



**REAL-WORLD, FULL-SCALE VALIDATION OF POWER BALANCING  
SERVICES FROM PACKETIZED VIRTUAL BATTERIES**



# GOAL

Coordinate diverse fleet of DERs to match demand to real-time supply signals.

Existing tools:

- TOU rates
- Direct load control
- Industrial DR
- Broadcast DR signal

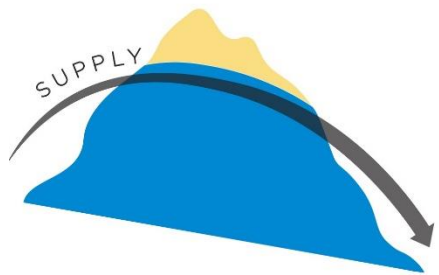
Priorities:

- Device agnostic
- Customer quality of service
- Scalability
- Cost-effectiveness
- Security
- Full-stack services

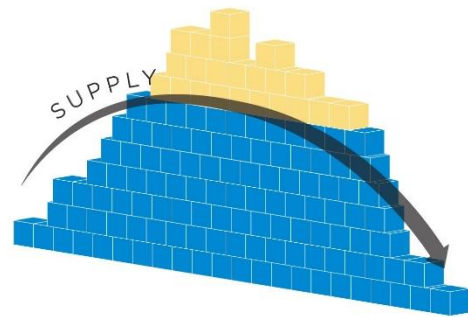
# HOW OUR TECHNOLOGY WORKS

Using ideas that run the Internet to coordinate millions of distributed energy devices:

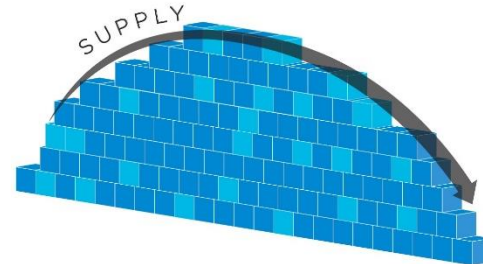
\$100 energy  
at the peak



BEFORE PACKETIZATION



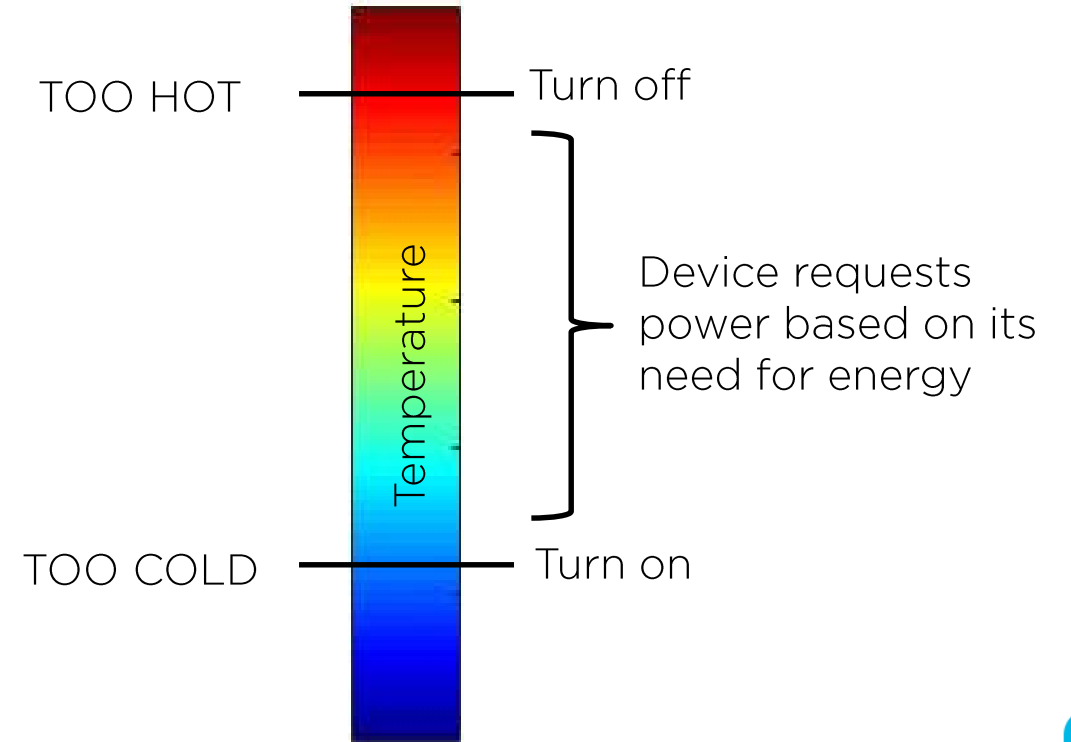
AFTER PACKETIZATION



AFTER RANDOMIZATION

\$100 energy  
becomes 2¢ energy

# DEVICE MANAGEMENT

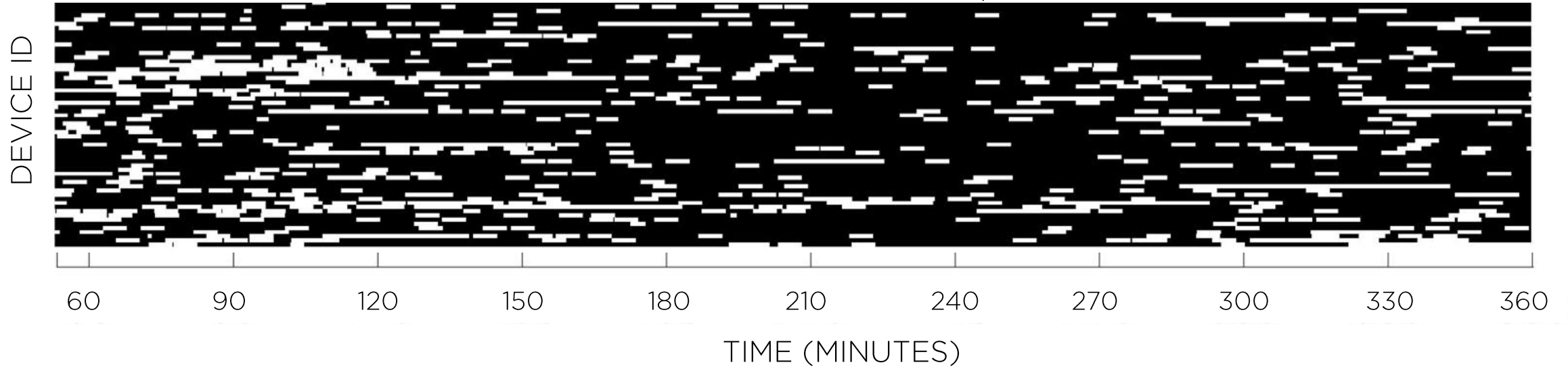


# TRADITIONAL VS. COORDINATED

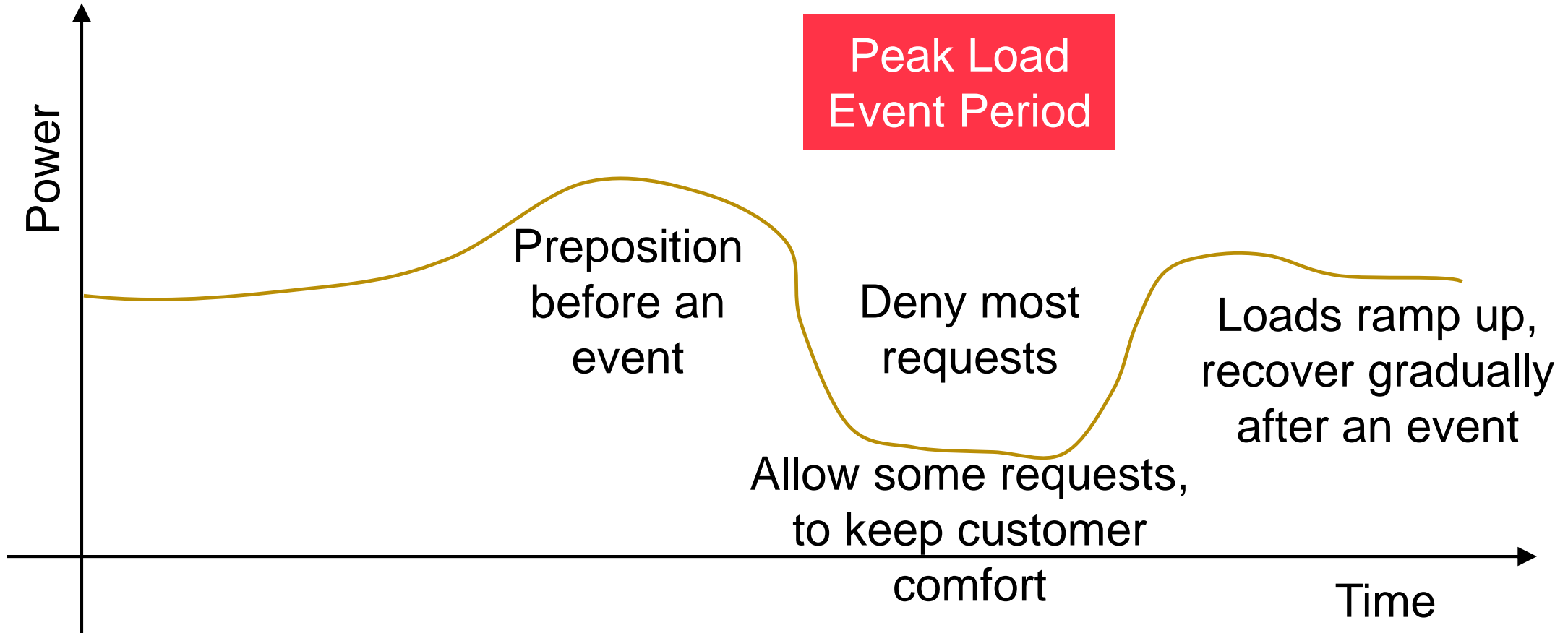
CONVENTIONAL THERMOSTAT (long on/off times)



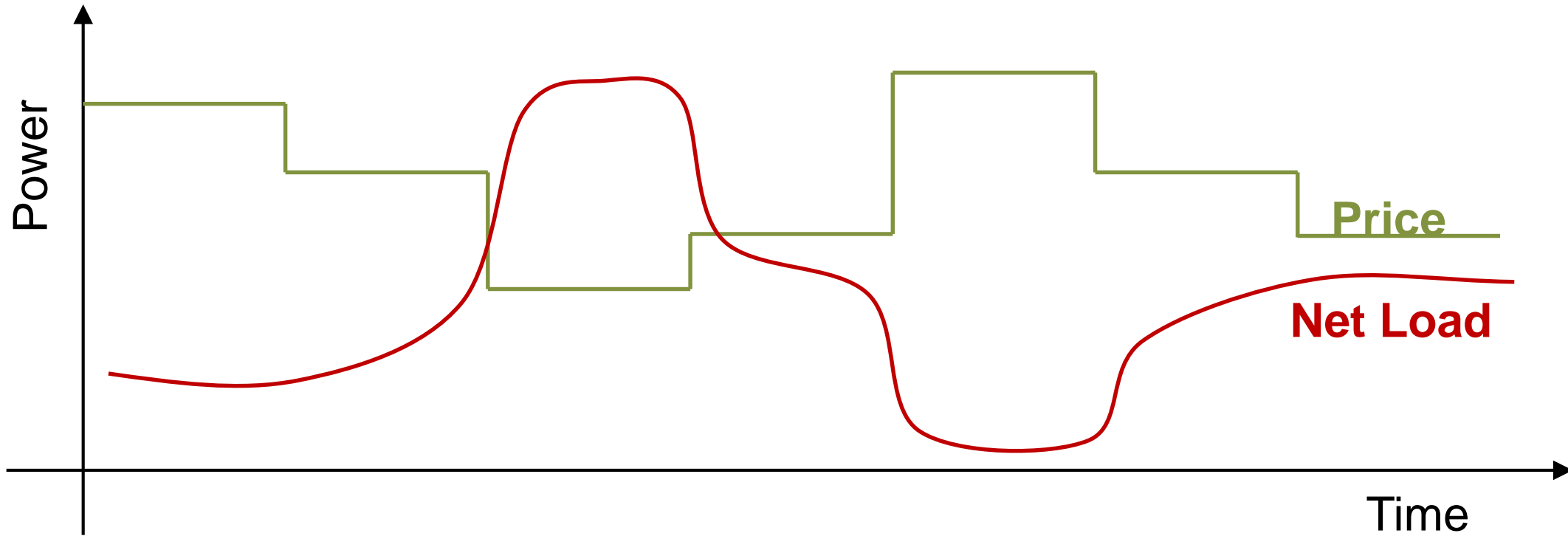
PACKETIZED THERMOSTAT (multiple short on/off times)



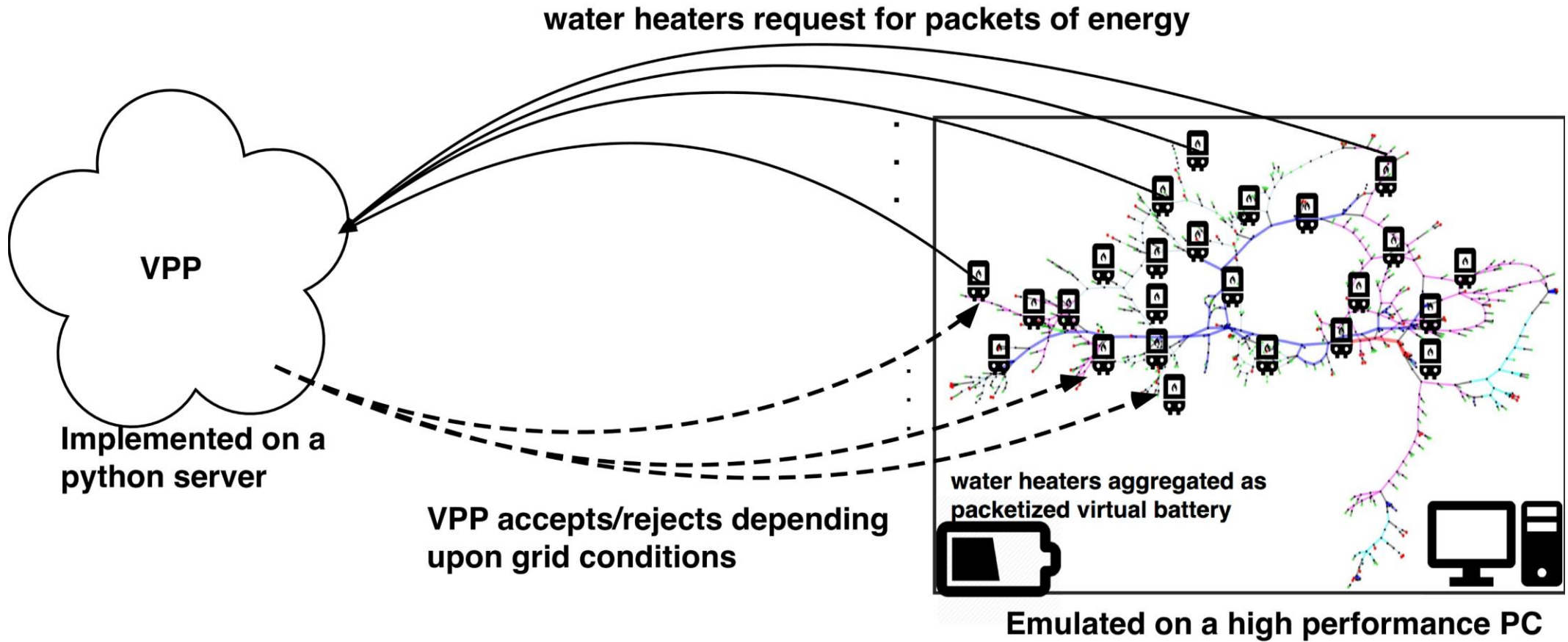
# PEAKCRUSHER SERVICE



# LOADSHAPER SERVICE

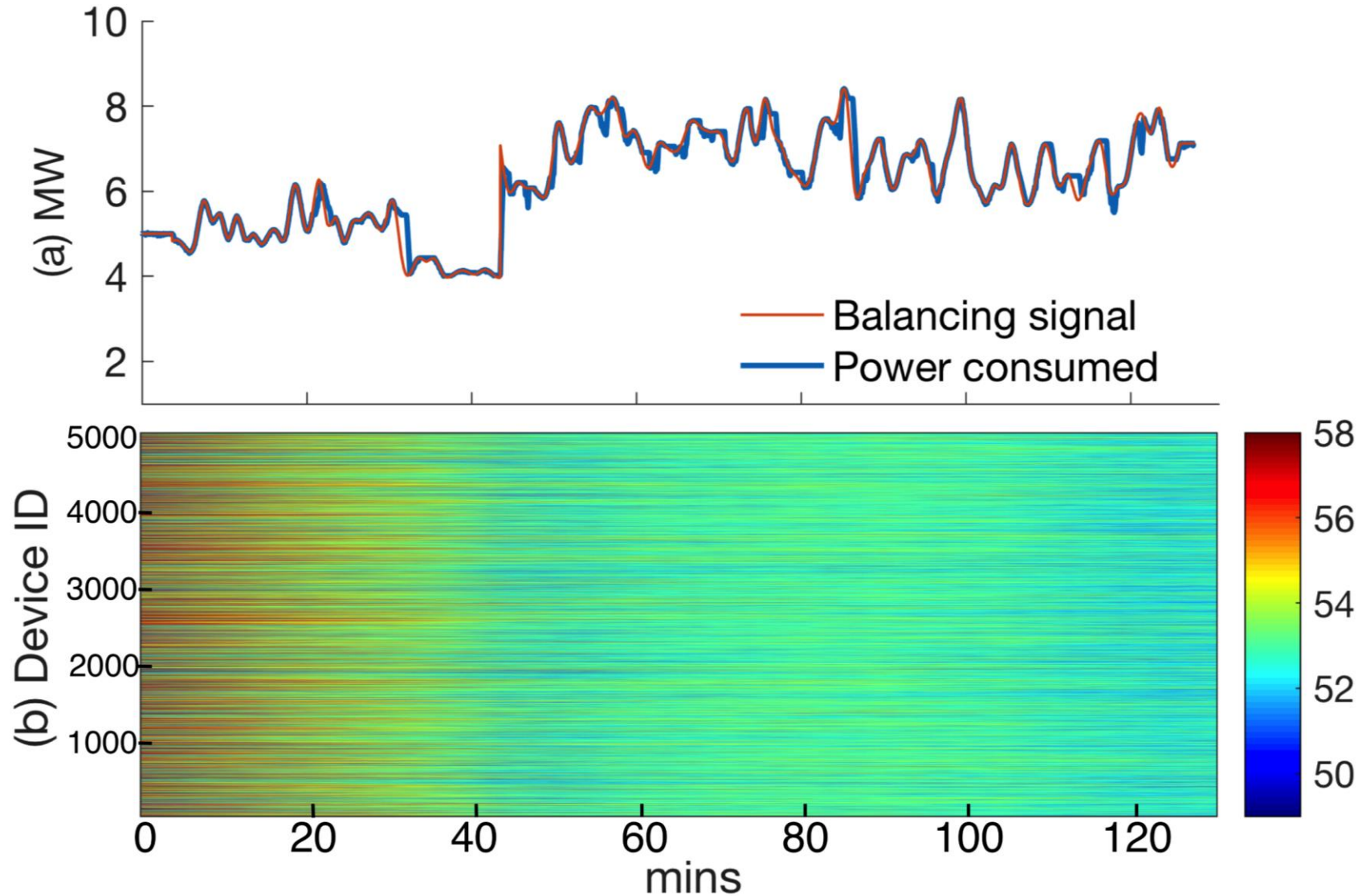


# CYBERPHYSICAL TESTBED





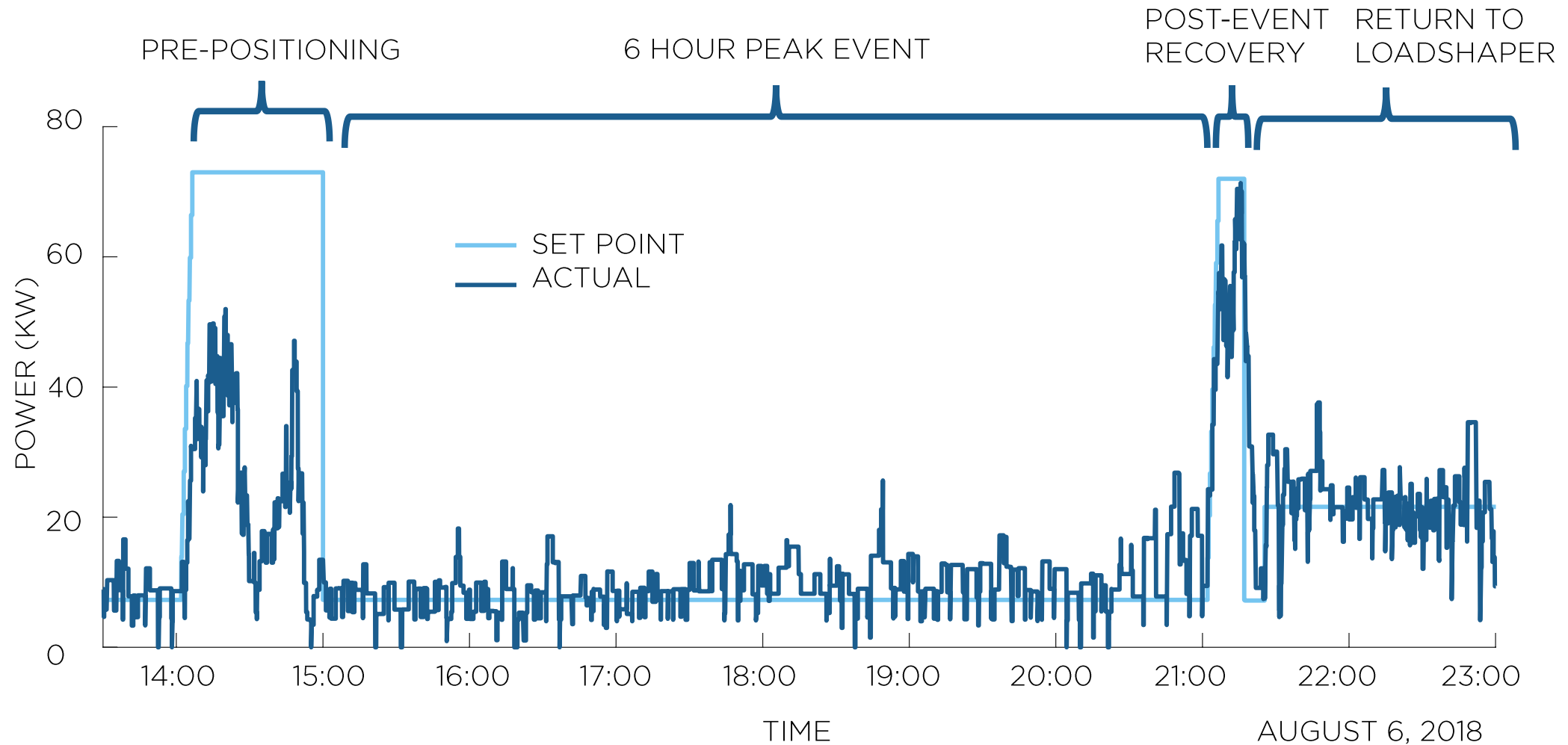
# CYBERPHYSICAL VALIDATION



**BUT DO REAL-WORLD APPLICATIONS GET US IN TO...**

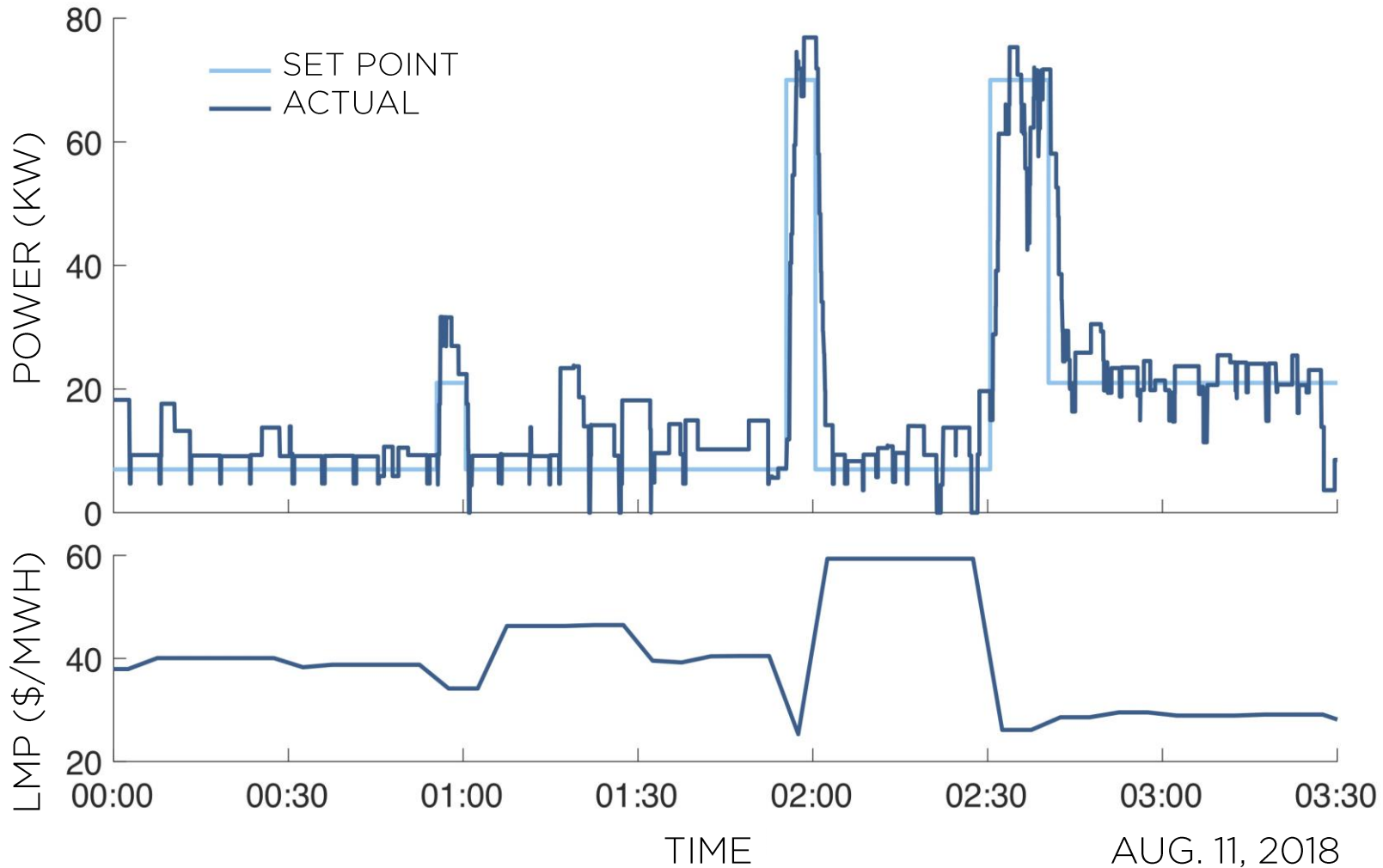
**HOT WATER?**

# PEAKCRUSHER IN REAL WORLD CONDITIONS



ABOUT 60 WATER HEATERS, VERMONT ELECTRIC CO-OP

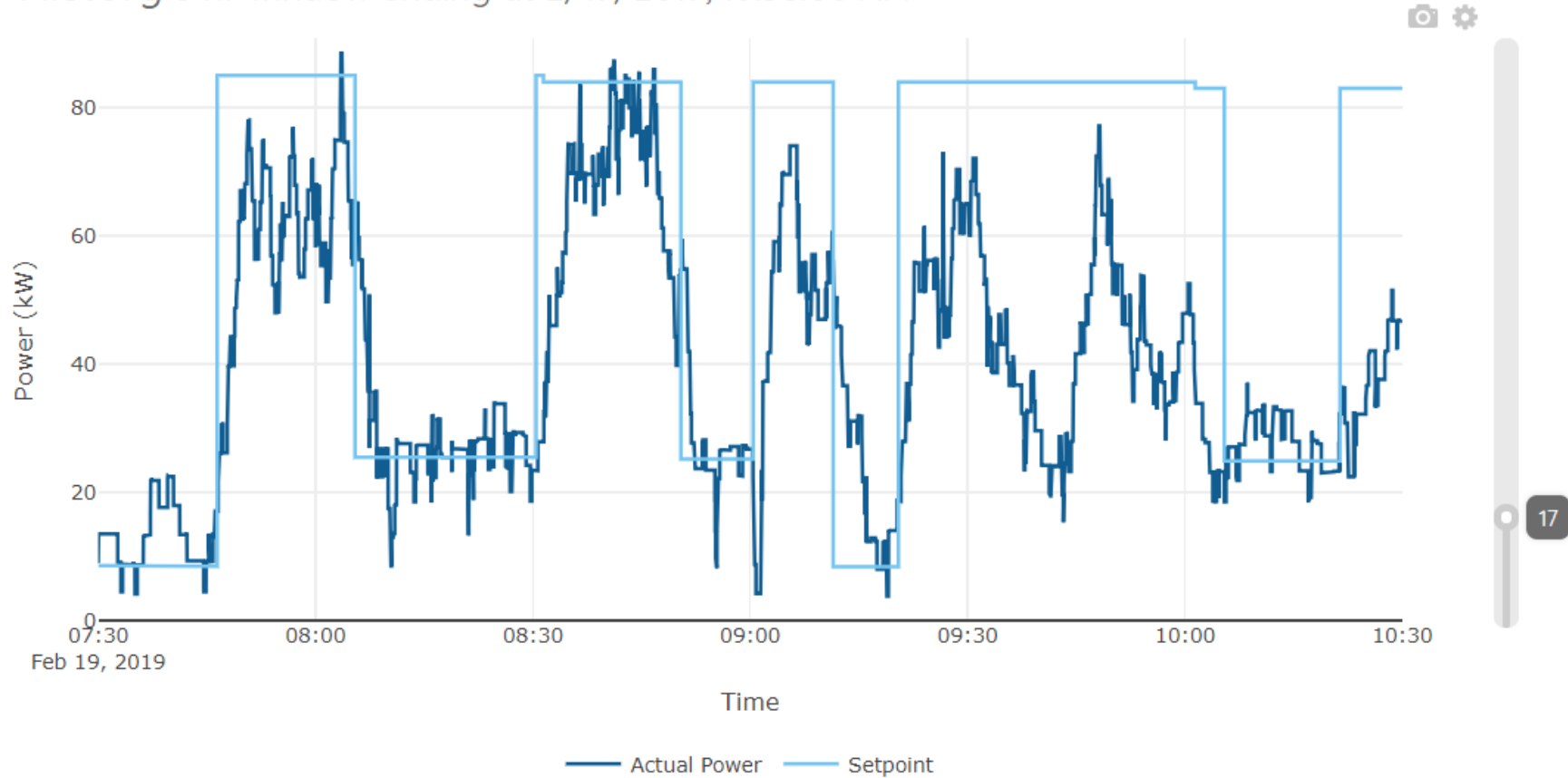
# LOADSHAPER IN ACTION



VIRTUAL BATTERY  
with about 60  
water heaters

# LOADSHAPER IMPROVES WITH 80 DEVICES

VPP History 3 hr window ending at 2/19/2019, 10:30:00 AM



# VALUE STACK FOR 1 DEVICE IN NEW ENGLAND MARKET

Value stack based on data from electric hot water heaters operating in Vermont

- High generation capacity costs
- Relatively low wholesale energy prices due to cost of natural gas, reducing arbitrage and ancillary services value
- Limited need for T&D CapEx

In locations with more substantial T&D constraints (aging infrastructure) T&D CapEx value increases substantially



GRID BALANCING  
(ancillary services)  
~ \$30/device/year



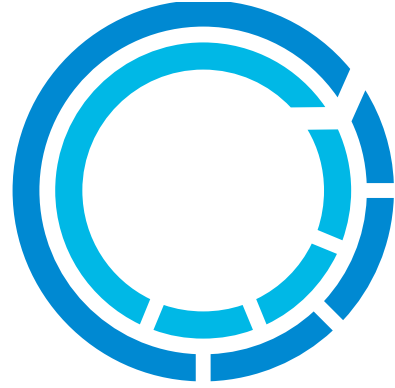
WHOLESALE ENERGY  
ARBITRAGE  
~ \$30/device/year



AVOIDED T&D CAPEX  
~ \$20/device/year



AVOIDED GENERATION  
CAPACITY (ICAP)  
~ \$100/device/year



# PACKETIZED

## ENERGY

**JOIN US**

**AS WE SMOOTH THE TRANSITION TO A CLEAN ENERGY FUTURE**

