation
- Daytime Solar generation displaced at approximately a 1:3 ratio

- Daily swings in net load are reduced
- Ramps are shorter and less steep
- Minimum net is higher relieving Pmin constraint
- Decreased need for flexibility services

Source: E3 Renewable Energy Flexibility Results, CAISO webinar Dec 9, 2013 and CALPINE-E3 study

Goals and Objectives

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- Goals:
  - Define flexible generation capabilities and limitations at the Geysers;
  - Avoid risks to geothermal facilities related to flexible operation; and
  - Determine costs associated with providing flexibility and ancillary services.
- Objectives:
  - Develop an integrated model that simulates flexible operation in wells, pipelines, power plants and throughout the Geysers steam field;
  - Conduct curtailment pilot tests in the Geysers steam field both around an isolated power plant, and at a location in which the steam field pipelines are cross-tied to several power plants;
  - Test mitigation strategies that will be needed to achieve flexible steam field operation;
  - Define the management strategy that will allow the Geysers to provide flexible capacity without posing significant risks to the reservoir, pipeline, wells, and power plants;

Investigating Flexible Generating Capabilities at The Geysers

Areas of Concerns

- Reservoir:
  - Daily production cycles will result in daily reservoir stress variations as a result of production-induced temperature and pressure changes.
    - Reservoir Stimulation
    - Changes in seismicity pattern
  - Cycling could change near wellbore behavior with effects in well deliverability.
  - Potential need to change injection strategy will affect steam recovery and seismicity patterns.

- Wellbore:
  - Loss of wellbore superheat may lead to condensation. When the steam condenses, hydrogen chloride gas in the steam ionizes to hydrochloric acid and leads to localized corrosion of upper wellbore, wellhead equipment and tie-in piping
  - Steam condensation can lubricate rocks and cause sloughing and obstruction ("bridging") of wellbores which are not lined through the reservoir

Areas of Concerns

- Steam Field:
  - Low steam flow in pipeline could increase the rate of heat loss in pipelines leading to steam condensation and potentially corrosion
  - Cycling steam flow rates will shift the location, pattern and severity of corrosion rates in steam pipelines compared to base-load operations
  - Beneficial dilution of high acid-chloride steam lost during cutbacks
  - Localized corrosion from mixing of wet steam and high-chloride steam
- Power Plants:
  - Non-condensible gases (NCG) can form gas slugs in low velocity sections of pipeline, such as cross-ties, that can overwhelm a power plant's gas removal system, or cause abatement system instability and/or unit trips.
  - Variation in gas chemistry can affect abatement system operation.
- Operations/Other:
  - Accurate steam flow rate metering is a critical challenge during deep flow rate cutbacks
  - Impact on condensate collection systems

Investigating Flexible Generating Capabilities at The Geysers

Project Tasks

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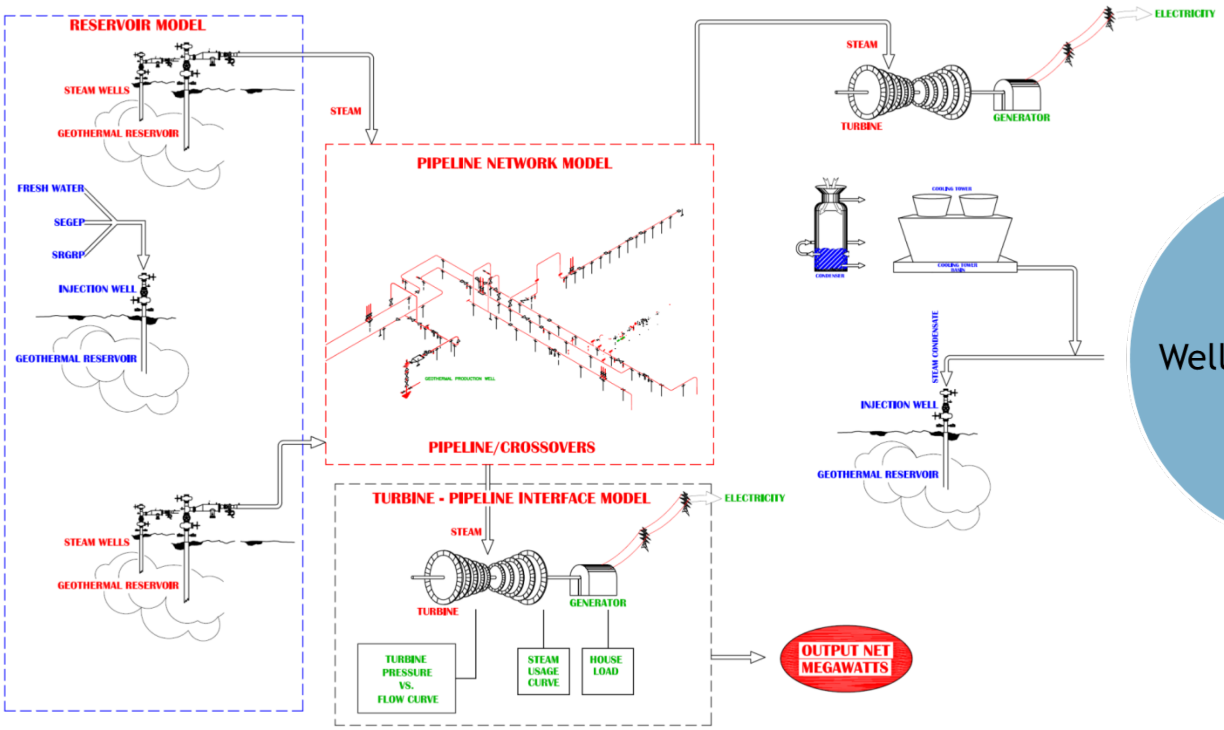
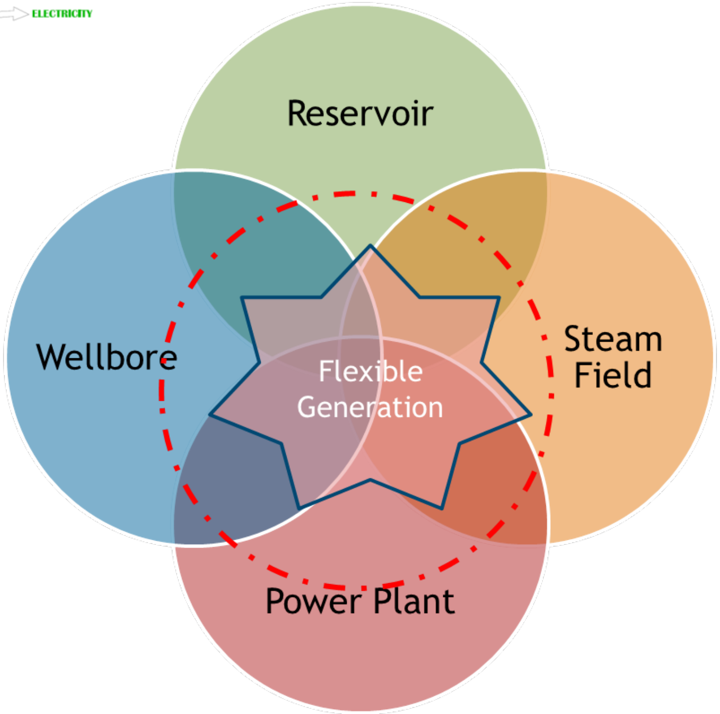
- Task 1, General Project Tasks
- Task 2, Develop an Integrated Production Model for the Geysers under Flexible Generation:
  - Develop modeling methods and tools for optimization of steam fields and power plants for flexible generation at the Geysers
- Task 3, Pilot Test Flexible Generation Scenarios and Field Management Tools:
  - Test various flexible generation scenarios;
  - Collect and provide data to assist with model validation.
- Task 4, Determine Field Management Strategies :
  - Define the limits of flexible operation
- Task 5, Evaluation of Project Benefits
- Task 6, Technology/Knowledge Transfer

Task 2: Develop an Integrated Production Model for Flexible Generation

Integrated Modeling Reservoir/Pipeline Network Simulation Model





Accomplishments:

- Test current model capabilities
- Test individual model components for wellbore and pipeline simulators
- Apply/validate in house wellbore simulator with pilot test data
- Model testing for curtailment scenarios (including valley fire)

Approach

- Objectives
  - Quantify the effects of load cycling on corrosion in steam wells and pipelines
  - Conduct field tests on representative wells and pipelines
  - Extrapolate to determine field wide effects
- Approach to quantify these effects
  - Task 3.1: Develop field testing plan & define test protocol
  - Task 3.2: Phase I - Individual well and component testing
  - Task 3.3: Phase II – Multiple well & pipeline testing
  - Task 3.4: Phase III – Integrated facility testing
  - Task 3.5: Phase IV – Test Mitigation Strategies
- Accomplishments
  - 3 cycling well tests
  - Detailed planning for field modifications for flex gen field testing
  - Cycling well testing in the Sonoma PP steam field
  - Place orders for long lead time equipment needed for field testing

Task 4: Field Management Strategies and Cost for Flexible Generation

- Goals:
  - Define the limits of flexible operation
  - Determine the costs of providing flexible generation
- Scope of Work:
  - Utilize modeling and pilot test results to define existing flexible operating limits in terms of magnitude, frequency, duration and ramp rate
  - Determine remote control, hardware and metering processes needed in order to minimize risks and costs associated with implementing system-wide flexible strategies
  - Evaluate overall costs for providing flexible generation at the Geysers

Task 4: Field Management Strategies and Cost for Flexible Generation

Approach

Risk Assessment Matrix

Likelihood		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Critical (5)
Almost Certain	5	5	10	15	20	25
Likely	4	4	8	12	16	20
Possible	3	3	6	9	12	15
Unlikely	2	2	4	6	8	10
Rare	1	1	2	3	4	5

Consequence

Likelihood ~ Curtailment scenario (magnitude, frequency, ramp rate)

Consequence ~ Infrastructure impact

Matrix of Flexible Operating Characteristics

	a	b	c
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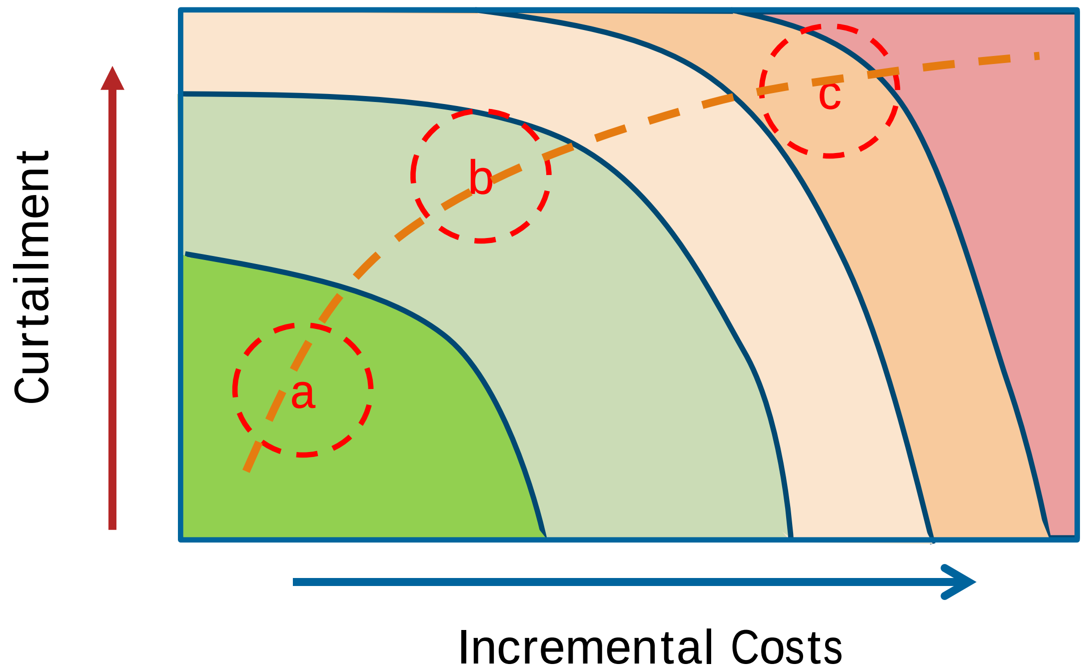

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