Understanding the potential for electricity savings and assessing feasibility of a transition towards DC-powered buildings

Brock Glasgo, Inês Azevedo, and Chris Hendrickson

Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh PA

Why DC?

Advantages:

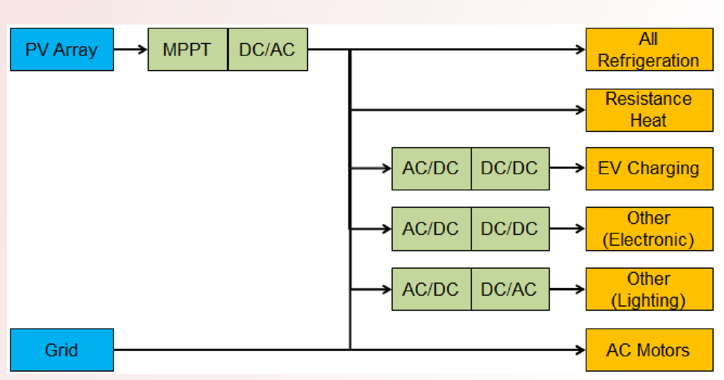
- We now have semiconductor-based power electronics that function as efficient DC-DC voltage transformers
- Much of the energy consumed in US homes is already transmitted as direct current at some point between the grid and the end load. Substantial electricity savings can be realized in a large number of buildings by eliminating the losses that occur when converting from one form of current to the other
- The only major loads in an average US home that do not presently have direct current in their power supply are those utilizing constant-speed induction motors or resistance heating elements. DC circuits have the potential to improve the reliability and reduce the cost of consumer electronics by centralizing AC-to-DC rectification duties from distributed, failure-prone power supplies to central, home-level rectifiers.
- Many DC appliances are inherently more efficient than the AC devices they could replace (LED lights, variable speed electronically commutated motors)

Disadvantages:

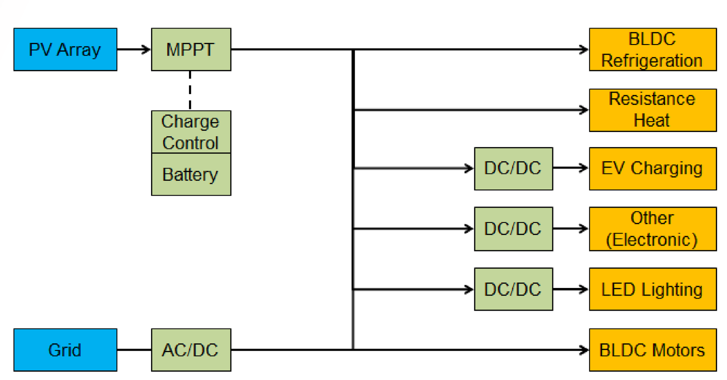
- Markets for DC appliances and components are small, resulting in high prices
- DC circuits at the residential level rely on wiring, circuit breakers, and switches which are not currently manufactured at a scale needed to supply broad adoption
- Engineers and technicians are not trained in DC systems, resulting in inflated design and installation costs of these systems
- Many utility programs are designed for AC (solar installation incentives, net metering programs)
- DC still perceived by many to be more dangerous than AC

Simulated scenarios

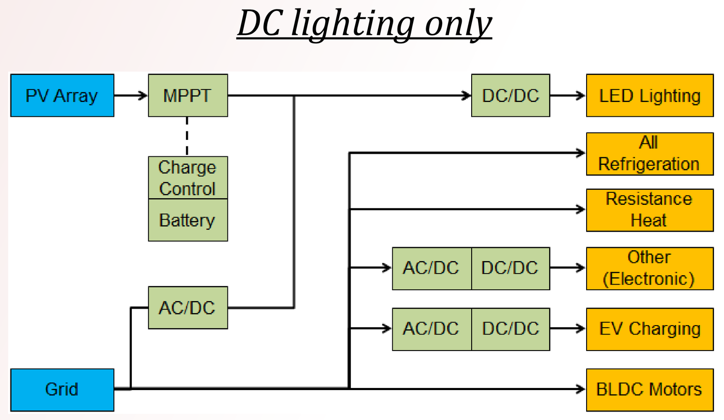
Traditional AC home with PV



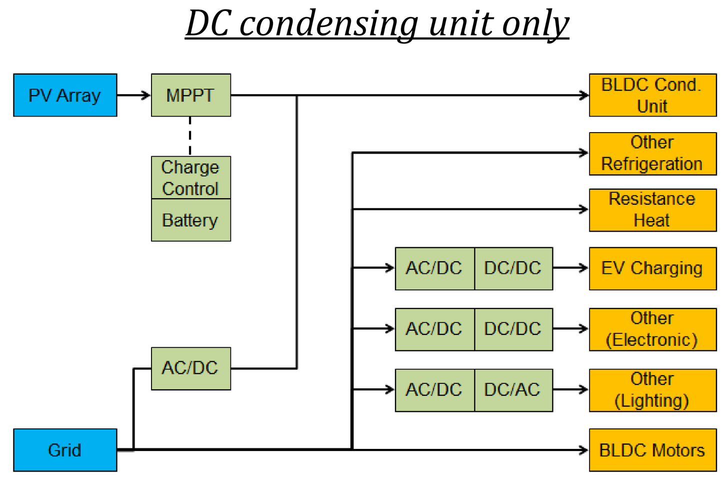
Whole-home DC



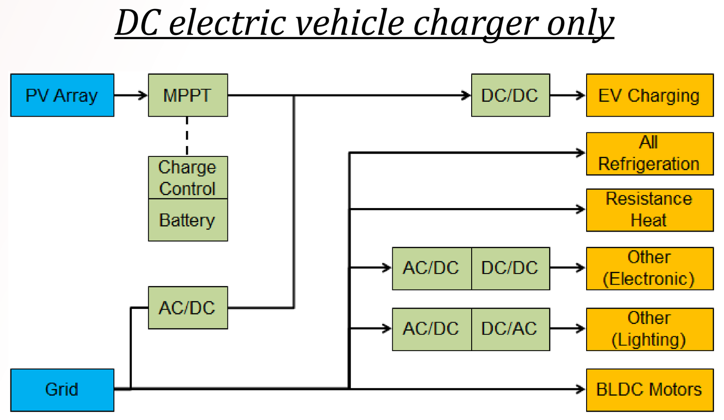
DC lighting only



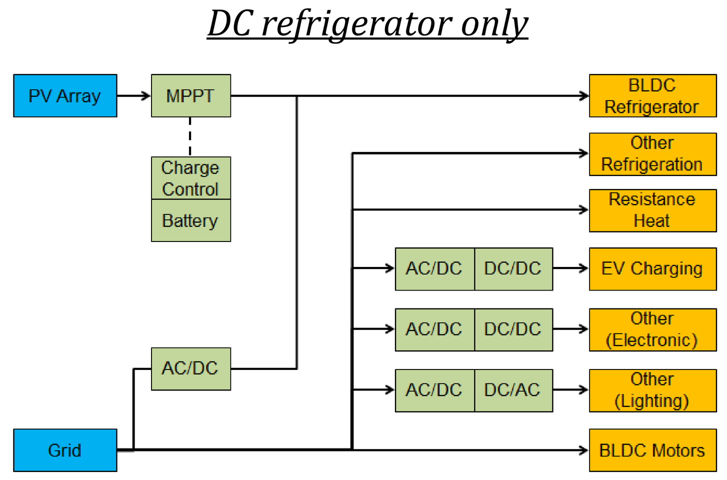
DC condensing unit only



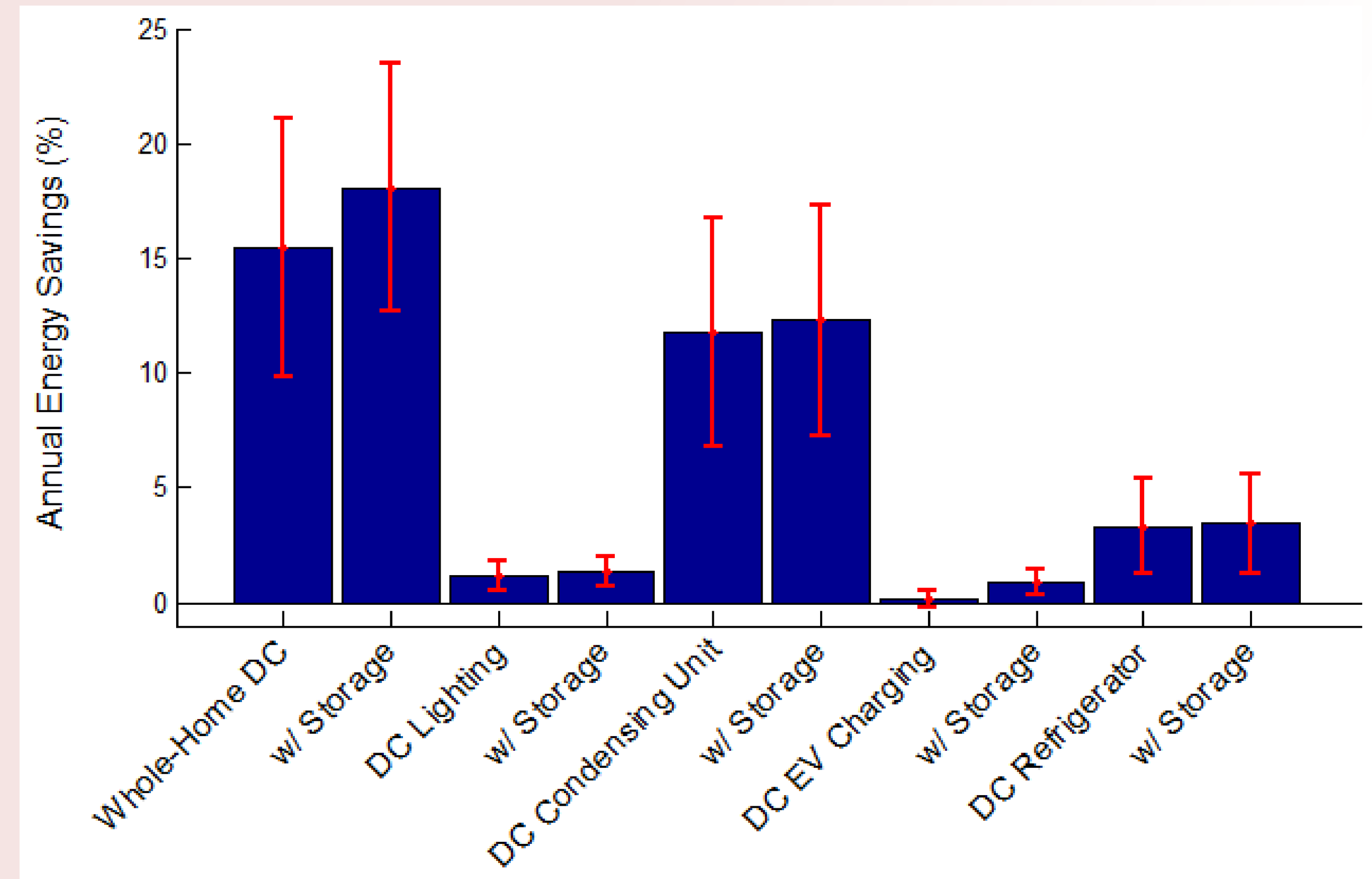
DC electric vehicle charger only



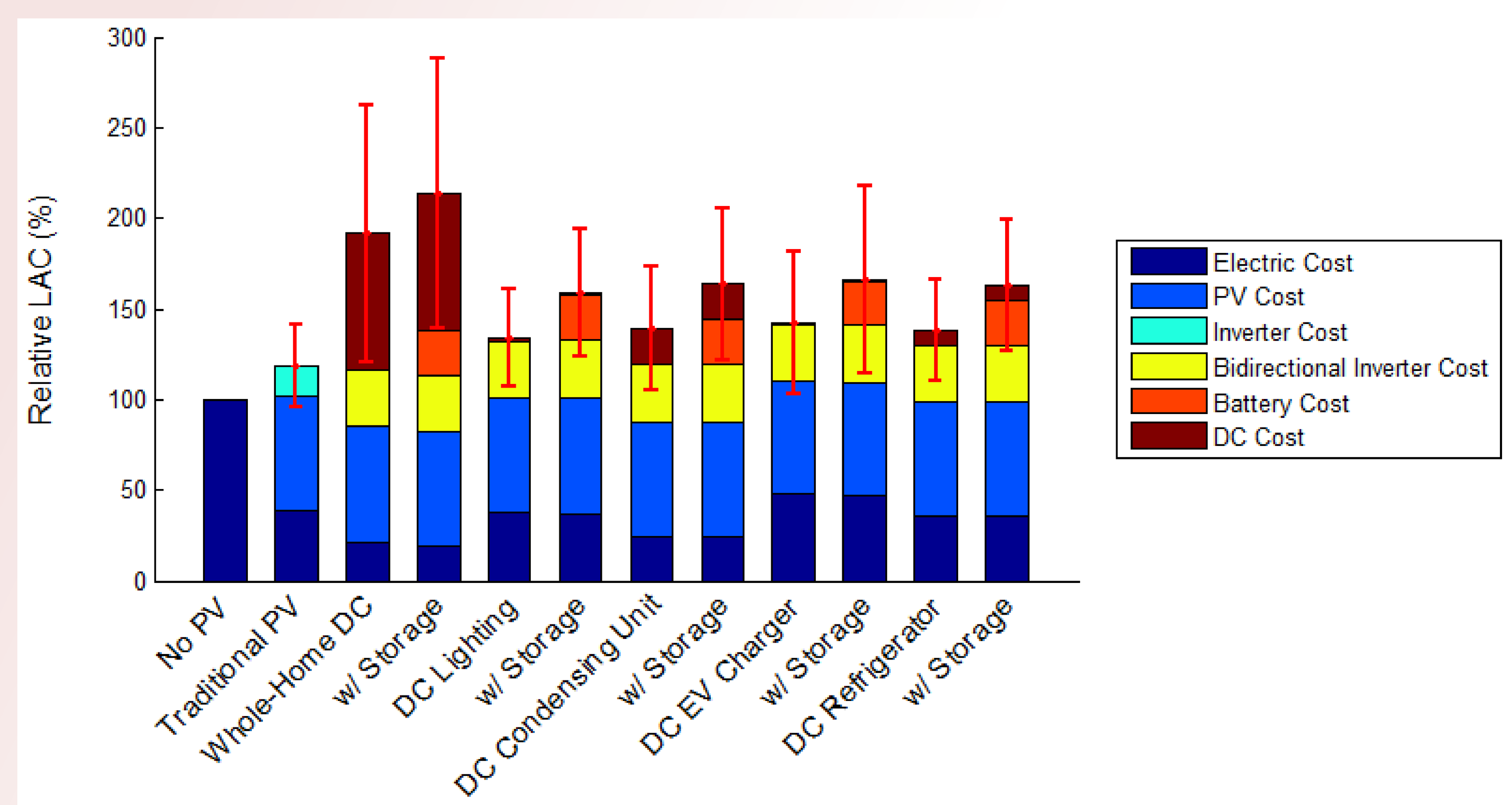
DC refrigerator only



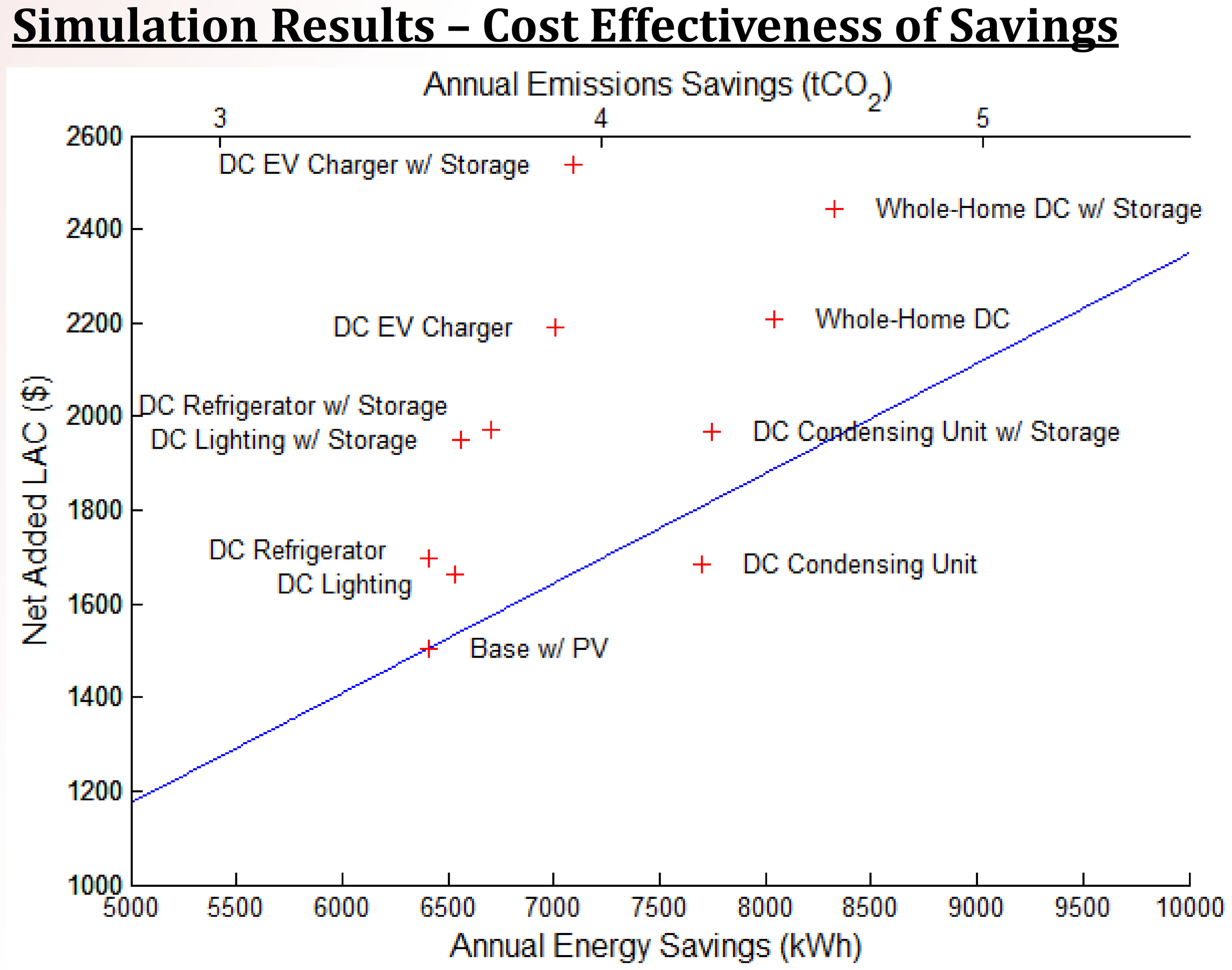
Simulation Results – Energy Savings



Simulation Results – Cost Savings



Simulation Results – Cost Effectiveness of Savings



Conclusions

- Direct-DC PV arrays are 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

Non-technical Barriers

Regulators

- National Electric Code (ANSI1/NFPA2) does not specify AC or DC under 600V, so no changes appear necessary at the distribution level

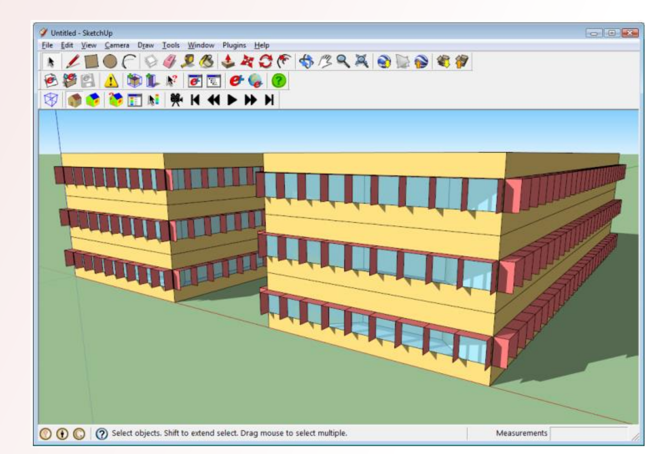
Utilities

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

Industry

- Specific subsidies for direct-DC systems would be premature
- Energy savings potential justifies pilot projects
- Utilities require AHRI1 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) will have to transition to a broader population of engineers, electricians, and building inspectors

Future Work – DC in Commercial Buildings



- Pacific Northwest National Labs has built (16) prototype commercial buildings in EnergyPlus in (17) different cities across the US
- Each building will be simulated with and without photovoltaics and with and without DC distribution and end uses

Future Work – Advanced Motor Technologies

- Electric motor systems account for around 43 to 46% of global electricity consumption [1]
- As efficiency requirements increase, attention is turning to advanced permanent magnet motors to meet future efficiency targets
- Many of these designs use a direct current input for variable speed operation, which lends itself to DC distribution circuits
- Future work will look at historical motor efficiencies and the potential impacts of advanced DC motor technologies to meet efficiency targets

[1] International Energy Agency. Energy Efficiency Policy Opportunities for Electric Motor-Driven Systems. 2011.

[2] Rajagopalan, S, Vairamohan, B, Samotyj, M. Electric Motors for the Modern World. EPRI.

Acknowledgements

We thank Carnegie Mellon University's Center for Climate and Energy Decision Making, and the Pecan Street Research Institute for their support of this work.