
# Energy Disaggregation

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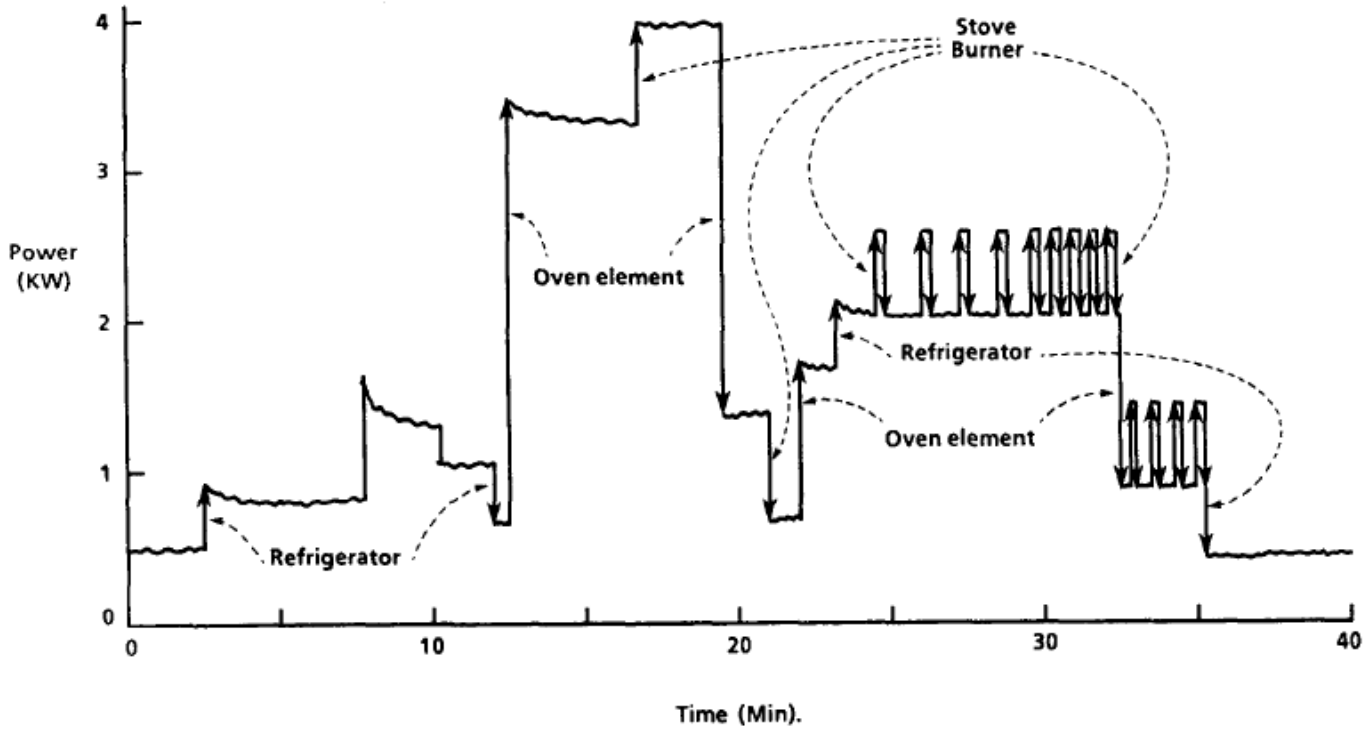
# What is Disaggregation?

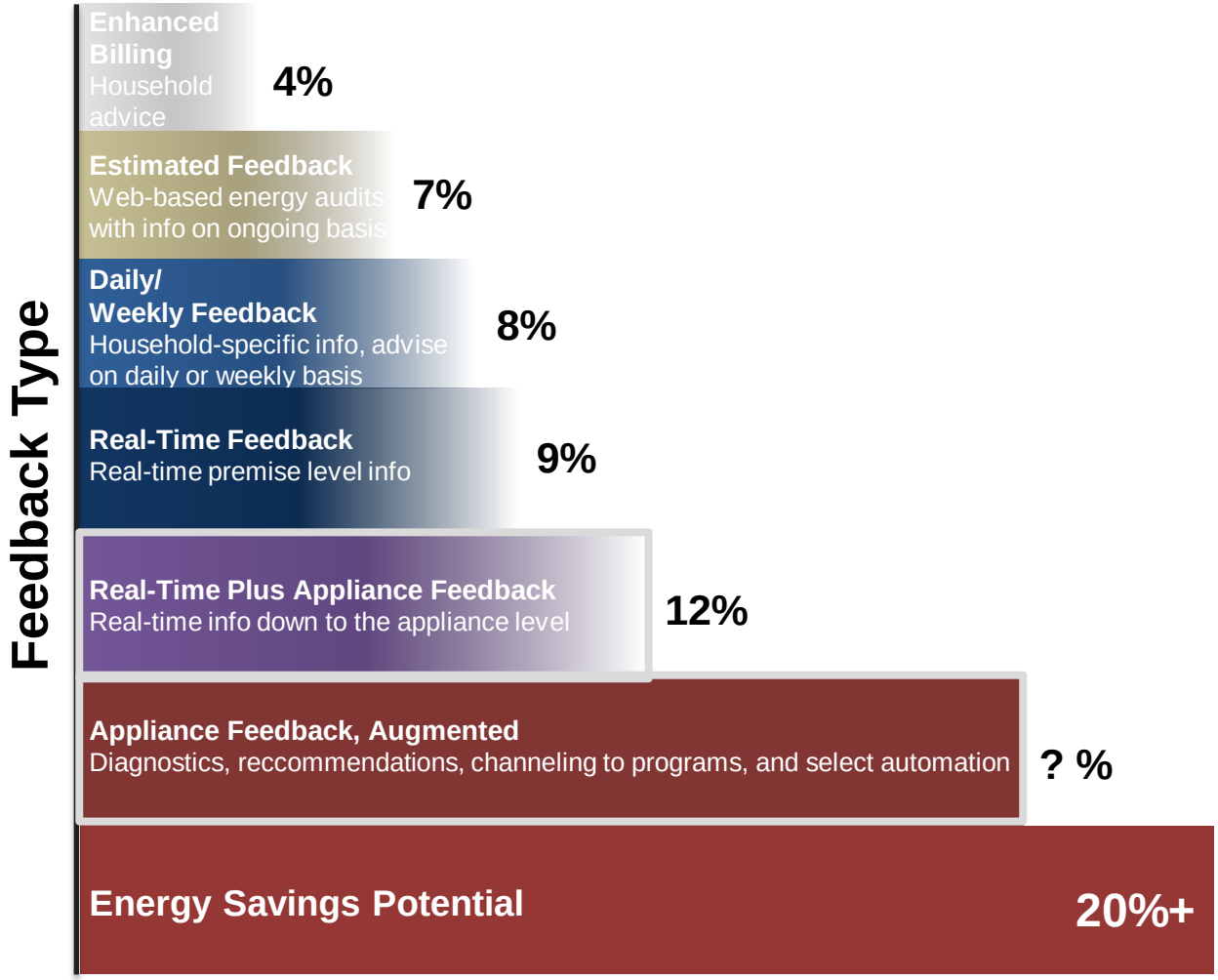
Disaggregation allows us to take a whole building (aggregate) energy signal, and separate it into appliance specific data (i.e., plug or end use data). A set of statistical approaches are applied to accomplish this.




# Overview

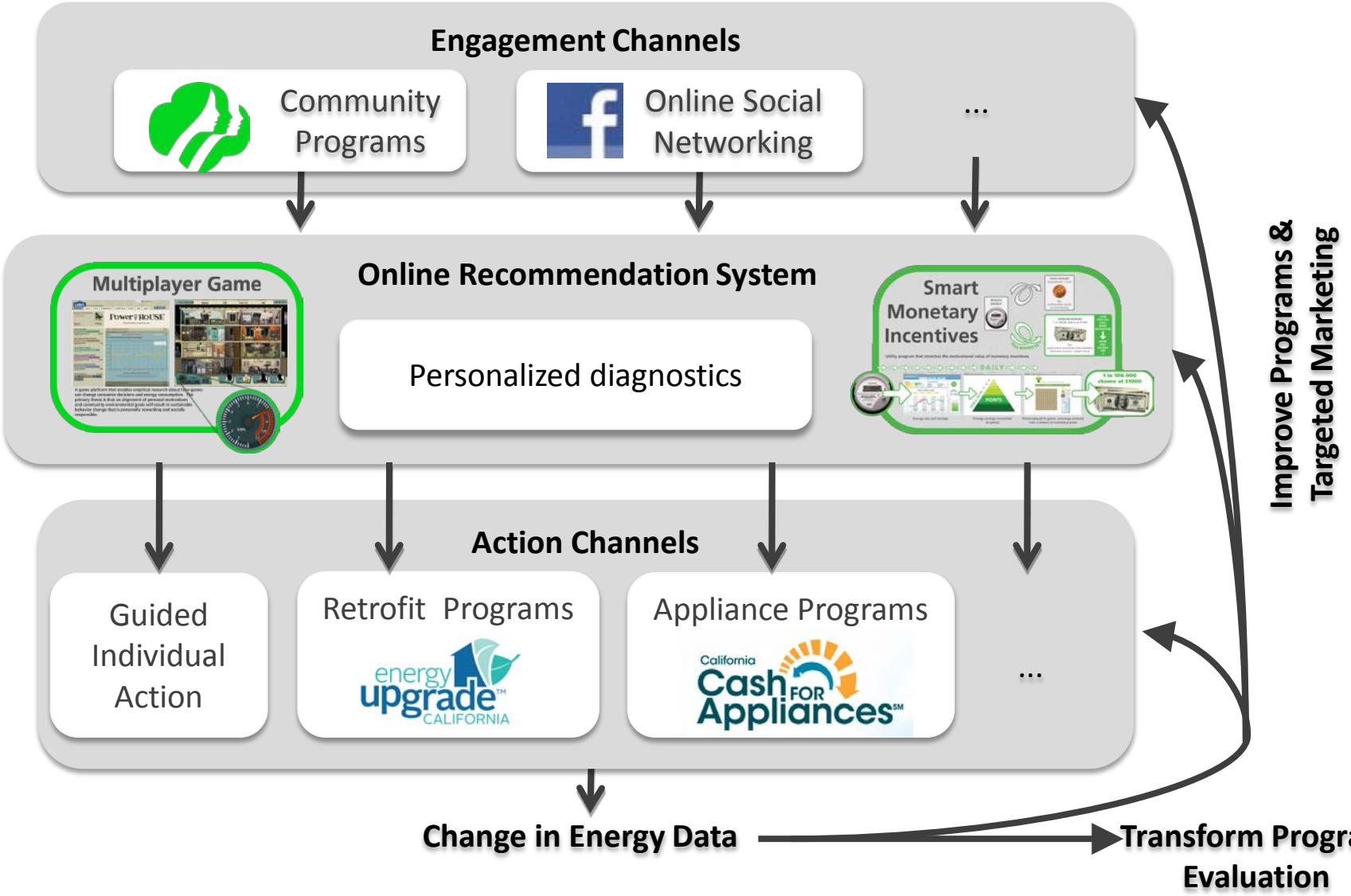
1. Why is appliance specific data useful?
2. Disaggregation algorithm requirements
3. Smart meters constraints
4. Recommendations for using the algorithms with smart meters

# Appliance-Specific Feedback




(Top 4 bars from Ehrhardt-Martinez, Donnelly, & Laitner, 2010)

# Appliance Feedback Augmented



# Benefits of Appliance-Specific Energy Use Data

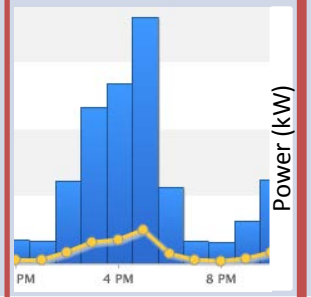
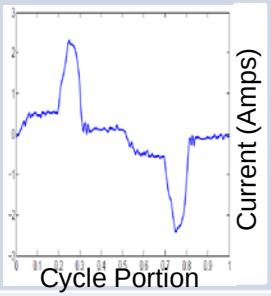
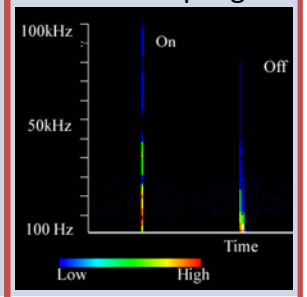
| Domain | Explanation |
|---|---|
| Residential Energy Reductions | 40+ studies on feedback reducing energy use, with limited appliance-specific work showing greater energy reductions |
| | Provides clear recommendations and detection of malfunctions; households can then be channeled into specific programs (e.g., audits, appliance replacements) |
| | Enables new behavioral approaches |
| Program Evaluation | Improved sensitivity to detect change from programs, and iteratively improve programs. |
| Targeted Marketing | Strategic, specific, energy efficiency segmentation & marketing |
| Economic Models and Policy Recs | Economic models can be improved through specificity to better inform policies, such as funding allocations |
| Commercial Energy Reductions | Large untapped savings |
| Building Research and Design | End use specific information could clarify why predicted (i.e., modeled) and actual building energy use are discrepant, to guide future improvements. |

# Hardware Options for **Getting Appliance-Specific Data**

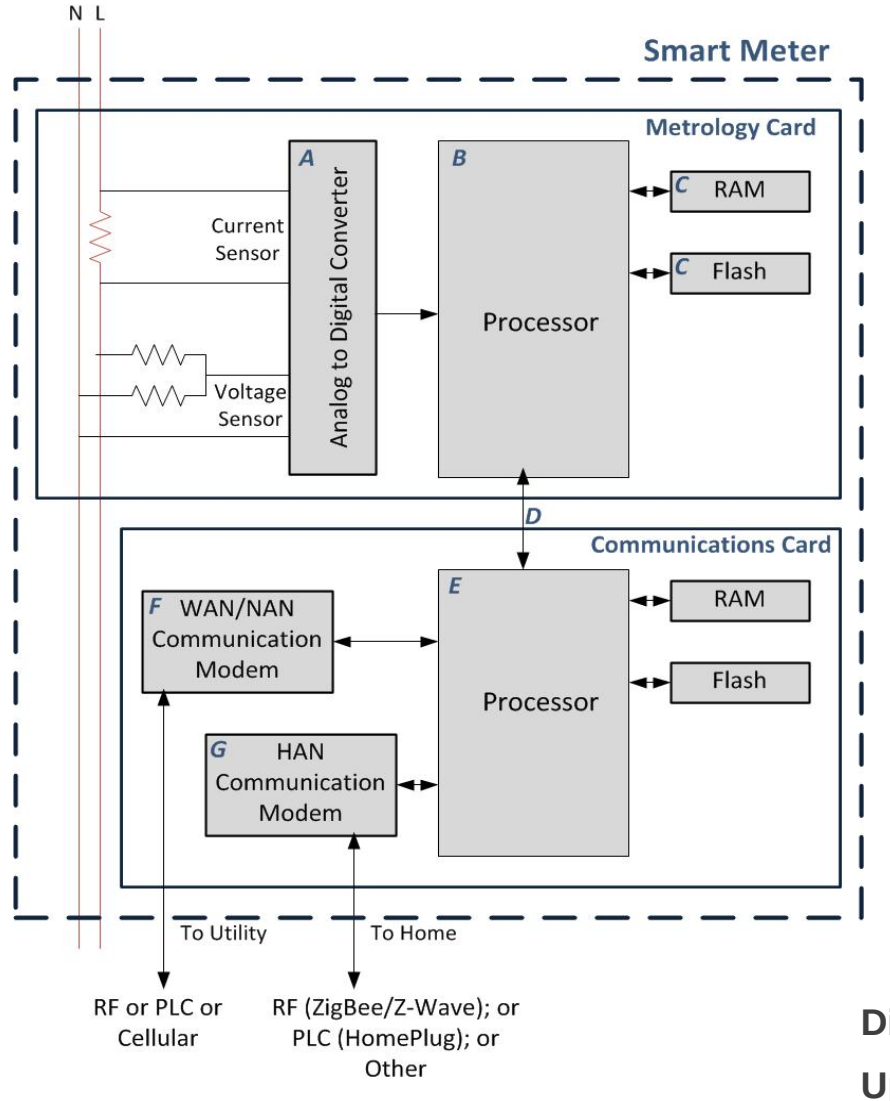
| | Sensing Technology | Cost to Consumer | Installation Effort | Adoption |
|---|---|---|---|---|
| Hardware Disaggregation | Plug Level Hardware Monitors (e.g., Kill-A-Watt, EnergyHub) | $30-$50/plug; $300-600/home | Most plugs – Med 240V plugs - Hard | Low; in existence for past 7-8 years |
| | Smart Appliances | $100+ additional compared to non-Smart appliances | Easy | 10-15 years after introduction for mass adoption |
| Software Disaggregation | House Level Current Sensor (example - TED, Blueline, Egauge etc.) | $200+/house | Very Hard | Low (high cost + high effort) |
| | Smart Meter | None | None | Very High & fast (installed by utilities) |

**Smart Meter is the lowest-cost & lowest installation effort sensor for consumers**

# Disaggregation Algorithm
# Data Requirements

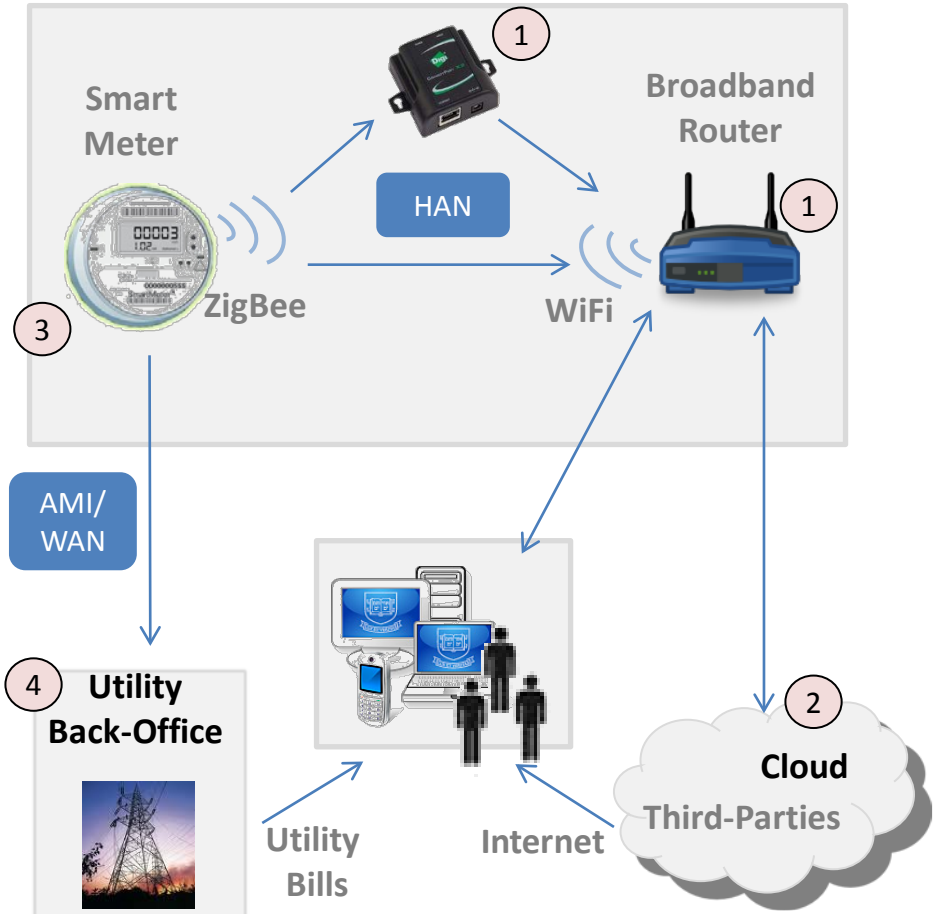
| Data Sampling Frequency | 1 hr – 15 min | 1 min – 1 sec | 10Hz – 2KHz | 10KHz – 15KHz | > 1MHz |
|---|---|---|---|---|---|
| Data Appearance | 1 hr PG&E   | <1 min Sampling   | Similar to adjacent graphs | KHz Sampling   | MHz Sampling   |
| Data Type Used by Algorithms | Visually observable patterns; duration and time of use if consistent | Steady state steps/transitions | Low order harmonics | Medium order harmonics to identify type of electrical circuitry in appliance | Very high order harmonics to identify both transients & the background noise by appliances |
| Appliances Identified | General categories of base load & variable load, and low accuracy of some large peak loads like AC | Top <10 appliance types - Refrigerator, ACs, Heaters, Pool Pump, Washers, Dryers etc. | Not Known, Few studies, perhaps because hardware cost same at 10KHz | 20-40 appliance types – toasters, computers, etc. along with larger loads identified by 1min-1sec algorithms | 40-100 specific appliances – e.g., differentiates 2 lights; requires separate power consumption data stream |

# Smart Meter Hardware Capabilities




| | | 1hr – 15 min | 1min-1sec | 10Hz-2KHz | 10KHz-MHz |
|---|---|---|---|---|---|
| A | **A/D Converter** | √ | √ | × (needs **firmware** upgrade) | × (needs **hardware** upgrade) |
| B | **Metrology Processor** | √ | √ | √ | Processor Dependent |
| C | **Memories** | √ | √ | √ | May support |
| D | **Serial Interface** | √ | √ | May be Borderline | × |
| E | **Comm. Processor** | √ | √ | √ | Processor Dependent |
| F | **WAN Comm.** | √ | × (needs **firmware** upgrade) | × | × |
| G | **HAN Comm.** | √ | √ | × | × |
| **Disaggregation** | | Outside Meter | | Only inside Meter | |
| **Upgrades** | | None | Firmware Only | | Hardware |

# Hardware Options for **Running** the Algorithms




| | | Sampling Frequency supported | Changes Required |
|---|---|---|---|
| 1 | Run on a Device In the House | Up to a few KHz | None for 1min. Enhanced HAN for a few KHz |
| | | >1MHz (plug level voltage sampling) | Plug Hardware required for sampling |
| 2 | Run in the Cloud on third party servers | Up to a few KHz | None for 1min-1sec; Enhanced HAN for a few KHz |
| 3 | Run in the Meter | Up to a few KHz; Hardware change required for 10-15KHz sampling | Upgrade A/D and Processor; Cost: ~$6-$10 In Meter ASP |
| 4 | Run in Utility Back Office | 1min -1sec | Meter Firmware |

Likely in the short term  Possible in long term  Less likely

# Recommendations

# Research

- **Improve disaggregation algorithms**

  To improve robustness and accuracy of the algorithms, while reducing frequency, processing, and training requirements. Priorities are: 1min-1sec, 10Hz-2KHz, 10-15KHz

- **Develop a common data set**

  That captures variability over appliances as well as operating conditions and make it available to developers – currently, a dearth of data is limiting dev't

  - **Organize a competition using this data set**

    As with prior algorithms, this would foster algorithm development at universities

  - **Establish definitions of accuracy**

    To enable comparison of algorithms, and answer critical questions

- **Establish testing facilities for evaluating algorithms in realistic environments**

  Determine real algorithm & smart meter capabilities by probing various components etc. Collaboration between universities and industry is useful here

# Smart Meters

## Leverage Existing Smart Meters

- **Upgrade firmware to make reactive power available in addition to active**
  This allows algorithms to disaggregate more devices
- **Upgrade firmware to support compression of data**
  Transmitting events/transitions instead of raw load profiles could significantly improve the frequency of data available to HAN devices, as band-with is currently a bottleneck

## Revise Future Smart Meter Specs

- **Support up to 15KHz of sampling frequency**
  Costs a few dollars and enables the next class of disaggregation algorithms
- **Explore using low-power WiFi instead of ZigBee**
  Enables consumers to receive data from the Smart Meters without purchasing additional hardware
- **Support disaggregation inside the Smart Meters**
  To avoid AMI or HAN network being the bottleneck in transmitting data out of Smart Meter
- **Add a serial port on meter to allow consumer owned device to directly access their load profile**
  Already being done in Europe to maximize the potential of energy savings for consumers

# Policy

- **Mandate enabling of ZigBee radios soon, at least in pilots**

  HAN activation & data would accelerate the development of disaggregation algorithms

- **Mandate that Utilities share the data collected during HAN Pilots anonymously with research institutes**

  Lack of real life data has been one of roadblocks for algorithm developers

- **Mandate that Utilities select HAN devices that allow consumers to access or share their data with any third party**

  Fosters innovation since small businesses can now sell directly to consumers and invest time into developing superior disaggregation solutions

- **Approve a rebate to make ZigBee gateways effectively free to consumers**

  No different from a $100 rebate available for an Energy Star refrigerator – disaggregation can provide much higher savings than a refrigerator alone

# Commercial Solutions

1. High Energy Audits
2. MyEnerSave, PlotWatt
3. Desert Research Institute, Navetas
4. GE, Intel, Belkin

# Collaborators

Abhay Gupta, MyEnerSave
Adrian Albert, Stanford
Gireesh Shrimali, CSLI
Zico Kolter, MIT

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# The **Benefits**

1. **Provide automated diagnostics**/personalized recs
2. **Motivate** action with specialized behavioral techniques
    - Novel incentives & rate structures, Feedback, Markets, Competitions, Data visualization
3. **Create the best programs** with speed, ease, cost, and scale
4. **Transform evaluation** by incentivizing utilities & encouraging diversification of behavioral programs
5. **Improve segmentation** for energy efficient marketing
6. **Improve building, and also appliance, research and design**
7. **Inform policy** with improved economic models

***→We believe these benefits will be significantly augmented with "Appliance-Specific" (or End-Use) Data***

# Recommendations

## Leveraging Existing Smart Meters

1. **Mandate enabling of the HAN soon, at least for pilots**
2. **Develop firmware upgrades to provide reactive power to HAN devices**
3. **Encourage HAN devices that allow consumers to access or share their data with any reputable third party, and provide rebates to make these free**
4. **Foster algorithm development to determine whether 10s-1min can give sufficient appliance recognition**

## Shaping Future Smart Meters

1. **Explore using WiFi instead of ZigBee**

   Enables consumers to get data from Smart Meters without purchasing additional hardware
2. **Support up to 15KHz of sampling frequency**

   Costs a few dollars and enables the next class of disaggregation algorithms
3. **Support disaggregation inside the Smart Meters**

   To avoid AMI or HAN network to be the bottleneck in transmitting data out of Smart Meter

## Research

- **Develop a common data set**

  that captures variability over appliances as well as operating conditions and make it available to researchers

- **Support algorithm development**

  With test facilities, evaluations, collaboration between industry and universities.

- **Organize a competition**

  as has been done previously with algorithm development, as this would utilize the dataset and foster algorithm development at universities and beyond.

- **Establish definitions of accuracy**

  to enable comparison of algorithms, and to assess the usefulness of higher sampling frequencies.

# The **Benefits**

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