Energy Cyber Physical Systems for Greener Residential Power:
Towards Sustainable Communities

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The opportunity space for Energy Cyber-Physical Systems (ECPS) innovation addressed by this position paper is low cost, resilient and greener residential power grids. Residential consumers demand more electricity and spend more for the electricity they consume than any other sector. Residences account for 35% of the electricity consumed annually in the United States, compared to 26% and 34% for industrial and commercial electricity, respectively (see Figure 1(a)). The total expenditure for residential (community) electricity is $140B, which is larger than the expenditures for industrial ($122B) and commercial ($22B) electricity[1]. Yet, the past and present focus of national research initiatives is on power generation and delivery systems at the regional level on a utility scale. Although utility-scale initiatives are also important for powering the nation, this workshop on ECPS is an opportunity to highlight the nation's electricity needs at a community level, and how innovations in CPS can address these needs.

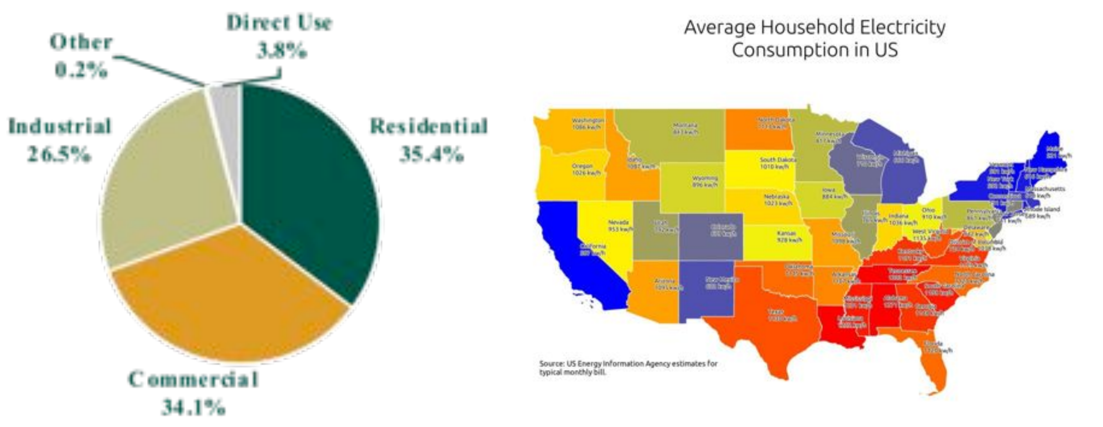

Figure 1: (a) Electricity consumption by sector[1] in the United States (2006), and (b) electricity consumption by State (Courtesy: US Energy Information Agency).

Residential power grids are highly distributed systems, which means that they consume significantly different amounts of electricity and rely on significantly different fuel sources. Figure 1(b) shows the electricity consumption in kW/hr per State indicating that the challenges in load balancing in one State are different from those in neighboring States, and these differences are more pronounced at the county and community levels. The sources of energy that are available to communities also vary widely. Figure 2 illustrates that the solar resource and wind resource both vary substantially from community to community even within a specific region of the country. The amount of hydropower available also varies significantly from region to region.

[1] U.S. Department of Energy, "Electric Power Annual – 2006", 2007.

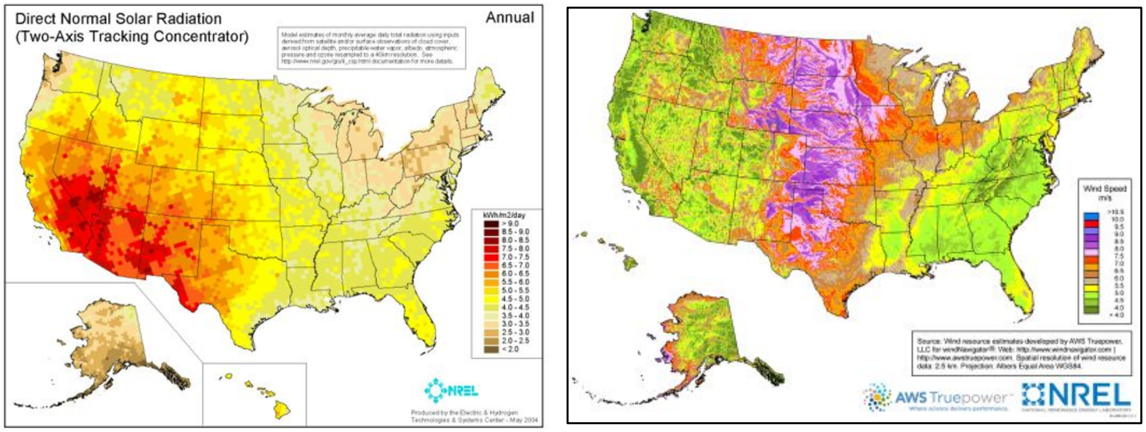

Figure 2: (a) Solar and (b) wind resource maps (Courtesy: National Renewable Energy Laboratory).

To facilitate the adoption of green sources of energy, we must minimize the cost of green energy by balancing intermittent and dispatachable sources of power primarily from fossil fuels and hydropower, but presently this balancing act occurs at the utility scale using power generated from solar and wind farms along with hydro power plants. *Our claim is that this non-collocated balancing approach is leading to slow adoption of green energy because balancing occurs at the regional level, not at the consumer level. By moving the load-balancing task to the community level, we can design collocated smart grid controls that minimize the cost of green energy and accelerate its adoption by communities and specifically residential consumers*. Furthermore, when given control of their energy consumption as in the hybrid vehicle marketplace, residential consumers of electricity are much more likely to change their energy use behavior because of the personal financial implications. The increasing number of zero net energy homebuilders coupled with advances in ECPS signals an opportunity to change this paradigm.

ECPS can enable load balancing techniques at the community level to sense, store, and control intermittent renewable energy sources, taking into account dynamic system behaviors as well economic and regulatory policy factors. But there are fundamental barriers to address to make ECPS for residential power possible: (1) predictive models are needed to capture the wide variations in renewable energy resources at the community level – currently, neither the models nor the validation testbeds are available for fully testing these models; (2) new sensing modalities are needed to detect faults and enable fault tolerant control of networks of power generation and energy storage systems that comprise residential smart power grids – currently, sensor technologies are insufficient to detect faults early enough to take proactive steps to correct the faults; (3) uncertainty quantification techniques are needed to take into account dynamics in the power grid as well as economic and policy differences at the community levels; and, (4) real-world testbeds are needed to capture variations in renewable energy sources so that competing ECPS ideas can be tested and compared side-by-side at the community level.