24th USAEE/IAEE
North American Conference
July 8-10, 2004, Washington, DC

Residential Energy Consumption:
Longer Term Response to Climate Change

Christian Crowley and **Frederick L. Joutz**

GWU Department of Economics and
Research Program on Forecasting

The authors wish to acknowledge John Cymbalsky (EIA) and Frank Morra (Booz Allen Hamilton) for their invaluable assistance running the NEMS simulations.

All errors and omissions rest with the authors.

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Support

This study is part of a larger joint effort supported by the EPA STAR grant

"Implications of Climate Change for Regional Air Pollution and Health Effects and Energy Consumption Behavior"

Our co-researchers in the project are from the Johns Hopkins University, Department of Geography and Environmental Engineering and the School of Public Health.

Context

The modeling efforts of the STAR grant are

1. Electricity load modeling and forecasting
   a. Hourly
   b. Long term
2. Electricity generation and dispatch modeling
3. Regional air pollution modeling
4. Health effects characterization

Aim of the Research

We consider first order effects of **hotter Summers** on residential and commercial energy demand.

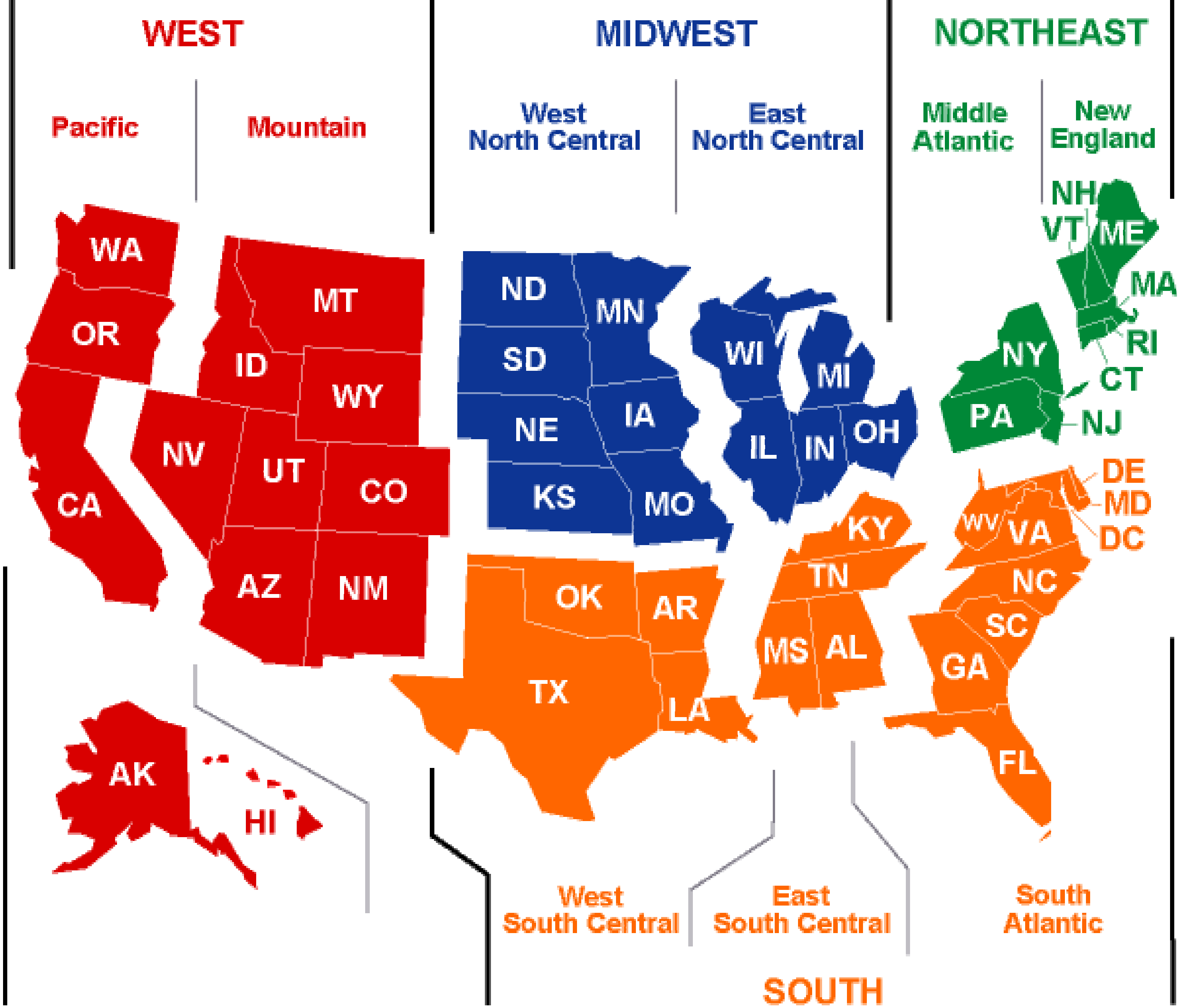
The EIA's **National Energy Modeling System** (NEMS, 2003) was used to predict the effects of warming on:

1. Energy consumption
2. Energy efficiency
3. Energy expenditure
4. Regional energy expenditure

"Residential Energy Consumption." Crowley and Joutz, GWU.

Methodology

- We developed Summer **warming scenarios** incorporating a range of Cooling Degree Day (CDD) increases.
- The scenarios allow for differences across the **nine US Census regions**.
- For example, the South West Central region has a longer Summer than New England, thus more CDDs under a warming scenario.



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US Census Divisions

Warming Scenarios

EIA base case (30-year average temperatures) results in 10,707 CDDs per year.

Introduce gradual warming over 2005-2025:

I. An increase of 2°F – the US logs 1,800 additional CDDs in 2025

II. Maximum historical CDD level – 2,629 CDDs in 2025, equivalent to a 3°F increase

III. An increase of 6°F – 5,400 additional CDDs in 2025

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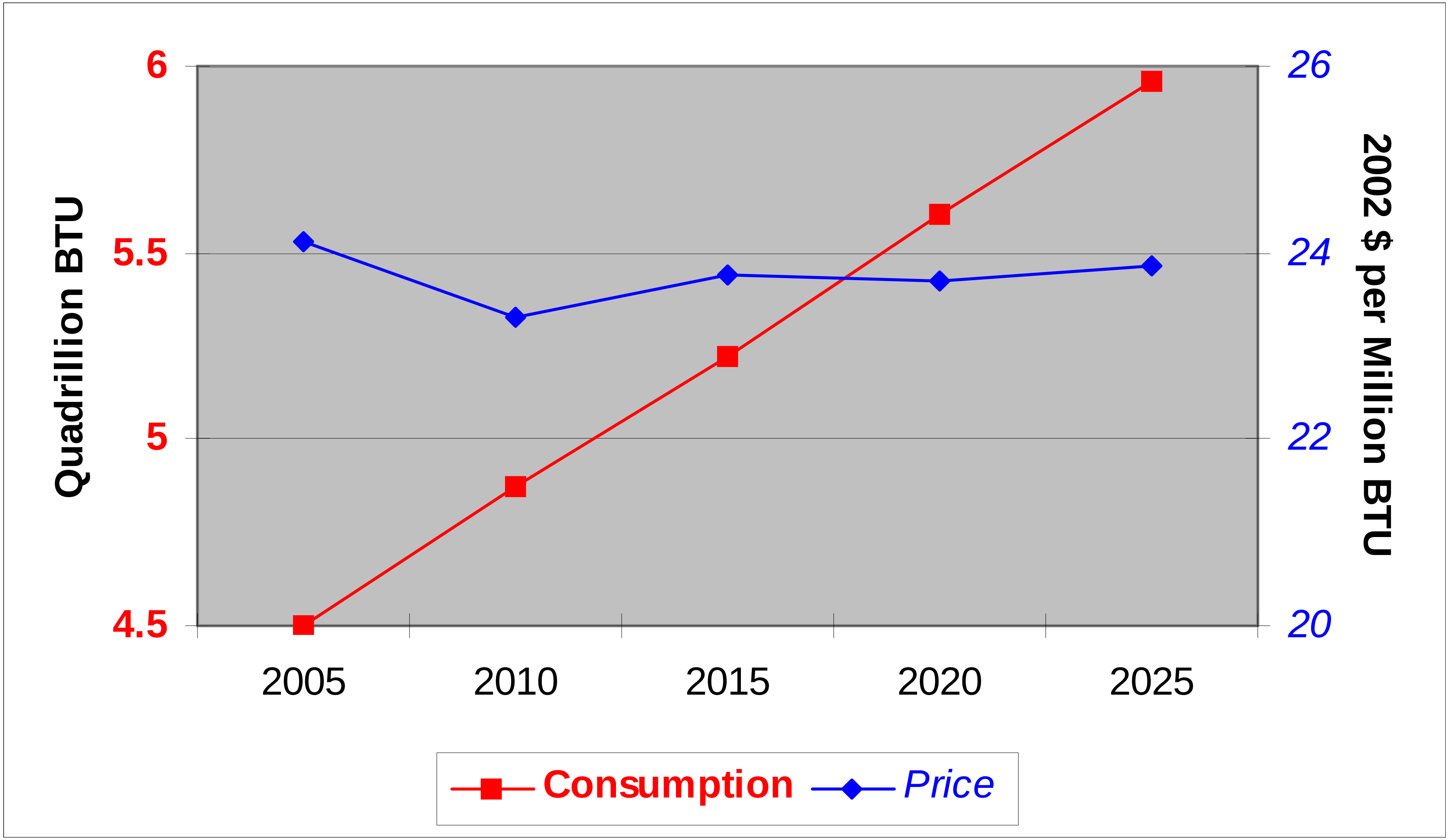
Base Case Residential Electricity - Consumption and Price



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NEMS Base Case Residential Electricity Price and Consumption

The base case expects that over the period to 2025

- Electricity consumption will increase by 32.4% to 5.96 Quadrillion BTU
- Prices will experience an initial fall, followed by a slight increase, for a net decline of 1.1%
- Increasing demand and falling price may be due to a predicted switch to cheaper generation (i.e. coal)
- Budget Share of residential electricity will decline from 2.2% to 1.5%

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Residential Electricity Expenditures (2002 dollars)

Region	2001	2025	Annual % Change
New England	868.4	943.6	0.35%
Middle Atlantic	913.9	956.6	0.19%
South Atlantic	**767.3**	**888.6**	0.61%
East North Central	842.6	984.3	0.65%
East South Central	1,136.2	1,337.7	0.68%
West North Central	1,042.1	1,203.9	0.60%
West South Central	**1,244.9**	**1,443.6**	0.62%
Mountain	794.3	883.1	0.44%
Pacific	788.0	718.5	-0.38%

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Residential Electricity Expenditures (2002 dollars)

- Lowest expenditures are in South Atlantic – $767/year
- Highest expenditures are in WSC – $1,245/year in 2001
- US expenditures increase 11.5% by 2025 (0.5% annualized)

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Base Case Descriptive Facts

	2002	**2025**	**Annual % Change**
Real Disposable Income (billion 2000 dollars)	6,578.0	12,933.0	2.86%
Population (millions)	288.9	347.5	0.77%
Households (millions)	110.3	137.8	0.93%
US Total Central Air Units (million units)	48.8	77.2	1.93%
SEER	10.5	13.1	n.a.

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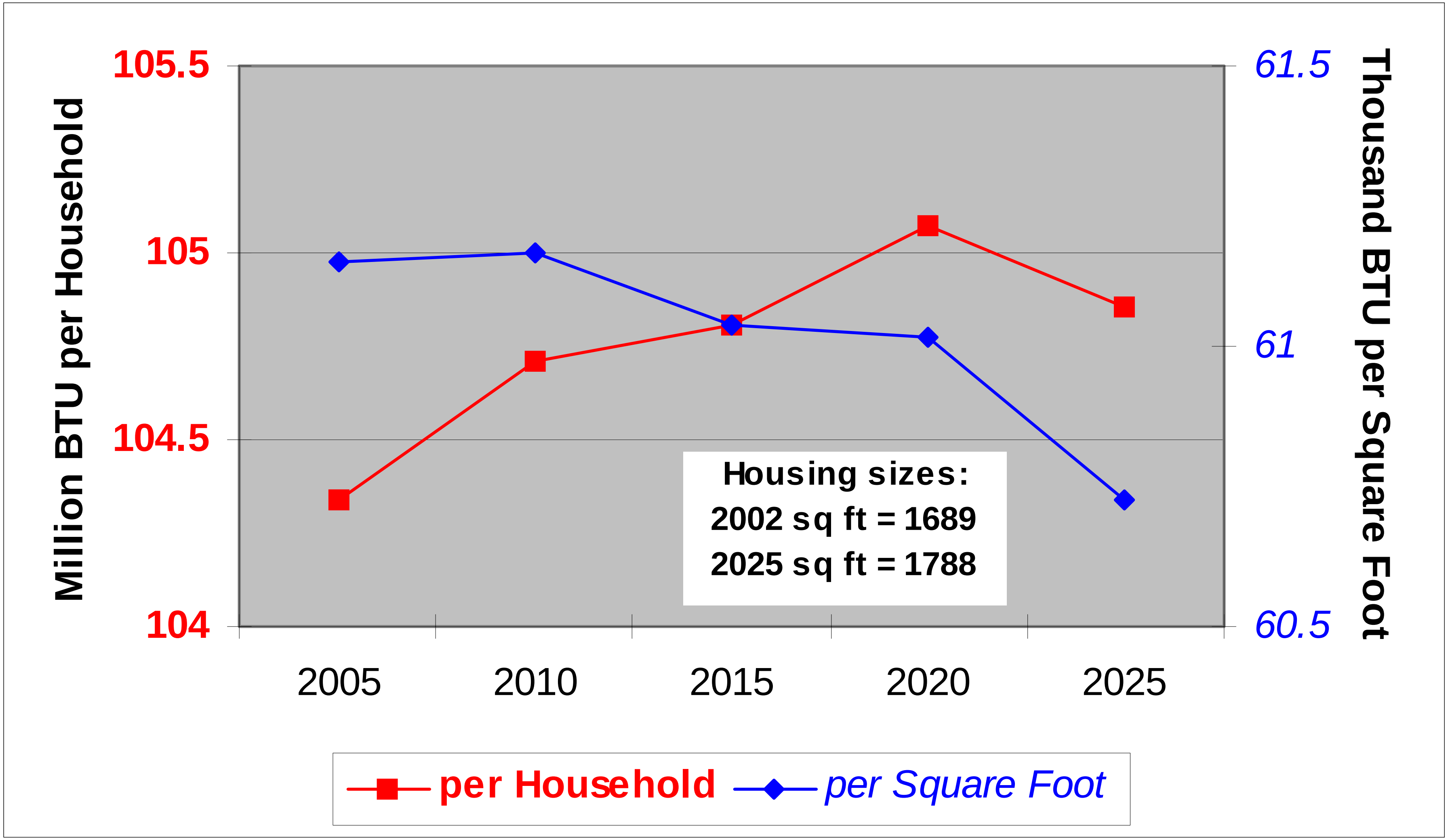
Base Case Total Residential Energy Consumption



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Total Electricity Consumption and Space Cooling

- We expect 30 million new households by 2025
- Household size declines from 2.6 to 2.5 persons
- Housing size by square foot increases 6%
- MBTU/HH increases by 0.5%
- TBTU/FT^2 declines by 0.7%

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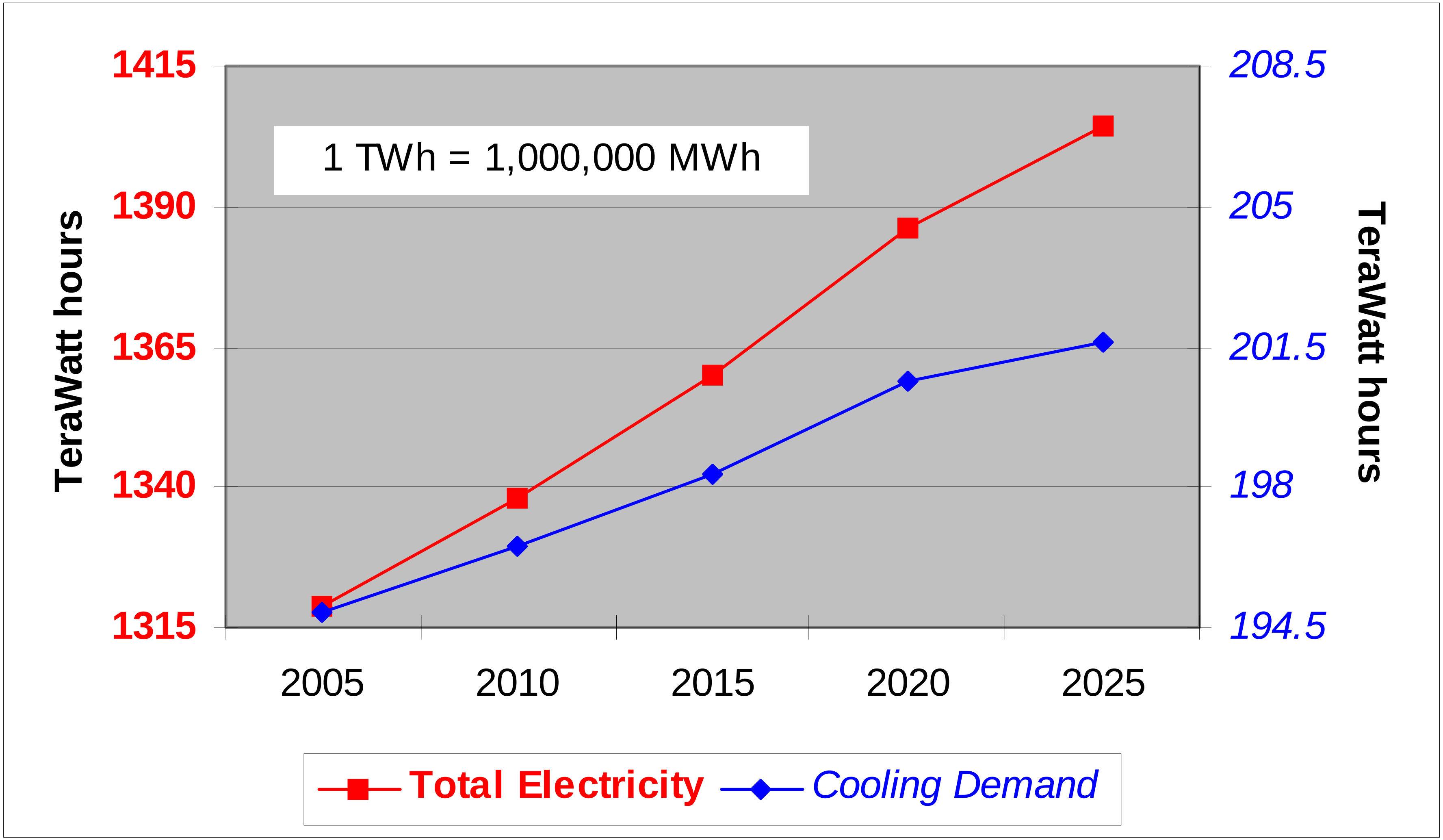
Total Electricity Consumption and Space Cooling



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Total Residential Electricity Consumption and Space Cooling

- Total residential electricity consumption increases 6.5%, to 1404 Terawatts

- Total space cooling increases 3.4% to 202 Terawatts

- Cooling’s share of total electricity consumption declines slightly to 14.4%

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Residential Electricity Prices (2002 cents per kWh)

	2002	**2025**
US	8.4	8.1
New England	**11.2**	**10.8**
Middle Atlantic	**11.2**	**10.8**
South Atlantic	7.9	7.6
East North Central	8.0	7.7
East South Central	**6.5**	**6.3**
West North Central	7.3	7.0
West South Central	7.8	7.5
Mountain	7.8	7.5
Pacific	10.2	9.8

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Residential Electricity Prices (2002 cents per kWh)

- New England and Middle Atlantic regions' electricity is most expensive at $0.11/kWh
- East South Central is cheapest: $0.065/kWh.
- Price per kWh for the US declines by 0.3 cents in real terms.

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Warming Scenarios

Temperature change by 2025:

I. 2°F increase = 1,800 additional CDDs

II. Maximum historical CDD level:
2,629 CDDs = 3°F increase

III. 6°F increase = 5,400 additional CDDs

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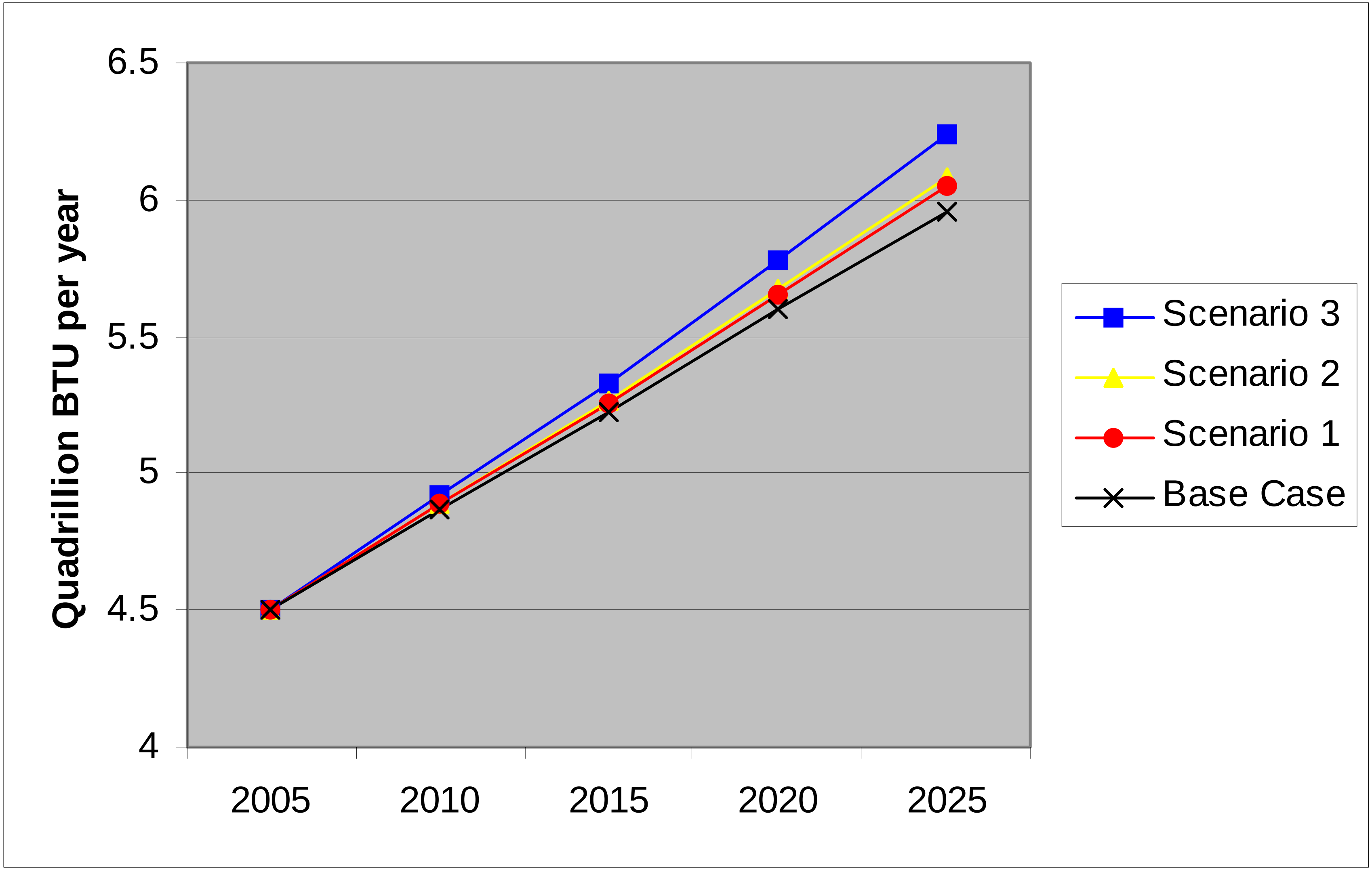
Residential Energy Consumption



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Residential Energy Consumption under the 3 Scenarios

- Base case consumption increases from 4.5 to 6.0 Quadrillion BTUs by 2025
- Scenario 1 shows an increase of an additional 1.4% over the base case
- Scenario 2 shows an increase of an additional 2.0% over the base case
- Scenario 3 shows an increase of an additional 4.7% over the base case.

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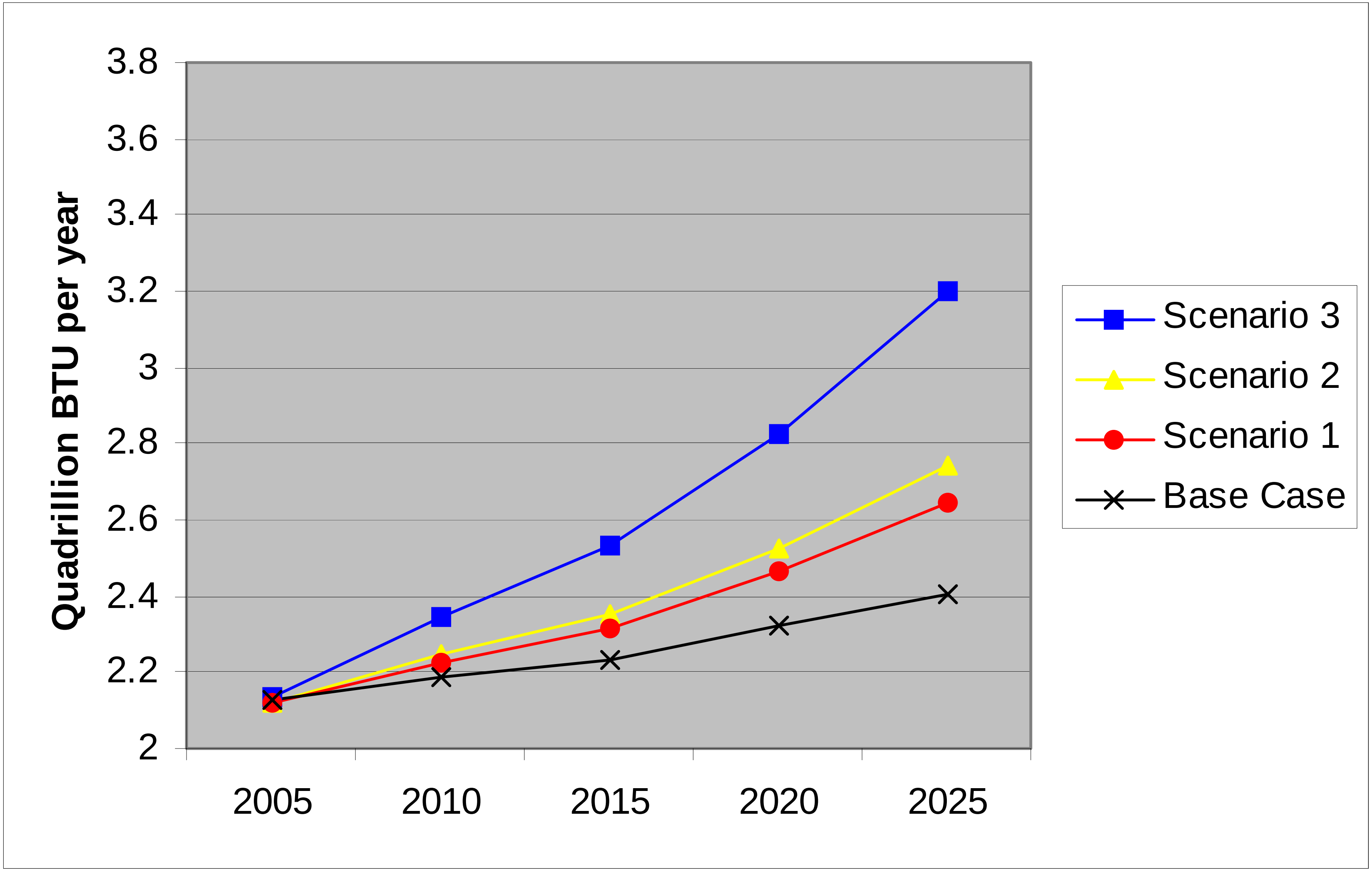
Space Cooling for Residential Energy Consumption



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Space Cooling for Residential Energy Consumption, 2005-2025

Base case is an increase from 623 to 704 TWh, with cooling accounting for 1.3% of residential energy consumption by 2025.

	Space Cooling (Terawatts)	Share of Total Energy
Scenario 1	776	1.4%
Scenario 2	803	1.4%
Scenario 3	938	1.7%

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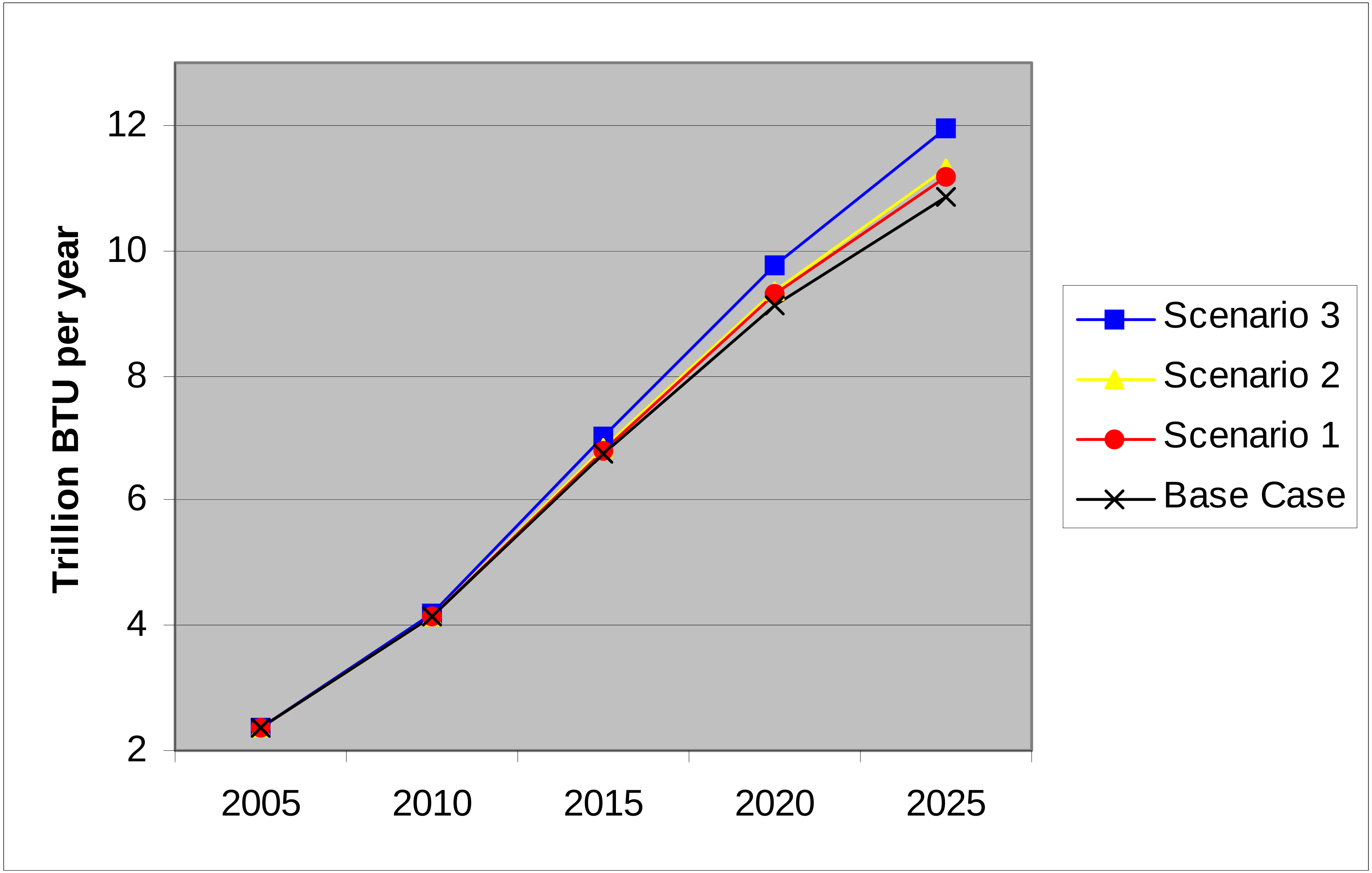
Non-marketed Renewables - Geothermal



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Conclusion

This study presents preliminary research into the impact of higher summer temperatures on residential electricity demand.

- EIA’s NEMS model (2003) was used for making projections from 2004-2025
- Three Scenarios using increases of 2°F, 3°F and 6°F over the time period
- Space Cooling Demand increases by 33% over the NEMS reference case with 6°F, and 10% in 2°F case

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Conclusion

- Our assumptions reduced household discount rate from 30% to 10%
- Fall in discount rate had little effect on technology adoption
- We do observe greater use of non-renewables, especially geothermal heat pumps
- Future efforts will focus on understanding technology choices and diffusion

- NEMS Residential Model Inputs
- Housing Stock Component
  - Housing starts
  - Existing housing stock for 1997
  - Housing stock attrition rates
  - Housing floor area trends (new and existing)
- Technology Choice Component
  - Equipment capital cost
  - Equipment energy efficiency
  - Market share of new appliances
  - Efficiency of retiring equipment
  - Appliance penetration factors
- Appliance Stock Component
  - Expected equipment minimum and maximum lifetimes
  - Base year appliance market shares
  - Equipment saturation level

“Residential Energy Consumption.” Crowley and Joutz, GWU.

- NEMS Residential Model Inputs
- Building Shell Component
  - Maximum level of shell integrity
  - Price elasticity of shell integrity
  - Rate of improvement in existing housing shell integrity
  - Cost and efficiency of various building shell measures
- Distributed Generation Component
  - Equipment Cost
  - Equipment Efficiency
  - Solar Insolation Values
  - System Penetration Parameters
- Energy Consumption Component
  - Unit energy consumption (UEC)
  - Heating and cooling degree days
  - Expected fuel savings based upon the 1992 Energy Policy Act (EPACT)
- Population
- Personal disposable income

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- ***NEMS Residential Outputs***
- Forecasted residential sector energy consumption by fuel type, service, and Census Division is the primary module output. The module also forecasts housing stock, and energy consumption per household. In addition, the module can produce a disaggregated forecast of appliance stock and efficiency. The types of appliances included in this forecast are:
- Heat pumps (electric air-source, natural gas, and ground-source)
- Furnaces (electric, natural gas, LPG, and distillate)
- Hydronic heating systems (natural gas, distillate, and kerosene)
- Wood stoves
- Air conditioners (central and room)

- ***NEMS Residential Outputs***

- Dishwashers
- Water heaters (electric, natural gas, distillate, LPG, and solar)
- Ranges/Ovens (electric, natural gas, and LPG)
- Clothes dryers (electric and natural gas)
- Refrigerators
- Freezers
- Clothes Washers
- Fuel Cells
- Solar Photovoltaic Systems

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- ***Technology Choice***
- The efficiency choices made for residential equipment are based on a log-linear function. The
- functional form is flexible, to allow the user to specify parameters as either life-cycle costs, or as
- weighted of bias, capital and discounted operating costs. Currently, the module calculates choices
- based on the latter approach. A time dependant function calculates the installed capital cost of
- equipment in new construction based on logistic shape parameters. If fuel prices increase
- markedly and remain high over a multi-year period, efficient appliances will be available earlier in
- the forecast period than would have otherwise.

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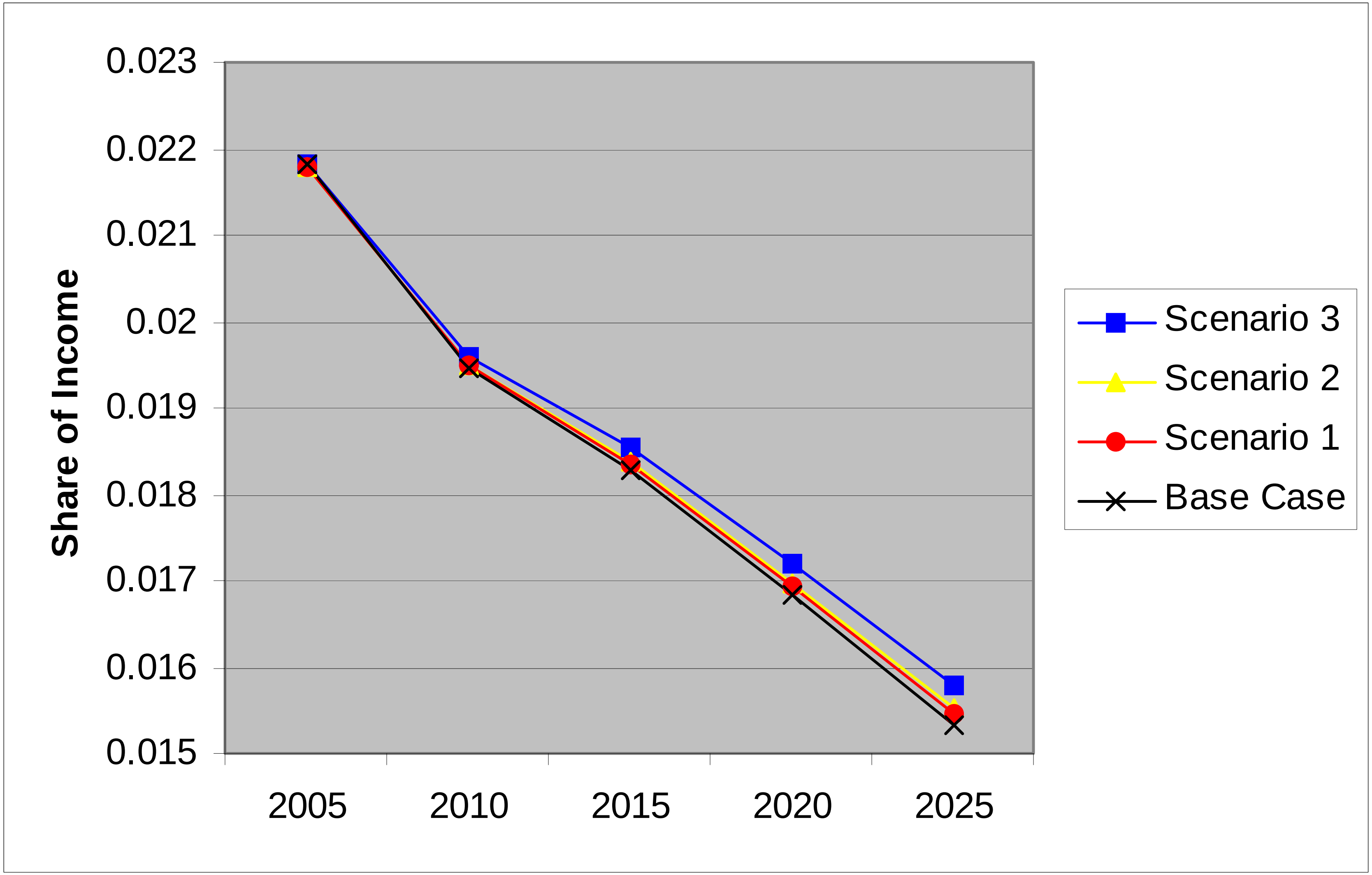
- ***Technology Switching***
- Space heaters, heat pump air conditioners, water heaters, stoves, and clothes dryers may be replaced with competing technologies in single-family homes. The amount of equipment which may switch is based on a model input. The technology choice is based on a log-linear function.
- The functional form is flexible to allow the user to specify parameters, such as weighted bias, retail equipment cost, and technology switching cost. Replacements are with the same technology in multifamily and mobile homes. A time dependant function calculates the retail cost of replacement equipment based on logistic shape parameters.

- ***Space Cooling: Room and Central Air Conditioning Units***
- Room and central air conditioning units are disaggregated based on existing housing data. The market penetration of room and central air systems by Census Division and housing type, along with new housing construction data, are used to determine the number of new units of each type. The penetration rate for central air-conditioning is estimated by means of time series analysis of RECS survey data.

- ***Water Heating: Solar Water Heaters***
- Market shares for solar water heaters are tabulated from the 1997 RECS data base. The module currently assumes that solar energy provides 55% of the energy needed to satisfy hot water demand, and the remaining 45% is satisfied by an electric back-up unit.

Residential Energy's Share of Real Disposable Income



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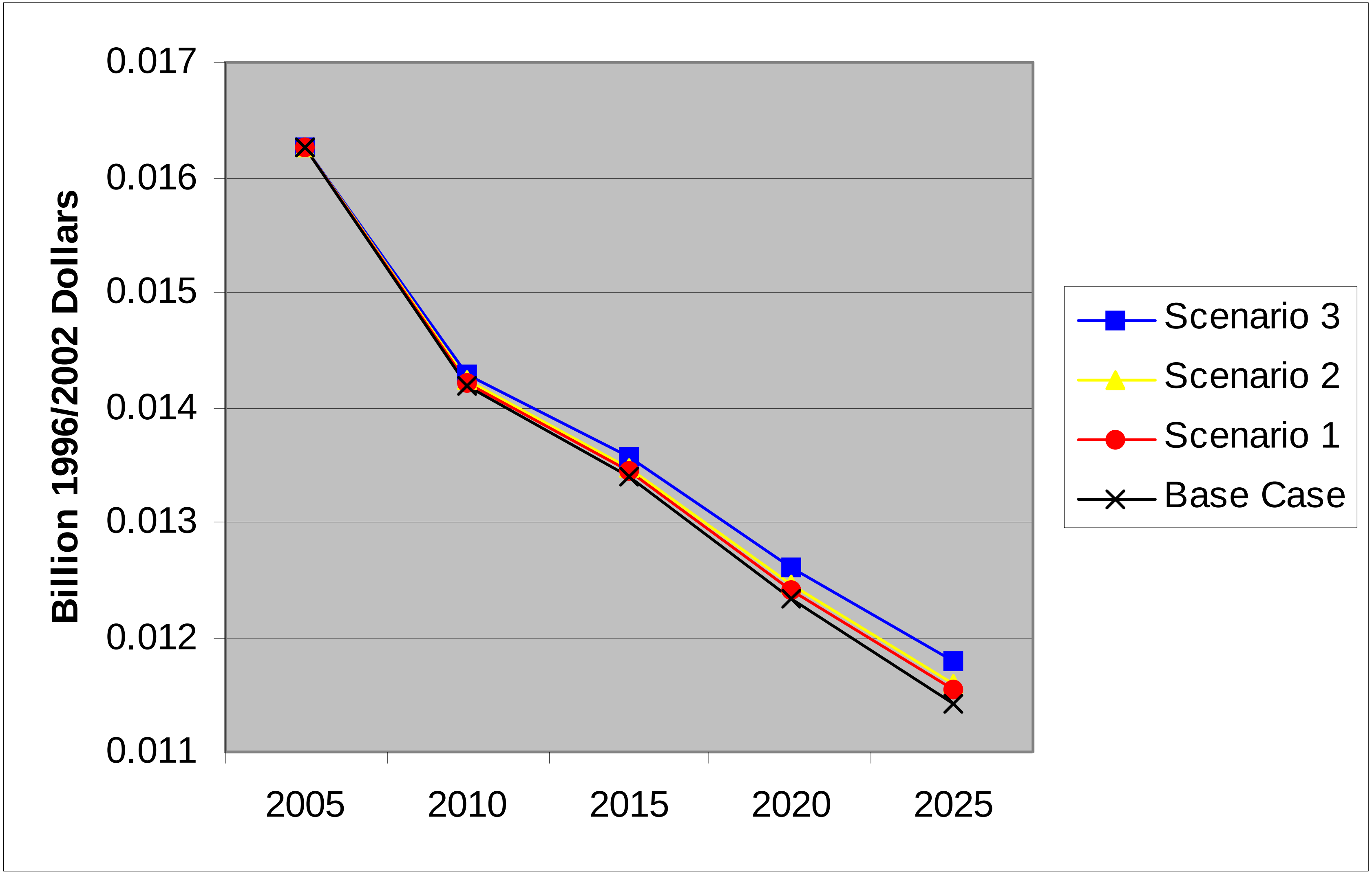
Residential Energy's Share of GDP



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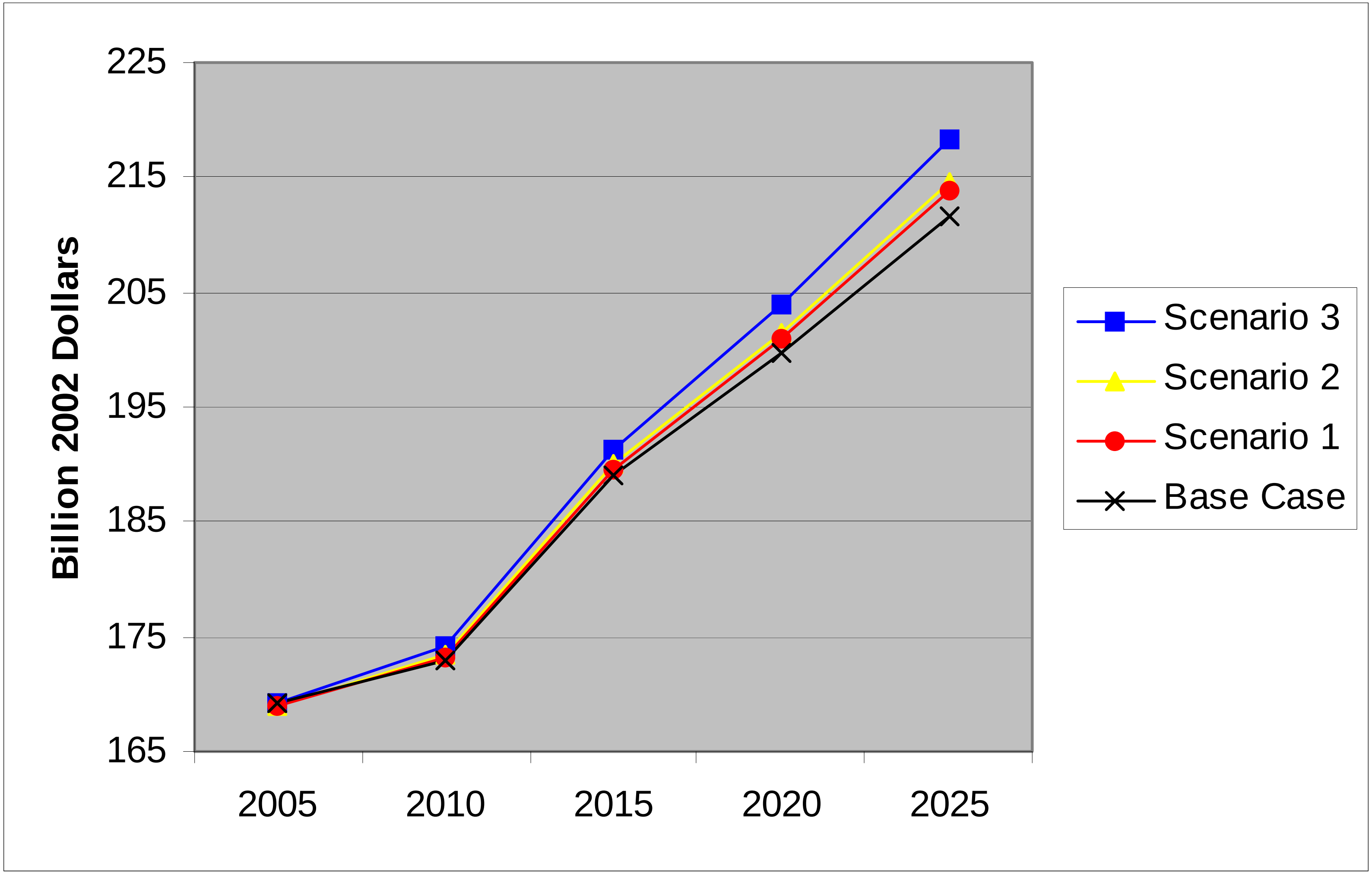
Non-Renewable Energy Expenditures (Residential)



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Non-Renewable Energy Expenditures (Residential)

- The Climate scenarios suggest an increase in

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Caveats

- Temperature warming due to climate change could be expected to reduce HDDs during Winter months.
- Without reliable scenarios for Winter warming, EIA assumptions for HDDs were not changed in our scenarios.
- Additional uncertainty may arise from increased variability in temperature associated with climate change.

Scenario I

For each Census Region:

1. Start with 30-year average annual CDDs (EIA reference case)
2. Determine days in cooling season
3. Calculate yearly CDD increment
4. Generate CDD series 2005-2021

Scenario I – Step 1

1. *Start with 30-year average annual CDDs*

Data is drawn from EIA's calculations of average annual CDDs between 1968 and 1997.

Scenario I – Step 2

2. *Determine days in cooling season*

Average temperatures over the past decade indicate the length of the cooling season.

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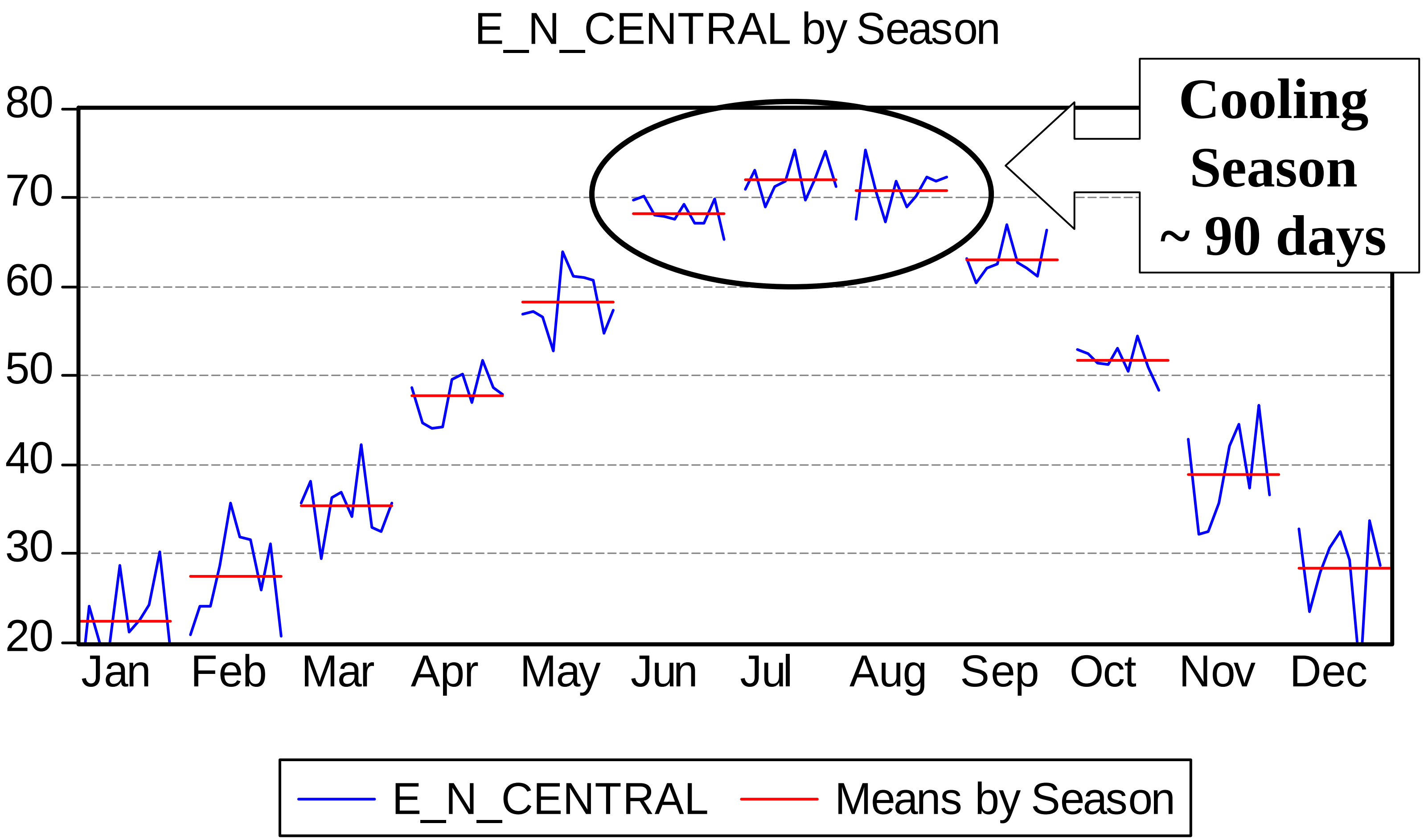
Monthly Temp (°F) 1993-2004



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Scenario I – Step 3

3. *Calculate yearly CDD increment*

2 CDDs for each day in the cooling season, phased in gradually over 2005-2025

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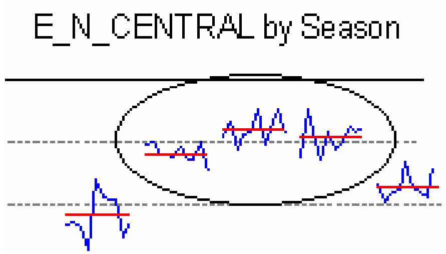
Example – CDD Increment

- East North Central region has 90 days in their cooling season:



- 2 CDD warming × 90 days = 180 CDDs added to the cooling season.
- Over 2005-2025 this is an increment of 8.6 CDDs per year.

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Scenario I – Step 4

4. *Generate CDD series for 2005-2025*

Starting with the 30-year average CDDs, increase each year's CDDs by the increment.

Census Region -->	East North Central
30 year ave CDDs	735
Increment	*8.6*
2005	743.6
2006	752.2
2007	760.8
2008	769.4
2009	777.9
2010	786.5

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Scenarios III

III. Gradual warming of 6°F over 2005-2025

Scenarios III is similar to I, but with a warming of 6°F rather than 2°F .

Census Region -->	East North Central
30 year ave CDDs	735
increment	*25.7*
2005	760.8
2006	786.5
2007	812.2

"Residential Energy Consumption." Crowley and Joutz, GWU.

Scenarios III and IV

III. Gradual warming to historical maximum

IV. One-time increase to historical maximum

Scenarios III and IV are also similar to I and II, but use the historical max CDDs as the target level for 2025.

Census Region -->	East North Central
30 year ave CDDs	735
max historical year	*2002*
max historical CDDs	*933*
increment	*9.4*
2005	744.5
…	…
2025	933.0

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NEMS Results

- Running the NEMS Residential, Commercial and Industrial modules with the standard assumptions results in an increase in cooling demand. Other variables remain largely unchanged.
- Recall that these are first order effects of Summer warming only.

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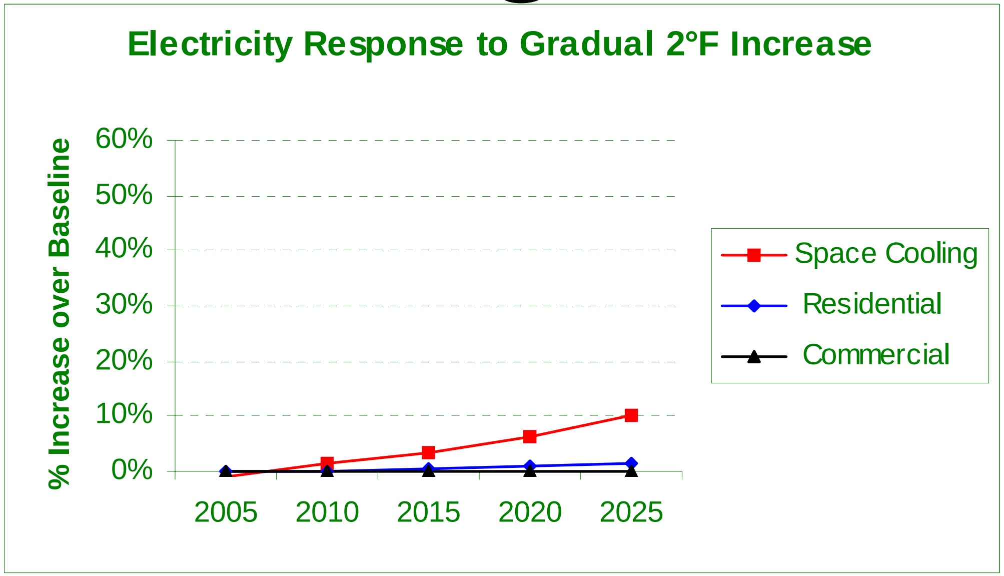
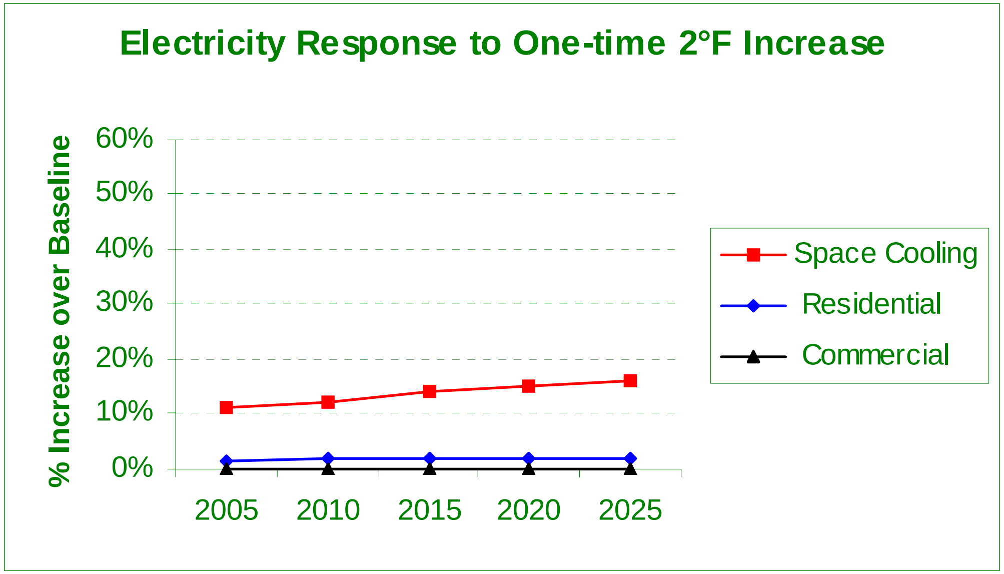
NEMS Results – Cooling Demand

Scenario I



Scenario II



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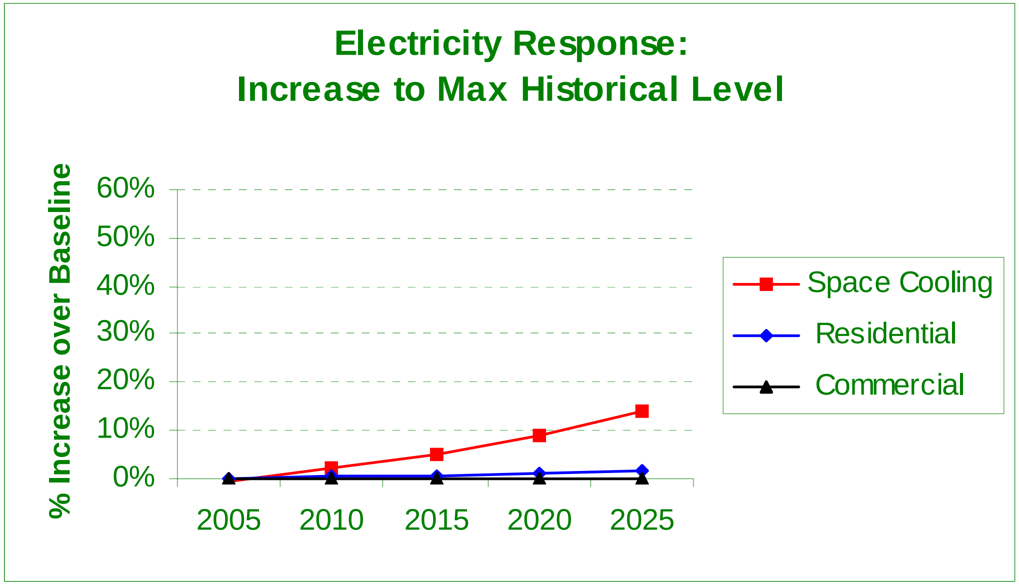
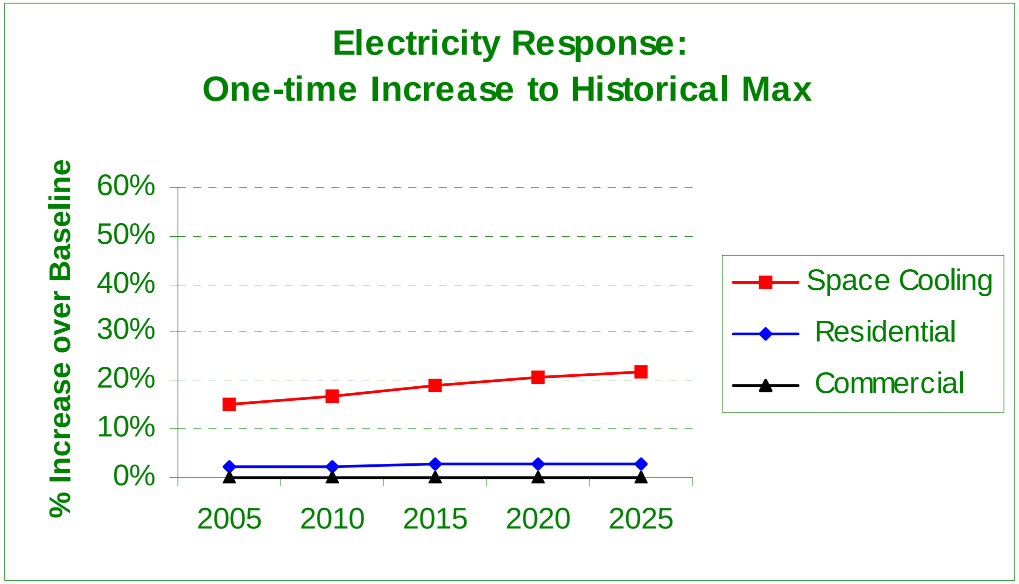
NEMS Results – Cooling Demand

Scenario III



Scenario IV



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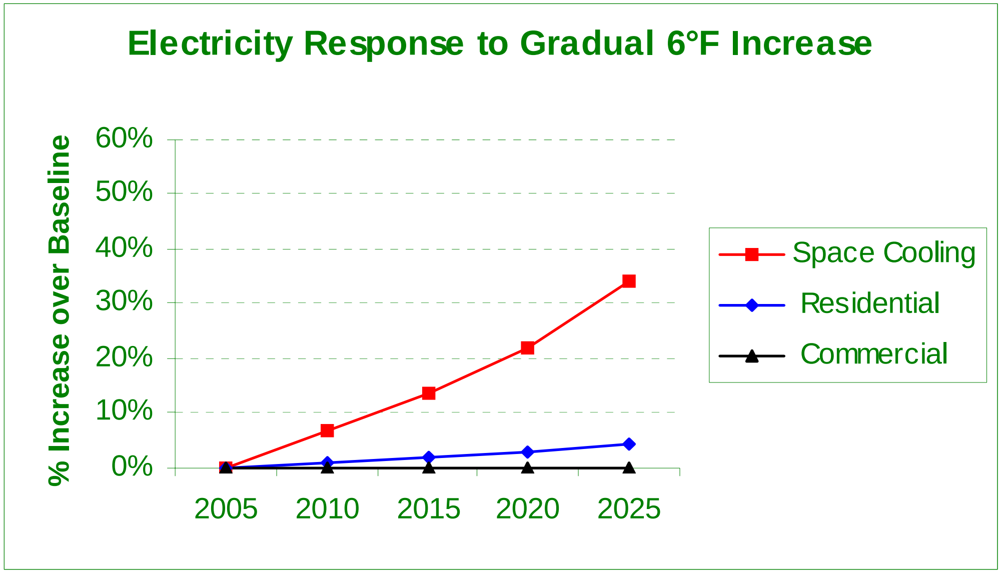
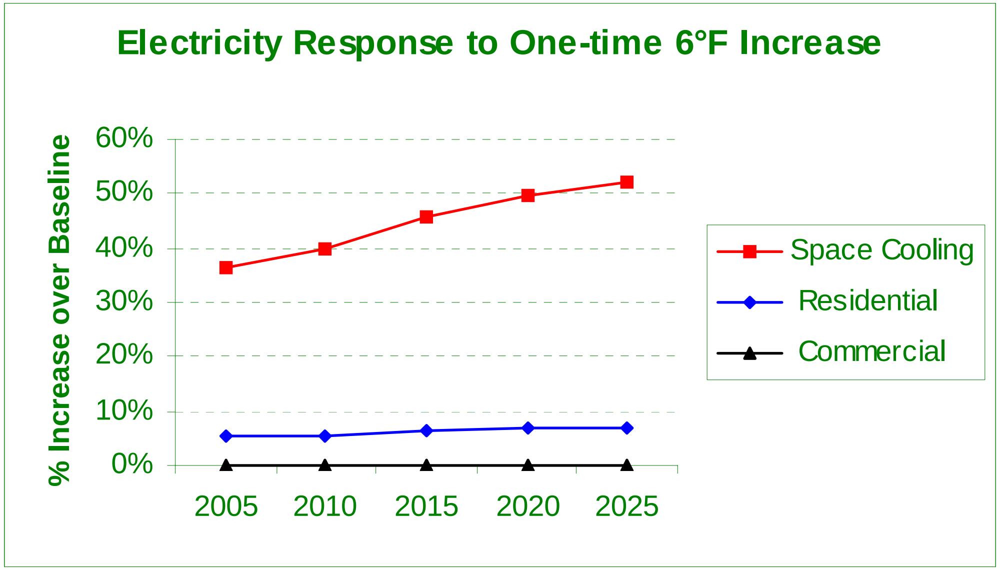
NEMS Results – Cooling Demand

Scenario V



Scenario VI



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Warming Scenarios

I. Gradual Warming of 2°F over 2005-2025

II. One-time Increase of 2°F in 2005

III. Gradual Warming to Historical Maximum

IV. One-time Increase to Historical Maximum

V. Gradual Warming of 6°F over 2005-2025

VI. One-time Increase of 6°F in 2005

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