The Expectations of Non-Intrusive Load Monitoring

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DSM Taiwan 201 7
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Computational Sustainability
Engineering Science

SFU

My Biography

I am an Adjunct Professor in Engineering Science at Simon Fraser University (SFU) and a Senior Software Engineer at Knowledge Network. I received my PhD in Computing Science at Simon Fraser University in 2014, and I have been a software engineer for over 20 years working for various local and international clients. My research interests include computational sustainability and the understanding of socioeconomic issues that pertain to technological advancement. I am an expert in data engineering and a world-renowned researcher in non-intrusive load monitoring (NILM) and disaggregation. I have been research NILM since 2012.

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Talk Format

- 20 minutes of presentation
  - **introduce** NILM and its components
  - **demonstrate** why NILM is important
  - **discuss** the future of NILM
  - **list** the realistic expectations of NILM

- 10 minutes of discussion (Q&A)
  - you ask me questions

What is NILM?

Non-Intrusive Load Monitoring

- Also know as **load disaggregation**
- Using **computation** to determine what appliance are running (and how much they consume) in a building from an aggregate smart meter reading.
- Try to **remove** the need for sensors.

Why NILM?

Understanding real-time house appliance feedback leads to energy conservation. A **meta-study** shows:

9% **reduction** with hourly total consumption feedback

14% **reduction** with real-time appliance specific feedback

Can be **motivated** by environmental and economical means.

The Paris Agreement (COP21)

USA as an example (2015 data)

- Reduce carbon emissions by 28% below 2005 levels by 2025

- In 2015, EPA reported a 12% reduction, to date
  - Leaving 16% still needing to be reduced (**960 Mt**)

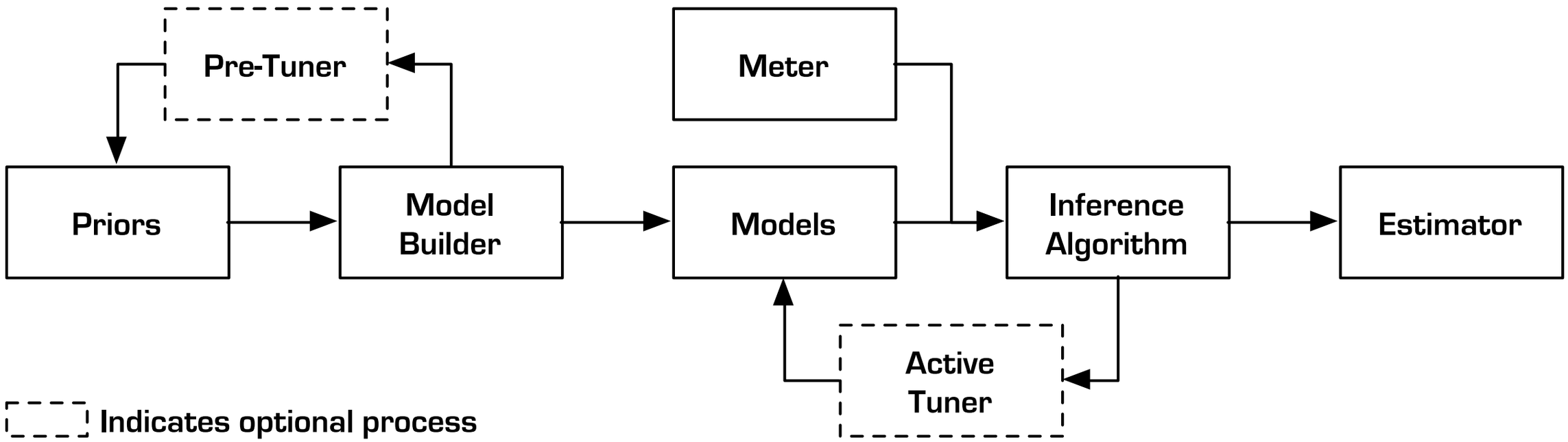
- EPA: households (incl. commercial) emit **847 Mt** per year
  - 12% of the total annual emissions
  - a further **115 Mt** would need to be reduced

- Reduction average of 14% ≡ **118.6 Mt** of carbon per year
  or 12.4% of the remaining 16% would be reduced

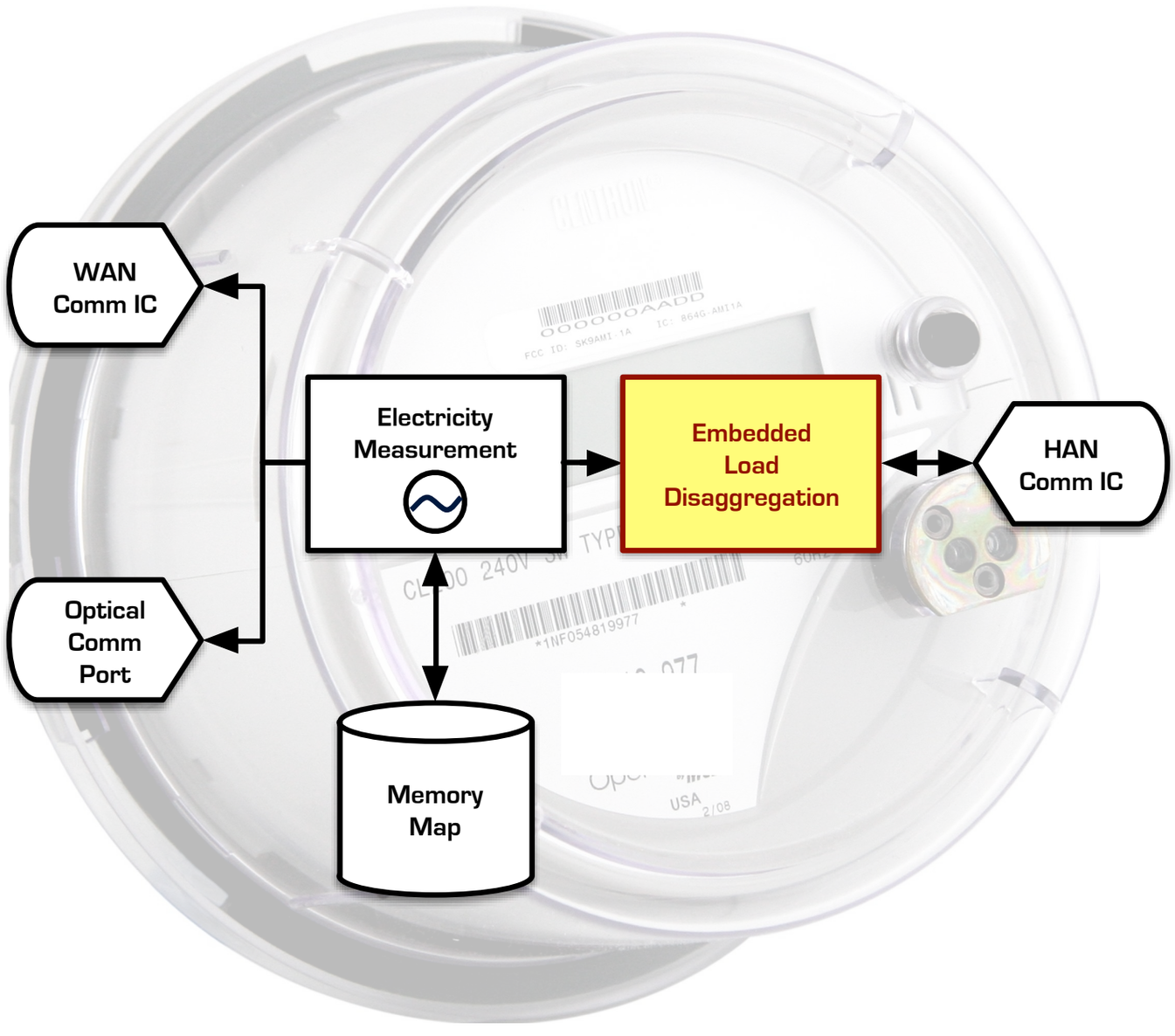
- **Goal met for this economic sector!**

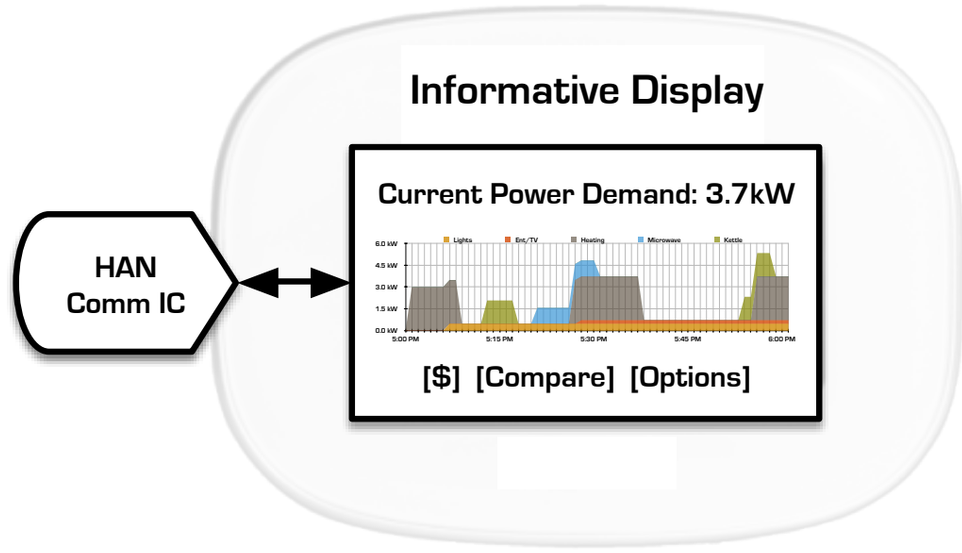
Disaggregator Anatomy

A generalized block diagram of a typical disaggregator.



A Smart “Smart Meter”





NILM Learning

Supervised NILM

- use sub-metered appliance data to build specific house models.

Unsupervised NILM

- use general appliances models and actively tune them to a specific house.

Unsupervised NILM

- Difficult to do!

- different sampling rates can lead to feature loss, **high-frequency vs low-frequency** sampling

- **vastly different** power signatures amongst same type of appliances

- learning can only have during **single load state changes**

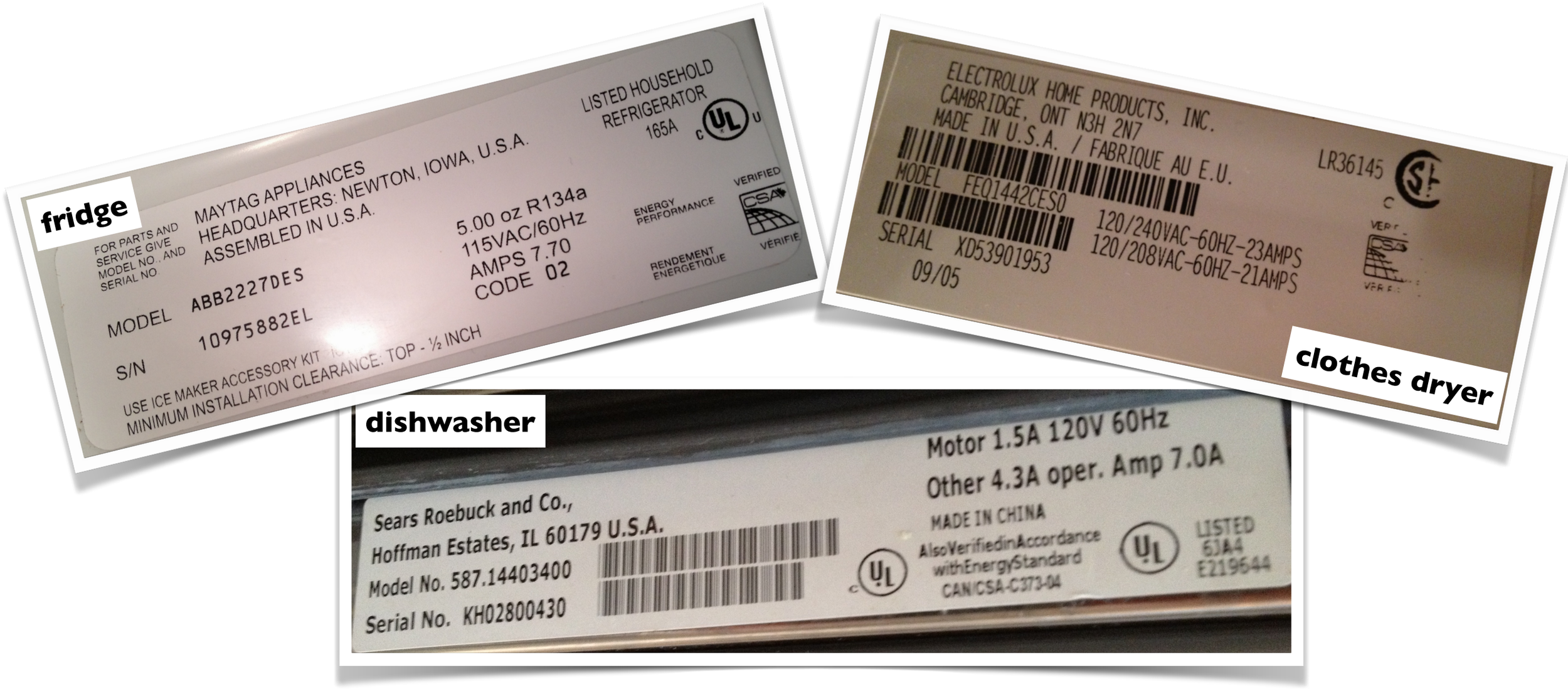
    - sometimes only during the **night** (e.g., Parson, 2014)

- **unable** to run in real-time on embedded systems, **reliably**, with the exception of cold appliances

Sampling Frequency

Frequency	Rate	Where	Measures
Ultra-High	MHz	products	harmonics, frequency analysis (V, A)
High	60Hz, kHz	products, research	
Low	**1Hz - 1/min**	**research**	**power (W), current (A)**
Ultra-Low	per 5, 10, 15 min per ½hr, 1hr	products, research	energy (kWh)

Lack Appliance of Facts



- **No** standard format
- **No** list of operational modes
- **Inaccurate** numbers reported
- Not helpful at all

Better Appliance Facts

Power Facts
Valeur Électricité

Sears Kenmore Dishwasher, Model No. 587.14403400
Sears Kenmore Lave-vaisselle, Modèle 587.14403400

Amount Teneur	Minute Duration Minute Durée
Not in use / Non utilisé 0.0A	—
Wash / Laver 6.4A	—
Light Cycle / Cycle Léger 6.4A	**4** min
Normal Cycle / Cycle Normale 6.4A	**25** min
Heavy Cycle / Cycle Lourd 6.4A	**40** min
Rinse / Rinçage 1.2A	**4** min
Heater / Réchauffeur 0.4A	**2** min

Energy consumption / Consommation énergétique

280 kWh
per year / par année

▼ This model / Ce modèle

250 kWh — 350 kWh

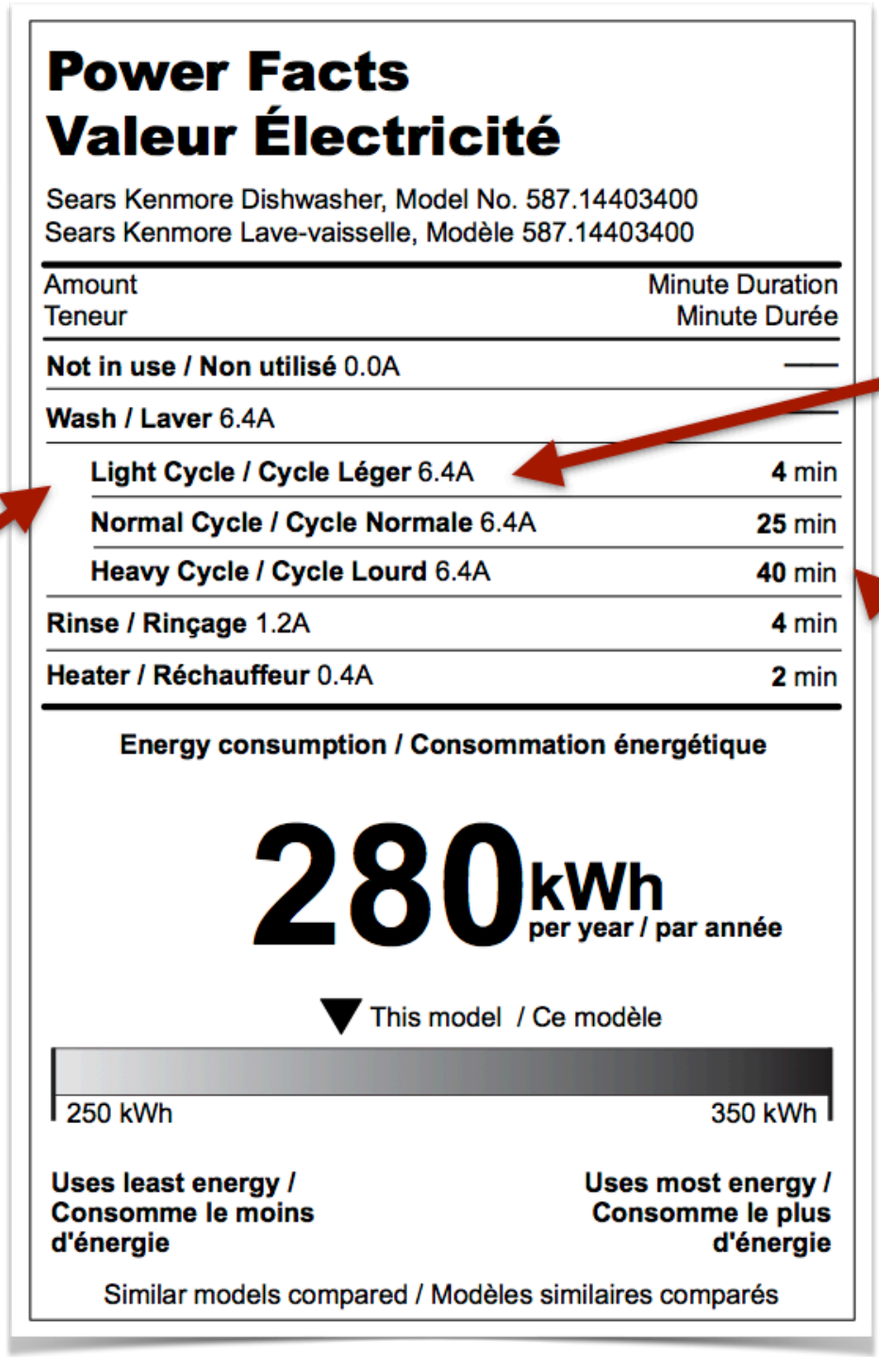
Uses least energy / Consomme le moins d'énergie

Uses most energy / Consomme le plus d'énergie

Similar models compared / Modèles similaires comparés

(the equivalent QR code)

Better Appliance Facts



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accurate numbers

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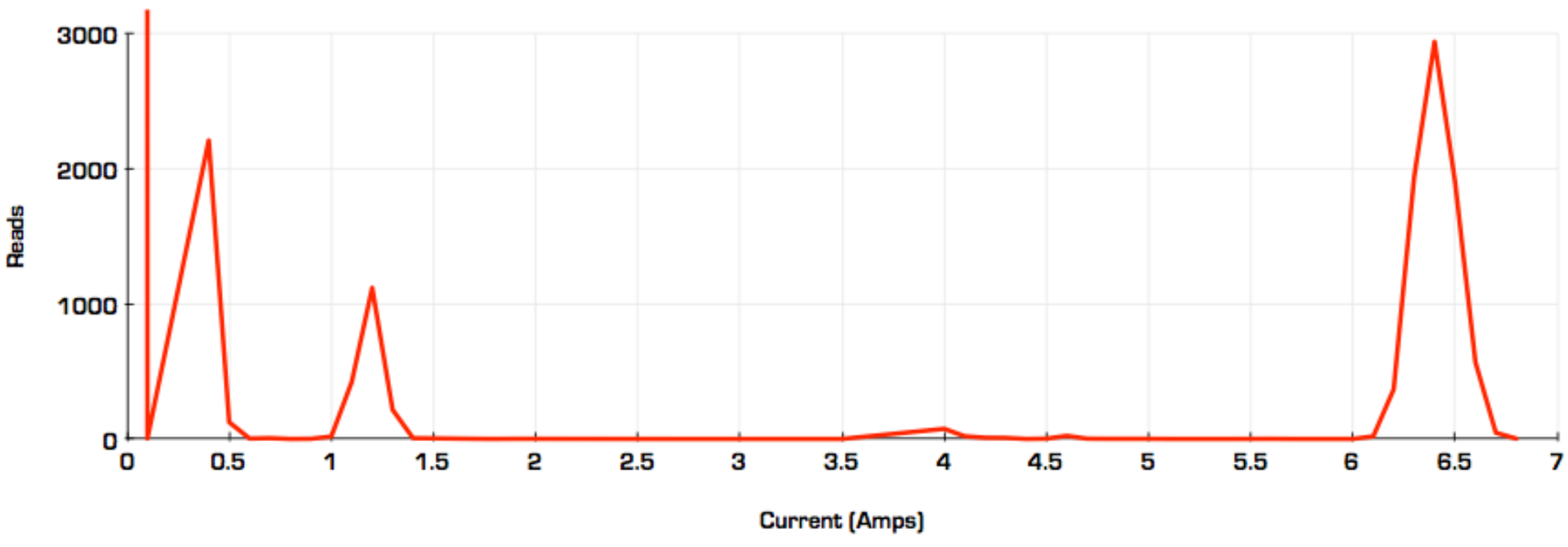
expected duration

Finding Load States

example of a dishwasher

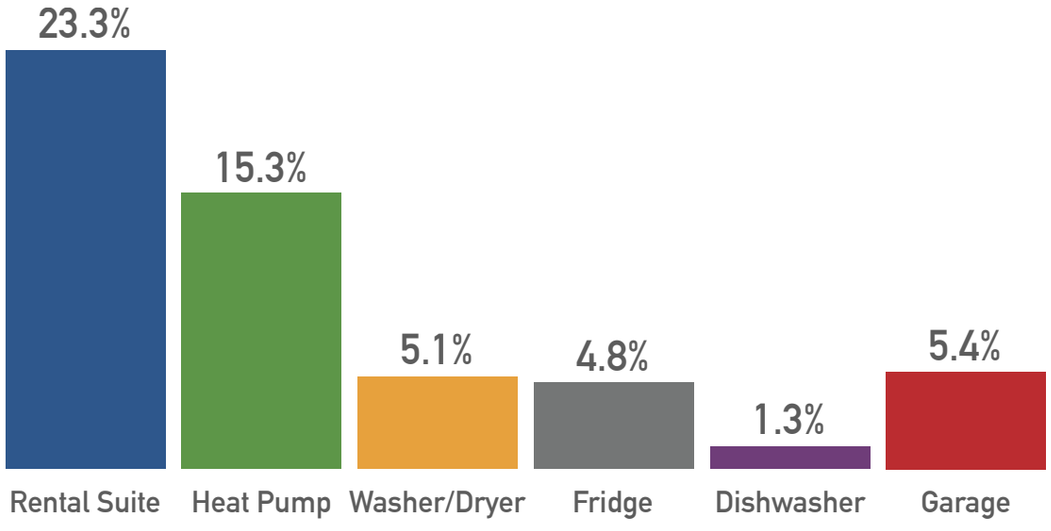
(a) 5 Hours of Real Power Consumption



(b) Distinct Current Measurements

Case Study

Uncovering energy savings unexpectedly. An old **1980's garage door lift** running but never used costing **$96/year** at **8¢/kWh**.



% USAGE OF SOME APPLIANCES (OVER 2 YEARS)

Total electricity costs over 2 years	$	1,787.09
Garage's energy usage (568 kWh)		5.38%
Cost of powering the garage door lift	**$**	**96.15**
Scenario A		
Cost of IoT/sensors (lowest cost)	$	1,640.00
Totals savings/(loss)	**$**	**(1,543.85)**
Payback in years		**34**
Scenario B		
Cost of smarter smart meter	$	0.00
Totals savings/(loss)	**$**	**96.15**
Payback in years		**0**

Toolsets

NILMTK, Version 3

- There exists a toolkit to test the accuracy, very good for testing supervised NILM

emuNILM (release date Dec 2017)

- **GOAL:** emulate the environment that **smart meters** and **home area network** (HAN) use (hardware and communication) so that NILM algorithms can can be tested in a *real-world-like* situation.

- This would be the ideal environment for testing **unsupervised NILM**.

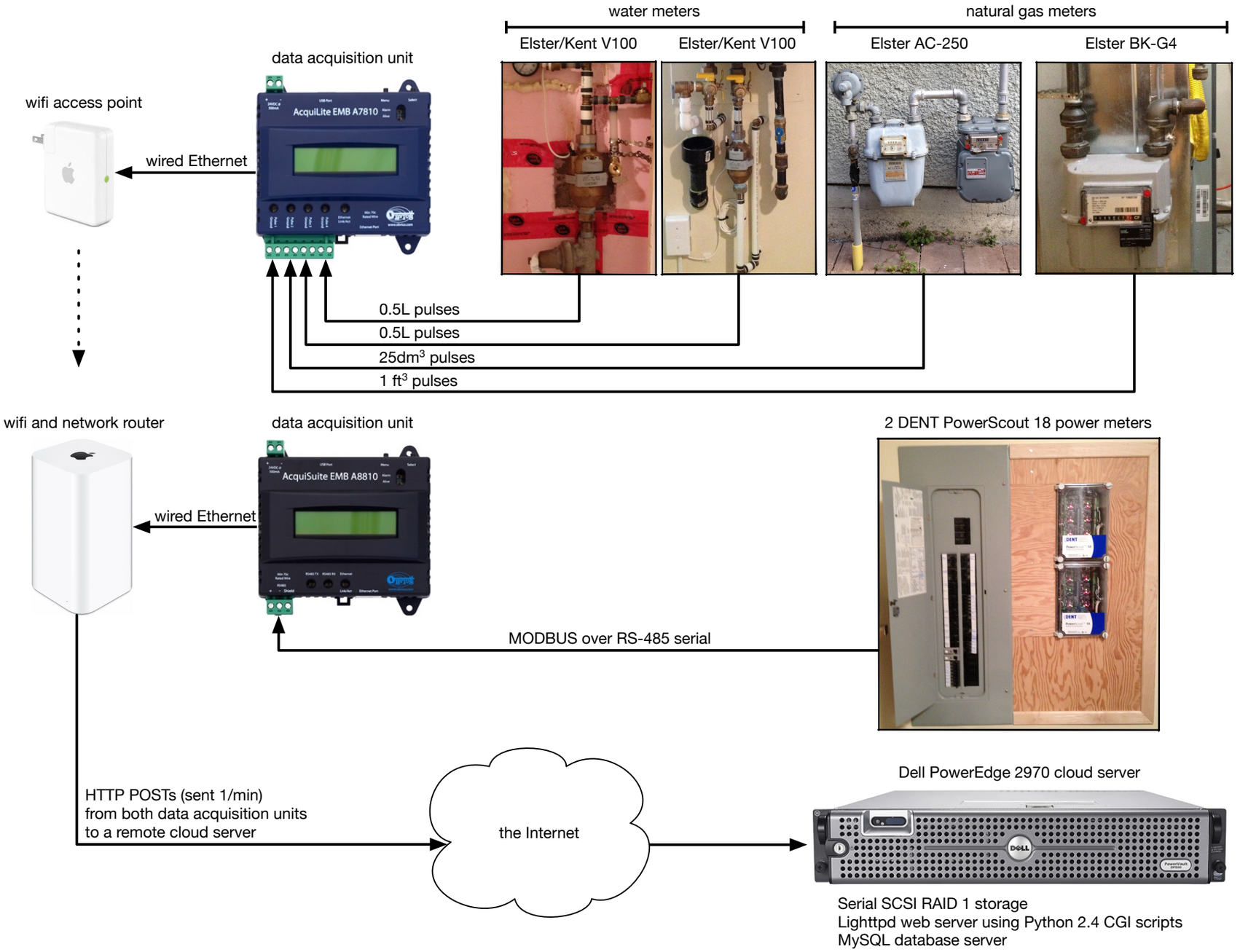
- Have **strict control** over environment and force NILM algorithm to run as if it would in the real-world… *no fancy tricks*

- Have other aggregate values as input at **different sampling** rates as in the real world; e.g., weather readings per 5 min.

A Call for Datasets

Datasets are expensive and time consuming to create, but we need them.

AMPds dataset data collection setup.



Privacy Concerns

Consumer Bill of Rights for Energy

ARTICLE I: ACCESS

The consumer has the right to know the power demands and signatures of each appliance, including the average, peak, and multiple-state power consumption. Access to this information must be made available via an informative display that would communicate directly to the smart meter, and not rely on the consumer having a computer or access to the Internet.

ARTICLE II: PRIVACY

The consumer's detailed appliance use information, or disaggregated data, belongs solely to the consumer. The consumer and producer jointly own aggregate power data. Data shall not be distributed to third parties except in anonymized and aggregated form, and with the consumer's express written consent.

ARTICLE III: SECURITY

The consumer has the right to expect that data is sent from the smart meter to the power utility and to devices in the home over a secure communication network.

ARTICLE IV: EQUALITY

The consumer has the right, no matter the socioeconomic situation, to equal opportunity to participate in energy conservation activities.

ARTICLE V: COMFORT

The consumer has the right to use energy to support basic comforts without shame or penalization.

ARTICLE VI: RE-ENTRY

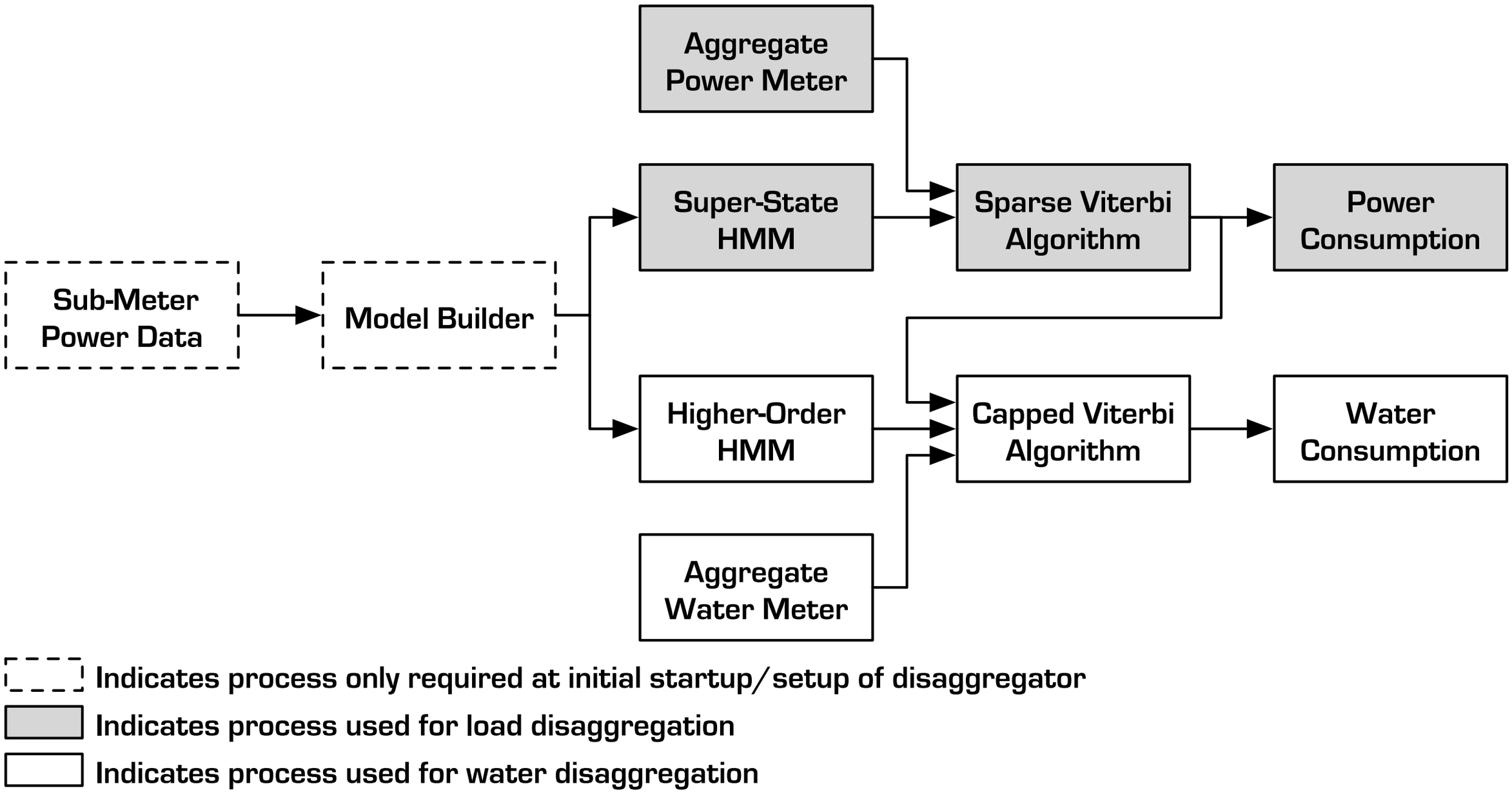
The consumer has the right to re-enter into programs that promote general energy conservation retrofitting. Programs must allow for staged completions in recognition of change of residence and budget constraints.

ARTICLE VII: MAXIMIZATION

The enumeration of the foregoing rights shall not be construed to deny or disparage others retained by the consumer.

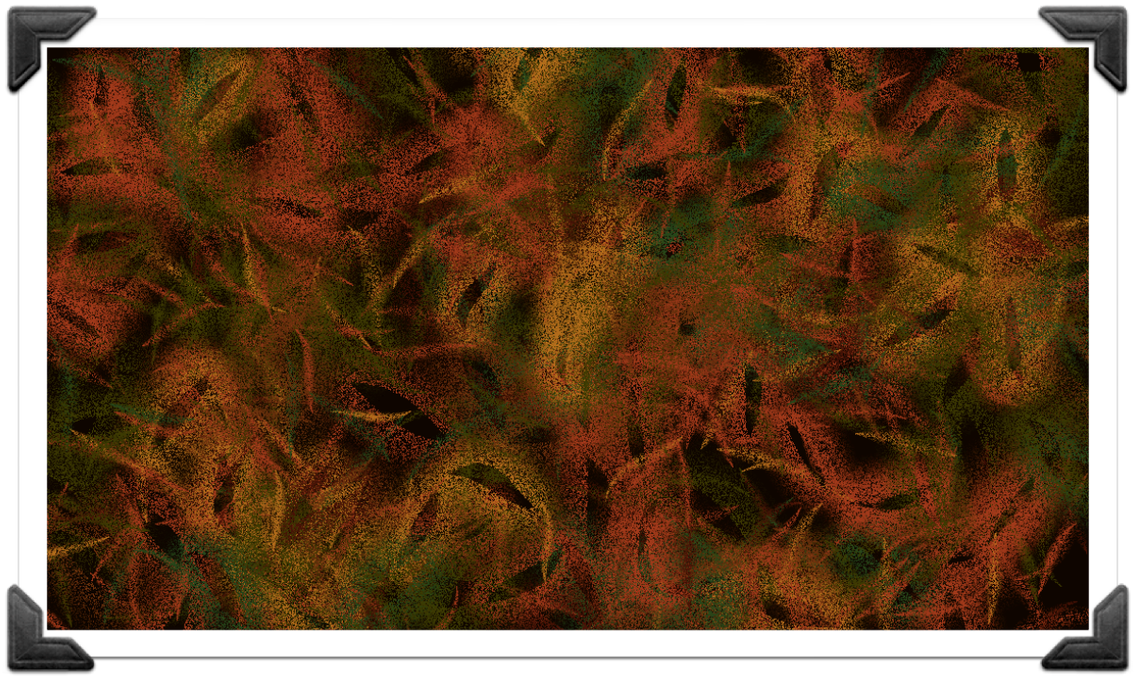
Multi-Fuel Disaggregator

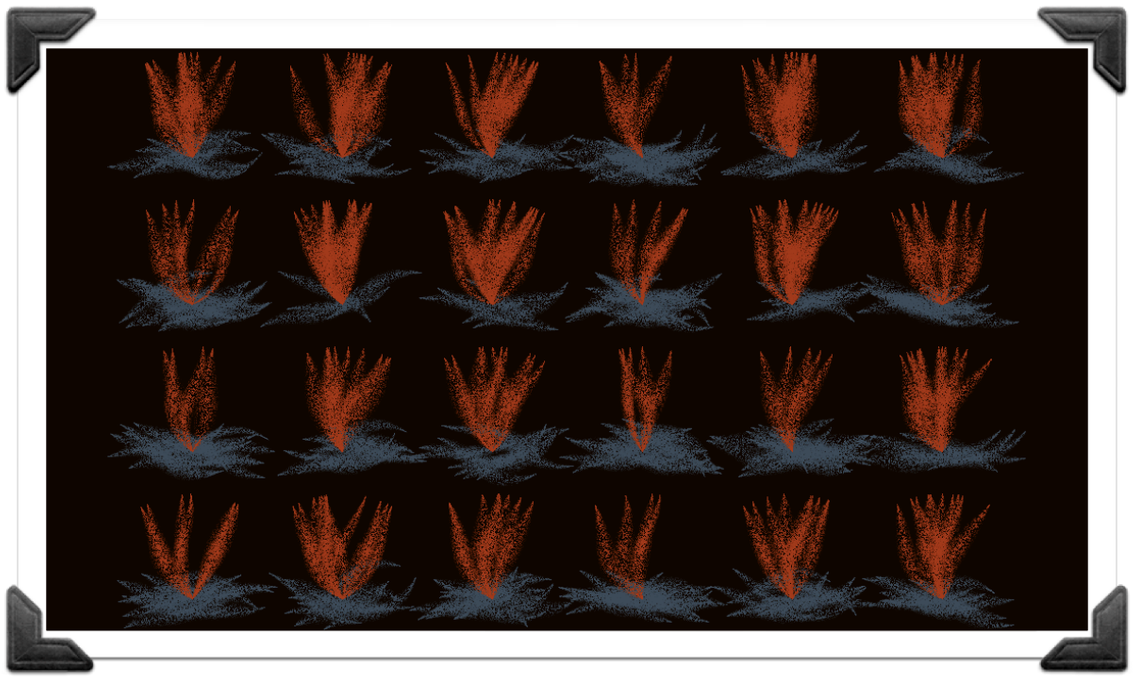
Use electricity to disaggregate appliance water usage.

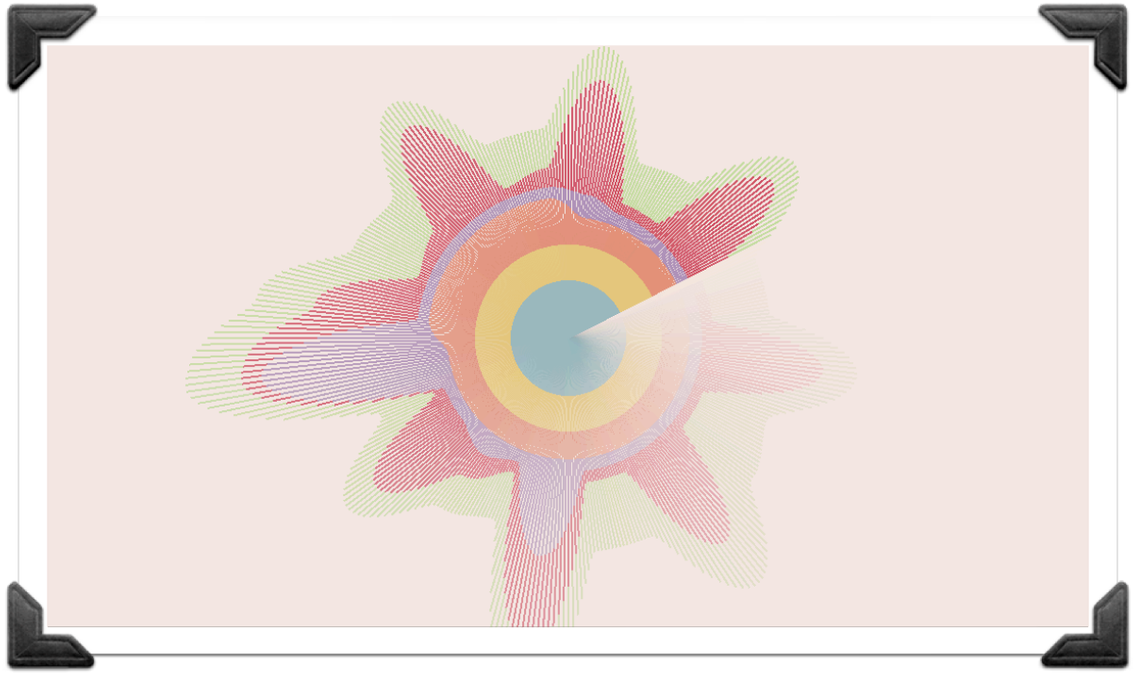


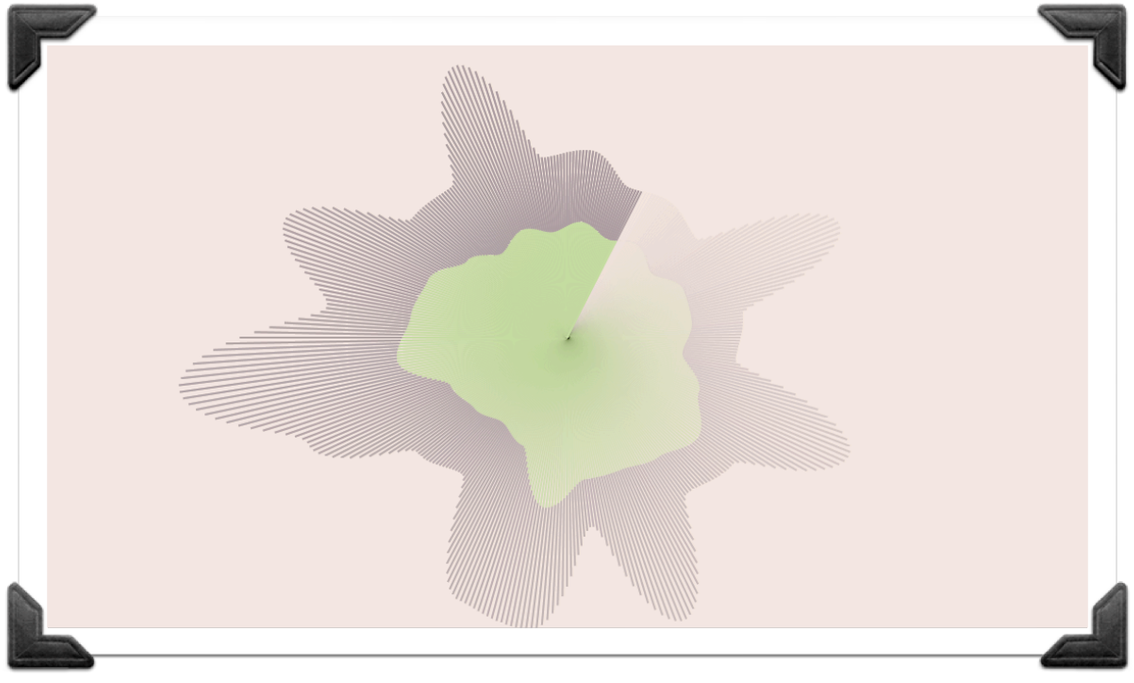
Eco-Visualizations

Abstractly Visualizing NILM Results as Art









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Further Readings

Stephen Makonin, Fred Popowich, Ivan V. Bajic, Bob Gill, Lyn Bartram.
Exploiting HMM Sparsity to Perform Online Real-Time Nonintrusive Load Monitoring.
IEEE Transactions on Smart Grid, vol. 7, no. 6, pp. 2575-2585 (2015).

Stephen Makonin, Fred Popowich.
Nonintrusive Load Monitoring (NILM) Performance Evaluation.
Energy Efficiency, vol. 8, no. 4, pp. 809–814 (2015).

Stephen Makonin, Bradley Ellert, Ivan V. Bajic, Fred Popowich.
Electricity, water, and natural gas consumption of a residential house in Canada from 2012 to 2014.
Scientific Data, vol. 3, no. 160037 , pp. 1-12 (2016).

Stephen Makonin, Laura Guzman Flores, Robyn Gill, Roger Alex Clapp, Lyn Bartram, Bob Gill.
A Consumer Bill of Rights for Energy Conservation.
Proceedings of the IEEE Canada International Humanitarian Technology Conference (IHTC), 2014.

Stephen Makonin.
Real-Time Embedded Low-Frequency Load Disaggregation.
PhD thesis, Simon Fraser University, School of Computing Science, 2014.

Bradley Ellert, **Stephen Makonin**, Fred Popowich.
Appliance Water Disaggregation via Non-Intrusive Load Monitoring (NILM).
Proceedings of the EAI International Conference on Big Data and Analytics for Smart Cities (BigDASC), 2015.

Stephen Makonin, Maryam H. Kashani, Lyn Bartram.
The Affect of Lifestyle Factors on Eco-Visualization Design.
Proceedings of Computer Graphics International (CGI), 2012.

Questions?

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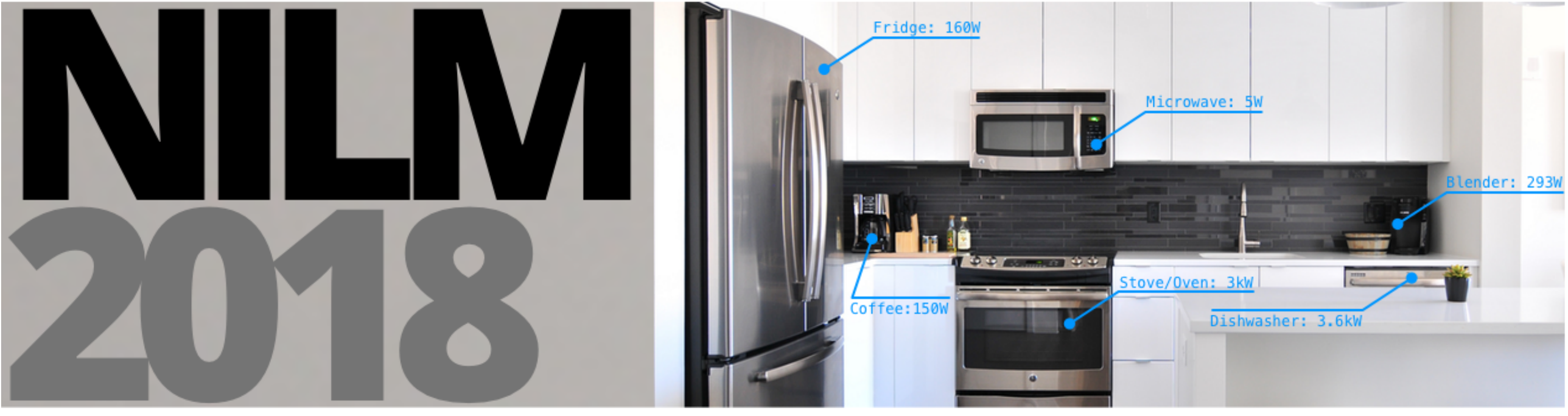

CALL FOR PAPERS & TPC

http://nilmworkshop.org/2018/

University of Texas, Austin, in **Austin, Texas** in **late February or early March 2018**

IMPORTANT DATES

Paper Submission Deadline:	December 29 (at 5pm EST)
Notification of Acceptance:	January 26
Final Paper Submission Due:	February 5
Registration Deadline:	February 24
Registration Fee:	FREE

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Mario Berges, Carnegie Mellon University

Stephen Makonin, Simon Fraser University

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