

Dispatchable Loads for Grid Health

Water Preheaters as Energy Storage

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Milestone in Renewable Energy

Four Gigawatts of Solar Energy
Produced in California and
Placed on the Power Grid



photo by Diana Accinelli

What Does this Mean?

- Hope
- Technical Hurdles

Hope

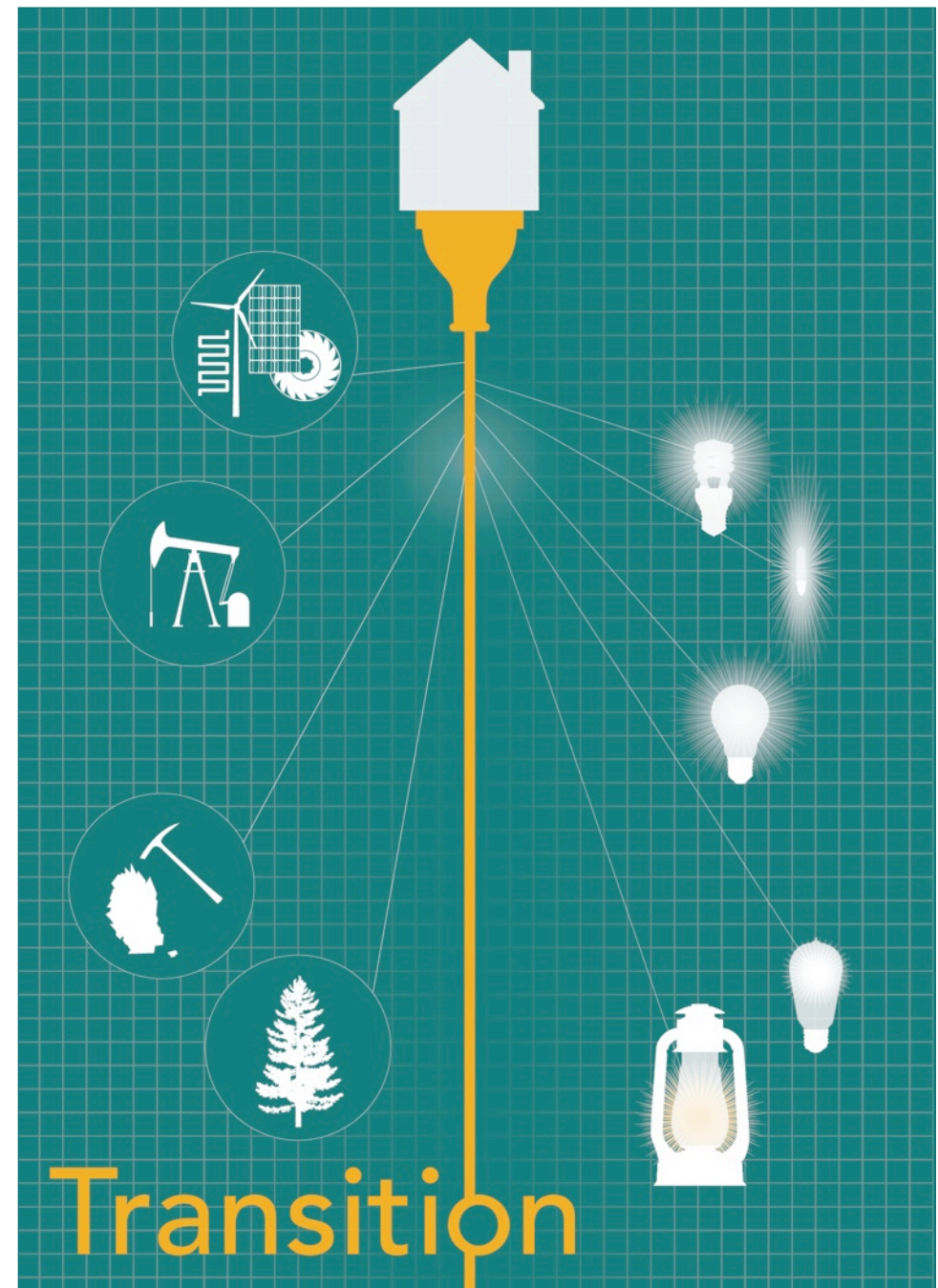
- More Carbon-Neutral
- More Sustainable
- Less Environmental Impact
- Improved Quality of Life



California Smart Grid Center graphic by Deborah Frost & Shanna Rossi

Technical Hurdles

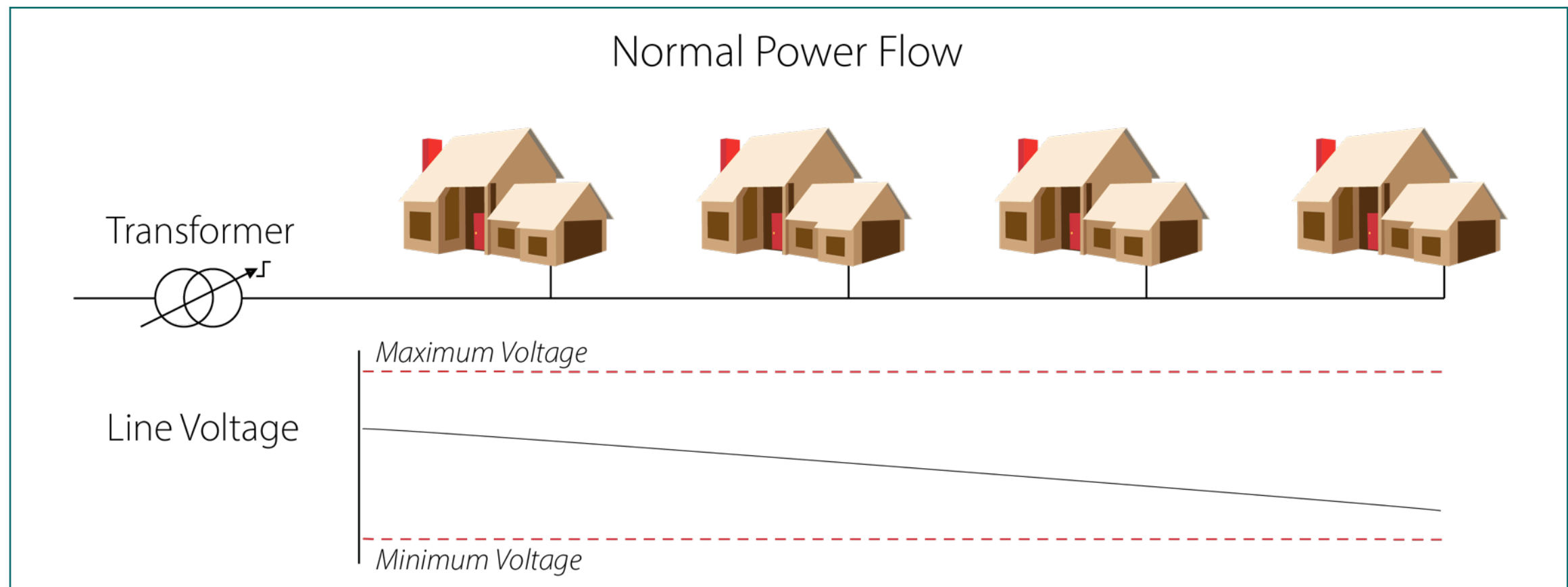
- Rapid Variability
- Generation and Usage Alignment
- Distributed Coordination
- Steady-State Overvoltage



California Smart Grid Center graphic by Deborah Frost & Shanna Rossi

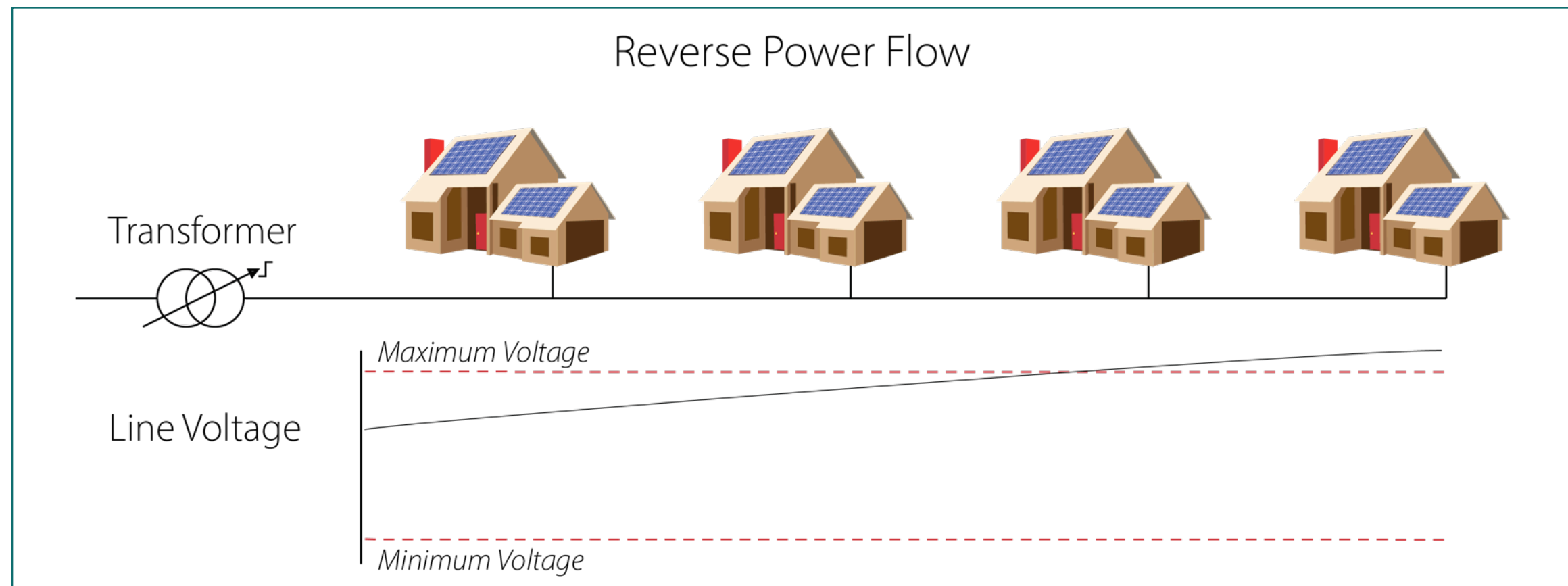
Traditional Power Flow

- Unidirectional
- Regulated



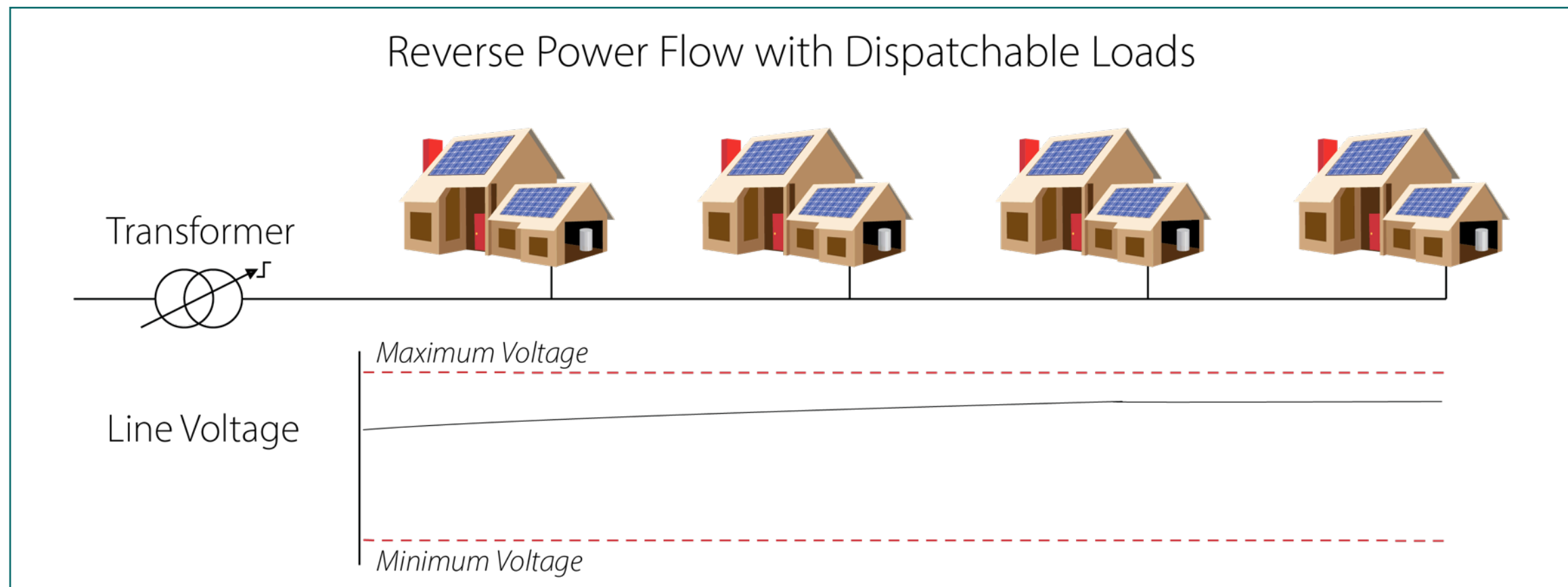
Overvoltage on Feeder Lines

- Localized Effects



Addressing Overvoltage

- No Curtailment
- No Electrical Storage



Research Objective

Facilitate the adoption of
renewable energy by
mitigation of undesirable
impacts of distributed
power generation



California Smart Grid Center graphic by Deborah Frost & Shanna Rossi

Electrical Storage

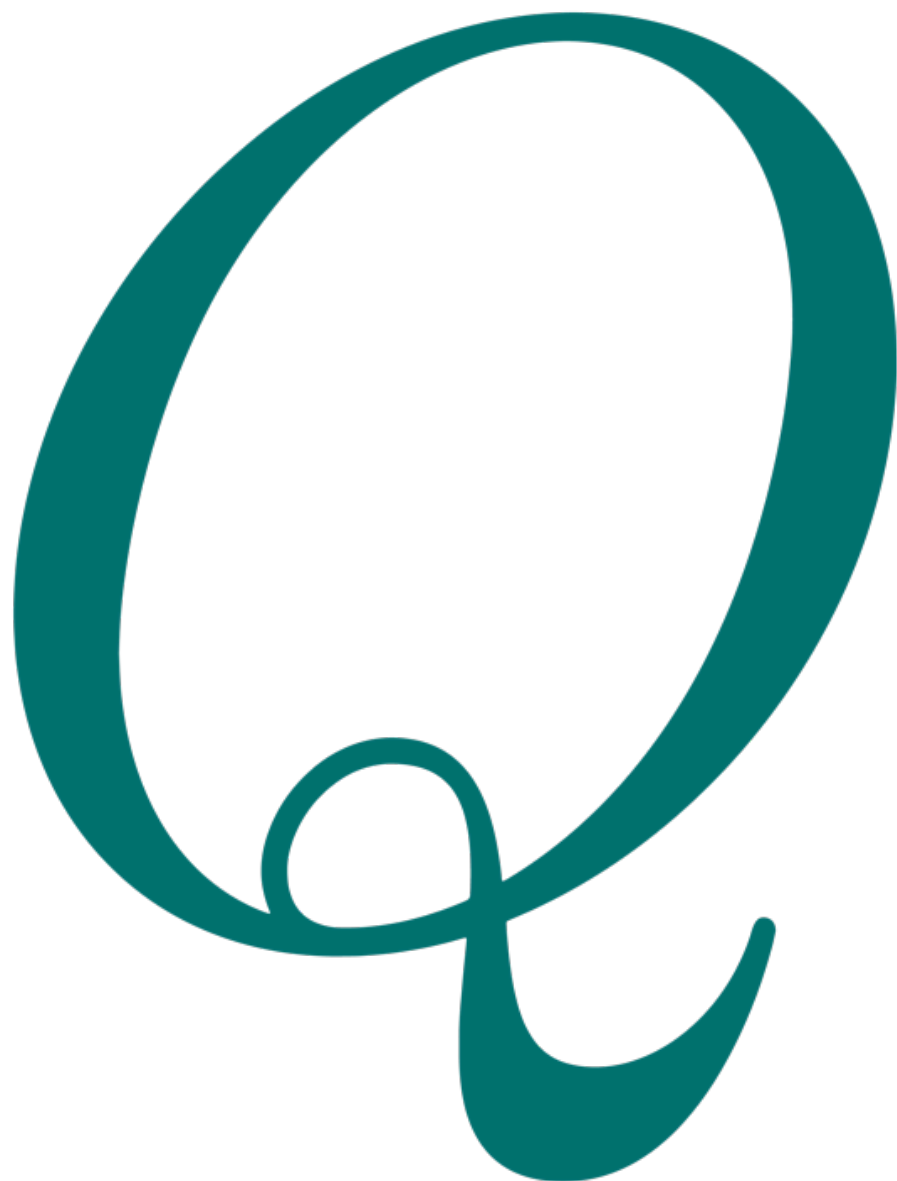
- Price
- Complexity
- Safety Concerns
- Space Consideration



photo by Robert Wortman

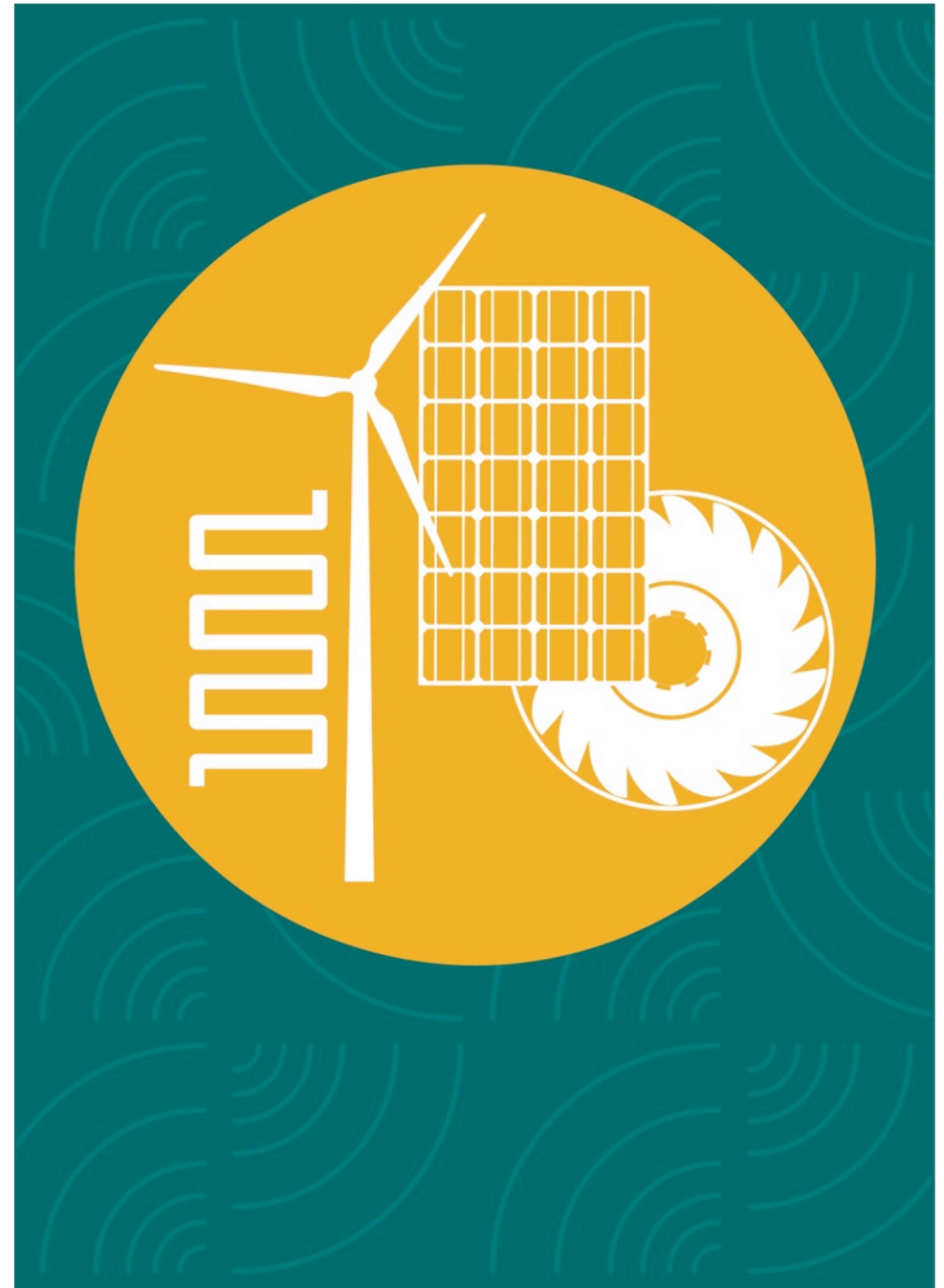
Thermal Storage

- Stores excess power generation as thermal energy
- Water heaters are:
 - Simple
 - Familiar
 - Relatively Inexpensive



Design Requirements

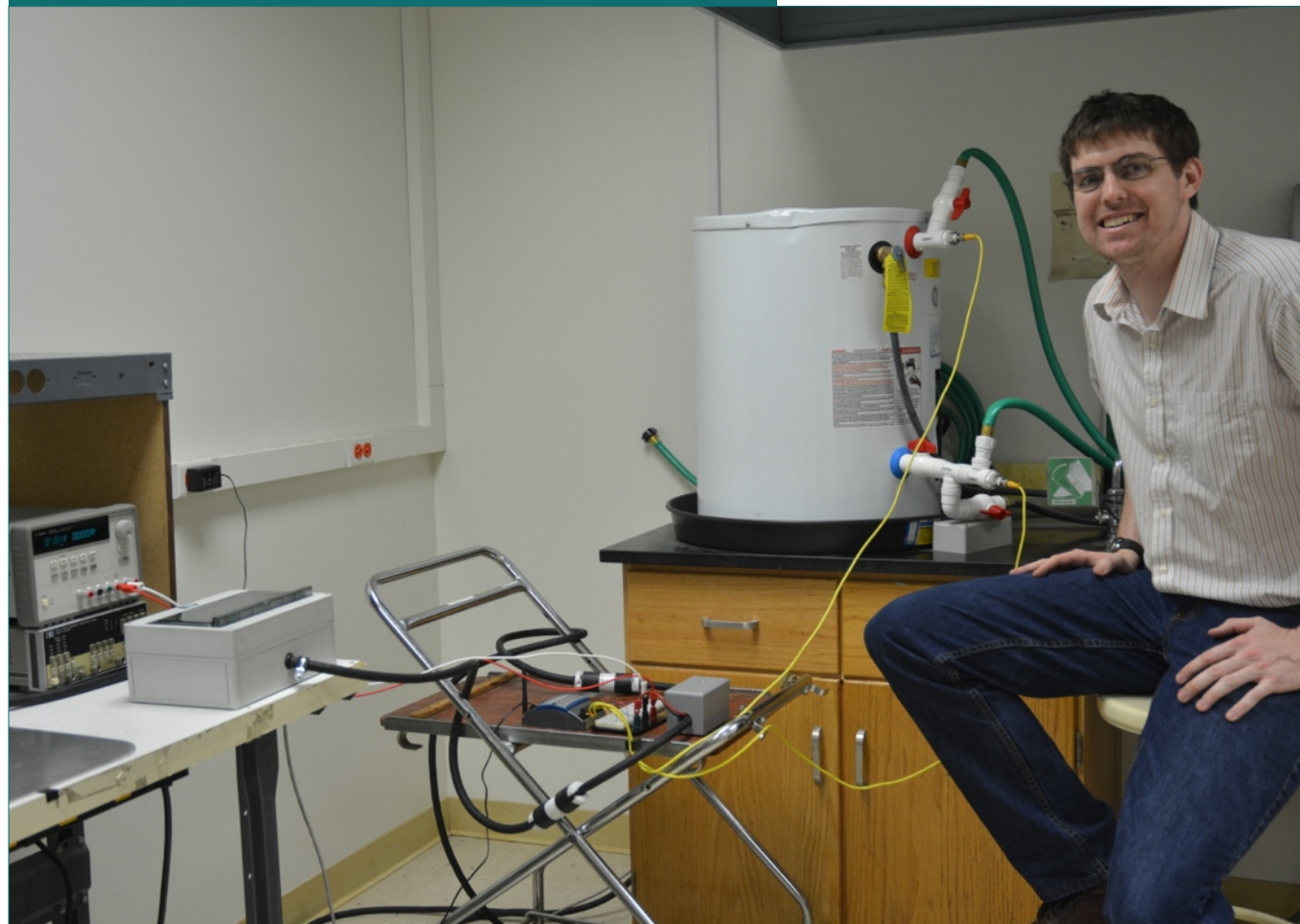
- Smart Default
- Manual Option



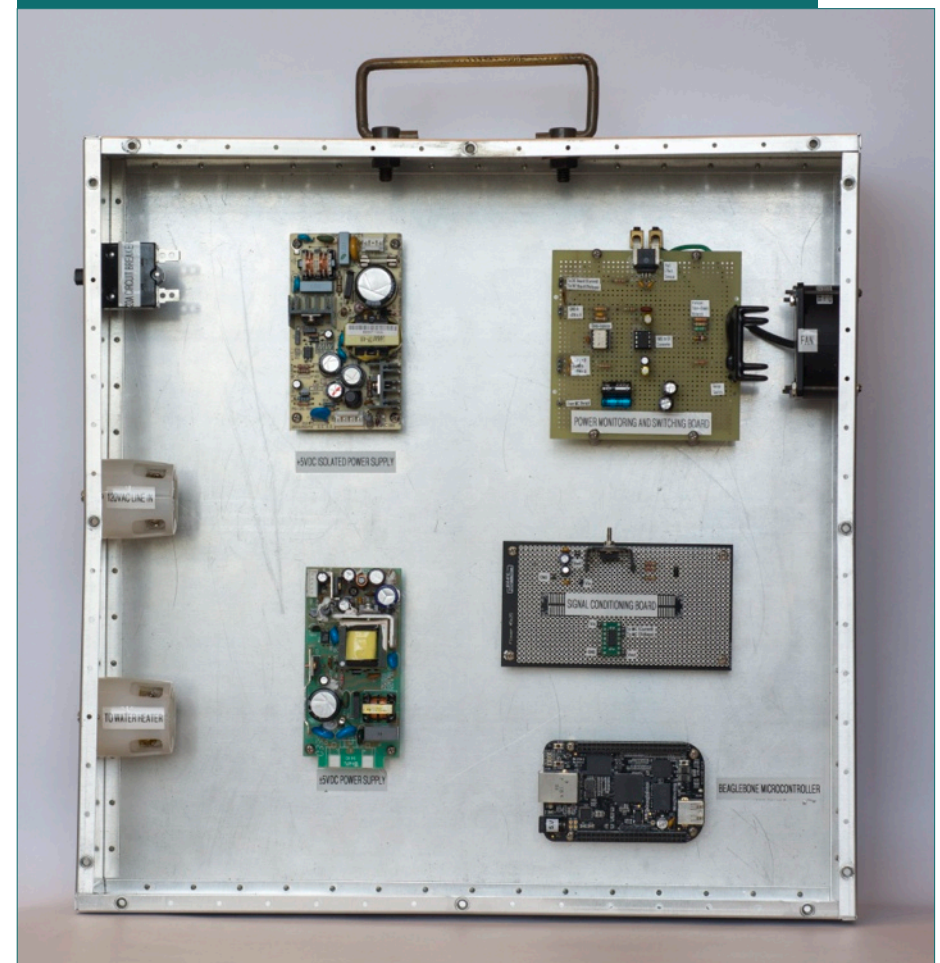
California Smart Grid Center graphic by Deborah Frost

Controller Prototypes

Rapid Prototype



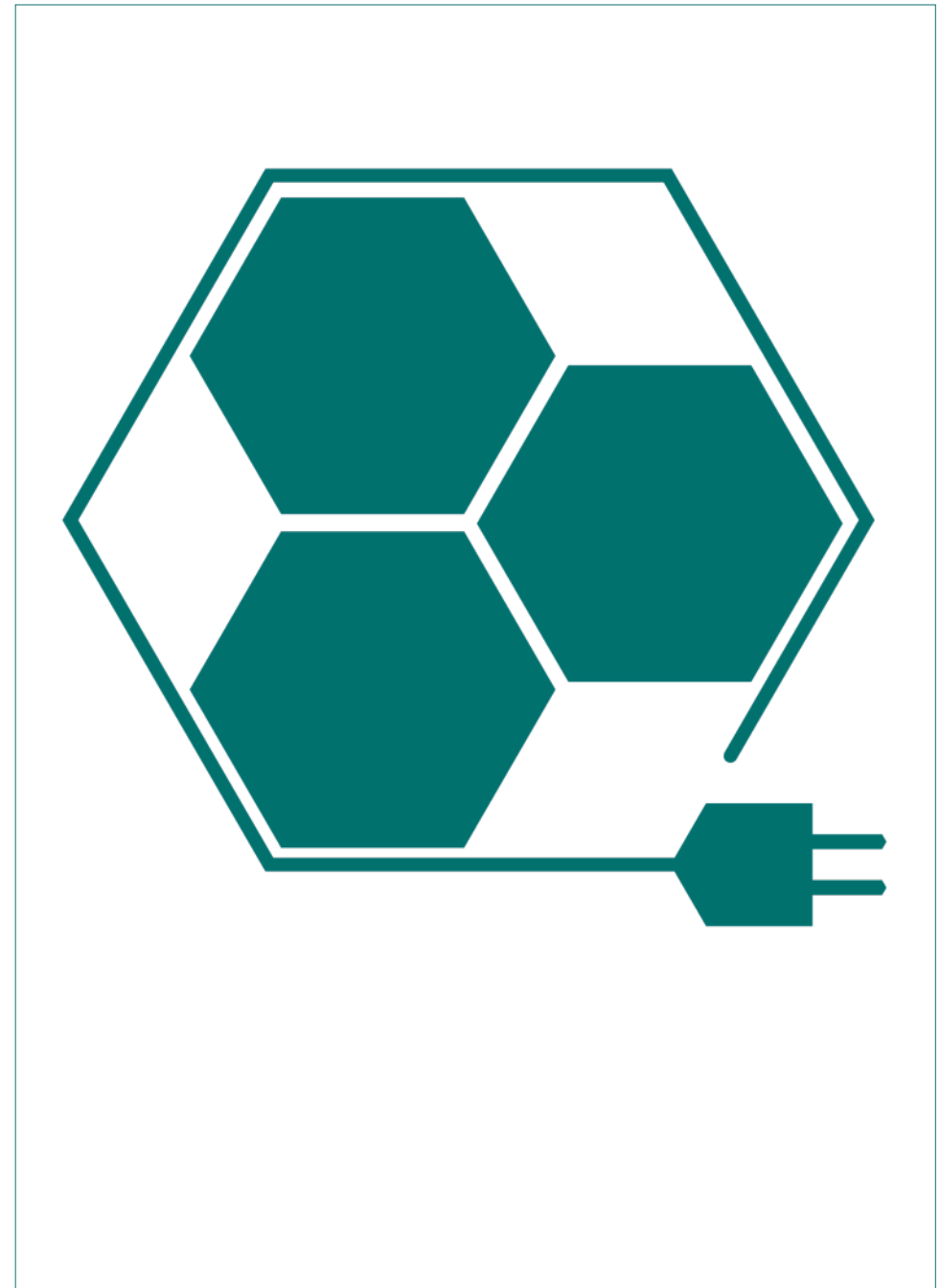
Reference Prototype



photos by Deborah Frost

Controller has 4 Systems

- Control System
- Voltage and current sensing system
- Line power path
- Mechanical support elements of chassis and internal power

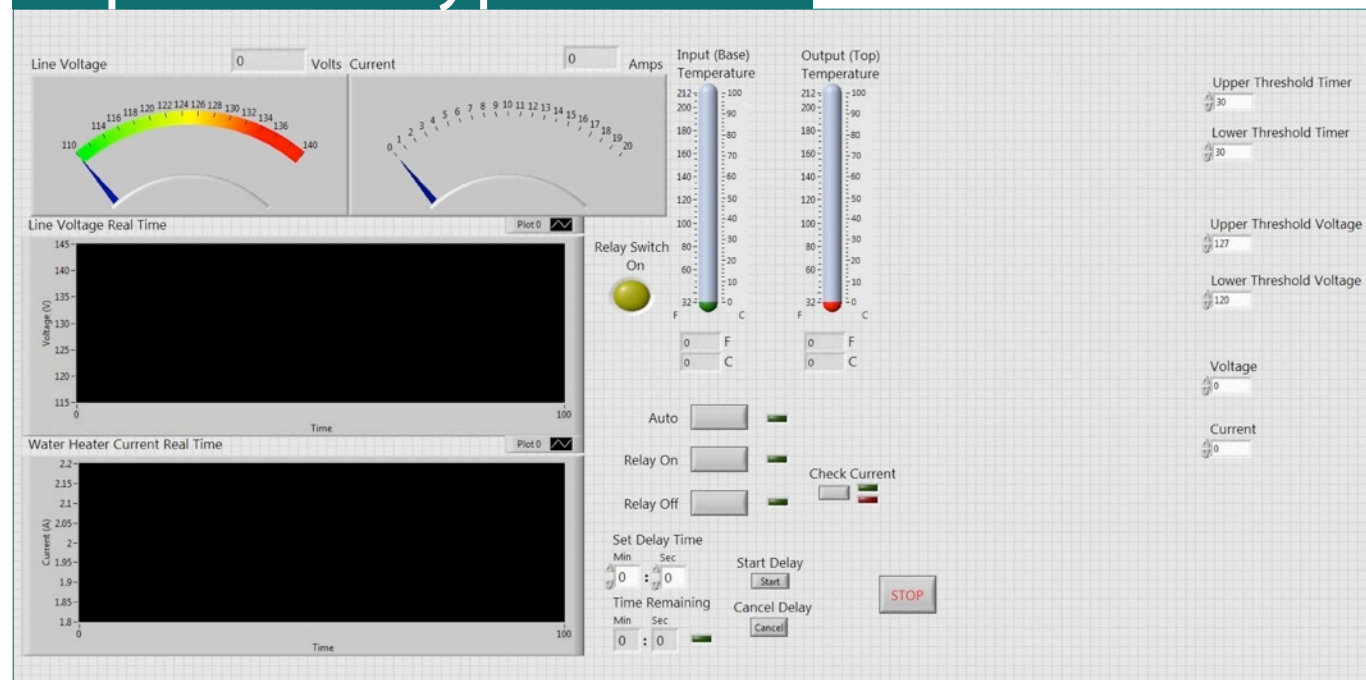


Control System

Requirements

- Automatic Mode
- Manual Mode
- Independent mode
- Wireless communication coordinating with AMI

Rapid Prototype



Reference Prototype



User interface by Andrew Spencer / photo by Deborah Frost

Voltage and Current

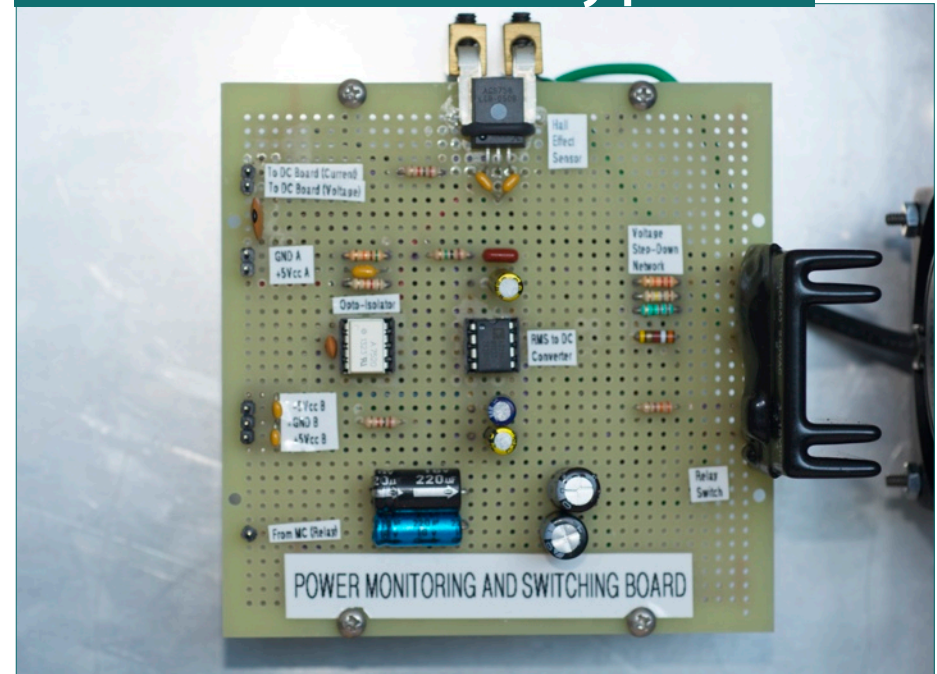
Requirements

- Monitor Voltage
- Heater Element Continuity

Rapid Prototype



Reference Prototype



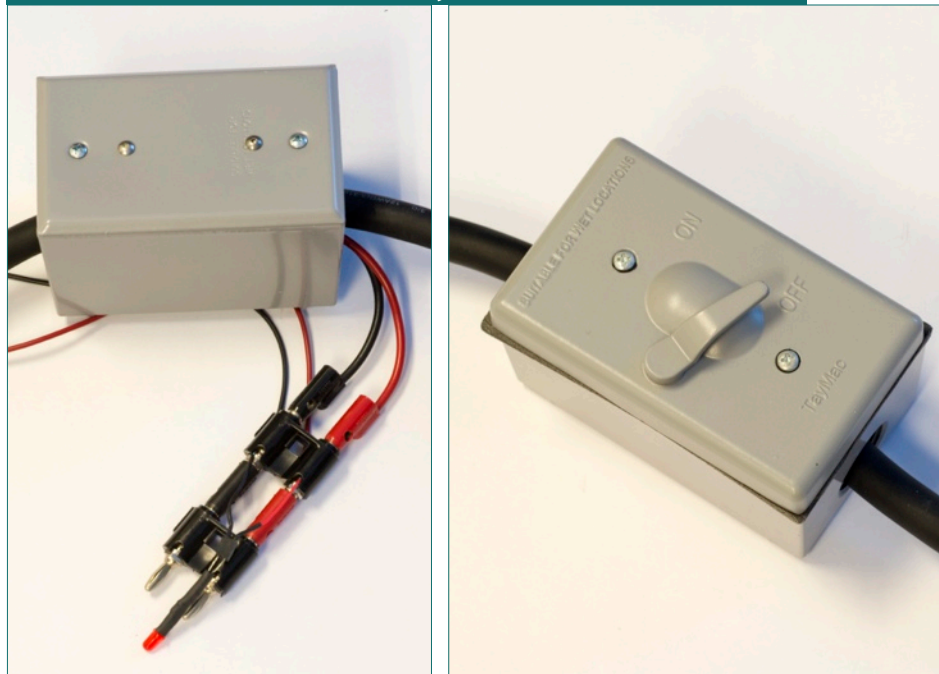
photos by Deborah Frost

Line Power Path

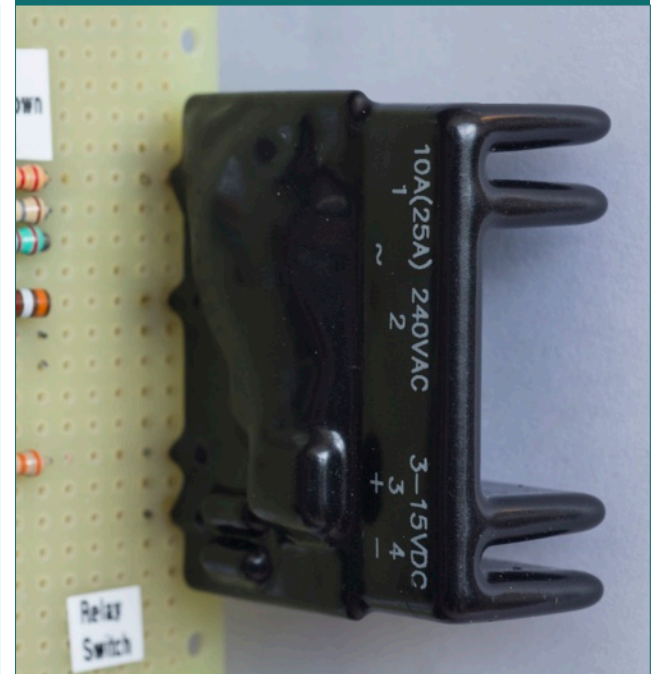
Requirements

- Safety
- Switching of the Load
- Setting Voltage Levels

Rapid Prototype



Reference



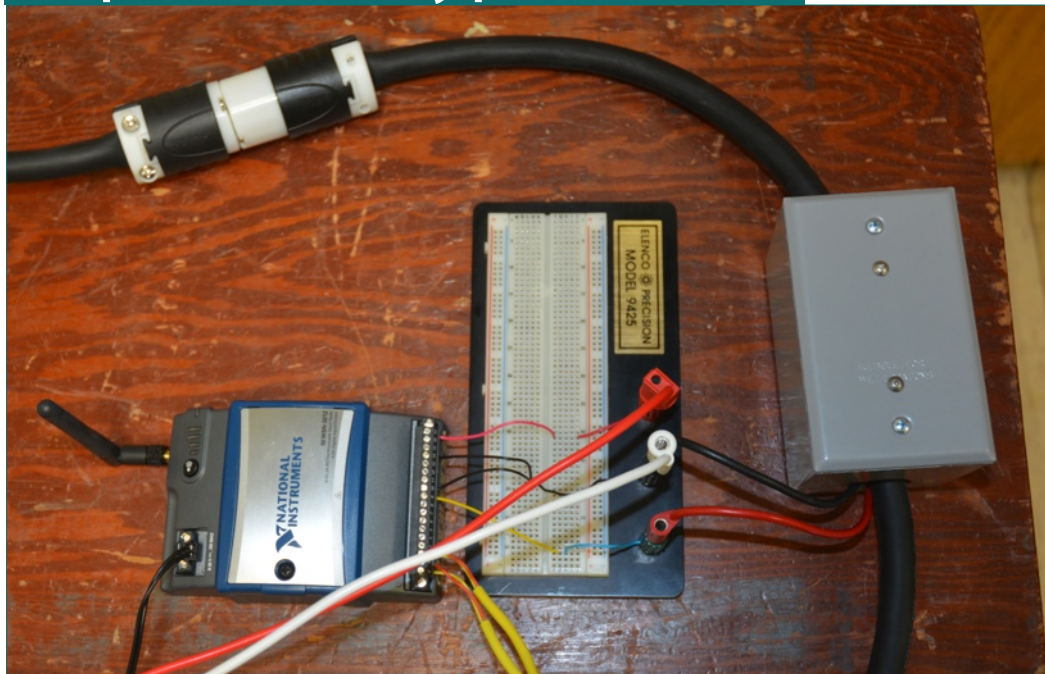
photos by Deborah Frost

Chassis and Internal Power

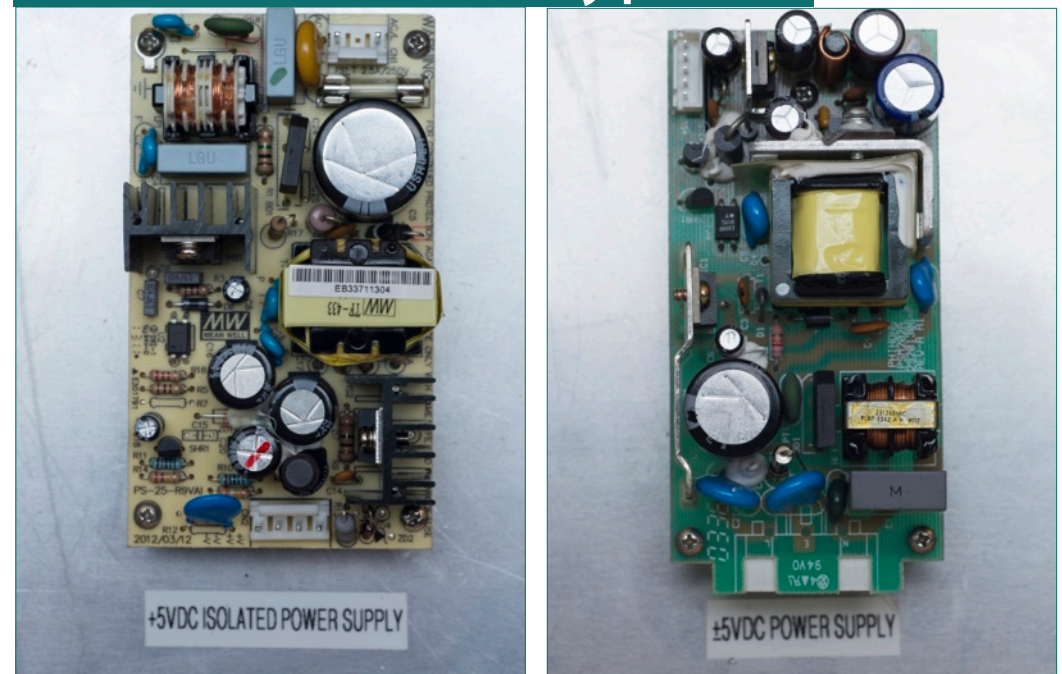
Requirements

- Safety
- System Power Needs

Rapid Prototype



Reference Prototype



photos by Deborah Frost

Test Rig

- Retail Water Heater
- Equipped with Temperature Monitoring Thermocouples
- Functional Plumbing



photo by Deborah Frost

Testing and Analysis

- **Operational Findings**
with rapid prototype
- **Design Findings**
with reference prototype

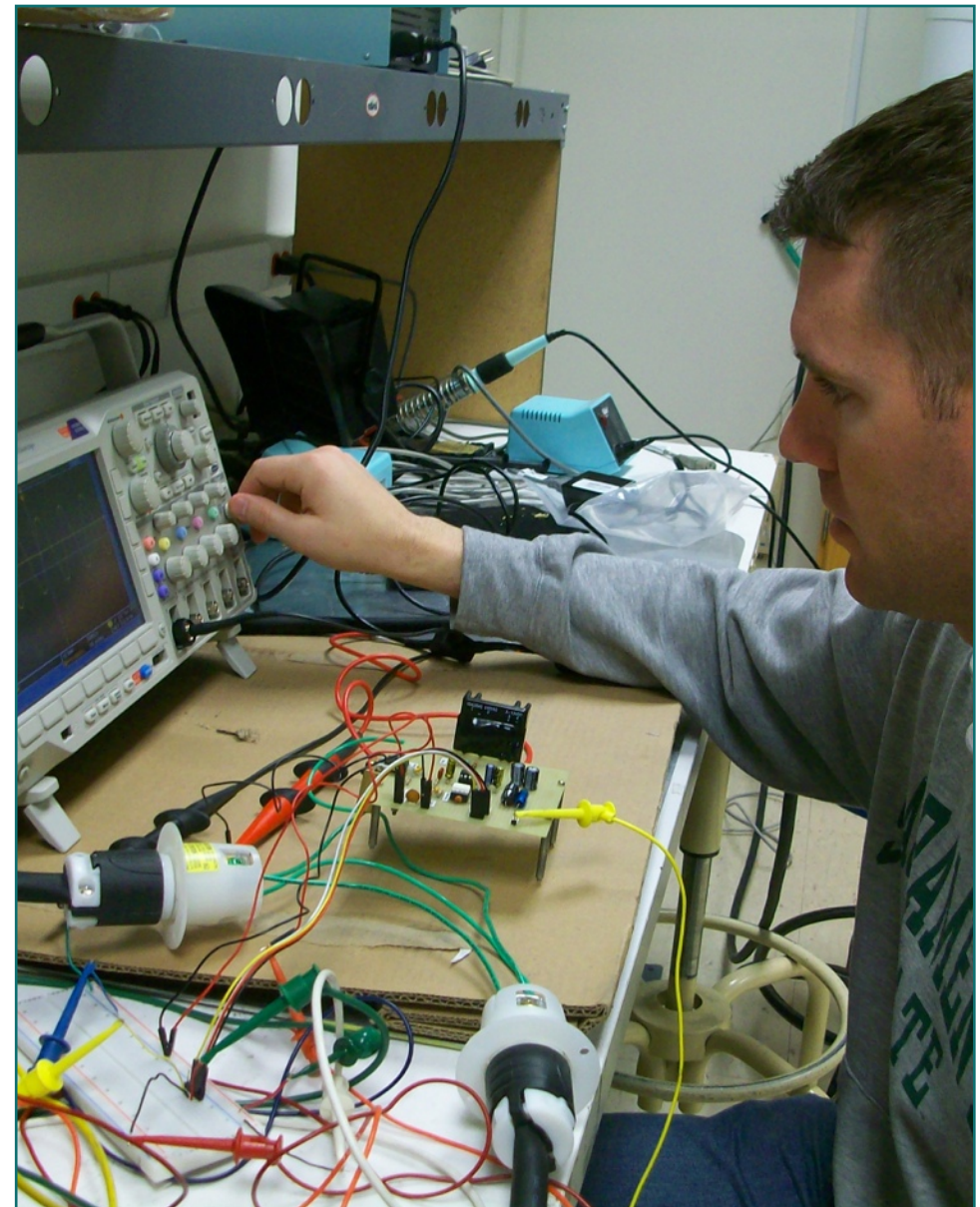
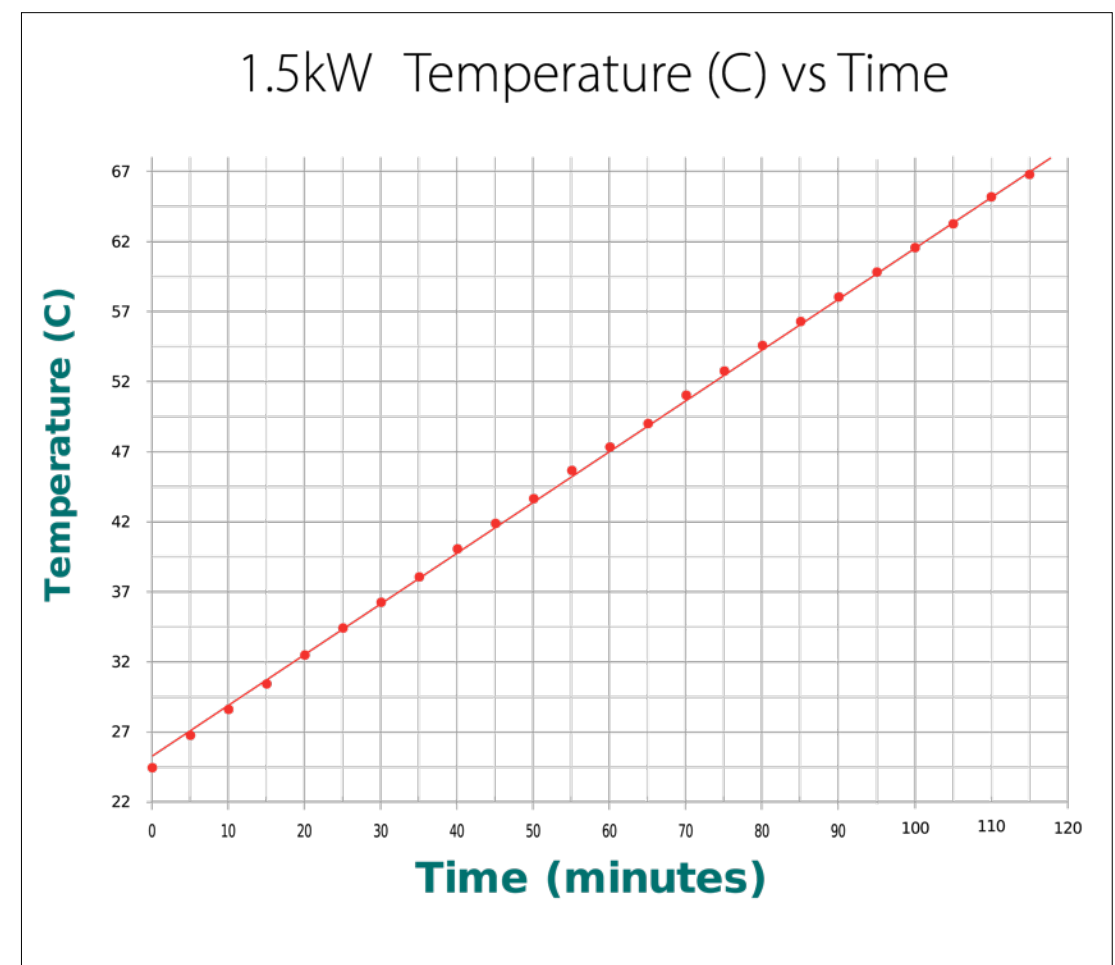
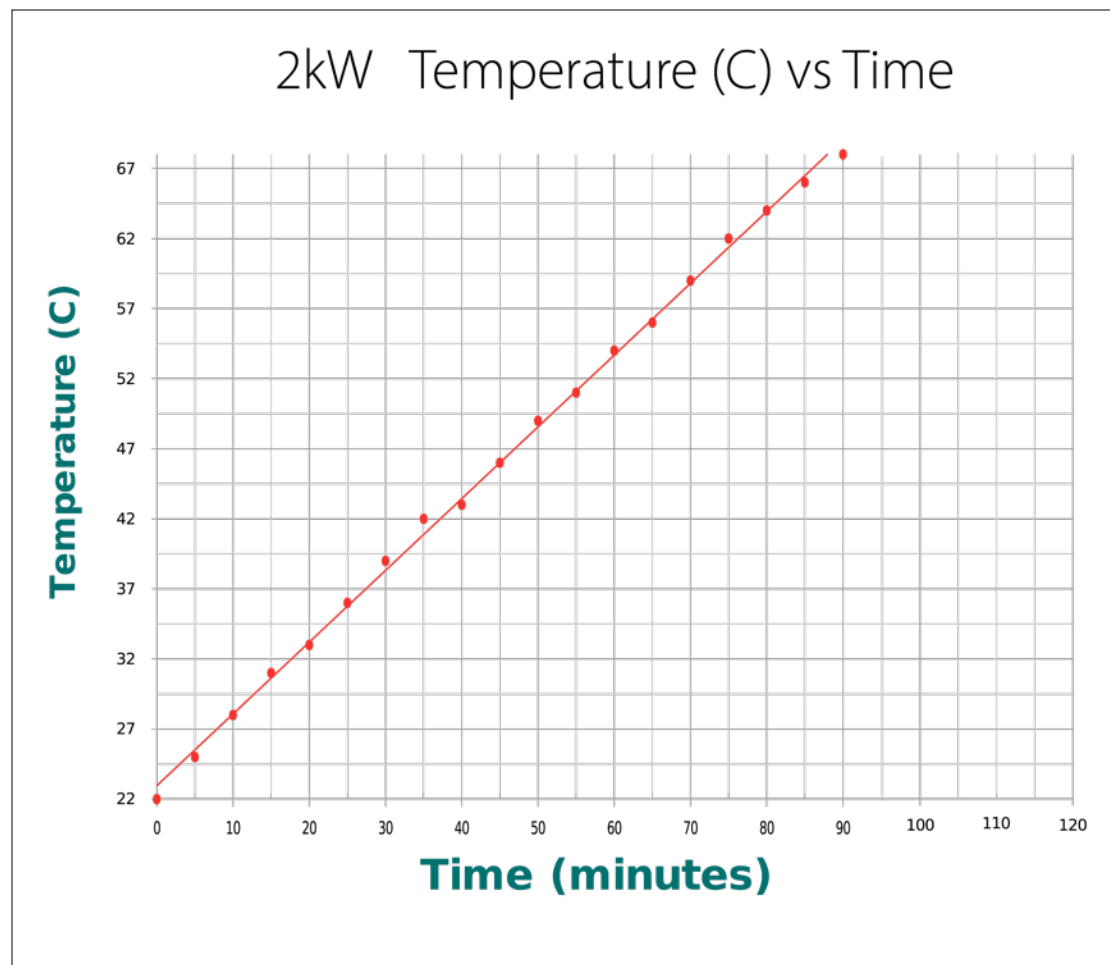


photo by Robert Wortman

Operational Findings

Thermal Characterization of the Heater

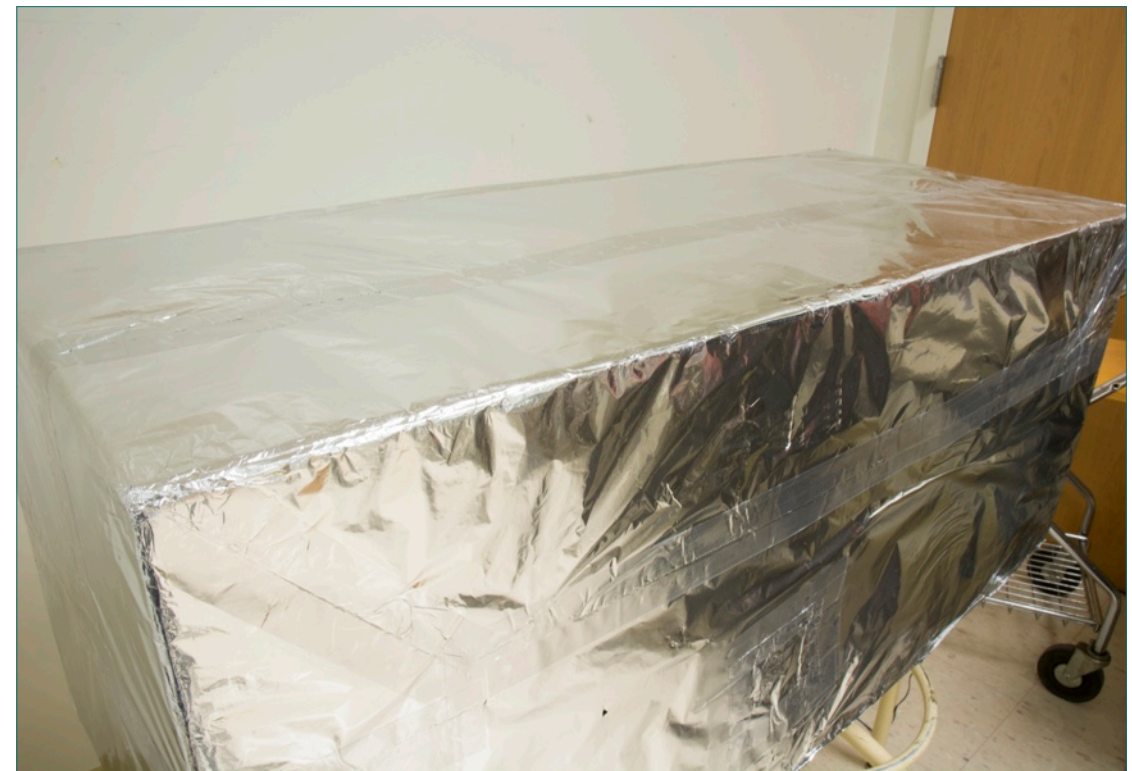
- Functionality of the components
- Water's traditional heating curve still holds true



Operational Findings

Wireless Capabilities

- Severe Interference
- Improvised Shielding

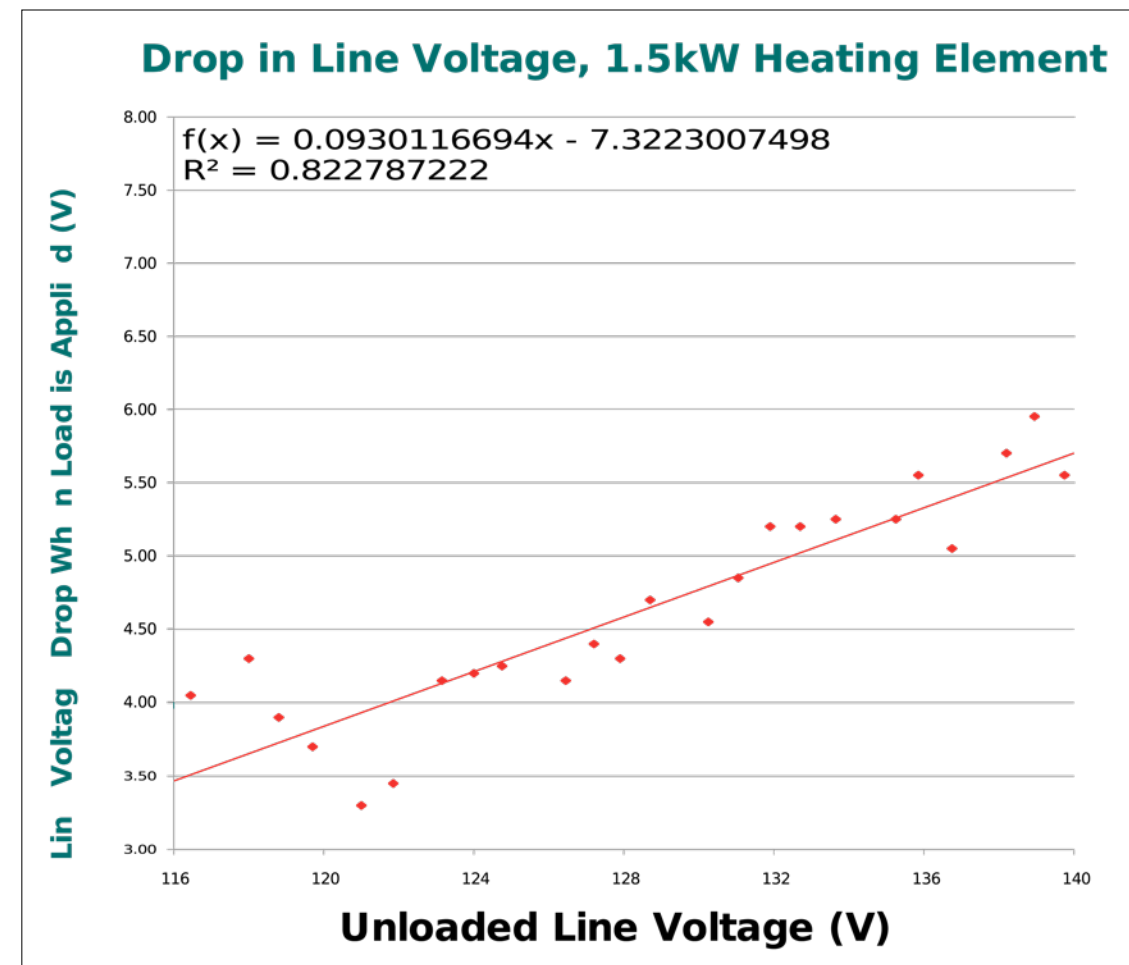
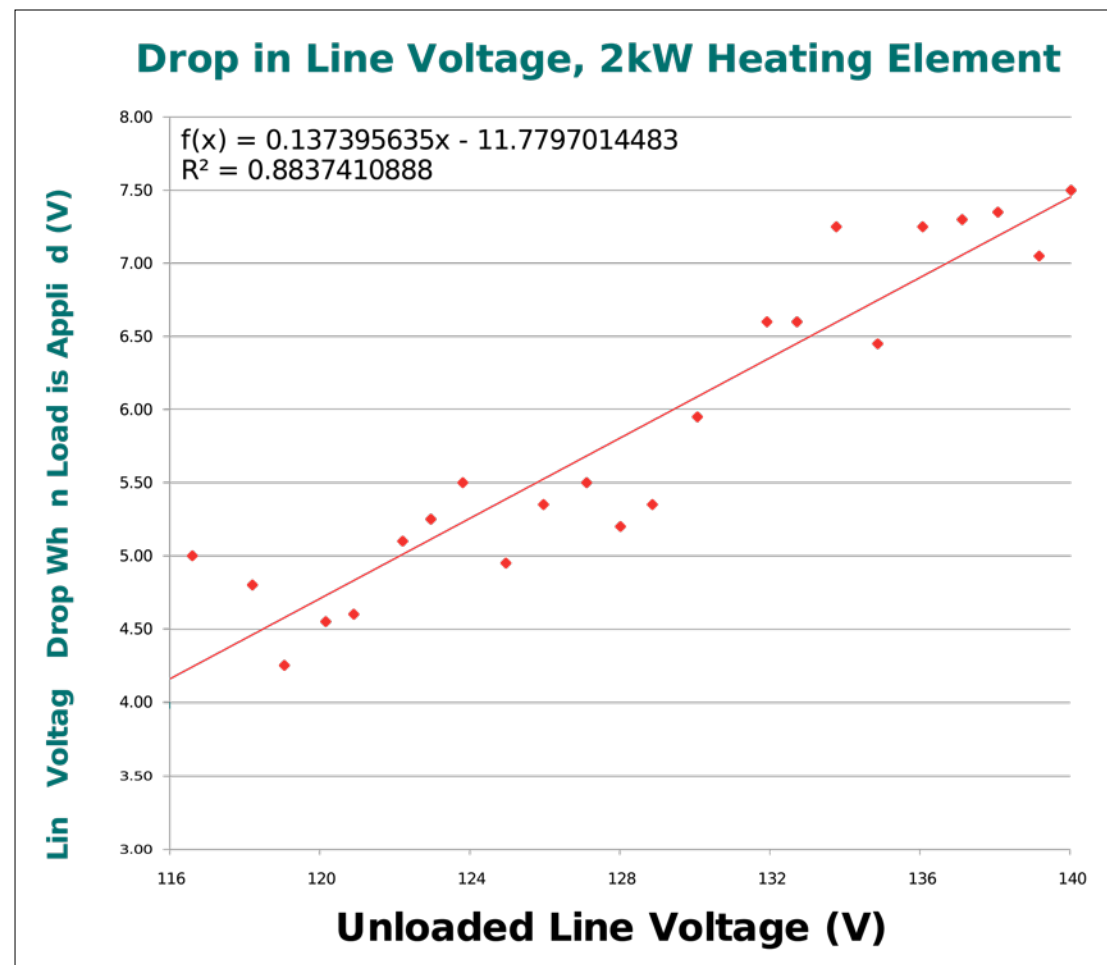


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Operational Findings

Quantitative Test on Change in Voltage

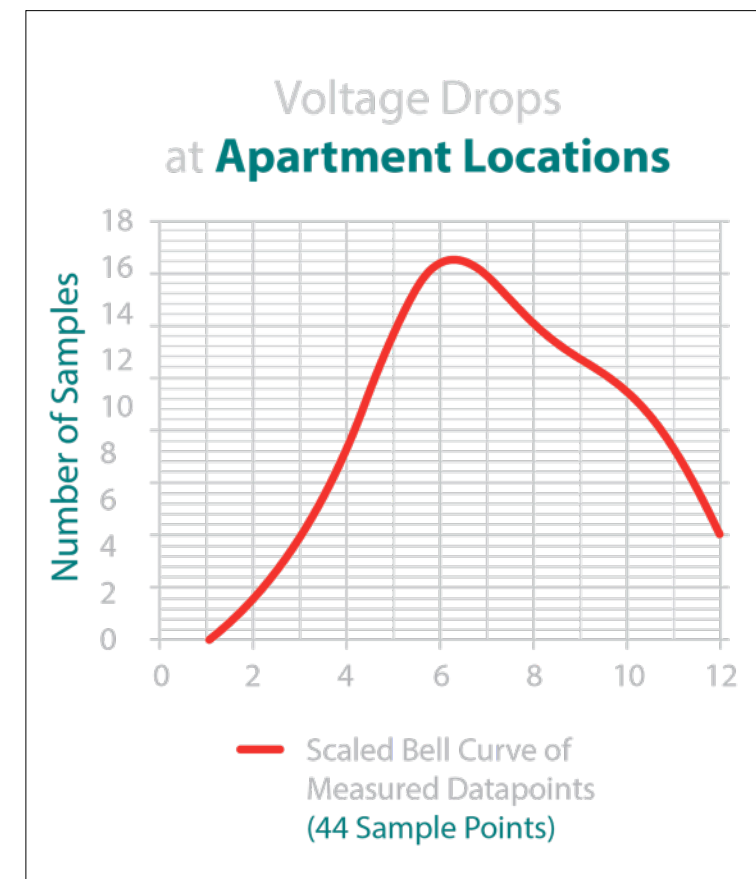
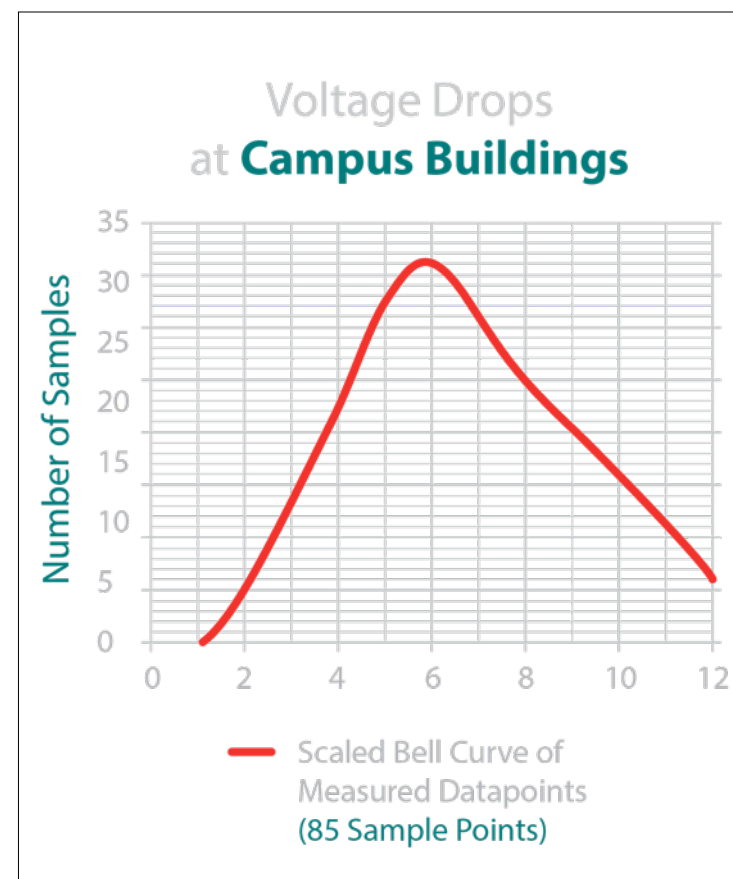
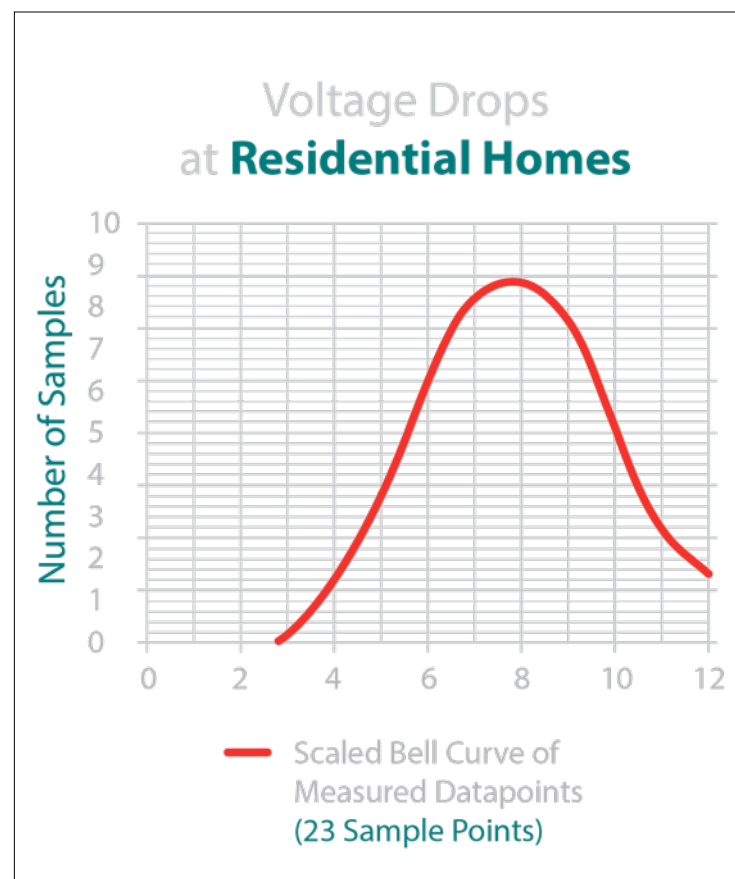
- Varies with Voltage Setpoint
- mostly linear, but erratic



Operational Findings

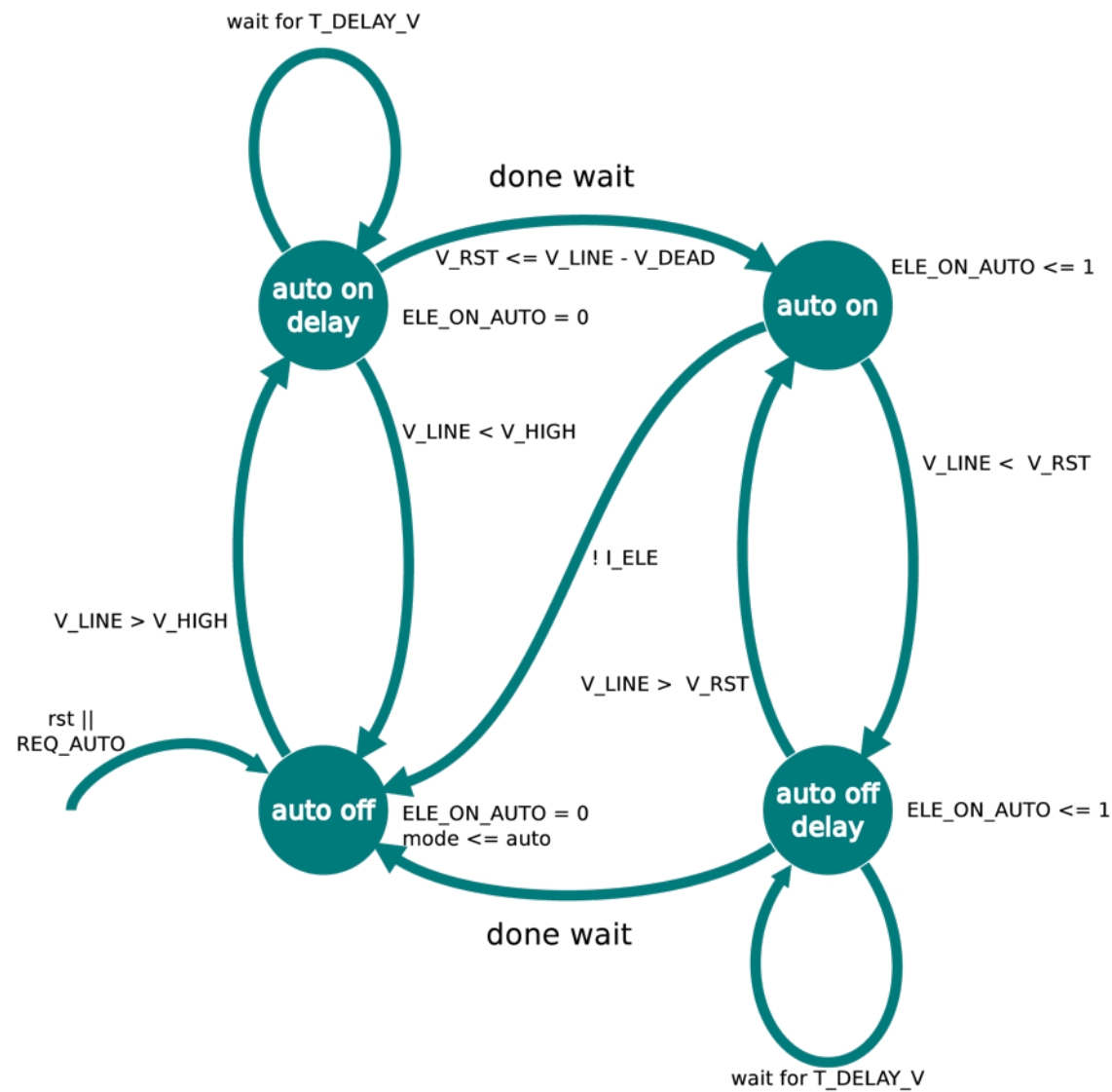
Qualitative Test on Change in Voltage

- Varies with Location
- Statistically normal, but high variance

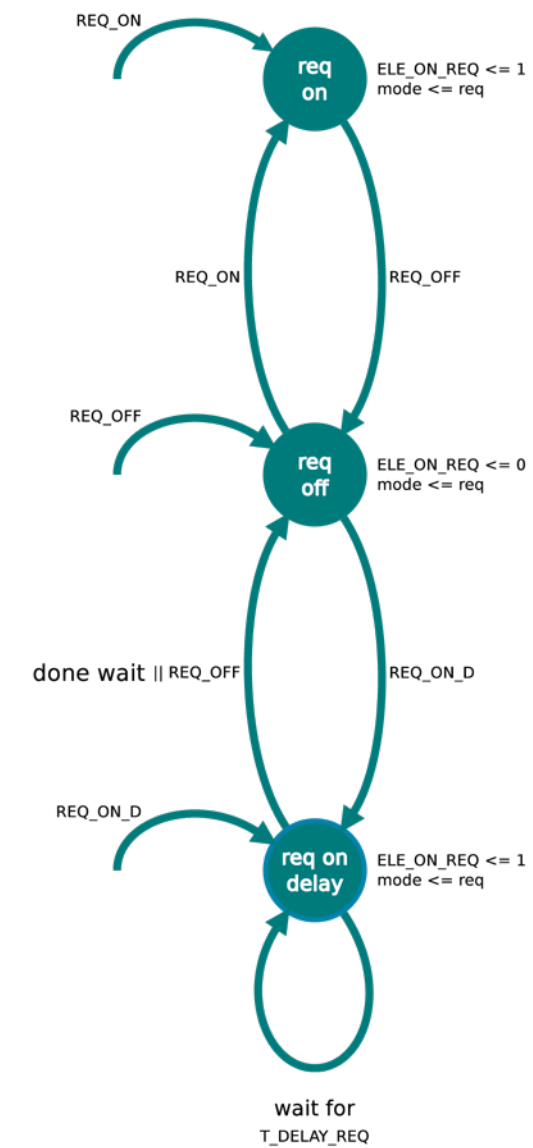


Operational Findings

Automatic

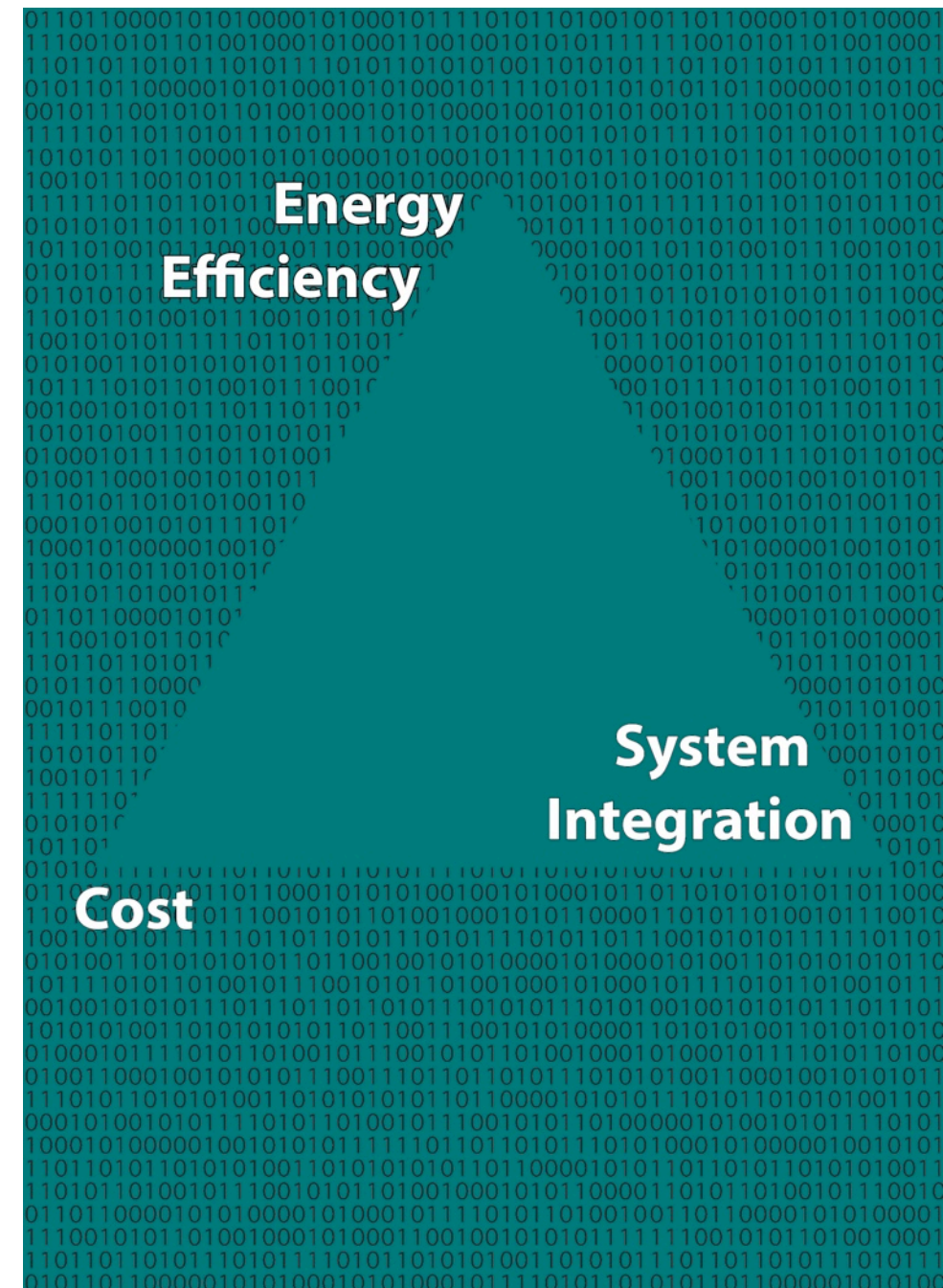


Manual



Design Findings

- Microcontroller
- Voltage Sensing Path
- Power Switching Device



Conclusions

- Mark Jacobson's Road Map
- Anticipating a need for almost 80 GW of residential PV in order for California to become powered completely by renewables



photo by Sacramento Utility District

Acknowledgments

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Without the work of fellow researchers Darrell Cahail, Robert Prior, and Andrew Spencer; the mentorship of Emir Macari and Russ Tatro; and the support of the California Smart Grid Center, this accomplishment would not have been possible.

Thank you

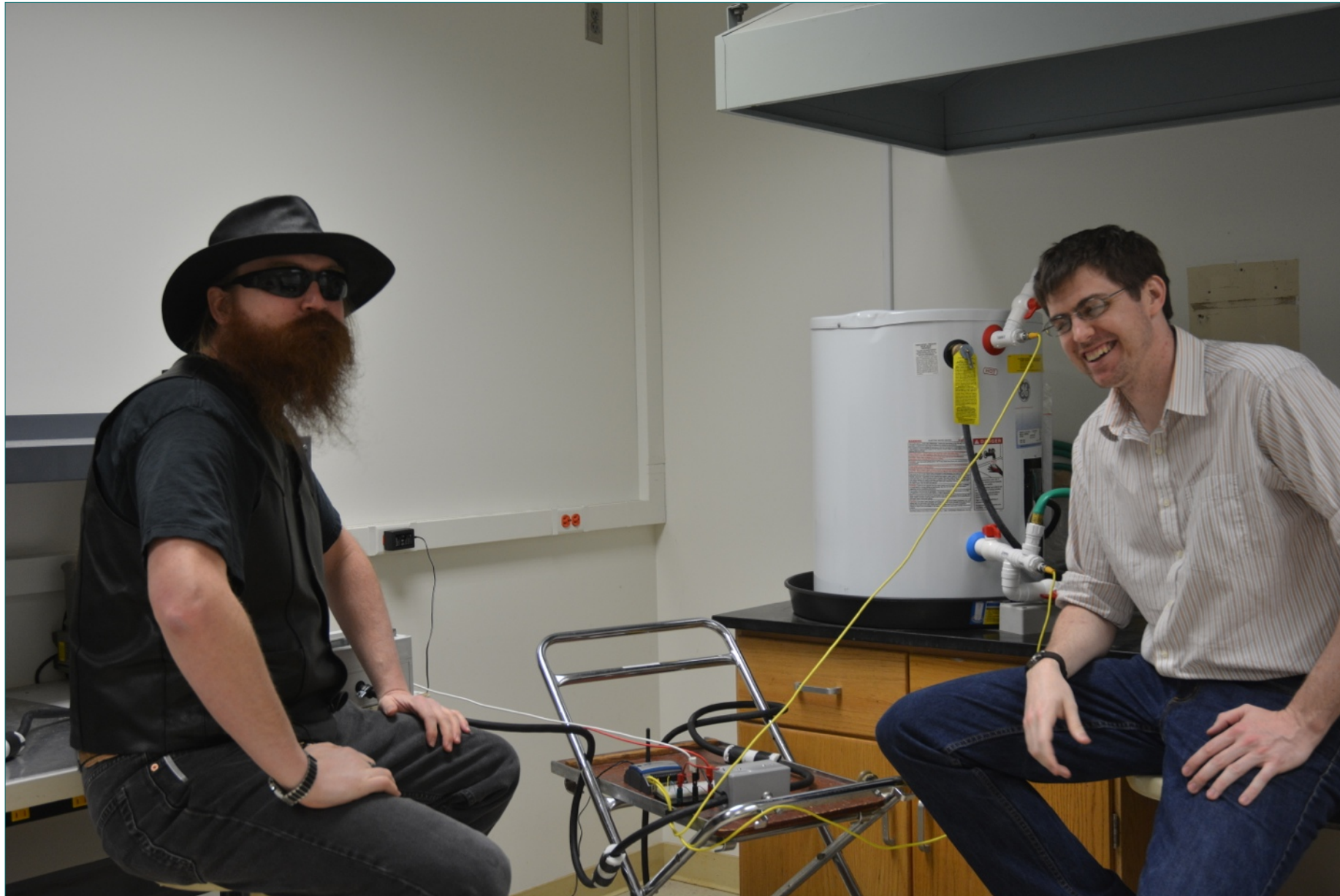


photo by Deborah Frost

What Questions Do You Have?



photo by Deborah Frost