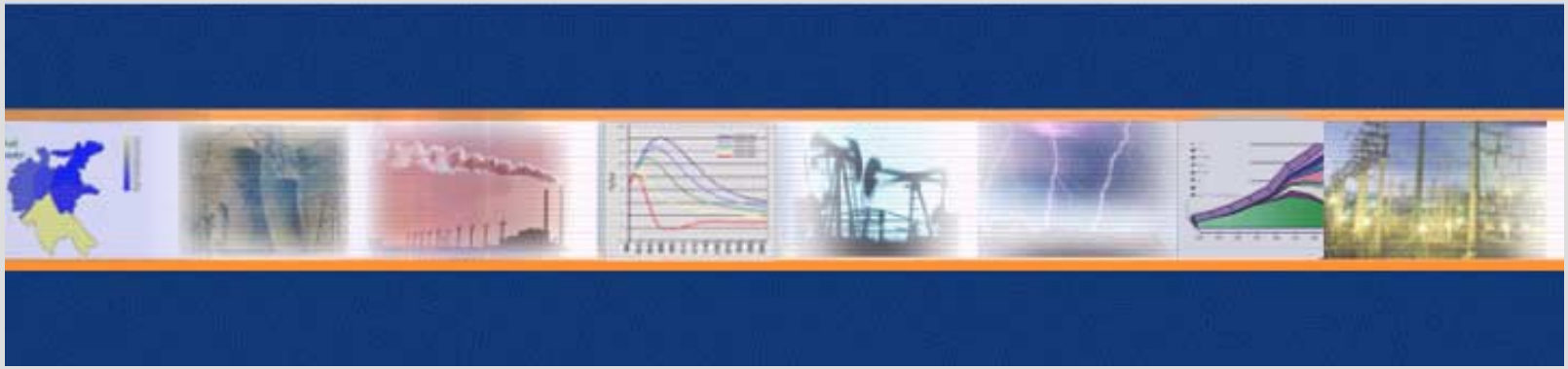
MARKAL MODEL APPLICATIONS FOR INDIA



ECONOMIC AND ENVIRONMENTAL MODELING WORKSHOP

MARKAL Model Structure and Formulation

MARKet ALlocation Model

- **Multi-period Linear Programming formulation**

- **Decision Variables like,**
  - Investment in technology capacities & their utilization
  - Energy consumption
  - Emissions
  - Electricity generation in different time periods

MARKAL Model Conceptual Structure

Techno-economic Database

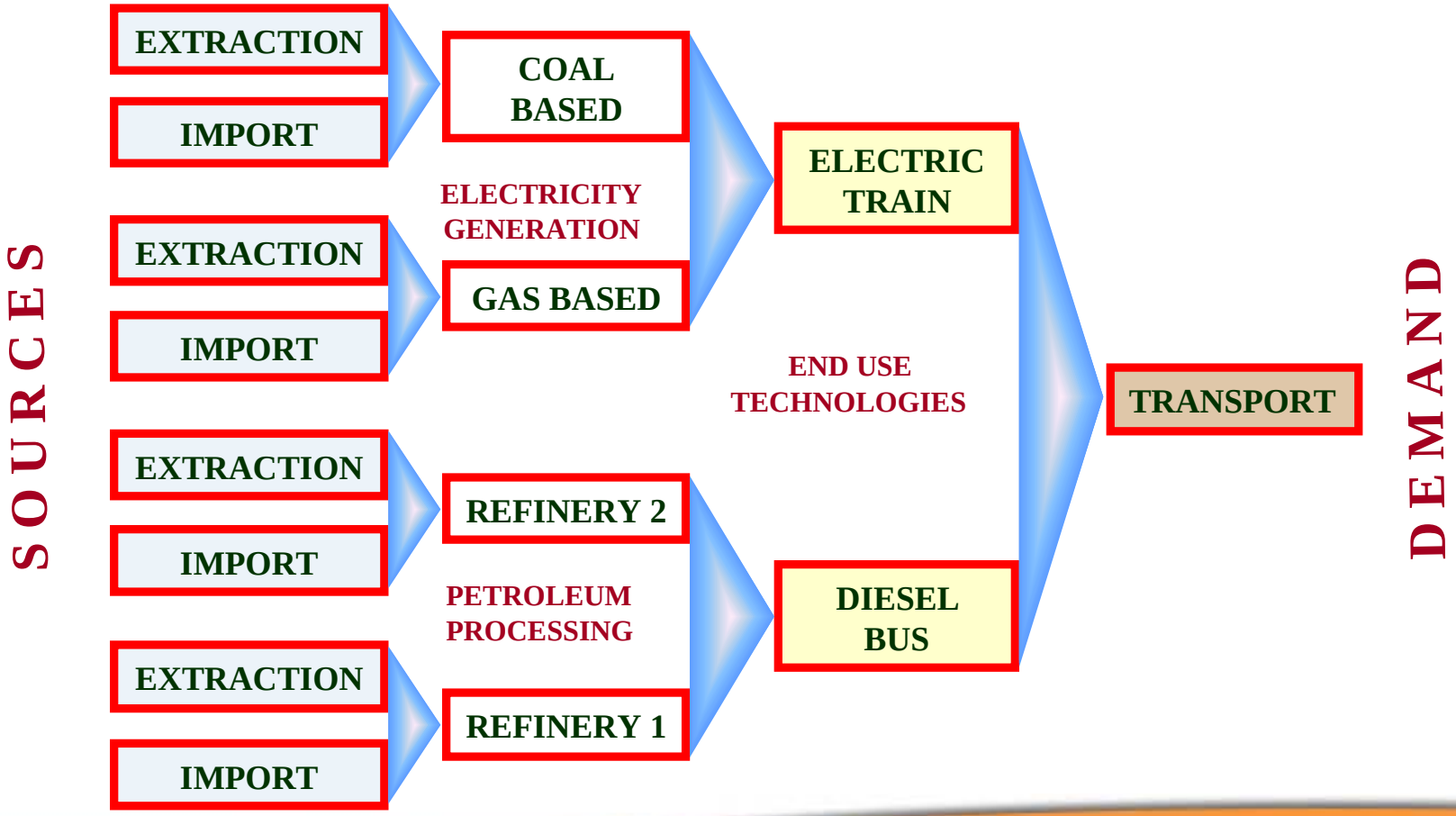
Economic Scenario

ANSWER MARKAL

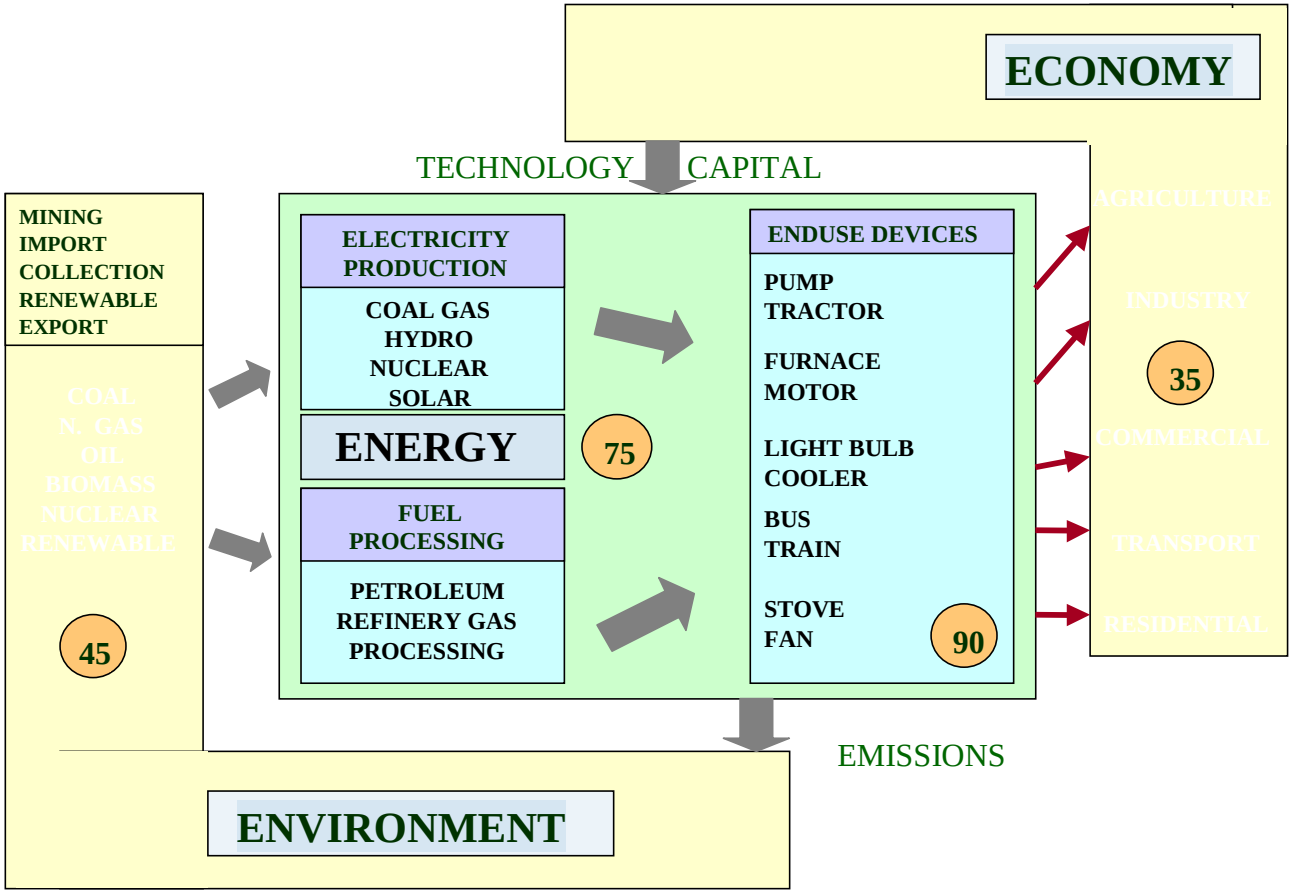
Economic Scenario

- Consumption and production of energy
- Total discounted cost
- Values of energy forms and emissions
- Introduction and abandonment of technologies

Typical Reference Energy System



Bottom up View of the Economy-Energy-Environment System



Objective Function

- Minimise long-term total discounted system cost (TDSC) which is the combination of five types of cash flows :

- TDSC = Technology Cost + Import Cost - Export Revenue - Salvage Value + Emission Tax

Constraints

1. Capacity transfer constraints (to account for technology vintage carry over time periods)
2. Energy carrier balance constraints (supply >= demand of fuel)
3. Cumulative reserve constraints (fuel extraction <= total reserves)
4. Electricity balance constraints (day and night time modeling for electricity system)
5. Process technology capacity utilization constraints (process activity <= available capacity)
6. Electricity production capacity constraints (electricity generation <= available capacity)
7. Electricity peaking constraints (extra capacity to meet peak demand)
8. Total emissions constraints (Carbon, SO_2 etc.)

Sectoral Demand Projection: Logistic Regression

$$Y_t = Y_0 \frac{\exp(a + bt)}{1+\exp(a + bt)}$$

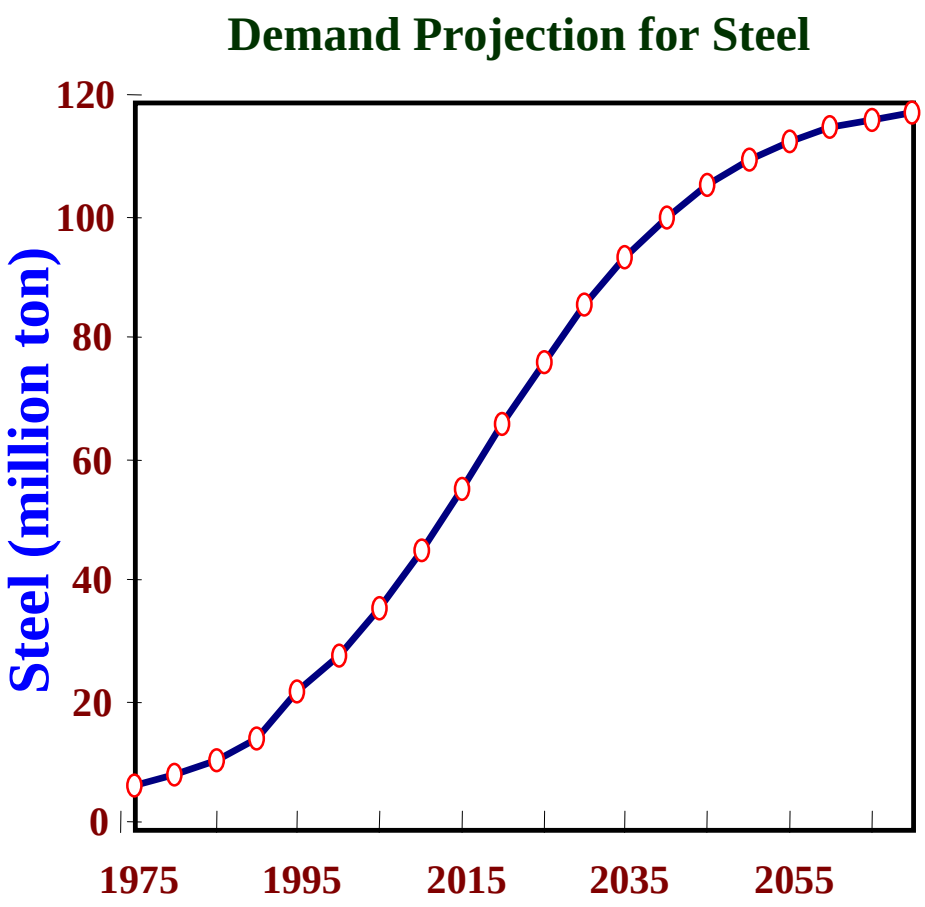
$$\ln((Y_t / Y_o)/(1- Y_t / Y_o)) = a + bt$$

t = time period

Y_t = level of demand at time t

Y_0 = asymptotic limit for the demand Y_t

a,b : Parameters to be estimated



MARKAL Model Application for India

Indian Emission Scenario Key Drivers

IA1: High Growth

- 7.7% GDP growth for next three decades
- Enhanced all-round infrastructure
- Accelerated market reforms
- High access to global finance & technologies
- Technology, information & industry driven

IA2: Business-As-Usual

- 5.5% GDP growth for next three decades
- Fragmented infrastructure development
- Slower market reforms
- Low globalization and liberalization
- Heavy-industry driven

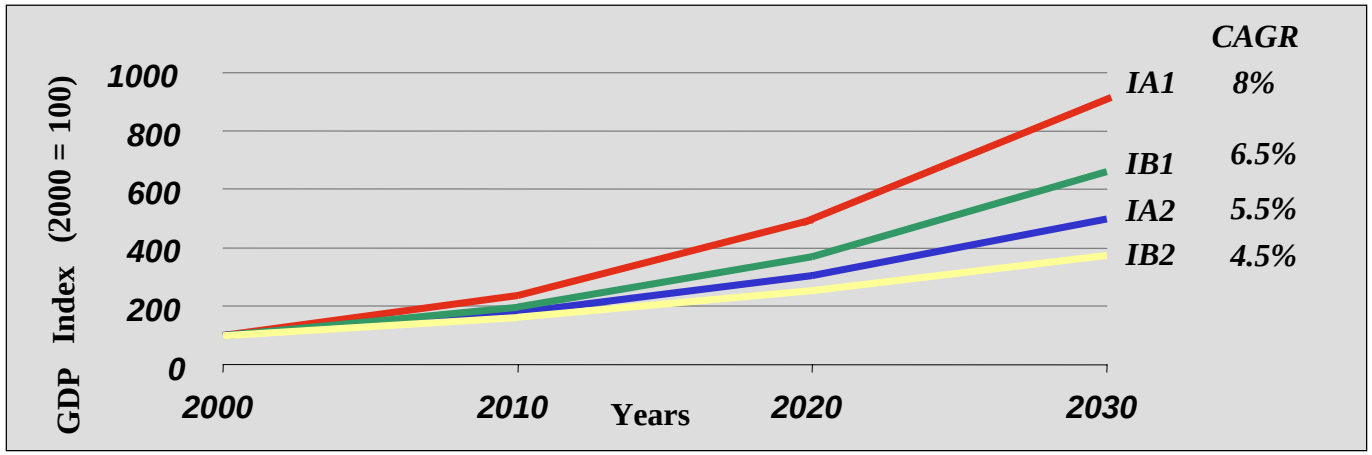
IB1: Sustainable Development

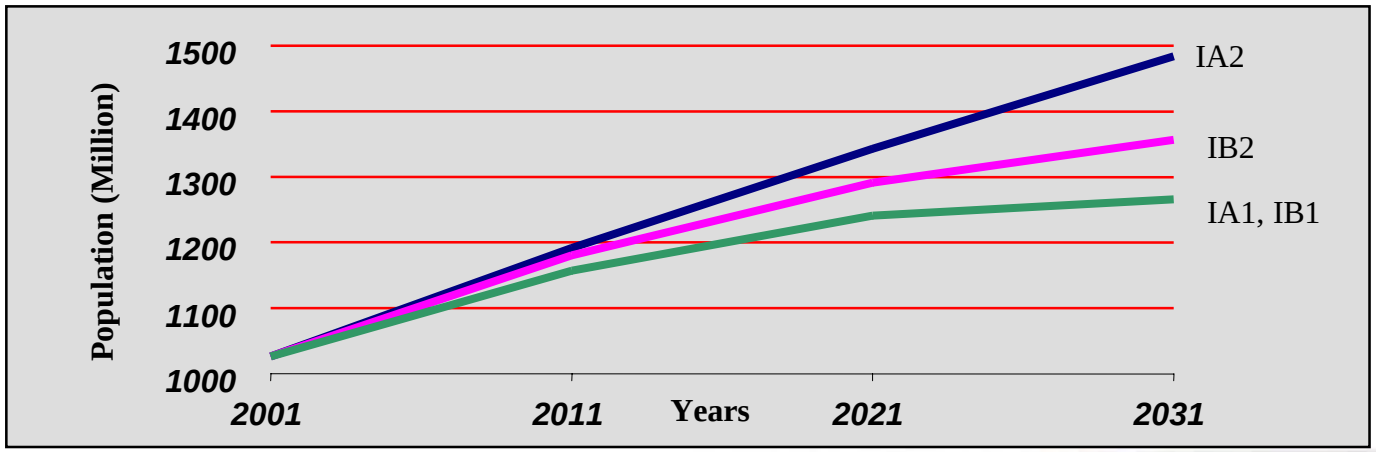
- 6.5% GDP growth for next three decades
- Strong environmental integrity of the economy
- Sustainable consumption all-round
- Dematerialization, renewable energy thrust
- Enhanced all-round infrastructure
- Lower income disparities
- High access to global finance & technologies

IB2: Regional Development

- 4.5% GDP growth for next three decades
- Fragmented infrastructure development
- Inward looking policies
- High regional disparities in development levels
- Slower shift away from agriculture
- Slower technology improvements

India: GDP and Population Projections

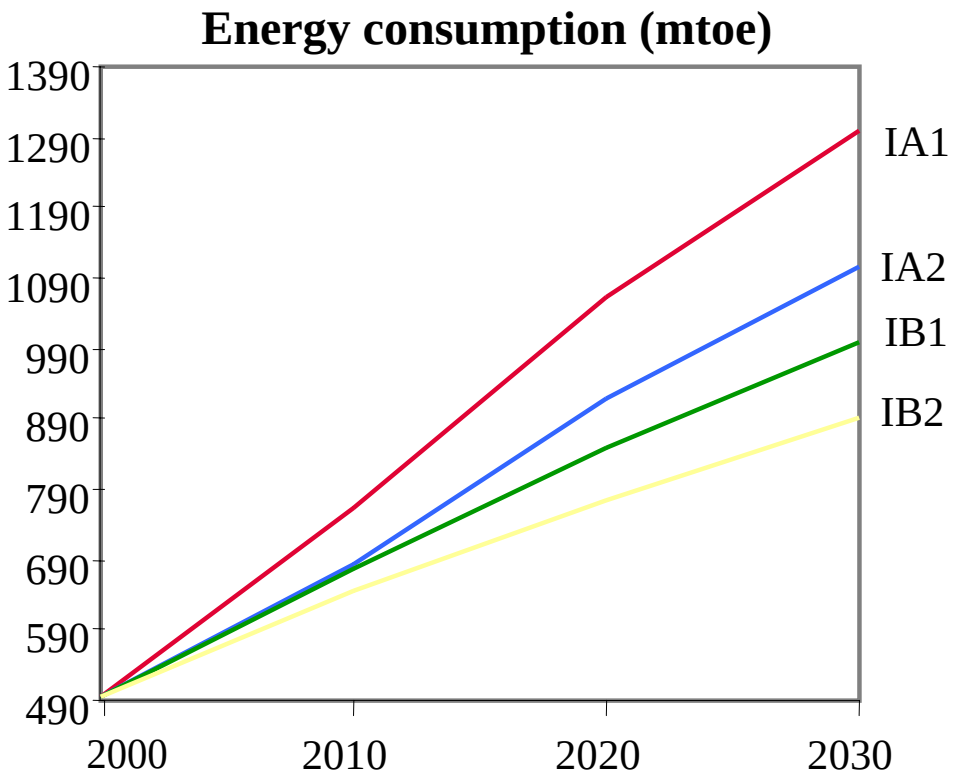


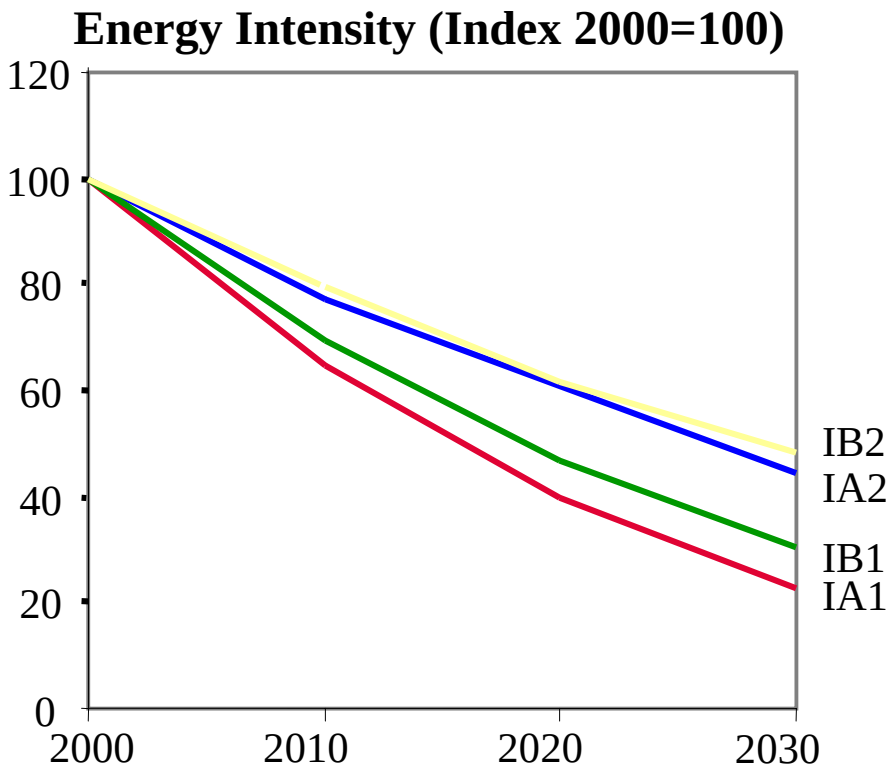


Developmental Pathways: A Comparison

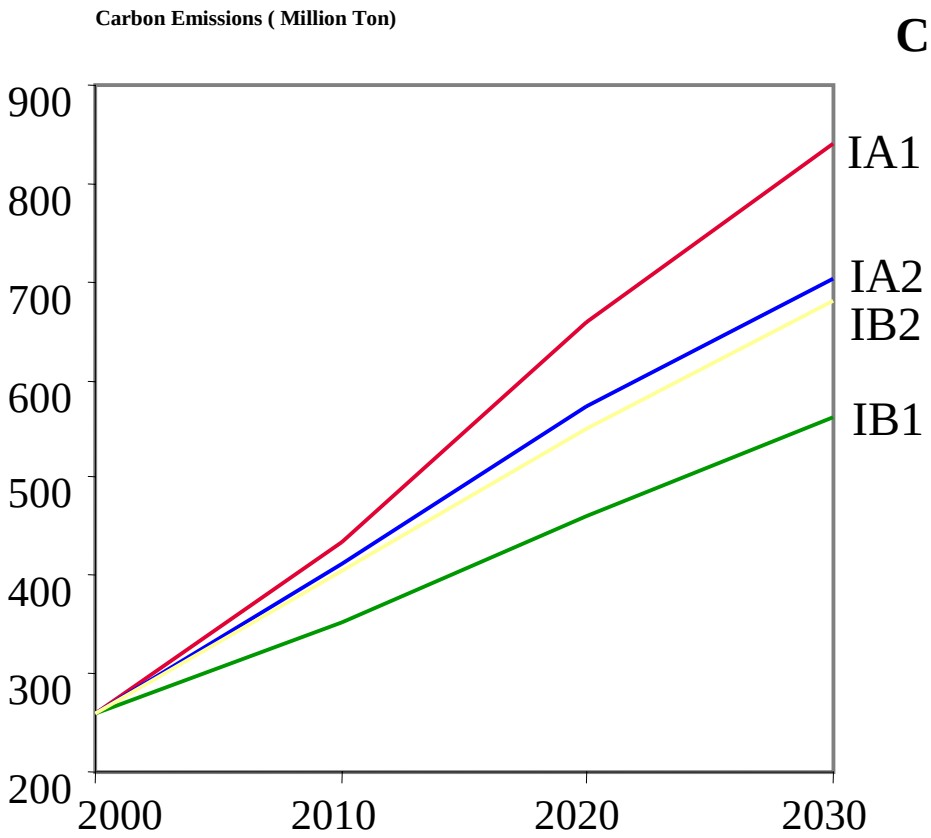
	IA1	IA2	IB1	IB2
GDP annual growth (2000-2030)	7.7%	5.5%	6.5%	4.5%
Cumulative Bt-CO_2 (2000-2030)	61	53	45	23
Per capita carbon, 2030 (tC)	0.63	0.47	0.49	0.39

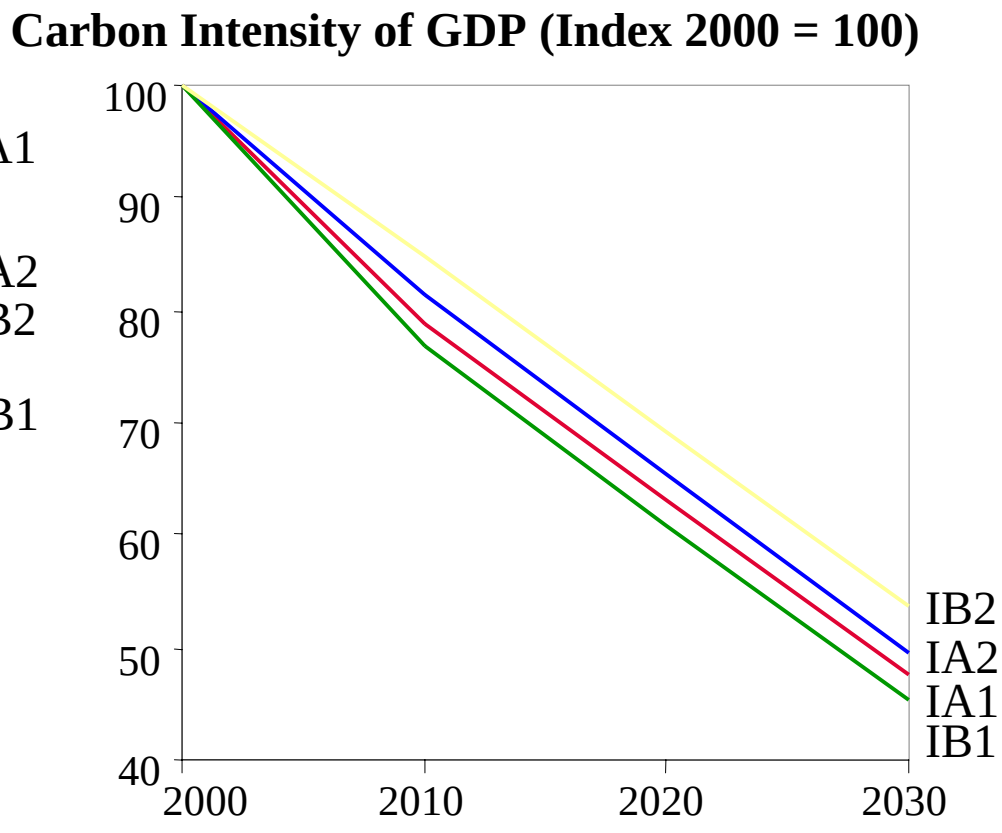
Energy Consumption Pathways



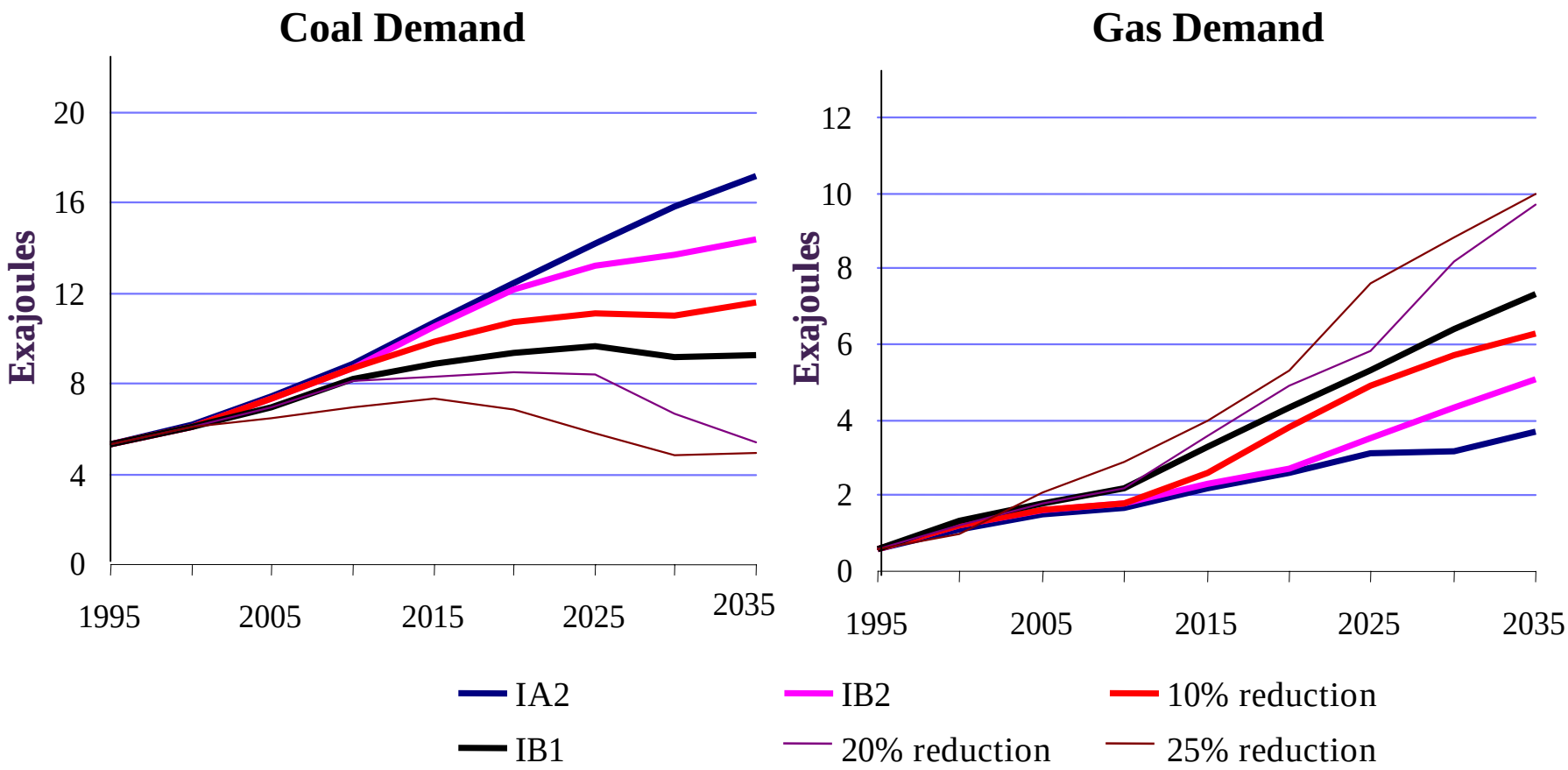


Carbon Emission Pathways



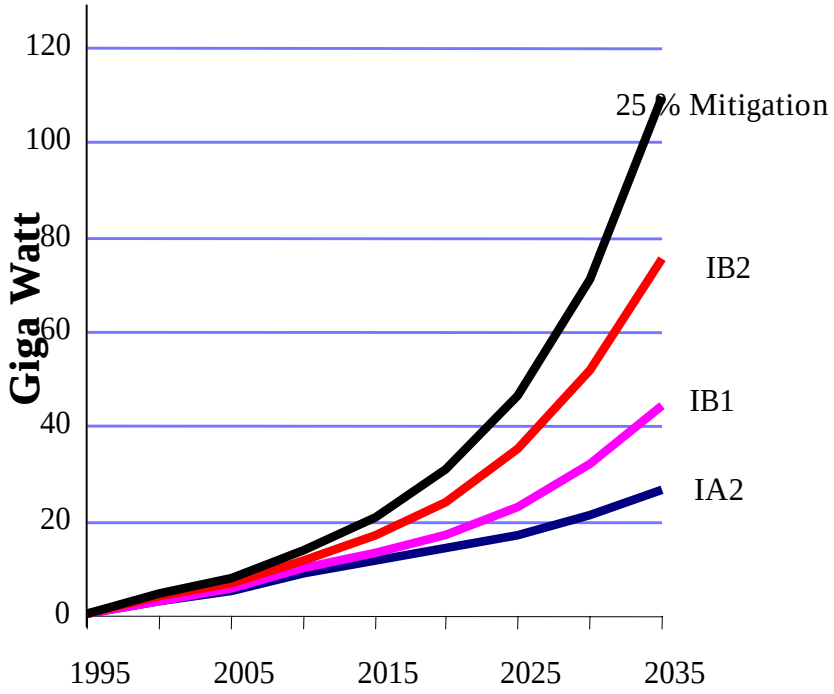


Implications of Path Dependence for Coal and Gas

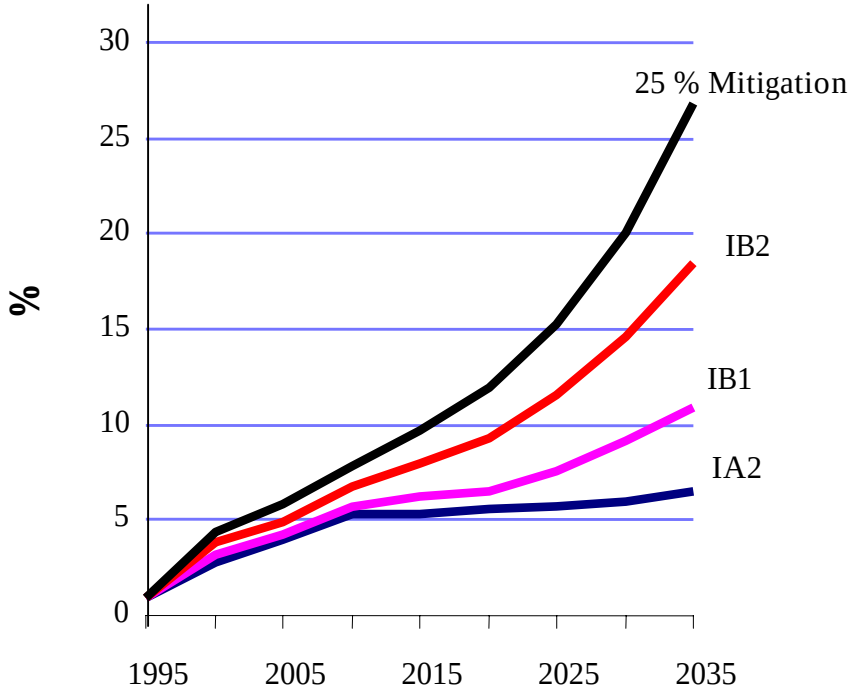


Implications of Path Dependence on Renewable Technology Penetration

Renewable Electricity Capacity

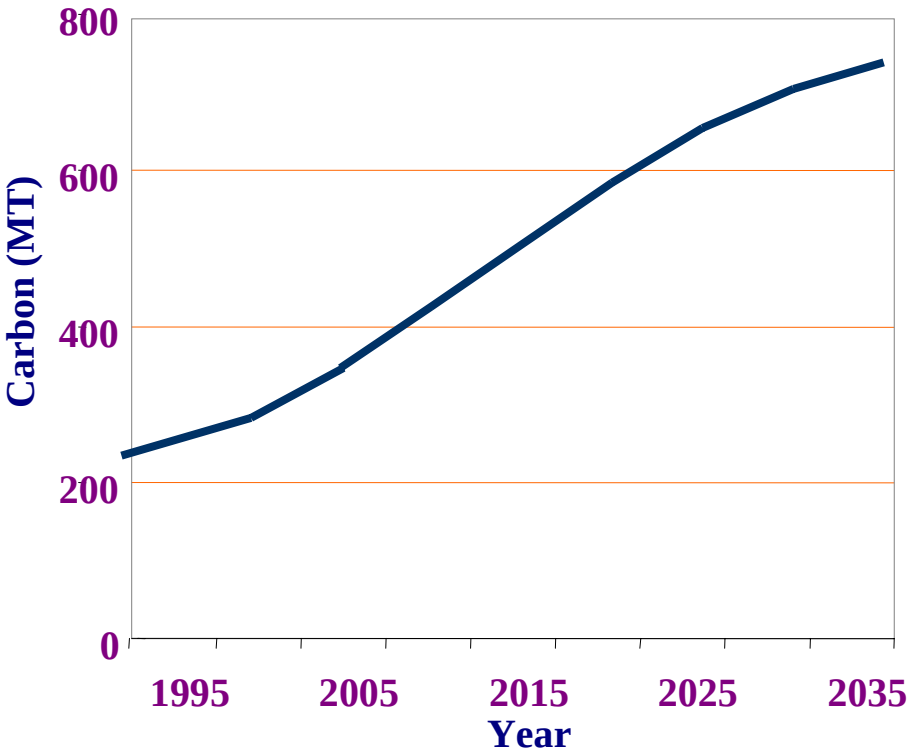


Share of Renewable

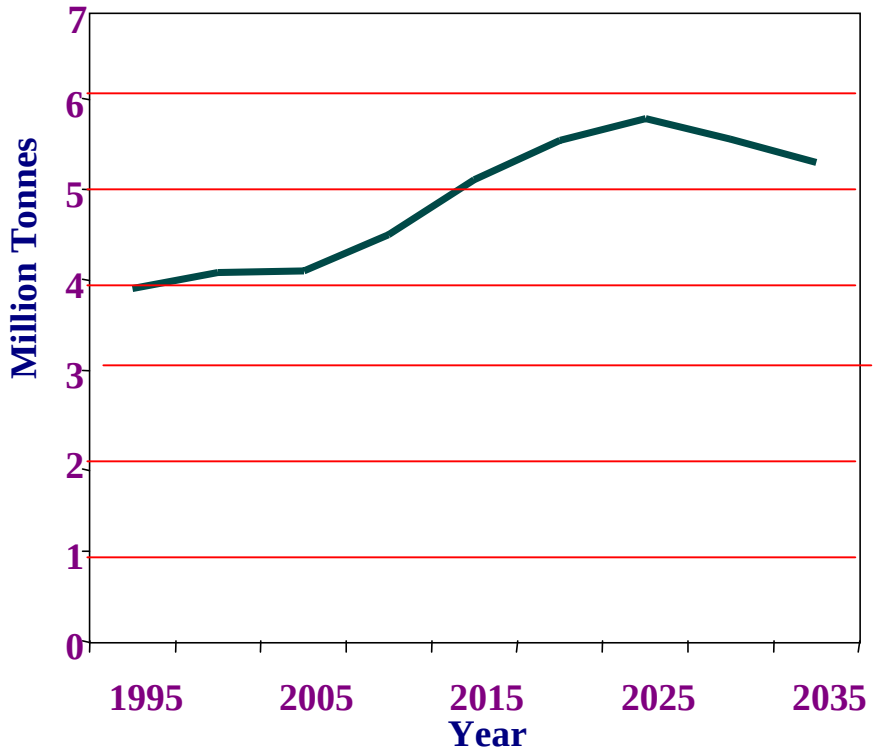


GHG versus Local Emissions in India (IA2 Scenario)

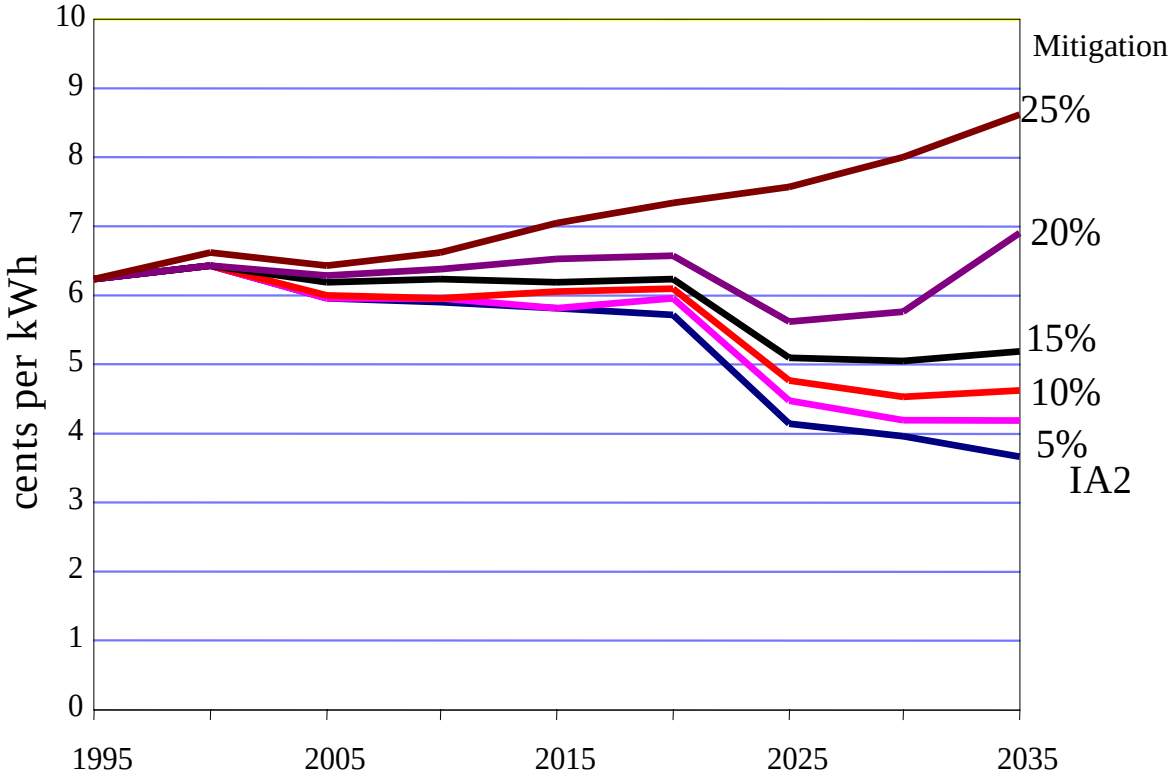
Carbon Emissions



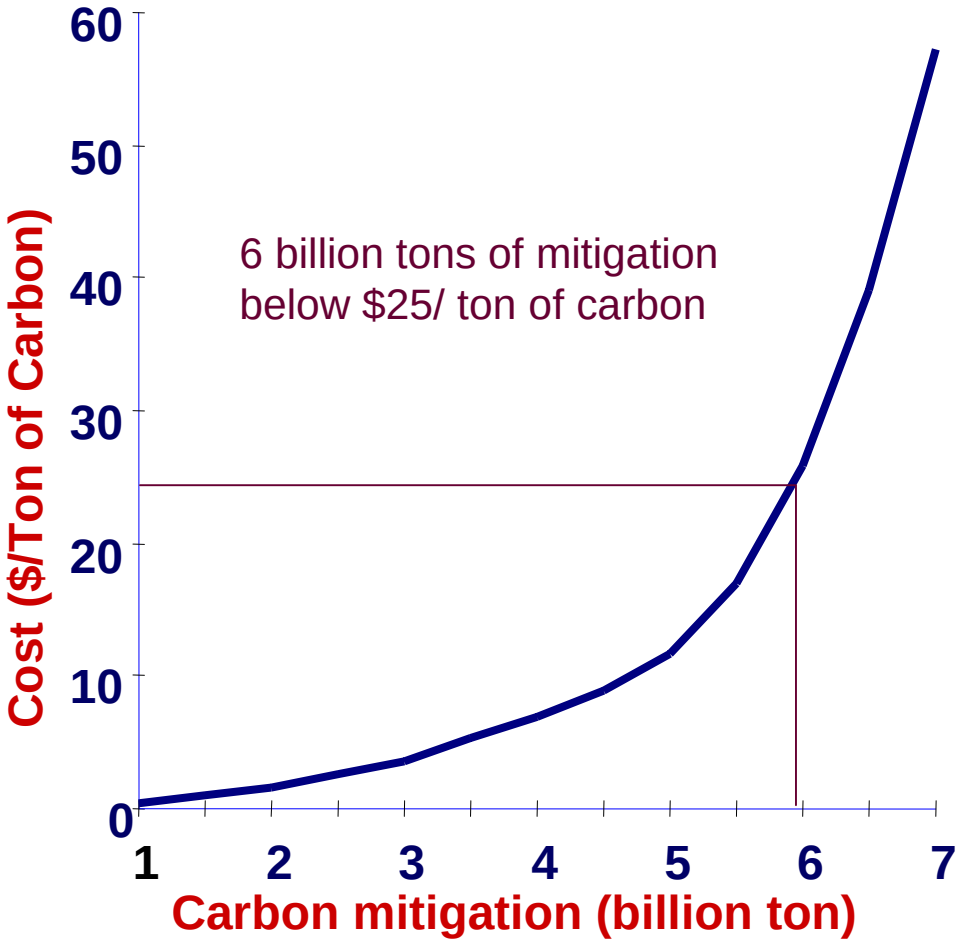
SO2 Emissions



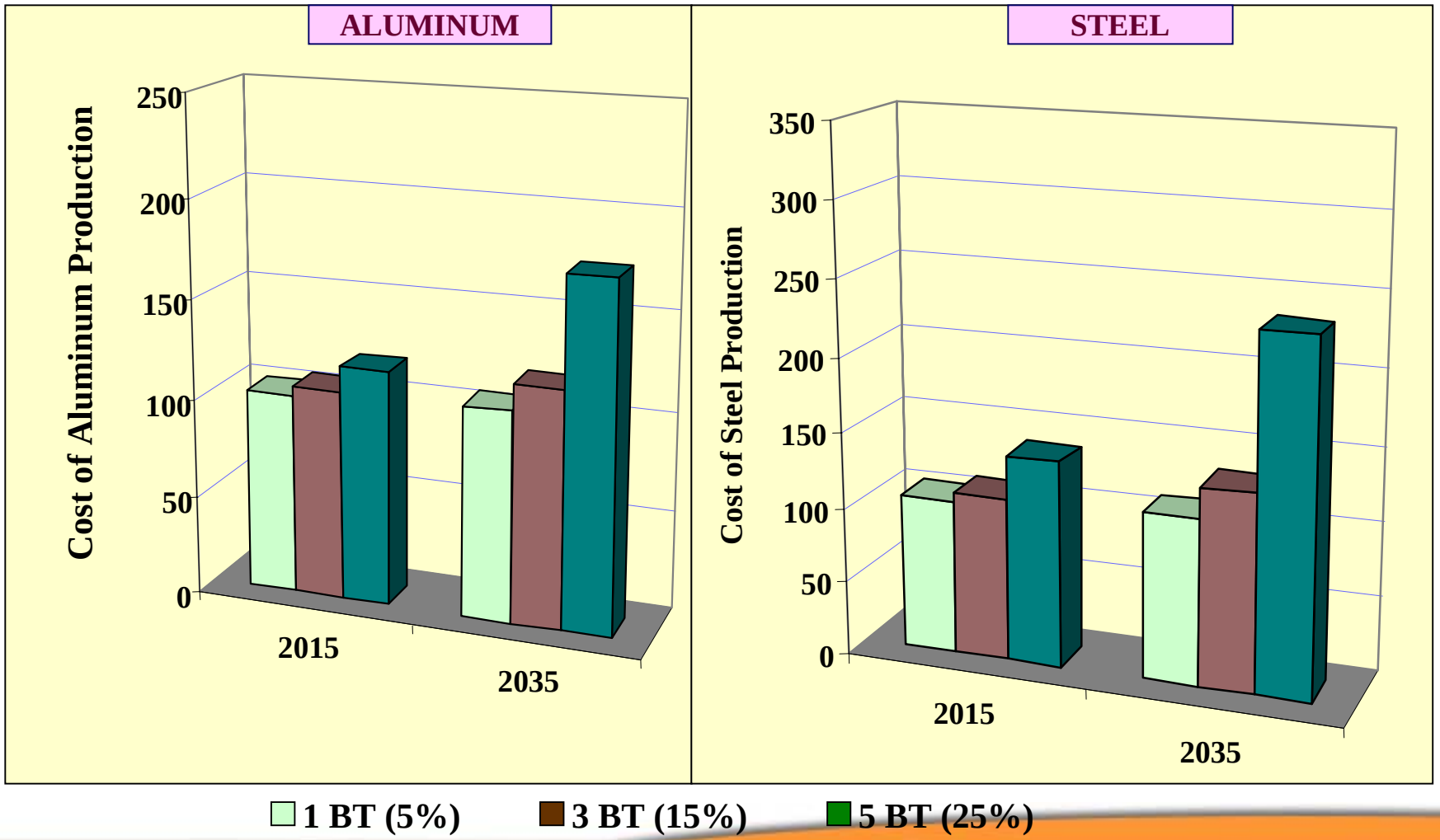
Implications of Mitigation: Electricity Price over IA2 Scenario



Marginal Cost of Carbon Mitigation (1995-2035)

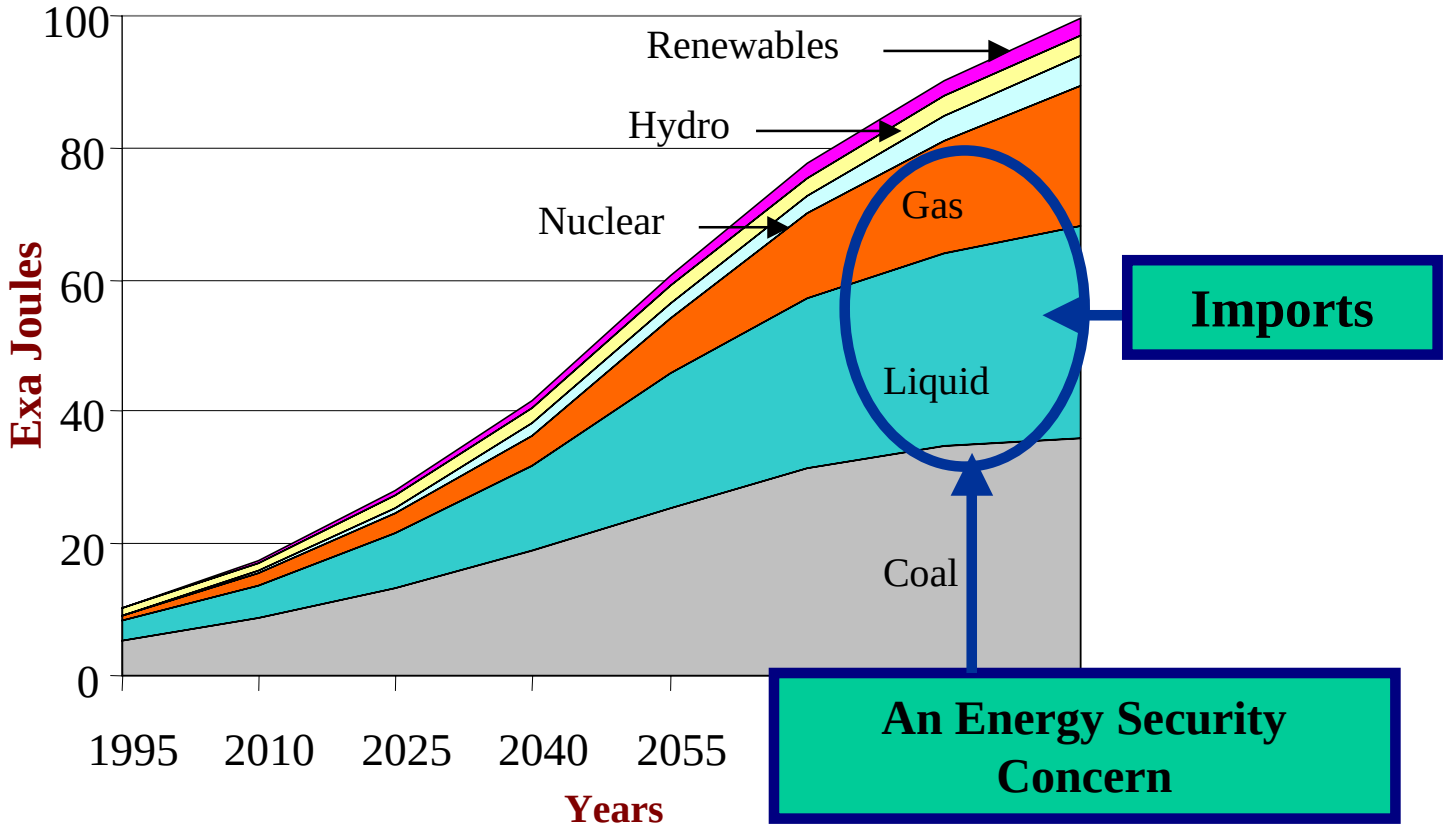


How Carbon Mitigation affects Production Cost?

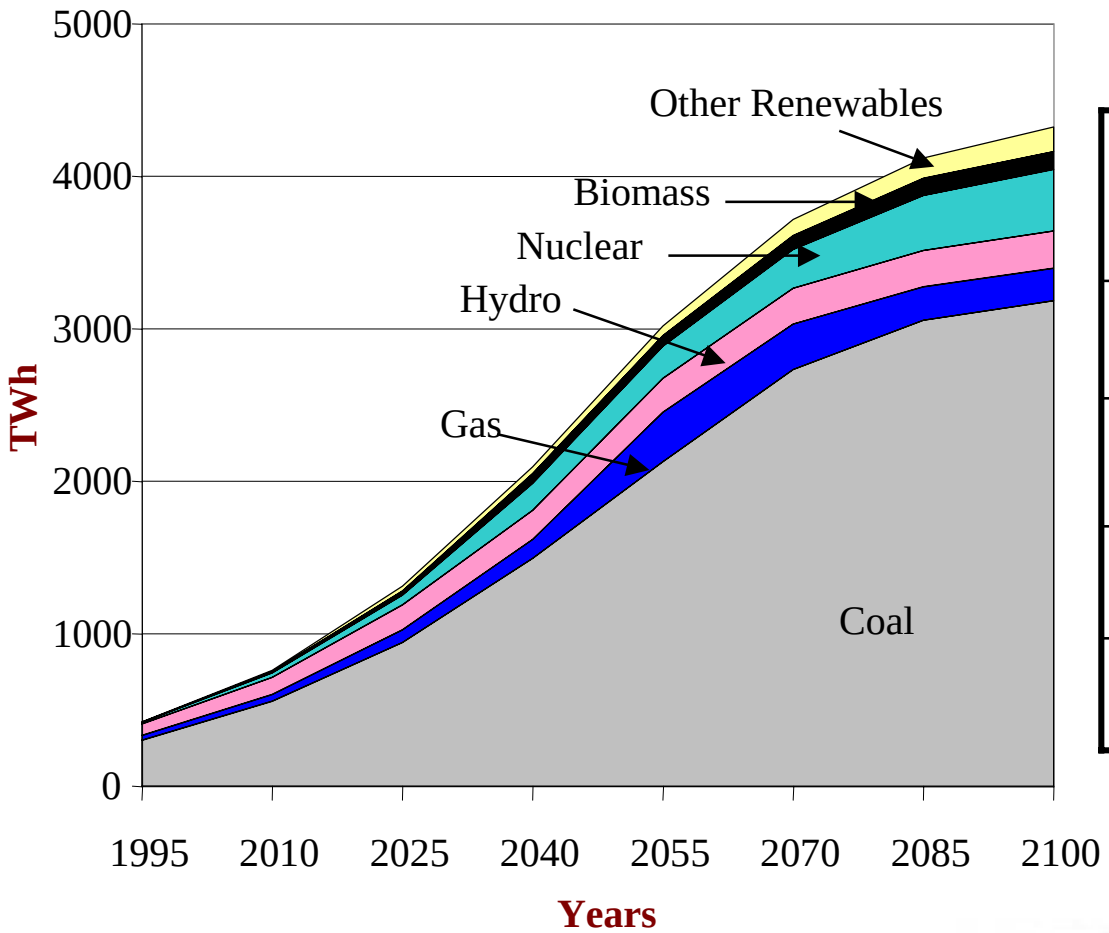


Long-term (100 Year) Analysis with ANSWER-MARKAL

Primary Energy Trend



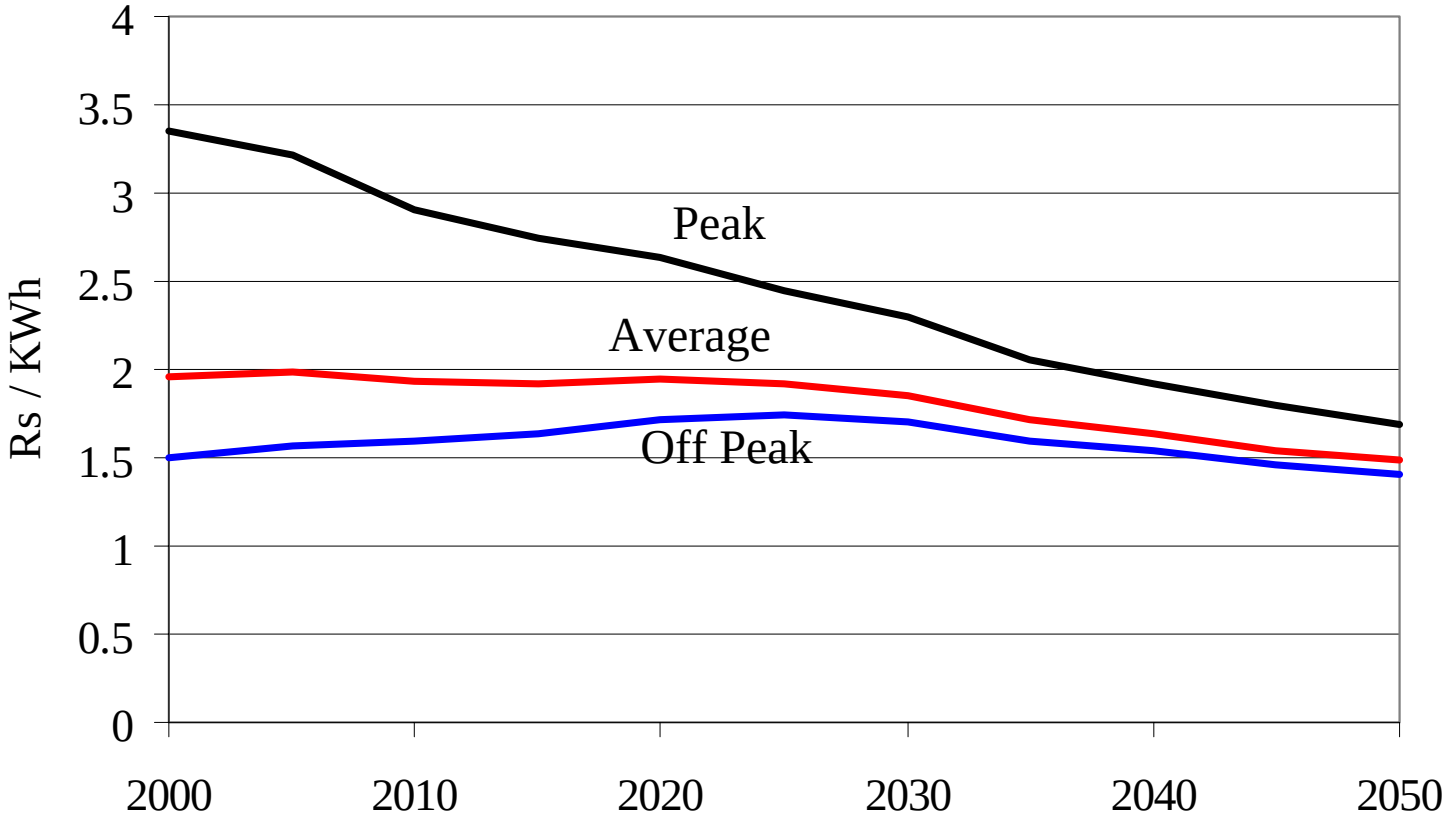
Electricity Trend



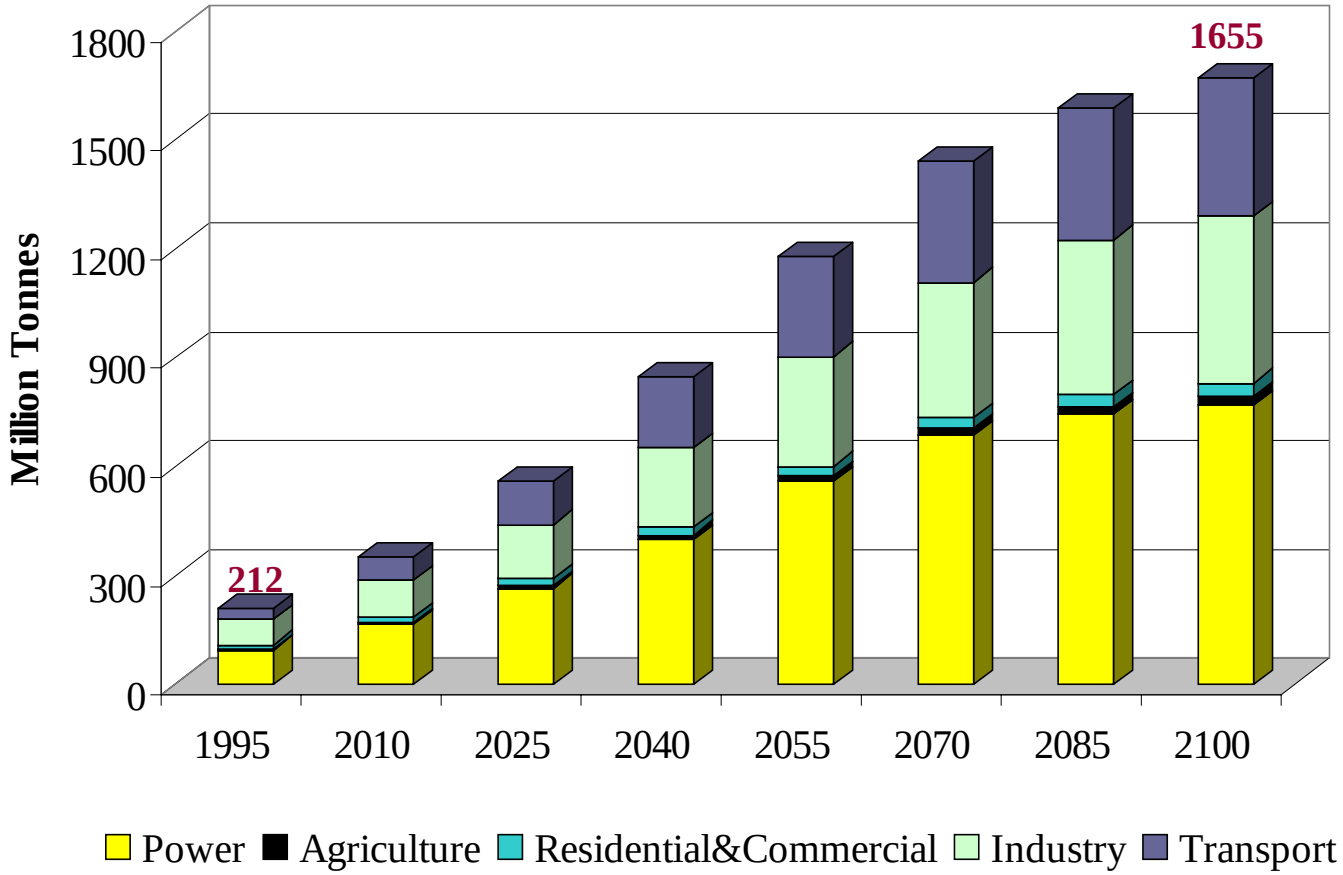
Electricity Generation (TWh)

Technology	1995	2100
Gas	33.1	212.3
Renewables	2.59	276.8
Hydro	75.9	244
Nuclear	8	405

LRMC of Electricity

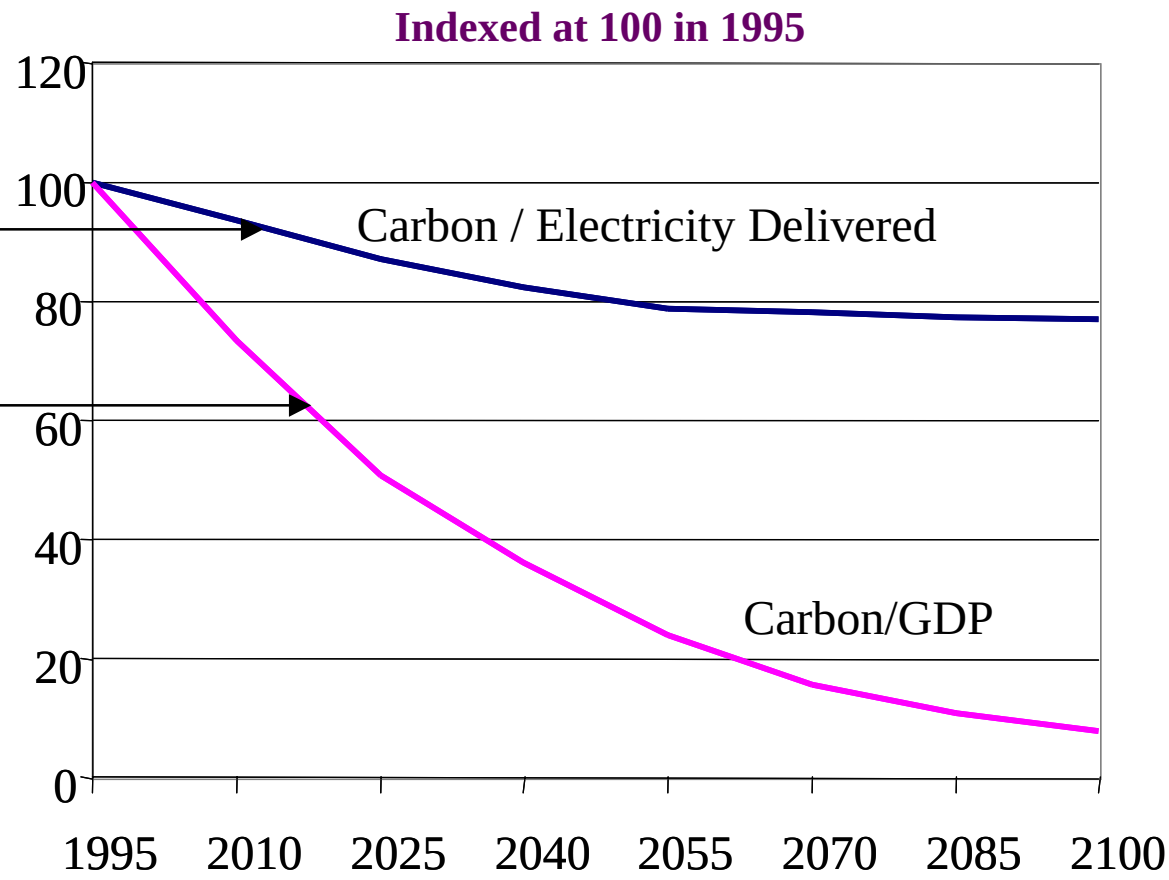


Long-term Carbon Emission Trend

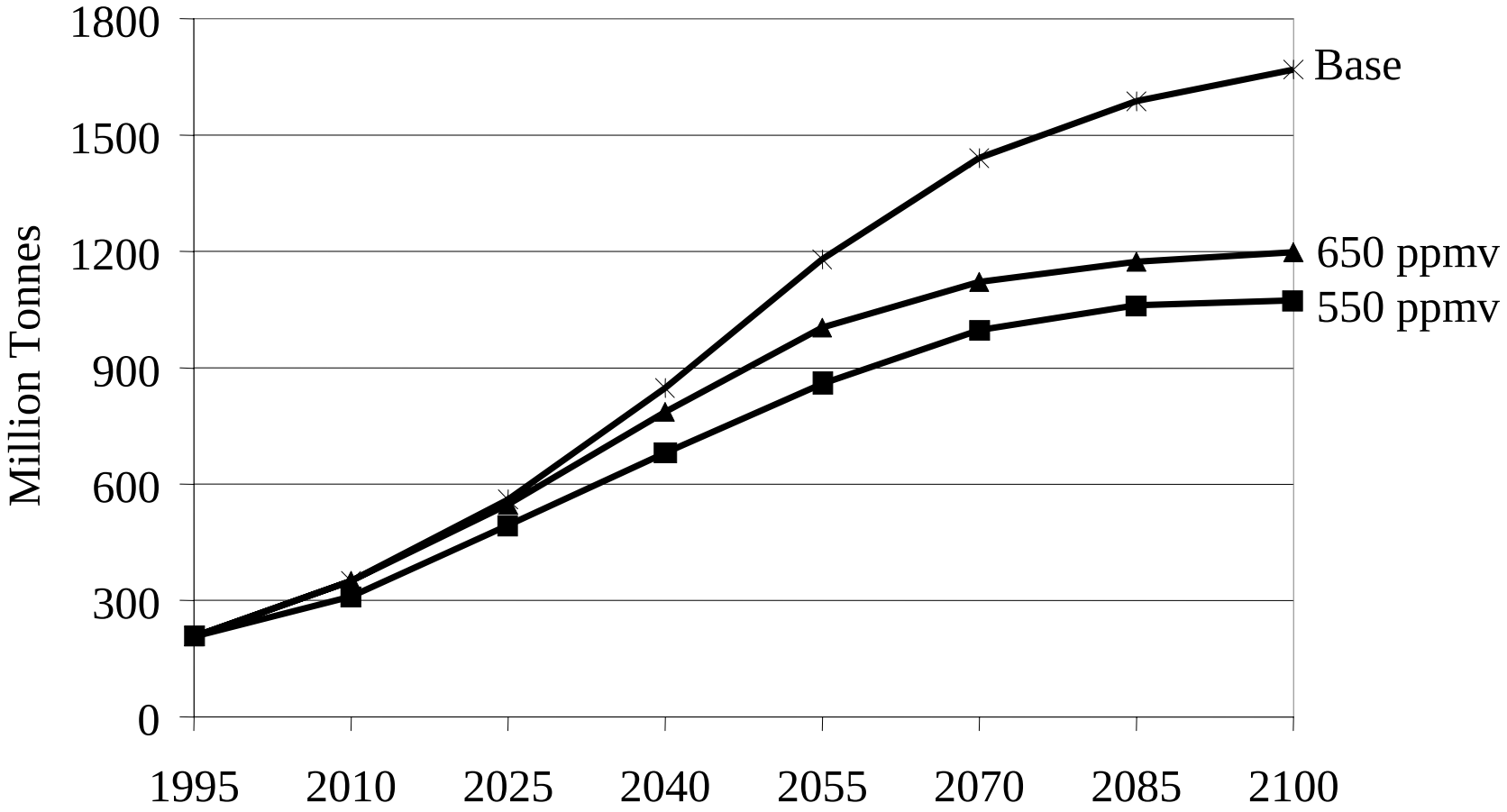


Future Intensities

- Carbon intensity of electricity reduces gradually
- Strong decoupling between GDP growth and carbon emissions

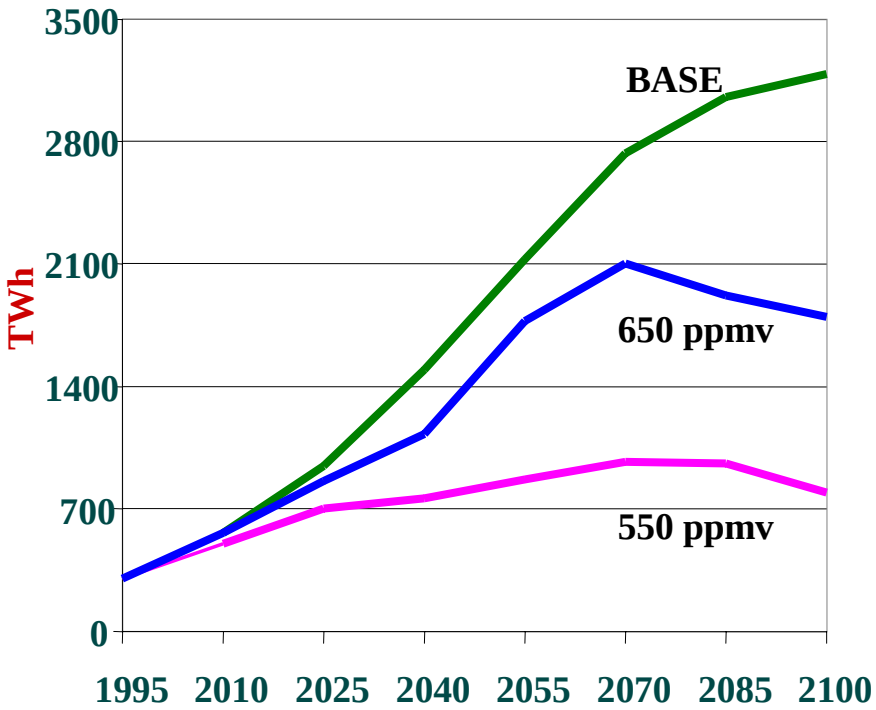


Carbon Emission Constraints

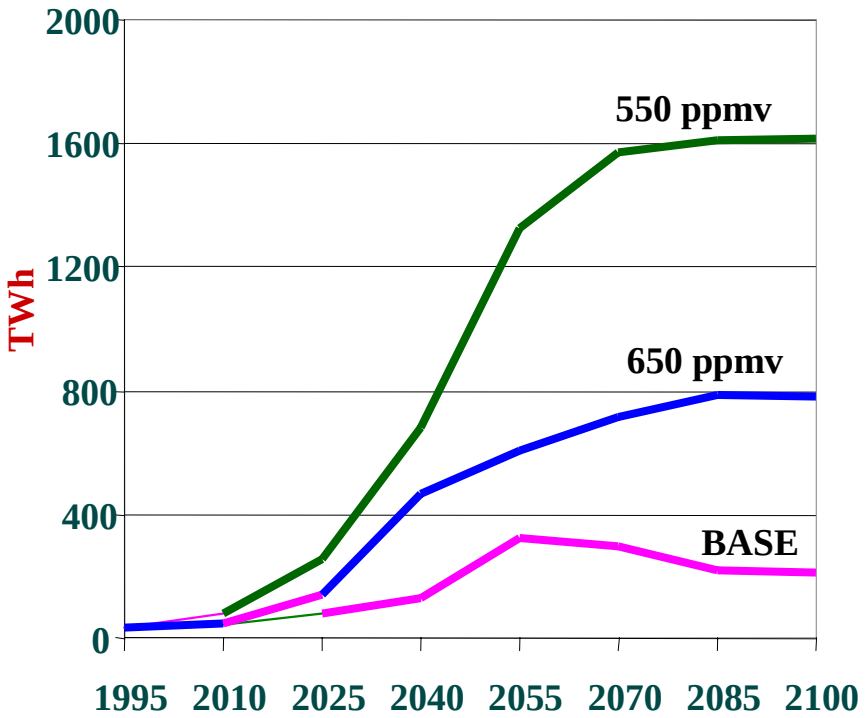


Impact on Fossil Technologies in Electricity

Coal Electricity

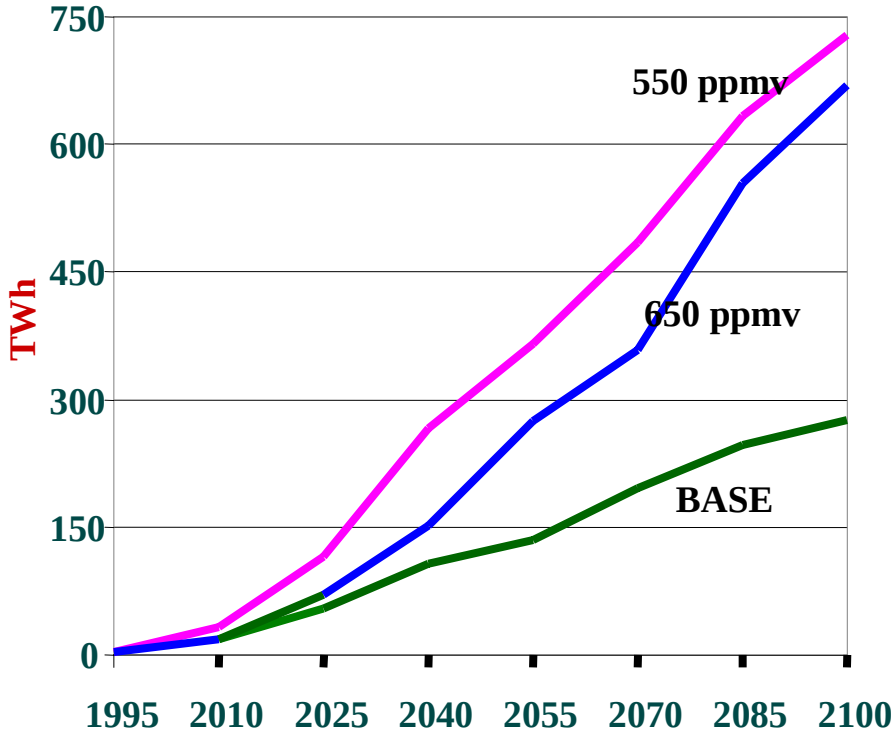


Gas Electricity

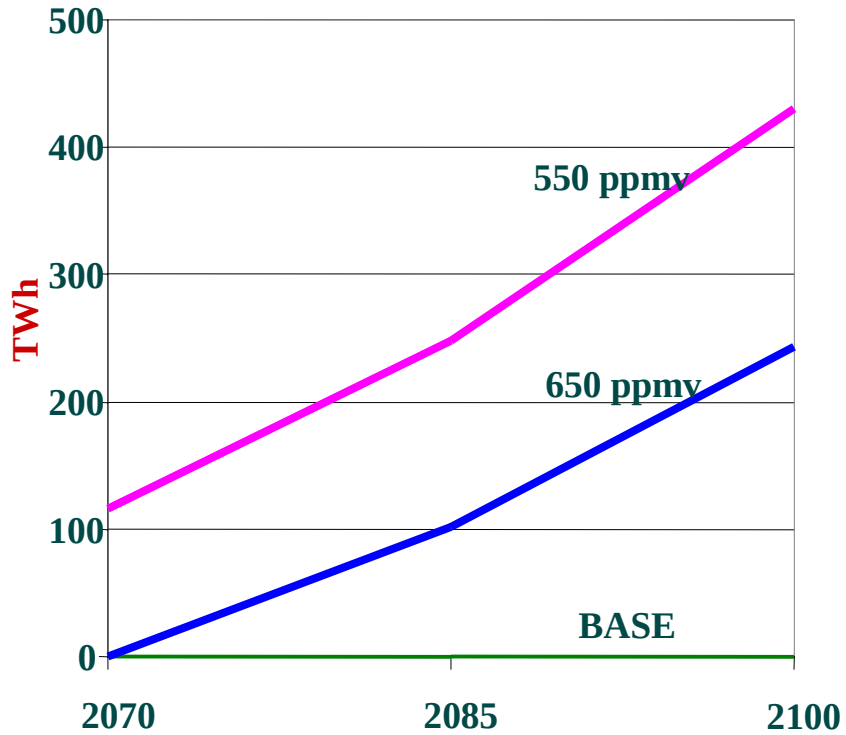


Impact on New and Renewable Technologies

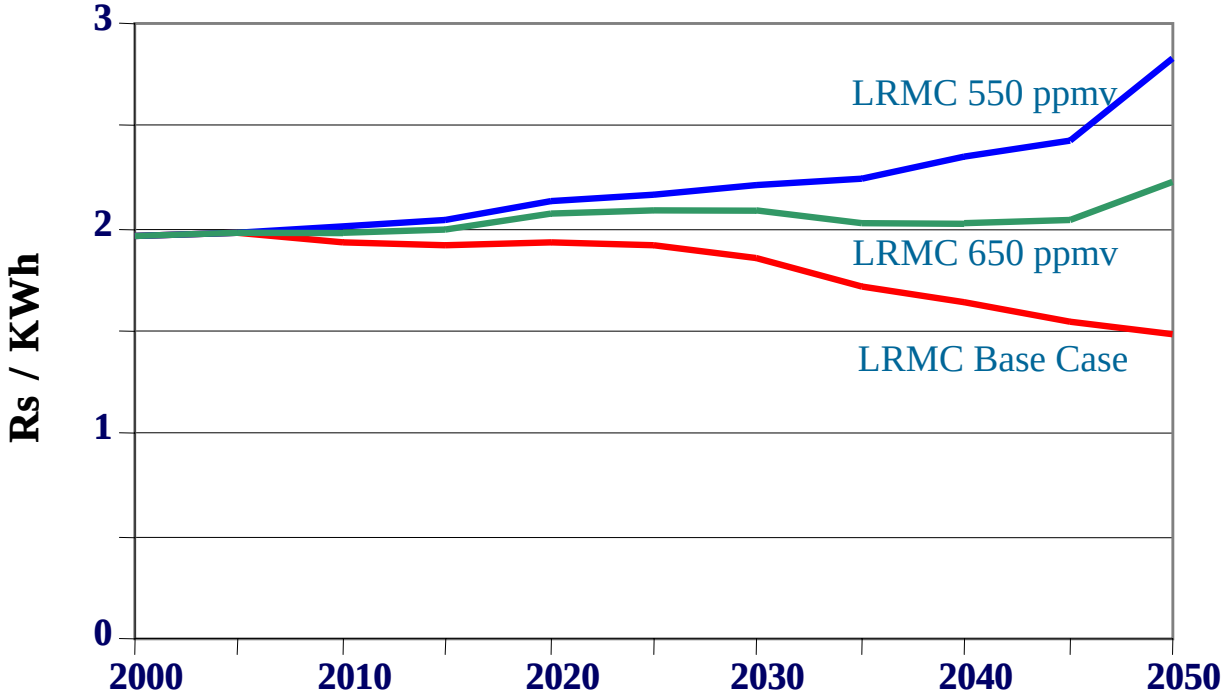
Renewable Technologies



Nuclear Fusion



Effect of Carbon Constraints on Electricity Cost



Thank you