Carnegie Mellon University

How much electricity can we save by using direct current circuits in homes?

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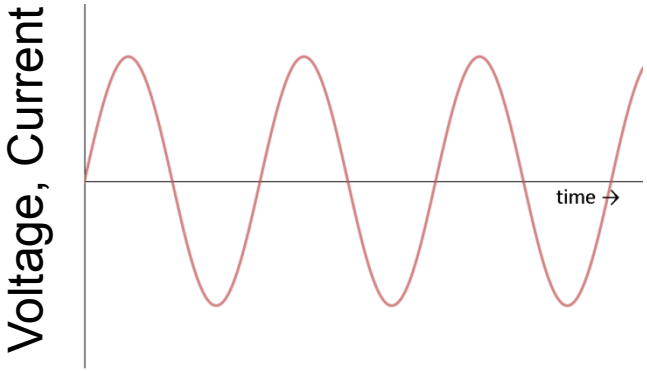
What is Direct Current?

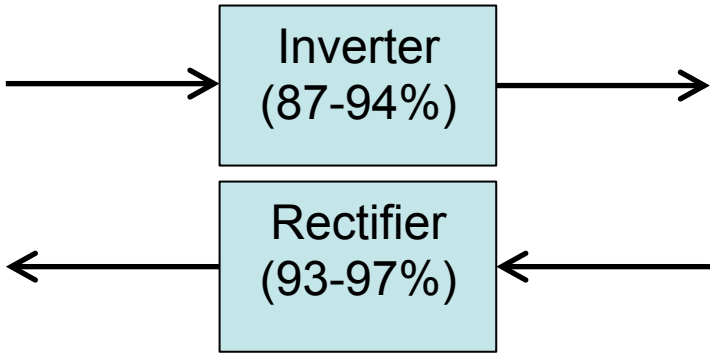
- Direct Current (DC)

- Batteries, digital circuits

- Alternating Current (AC)



- Nearly all grid electricity
- All distributed electricity



Overview

Goal

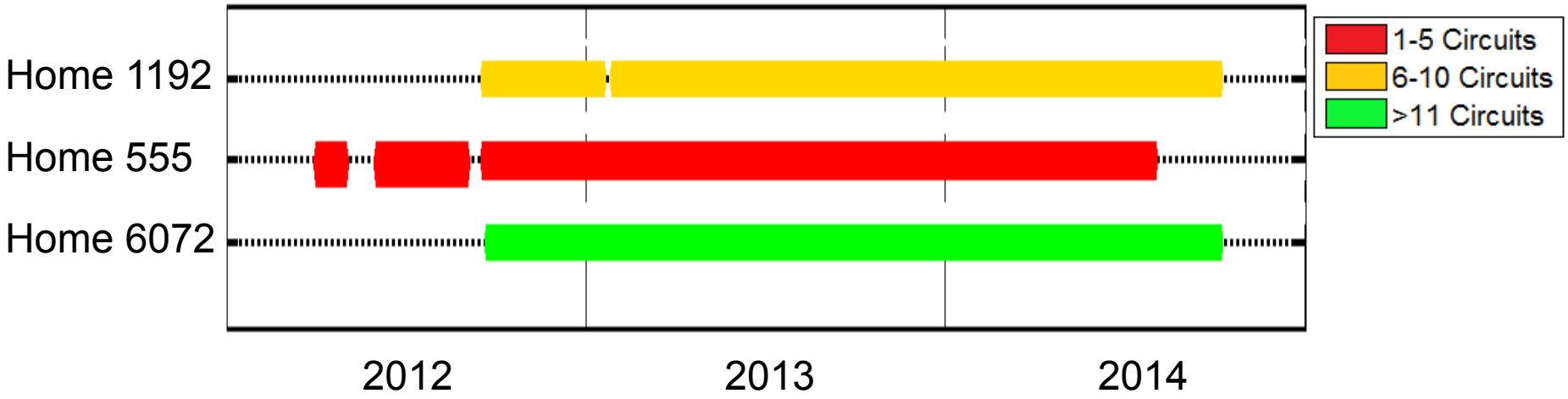
- Assess the technical energy and economic savings of a transition to DC-powered homes…
- …using a unique dataset of actual home load data submetered in Austin, TX

Why DC?

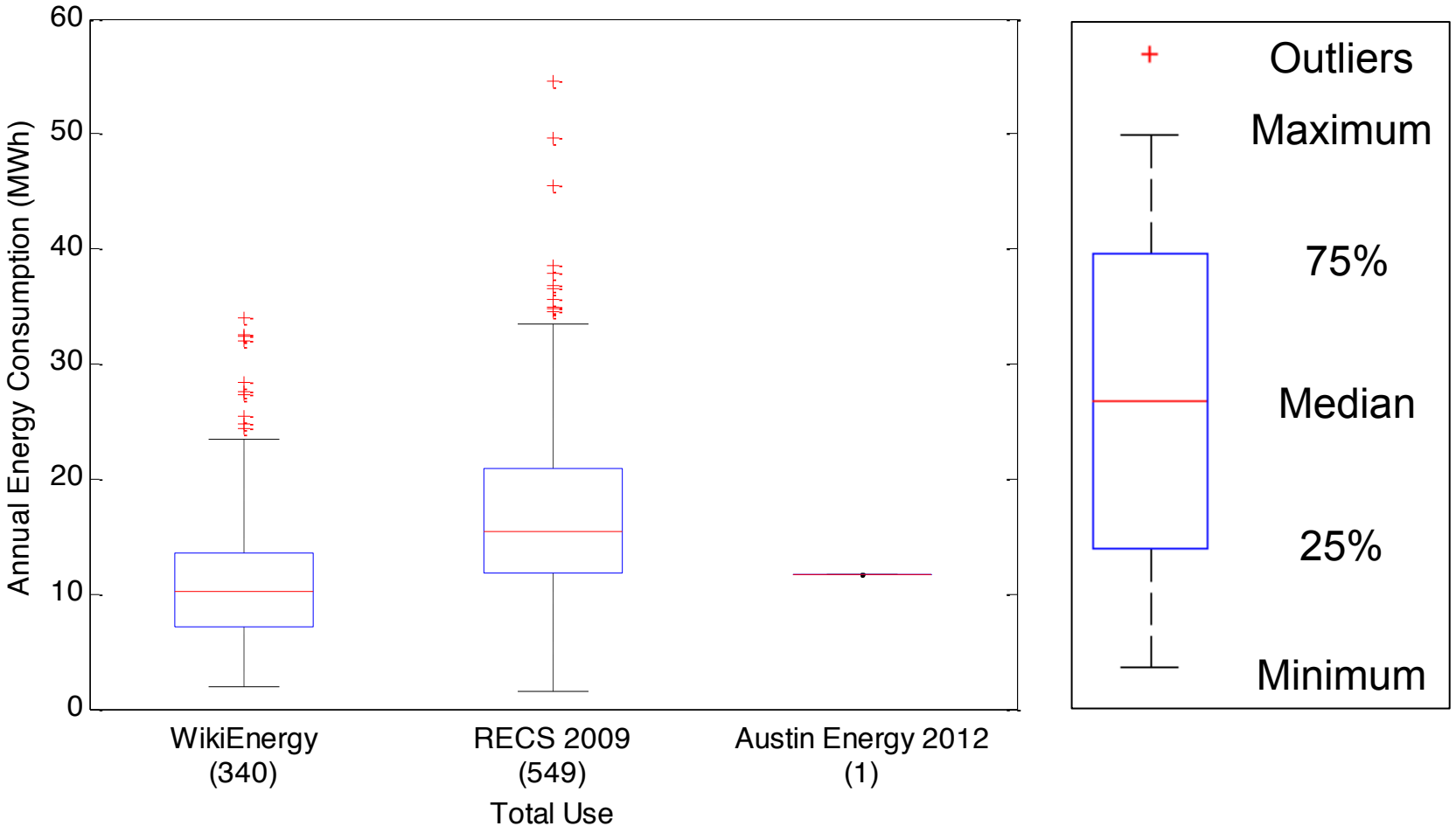
- Semiconductor-based power electronic DC-DC converters
- Consistent growth in distributed generation sources that generate DC
- Growing fraction of DC use in buildings
  - CFL and LED lighting
  - All consumer electronics
  - Variable speed motors

Monitored Load Data

- Provided by the Pecan Street Research Institute
  - Sample contains ~700 volunteer homes monitored at 1-minute intervals (aggregated to 15-minute)
    - Whole-home-, circuit- and appliance level
    - Survey results, audit records, intervention records, etc.
  - Monitoring from January 2012 through present
  - Homeowners work with Pecan Street to choose which appliances/ circuits to monitor
  - Gantt charts used to show data quality and availability across time



Data Validation



- RECS sample filters – single-family, detached homes in Texas with central AC

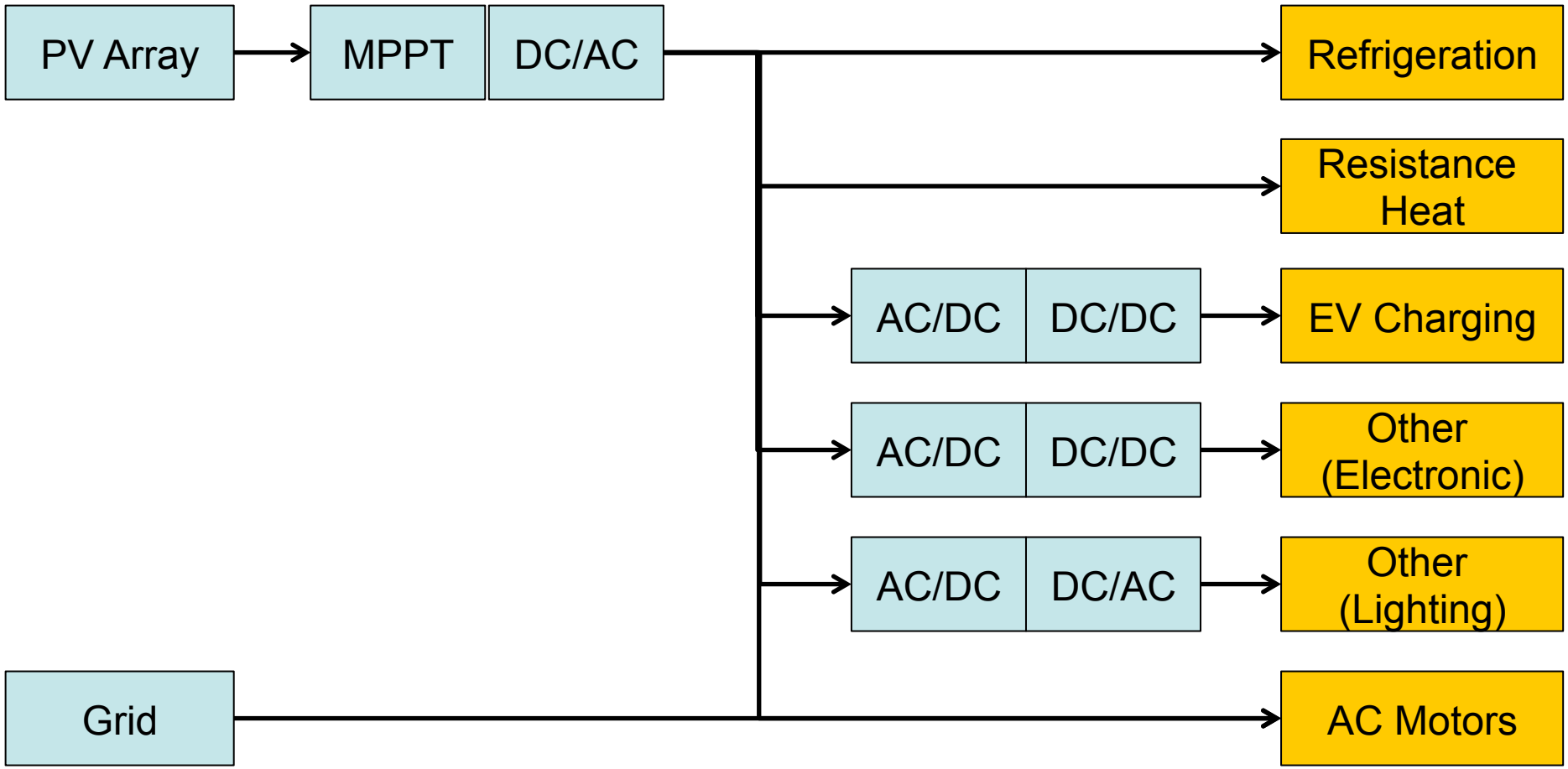
Appliance Classification

Existing Load	Appliances	% of Sample Home Use	% of RECS Use
Resistance Heating	Oven, range, electric clothes dryer, dishwasher, electric water heater	5%	13%
EV Charging	Electric vehicle charging	11%	0%
Other (electronics)	All electronics, plug loads, lighting	34%	41%
AC Motors	Kitchen disposal, clothes washer, central air supply fan, gas clothes dryer, vent hood fan	15%	5%
Refrigeration	Air conditioning condensing unit, refrigerator, freezer, wine cooler	35%	41%

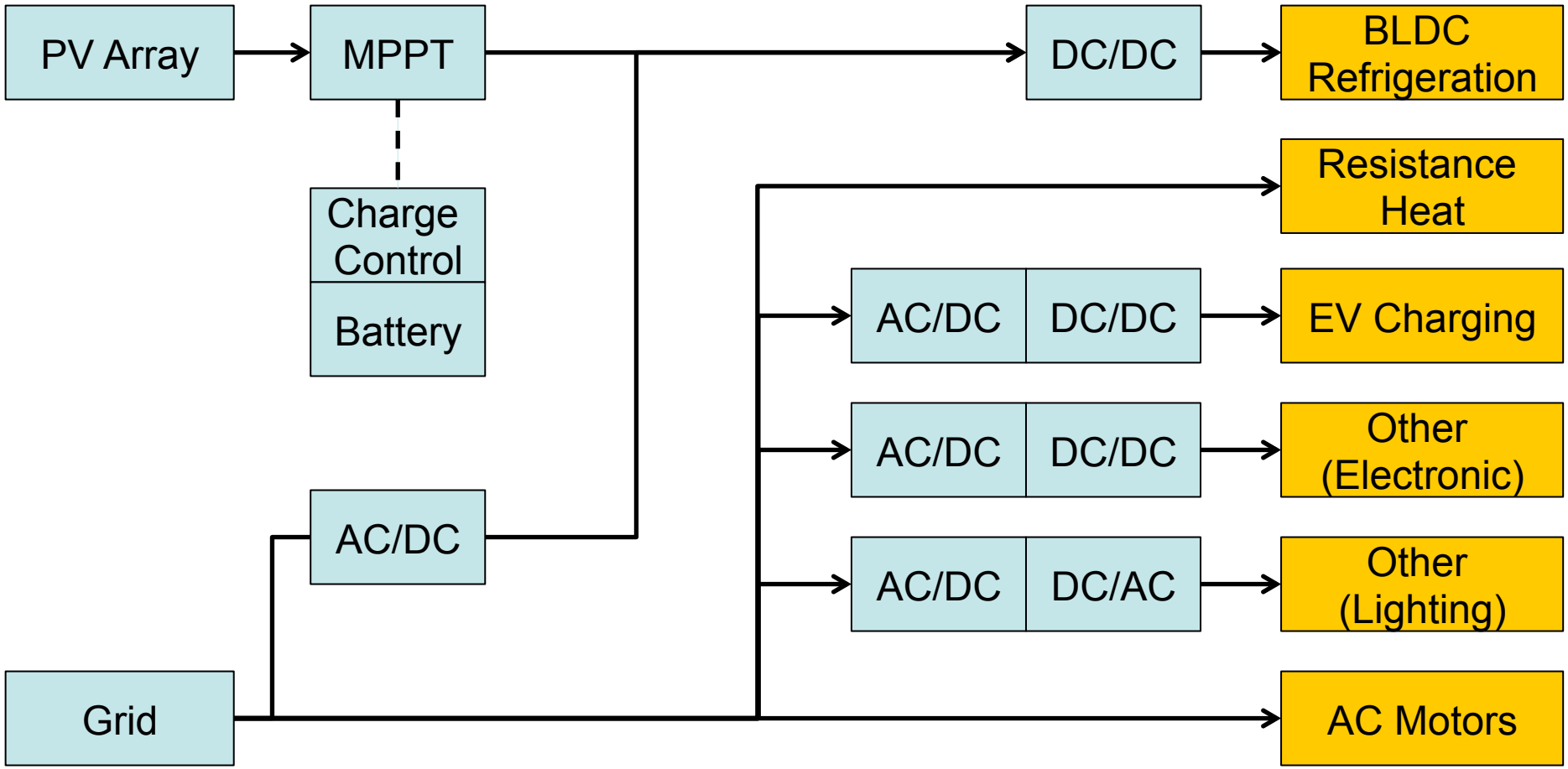
Technical Feasibility & Savings

Existing Load	Proposed DC Alternative	Energy Savings
Resistance Heating	No Change	No Change
EV Charging	Eliminate (1) rectification stage	3-7%
Other (electronics)	Eliminate (1) rectification stage	3-7%
Other (lighting)	Eliminate (1) rectification stage and convert to LED	7-28%
AC Motors	Brushless DC (BLDC) Motors	5-15%
Refrigeration	Variable speed BLDC compressors	34-52%

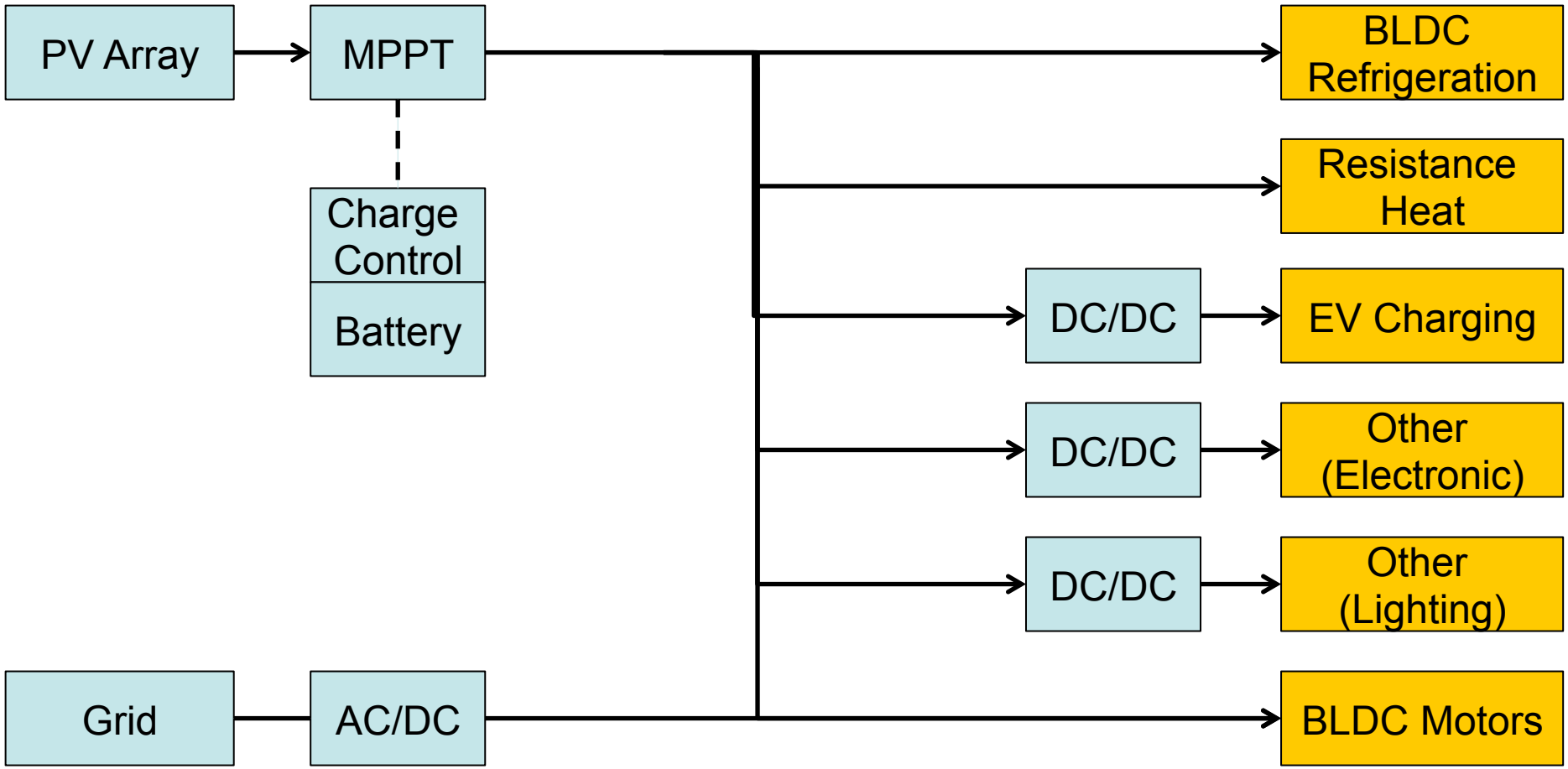
Existing Home Power Supply



Simulated Home Power Supply



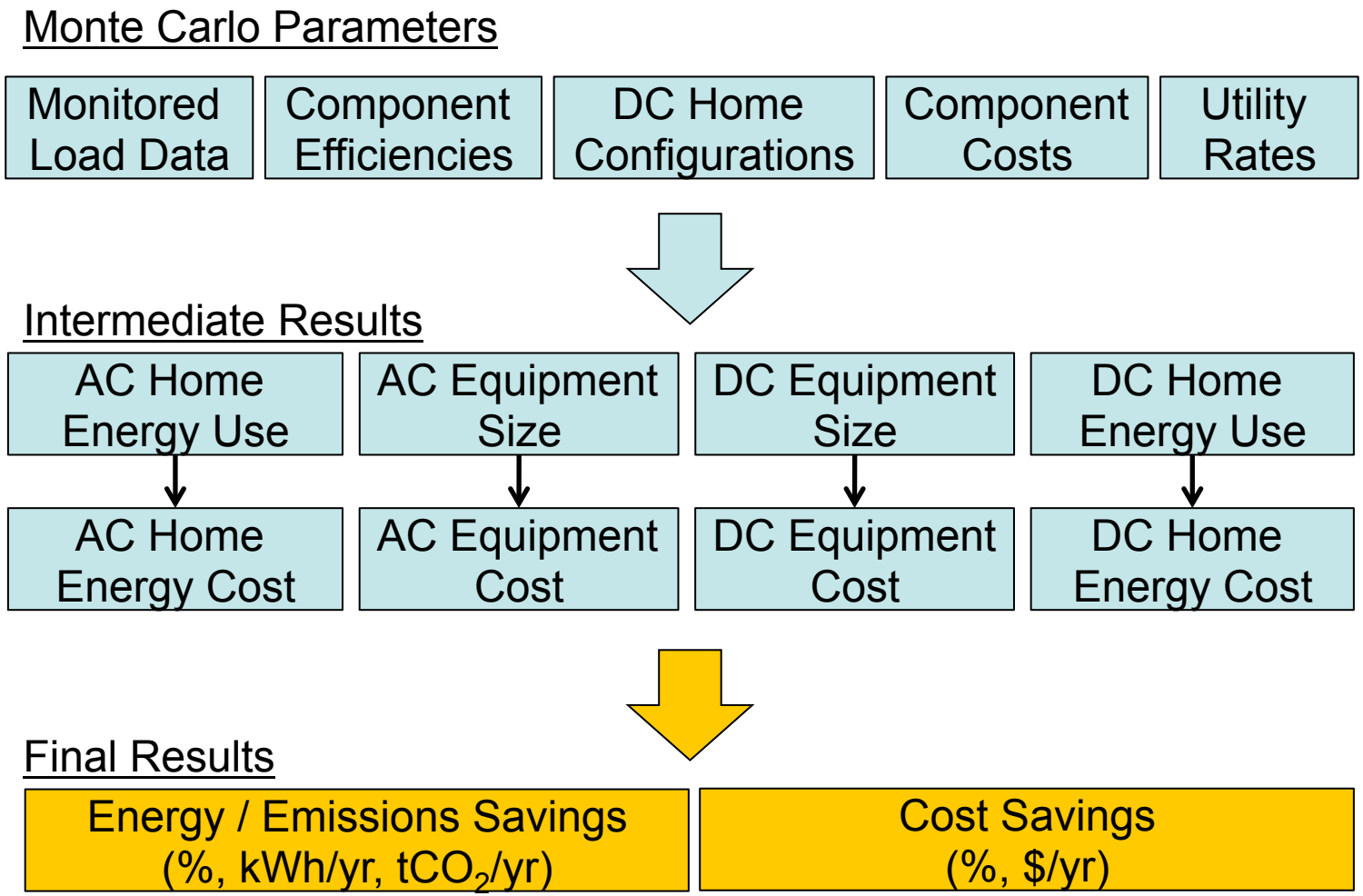
Simulated Home Power Supply



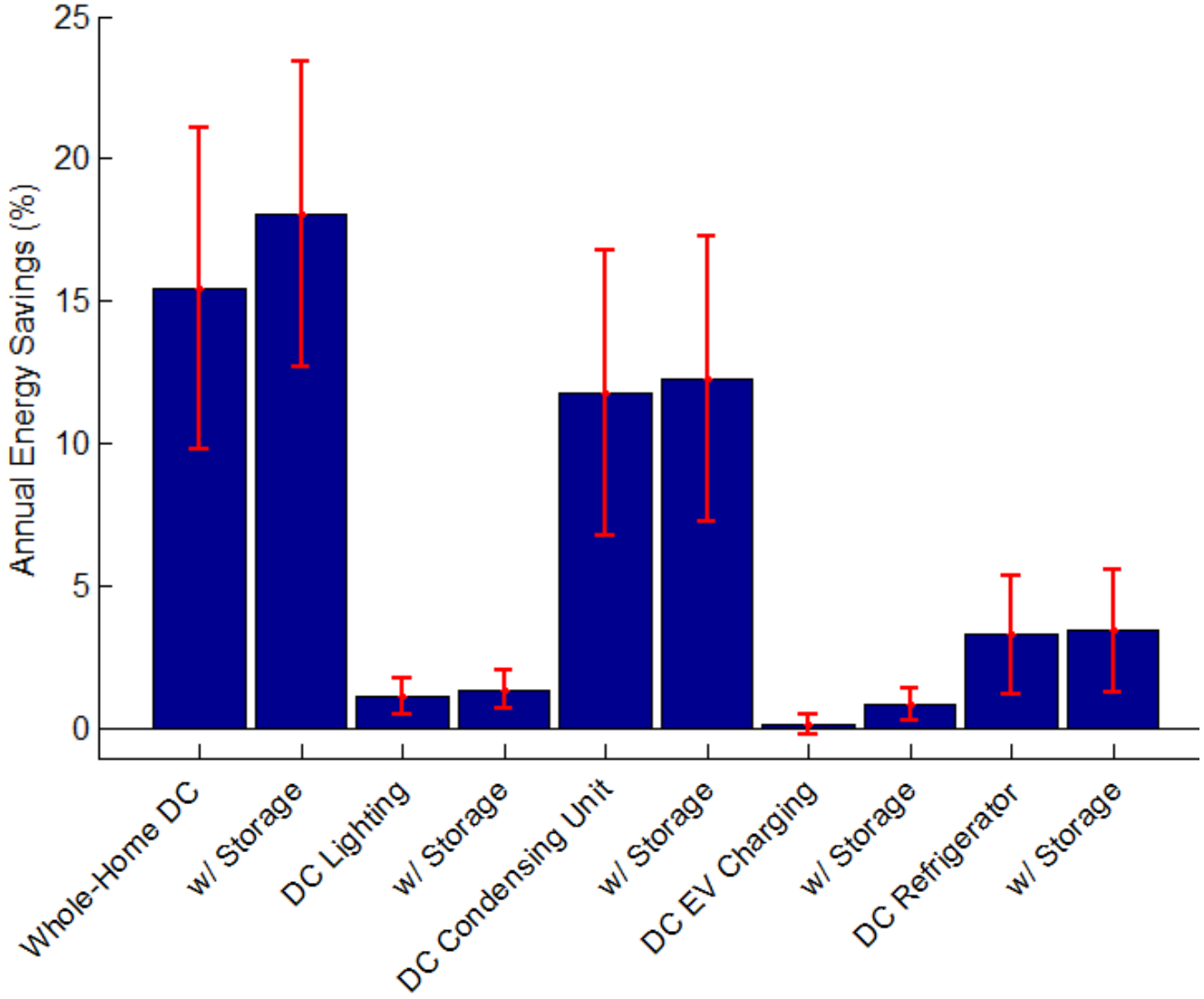
Key Assumptions

- Efficiencies of first-generation residential DC appliances maintain current niche market efficiencies
- DC devices will increase capital costs
  - Circuit breakers
  - Air conditioning condensing units
  - Central air supply fans
  - Refrigerators
- Similar degradation of AC-DC and DC-DC power supply efficiencies at part load
- 120V standard is adopted
- DC will be implemented in new construction only

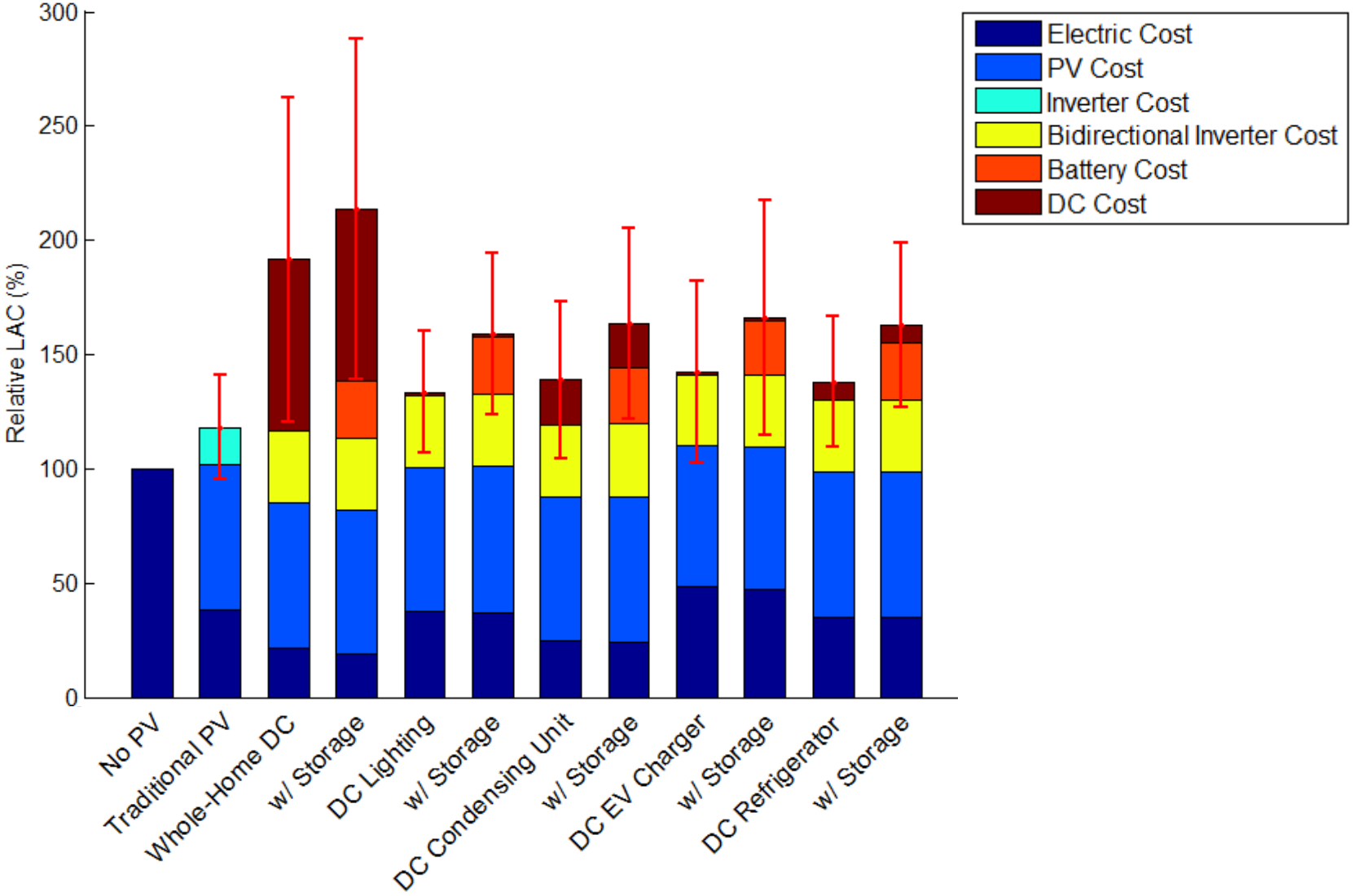
Monte Carlo Simulation



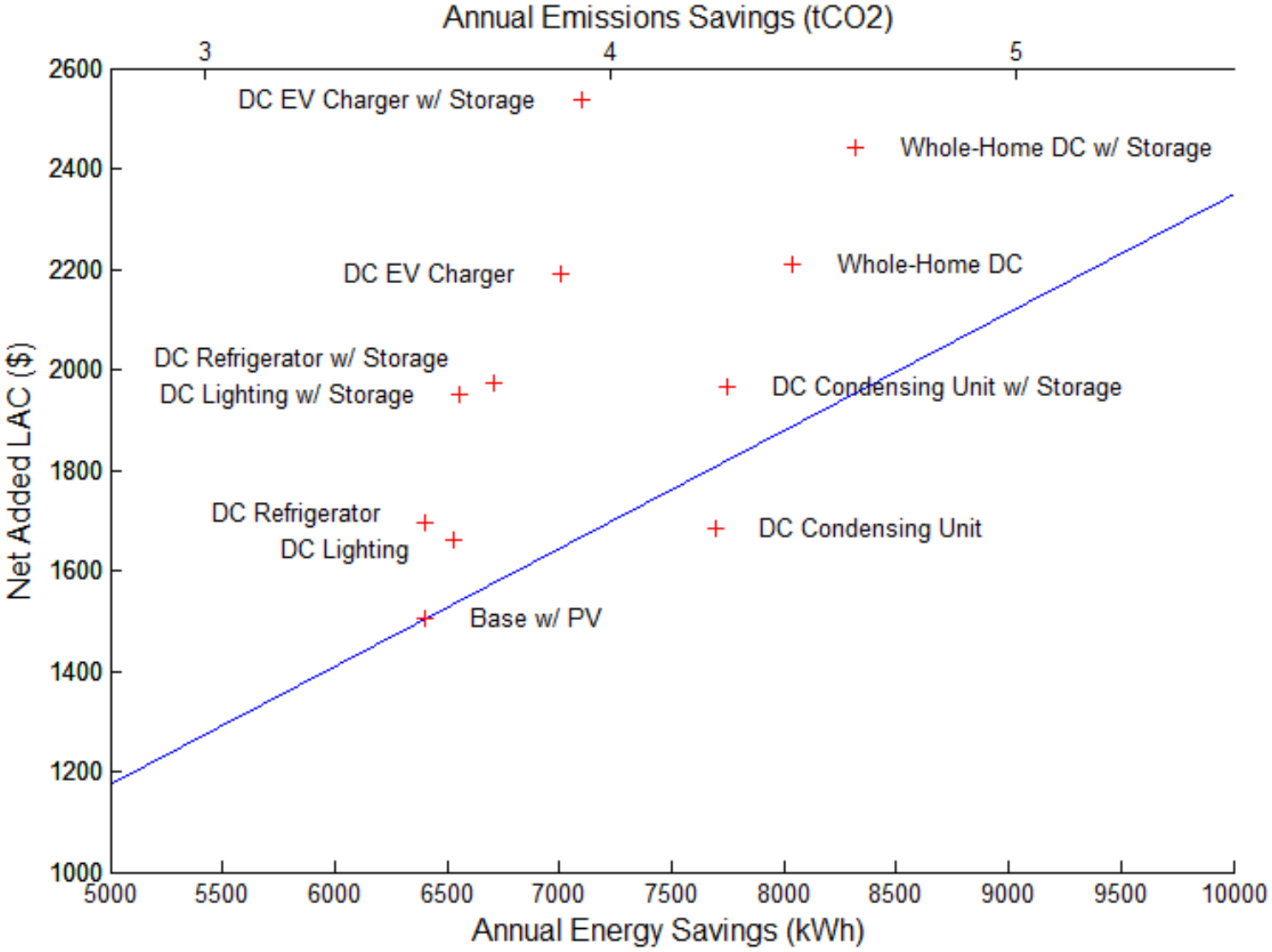
Results – Energy Savings



Results – Cost Savings



Cost Effectiveness



Quantitative Conclusions

- Direct-DC distribution of PV energy is a feasible means of generating energy and emissions savings
- Single DC circuits serving brushless DC condensing units match (exceed) the cost-effectiveness of traditional PV arrays
- Storage for excess solar PV energy not cost effective in any of the simulated configurations

Regulators' Perspective

- National Electric Code (ANSI[1]/NFPA[2]) does not specify AC or DC under 600V, so no changes appear necessary at the distribution level
  - Any home with a PV array already has a DC circuit
- Adoption of 120VDC standard
  - …maintains existing wiring losses
  - …maintains similar wiring/switch/breaker costs

[1] American National Standards Institute
[2] National Fire Protection Association

Utilities' Perspective

- All changes occur downstream of meter
- Net metering programs credit generation per AC kWh
  - Assumes a conversion loss and undervalues direct-DC consumption
- Utility solar installation incentives programs are administered based on installed AC capacity
  - Unclear whether DC systems would be eligible
- Specific subsidies for direct-DC systems would be premature
  - Lack of voltage standard, residential-specific appliances
  - Brushless DC condensing units present the best opportunity

Industry's Perspective

- Energy savings potential justifies residential pilot projects
- Utilities require AHRI[1] certification and performance guarantees for condensing unit rebates
  - Certification would allow early adopters of DC condensing units the same benefit available to less efficient AC units
- Experience with DC circuits (power plants, commercial buildings, telecom) will have to transition to a broader population of engineers, electricians, and building inspectors

[1]Air-conditioning, Heating, and Refrigeration Institute

Acknowledgements

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