Heat Pump Water Heater Technology Development

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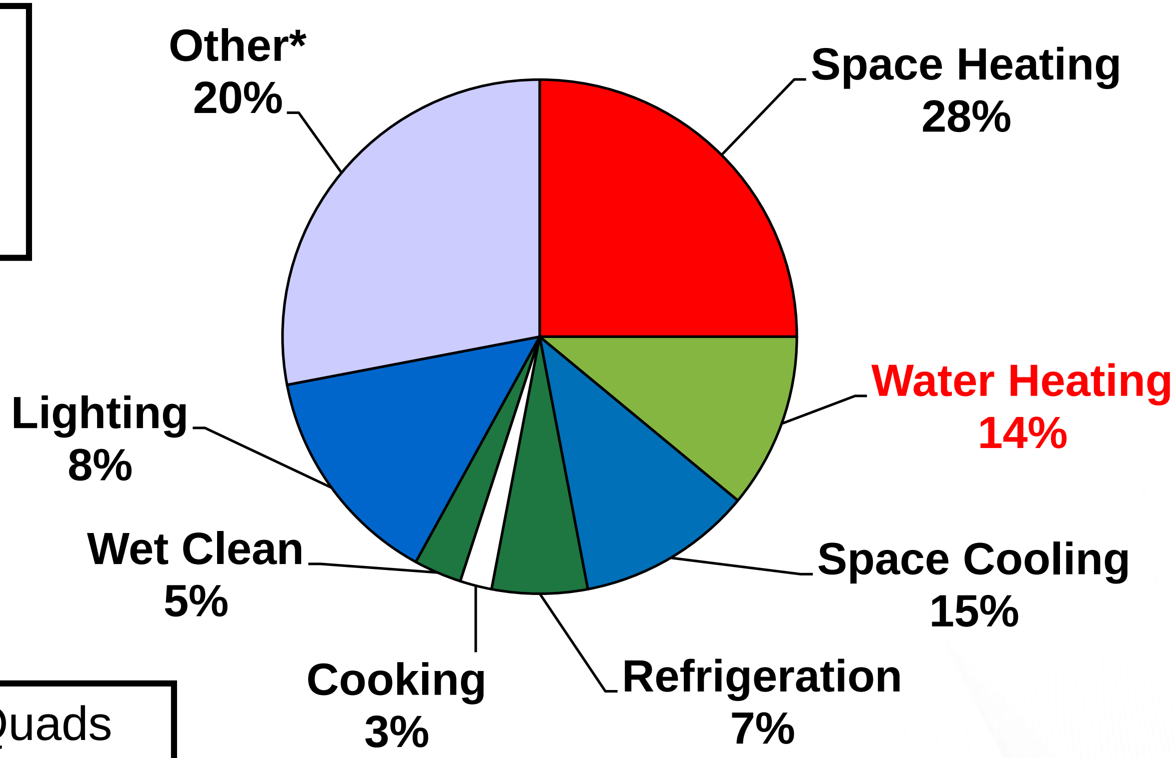
Oak Ridge National Laboratory

EEBA High Performance Home Summit 2017

ORNL is managed by UT-Battelle
for the US Department of Energy

Residential Water Heating Energy Consumption

Water heating accounts for 2.9 Quads of primary energy

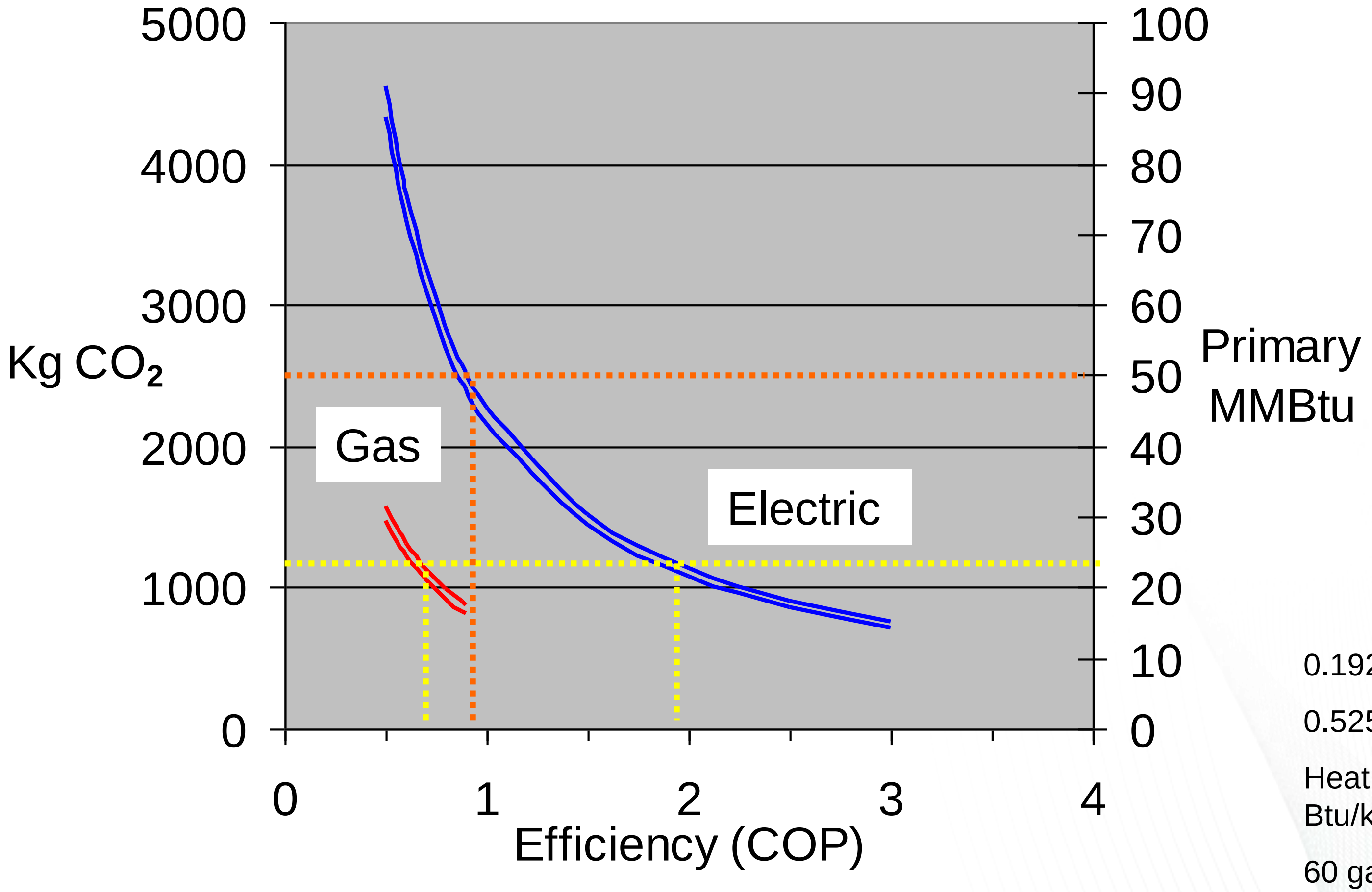


Electric – 1.44 Quads
Gas – 1.31 Quads

2015 total consumption: 21.1 Quads

*Televisions, computers, small appliances, electronics

2005 Minimum Efficiency Standards Close to Thermodynamic Limits…Best Option was Efficiency Improvement for Electrics



Notes:

0.192 kg CO_2/kWht;

0.525 kg CO_2/kWhe;

Heat rate: 11,045 Btu/kWh;

60 gal/da usage

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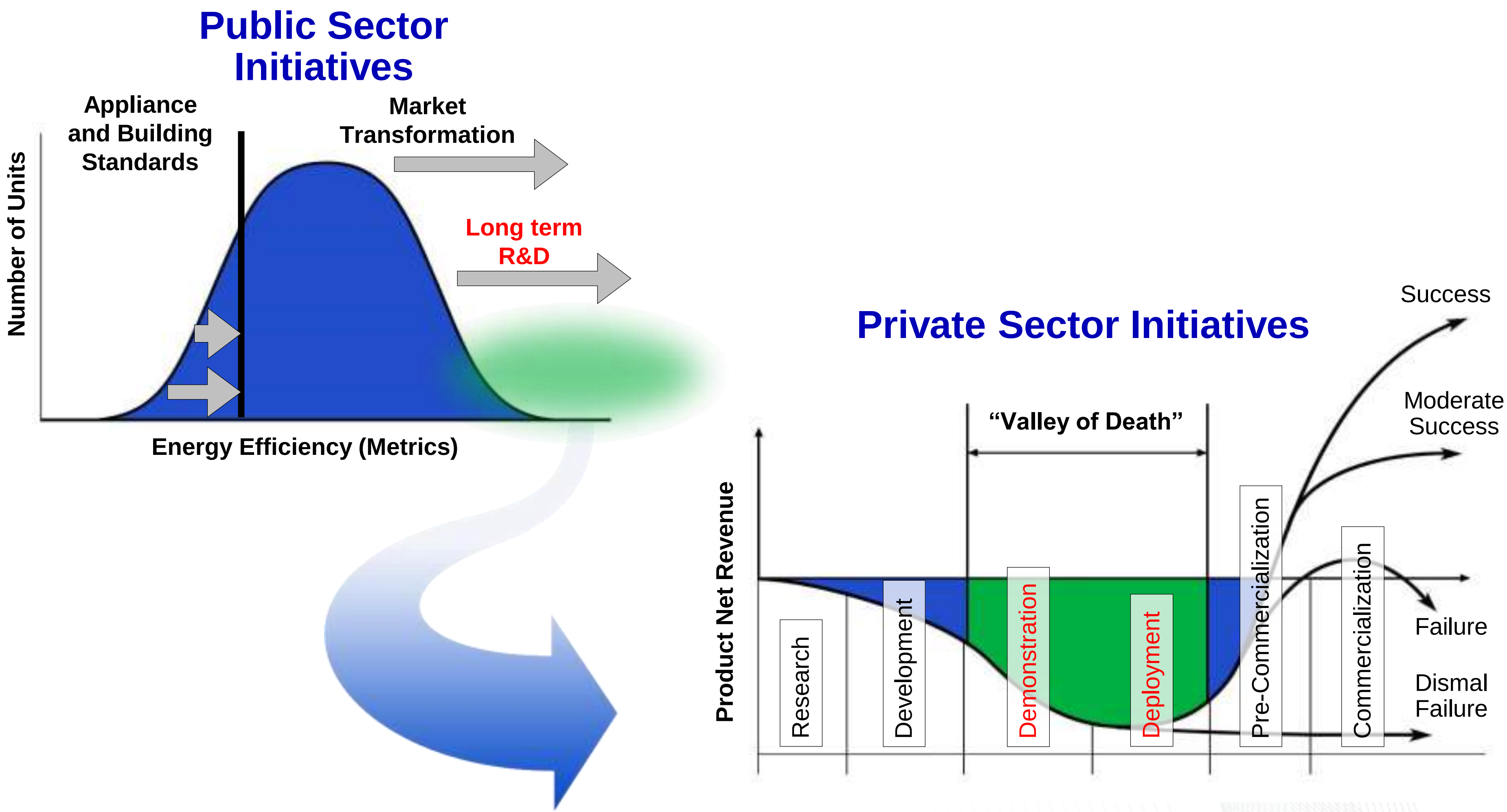
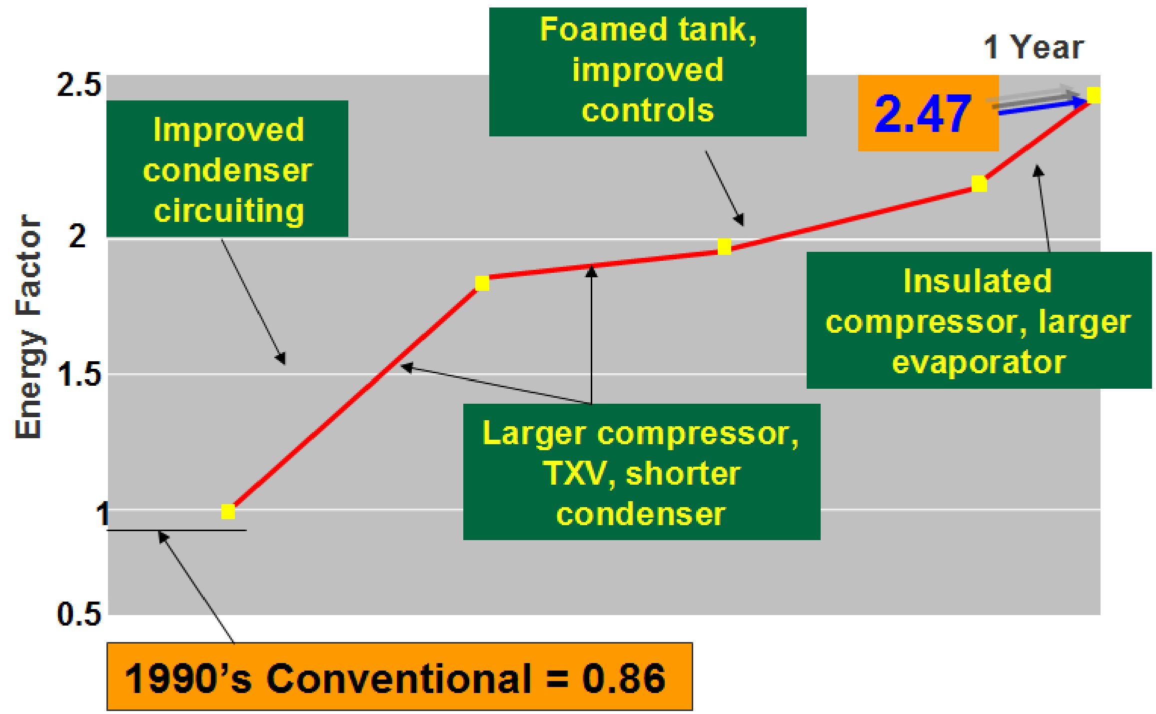
ORNL Participates in Public/Private Partnerships to Facilitate New Products Coming to Market

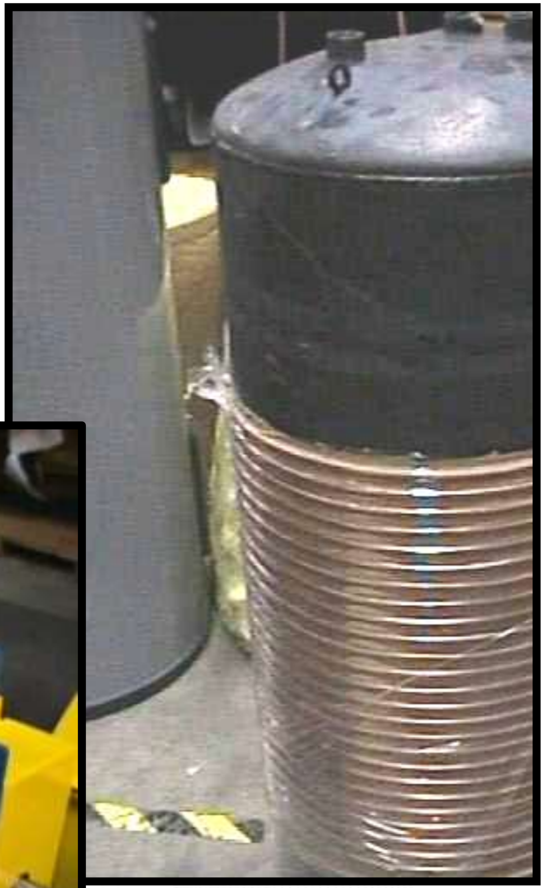


Development of 1st Generation HPWH Required Significant Engineering Effort

- Original concept originated through ORNL subcontract with Arthur D. Little (ADL)
  - 2 patents, late 90’s
- Enviromaster International (EMI) licenses technology & produced initial prototype around 1998
  - Constructed initially for anticipated field test
  - Dismal performance (EF=1.04)
- ORNL investigates ways to improve performance
  - Successfully increased EF to >2.4



Major Improvement was the Wraparound Condenser Design Resulting in Improved Heat Transfer



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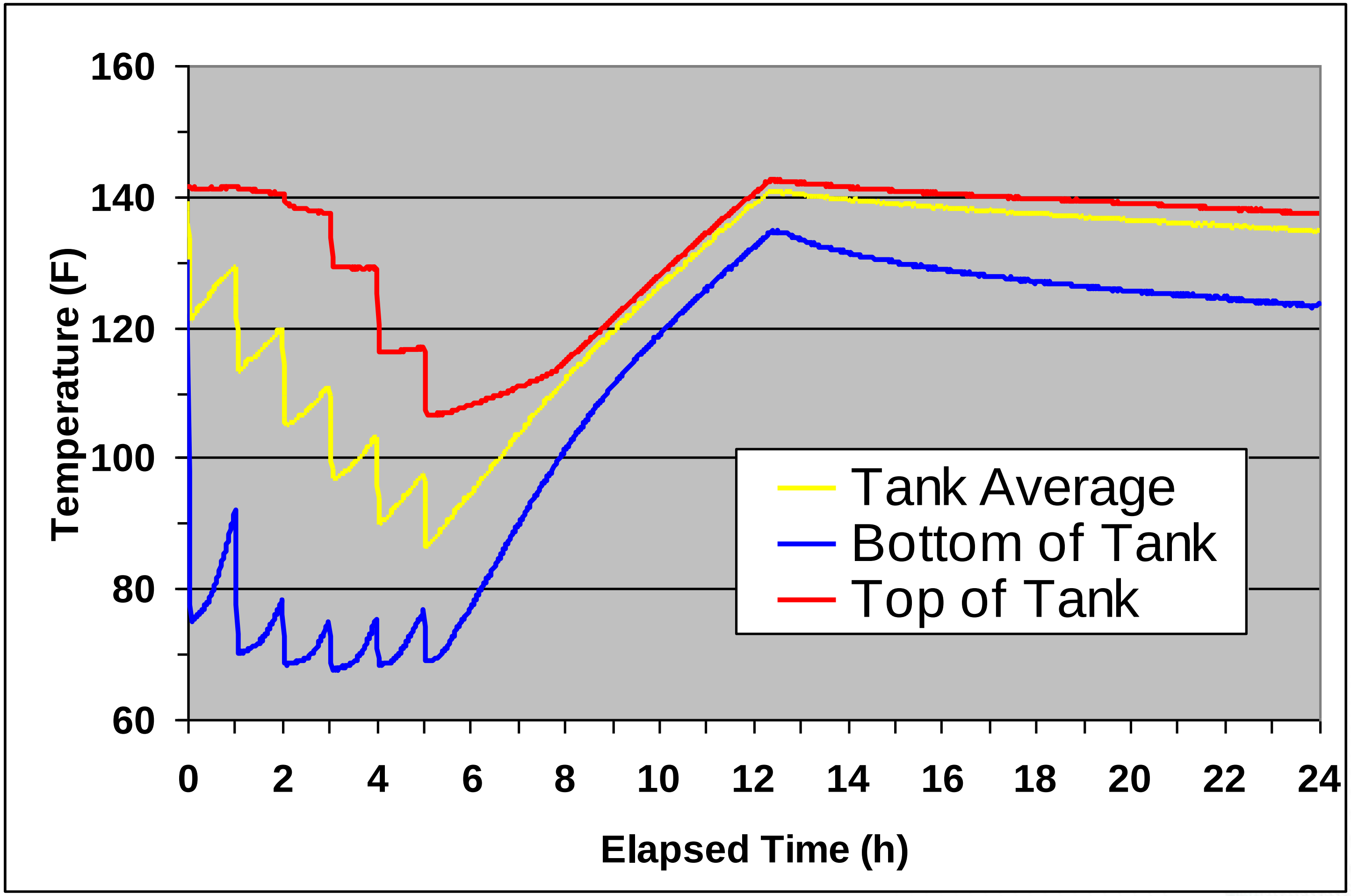
Laboratory and Field Testing Conducted on HPWH

- durability testing
  - simulation: 10-years of real world use
  - conclusions: hardware robust, control modifications successful
- field testing
  - 18 units in homes across the U.S.
  - 55% average energy savings (1+ years)

Accelerated Durability Evaluations Found Nothing Unexpected

Temperature Response Suggested Zero Need for Supplemental Heating



Note: Test accomplished based on DOE *24-h Simulated Use Test Procedure* for Water Heaters

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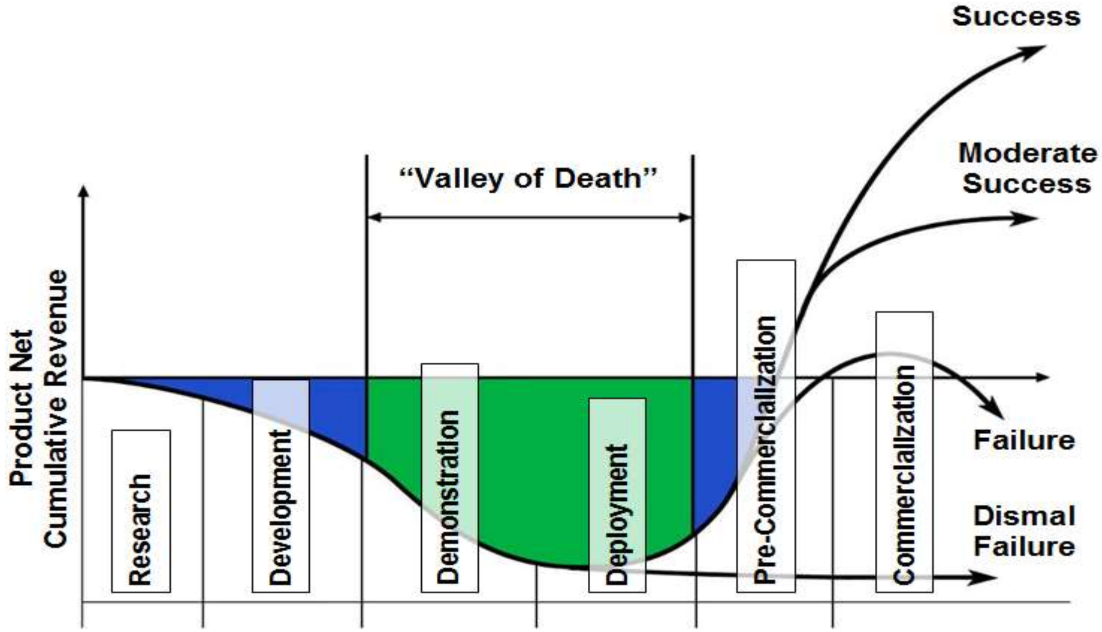
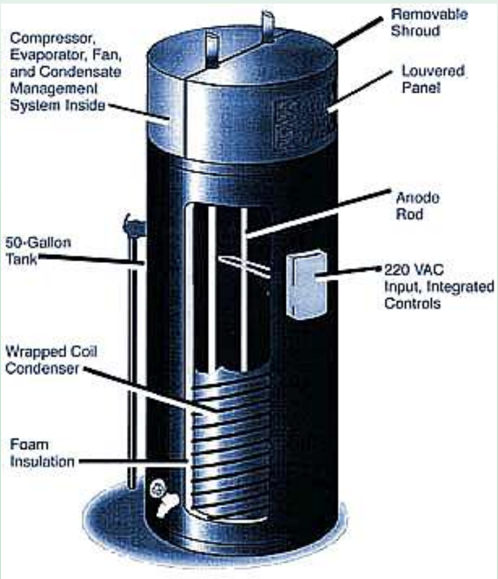
Unfortunately, EMI HPWH Product Died in “Valley of Death”

- EMI offered units from ~2002-2005
  - ~$1200-1500 installed cost
  - Very limited marketing & sales support resources (small manufacturer)



2nd Attempt Proved more Successful

ORNL's extensive HPWH experience and Watter$aver technical success attracted GE as CRADA partner in 2007.*



Reliability (accelerated life) test set up at ORNL: 10 units undergo >2500 cycles; equivalent to 10 yrs normal duty (2008-2009)

Final GE GEO Spring™ product design

First DOE Energy Star water heater

Strong GE ad campaign

- Spurred Rheem & AO Smith to introduce similar products
- "Valley of Death" may be averted this time
    - 2009 sales of HPWHs up >600% vs. 2008

Hot water energy savings of more than 50% in residential buildings.

Cooperative Research and Development on Heat Pump Water Heater

- 2007
  - contact between ORNL and GE on heat pump water heaters initiated
- 2008
  - ORNL/GE CRADA started
  - Energy Star program requirements and eligibility criteria for residential water heaters issued
  - product plans to meet requirements disclosed by GE
- 2009
  - Energy Star (ES) criteria effective [energy factor (EF) ≥ 2.0, first-hour rating (FHR) ≥ 50 gallons, etc. for storage heat pump class]
  - GE HPWH listed as Energy Star (EF = 2.35, FHR = 63 gal)
  - GE HPWH introduced to market

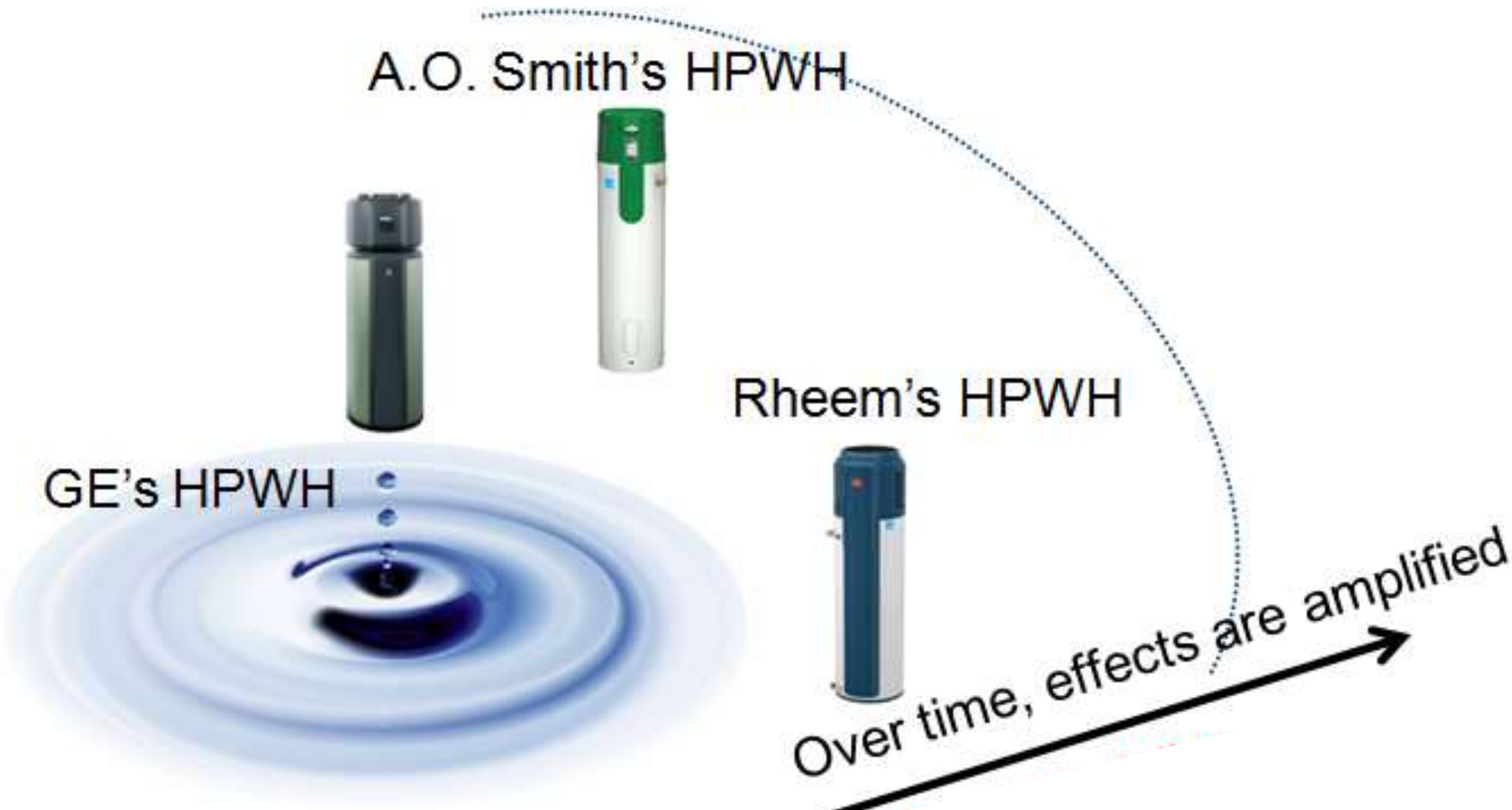
ORNL Efforts to Assist GE in Developing a Successful HPWH Product:

- involved in multiple sequential development stages
- capacity testing
- efficiency testing
- reliability life testing
- component assessment
- control assessment
- system modeling/assessment
- hardware troubleshooting
- software troubleshooting
- alternative working fluid testing (FY 2011)
  - HFO-1234yf

Utility Bill Savings of HPWH Relative to 50-Gallon Standard Electric Tank Water Heater

- Based on GE estimates:
- HPWH saves 62%
- on an annual basis:
  - 3025 kWh
  - $320
- 1 year payback in some areas w/rebates
- availability:
  - Lowe's
  - Sears
  - other distributors

Ripple effects of GE-ORNL HPWH CRADA



Integrated Heat Pump (IHP) for Residential or Small Commercial Building Applications

- Goal: multifunction electric heat pump (space conditioning, water heating, dehumidification, and ventilation)
  - Conceptual designs developed for both air-source and ground-source versions
    - Two-speed and variable speed compressor versions; variable speed fans and pumps
    - Potential 50% to 65% energy savings for HVAC/WH vs. suite of individual systems (13 SEER ASHP, 0.9 EF WH, 1.4 EF standalone dehumidifier, whole house ventilation per ASHRAE 62.2)
  - CRADAs in place with two major manufacturers to develop initial products
    - Ground-source version introduced to market in 2012
    - Air-source version by 2013/14

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GS-IHP Equipment Description

- 7.6 kW (26kBtu/h) nominal cooling capacity
- 303 L (80 gal) hot water storage tank with EF rating of 0.94
- 4-zone control system
  - Upstairs
  - Master Bedroom
  - Living Area
  - Basement

GS-IHP Modes of Operation

Mode	Heat Source	Heat Sink
Space Cooling	Indoor Air	Ground Loop
Space Heating	Ground Loop	Indoor Air
Space Cooling plus Water Heating	Indoor Air	Domestic Hot Water
Dedicated Water Heating	Ground Loop	Domestic Hot Water

Prioritizes water heating in the winter unless the indoor temperature falls below a programmable threshold.

GS-IHP Dedicated Water Heating

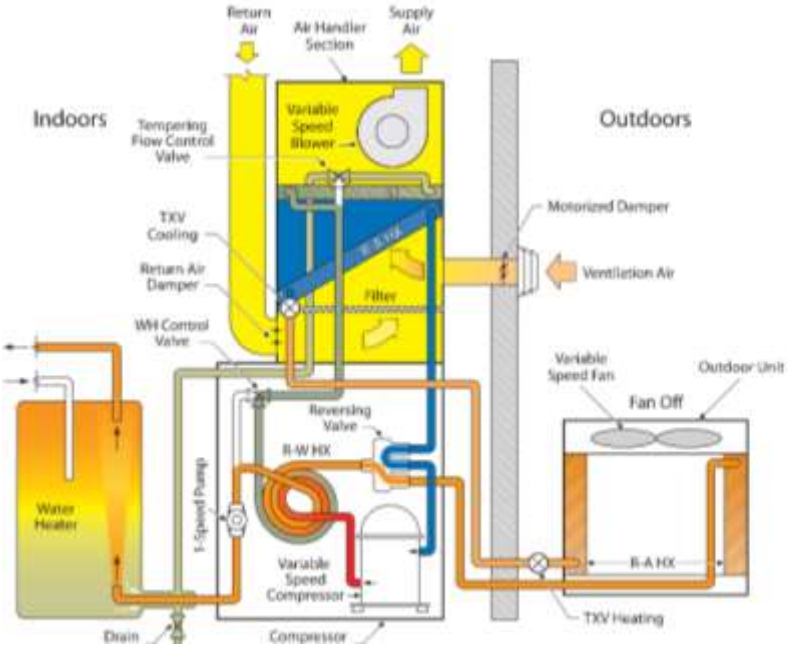
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Average EWT (°C)	21.6	26.9	N/A	24.9	21.6	15.2	11.4	6.7
Average Water Heating Capacity (kW)	3.39	2.77	N/A	3.00	3.72	4.41	4.58	4.77
Average Total Power (kW)	1.44	0.68	N/A	0.76	0.92	1.22	1.39	1.60
Average COP (W/W)	4.0	4.1	N/A	3.9	4.0	3.6	3.3	3.0
Runtime (h)	5.6	2.4	N/A	14.2	35.0	59.0	53.6	62.0

GS-IHP Predicted Annual Performance

		GSIHP	Baseline Equipment	Percent Savings Over Baseline
Space Cooling	COP	4.9	3.7	
	Delivered (kWh)	8432	8432	
	Consumed (kWh)	1707	2298	25.7%
Space Heating	COP	4.1	2.4	
	Delivered (kWh)	10524	10524	
	Consumed (kWh)	2539	4337	41.5%
Water Heating	COP	3.8	1.0	
	Delivered (kWh)	2733	2733	
	Consumed (kWh)	726	2733	73.4%
Total	Consumed (kWh)	4972	9368	46.9%

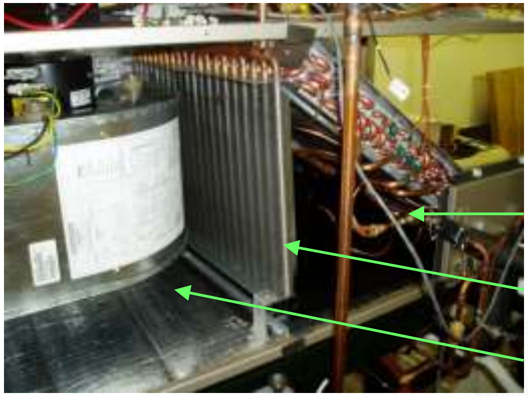
AS-IHP Concept - Nordyne

- **Full integration to heat, cool, ventilate, dehumidify, and heat water as needed**
- **AS-IHP concept, in dehumidification/ventilation/WH mode, shown at right - many modes possible**
  - H or C/ventilation/WH
  - Dedicated water heating
  - Dedicated dehumidification and/or humidification
  - Ventilation air pre-treatment; H in winter, C & dehumidify in spring/summer/fall



- **Lab prototype constructed and tested**

Possible AS-IHP packaging approach



Lab prototype air handler

ref/air HX

water/air HX

blower

The New Face of Water Heating

Future Regulation

Demand Response

Home Connectivity

Big Data

Energy Efficiency

Construction Codes

Renewables

Smart Appliances

HPWH – Potential Benefits Energy and Load Control

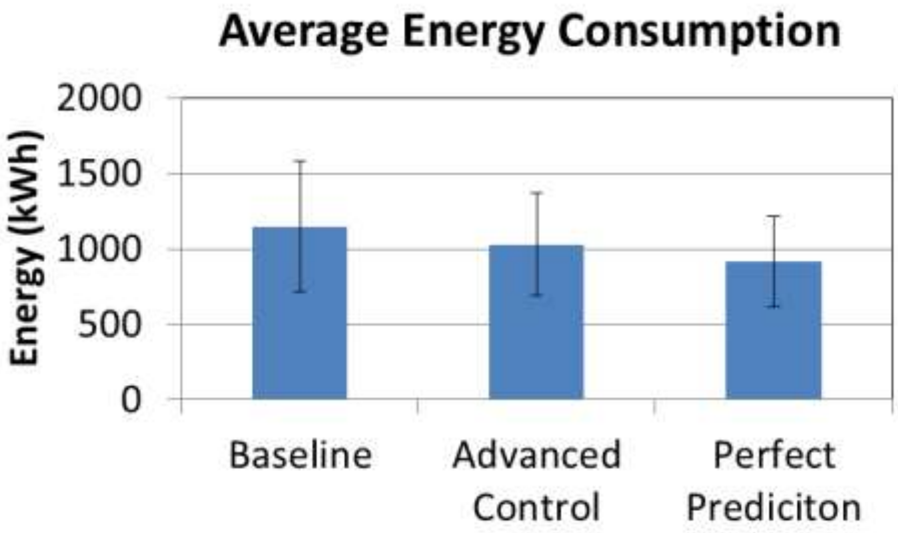
- Potential benefits to homeowner through higher efficiencies
  - research at ORNL has shown efficiency improvements of 9% with potential for up to 19% using advanced control strategies
- Potential benefit to utilities through load shifting and storing excess renewable energy
  - energy consumption during peak periods can be reduced to zero with minimal or no impact on performance
  - heat water when excess renewable energy is available
- Smart controllers can learn consumer (usage) and utility (peak periods) behavior and develop a strategy for controlling tank temperature to meet needs of both

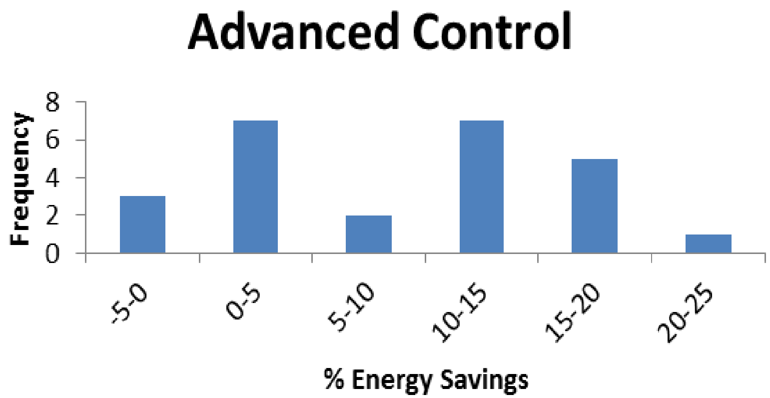
Advanced HPWH Control for Energy Savings

- Maximize energy efficiency of HPWH by eliminating electric resistance use with advanced tank temperature set point control
  - Forecast future water draws
  - Tailor control to homeowner usage and utility requirements
  - Developed set point control algorithm
  - Used hot water draw data from real homes into HPWH computer models to simulate energy savings from advanced control
  - Spot checked modeled results with HPWH in Lab

Advanced HPWH Control – ORNL Test Results

- 25-home study

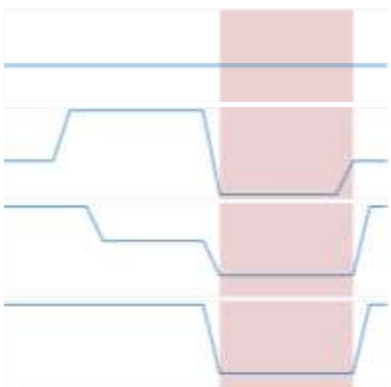




	Advanced Control Savings	Perfect Prediction Savings
Average	8.9%	18.5%
Standard Deviation	7.4%	8.2%
Minimum	-0.8%	3.9%
Maximum	24.4%	39.5%

HPWH Load Shifting – ORNL Test Results

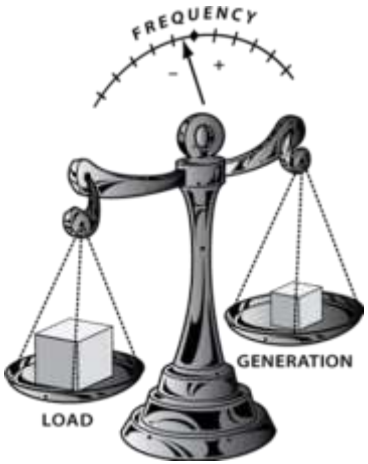
- % of time tank water < 115°F



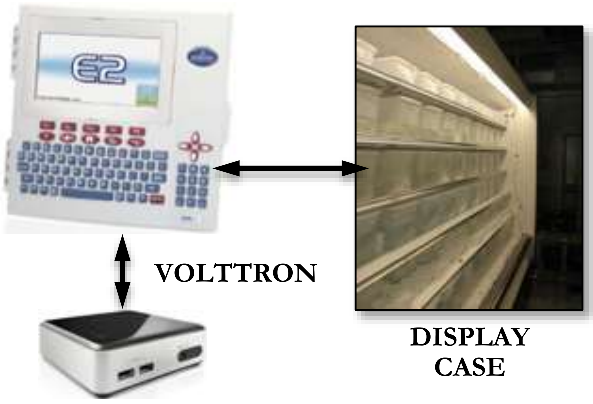
	Low Water Consumption (kWh)	Medium Water Consumption (kWh)	High Water Consumption (kWh)
Baseline	5%	9%	5%
Schedule 1	0%	0%	1%
Schedule 2	0%	5%	1%
Schedule 3	0%	0%	0%

Transactive Energy – Energy Efficiency & Grid-Responsive

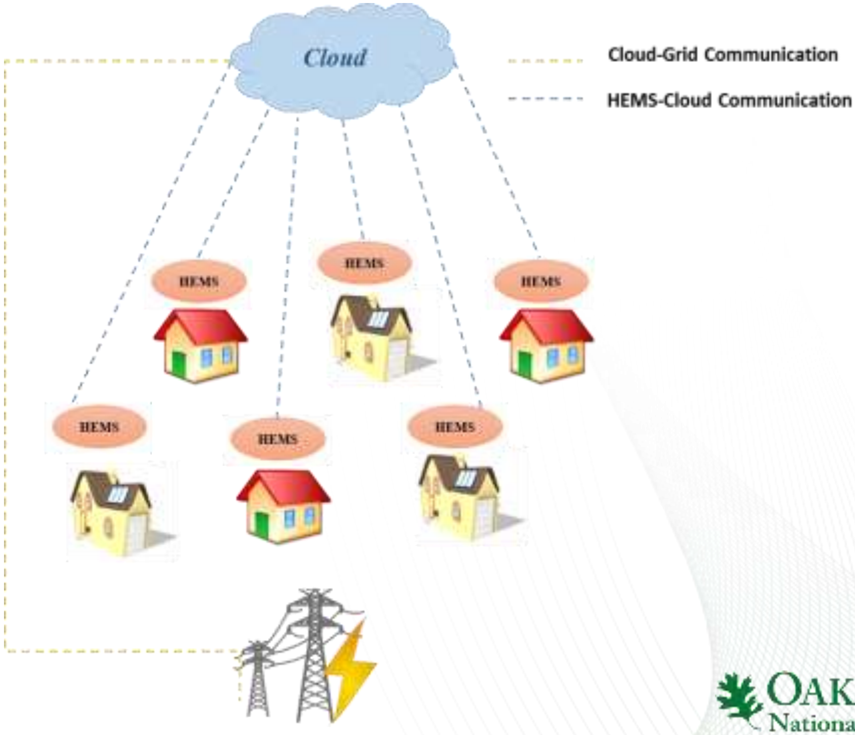
- High-speed wide area control of loosely coupled loads
- VOLTTRON Platform
  – Unlocking load control potential
  – Demonstrated in supermarket application



Buildings projected to be 80% of load growth through 2040



EMERSON
Climate Technologies



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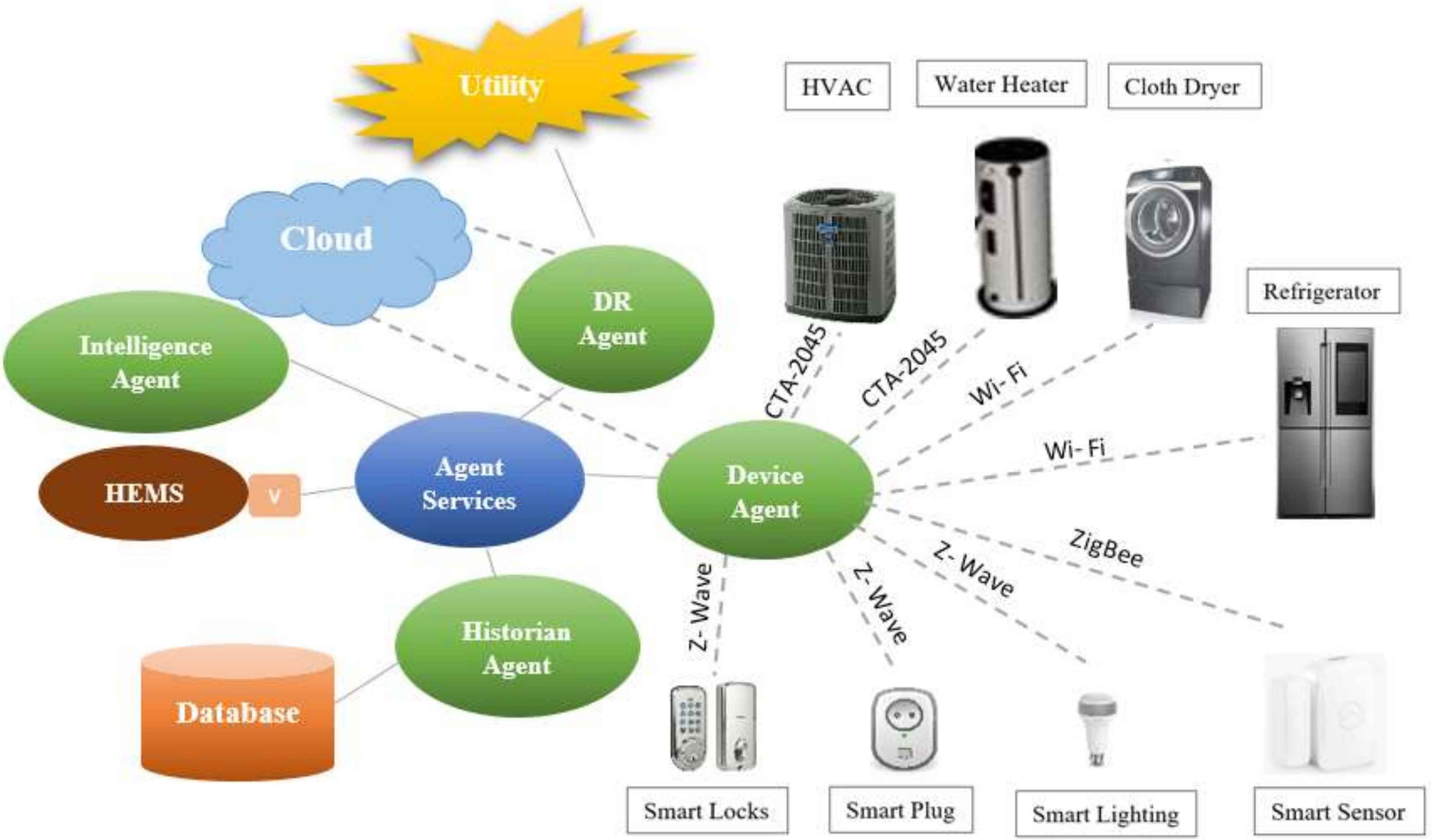
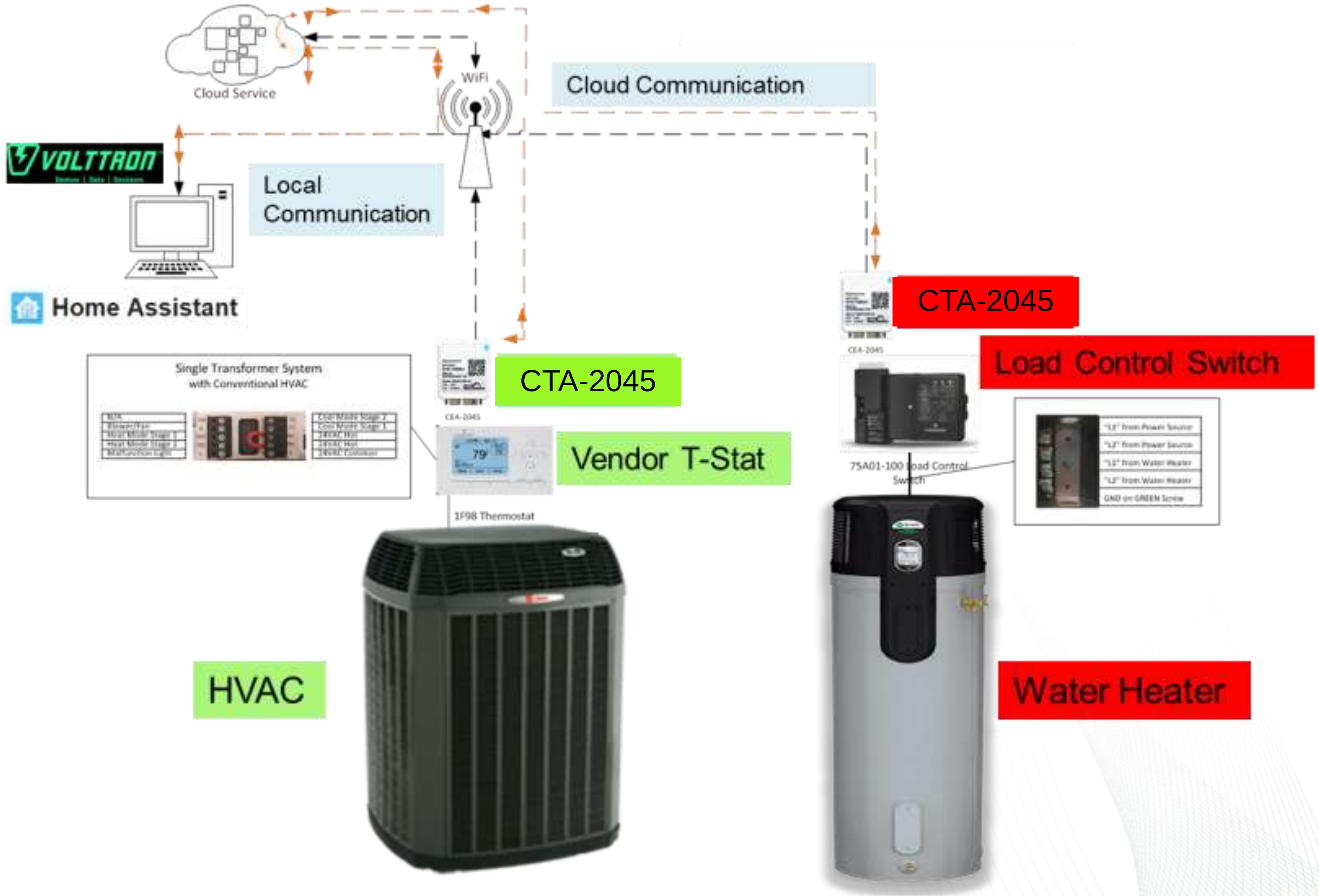
Approach – Coordinated Control of Major Loads in Home



Approach – Employ Cloud and Local Communication



Key Accomplishments

HVAC/WH Connections

- Obtained hardware (CEA-2045 plug, Emerson (White Rodgers) thermostat, A.O. Smith load control switch
- Evaluated communication options
  - vendor cloud service
  - local communication
- Established connection with Emerson T-stat and CEA-2045 plug using SkyCentrics cloud service
- Established connection with Emerson T-stat locally

Key Accomplishments

- Completed end-to-end communication with HVAC and water heater and demonstrated HVAC/WH control in laboratory and house
- Developed demand response control algorithms
- Developed fault detection capability

Next Steps and Future Plans

- Test functionality, reliability, and energy/demand control/cost savings
- Develop partnerships and expand homeowner amenities
  - Southern Company Neighborhood of the Future
- Add additional devices/ components to the HEMS
  - lighting
  - security