The AMIGA Model: Reflecting Bottom Up Technology within a CGE Framework

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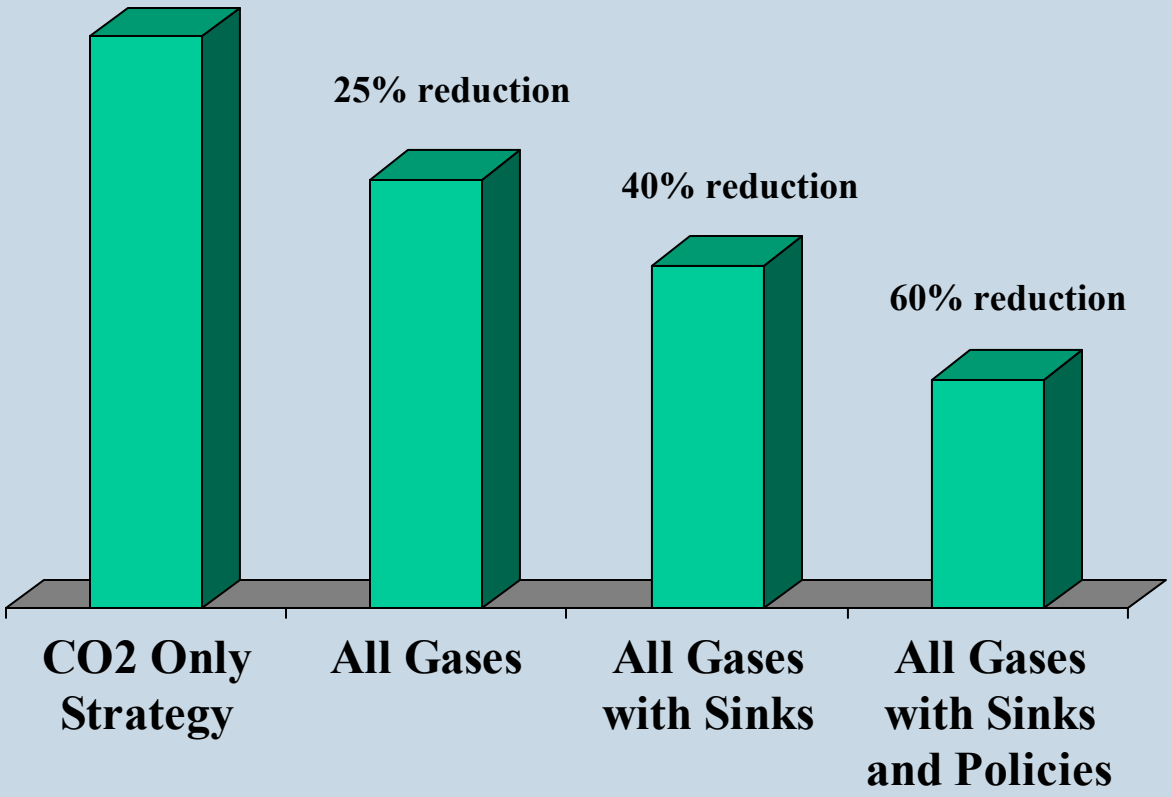
Outline of Presentation

- Some Preliminary Perspectives on Evaluating Technology Scenarios
- Brief Description of the All-Modular Integrated Growth Assessment (AMIGA) Modeling System
- Simulate the possible differences between a business-as-usual reference case and a moderate energy policy (technology investment)
- Show illustrative macroeconomic impacts of incremental increases in the technology investments.

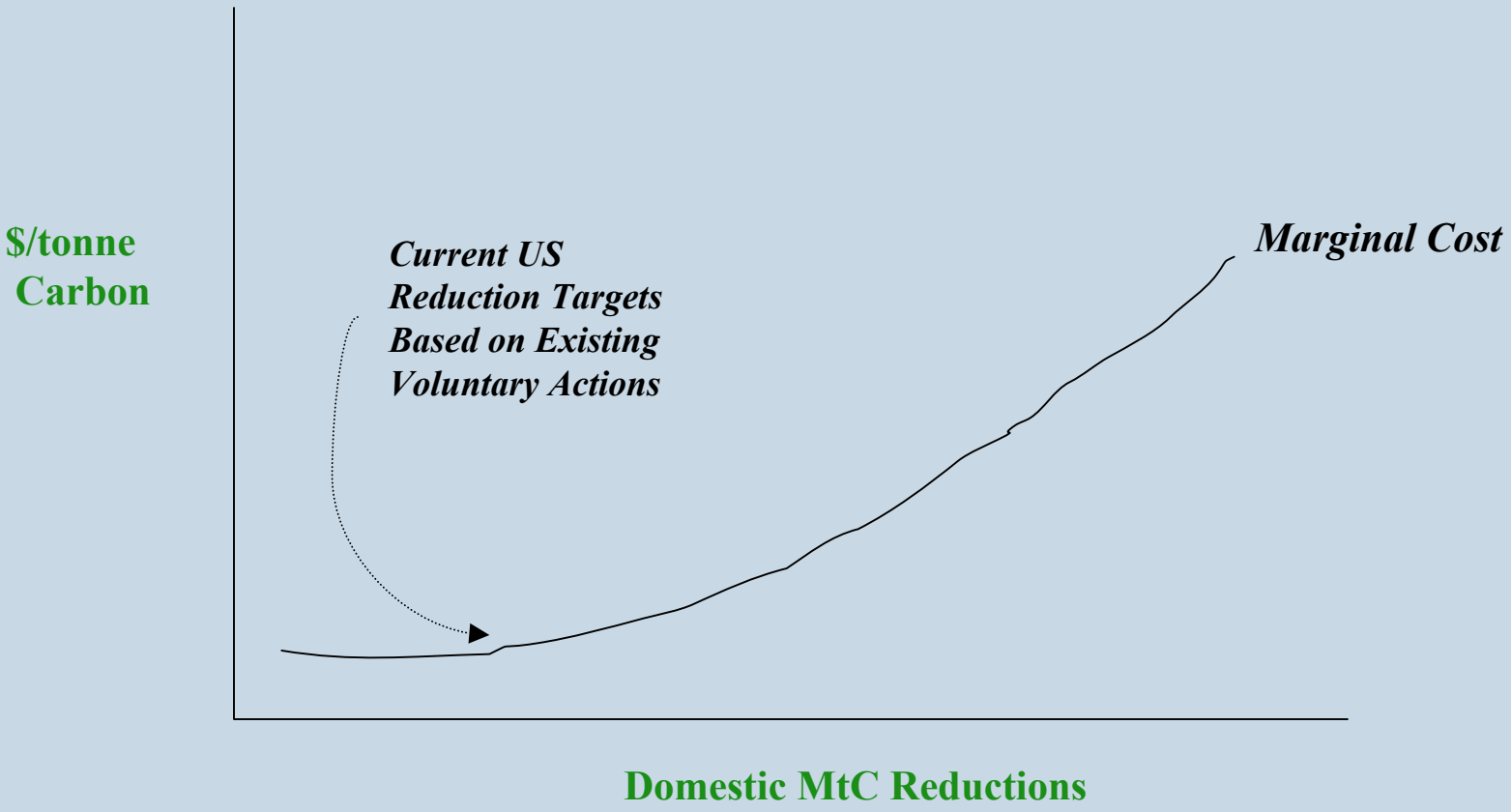
Some Preliminary Perspectives

Costs of Achieving a Climate Goal

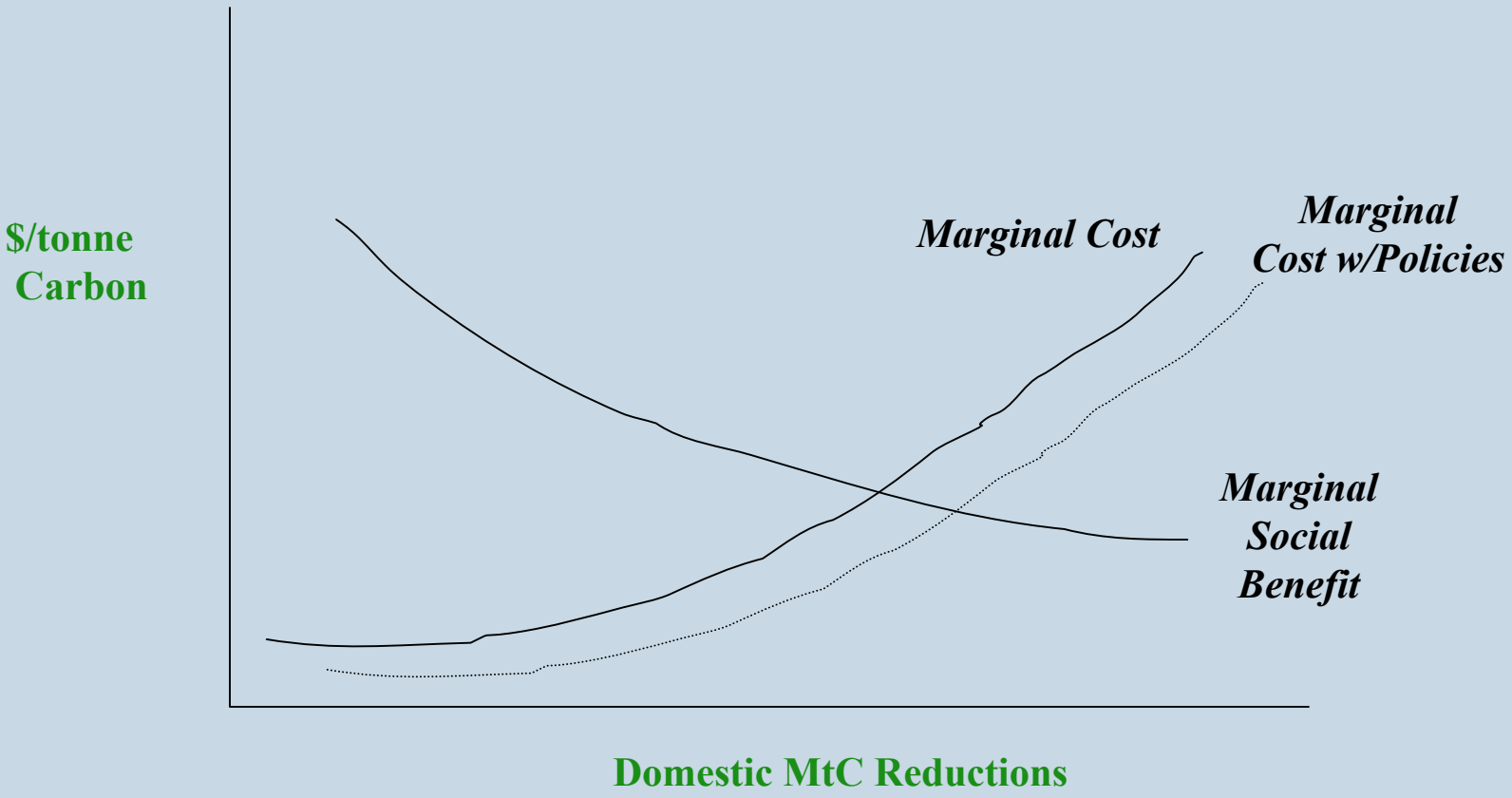


But this, of course, tells us very little about social benefits. . . .

The Conventional Abatement Cost Curve



Yet a Different Result Using Costs <u>and Benefits</u>

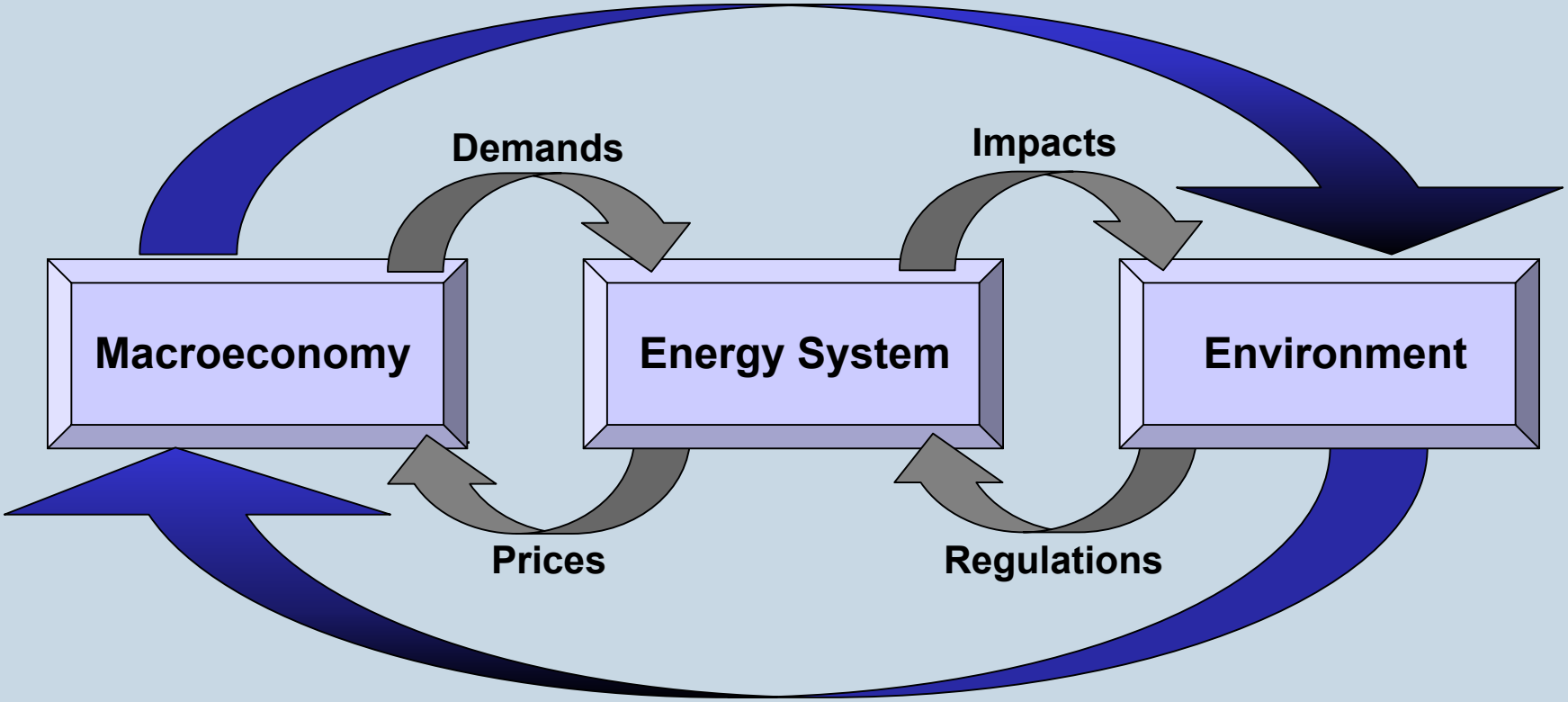


About the AMIGA Model

AMIGA Is a Comprehensive Model that Integrates Energy Markets, Technologies, and Policies

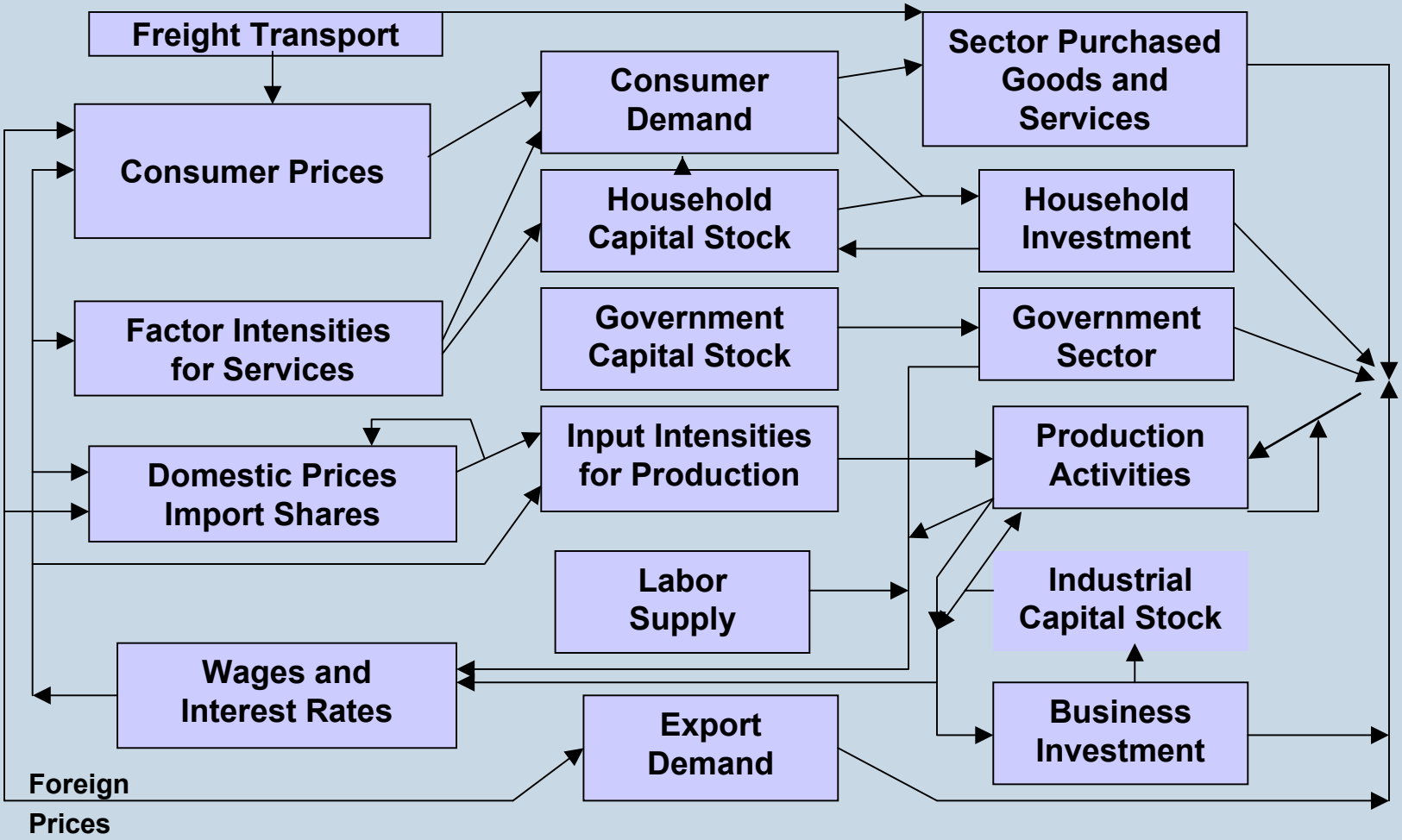
- The AMIGA Modeling System is a general equilibrium model developed and supported by the Argonne National Laboratory that:
  - Examines the impact of changes in more than 200 individual sectors (in terms of both dollar measures and physical units).
  - Programmed in the structured C language, AMIGA integrates a detailed energy market specification within a structural economic model.
  - Calculates both prices and macroeconomic variables as consumption, investment, government spending, employment, and GDP.
  - Provides equilibrium paths from the present through the year 2050, with the capability of extending the time horizon out to 2100.
  - Previously handled only carbon emissions, but now enhanced to include SO_2, NO_x, and mercury emissions, including the ability to reflect early allowances and banking; with work underway to include the full basket of greenhouse gas emissions.

AMIGA is a 200-Sector Model that Captures Important Economic-Energy-Environmental Linkages

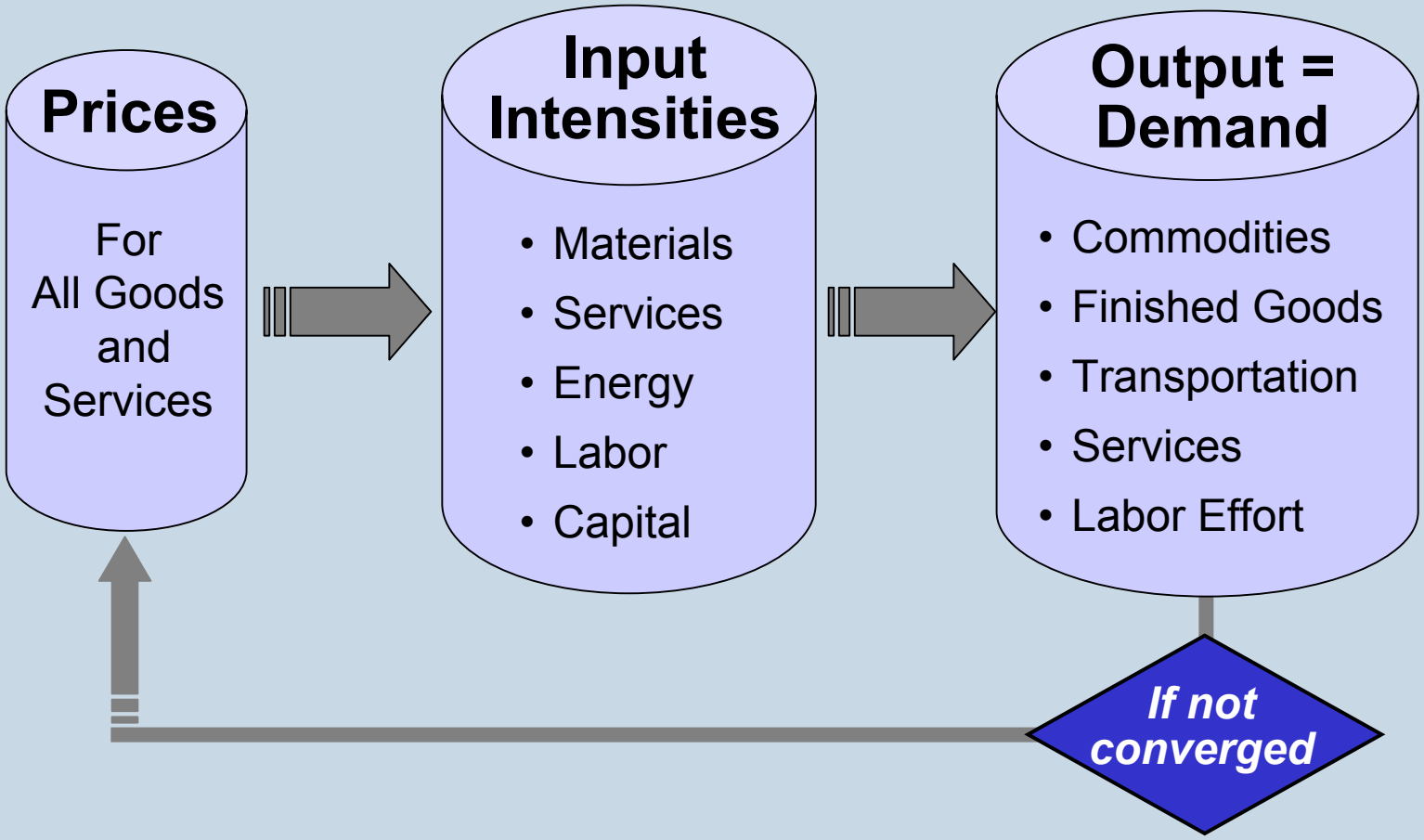


Note: For a more complete description of the AMIGA model, see *A Framework for Economic Impact Analysis and Industry Growth Assessment: Description of the AMIGA System*, Donald A. Hanson, Argonne National Laboratory, Argonne, IL.

AMIGA Includes the Components of Demand and the Inputs to Production



AMIGA is a General Equilibrium Model that Uses Input Intensities to Calculate Both Prices and Intermediate Demand Quantities

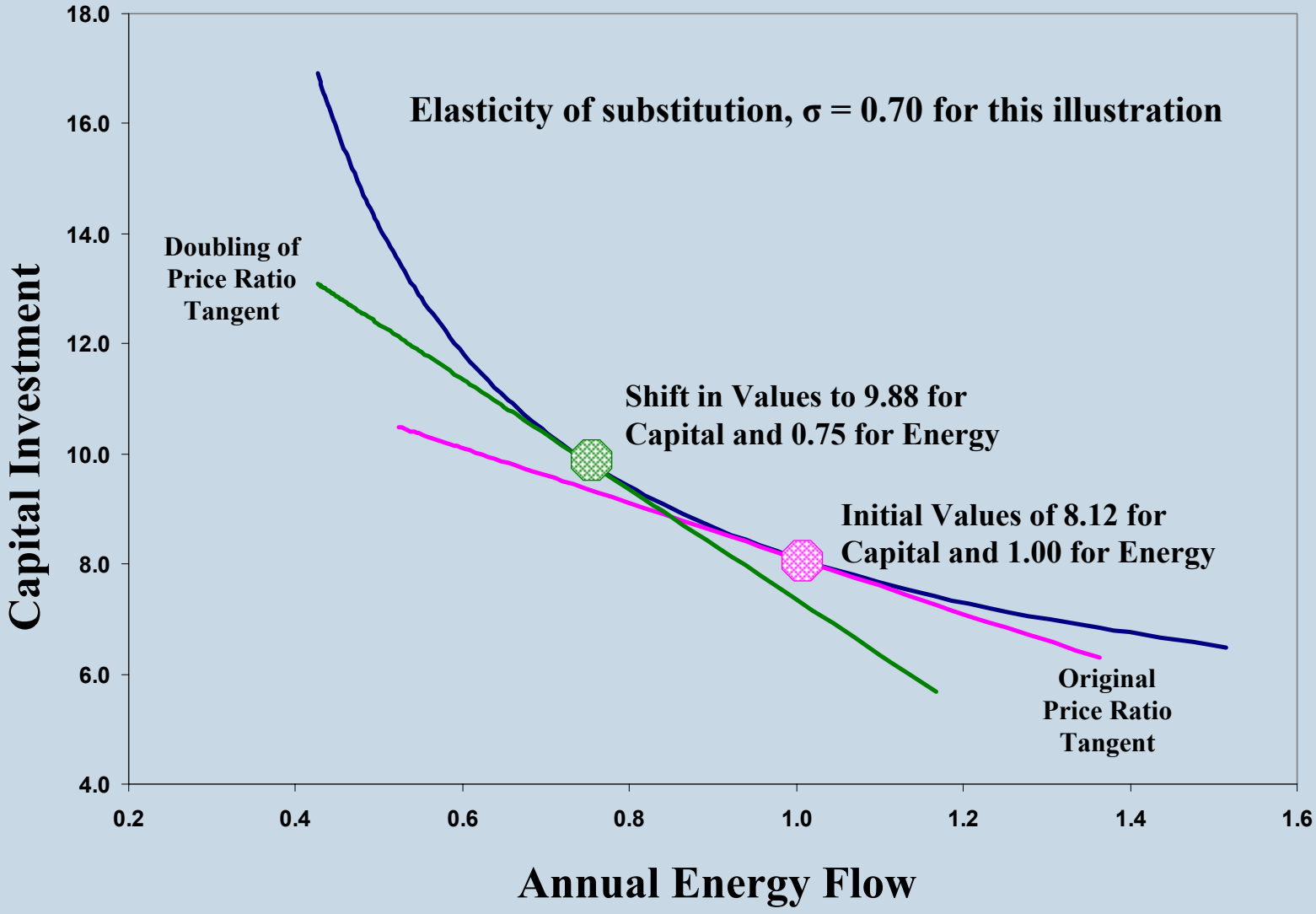


Representation of Factor Demands

- Product outputs, material inputs, labor, capital, and energy are all related though production processes and technology. Expansion of labor input, investment, and technical advances drive economic growth over time.
- The basic representation for the model of "ideal" factor demands is obtained from the following nested production structure: for each sector *i* at time *t*:
  - *Sector Output = f (Utilized Capital, Labor Input)*
  - *Utilized Capital = f (Production Capital, Energy Services)*
  - *Energy Services*$_j$ *= f*$_j$ *(Energy-Saving Capital, Energy Input)*

    where *Energy Services* can be provided by multiple energy forms, denoted by *j*.
- Energy services are influenced by a price ratio such that a doubling of the ratio can be achieved by either a doubling of the carbon charge or a 50% reduction in the hurdle rate.
- Technology can be represented in a discrete technology choice format, or in a cost curve format based on the available technologies for a given service demand.

Energy Services Isoquant Showing Relationship between Capital, Energy, Price Ratio



Changes in Capital and Energy as a Result of Doubling the Energy Price Ratio

- Under the assumption that
  - energy prices increase by 50%
  - while hurdle rates decrease from 20% to 15%
- the price ratio will double
  - from 1.00 / 0.200 which equals 5.0
  - to 1.50 / 0.15 which equals 10.0
- In this case
  - Capital investment will increase from 8.12 to 9.88 (22%)
  - Annual energy flow will decrease from 1.00 to 0.75 (-25%)
- Project payback will be
  - (9.88 - 8.12) / 0.25 = 7.04 years under the old energy prices
  - (9.88 - 8.12) / (0.25 * 1.50) = 4.69 years with the new energy prices

Recalling a Basic Economic Relationship

$$GDP = \sum_{i=1}^{K} P_i \left(X_i - \sum_{j=1}^{K} A_{i,j} \right) = \sum_{i=1}^{K} P_i \left(C_i + G_i + I_i + X_i - M_i \right)$$

where GDP is Gross Domestic Product; K is the number of products; P_i is the price of product i; X_i is the gross output of product i; A_{ij} is the domestic use of product i in the production of product j; C_i is the domestic consumption by households of product i; G_i is the domestic consumption by government of product i; I_i is the domestic investment uses of product i; X_i is the gross exports of product i; and M_i is the gross imports of product i; and all of this, in turn, equals the disposition of net output among final demand sectors.

In AMIGA, the GDP Accounting has One Important Feature not seen in Other Models

The model tracks the net impact of an "investment-led" energy efficiency strategy as it results in:

(1) a greater investment in efficient/low-carbon technologies,
(2) an increased consumption as a result of energy bill savings,
(3) added R&D, incentives, and market development programs, and
(4) reduced oil imports; and

all of which can lead to a small but net positive gain for the economy.

This concept was tested in a scenario designed to reflect a set of moderate energy policies through the year 2050. Notably, the scenario reflects an investment-led technology strategy that underpinned the recent DOE Study, Scenarios for a *Clean Energy Future*.

Scenario Assumptions for a Moderate Energy Policy

- The reference case approximates the AEO 2001, as might be reasonably extended through 2050.
- Policy initiatives assume a 2002 start date with a slow ramp up through the year 2050.
- Technology policies generally follow the moderate energy policy of the November 2000 *Clean Energy Future* study.
- The effect of the policies are extended beyond the 2020 time horizon of the CEF study through the year 2050.
- The policies are driven primarily by incremental program expenditures for Energy Star-like voluntary programs and increased research and development initiatives.
- The scenario also reflects a carbon charge rising from $27/tC in 2010 to about $64/tC by 2035 and holding at that level through 2050.

The Model Adds Capacity in New Energy Supply Technologies

- Coal – 4 types of re-powering and gasification technologies,
- Nuclear – evolutionary and advanced designs,
- Gas – both conventional and advanced natural gas combined Cycle (NGCC) units, peakers, and advanced turbines,
- Municipal solid waste,
- Large combined heat and power (CHP) units by fuel type, such as natural gas or biomass,
- Fuel cells systems,
- Other distributed generation,
- Renewable technologies, including

  Wind, Geothermal, Hydroelectric, Biomass co-firing, Biomass gasification combined cycle, Building Integrated PV, Solar, and other

The Model Also Adds Capacity for Energy End-Use Technologies

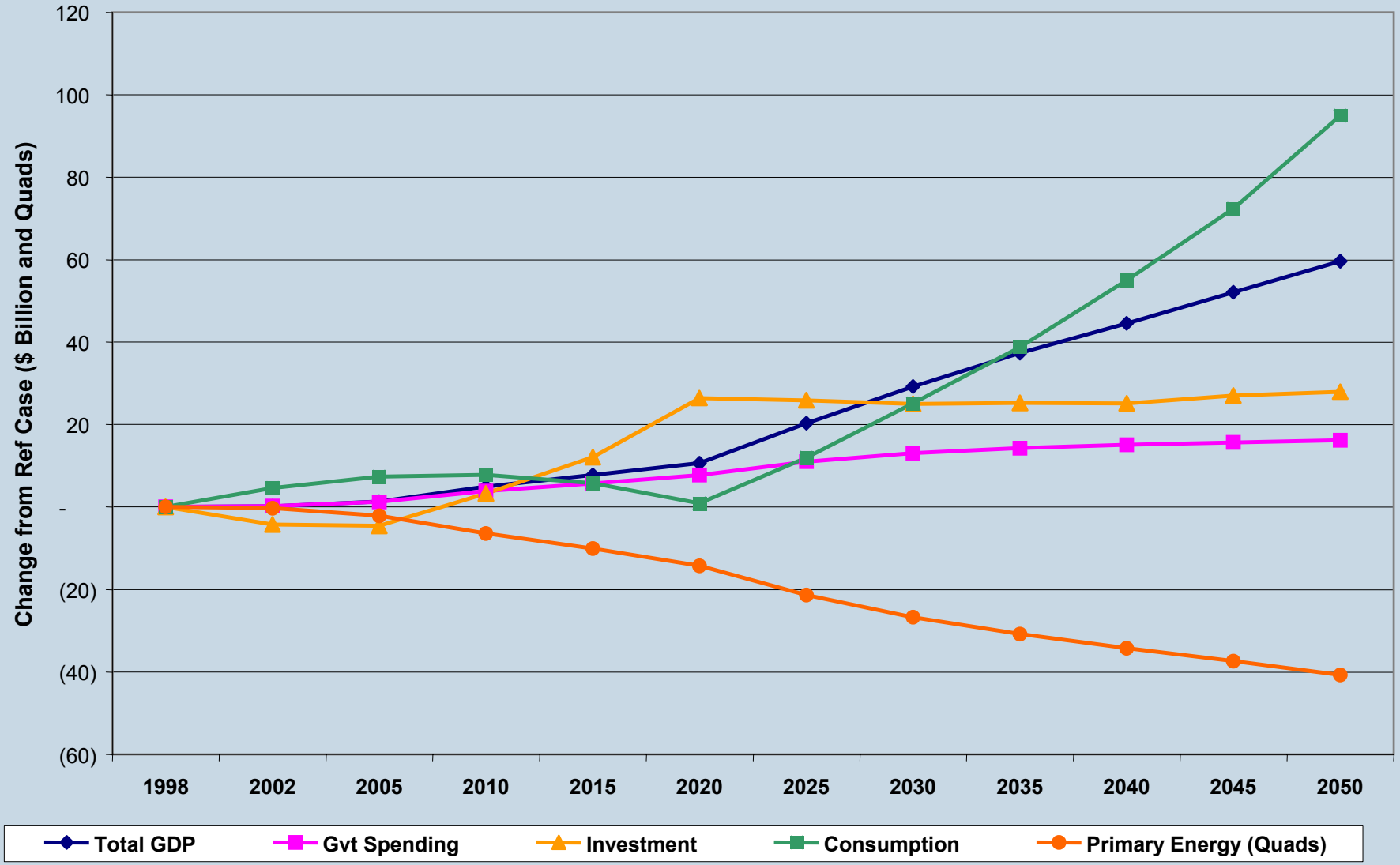
- Based on
  - Engineering cost-of-energy estimates,
  - Supply function analysis, and
  - Consumer preferences based on a distribution of hurdle rates unique to end-use sector, energy service, and fuel type
- Including
  - Light and heavy duty vehicles for both passenger and freight services,
  - Industrial processes, and
  - Building technologies

Some of the Policy Drivers

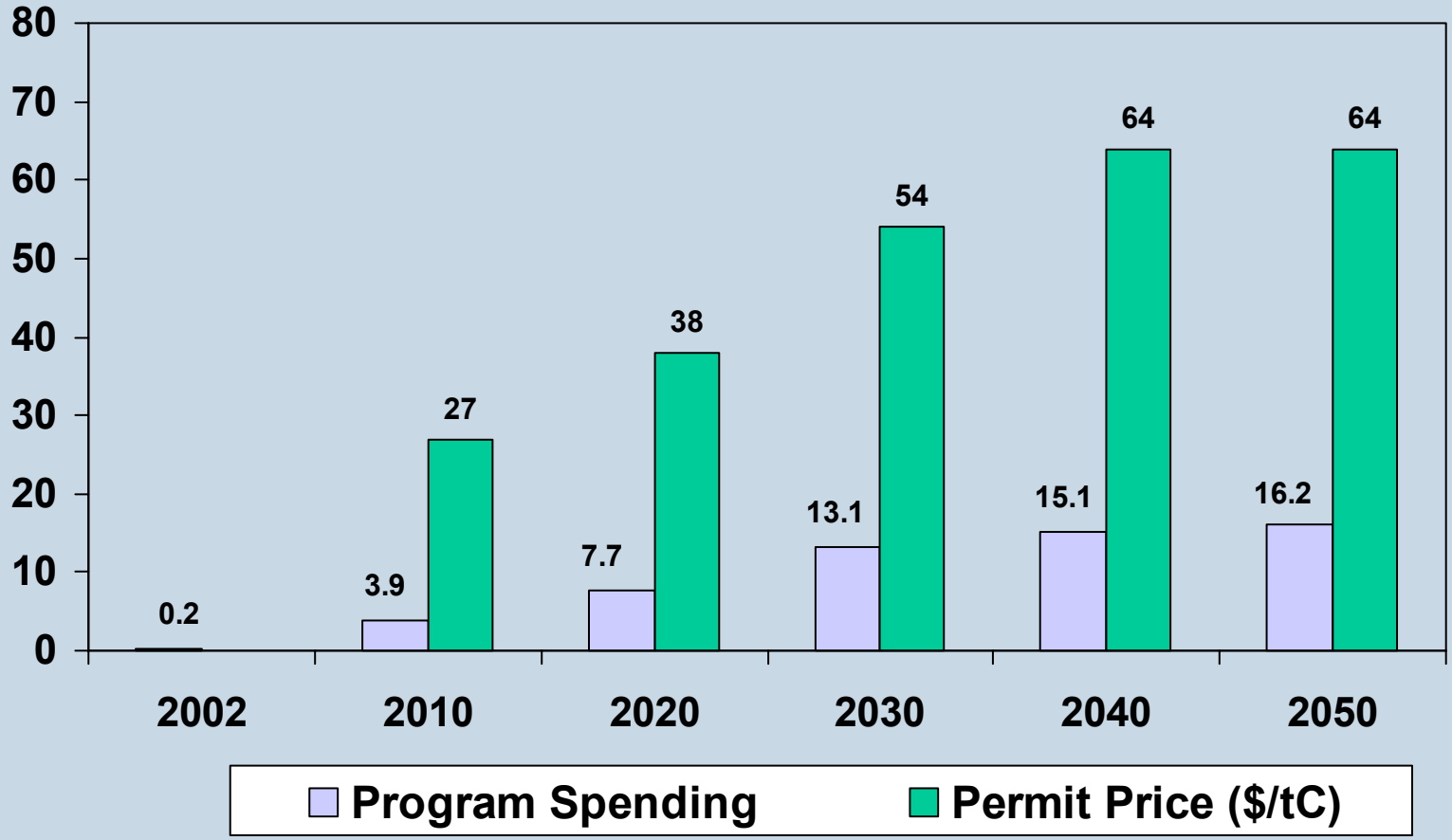
- Public and private sector cooperation and partnerships,
- Experience curves or learning from adoption,
- The Technology Investment (TI) Scenario, including production incentives on both energy supply and end-use, and
- Renewable portfolio standards
  - Advanced technology generators produce credits
  - Other generators must hold credits proportional to their output
  - Hence we have a market in these credits
  - With little impact on electricity prices (e.g., a 1 cent credit price per renewable kWh x 10% standard = 0.1 cents per total kWh)
  - But with a potential significant impact on natural gas prices as reduced demand puts a downward pressure on wellhead prices

Scenario Results

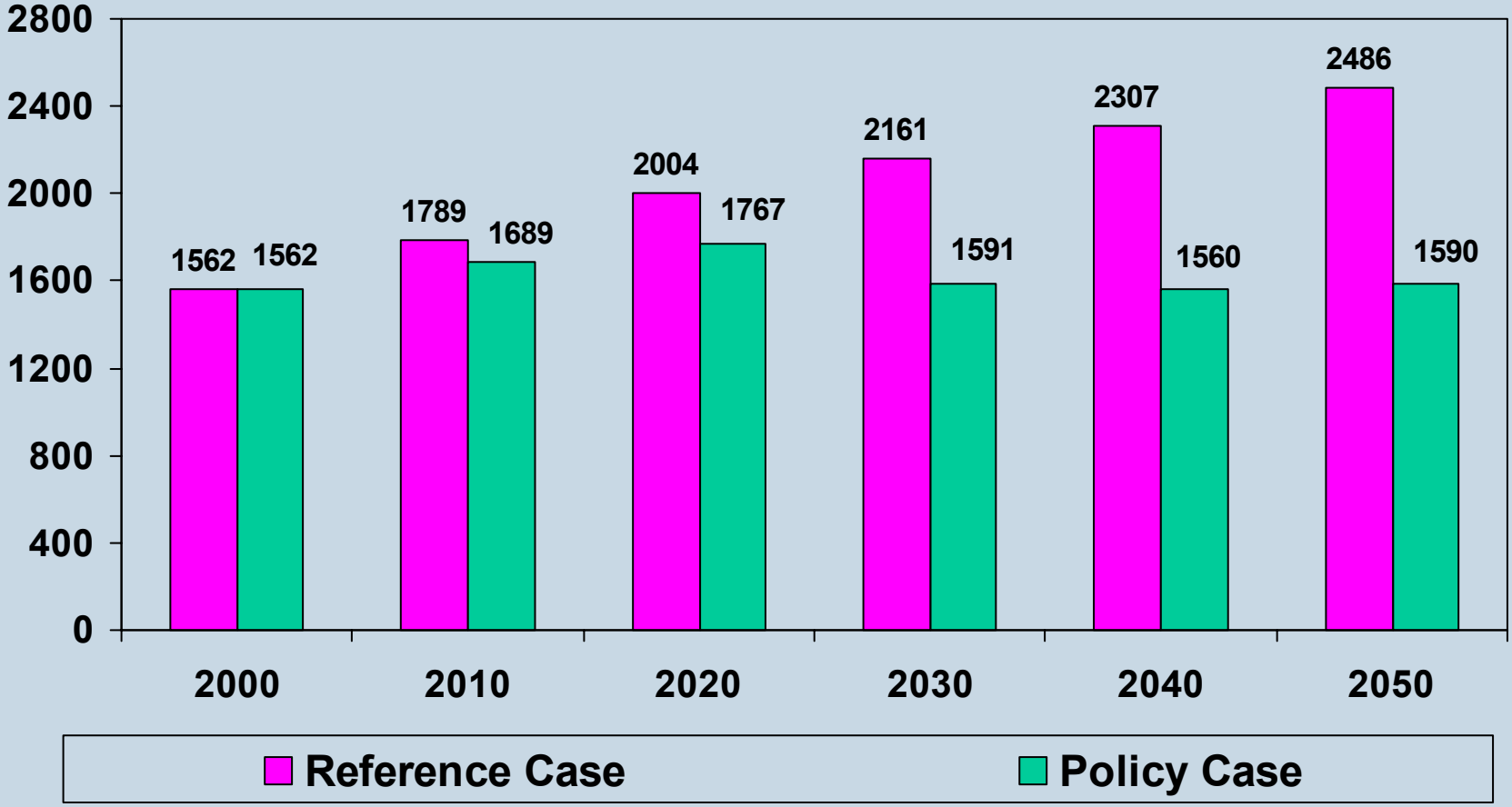
Macroeconomic Impacts of Moderate Energy Policy-Driven Scenario



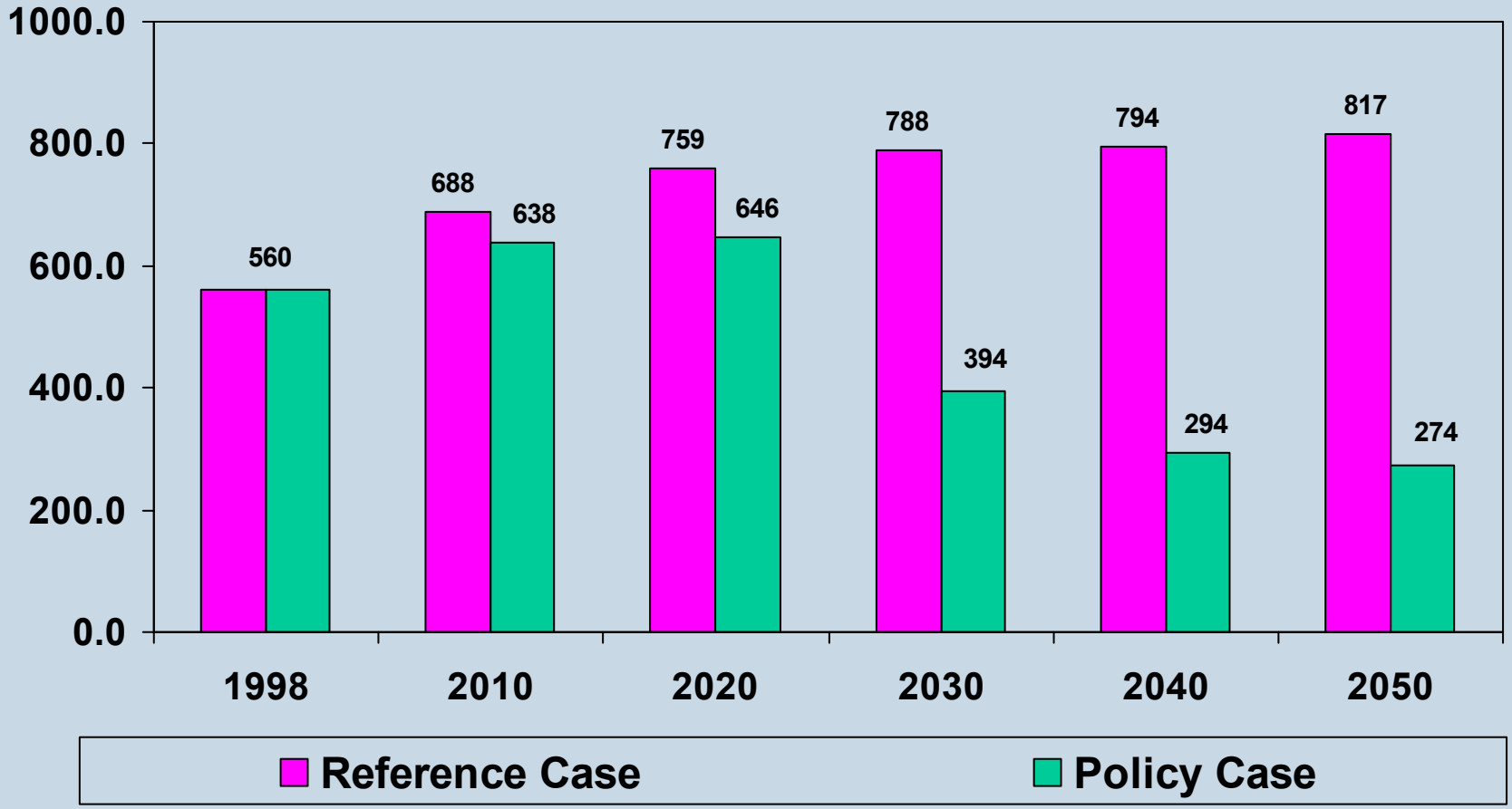
Policy Case Program Expenditures and Permit Price
(Billion 1999 dollars and 1999 $/tC)



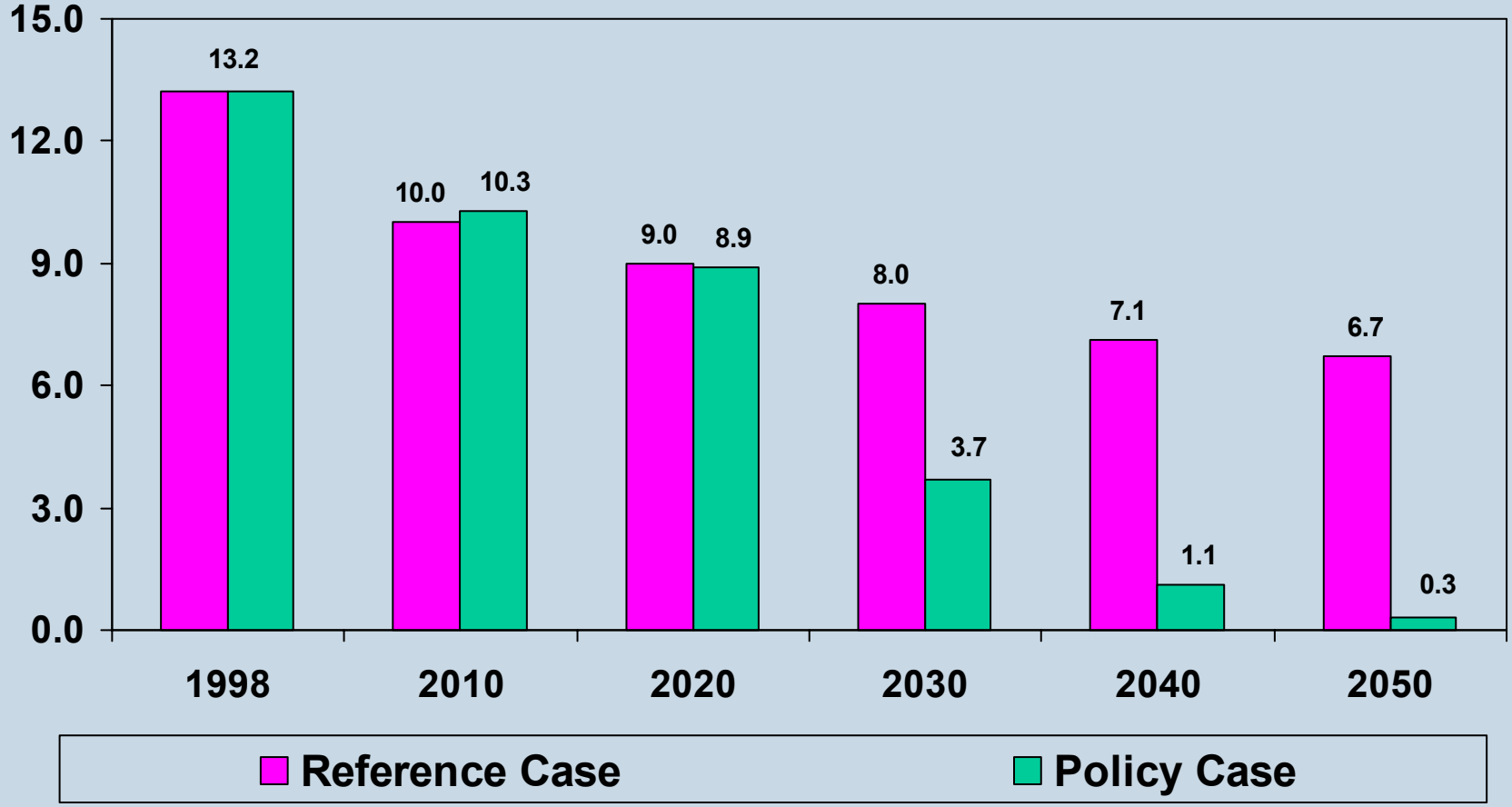
Economy-wide Carbon Emissions
(Million Metric Tons)



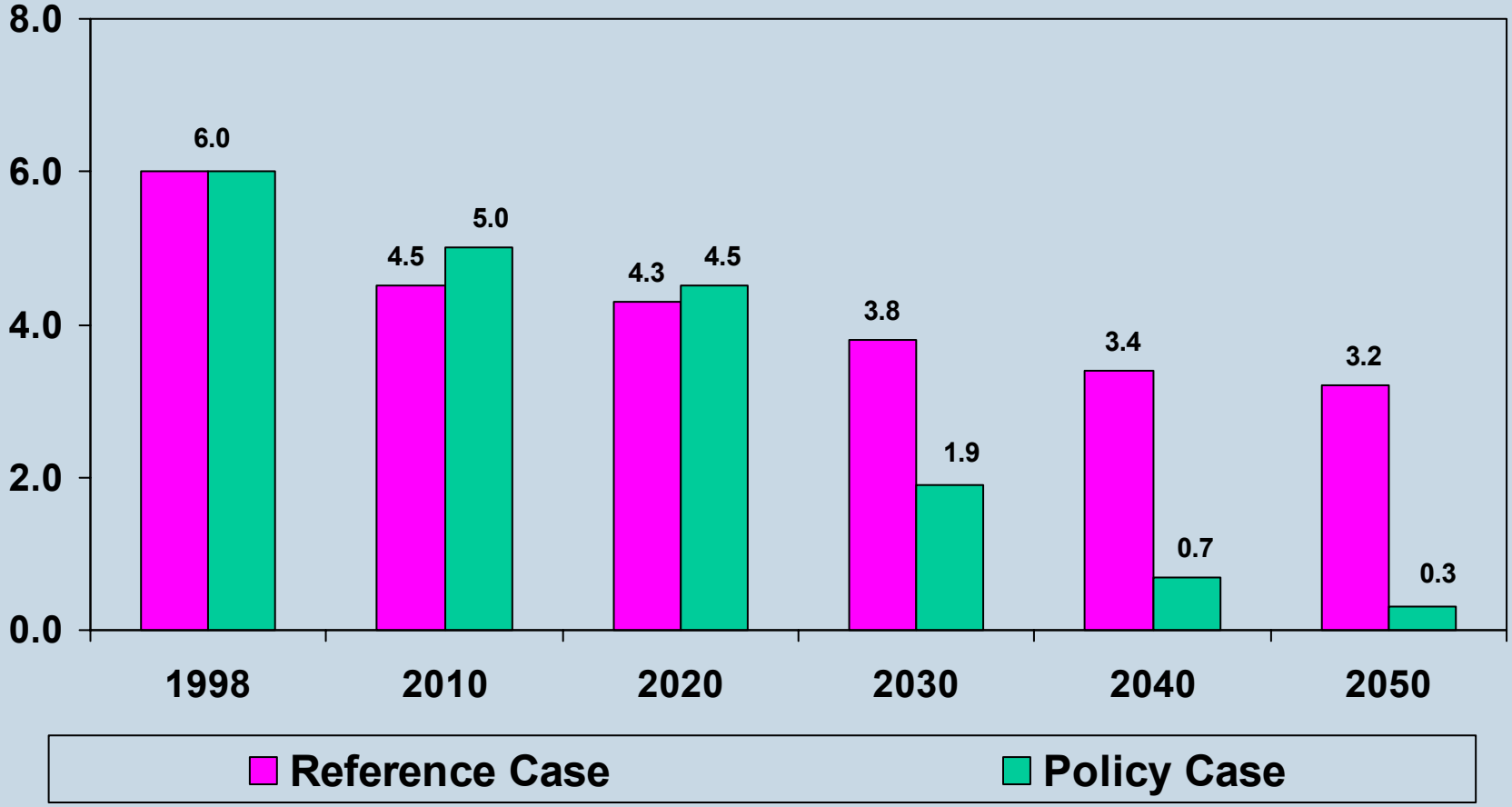
Electricity Sector Carbon Emissions
(Million Metric Tons)



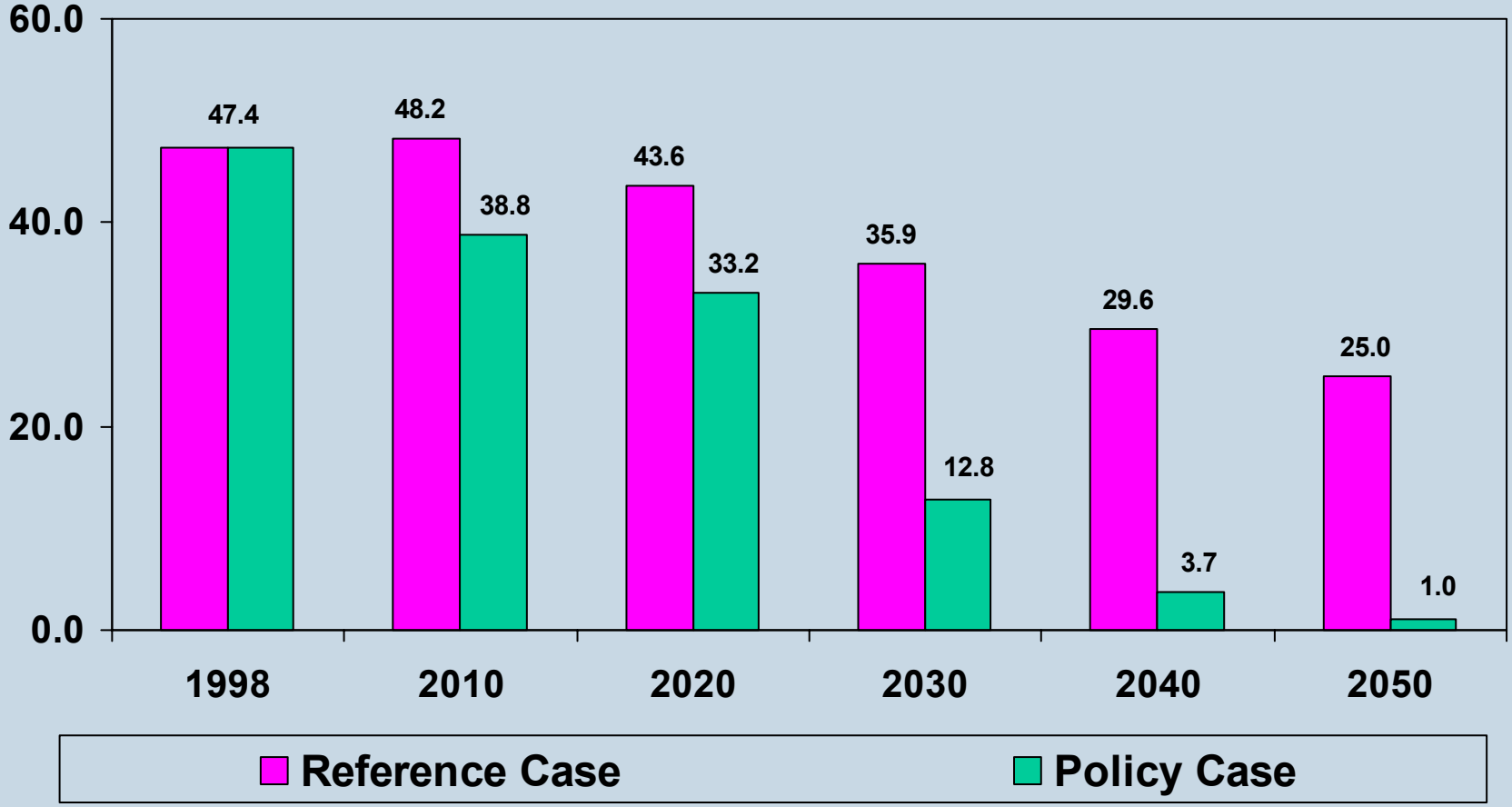
Electricity Sector SO_2 Emissions
(Million Short Tons)



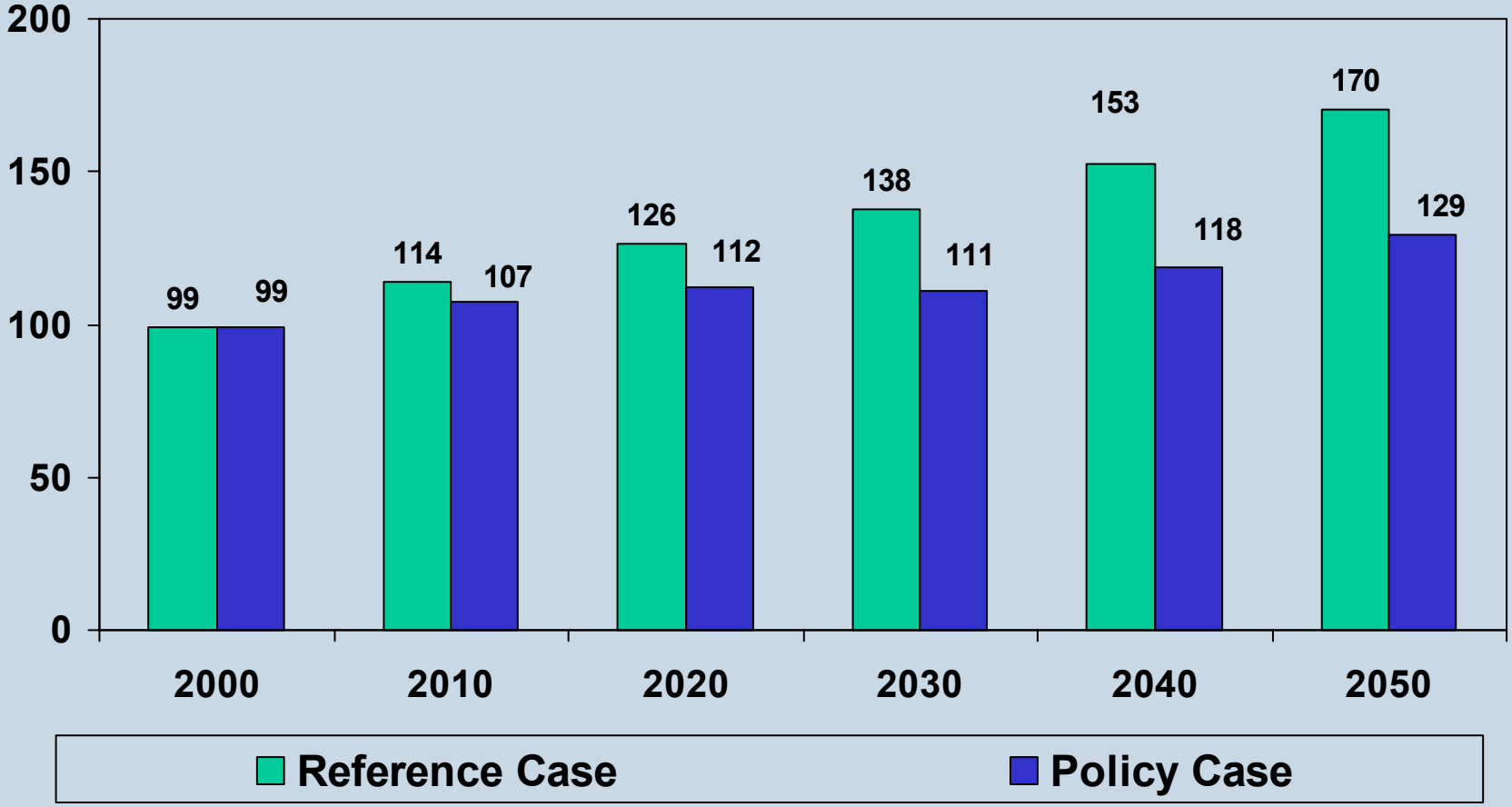
Electricity Sector NO_x Emissions
(Million Short Tons)



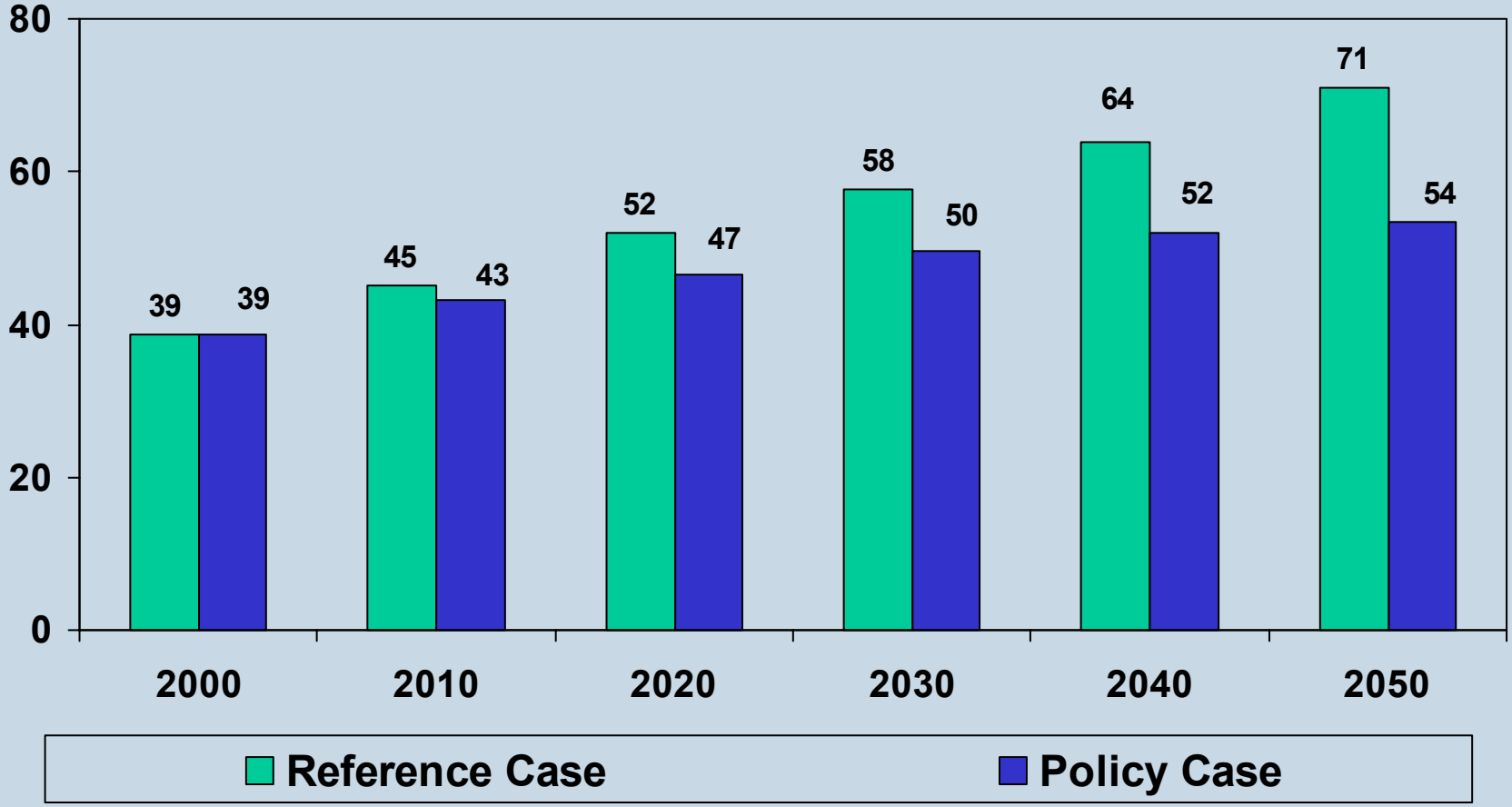
Electricity Sector Hg Emissions
(Short Tons)



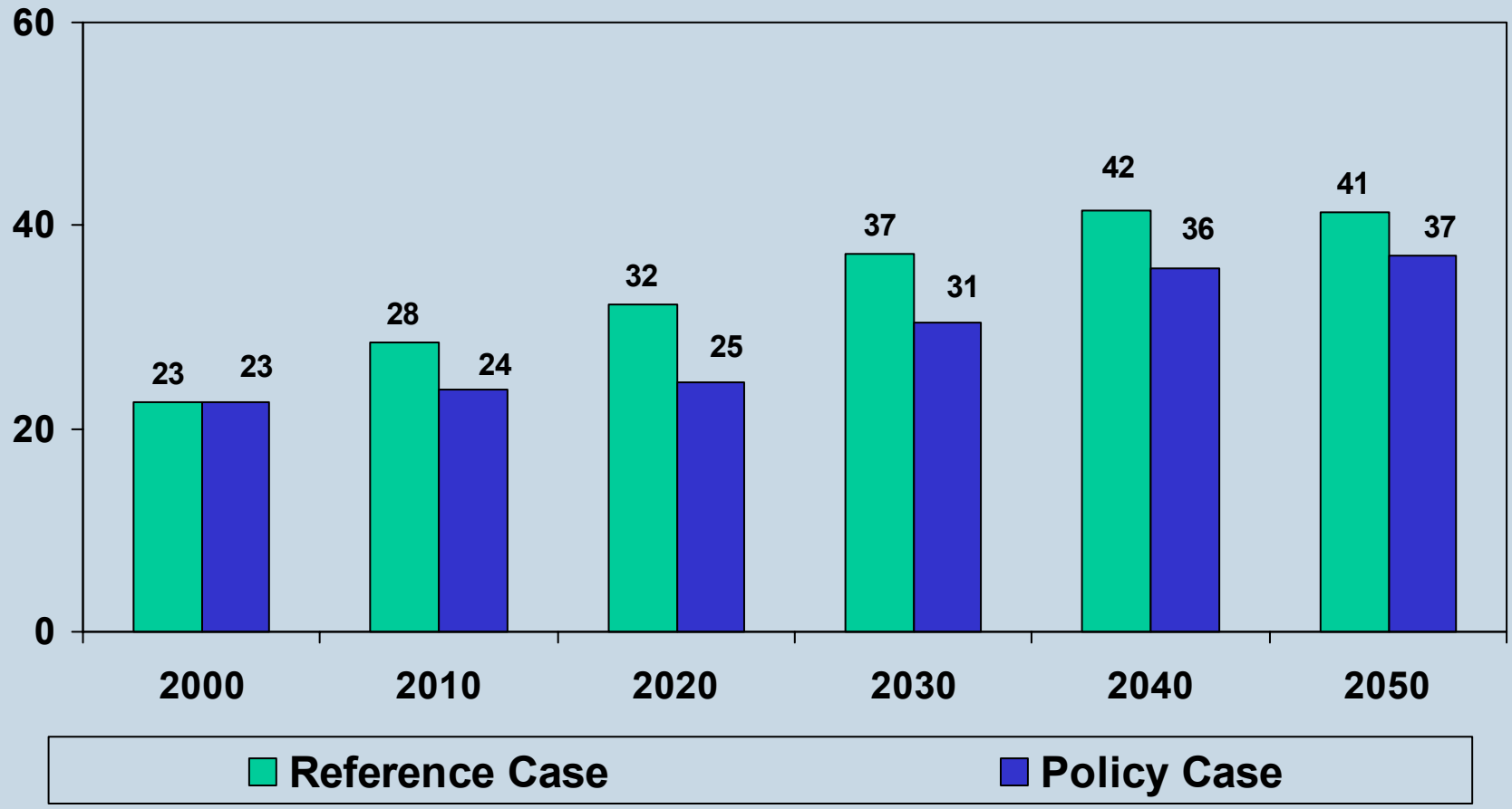
Total Primary Energy Consumption
(in Quadrillion Btus)



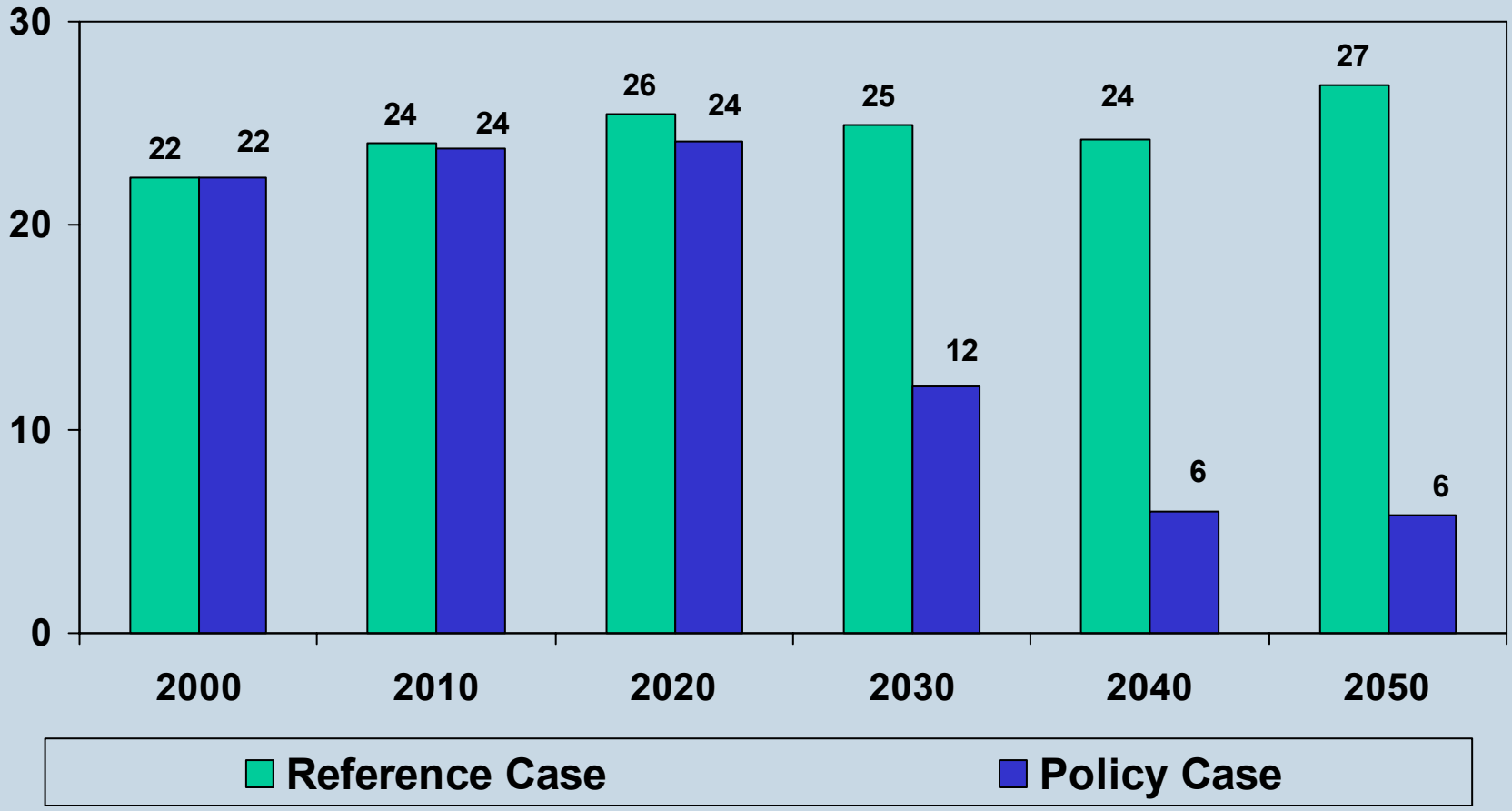
Total Petroleum Consumption
(in Quadrillion Btus)



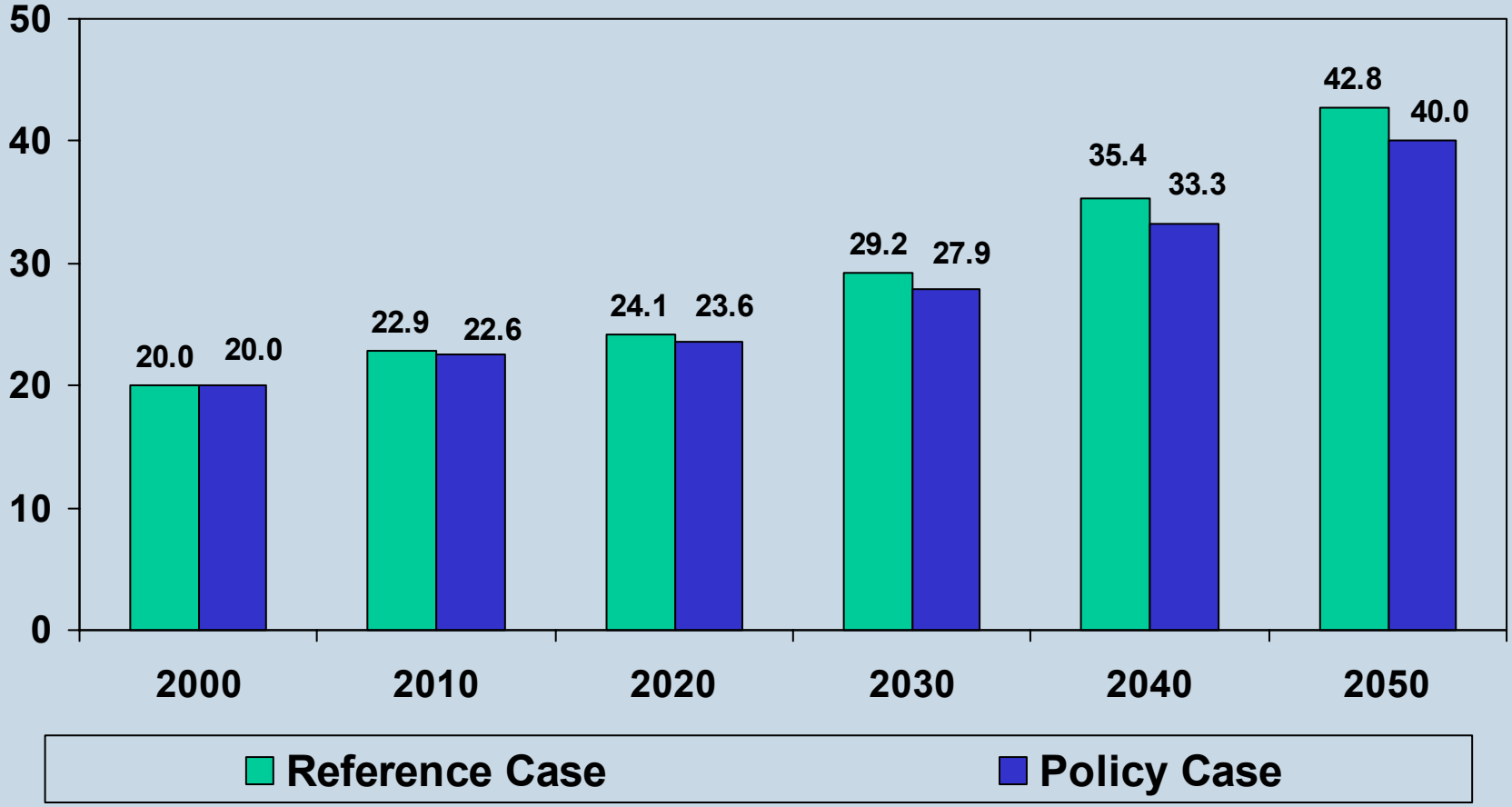
Total Natural Gas Consumption
(in Quadrillion Btus)



Total Coal Consumption
(in Quadrillion Btus)

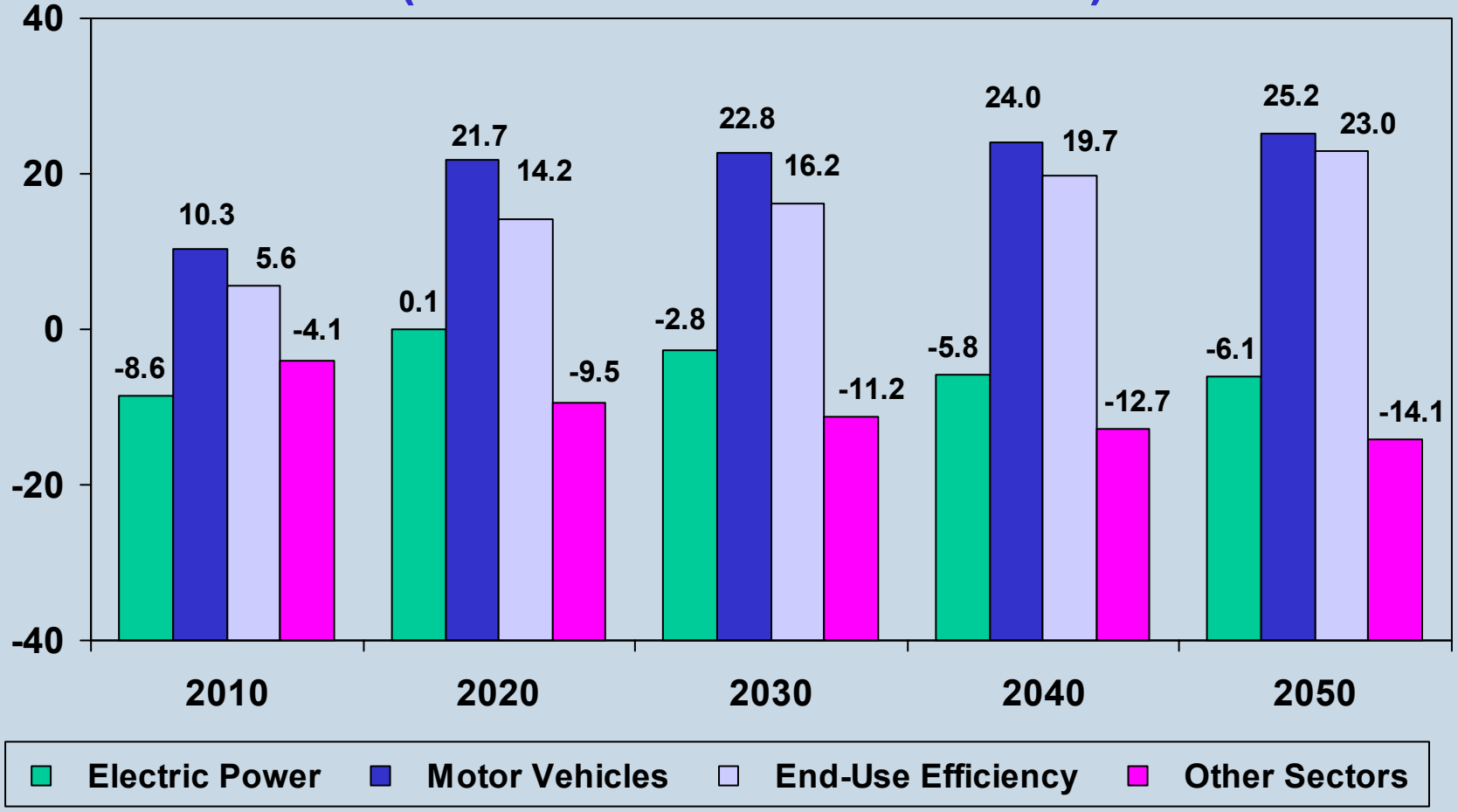


World Oil Price
(in 1999 dollars per barrel)

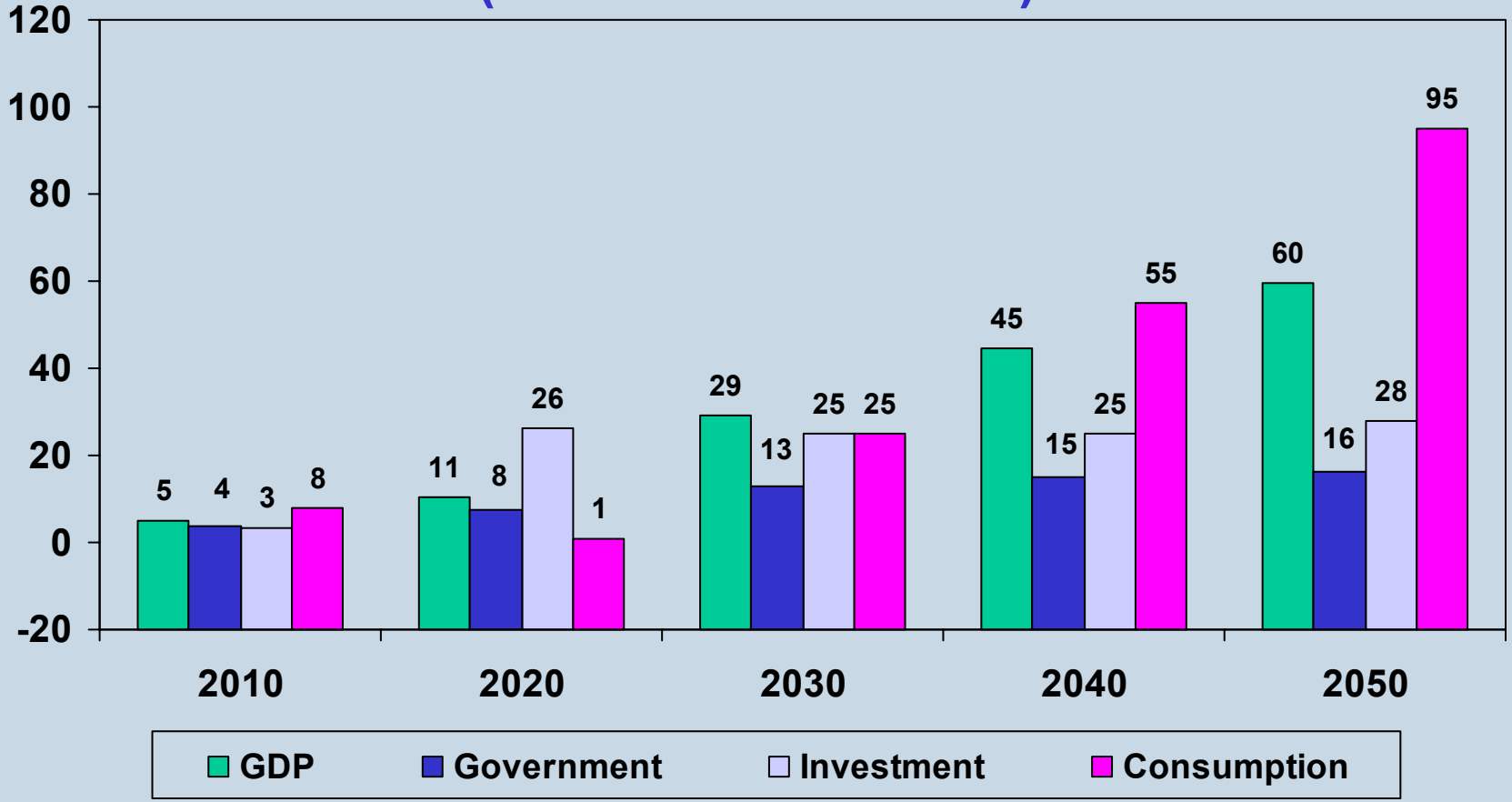


Changes in Policy Case Investments Compared to Reference Case

(in Billions of 1999 dollars)



Change in GDP Components Compared to Reference Case
(billion 1999 dollars)



Some General Conclusions

- Complementary programs and energy efficiency measures are important for meeting emissions targets at a lower cost.
- Providing both an adequate policy signal and sufficient financial incentive to stimulate more productive investments, over a longer time horizon, is critical to enhancing personal consumption and GDP growth
- Program spending, including increased support for voluntary program initiatives (such as Energy Star) and public/private research and development, are also an important complementary strategy
- To properly evaluate overall macroeconomic impacts, a model should be able to track changes in investment, changes in energy expenditures, and impacts on personal consumption. With the right flexibility, substantial emission reductions can be achieved at a small but net positive GDP and consumption impact.

For more information on the material referenced in this summary, contact:

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The preliminary findings contained in this conference presentation are believed to rely on credible and accurate sources of information. Any errors in the analysis are solely the responsibility of the analytical team completing the assessment. The results of the climate scenarios described herein should not be construed as reflecting the official views of the U.S. Environmental Protection Agency, Argonne National Laboratory, or the U.S. Government.