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# The Value of End-Use Efficiency Technology

*GTSP Technical Workshop*

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# OUTLINE

*This talk will present analysis of the long-term contribution of end-use efficiency improvement to climate mitigation.*

## Context

Stabilizing Climate

## Modeling Approach

O^bj^ECTS Framework

End-Use Technology: Buildings, Industry, Transportation

## Value of Energy Efficiency

Long-term Energy Impact

Climate Policy Impact

Value Towards Meeting Climate Stabilization Goals

## Conclusions

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Edmonds and Smith (2006) "The Technology of Two Degrees" In: Avoiding Dangerous Climate Change (Cambridge University Press).

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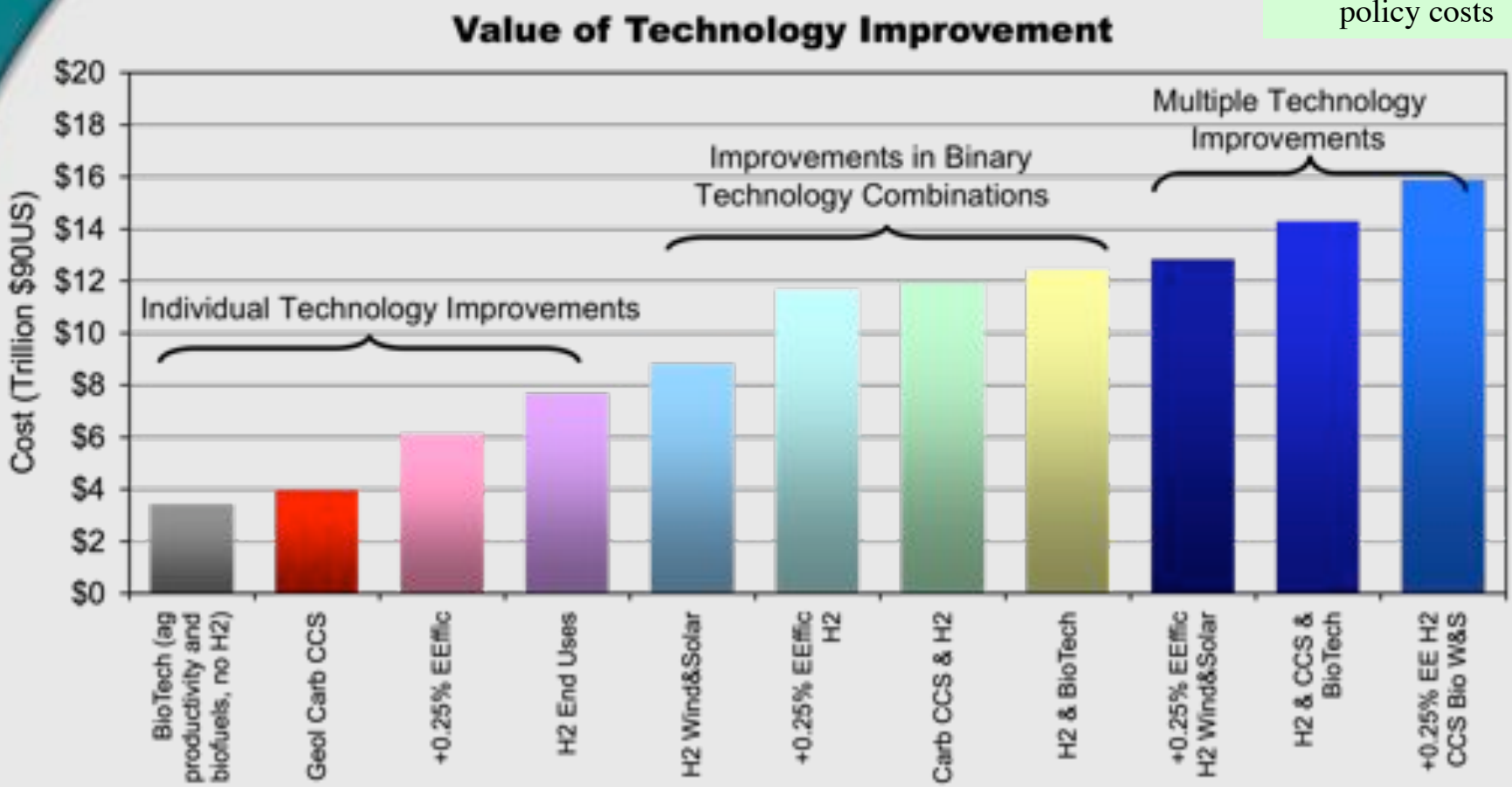
# The role of technology is to control costs

Discounted global policy costs




**Base Case Cost: $18 Trillion**

*The value of a technology for climate mitigation needs to be considered over the long term and globally, and depends on the availability of other technologies.*

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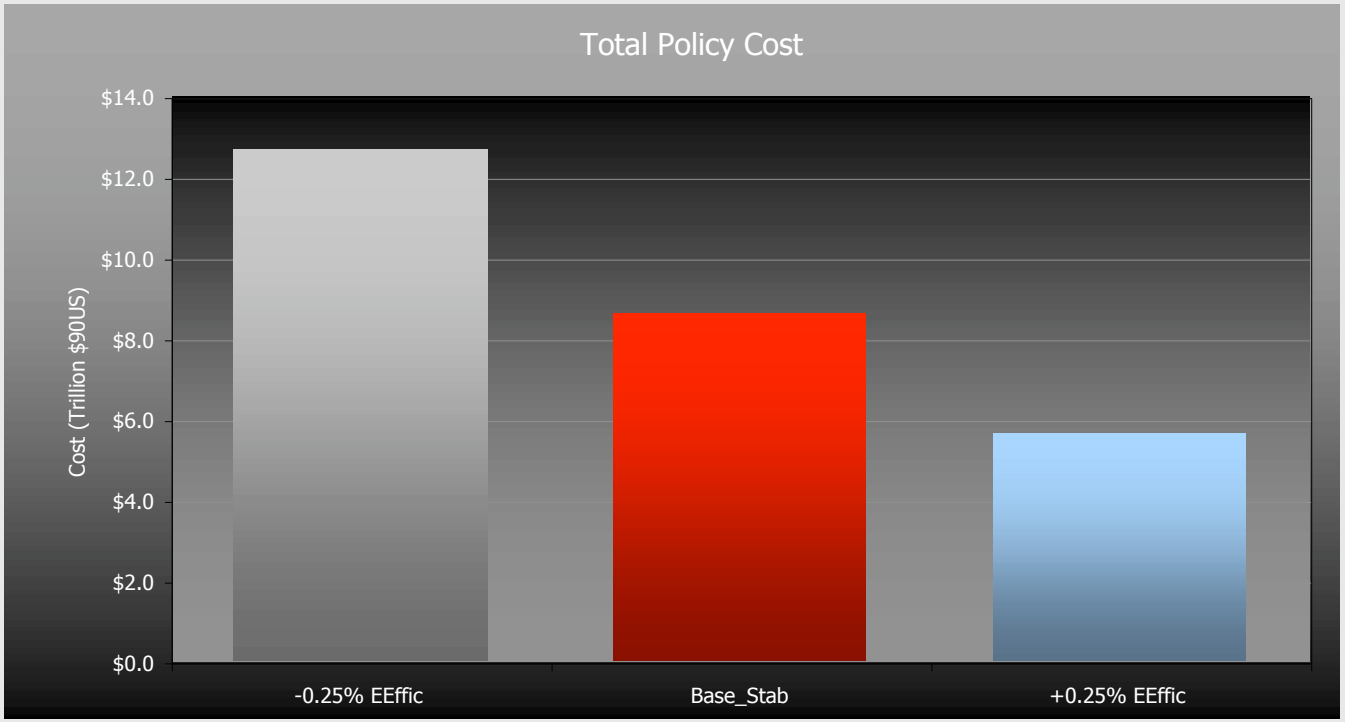
# Motivation

*One of the primary motivations of this work was to better determine the role of energy efficiency. While the potential is large, we wanted to examine the role of specific technologies.*




Increased efficiency lowers substantially the cost of achieving a specific climate stabilization target.

***Also**, if we do not achieve our baseline gains in efficiency costs increase.*

This calculation used an aggregate formulation for energy demand.

*We need to understand how much **specific technologies** can contribute to efficiency improvement.*

*Same for renewables.*

# 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.***

# Modeling Energy End Use Technologies

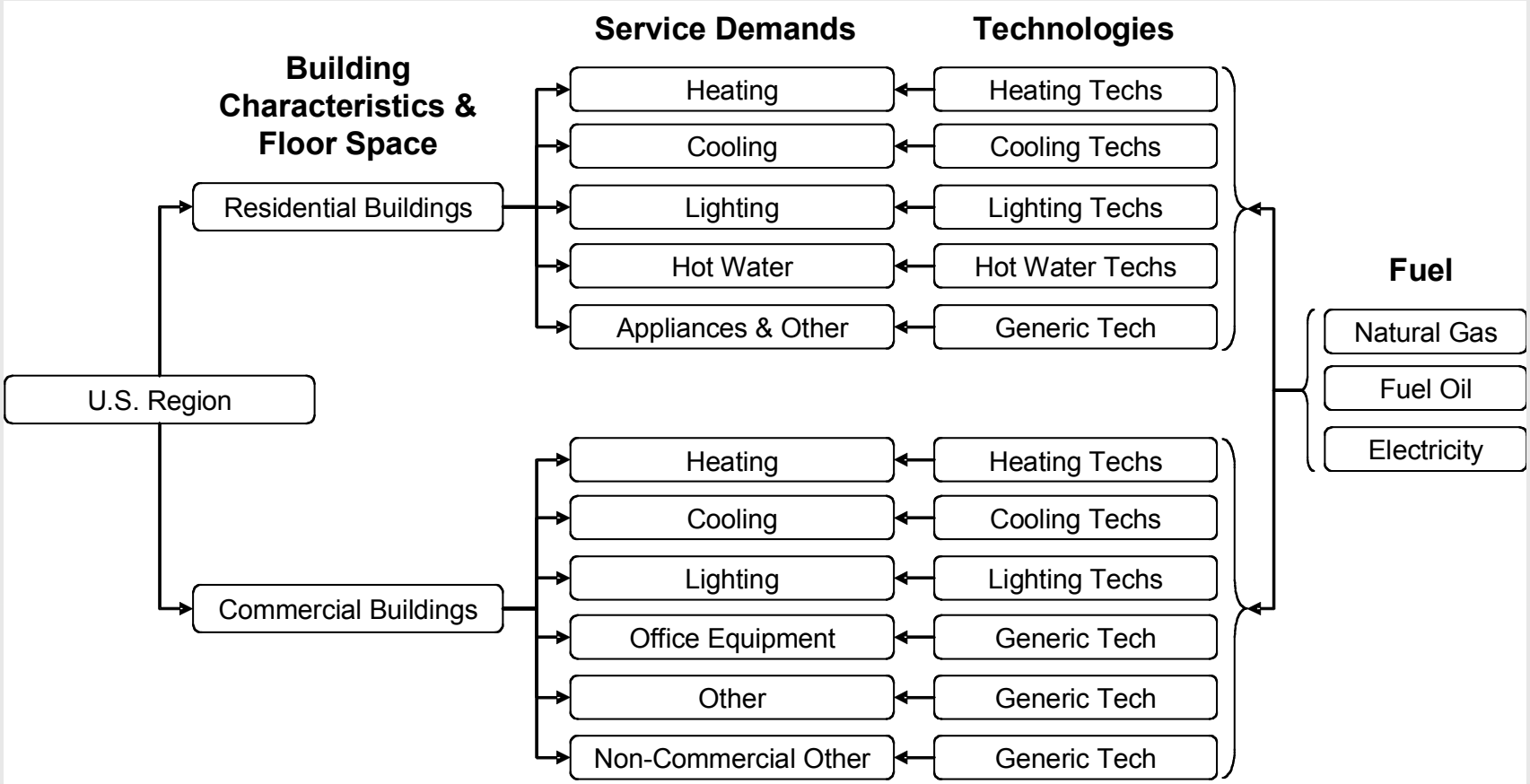
- Developing detailed end-use sector models
  - Completed U.S. versions provide a wealth of insights
  - Versions for other regions desirable, but limited by data
- The Details Matter
  - Evolution of underlying service demands
    - Growth in information and “other” technologies in buildings, air travel in transportation
  - Switching to lower carbon fuels
    - There are ample opportunities to electrify the buildings sector
    - Process heat provides a floor in the industrial sector
    - Technology drives the opportunities in the transportation sector
  - Opportunities for efficiency gains vary by application (e.g., existing efficiency is high in boilers and motors)
- Detail is embedded in a global, long-term model
  - Trace the impacts of individual end-use technologies (e.g., solid-state lighting) through to energy transformation, emissions, concentrations, and radiative forcing.
  - Endogenous energy prices and feedbacks

# Building End-Use Model

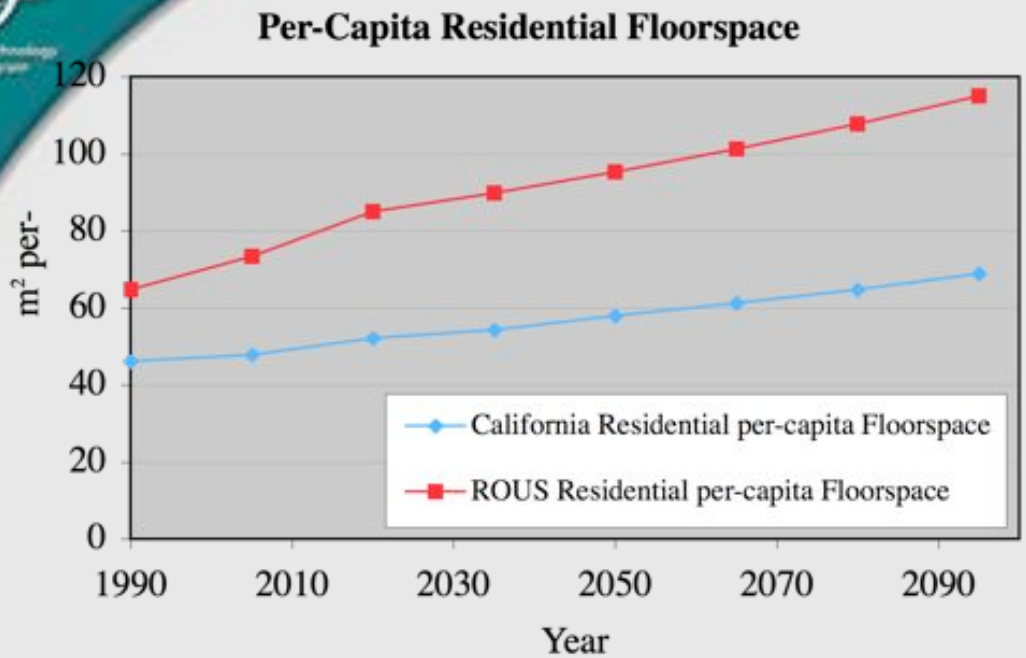
Structure is based on services and the technologies that can supply these services.

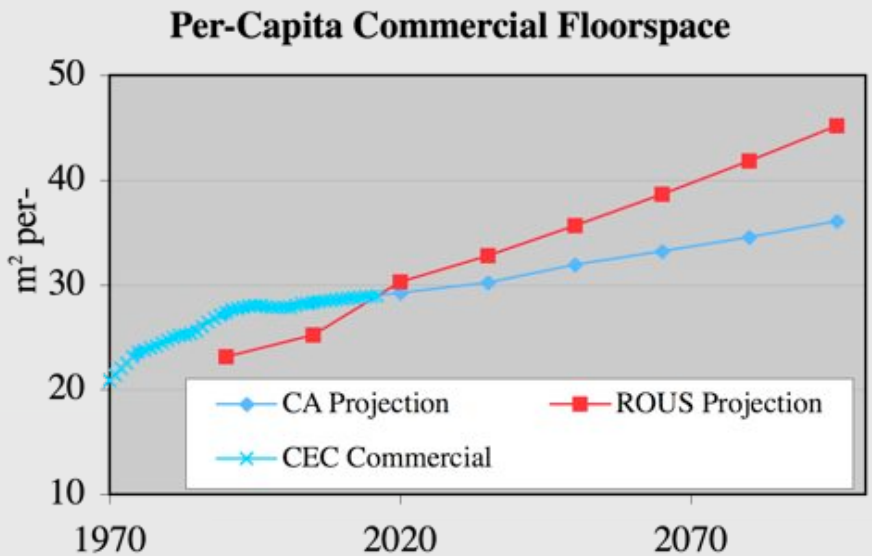
The model based on simple physical representation of buildings.

- Buildings are characterized by floorspace.
- Heating and Cooling services include internal gains.



# Floorspace Scenarios




**The foundation of a building scenario are floorspace assumptions.**

California has much smaller per-capita residential floorspace, apparently, with a slower growth rate.

While commercial building comparisons are particularly prone to uncertainty due to definitional issues, it appears that California is comparable to the rest of the US in per-capita commercial floorspace, although the growth rate may be much less.

# Insights from the Buildings Sector

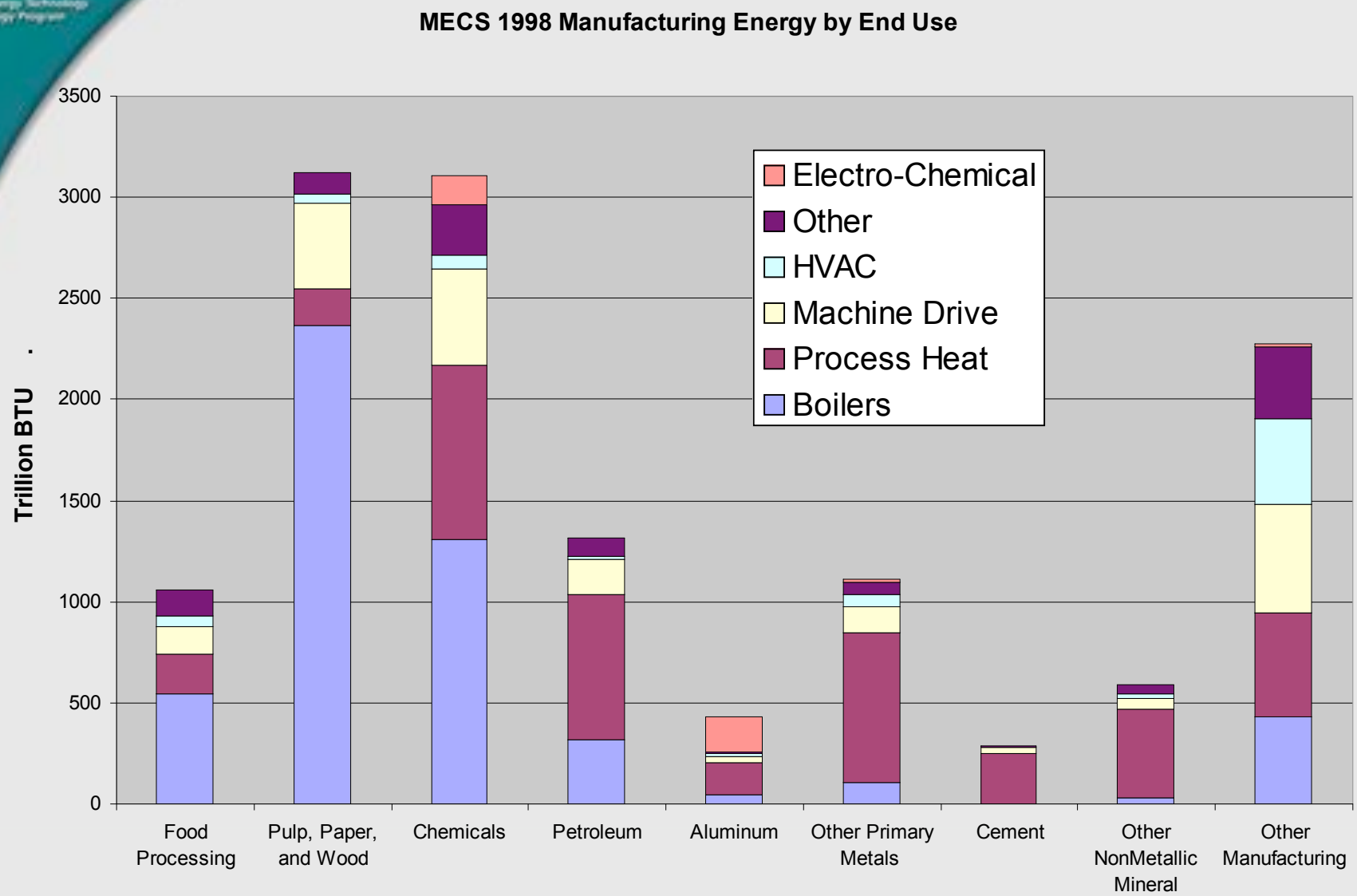
- Information and “other” services are growing:
  - Large driver of demand evolution
  - Increases electrification
  - Impacts on heating and cooling demands through internal gains.
- There are ample opportunities to electrify in the buildings sector in response to carbon policy
- Electric heating technologies provide an important avenue for efficiency gains and electrification
- Building shell changes are a significant driver of future demands

# Modeling Industrial Energy

Our Industrial energy model focuses on:

- Key **industry groups** that differ in terms of their long-term growth and consequent demand for energy services,
- **Major energy end-uses** (i.e., services or processes), with potential for process improvements where possible, as well as the potential for cogeneration of heat and power, and
- Within each energy end- use, a set of explicit **technology and fuel options** that will compete, based on relative economics and engineering limits, to provide each of these energy services in each industry group.

# Industrial Categories in ObjECTS




*Industries are grouped by similarity in driving factors and energy service demands.*

# Lessons from Modeling of Industrial Energy Use

- Detail is important in identifying challenges and opportunities for reducing emissions in the Industrial Sector.
- The US model provides insights into the global issue, as the technologies and processes available will be similar.
- Significant technical potential for efficiency improvements from process changes (e.g., membranes, electric arc furnaces, gasification, overall process design)
  - Need case studies to identify magnitude and service shifts.
- Will be a challenge to model future regional demands for products of specific industries.
  - Unlike buildings and transportation services, industrial products can be shipped internationally.
  - Becomes an issue when carbon policies differ regionally, but not so much in the long-term under a global policy.

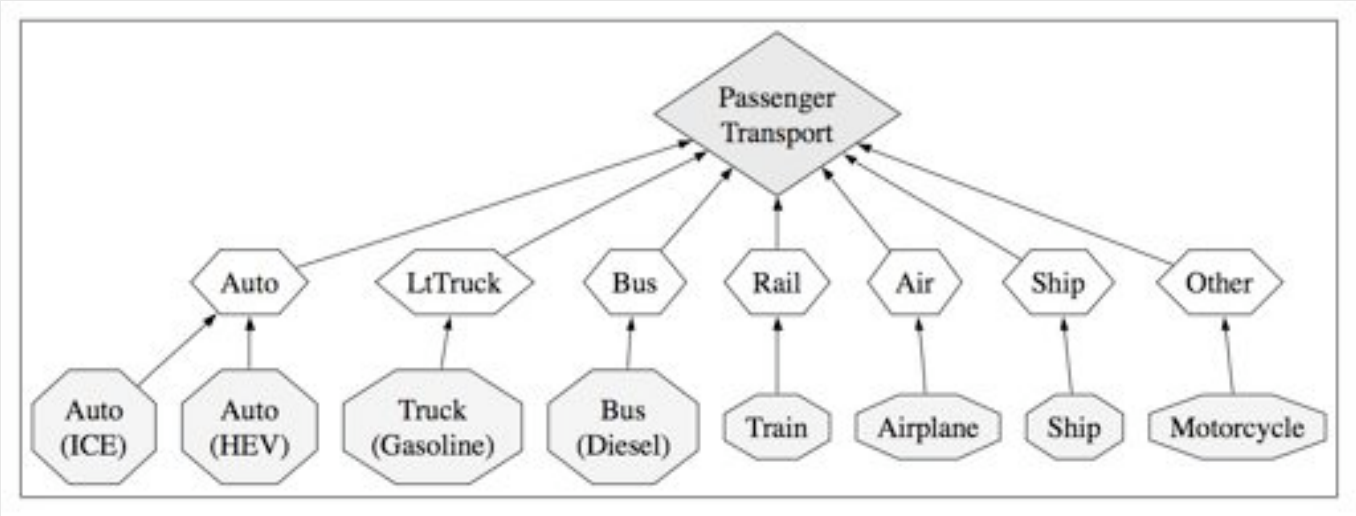
# Transportation Modeling

Our current global representation of transportation is at an aggregate level, where one generic transportation service is provided by a variety of fuel modes.

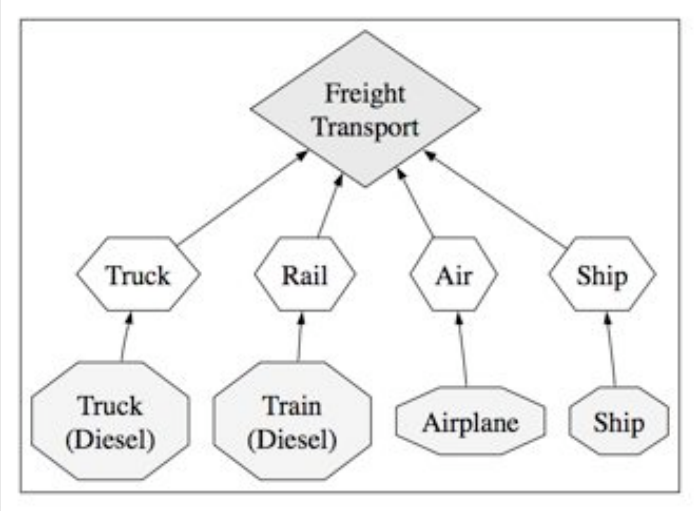
A more detailed US representation of the transportation sector has been implemented that represents specific service demands (passenger and freight) by mode and technology.

- This representation of transportation
  - Better simulates global markets for petroleum and potential future transportation fuels.
  - Enables examination of technology shifts due to carbon policies.
  - Enables analysis of the effect of fuel efficiency

# Transportation Detail




*Transportation demand is classified by type of service (passenger and freight), mode (auto, rail, bus), and technology (ICE, hybrid).*



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# Value of Energy Efficiency in a Climate Context

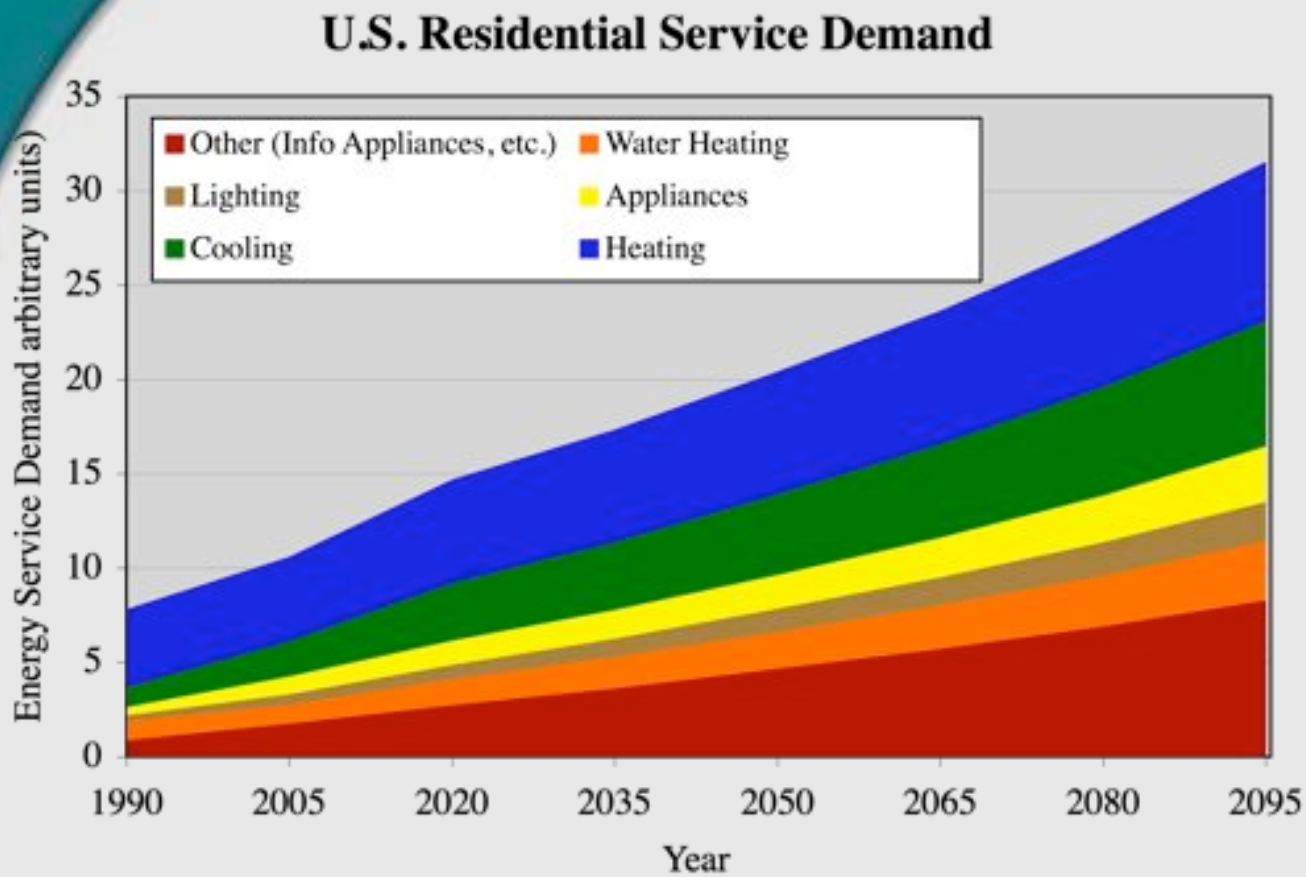
# Analysis Overview

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 CCSP 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

# Increasing Service Demands

## *Context for Future Energy Consumption*

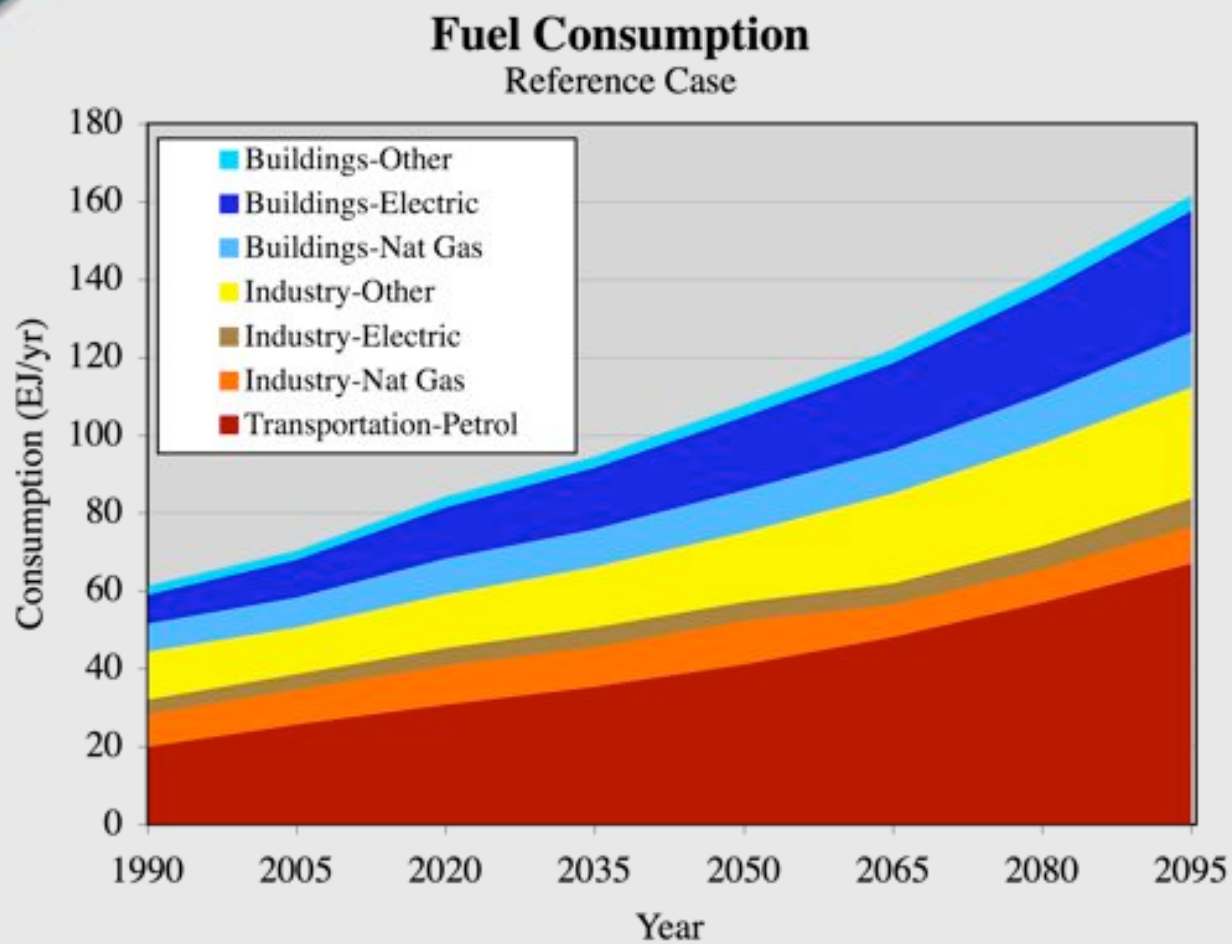



There is a strong historical record of increasing demands on a per-capita basis for floor space and transportation services.

Coupled with population growth, the results in a significant growth in the demand for energy services.

- Heating service grows relatively slowly due to internal gains & increased shell efficiency.
- Cooling increases faster since internal gains add to cooling demand (increases in building shell are also partially negated by increases in internal gains)
- Large growth in “other” demands.

# 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.

# Technology Scenarios

Three scenarios were constructed.

- Reference Case

  Continued technological advance in all end-use sectors. Advances chosen to be at a level that is “likely to occur” with existing policies.

- Advanced Case

  Further technological advances are assumed. Research goals for advanced end-use technologies are met allowing cost effective production and deployment.

- No Tech Change

  “Strawman” case with no technological advances

  - While this is not a realistic future pathway, this allows us to determine the impact of technological change in the reference case.

*In all three cases, technology choices are determined by economic competition (using a logit choice model).*

# Technology Scenarios

The cost and efficiency of the stock of each end-use technology is specified as a scenario parameter in each year for the reference and advanced cases. For example:

| | | Reference | Advanced | |
|---|---|---|---|---|
| Solid State Lighting | 2050 | 122 | 152 | Lumens/W |
| Solid State Lighting | 2095 | 127 | 186 | Lumens/W |
| | | | | |
| Hybrid Electric Cars | 2050 | 35 | 58 | mpg |
| Hybrid Electric Cars | 2100 | 39 | 75 | mpg |
| | | | | |
| Industrial Processes | 2050 | 1.05 | 1.14 | - |
| Industrial Processes | 2100 | 1.09 | 1.31 | - |

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# Technology Scenarios: Residential Building Assumptions

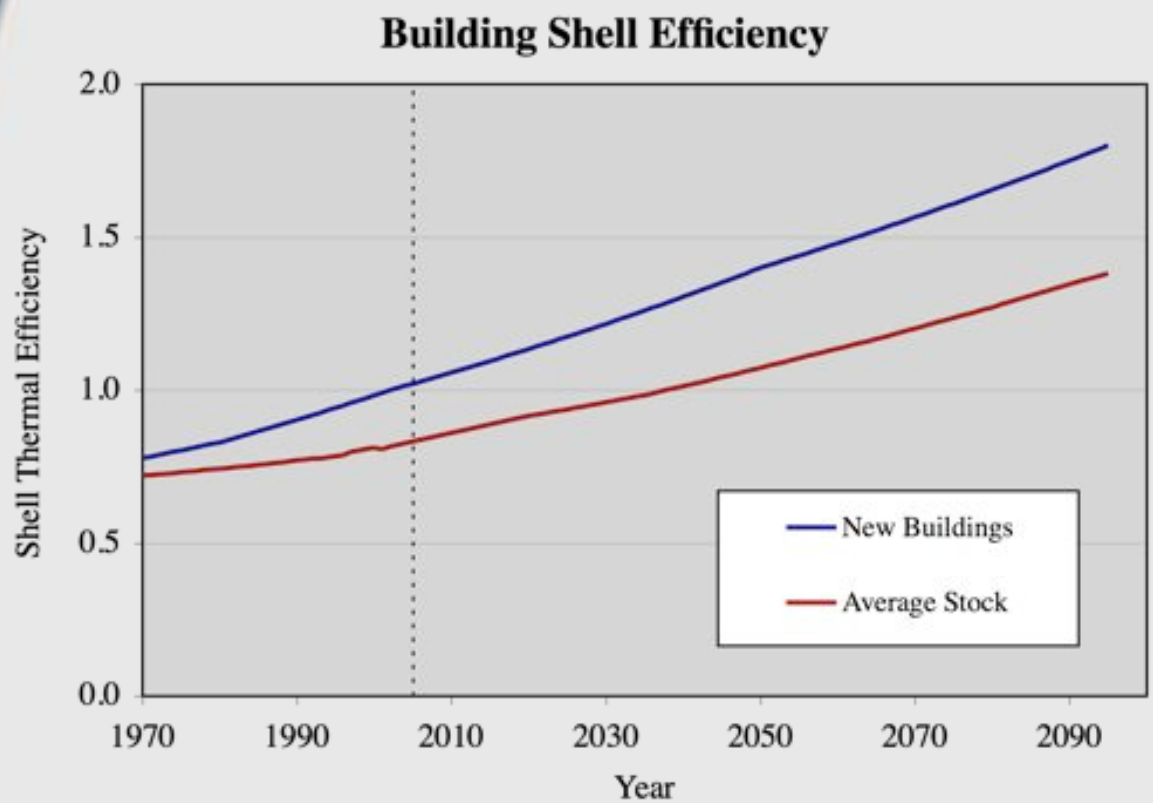
| | Historical | | Reference | | Advanced | |
|---|---|---|---|---|---|---|
| **Residential Equipment** | **1990** | **2005** | **2050** | **2095** | **2050** | **2095** |
| Shell efficiency (indexed to 2005) | 1.03 | 1.00 | 0.81 | 0.63 | 0.76 | 0.47 |
| **Heating: energy out/energy in** | | | | | | |
| Gas furnace | 0.70 | 0.82 | 0.88 | 0.91 | 0.88 | 0.91 |
| Gas heat pump | na | 1.30 | na | na | 1.67 | 1.90 |
| Electric furnace | 0.98 | 0.98 | 0.99 | 0.99 | 0.99 | 0.99 |
| Electric heatpump | 1.61 | 2.14 | 2.49 | 2.58 | 2.82 | 3.02 |
| Fuel oil furnace | 0.76 | 0.82 | 0.85 | 0.87 | 0.85 | 0.87 |
| Wood furnace | 0.52 | 0.58 | 0.66 | 0.68 | 0.66 | 0.68 |
| **Cooling: energy out/energy in** | | | | | | |
| Air Conditioning | 2.16 | 2.81 | 3.76 | 3.90 | 4.18 | 4.47 |
| **Water heating: energy out/energy in** | | | | | | |
| Gas water heater | 0.52 | 0.56 | 0.80 | 0.91 | 0.80 | 0.91 |
| Gas hp water heater | na | na | na | na | 1.53 | 1.91 |
| Electric resistance water heater | 0.84 | 0.88 | 0.95 | 0.96 | 0.95 | 0.96 |
| Electric heatpump water heater | na | na | na | na | 2.39 | 2.51 |
| Fuel oil water heater | 0.51 | 0.55 | 0.56 | 0.58 | 0.56 | 0.58 |
| **Lighting: lumens per watt** | | | | | | |
| Incandescent lighting | 15 | 15 | 17 | 18 | 17 | 18 |
| Fluorescent lighting | 65 | 75 | 100 | 107 | 100 | 107 |
| Solid-state lighting | na | na | 122 | 127 | 152 | 186 |
| **Appliances and other: indexed to 2005** | | | | | | |
| Gas appliances | 0.96 | 1.00 | 1.66 | 1.72 | 1.66 | 1.72 |
| Electric appliances | 0.70 | 1.00 | 1.42 | 1.47 | 1.58 | 1.80 |
| Gas other | 0.99 | 1.00 | 1.12 | 1.25 | 1.12 | 1.25 |
| Electric other | 1.04 | 1.00 | 0.98 | 1.01 | 1.42 | 1.47 |
| Fuel oil other | 0.99 | 1.00 | 1.05 | 1.09 | 1.05 | 1.09 |

# Building Shell Improvements

The thermal characteristics of the building shell have a substantial impact on energy consumption.

Buildings are long-lived, so important to consider stock effects.

⇒ A stock model of U.S. residential buildings was developed to guide our assumptions on long-term average building stock shell efficiency.

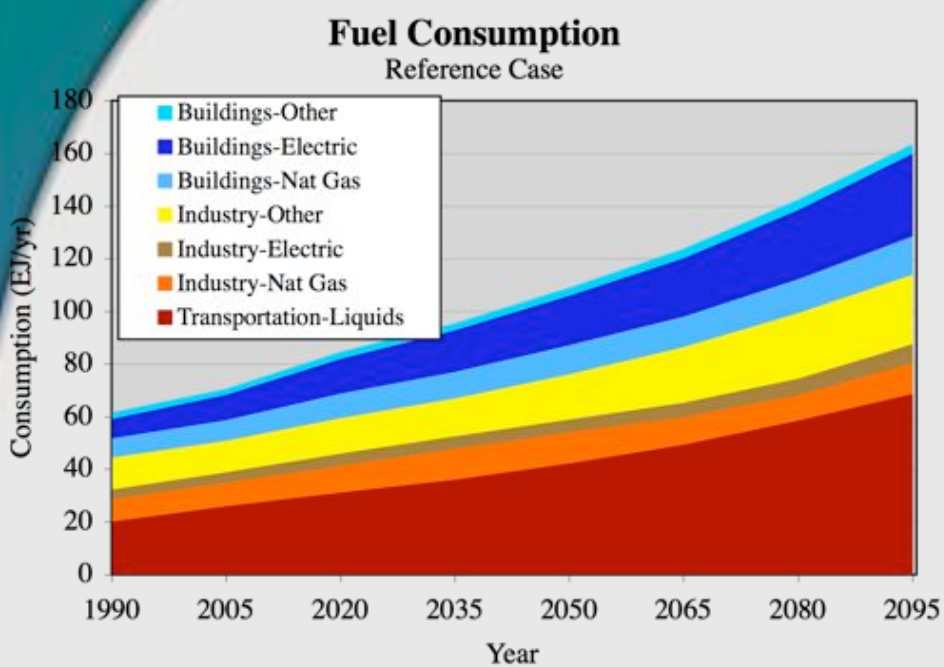


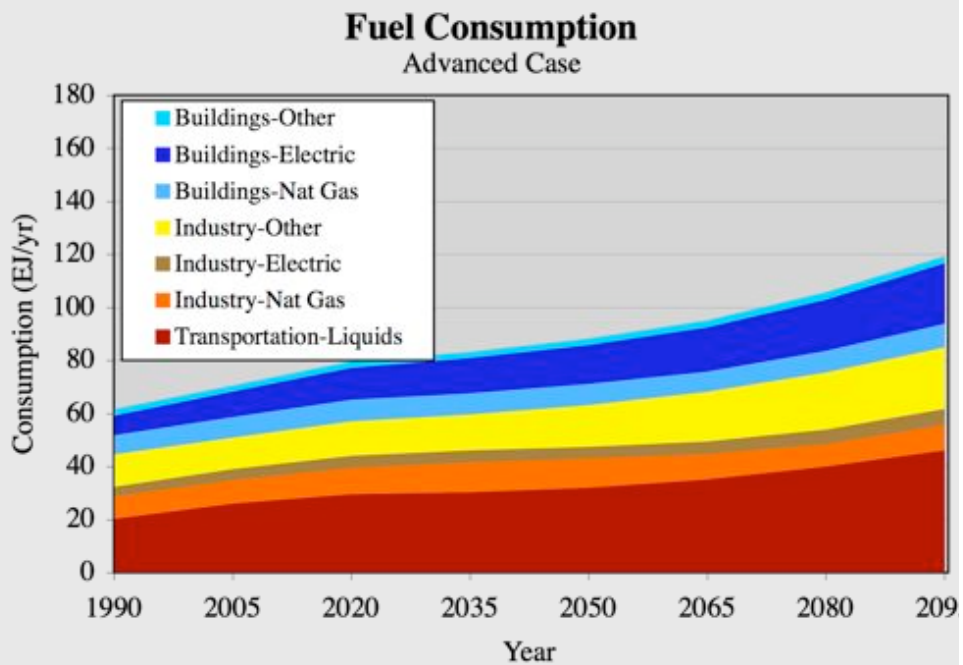

While there is some uncertainty in the past characteristics of building stock, the main effect is that improvements in average stock lag far behind new building improvements.

⇒ Retrofit options may be important (but more expensive)

⇒ Important to understand difference between average and best practice

# Energy Consumption: The Impact of Efficiency



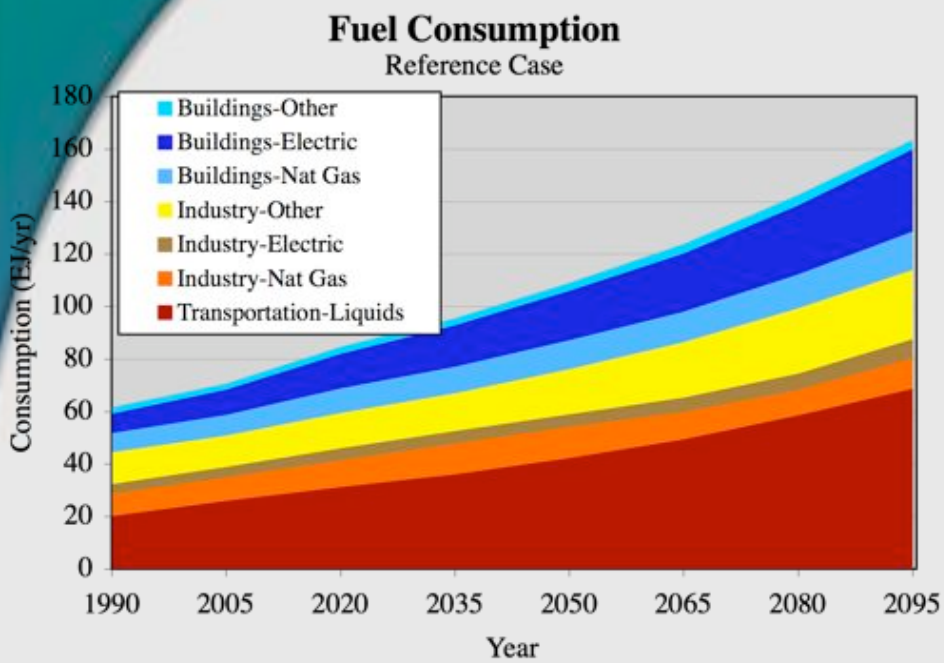

– Energy consumption increases substantially in the reference case.

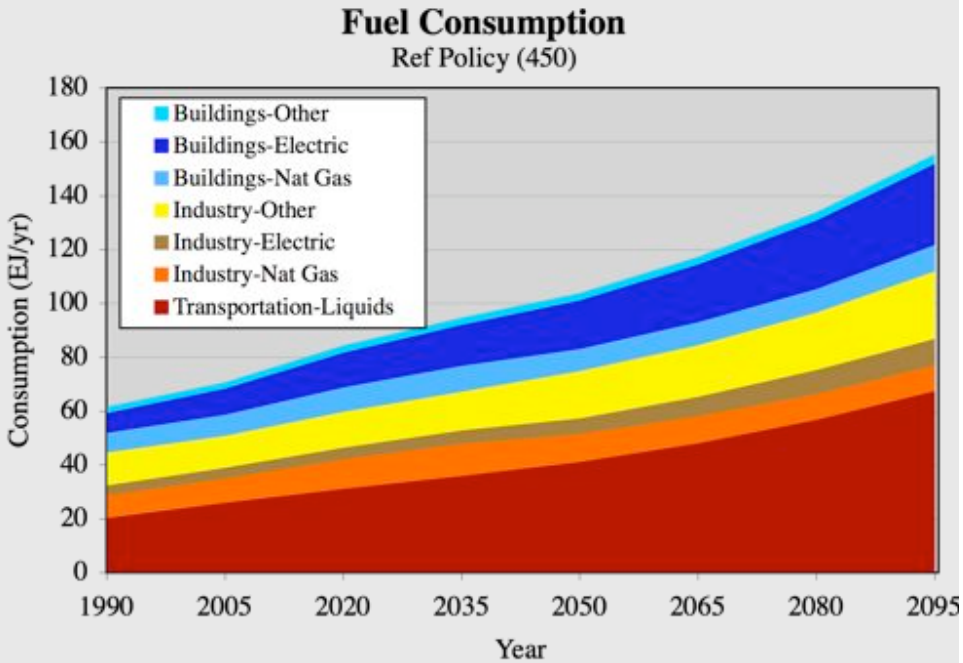
– More advanced energy efficiency options decrease the growth rate

*Even more efficiency could, theoretically, stop energy demand growth, but this is difficult.*

***It is the stock average chosen by consumers that counts**, not the best performing technology.*

# Energy Consumption: The Impact of Climate Policy



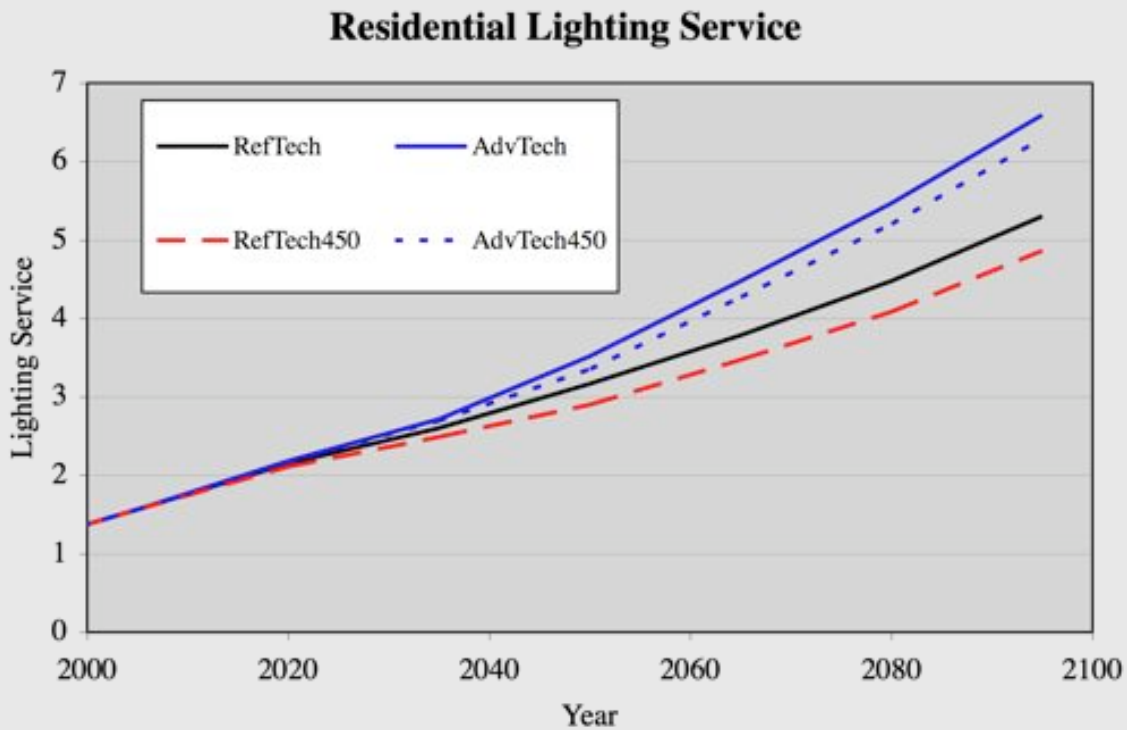




- Under a climate policy the major effect is a switch to electricity, where possible. The transportation sector switches in part to biomass-liquids such as ethanol. This effect seen particularly in buildings and industry.
- This could also happen in the transportation sector with plug-in hybrids (not included in this scenario).
- The consumption of energy services decreases slightly due to higher prices.

*Energy efficiency has a potentially much larger impact on end-use energy consumption than climate policy alone.*

# Energy Service Changes: Climate Policy and Efficiency

*Lighting service can be measured, for example, in Lumen-hours.*




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

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

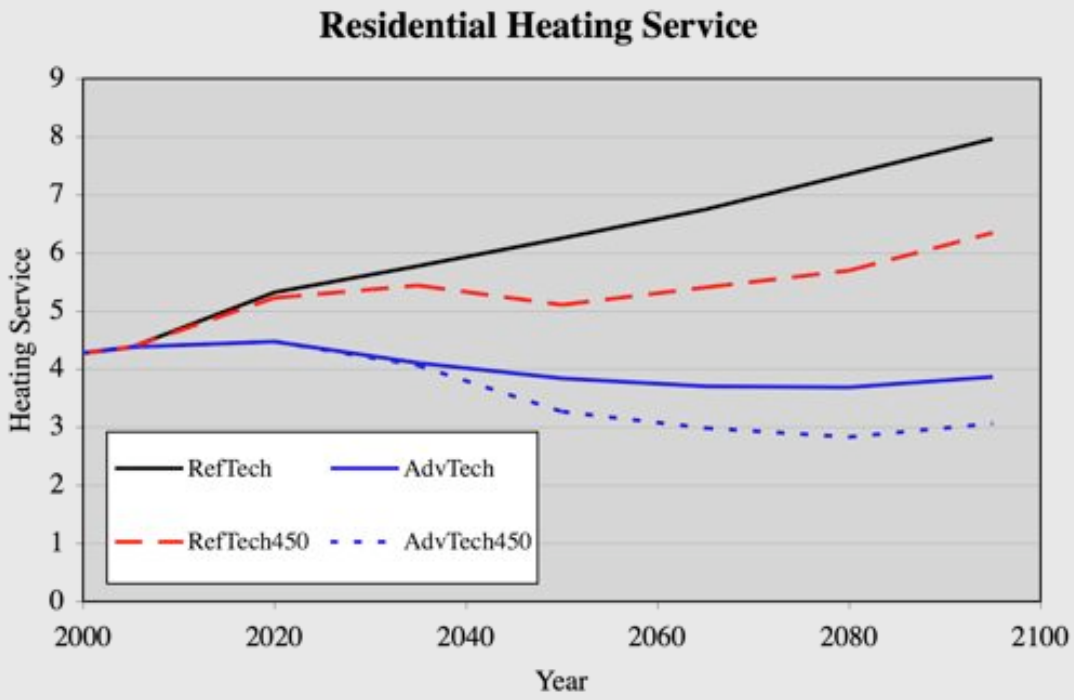
– A climate policy increases prices and reduces demand

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

And, carbon prices are lower overall.

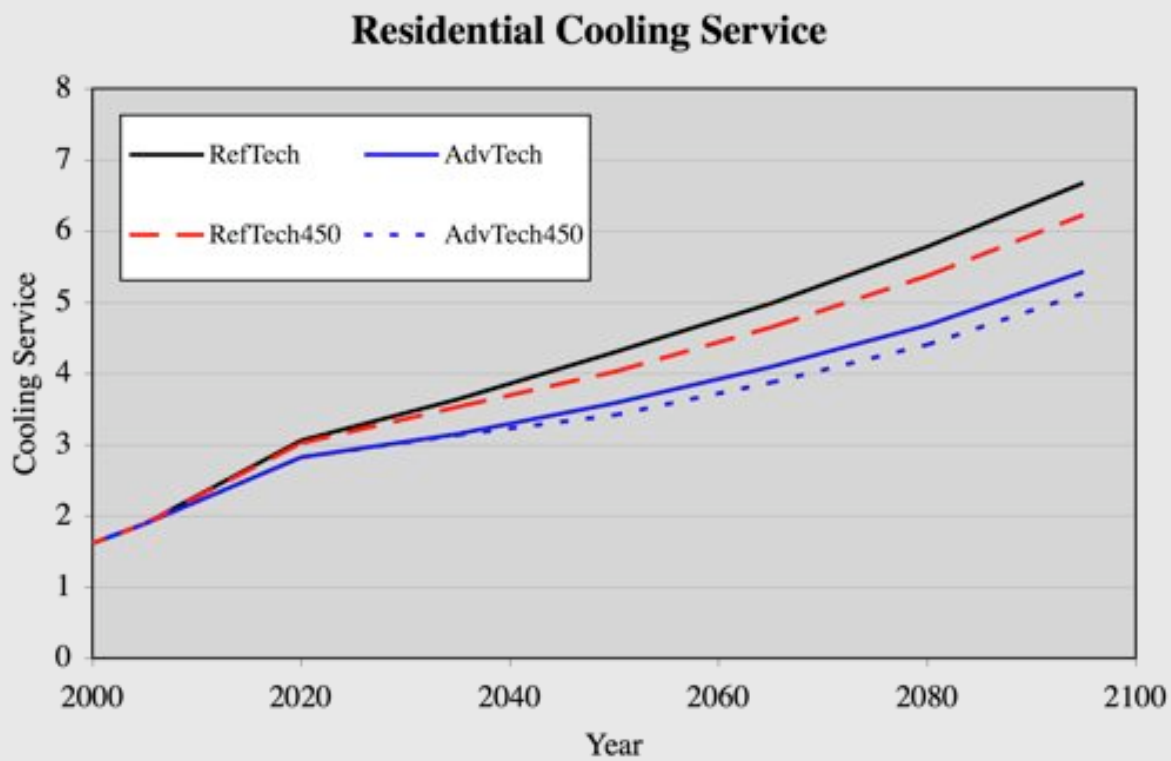
*Energy service demand is not constant across scenarios and technology options.*

# 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 effect is similar

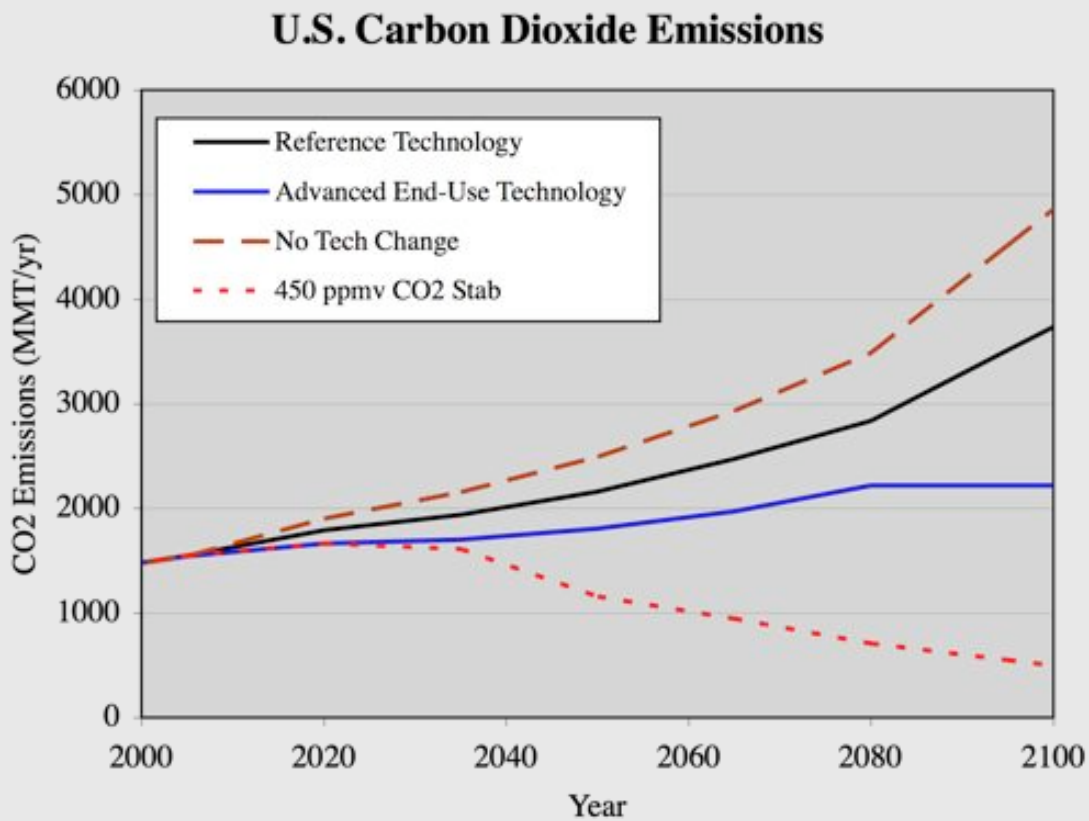
# Energy Service Changes: Cooling Service




– The changes in cooling service are much smaller overall

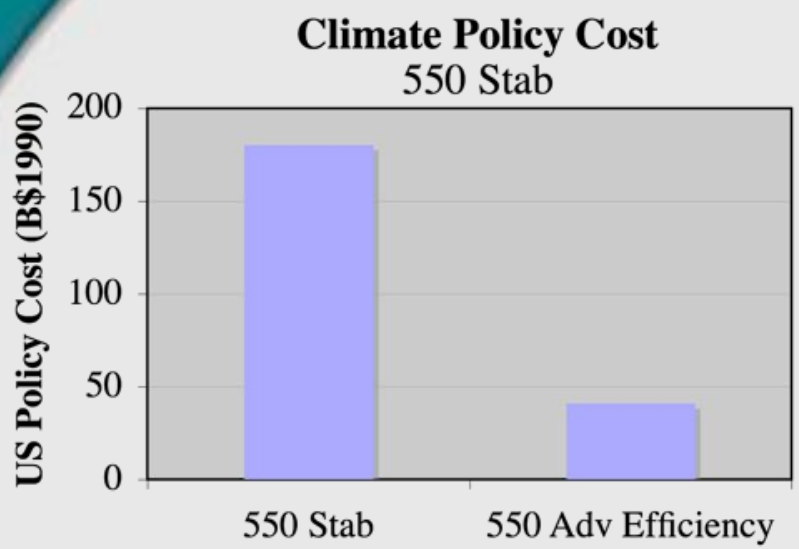
Building shell improvements reduce thermal heat flux into the building but also better trap internal gains! So less impact overall.

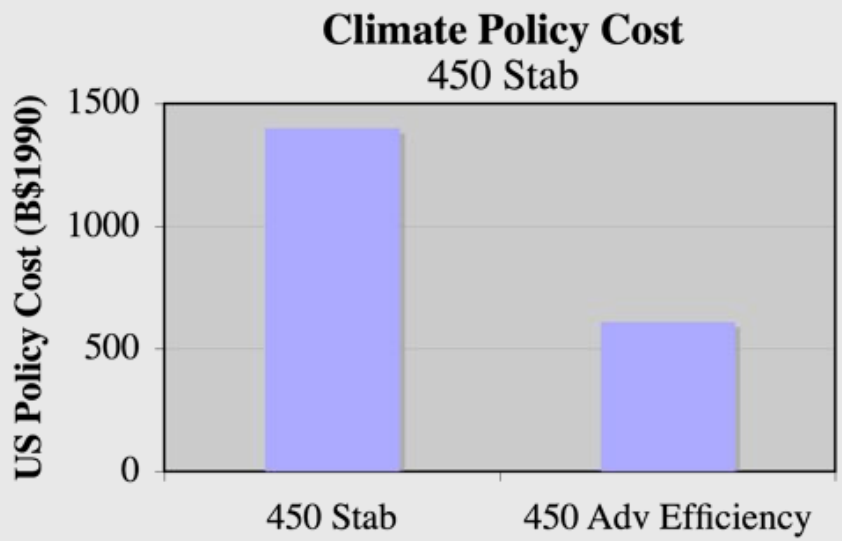
# Carbon Dioxide Emissions




- Without the technological advances embodied in reference case end-use technologies, U.S carbon emissions would be 30% larger by the end of the century.
- Emissions under the advanced scenario increase slowly.
- Even with these advances in end-use efficiency, however, carbon emissions do not fall and atmospheric $CO_2$ concentration would continue to increase.

# Value of End-Use Technology




The figures show the total U.S. discounted climate policy cost with reference technology and the case with improved end-use energy efficiency.

The deployment of advanced energy efficiency technologies lowers the cost of achieving a climate policy by 55-75% as compared to the reference case.

The relative value of efficiency is somewhat smaller for more stringent targets. For more stringent targets, emissions reductions are required earlier – which gives efficiency less time to deploy (although the effect of past efficiency policies is still present).

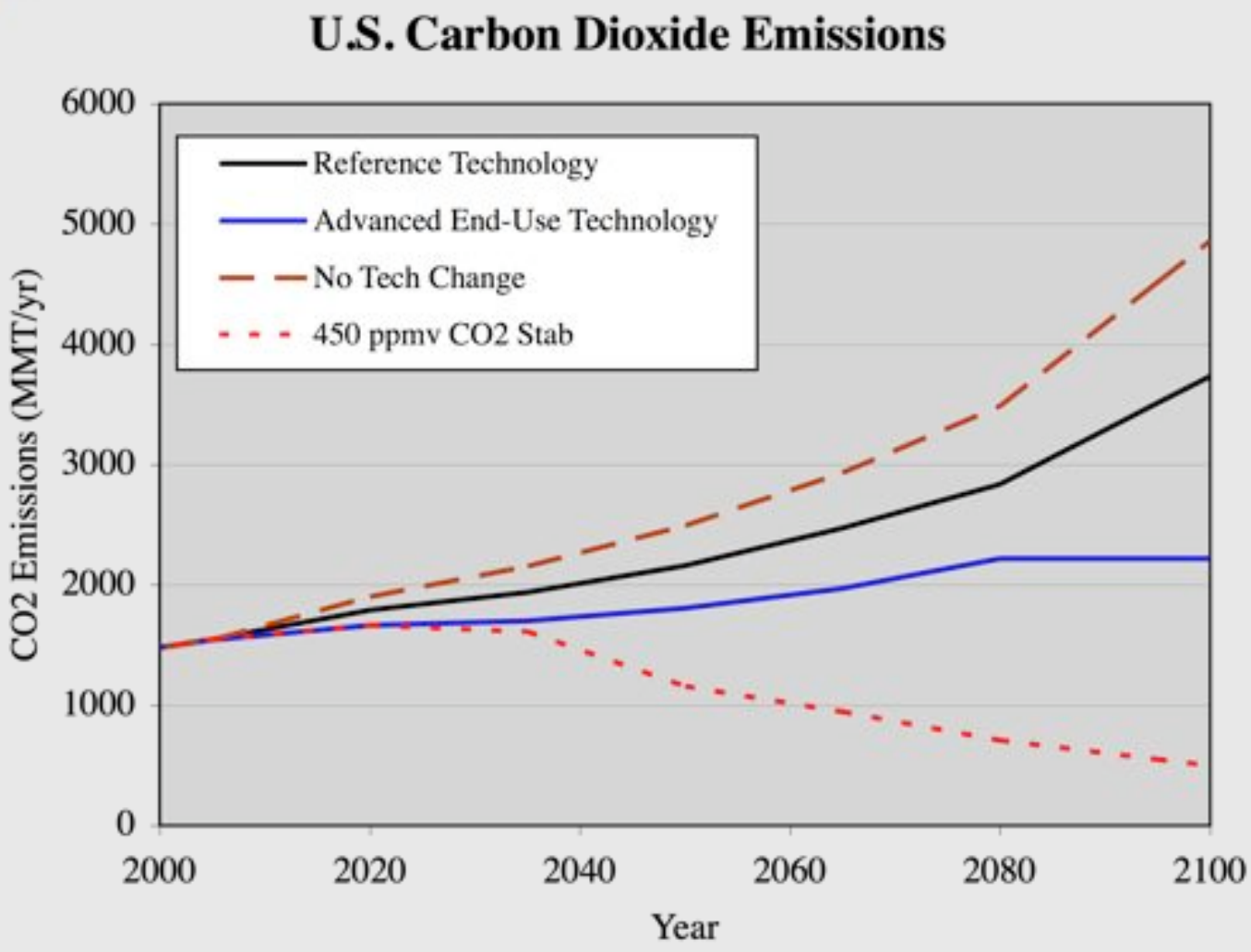
The absolute value is still much larger, however, given the overall higher costs of tighter targets.

**Cost defined as total discounted U.S. carbon payments.*

# Summary

- Enhanced energy efficiency as substantial value in a climate context.
  - *A suite of energy efficiency improvements cut policy costs by 25-45% (but we would have to have started yesterday…)*
  - *The absolute value of efficiency is higher with stronger climate targets*
- Energy efficiency could ultimately flatten, or perhaps even slightly reduce, U.S. carbon emissions.
  - *This is not sufficient, however, to stabilize the climate since emissions have to ultimate decline toward zero!*
- Energy efficiency policies can have a much larger impact on end-use energy demand than climate policies.
  - *Given the same suite of technological options, climate policy induces some end-use shifts.*
  - *Have not resolved the question of induced technological change (but if a technology is not there, its not there)*
- Long-lived infrastructure substantially affects the impact of efficiency
  - *Applies to sectors such as transport as well due to manufacturing infrastructure and road networks.*

# Carbon Dioxide Emissions




***The bottom line for climate: carbon dioxide emissions***

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