Technology Choice in an Integrated Assessment Model

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Energy Collaborative Analysis Initiative Workshop

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OUTLINE

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This talk will describe the mechanism used to model technology choice in the long-term integrated assessment model ObjECTS MiniCAM.

- **Integrated Assessment**
- **The ObjECTS MiniCAM**
- **Logit Choice Formulation**
- **Analysis Example**
- **Summary**

INTEGRATED ASSESSMENT

IAM's: Tools for Long-Term Analysis

Integrated assessment models (IAMs)

- Combine information from numerous disciplines into one framework.
- Each model makes different tradeoffs between completeness and complexity, depending on its purpose.

IA Models Are Not "Truth Machines"

- IA models are not predictive — we can't "forecast" many of the most important factors such as technology or human socio-economic developments.

IA Models Are Tools, useful to examine:

- possible futures with different assumptions for energy technologies, economic growth rates, etc. *(thereby producing emission scenarios)*
- the relative costs of GHG emissions reductions under different scenarios for technology and policy assumptions
- what are the important linkages?
- where are the lever points?

Integrated Assessment

The goal of long-term integrated assessment analysis is to gain insights, for example into the potential role of different technologies; the way different technologies interact (*e.g.*, compliments or substitutes); and the effect of interactions between different components in the system.

We can't predict the state of the energy or human system in 50 or 100 years.

But by combining things can be safely assumed:

- the sun will only shine in the daytime, people will live and work in buildings, and demand for personal mobility will continue to increase

With plausible assumptions for more uncertain parameters (or multiple sets thereof):

- Technology will continue to improve in general
- New technologies will be developed and deployed
- Population and income will increase

We can:

- Provide a context for decisions now that have long-term implications
- Explore the potential role of different technologies (*e.g.*, in lowering emissions mitigation cost)
- Examine what will be necessary to meet specific policy goals (*e.g.* stabilization targets)

Kim, S.H., J. Edmonds, J. Lurz, S. J. Smith, and M. Wise (2006) The ObjECTS Framework for Integrated Assessment: Hybrid Modeling of Transportation *Energy Journal* (Special Issue #2) pp 51-80.

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The O^{bj}ECTS Framework

The Object-oriented Energy, Climate, and Technology Systems (O^{bj}ECTS) Framework uses a modular, data-driven architecture to model energy and agricultural systems.

- Implemented in C++
- Enables detail where needed
- Input data determines the market structure, sector definitions, fuels, and linkages.

The O^{bj}ECTS MiniCAM implementation

- Same basic partial-equilibrium equation structure.
- Substantially more flexibility in structure of the energy system.
- Now contains detailed representations of end-uses, renewables, and vintaged technologies.

As an integrated model, O^{bj}ECTS MiniCAM incorporates endogenous energy and agricultural prices, supplies, and demands.

Climate Stabilization

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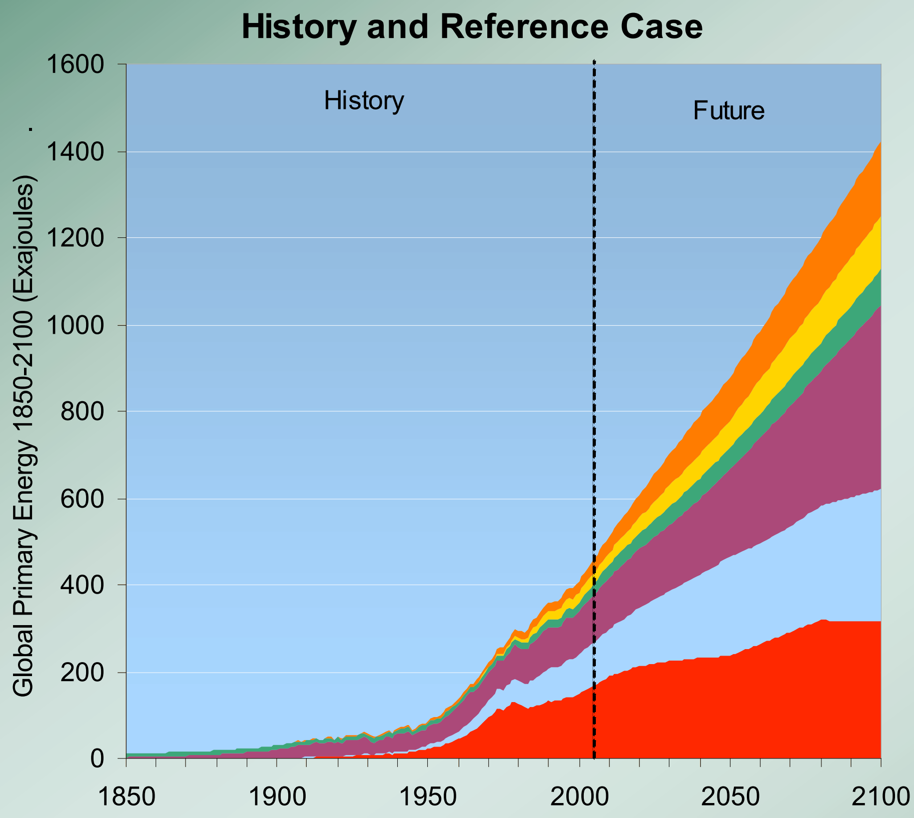
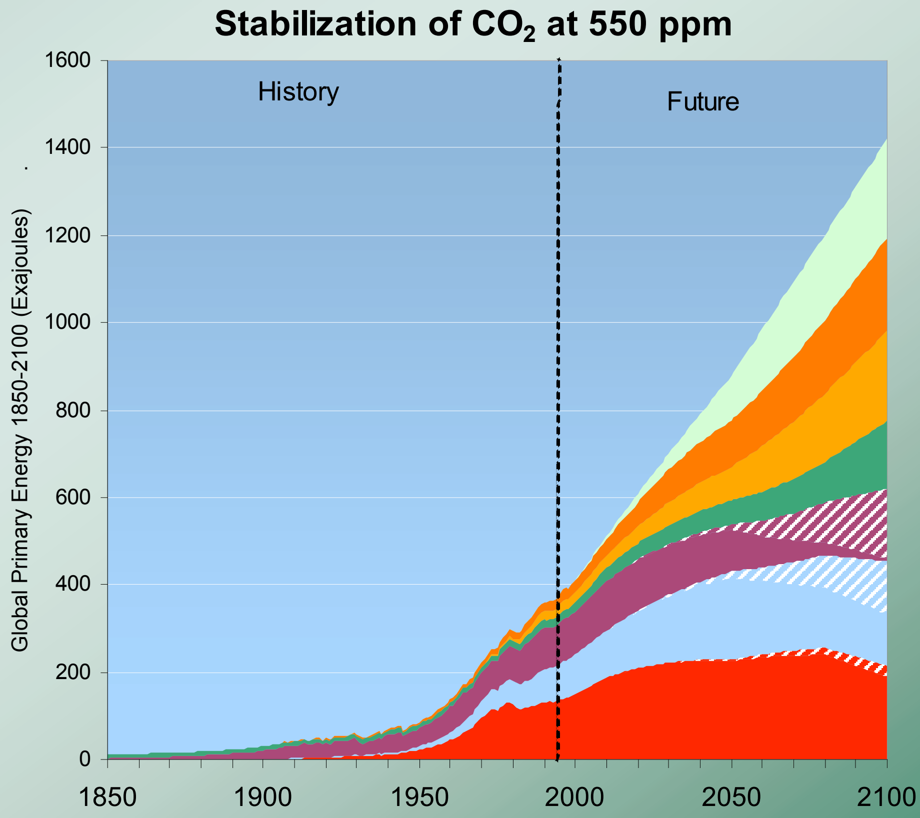
Model the globe, over 100 years, in 14 regions





Substantial changes & many options will be required to stabilize concentrations.

- Oil
- Natural Gas
- Coal
- Biomass Energy
- Non-Biomass Renewable Energy
- Oil + CCS
- Natural Gas + CCS
- Coal + CCS
- Nuclear Energy
- End-use Energy

Applications

The MiniCAM model has been applied to long-term analysis in numerous national and international contexts.

- Every IPCC Scenario exercise (S90 SAR, TAR, etc.)
- IPCC Special Report on Emissions Scenarios (SRES)
- Energy Modeling Forum
- US Climate Change Science Program (CCSP) Scenarios (one of 3 IAMs)
- US Climate Change Technology Program (CCTP) Scenarios
- Numerous published papers, book chapters, and reports.

LOGIT CHOICE MODEL

MiniCAM Technology Competition – Based on Economics

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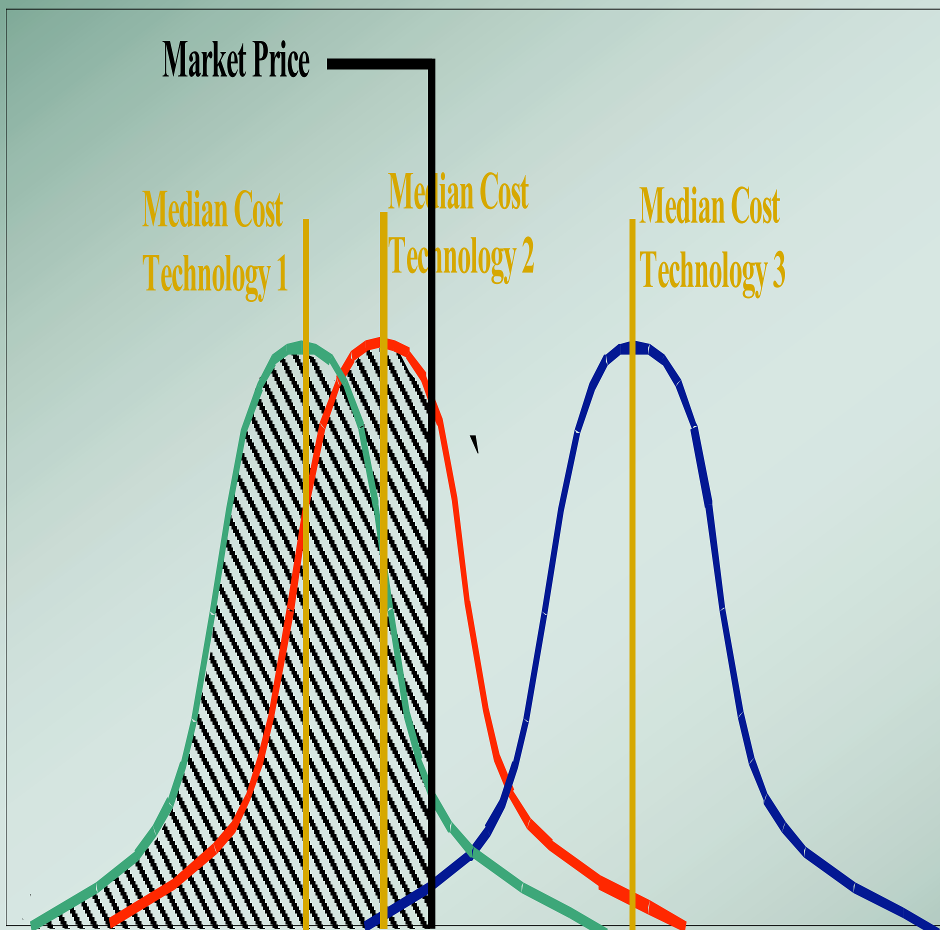
A Probabilistic Approach



- Economic competition among technologies takes place at many sectors and levels.
- Assumes a distribution of realized costs due to heterogeneous conditions.
- Market share based on probability that a technology has the least cost for an application.
  - Avoids a “winner take all” result.
  - “Logit” specification.

Logit Implementation

The share of any technology, or group of technologies is determined by the following equation (Normalized so sum of shares = 1):

$$\text{Share} \propto \text{Weight}_{\text{coef}} \bullet \text{Cost}^{\text{-Logit-exponent}}$$

Have three parameters to set/adjust:

Weight Coefficient	historical periods: Calibration parameter; for future periods: controls technology availability	*Calibration result provides information on model consistency.*
Logit Exponent	Input parameter	*Larger exponent results in "sharper" technology shift*
Cost	Combination of exogenous input (non-fuel costs) and endogenous model results (fuel prices)	*Can be modified to account for additional cost components (e.g. time value)*

This method allows quantification of the potential long-term role of energy efficiency in a relatively transparent and straightforward manner.

Multi-level choice

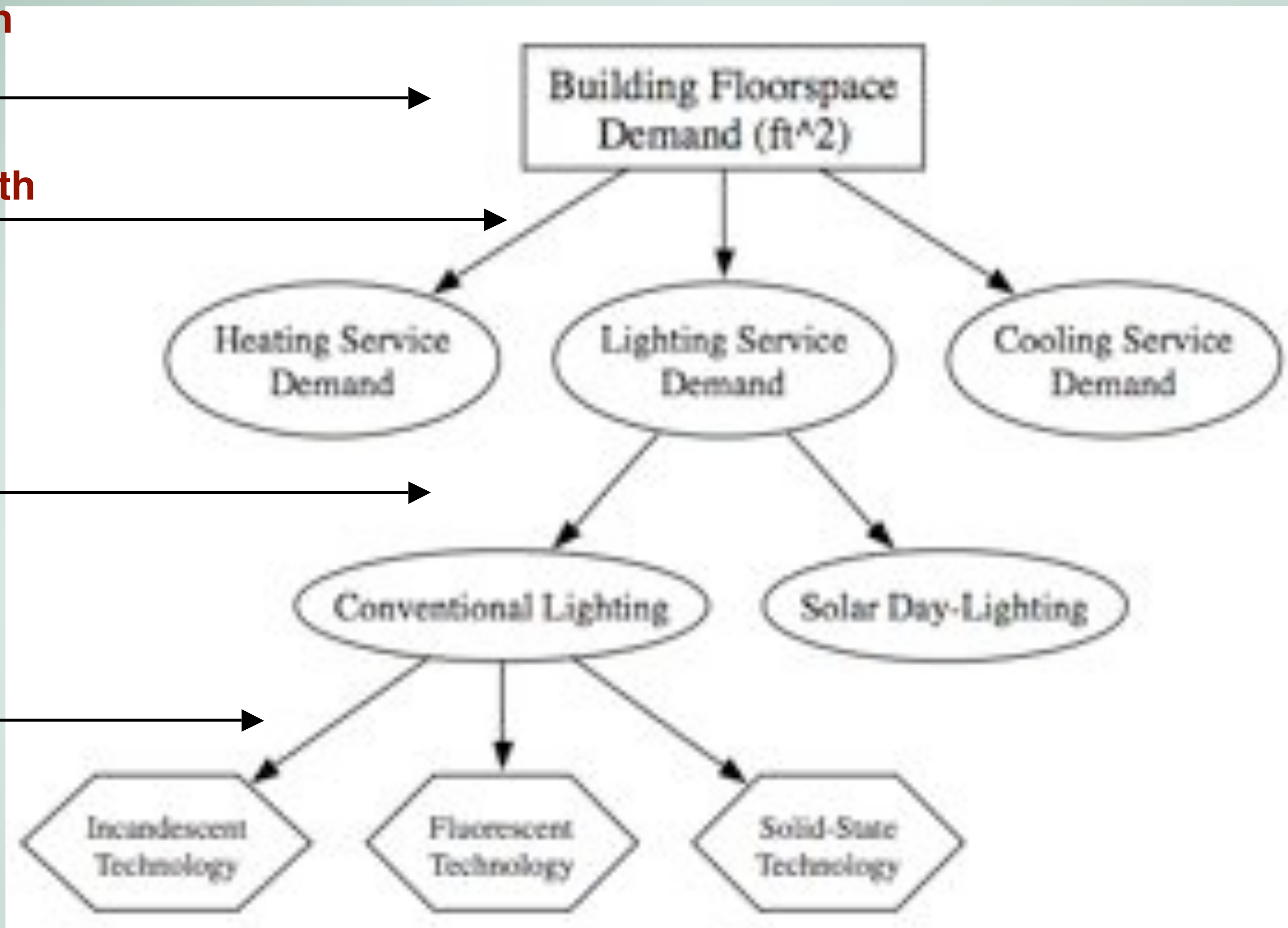
Technology choice can occur at multiple levels, including response at the level of overall demand for a service. For example:

Demand Function (with price response):

Demand Functions (with price response):

Level 1 choice:

Level 2 choice:



ANALYSIS EXAMPLE: VALUE OF ENERGY EFFICIENCY IN A CLIMATE CONTEXT

Analysis Overview

We wish to determine the value of energy efficiency in terms of lowering the cost of meeting climate goals in the United States. Our analysis setup:

- ▶ Uses detailed end-use sectors in the US that have physical service demands (floorspace, passenger-km, etc) and specific categories of end-use technologies (natural gas or heat pump furnaces, etc.).
  - Residential Buildings
  - Commercial Buildings
  - Industry
  - Transportation
- ▶ Used globally constrained emissions to define US emissions constraints
  - US emissions to follow path found from global climate stabilization solution
- ▶ U.S. costs of stabilization determined with reference and advanced suite of energy efficiency technologies
  - Reference case technologies follow evolutionary pathway with still substantial improvement over the century.
  - Advanced suite has further improvements and some additional technologies

Reference & advanced scenarios difficult to define rigorously!

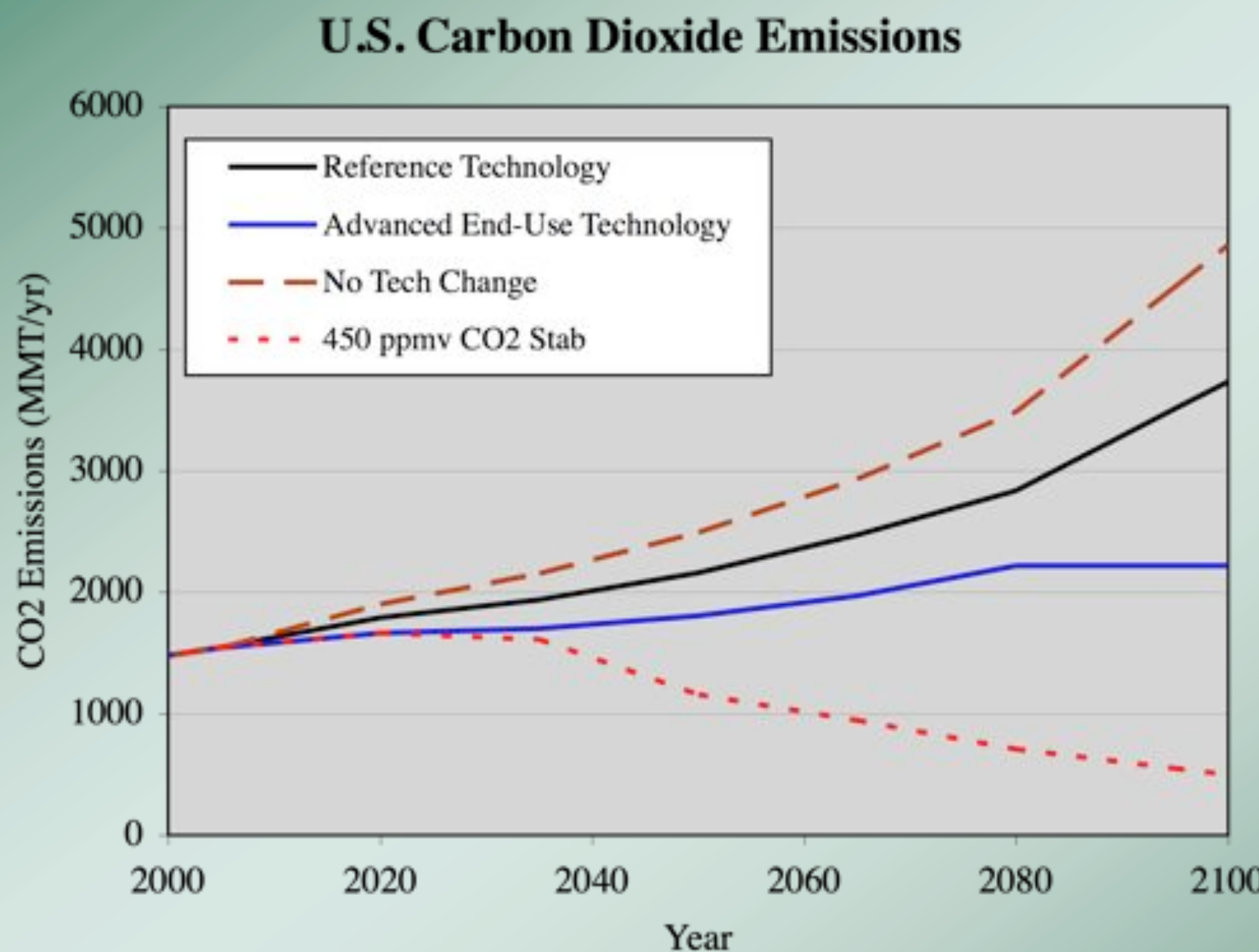
(But at least we can be explicit about what has been assumed)

Technology Choice

As in example diagramed previously, technology choice can occur at multiple levels.

- Allow choice between different groups of technologies that supply the same service
  - Gas heating, electric heating, etc.
- Allow choice between different technologies that may compete more directly
  - Residential lighting supplied by: incandescent, fluorescent, & solid-state
- Exogenously specify efficiency over time
  - Otherwise need to solve problem of technological change/success-failure and diffusion
- Define two (or more) scenarios, reference and advanced, to explore potential of improved efficiency

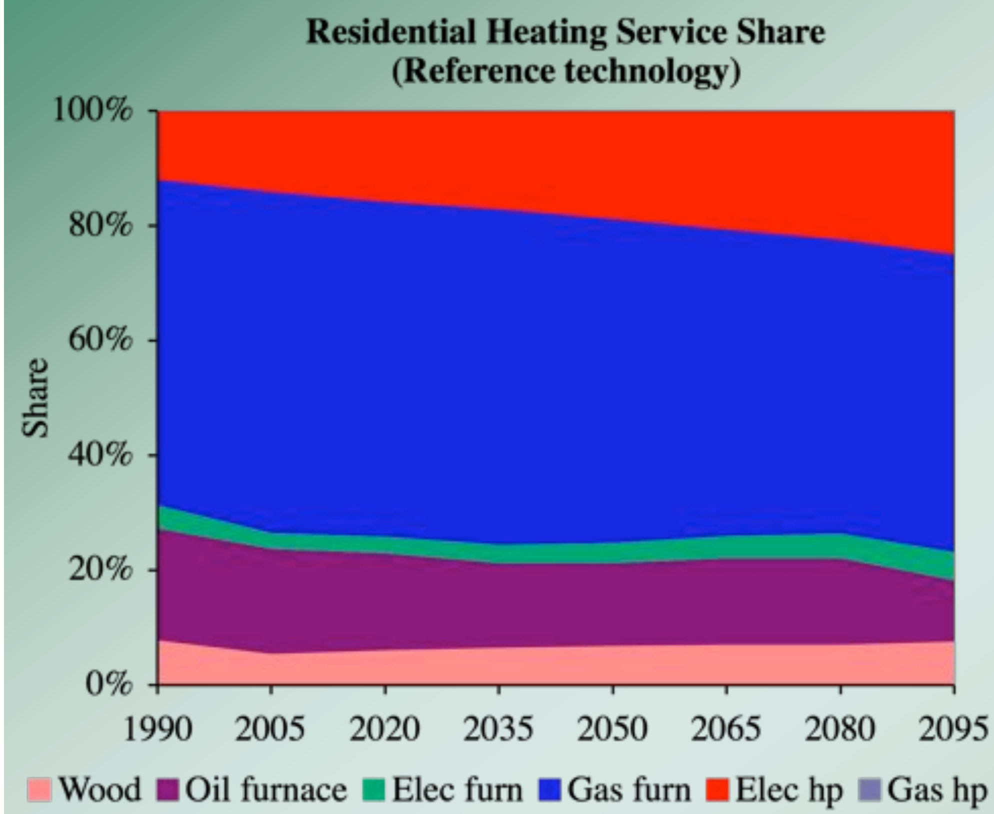
Carbon Dioxide Emissions

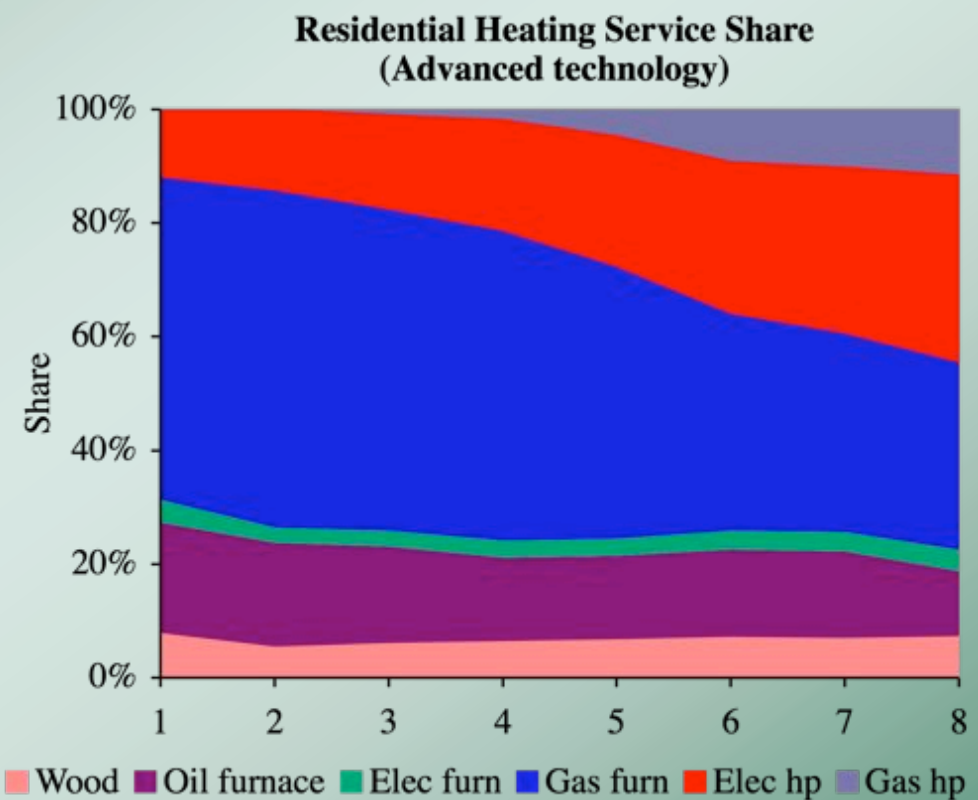


The reference and advanced cases provide a bound to technology choice. Climate policy would likely spur innovation and the adoption of more efficient technologies — the “actual” trajectory would likely be somewhere in-between these cases.

Note that efficiency does not “solve” the climate problem, but it does make stabilization easier to achieve.

Technology Choice Results: Residential Heating

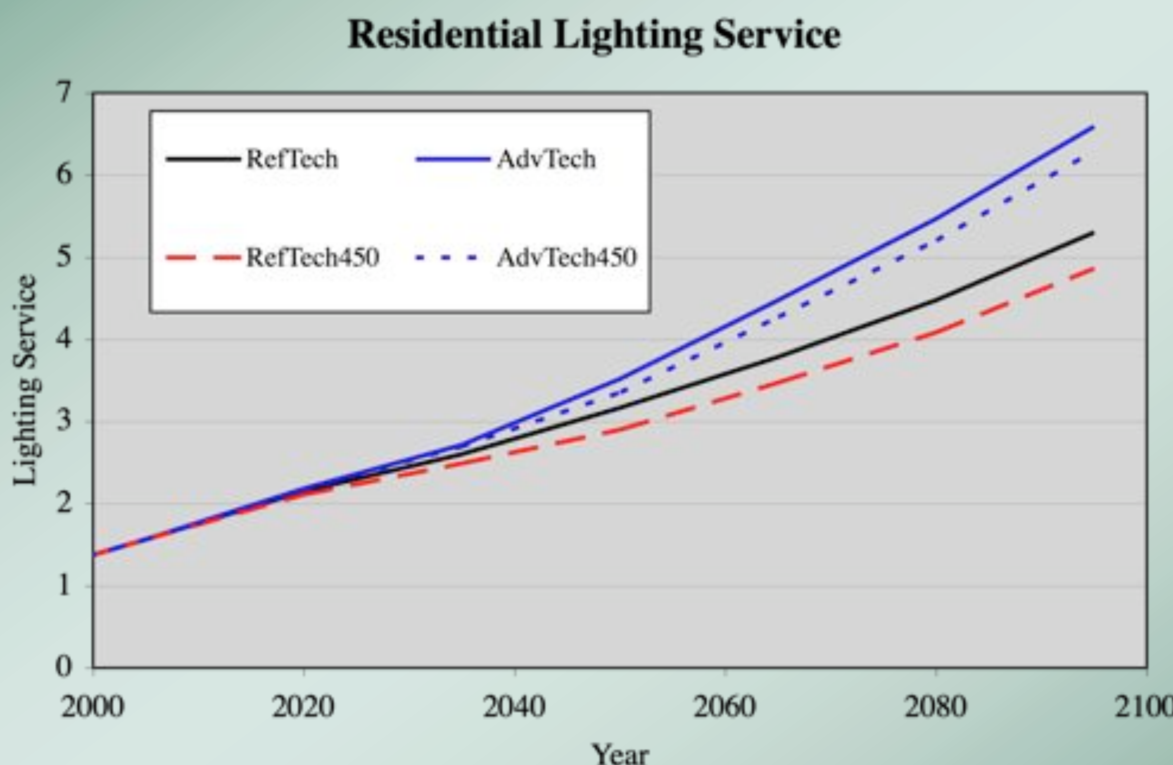




In the advanced case,heat pump technologies gain a larger market share. Conventional gas furnaces still have a significant role. The decrease in heating service needed in the advanced case (due to building shell improvements) means that heating cost plays a smaller role than in the reference case.

Demand Response due to Climate Policy and Efficiency

lighting service demand ∝ floorspace • (lighting service cost)$^{\text{price elasticity}}$



– More efficient technologies lead to an expansion in technology use.

While the magnitude of the effect is uncertain the sign is known!

– A climate policy increases prices and reduces demand

Although less so in the advanced case since energy prices have less impact.

And, carbon prices are lower overall.

The opposite is seen for heating – due to the combined effect of building shell and furnace efficiency improvements

Summary

- A multi-level logit structure provides a flexible mechanism for modeling technology choice.
- Key questions: how to determine appropriate structure and parameter values.

  *The **sharing hierarchy** should be structured so that like completes with like as much as possible.*

  ***Share weight** values resulting from historical calibration provide a measure of how well the model simulates reality. Calibration share weights all = 1 would indicate the model perfectly captured reality.*

  ***Logit exponent** values can sometimes be bounded by comparing with historical data, by requiring simulation results to smoothly depart from the historical trend (however, sometimes a rapid deviation is reasonable!)*

- Methods of improving estimates of these parameters could be explored.

  Comparisons with historical trends possible – although data in some cases is limited (e.g. lighting technology shares).

  For some technologies, such as heating, load factors vary spatially in ways that are potentially amenable to modeling — could explicitly estimate cost distributions.

  Vintage stock ,electric peak vs base-load, and so on are often folded into the logit - although this can make it more difficult to compare to real-world data.

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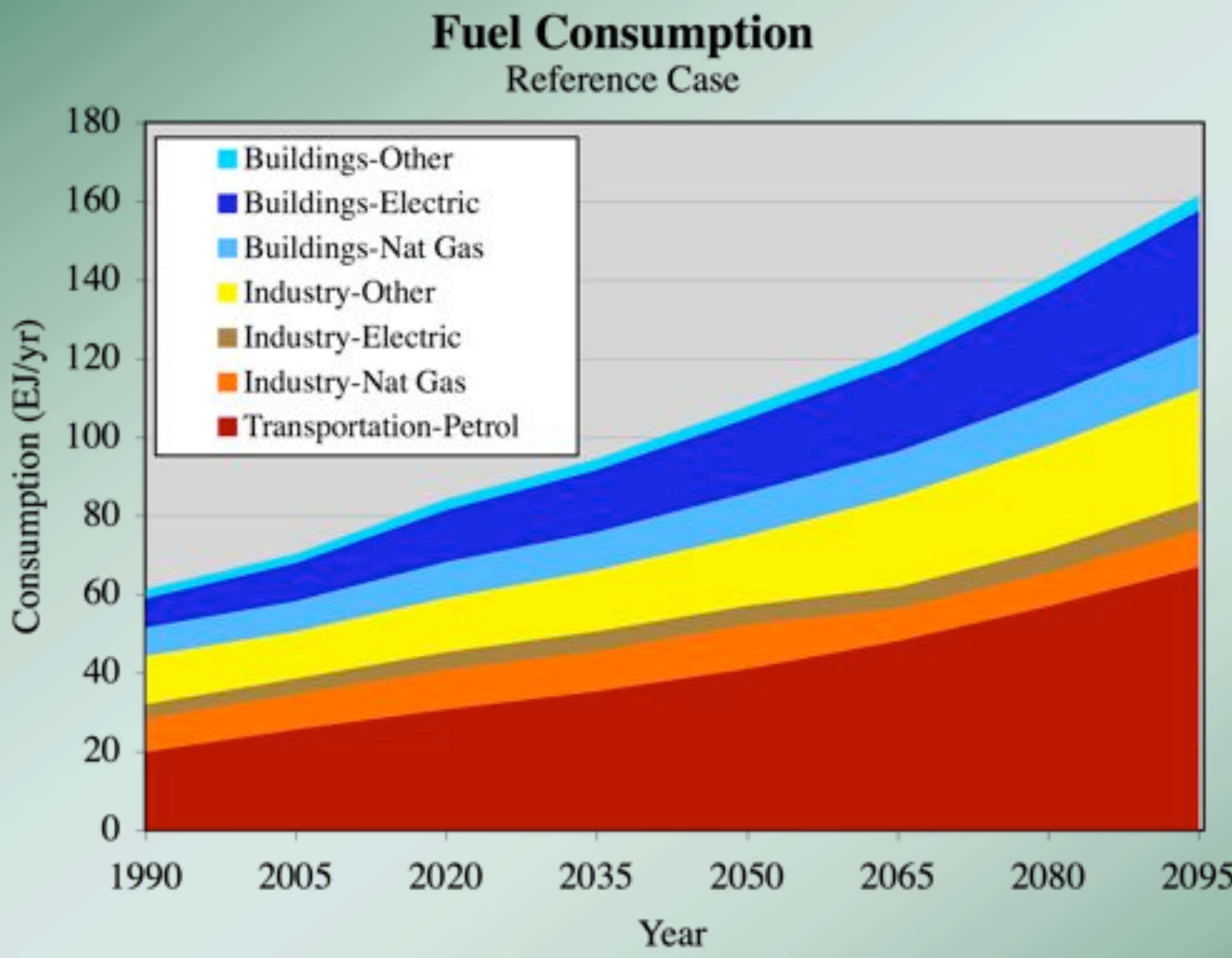
THANK YOU

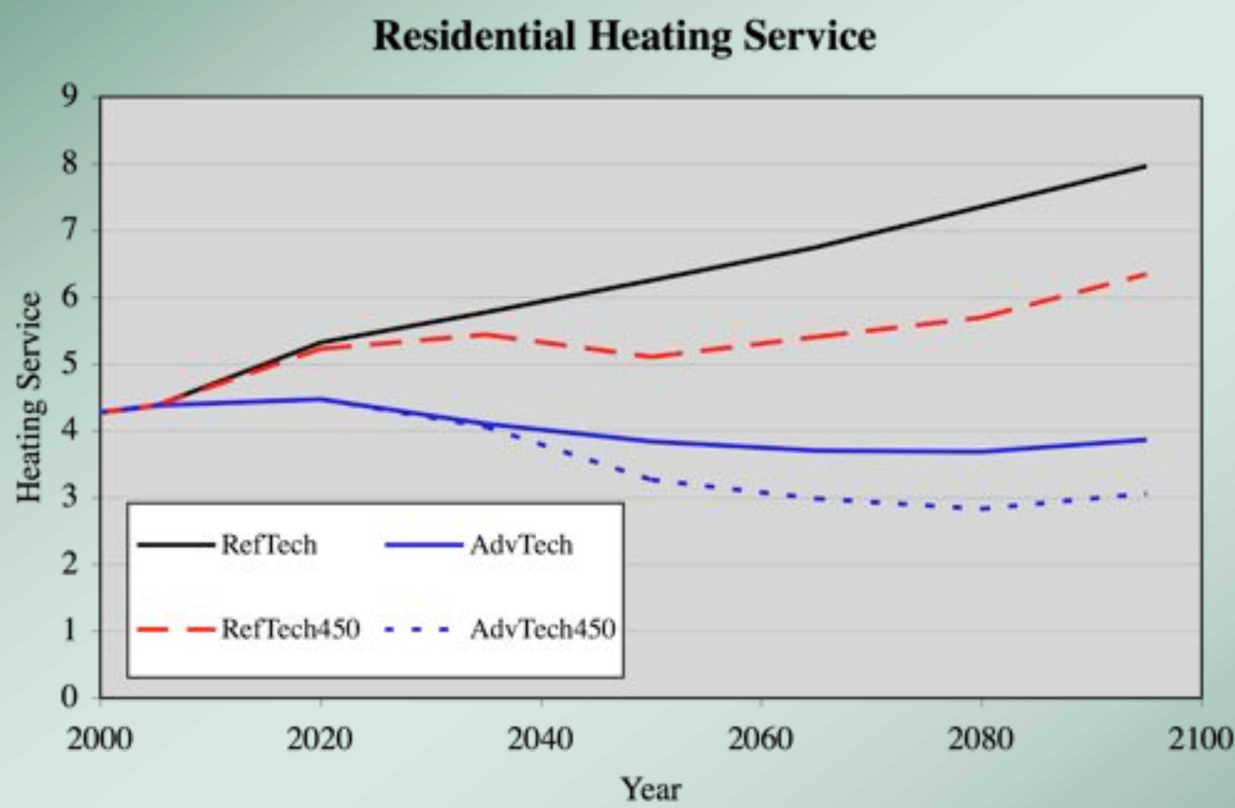
ADDITIONAL SLIDES

Energy Consumption



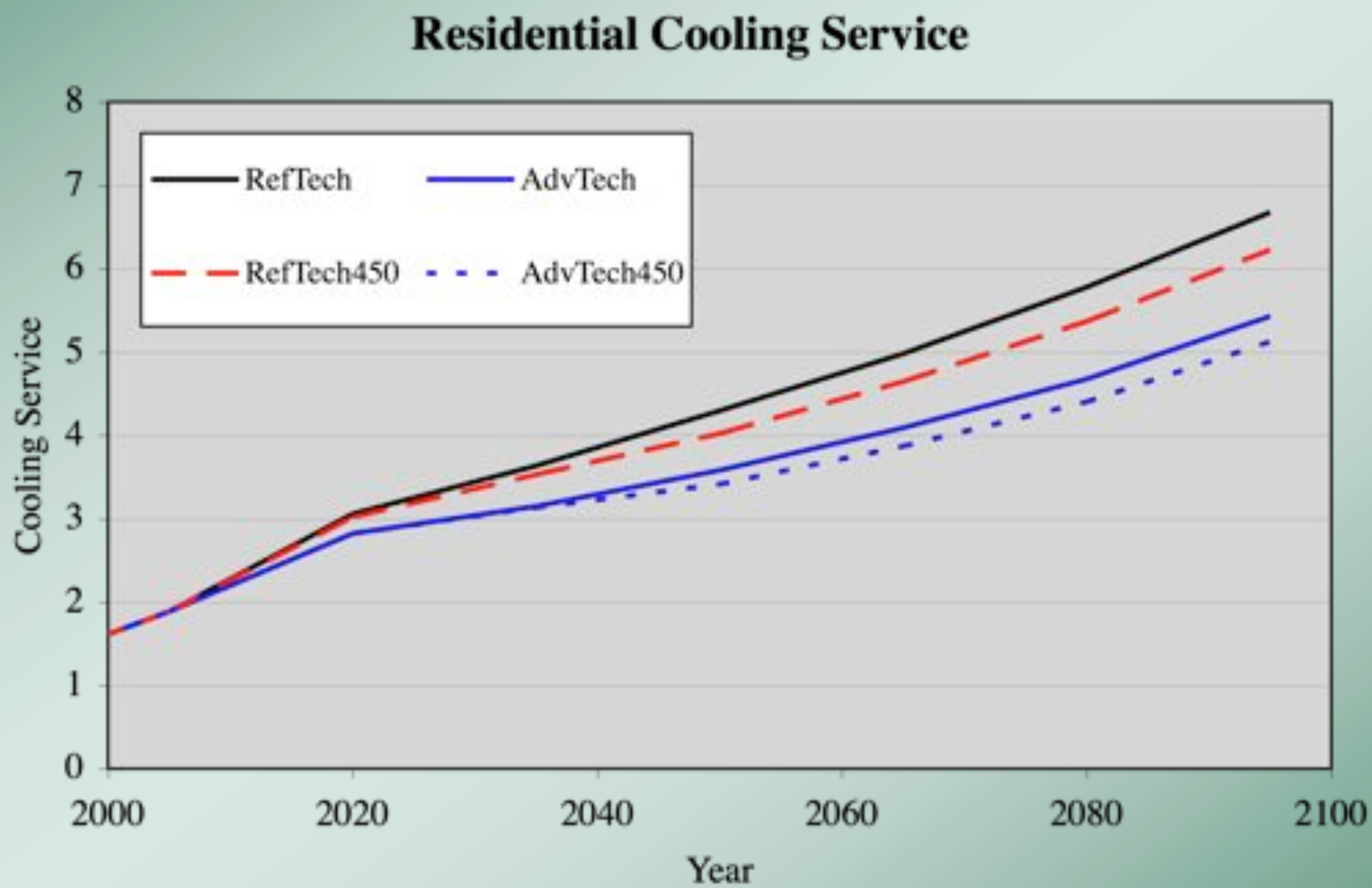
– Due to efficiency improvements energy consumption does not increase as rapidly as service demand.
– The share of building and transportation energy use increases with time as these demands grow with population and income.

Energy Service Changes: Heating Service



– With heating services, efficiency reduces net service because of the combination of more efficient furnace technology (lowers costs) and improved building shell (lowers inherent need for heating)
– Climate policy is similar in effect

Energy Service Changes: Cooling Service



– The changes in cooling service are much smaller overall

Building shell improvements reduce thermal heat flux into the building but also better trap internal gains! So less impact overall.