2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Grid-Supportive Loads:

Grid Services from Fast-responding Residential and Commercial Loads

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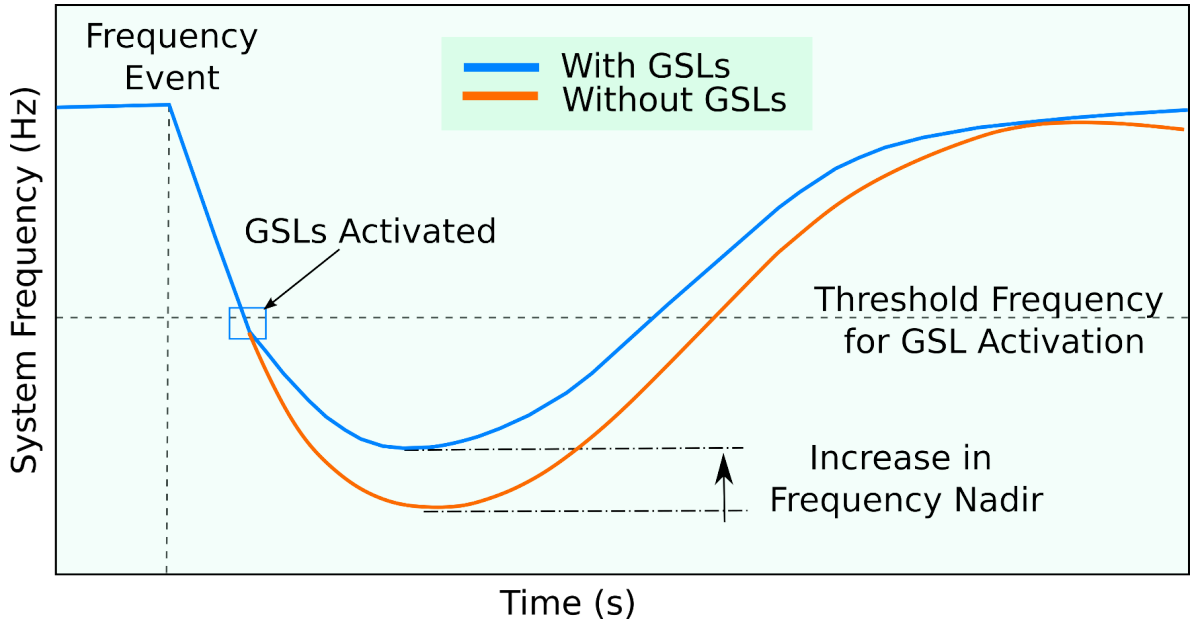
Grid-Supportive Loads



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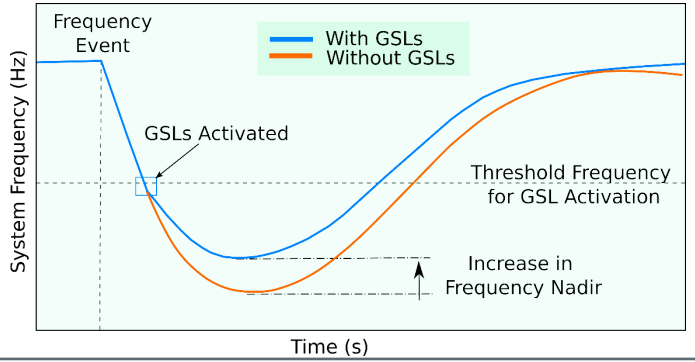
Project Summary

OBJECTIVE, OUTCOME, & IMPACT

The project objective is to evaluate and demonstrate the benefits of Grid-Supportive Loads (GSL) and to engage and provide information with industry stakeholders to bring GSL technologies to market. The objective aligns with the National Blueprint's strategy to "transform the grid edge".



TEAM & PARTNERS

NREL:

- Michael Blonsky
- Yeongrack Son
- Ellie Estreich
- Sunil Subedi

STATS

Performance Period: FY20-FY24

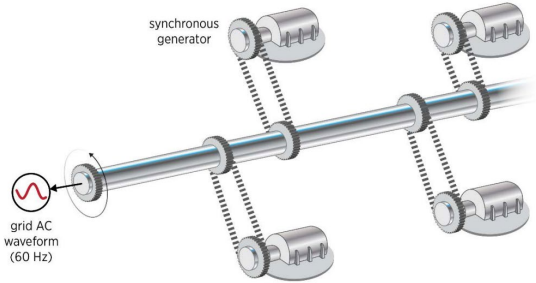
DOE Budget: $200k (FY24), Cost Share: $0

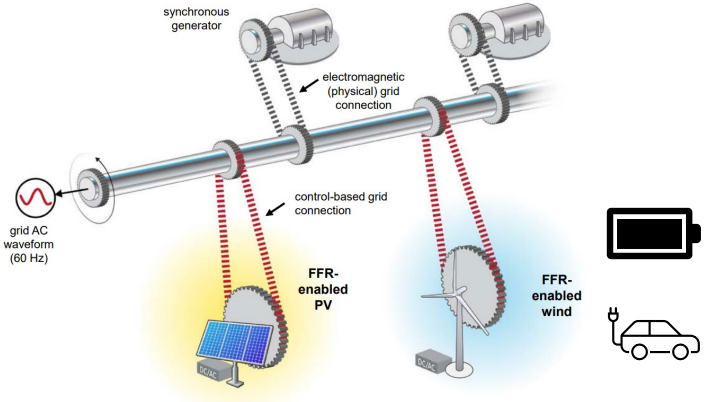
Milestone 1: Publish GSL techno-economic analysis

Milestone 2: Complete lab-scale evaluation

Milestone 3: Engage with industry partners

Problem





Electric Machines (with inertia)

- Fossil fuel generators
- Hydro and nuclear generators
- Motor-based loads

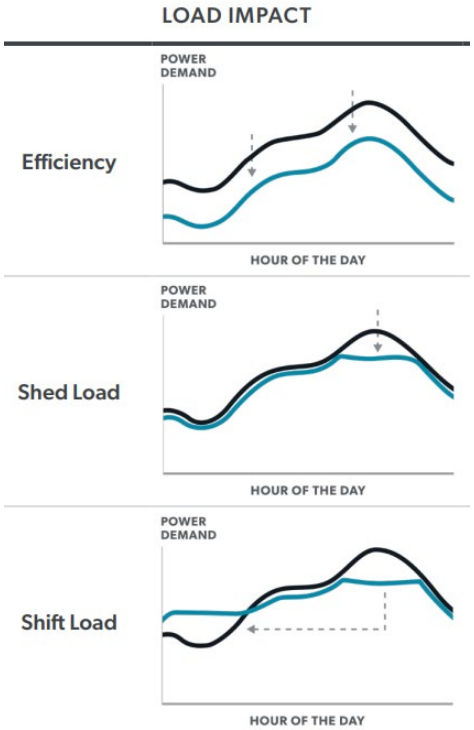
Inverter-Based Resources (no inertia)

- Solar and wind generators
- Batteries and EVs
- Power electronics-based loads

As grid inertia decreases, more frequency responsive resources are required.

Image source: Inertia and the Power Grid: A Guide Without the Spin

Alignment and Impact



The project objective enables **load modulation**, a key component of transforming the grid edge

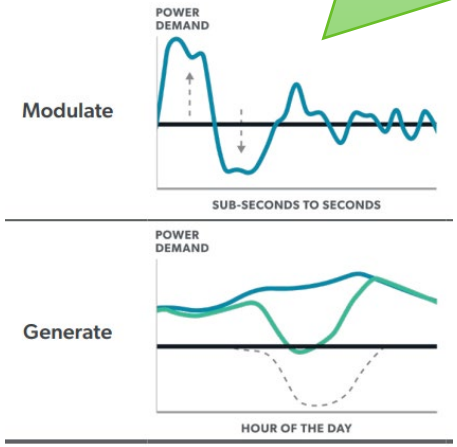


Image source: A National Roadmap for Grid-Interactive Efficient Buildings

Alignment and Impact

Project impacts:

- Stabilize and **lower grid ancillary service costs**.
- Lower curtailment and **increase the value of renewable generation**.

Project success aligns with the National Blueprint and GEB Roadmap:

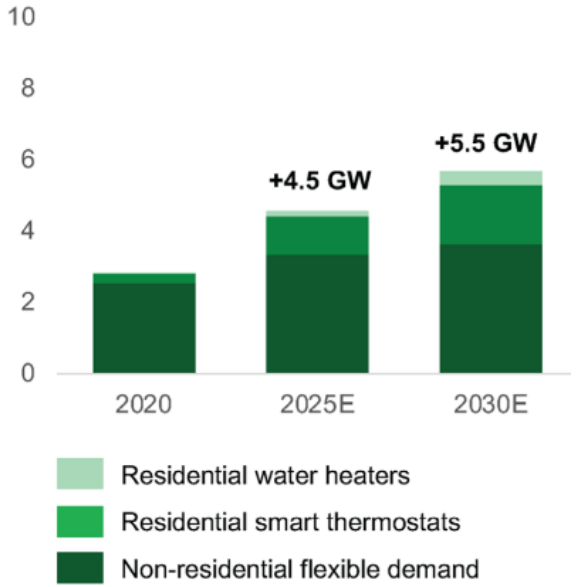
- Enables grid services that can “**transform the grid edge**.”
- **Reduces grid costs** and improves renewable integration.
- Aligns with **decarbonization, affordability, and resilience goals**.

Approach

- Slow progress in this space:
  - Research dates to at least 2013 (PNNL's Grid Friendly Appliances).
  - Hawaiian Electric provides frequency response from water heaters (EnergyScout).
  - Mostly used relays for direct load control.
- Similar inverter-based controls already exist:
  - Institute of Electrical and Electronics Engineers (IEEE) Standard 1547 for distributed PV and batteries.
  - Uses frequency-watt droop curves.
- Renewed interest for EV charging:
  - CA Mobility Center and North American Electric Reliability Corporation paper on grid-friendly charging.
  - Vehicle Technology Office projects on vehicle-grid integration (EVs@Scale).

Approach

High growth expected for flexible building loads (heat pumps, refrigerators, and water heaters).



Massive growth expected for EVs and EV chargers.

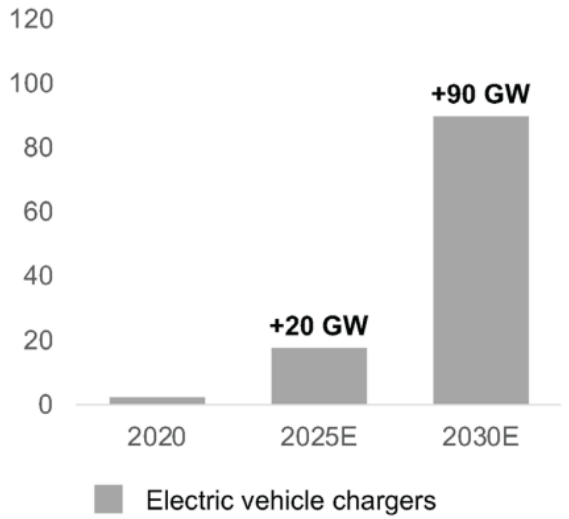


Image source: [Pathways to Commercial Liftoff: Virtual Power Plants]

Approach

- Grid-Supportive Loads (GSLs) are **power electronics-based loads** that can provide **fast frequency response and voltage support.**

- GSLs are small end-use loads that can reduce power for a few seconds to minutes with **minimal impact on the device or user**. They can include:
  - Variable-speed heat pumps.
  - Refrigerators with variable frequency drives (VFDs).
  - EVs and EV chargers.
  - Plug loads with energy storage.

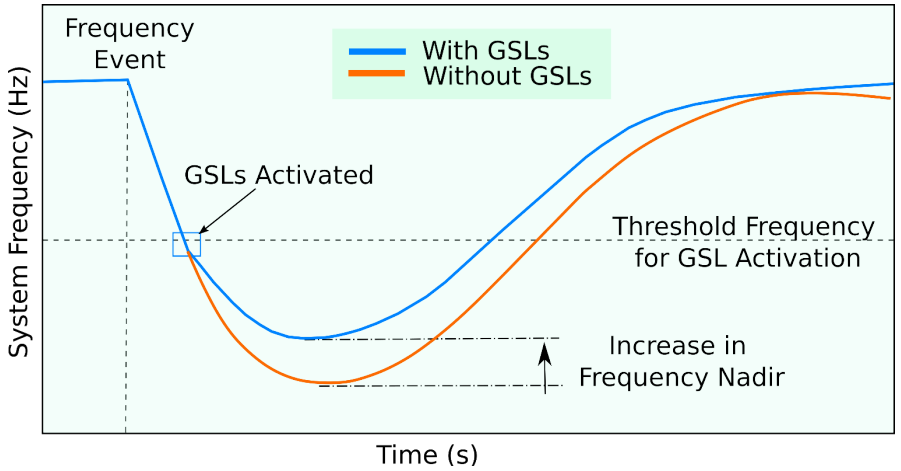
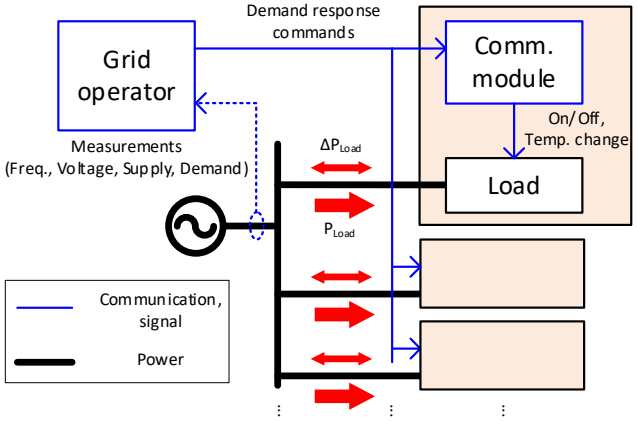


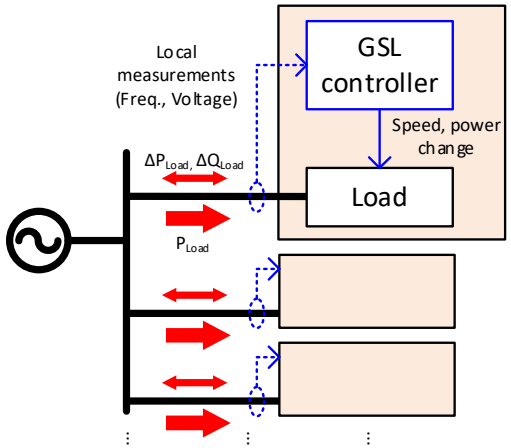
Image source: Hardware Implementation and Market Impacts of Grid-Supportive Functions in End-Use Loads

Approach

- Conventional demand response **requires a control signal** from grid operator
  - Suitable for longer response times.
  - Cybersecurity concerns due to communication.



- GSLs use local grid measurements to **autonomously control** their power
  - No communication delays, can respond in 10-100s of milliseconds.
  - Limited cybersecurity concerns.

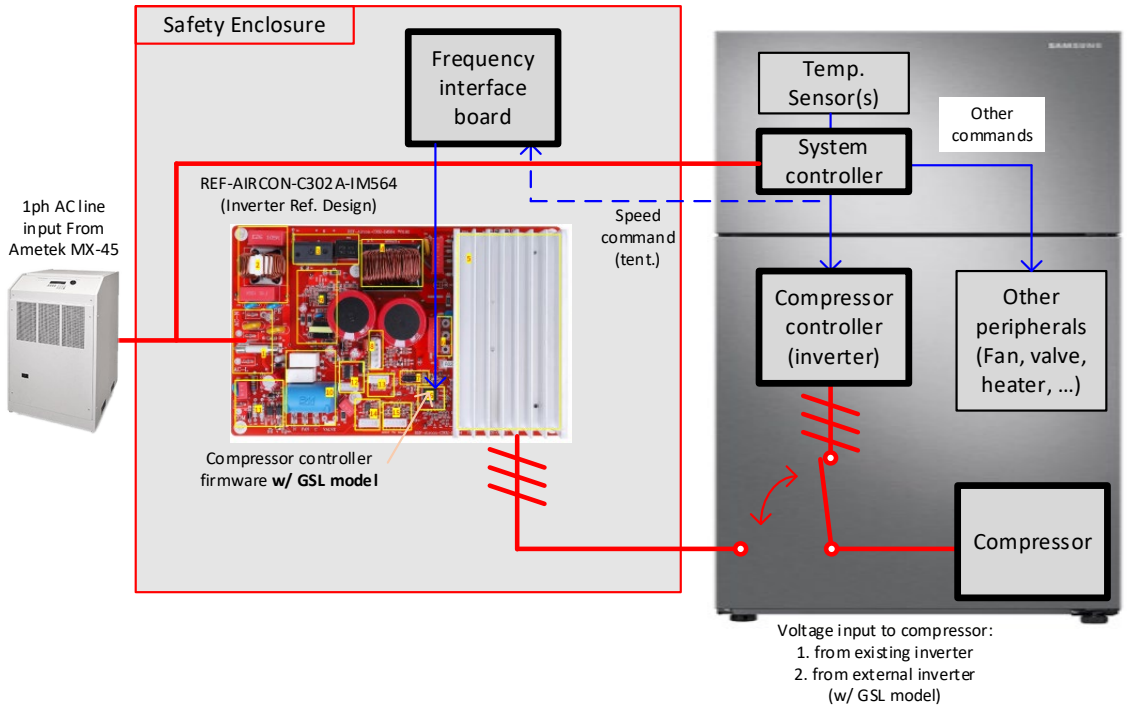


Approach

- Simulation and Hardware Evaluation
  - Stability analysis.
  - Grid simulations.
  - Laboratory testing.
- Techno-Economic Analysis
  - Technical potential.
  - Cost-benefit analysis.
  - Ancillary service market analysis.
- Industry Engagement
  - Industry discussions and presentations.
  - Standards development.
  - Demonstration pilot plans.

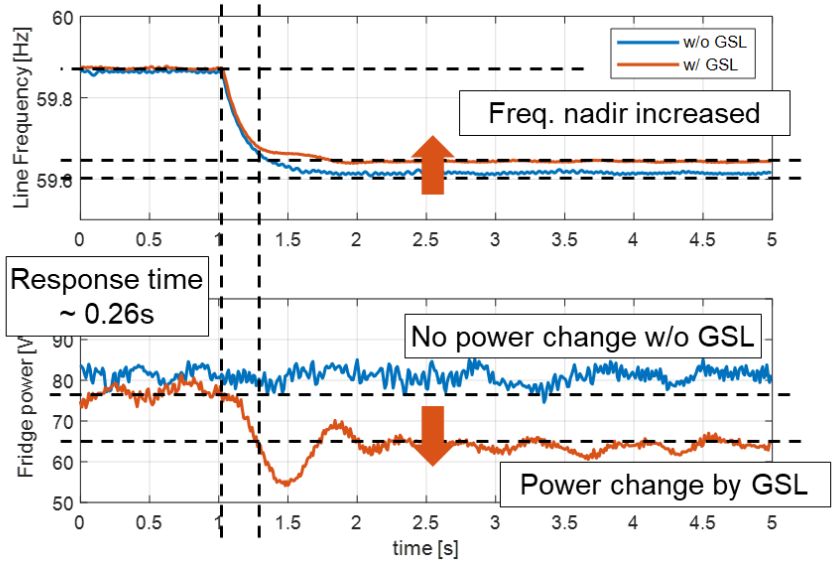
Progress and Future Work

- Laboratory hardware evaluation conducted to understand GSL performance.
- Tested in NREL's Energy Systems Integration Facility:
  - Commercially available refrigerator (with VFD).
  - Inverter reference board with custom software.
  - Grid simulator.
- Multiple controls considered:
  - Frequency-Watt (closed loop and open loop).
  - Volt-Watt (open loop only).
  - Volt-VAR (in progress).

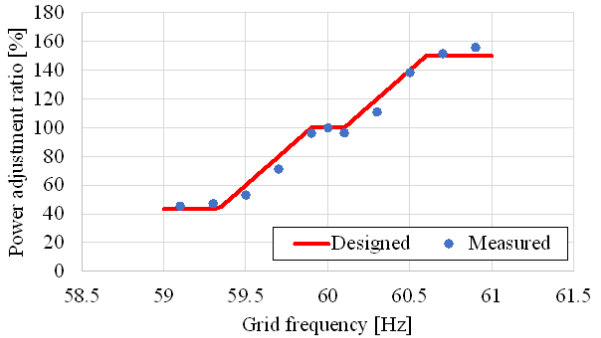


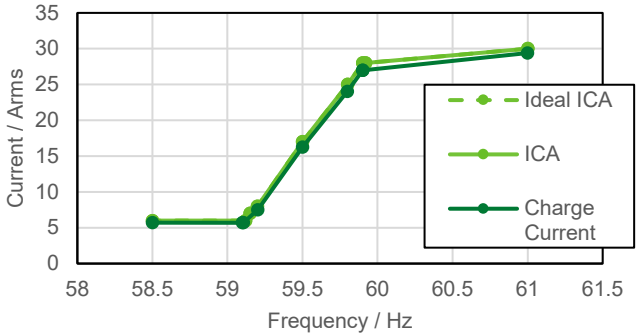
Progress and Future Work

Closed-loop frequency response time of 0.26 seconds



Power adjustment errors within 10% for fridge and EV charger





Progress and Future Work

GSLs can provide >100% of the U.S. frequency response requirement:

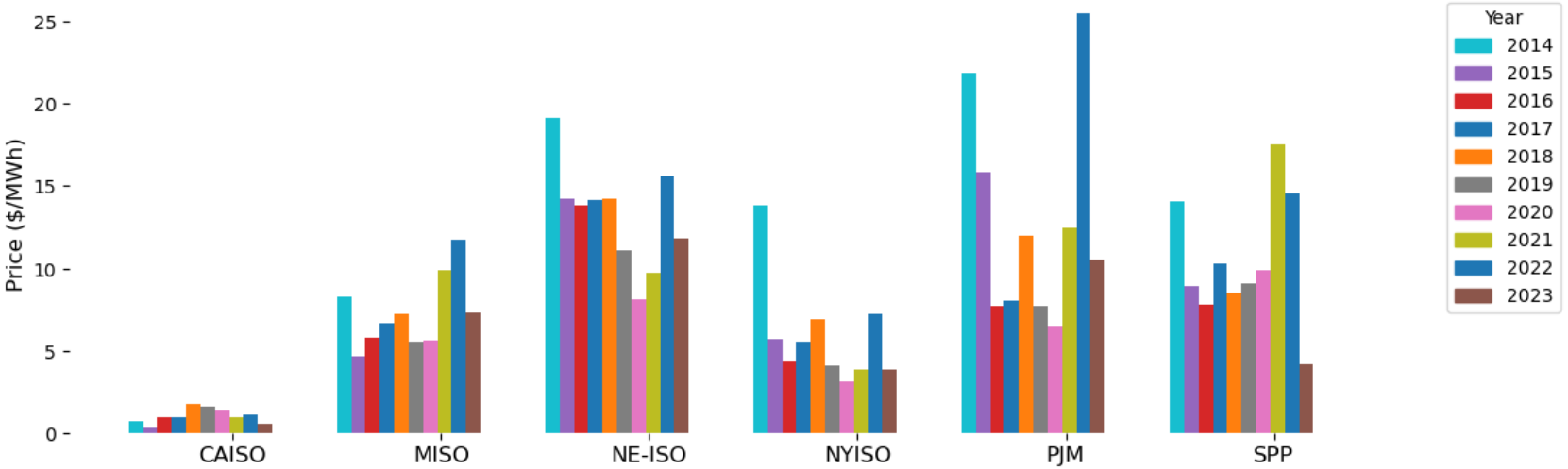
Device	Units Required to Meet Current U.S. Requirement	Available Units	% of Current Requirement
Refrigerators	184 million	123 million	67%
Level 2 EV Chargers	14 million	21 million	149%
DCFC EV Chargers	565,000	182,000	32%
Heat Pumps	13.2 million	17.8 million	134%

Regulation market value exceeds implementation costs:

Device	Average Power	Lifetime	Lifetime Benefits	Estimated Cost
Refrigerators	55 W	10 years	$4.81	$0.52
Level 2 EV Chargers	179 W	10 years	$15.65	$0.52
DCFC EV Chargers	605 W	10 years	$53.00	$3.50

Progress and Future Work

- Ancillary service market dynamics
  - Higher demand due to decarbonization.
  - New technologies (batteries).
  - Various market design changes.
  - **No significant price trends.**
- Ongoing work on ancillary service value
  - Peak demand vs. baseload.
  - Frequency vs. voltage regulation.
  - Interactions with demand response.



Progress and Future Work

- Industry engagement activities:
  - Report feedback and interviews.
  - Conference presentations (IEEE APEC, ECCE).
  - Discussions with grid operators, manufacturers, and regulators.

- Concerns about market adoption and scalability:

Technical Issue	Market Concern
Autonomous control limits measurement and verification	Can’t scale without grid operator trust
Limited value for single device ($1 per device per year)	Active programs are too expensive
Relatively small market (vs. demand flexibility)	Low priority for most stakeholders

Progress and Future Work

- Standards development:
  - Low-cost market implementation pathway.
  - Developed a GSL generalized model.
  - Discussing with CA Energy Commission's Flexible Demand Appliance Standards.
  - Discussing with IEEE Standards body.

- Planning for a demonstration pilot:
  - Discussing with a grid operator in Hawaii.
  - Discussing with an appliance manufacturer.
  - Demonstration plan for FY25.

Progress and Future Work

FY25 Plans:

- Additional simulation and lab testing:
  - Island grid simulations.
  - Volt-VAR evaluation.
  - Evaluation of new devices and control strategies.
- Complete ancillary service market analysis.
- Industry engagement activities:
  - Ongoing discussions and presentations.
  - Standards development.
  - Demonstration pilot plan.

Thank you

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Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$350k				$200k				$200k			
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q2 Milestone: Hardware Testing Plan												
Q3 Milestone: Industry Feedback												
Q1 Milestone: Hardware Results												
Q2 Milestone: Industry Engagement (G/NG)												
Q4 Milestone: FY24 Final Report												
Q3 Milestone: GSL Hardware Paper												
Current/Future Work												
Q1 Milestone: GSL Market Paper												
Q2 Milestone: Industry Presentations												

- Hardware paper delayed due to lab evaluation delays and additional simulation tasks

Team

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Research Support

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