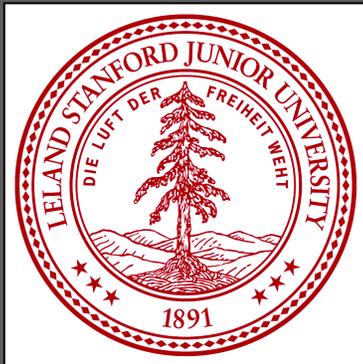# End-Use Technology Choice in the National Energy Modeling System (NEMS)

An Analysis of the Residential and Commercial Sectors

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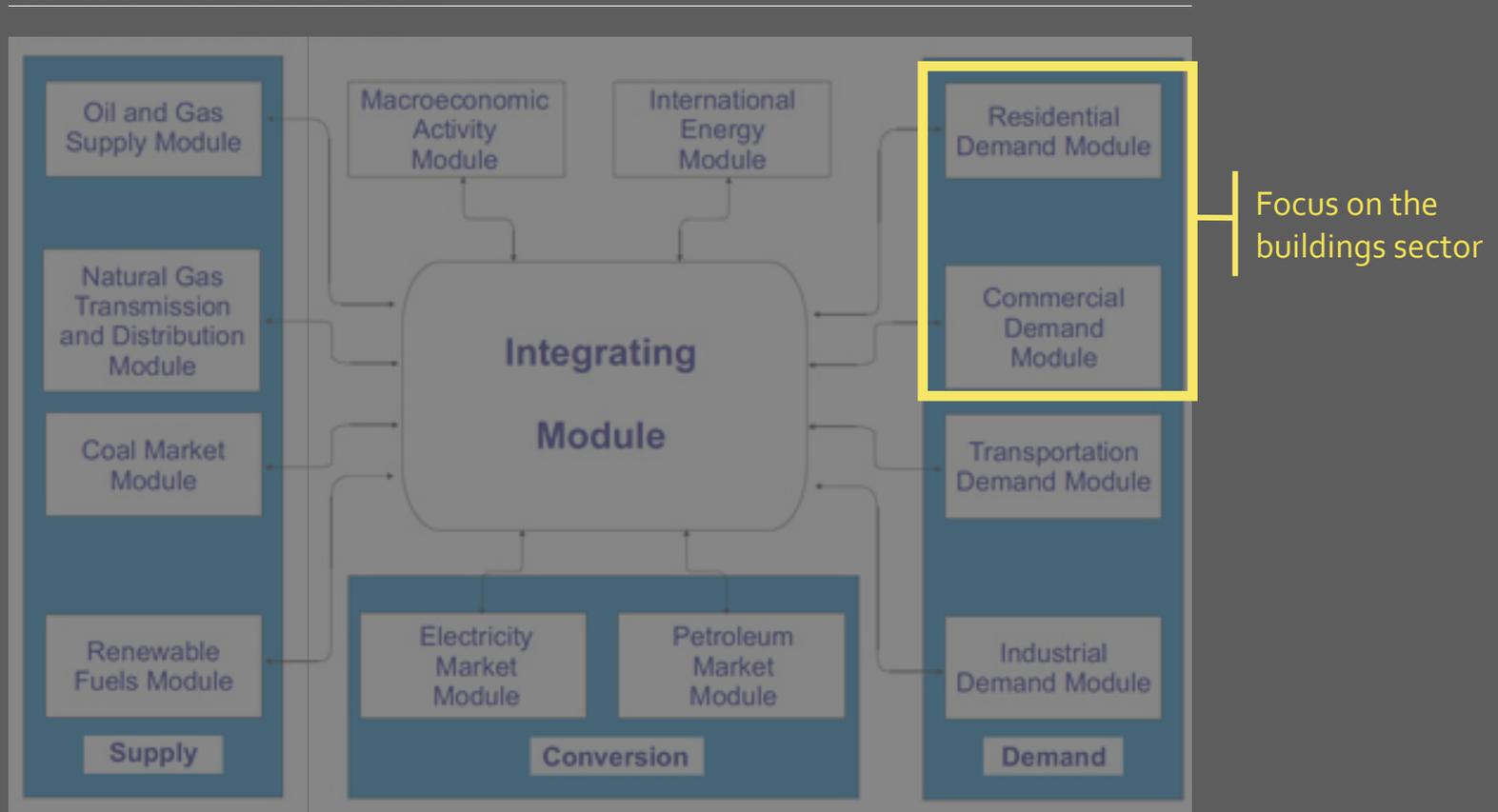Stanford University

This Talk Will Address Three Questions

1. How does NEMS generate energy demand in the buildings sector?

2. How important are consumer decisions about end-use equipment?

3. How can insights from the behavioral sciences community improve U.S. policy analysis?

National Energy Modeling System (NEMS)

- The flagship model of the Energy Information Administration (EIA):
  - Used for Annual Energy Outlook forecasts
  - Used for energy and climate policy analysis e.g. Waxman-Markey (EIA 2009b), Inter-laboratory Working Group, 2000, and U.S. compliance with the Kyoto Protocol (EIA 1998)

- Hybrid approach to energy-economy interactions
  - Rich, bottom-up technology approach
  - General equilibrium effects

- Disaggregated by regions:
  - 9 Census divisions (Demand Sectors)
  - 15 Electricity market regions
  - 5 Petroleum market regions

National Energy Modeling System (NEMS)

Q1: How Does NEMS Generate Energy Demand in the Buildings Sector?

```
┌──────────────┐      ┌──────────────┐      ┌──────────────┐
│   Economic   │      │  Demand for  │      │  Technology  │
│   Activity   │─────▶│    Energy    │─────▶│  Choices and │
│     and      │      │   Services   │      │    Energy    │
│  Structure   │      │              │      │ Consumption  │
└──────────────┘      └──────────────┘      └──────────────┘
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Exogenous forecast with endogenous feedback

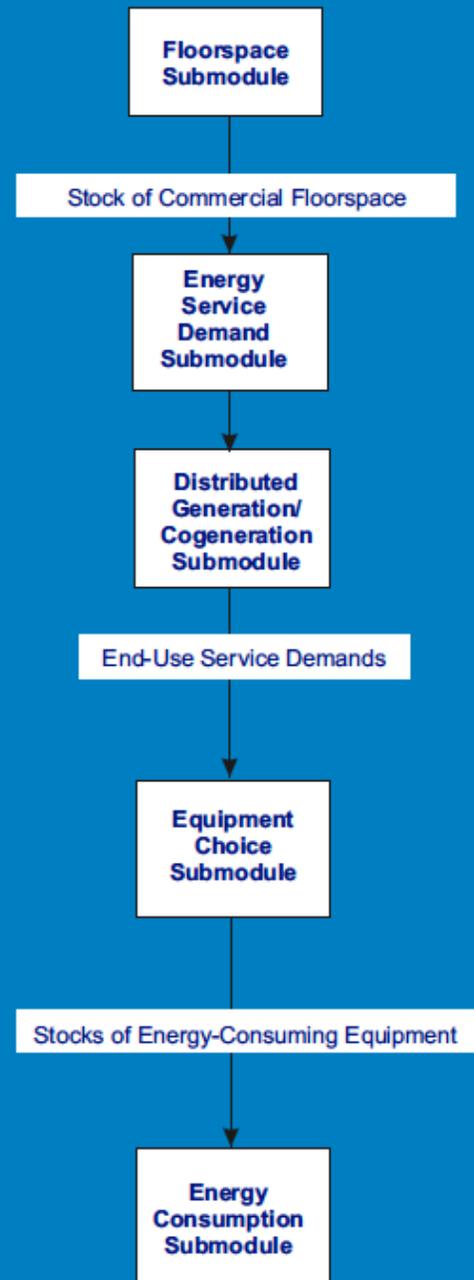**Model calibrated to historical data**

The component modules represent
- individual sectors of U.S. energy market
  supply, demand, and conversion segments
- local and global economies
- international energy market feedbacks.

Q1:   Commercial Sector Overview

- Floorspace and appliance stock model

- Projects fuel consumption for
  - 9 Census groups (geographical)
  - Eleven categories of commercial building (e.g. Assembly, Education, Lodging, Healthcare),
  - ten services (e.g. space heating, space cooling, water heating, cooking)
  - thirteen fuel types (e.g. electricity, natural gas, kerosene, wood).

Commercial Demand Module

Floorspace Submodule

↓

Stock of Commercial Floorspace

↓

Energy Service Demand Submodule

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Distributed Generation/ Cogeneration Submodule

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End-Use Service Demands

↓

Equipment Choice Submodule

↓

Stocks of Energy-Consuming Equipment
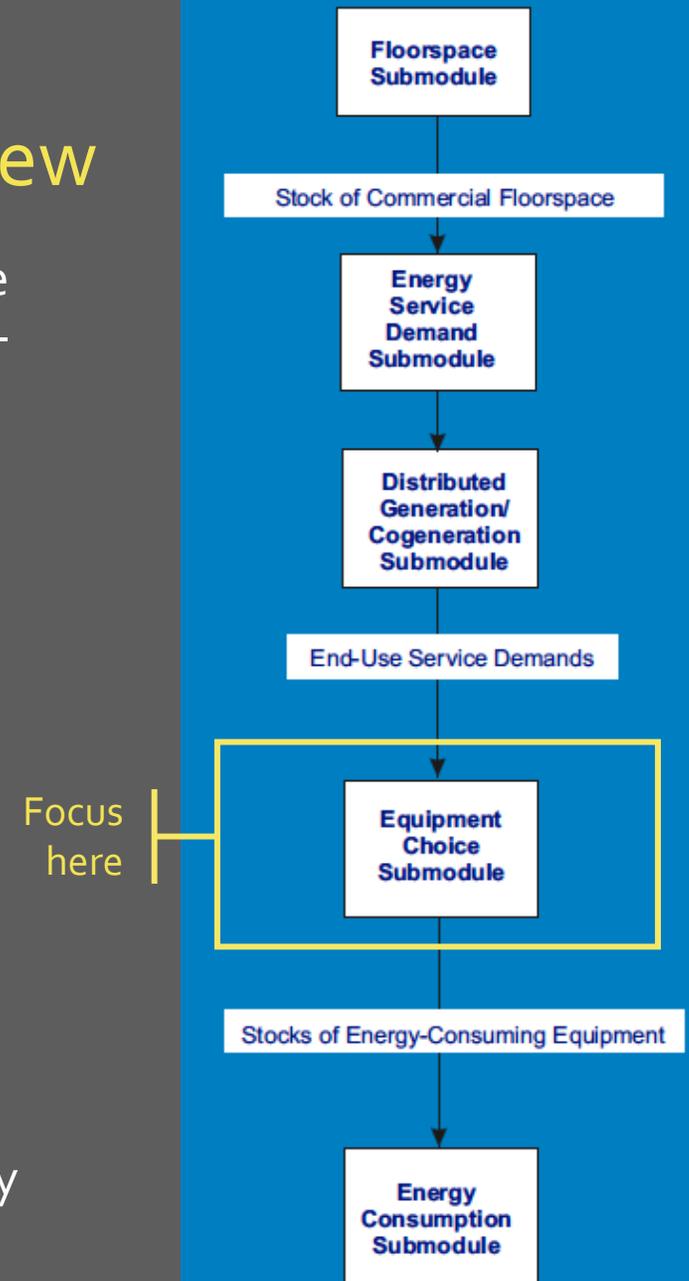
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Energy Consumption Submodule

Q1:   Commercial Sector Overview

- Commercial floorspace segmented into three categories, each with a rule for choosing end-use technologies.
  - New Equipment, Replacement, Retrofit
  - Least Cost, Same Fuel, Same Technology

- Agents in model choose least-cost technologies using a discount rate to calculate net present value (NPV).

$$Annualized\ Cost = Capital\ Cost * \frac{Effective\ Hurdle}{1 - (1 + Effective\ Hurdle)^{LifeSpan}}$$
$$+ Operating\ Cost * Capacity\ Factor$$

$$Effective\ Hurdle = Treasury\ Rate + Time\ Preference\ Premium$$

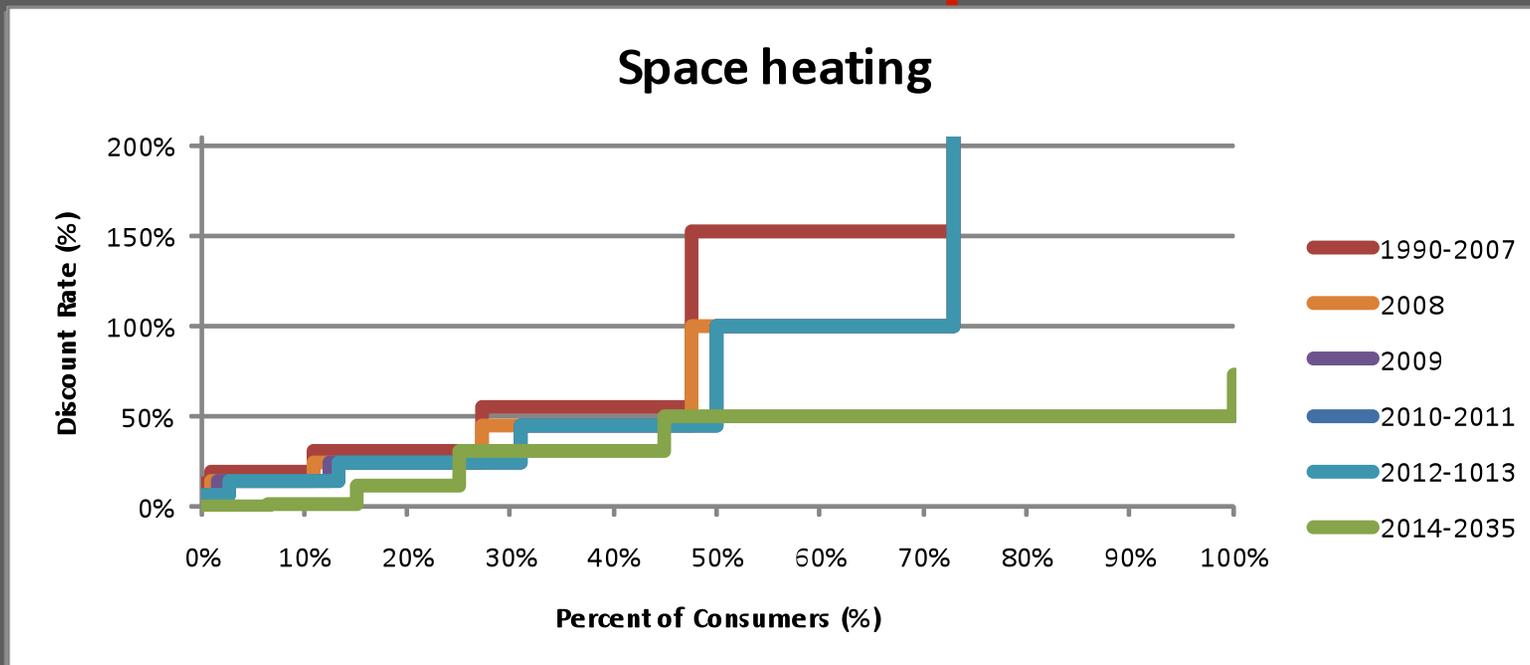- Data from EIA's Commercial Buildings Energy Consumption Survey (CBECS)

Commercial Demand Module

Floorspace Submodule

Stock of Commercial Floorspace

Energy Service Demand Submodule

Distributed Generation/ Cogeneration Submodule

End-Use Service Demands

Focus here

Equipment Choice Submodule

Stocks of Energy-Consuming Equipment

Energy Consumption Submodule

Q1: Residential Sector Overview

- Building shell and appliance stock model

- Three house types:
  - single-family
  - multifamily homes
  - mobile homes

Residential Demand Module

```
┌─────────────────┐
│    Housing      │
│     Stock       │
│   Submodule     │
└─────────────────┘
         │
Stock of Structures by Type and Vintage
         │
┌─────────────────┐
│    Appliance    │
│     Stock       │
│   Submodule     │
└─────────────────┘
         │
Surviving Stock of Appliances
         │
┌─────────────────┐
│   Technology    │
│     Choice      │
│   Submodule     │
└─────────────────┘
         │
Average Efficiency of Appliance Stock
         │
┌─────────────────┐
│     Shell       │
│   Integrity     │
│   Submodule     │
└─────────────────┘
         │
Building Shell Efficiencies
         │
┌─────────────────┐
│   Distributed   │
│   Generation    │
│   Submodule     │
└─────────────────┘
         │
┌─────────────────┐
│      Fuel       │
│   Consumption   │
│   Submodule     │
└─────────────────┘
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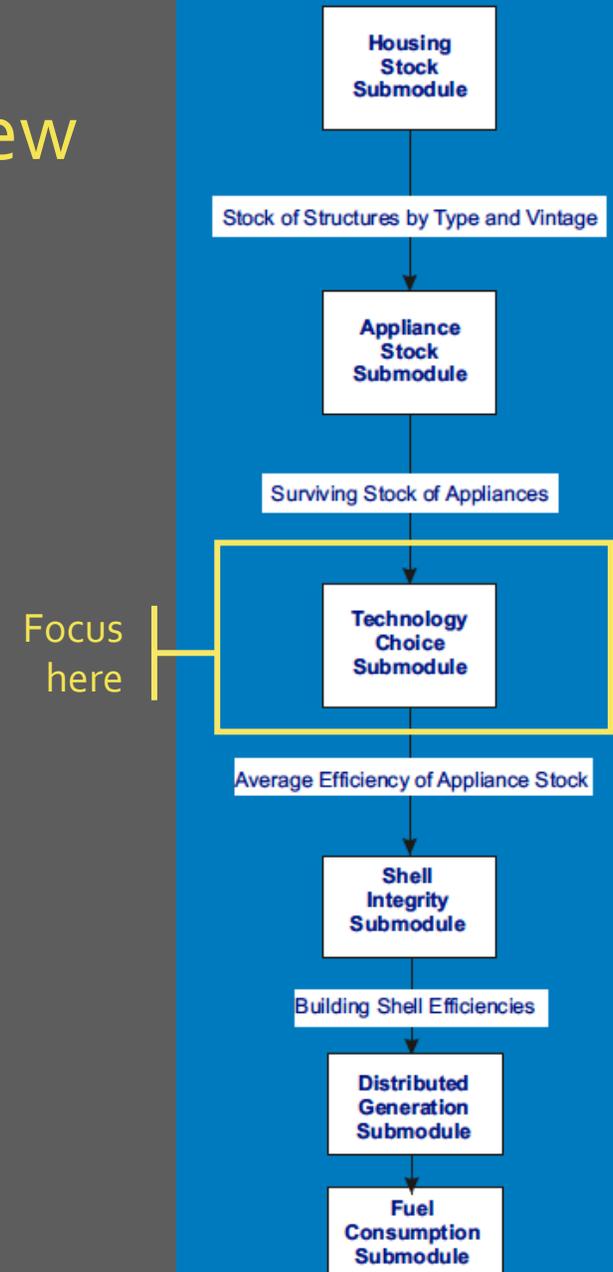
Q1: Residential Sector Overview

- The residential module uses a logit function to assign end-use technologies:

$$weight_i = e^{\left[(B_1 \times CapitalCost) + (B_2 \times OperatingCost)\right]}$$

$$market\_share_i = \frac{weight_i}{\sum\limits_{i} weight_i}$$

- Data from EIA's Residential Energy Consumption Survey (RECS)

Residential Demand Module

Housing Stock Submodule

Stock of Structures by Type and Vintage

Appliance Stock Submodule

Surviving Stock of Appliances

Focus here

Technology Choice Submodule

Average Efficiency of Appliance Stock

Shell Integrity Submodule

Building Shell Efficiencies

Distributed Generation Submodule

Fuel Consumption Submodule

Q1: Residential Sector Inputs

RTEKTY.txt: Residential Technology Equipment Type

Energy service	Equipment class	Equipment type	Implied discount rate
Space heating	all	all	15%
Space cooling	1	1 - 3	14%
	2 - 5	4 - 14	15%
Clothes washers	all	all	30%
Dishwashers	all	all	15%
Water heating	1 - 2	1 - 9	30%
	3	10 - 12	15%
	4 - 5	13 - 17	30%
Cooking	all	all	83%
Clothes drying	1	1 - 2	47%
	2	3 - 4	90%
Food refrigeration	all	0	19%
Food freezing	all	0	37%

Example of Services and classes:

- Space Cooling
  - Room Air Conditioners
  - Central Air Conditioning
  - Electric Heat Pumps
  - Geothermal Heat Pumps
  - Natural Gas Heat Pumps

- Clothes Drying
  - Natural Gas
  - Electric

Q2: How Important Are Consumer Decisions About End-Use Equipment?

- To answer this question, we set up and ran a local copy of NEMS release: AEO2010.
  - No Macroeconomic Activity Module (MAM)
  - All other modules engaged including the OML

- For each buildings sector—Residential and Commercial—a suite of input variables describes the consumer decision making process.
  - Commercial Sector: a "hurdle rate" describes the discount rate employed by different segments of the market to calculate NPV.
  - Residential Sector: a logit function uses two parameters to weight sensitivity to capital costs and sensitivity to operating costs.

Q2:   How Important Are Consumer Decisions About End-Use Equipment?
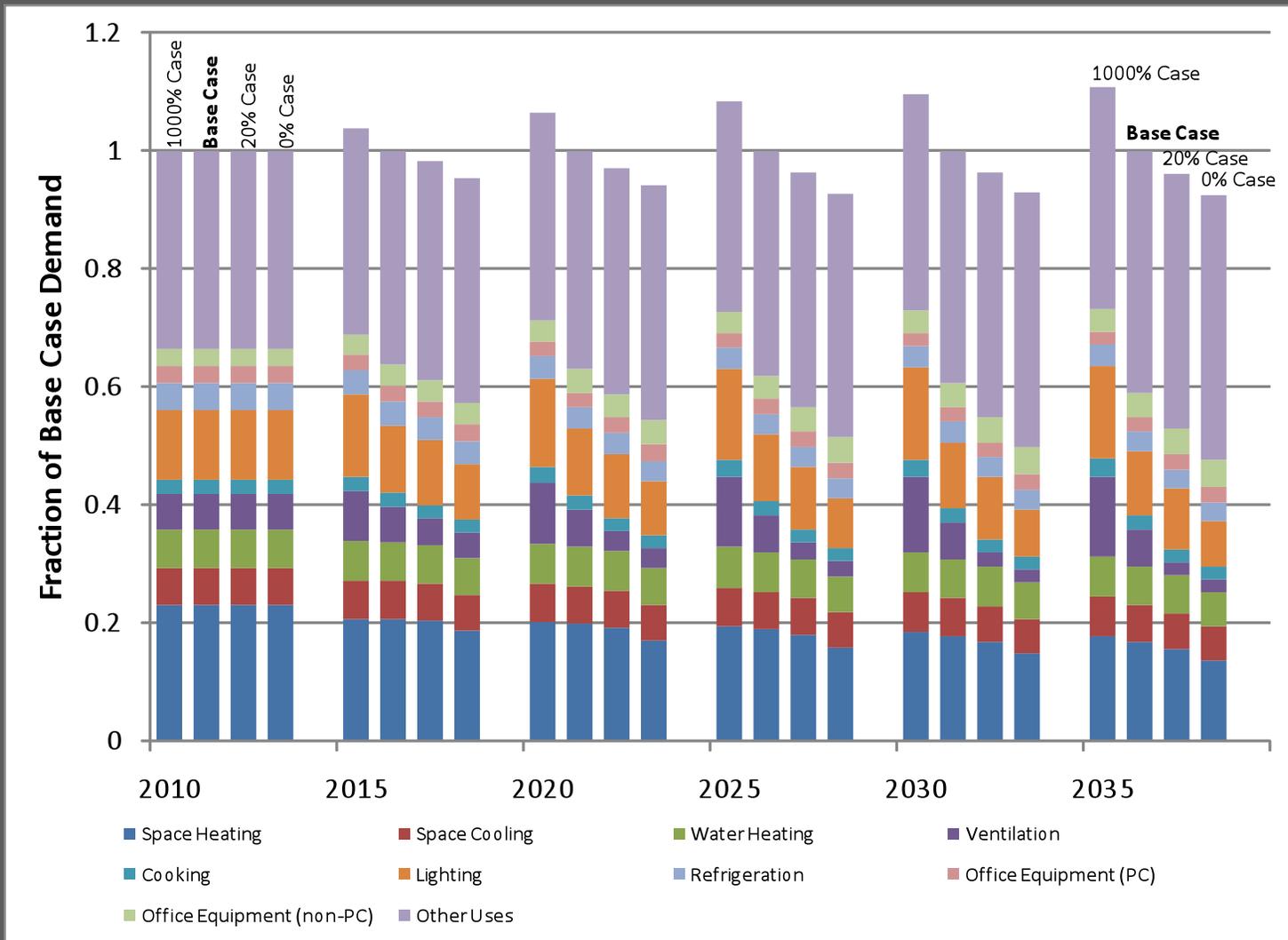
Four Scenarios:

1. Base Case. Set parameters equal to those used in the base case in the 2010 Annual Energy Outlook (EIA 2010).

2. Maximum Efficiency. Set all parameters so that effective discount rate matches the federal funds rate (~4%), as though consumers had excellent financing options and paid strict attention to all costs.

3. Moderate Efficiency. Set all parameters so that effective discount rate is ~20%, as though consumers had credit-card financing rates and paid strict attention to all costs.

4. Minimum Efficiency. Set all parameters so that effective discount rate is ~1000%, as though consumers only wanted to minimize first costs.

Q2: Commercial Sector Results

- Final Energy demand in the Commercial sector
  - Top: absolute energy demand
 - Bottom: relative to the base case

Top chart — Quadrillion BTUs (y-axis) vs years 2010–2035 (x-axis):
- Minimum Efficiency — 9.0%
- Base Case
- Moderate — -5.0%
- Maximum Efficiency — -9.0%

Bottom chart — Fraction of Base Case Demand (y-axis) vs years 2010–2035 (x-axis):
- 0.99 Quads
- 11.03 Quads
- -0.55 Quads
- -1.00 Quads

Q2: Commercial Sector Results

Chart: Fraction of Base Case Demand (y-axis, 0 to 1.2) by year (2010, 2015, 2020, 2025, 2030, 2035). Each year group shows four bars labeled 1000% Case, Base Case, 20% Case, 0% Case.

Legend:
- Space Heating
- Space Cooling
- Water Heating
- Ventilation
- Cooking
- Lighting
- Refrigeration
- Office Equipment (PC)
- Office Equipment (non-PC)
- Other Uses

Q2: Residential Sector Results

- Final Energy demand in the Residential sector
  - Top: absolute energy demand
  - Bottom: relative to the base case
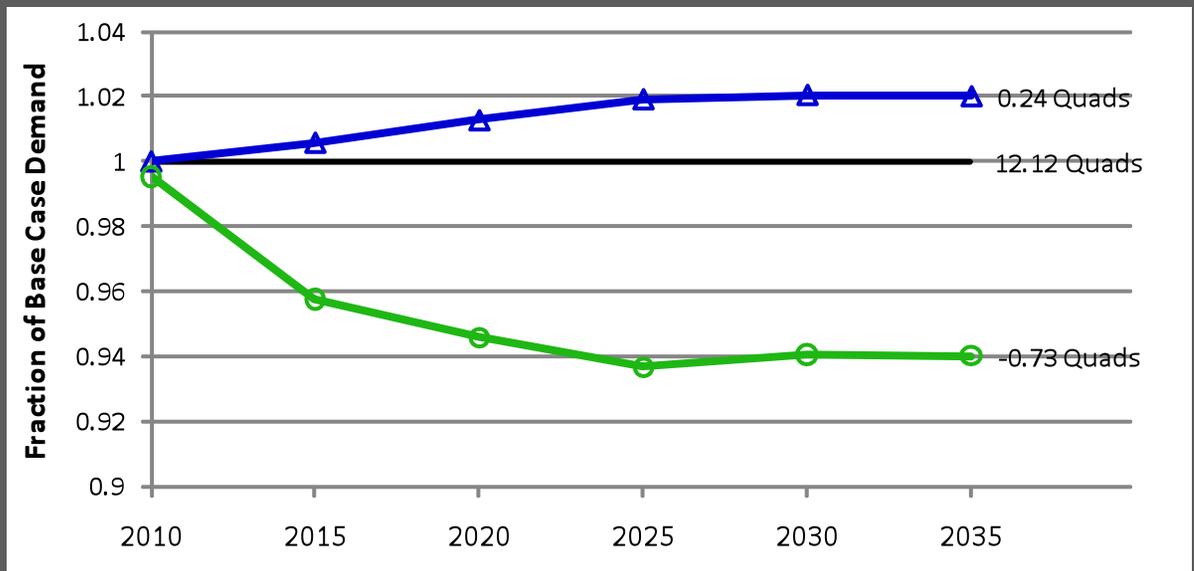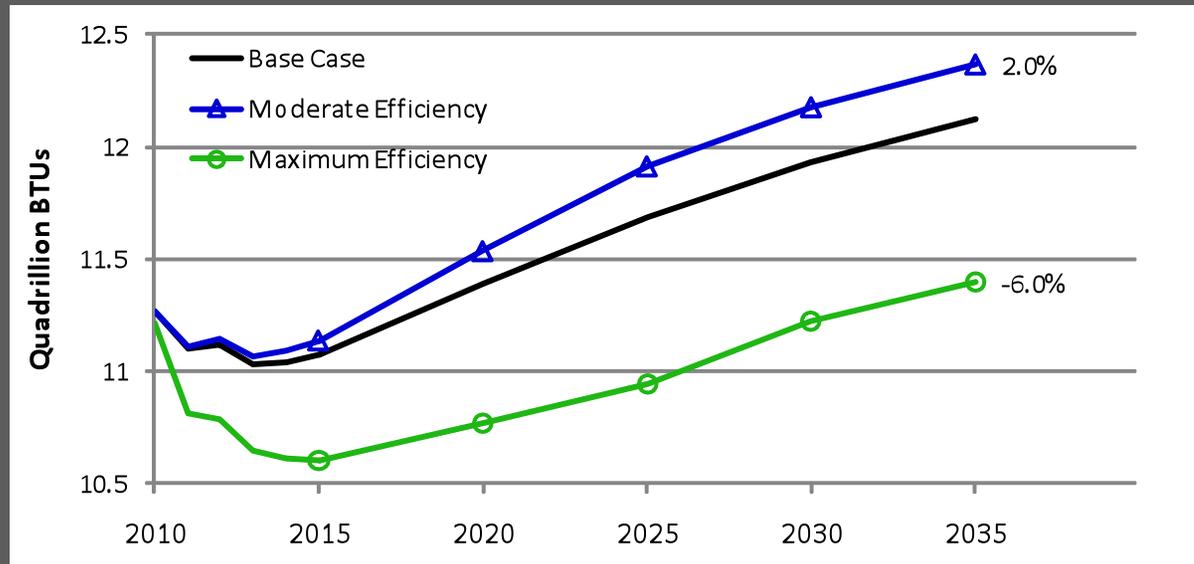
Q2: How Important Are Consumer Decisions About End-Use Equipment?

- As described in NEMS, there are huge market imperfections in the commercial sector, and significant room for improving decisions consumers in this sector make about end-use appliances.

- There is some room for savings in the residential sector, but not as much as in the commercial sector

- In general the way people choose end-use technologies has important consequences for future energy consumption (as discussed previously by Kydes, 1999).

- However, the primary determinants of energy demand in NEMS are not found in the process of technology adoption. Rather, the way NEMS projects economic activity and translates that activity into demand for energy services dominates the process.

Q3:   How Can Behavioral Science Improve U.S. Policy Analysis?

- Fixing behavioral assumptions into the future is not an appropriate way to analyze the policies that might affect those behaviors (Koomey, 2002).

- But what parameters should EIA use? Can we accurately project changes in behavioral parameters ex ante?

- Can the behavioral sciences community create scenarios about technology adoption that can be translated into the NEMS framework?

Q3: Policy vs modeling

- Need the same language:
  - Policymakers emphasize labeling and other behavioral interventions, and NEMS should adapt to these interests (e.g. EPA's Energy Star, EERE's Home Energy Score labels)

- New research and data is needed to effectively estimate reasonable behavioral parameters and trajectories
  - Models need to move closer to how decision makers make choices

- Ignoring behavioral change isn't the same as controlling for it
  - NEMS specifies fixed behavioral patterns when forecasting, and those assumptions drive its results.
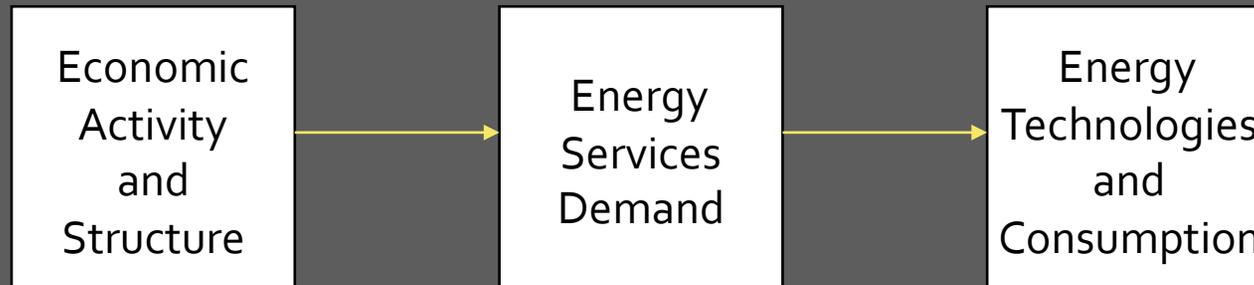
Three Questions

1. How does NEMS generate energy demand in the buildings sector?

    – *NEMS projects economic activity, derives demand for energy services , then chooses technologies to satisfy that demand using a neoclassical economic framework.*

2. How important are consumer decisions about end-use equipment?

    – *By 2035, +/- 1.0 quads of final energy in Commercial sector*

     less dramatic in the Residential sector

    – *But not the primary determinant of energy demand in NEMS forecasts.*

3. How can insights from the behavioral sciences community improve U.S. policy analysis?

    – *Be smart, skeptical consumers of policy analysis based on energy modeling.*

    – *Help generate plausible parameters or scenarios that could be used by EIA or other modeling teams.*

Thank you for your time

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