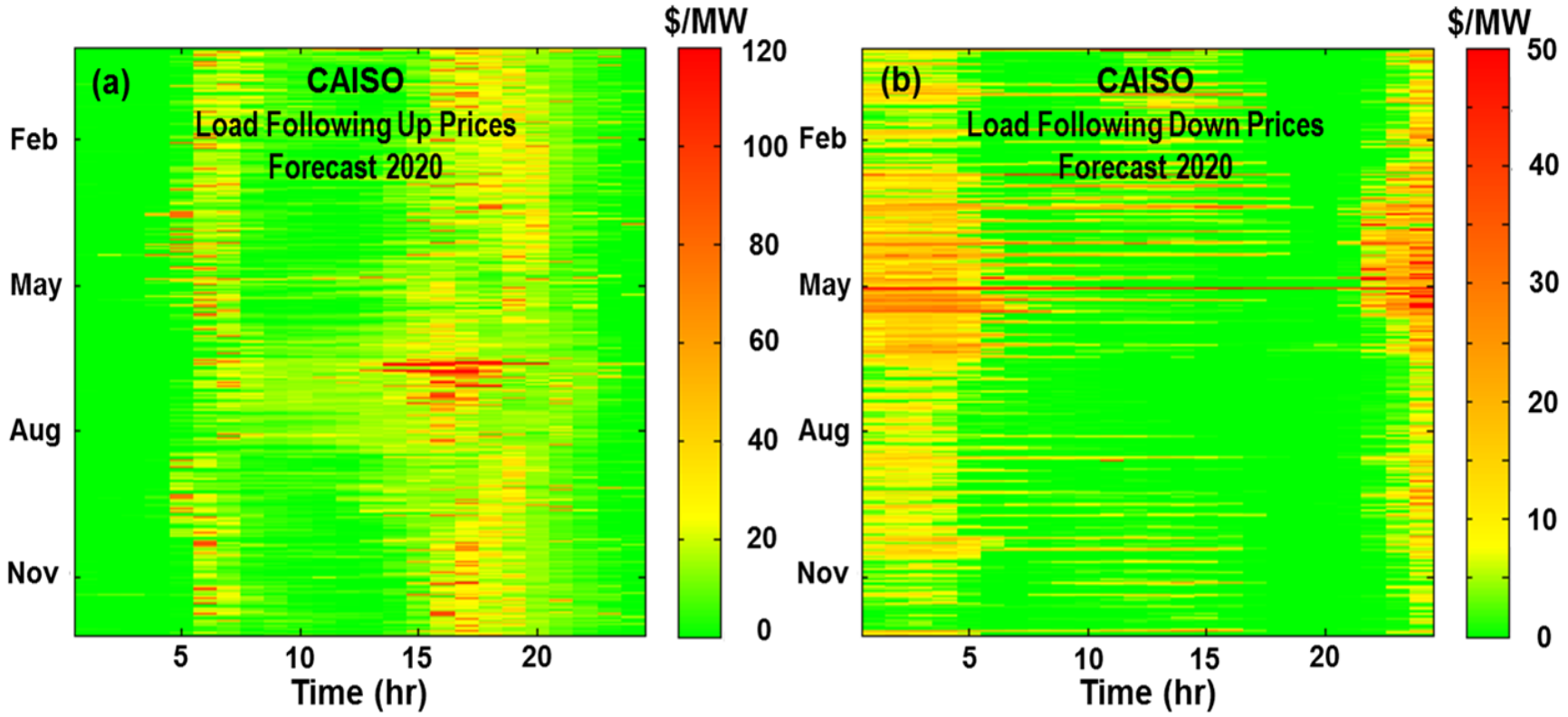


The Value of Geothermal Power for Integration of Intermittent Generation

Project Officer: Elisabet Metcalfe

Total Project Funding: $200k

May 12, 2015

Thomas Edmunds

Lawrence Livermore National Lab

Systems Analysis

Relevance/Impact of Research

Project objective

- Estimate additional revenues that geothermal plant operators could earn by providing flexibility (frequency regulation, load following, spinning reserve, and non-spinning reserve) to the system operator.
- Revenues from flexible operations in California estimated for the year 2020 under a system with 33% renewable energy.

Unique contributions

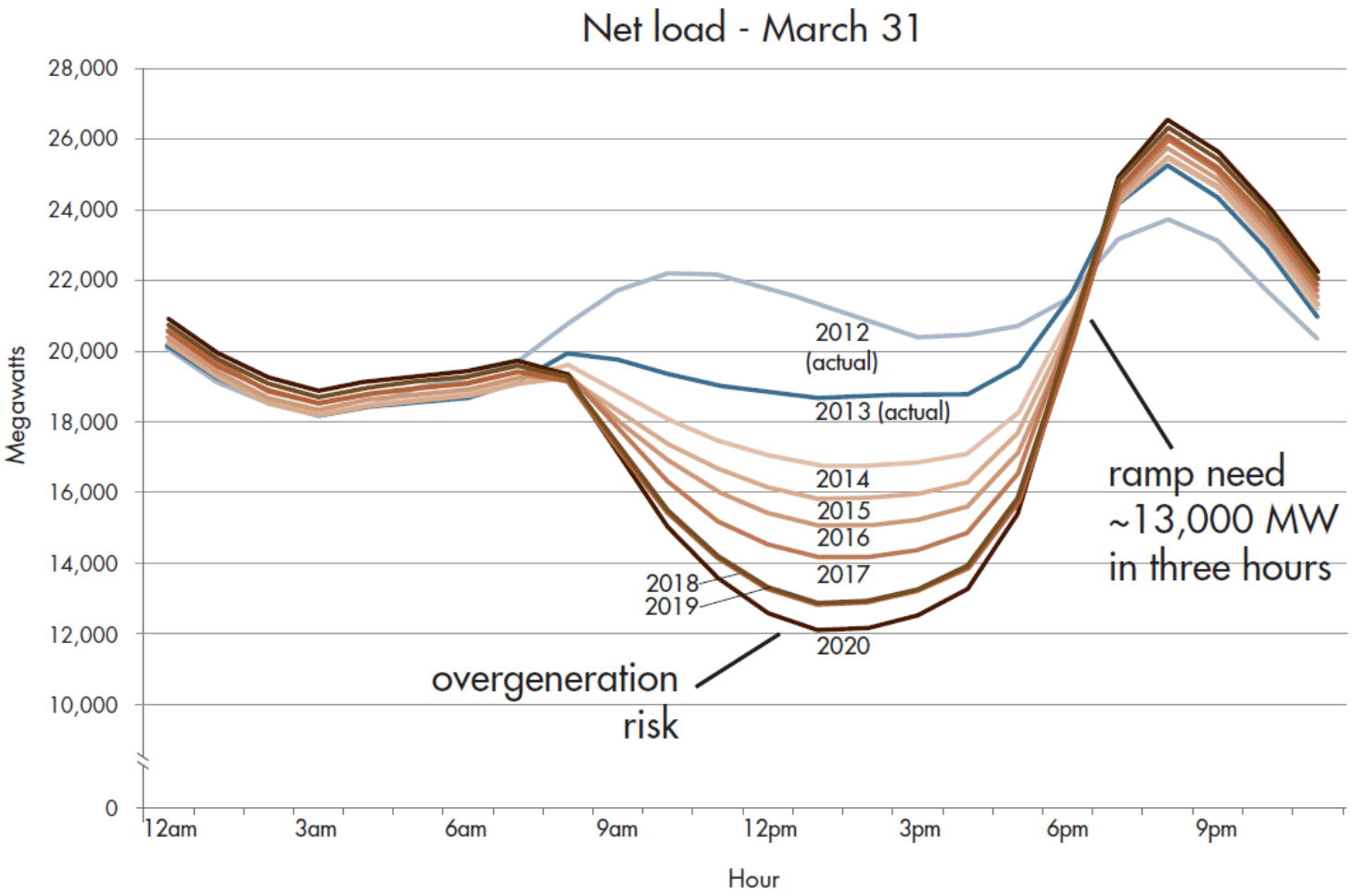
- The project utilizes unique stochastic weather and production simulation models developed at LLNL in previous externally-funded research efforts.

Scientific/Technical Approach

- General assessment of anticipated market conditions in California in year 2020 with 33% renewable generation
  - Gov. Brown recently announced goal of 50% by 2030
- Weather and renewable generator model of the western U.S. that provides an ensemble of 30 possible renewable generation profiles for each day of the year
- Stochastic grid optimization model that minimizes expected cost of operating system given the uncertain inputs
- Assumed new business models and contract structure allow geothermal generators to provide needed flexibility
- Geothermal dispatch logic to estimate additional revenues

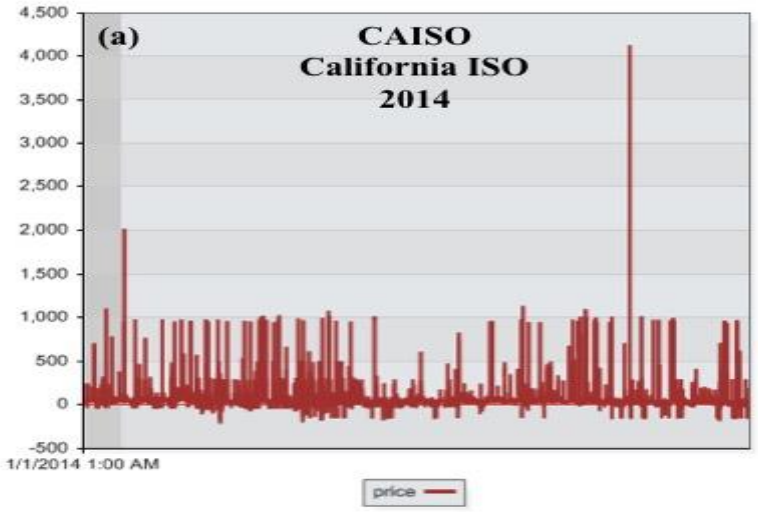
California ISO's "duck chart" shows drop in net load mid-day due to solar generation

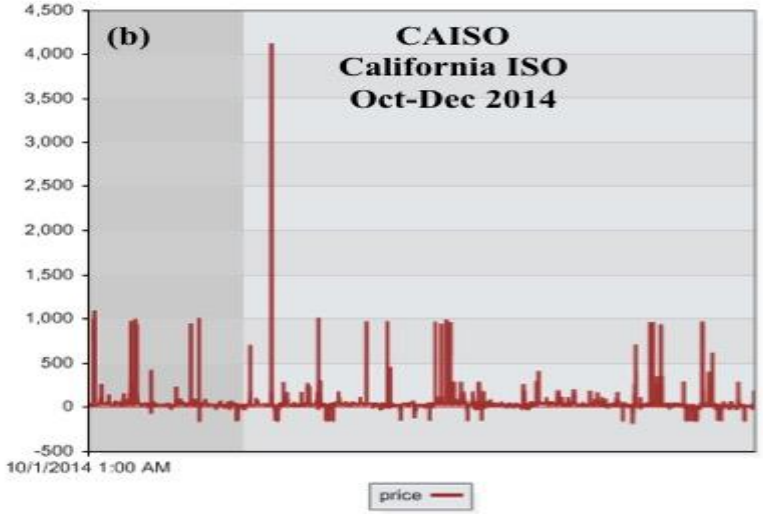
Figure 2: The duck curve shows steep ramping needs and overgeneration risk

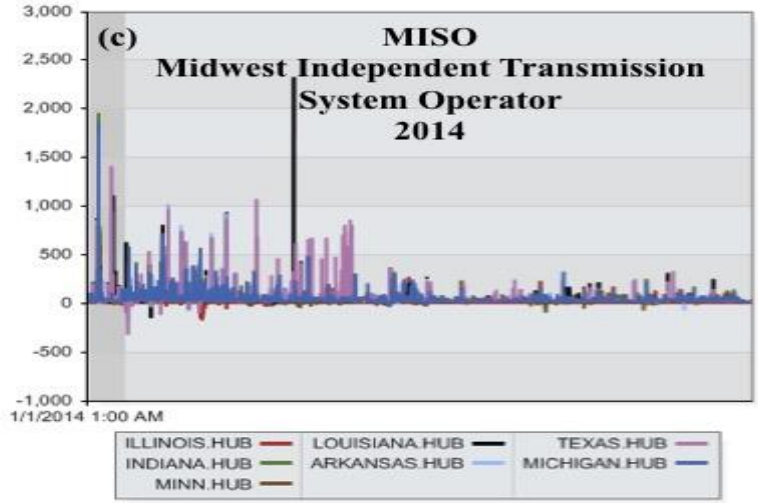


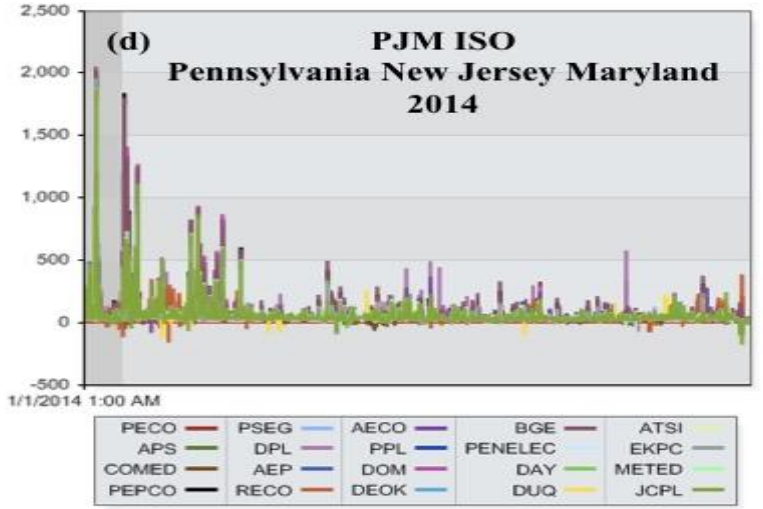
http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Energy Prices in CAISO, MISO and PJM in 2014

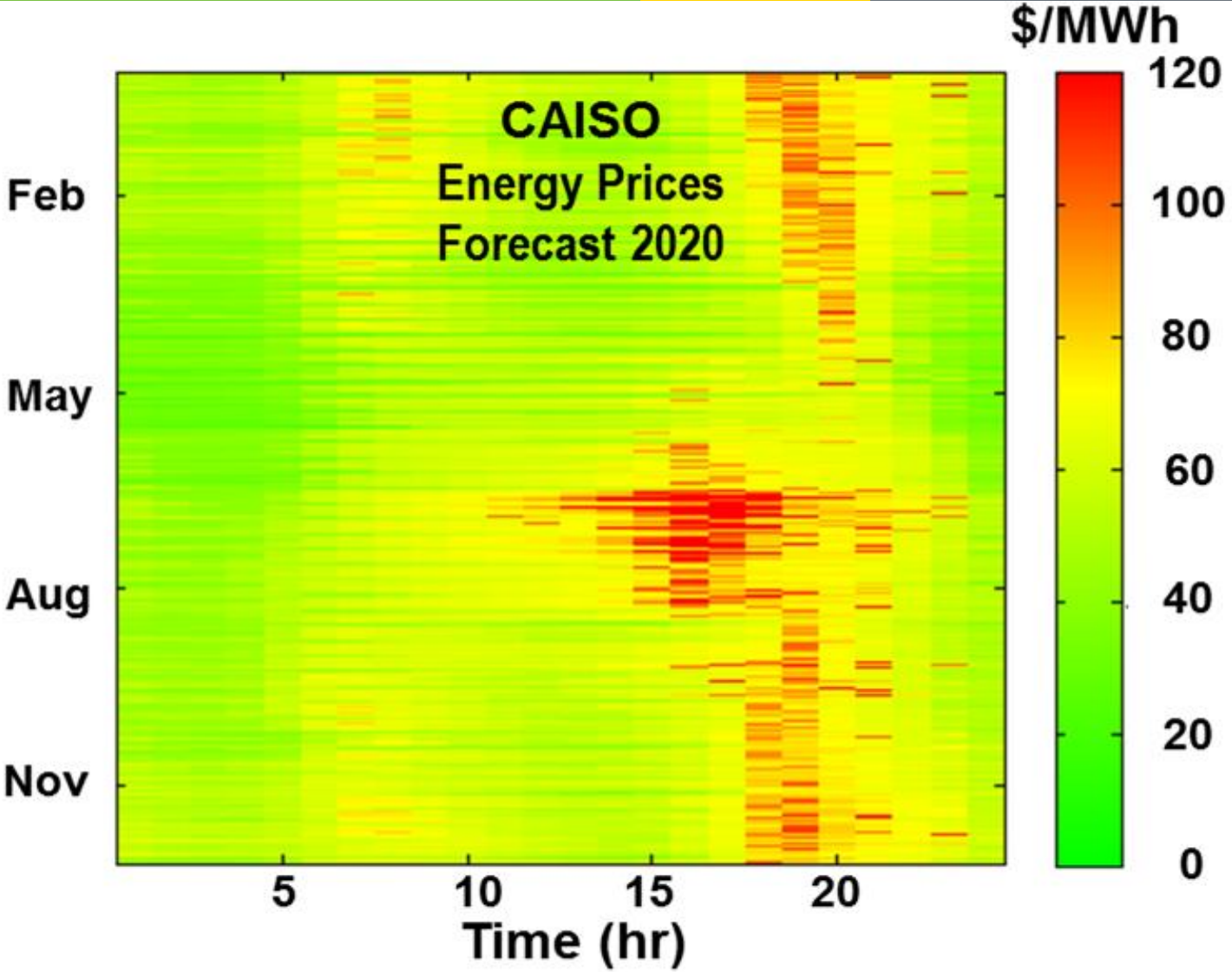








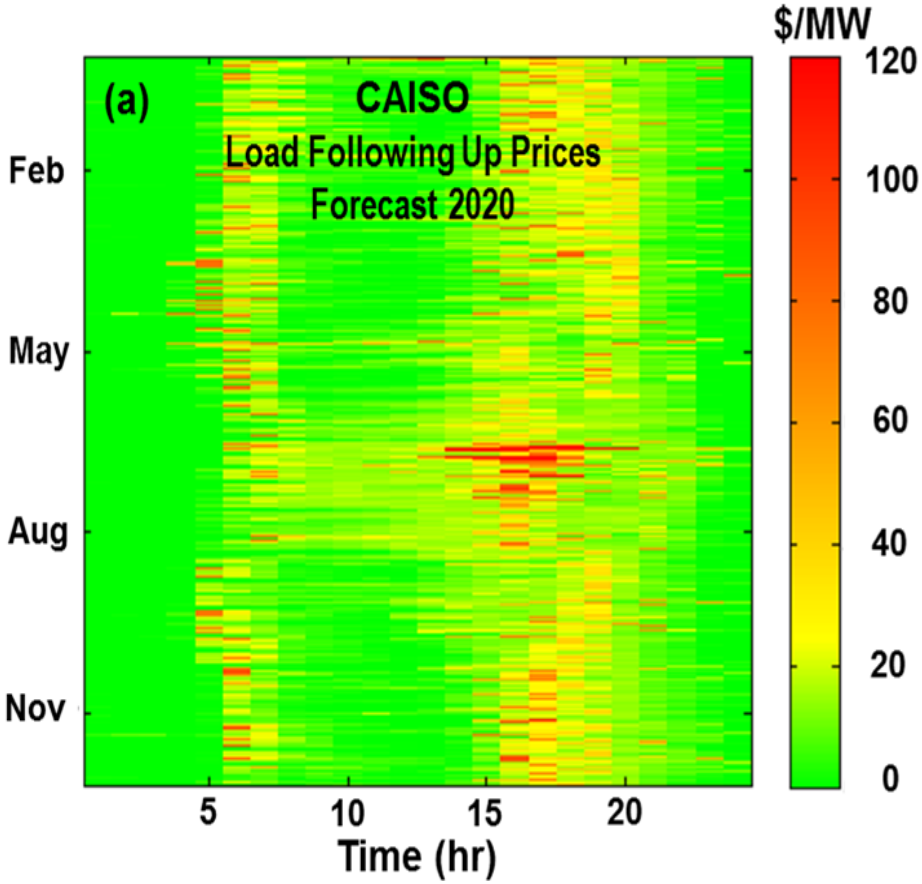
Hourly average energy prices will be volatile in 2020

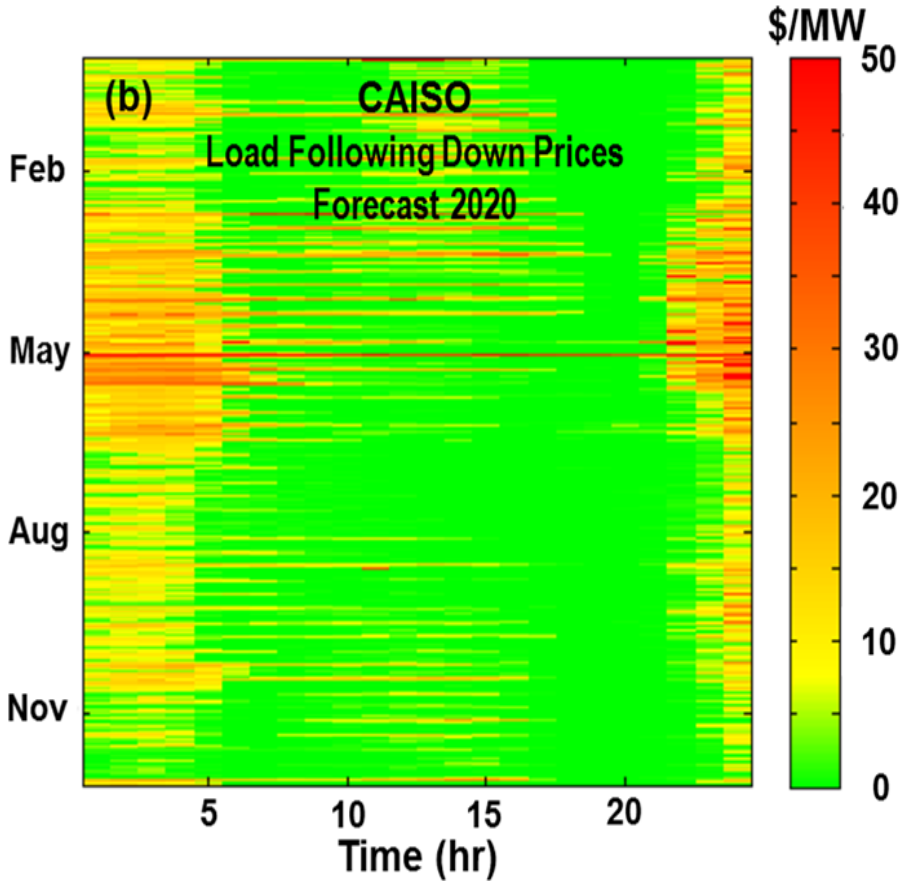


Avg = $60/MWh

Total = $500k/MW-yr

Higher load following prices in 2020 reflect this volatility





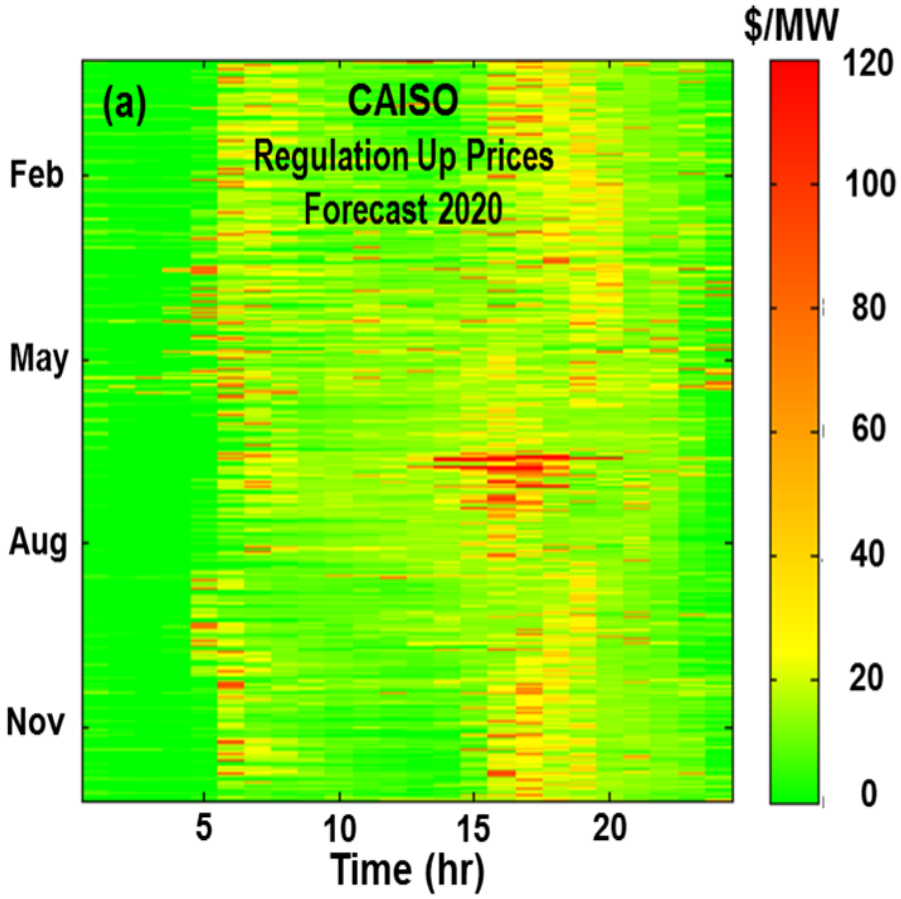
Avg = $11/MW

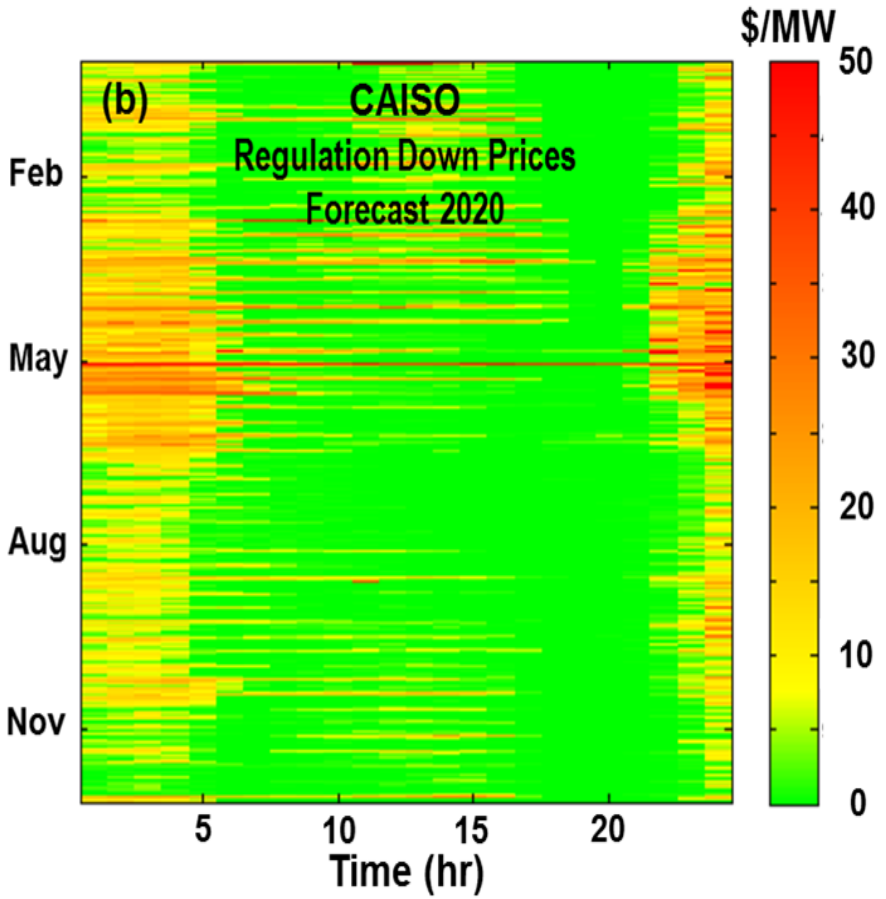
Total = $100k/MW

Avg = $4/MW

Total = $30k/MW

Regulation price patterns reflect more short periods of higher prices





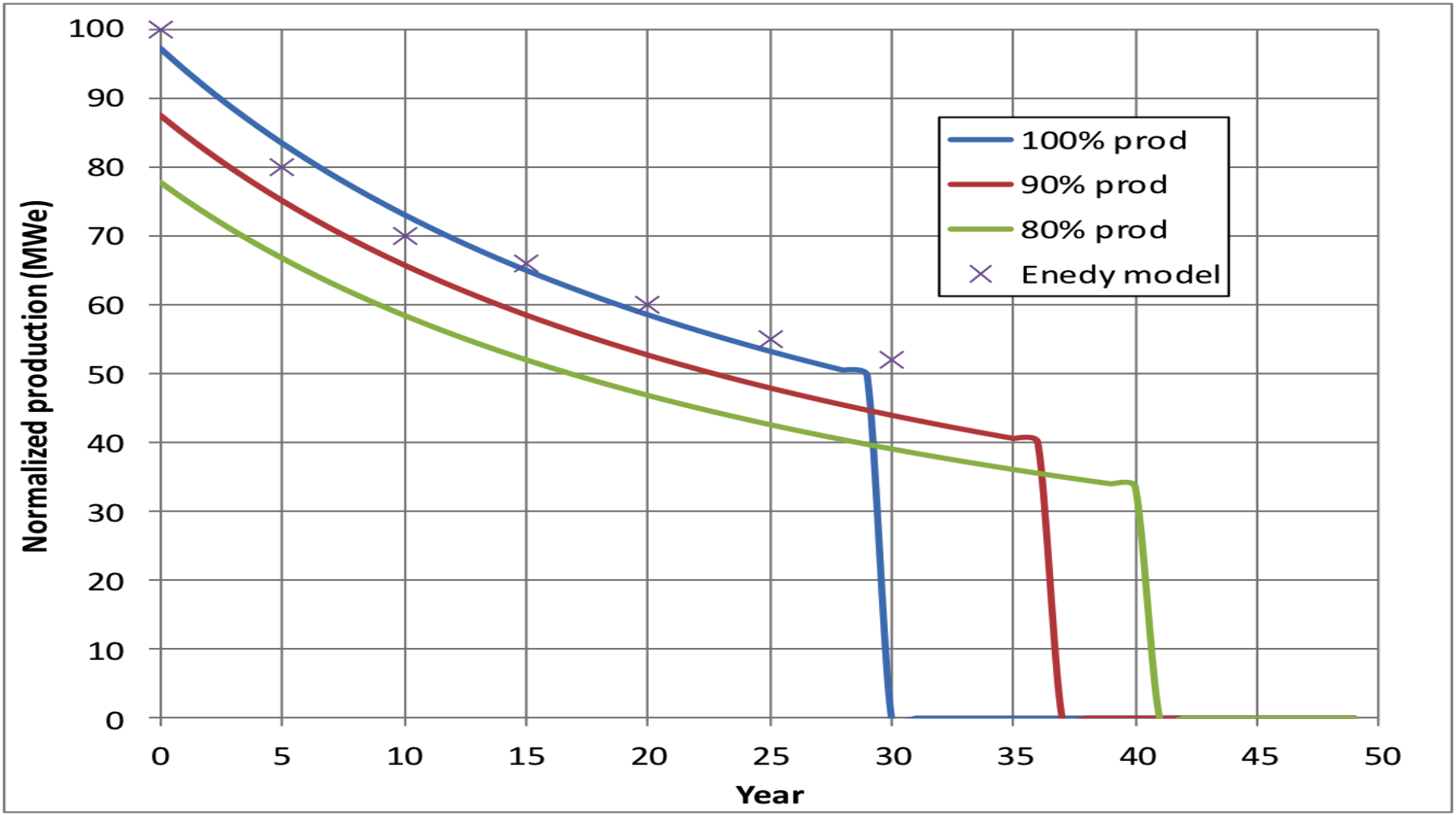
Avg = $14/MW

Total = $120k/MW

Avg = $5/MW

Total = $40k/MW

Production rates from normal and flexible operations – extended well life



Current geothermal PPAs have high, energy-only payments

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Plant	Price ($/MWh)	Escalation (%/yr)	Comments
ORMAT – Campbell	99		~$800k/MW-yr
Cyrg Energy – New Mexico	98	2.75	
Trans Alta-Mid American	70	1.5	~$600k/MW-yr
U.S. Geothermal-Nevada	90	1	
ORMAT - Puna			8 of 38 MW plant is flexible

No incentive to reduce MWh deliveries unless ancillary service prices exceed energy price.

Capacity credit of ~$100k/MW-yr?

Accomplishments, Results and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Accomplishments/Progress to date.
  - Unique representation of uncertainty and variability in renewable generation and how grid operators would manage it using stochastic optimization methods

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Estimation of annual revenues from baseload operations during a typical year. Assessment of geothermal generator capability to provide regulation services. Estimation of additional revenues that could be earned by providing regulation services.	Same	Q2 FY14

Accomplishments, Results and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Assessment of geothermal generator capability to provide load following services. Estimation of additional revenues that could be earned by providing load following services. Memo and presentation to DOE documenting results of tasks 1 and 2.	Same	Q3 FY14
Evaluation of geothermal reservoir management with dynamic characterization.	Same	Q4 FY14
Economic analysis and final report	Same	Q1 FY15
Present results at Stanford Workshop	Same	Q2 FY15

Future Directions

- Project completed in January 2015
- Additional modeling and analysis would be needed to examine proposed higher renewable generation targets for California (50%) and other western states, or examination of other markets such as the island of Hawaii.

Milestone or Go/No-Go	Status & Expected Completion Date

Summary

- Expect increased level and volatility of energy and ancillary service prices
- Current geothermal contracts not configured to respond
- Flexible contracts could provide access to other revenue streams
- Financial penalties for deferral of energy revenues

Publications

- Edmunds, Thomas A., Pedro Sotorrio, Jeffrey M. Bielicki, and Thomas A. Buscheck Geothermal Power for Integration of Intermittent Generation, Geothermal Resources Council Transactions, Vol. 38, (2014).
- Edmunds, Thomas A., Pedro Sotorrio, and Thomas A. Buscheck, The Value of Geothermal Power for Integration of Intermittent Generation, FY14 Final Report, LLNL-TR-664520 (November 2014).
- Edmunds Thomas and Pedro Sotorrio, Ancillary Service Revenue Potential for Geothermal Generators in California, PROCEEDINGS, Thirty-Ninth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January 26-28, 2015, SGP-TR-204.