The demand-side grid (dsgrid) model

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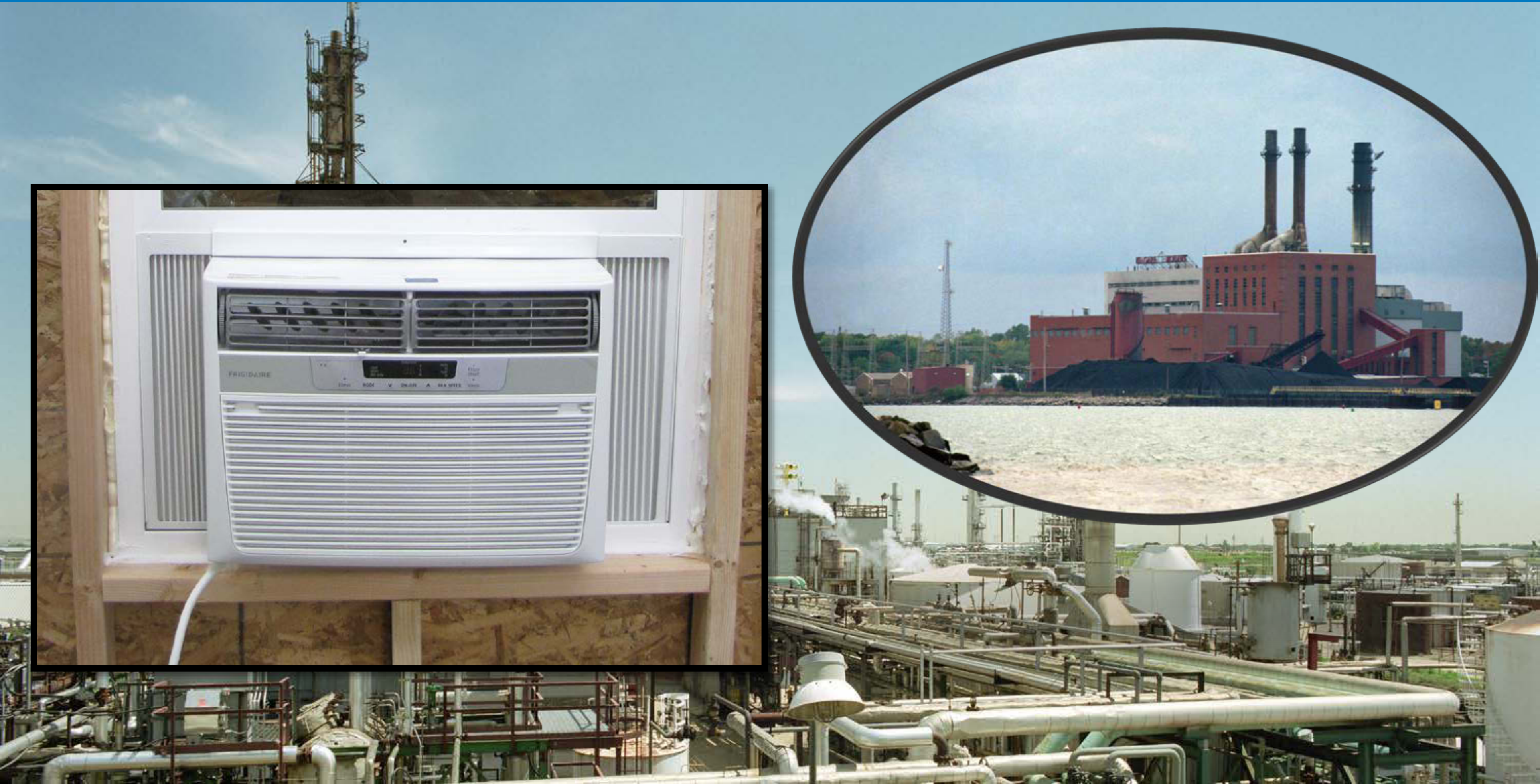
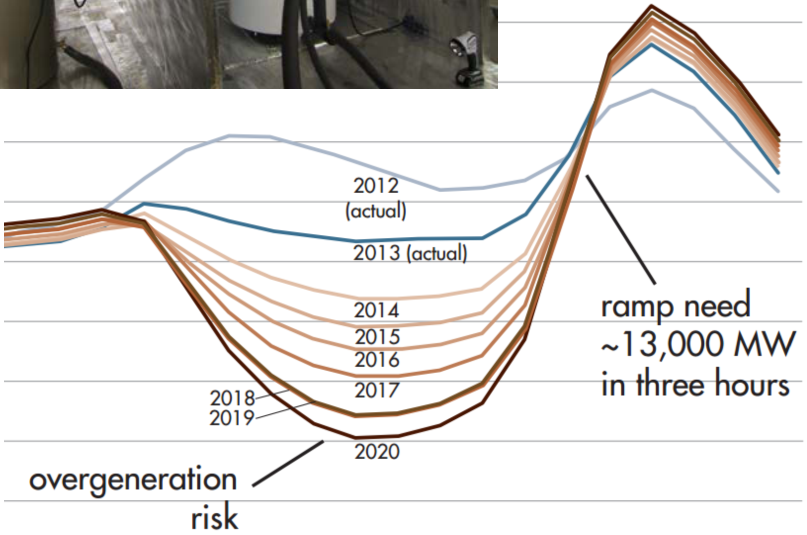
20th century energy perspectives





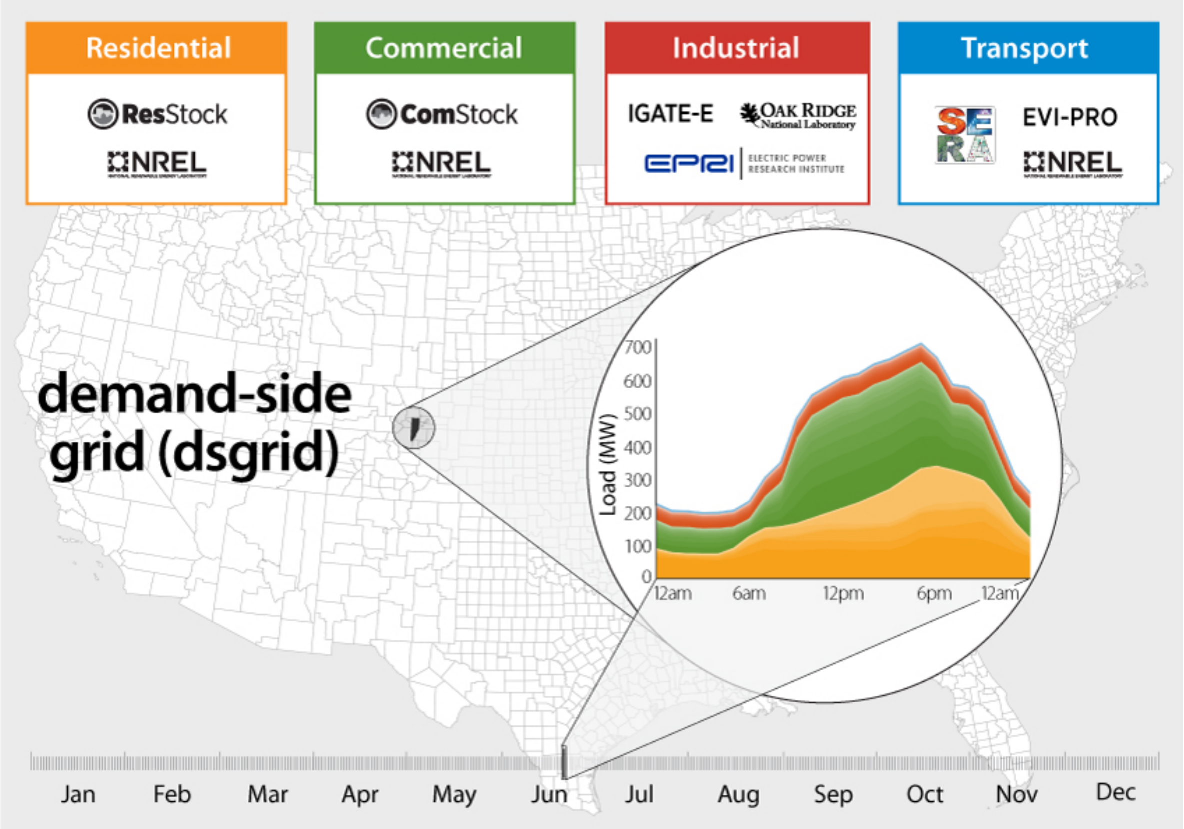
Source: https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Emerging 21st century perspectives

The demand-side grid (dsgrid) model creates highly resolved time-synchronous load data by leveraging sector-specific modeling expertise

Bottom-up modeling of buildings, industry, and electric vehicles to enable:

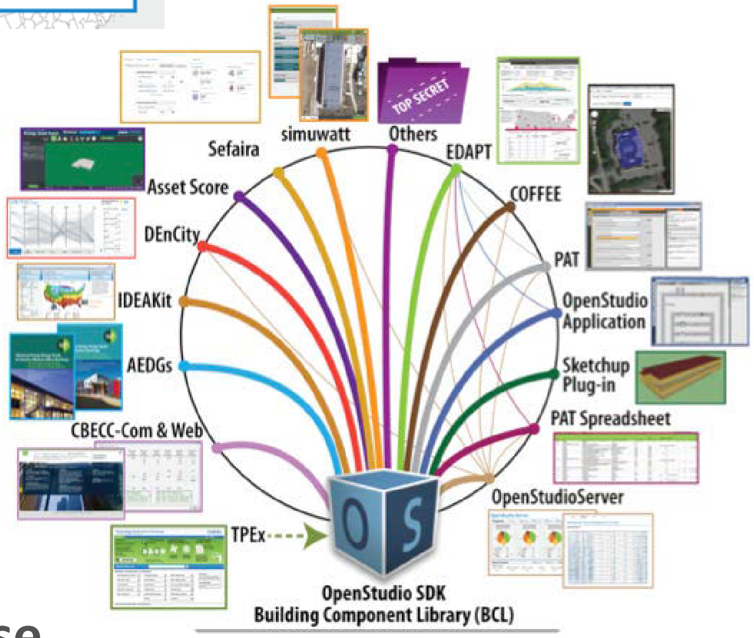
- Future projections and what-if scenarios **for load shape** in addition to magnitude
- Realistic estimates of potential **load flexibility** (i.e., demand response)
- Understand **interactions** between energy efficiency and demand response potential (also renewables and DERs)



Residential	Commercial	Industrial	Transport
ResStock, NREL	ComStock, NREL	IGATE-E, Oak Ridge National Laboratory, EPRI Electric Power Research Institute	SERA, EVI-PRO, NREL

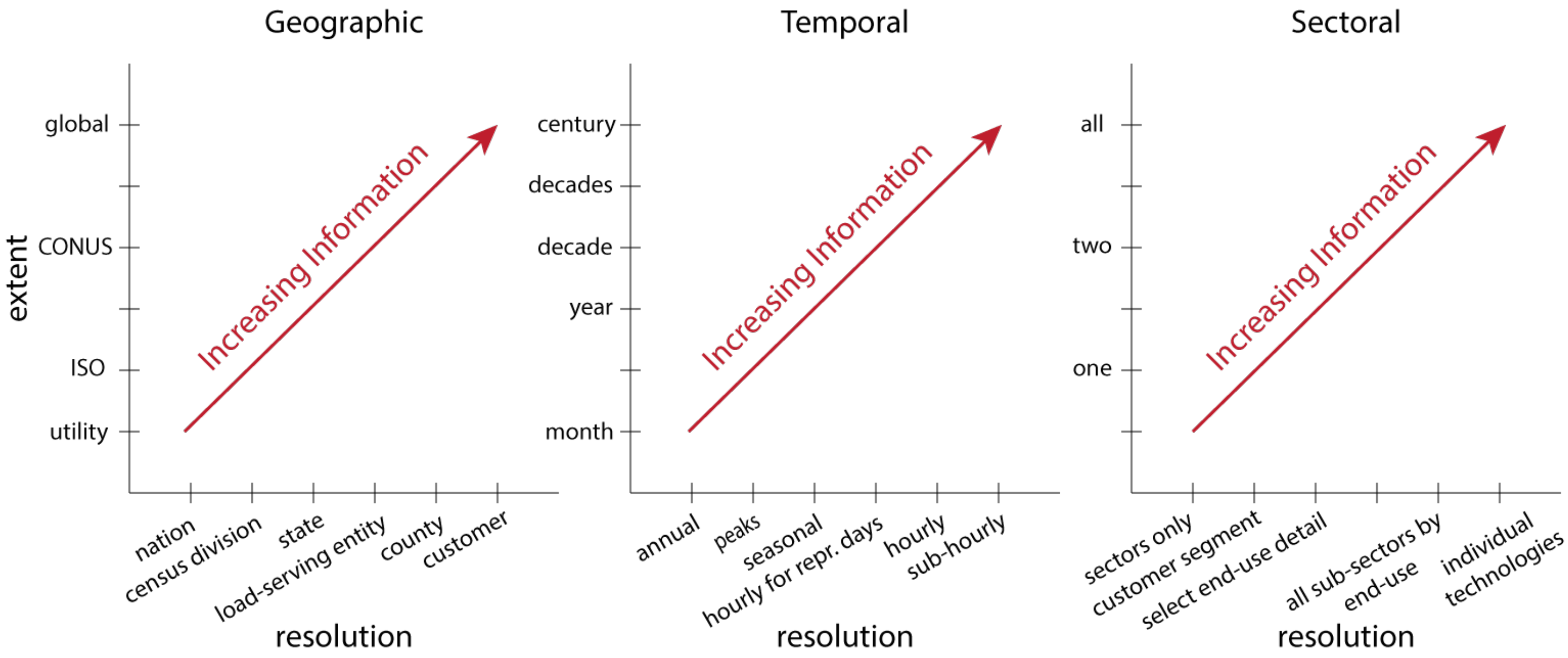
dsgrid leverages decades of sector-specific energy modeling

- High-quality modeling of each sector
- Breaks down energy-sector silos to enable cross-disciplinary understanding and holistic design

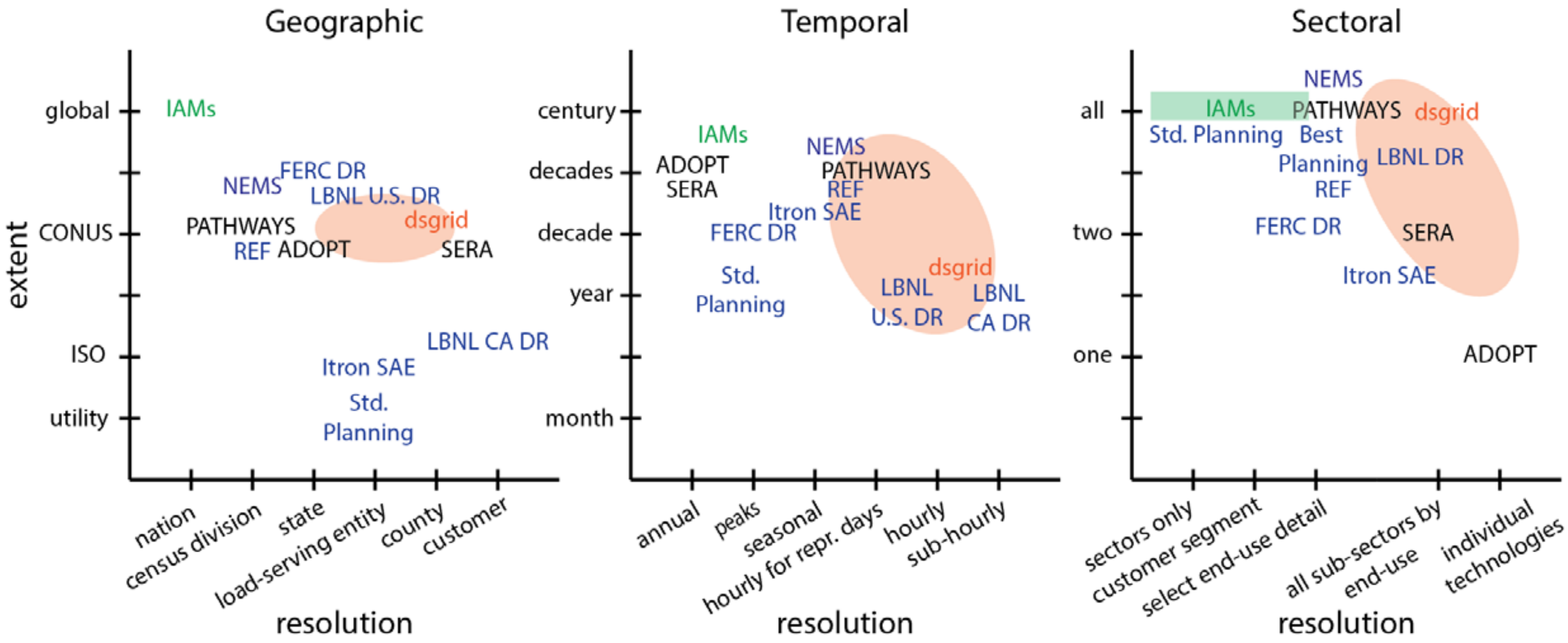


Buildings represent 71% of U.S. electricity use, and building energy modeling is a particularly mature field

Load models vary in extent, resolution, data, and methods



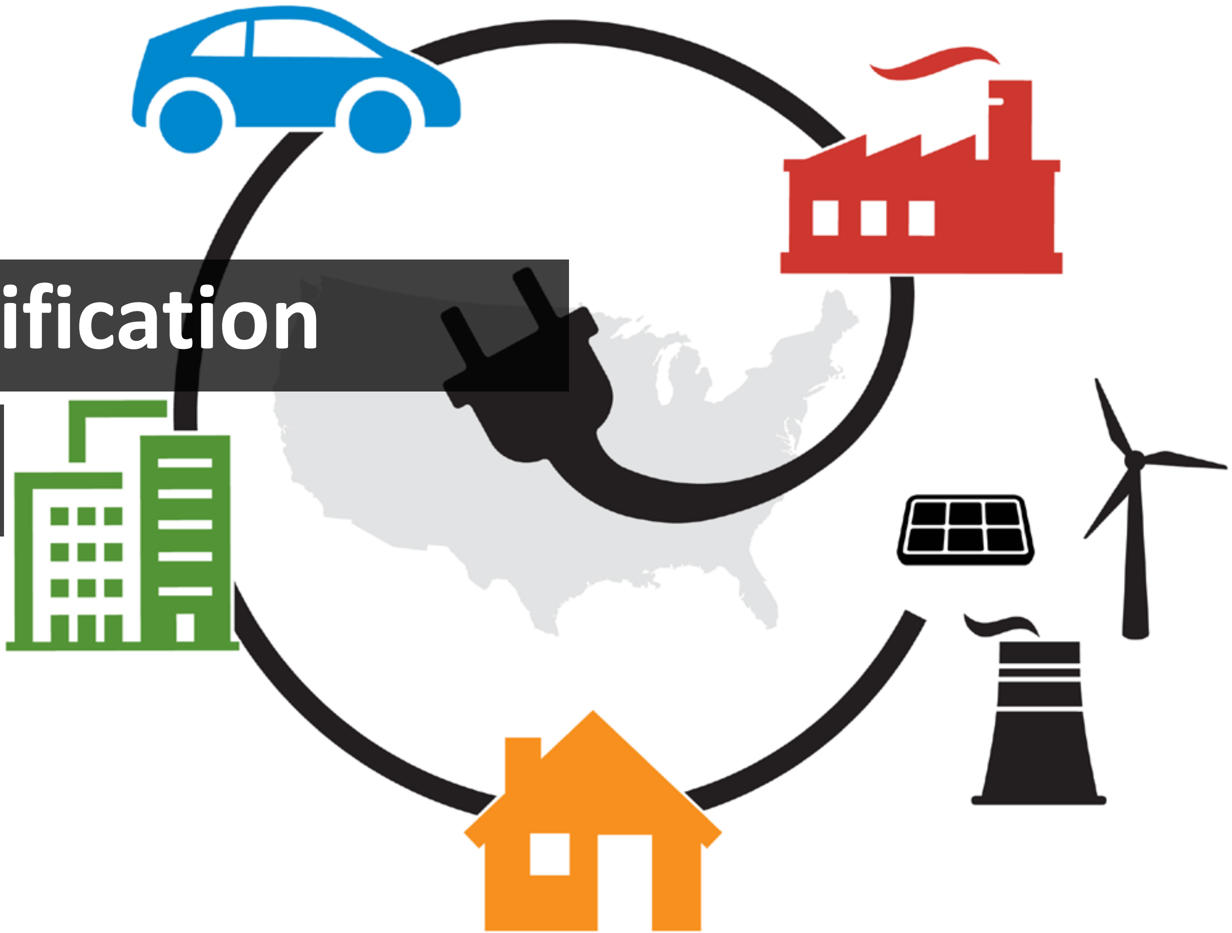
dsgrid provides high resolution for large geographic and temporal extents



DR	Demand Response (Potential Studies)	**NEMS**	National Energy Modeling System
FERC	Federal Energy Regulatory Commission	**Planning**	Refers to utility/ISO/PUC planning efforts
IAM	Integrated Assessment Model	**REF**	Renewable Electricity Futures (Study)
LBNL	Lawrence Berkeley National Laboratory	**SAE**	Statistically Adjusted End-Use (Model)

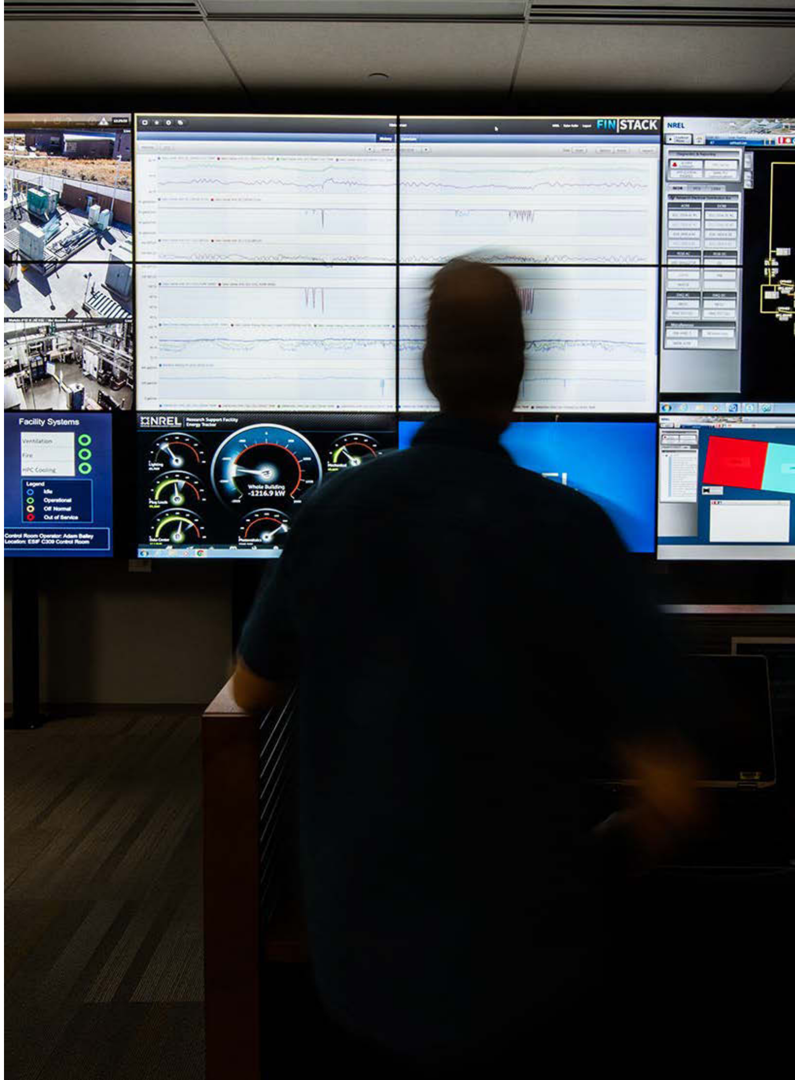
This graphic only shows load model resolution. The modeling resolution for other energy system components (e.g., electricity supply) modeled by the referenced tools (e.g., IAMs or NEMS) may differ.

EFS: The Electrification Futures Study



nrel.gov/EFS

How do we plan for **widespread electrification?**



NREL-led collaboration, multi-year study

Collaborators from:

- EPRI
- Evolved Energy Research
- Northern Arizona University
- Oak Ridge National Laboratory
- Lawrence Berkeley National Laboratory
- U.S. Department of Energy

NREL NATIONAL RENEWABLE ENERGY LABORATORY

- Strategic Energy Analysis
- Transportation and Hydrogen Systems
- Buildings and Thermal Systems

+ **Technical Review Committee** of 19 experts from industry and consultants, labs, government, NGOs

Study sponsored by U.S. DOE-EERE Office of Strategic Programs

Answering crucial questions about:

Technologies

What electric technologies are available now, and how might they **advance**?

Consumption

How might electrification impact electricity **demand** and **use patterns**?

System Change

How would the electricity system need to **transform** to meet changes in demand?

Flexibility

What role might **demand-side flexibility** play to support reliable operations?

Impacts

What are the potential **costs, benefits, and impacts** of widespread electrification?

Progress to date

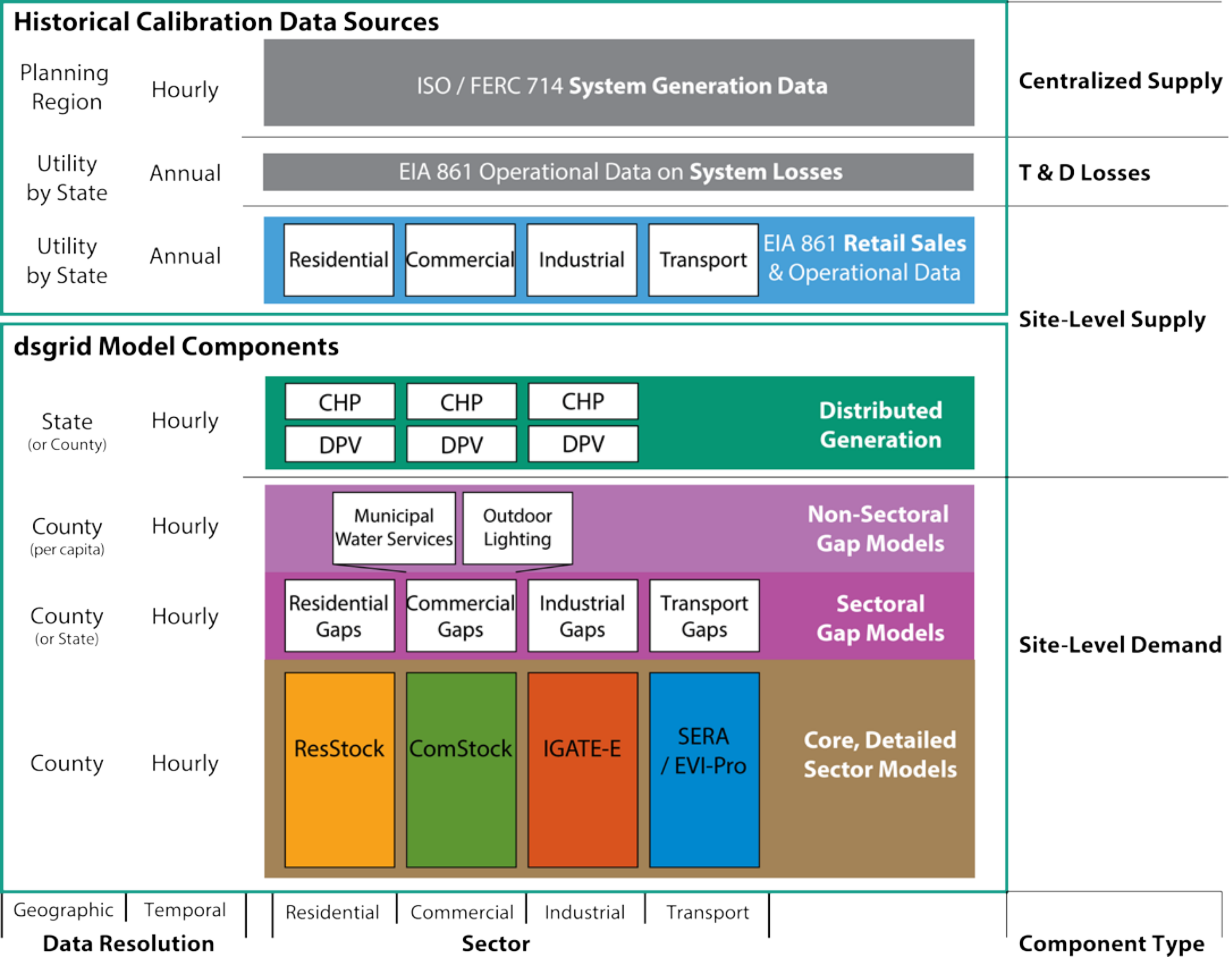
- Technology cost and performance (December 2017)
- Demand-side adoption scenarios (June 2018)
- dsgrid model documentation (August 2018)
- Supply-side evolution scenarios (2019)
- Impacts of electrification (2019)
- Electricity system operations (~2020)
- Value of demand-side flexibility (~2020)

Published

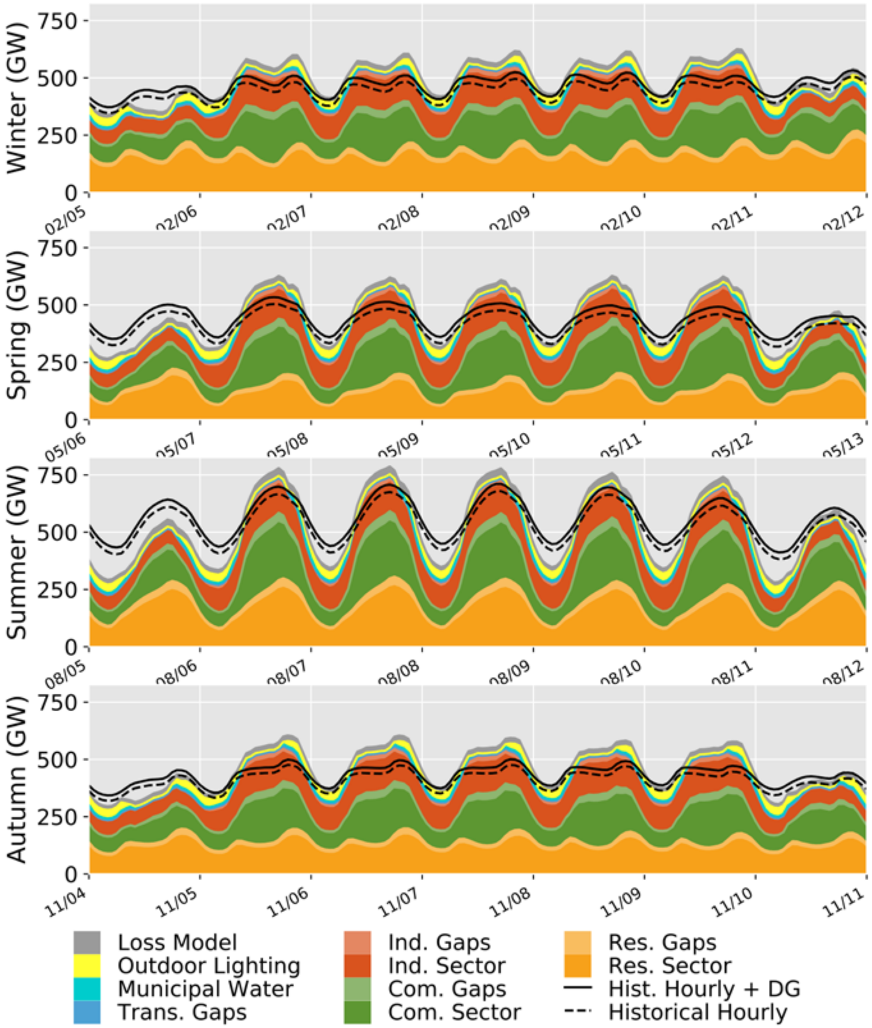
Ongoing and Planned

Note: Future work scope is tentative

dsgrid model architecture

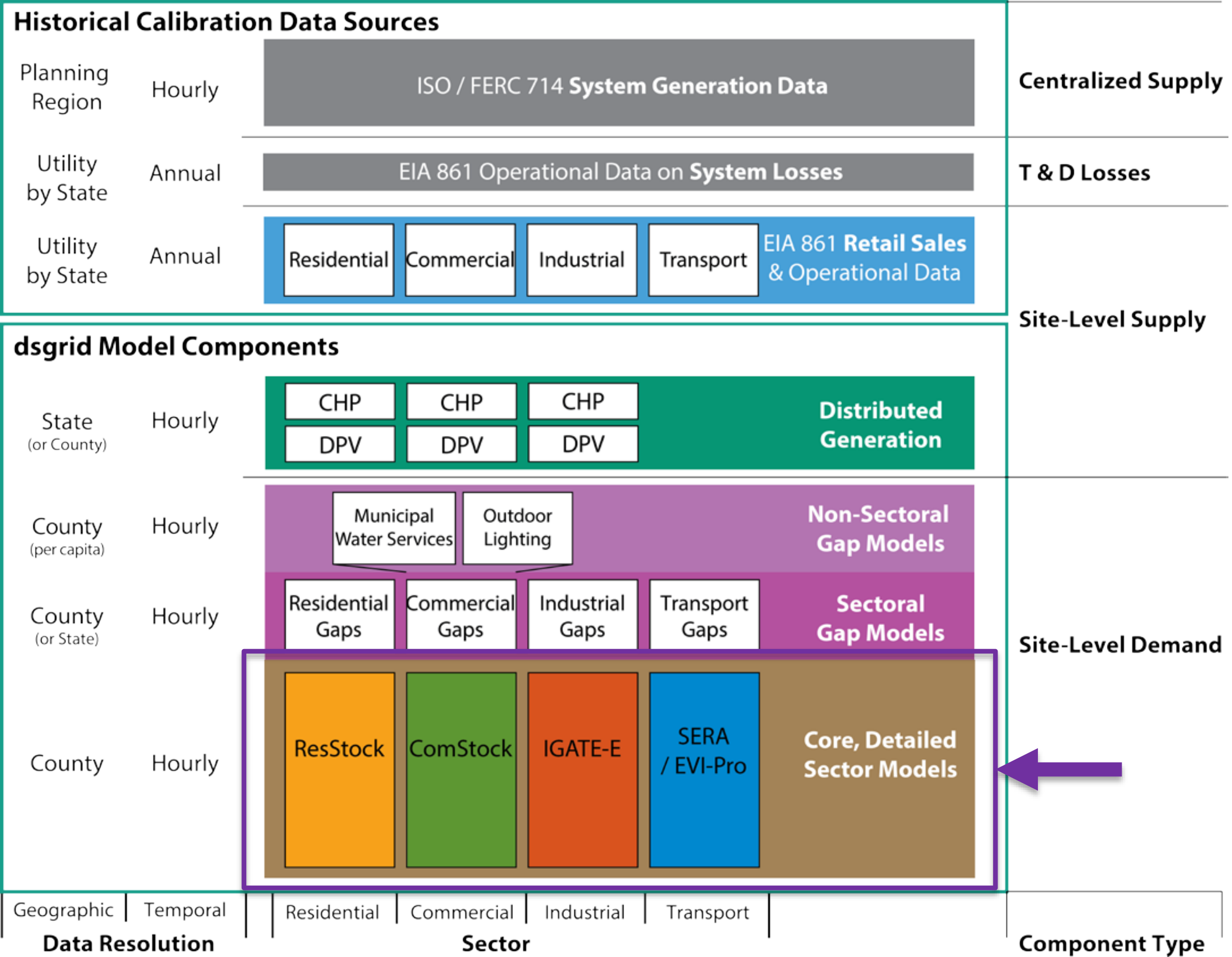


dsgrid model documentation: methods and 2012 U.S. electricity demand

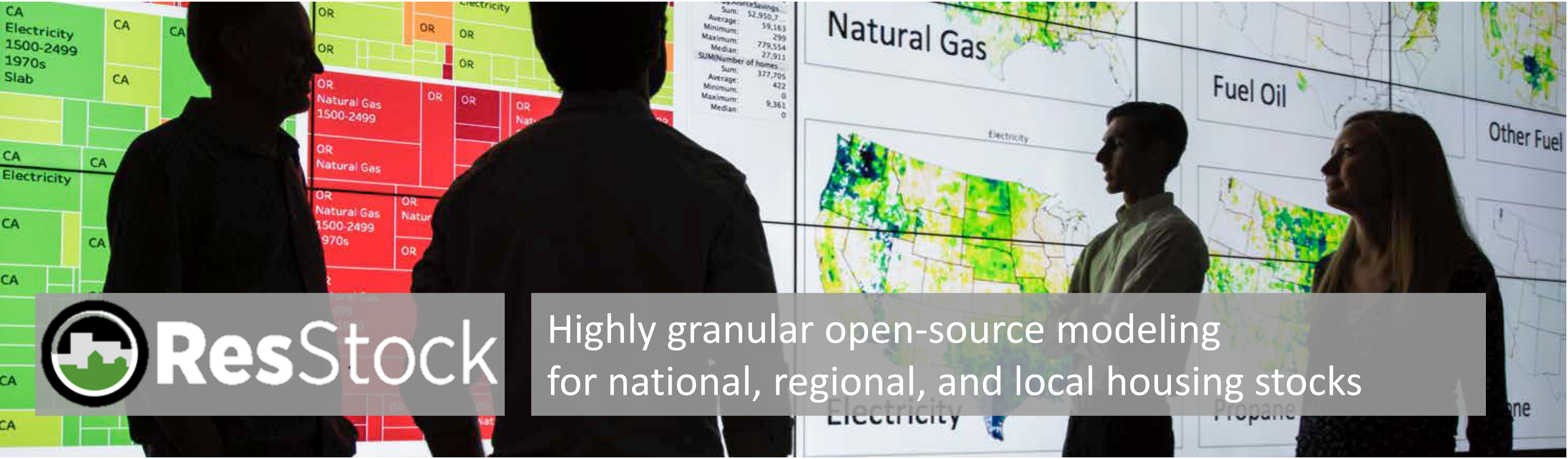


Hourly data for the contiguous United States (CONUS) for four representative weeks, aggregated by model component

dsgrid model architecture

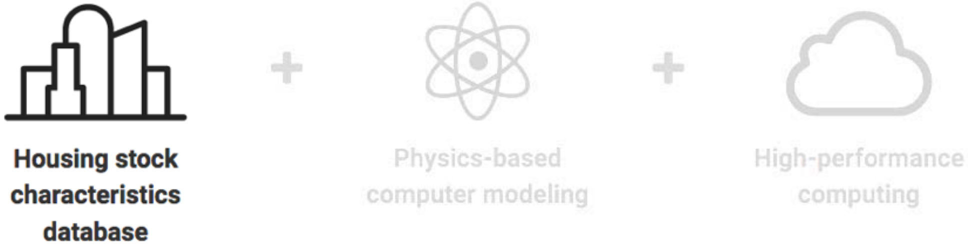


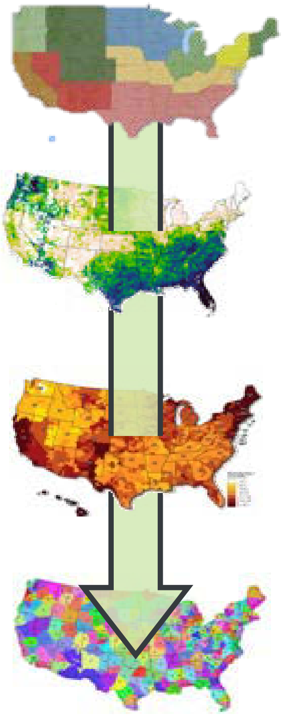
Housing stock characteristics database + **Physics-based computer modeling** + **High-performance computing**



ResStock

Highly granular open-source modeling
for national, regional, and local housing stocks





Building Characteristics	EIA	**Res. Energy Consumption Survey (RECS)**
	NAHB	**Homebuilder Surveys**
	IECC	**Historical Energy Codes**
Census Data	Census	**American Community Survey (ACS)**
Costs	EIA	**Electricity and fuel costs**
	NREL	**OpenEI.org Utility Rate Database**
	NREL/Navigant	**Measure Cost Database**
Climate Locations	NREL	**TMY3 weather data**

Housing stock characteristics database

+

Physics-based computer modeling

+

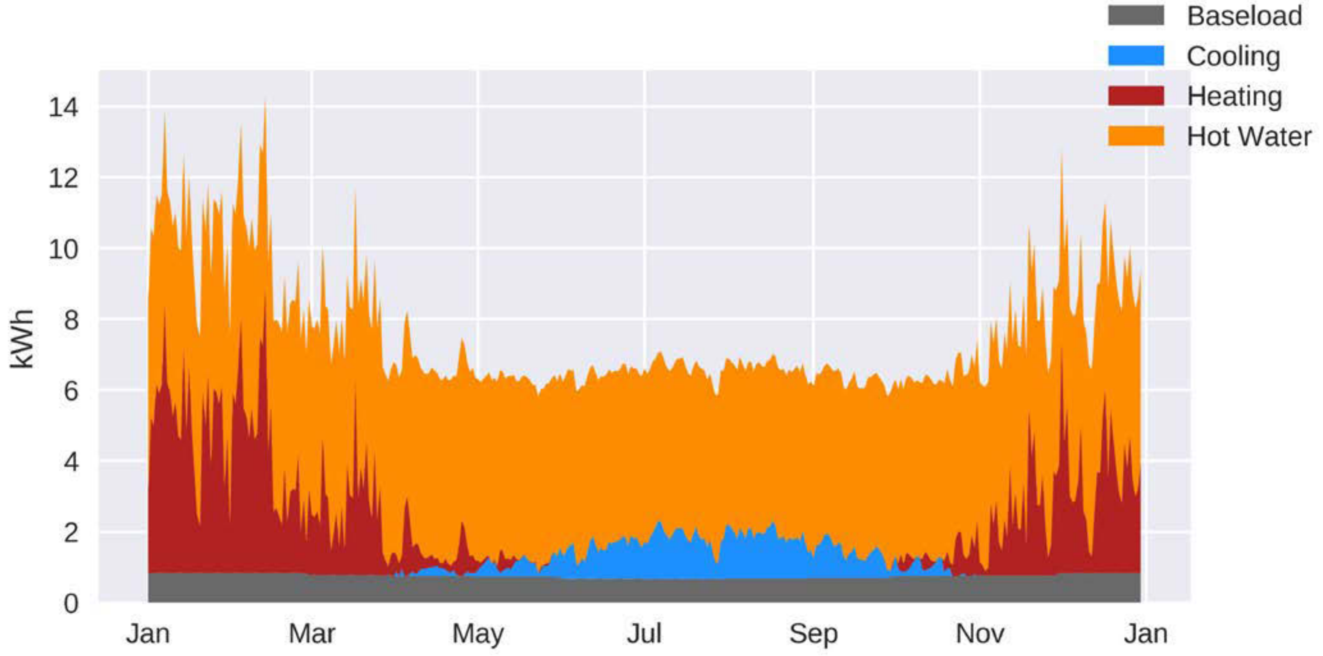
High-performance computing

U.S. DOE Tools

OpenStudio

EnergyPlus

Detailed sub-hourly energy simulations

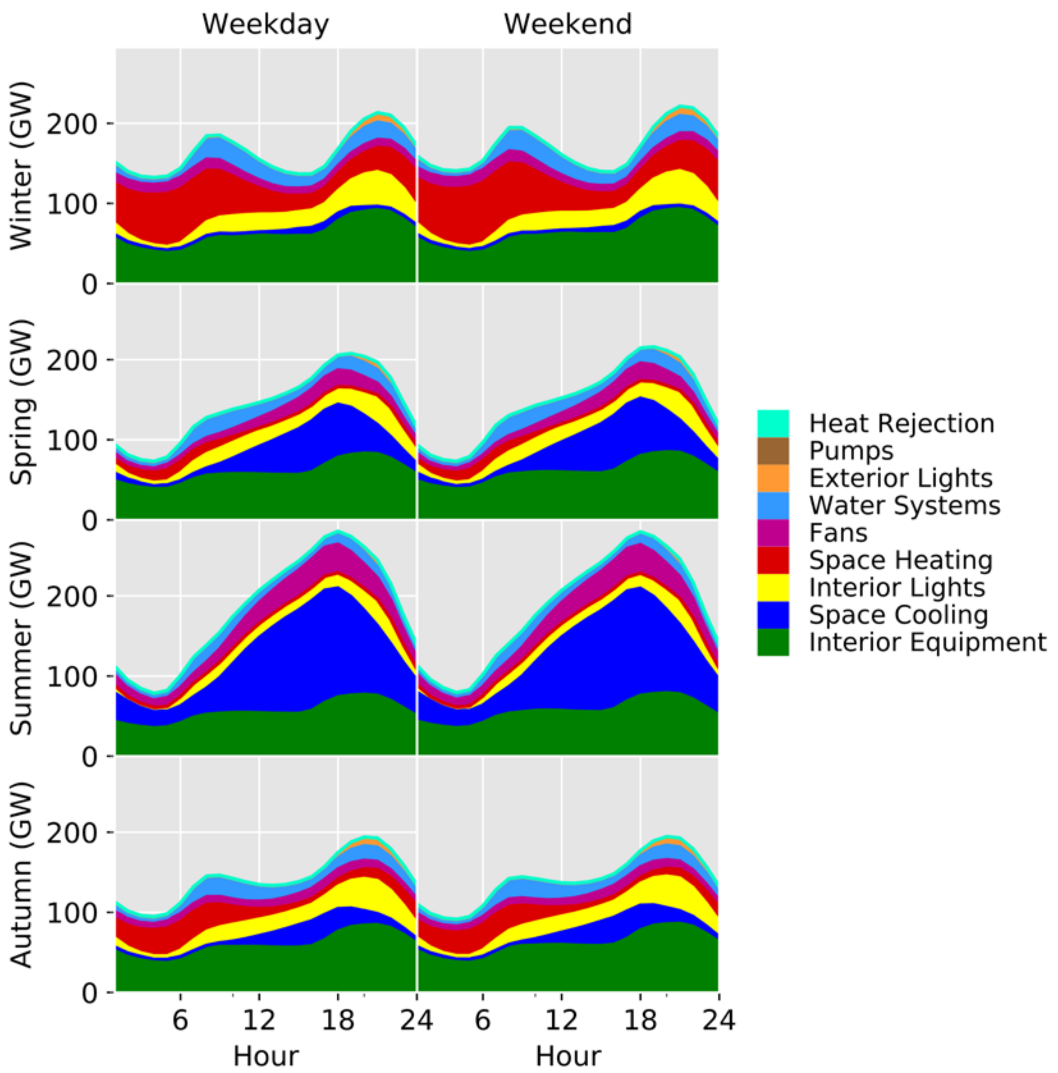


Housing stock characteristics database + Physics-based computer modeling + **High-performance computing**

350,000 | simulations for baseline U.S. single-family housing stock

Residential electricity load shapes by season

- Interior equipment is the largest end use, comprising 33% to 48% of electricity depending on census division
- Importance of space cooling, interior lighting, and space heating varies more by season and region



Empirical commercial building data for contiguous U.S.

Hierarchical conditional probability tables of building parameters

Dependency=proto_bldg_type	Option=pre_1920	Option=1920_1945	Option=1946_1959	Option=1960_1969	Option=1970_1979	Option=1980_1989
full_service_restaurant	0.098806613	0.13032097	0.114418722	0.096090955	0.144336141	0.130175422
hospital	0.015405032	0.004327187	0.123804138	0.075188748	0.335311284	0.092153379
large_hotel	0.008542008	0.012454725	0.009387688	0.070104765	0.223395733	0.15919276
medium_office	0.10468834	0.097196516	0.127730666	0.094582263	0.131960126	0.1796334
midrise_apartment	0.002644052	0.081699064	0.103358993	0.213227542	0.11852058	0.134194279
outpatient	0.048023034	0.050479293	0.075820622	0.114023303	0.170487833	0.222382135
primary_school	0.016164851	0.086079351	0.120412847	0.159539927	0.077635691	0.130621529
quick_service_restaurant	0.033023279	0.057357111	0.020960154	0.090178428	0.121910676	0.192090545
retail	0.115802683	0.138762132	0.101692793	0.105342157	0.10079961	0.135504624
secondary_school	0.014309296	0.086260296	0.133977031	0.149113152	0.193802632	0.075279282
small_hotel	0.036411376	0.111089886	0.155910617	0.179224164	0.147104216	0.163988824
small_office	0.038216844	0.061965679	0.074320253	0.113104302	0.128288664	0.208303279
strip_mall	0.035470153	0.016794282	0.101305444	0.103133424	0.204018358	0.193143574
warehouse	0.043741998	0.080944546	0.089784144	0.110645779	0.122267319	0.2024033

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Sample of building characteristic values (x350,000)

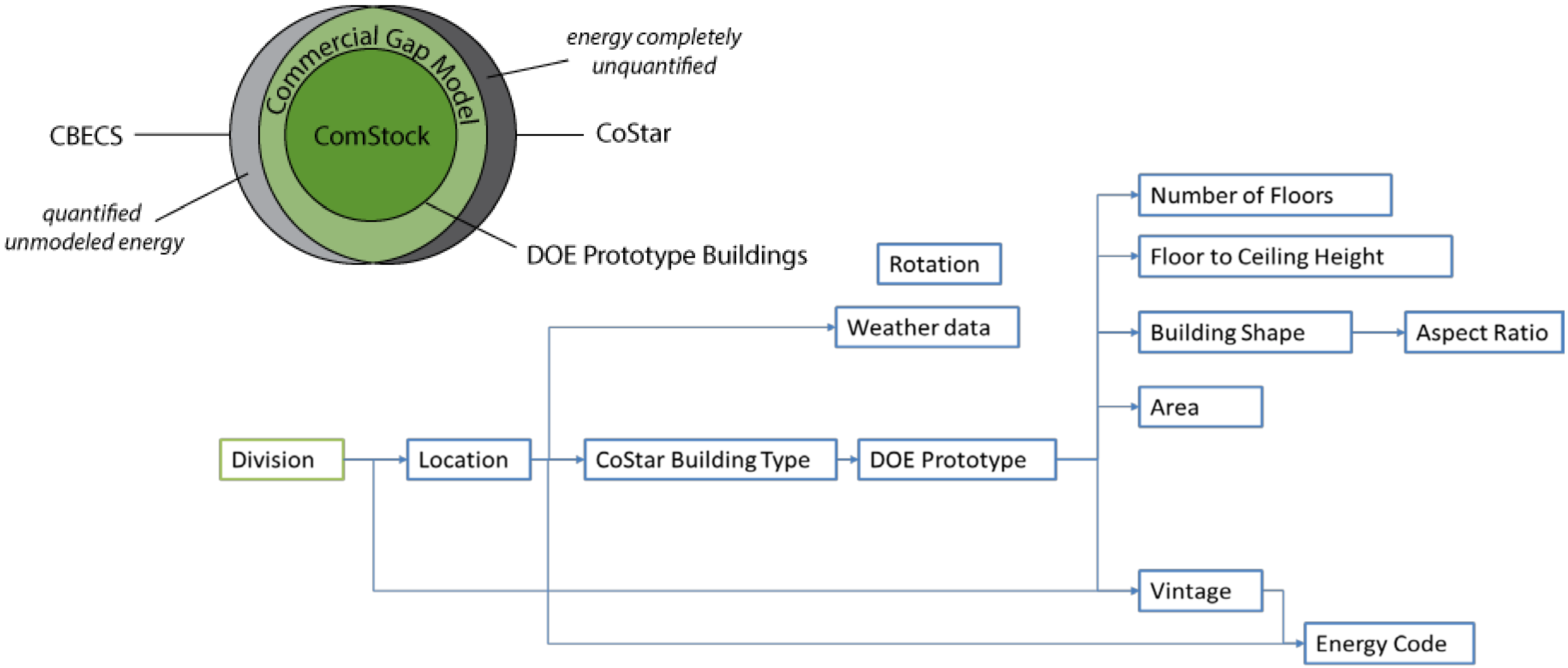
EnergyPlus Building Simulations (x350,000)

Per-county scaling with weighting factor

County-level aggregate load profiles with end-use breakdowns

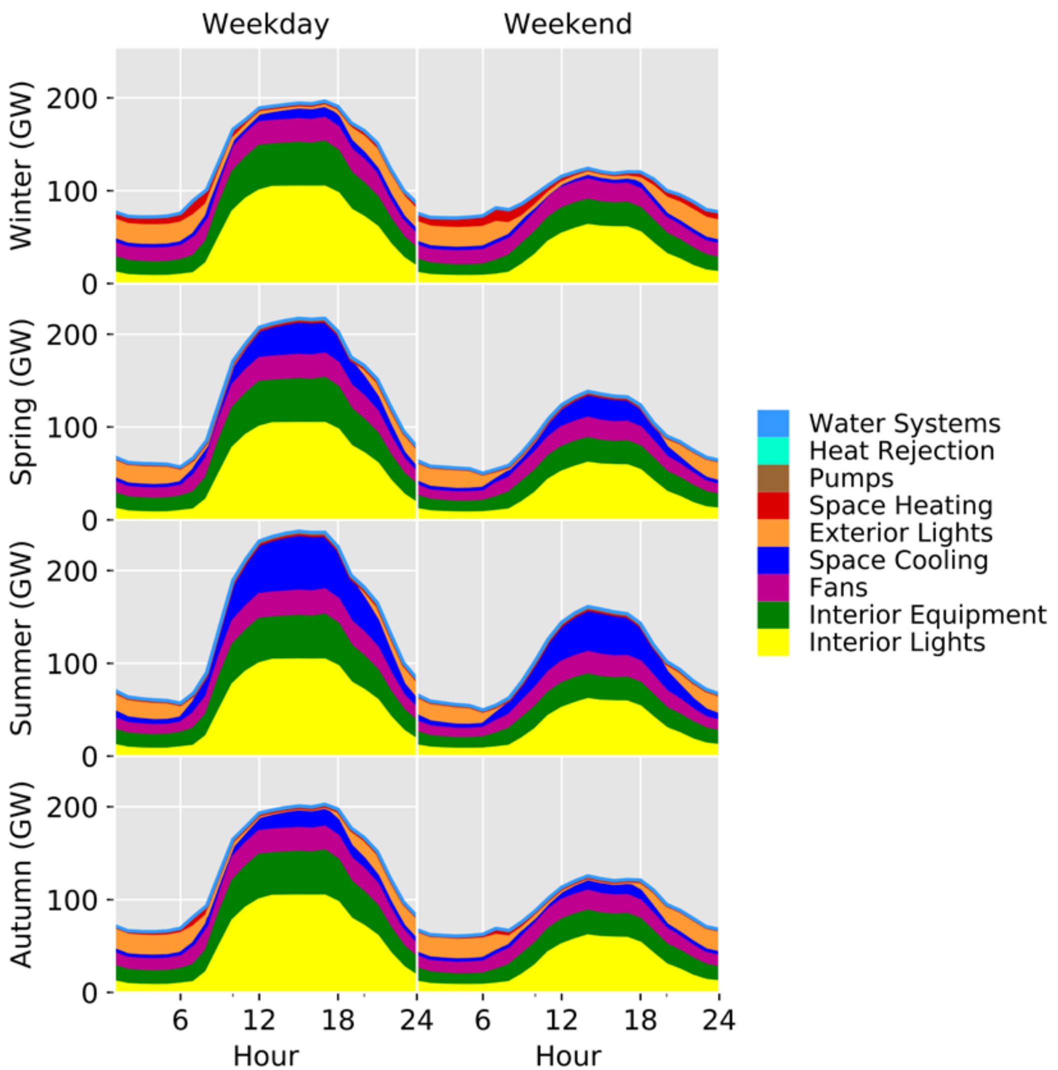
ComStock: commercial building modeling approach

Commercial building data relationships



Commercial electricity load shapes by season

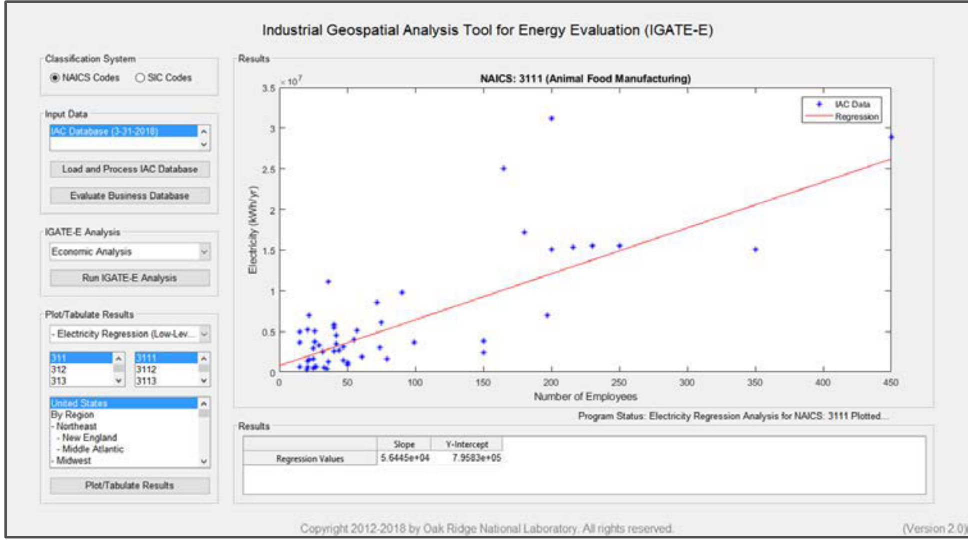
- More prominent role for lighting and fans, compared to residential buildings
- End use proportions vary by building type/subsector:
    - Interior equipment is prominent in offices
    - Interior lighting is prominent in retail buildings

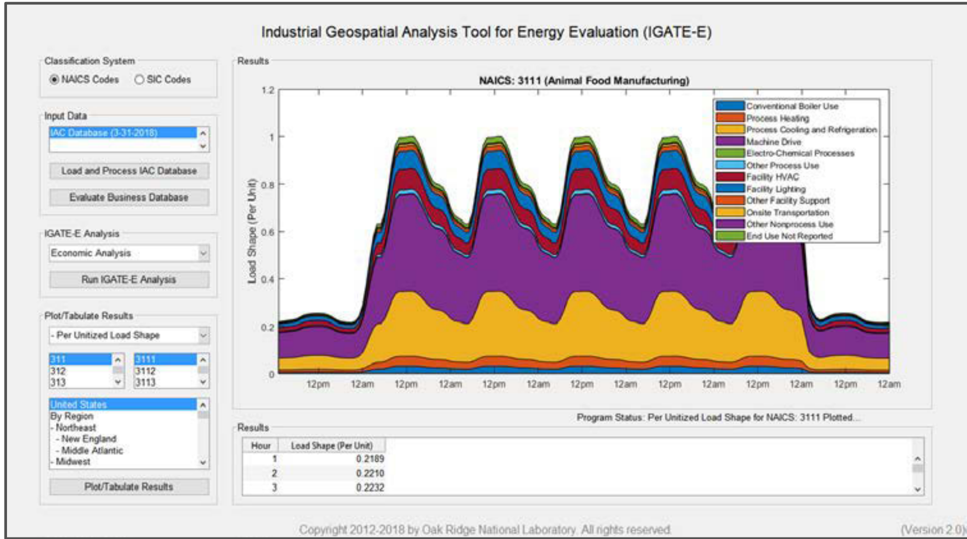


Industrial manufacturing modeling approach

IGATE-E developed by ORNL and EPRI

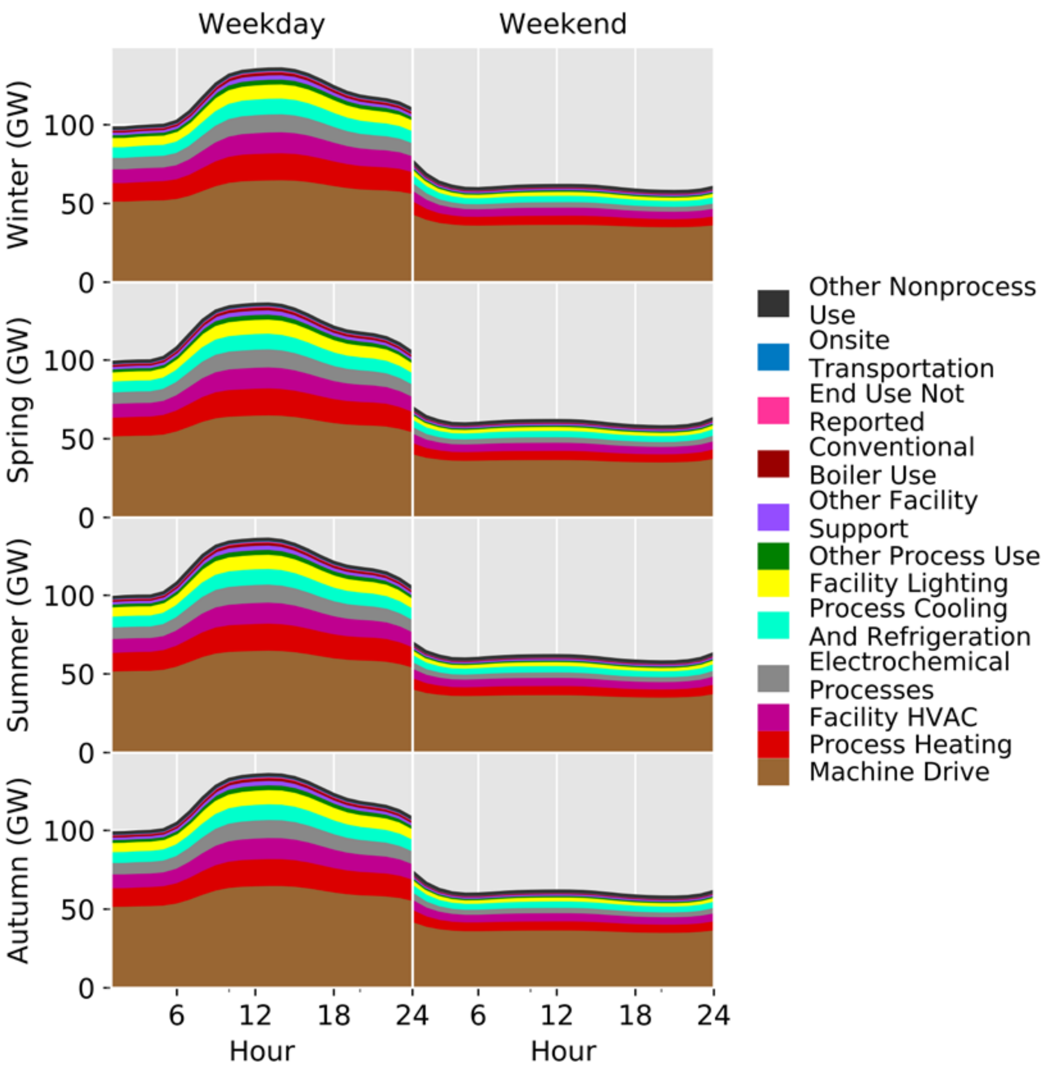
Characteristics	Methods: Regression Analysis	Methods: Energy Analysis (Initial)	Methods: Energy Analysis (Optimized)	Methods: Load Factor Analysis	Methods: Load Shape Analysis	Data Sources: IAC Database	Data Sources: MNI EZ Select Database	Data Sources: 2014 EIA MECS	Data Sources: EPRI Load Shape Library	
Location (State/County/Zip Code)		X					X			By Plant
Industry Code (NAICS/SIC)	X	X		X		X	X			By Plant
Energy Consumption (kWh or MMBtu/yr)	X			X		X				By Plant
Electricity Demand (kW/month)				X		X				By Plant
Number of Employees	X	X				X	X			By Plant
Industry Code (NAICS/SIC)			X		X			X		By Industry
Energy Consumption (kWh or MMBtu/yr)			X					X		By Industry
End-Use Energy Consumption (kWh/yr)					X			X		By Industry
Load Shapes by End-Use					X				X	



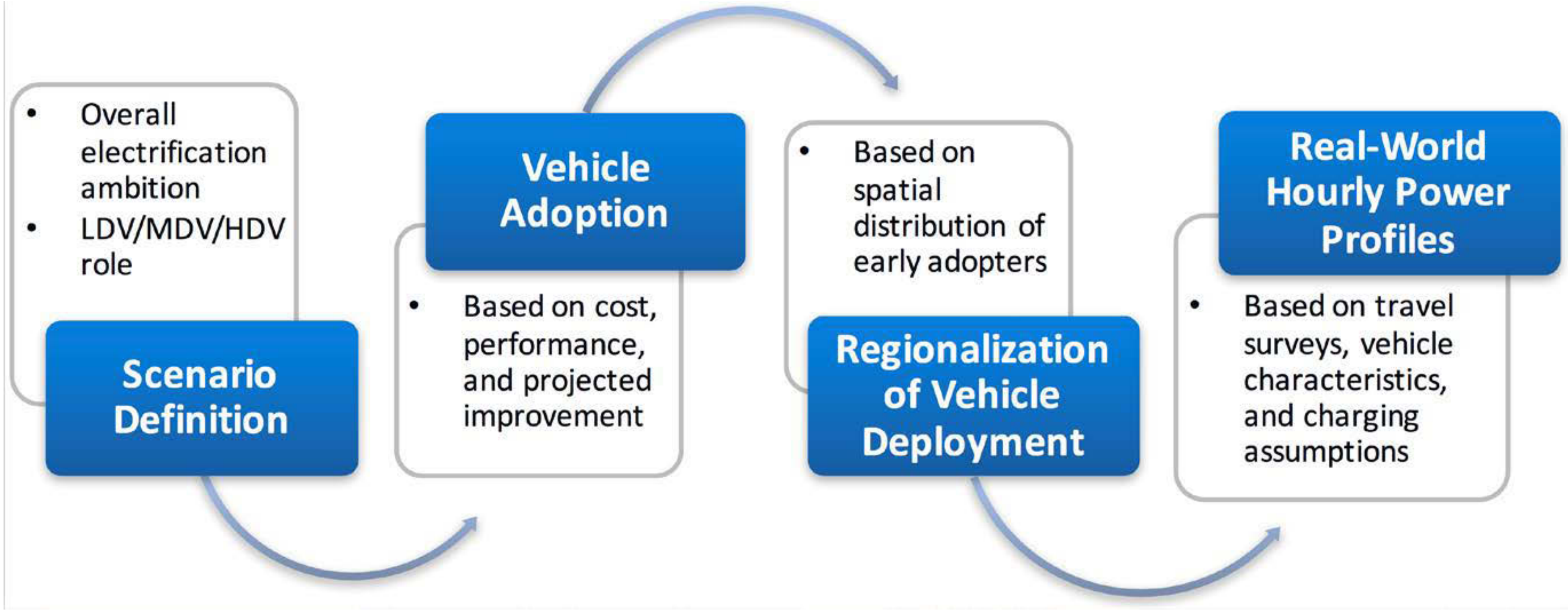


Manufacturing electricity load shapes by season

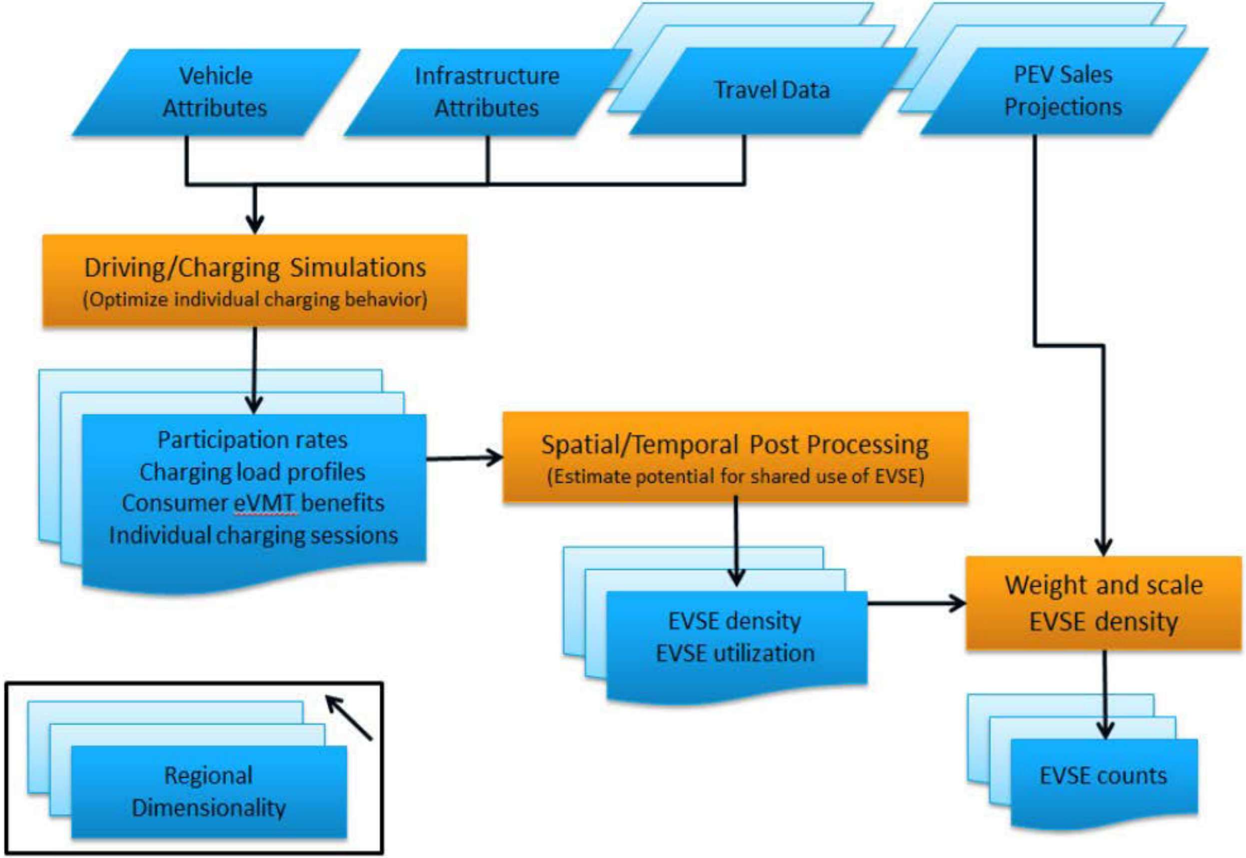
- Energy modeling is less developed in part because of industry / manufacturing heterogeneity
- IGATE-E/dsgrid models 86 different subsectors
- Electricity use is dominated by machine drive, process heating, and facility HVAC, with considerable subsector variation



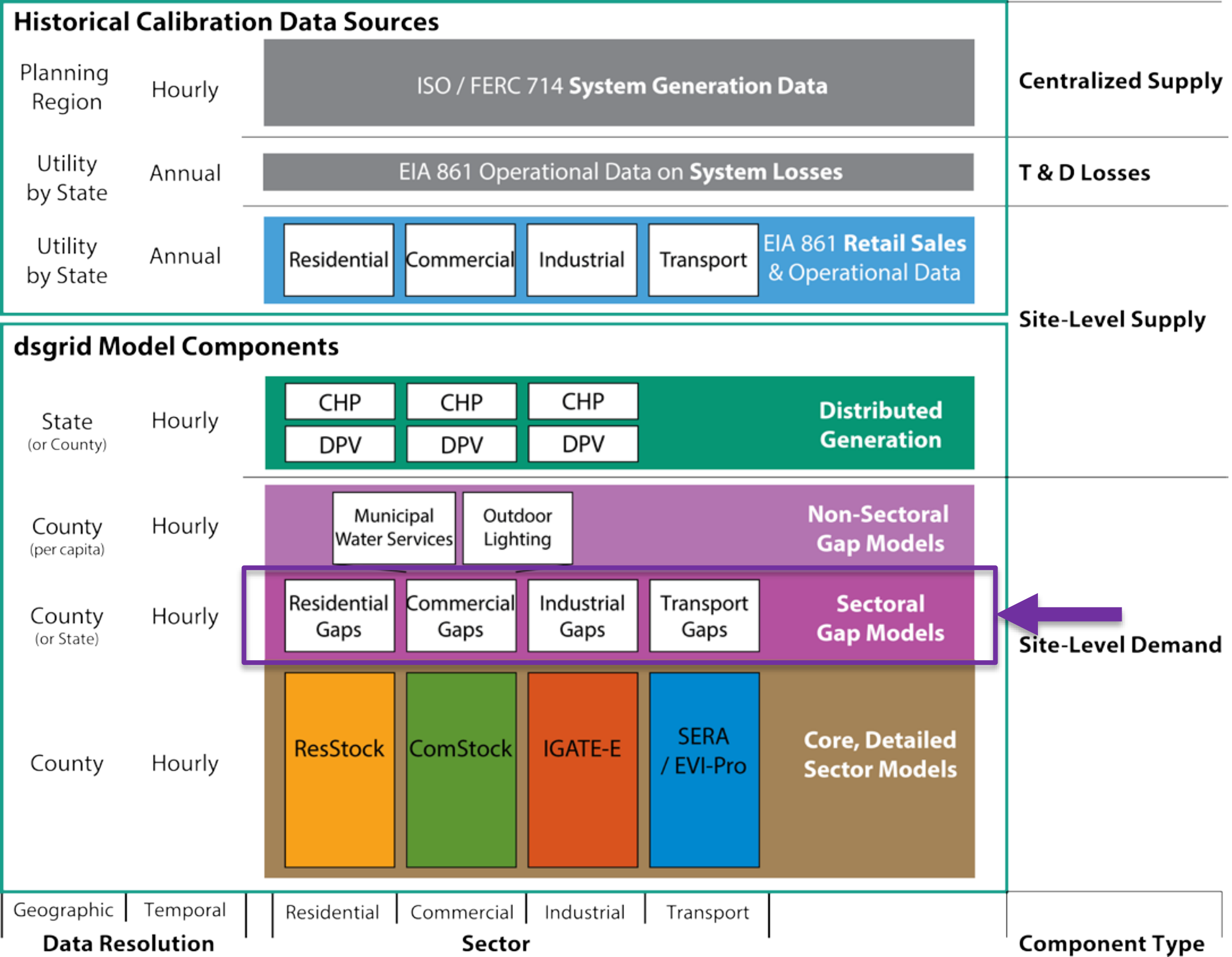
Transportation – electric vehicle modeling approach



Transportation – charging profiles from EVI-Pro



dsgrid model architecture

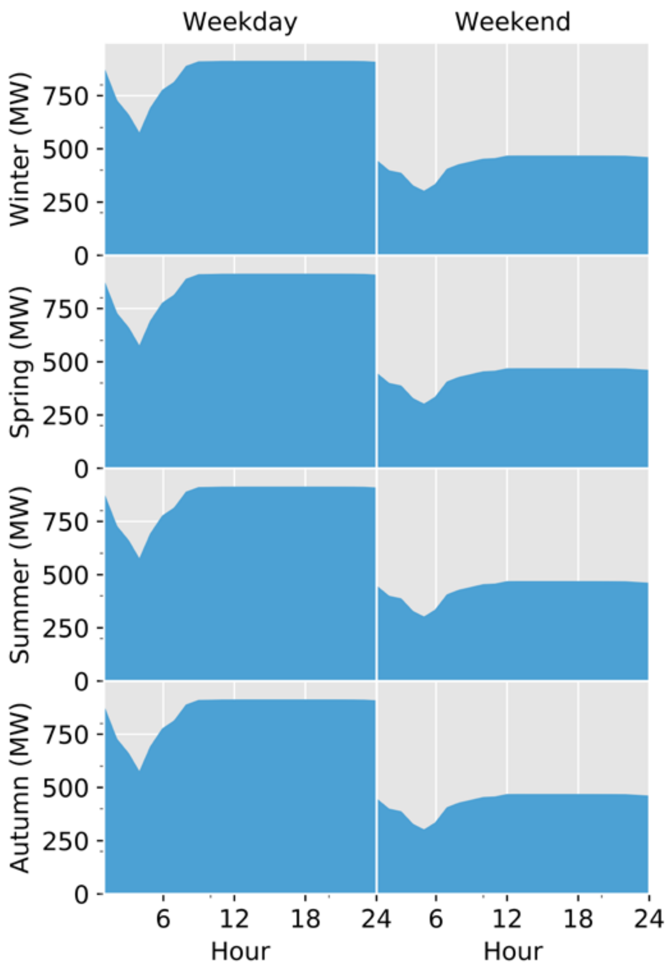


Transportation gap model of electricity used by passenger trains

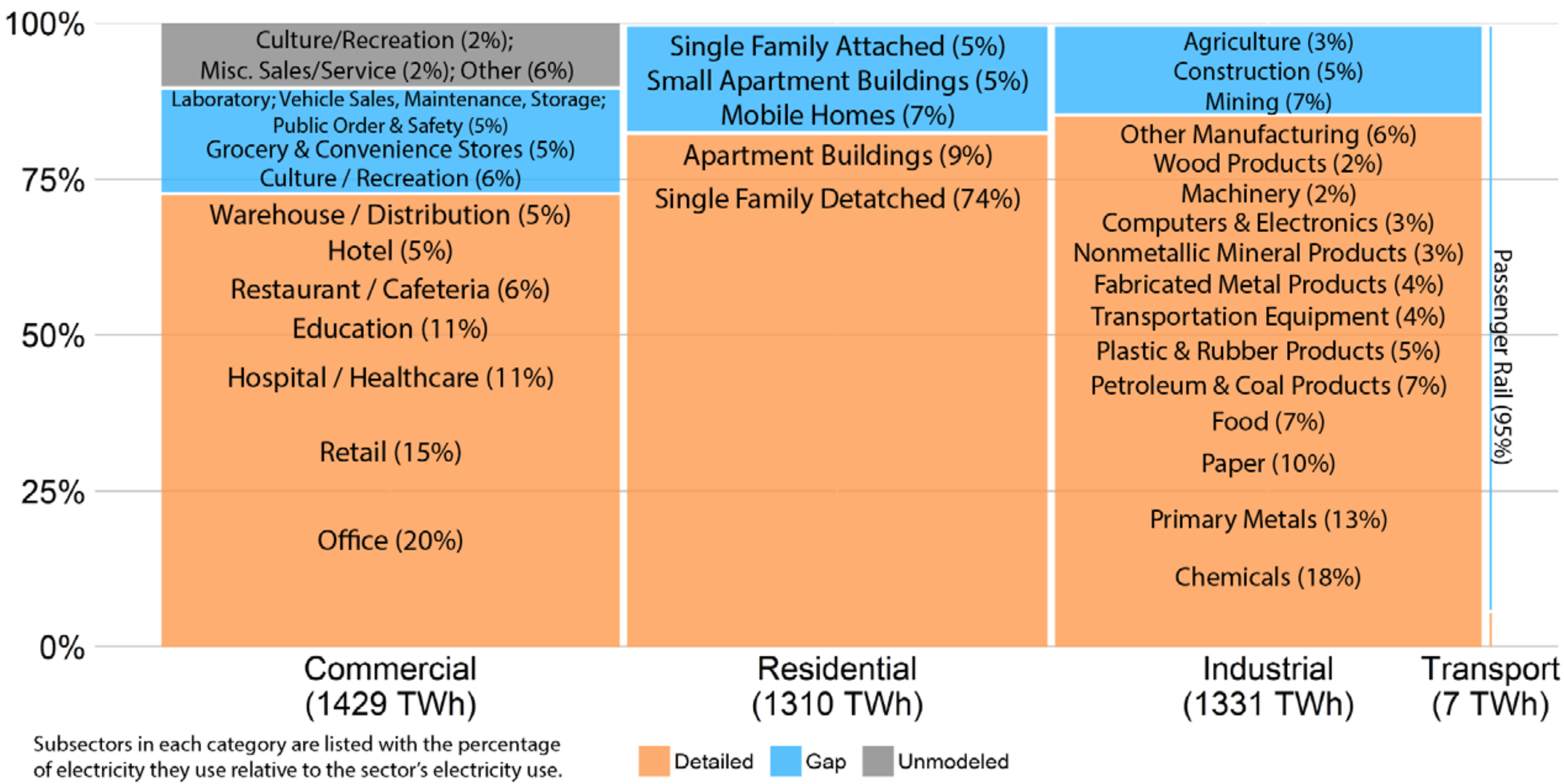
Census Division	Total GWh)	Total (%)
Mid Atlantic	3,304	51.5
South Atlantic	793	12.4
New England	709	11.0
Pacific	706	11.0
East North Central	623	9.7
Mountain	124	1.9
West South Central	114	1.8
West North Central	43	0.7
East South Central	2	0.0
Total	6,417	100.0

Electric vehicles not modeled in the 2012 data set because deployment at that time was small and regionally concentrated

Seasonal, weekday/weekend load shapes for CONUS

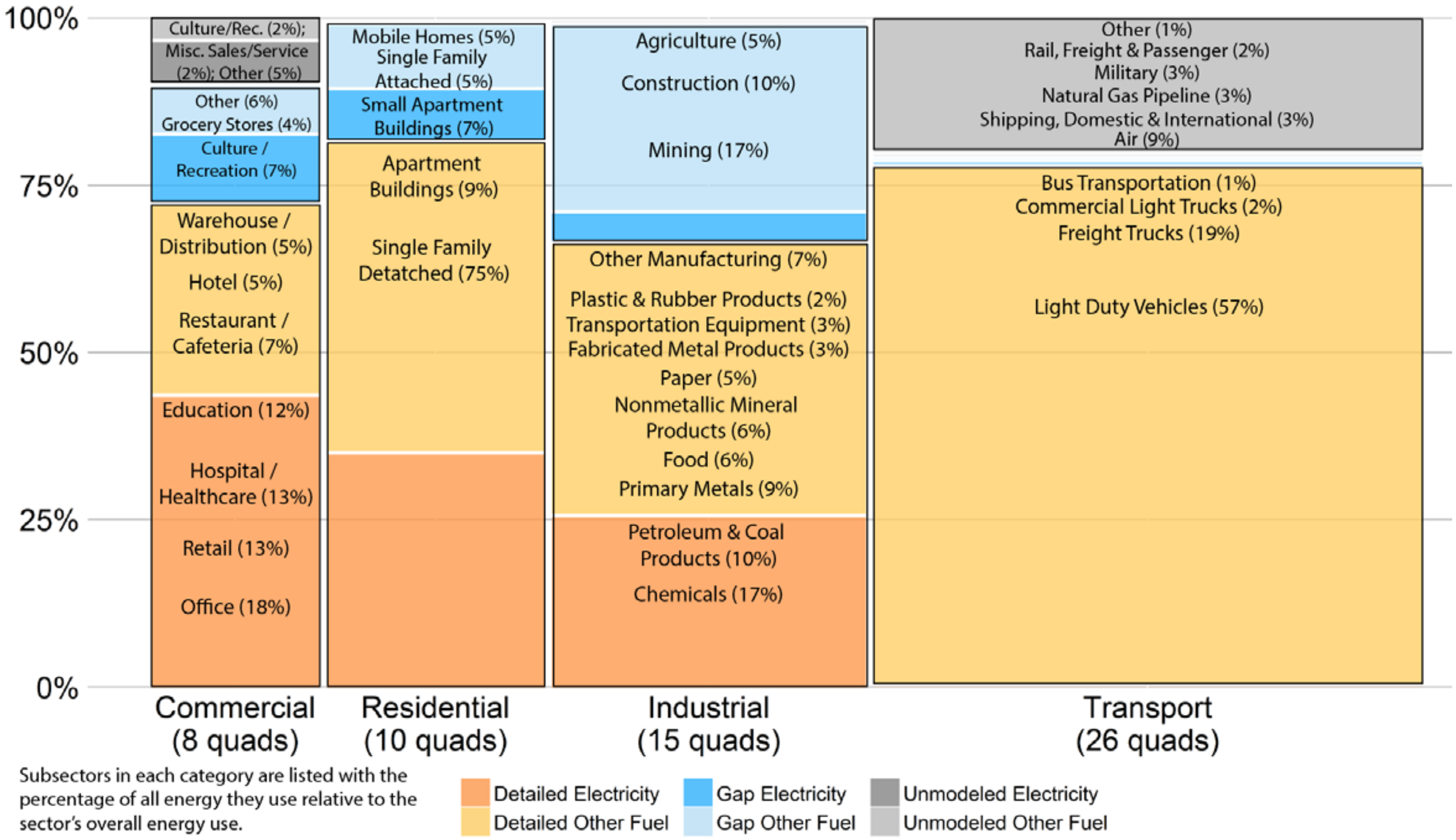


dsgrid models about 80% of 2012 U.S. electricity use in detail



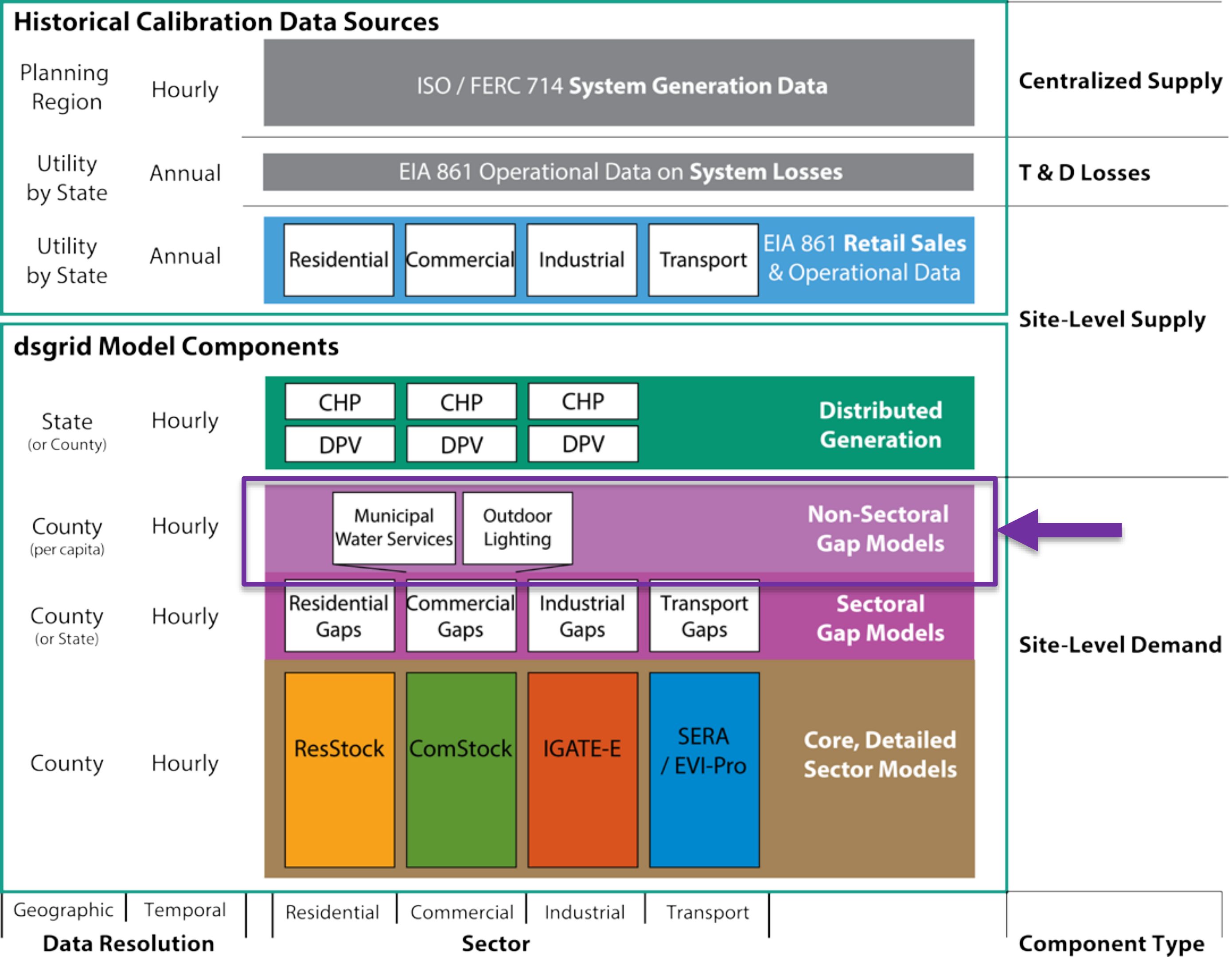
Subsectors in each category are listed with the percentage of electricity they use relative to the sector's electricity use.

dsgrid models about 76% of 2012 U.S. site energy use in detail



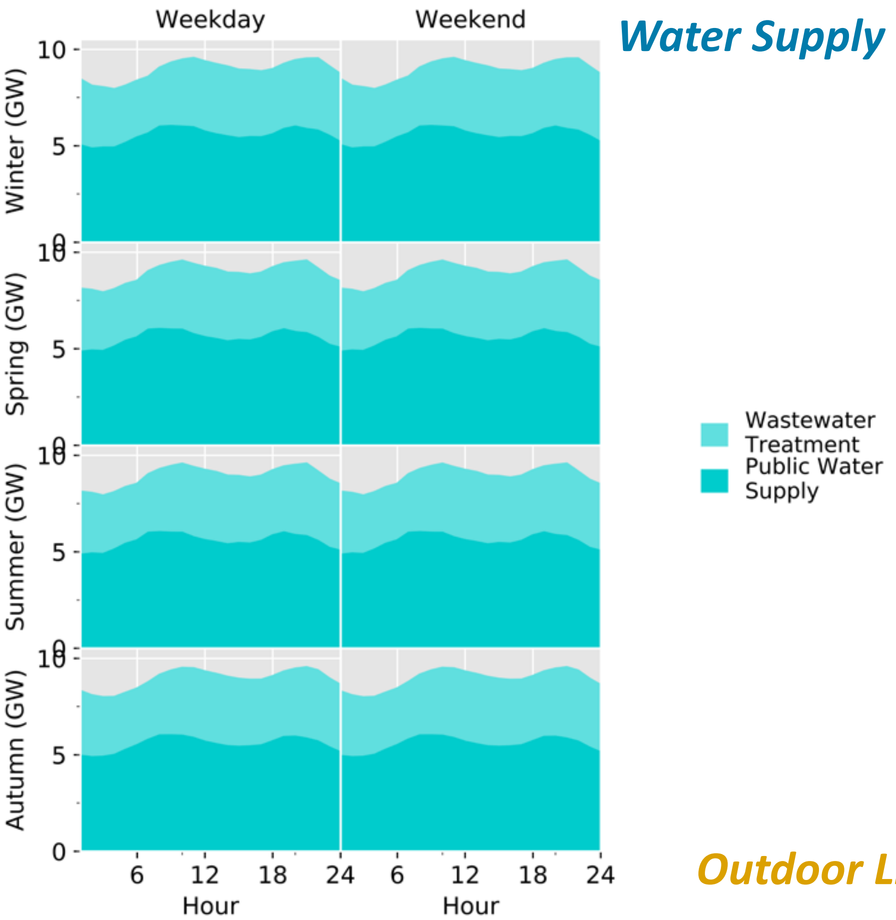
Subsectors in each category are listed with the percentage of all energy they use relative to the sector's overall energy use.

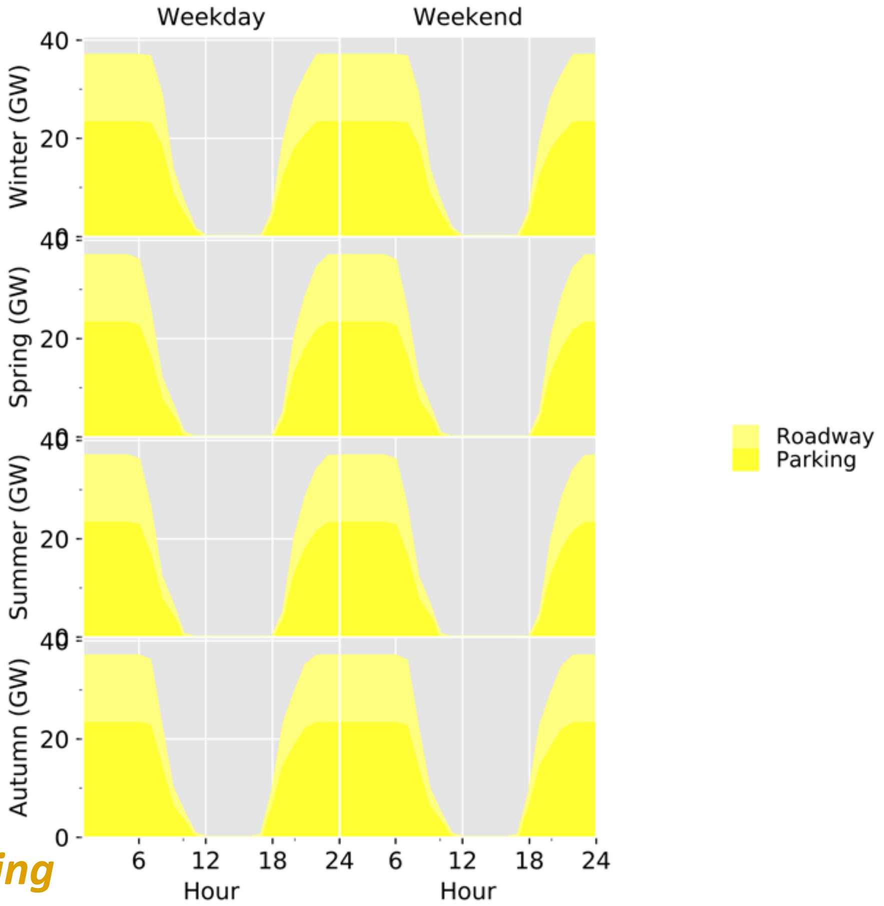
dsgrid model architecture



Municipal services not captured in the sector models

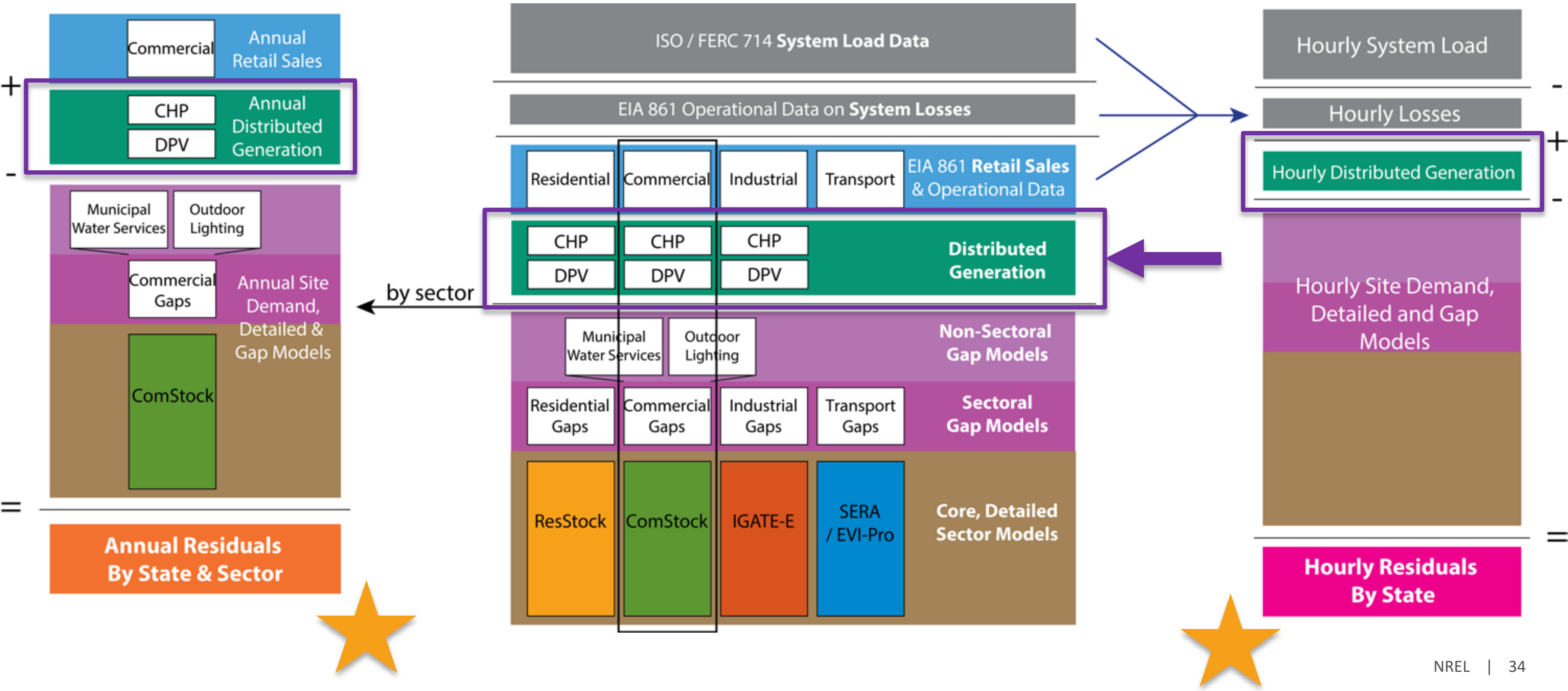
Water Supply



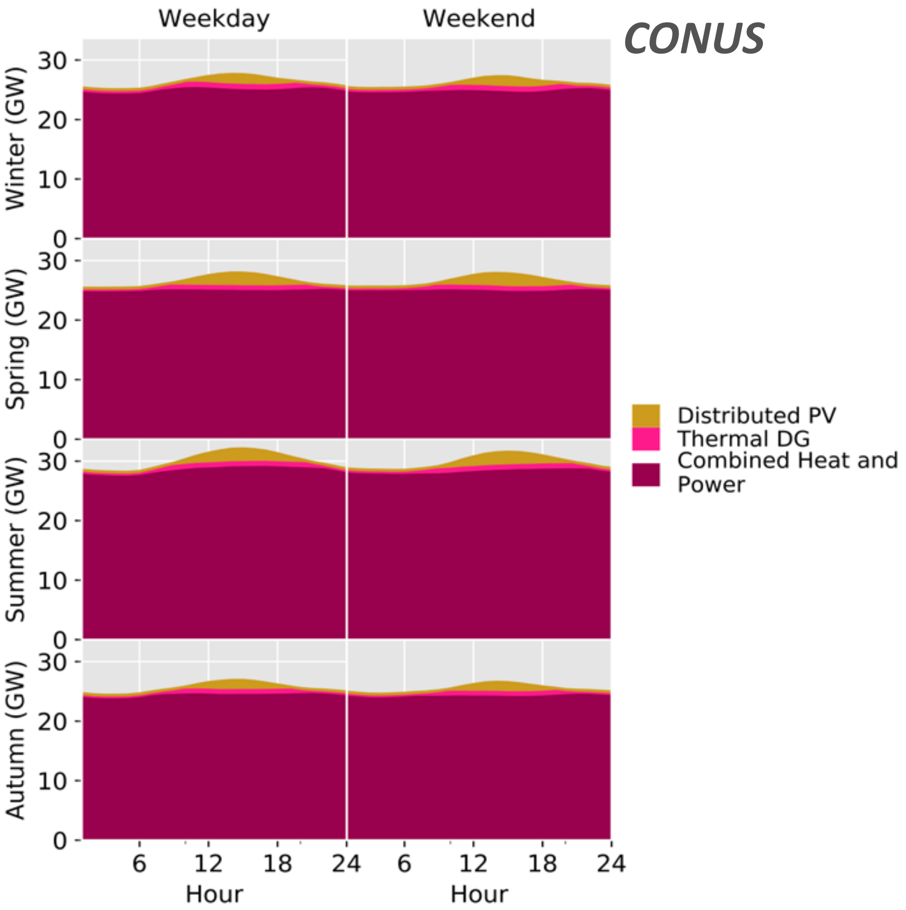


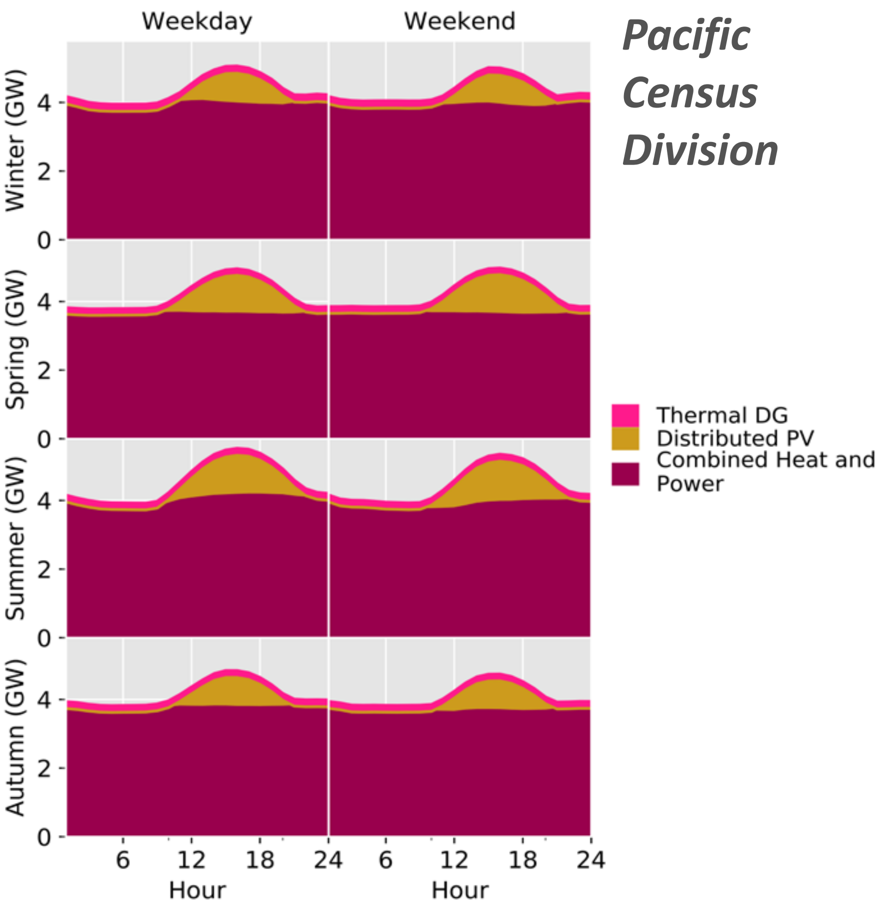
Outdoor Lighting

Validation against historical data requires distributed generation estimates

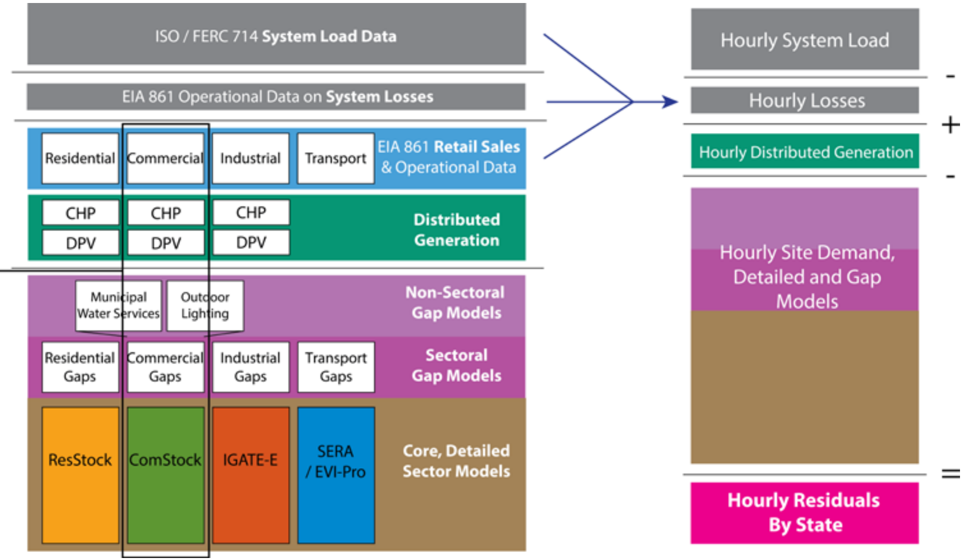


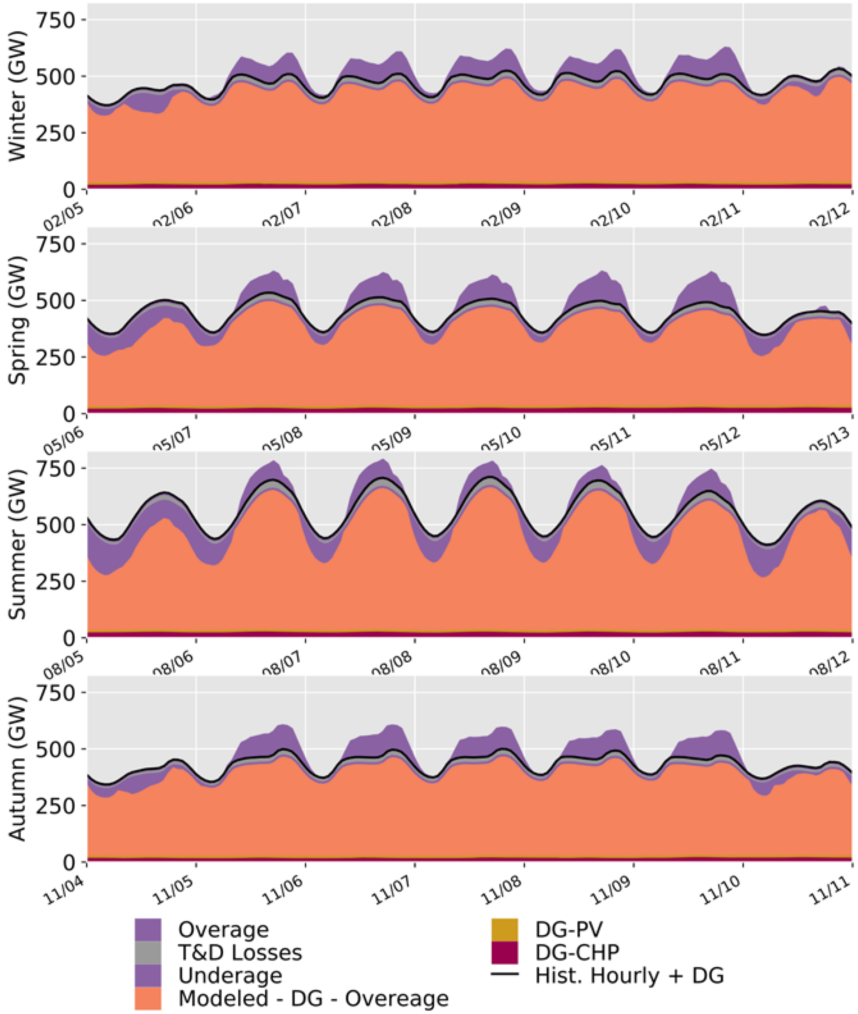
Distributed solar and combined heat and power



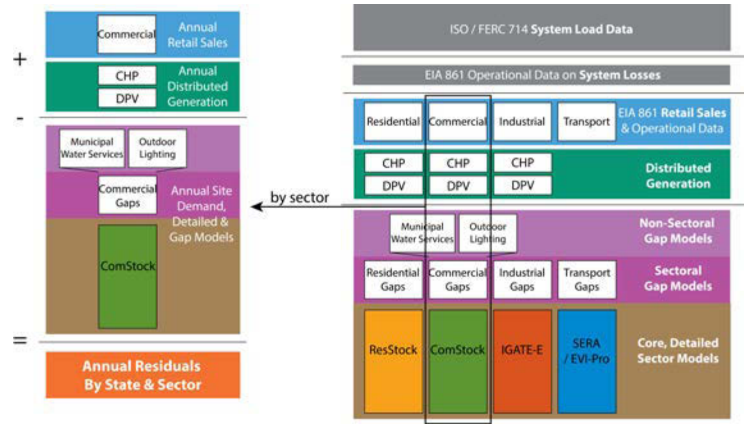


Hourly data roughly validates, but also reveals need for additional calibration





Annual sector-level residuals reveal a similar story

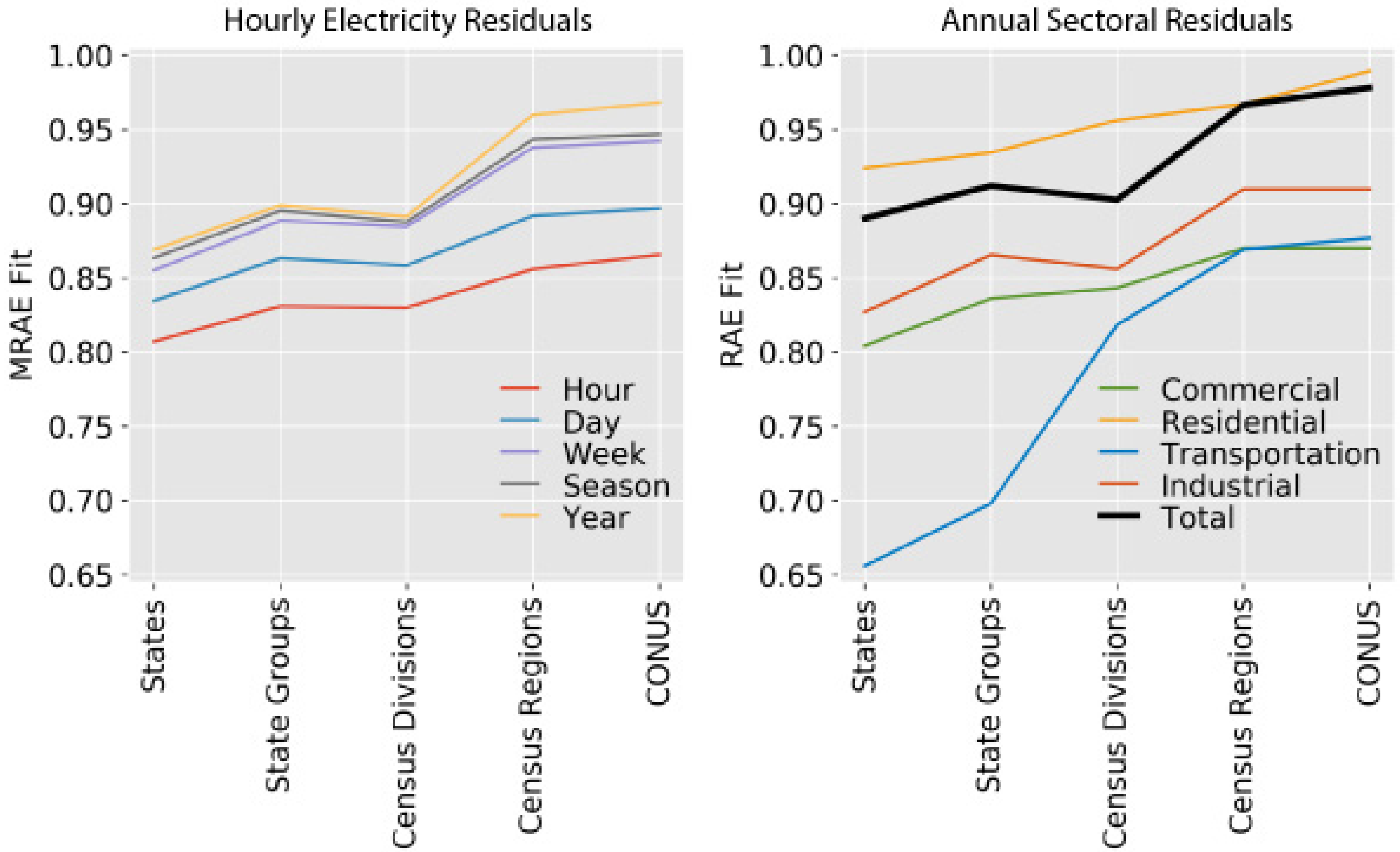


Component Type	Component Name	Residential (TWh)	Commercial (TWh)	Industrial (TWh)	Transport (TWh)	Total (TWh)
Top-down	Hourly load					3,910
Derived	T&D losses					199
Top-down	Annual energy	1,370	1,350	981	7	3,708
dsgrid	Distributed generation	3	31	204	–	237
dsgrid-core	Gap models	218	454	184	6	862
dsgrid-core	Detailed sector models	1,169	1,107	893	–	3,170
Derived	Total site energy[a]	1,372	1,381	1,184	7	3,945
Derived	Annual sector residuals[b]	-15	-180	107	1	-87
Derived	Hourly residuals					-126

[a] Total site energy is the top-down annual energy plus distributed generation. This is all the load we are expecting to model with the bottom-up detailed sector and gap models.

[b] The sector level residuals are equal to the total site energy minus the gap and detailed sector model components.

Summary model fit statistics

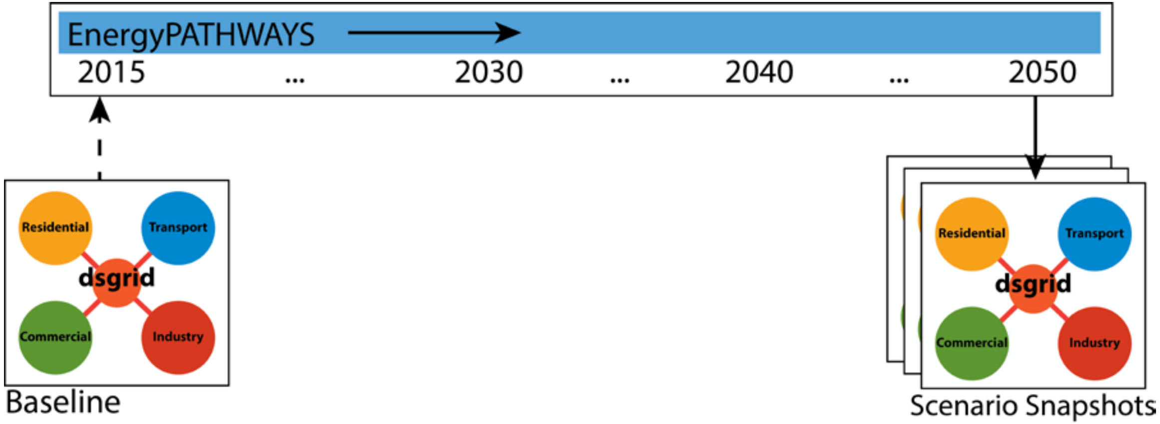


Next steps

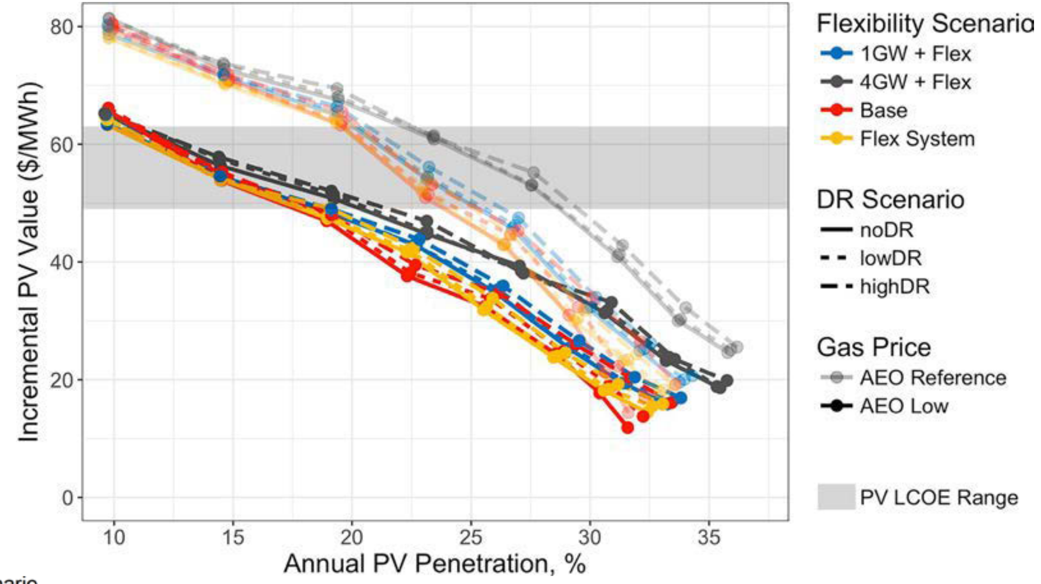
Ongoing and planned work to:

- Create future load data sets (electrification, load modernization)
- Estimate flexibility potential
- Model demand response resource/programs in grid models

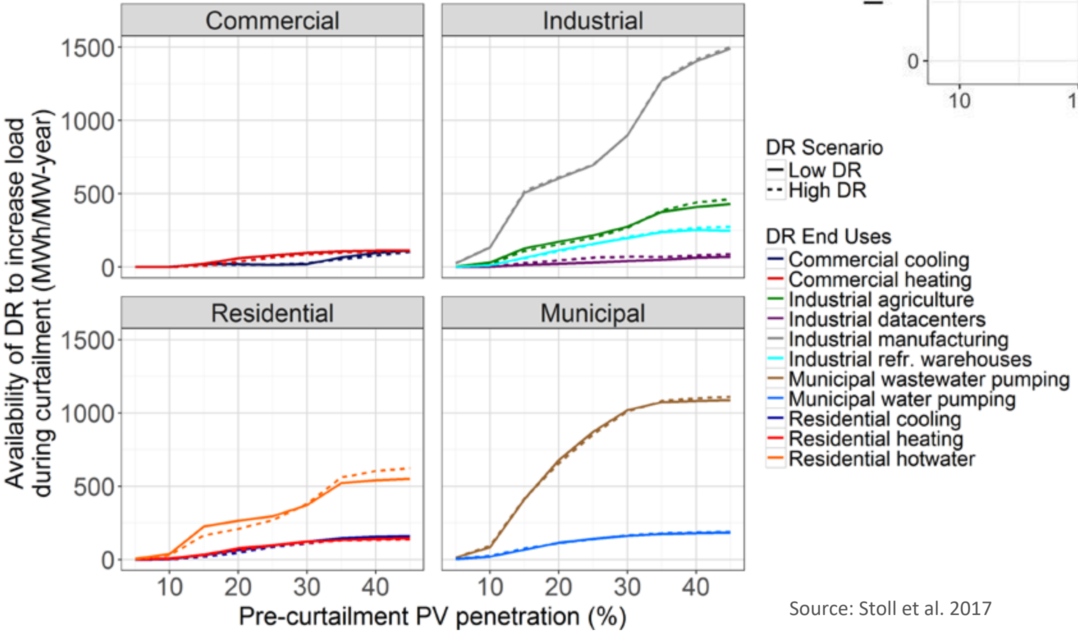
Electrification Futures Study plan to develop future load scenario snapshots for production cost modeling



Related work: value of flexibility, including demand response



Source: Hale et al. 2018



Source: Stoll et al. 2017

Ability of flexible resources to preserve the value of solar photovoltaics (PV) at high penetrations depends on time of availability and operational constraints.

dsgrid team

Modeling Leads

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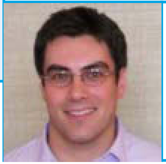

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All graphics and results on slides 13-15 and 20-39 from the **dsgrid model documentation**

Thank you

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