End-Use Load Profiles for the U.S. Building Stock

Natalie Mims Frick, LBNL
Eric Wilson, NREL

December 10, 2019

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Logistics

- We're recording the webinar and will post it on LBNL's website.
- Because of the large number of participants, everyone is in listen mode only.
- Please use the chat box to send us your questions and comments any time during the webinar.
- Moderated Q&A will follow, with speakers responding to questions typed in the chat box.
- The recording and webinar slides will be posted at https://emp.lbl.gov/projects/time-value-efficiency

Today's Speakers

- **Monica Neukomm** is a clean energy professional with over ten years of experience at DOE working to accelerate uptake of high performance building technologies and policies. She has served in increasingly senior roles in the U.S. government, including director level positions responsible for coalition building with industry, government, and non-profit leaders. Monica is currently supporting the Building Technologies Office and coordinating the Grid-interactive Efficient Buildings initiative.
- **Natalie Mims Frick** is an Energy Efficiency Program Manager in the Electricity Markets and Policy Group at Lawrence Berkeley National Laboratory. Natalie conducts research and manages projects on energy efficiency technical assistance, policy, program design, implementation and evaluation.
- **Eric Wilson** is a Senior Research Engineer at the National Renewable Energy Laboratory. He leads the development of ResStock, an analysis framework for residential building stock modeling.

Presentation Outline

- Grid-interactive Efficient Buildings overview
- Project background
- Market needs and use cases
- Data needs and identified gaps
- Next steps
- Q&A

U.S. DEPARTMENT OF ENERGY

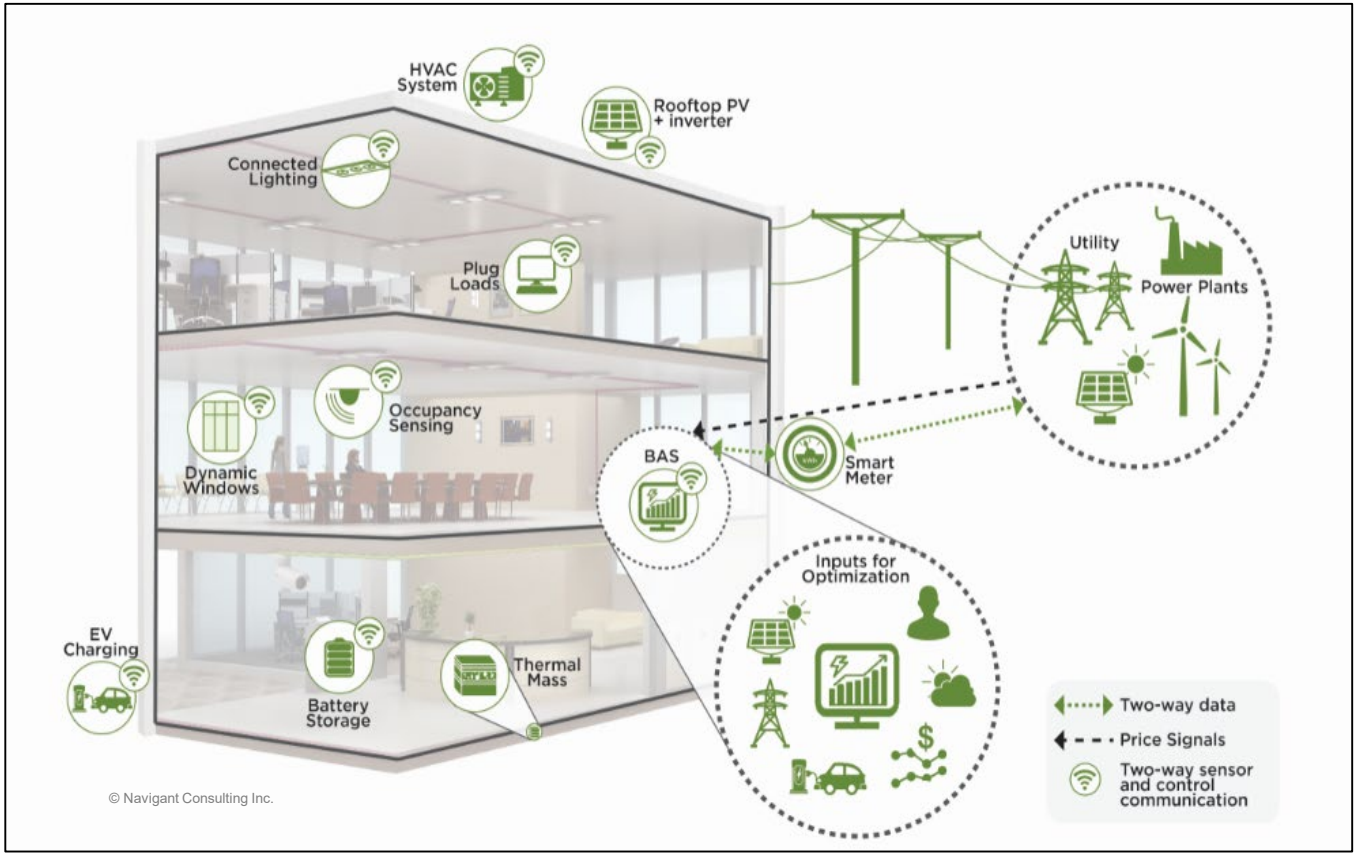
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Grid-interactive Efficient Buildings Overview

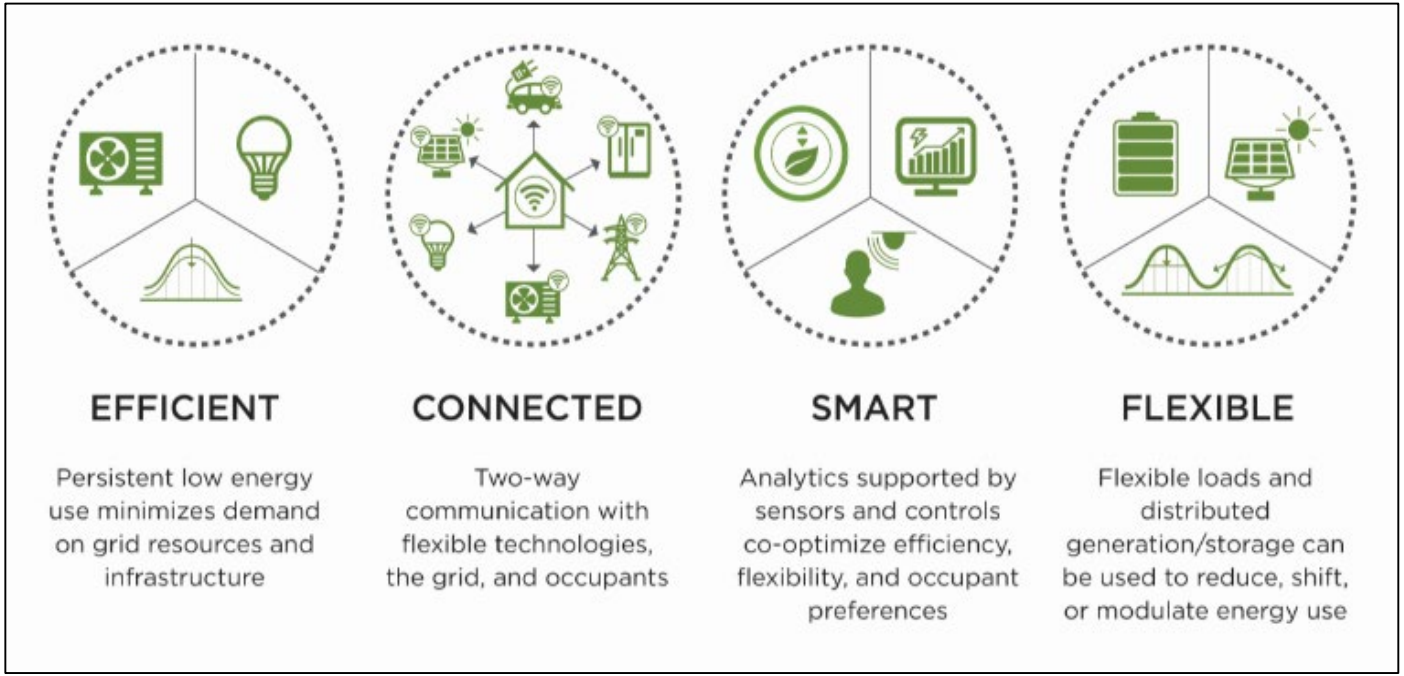
December 10, 2019

Monica Neukomm
Building Technologies Office, DOE
www.energy.gov/eere/buildings/geb

Grid-interactive Efficient Building Initiative



Key Characteristics of GEBs



BTO's grid-interactive efficient buildings portfolio

VALUATION

How do *time & the interaction of flexibility options* impact value?

Identify values to stakeholders, quantification of national value.

TECHNOLOGY OPTIONS

Which end use technologies provide solutions to specific grid needs?

Prioritize technologies / solutions based on grid services.

OPTIMIZATION

How to maintain or improve services while optimizing for flexibility?

Solutions that meet grid operator & building occupant needs.

VALIDATION

Do technologies perform as predicted and meet grid & occupant needs?

Verification of technologies / strategies, increasing confidence in the value of energy flexibility.

MONICA NEUKOMM

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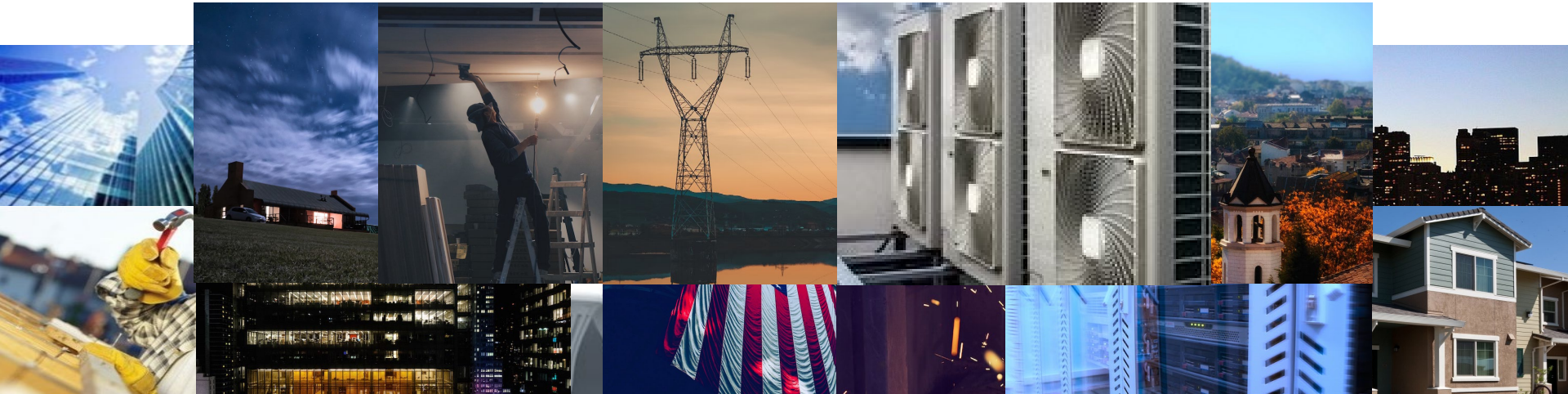
Building Technologies Office, U.S. DOE

www.energy.gov/eere/buildings/geb



Project Background

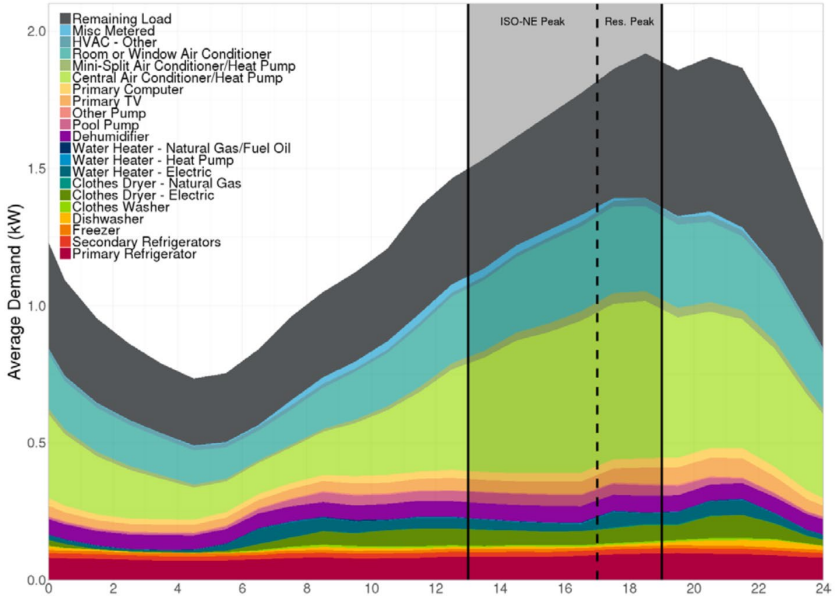
What is an End-Use Load Profile?

End-use load profiles…

- describe how and when energy is used

End-use load and savings profiles are…

- needed for R&D prioritization, utility resource and distribution system planning, state and local energy planning and regulation
- the most essential data resource currently missing for Time-Sensitive Valuation of Energy Efficiency
- critical for widespread adoption of grid-interactive and efficient buildings.

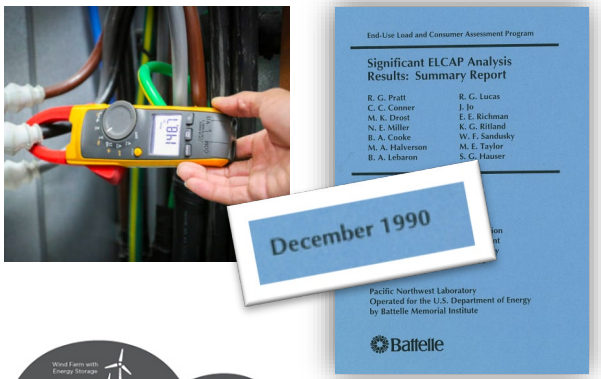


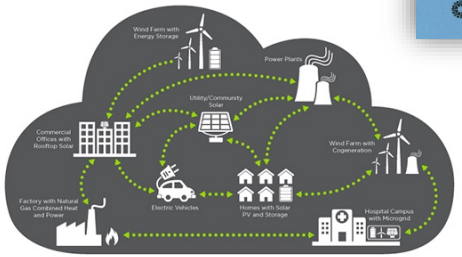
Source: Navigant Massachusetts RES 1 Baseline Load Shape Study

Challenge & Opportunity

Challenge

- Existing end-use load profiles are often outdated and limited to certain regions and building types because of the high cost of traditional end-use sub-metering.
- They are insufficient for accurate evaluation of numerous emerging use cases of grid-interactive and efficient buildings.





Source: Navigant

Opportunity

- New ResStock™ and ComStock™ models statistically represent energy use of U.S. buildings.
- Models produce hourly end-use load profiles, but calibration efforts to date have focused on annual energy use.

ResStock
ComStock

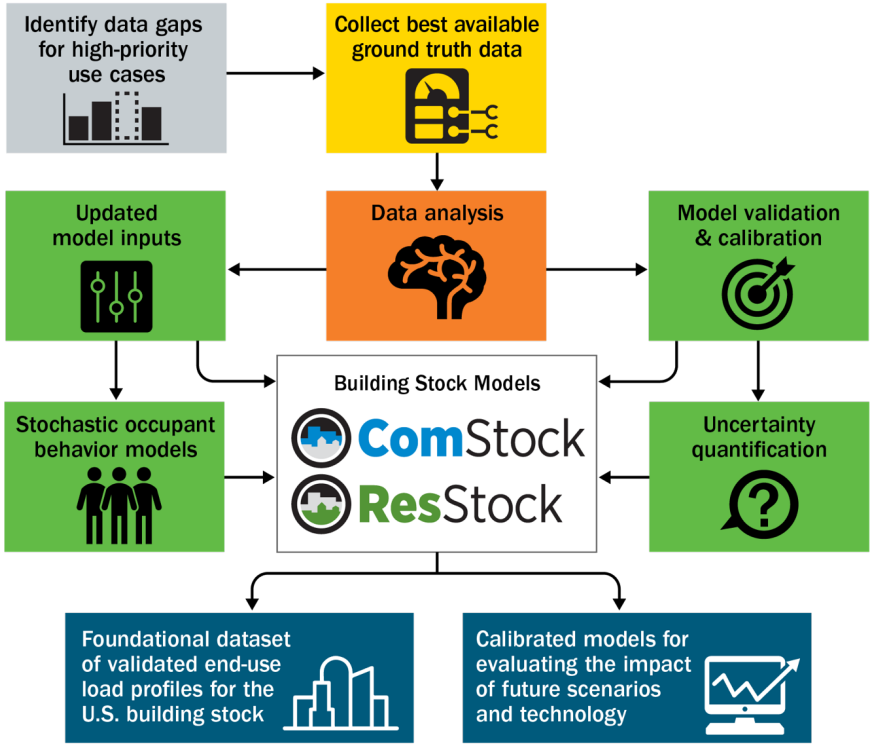
Solution: A Hybrid Approach (1)

Hybrid approach combines best-available ground-truth data—

- submetering studies,
- whole-building interval meter data, and
- other emerging data sources

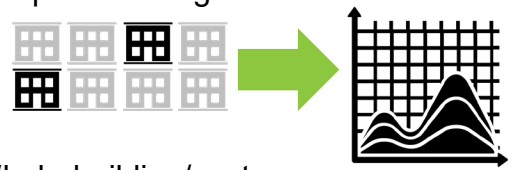
—with the reach, cost-effectiveness, and granularity of physics-based and data-driven building stock modeling capabilities

The novel approach delivers a nationally-comprehensive dataset at a fraction of the historical cost.



Solution: A Hybrid Approach (2)

End-use data for sampled buildings



End-use profiles for sample

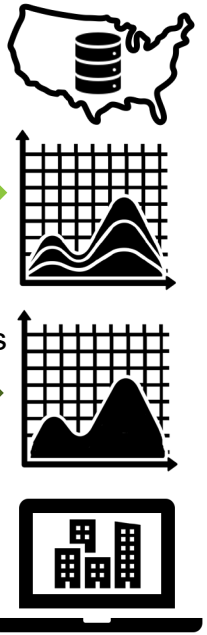
Whole-building/sector data from multiple regions

Aggregate AMI load profile for each building type in a region

Solution: A Hybrid Approach (2)

End-use data for sampled buildings

Whole-building/sector data from multiple regions

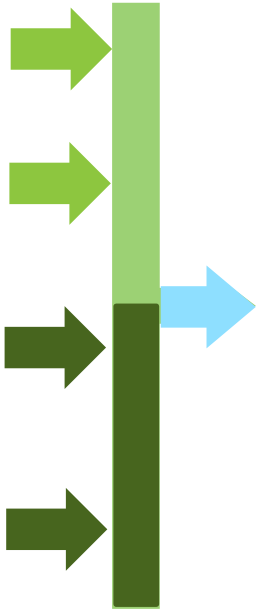


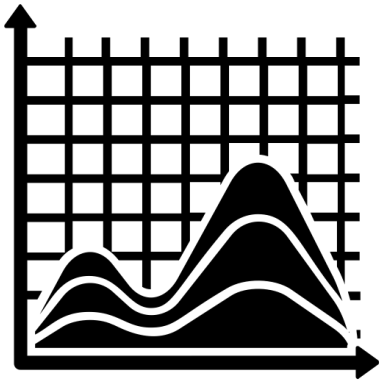
National ResStock/ComStock characteristics data

End-use profiles for sample

Aggregate AMI load profile for each building type in a region

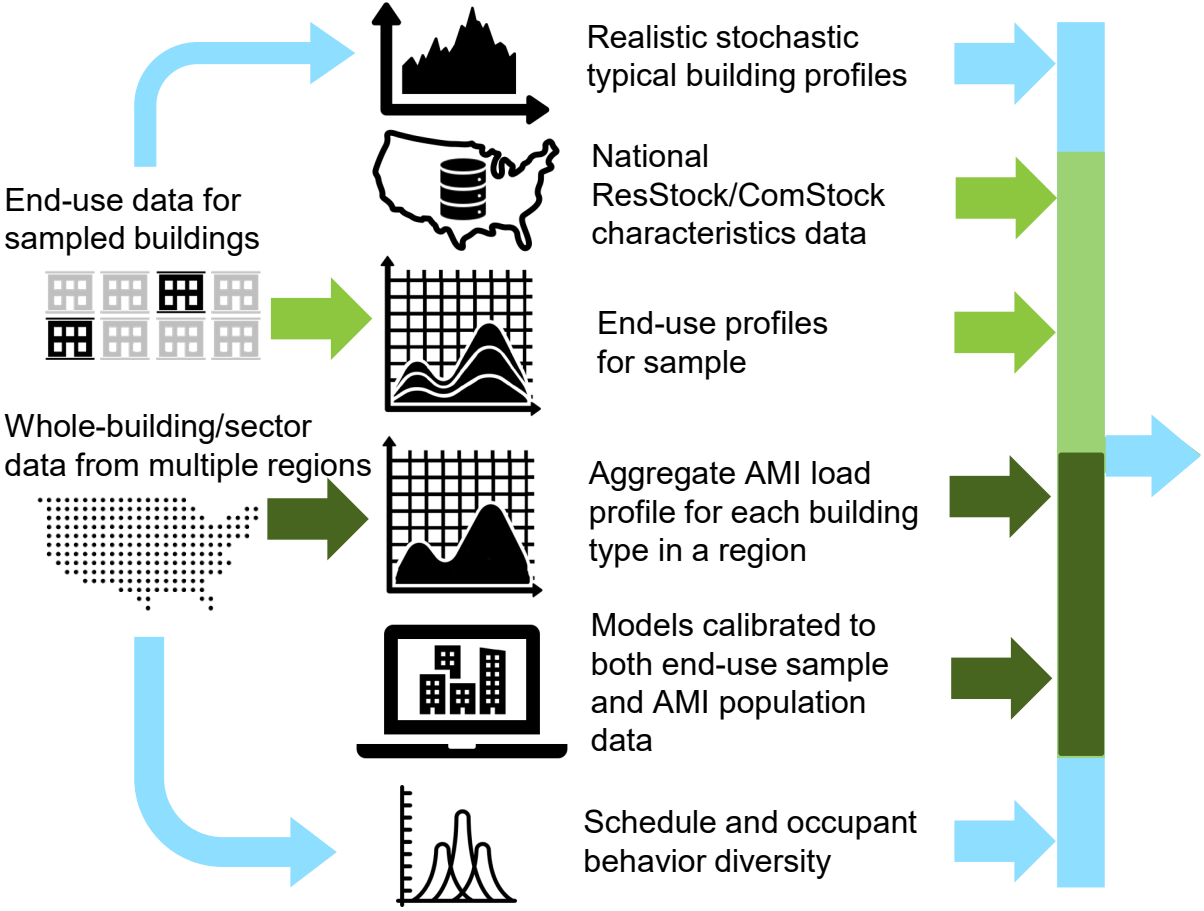
Models calibrated to both end-use sample and AMI population data

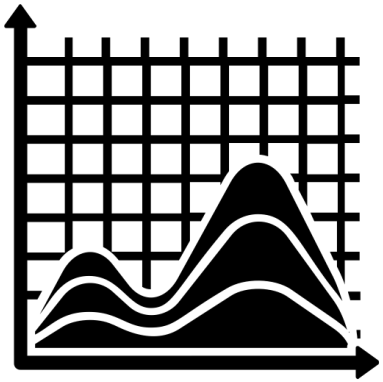




- Validated at *both* the end use level and population level
- Validated diversity and individual typical building profiles as well (enables more use cases)

Solution: A Hybrid Approach (2)





- Validated at *both* the end use level and population level
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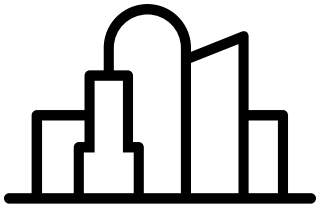
Project Outcomes| Calibrated Building Stock Models

ComStock ResStock



Building stock characteristics database

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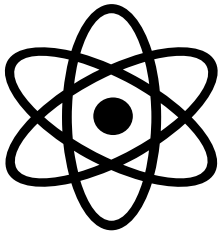

Physics-based computer modeling

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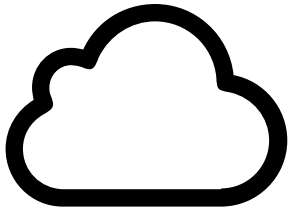


High-performance computing

- DOE-funded, NREL-developed models of the U.S. building stock
- 100,000s of statistically representative physics-based building energy models (BEM)
- Use DOE's flagship BEM tools OpenStudio and EnergyPlus
- Produce hourly load profiles, but calibration to-date has focused on annual energy consumption

Project Outcomes| Working List of End Uses

Commercial

- HVAC
  - Heating
  - Cooling
  - Fans
  - Pumps
  - Heat rejection
  - Humidification
  - Heat recovery
- Service water heating
- Refrigeration
- Plug and process loads
- Lighting
  - Interior
  - Exterior

Residential

- HVAC
  - Heating
  - Cooling
  - Furnace/Air-conditioning
  - Boiler pumps
  - Ventilation fans
- Domestic water heating
- Major appliances
  - Refrigerator
  - Clothes washer
  - Clothes dryer
  - Dishwasher
  - Cooking range
  - Pool/spa pumps & heaters
- Miscellaneous plug loads
- Lighting
  - Interior
  - Exterior

Project Outcomes| Working List of Building Types

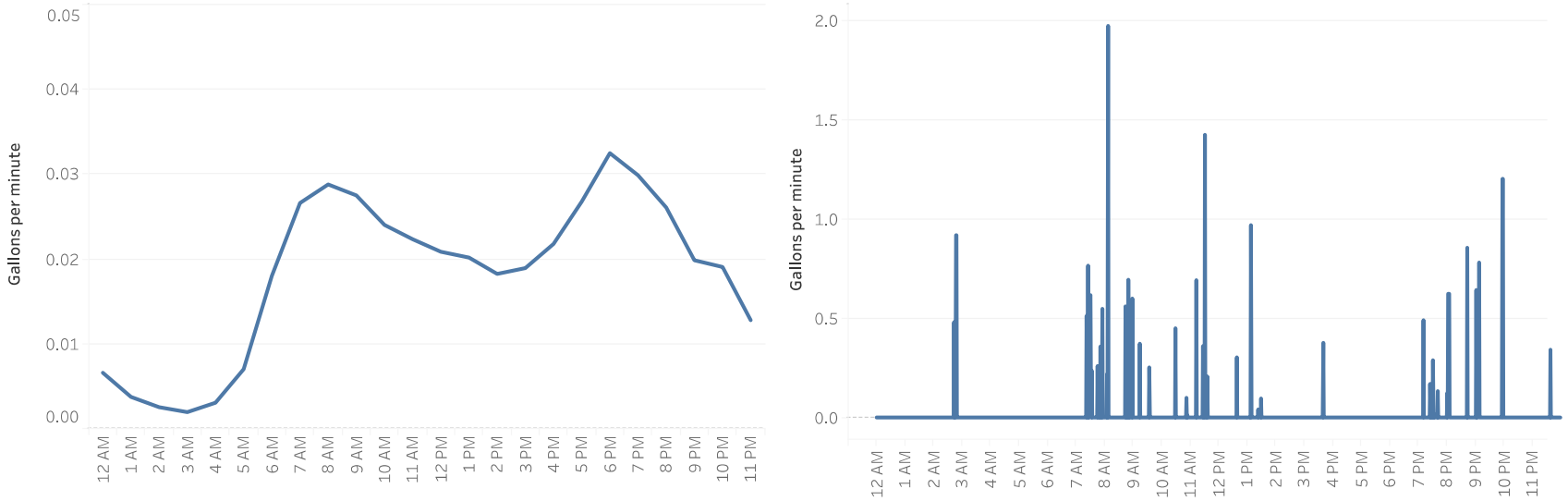
Commercial

- Small Office
- Medium Office
- Large Office
- Stand-alone Retail
- Strip Mall
- Primary School
- Secondary School
- Outpatient Healthcare
- Hospital
- Small Hotel
- Large Hotel
- Warehouse (non-ref.)
- Quick Service Restaurant
- Full Service Restaurant
- Supermarket
- Mid-rise Apartment
- High-rise Apartment

Residential

- Single-Family Detached
- Single-Family Attached
- Multifamily low-rise

Project Outcomes| Aggregate and Individual Load Profiles



Example aggregate versus individual EULP concept demonstration using water draws

Project Team

NREL
Transforming ENERGY


Eric Wilson (PI)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Elaina Present


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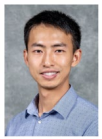
Han Li


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Dr. Ralph Muehleisen


Dr. Qi Li

EPRI | ELECTRIC POWER RESEARCH INSTITUTE


Chris Holmes


Krish Gomatom

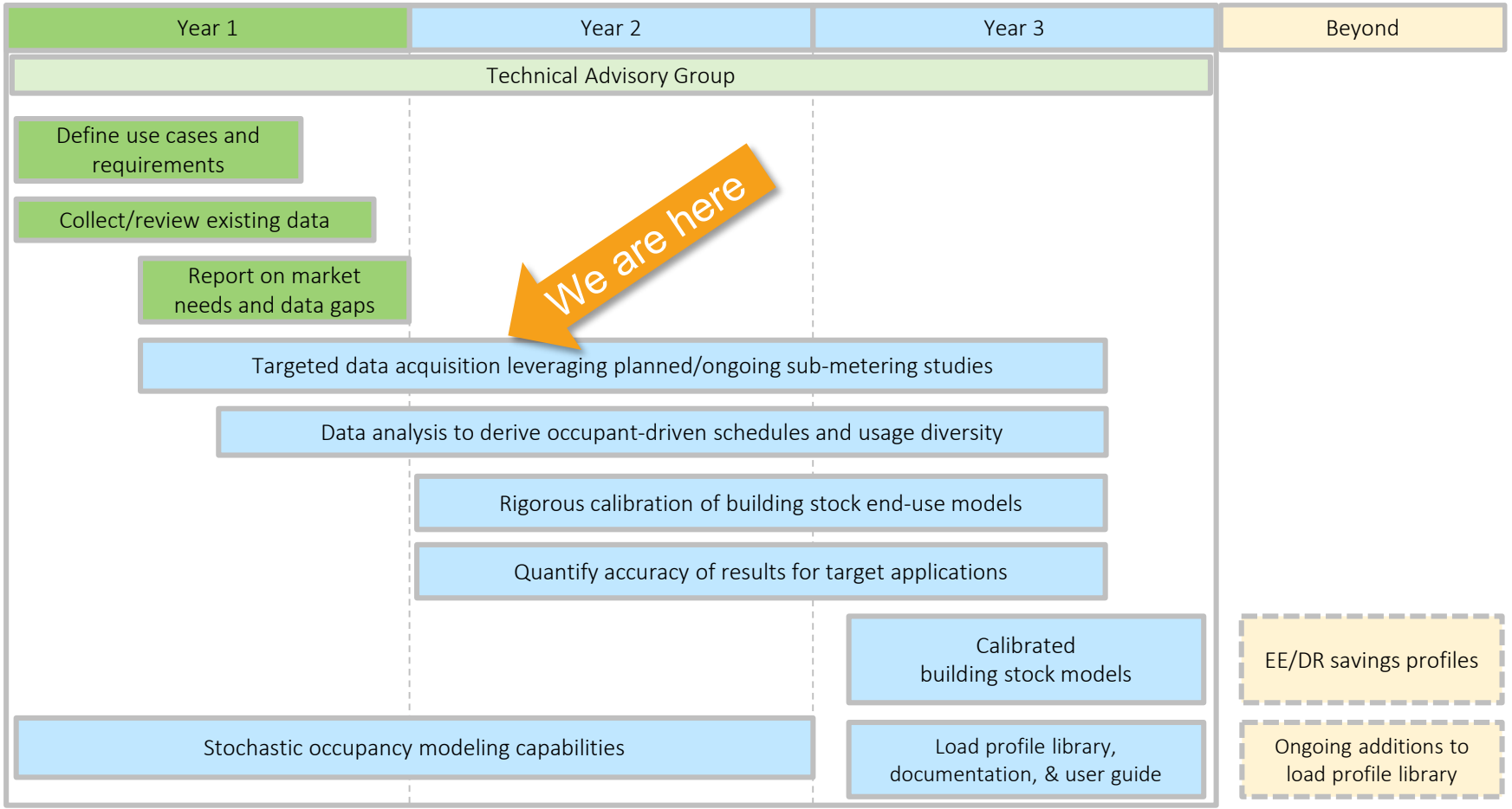
nep
Northeast Energy Efficiency Partnerships


Elizabeth Titus

Stakeholder Engagement

- Created technical advisory group with over 65 members representing utilities, regulators, experts and consultants, energy efficiency regional organizations and vendors.
  - Held first technical advisory group meeting in November 2018.
  - Convened second (in-person) technical advisory group meeting in March 2019—focused on identifying market needs, use cases and data gaps.
  - Third meeting was in June 2019
  - Fourth meeting is in December 2019
  - Slides are available on our project website

Project Timeline

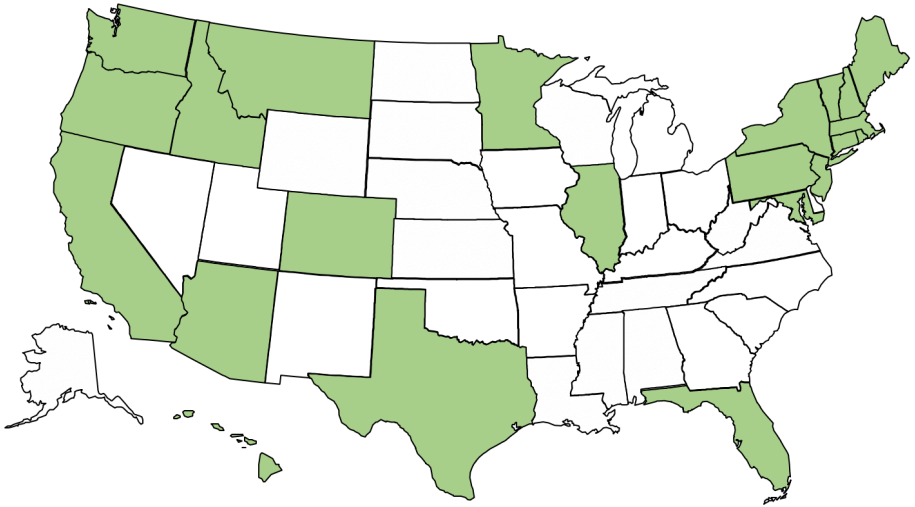


Market Needs and Use Cases

Year One Report is Available

End Use Load Profiles for the U.S. Building Stock: Market Needs, Use Cases and Data Gaps is available now

Market Needs | Existing Publicly Available End Use Load Profiles



States with Publicly Available End-Use Load Profile Data*

- We developed an inventory of publicly available end-use load profiles.
- The inventory is now available on LBNL's website: https://emp.lbl.gov/publications/end-use-load-profile-inventory

*There are significant differences in the number of load profiles available in each state. See the inventory for more detail.

Market Needs| Use Case Identification

- Use cases: type of process or analysis that utilize end-use load profiles
- The project team and technical advisory group brainstormed and prioritized use cases
- 10 most mentioned use cases are presented in the report
  - Electricity Resource Planning
  - Energy Efficiency Planning
  - Policy and Rate Design
  - Transmission and Distribution System Planning
  - Program Impact Evaluation
  - Demand-Response Planning
  - Improved Building Energy Modeling
  - Electrification Planning
  - Emissions Analysis
  - PV Planning
- Use cases informed data requirements for modeling

Use Cases | Data Fidelity Requirements

Use Case Data Requirements

Use Case	Time Resolution	Geographic Resolution	Electrical Characteristics
Electricity Resource Planning	Hourly or peak day	Service territory	Real power
Energy Efficiency Planning	Hourly or peak day	Service territory	Real power
Policy and Rate Design	15 min to hourly	City, climate zone, or state	Depends on application
Transmission and Distribution System Planning	15 min or smaller	Distribution feeder	Real and reactive power
Program Impact Evaluation	Hourly	Service territory	Real power
Demand-Response Planning	15 min to hourly	Service territory	Real power
Improved Building Energy Modeling	15 min	Region	Real power
Electrification Planning	Hourly	Service territory or smaller	Real power
Emissions Analysis	Hourly	Service territory or larger	Real power
PV Planning	1 min	Weather station	Real power

Use Cases | Data Fidelity Requirements

Time Resolution

- **15-minute**

- Highest impact cases require only hourly results
- PV Planning is the only top use case that requires less than 15-minute data

Geographic Resolution

- **Utility territory**

- Distribution System Planning requires feeder-level data
- A “mix-and-match” approach from a bank of load profiles could help build specific utility and feeder level information

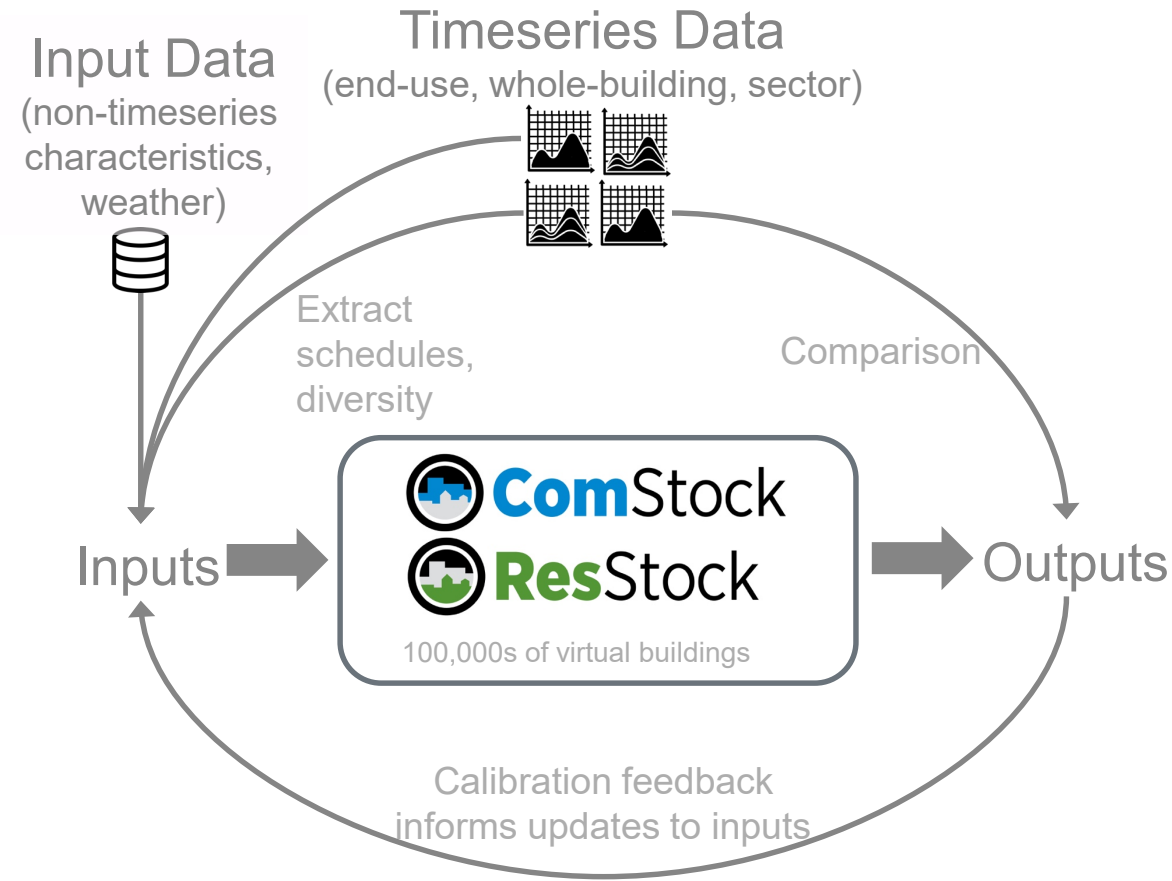
Electrical Characteristics

- **Real power**

- Some distribution system planning use cases might benefit from reactive power
- Data requirements for some use cases are not well understood

Data Needs and Identified Gaps

How are we using data?



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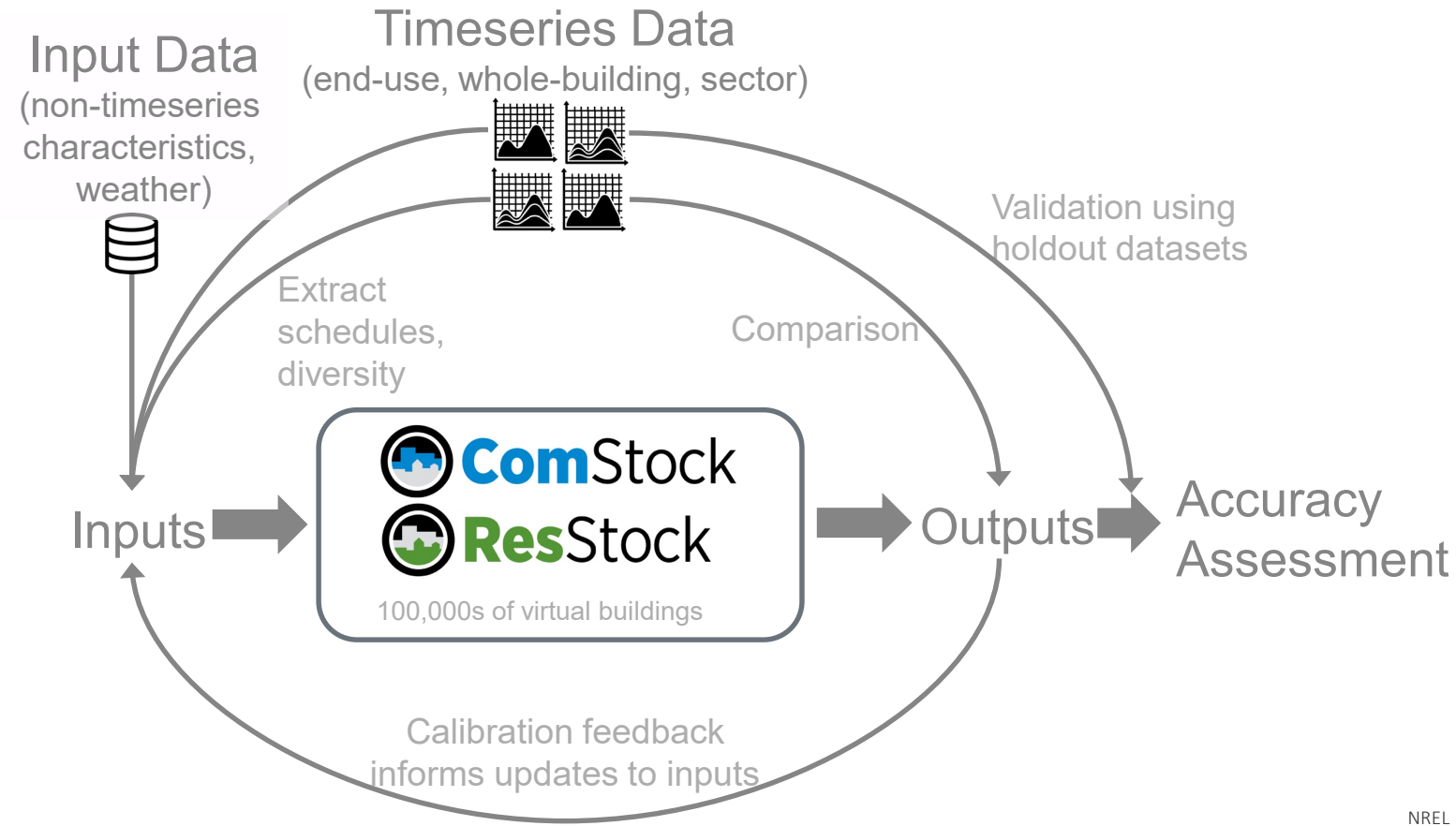

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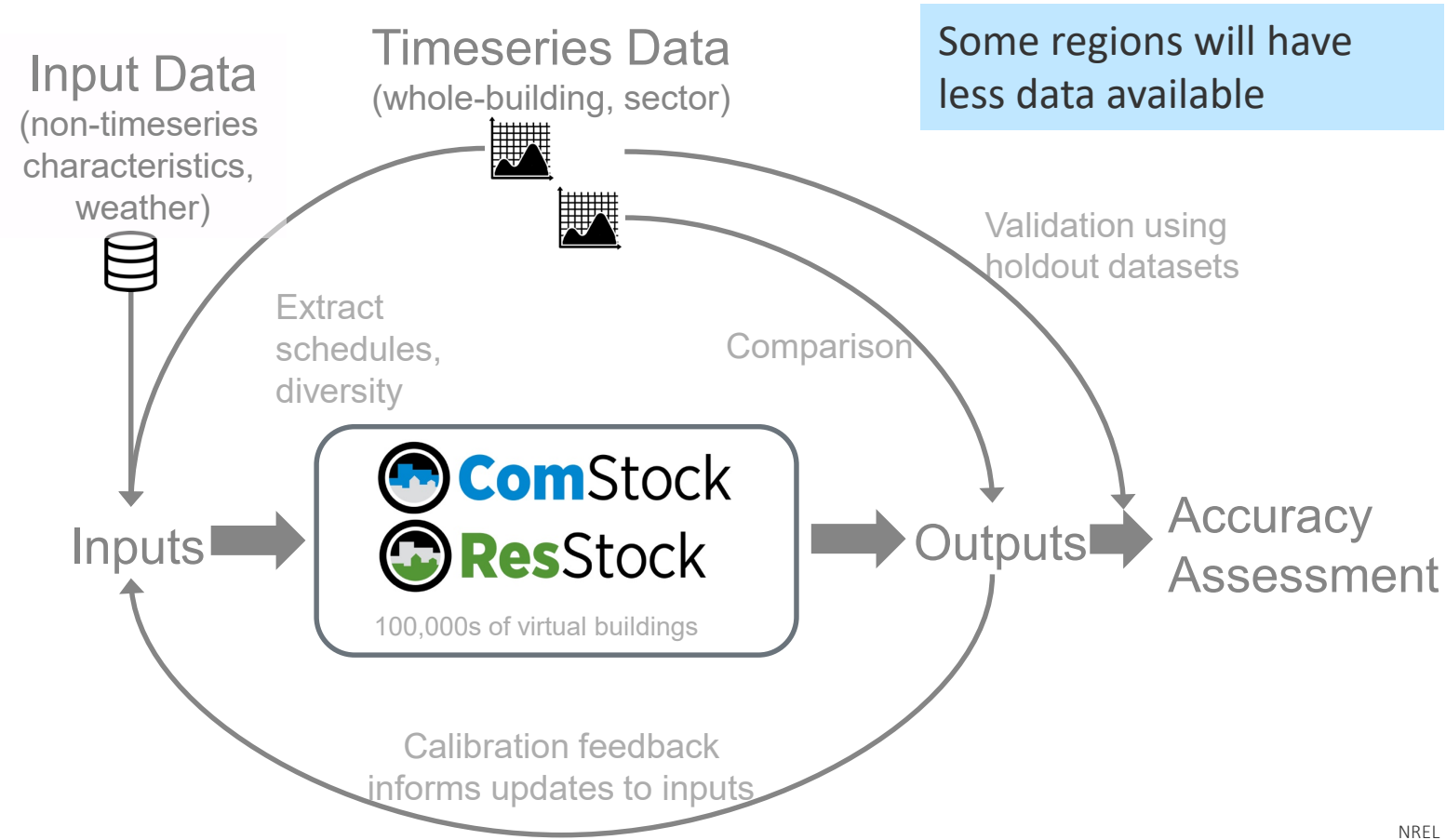


Model Input Data (1)

- *Schedule-related inputs* (e.g., business hours, lighting on/off schedules)
  - Directly related to human behavior within the building
  - Includes variability and saturation of different behavior types across the building stock
  - Directly affect the timing of energy use
- *Characteristic inputs* (e.g., floor area, lighting power density, HVAC system type)
  - Physical description of the building, its equipment, and the saturation of these components across the stock
  - Indirectly affect the magnitude and timing of energy use
- *Environmental inputs* (e.g., temperature, humidity)
  - External to the building.
  - Directly affect the timing and magnitude of energy use

Model Input Data (2)

The project team:

- Reviewed all 657 existing inputs to ResStock and ComStock and their sources
- Identified a subset of 78 inputs most relevant to time-series outputs needed for the top-priority use cases
- For this subset of 78 inputs, the team identified additional data sources for improving model inputs

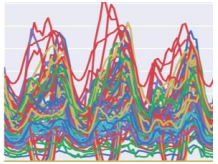
Ongoing sensitivity analyses will be used to prioritize input parameters to update as part of calibration

Model Calibration Data

Summary of Calibration Data Classes

Type of Calibration Data	Summary of Availability
Utility Sales: Annual sales/consumption data by sector by utility	Universally available from U.S. Energy Information Administration (EIA)
Load research data: Utility customer class aggregate load shapes	Acquired for ~20 utility companies and the Electric Reliability Council of Texas
Advanced metering infrastructure (AMI): Whole-building AMI data	Acquiring in multiple census divisions, via nondisclosure agreements with utility companies
AMI + Metadata: Building characteristic metadata joined with AMI data	Acquiring for a subset of the AMI data sets
Submetered: End-use metering data, including smart thermostat data	Multiple (3+) strong data sets available for residential; few data sets available for commercial buildings

Approach – Example Data Source Usage



Load research data

- 192 customer class profiles from 20 utility companies
- 60-min interval data
- E.g., residential w/o electric heat, large general service

Value derived through analysis

- Sector total ground truth
- Non-weather dependent load shape/magnitude
- Cooling/heating season length/magnitude

ComEd
An Exelon Company

ComEd Anonymous Data Service

- All ~4 million meters in northern Illinois
- 30-min interval data
- Meters tagged with ZIP/ZIP+4 code and customer class

All listed above, plus

- Diversity in customer base load and cooling/heating patterns
- Statistical conditional demand disaggregation (if paired with saturation surveys)
- Demographic correlations

neea

Residential Building Stock Assessment: Metering Study (2011)

- 100 homes in northwest U.S.
- 15-min sub-metered circuits
- Home audit data available from larger RBSA study

All listed above, plus

- End-use ground truth data for one region (some end-uses transferrable to other regions)
- Correlations with audit data

Addressing Data Gaps

From the initial data collection, the largest identified gap is submetered data for commercial buildings

To address this gap, we are:

1. Conducting a targeted market research effort to identify data sets for potential purchase (BAS data, EM&V studies, etc.)
2. Studying transferability between building types and regions

Next Steps | Assessing Accuracy (1)

- The most important component of this project is the fidelity of the EULPs produced through our work. Therefore, it is crucial that we develop a robust process for quantifying model accuracy and uncertainty.
- The goal of this project is to produce both aggregate and individual EULPs, so there will be a suite of metrics and techniques to evaluate the accuracy across multiple dimensions.

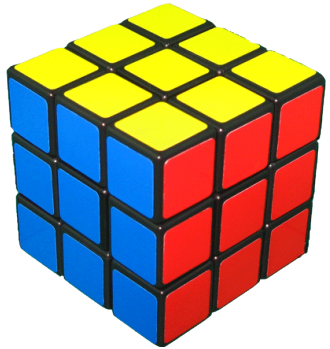
Next Steps | Assessing Accuracy (2)

Multifaceted Calibration

1. Annual – Whole-Building
2. Annual – End Uses
3. Annual – Diversity
4. Timeseries – Whole-Building
5. Timeseries – End Uses
6. Timeseries – Diversity

Each dimension has:

- metrics,
- visualizations,
- relevant data sources,
- relevant inputs to update



By calibrating six different dimensions, we can ensure accuracy by bounding errors and variability of results.

Next Steps |Project Goals

- In the next year, we will
  - Continue procuring AMI data and commercial building end use data
  - Continue residential and commercial occupancy modeling
  - Develop framework for uncertainty quantification
  - Complete residential sector calibration for the first region

If you are aware of potential utility AMI data, please reach out to load.profiles@nrel.gov

Thank you

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https://www.nrel.gov/buildings/end-use-load-profiles.html

www.nrel.gov

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Questions?

www.nrel.gov

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