ARPA-E GENSETS Program

GENerators for **S**mall **E**lectrical and **T**hermal **S**ystems

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Program Director
Advanced Research Projects Agency – Energy (ARPA-E)
U.S. Department of Energy

GENSETS Kickoff Meeting, October 21-22, Chicago

Meet the ARPA-E GENSETS team

Ji-Cheng (JC) Zhao
Program Director

John Tuttle
Senior T2M Advisor

Gokul Vishwanathan
Technical SETA

AnneMarie Lewis
Technical SETA

Aron Newman
Technical SETA

Jessica Kaplan
Programmatic SETA

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Programmatic SETA

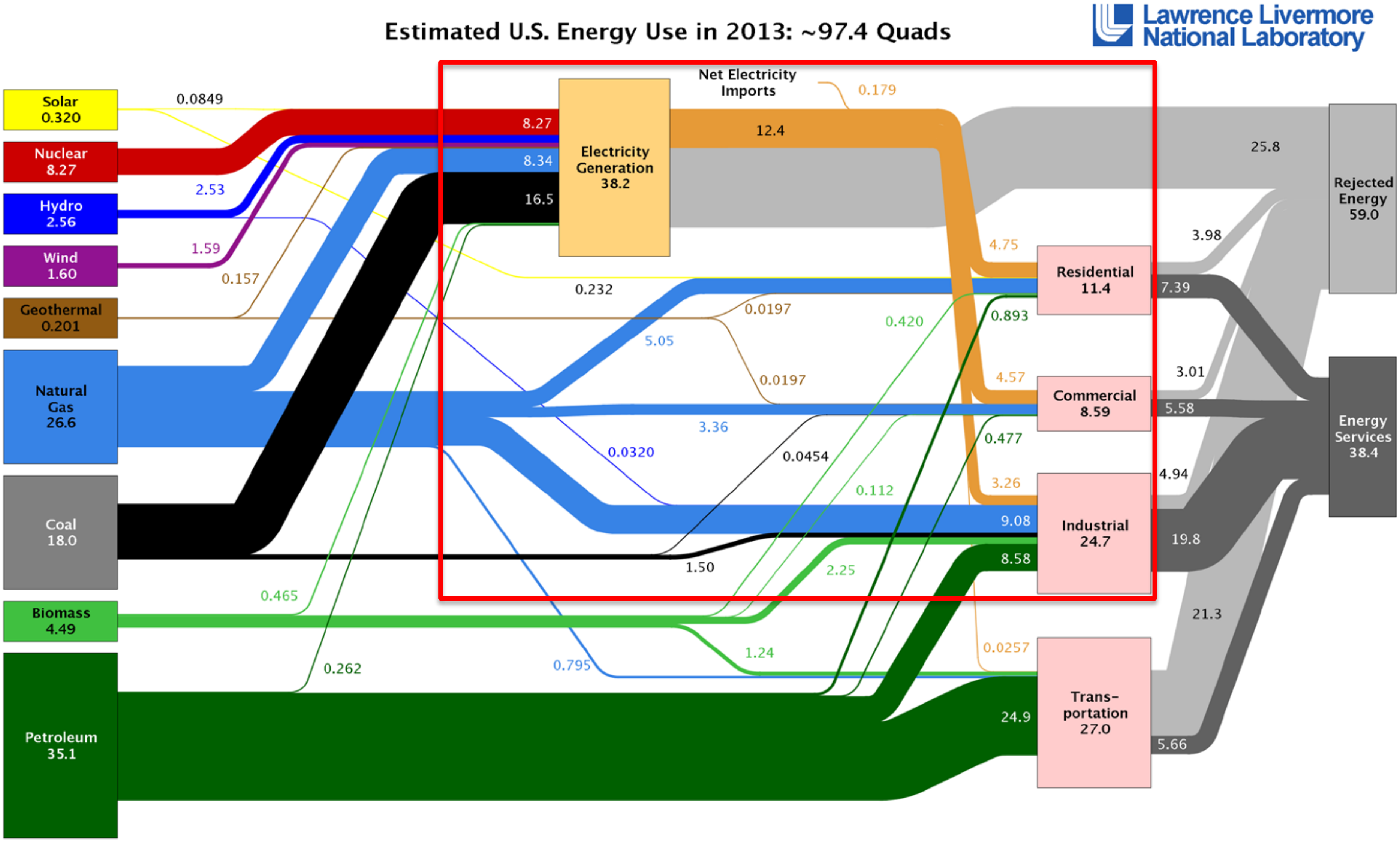
Cybil Redmond
Programmatic SETA

Ashwin Salvi
Fellow

William Regan
Former Fellow

Thank Bryan Willson and Chris Atkinson for their help!

US annual energy use (2013 data)



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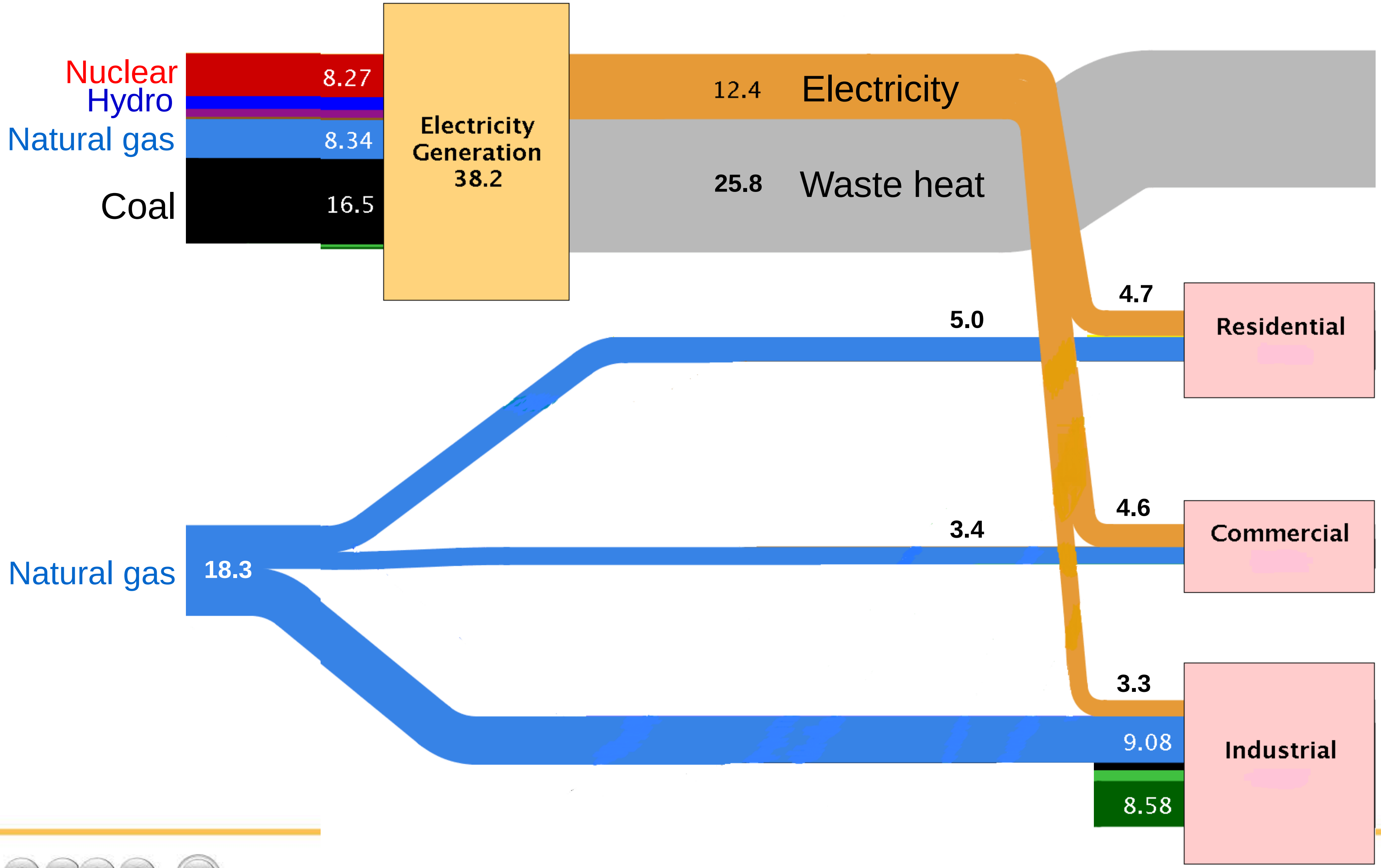
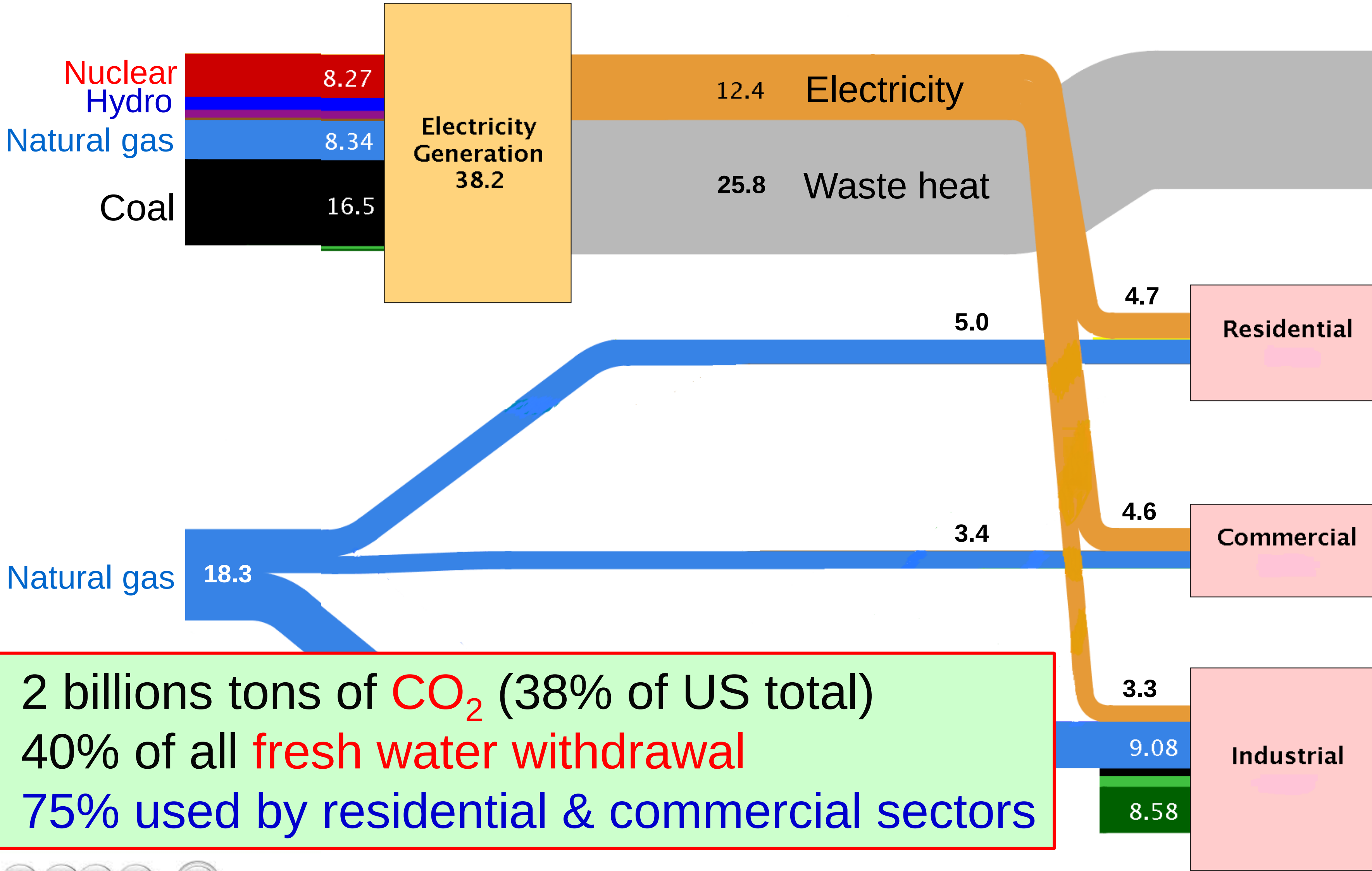
1 quad ≈ 300 TWh ≈ 300,000 GWh ≈ 300,000,000 MWh

US annual electricity generation statistics



Simplified 2013 data *Sources: LLNL, EIA, EPA*

US annual electricity generation statistics



- 2 billions tons of CO_2 (38% of US total)
- 40% of all fresh water withdrawal
- 75% used by residential & commercial sectors

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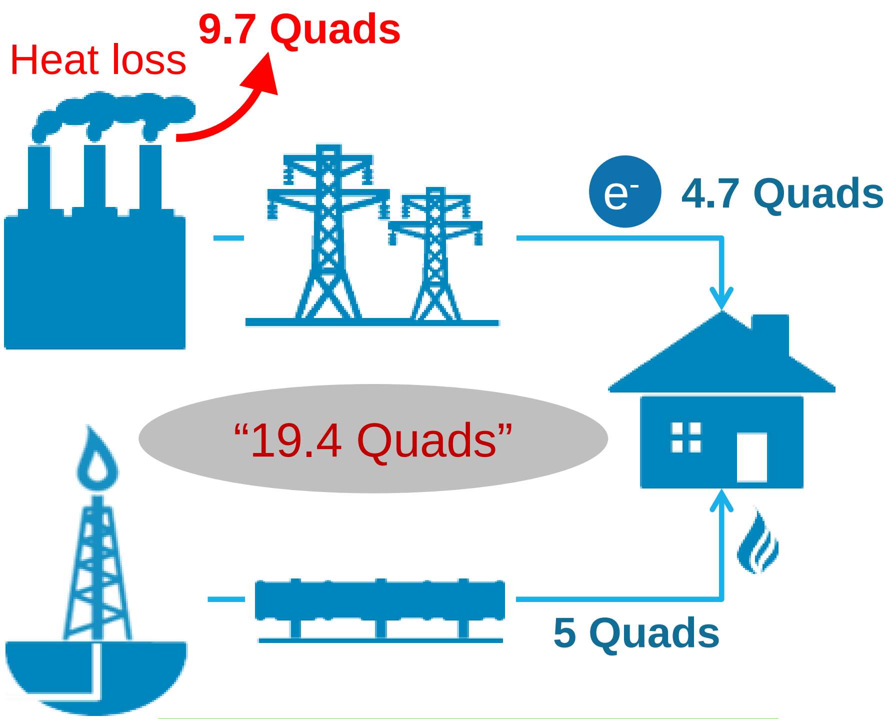
Simplified 2013 data *Sources: LLNL, EIA, EPA*

US residential sector annual energy use

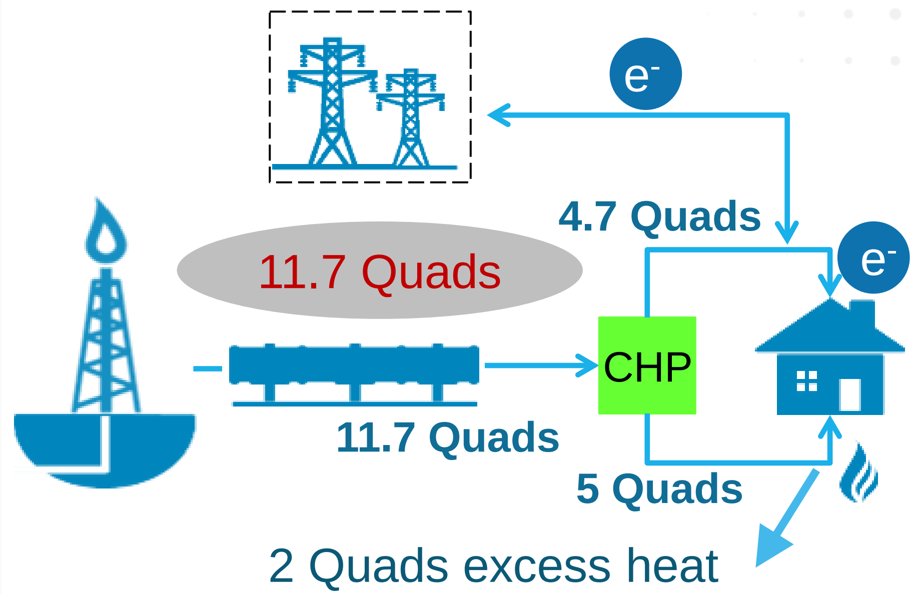
Centralized Electricity Generation



Overall efficiency: 50%

Combined Heat and Power (CHP)

40% electrical efficiency



Overall efficiency: 83%

- 2.5 quads of energy savings potential
- 200 millions tons of CO_2 reduction (4% US total ≈ 40 M cars)
- 4% reduction of US fresh water withdrawal

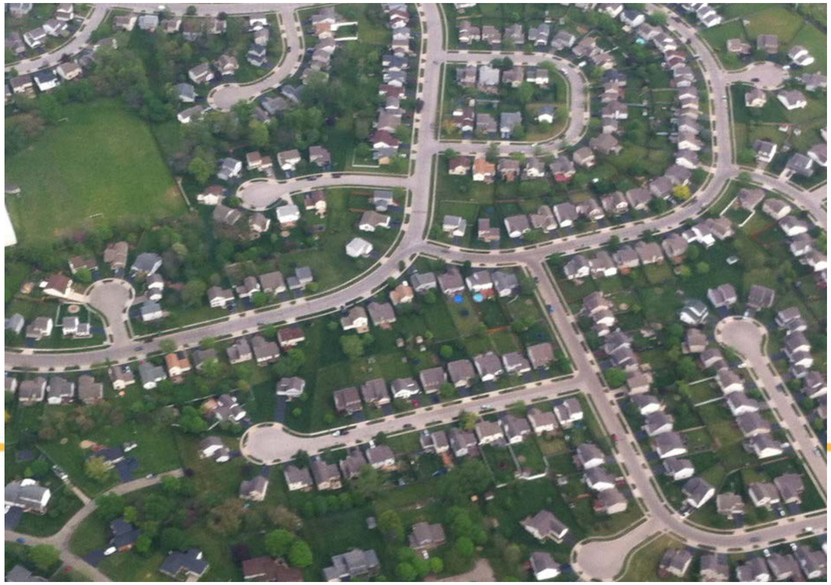
Why haven't you bought a generator for your home?

~ 500,000 US homes have backup generators

<1,000 of 110,000,000 US homes have CHP systems

- Low fuel to electricity efficiency (<26%)
- High cost for long durability ones (>$6,000)
- Low lifetime for low-cost generators (<1 yr)
- Large kW size than optimal

70 million US homes have piped-in natural gas already



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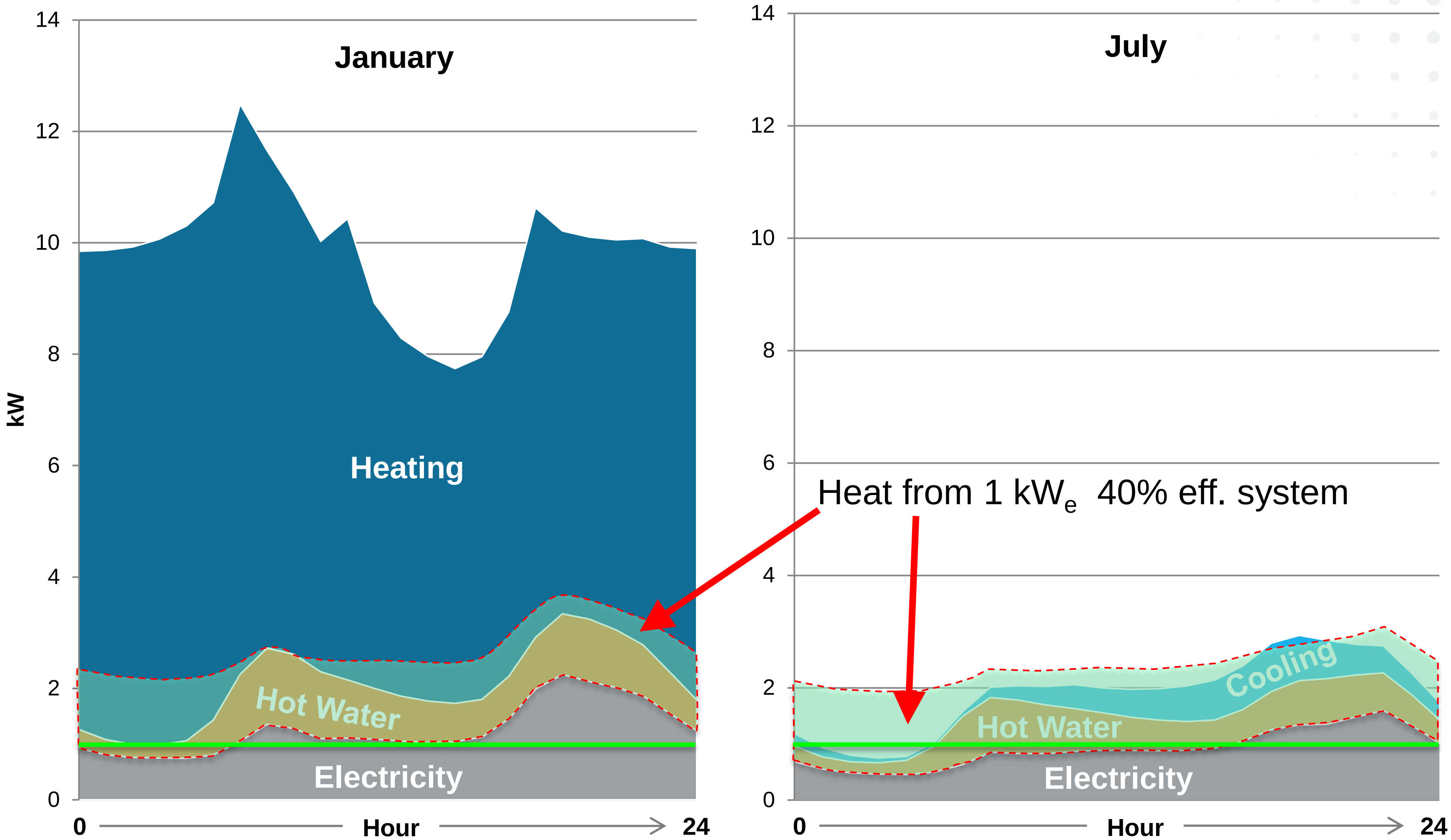
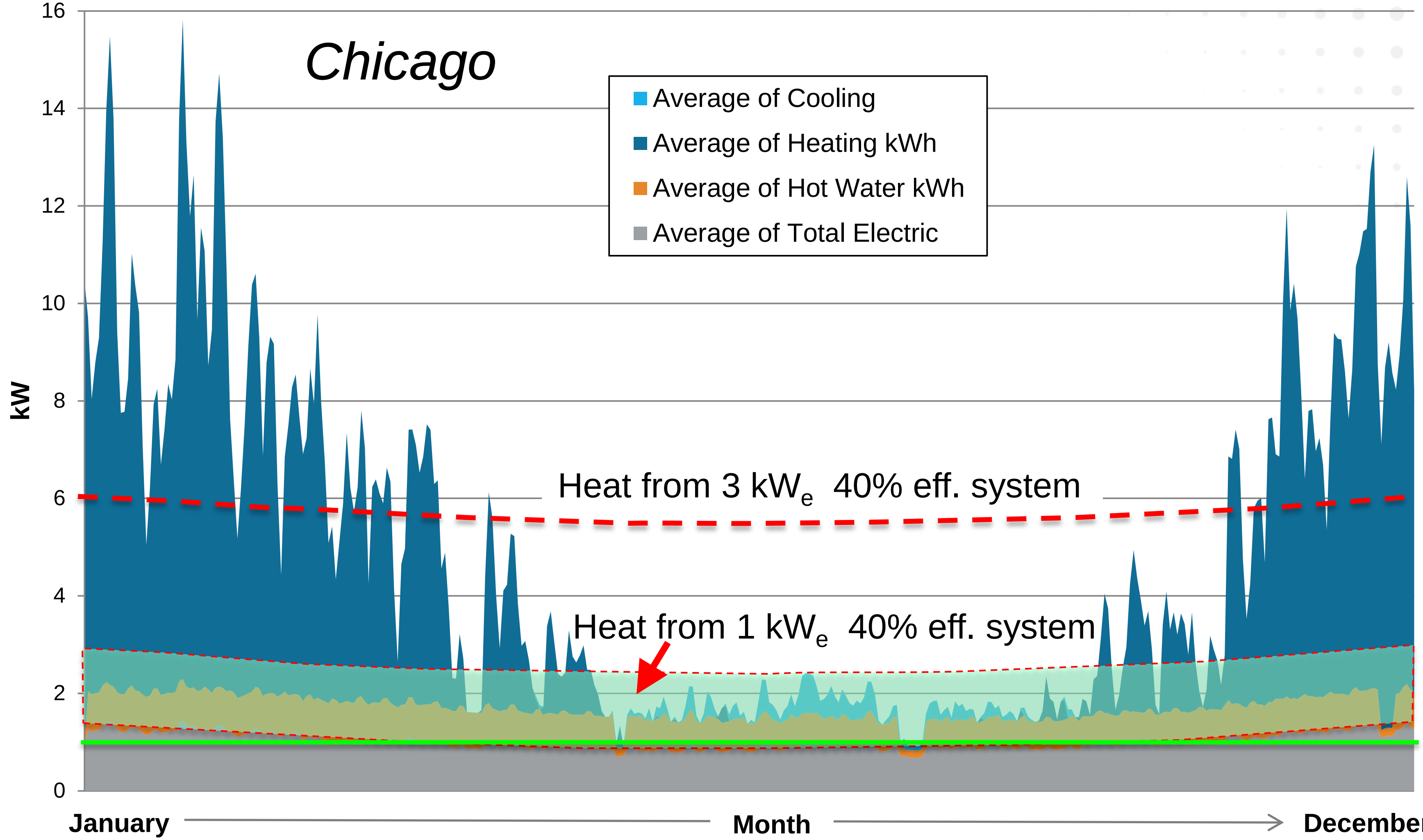
Hourly residential load profile: Chicago



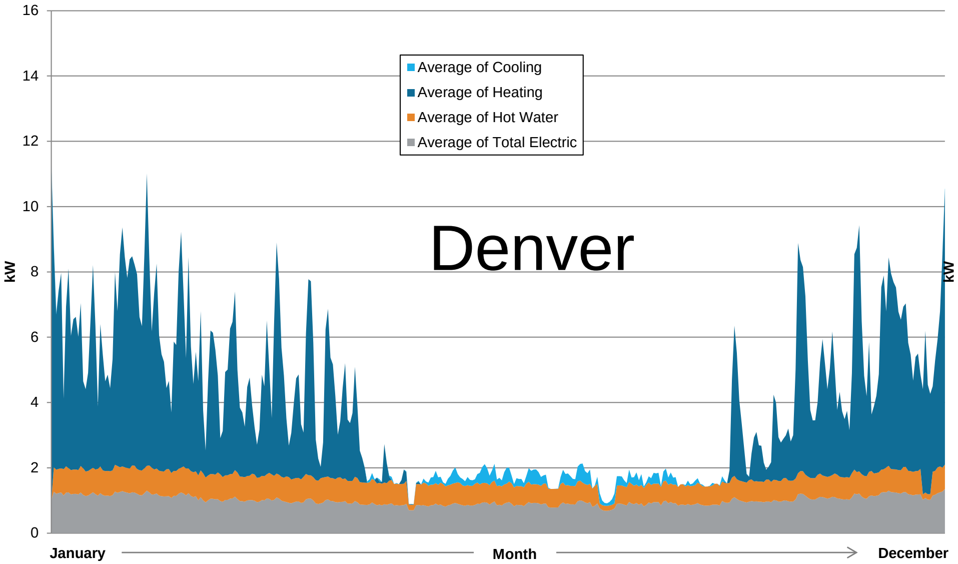
Source: NREL BEopt

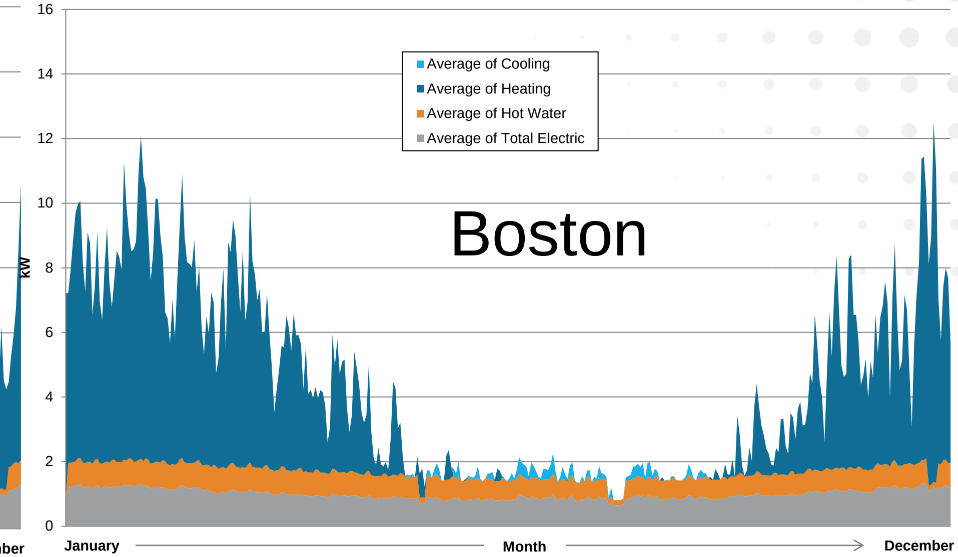
Annual residential load profile: Chicago

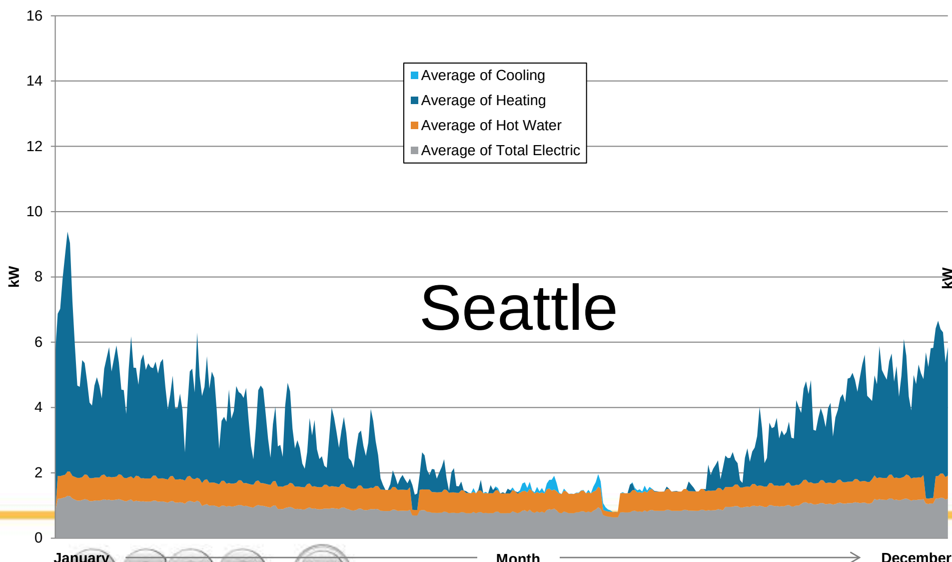


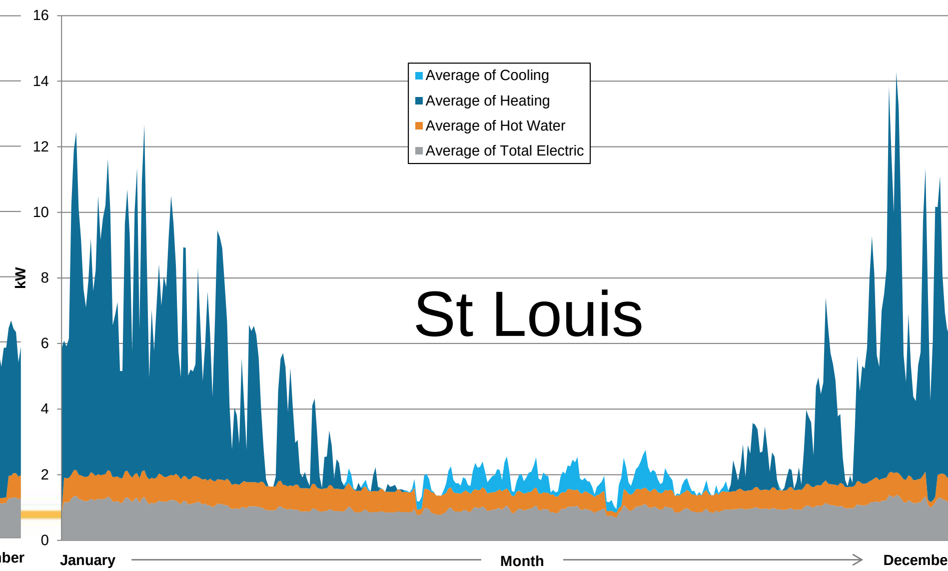
Source: NREL BEopt

Annual residential load profiles









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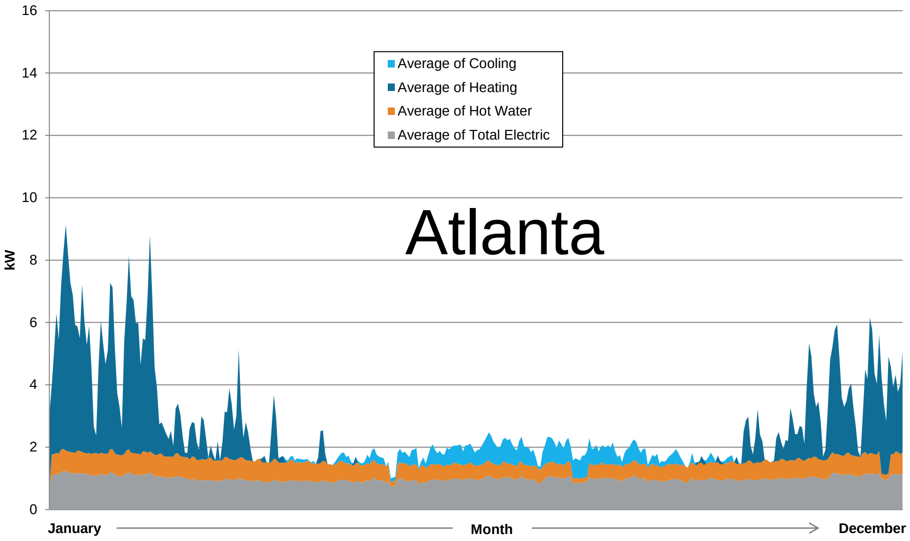
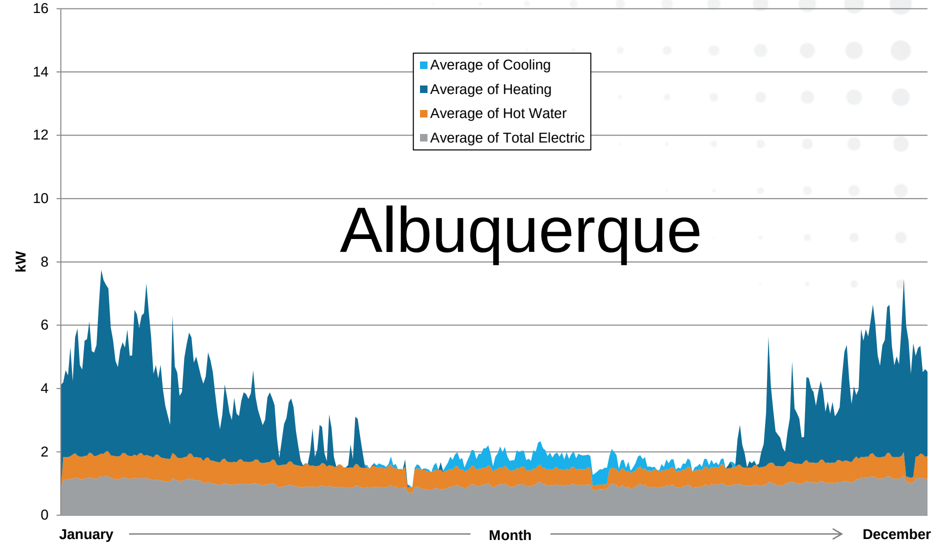
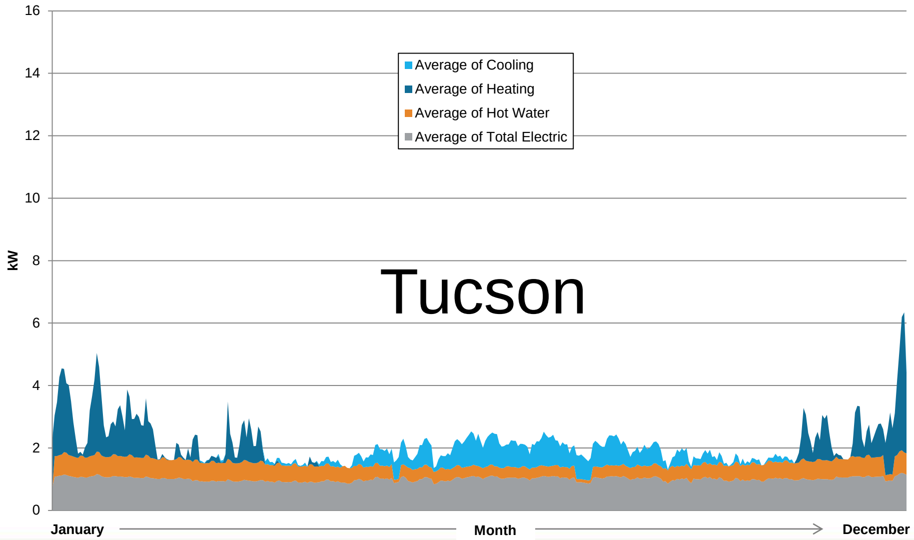
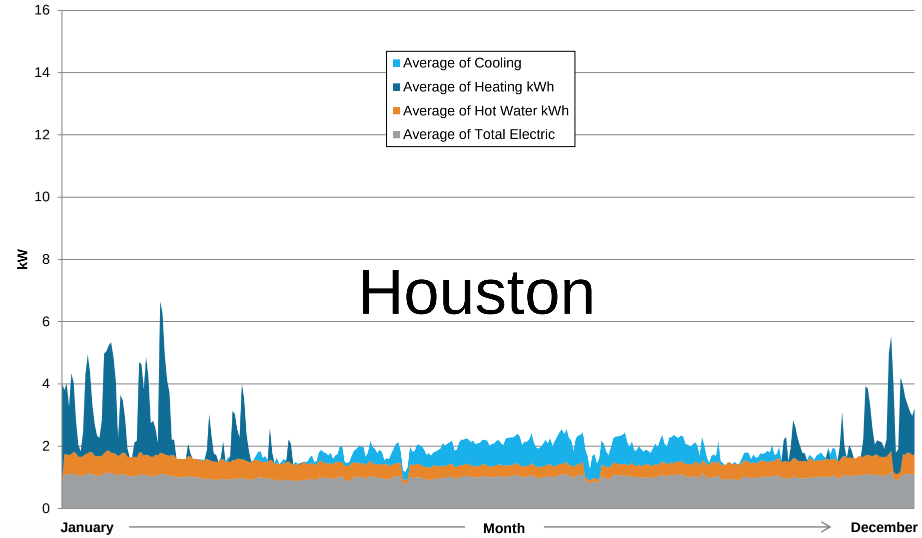
Source: NREL BEopt

Annual residential load profiles









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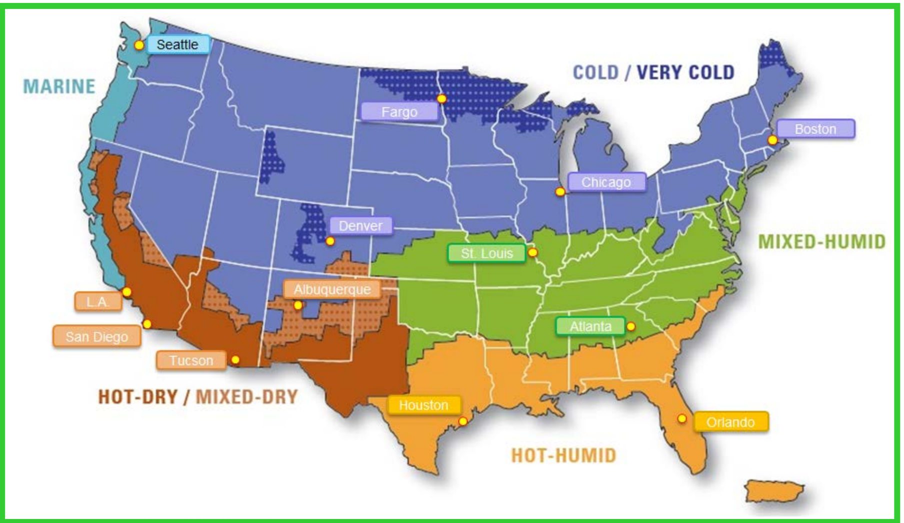
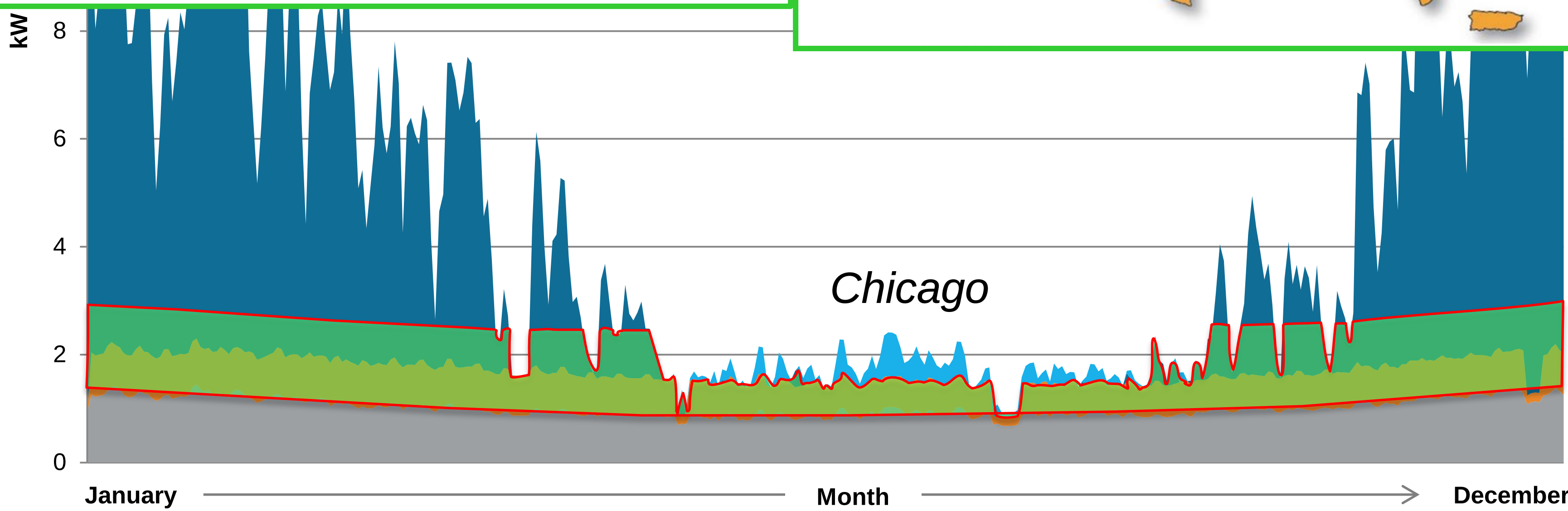
Source: NREL BEopt

Energy saving calculations

- Integrate usable heat hourly to a yr
- Average across each climate zone
- Multiply the number of homes with natural gas at each zone
- Obtain total energy saving by usable heat = **3.1 quads** per year for all US residential homes





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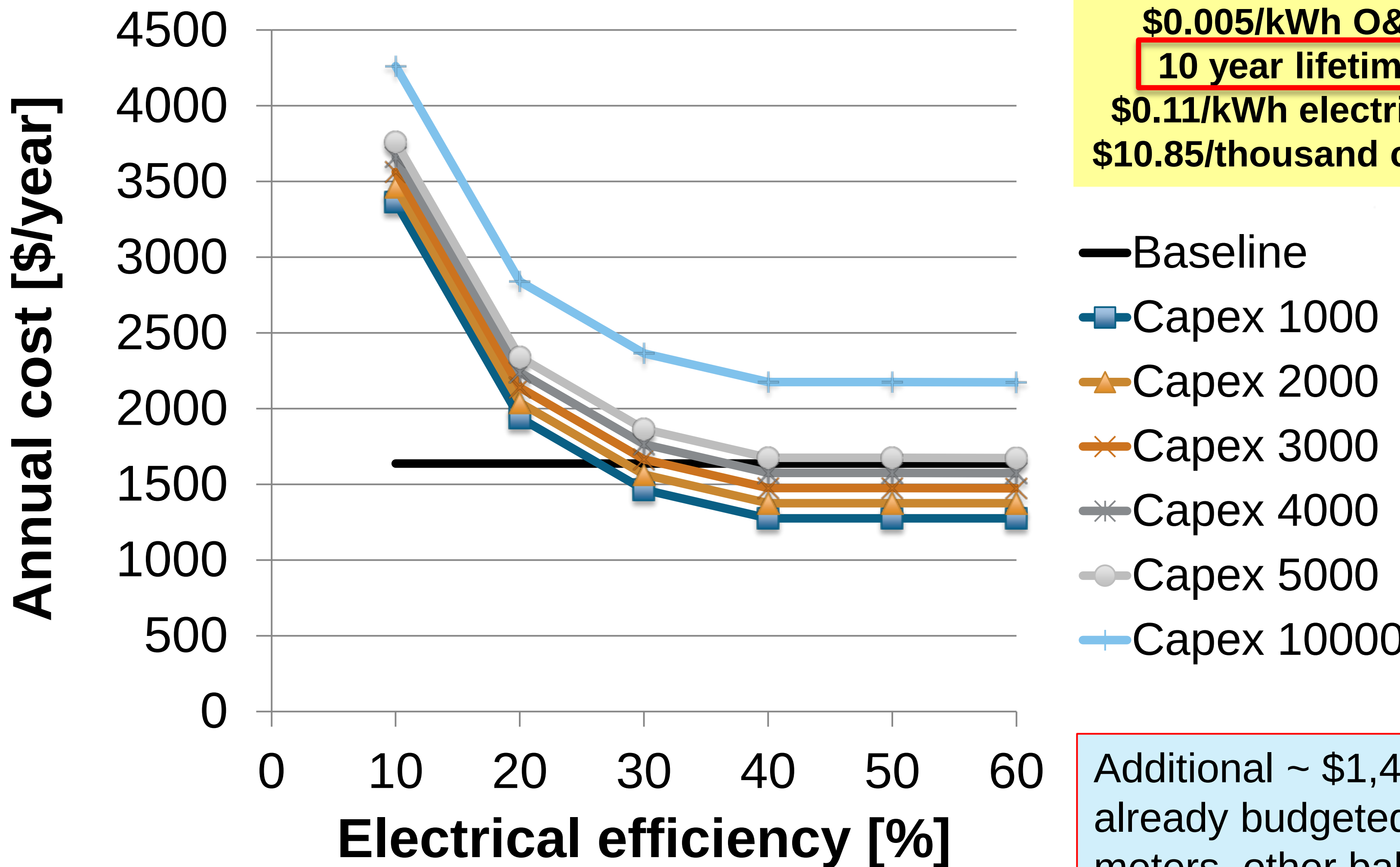
Techno-economic analysis



Assumptions
1 kW electrical load
1.5 kW heat load
90% capacity factor
$0.005/kWh O&M
10 year lifetime
$0.11/kWh electricity
$10.85/thousand cf NG

Additional ~ $1,400 already budgeted for meters, other balance of plant & installation

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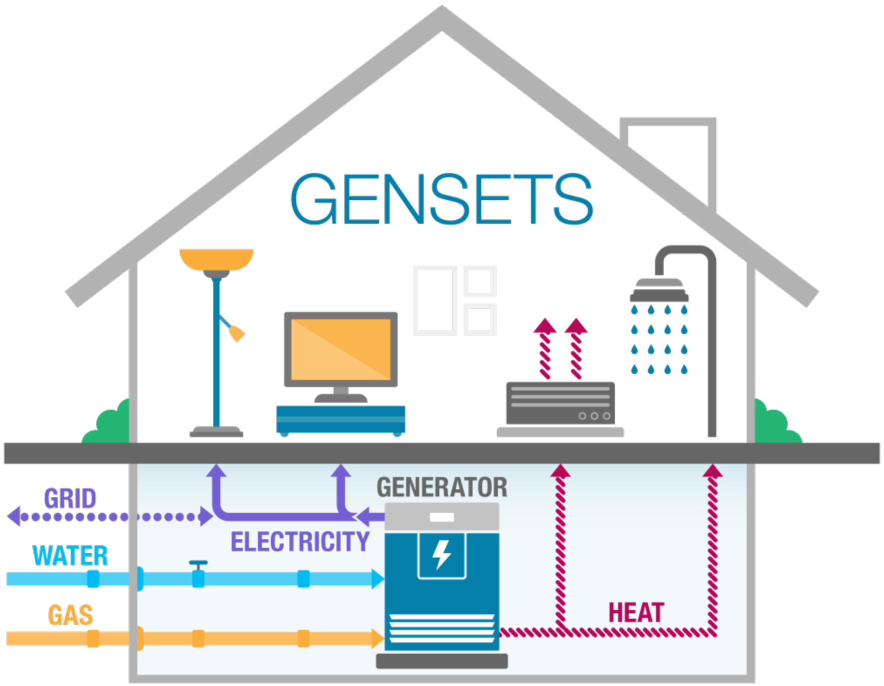
GENSETS: GENerators for Small Electrical and Thermal Systems



- 1 kW electricity system
- 40% electrical efficiency
- 10 year durability/life
- $3,000 system cost

- Save energy (~ 2.5 quads)
- Save $ (~ 4-5 year payback)
- Reduce CO_2 by 200 million tons
- Reduce fresh water withdrawal (~4% of US total)
- Increase power reliability
- $200 billion business opportunity

Technologies to enable widespread deployment of CHP systems for residential & commercial sectors

Long-Term Objectives and Metrics (Primary)

Number	Property	Primary Target
1.1	Electrical power generation capacity	1 kW_e
1.2	Fuel to electricity conversion efficiency (LHV)	≥40%
1.3	Useful heat energy output (>80°C)	>1kW/kW_e
1.4	Capacity factor	≥99.9 %
1.5	Complete system cost excluding installation/balance of plant costs	≤$3,000
1.6	System lifetime	≥10 years
1.7	Total system-out NOx	≤0.07 lb/MWh
1.8	Total system-out CO	≤0.10 lb/MWh
1.9	Total system-out VOC	≤0.02 lb/MWh
1.10	Total system-out PM	≤0.40 g/kWh
1.11	Total system-out CO_2 equivalent (CO_2 & CH_4)	≤1100 lb/MWh
1.12	System noise	≤55 db(A) 3 ft. away

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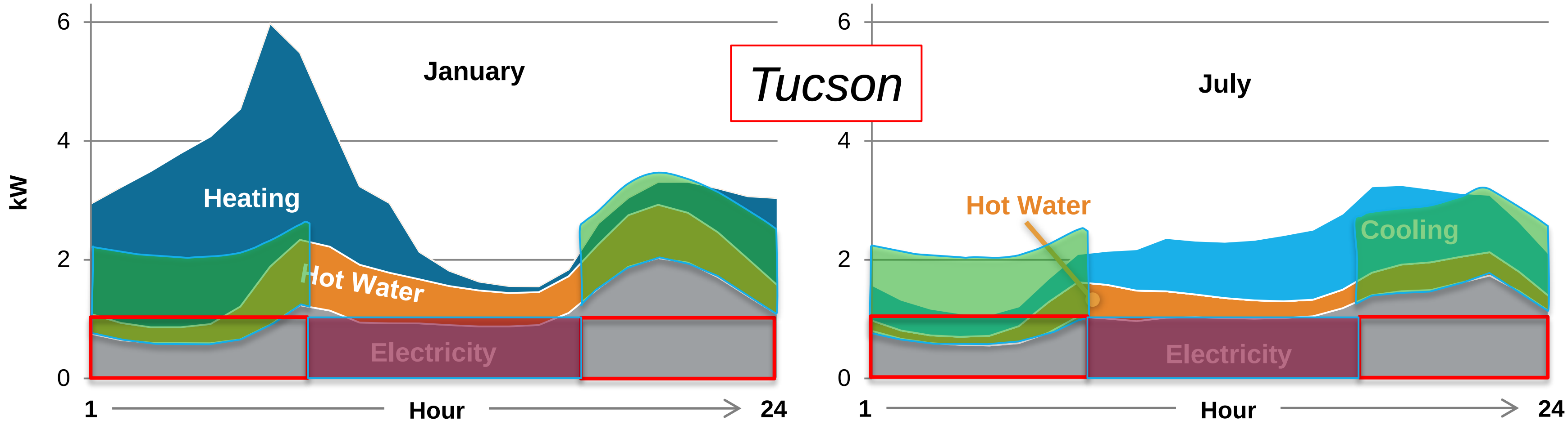
Long-Term Objectives and Metrics (Secondary)

Number	Property	Secondary Target
1.13	Methane number for operation	≥70
1.14	Number of regular maintenance services	≤1/year
1.15	Operation and maintenance cost	≤$ 0.005/kWh
1.16	Time for regular maintenance	≤60 minutes/service
1.17	System mass	≤150 Kg

Other modes of operation…

Integration with solar … load-leveling … load-peaking



Source: NREL BEopt

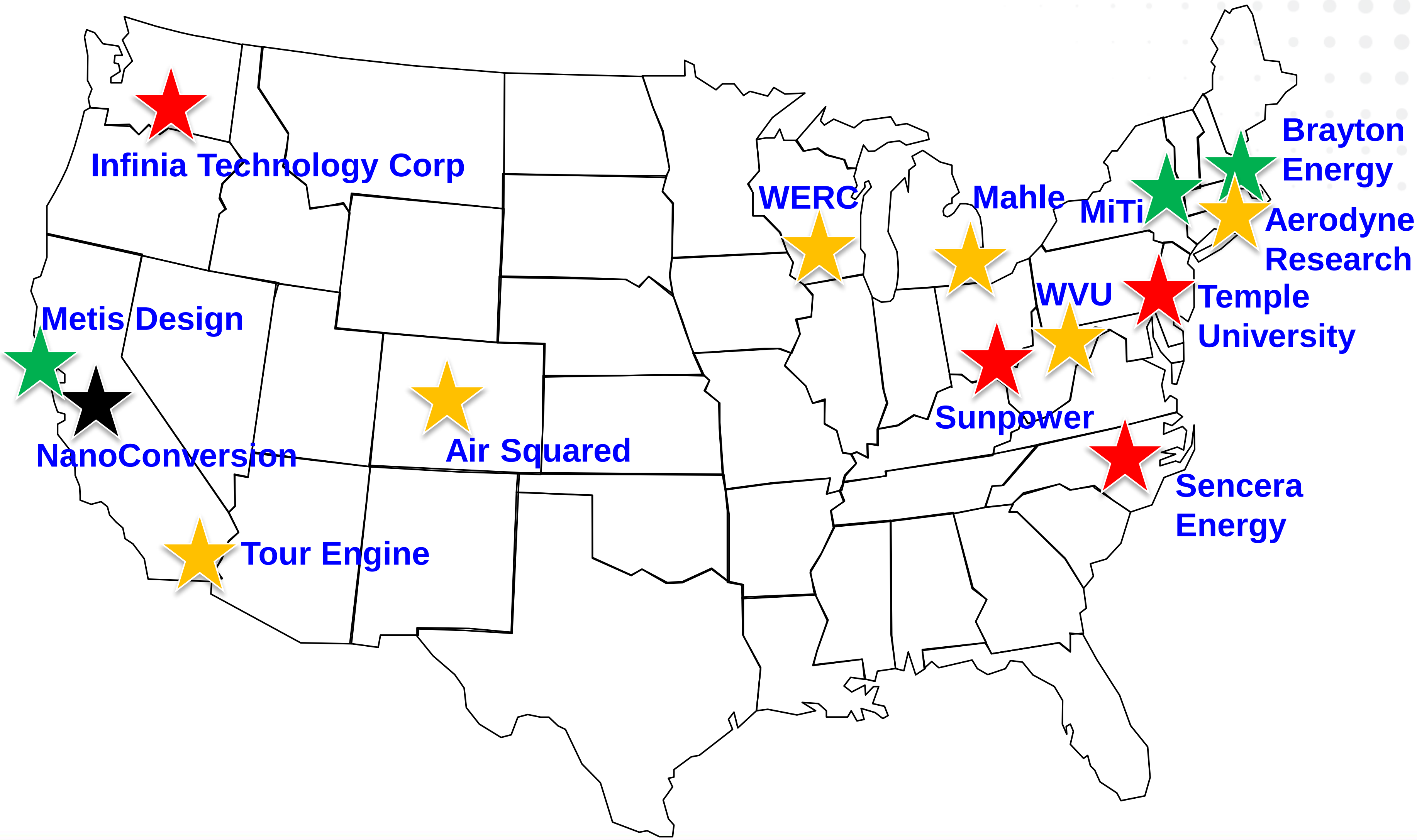
GENSETS Program Awards

$32 million total for 14 teams

- 6 ICE teams
- 4 Stirling engine teams
- 3 Microturbine teams
- 1 Sodium electrochemical cycle team

12 small businesses, 2 universities, 1 large business

GENSETS Portfolio



GENSETS Portfolio Technologies (Page 1 of 2)

Project	Technology type	Key Technologies
West Virginia University (WVU)	ICE	Free piston, spark-ignited stoichiometric ICE
Aerodyne Research Inc.	ICE	Free piston, homogeneous charge compression ignition ICE
Wisconsin Engine Research Consultants, LLC (WERC)	ICE	Spark Assisted Compression Ignition (SACI) ICE
Mahle Powertrain	ICE	Turbulent Jet Ignition (TJI) ICE
Tour Engine Inc.	ICE	Novel split cycle ICE with a shuttle valve for transferring working fluid
Air Squared Inc.	ICE	Scroll expander based waste heat recovery for SACI ICE
Brayton Energy	Microturbine	Sub-atmospheric microturbine employing screw compressor and expander
Metis Design Corporation (MDC)	Microturbine	Microturbine with rotating vaneless diffuser (RVD) and low swirl burner
Mohawk Innovative Technology Inc. (MiTi)	Microturbine	Very high speed microturbine with tessellated compressor and expander & airfoil bearings

GENSETS Portfolio Technologies (Page 2 of 2)

Project	Technology type	Key Technologies
Temple University	Stirling engine	Free Piston Stirling Engine (FPSE) manufactured using additive manufacturing with a high temperature heater head
Sunpower, Inc.	Stirling engine	FPSE based on their 80 W Advanced Stirling Converter for space applications with gas bearings
Infinia Technology Corporation (ITC)	Stirling engine	FPSE with a high temperature heater head and flexure bearings
Sencera Energy	Stirling engine	Kinematic Stirling engine employing flexures instead of pistons
NanoConversion Technology (NCT)	Solid-State	Sodium ion expansion cycle with adiabatic combustor

Technology Leverage

- **Space & Aerospace Technology to Civilian Applications:**
  - Stirling engines
  - Jet engine superalloys
  - Sodium electrochemical cycle (AMTEC)
- **Automotive Technology to Home Applications**
  - Internal combustion engines
  - SiC developed for turbo-chargers
  - Massive manufacturing experience

Technology leverage across the teams can be very beneficial

Common challenges

- **Installation, Integration and Interfacing**
  - Eric Guyer (Yankee Scientific): *First-hand experience of installing residential CHP systems*
  - Steve Willard (EPRI): *Grid integration of micro-CHP distributed generation – EPRI perspective*
  - Kris Jorgensen (A.O. Smith): *Perspectives on residential µ-CHP*
- **Combustion at Small Scale**
  - Yiguang Ju (Princeton): *Small scale combustion and power generation: challenges and opportunities*
- **Materials and Manufacturing**
  - Andrew Carter (Stratasys): *Additive manufacturing*

Common challenges

- **Technology to Market:**
  - Frank Felder (Rutgers): *Economic thinking and tools to value the acceleration of technology in residential GENSETS*
  - Selma Matthews (CERDEC): *Small tactical electric power*
  - Don Sevier (Southwestern Energy): *Oil and gas industry electric power for upstream operations*
  - Steve Simons (Sempra Energy): *SoCalGas clean generation program*
  - Joel Bluestein (ICF International): *Residential CHP – economics and markets*
  - Rick Murphy (AGA): *Why natural gas market fundamentals support long term investments in technology developments*

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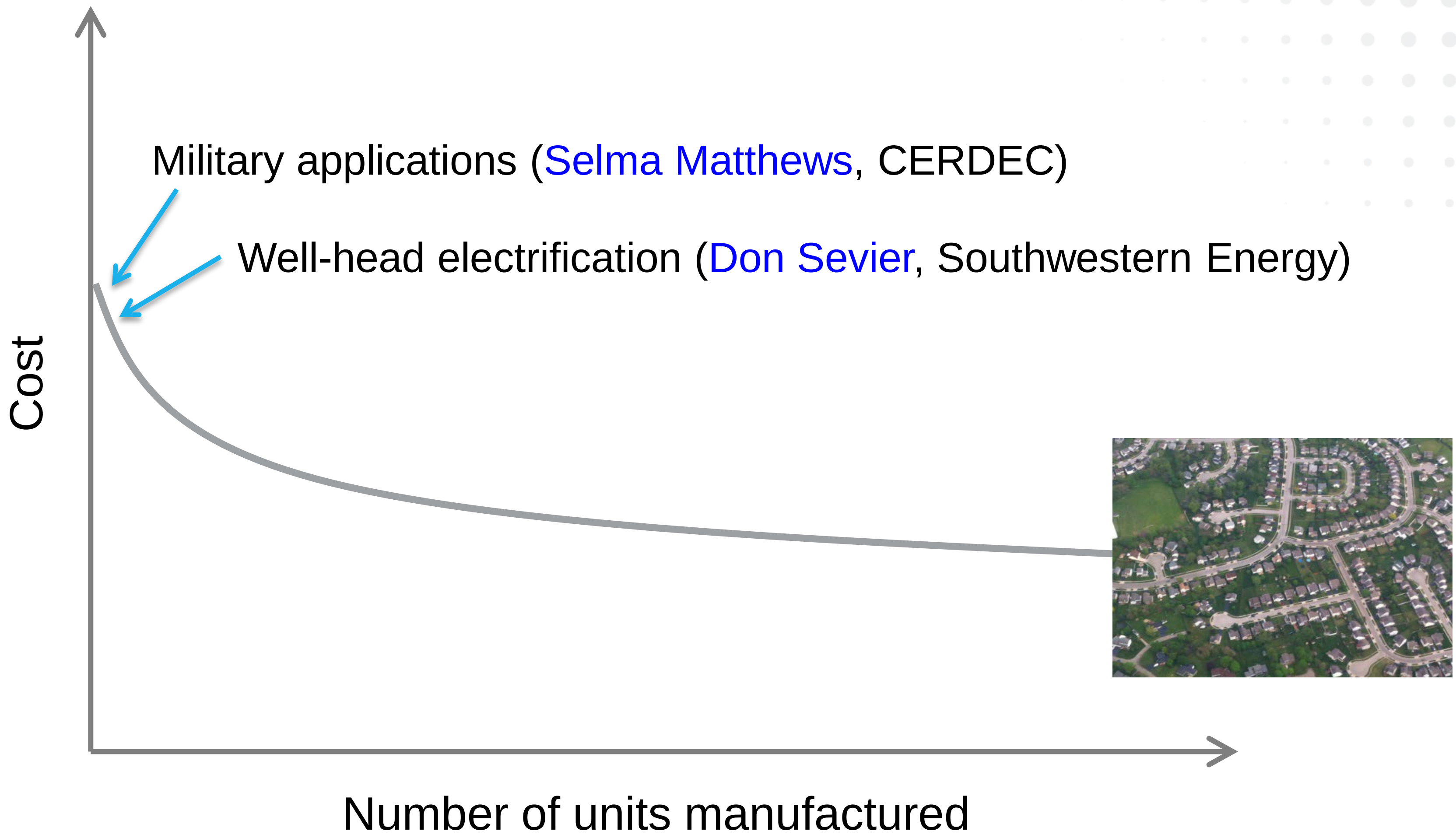
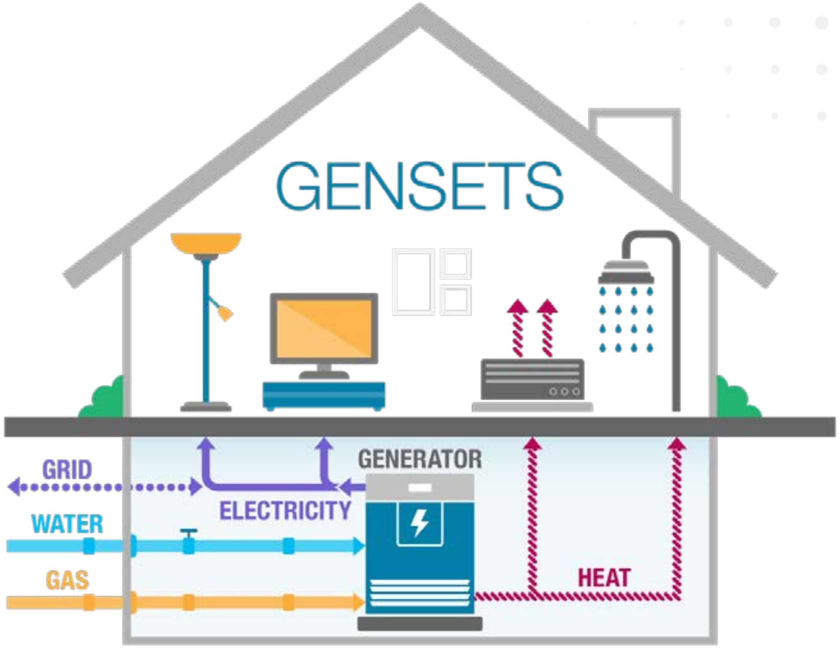
Potential early adopters



Effective integration with hot water tanks & HVAC

- 2.5 to 5 kW_{th} system
- High efficiency
- Low cost: < $100 / kW_{th}
- 10 year lifetime
- Easy integration with hot water tanks and HVAC's
- Efficient heat to cooling technology
- Low manufacturing / development cost



DAY 1: Wednesday, October 21st			
8:30 – 9:00 AM	Arrival	Registration and Continental Breakfast	
9:00 – 9:15	Welcome and Overview	Welcome from the ARPA-E Leadership	Ellen Williams ARPA-E
9:15 – 9:45		Welcome to the GENSETS Community	JC Zhao ARPA-E
9:45 – 10:15	Technology Tutorials	First-Hand Experience of Installing Residential CHP Systems	Eric Guyer Yankee Scientific
10:15 – 10:45		Small Scale Combustion and Power Generation: Challenges and Opportunities	Yiguang Ju Princeton University
10:45 – 11:00	BREAK		
11:00-11:20	Technology Opportunites and Challenges	Grid Integration of Micro-CHP Distributed Generation - EPRI Perspective	Steve Willard EPRI
11:20-11:40		Why Natural Gas Market Fundamentals Support Long Term Investments in Technology Development	Rick Murphy American Gas Association
11:40-12:00		Residential CHP – Economics and Markets	Joel Bluestein ICF International
12:00-12:30 PM		Panel Session – Q&A	
12:30-1:15	LUNCH		
1:15- 1:45	Technology Tutorials	Advanced Manufacturing Services: Additive Metals	Andrew Carter Stratasys Direct Manufacturing
1:45 – 2:45	Project Overviews	8-min Program Overview Presentations	Project PIs
2:45 – 3:00	BREAK		
3:00- 4:00	Project Overviews	8-min Program Overview Presentations	Project PIs
4:00 – 4:15	Programmatics	Best Practices for Working with ARPA-E	Jessica Kaplan Booz Allen Hamilton
4:30– 6:00	POSTER SESSION		
6:30 – Onward	Dinner on Your Own		

DAY 2: Thursday, October 22nd

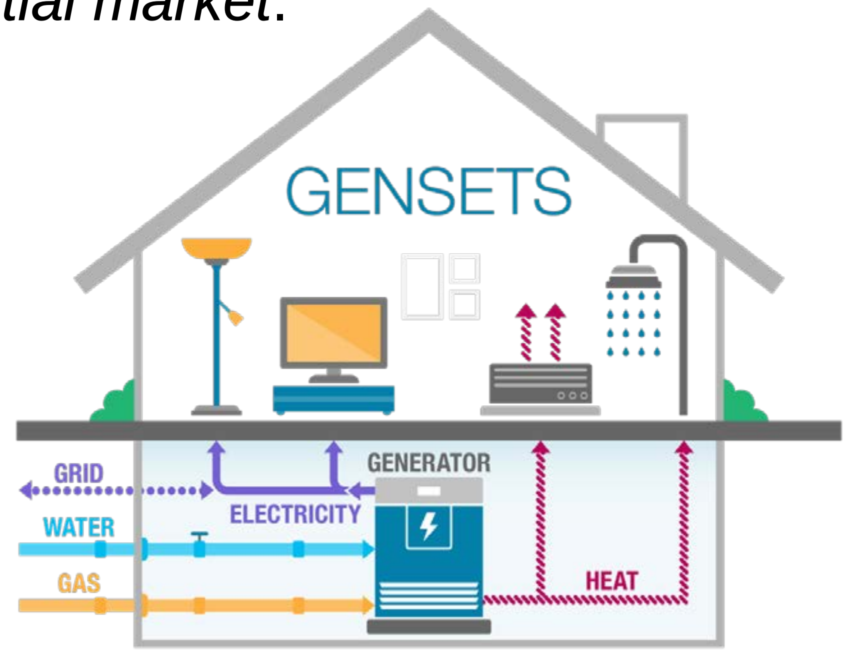
8:30 – 9:00 AM	Breakfast		
9:00 – 9:05	Welcome to Day 2		JC Zhao ARPA-E
9:05 – 9:25	T2M Introduction		John Tuttle ARPA-E
9:25 – 9:45	Economic Thinking and Tools to Value the Acceleration of Technology in Residential GENSETS		Frank Felder Rutgers University
9:45 – 10:05	Natural Gas for Distributed Energy	SoCalGas Clean Generation Program	Steve Simons Sempra Energy
10:05 – 10:25	Markets & Applications	Perspectives on Residential μ-CHP	Kris Jorgensen A.O. Smith
10:25 – 10:45	BREAK		
10:45-11:15	Early adopter markets	Small Tactical Electric Power	Selma Matthews U.S. Army CERDEC
11:15-11:45		Oil and Gas Industry Electric Power for Upstream Operations	Don Sevier Southwestern Energy
11:45-12:00		Closing Remarks	JC Zhao ARPA-E
Adjourn (Lunch on Your Own)			

Bloomberg Research Note, October 16, 2015:

US CHP: Don’t Try This at Home?

“*Currently, there are no good products on the market that are suitable for small private residences. A typical home, which has relatively small thermal load demand, would require a system no bigger than 1kW*.”

“*… as of today, there is simply no readily-available technology to serve the residential market*.”



A generator in every home