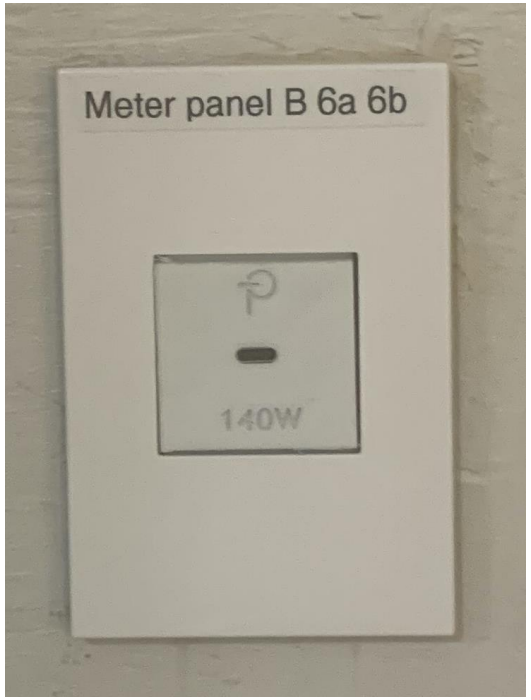
A Behind-the-Wall DC Bus to Power Low-Voltage DC Products



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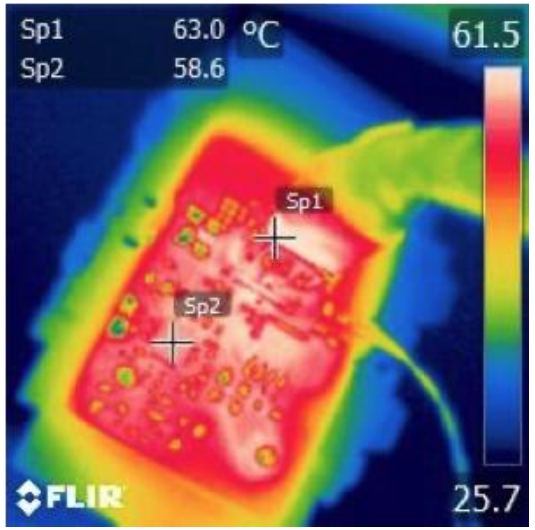
Project Summary

Objective and outcome

- Develop a 240W USB-C receptacle
- Evaluate USB-C as a DC plug-load standard
- Examine potential for ecosystem of USB-C loads
- Study thermal effects of in-wall electronics



Team and Roles

- Power Integrations Inc.
  - Develop and test USB receptacle
- Lawrence Berkeley National Laboratory
  - Conduct analytic, market, and experimental research around USB receptacle

Stats

Performance Period: 9/1/21 – 9/30/23

DOE budget: $500k, Cost Share: $500k

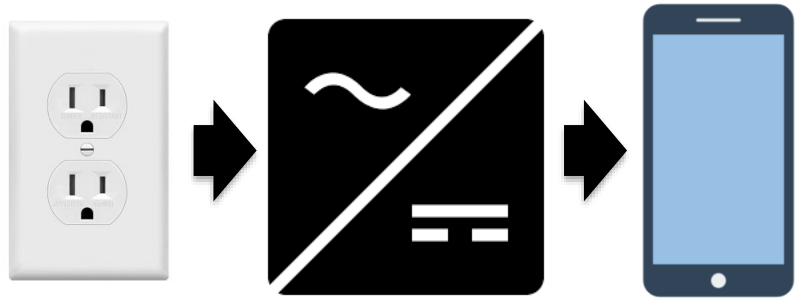
Milestone 1: Groundwork Research – 12/30/22

Milestone 2: Benchtop Experiment – 6/30/23

Milestone 3: Field Experiment – 8/30/23

Problem Statement

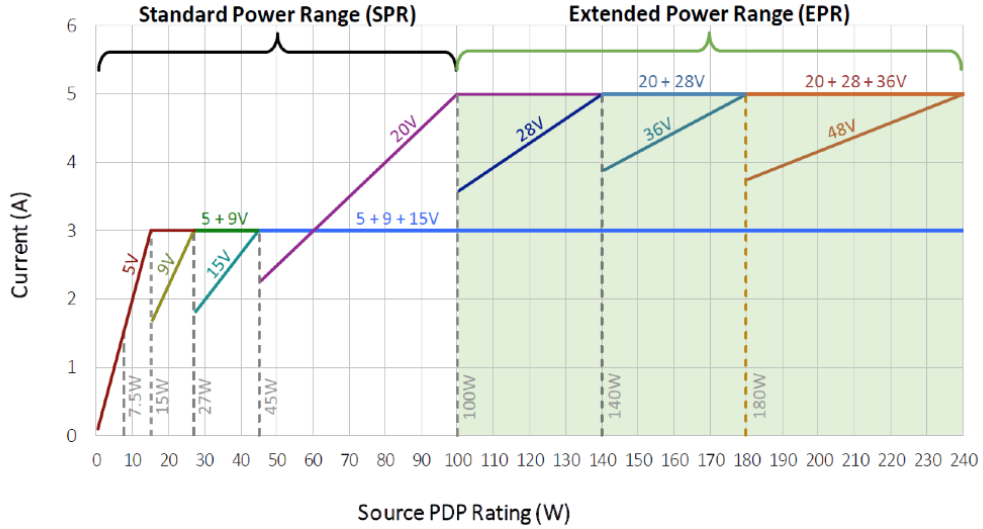
- Average American homes have 24 pieces of electronics[1]
  - $1028 billion consumer electronics market[2]
- Electronic loads are internally DC (direct current), but wall power is AC (alternative current)
- Wall adapters perform AC/DC conversion
  - 88% minimum average efficiency (>50W)[3]
  - 0.2W maximum standby power[3]
  - 500,000 tons of wall adapters discarded annually[4]
  - Wall adapters are annoying!



1. McCue, TJ. 2013. “24 Electronic Products Per Household – Got Recycling?” Forbes
2. Statista: Consumer Electronics – Worldwide
3. Level 6 efficiency standards for wall adapters
4. https://arstechnica.com/science/2017/12/just-20-percent-of-e-waste-is-being-recycled/

Alignment and Impact – Project Goal

- Where should the AC/DC conversion happen?
  - Can we move it upstream?
  - First step toward DC buildings?
- Project Goal: Develop a 240W USB-C receptacle
  - High efficiency, low standby
  - 20+ year life span
  - Opportunities for demand response
- Evaluate USB-C as a universal DC plug-load standard
- Examine potential ecosystem for USB-C plug loads (<240W)
- Study thermal effects of in-wall power electronics



NEMA 5-15 receptacle

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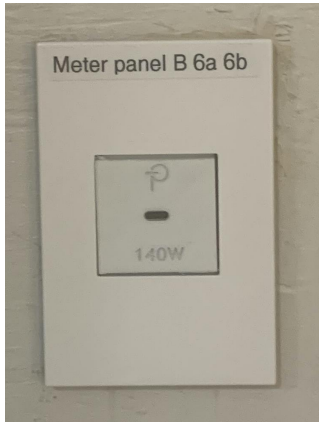

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Alignment and Impact – BTO Goals

- BTO Goal: Greenhouse gas emissions reductions
  - 3-8% increase in efficiency per plug load
  - Decrease in national consumption at scale
    - 0.7-2% due to increased efficiency
    - 0.5-1% due to reduced standby consumption

- BTO Goal: Power system decarbonization
  - Renewable integration in DC buildings
  - Opportunities for load shifting and demand response

- BTO Goal: Energy justice
  - USB-C receptacle improves life cycle cost over wall adapter
  - Touch safe
  - Reduce waste

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

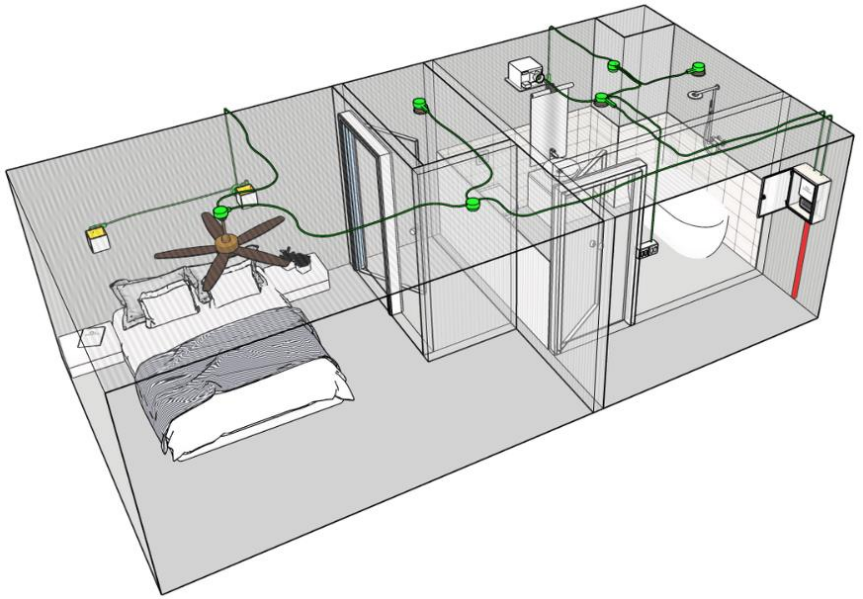
Energy justice

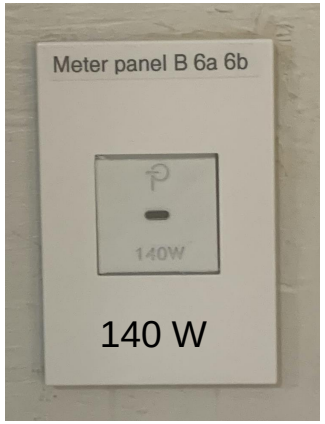
40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

Approach – Current Solutions for Upstream Conversion

How is the problem being addressed today and where do current solutions fall short?

- Hybrid buildings with hard-wired DC loads
  - Lighting and fans on low power DC circuit, everything else AC
  - DC microgrid for solar, storage, and EV charging
  - Good first step, but no plug loads
  - Higher equipment cost, though maybe offset by lower installation cost
- For plug loads, need a ubiquitous DC plug format
  - Power over Ethernet – Cat5 is expensive, only allows up to 100W
  - Safe-D-Grid – 600V 40A: great for appliances but overkill for electronics
- USB-C
  - Already widely popular for electronics
  - Today's USB receptacles are only 15W





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240 W

Approach – Our Approach and Plan

What is novel and promising about the approach taken in this project? What is the plan to deliver intended outcomes?

- Everybody already loves the USB ecosystem. Let's make it better!
- A 240W USB receptacle:
  - Enables numerous opportunities for new USB loads
  - Allows customers to ditch the wall adapter
  - Seduces customers with the concept of USB plug loads
- Eventually… replace customer's NEMA 5-15 loads

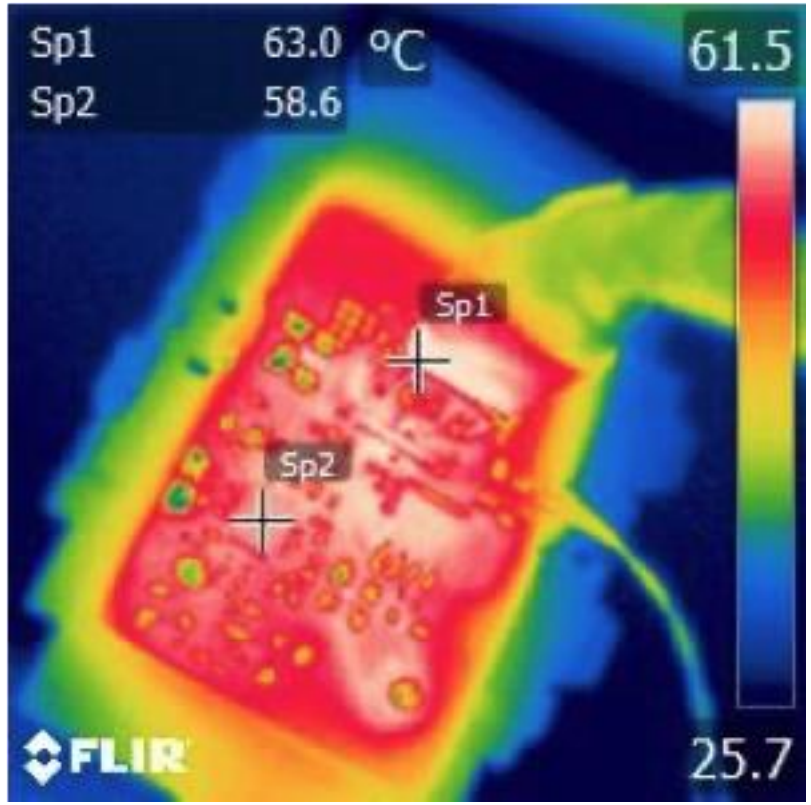
- Power Integrations will develop the receptacle, LBNL will explore the market opportunities
  - USB-C market research, customer discovery interviews
  - List of recommended USB-C plug loads up to 240W
  - Analyze efficiency and cost benefits of receptacle
  - Benchtop testing to determine thermal consequences of internal loss in a wall section
  - Field test to evaluate product usage in a home

Approach – Risks and Mitigation

What are the barriers, technical challenges, and project risks?

What mitigation strategies are in place?

- Technical Risk: Impossible to fit a 240 W power supply in a 2x4” receptacle box
  - Mitigation: Power Integrations will initially design a 140 W receptacle. They will later upgrade it to 240 W
- Technical Risk: Receptacle cannot dissipate enough heat when in a wall – 5% loss -> 12W. Potential temperature and fire risk
  - Mitigation: Power Integrations and LBNL will do extensive thermal testing to determine the heat dissipation capabilities. Later designs can include improved heat sinking to the face plate if deemed necessary



Approach – Commercialization and Validation

How will you commercialize, transform the market, address a barrier, and/or engage stakeholders, if any? How will the expected benefit be demonstrated/validated?

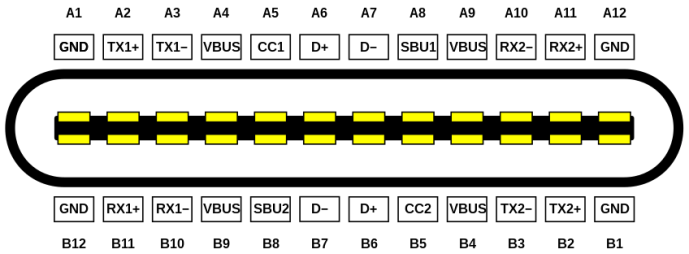
- Commercialization strategy
  - Power Integrations intends to sell the USB-C receptacle
  - LBNL's groundwork research can guide their market strategy
  - Multiple DC vendors, electricians, and developers have been engaged in this study and are excited about the eventual product. Further effort will be needed to engage load manufacturers to develop USB-C loads
- Short-term validation of USB-C receptacle
  - Lab testing on efficiency
  - Analysis on cost
- Long-term validation of impact on market and DC industry
  - Adoption of receptacle by building developers and DC companies
  - Customer and product transition toward USB-C
  - Eventually: the complete replacement of NEMA 5-15?

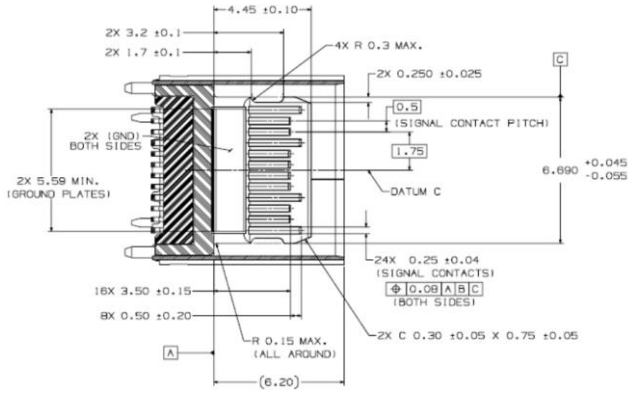
Progress – Market Study

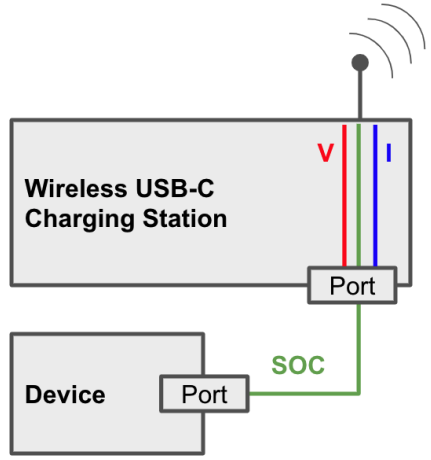
- Major accomplishments, tasks, and deliverables
  - Customer discovery interviews of developers, electricians, safety gurus, DC experts, USB engineers
  - Analysis and list of plug loads that could adopt 240W USB-C
- Unexpected issues - none
- Lessons learned – interviews
  - NEC currently requires AC outlet every 12 feet (6 in kitchens)
  - Electrolytic capacitors may limit USB receptacle life span
  - Internal temperature may be an issue; may need shut-off thermistor and face-plate heat sink
  - Recommends go to market immediately. Differing opinions on optimizing for size vs compatibility
  - Receptacle could enable demand response and/or distributed storage
- Lessons learned – load list
  - 6 plug loads already have USB-C – mostly electronics
  - 38 plug loads could take 240W USB-C – many devices have a wide power range
  - 16 plug loads require higher power – mostly kitchen, but also vacuum, hair dryer, and random others
  - Overall, DC buildings will likely need 380V receptacles, particularly in kitchen

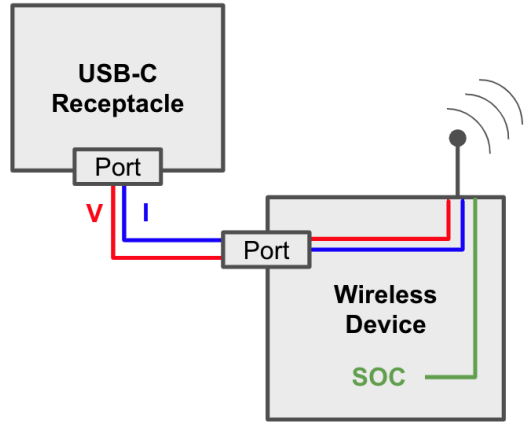
Progress – Protocol Exploration

- Major accomplishments, tasks, and deliverables
  - Documented USB-C standard, particularly involving high-power modes
  - Created wish list of future additions to standard
- Unexpected issues - none
- Lessons learned
  - Explored how the receptacle could enable:
  - Energy reporting – communication paths between receptacle and devices
  - Demand response – command power port to curtail



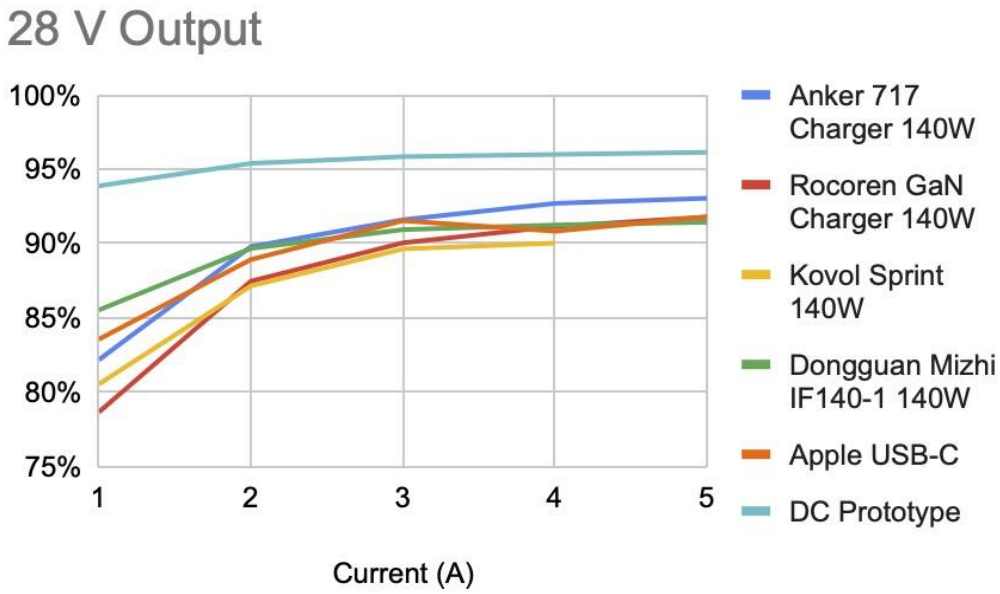






Progress – Efficiency and Cost Analysis

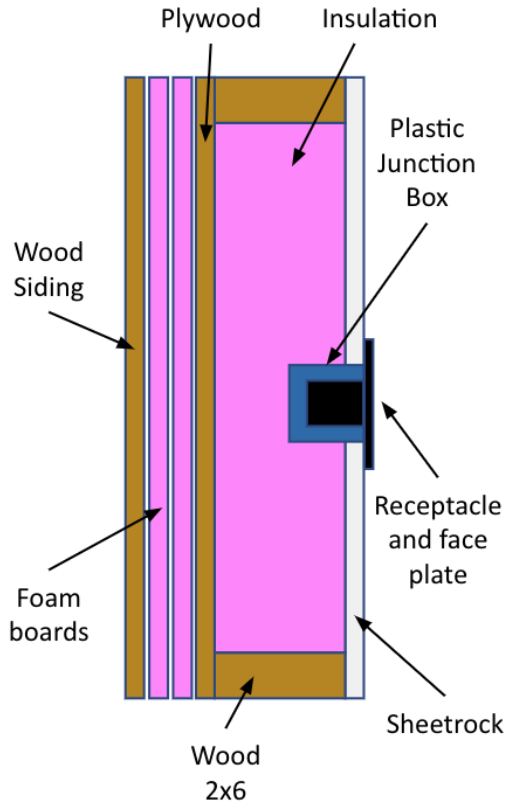
- Major accomplishments, tasks, and deliverables
  - Analyzed and compared losses and efficiency to wall adapters
  - Analyzed and compared cost to wall adapters
- Unexpected issues - none
- Lessons learned - Efficiency
  - 10.97% average efficiency over all operating points
  - Receptacle could save 0.7% residential energy (23.6 TWh/yr)
- Lessons learned – Cost
  - Receptacle expected market entry: $94.40
  - Medium equivalent AC adapter: $99.00
  - Receptacle estimated mature market: $31.35
  - Mature market cost: 50% more than GFCI but still less than AC adapter

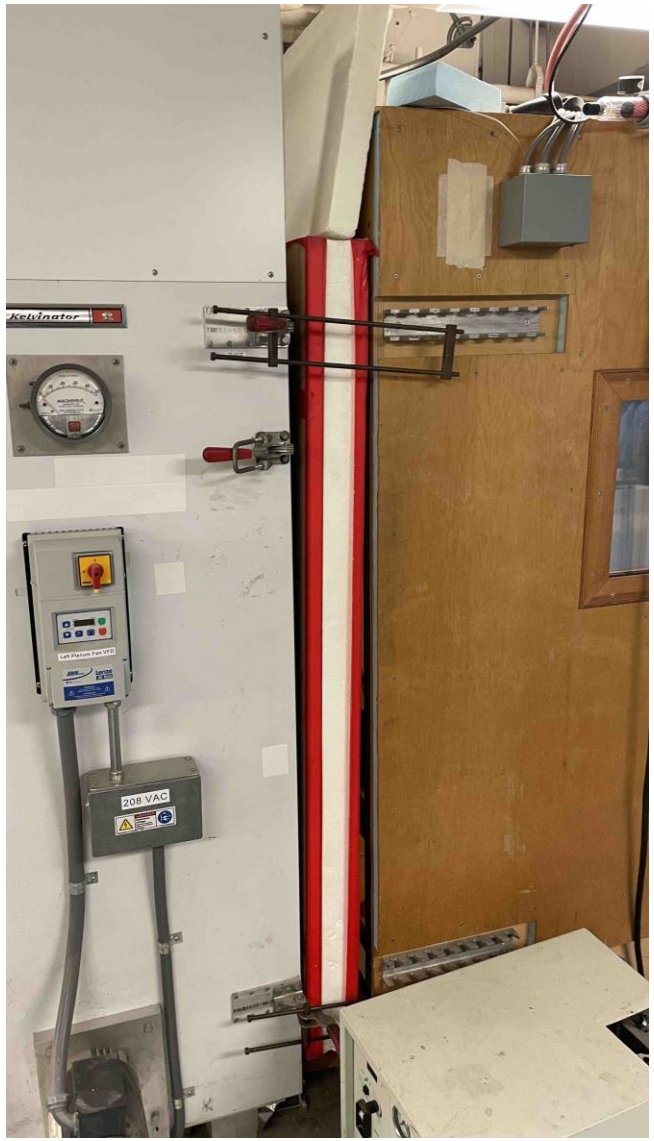


AC adapter Maximum Port Power (W)	Median Cost (USD)
100 (20 V, 5 A)	$77
140 (28 V, 5 A)	$99
240 (48 V, 5 A)	$140

Future Work – Benchtop Experiment

- Investigate the thermal effects due to electrical losses in the receptacle
- Setup
  - Build a Title 24 compliant wall section with the receptacle
  - Use temperature probes and heat flux sensors to measure thermal effects
  - Use a thermal double chamber to regulate external temperature
- Questions
  - What is the internal steady state temperature?
  - Does it overheat or melt?
  - Where and how is the heat dissipated?
- Bigger picture – What does this imply about power electronics behind the wall in general?





Future Work – Field Testing

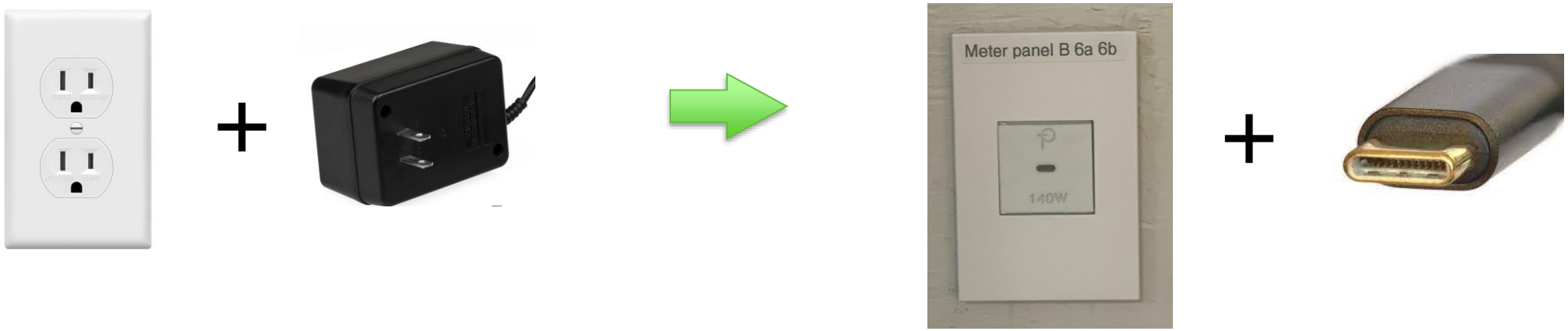
- Study how the USB-C receptacle is used in a home
- Sites
  - Duke Energy DC Home
  - Residence TBD
- Document load profiles and connected loads
- Bigger picture
  - Attempt to understand how and when customers would use the receptacle
  - Load profiles useful for future demand response or distributed storage studies

- Plans beyond end of project
  - Power Integrations will go to market with the receptacle
  - LBNL will connect them with the appropriate developers and load manufacturers to develop the USB-C ecosystem

So… where should the AC/DC conversion occur?

- We still don't have a definitive answer
- Evaluated one solution: moving it to the receptacle
- Thus far, feasibility results are promising

- *AC/DC conversion at the receptacle makes sense!*
  - *…once more loads adopt 240W USB-C input*



Thank You

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