Smart Home Hardware-in-the-Loop Testing

Annabelle Pratt, Power Systems Engineering Center

4th International Workshop on Grid Simulator Testing
Golden, CO, USA

April 25-26, 2017

NREL/PR-5D00-68760

**Grid Modernization
Multi-Year Program Plan**

Grid Modernization relies on an
**advanced modern grid
planning & analytics platform**

*Enable design of
clean distribution systems made possible by:*
"new grid developments including
**proliferation of smart
consumer end-use devices**
on the customer side of the meter"
and
"**new approaches for distributed control and
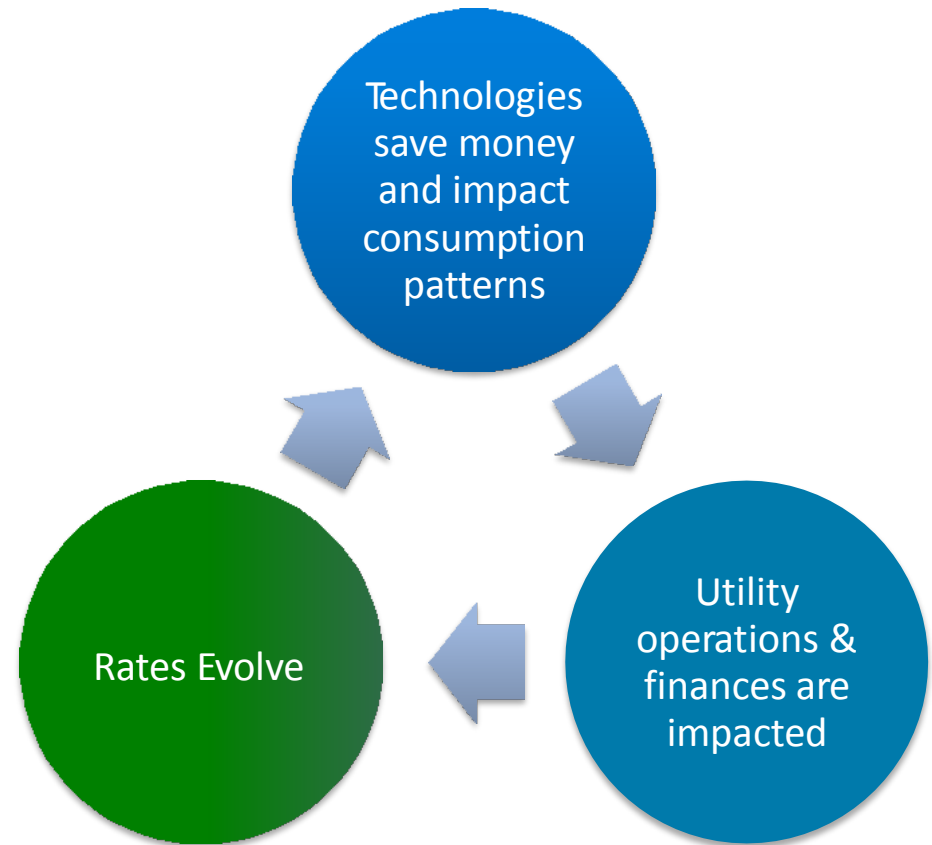coordination across local intelligent assets.**"

Modern Grid Analytics Platform

Premise:

Systematic modeling is necessary to identify overall impacts and avoid unintended consequences

Development funded through NREL's Laboratory Directed Research and Development (LDRD) program

Technologies save money and impact consumption patterns

Utility operations & finances are impacted

Rates Evolve

Home energy management system (HEMS) is a key technology:

- Nascent, growing market
- Can also represent smart thermostat/appliance

Transactive Energy is a proposed framework in which HEMS:

- Automatically reacts to an energy price signal on behalf of the homeowner
- Returns information (power forecast) to node issuing the price signal
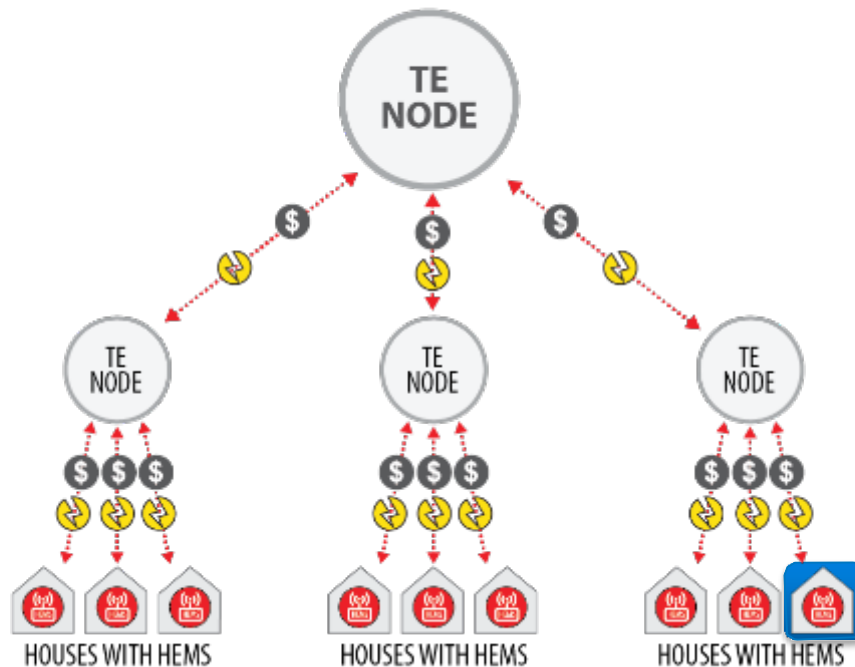
Hardware

Image created by Josh Bauer, NREL

Home Energy Management Systems

- **Schedules operation of appliances and distributed energy resources (DERs)**
  - e.g., thermostat setpoint, electric vehicle charging rate
- **Co-optimizes multiple objectives**
  - e.g., comfort, cost, energy use
- **Based on inputs**
  - *Preferences*: e.g., desired air/water temperature, EV charge completion time
  - *Electricity price & weather forecasts, DR request*
  - *Sensors:* e.g., temperatures, lighting level
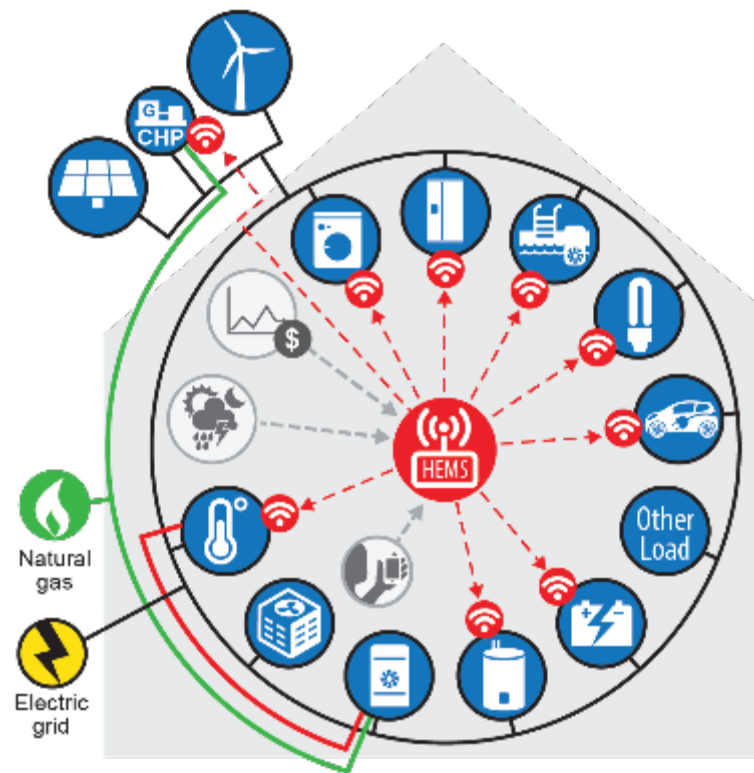
Approach:

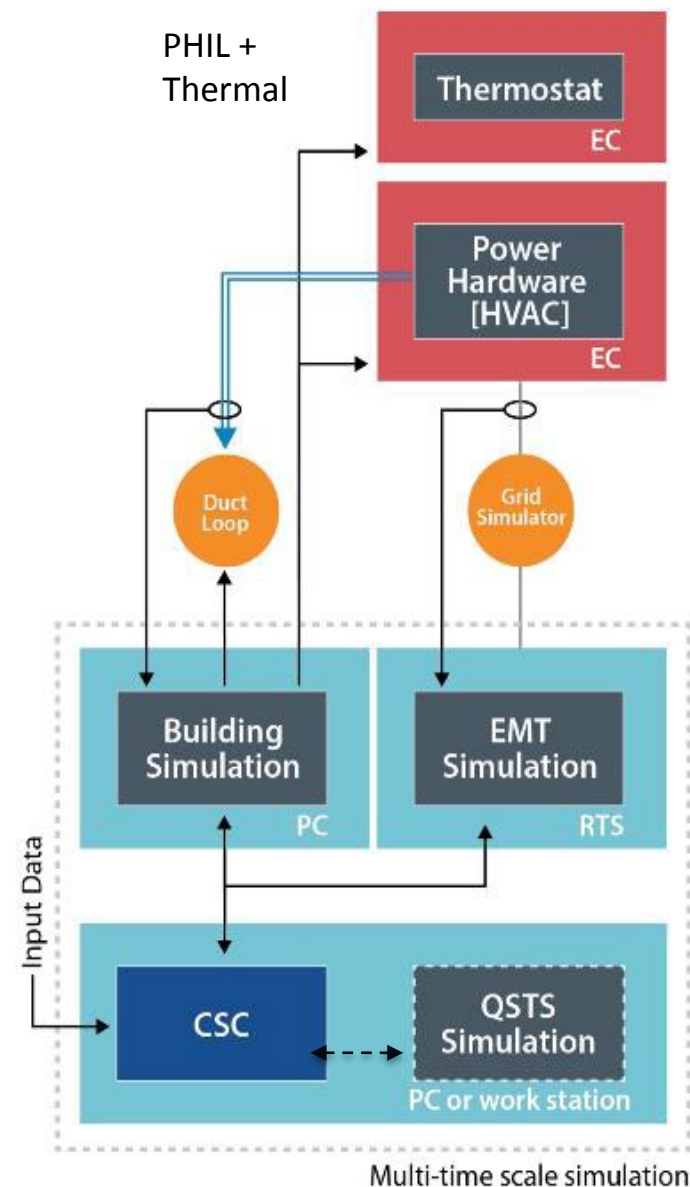Model Predictive Control (MILP), Stochastic

PHIL

PHIL CO-SIM
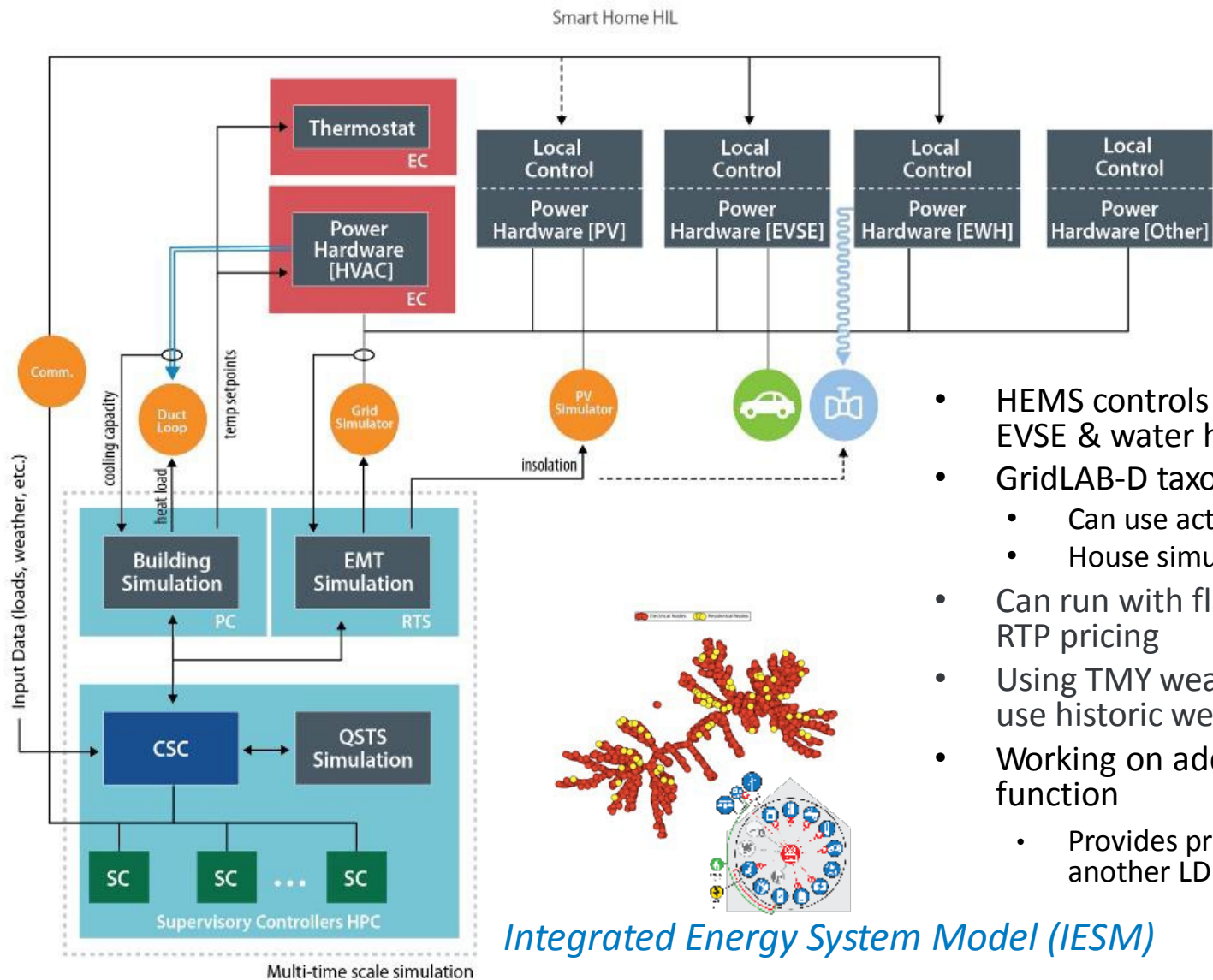
Multi-time scale simulation
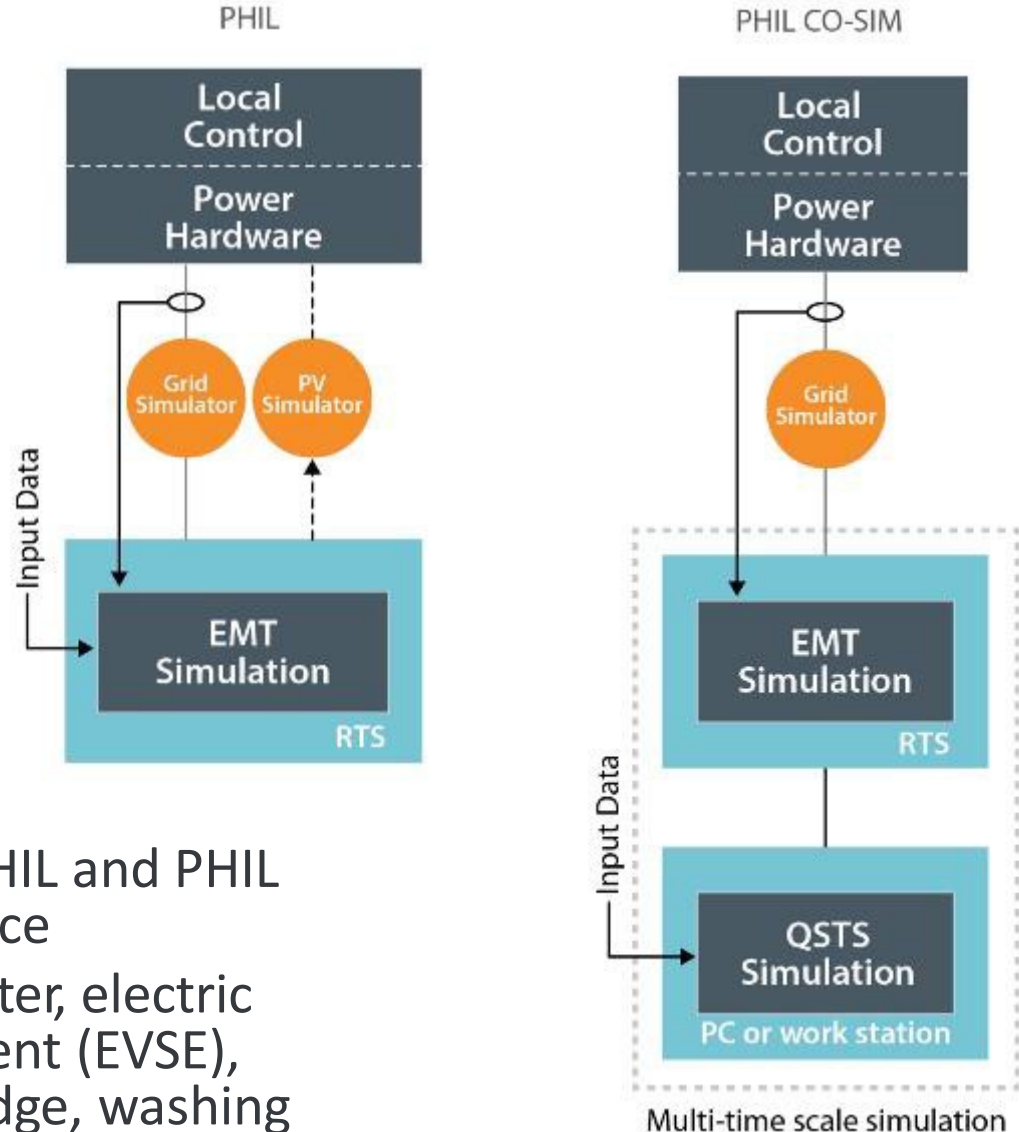
- Builds on prior power HIL and PHIL co-simulation experience
- Photovoltaic (PV) inverter, electric vehicle supply equipment (EVSE), water heater, stove, fridge, washing machine, etc.

Power and Thermal Hardware-in-the-Loop

- Air conditioner (HVAC)
  - o Thermostat separate local control
- Building simulation (EnergyPlus)
- Co-simulation coordinator (CSC)
  - o feeder
  - o building simulation

PHIL + Thermal

Thermostat
EC

Power Hardware [HVAC]
EC

Duct Loop

Grid Simulator

Building Simulation
PC

EMT Simulation
RTS

Input Data

CSC

QSTS Simulation

PC or work station

Multi-time scale simulation

Smart Home HIL

- HEMS controls thermostat, EVSE & water heater
- GridLAB-D taxonomic feeders
    - Can use actual feeders
    - House simulations
- Can run with flat, TOU and RTP pricing
- Using TMY weather, could use historic weather data
- Working on adding DSO function
    - Provides prices to HEMS, another LDRD

Integrated Energy System Model (IESM)

Next steps and impact

- Complete smart home HIL setup
- Complete multiple simulations
  - Vary position of house on feeder
  - Run with and without HEMS
  - Vary weather conditions
  - Vary prices
- Add DSO layer and run additional simulations

- Outcome: a power and controller HIL test bed that can support simulation of modernized grid with proliferation of smart consumer devices

Thank You!

Annabelle Pratt, Ph.D.
Principal Engineer
Power Systems Engineering Center
National Renewable Energy Laboratory
annabelle.pratt@nrel.gov

www.nrel.gov