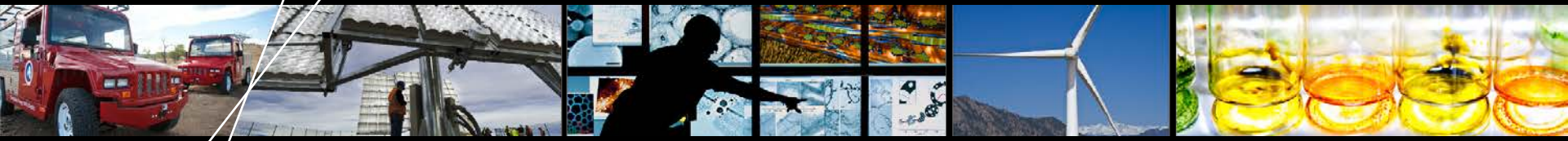
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Residential Energy Efficiency Potential Analysis



EEBA Conference

Denver, Colorado

October 7, 2015

Craig Christensen

Objective

Expand analysis from individual buildings to regional/national scale

Provide predictive capability to accurately assess technical/economic potential of building energy efficiency and solar, accounting for the full range of U.S. building stock characteristics and weather.

Utilize:

- Data (building characteristics from EIA/RECS, etc.)
- Models (EnergyPlus building energy simulations)
- High performance computing (hundreds of thousands of simulations)

Possible Users/Uses

Federal

- Policy Analysts
  - Carbon savings potential
- DOE/BTO
  - RBI BA Solution Center
  - ET technology potential
  - Codes and Standards
  - Staged Upgrade Initiative (SUI)

Non-Federal

- NGO's , Advocates
- Program Planners (Utility, Regional, State and Local)
  - Technology selection
  - Potential studies
  - Setting incentives

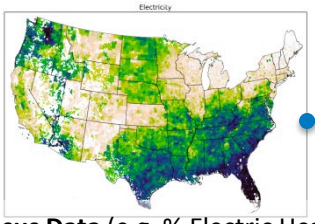
Private

- Manufacturers
  - Prioritized technology R&D and product development
  - Marketing
- Vendors/Retailers
  - Product offerings
  - Marketing

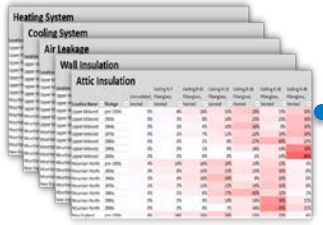
Residential Building Stock Analysis

Modeling the entire **U.S. housing stock** with **unprecedented granularity**

216 **Climate Locations**

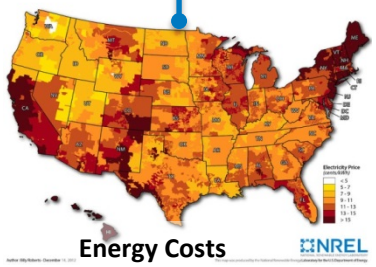


Census Data (e.g. % Electric Heating)



Database of building component **probability distributions**

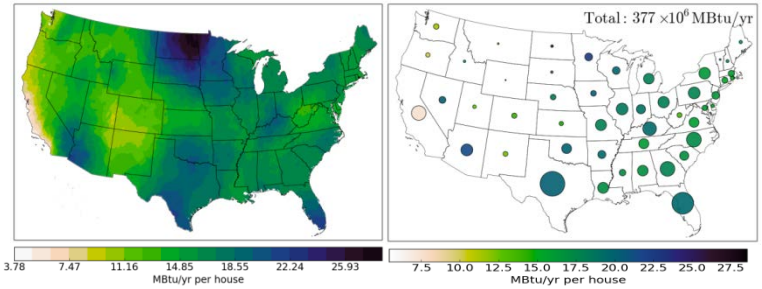
EE Potential Tool



Energy Costs

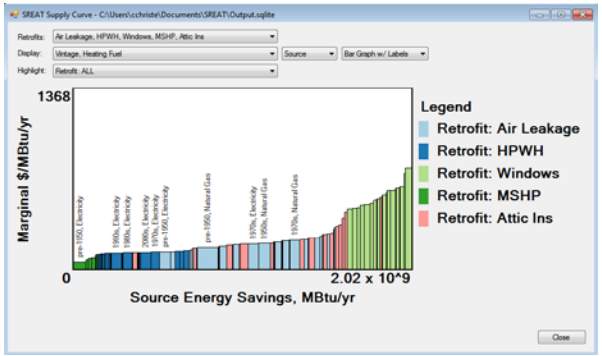
Per House *maps indicate local homeowner savings*

Aggregate *maps indicate market size/impact by state*

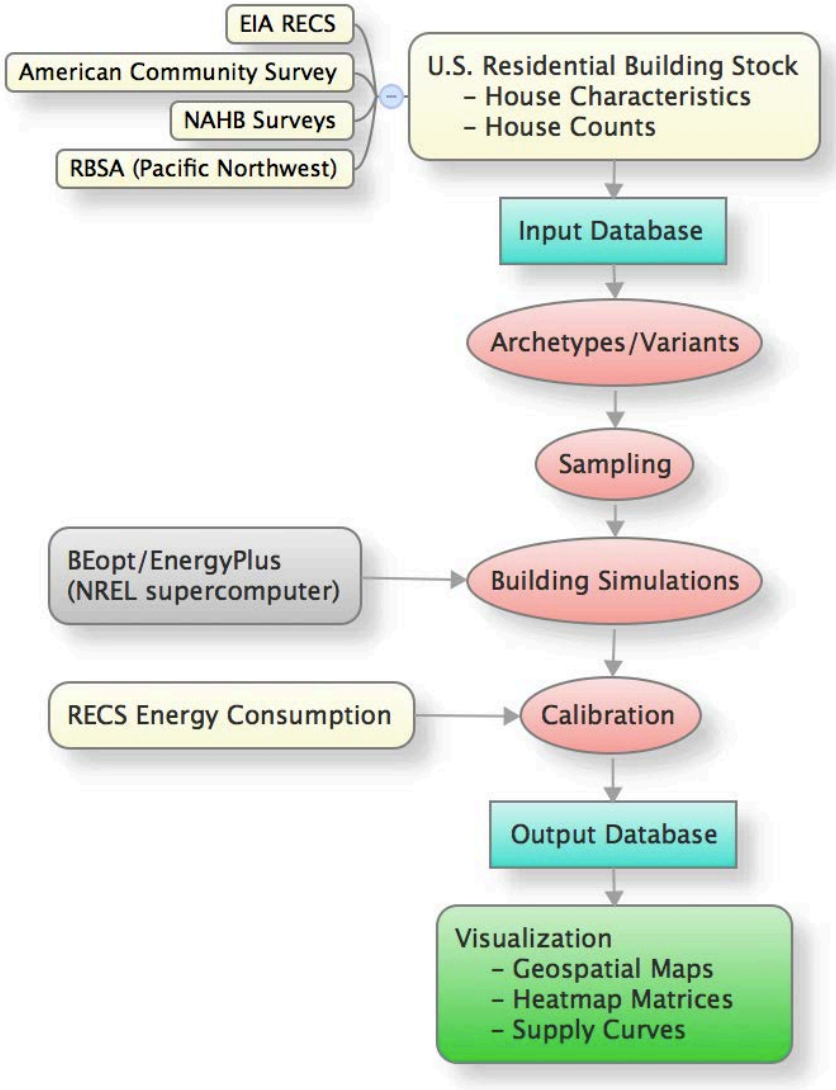


Technical potential of 2-pane low-E windows (replacing 1-pane)

High-granularity ***supply curves*** *show the value of* ***targeted deployment***



Approach



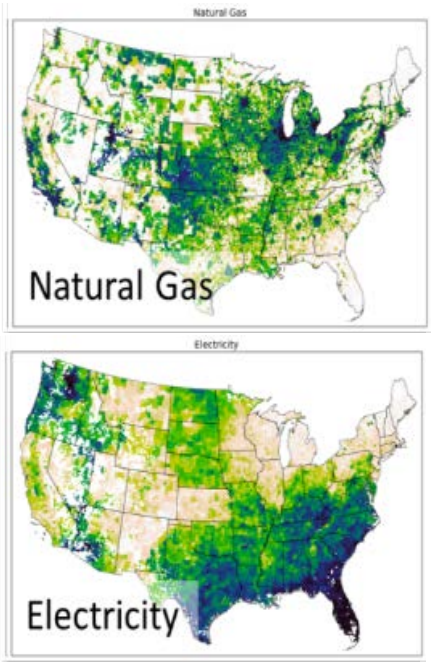
1. **Housing Stock Characteristics**
   – Input Database
2. **Archetype Buildings/Occupants**
   – Auto-Generated Models
3. **Building Simulations**
   – High Performance Computing
4. **Validation/Calibration**
   – Comparison to RECS consumption data
5. **Output Visualization**

1) Data Sources for Housing Stock Characteristics

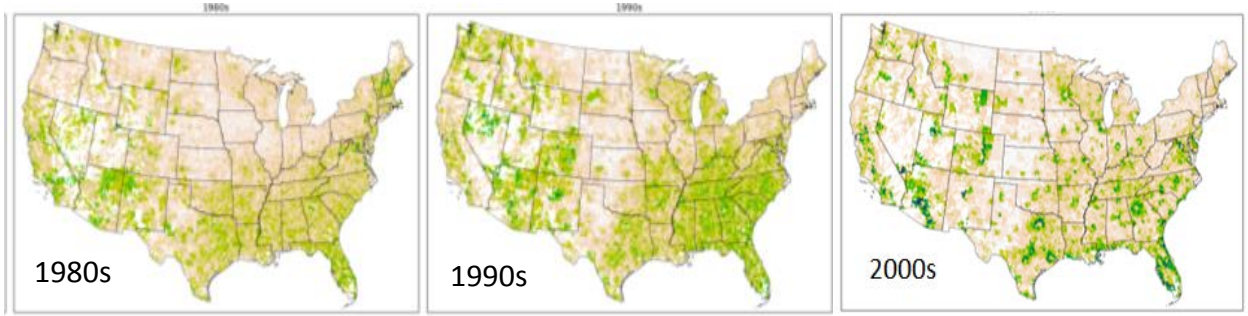
Probability distribution data	Data Sources: 2012 ACS	2009 RECS	NAHB Surveys	RBSA	IECC Codes	Ritschard et al. 1992	Chan et al. 2012	HES Eng. Doc.	Geographic Resolution	Dependencies: Location	Vintage	Heating Fuel	Floor Area	Number of Stories	Found. Type	Usage Level
Total # single-family detached	●								C	✓						
Vintage %s	●								C	✓						
Heating fuel %s	●								C	✓						
Floor area %s		●							R	✓	✓					
Foundation type %s		●	●						R	✓	✓					
Attached garage %s		●							R	✓	✓					
Number of stories %s		●							R	✓	✓		✓			
Heating/DHW system types/ages		●	●						R	✓	✓	✓				
Cooling system type/age		●							R	✓	✓					
Cooking, clothes dryer fuel		●							R	✓		✓				
Heating, cooling setpoints		●							U.S.							
Lighting, appliances, MELs[a]		●							R	✓			✓			✓
Window type		●			●				R	✓	✓					
Wall insulation[b]			●		●	●			R	✓	✓					
Foundation insulation[b]			●		●				R	✓	✓				✓	
Ceiling insulation[c]			●	●	●				R	✓	✓		✓			
Air leakage							●		R	✓	✓		✓	✓		
Equipment efficiency (Htg, Clg, WH)			●					●	U.S.							

C = Census tract (avg. 4,000 people)
R = Regional (27 RECS reportable domains, 10 census divisions, or 8 IECC climate zones)

Heating Fuel Type



Vintage
(% by Decade Built)



2) Archetypes/Characteristics/Climates

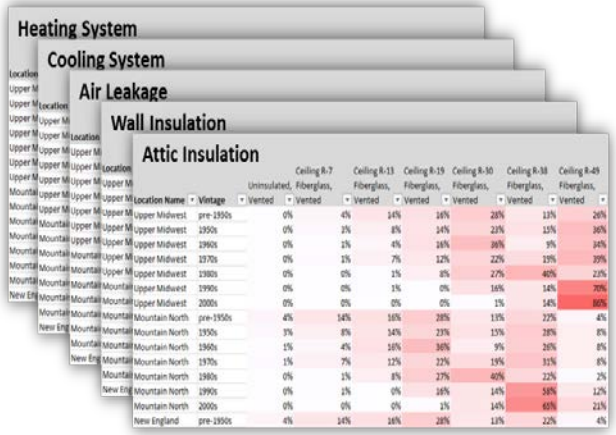
To represent the U.S residential building stock, **auto-generate simulation models** for combinations of archetypes/characteristics/climates, ranked by **house-count weighting factors**.

Archetypes

- **7** Vintages
- **6** Heating fuel types
- **5** Foundation types
- **6** Floor areas
- **3** # Stories
- **2** Attached garage?
- **3** Occupancy usage levels
- **2** Daytime occupancy?

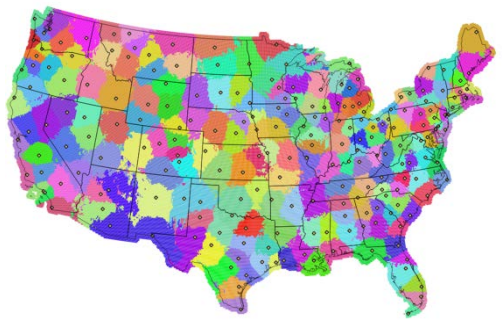
~45K
Possible
Combinations

Characteristics



~6M
Possible
Combinations

Climates

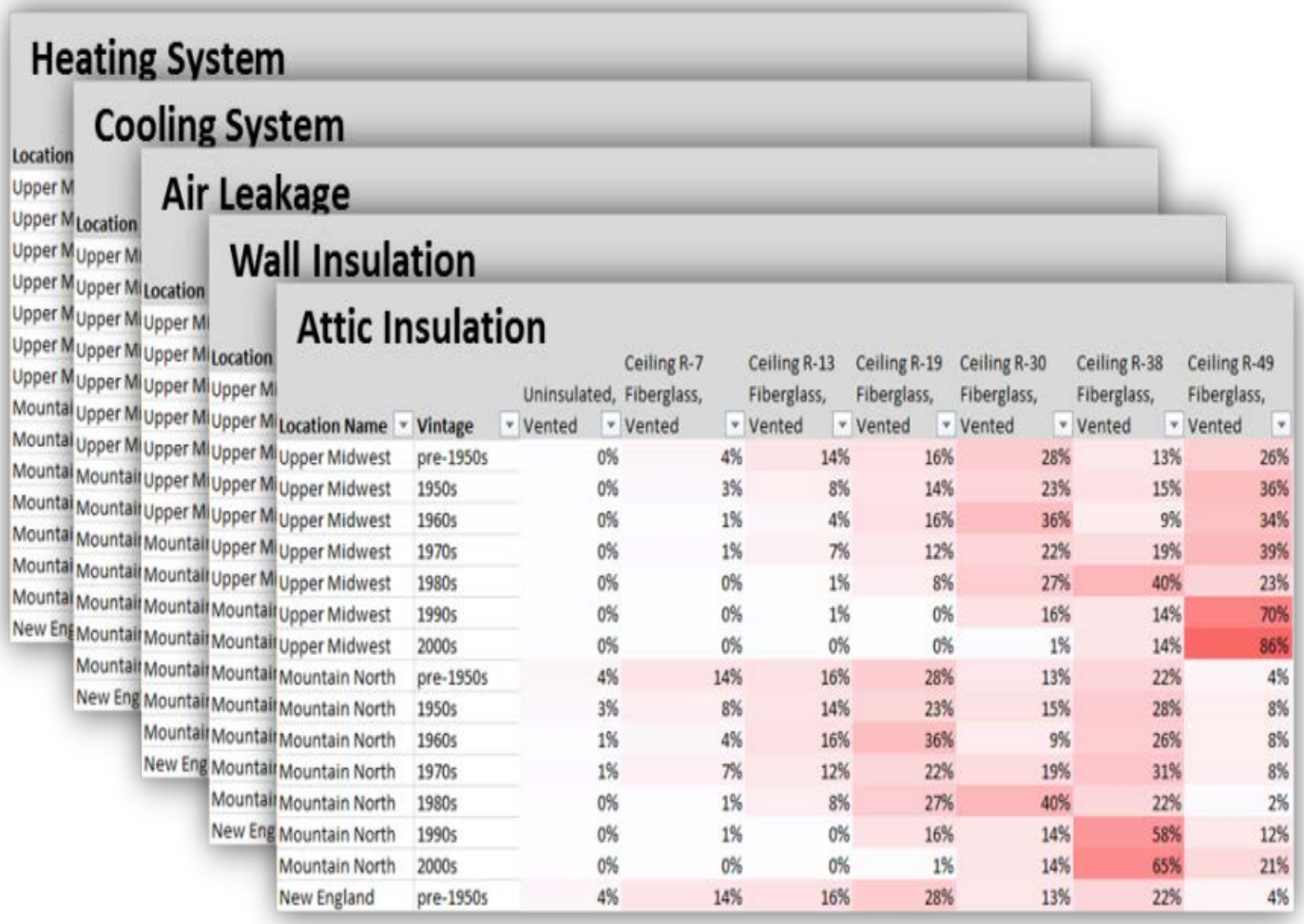


1080
545
250
125
?

Note: Not all possible archetype/characteristic/climate combinations have non-zero house-count weighting factors.

2) Archetypes/Characteristics/Climates

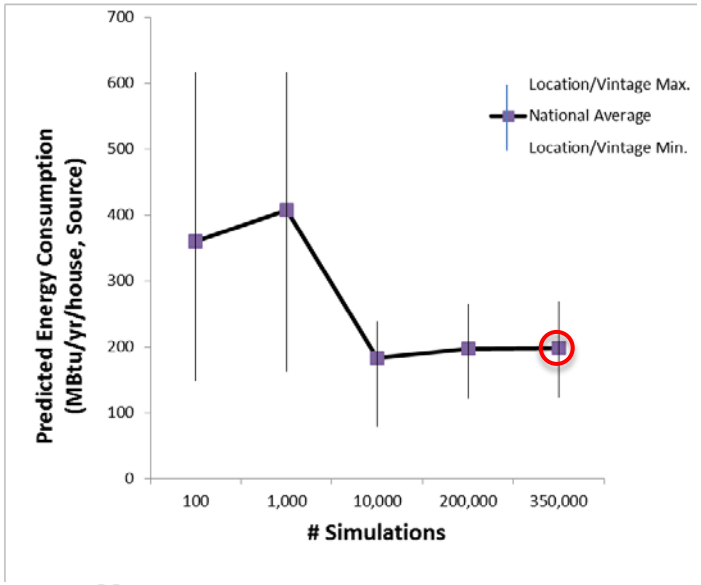
Characteristics

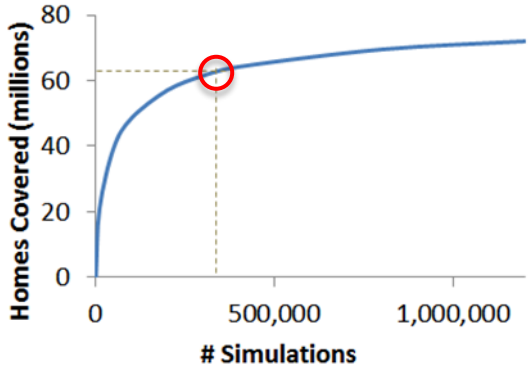


Location Name	Vintage	Uninsulated, Vented	Ceiling R-7 Fiberglass, Vented	Ceiling R-13 Fiberglass, Vented	Ceiling R-19 Fiberglass, Vented	Ceiling R-30 Fiberglass, Vented	Ceiling R-38 Fiberglass, Vented	Ceiling R-49 Fiberglass, Vented
Upper Midwest	pre-1950s	0%	4%	14%	16%	28%	13%	26%
Upper Midwest	1950s	0%	3%	8%	14%	23%	15%	36%
Upper Midwest	1960s	0%	1%	4%	16%	36%	9%	34%
Upper Midwest	1970s	0%	1%	7%	12%	22%	19%	39%
Upper Midwest	1980s	0%	0%	1%	8%	27%	40%	23%
Upper Midwest	1990s	0%	0%	1%	0%	16%	14%	70%
Upper Midwest	2000s	0%	0%	0%	0%	1%	14%	86%
Mountain North	pre-1950s	4%	14%	16%	28%	13%	22%	4%
Mountain North	1950s	3%	8%	14%	23%	15%	28%	8%
Mountain North	1960s	1%	4%	16%	36%	9%	26%	8%
Mountain North	1970s	1%	7%	12%	22%	19%	31%	8%
Mountain North	1980s	0%	1%	8%	27%	40%	22%	2%
Mountain North	1990s	0%	1%	0%	16%	14%	58%	12%
Mountain North	2000s	0%	0%	0%	1%	14%	65%	21%
New England	pre-1950s	4%	14%	16%	28%	13%	22%	4%

3) Building Simulations

Architype building simulations were run (using BEopt/EnergyPlus on NREL's **high-performance supercomputer**).



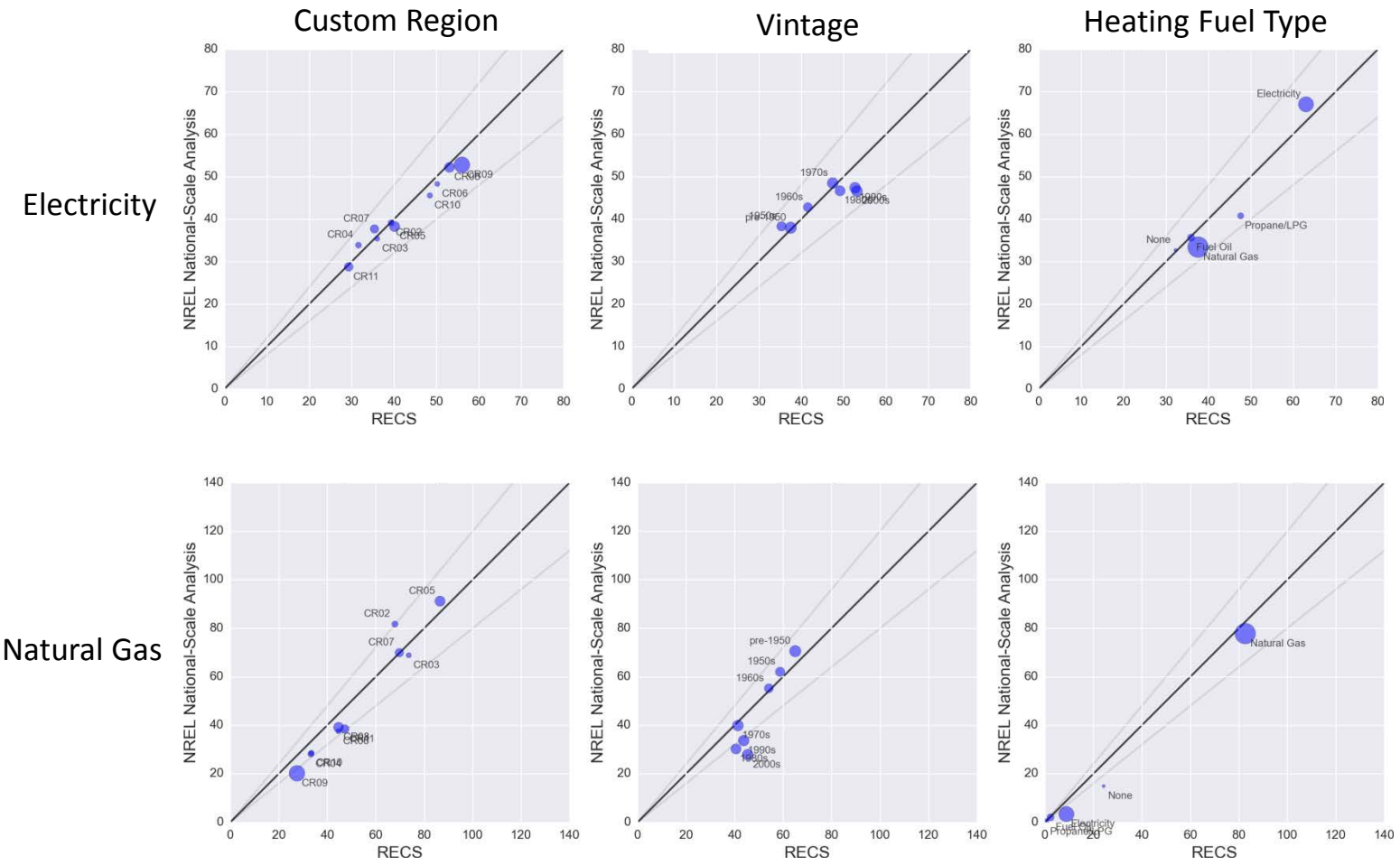


- Simulations based on **sample of high house-count combinations** of archetypes/characteristics/climates
- 350K simulations for existing homes (**1.2 million simulations** w/retrofits)
- 2.4 years worth of CPU runtime
- Simulations cover 62 million homes; results will be scaled to represent all 72 million single family detached homes

4) Validation/Calibration

Modeled (y-axis) vs. EIA/RECS (x-axis)

Average Source Energy per House: 10^6 Btu/yr



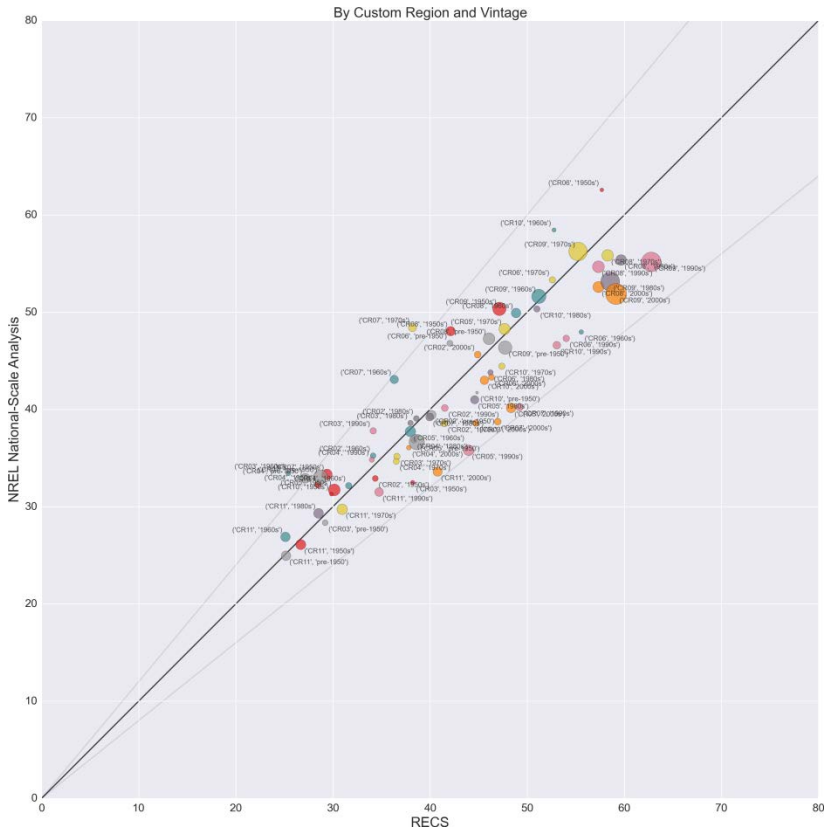
4) Validation/Calibration

Modeled (y-axis) vs. EIA/RECS (x-axis)

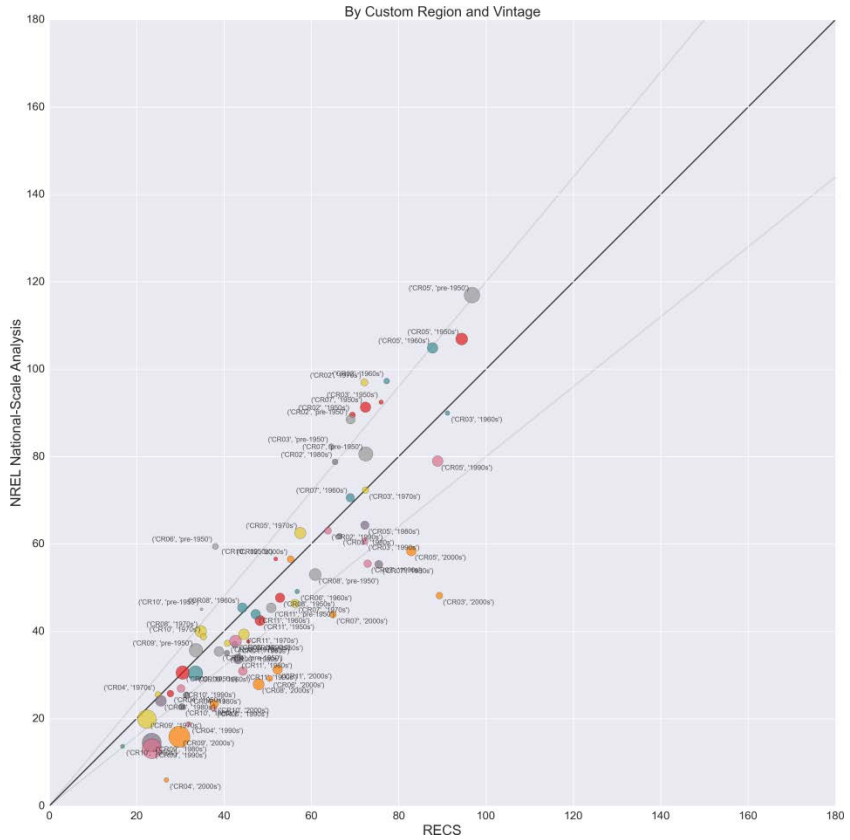
Average Source Energy per House: 10^6 Btu/yr

Disaggregated by Region and Vintage

Electricity



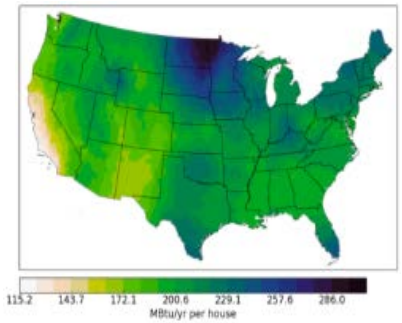
Natural Gas

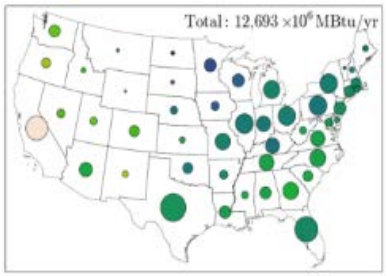


5) Output Visualization

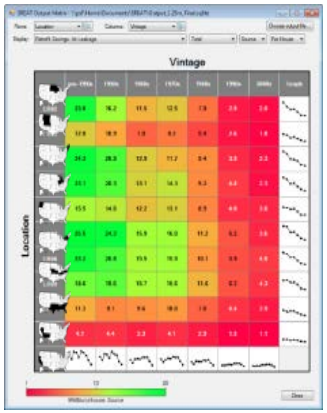
Results, from the output database, **can be sliced in many ways** (consumption, retrofit savings, end uses, year-built, fuel types, etc.) and **visualized in various forms**.

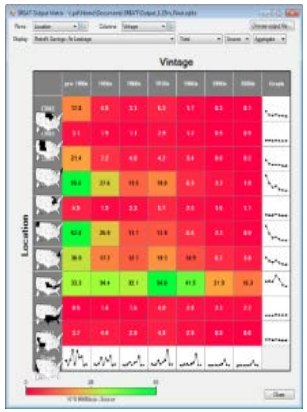
Maps



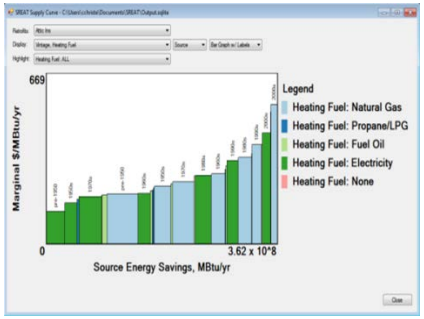


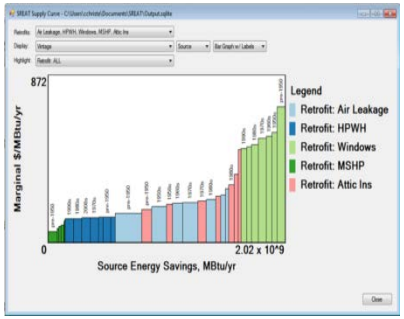
Matrices





Supply Curves

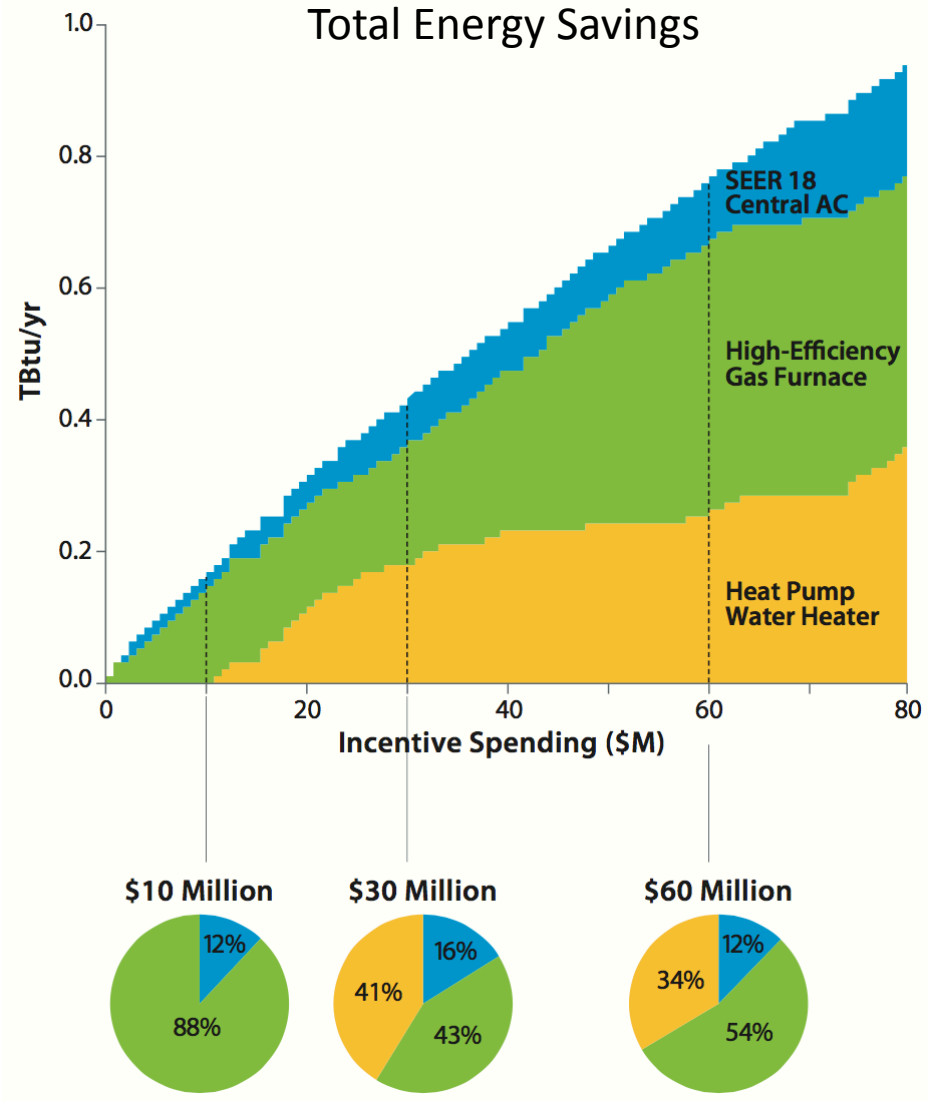




Applications

How best to **allocate an incentive budget**?

Cost-optimal distribution of incentive spending depends on the size of the budget



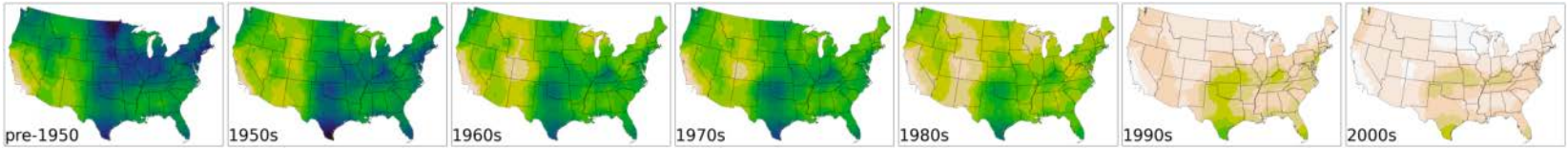
(Illustrative Example)

Preliminary Results

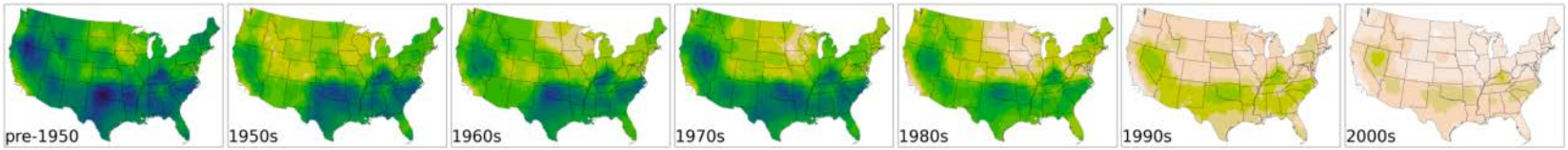
National Program Planners

Target Markets – by Location and Year-Built

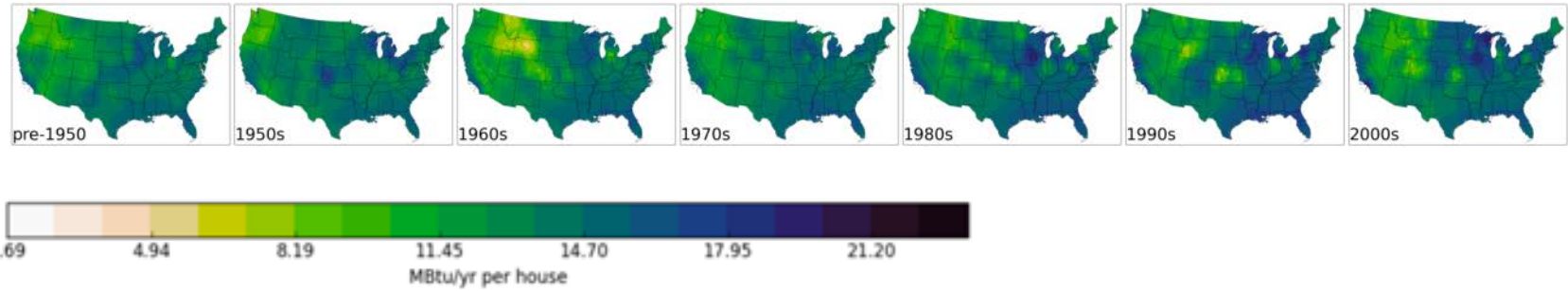
Air Sealing (to 5 ACH50)



Attic Insulation (to R49)



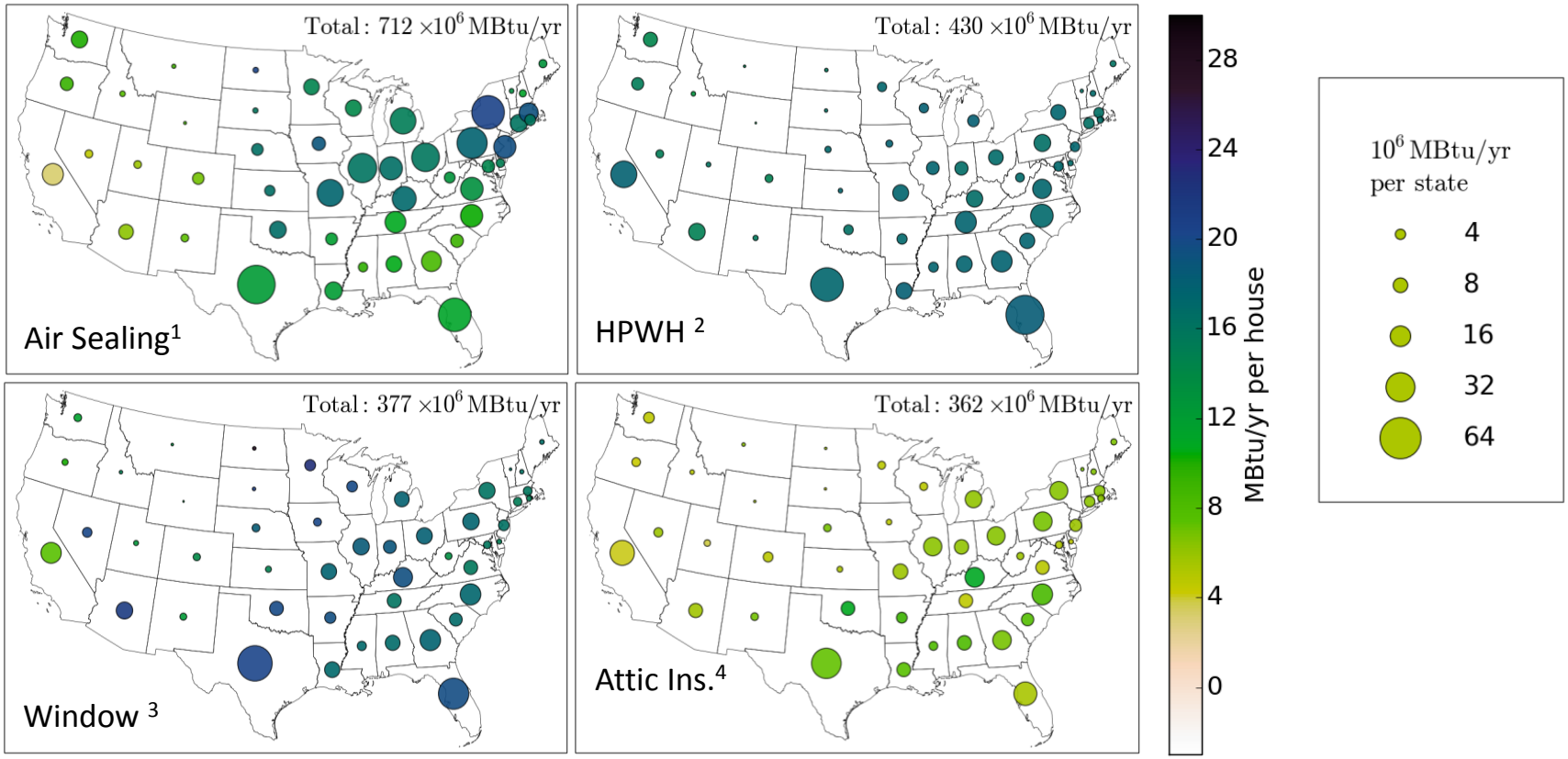
Heat Pump Water Heater



Preliminary Results

Policy Analysts

Quantify Aggregate Savings Potential



Technical Potential:

[1] to 5 ACH50

[2] replacing electric tank WH

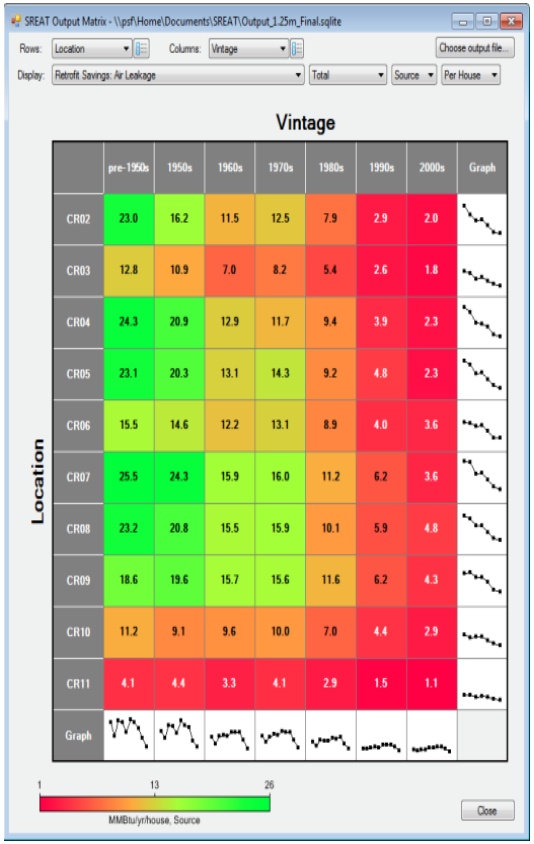
[3] single pane to double low-e

[4] to R-49

Preliminary Results

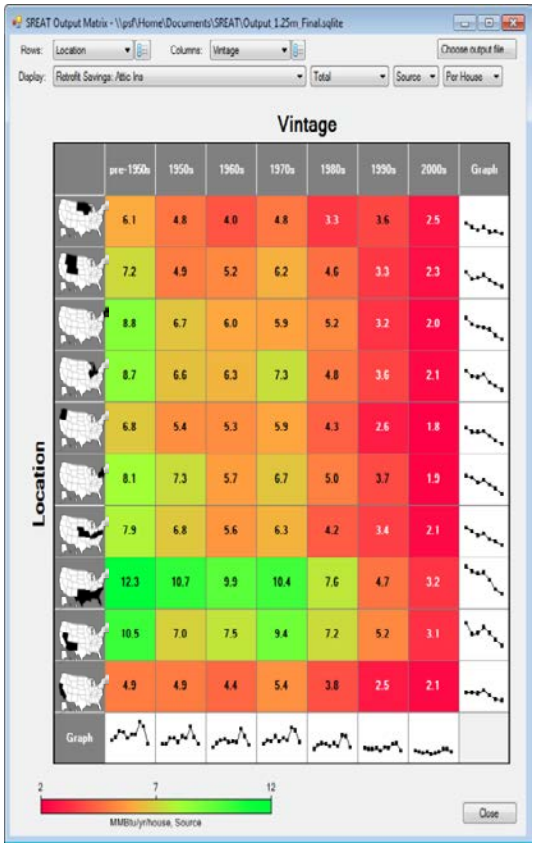
by Region and Vintage

Air Sealing



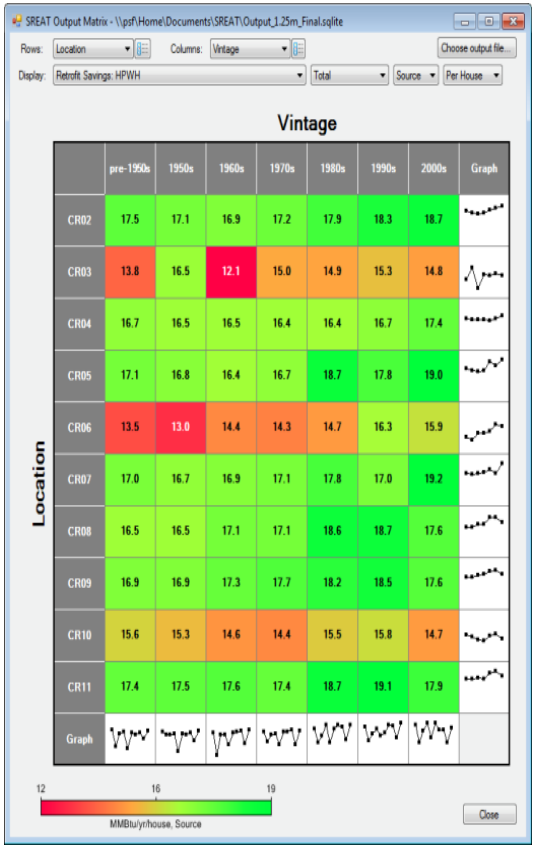
Retrofit to 5 ACH50

Attic Insulation



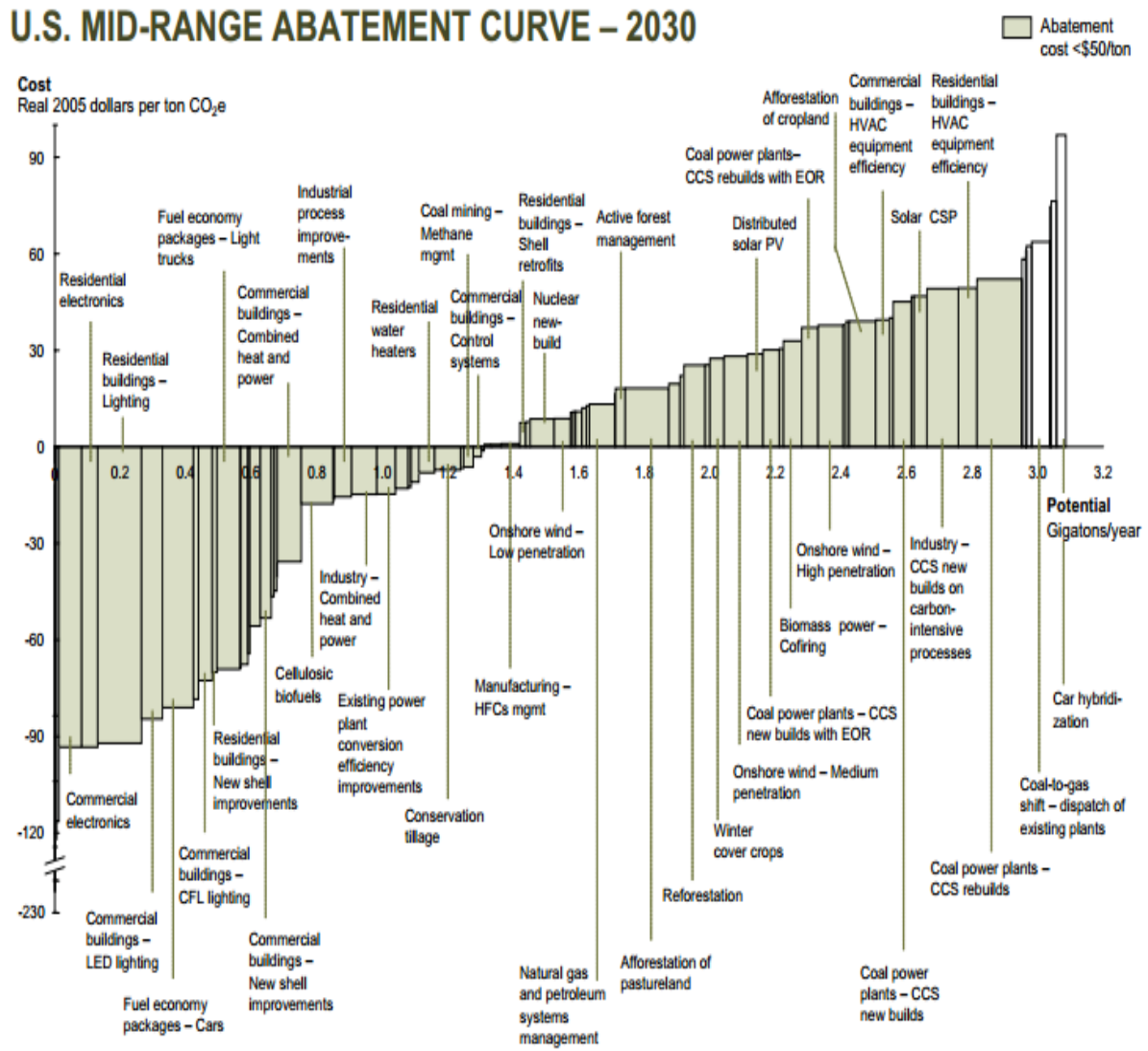
Retrofit to R-49

Heat Pump Water Heater



Retrofit Electric WH's

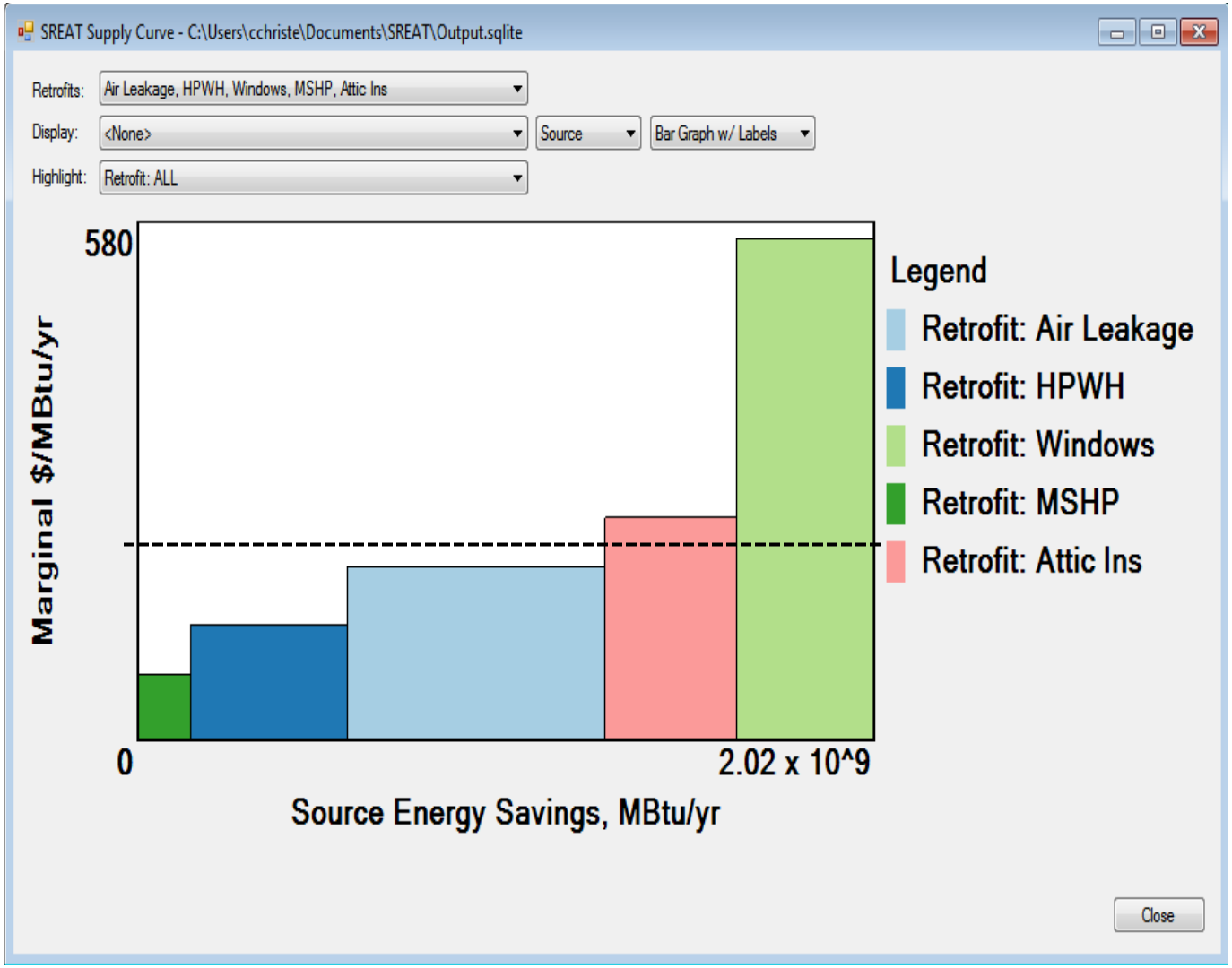
Supply Curves -- McKinsey Carbon Abatement Example



Source: McKinsey analysis

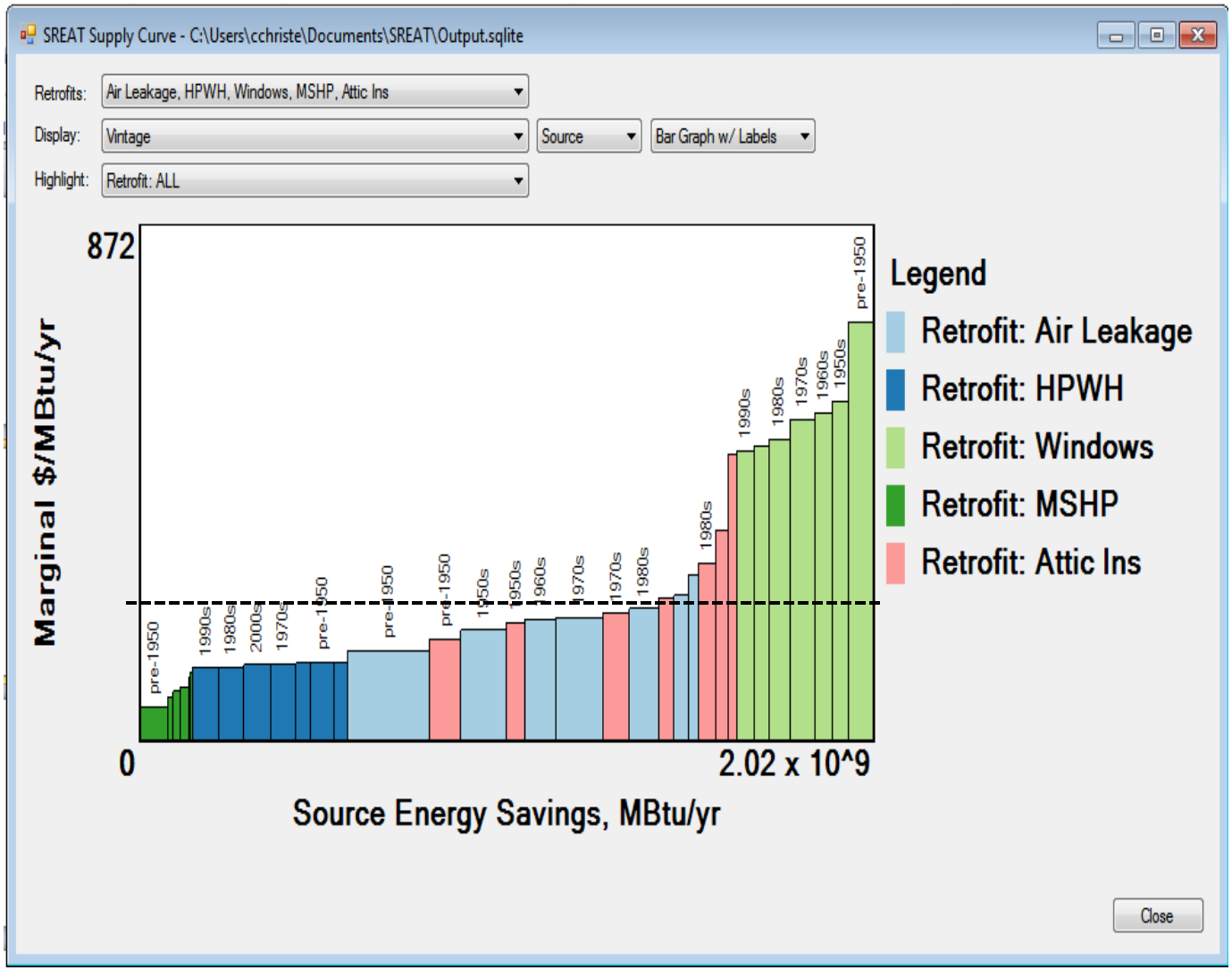
Supply Curves

by Retrofit



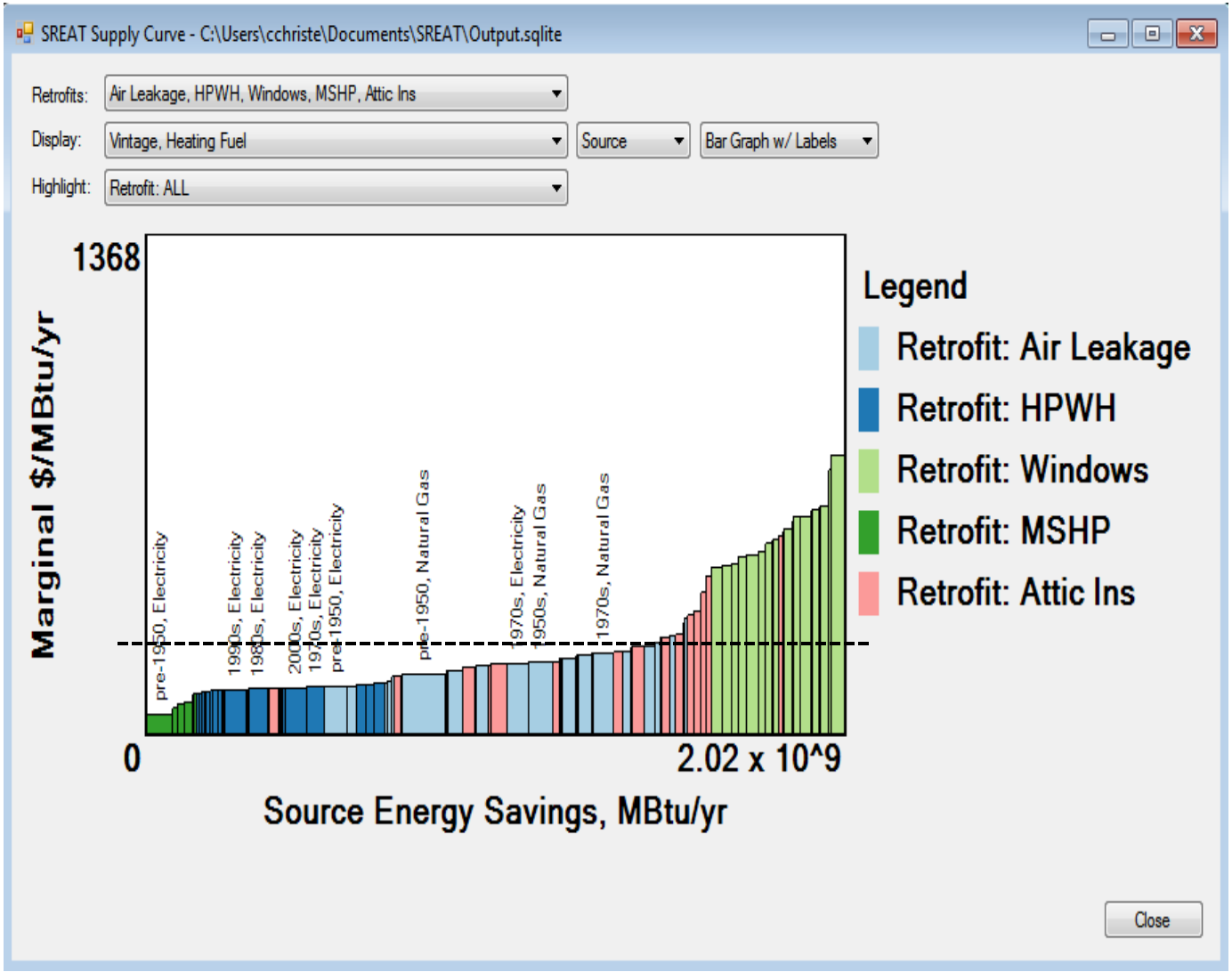
Supply Curves

by Retrofit and Vintage



Supply Curves

by Retrofit, Vintage and Heating Fuel Type



Conclusion

Combining building characteristics data with simulation-based modeling can be used to answer a wide range of what-if questions regarding U.S. building energy consumption and the potential for energy efficiency.

Next Steps and Future Plans

Next Steps and Future Plans:

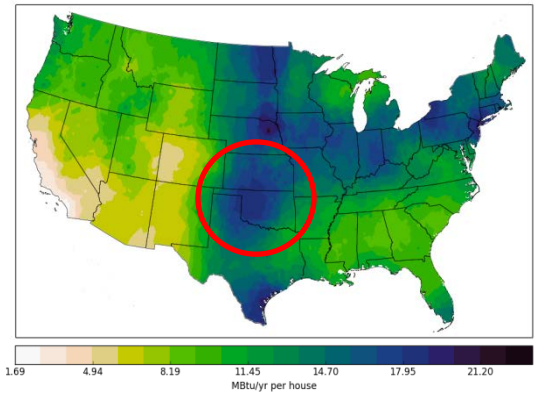
- Work with user audience to explore specific use cases
- Coordinate with NREL Commercial Buildings Group
- Collaborate on OpenStudio version (that can use cloud computing)
- BPA Regional Analysis Tool (FY2016)
- Calibration to utility hourly load shapes

Preliminary Results

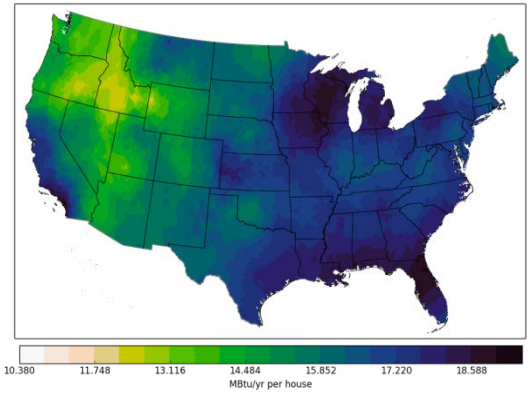
State and Local Program Planners

Identify Best Upgrades -- for a Particular State (e.g., Oklahoma)

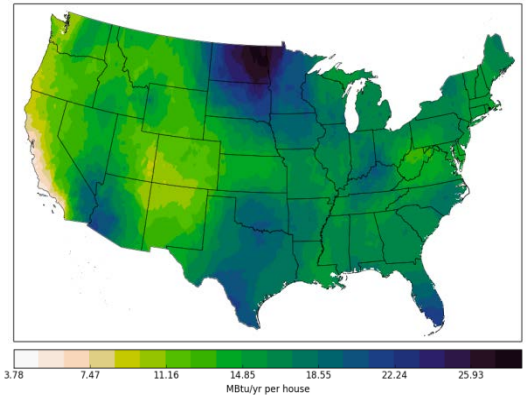
Air Sealing [1]



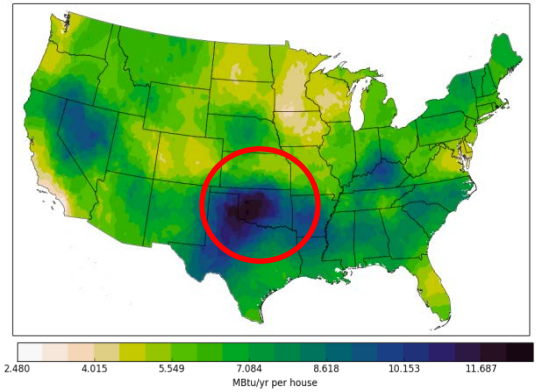
Heat Pump Water Heater [2]



Double-pane, low-e [3]



Attic Insulation [4]



(MBtu/yr per home)

Technical Potential:

[1] to 5 ACH50

[2] replacing electric tank WH

[3] single pane to double low-e

[4] to R-49