

Initial efforts in digital measurement for U.S. EIA's consumption data program



For

IEA G20 End-Use and Energy Efficiency Metrics Initiative

Session 5 – The role of new technologies/digitalization for end use data collection

November 21, 2019| Paris

By

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Overview

- Background
- EIA's research and program goals
- Phase I, Phase II
- Lessons learned
- Future steps

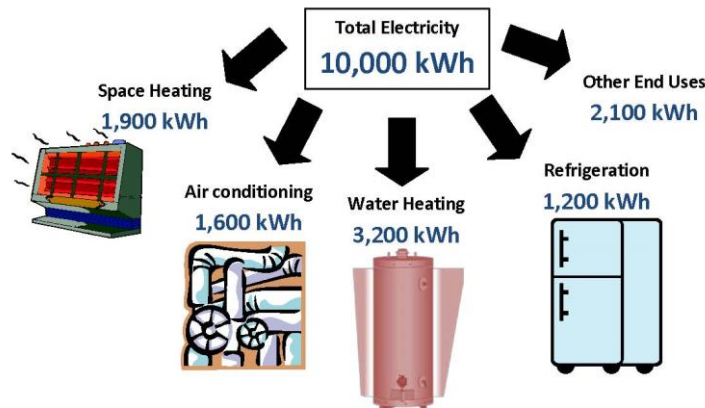
Background: End-use modeling methods at EIA currently rely on engineering components

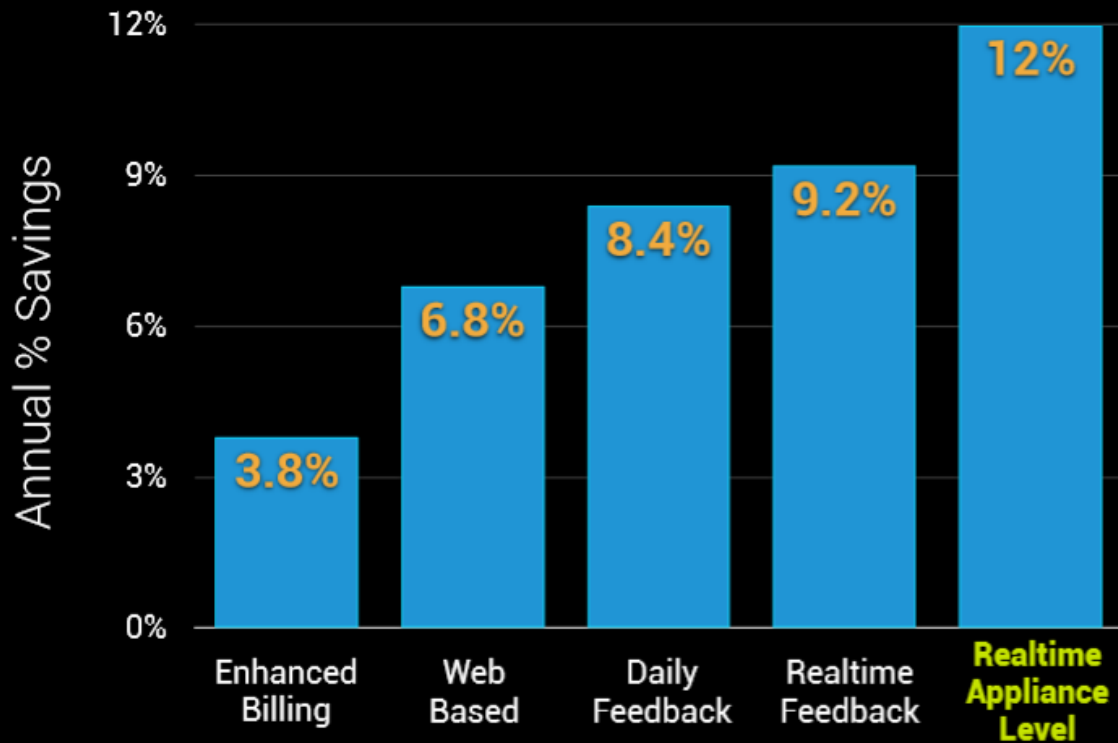
Stage 1: Household respondents report housing characteristics and usage behavior (voluntary)

Stage 2: Energy Suppliers provide consumption data for sampled units (response is mandatory)

Stage 3: Produce individual end-use estimates using engineering-based models

Stage 4: To obtain the final end-use estimates for each housing unit, we calibrate the engineering result to agree with the annualized energy supplier amount





Based on 36 studies between 1995-2010. Summarized by Ehrhardt-Matinez et al.

Electricity

Saturday February 2 | 0:38

\$319.18 / 1081.3 kWh used this month

Currently
Using

270 W

Usage in
Past 1 Min



Usage Over
Last 7 Days
(kWh)

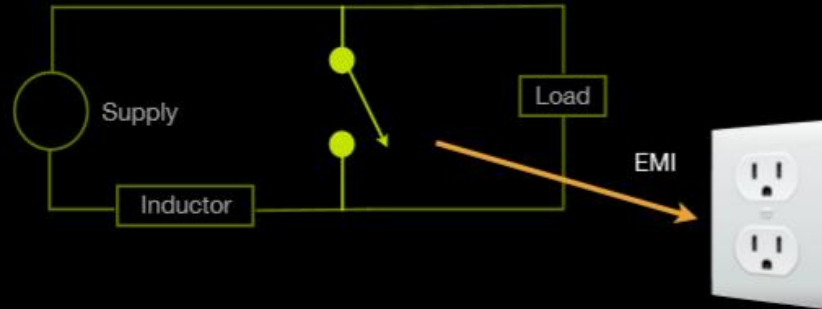


Usage Details

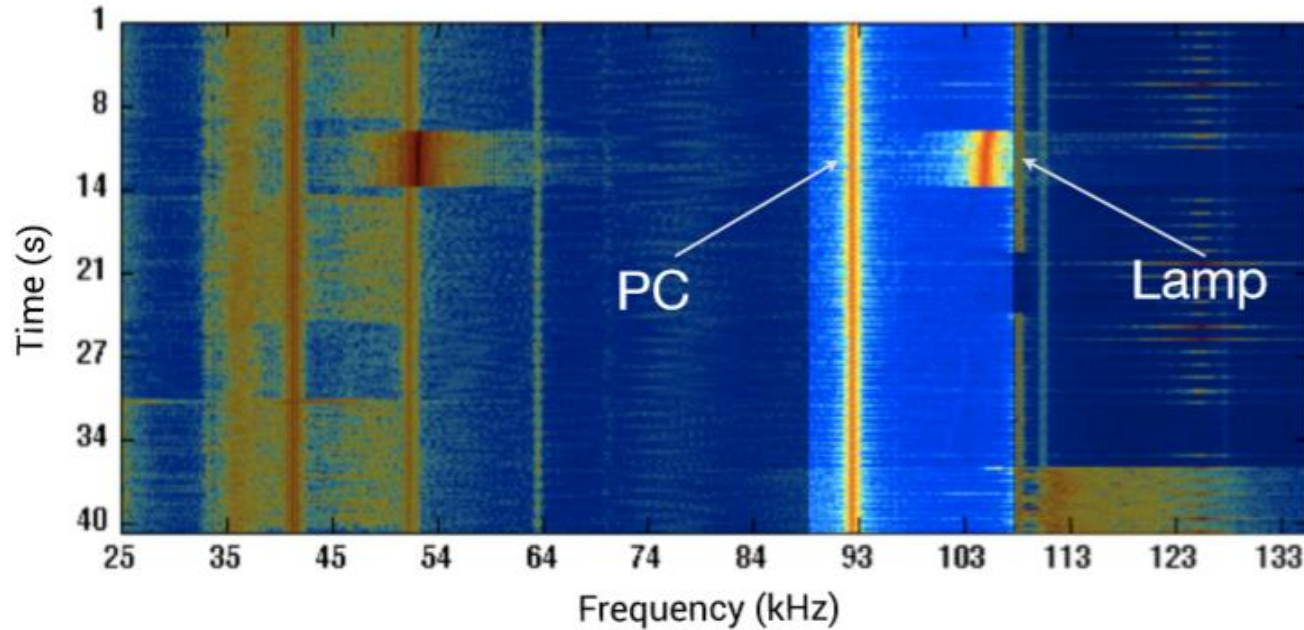
Pool Pump	●	32%
DVR	●	11%
Kitchen Fridge	●	7%
Kitchen Light	●	6%
Master Bedroom TV	●	5%
Garage Fridge	●	5%
Varsa's PC	●	5%

Master Bedroom Lights	●	5%
HVAC Fan	●	5%
Living Room TV	●	3%
Dish Washer	●	3%
Sy's Laptop	●	3%
Living Room PC	●	2%
Others	●	8%

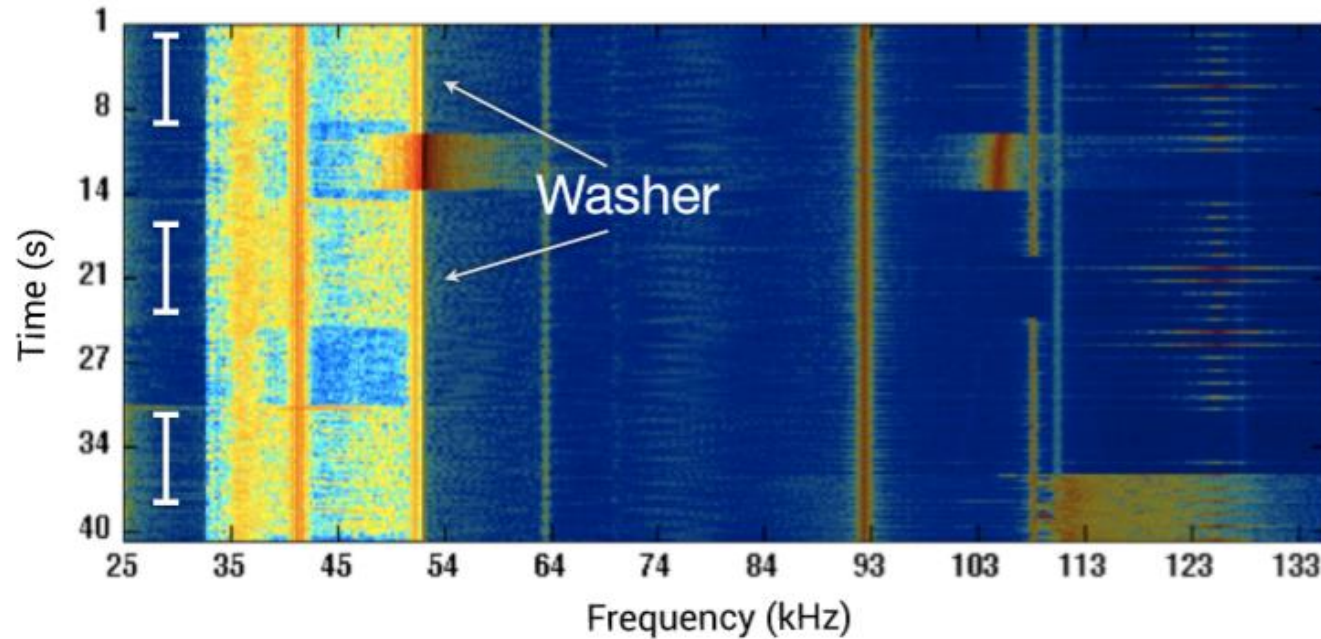
Switching Operation generates high frequency Electro-Magnetic Interference (EMI)



What EMI on power line looks like



Washing Machine EMI





EIA's “submetering” i.e. NILM project

NILM = non-intrusive load monitoring

Research questions for a digital measurement research program within an official statistics program

Can we measure characteristics and consumption simultaneously, objectively?
Scale nationally?

- Test readiness of whole-home “submetering” i.e. NILM technology
- Validate current RECS end-use models
- Attempt to detect and measure more “miscellaneous”, i.e. “other” end uses
- Explore real-time measures of current & new energy uses in the home
- Test capacity for real-time collection, processing of large amounts of data

Outcome Goals

- Confirm coverage of end-uses
- Evaluate accuracy of measured and modeled end-uses
- Collect sufficient data to provide insight and feedback on the RECS modeling process.
- Test new technologies for collecting end-use data; identify a technology that's sufficiently useful

EIA Analysis Plan

- Compare usage patterns from the submeter results against self-reported respondent data (e.g., number of clothes washer cycles)
- Compare reported behavioral characteristics against self-reported respondent data (e.g., Did you use heated drying cycle for dishwasher?)
- At the household level, compare actual end-use consumption from submetered data to the 2015 RECS model results
- Prioritize the research into end use tiers; identify areas that show promise
 - Tier 1 – Refrigerators, Dishwashers, Clothes Washers, Dryers, Cooking, Air Conditioning, Heating, Water Heating
 - Tier 2 – Computers, Televisions, Home Entertainment
 - Tier 3 – Lighting, Rare End Uses, Residual

Timeline – residential submetering

- Oct 2017 – EIA awards contract to Pacific Northwest National Laboratory
 - Nov 2017 through Apr 2018 – Worked with PNNL to determine correct technology, recruit sample households, and acquire submeters
-
- Apr 2018 – Begin installation on 8 homes (*Small Pilot*)
 - Sept 2018 – Begin installation on additional homes (*Pilot*)
 - Nov 2018 – Begin evaluation of *tier one end uses*
 - May 2019 – Complete one full year of submeter data collection
-
- Jan 2020 – Update *household questionnaire* for RECS 2020
 - Sept 2020 – Potentially include submeter data collection on a subsample of RECS 2020
 - Jan 2021 – Apply results to RECS 2020 *end use models*

Phase I

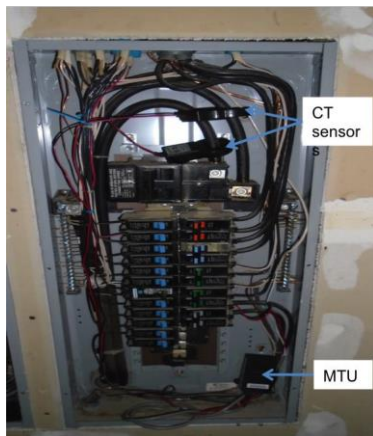
Background

PNNL Plan

- Evaluate applicability of disaggregation to improve RECS end use estimates
- Phase I: Validate performance
- Phase II: Augment existing pilot
 - Complementary task with AMI data disaggregation
 - Through late 2019

Submetering & Disaggregation Technology

Disaggregation with different sources of inputs



CT sensors installed in breaker panel



Utility meter adapter/recorder



Utility meter wireless sensor



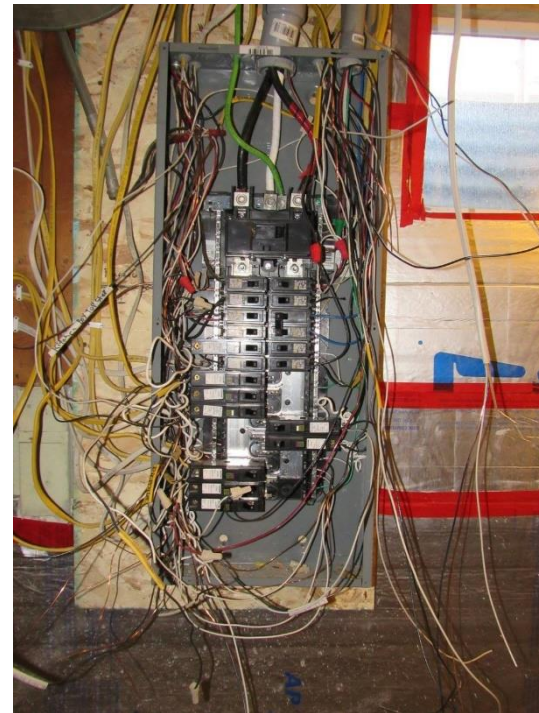
EMF sensor installed at breaker panel



Data from the Utility Smart meter

Phase I

- Recruitment – PNNL staff candidates (Portland, OR)
 - Number & locations of electrical panels (with pictures)
 - Electric loads
 - Unique loads
- Homeowner agreements
 - PNNL legal and contracts offices
 - Data privacy
- Subcontractor selection
 - Local presence
 - Communications & electrical engineering expertise



Avoid!

Submetering & Disaggregation Technology

	Ground Truth	Product A	Product B	Product C
Technology	Submeter	Disaggregation	Disaggregation	Disaggregation
Hardware Cost (\$)	\$720	\$270 (+\$50 for PV)	\$160	\$780
Labor to Install & Setup	8 hours	1 hour	15-45 min	5 hours
Labor to Remove	4 hours	1 hour	None	2 hours
Estimated Total Cost (\$)	\$2,200	\$600	\$300	\$1,600
Electrician to Install?	Yes	Yes	No	Yes
WiFi Performance	Average	Good	Poor	Good
Maintenance Support	Low	Low	High	Low

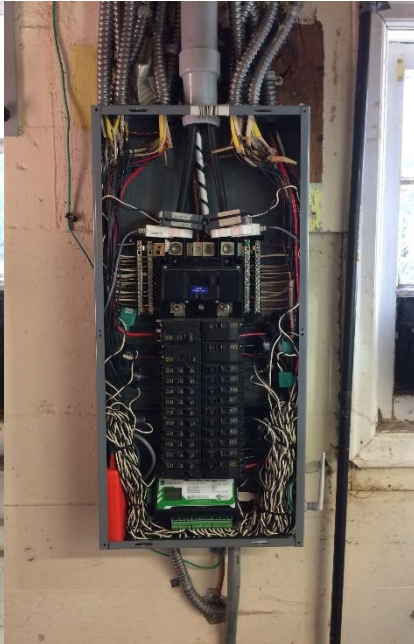
Product B changed algorithms

Product C removed from evaluation

Phase I



Before



No Enclosure



External
Enclosure



Attached to
Utility Meter

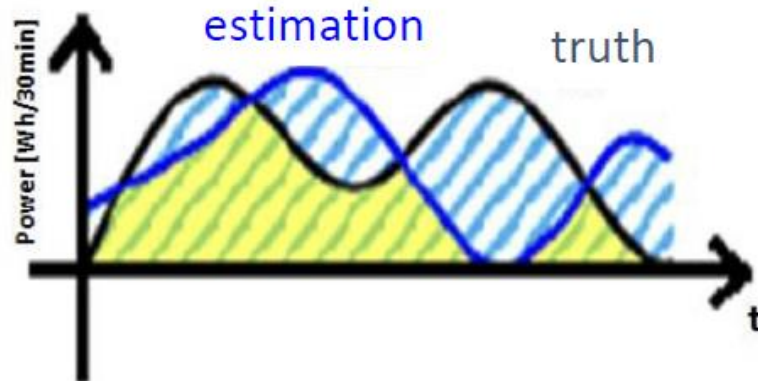
Data and Results

Match Rate (MR) demonstrated as a good measure of accuracy

$$\text{MR} = \frac{\sum_{i=1}^N \min \{E_i, \hat{E}_i\}}{\sum_{i=1}^N \max \{E_i, \hat{E}_i\}}$$

$\hat{E}_i$ = Estimated energy @ each time interval

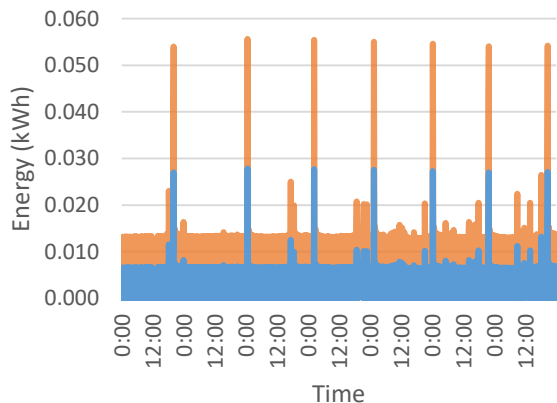
E_i = Metered energy @ each time interval



Data and Results

MR = 50%

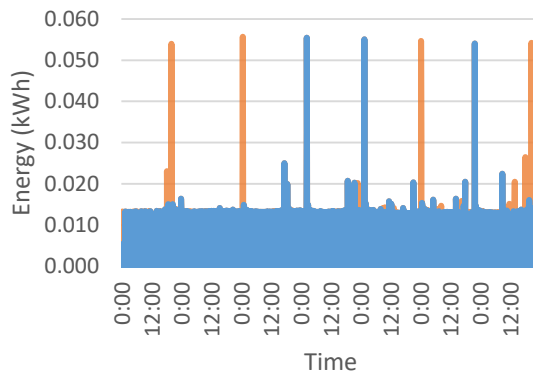
50% Under-Estimation



Metered Estimated

MR = 70%

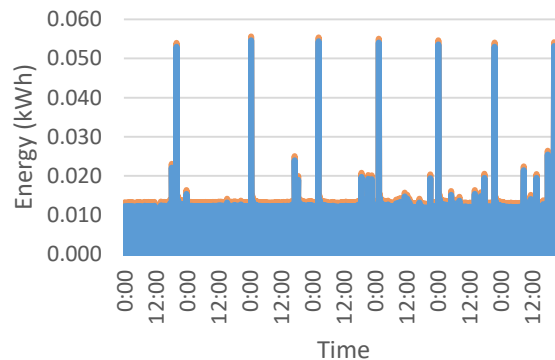
25% Missed Events



Metered Estimated

MR = 90%

Consistent Under-Estimation by
Constant (0.001 kWh each 5 min)



Metered Estimated

Data and Results

Product A shows the most potential based on limited data

Great	MR $\geq$ 70%
Fair	50% $\leq$ MR < 70%
Poor	MR < 50%
NA	not monitored or not disaggregated

Match Rate – Overall

	Refrigerator	Dryer	Dishwasher	Cooking	Furnace	HVAC	Domestic Hot water	Clothes Washer
Product A	75.9%	76.8%	73.8%	32.2%	71.2%	7.2%	45%	52.6%
Product B1	49.1%	0.6%	10.6%	30%	NA	21.7%	9.9%	NA
Product B2	NA	37.8%	13.8%	16.6%	NA	15.3%	5%	NA

Great Performance

Based on only 1 home w/ gas
cooktop & electric oven

Based on only 1 home w/ central AC
Heat pump not identified

Based on 1 home w/
electric water heater
3 homes w/ gas

Based on only 1 home
Not monitored in 2 of
4 homes

Data and Results

Product B has a promising product design, but communications reliability and accuracy are inadequate for large-scale disaggregation

	Advantages	Disadvantages
Installation	• < 1 hour • No electrician needed • Potential for participants to self-install	• Indoor + outdoor installation • Repeater or mesh network needed in some cases
Cost	• Lowest	
Maintenance	• Customer service is helpful	• Poor communication strength • Frequent participant engagement needed
Monitoring		• Does not ID all priority end uses • Difficult to map disaggregation to ground truth • Poor identification & accuracy

Data and Results

Product A demonstrated the most potential and warranted further investigation

	Advantages	Disadvantages
Installation	• < 1 hour	• Electrician needed for typical person
Cost	• Reasonable cost	
Maintenance	• Occasional participant engagement needed • No major data losses after communication issues resolved	• Heavy bandwidth consumption • Data lost if device offline > 8 hrs
Monitoring	• Easy to map to ground truth • Great and fair accuracy shown for several end uses • High sampling rate	• Installed in subset of homes (limited data sample)

Lessons Learned

Site Challenges	Best Practices
WiFi in Garages & Basements	• WiFi signal strength meter • WiFi repeaters added to three homes • Mesh network WiFi system • Validating online/offline devices • Protocol for re-establishing communications
Shared & Mislabeled Circuits	• Identify inactive circuits • Testing of end uses on circuits • Collect model numbers • Plug load monitors

Program update, February 2019

- DOE's Pacific National Lab (PNNL) completed most of a small pilot of several devices complemented with "ground truth" technologies
- As of February 2019, PNNL had spent about 30% of \$400,000 budget.
- Completing options around a small pilot would spend out that budget, with \$60,000 left for other work.

Summary of Options after Phase I

Option	Enhanced Small Pilot	Second Pilot with no Ground Truth	Second Pilot with Ground Truth	Second Pilot with NEEA Ground Truth	Utility Company AMI Data
Additional Homes	4	20	6	9	62
Cost	1K	5K	5K	5K	7.5K
Device	Device 1	Device 2	Device 3	Device 4	Device 5
Ground Truth	Tune-up	No	Yes	NEEA	ORNL

Recommendations for Phase II: Enhance Small Pilot, after testing several devices

- Return to all 8 small pilot homes.
- Improve ground truth (circuit level) mapping.
- Remove rejected device from the 4 homes; install selected device.
- Potentially add cellular data transmission to at least one home.

Recommendations accepted; work ongoing

- Enhanced Small Pilot, added chosen device to other four homes
- Initiate partnership with Utility on the AMI & ground truth Option.
- Explore partnership with energy efficiency association (NEEA or EPRI) Option. Board approval failed in the former; work on the latter is ongoing.
- If any new homes are selected for this project, ideally they should be all-electric homes to manage research complexity (e.g., no gas heating and water heating).

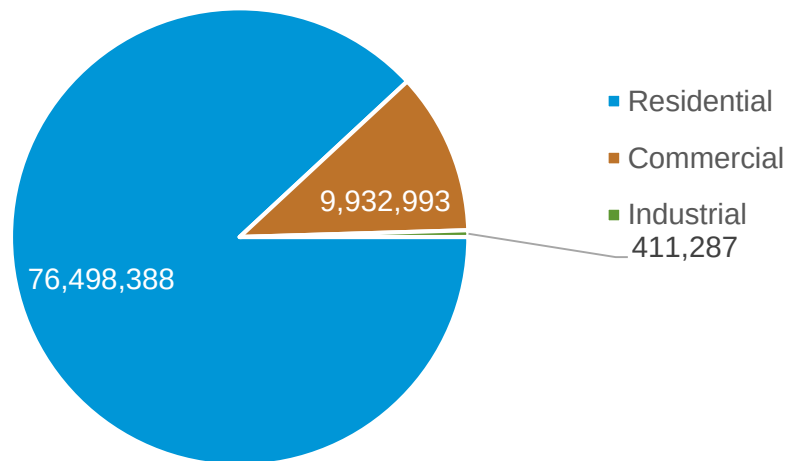
Phase II

Additional efforts – Second Pilot as part of NEEA EULR

- Enter into an agreement with the Northwest Energy Efficiency Alliance to work with homes already included in the End-Use Load Research (EULR) project, which is the latest update to their Residential Building Stock Assessment (RBSA) series.
- Install selected technology in 9 homes and administer the RECS instrument. Select all-electric homes. Use data sharing agreement with DOE already in place.
- Use the NEEA-installed technology as the ground truth. NEEA has installed a 25 channel circuit-level monitor in each home. No plug-load monitors.
- Total cost about \$50,000, about 4-5 months for the project to be up and running.
- Pursue similar public/private partnership with the Electric Power Research Institute (EPRI) in California.

In 2018, the U.S. had about 87 million advanced (*smart*) metering infrastructure (AMI) meters; about 88% were residential installations

Number of AMI installations by sector, 2018

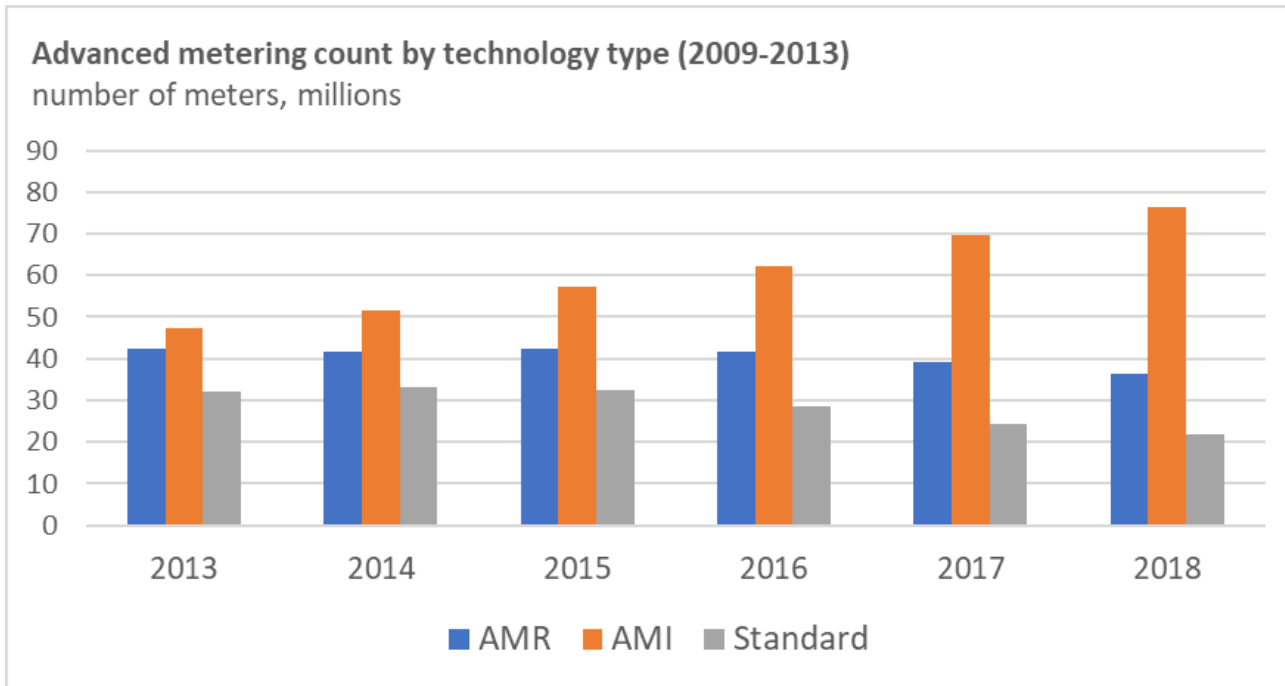


AMI = Advanced Metering Infrastructure

AMI electricity meters measure and record usage data at an hourly minimum and provide usage data to consumers and energy companies at least once daily

Source: U.S. Energy Information Administration, <https://www.eia.gov/tools/faqs/faq.php?id=108&t=3>

U.S. Residential Metering



AMI = Advanced Metering Infrastructure

AMI electricity meters measure and record usage data at an hourly minimum and provide usage data to consumers and energy companies at least once daily

AMR = Automated Meter Reading

AMR electricity meters collect usage data for billing purposes only and only support one-way data transmission, typically from the customer to the distribution utility.

Source: U.S. Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report." Form EIA-861S, "Annual Electric Power Industry Report (Short Form)." https://www.eia.gov/electricity/annual/html/epa_10_10.html

Option – AMI Disaggregation

- Enter into an agreement with an electric utility to receive AMI data from 62 homes
- PNNL will recruit one or two vendors to attempt to disaggregate the AMI data. PNNL will analyze the ground-truth data.
- Estimated costs about \$60,000 with extra \$15,000 for unknown risks.
- Scale of utility project was a concern

Next Steps – Phase II

Augment Phase I

- Install Product A in the four homes without it
- Remove the other disaggregation products from pilot
- Revisit all homes to improve ground truth

Disaggregation of Higher-Frequency AMI Data

- Matched pair of AMI data and ground truth data
- Analyze the ground truth data for baseline
- Partner with vendor(s) to disaggregate AMI data
- Compare disaggregation results with ground truth

Conclusions

- Homeowner acceptance, communications reliability, cost, and accuracy varies between load disaggregation products
- One of the three load disaggregation products demonstrated strong potential to support EIA's end uses program and merited further evaluation
- Two other products are likely intended for consumer apps; as such, measurement quality serves other objectives
- Utility/other partnerships on AMI data disaggregation may offer a scalable, cost effective solution for understanding end-use energy consumption
- This technology is still evolving; EIA will continue efforts as long as a few, key end uses prove sufficiently reliable and accessible

Prologue

Developments that may unlock elusive measurement and efficiency

- Measuring and/or modeling lighting usage is highly desirable and difficult; new electricity delivery may provide new ways to measure lighting
- Case Study: Power over Ethernet (PoE) in the Sinclair Hotel retrofit, Fort Worth, Texas
 - PoE powers more than 2,000 lights and amenities via an IP address on a computer network
 - Reduction of building's energy consumption by 30 to 40 percent
 - Professional electricians are not required for installation, saving thousands in labor costs
 - PoE offers immediate notification should a PoE device go out anywhere in the hotel
 - The world's first UL 924 lithium ion battery provides up to 3 hours of backup power for integrated lighting and end uses

<https://www.architecturaldigest.com/story/the-sinclair-hotel-is-the-first-in-the-world-to-power-itself-with-this-new-technology>

A few references

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