

Non-Intrusive Load Monitoring

Emerging Technologies Showcase

August 14, 2013

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Chris Holmes – EPRI
Dave Kresta – NEEA

Welcome. Today's webinar is being recorded and will be posted at:

- www.E3Tnw.org
- www.ConduitNW.org

Evaluation of NILM Technologies for End-Use Load Disaggregation, Measurement & Customer Load Information

Krish Gomatam, Senior Engineer (EPRI)

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August 15, 2013

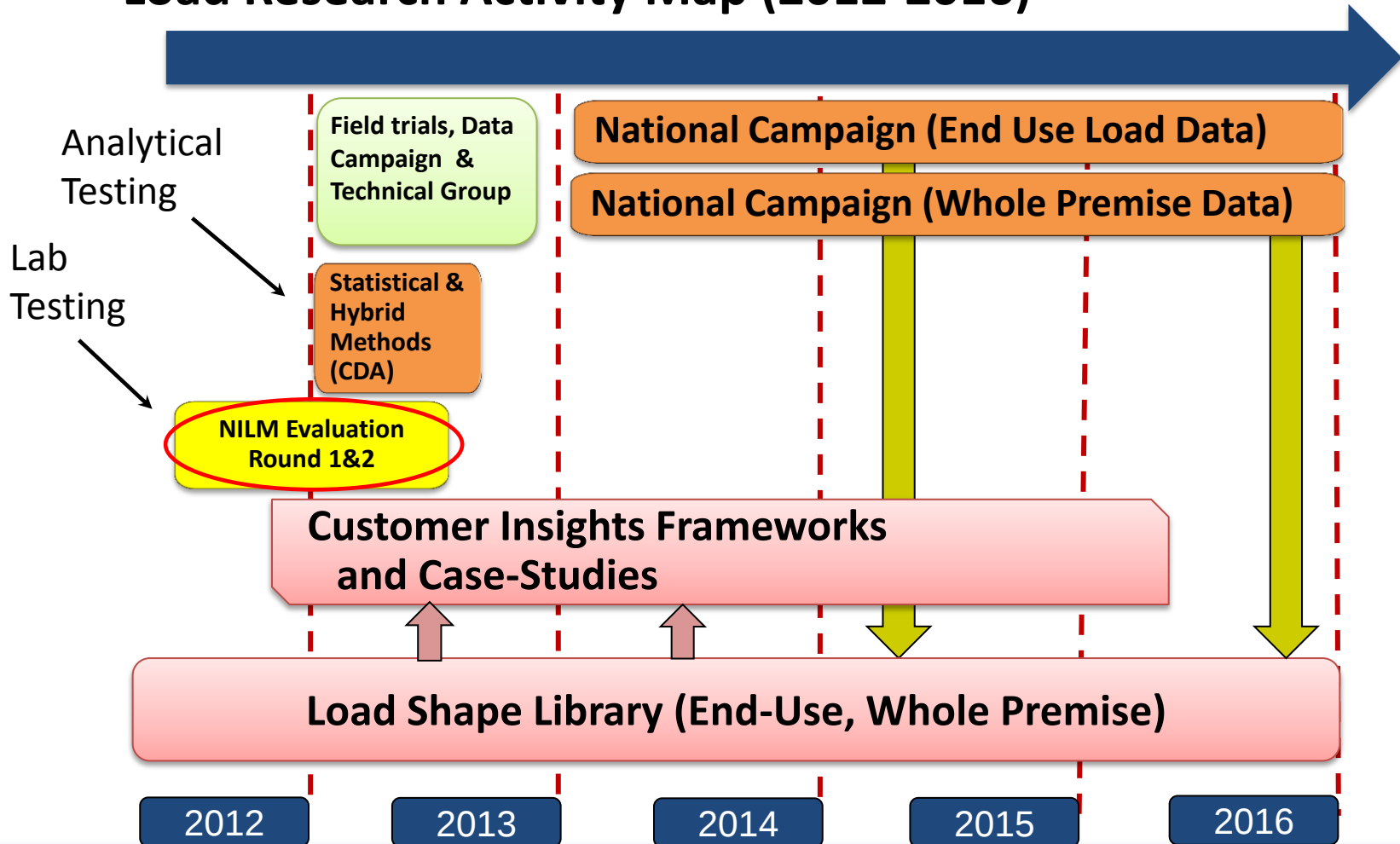
Objectives

- The Big Picture
- Update project advisors on round 1
 - ❑ Summary of results
 - ❑ Seek feedback on the evaluation method, results, report content, other
 - ❑ Lesson learned, gaps to be addressed.
- Discuss round 2
 - ❑ Longer duration test
 - ❑ Modifications to the set up
 - ❑ Additional loads
 - ❑ Additional test scenarios
- Next steps



Customer Insights and End-Use Data Collection

Load Research Activity Map (2012-2016)



Concept of NILM

What is NILM ?

Analytical methods or technologies that measure an aggregate quantity such as whole premise energy consumption (kWh), voltage, current and determine individual load consumption (kWh) without actual measurement of individual loads

Originally developed by Dr. G.W.Hart at MIT in the 1980s funded by EPRI.

Key benefits

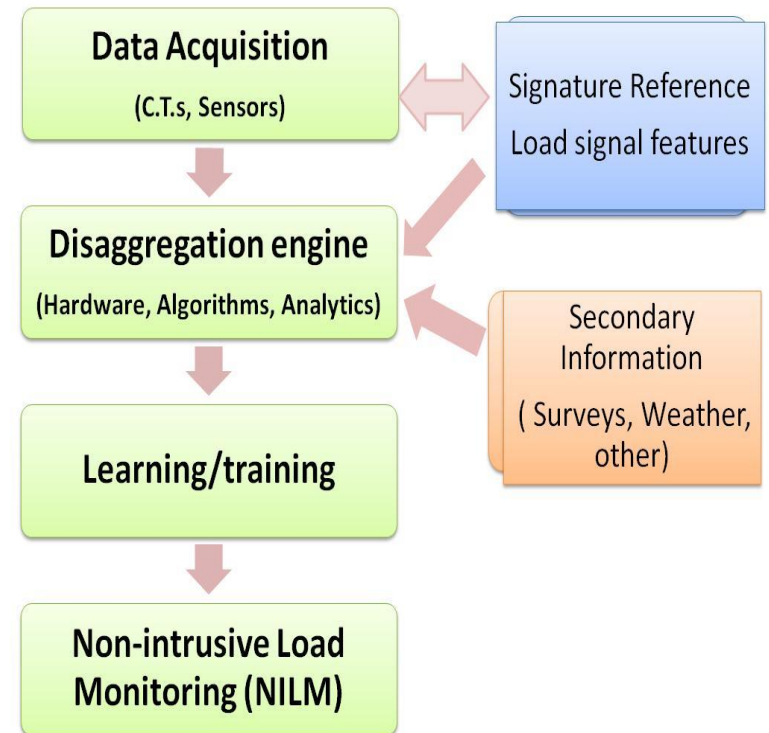
Non-intrusive: Permits measuring individual end use loads without entering customer premises

Cost of Implementation:

Much lower compared to submetering

Applications

Real-time energy/cost feedback, energy management, load research and equipment diagnostics



NILM Evaluation Objectives

Measurement Accuracy



- Average Accuracy (%) of Disaggregated Loads
1-min., 5-min., 15-min., 60-min., daily and weekly consumption periods.

Disaggregation Performance



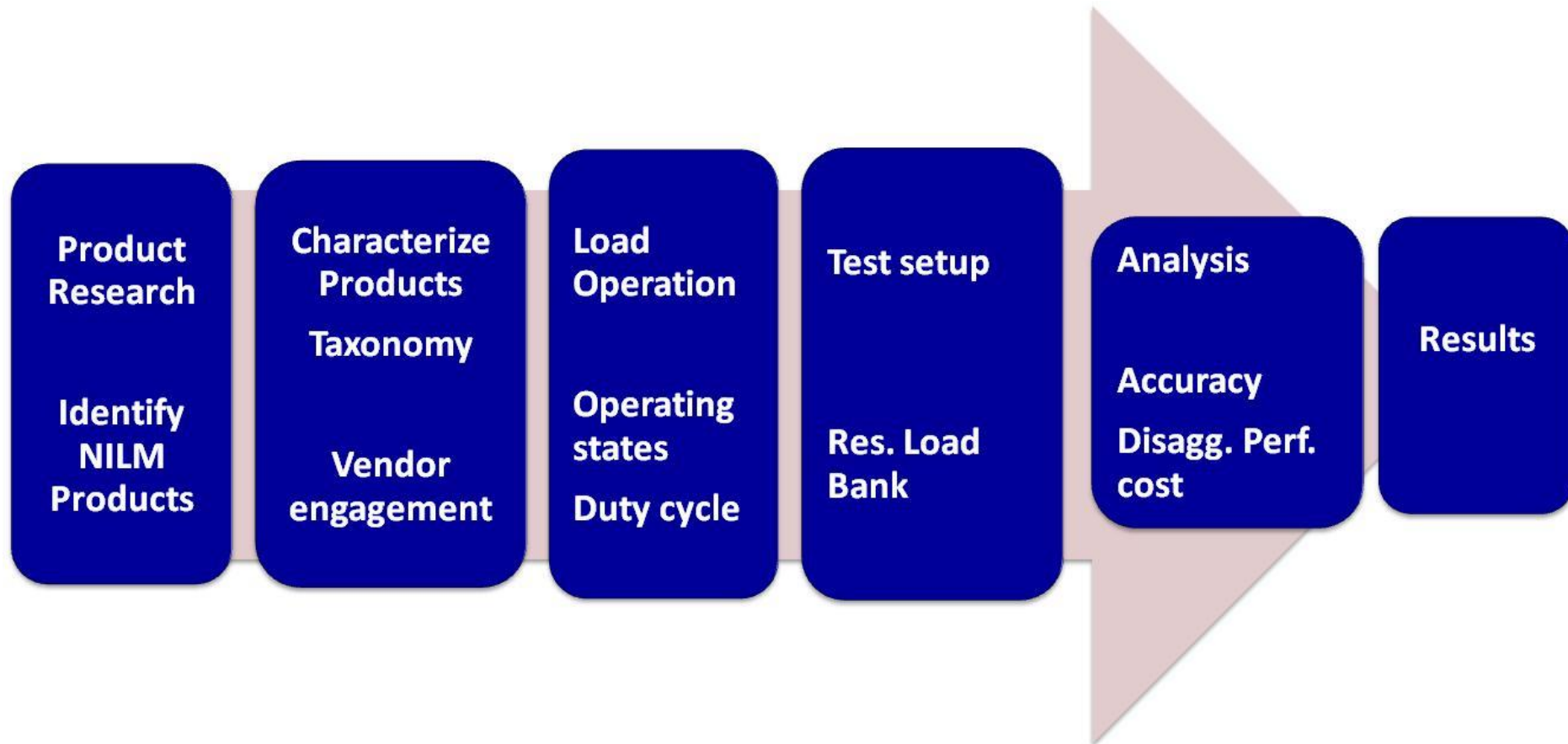
- Number of loads isolated
- Total Premise Energy Estimated (%)

Cost



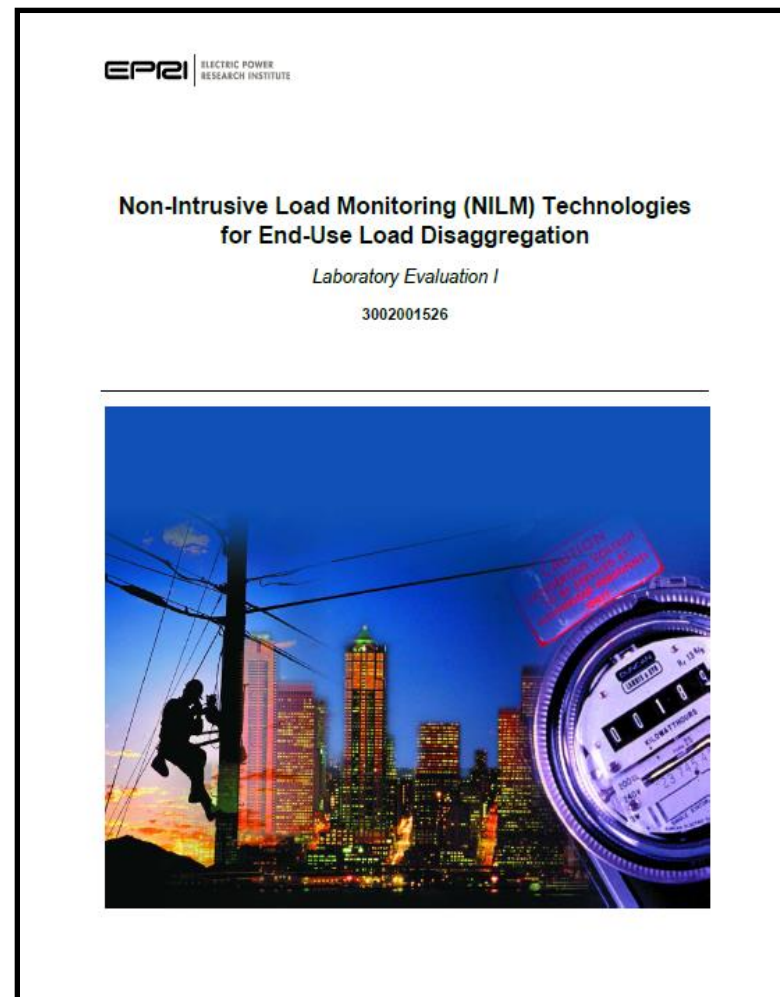
- Initial Installation
- O & M 5-Year Annual Average Cost

NILM Supplemental Project Activity



NILM Round 1 Final Product

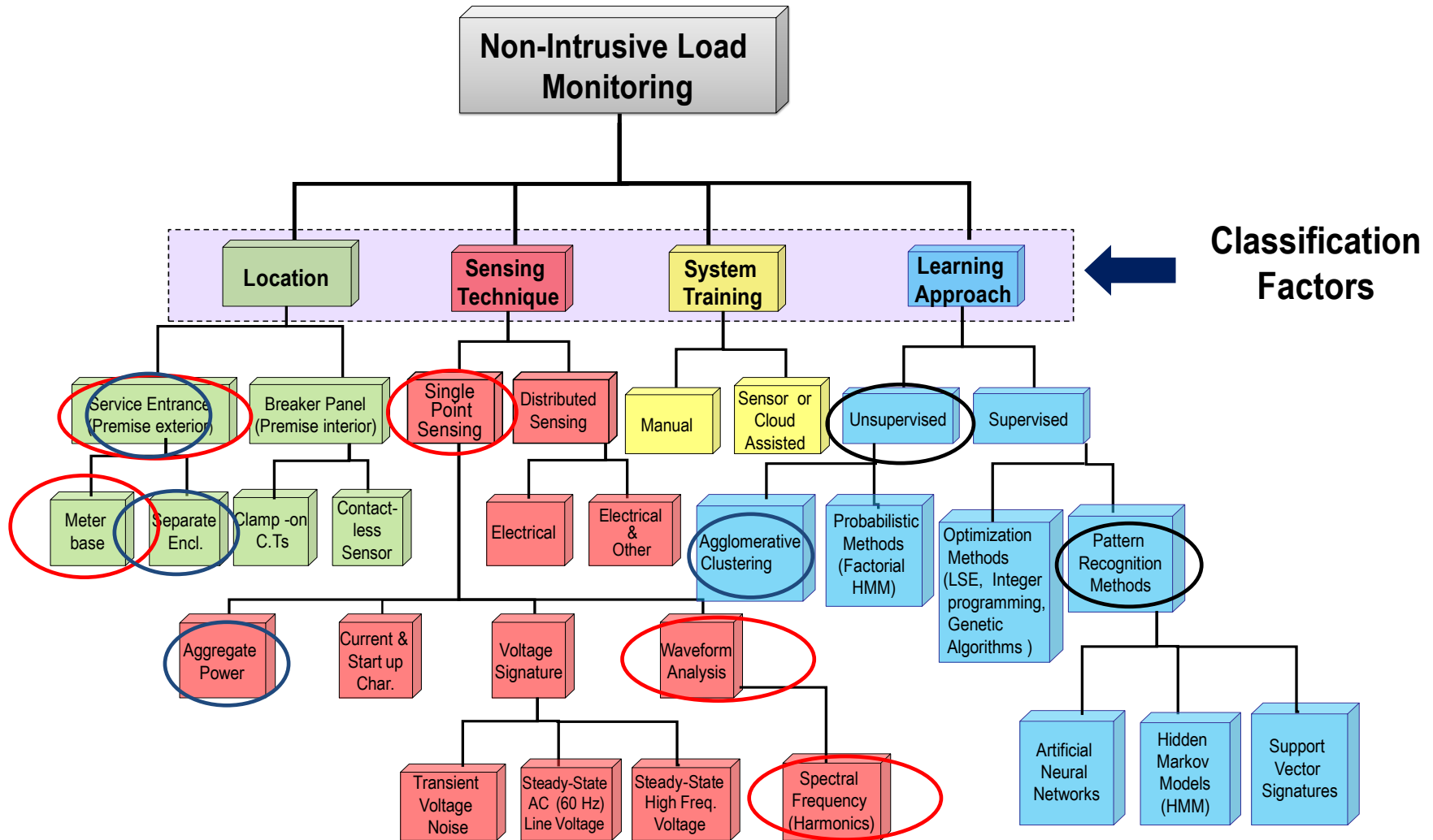
- Final report available to the Public for download from EPRI.com
- Product ID # 3002001526
- If you encounter issues downloading the report –
 1. Contact the Order Center
1-800-313-3774 (Option 2) or
650-855-2121, or contact
via email at orders@epri.com.
 2. Contact one of us :
Chris Holmes (cholmes@epri.com)
Krish Gomatam
(kgomatom@epri.com)



Assessment Factors of Interest

- The objective is to measure three key factors for all the technologies
 - ❑ Accuracy of measurement relative to metered value
 - ❑ Disaggregation performance (load separation)
 - ❑ Repeatability of disaggregation (whether loads can be separated accurately and repeatedly)
- Other factors of interest include(may vary by specific design) :
 - ❑ Comparison of the sum of disaggregated end use loads to whole-house meter read (over the duration of a day)
 - ❑ Variance in accuracy, skew, performance variation by sensor type (hardware vs. software and subtypes within)
 - ❑ Implementation and cost

NILM Approaches: Methods & Taxonomy



Interface for controlling and measuring individual loads

TESTING
DO NOT DISTURB

AMI Meter

**NILM
Product A**

**NILM
Product B**

Figure 1 shows four examples of loads in the NILM test facility. The top-left image shows a laundry room setup with a water heater, dish washer, lights, and a clothes washer/dryer. The top-right image is a graphic with the text 'NILM Product C'. The bottom-left image shows a television and electronics setup on a desk. The bottom-right image shows a kitchen setup with a stove and various kitchen loads on a counter.

The figure consists of two vertically stacked charts sharing a common x-axis representing dates from 31/5 to 22/6. The top chart, titled 'AMI_Watthrs(60)', plots 'Average Energy (Watt-hours)' on the y-axis, ranging from 0 to 7000. The bottom chart plots 'Average Energy Change (Ecart)' on the y-axis, ranging from -20.0% to 60.0%. A large blue arrow points from the 'Average Energy (Watt-hours)' label to the top chart. The bottom chart includes a legend for 'Ecart' and a green shaded area on the right side. The top chart has a green bar on the right side.

Date	Average Energy (Watt-hours)	Average Energy Change (Ecart)
31/5	~2000	-5.2%
1/6	~2000	-5.6%
2/6	~2000	-6.0%
3/6	~2000	-7.2%
4/6	~2000	-3.1%
7/6	~2000	-3.1%
8/6	~2000	-2.9%
9/6	~2000	-3.0%
10/6	~2000	-3.3%
11/6	~2000	-3.1%
12/6	~2000	-3.1%
13/6	~2000	-3.2%
14/6	~2000	-6.9%
15/6	~4500	54.4%
16/6	~3000	19.0%
17/6	~2500	6.2%
18/6	~2000	-1.5%
19/6	~2500	15.9%
20/6	~2000	3.3%
21/6	~2500	13.8%
22/6	~2500	14.0%

Round 1 Evaluation - Metrics and Definitions

Measurement Accuracy

- ❑ An average measure of deviation between the NILM estimation and the actual measurement in the laboratory for each disaggregated load.
- ❑ Expressed as a percentage of the average actual watt-hour (Wh) value measured in the laboratory over similar interval resolution.
- ❑ Larger differences observed in the measurement accuracies at higher resolutions than at lower.
- ❑ Assessment performed over 1-minute, 5-minute, 15-minute, 60-minute, daily and weekly.

Clock synchronization and data /communication network propagation delays can impact measurement accuracy at higher resolutions.

Round 1 Evaluation - Metrics and Definitions (2)

Disaggregation Performance

- Refers to the ability of the NILM unit to isolate the loads over the duration of the test.
- Two factors of interest:
 - ❑ Number of isolated loads as part of the disaggregation
 - ❑ Estimated daily premise energy consumption estimated through disaggregation

Cost

- Average cost at the end of five years assuming O&M cost remains the same over the five year period
- Cost data provided by the manufacturer or vendor.
- In cases where third-party hardware was procured for evaluating a specific product, actual costs are quoted.

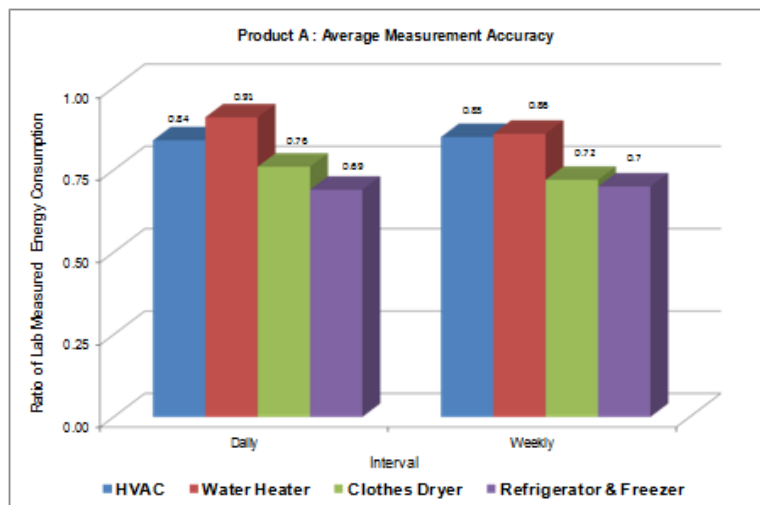
Example : Product A

Software Approach (Cloud-based Disaggregation)

Product A : Average Measurement Accuracy

Period	Interval	HVAC	Water Heater	Clothes Dryer	Refrigerator and Freezer
10/8/12-10/21/12	Daily	0.844 [$\bar{x}$ = 389.352 σ = 42.672]	0.914 [$\bar{x}$ = 484.823 σ = 63.891]	0.764 [$\bar{x}$ = 1056.789 σ = 72.903]	0.691 [$\bar{x}$ = 1387.982 σ = 79.092]
	Weekly	0.857 [$\bar{x}$ = 923.456 σ = 82.893]	0.865 [$\bar{x}$ = 1236.562 σ = 74.983]	0.725 [$\bar{x}$ = 2456.914 σ = 69.467]	0.704 [$\bar{x}$ = 1320.814 σ = 79.762]

Note: Values in bold represent average measurement accuracy. Mean ($\bar{x}$) and standard deviation (σ) of the differences between NILM estimated and actual measured values are shown in watt-hours



- Output resolution is daily and weekly
- Four (4) isolated and labeled loads
- HVAC and WH estimations are in the 84-91% accuracy range.
- Refrigerator /freezer and dryer estimations are relatively lower in accuracy (69-76%)
- Estimations are all over-estimated over the period assessed.
- Distributions wider for clothes dryer and refrigerator.

Product D

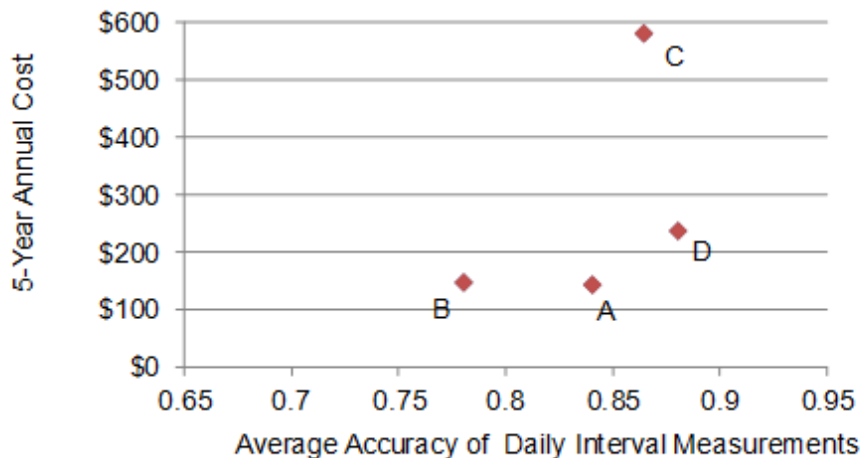
Hardware Approach (Agg. Power + Waveform Analysis)

Product D: Average Measurement Accuracy											
Period	Interval	HVAC	Water Heater	Pool Pump	Clothes Dryer	Refrigerator	Freezer	Lights	Range	Microwave	Fans
10/8/12-10/21/12	5 min.	0.838 [$\bar{x}$ = -3.789 σ = 1.120]	0.858 [$\bar{x}$ = -2.402 σ = 13.945]	0.858 [$\bar{x}$ = -19.833 σ = 12.083]	0.828 [$\bar{x}$ = -14.281 σ = 42.934]	0.784 [$\bar{x}$ = -12.982 σ = 22.079]	0.802 [$\bar{x}$ = -3.514 σ = 22.100]	0.844 [$\bar{x}$ = -32.192 σ = 39.931]	0.828 [$\bar{x}$ = -12.39 σ = 21.921]	0.798 [$\bar{x}$ = -9.892 σ = 38.983]	0.845 [$\bar{x}$ = -0.29 σ = 89.241]
	15 min.	0.842 [$\bar{x}$ = -10.894 σ = 7.239]	0.868 [$\bar{x}$ = -6.092 σ = 19.789]	0.867 [$\bar{x}$ = -23.87 σ = 41.278]	0.842 [$\bar{x}$ = -43.701 σ = 51.102]	0.773 [$\bar{x}$ = -53.20 σ = 56.391]	0.848 [$\bar{x}$ = -28.713 σ = 22.945]	0.866 [$\bar{x}$ = -9.22 σ = 26.339]	0.838 [$\bar{x}$ = -11.961 σ = 19.02]	0.823 [$\bar{x}$ = -12.93 σ = 82.781]	0.854 [$\bar{x}$ = -3.023 σ = 89.411]
	60 min.	0.866 [$\bar{x}$ = -23.892 σ = 11.023]	0.876 [$\bar{x}$ = -96.10 σ = 18.937]	0.884 [$\bar{x}$ = -99.856 σ = 52.097]	0.804 [$\bar{x}$ = 165.529 σ = 69.077]	0.789 [$\bar{x}$ = 198.60 σ = 72.789]	0.864 [$\bar{x}$ = -87.801 σ = 78.933]	0.868 [$\bar{x}$ = 107.371 σ = 129.13]	0.848 [$\bar{x}$ = -12.821 σ = 49.865]	0.838 [$\bar{x}$ = -210.873 σ = 59.661]	0.848 [$\bar{x}$ = -13.20 σ = 62.381]
	Daily	0.880 [$\bar{x}$ = 190.298 σ = 16.370]	0.874 [$\bar{x}$ = 148.291 σ = 56.378]	0.894 [$\bar{x}$ = 1298.983 σ = 60.818]	0.848 [$\bar{x}$ = 1033.72 σ = 97.66]	0.804 [$\bar{x}$ = 846.021 σ = 73.971]	0.878 [$\bar{x}$ = 779.02 σ = 112.90]	0.884 [$\bar{x}$ = 281.184 σ = 38.11]	0.847 [$\bar{x}$ = 362.397 σ = 119.723]	0.820 [$\bar{x}$ = 442.093 σ = 89.801]	0.842 [$\bar{x}$ = 301.931 σ = 94.13]
	Weekly	0.894 [$\bar{x}$ = 620.092 σ = 27.787]	0.881 [$\bar{x}$ = 1092 σ = 92.387]	0.898 [$\bar{x}$ = 2063.980 σ = 97.071]	0.852 [$\bar{x}$ = 1493.33 σ = 102.821]	0.828 [$\bar{x}$ = 1713.1 σ = 117.238]	0.872 [$\bar{x}$ = 2660.829 σ = 118.92]	0.875 [$\bar{x}$ = 1023.20 σ = 133.12]	0.842 [$\bar{x}$ = 1597.821 σ = 168.921]	0.838 [$\bar{x}$ = 1932.88 σ = 194.231]	0.843 [$\bar{x}$ = 1232.192 σ = 129.931]
Note: Values in bold represent average measurement accuracy (%). Mean ($\bar{x}$) and standard deviation (σ) of the differences between NILM estimated and actual measured values are shown in watt-hours.											

- Output resolution : 5-min,15-min,60-min,daily and weekly
 - Ten (10) loads isolated and labeled (or annotated)
 - HVAC ,WH, Pool pump, dryer and lighting estimations are in the 80-89% accuracy range.
 - Refrigerator, freezer, microwave and fan estimations are in 77-84% accurate
 - 15-minute load estimations are over and under-estimated over the period assessed.
- Distributions are fairly tight around the mean difference.

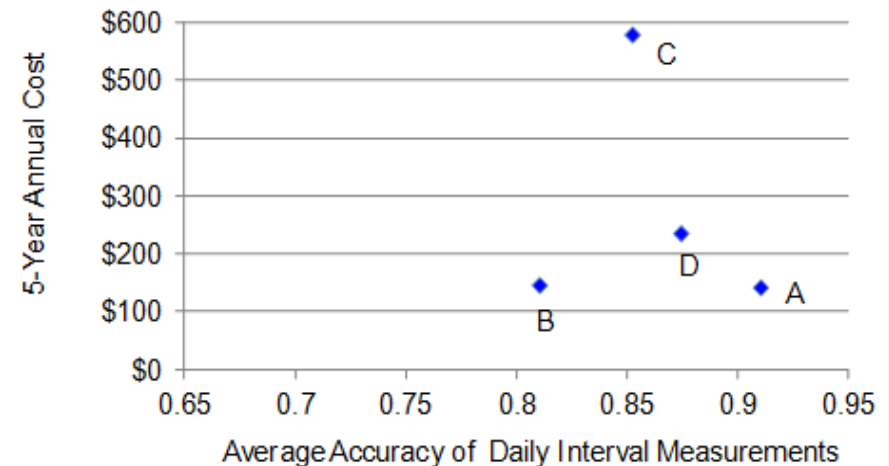
HVAC and WH – Cost vs. Accuracy

HVAC : Accuracy vs. Cost



Annual cost for Product D is based on 100 installed units.

Water Heating: Accuracy vs. Cost



Annual cost for Product D is based on 100 installed units.

NILM Phase I : Results

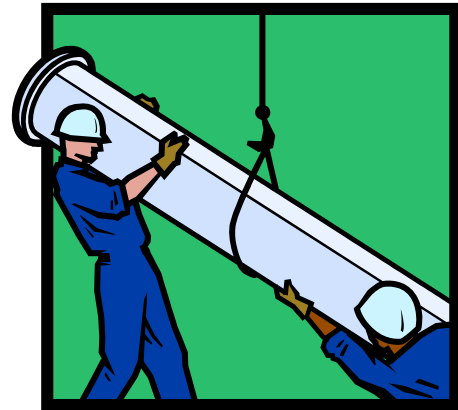
- NILM is an evolving technology
- Four(4) to eight(8) end-use loads disaggregated by evaluated products
- Best 15-minute disaggregation accuracy ~ 87% .
- HVAC, WH loads relatively easier for disaggregation, more accurate than others.
- Clothes dryer, Refrigerator challenging for disaggregation, least accurate
- Hardware based, waveform approaches seem to be more accurate than others, but more expensive based on 5-year costs.
- Complex algorithms and technologies being commercialized. Disaggregation performance expected to improve.

Next Steps

- Second round of lab. evaluation for residential NILM, with 4 additional vendors (April-May 2013)
 - More detailed statistical analysis of residuals
 - Long-term testing (3-4 months)
 - New loads to be included (HPWH, DHP, advanced lighting, PV, Electric vehicle chargers)
- Evaluation of NILM for commercial sector applications (by commercial building type)
- Lab. evaluation of European NILM products for residential.

NILM Field Assessment

- Field evaluation of residential NILM
- TVA taking the lead including procurement of NILM devices and managing installations.
- Installations at 30 residential sites located at Glasgow, KY
- Installations to begin Summer 2013
- Any interest from advisors to collaborate?



NILM Industry Workshop

- NILM Standards Working Group in October/November 2013.
- Focus is to foster utility and other stake holder participation, engagement with NILM vendors
- Coordinate formation of an interest/working group addressing:
 - Product specifications
 - Standards/accuracy definitions
 - Evaluation protocols
 - Metrics to measure performance

More details to be announced soon.



Together...Shaping the Future of Electricity

Sneak Peak: NILM Field Study

**Dave Kresta, Product Manager,
Emerging Technology**

Northwest Energy Efficiency Alliance

August 15, 2013

Agenda



Study Overview
Equipment
Challenges

Study Objectives

Determine ability of non-intrusive load monitoring (NILM) devices to disaggregate and measure electric end-use loads in “real-world” situations in a variety of single family homes throughout the Northwest

Field Study Structure

- ❑ Collaboration between Pacific Northwest National Labs (PNNL) and NEEA
 - NEEA focusing on field study
 - PNNL focusing on analytics, field test protocols
- ❑ PNNL is testing equipment in its lab homes
 - 2 homes, simulated occupancy
- ❑ NEEA is testing equipment in a sub-set of RBSA Metering homes
 - 30 fully metered homes, real-life occupancy

Study Tasks

Pre-test assessment, study design [complete]



Select and acquire equipment [4/2013 – 8/2013]



Develop Analysis approach (PNNL) [ongoing]



Test equipment in RBSA Metering test lab/PNNL lab homes [7/2013 – 8/2013]



Install equipment in RBSA Metering homes and PNNL lab homes [8/2013 – 9/2013]



Monitoring period [10/2013 – 12/2013*]



Data analysis & report [1/2014 – 4/2014]

*PNNL will be keeping the lab home monitoring active for a longer period of time, TBD.

Planned Test Equipment

Hardware:

- ☐ Belkin
- ☐ Enetics
- ☐ Energy Aware

Software-only:

- ☐ PlotWatt
- ☐ Bidgey



Plan to test each product in 5 – 7 homes

Challenges

- ❑ Some equipment not quite ready for release
 - Schedule pushed out by 2+ months
- ❑ Some manufacturers wary about sharing data
- ❑ Data formats highly variable

Thank you

Filling the
Energy
Efficiency
Pipeline

Accelerating
Market
Adoption

Delivering
Regional
Advantage



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Next Webinar

Wednesday, Sept. 18, 2013 at noon PST

Topic TBD

Stay tuned to register at www.e3tnw.org/webinars

More information about emerging technologies:

E3T database: www.e3tnw.org

E3T Program: www.bpa.gov/energy/n/emerging_technology/

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