Self Consuming PV with thermal Energy Storage

≤1kW PV micro-grid

Babak Hamzavy
3/21/2018

Outline

- Southern Research Institute
- Southern Research Collaborative project
- Hot Water Heater Pump Early studies and proof of concept
- Southern Research approach and configuration
- Data from EIA on heating and cooling in the US.

Southern Research: Overview

- Southern Research is a non-profit 501(c)(3) organization with nearly 500 scientists and engineers working across four divisions:
  - Drug Discovery
  - Drug Development
  - Engineering
  - Energy & Environment
- With Alabama Power chief Tom Martin driving the push, nearly 80 business and industrial leaders signed up as incorporators of the new research institute in 1941
- Southern Research is headquartered in Birmingham, Alabama, with additional laboratories and offices in:
  - Wilsonville, AL
  - Frederick, MD
  - Durham, NC
  - Houston, TX
  - Cartersville, GA

Southern Research: E&E Division

Food, Water, Energy

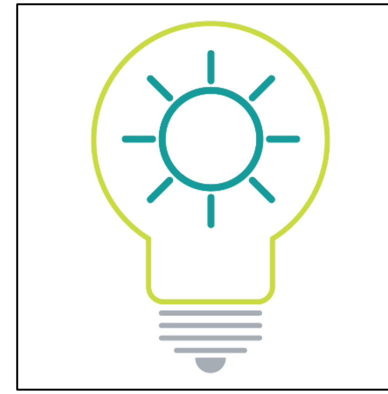
Ongoing efforts to create process models to optimize efficiency and improve economics of food production. We are actively engaged with our partners in search of innovative, long-term solutions to lead food production into the future.

Clean Water

Developing technology to ensure the adequate supply of clean, safe water for the next generation. Technologies include: industrial wastewater treatment, continuous water quality monitoring devices, biological systems for salinity management, among others.

Resource Recovery

At Southern Research, we're developing technologies for generating energy and recovering valuable resources from waste streams and other non-traditional sources.



Thermal and Renewable Systems

SR is committed to leading the development of thermal energy storage for grid-scale electricity generation via CSP.

SR has developed a business focused on testing and development of distributed energy generation and storage systems.

Southern Research: E&E Division

Sustainable Chemistry and Catalysis

We're currently developing a process for a biomass derived sugars conversion to acrylonitrile and other alternative fuels. SR has developed a new business focused on development of catalysts, sorbents and sustainable processes utilizing these materials.

Advanced Fossil Energy

We are actively engaged with our partners to develop new carbon capture technologies, optimize trace metal emission controls, reduce water consumption, convert coal to liquid fuels, and improve combustion efficiency to reduce carbon emissions.

Nuclear

Southern Research is working to usher in the next generation of innovative nuclear reactor designs that are simpler than their predecessors and benefit from over half a century of experience.

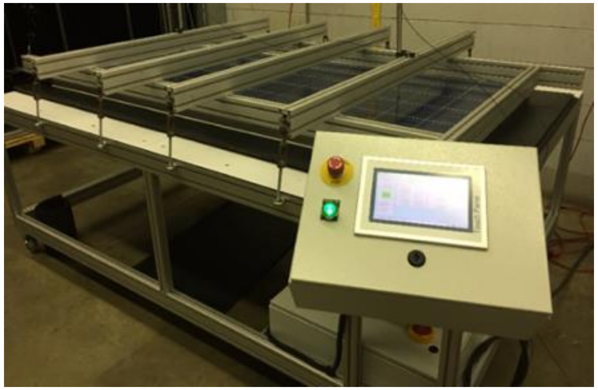
Energy Storage

SR, with the utility and energy storage industry, academia, government, and tech vendors, is home to the new Energy Storage Research Center (ESRC) which will develop joint ES research, demo and test projects focused on the SE as well as the U.S. overall.

Southern Research Current Collaborative Program

- DOE Funded project (DE-EE0007137) "Novel Accelerated Aging Protocols for Photovoltaic Modules."
- Physics of PV module degradation and power loss.
- The service environment performance assessed and correlated with qualification standard test protocols.
- EPRI, Sandia National Labs, Southern Company Service, and Southern Research

Southern Research PV laboratory



- Pasan Solar simulator.
  - Instrumentation and fixture to IV curve trace up to utility scale PV panels at any angle.
- Electroluminescent imaging
- IR thermography.
- Low Force Vibration tests using a Spectral Dynamics Inc., Model: SD-1510 230M/ SPA602 /ACU402.
- Environmental chamber capable of thermal cycling (-40°C to +160°C, in conjunction with high RH).
- Kipp and Zonen outdoor UV monitoring capability
- Light fixture for UV exposure under controlled environmental conditions.

Existing and Future Test Pads: ESRC

Thermal Energy Storage

Self Consuming PV micro grid

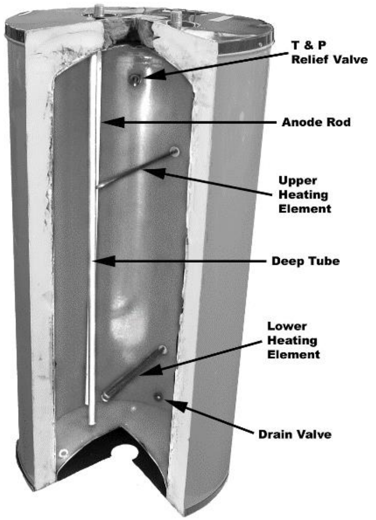
+

Heat Pump Water Heater

Electric Water Heating Technologies

Electric Resistance Storage

- Maximum Efficiency of 1
- Typical input ~ 4000 W
- Typical residential size ~ 50 gal. (190 L)



Electric Resistance Instantaneous

- Maximum Efficiency of 1
- Requires Large Inputs: 12 kW to 60 kW
- Eliminates standby loss

Heat Pump Water Heater

- Coefficients of Performance of 3+
- Provides space cooling
- More expensive

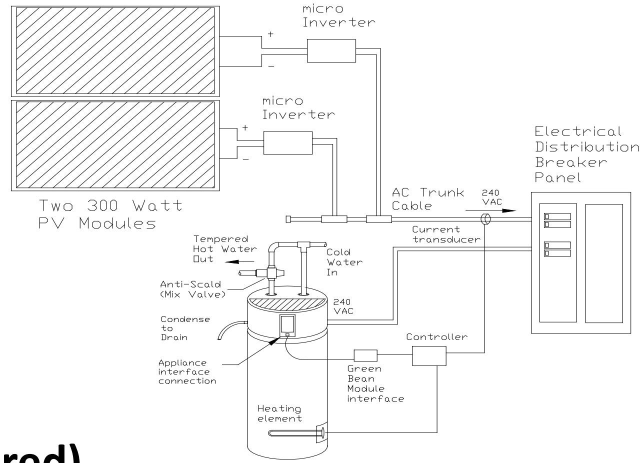
PV-Heat Pump Water Heater
Background studies and Proof of concept

- Jeff Maguire *et al* at NREL (National Renewable Energy Laboratories), “Regional Variation in Residential Heat Pump Water Heater Performance in the U.S.” 2013
- https://aceee.org/files/pdf/conferences/hwf/2013/1C-slater.pdf
- Tim Merrigan National Renewable Energy Laboratory, Intersolar North America 2015
- Carlos Colon *et al* at FSEC (Florida Solar Energy Center), “PV-Driven Heat Pump Water Heater FSEC-CR-2043-16.” 2017

Prototype Overview: PV-HPWH

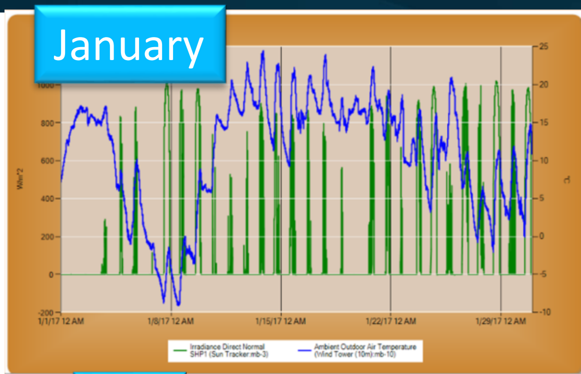
Testing at Florida Solar Energy Center (FSEC) Hot Water Systems Laboratory

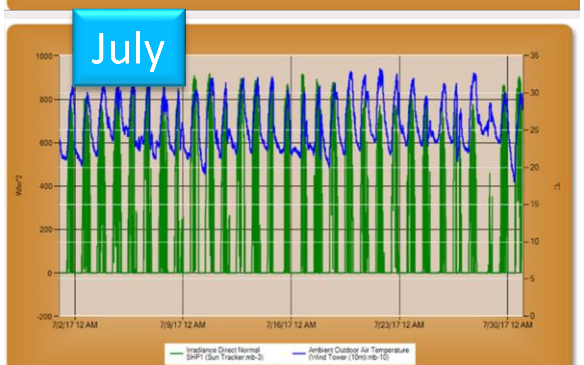
- Current gen: HPWH COP ~2.5
- Add dedicated 620 W PV
- Single axis (tilt) tracking
  - Maximize seasonal output
  - Max. PV output in winter when loads greatest
- Programmed thermal storage
  - Normal tank set: 52 C
  - When solar availability hi, set tank temp to 70 C
- <u>Lower cost than solar thermal; similar performance</u>

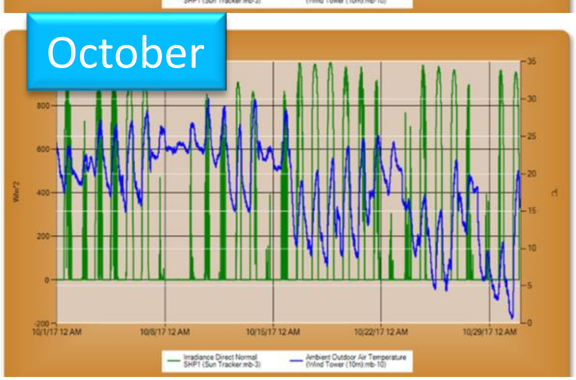


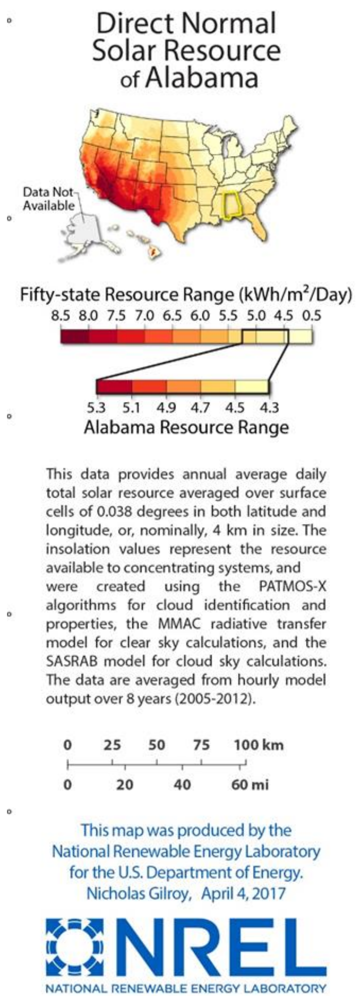
PV-driven HPWH (AC-powered)

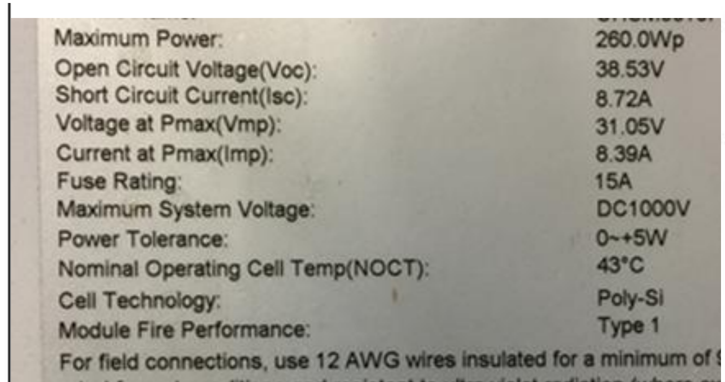
SR Novel Micro Grid Application PV + Storage (thermal + electrochemical)









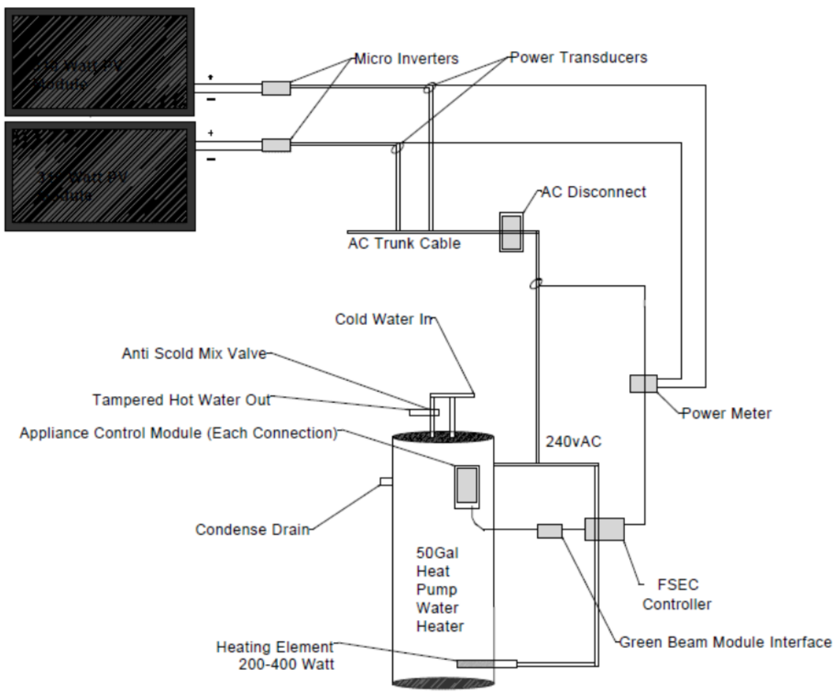


Maximum Power:	260.0Wp
Open Circuit Voltage(Voc):	38.53V
Short Circuit Current(Isc):	8.72A
Voltage at Pmax(Vmp):	31.05V
Current at Pmax(Imp):	8.39A
Fuse Rating:	15A
Maximum System Voltage:	DC1000V
Power Tolerance:	0~+5W
Nominal Operating Cell Temp(NOCT):	43°C
Cell Technology:	Poly-Si
Module Fire Performance:	Type 1

For field connections, use 12 AWG wires insulated for a minimum of

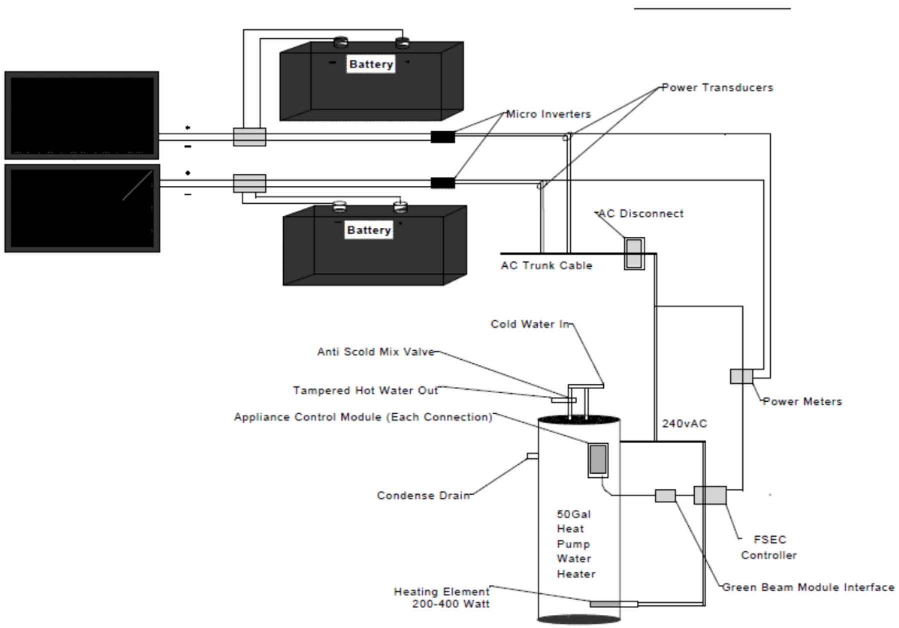
South Facing (Fixed Tilt 10 deg)

Phase 1-Southern Research HPWH configuration



- Phase I duplicating work by NREL/FSEC using the next generation water heater as an example high COP values.
- Long term effects of component degradation (No external Power)
- Efficiency without external power
- Water temperature feasibility/thermal cycling without external input power
- Impact on efficiency based on SE weather fluctuations.
- Gauging the amount of cooling supplied by the system.
- Developing a better understanding of delivery pipe ID and length impact on flow and heat pump water heater efficiency.

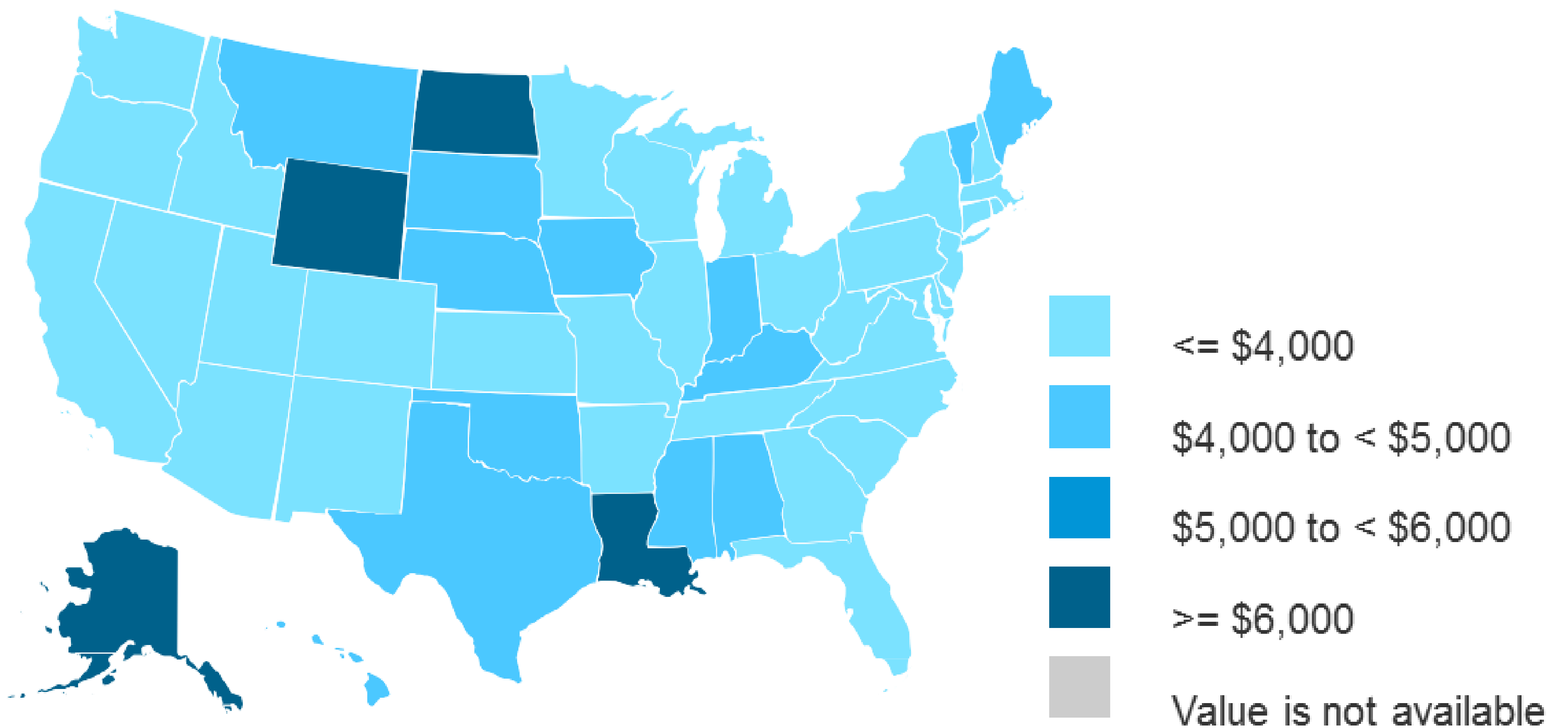
Phase II (augmented with Electrochemical Energy Storage)



- Configuration takes into account an Energy Storage Element.
- Battery (as a function of technology)
- Control system harmonizing various ESS into the configuration
- Max duration storage
- Battery size as a function of the weather.
- Heat loss per PV hours off and battery SOC
- Maintain water temp and charge battery
- Compressor load on the system
- Different irradiance scenarios with respect to the weather conditions.
- Battery size as a function of use cases and battery technology

Heating, Cooling statistics in US
EIA data

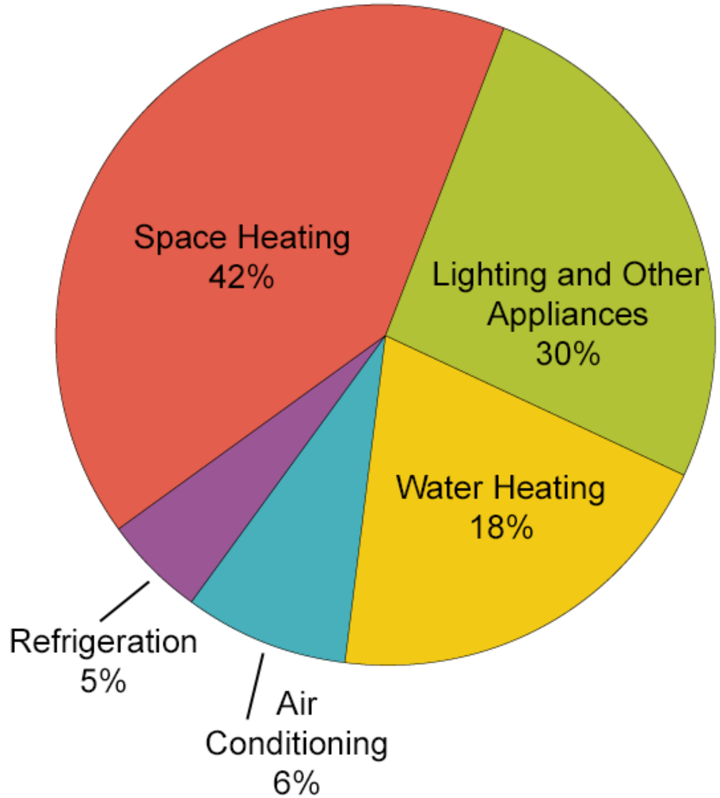
Rankings: Total Energy Expenditures per Capita, 2015



United States Energy Consumption (Region)

Region	Number of Customers	Average Monthly Consumption (kWh)	Average Price (cents/kWh)	Average Monthly Bill (Dollar and cents)
Pacific Noncontiguous	714,201	539	24.36	131.24
New England	6,290,389	616	18.81	115.93
East South Central	8,248,665	1,198	10.86	130.20
West North Central	9,345,853	917	11.79	108.13
Mountain	9,529,171	848	11.65	98.80
West South Central	15,687,117	1,154	10.59	122.17
Middle Atlantic	15,964,597	698	15.68	109.50
Pacific Contiguous	18,137,554	648	14.59	94.58
East North Central	19,937,976	785	13.06	102.55
South Atlantic	27,213,237	1,107	11.56	127.97

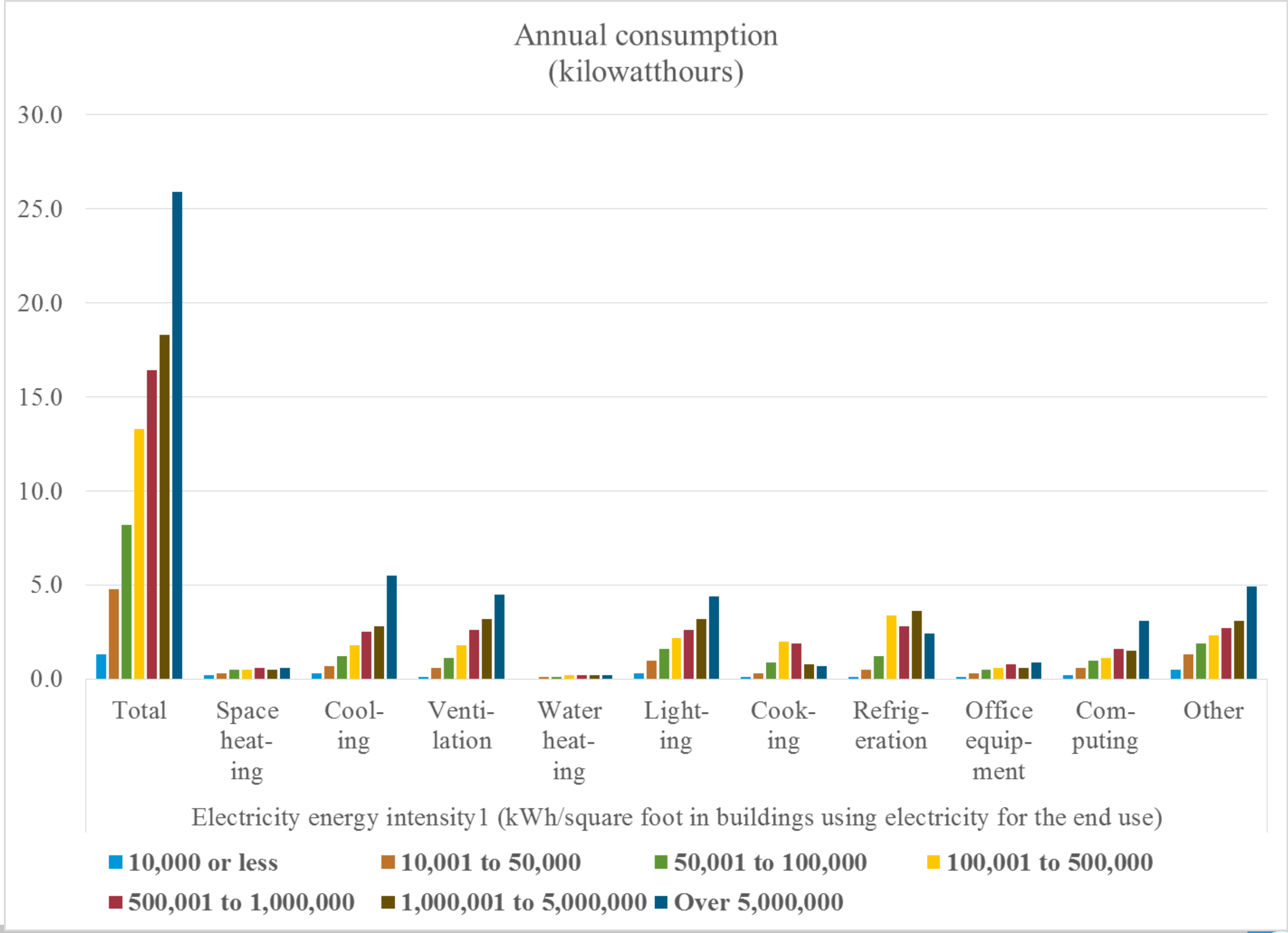
How Energy Is Used in Homes (2009)*



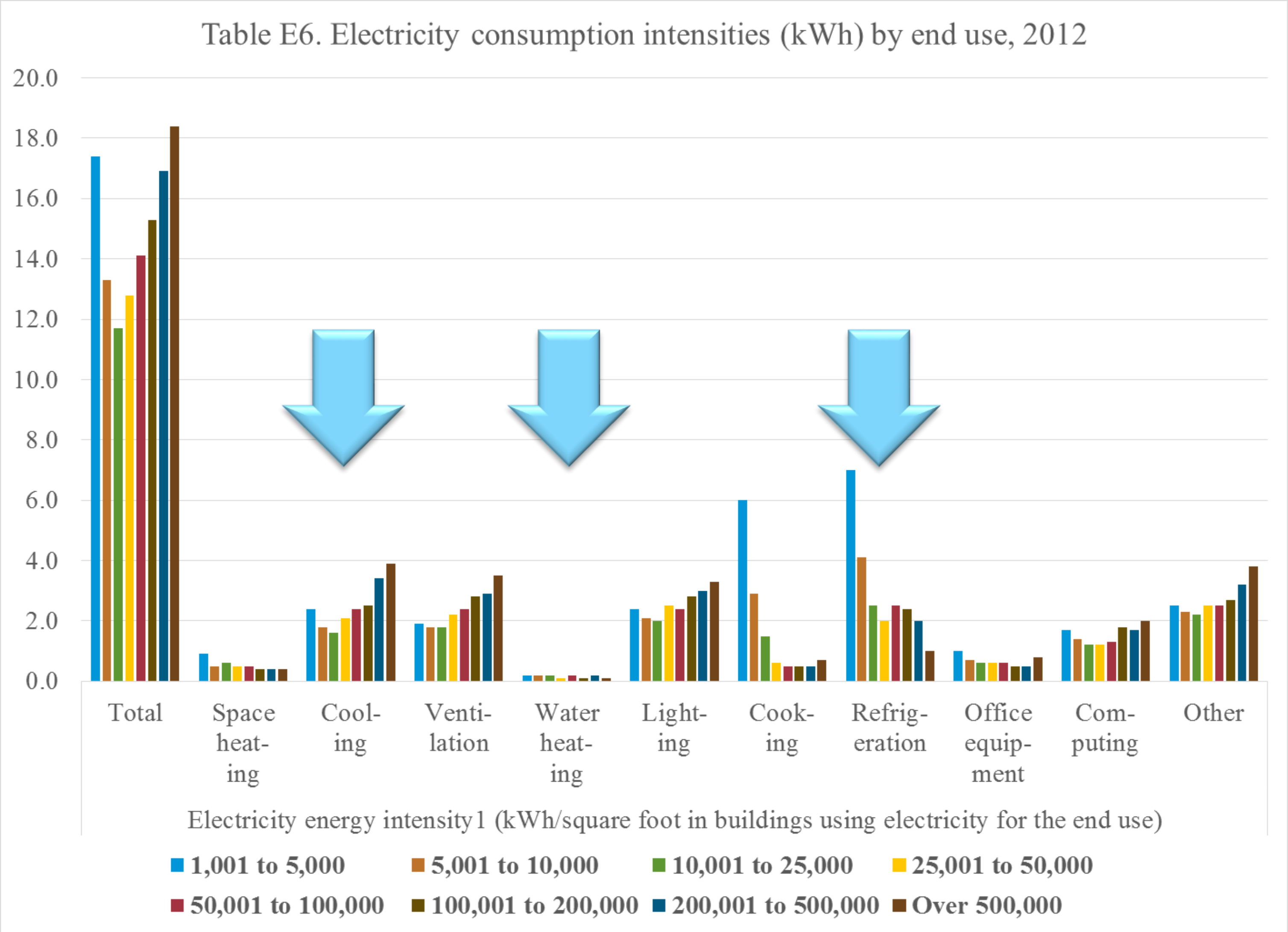
* 2009 is the most recent year for which data are available.

Source: U.S. Energy Information Administration, *Residential Energy Consumption Survey (RECS) 2009*.

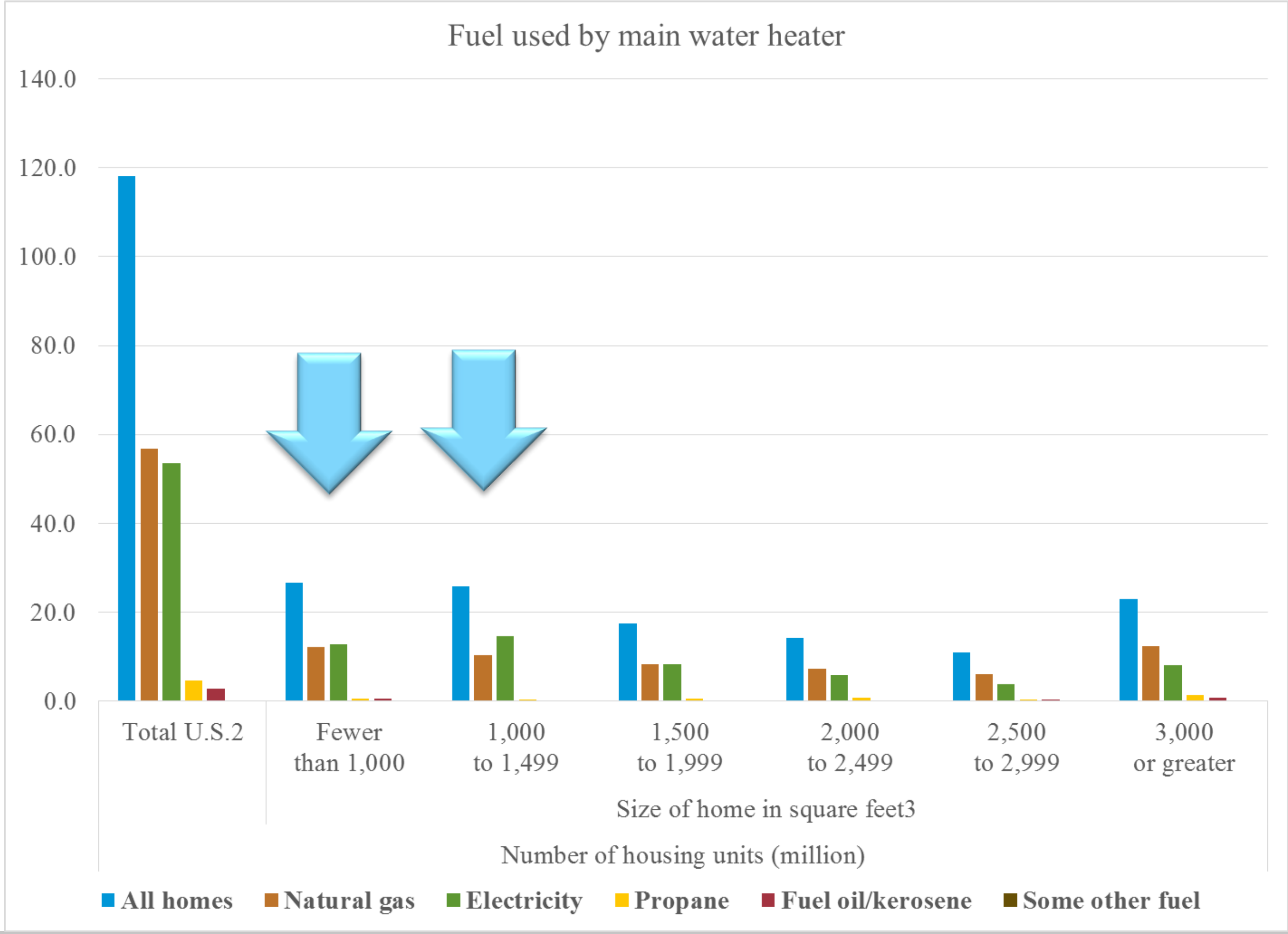
Annual consumption (kilowatthours)



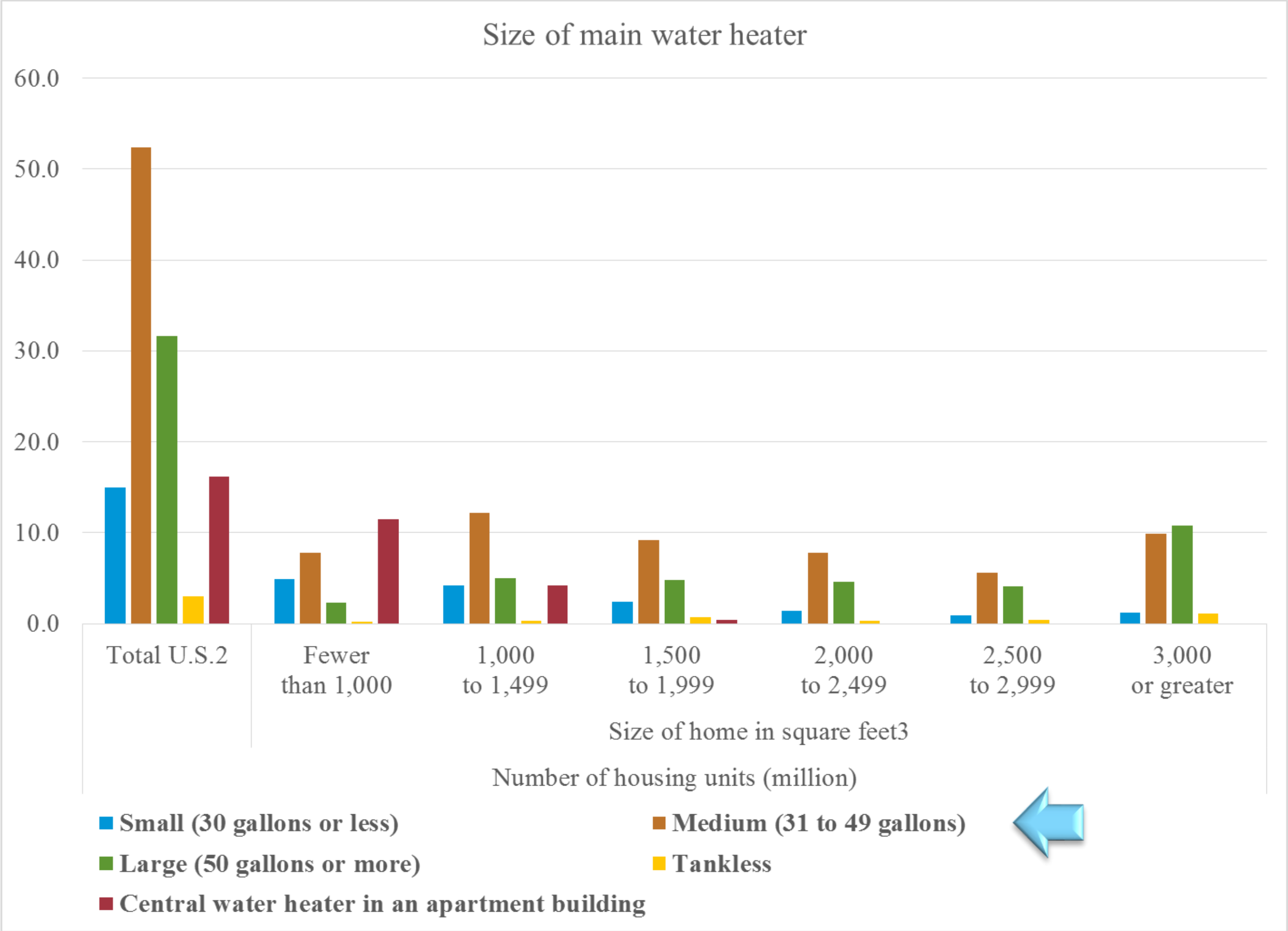
Consumption Intensity (Building Foot Print)



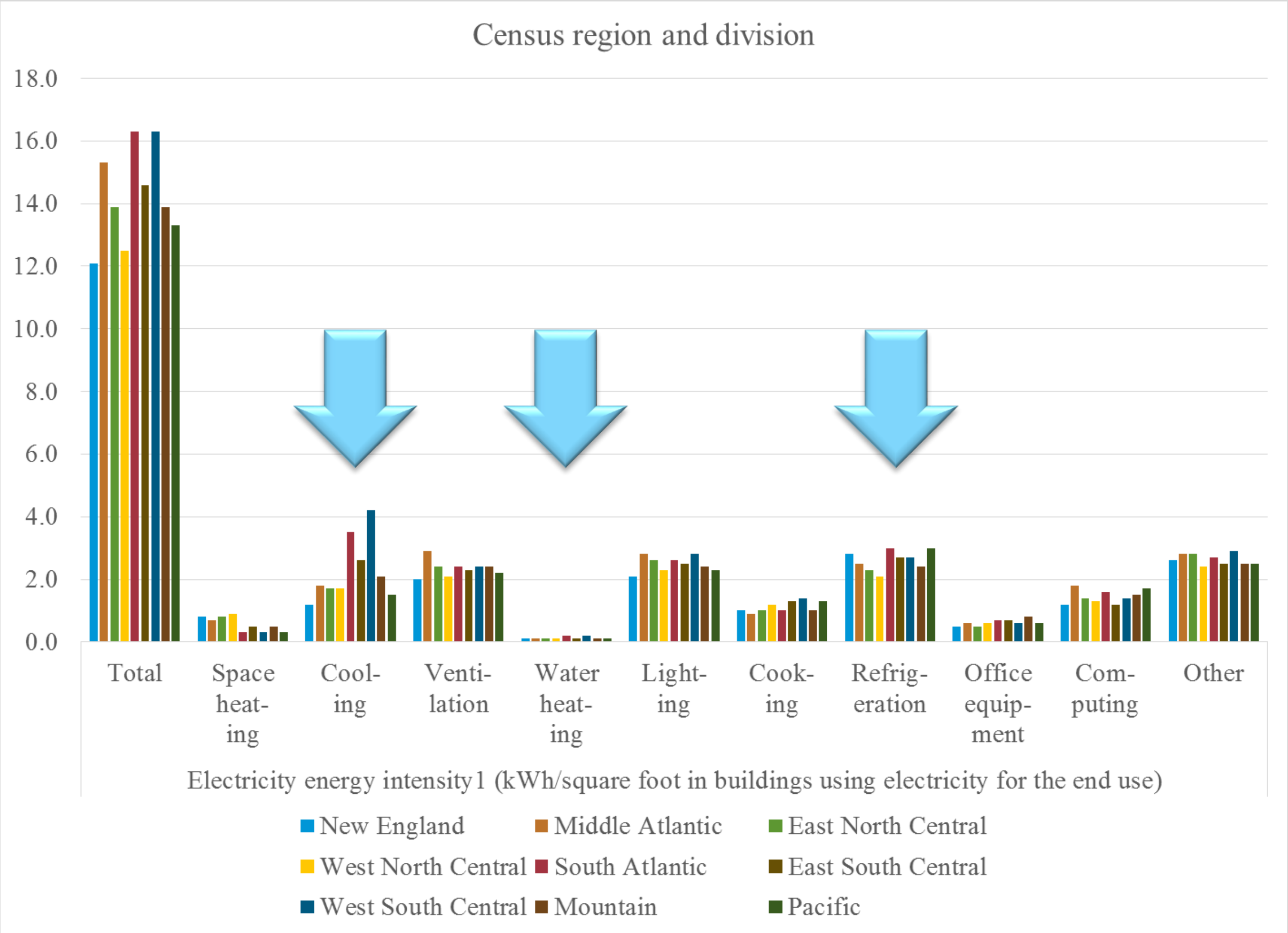
Main Water Heater Fuel Source



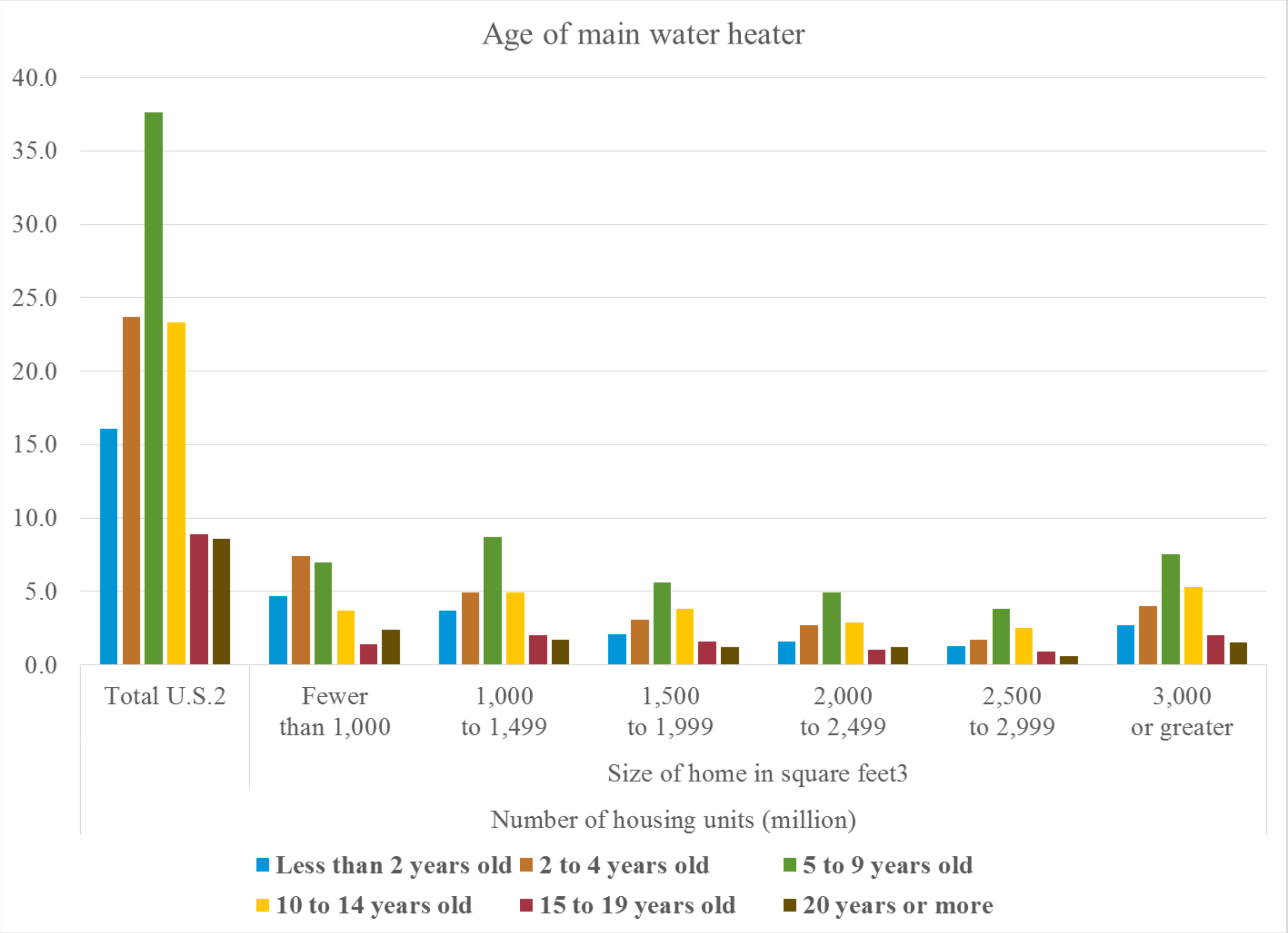
Water Heater By Size



Consumption Intensity (Region)



Main Water Heater by Age



Some thoughts

- In terms of energy intensity cooling and heating are more significant
- Potential for innovation is more impactful and possibly salient in refrigeration, heating and ventilation.
- These areas may be more critical to growth and new applications

Thank you For your attention