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Residential Energy Consumption:
Longer Term Response to Climate Change

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Context

- This study is part of a larger joint effort supported by an 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 (cont.)

The four modeling efforts of the project 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

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Aim of the Research

- Our goal is to consider first order effects of hotter Summers on residential and commercial energy demand.
- We developed Summer warming scenarios incorporating a range of Cooling Degree Day (CDD) increases.
- The Scenarios are by the 9 Census regions.

Aim of the Research

The EIA's National Energy Modeling System (NEMS) was used to predict the effects of these scenarios on

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

Warming Scenarios

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

II. Gradual Warming up to Maximum Historical level of CDDs (1968 - 2003)

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

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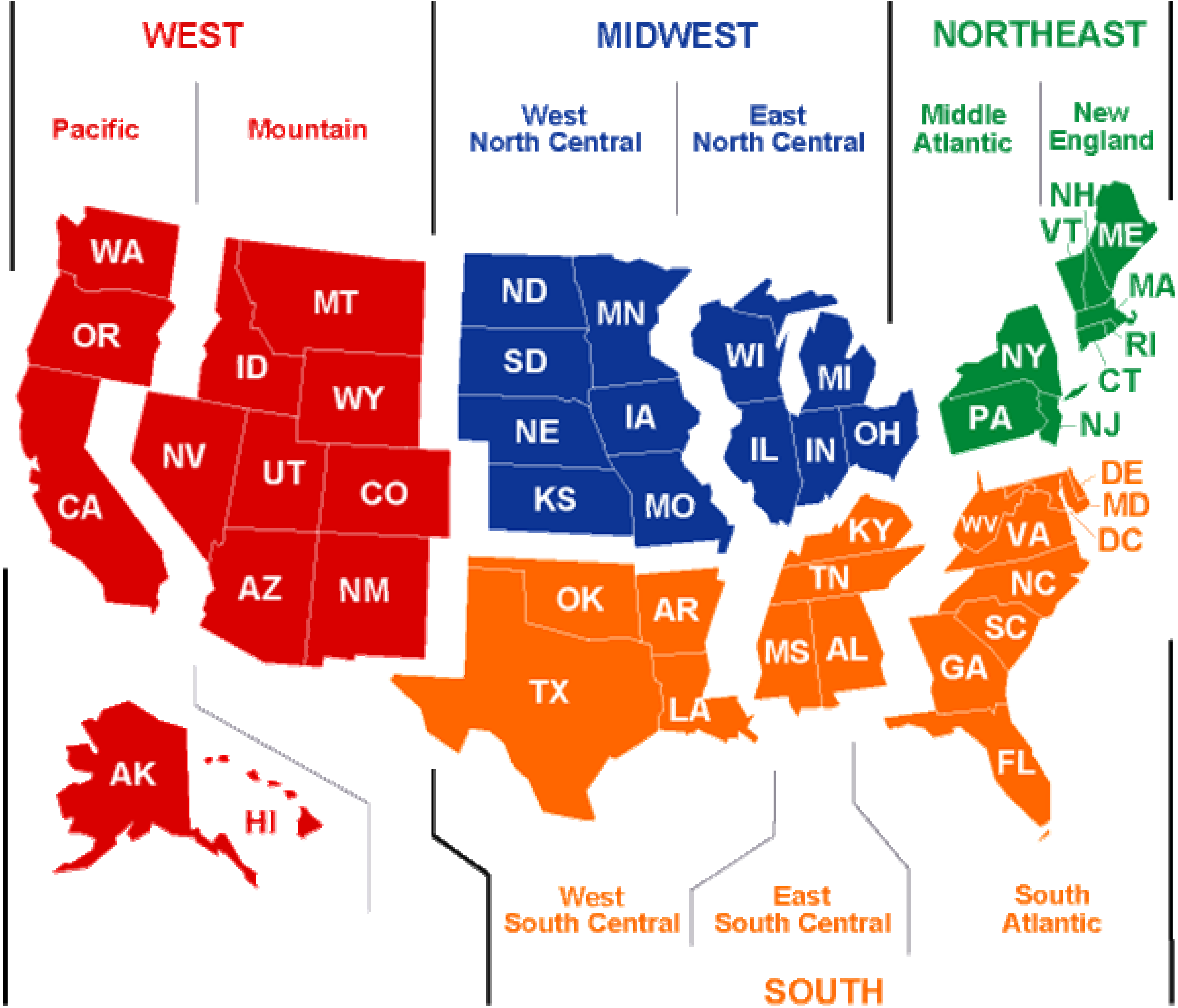

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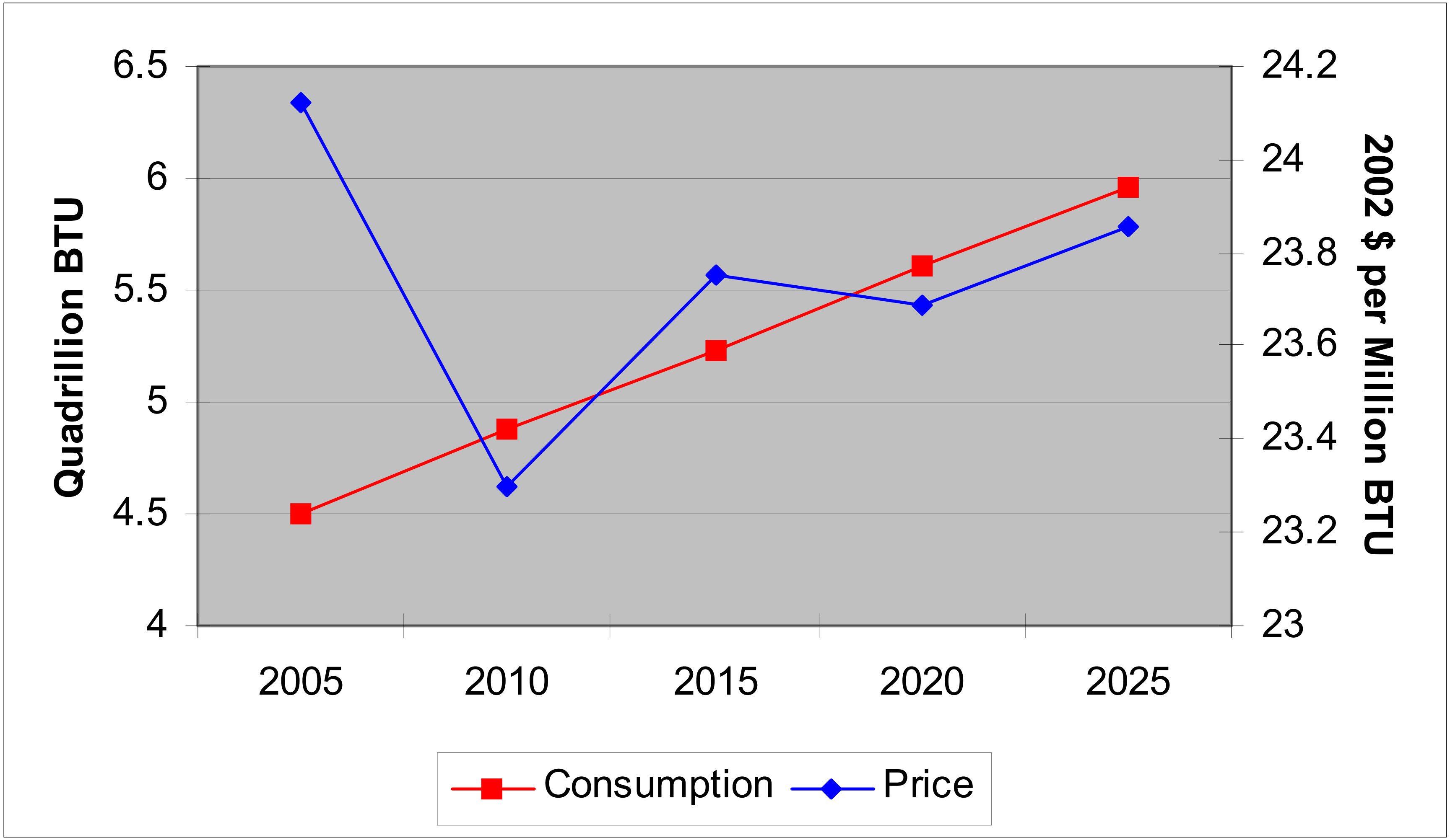
US Census Divisions

NEMS Base Case Residential Electricity - Price and Consumption



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

NEMS Base Case Residential Electricity - Price and Consumption

- The Reference Case 2005-2025 suggests that:
  – Consumption rises by 1.5 Quadrillion BTU
  – Prices are expected to decline by 5% by 2010 then rise slightly, but on net decline.

    Budget Share of residential electricity declines 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)

- Most expensive region is WNC $1,250/year
- Cheapest region South Atlantic $770/year

- Expected to increase by about 20% over the next 20 years. (0.6% annualized)
- Less than Real Disposable Income growth

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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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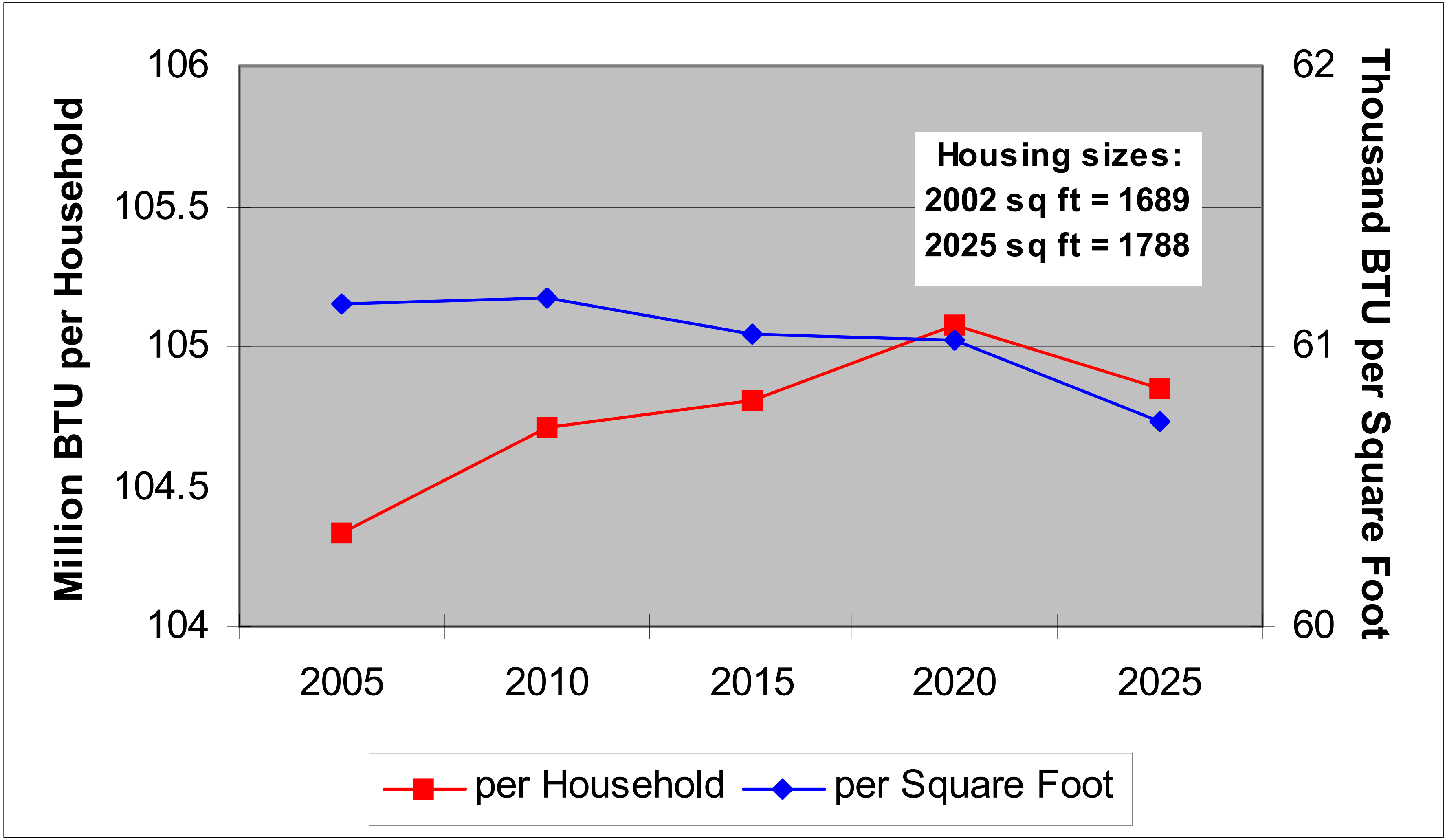
Base Case Total Residential Energy Consumption



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Total Electricity Consumption and Space Cooling

- NEMS Reference Case
- 30-year Temperature Average
- Households rise by 30 million
  - Decline from 2.6 to 2.5 persons/household
- Housing Size by square foot increase by 6%
- MBTU/HH decline by 0.25%
- TBTU/FT^2 decline by 0.25% as well

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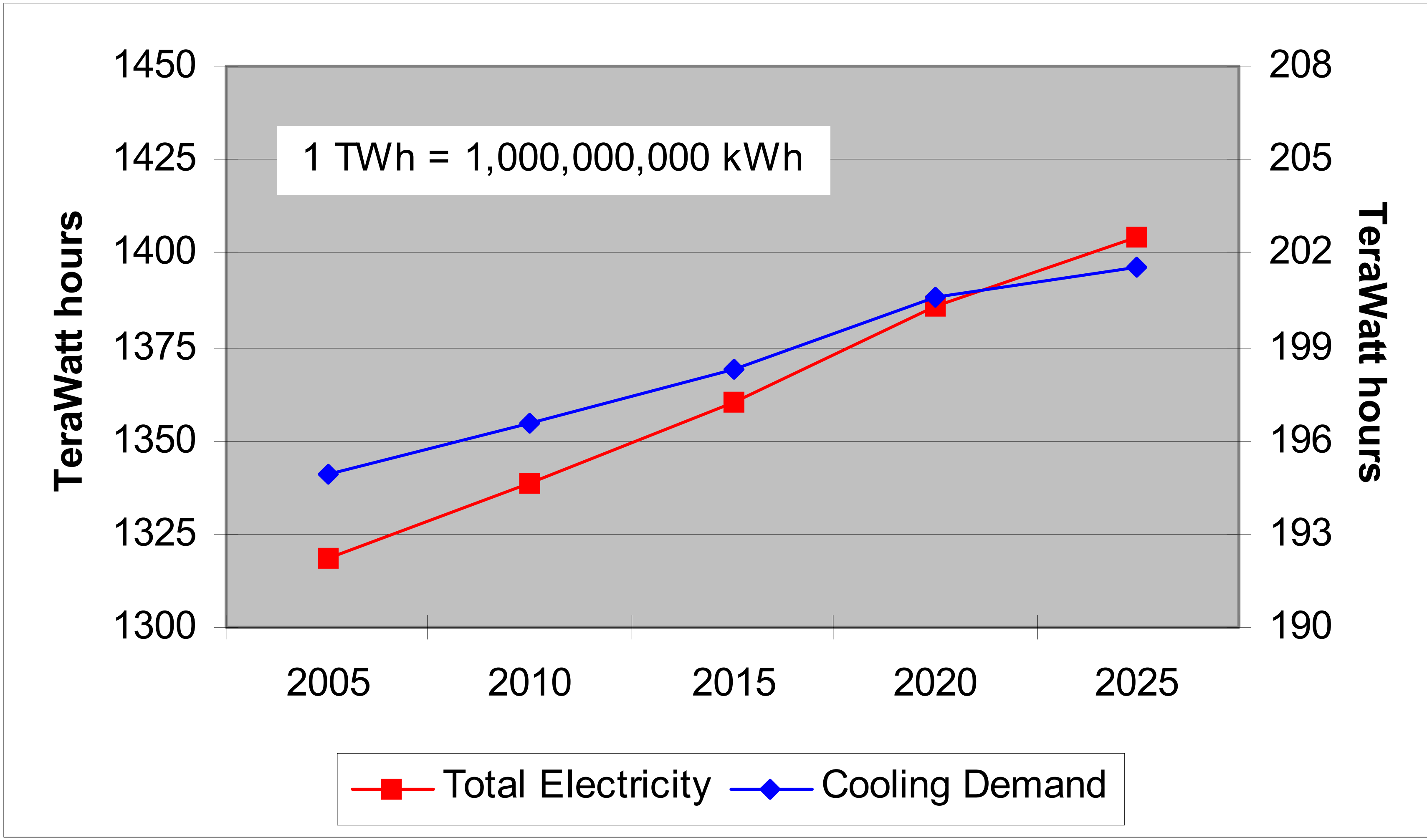
Total Residential Electricity Consumption and Space Cooling



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Total Residential Electricity Consumption and Space Cooling

- Total residential consumption increases from 1320 Terawatts to 1405 Terawatts, 5%
- Total space cooling consumption increase from 195 Terawatts to 202 Terawatts.
- Cooling's share of total consumption declines slightly to almost 14% .

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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 (NY,NJ) is most expensive 11 cents / kWh

- East South Central cheapest 6.5 cents / kWh.

- In real terms price per kWh declines by 0.3 cents.

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Warming Scenarios

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

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

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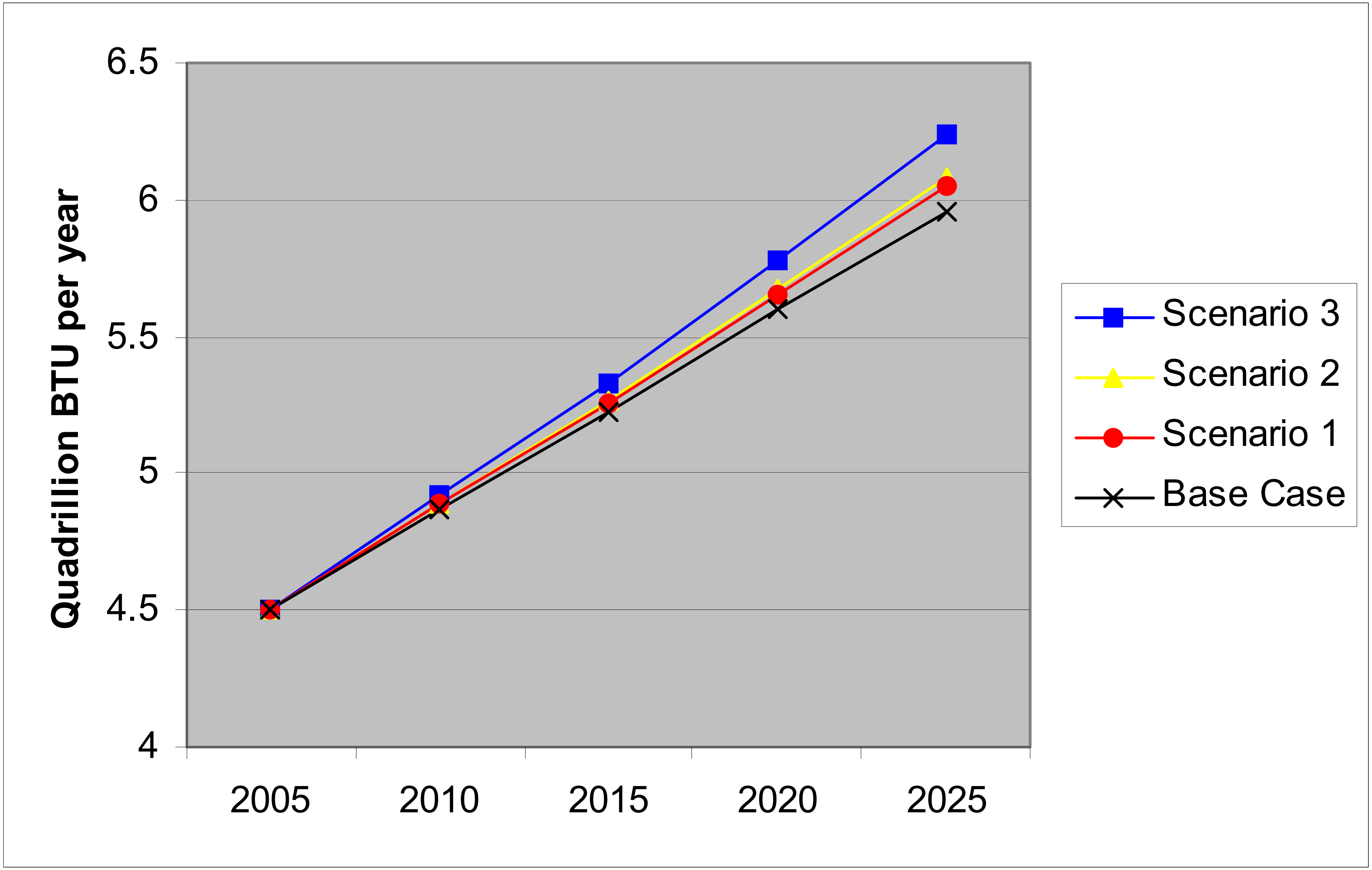
Residential Energy Consumption



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

Residential Energy Consumption under the 3 Scenarios

- Consumption increases from 4.5 over 6.2 Quadrillion BTUs next 20 years in Reference Case
- Case 1-2 leads to additional 0.1 Quadrillion BTUs or nearly 2%.
- Worst Case Scenario increase of 0.3 Quadrillion BTUs or about 5%.

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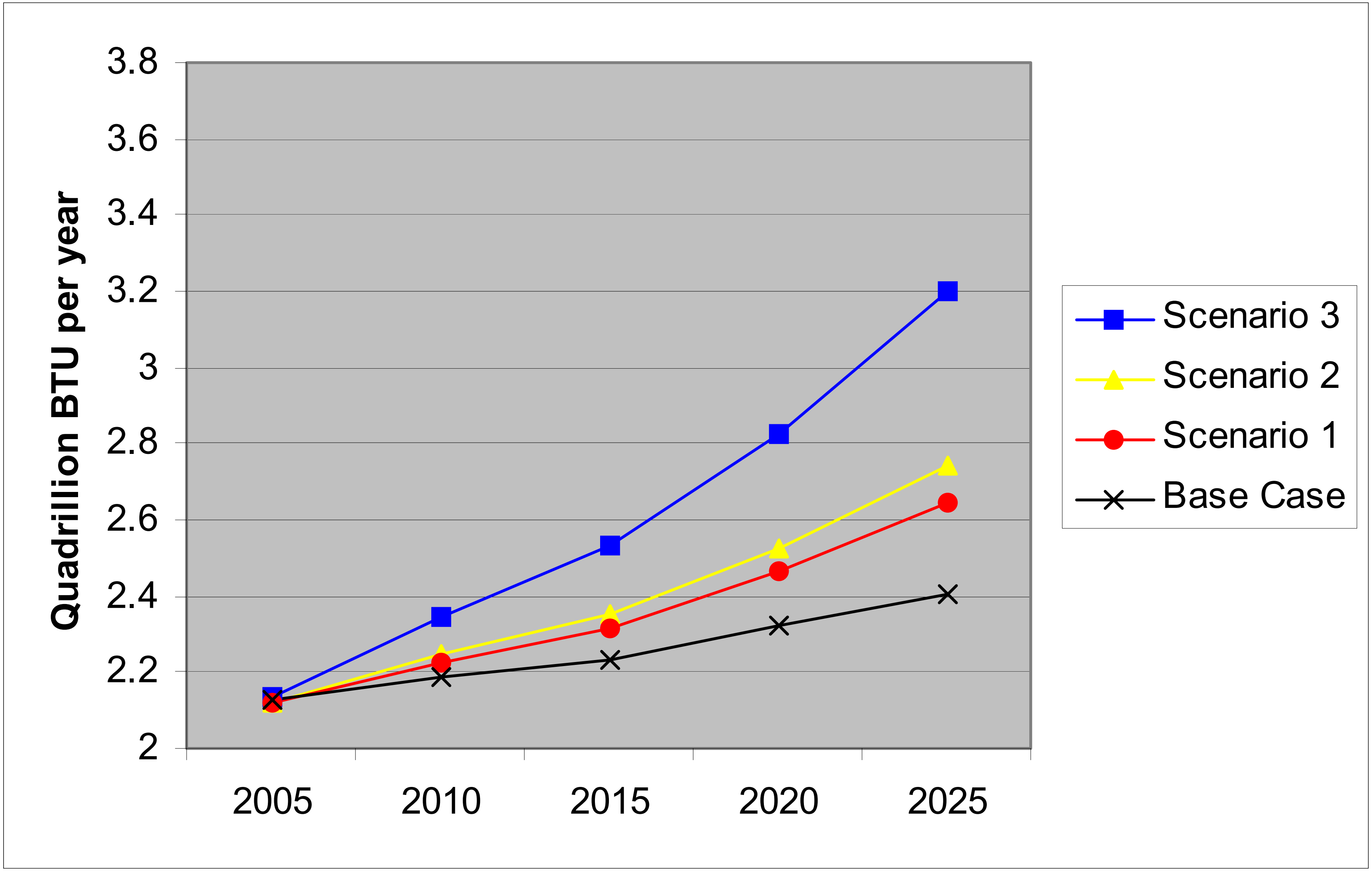
Space Cooling for Residential Energy Consumption



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Space Cooling for Residential Energy Consumption, 2005-2025

- NEMS projection is to increase from 2.1-2.4 Terawatts

	Terawatts	Share of Total
Scenario 1	2.65	44%
Scenario 2	2.75	46%
Scenario 3	3.2	54%

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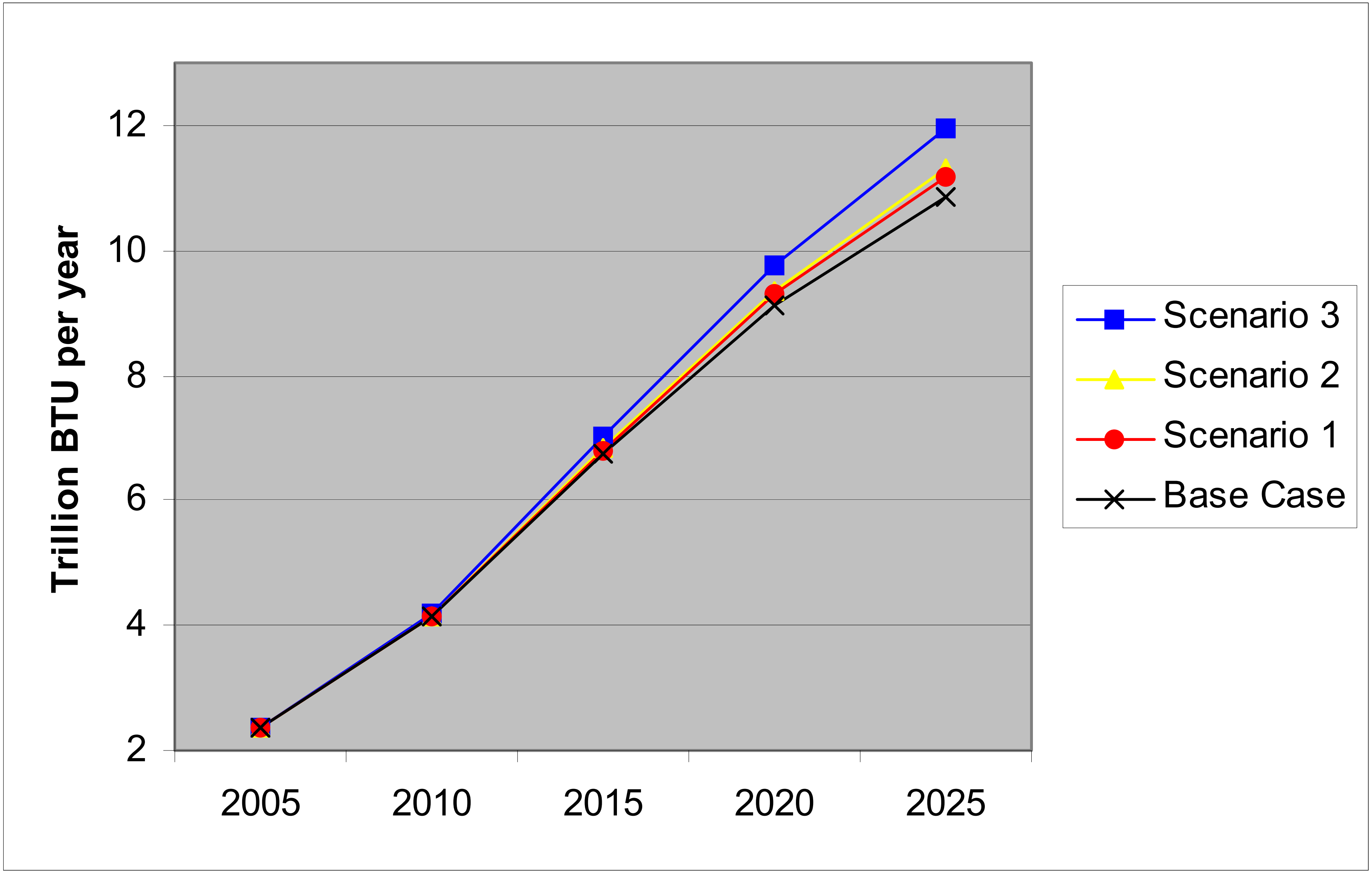
Non-marketed Renewables - Geothermal



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Conclusion

- Preliminary research into the impact of higher summer temperatures on residential electricity demands.
- EIA's NEMS model was used for making projections from 2004-2025
- Three Scenarios using increases of 2F, XF, and 6F over the time period.
- Space Cooling Demand increases by 40% in worst case and 10% in 2F case over the NEMS reference case.

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Conclusion

- Assumptions reduce 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: passive solar and geothermal heat pumps.
- More work to be done.
- Understanding the 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

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

- ***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)

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

- ***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

- ***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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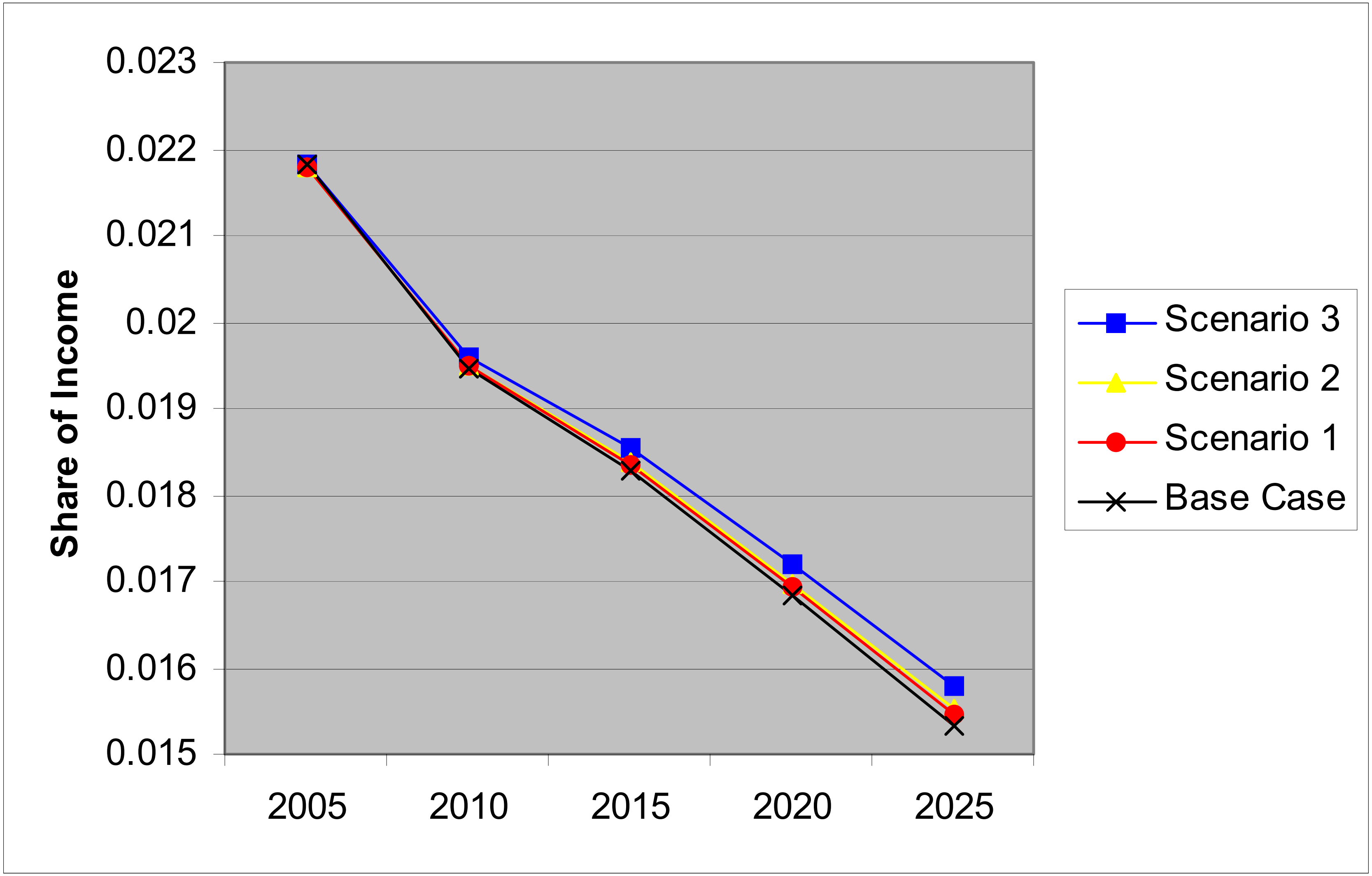
- ***Technology Switching***
- Space heaters, heat pump air conditioners, water heaters, stoves, and clothes dryers may be replaced with competing technologies in single-family homes. The amount of equipment which may switch is based on a model input. The technology choice is based on a log-linear function.
- 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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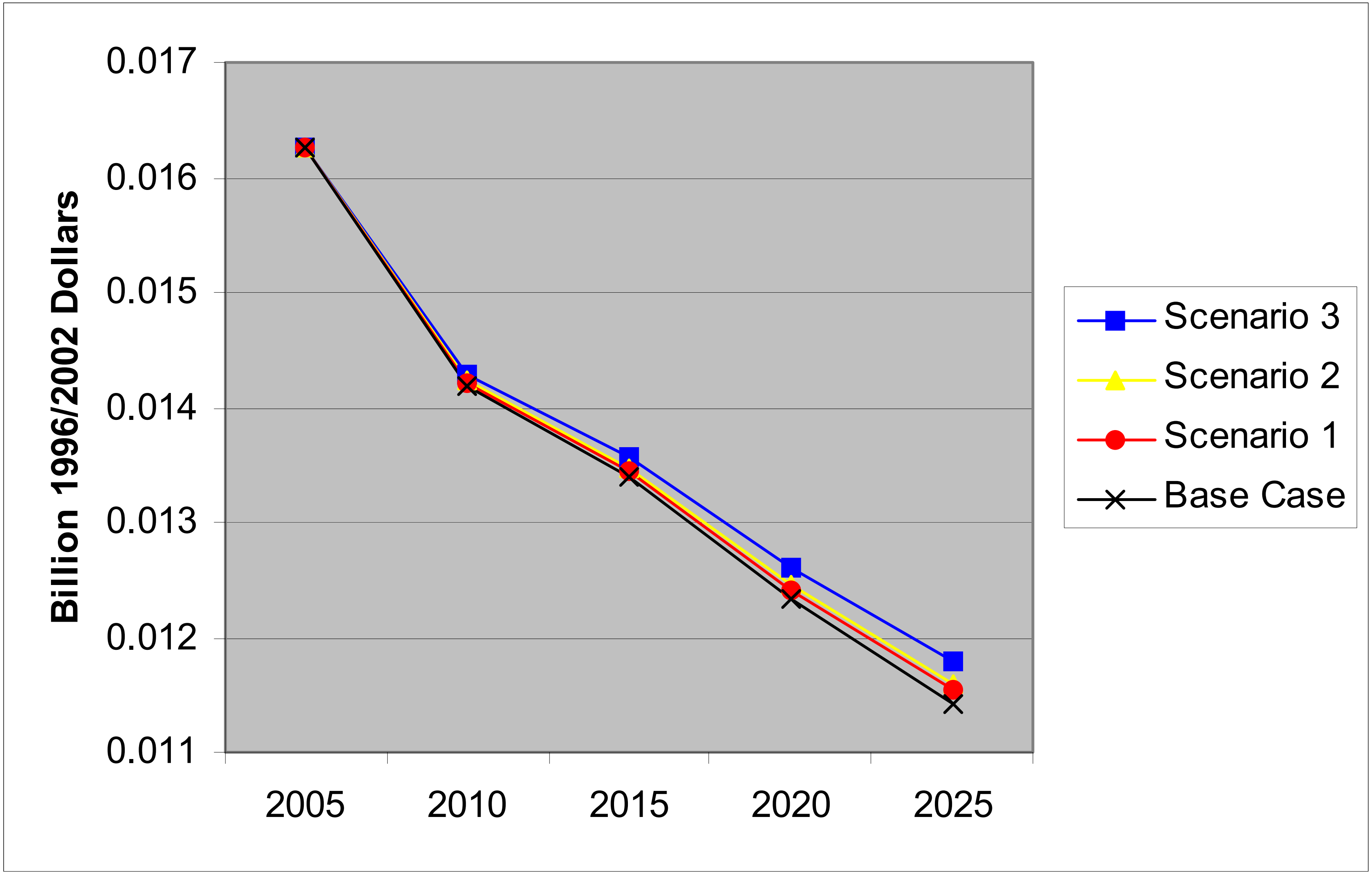
Residential Energy's Share of GDP



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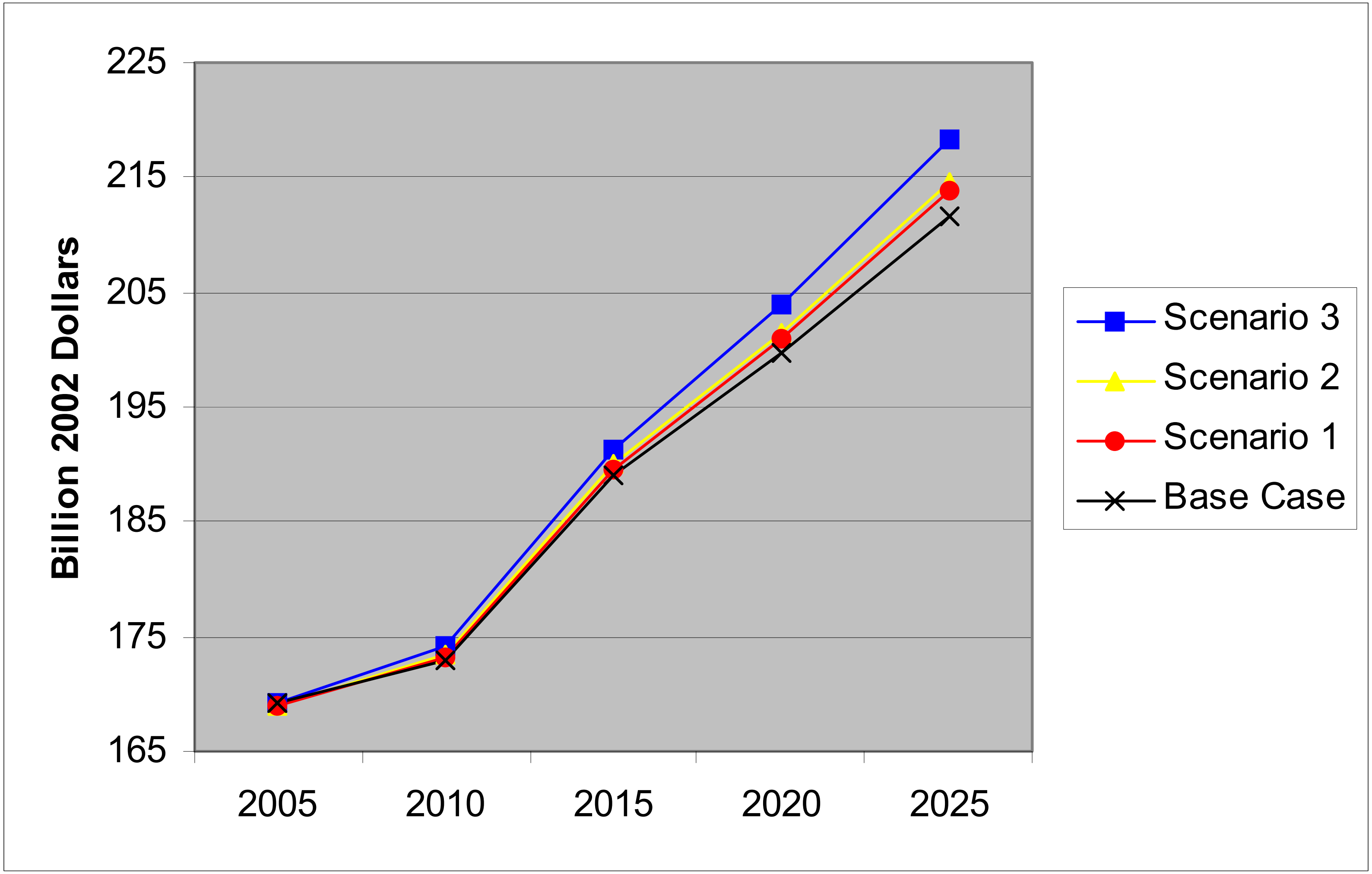
Non-Renewable Energy Expenditures (Residential)



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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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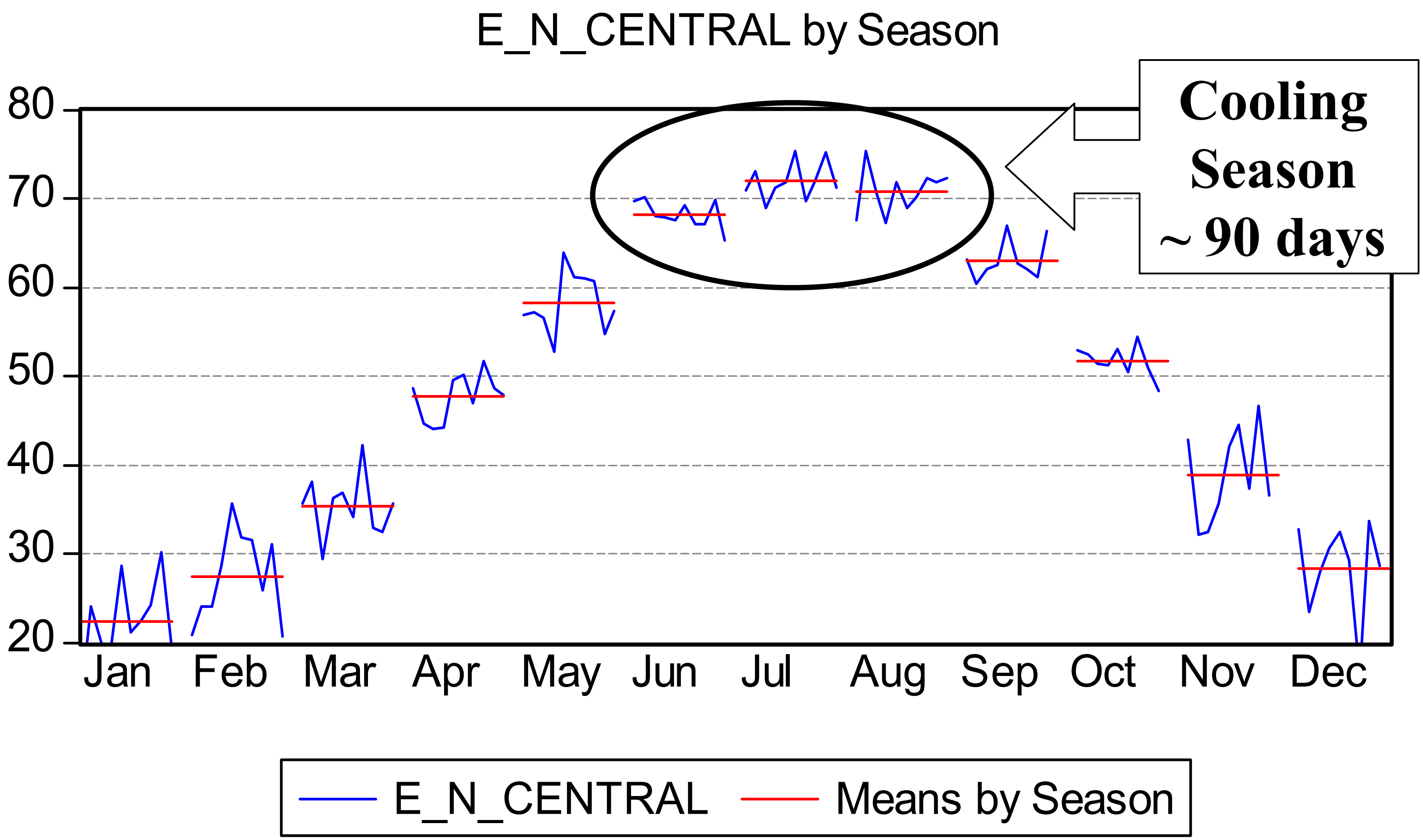
Monthly Temp (°F) 1993-2004



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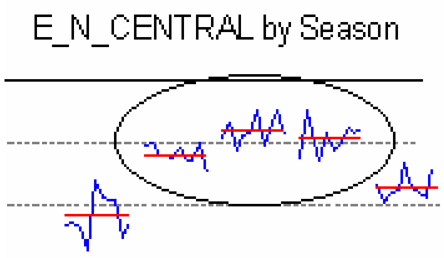
Scenario I – Step 3

3. *Calculate yearly CDD increment*

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

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

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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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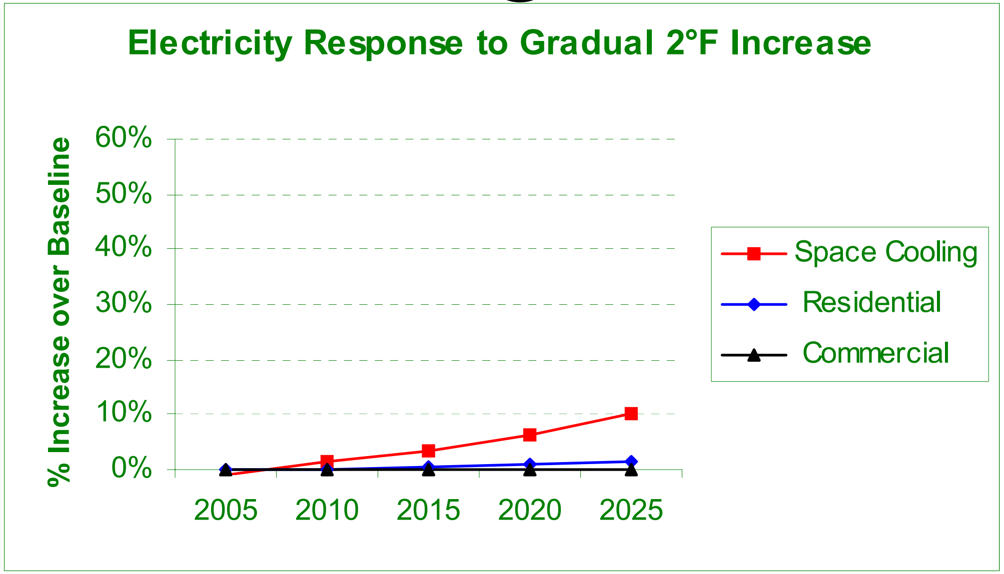
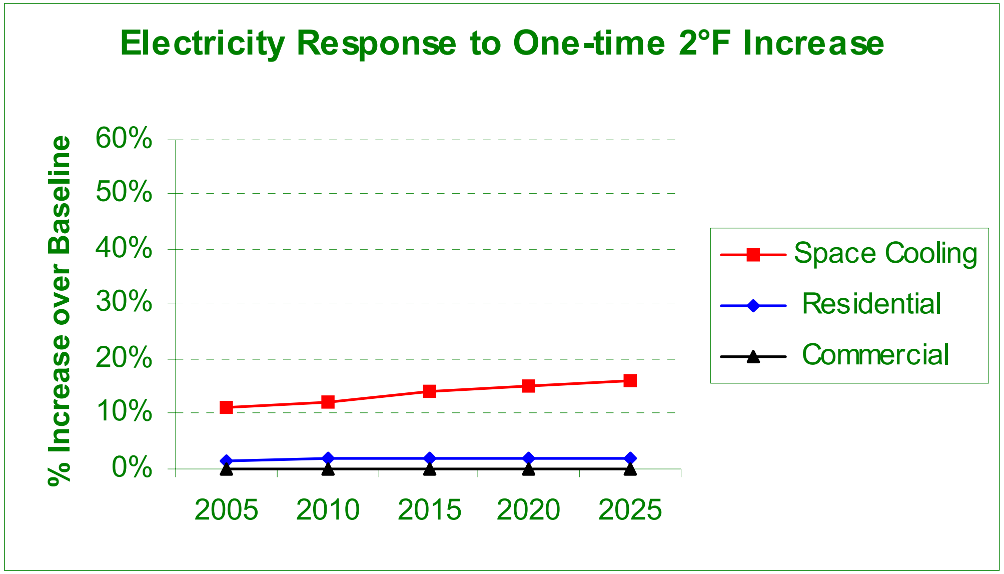
NEMS Results – Cooling Demand

Scenario I



Scenario II



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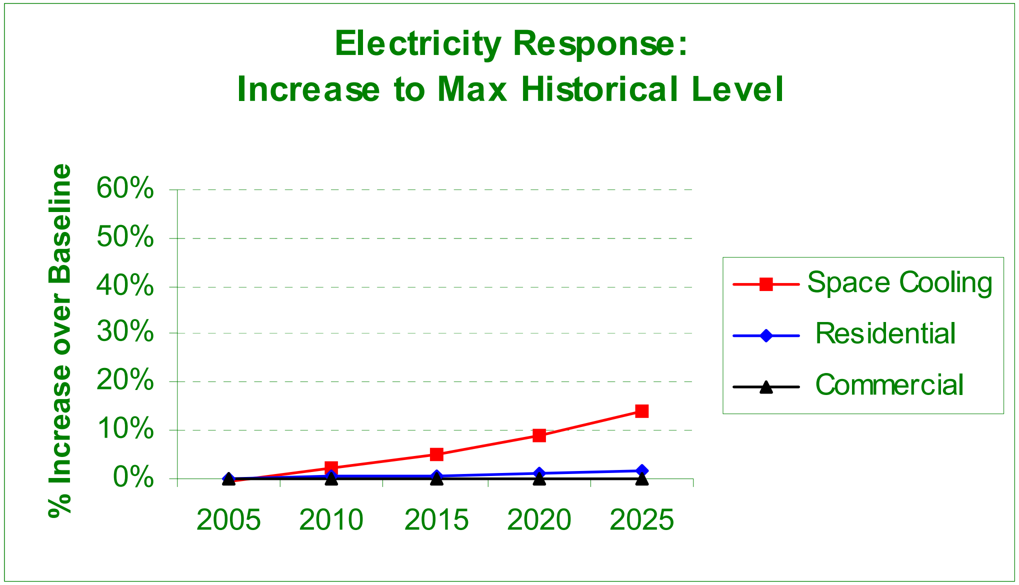
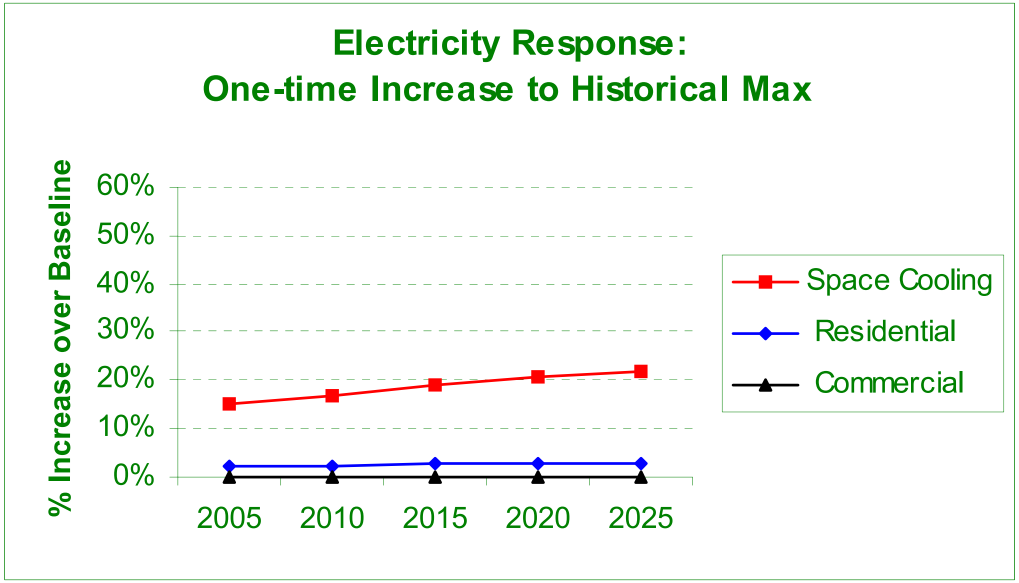
NEMS Results – Cooling Demand

Scenario III



Scenario IV



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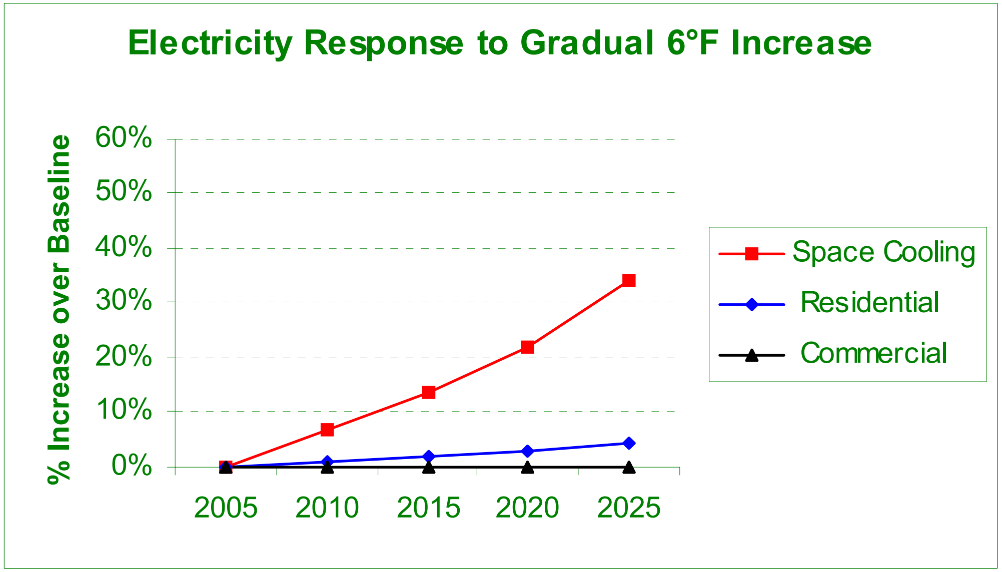
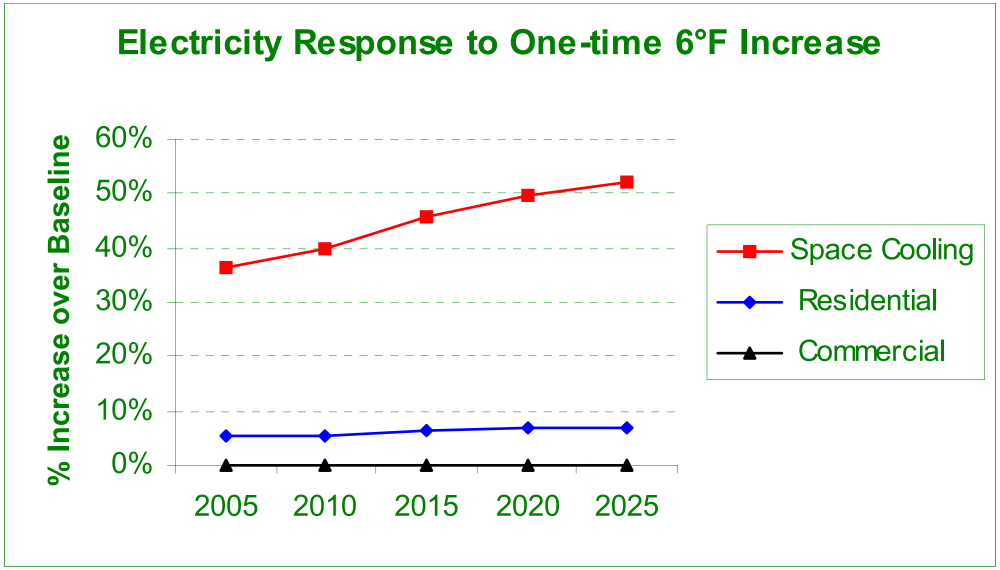
NEMS Results – Cooling Demand

Scenario V



Scenario VI



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

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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