AI for Refrigeration Energy & Outage Resilience

Grid Fruit, LLC
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Award No. SC0020822, FOA No. DE-FOA-0002381

Project Summary

Objective and outcome

- Fine tuning and completing Phase I's technology
- Visualization and developing customer-facing dashboard
- Physical demonstration of resulting technology and customer acquisition

Team and Partners

- Javad Mohammadi, PhD - CTO
- Mahnoush Babaei, PhD – Director of Engineering
- Sohil Apte - Data Dashboards and UI/UX
- Jesse Thornburg, PhD - CEO (PI)
- Oak Ridge National Laboratory
- Vermont contractors (VT Energy Control Systems, ARC Mechanical, Lawrence and Lober Electric)

Stats

Performance Period: 8/23/2021-8/22/2023

DOE budget: $1,100k, Cost Share: $13.7k

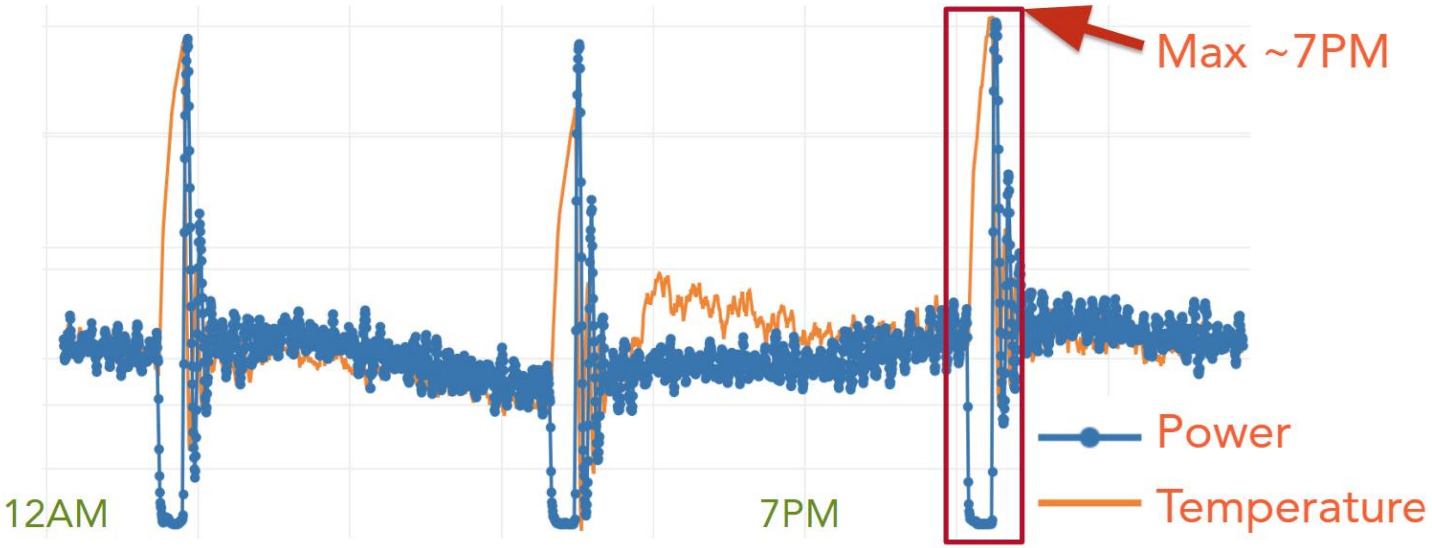
Milestone 1: Resilience - Predictive analytics for commercial refrigeration operations

Milestone 2: Maintenance - Dashboard with real-time analytics/alerts

Milestone 3: Coordination - Demonstration of coordinating commercial refrigeration units

Problem

- Up to 60% of energy usage goes to refrigerators and freezers in supermarkets, groceries, and convenience stores (costing up to $112,000/year for a large store)
- They incur over three times the energy cost of their next highest energy burden, lighting



DATA FROM STORE PILOT
ENTROPY+

- Optimized controls and monitoring reduces this by timing defrost and compressor cycled
- Stores would benefit with lower energy bills and utilities benefit with lower peak demand

Alignment and Impact

Contributing to EERE/BTO goals by:

- Reducing energy consumption around 4% per store
- Lowering GHG Emissions by 5%-15% per store
- Relieve cost burden on store owners by reducing their energy bills (dependent on utility tariff structure, e.g., over 9% savings in Southern California)

For example, across the network of partner Southern California Edison, we project:

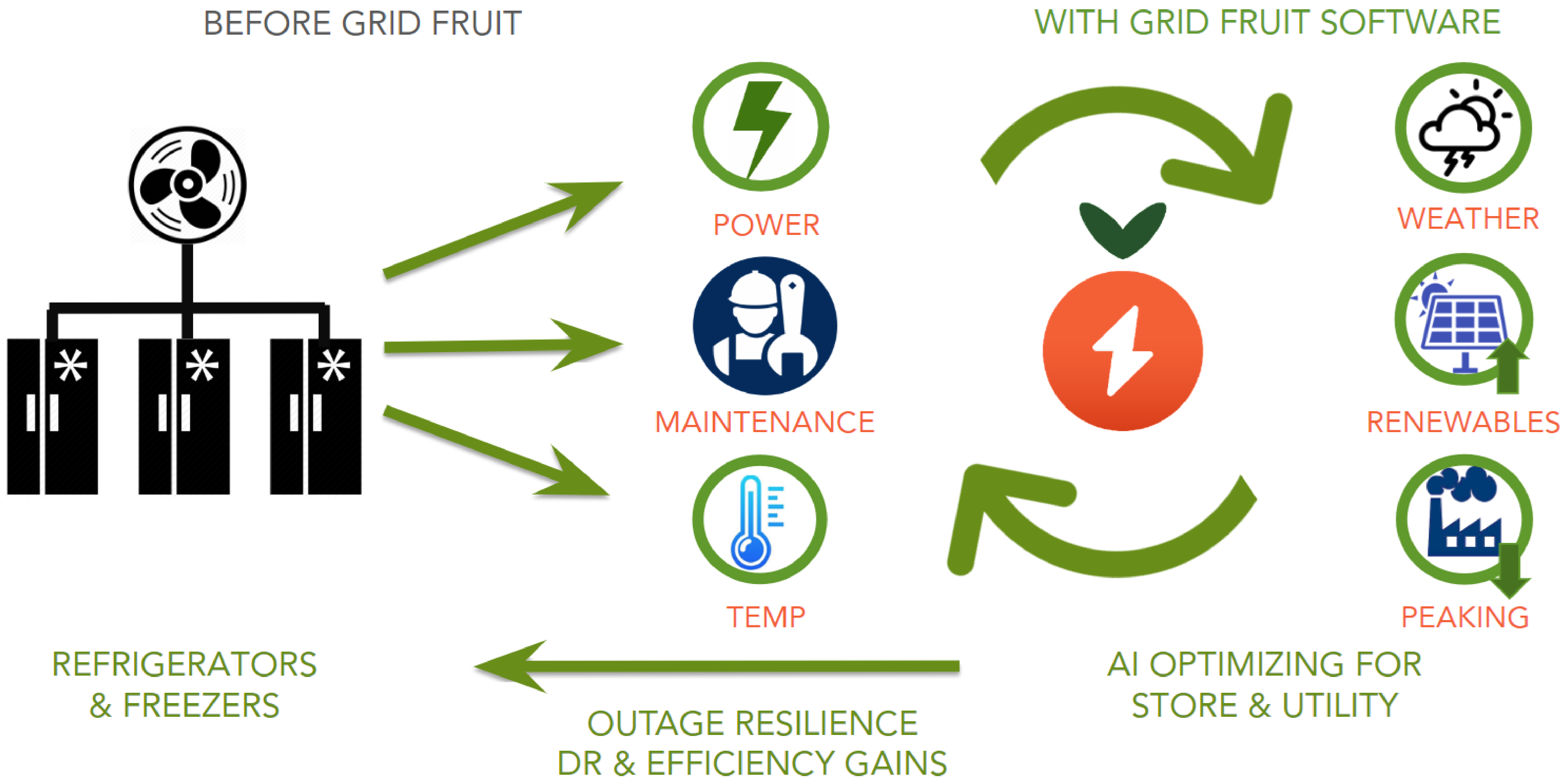
- Lowering aggregate store GHG Emissions by 91.7 kt CO2/year
- Reducing aggregate store energy bills by $105M per year

Alignment and Impact

Demonstrating the above impact areas by:

- Fine tuning and completing phase I’s technology
- Visualization and developing customer facing dashboard
- Physical demonstration of resulting technology and customer acquisition

Approach



BEFORE GRID FRUIT
WITH GRID FRUIT SOFTWARE
POWER
MAINTENANCE
TEMP
WEATHER
RENEWABLES
PEAKING
REFRIGERATORS & FREEZERS
OUTAGE RESILIENCE DR & EFFICIENCY GAINS
AI OPTIMIZING FOR STORE & UTILITY

Approach

Technical Objective 1: Algorithm Development and Model Validation

- Data collection
- Data cleaning
- Stand-alone control
- Coordinated control

Approach

Technical Objective 2: Dashboard with Real-time Analytics/Alerts

- Connect dashboard application with data series database
- Visualization of expected operation with no Grid Fruit control (monitoring)
- Visualization of expected operation with Grid Fruit control (AI optimization)

Approach

Technical Objective 3: Physical Implementation and Demonstration of Coordinating Multiple Commercial Refrigeration Units

- Communication and hardware resilience

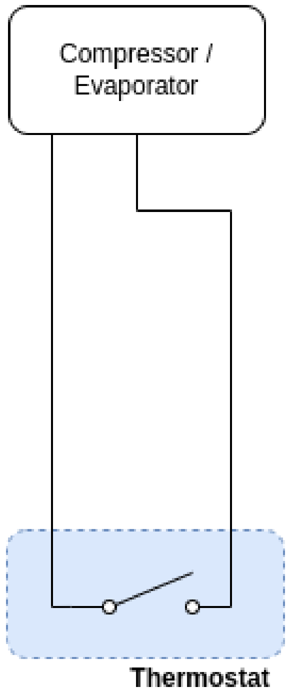
- Physical demonstration:
  - Baseline
  - Islanded mode
  - Coordinated mode

- Verifying resiliency benefits:
  - Improving food protection against outage
  - Coordinated grid saving responses
  - Back-up power distribution

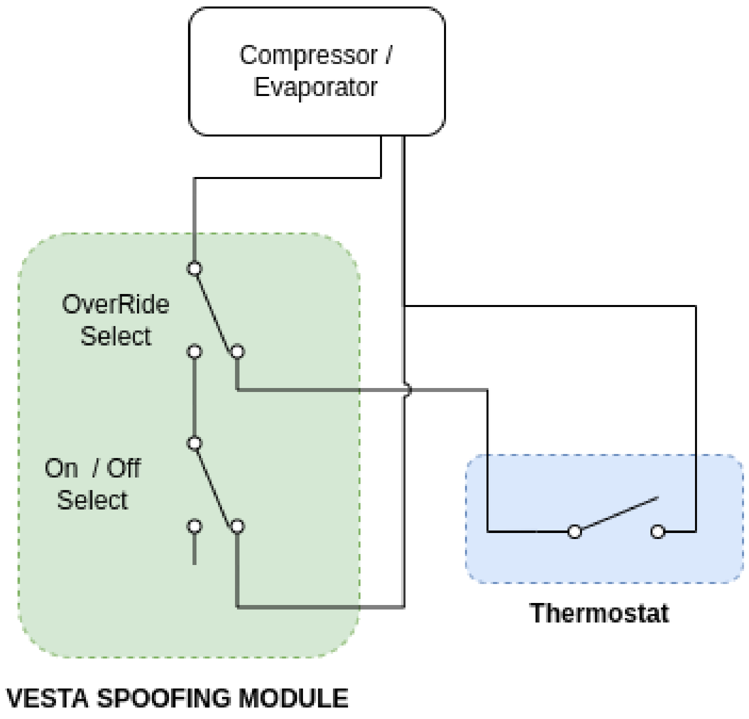
Approach

Refrigeration controller with override

- Leaves original thermostat intact as failsafe to protect food inventory
- “Spoofing” temperature signals allows forcing compressor on/off



AS ORIGINALLY INSTALLED



With OverRide Option

Two SPDT relays manage override. The first 'Override Select' fails safe to using the original thermostat. When the first relay is active, the second relay either completes the circuit to activate the refrigeration, or leaves the circuit open to disable refrigeration. This allows the Vesta to force or prevent cooling regardless of the actual temperature.

Progress

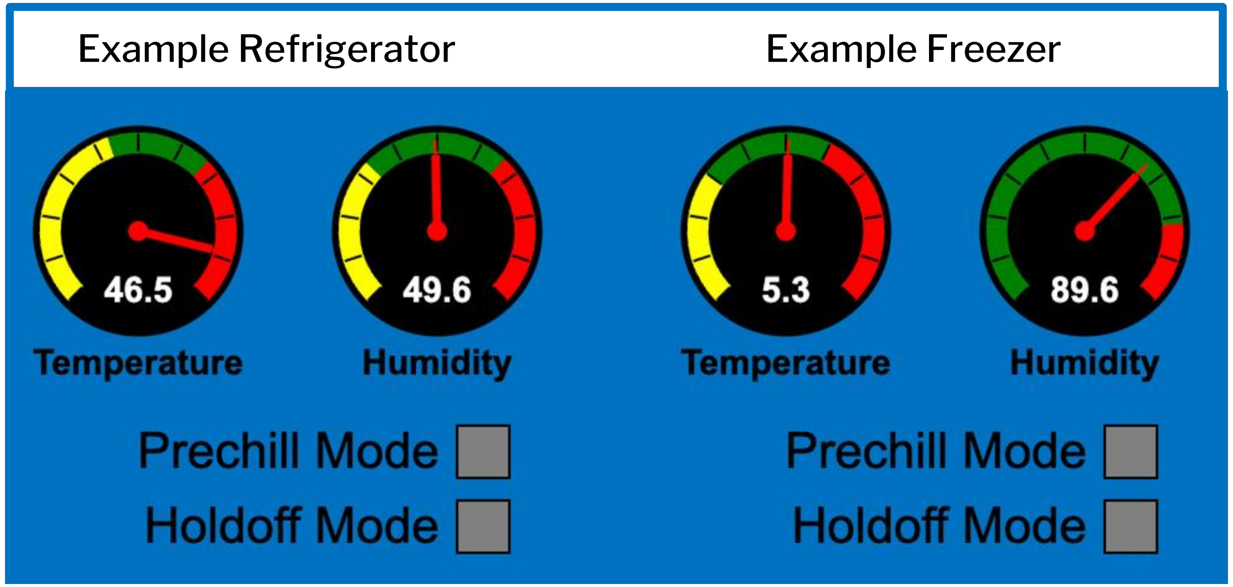
Integration with the following variables for store refrigeration units:

- Low Temp Limit – lowest allowable cooler temperature
- High Temp Limit – highest allowable cooler temperature
- PreChill command – command from the remote controller to enter PreChill mode
- HoldOff command – command from remote controller to enter HoldOff mode after PreChill
- PreChill Mode – operating mode for forced cooling
- HoldOff Mode – operating mode for minimum energy usage
- Normal Mode – operating using the coolers own controls
- PreChill time limit – maximum allowable time for PreChill cycle
- HoldOff time limit – maximum allowable time for HoldOff cycle
- Cold Alarm Delay – time to wait in ‘too cold’ condition before sending alarm message
- Warm Alarm Delay – time to wait in ‘too warm’ condition before sending alarm message

Progress

Vermont pilots in two small groceries

- Customer-facing interface
  - Users see when their units are in the expected zone (green) or unexpected zone (red)
  - Prechill Mode and Hold-off Mode correspond to Load Building and Load Shedding events, respectively
  - Pre-chill/Hold-off mode switches indicate to the business which control is activated in real-time



- Alert medium
  - Out-of-bounds alerts comminated via email in real-time
  - Alert criteria decided by the store owner/maintenance team

Progress

Vermont pilots in two small groceries

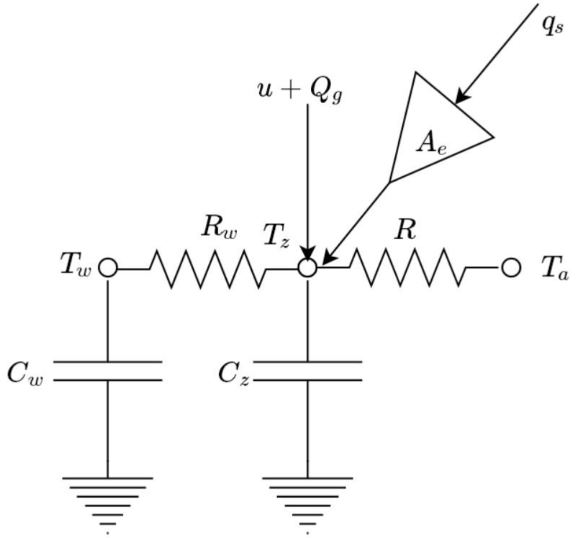
- Continuous monitoring
  - Temperature
  - Humidity
  - Evaporator Amps
  - Compressor Amps

Charted data presented and updated on the business's private dashboard in real-time

Progress

System identification for refrigerator’s thermal system:

- Utilizing a semi-physical thermal network structure for refrigeration systems
- Leveraging gray-box modeling approach instead of black-box have advantages as follows:
  - Parameters of the model including thermal resistance and capacitances have physical meanings
  - Conservation of energy is satisfied
- In addition to the conventional identification approaches, we use a Lumped Disturbance Modeling approach to account for unmeasured thermal disturbances



Simple RC circuit

Future Work

California pilot in 6 -10 convenience stores

- Finalizing agreement to pilot with large-scale store chain operating in 37+ states
- The efforts will be coordinated with the chain's trusted and long-time vendor
  - Alert will be communicated through vendor's established system
  - Talks in progress to ensure seamless integration of data collection/visualization/controls
- AI optimization will unlock:
  - Store-level energy savings
  - Demand response rebates

Future Work and Obstacles

Beyond refrigeration: Applying the basic technology to support nation-wide electrification trend (e.g., Electric Vehicle adoption)

- Predicting outages and building resilience into decision-making models

- Pilot testing and customer engagement
  - Better understanding of customers' perspective on resiliency
  - Complementing physics-based models with data-driven insights
  - Seamless integration with chain's trusted legacy platforms /trusted vendors

- Obstacles to Phase II project
  - COVID-driven delays due to overbooked tech contractor partners
  - Commissioning plan of partner's test facility was disrupted, compounded by difficulties with talent retention and electrician shortages
  - Together these factors delayed the start of physical tests by over one year

Thank You

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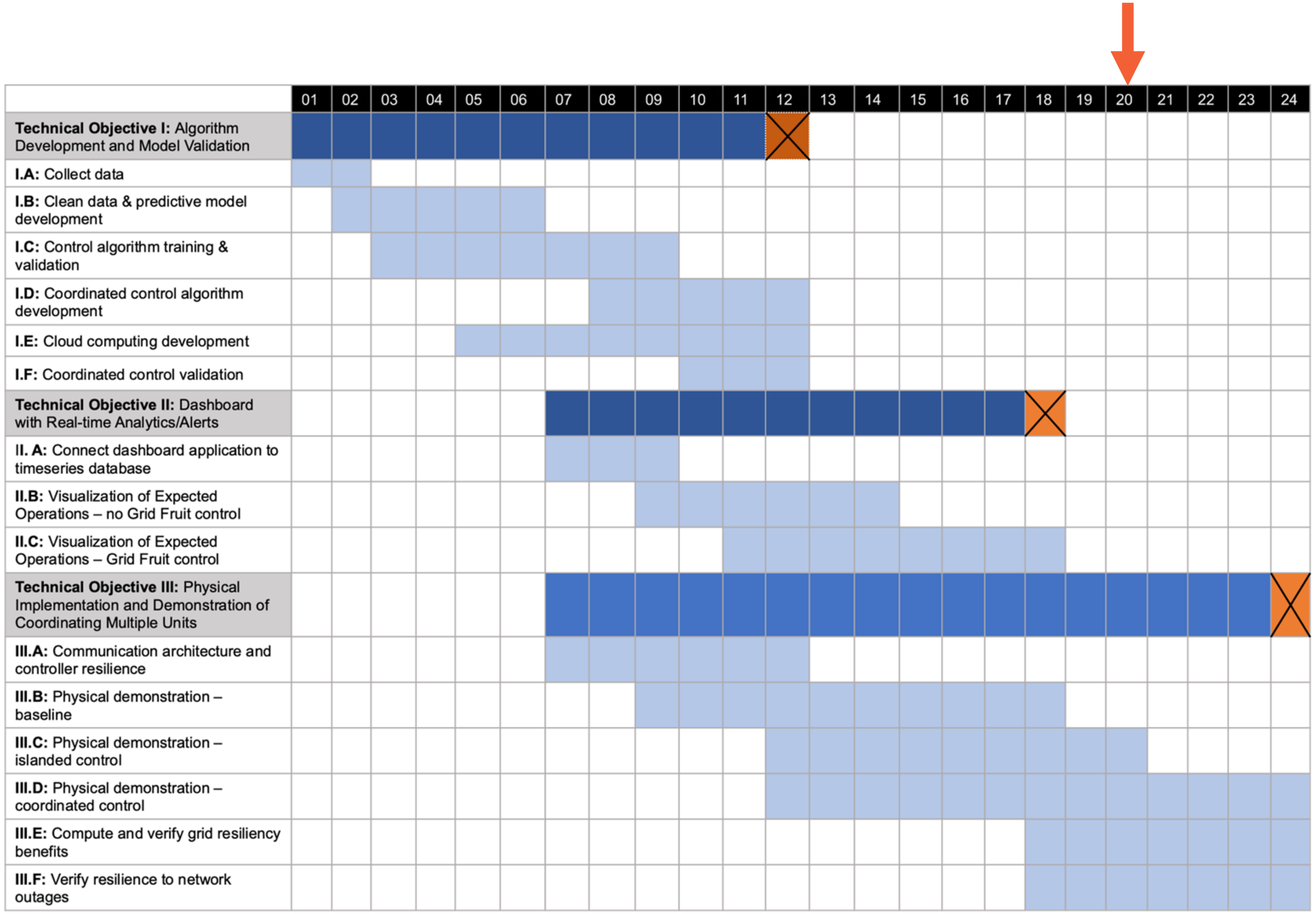
REFERENCE SLIDES

Project Execution



- Slips in schedule due to COVID delays and overbooked tech contractor partners
- Commissioning plan of partner’s test facility was disrupted, compounded by difficulties with talent retention and electrician shortages (together delaying physical tests by over a year)

Team

Jesse Thornburg, PhD – CEO (PI)

MIT Stanford

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TEXAS The University of Texas at Austin
Carnegie Mellon University

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Simulation Pilot

HIGHLIGHT - EPRI-and-SCE PILOT

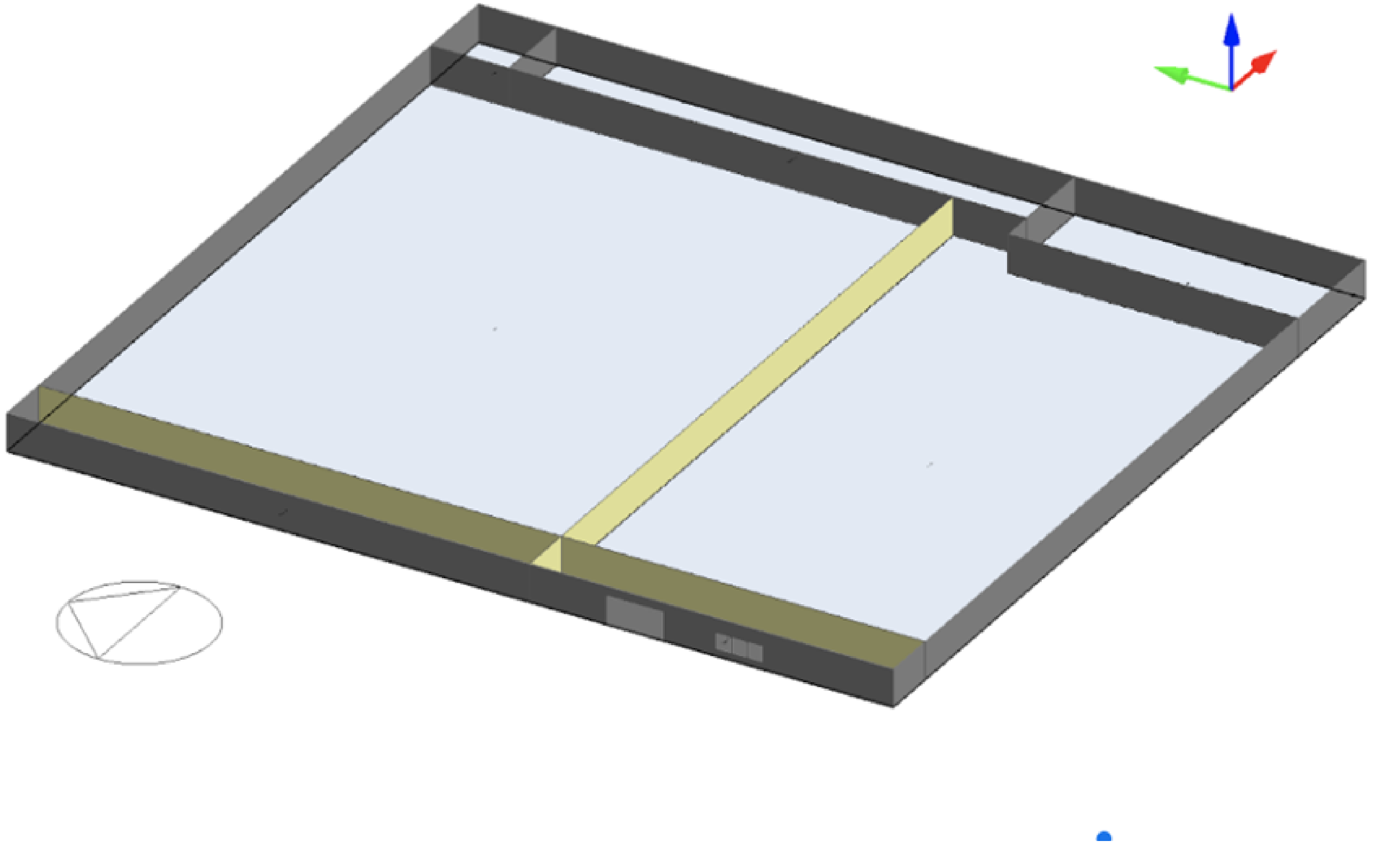
- Digital twins of 7-Elevens across SCE climates
- Optimized defrost timing
- Staggered demand spikes across each store & whole utility (11,990 stores)
  - 10 MW reduction (12.7%) in summer on-peak demand (LA county)
  - Reduced average peak demand and monthly peak demand in every month

SOUTHERN CALIFORNIA EDISON

Simulation Pilot

HIGHLIGHT - EPRI-and-SCE PILOT: 7-ELEVEN MODELS ANTICIPATE & AVOID COSTLY EVENTS

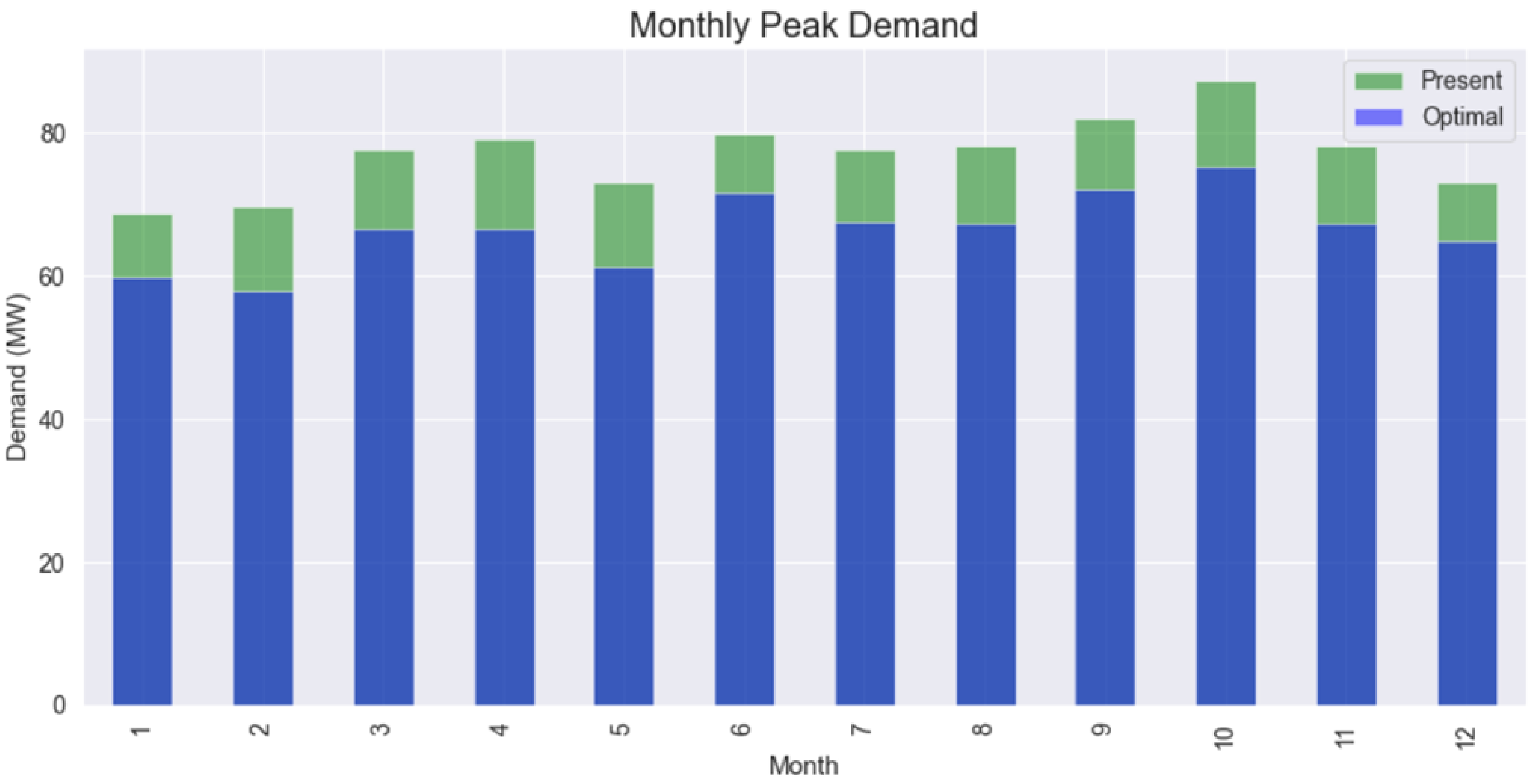
- Physics-based digital twins of stores (e.g., 7-Elevens) fill in gaps from data
- Defrost schedules by month and climate zone optimized for minimal monthly store charge
  - Utility time-of-use pricing (seasonal)
  - Utility demand charges (minimizing peaks)



Simulation Pilot

HIGHLIGHT - EPRI-and-SCE PILOT: SCE DEMAND CHARGE REDUCED UP TO 20%

- Predicted store load profile
- Optimized defrost schedule to minimize energy bills
- Coordinated refrigeration with patterns of HVAC, lighting, and shopper traffic

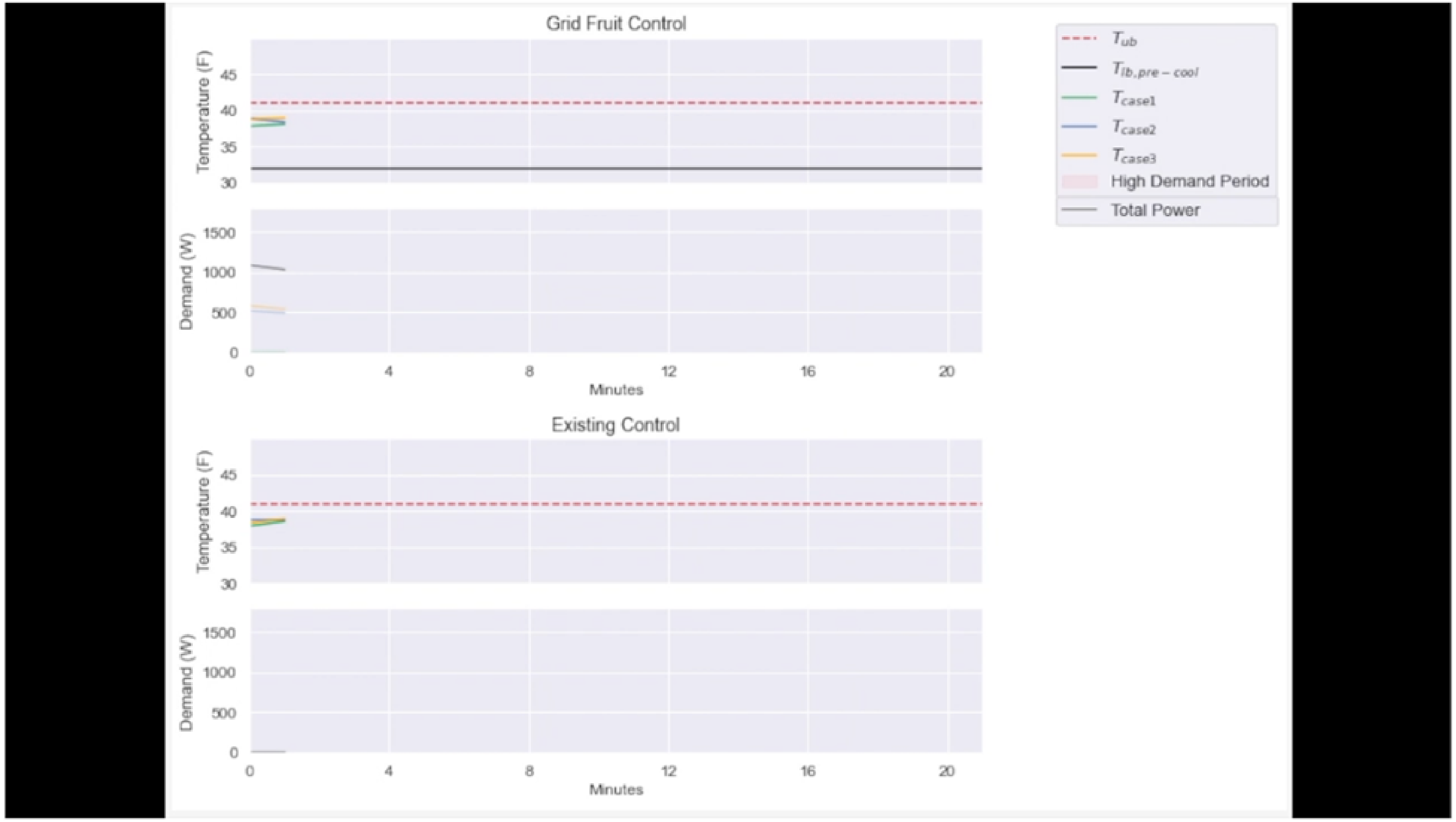


Aggregate Peak of LA County's 2204 Convenience Stores

Simulation Pilot

HIGHLIGHT - COORDINATED CONTROL OF 3 REFRIGERATORS

- 28% lower refrigeration electricity consumption during high demand period
- 64% lower peak demand during high demand period
- 32% lower peak demand during business hours



EERE/BTO goals

The nation’s ambitious climate mitigation goals

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Power system decarbonization

100% carbon pollution-free electricity by 2035

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

EERE/BTO’s vision for a net-zero U.S. building sector by 2050