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EPRI End-Use Load Research: An Update

P170A: Analytical Frameworks

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Presentation Outline

1. **EPRI End-Use Overview**
2. **Making the Case for End-Use Load Data Collection**
   a. EE&DR M&V – audits, program design, appliance diagnostics
   b. Load Forecasting
   c. Rates and Pricing (Efficient)
   d. T&D Planning
   e. Integrated Resource Planning (IRP)
   f. Customer Service and Operations
   g. Load shape volatility
3. **Prior and On-going EPRI Research**
   a. End-Use Environmental Impacts
   b. "Driving down the cost of end-use load data"
   c. Direct Measurement/statistical/wave form/hybrid
   d. Load shape library – what this entails, the on-going nature of this but that it lacks statistical validity, robustness and coherence
4. **Current Projects**
   a. Load shape work with Saudi Electric Company that will use NILM devices
   b. Load shape work with New York utilities using NILM devices
5. **Vision for Future**
   a. Pre-demo analysis, roadmapping, background – clearly define what is needed, gaps, and plans
   b. Regional load shape research effort to collect load shape data from multiple utilities in multiple regions on customer technologies including loads such as efficient appliances, electric vehicles; energy storage, and generation such as PV

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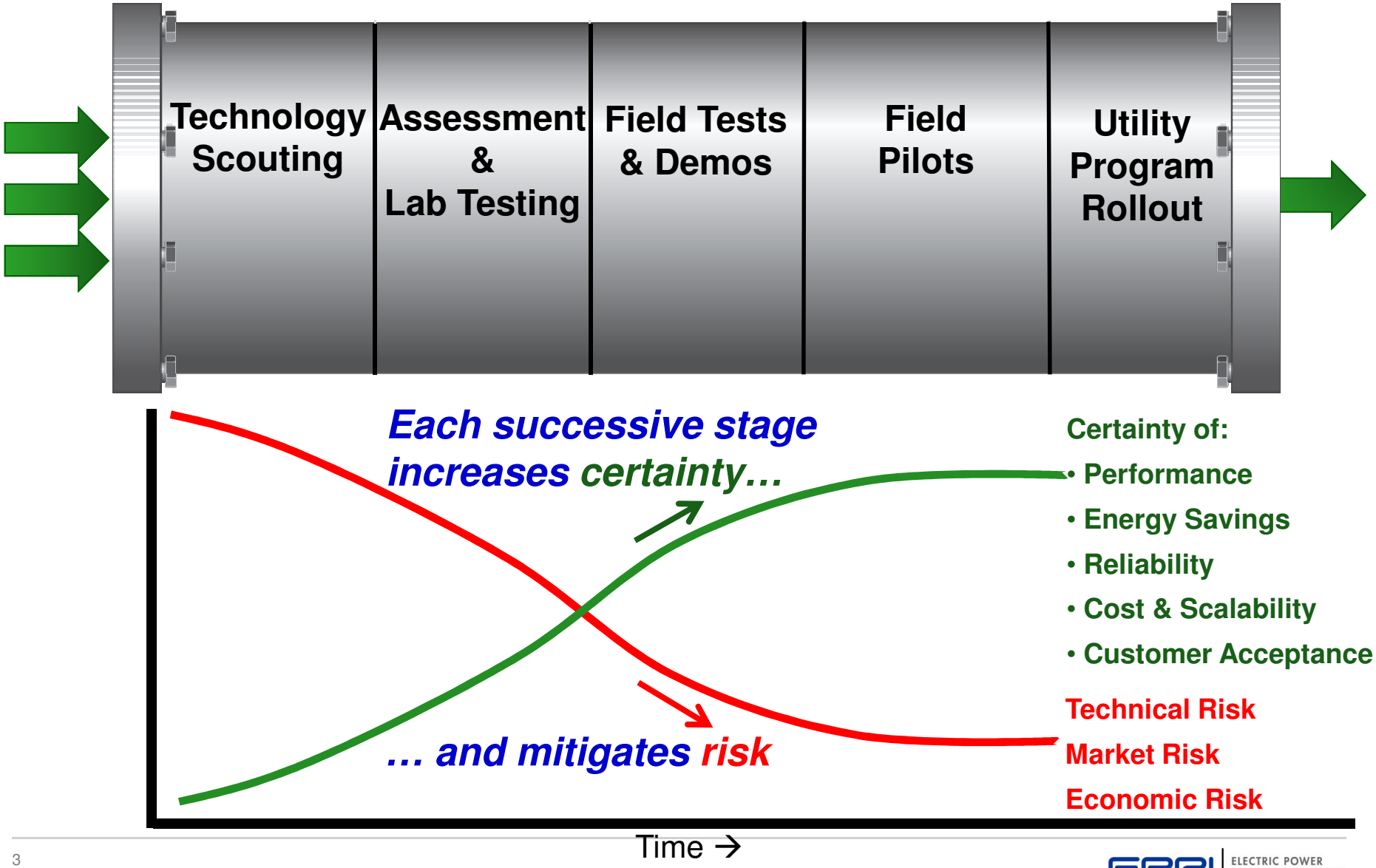
EPRI is Advancing End-Use EE & DR Technology Through the Development Pipeline



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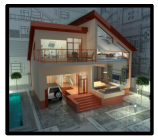
Sampling of End Use Technologies Under EPRI Evaluation – Current Snapshot

Technology Scouting

DC Architecture for ZNE Homes



Phase-Change Materials

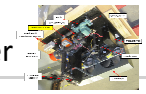
Wireless Sensors

Advanced Energy Management

Multi Protocol Routers

Next generation Heat Pumps

Next generation Heat Pump Water Heaters



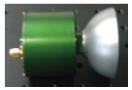
Assessment & Lab Testing

Variable Speed Circulation Pumps

Advanced Refrigeration

Efficient , DR-Ready Products

Plasma Lighting



Desiccant Dehumidification

Dimmable LEDs

Non-intrusive load monitoring

R&D Field Tests/Demos

Variable Capacity Space Conditioning

Heat Pump Water Heaters (Gen. 2)

Controllable High Bay Lighting

Data Centers EE Technologies

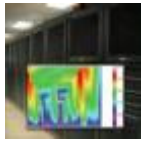
Advanced Rooftop Air Conditioners

Automated DR and Energy Management

Field Pilots

Smart Thermostats

Data Center Airflow Management



VRF Heat Pumps

Integrated Whole Buildings

Program Rollout

LED Street and Area Lighting

High Efficiency Refrigerators

Heat Pump Water Heaters (Gen. 1)

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End-Use Energy Efficiency and Demand Response Program (P170)

Analytical Frameworks (170A)

- 170.002 Impact of Energy Efficiency on Emissions of CO_2 and Other Pollutants
- 170.005 Load Research
- 170.024 Customer Data Mining and Analytics

Demand Response Systems (170B)

- 170.006 DR-Ready Technologies
- 170.007 Thermal Energy Storage
- 170.009 Intelligent Homes & Buildings
- 170.018 Evolution of Demand Response Markets

Energy-Efficient Technologies (170C)

- 170.013 HVAC & Water Heating
- 170.019 Motors & Drives
- 170.020 High Performance Buildings
- 170.021 Lighting and Electronics
- 170.025 Data Centers

Energy Efficiency Technology Readiness Guide

Technology Innovation Projects

Supplemental Projects – Utility & Government

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End-Use Environmental Impacts

Scope

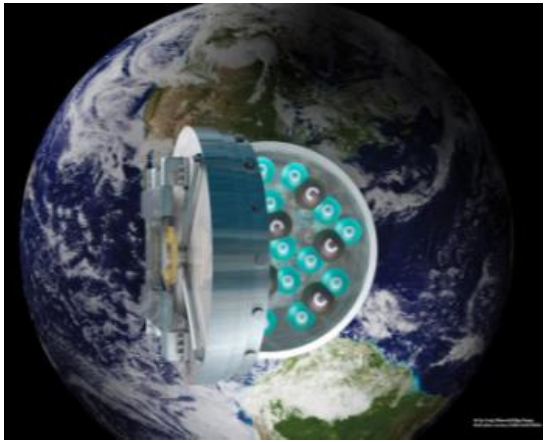
- Update CO_2 calculator with latest REGEN model results based on 2015 base case
- Capability to assess estimates for SO_x, NO_x, and Hg along with CO_2 emissions
- Streamline model inputs to facilitate faster turn around of results

Road Map Alignment

- Data Analytics - Environmental

Value

- Helps participants value impact and quantify benefits of EE & DR portfolios in support of regulatory filings
- EPRI research provides unbiased technical input to inform policy decisions
- EPRI research can support Member participation in development of states' 111(d) Response Plans



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"Driving Down the Cost of End-Use Load Collection"

Challenge

"Capturing end-use data is complex, intrusive and expensive to collect

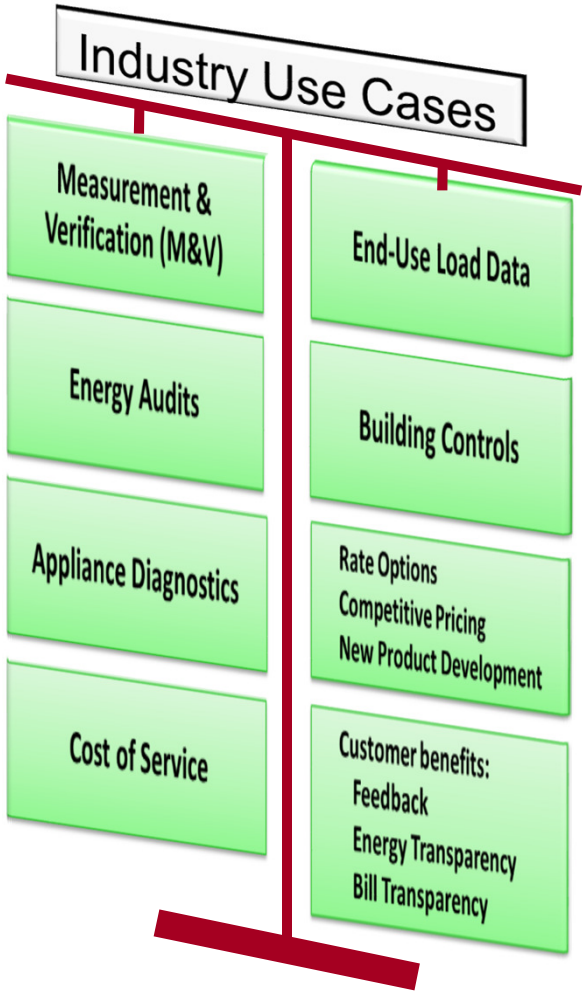
Current Situation

- New digital technology, new metering technology and new communication technology have combined to drive down the cost of collecting interval data from customers.

EPRI Focus

Assessing three areas of load data collection technology for cost/accuracy /suitability in applications:

- Conditional Demand Analysis (CDA)
- Non-Intrusive Load Monitoring Devices (NILM)
- Inexpensive Sensors
- Data Repository (Load Shape Library)



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2014-2015 Technology Innovation (TI) Project CDA – Concept Validation

Objective and Scope:

- Concept validation of statistical methods for combining survey data with AMI interval data to produce end-use load shapes
- Can AMI data be paired with survey data to produce statistically relevant end-use load shapes at acceptable levels of accuracy and cost?
- EPRI is working with BPA to obtain the Residential Building Stock Assessment (RBSA) dataset providing a "ground truth" for feasibility assessment

Road Map Alignment

- End-Use Load Research

Value

- Increases the value of AMI data
- Provides expanded data availability for behavioral research
- Drives down the cost of end-use load data collection

Risks and Uncertainties:

- Adequacy of the survey may drive results
- Statistical Interpretation of individual load shapes must be developed

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TI Project: Hourly CDA Approach – *Diversified Load Shapes*

- Takes advantage of (relies upon) the *variation* of end-use appliance ownership (survey data) to statistically infer the *components* of customers' hourly load profiles (AMI data) across a large number of customers.
- Approach: Regression analysis applied to hourly *load* data, using variables from *survey* data on major end-use applications to allocate total load to end uses
  - Comparing total loads of two identical houses, where only one has electric water heater; difference between loads is load of water heater
  - Regression analysis makes those comparisons across hundreds of customers & all included end uses
  - Result produces a "diversified end use load shape" for a group or class of customers
  - Cost to collect is far less than other methods

Results show that using RBSA data (BPA) for those sites where the ground truth metering captures the majority of household consumption and when the survey data is accurate - conditional demand analysis (CDA) produces high quality end-use load shapes

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TI Project: Hourly CDA Approach – Results

Results show that using RBSA data (BPA) for those sites where the ground truth metering captures the majority of household consumption and when the survey data is accurate - conditional demand analysis (CDA) produces high quality end-use load shapes

- **CDA explains differences in kWh use among homes as a function of differences in appliance stocks. So CDA has difficulty measuring end-uses that have high saturation rates such as refrigerators**
- **CDA has difficulties measuring loads for end-uses with low saturation rates. Swimming pools and barns were complicated situations**
- **Sample sizes should be larger to provide improved accuracy, i.e. >500**
- **Survey design and administration is critical in order to reduce measurement error**
- **Data cleaning is important**

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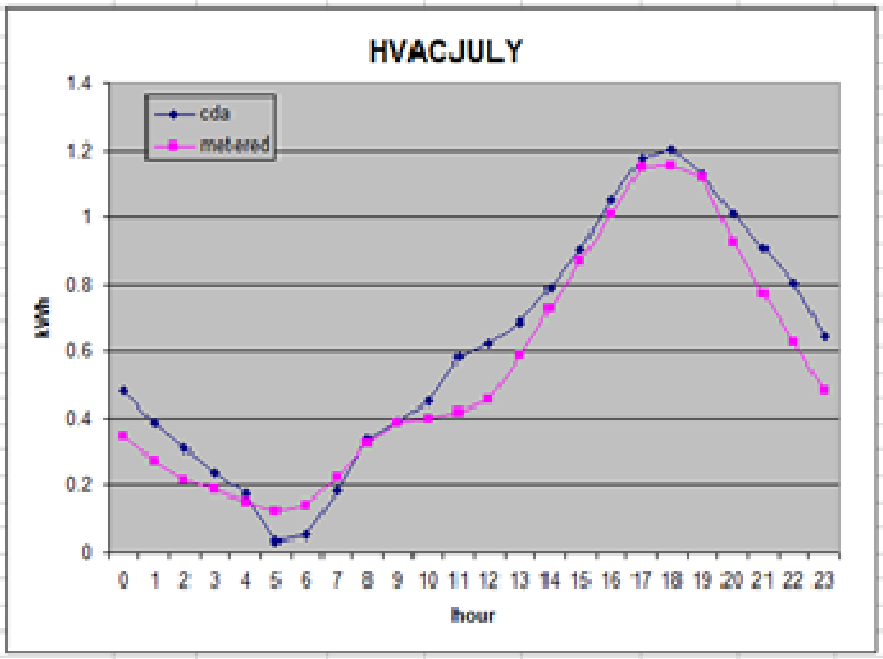
Results from RBSA CDA Analysis (Selected_1)

DAYTYPE	WD						
Average of HVACJULY	STAT	METHOD					
	mean		sd		sd of the mean		mean
HOUR	cda	metered	cda	metered	cda	metered	diff²
0	0.482	0.346	0.533	0.671	0.081	0.022	0.019
1	0.388	0.271	0.423	0.583	0.064	0.019	0.014
2	0.310	0.212	0.379	0.484	0.058	0.016	0.010
3	0.236	0.188	0.313	0.444	0.048	0.015	0.002
4	0.173	0.152	0.256	0.375	0.039	0.012	0.000
5	0.034	0.122	0.051	0.316	0.008	0.010	0.008
6	0.052	0.140	0.073	0.391	0.011	0.013	0.008
7	0.183	0.223	0.250	0.808	0.038	0.026	0.002
8	0.334	0.325	0.417	1.111	0.064	0.036	0.000
9	0.390	0.389	0.470	1.270	0.072	0.042	0.000
10	0.451	0.400	0.555	1.128	0.085	0.037	0.003
11	0.580	0.418	0.637	0.977	0.097	0.032	0.027
12	0.624	0.454	0.705	0.860	0.108	0.028	0.029
13	0.687	0.587	0.827	1.075	0.126	0.035	0.010
14	0.790	0.728	0.922	1.172	0.141	0.038	0.004
15	0.907	0.867	0.995	1.235	0.152	0.040	0.002
16	1.056	1.008	1.090	1.285	0.166	0.042	0.002
17	1.179	1.148	1.215	1.348	0.185	0.044	0.001
18	1.203	1.156	1.192	1.340	0.182	0.044	0.002
19	1.128	1.118	1.159	1.306	0.177	0.043	0.000
20	1.010	0.929	1.025	1.162	0.156	0.038	0.007
21	0.909	0.773	0.848	0.988	0.129	0.032	0.018
22	0.802	0.627	0.780	0.917	0.119	0.030	0.031
23	0.646	0.484	0.669	0.827	0.102	0.027	0.026
Sum	13.9	12.6					√(∑diff²/24)
Homes	43	43					0.096



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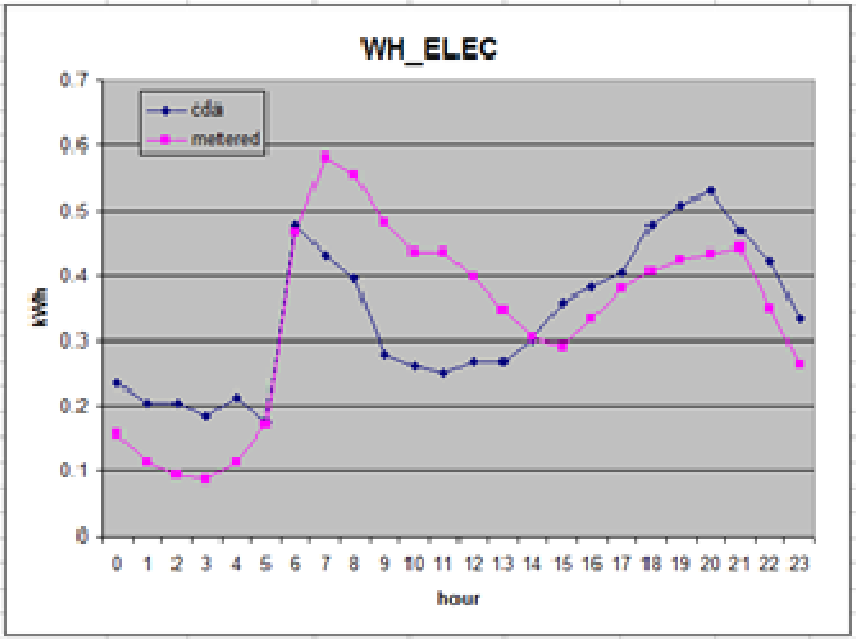
Results from RBSA CDA Analysis (Selected_2)

DAYTYPE	WD						
Average of WH_ELEC	STAT	METHOD					
	mean		sd		sd of the mean		mean
HOUR	cda	metered	cda	metered	cda	metered	diff²
0	0.233	0.157	0.129	0.376	0.017	0.003	0.006
1	0.204	0.113	0.129	0.268	0.017	0.002	0.008
2	0.204	0.094	0.125	0.238	0.017	0.002	0.012
3	0.183	0.087	0.108	0.217	0.014	0.002	0.009
4	0.214	0.114	0.120	0.257	0.016	0.002	0.010
5	0.175	0.170	0.065	0.387	0.009	0.003	0.000
6	0.477	0.467	0.221	0.845	0.030	0.007	0.000
7	0.432	0.581	0.198	0.941	0.026	0.008	0.022
8	0.395	0.555	0.111	0.810	0.015	0.007	0.026
9	0.279	0.482	0.085	0.750	0.011	0.006	0.041
10	0.261	0.436	0.045	0.743	0.006	0.006	0.031
11	0.250	0.437	0.043	0.743	0.006	0.006	0.035
12	0.268	0.397	0.075	0.702	0.010	0.006	0.017
13	0.268	0.348	0.073	0.629	0.010	0.005	0.006
14	0.303	0.305	0.084	0.583	0.011	0.005	0.000
15	0.358	0.292	0.155	0.562	0.021	0.005	0.004
16	0.382	0.334	0.195	0.596	0.026	0.005	0.002
17	0.405	0.380	0.247	0.627	0.033	0.005	0.001
18	0.477	0.407	0.306	0.657	0.041	0.006	0.005
19	0.509	0.425	0.309	0.701	0.041	0.006	0.007
20	0.530	0.435	0.311	0.737	0.042	0.006	0.009
21	0.468	0.444	0.244	0.750	0.033	0.006	0.001
22	0.423	0.349	0.184	0.652	0.025	0.006	0.005
23	0.334	0.265	0.126	0.578	0.017	0.005	0.005
Sum	7.7	7.8					$\sqrt{(\Sigma diff^2/24)}$
Homes	56	56					0.105



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Load Disaggregation Using NILM – Cost versus Accuracy versus Applicability Assessment

Objective and Scope

- New 3-4 products; total 7-8 NILM products to be evaluated in simulated household – Knoxville lab
- New European simulated household (50Hz/240V) lab in Knoxville and testing of 10-12 products
- Focus on performance metrics and statistics
- New loads to be included (HPWH, DHP, advanced lighting, electric vehicle chargers, inverter based loads)

Roadmap Alignment

- End-Use Load Research

Value

- New algorithms and computational methods are unlocking the potential for access to end-use load data
- Improved accuracy for load forecasting, market planning, and rate design
- Improve the understanding of customer needs and behaviors

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End-Use Load Measurement: Direct vs. Indirect Methods

- Direct Measurement: Sensor Installed at Appliance or Circuit Breaker
- Pattern Recognition (No sensor, usage data)
  - Total Usage
  - Minimum & Excess usage
- Cluster/Event-based Analysis
  - Isolates loads on electrical characteristics
  - Edge data clustering

- Statistical
  - Statistically Adjusted Engineering Estimates (SAE) (single site approach)
  - Proportional Fitting: Adjust end-use loads to known totals
  - Hourly (CDA): Regression method that uses variance in appliance presence to estimate aggregate customer or class load shapes
  - Hybrid: CDA with addition of NILM or engineering estimates
- Harmonic Frequency Analysis
  - High frequency data analysis/ Fourier transform

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Comparison of NILM Vendor Products

Manufacturer	Product	Target Market	Technology Category	Data Acquisition Rate	Learning Approach	Disaggregation Algorithm	Applicability to Study
Enetics	SPEED	Utility	Utility Meter Device	2-5 kHz	Automatic	Cluster/Event-based	Meets specific needs of project
Belkin	WEMO	B2C	In home sensors	10-15 kHz	Automatic	Harmonic	Not commercially available
Bidgely	Home Beat	B2C, ESCO	Gate way device for smart meters	1-10 seconds	Automatic	Statistical	Requires compatible smart meter
LoadIQ	Enable.EI/EI.X Series Monitor	B2C, ESCO	Sensor based load disaggregation	10 kHz	Guided	Cluster /Event-based	Start-up company, sensing device not tested to Saudi conditions
Onzo	Load Disaggregator	Utilities/ESCO	Software Only	1 to 15 minute	Automatic	Statistical	Would require 1-minute premise level data or less to achieve reasonable accuracy
WattGo	WattGo	ESCO	Software Only	1 to 15 minute	Automatic	Statistical	Would require 1-minute premise level data or less to achieve reasonable accuracy
Informetics	Consultants with purpose built apps.	Utilities, ESCO	Purpose built modeling applications	1 to 15 minute	Automatic	Statistical	Not a technology vendor

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Comparison of NILM Vendor Products

Manufacturer	Product	Target Market	Technology Category	Data Acquisition Rate	Learning Approach	Disaggregation Algorithm	Applicability to Study
Smappee	Smappee	B2C, ESCO	Sensor and load disaggregation	1 minute	Manual	Event based	B2C product, uses customers wifi
Navetas	LOOP	B2C, ESCO	Sensor and load disaggregation	10kHz	TBD	Cluster /Event-based	B2C product, uses customers wifi
Wattics	Wattics	B2C, ESCO	Sensor and load disaggregation	1 minute	TBD	Statistical	B2C vendor, can also use AMI data but requires high resolution
Yetu	One Gateway	B2B2C	Gateway Device	Unknown	Unknown	Statistical	Not applicable
Fludia	Fludia	ESCO, B2B	Sensors, software	1 minute	Automatic	Statistical	Have load disaggregation module but would require high resolution data
Bosch	Under delayed development						Product under development.
Energy Aware	Power Blaster	B2C, ESCO	Sensor, load disaggregation	1 minute	Manual	Statistical	B2C product, uses customers wifi
Energy, Inc.	TED 5000	B2C	Sensor, Circuit level	1 minute	Circuit meter	Circuit meter	No disaggregation, just metering
PlottWatt	PlottWatt	B2C	Software only	1 minute	Automatic	Statistical	Uses CTs at the breaker panel

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Field Observations

- Larger loads were detected with ~ 80-85% accuracy in most homes
- Consistent accuracy and reliability is a requirement for TVA and utilities in general.
- Heat pump water heaters were not identified and in some cases mis-classified as well pumps.
- Load model and algorithm calibration completed by Enetics for heat pump water heaters.
- Furnace blower fans was not identified in all homes or most homes. Motor load identification within NILM seems weak.
- Appliances such as Refrigerators, Dish washers and Clothes washers/dryers though detected correctly and consistently but accuracy was generally lower (75-82%) .
- TVA expressed the need to improve NILM algorithmic performance by working with the vendor Enetics.

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Technology Innovation: Low-Cost, Wireless Sensors for End-Use Energy Metering

Objective and Scope

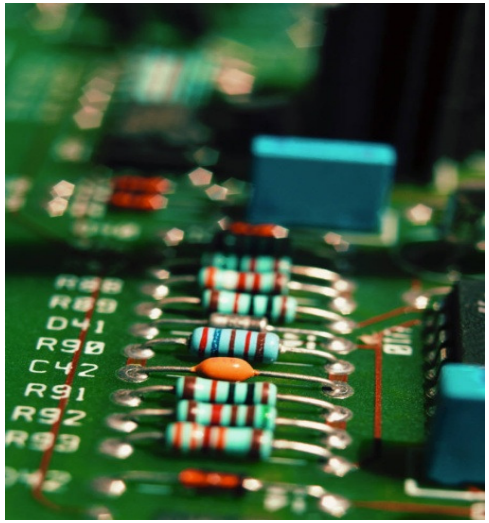
Lab evaluation of low-cost (< $100 per node),easy-to-deploy sensors for real-time end-use data acquisition

Roadmap Alignment

– End-Use Load Research

Value

– Provide a basis for understanding the cost versus accuracy, ease of deployment of alternative technologies
– Industrial sector - key area of focus
– Stimulate the development of newer low cost methods to collect end-use load data for supplier and customer benefit
– Accelerate the collection of utility grade end-use data for innovative rate and product offerings
– Improve the understanding of customer needs and behaviors



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Hybrid Methods

- Uses a combination of statistical, direct and indirect methods to reduce variation and improve accuracy, thereby decreasing the number of sample sites for the equivalent level of precision
  - **Kingdom of Saudi Arabia** – Class and end-use load shape development. EPRI is working with DNV-GL to develop end-use load shapes for their residential class. A combination of methods is being deployed which include conditional demand analysis (CDA) and non-intrusive load monitoring methods (NILMs)
  - **NGRID** - New York has issued a RFP intended to collect residential and small commercial end-use load shapes using NILMs technology. This is also a collaborative project with DNV-GL

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EPRI Load Shape Library 3.0 – Two New Databases

- Updating EPRI's **Load Shape Library 3.0** for release by December 2015
  - Combines 2014 and 2015 deliverables
  - Two new databases of actual measured data
  - ***NEW:*** updated design using SQL as the database engine
  - Updated analytical functions such as additional filters, menus and functions
  - Updated reporting functions

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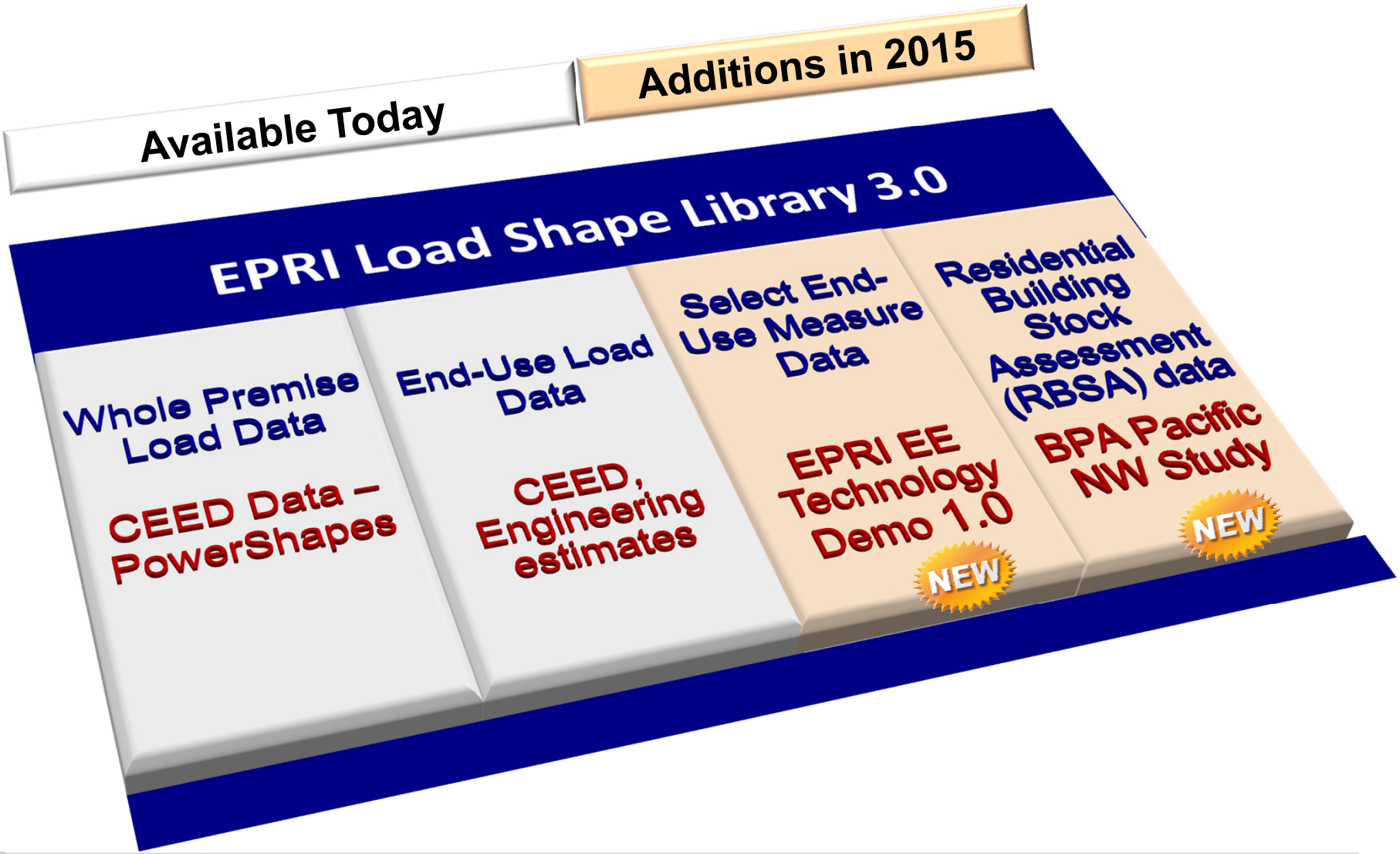
Load Shape Library 3.0: The Big Picture



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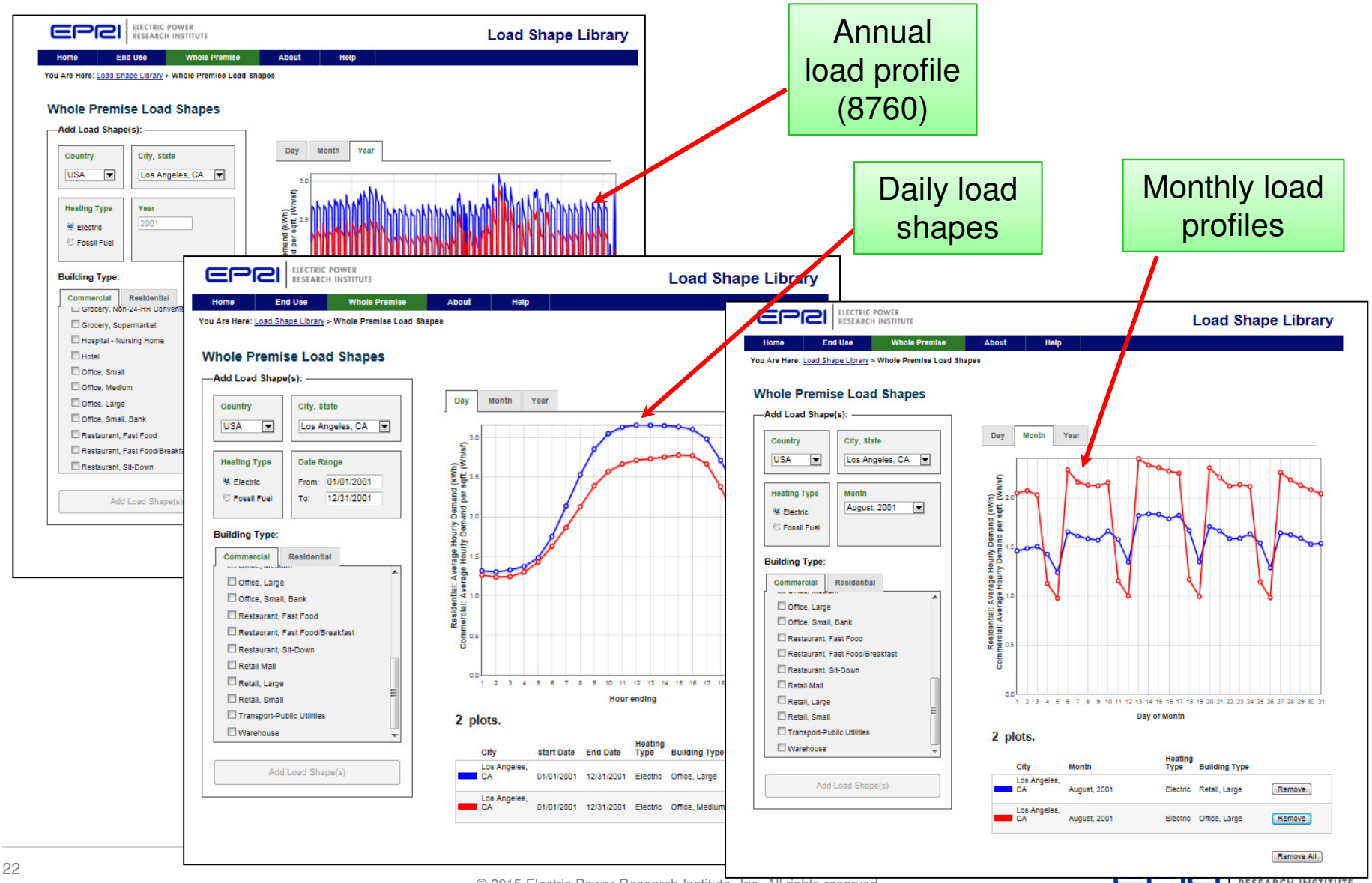
Load Shape Library 2.0 (Whole Premise)



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What Does the Load Shape Library 3.0 Offer ?

- Primary goal is provide aggregate load shapes by climate zone and utility (anonymized)
- Individual site data can be downloaded without visualization options
- Many ways for analysis – provide generic analytical functions to compute load shapes on hourly, daily, weekly basis.
- Custom functions can be employed by users on the downloadable CSV data
- Season and day types options along with user-selected day types
- Capability to include non-electric and thermal performance
- May or may not correlate with electric load shapes

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Key Updates and Enhancements in 2015

Database Design, Structure

- SQL database design
- Scalable design to accommodate national campaign load data
- Updated analytical and reporting functions
- Public access of the tool allowed

Data Functions

- Aggregation by Climate zone, Utility
- Updated functions to enter total annual end-use or peak end-use consumption by region.
- User-selectable calendar functions: Peak/off-peak seasons, system peak and customer peak

Reporting

- Actual hourly kW instead of unitized end-use values
- Monthly, weekly, daily analytical functions for charting load shapes
- Sorting functions for daily, monthly and seasonal load characteristics
- Aggregate load analysis functions by climate zone, utility, end-use load, efficient measure and building types
- Electric, non-electric (water usage, ID/OD air temp., Water inlet/outlet temp.)
- Aggregate data presented in tables, charts and other visual comparisons
- Load Shape Annotation

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Pacific Northwest Residential Building Stock Assessment (RBSA) Data - 2011

- Public dataset of end use metered single-family residential data for a100 home sample from the PNW region
- Data will be included as a separate database in the Load Shape Library 3.0
- RBSA was developed to provide an inventory and profile of existing residential building stock in the Northwest based on field data from a representative, random sample of existing homes
- Data collected includes field surveys such as general demographic information, occupant attitudes, participation in efficiency programs, lighting inventory, building envelope characteristics, and end-use load usage.

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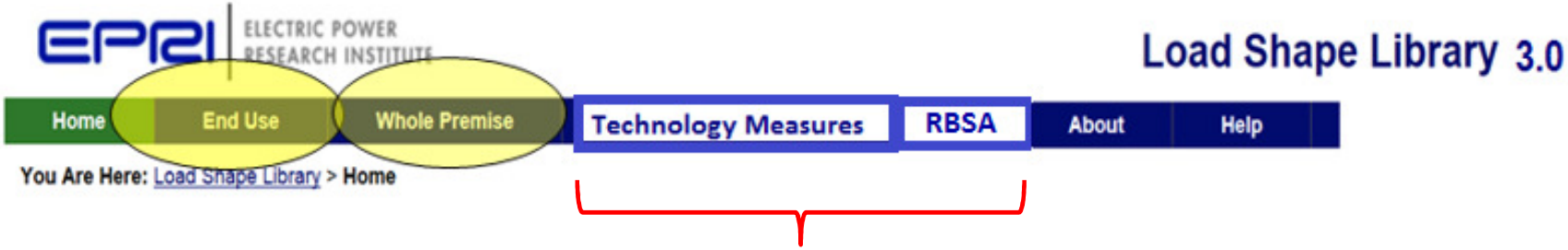
Load Shape Library 3.0 (Public Web Portal)



2015 Additions

Home

Welcome to the Load Shape Library 3.0 developed by EPRI under the utility collaborated research program 170 A for the Year 2015

- Develop a Measure Database and web portal as part of the Load Shape Library 3.0 design.
- Employ one to two technology measures (HPWH, Efficient Appliances) from EE Technology Demonstration 1.0 to populate the database.
- Implement a SQL database and a re-designed web portal to deliver analytical functions for visualization and data delivery.

Optimized for Mobile Devices

Browsers supported IE 8-10, Firefox, Google Chrome, Safari, Others

http://loadshape.epri.com

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http://loadshape.epri.com

Under Construction…..

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The Integrated Grid – Pre-Demo Project

Objective and Scope:

- Understand how the integration of customer energy technologies may alter load shapes and impact the overall grid.
- Characterize the Usage, Shape, Flexibility and Volatility of selected technologies
- Evaluate aspects of the technologies that need to be studied in terms of customer response and customer preferences
- Identify Research Gaps and Develop Roadmap to bridge those gaps

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Conclusions

- Investigating ways to “Drive down the cost of end-use load data collection”
  - Statistical methods seem to show promise to achieve low cost accurate end-use load shape
  - Wave form methods have high accuracy but higher cost than statistical methods
  - Combination methods (hybrid) may produce multiplied increases in accuracy and multiplied reductions in sample sizes and therefore cost
- EPRI has developed a repository to house end-use data that include whole premise, end-use, technology and RBSA data and continues to add to and improve the functionality

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