NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Energy Reliability in a Changing Landscape

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Federal Utility Partnership
Working Group Meeting
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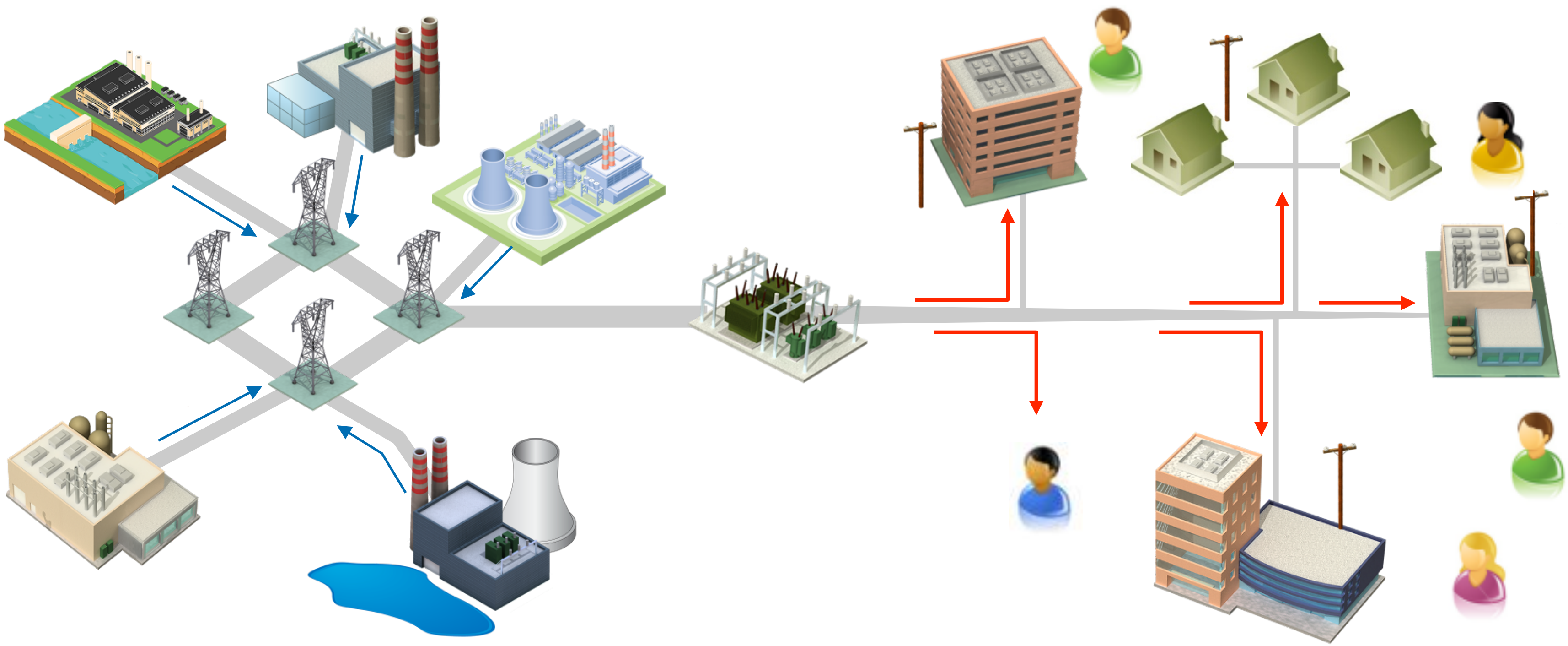
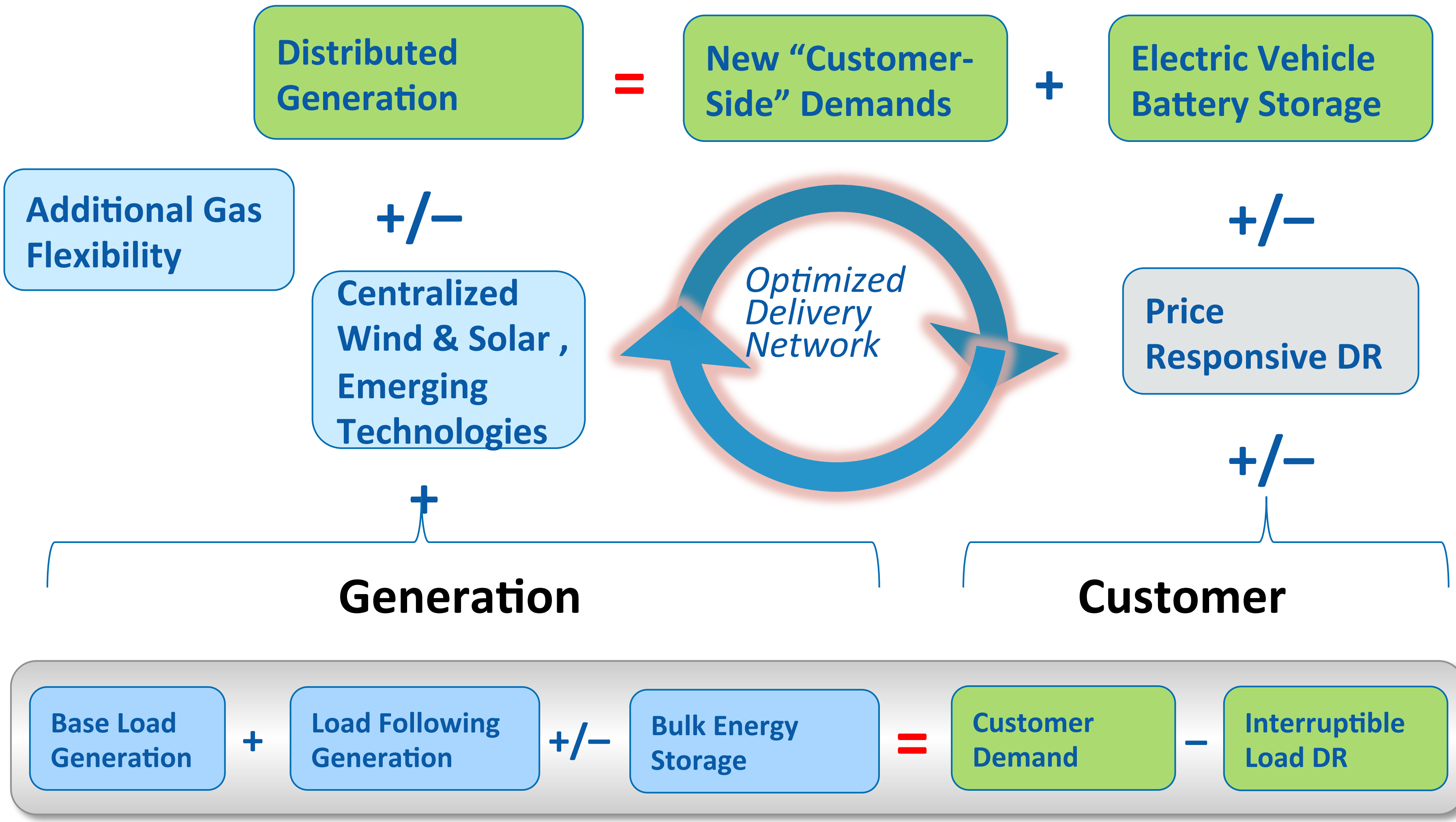
Today's Power System



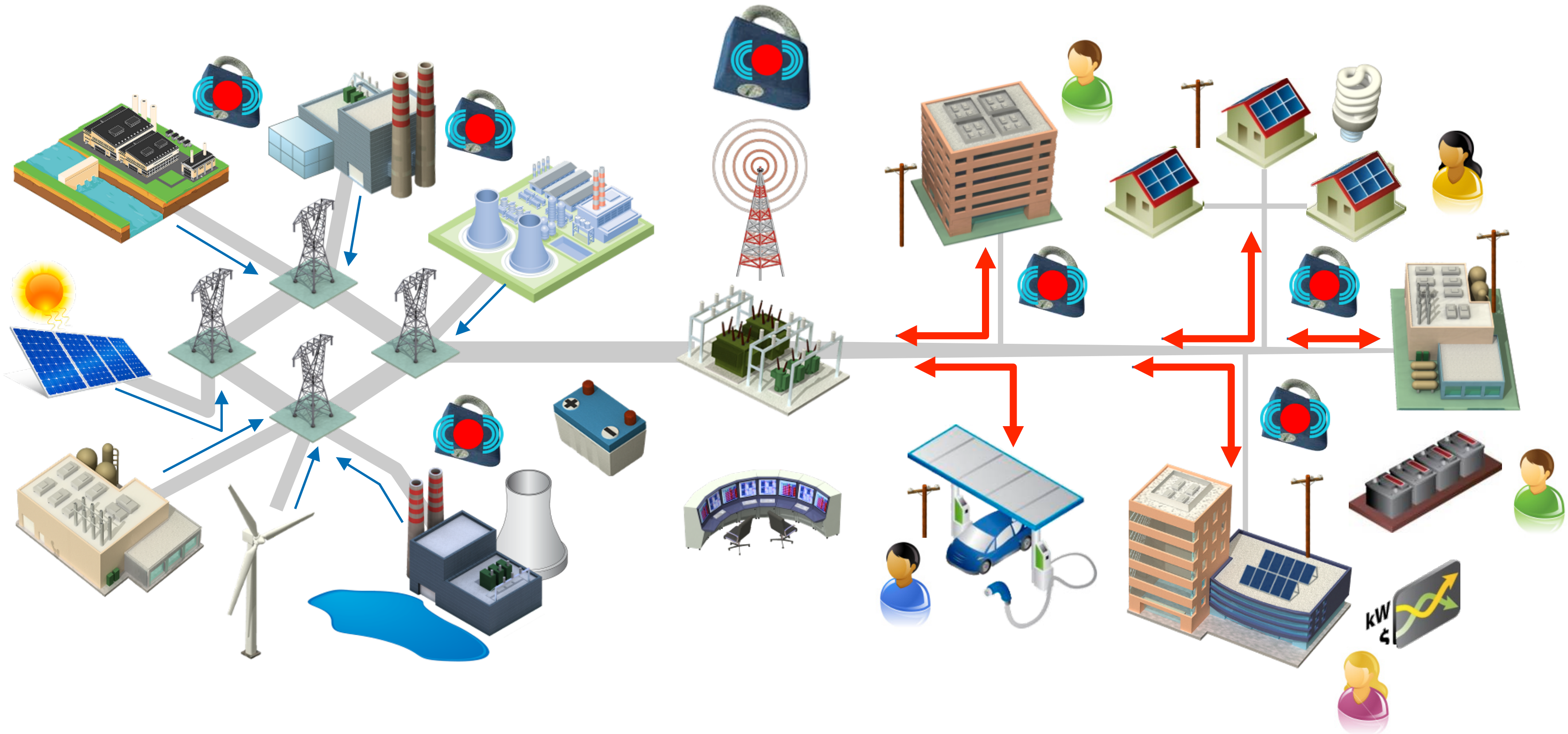
Generation **Delivery** **Customer**

Base Load Generation + Load Following Generation +/– Bulk Energy Storage = Customer Demand – Interruptible Load DR

New Technologies, New Challenges



Tomorrow's Power System …



How Soon? How Fast? What Business Model(s)?

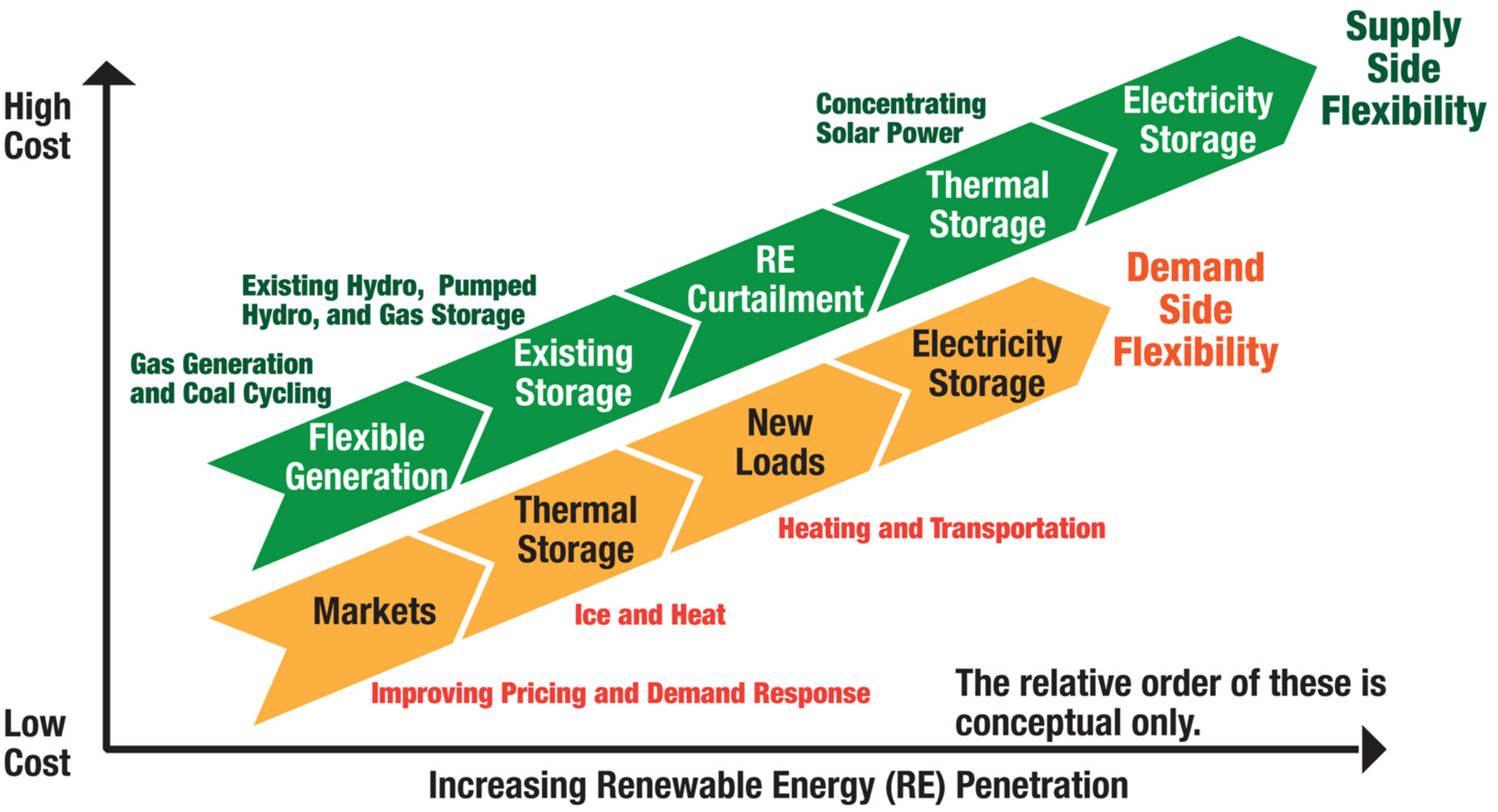
The Future Customer Experience

- Energy Efficiency
- Smart Appliances
- Electric Vehicles
- Distributed Energy Resources
- Grid Flexibility

The Future Utility Experience

- From Reactive to Predictive
  - Dynamic state estimation
  - Effective controls require seamless communications (and data access) across the electric system
- Advanced Disturbance Analysis
- Real-time Control of Wide-Area Networks
- Grid Flexibility Optimized for High Gas and RE
- Real Time Optimized Market Operation

Flexibility Options for Improved RE Integration



Late 1990's Control Centers (ComED)

IESO Ontario

Two State-Of-The-Art Control Centers

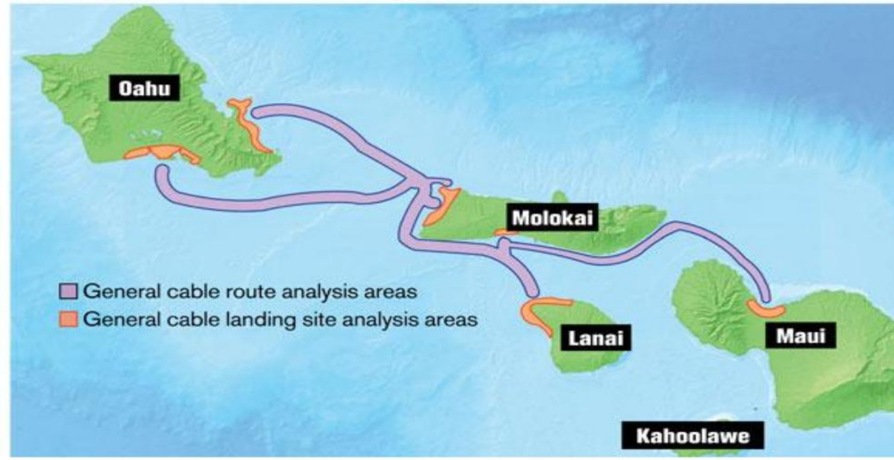
PJM

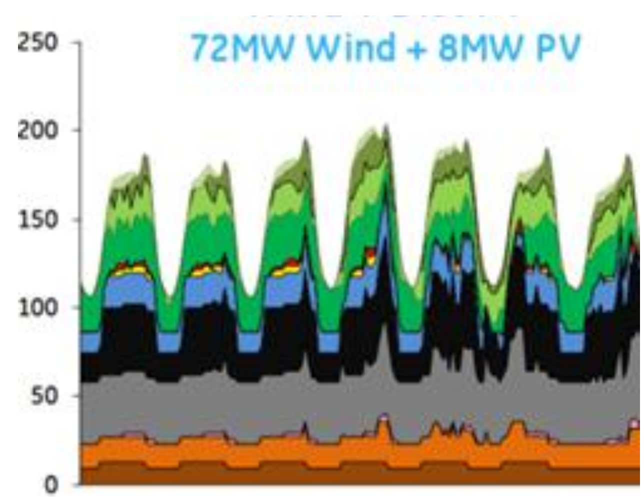
Successful Partnerships with Grid Stakeholders a Key to Meeting Challenges

- Every Region Has Their Unique Grid Challenges
- Successful Partnerships Required to Implement Innovation
- Best Practices for Successful Partnerships
  - Utility partnerships important to enhance energy reliability
  - Utilities Conservative by Nature
    - Partnerships to reduce uncertainty in new utility operating paradigms
- Example: Grid integration analysis brings together utilities, national labs, grid experts, and key state stakeholders in Hawaii

Hawaii as a High RE Penetration Model

- Determine the change in operating characteristics (commitment/dispatch) and operating cost
- Assess the dynamic performance of the grid system
- Identify the system level reliability challenges associated with high renewable scenarios
    - Assess the impact of each mitigation approach across the many timescales of system operation

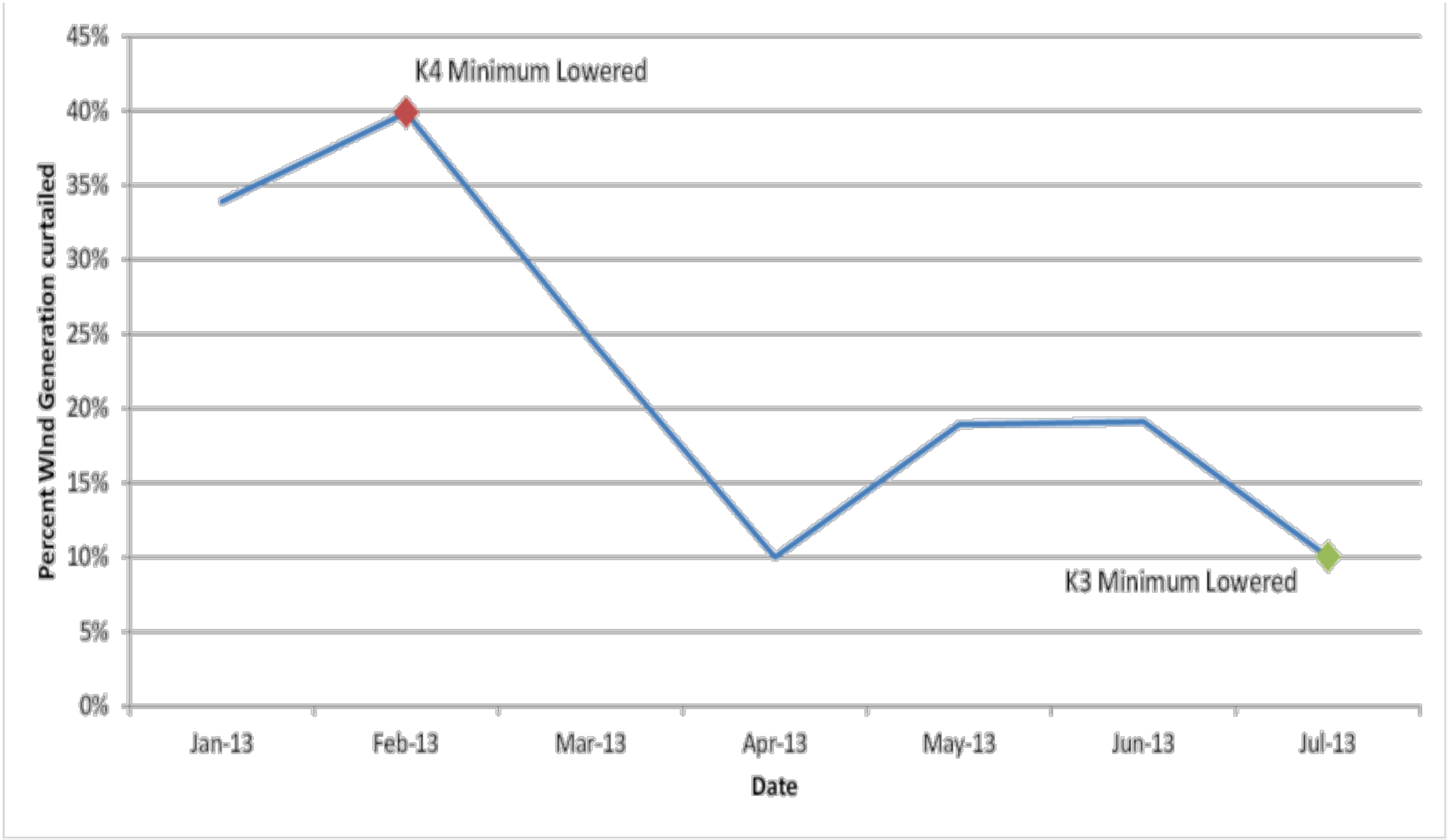




Partners: HECO, MECO, HNEI, GE, AWS Truepower, Hawaii State, PUC, TRC of local, national, & international experts

Hawaii Solar Integration Study - Impacts

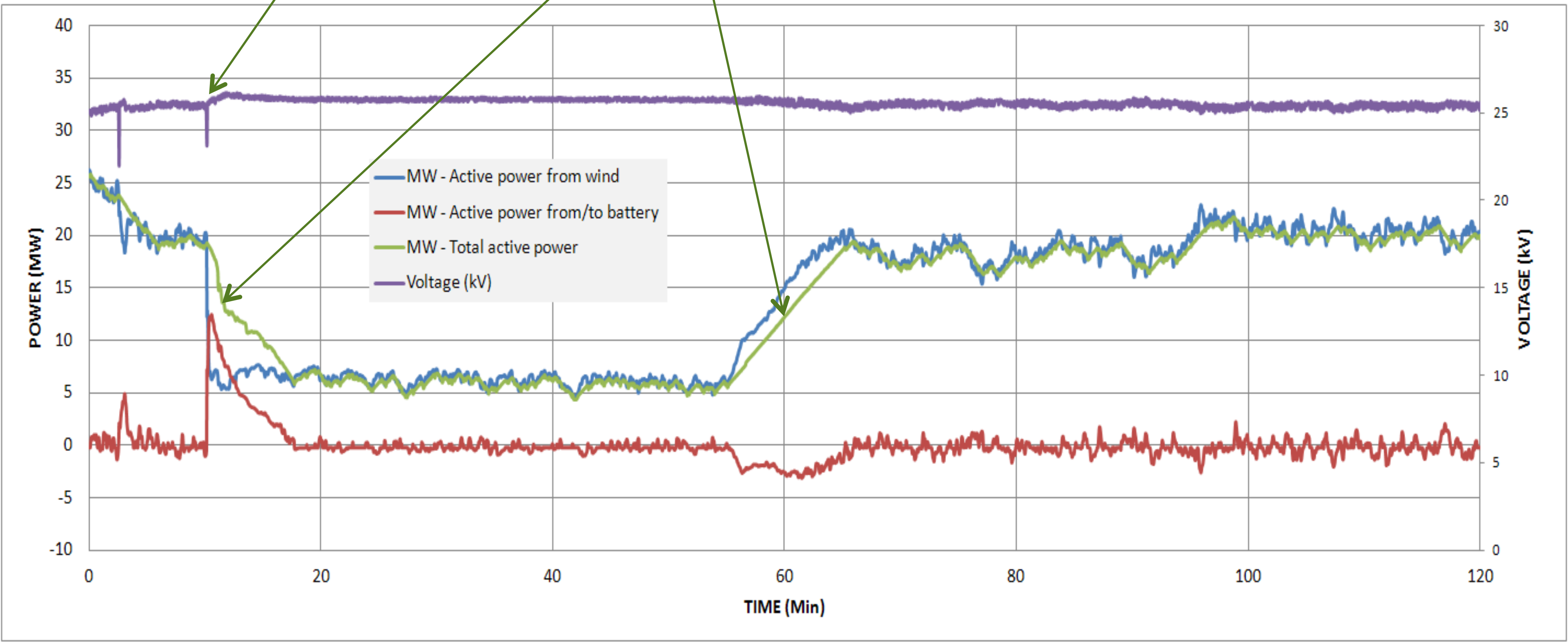
From Docket No. 2011-0092-MECO 2012 Test Year Rate Case - Maui Electric System Improvement and Curtailment Reduction Plan



Monitoring and Analysis of Kahuku Wind/storage System

Low voltage event caused number of turbines to trip off

Batteries help to limit rate of change of power after the fault and during recovery



Distribution Example - 1.8 MW PV System Options to Mitigate Voltage Issues

Option	Maximum Steady State Voltage (120 Volt scale)	Maximum Voltage Fluctuation at site	Max Voltage Fluctuation at upstream regulator	Cost
W/O Mitigation	125.3	2.3	1.0	$0
Absorbing PF Solution (1)	124.0	1.2	0.2	$2,200
500 kVA/1500 kWh Battery (2)	125.0	0.5	0.1	$1.11M
750 kVA/3000 kWH Battery	124.7	0.0	0.0	$2.19M
477 ACSR Option	124.9	1.3	1.1	$266k

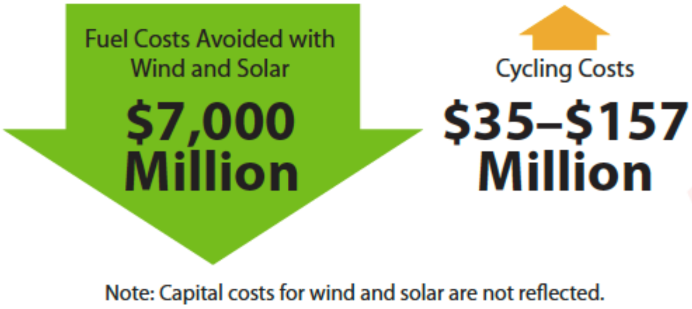
1 – Maximum steady state voltages calculated during low-load times
2 – Power factor for study was 0.97 (ABSORBING)

Regional Partnerships Across Technology Spectrum = Grid System Solutions

Western Wind and Solar Integration Studies – Interconnect wide study with diverse stakeholder input

- Phase 2: Cycling Cost and Emissions Impacts
    - Determine emission impacts of cycling
- Phase 3: Frequency Response and Grid Impact
    - Reliability impacts of high RE
    - Example: What happens to the transmission grid's frequency with high penetration of distributed PV at low load?

From a system perspective, cycling costs are relatively small



Questions and Discussion

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