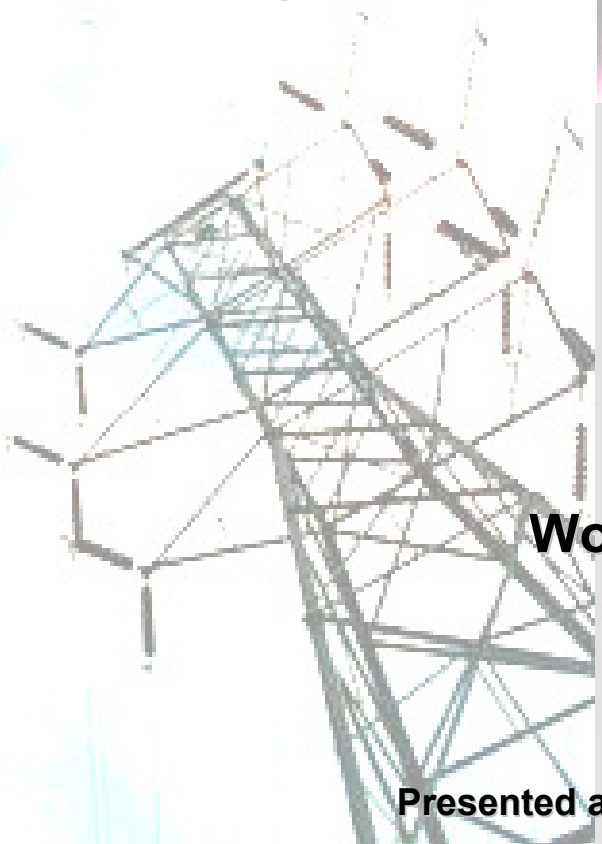
COMPARATIVE ASSESSMENT OF ENERGY OPTIONS AND STRATEGIES UNTIL 2025

OVERVIEW AND RESULTS



Analysis Conducted by a Team of Analysts from:

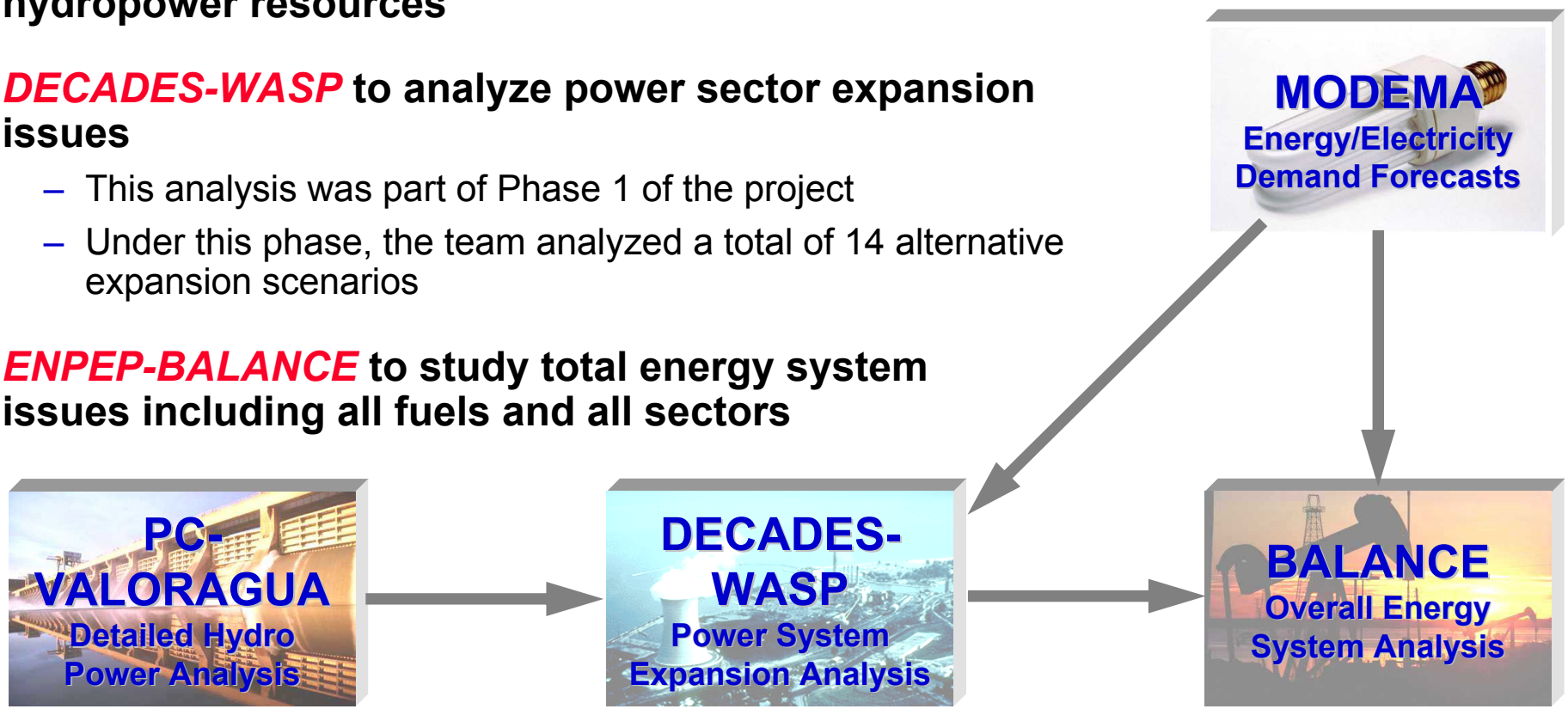
SENER
UNAM
CONAE
IMP
IIE
INE
PEMEX
CFE

Work Sponsored by
IAEA, USDOS

Presented at SENER on February 28, 2003

The Study Team Used a Set of Analytical Tools to Conduct the Analysis

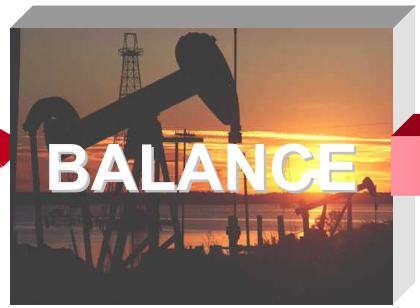
- ***MODEMA*** **to develop the energy demand projections based on the underlying macroeconomic growth assumptions**
- ***PC-VALORAGUA*** **for detailed analysis of Mexico's hydropower resources**
- ***DECADES-WASP*** **to analyze power sector expansion issues**
  - This analysis was part of Phase 1 of the project
  - Under this phase, the team analyzed a total of 14 alternative expansion scenarios
- ***ENPEP-BALANCE*** **to study total energy system issues including all fuels and all sectors**



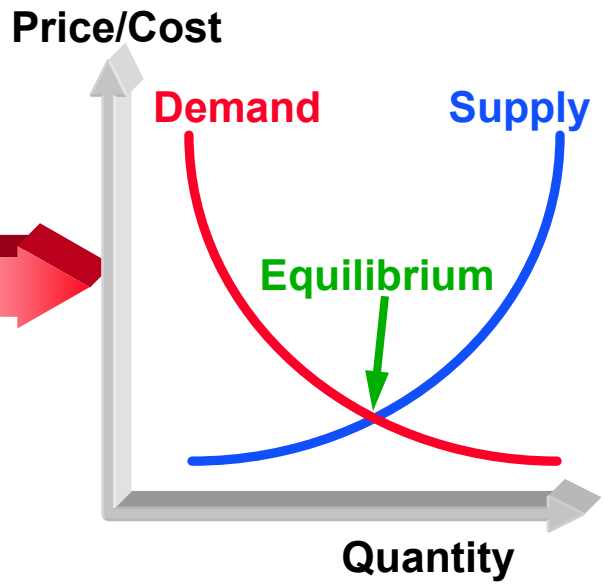
BALANCE Determines the Equilibrium Supply-Demand Balance of the Entire Energy System

INPUT

- Energy system structure
- Base year energy flows and prices
- Energy demand growth projections
- Technical and policy constraints

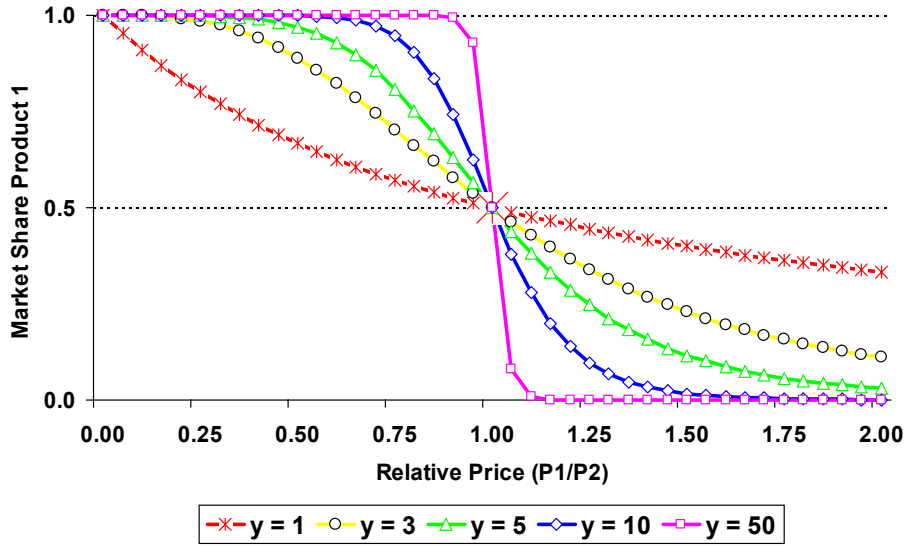


OUTPUT

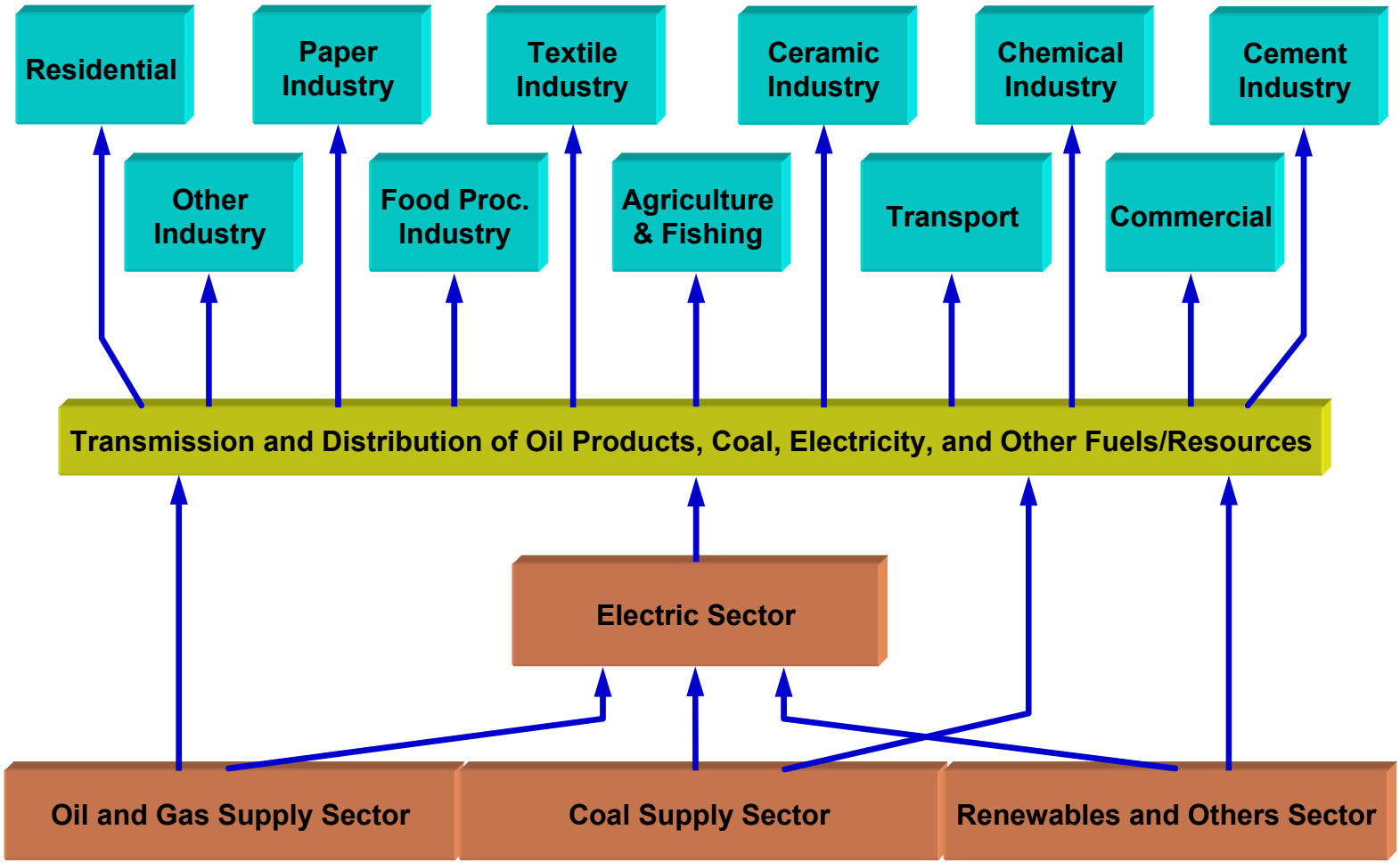


BALANCE Uses a Logit Function to Estimate Market Shares of Different Technologies or Fuels

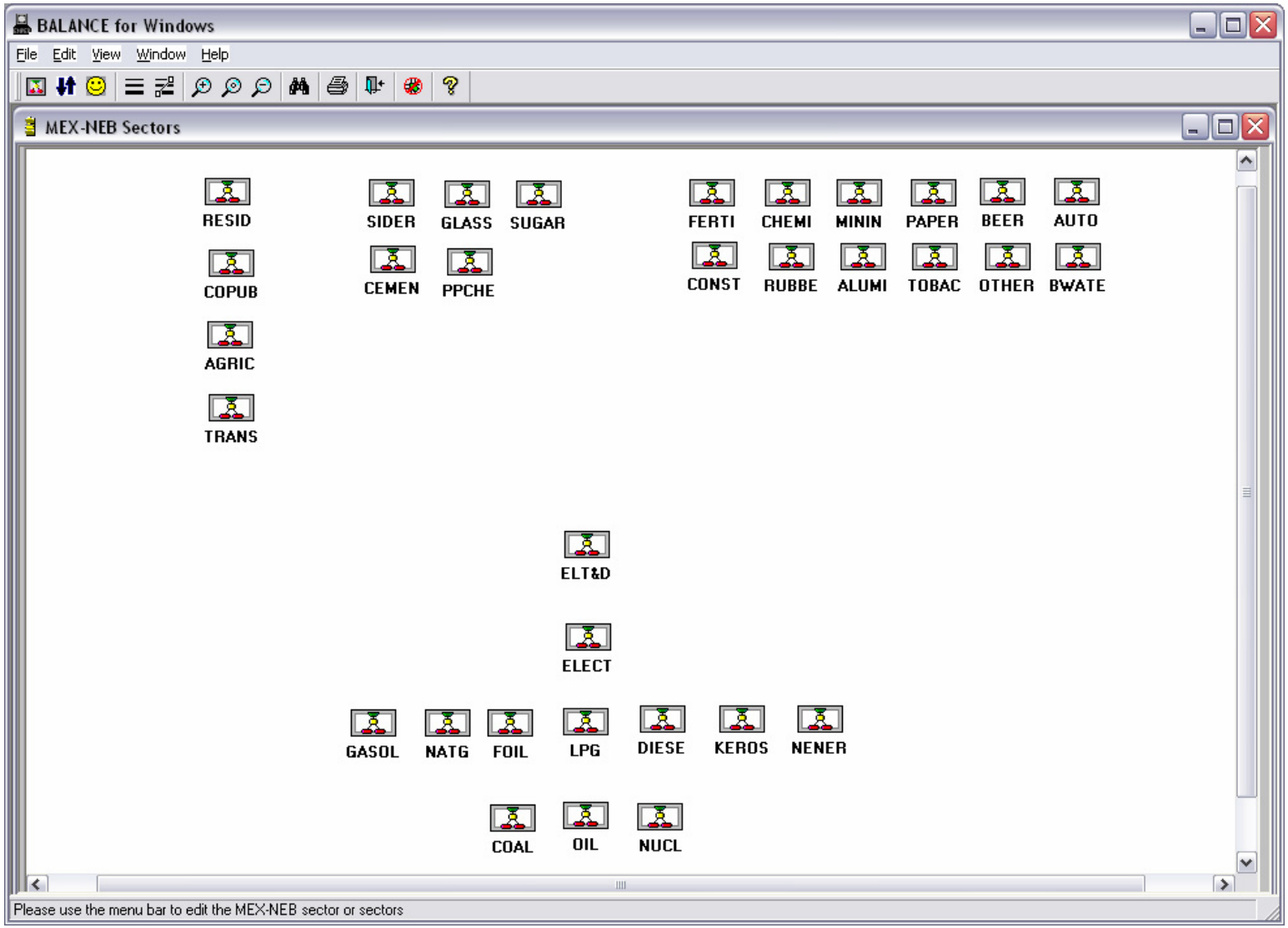
- Market share calculation assumes "ideal market" subject to government policies, fuel availability, and market constraints
- A lag factor accounts for delays in capital stock turnover
- The result is a nonlinear, market-based, equilibrium solution within policy constraints, not a simple, linear optimization
- No single person or organization controls all energy prices and decisions on energy use
- All decision makers optimize their energy choices based on their own needs and desires



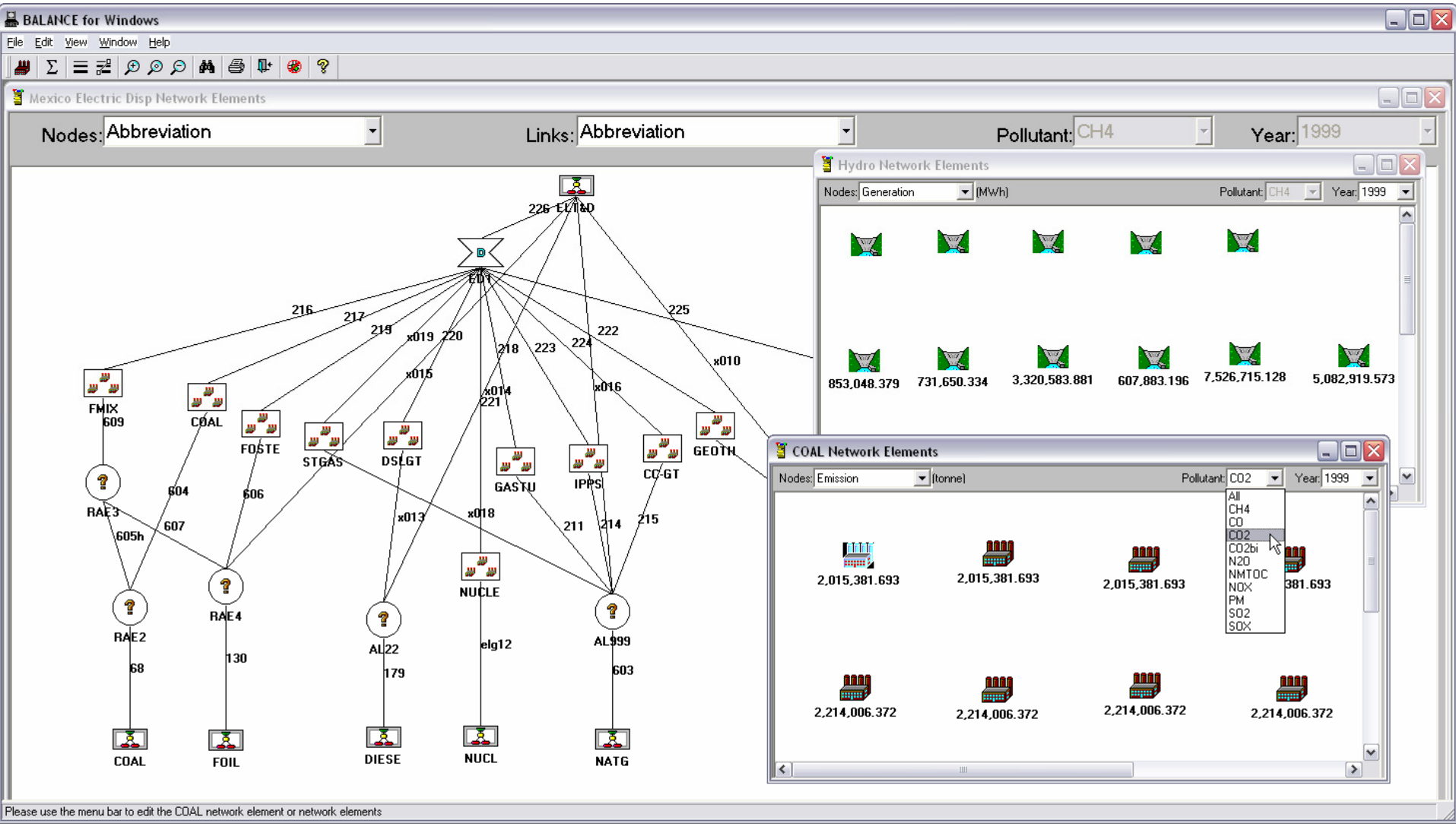
BALANCE Uses an Energy Network to Simulate Energy Markets



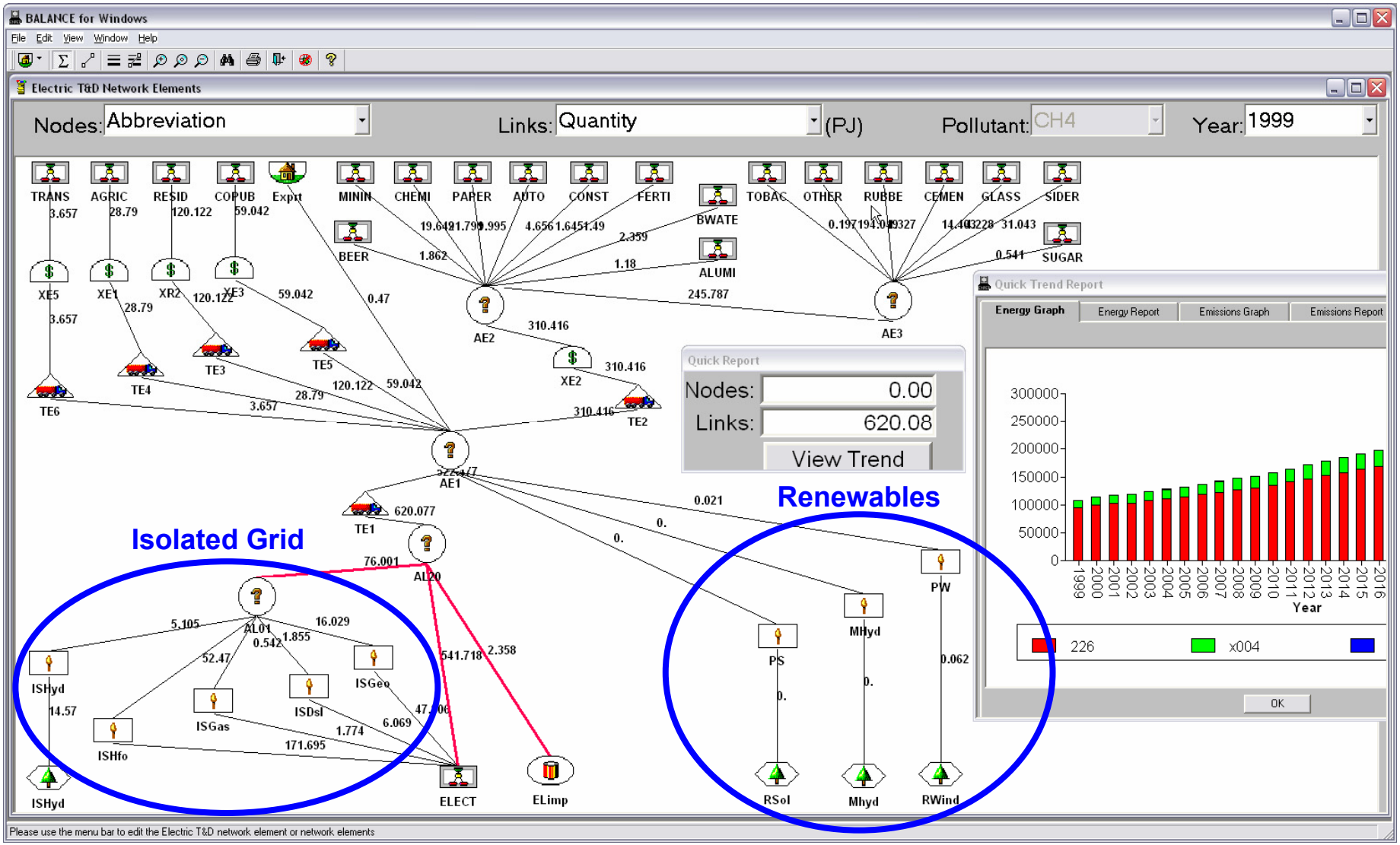
The Mexican Network Configuration Includes 3 Supply Sectors, 9 Conversion and T&D Sectors, and 21 Demand Sectors



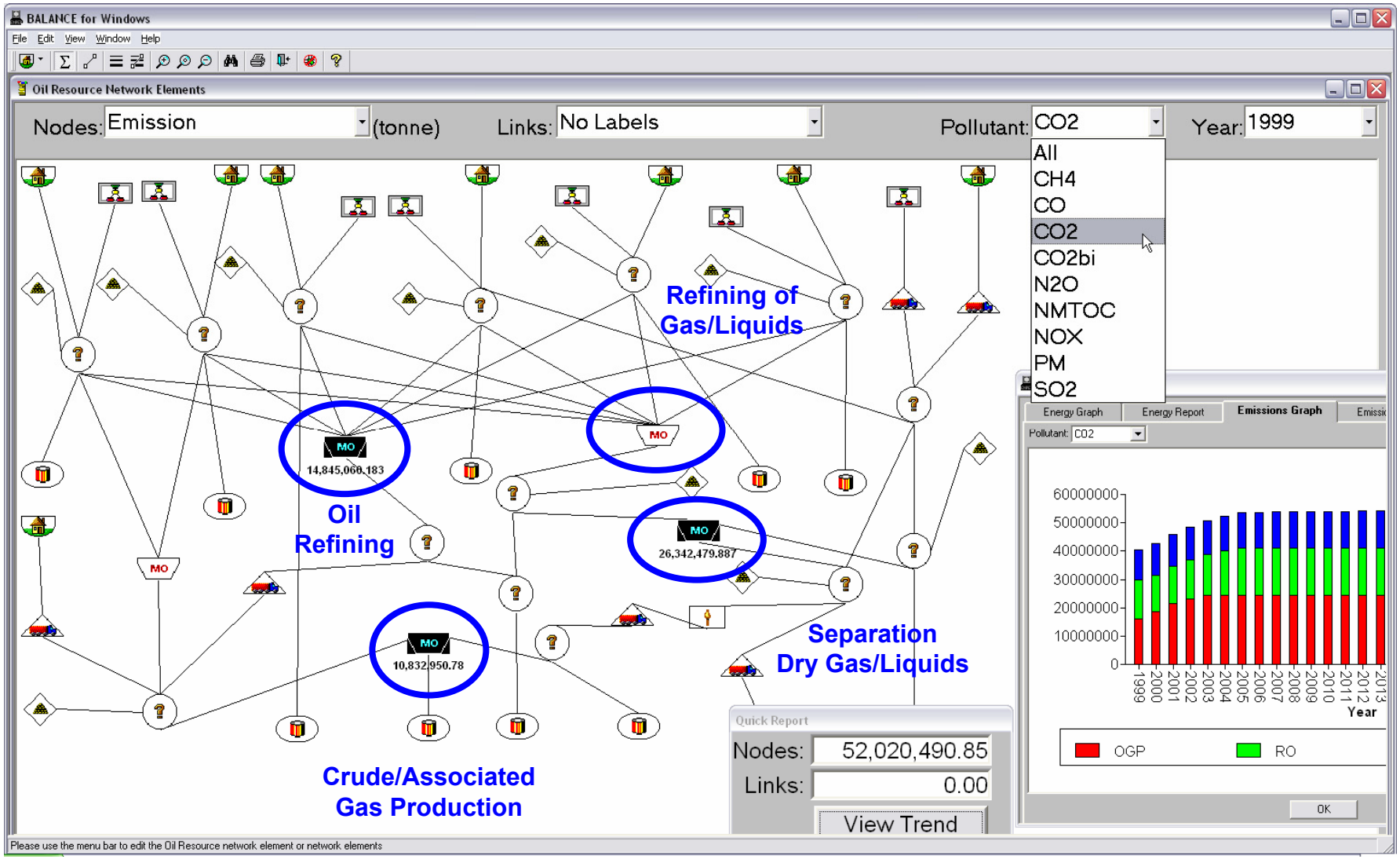
The Team Modeled Each Sector at Different Levels of Detail: Mexico's Interconnected Power System is Represented at the Unit Level



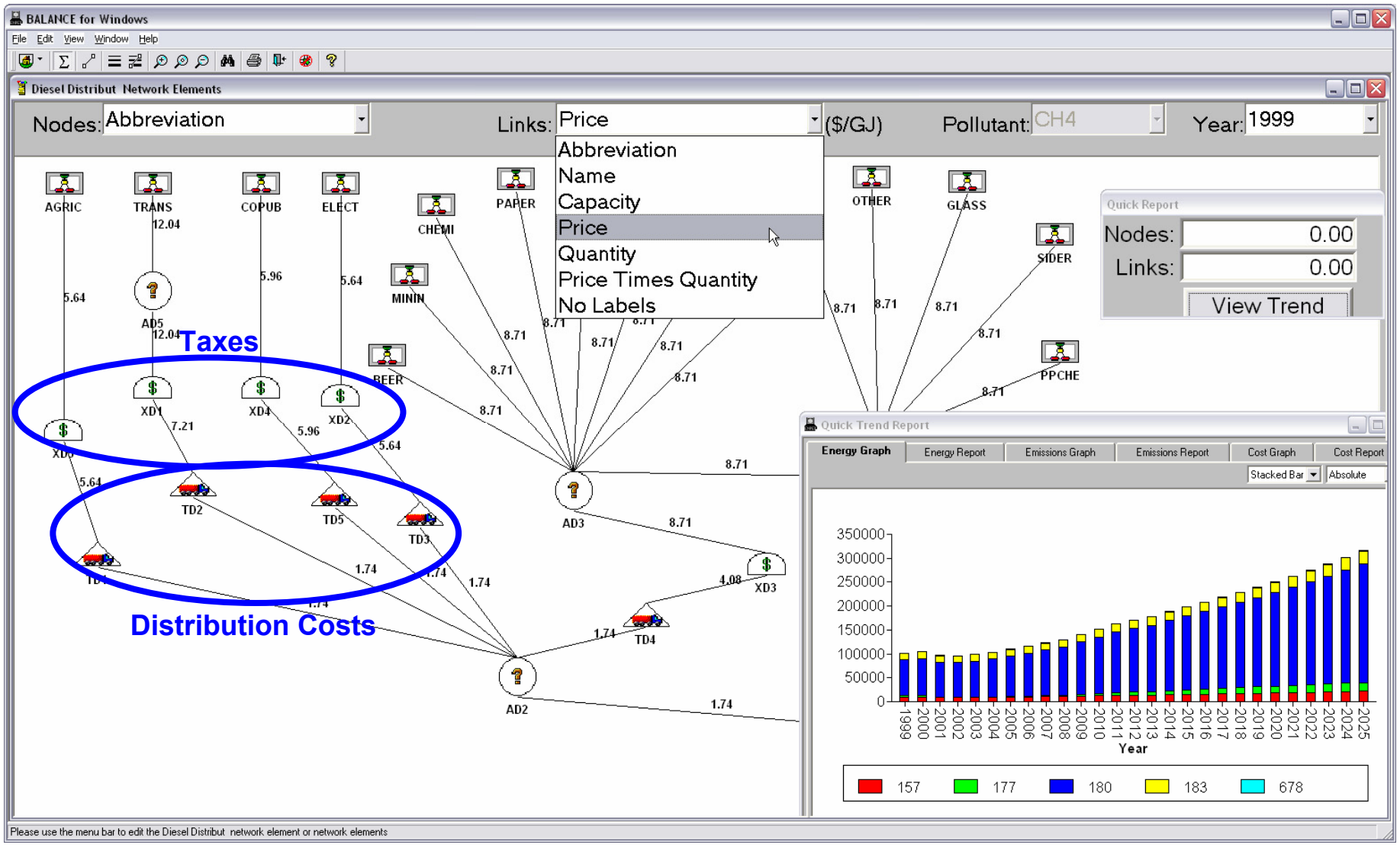
The Isolated Power System is Modeled as Aggregated Fuel Groups (Same for Renewables)



Oil and Gas Production is Combined into one Sector and Contains All Major Processes (and Emissions)

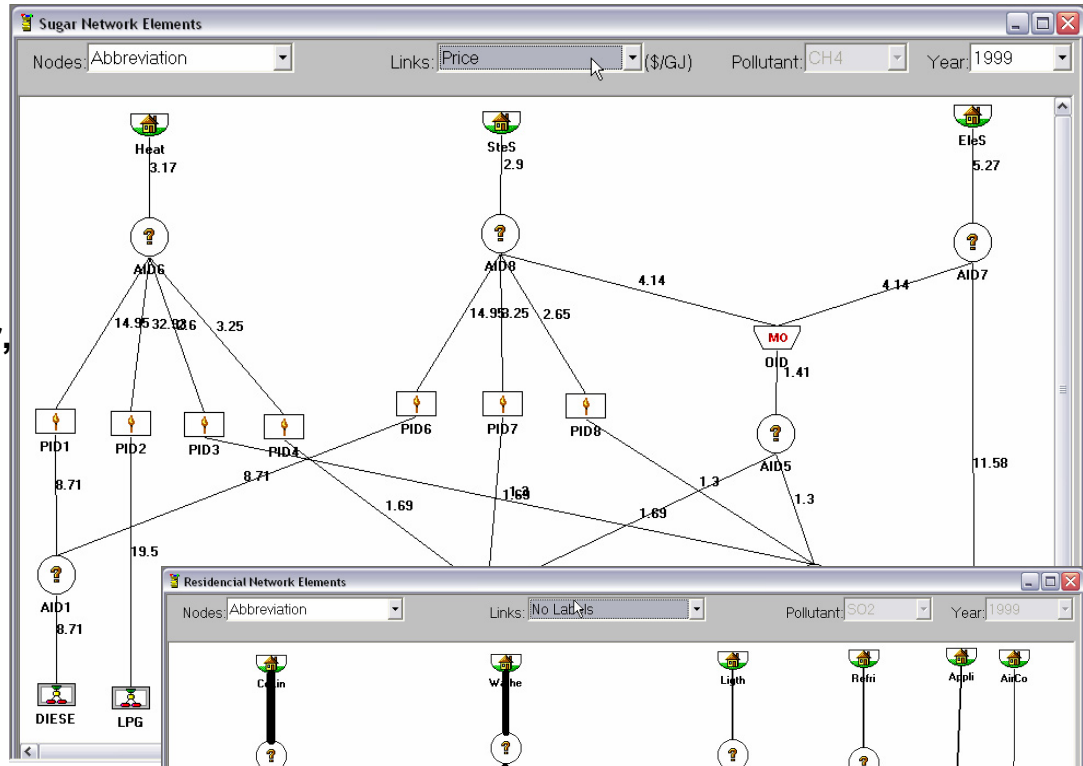


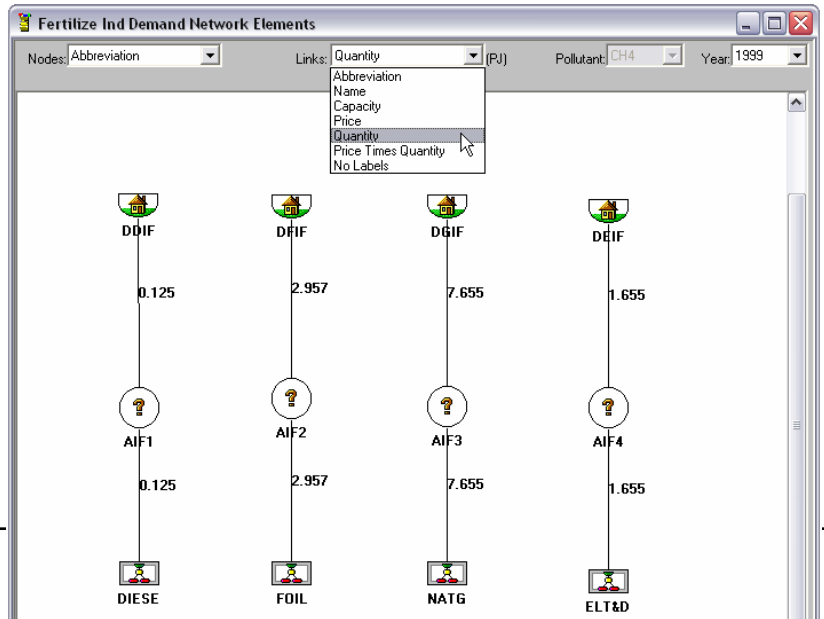
T&D Sectors Incorporate Distribution Costs and Taxes

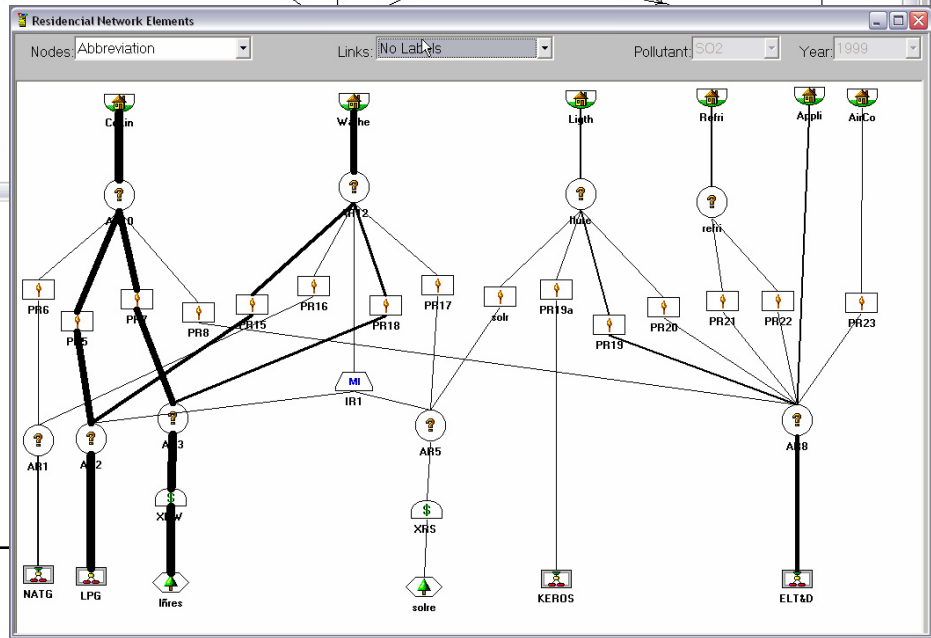


The Level of Detail on the Demand Side Varies with Data Availability

- **Detailed Useful Energy Representation**
  - Residential
  - Sugar, Cement, Glass, Metallurgical, Petrochemical
- **Final Energy Representation**
  - Commercial/Public, Agriculture
  - Fertilizer, Construction, Chemical, Rubber, Mining, Aluminum, Paper, Tobacco, Beer, Auto, Bottled Water, Others
- **Mix**
  - Transport







Data Availability and Data Quality

- **Supply side information is extensive, well documented, and of good quality**
  - Power sector information available from CFE
    - Generation and fuel consumption data from annual report "*Informe de Operacion*"
    - Unit characteristics directly from CFE's Investment Planning and Expansion Analysis Departments
  - Oil and gas sector
    - National energy balance "*Balance Nacional de Energia 2001*"; price statistics from SENER/IEA
    - Annual forecasts for different products: "*Prospectiva Gas Natural*", "*Prospectiva LPG*", "*Prospectiva Petroliferos*"
    - Cost data less reliable; some information available from PEMEX
  - Other supply sectors
    - National energy balance from SENER
    - Information from UNAM

- **Demand side information is more limited**
  - Detailed industrial energy data available for 5 branches (UNAM and SENER)
  - Information for residential, transport, commercial/public, and agriculture came from IMP, INE, and CONAE
  - No cost data available; used information from international literature
  - SENER is in the process of collecting regional demand data

For the Power Sector, the Team Analyzed a Total of 14 Scenarios

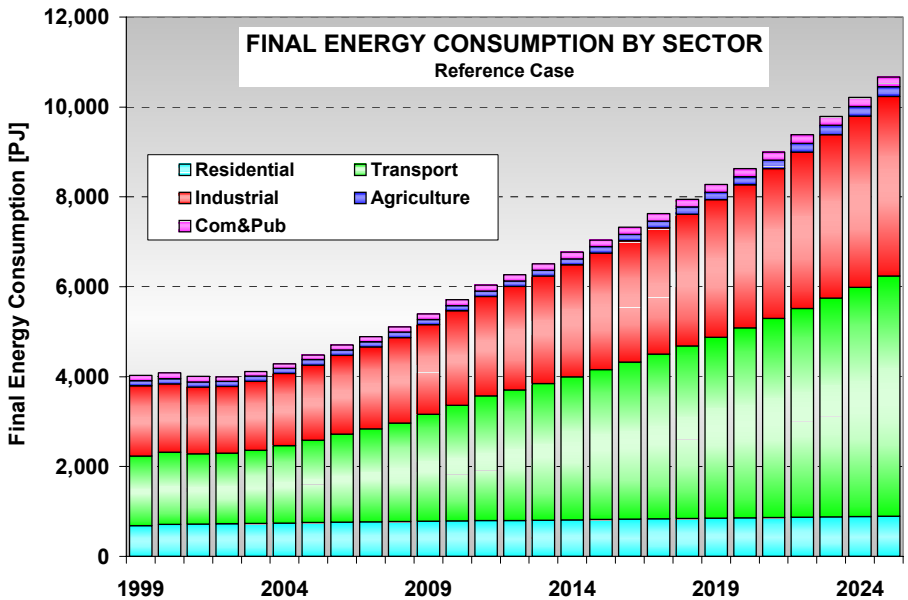
- **Base case**
- **High-load growth case (6.5% instead of 5% per year)**
- **Variations on fossil fuel prices**
  - Natural gas increases to 4.0 instead of 2.9 $/tcf
  - Natural gas peaks at $12.0/tcf and then declines to $4.0/tcf by 2025
- **Nuclear scenario**
  - One forced nuclear unit
  - Reduction in nuclear capital costs by 48%
- **Limitations on natural gas supply**
  - Limit on annual additions of combined cycle units
  - Limit on power sector gas supply (supply constant after 2010)
- **Variations on discount rate (8% to 12%; 10% under Base Case)**
- **Variations on target system reliability**
  - Increased reliability (loss of load probability of 1 day per year instead of 3 days)
  - Decreased reliability (LOLP of 5 days)
  - Decrease in system reserve margin

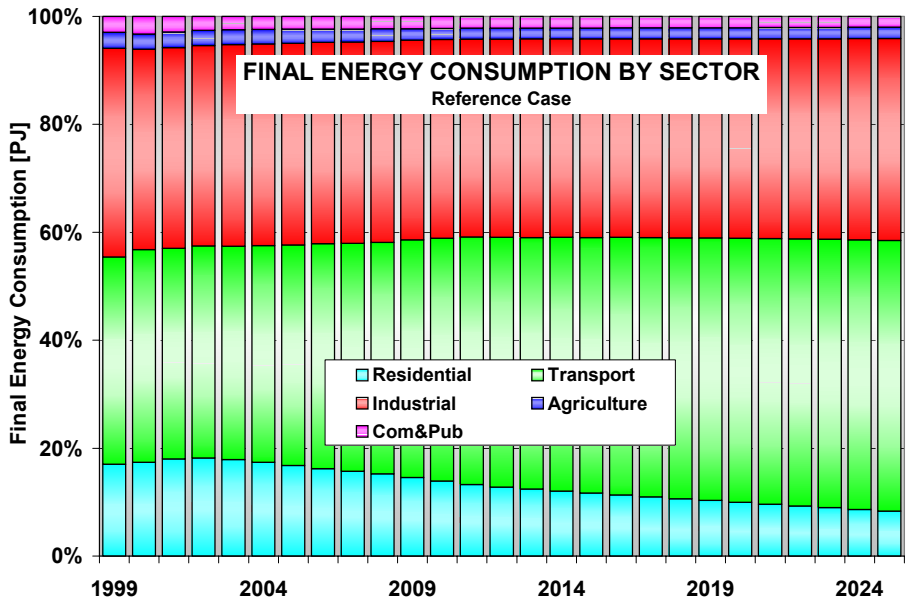
For the Entire Energy System, The Team Analyzed 4 Scenarios using the Following Main Assumptions

- **Reference Case**
  - Study period is 1999 to 2025
  - No limitation on gas supply
  - Power sector expansion options include nuclear, combined Cycle, gas turbine, imported coal, and hydro
  - GDP grows at 4.5% (2002-2011) and 3.5% until 2025; Population growth rate drops from 1.33% (2000-2010) to 1.02% (2011-2020) to 0.82% until 2025
- **Limited Gas Supply Scenario**
  - Gas supply is limited starting in 2009
  - Limit applies to *power sector only* and allows a maximum of 3 CCGT units per year
- **Renewables Scenario**
  - Renewables implemented in *power sector only*
  - Includes 50 MW wind farms and 5 MW solar photovoltaic stations
  - Cost assumptions include "experience curve" that leads to a reduction in costs as the installed capacity increases (wind from $1154/kW in 1999 to $536/kW in 2019)
- **Nuclear Scenario**
  - Assumes one additional nuclear unit to come on-line in 2012
  - Capital cost is $2485/kW; Capacity is 1314 MW

Reference Case: Final Energy Consumption is Projected to Grow from 4,030 to 10,700 PJ with Transportation Growing the Fastest

- Final energy consumption is growing on average by 3.8% and more than doubles over the forecast period
- Transport sector consumption grows at 4.9% leading to an increase in the sectoral share from 38% (1999) to 50% (2025)
- Residential growth is the slowest at 1.0%; share declines from 17% to 8%
- Transport and industry account for 88% of total final consumption by 2025

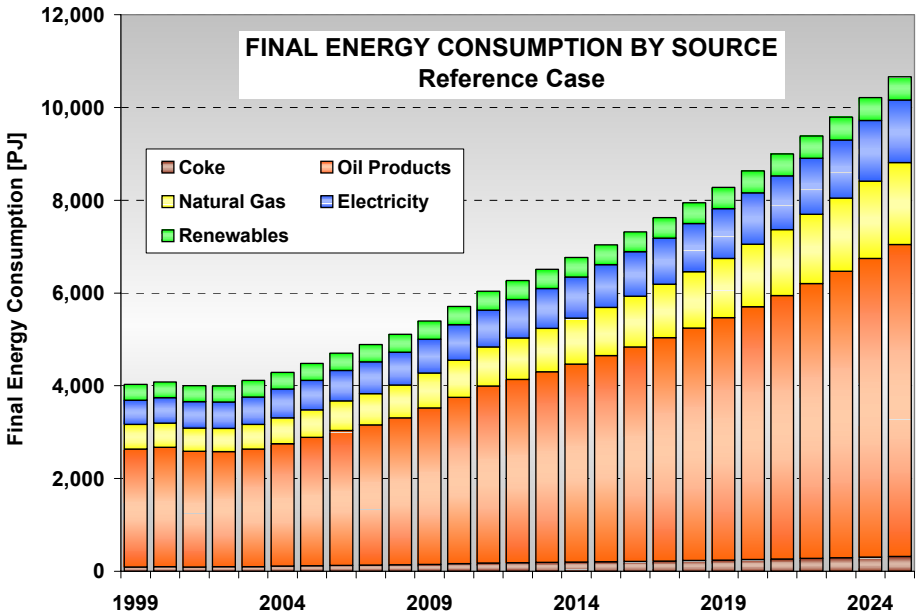


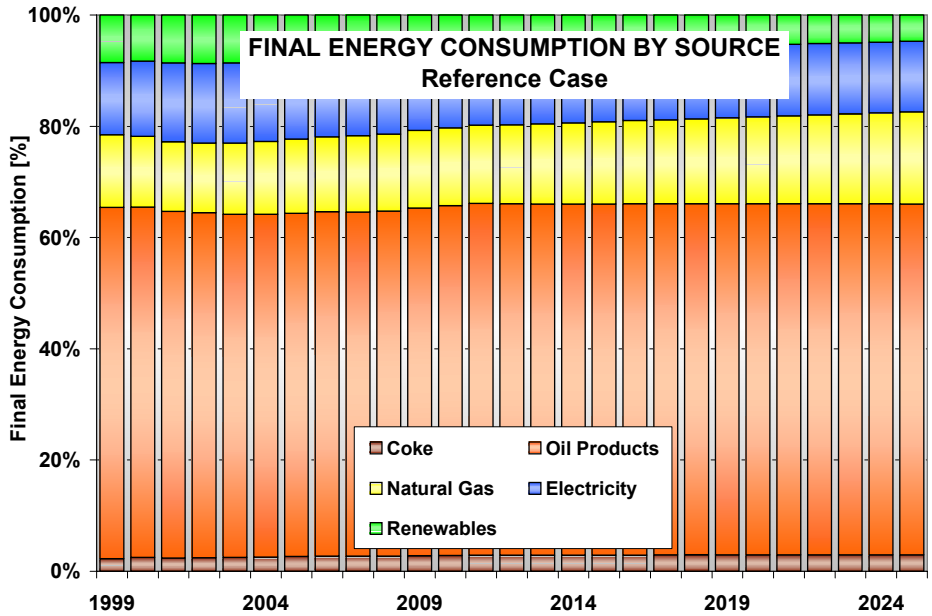


Reference Case: Oil Products will Continue to Dominate Final Energy Consumption

- The share of oil products in final consumption will remain at approximately 63% throughout the study period

- Natural gas is projected to grow at 4.8% from 526 PJ to 1,764 PJ increasing its share from 13% to 17%

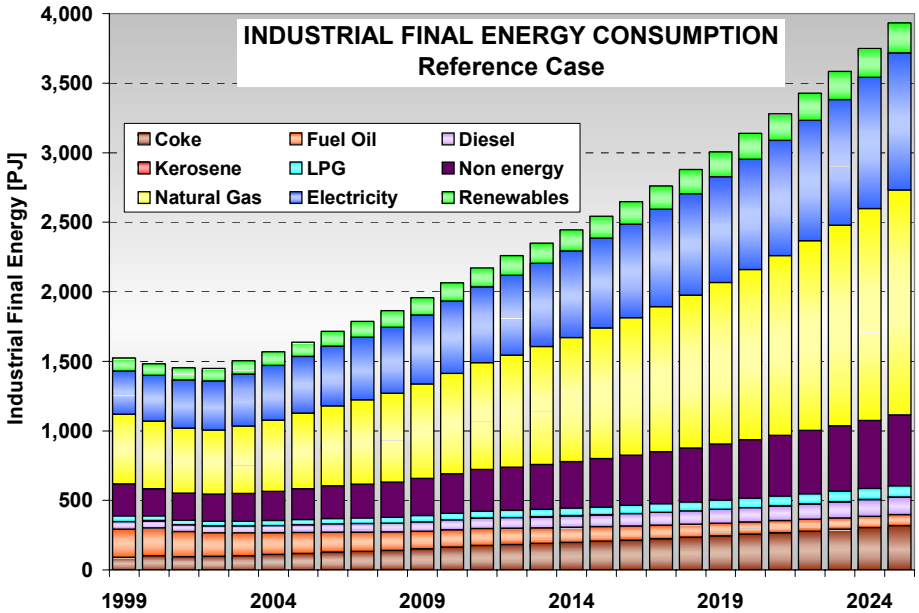


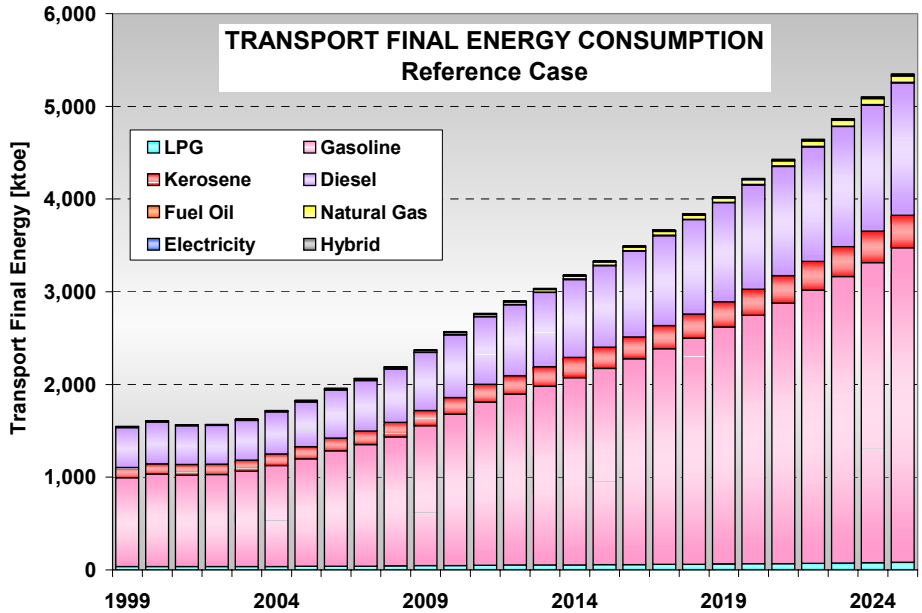


Reference Case: Industrial and Transport Consumption

- **Industrial consumption is expected to grow at 3.7% from 1,561 PJ (1999) to 3,992 PJ (2025); natural gas penetration will increase from 32% to 40% at the expense of fuel oil which drops from 13% to 2%**

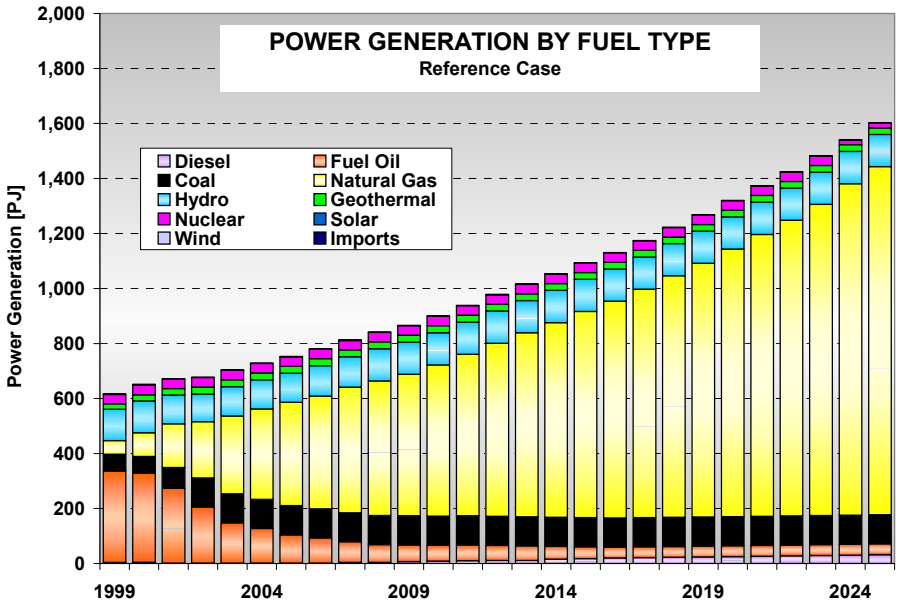
- **Transport sector final consumption grows at 4.9% from 1,547 PJ to 5,349 PJ; fuel shares change very little: gasoline and diesel combined account for 90% of total transport consumption**

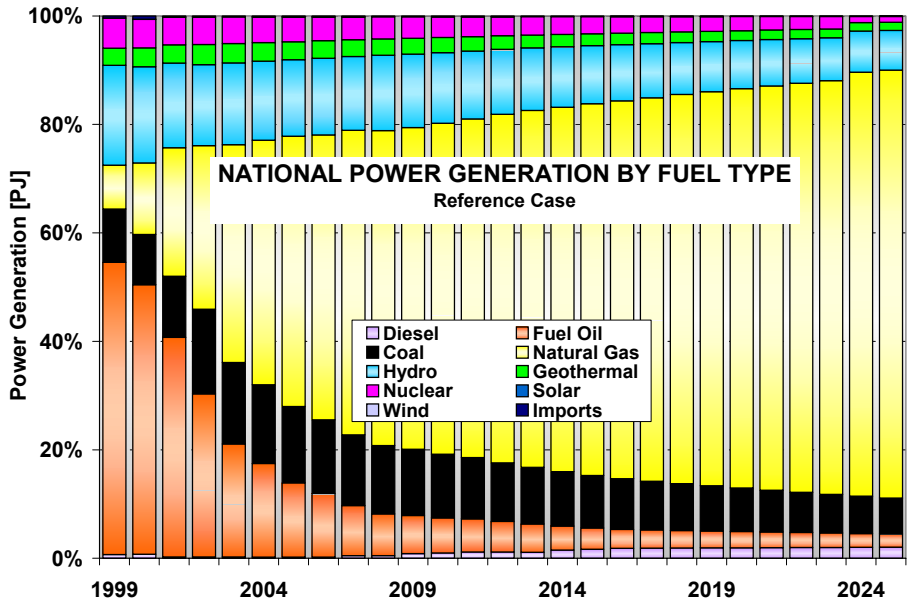




Reference Case: Power Generation will be Dominated by Natural Gas, while Fuel Oil Declines Due to Retirements

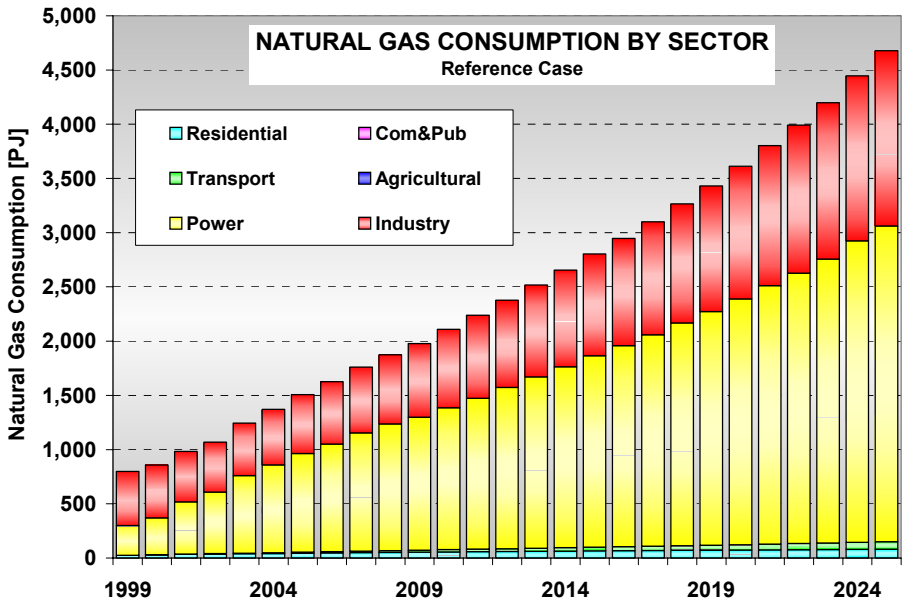
- **Natural gas-fired generation increases from 50 PJ to 1,265 PJ (out of 1,603 PJ total) in 2025; natural gas generation share increases from 8% to 79%**
- **Fuel oil-fired generation decreases from 333 PJ to 39 PJ in 2025; fuel oil generation share decreases from 54% to 2.5%**
- **Generation from renewables (hydro, geothermal, wind, solar) increases only slightly from 133 to 142 PJ**

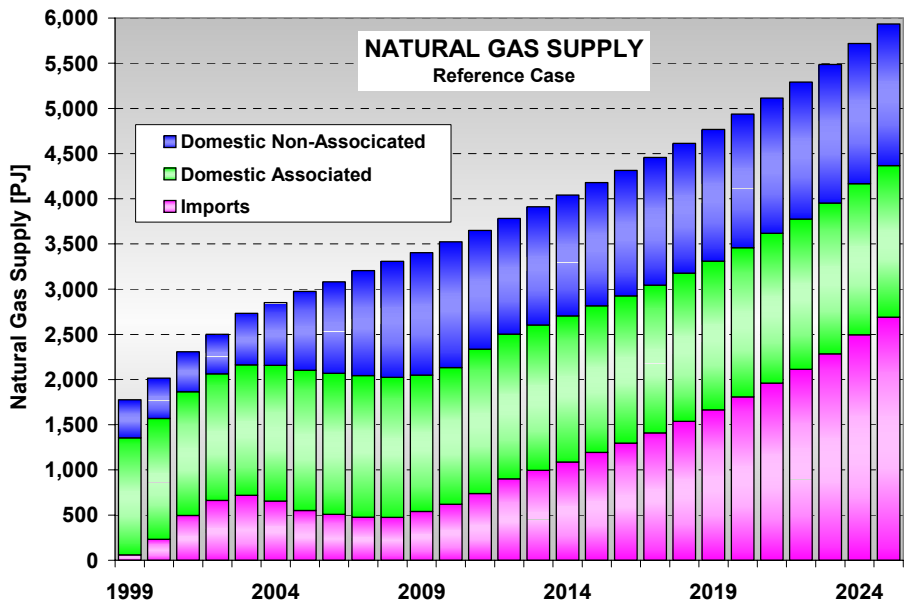




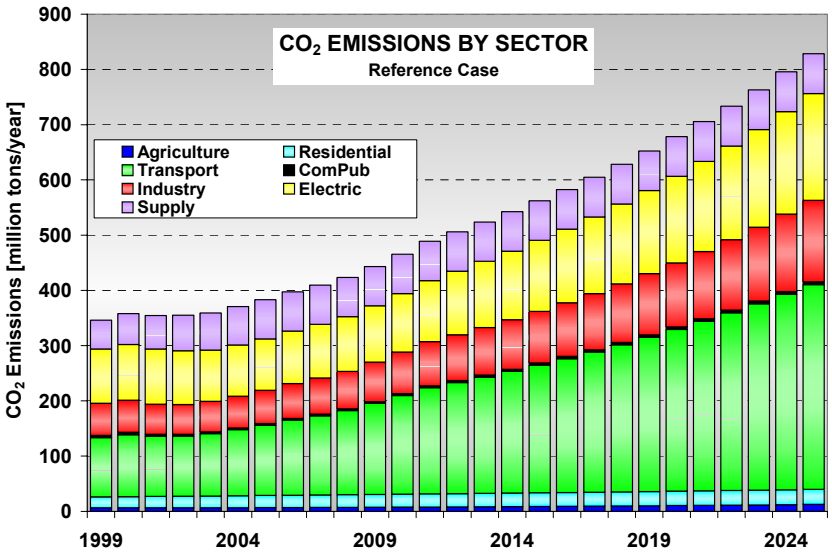
Reference Case: Natural Gas Consumption is Primarily Driven by Power Generation leading to a Near-Term and Long-Term Need for Natural Gas Imports

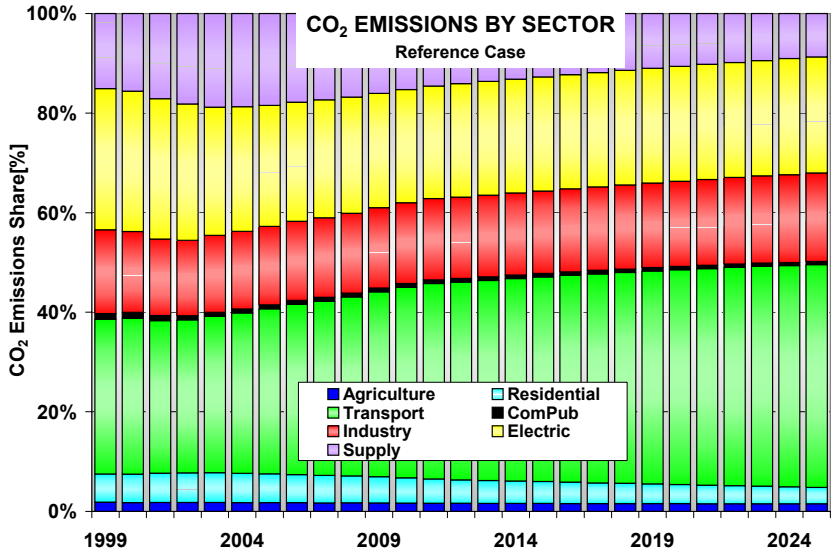
- **In 1999, industry accounts for 63% of natural gas consumption while power generation accounts for 34%; By 2025, the shares will change to 35% industry and 62% power generation**
- **Because the domestic gas production is assumed to be constant for the first 4 years (as given in the latest *Gas Prospectiva*), there appears to be an immediate need for additional gas imports**
  - Once gas production increases, imports will decline until 2008
  - In 2009, the domestic refining is projected to reach its capacity, resulting in constant associated gas production, contributing to a further increase in gas imports

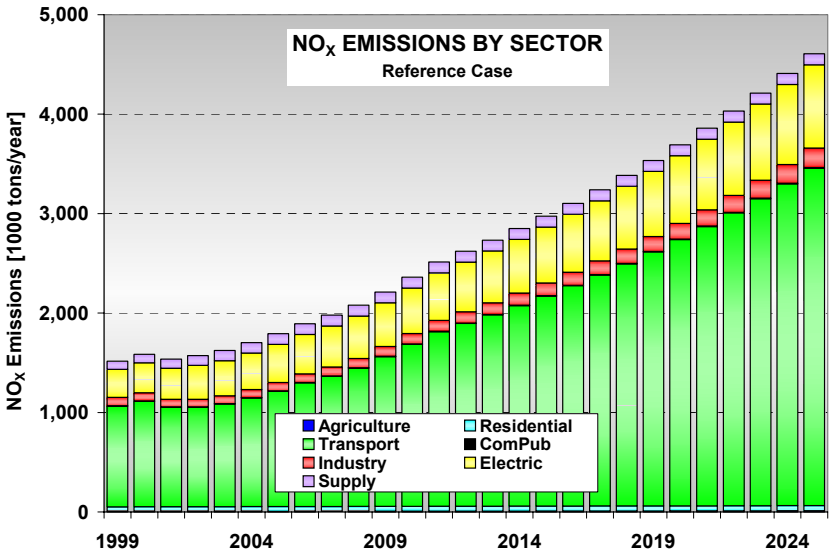


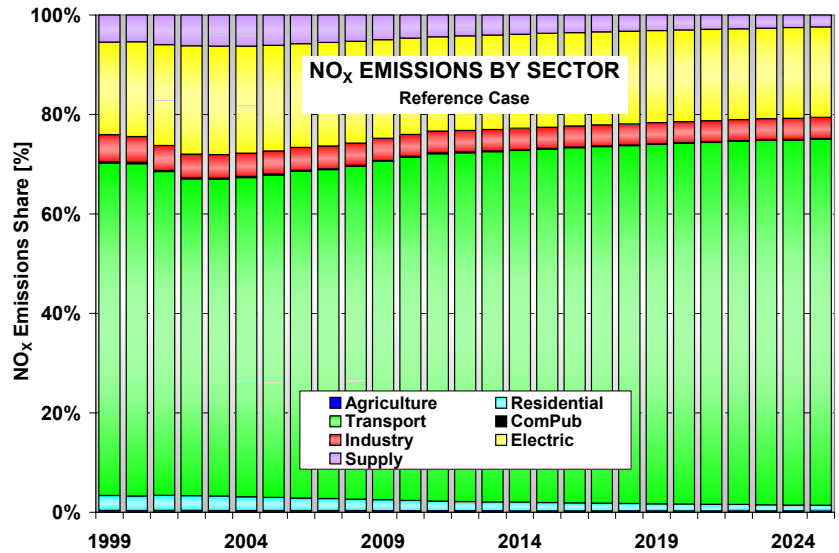


Reference Case Emissions by Sector:
CO_2 will Increase from 346 to 828 million tons/year
NO_X will Increase from 1.5 to 4.6 million tons/year

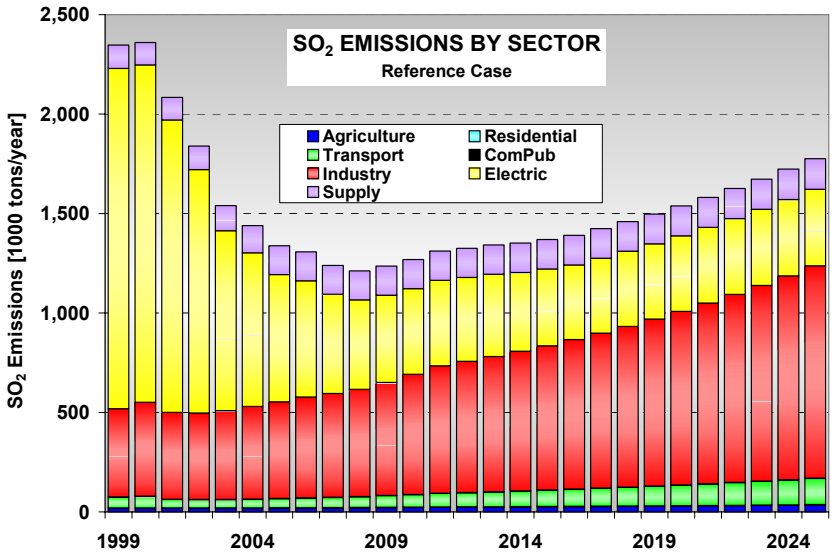


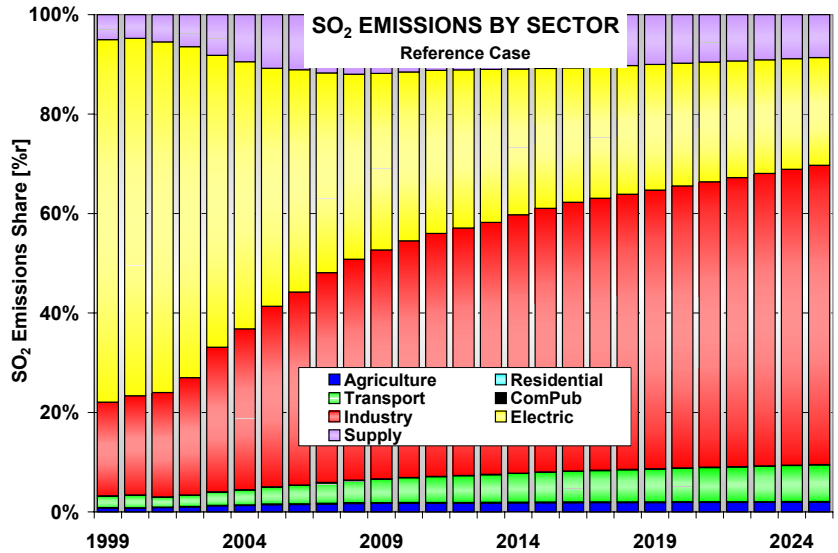


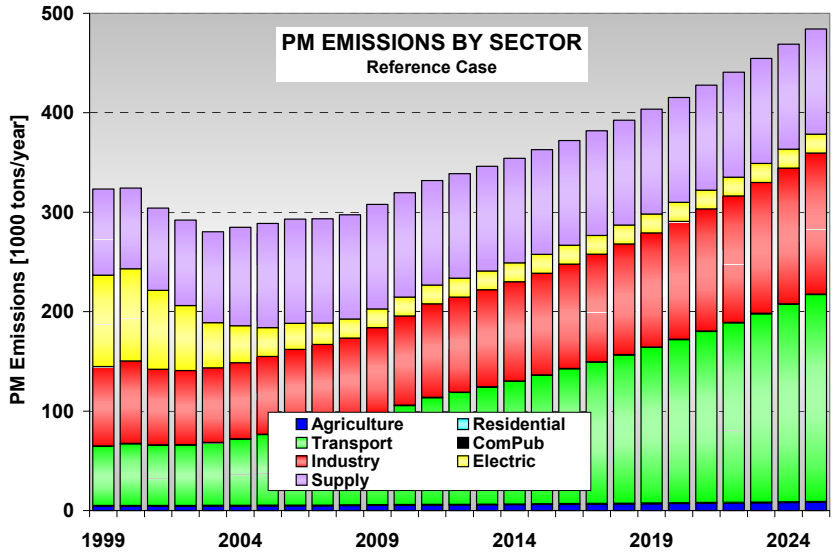


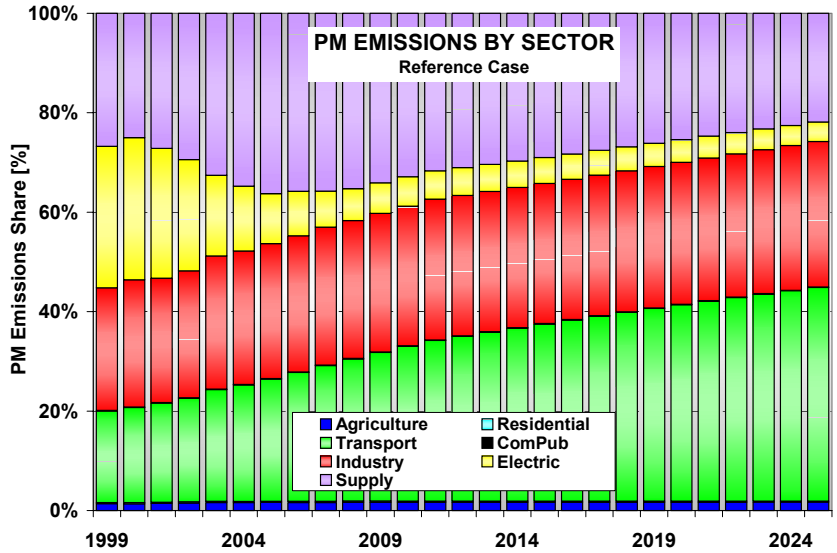


Reference Case Emissions by Sector: SO_2 will Decrease from 2.3 to 1.8 million tons/year PM will Increase from 323 to 484 ktons/year





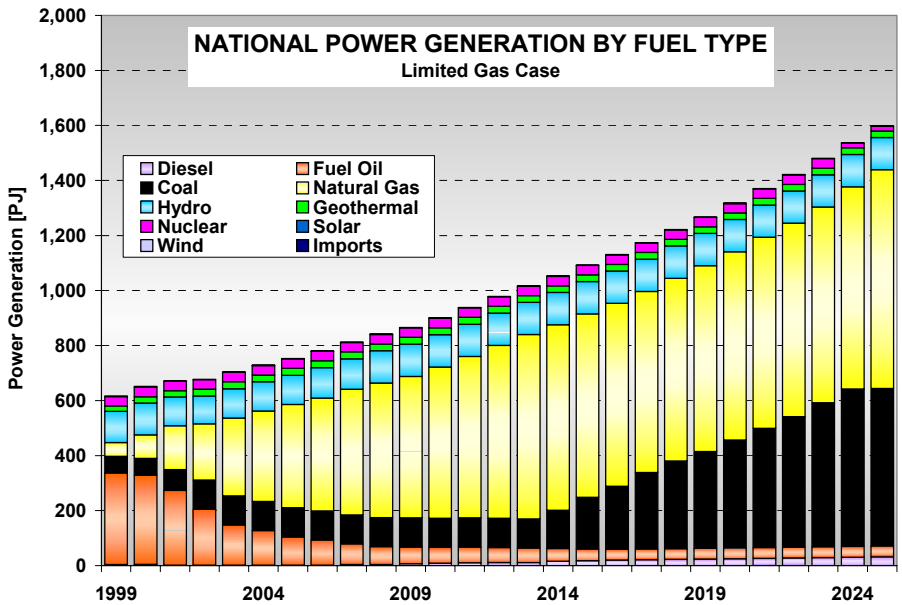


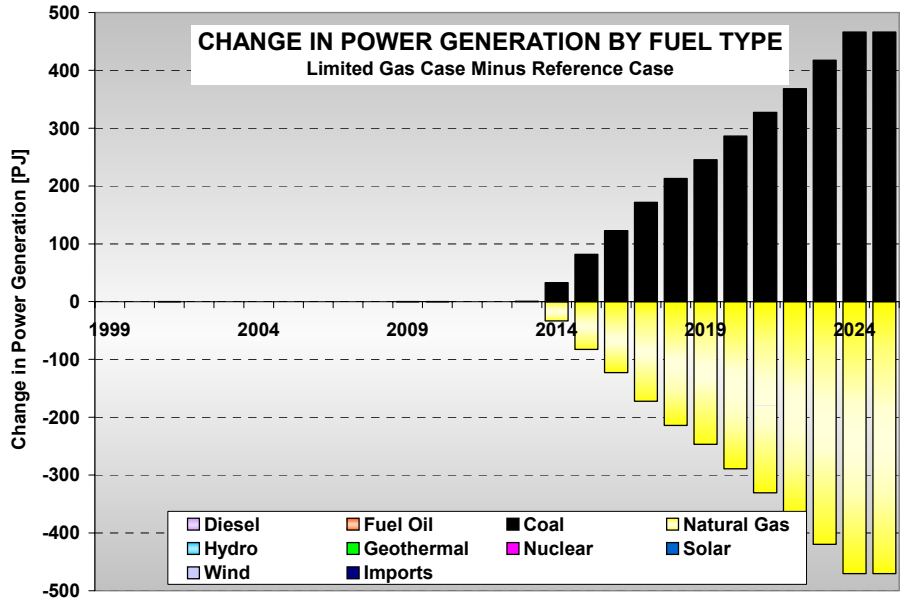


Limited Gas Scenario: Imported Coal Replaces Natural Gas for Power Generation

- By 2025, natural gas accounts for 50% (795 PJ) of total generation; this is down from 79% (1265 PJ) under the Reference Case

- Coal-fired generation is projected to grow to 572 PJ (36% of total) by 2025; this is up from 7% (106 PJ) under the Reference Case

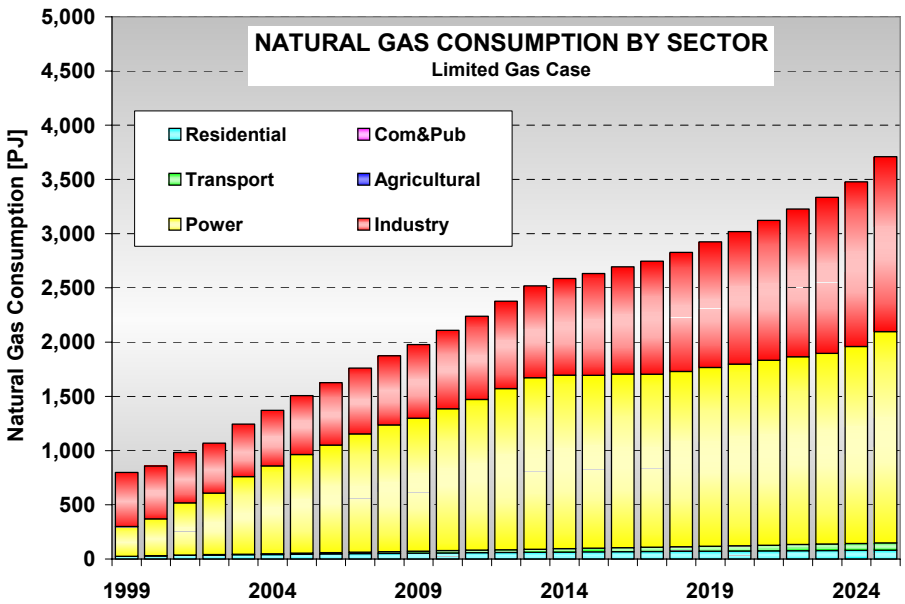


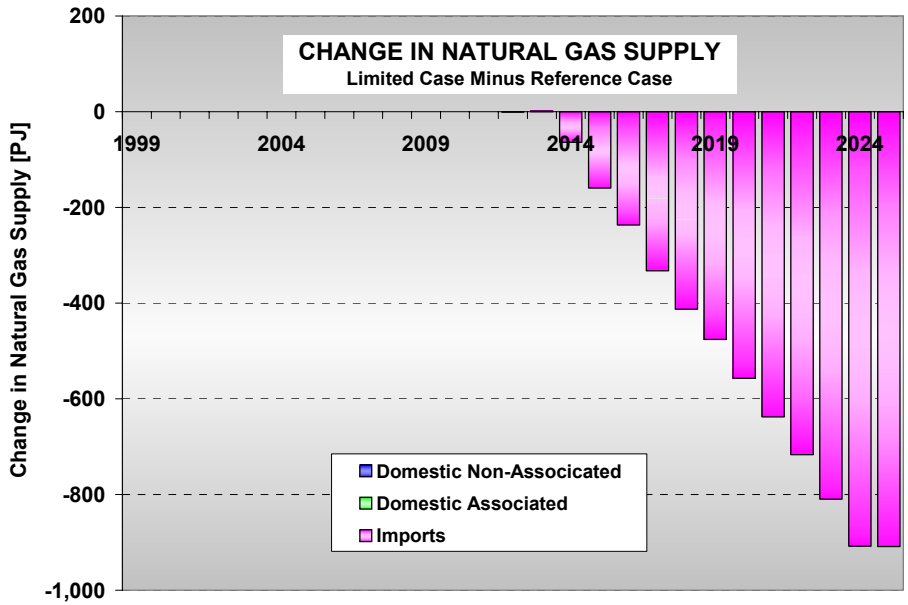


Limited Gas Scenario: Power Sector Gas Consumption is Reduced Substantially Lowering Future Gas Imports

- **Starting in 2013, growth in power sector gas consumption slows noticeably (growth rate of 1.8%/yr for 2013-2025 compared to 5.2% in Reference Case)**

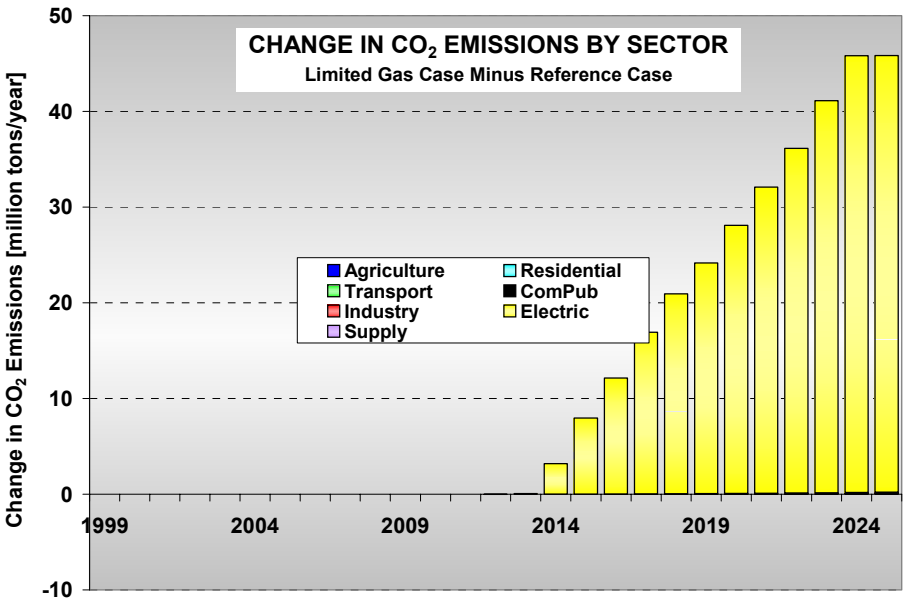
- **The reduction in gas-fired generation leads to a drop in natural gas imports of up to 909 PJ or 34% by 2025**

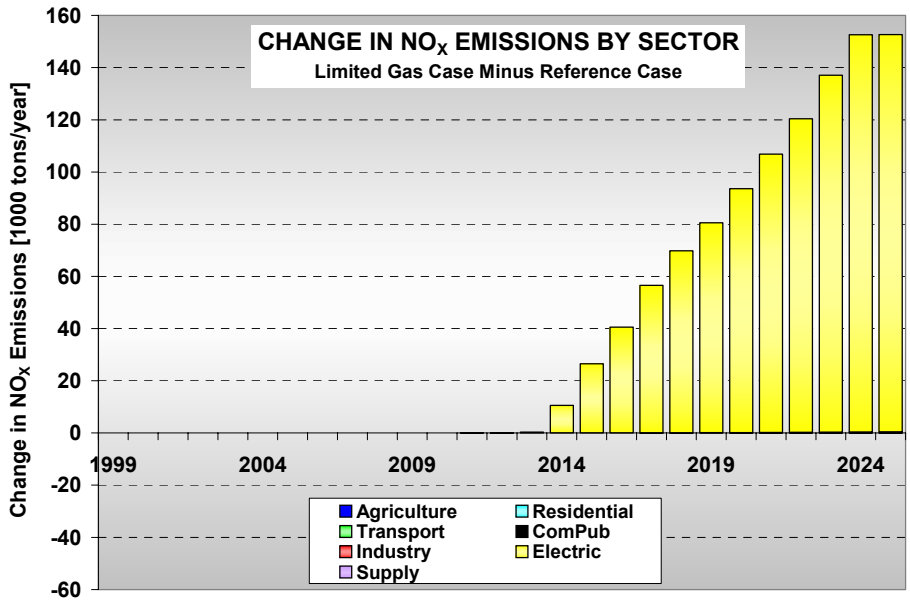




Limited Gas Scenario: The Extensive Use of Import Coal Instead of Gas Comes at an Environmental Expense

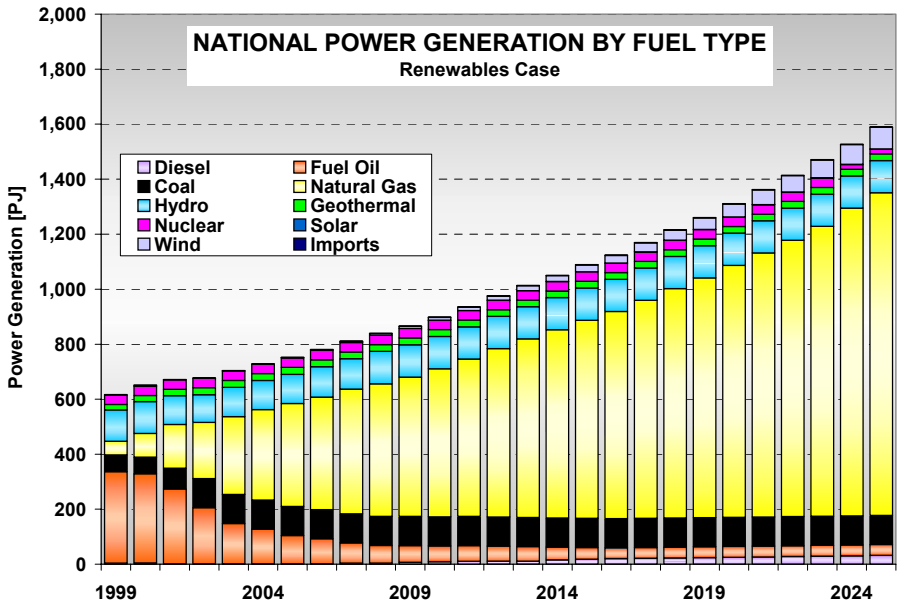
- **The increased coal-fired generation results in higher CO_2 emissions of up to 45.8 million tons per year (2025) over the Reference Case; this represents a 24% increase in power sector CO_2 emissions and a 5.5% increase of total national CO_2 emissions**
- **Similarly, NO_X, SO_2, and PM emissions are all forecast to increase**
  - NO_X up to 153,000 tons (2025); 18%/3.3% increase in power sector/national NO_X emissions
  - SO_2 up to 119,000 tons (2025); 30%/6.7% increase in power sector/national SO_2 emissions
  - PM up to 17,000 tons (2025); 83%/3.4% increase in power sector/national PM emissions

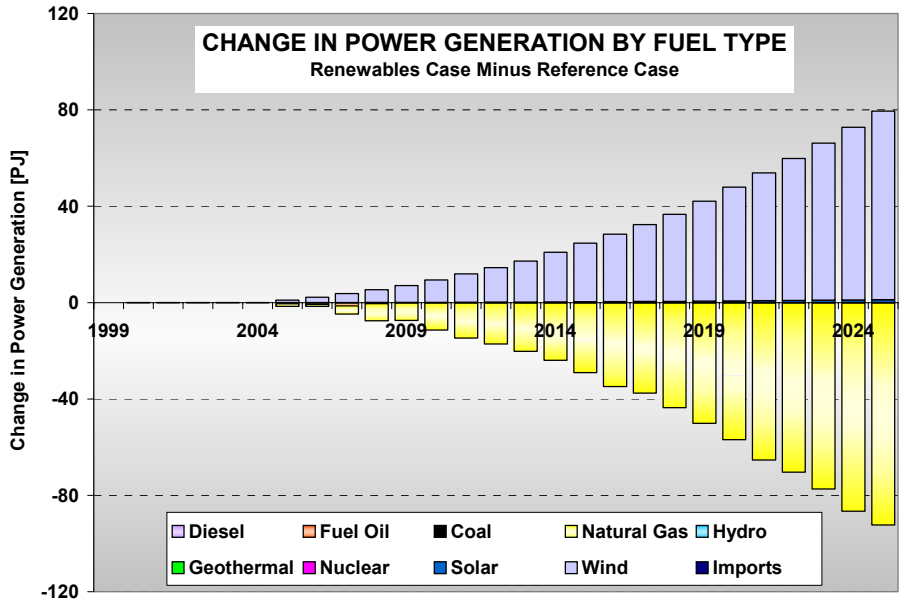




Renewable Scenario: Wind will Replace Gas-Fired Generation and will be the Dominating Renewable Power Generation Resource

- Wind power is projected to increase from 0.02 PJ (1999) to 78.4 PJ accounting for 4.9% of total generation by 2025; this represents 9,500 MW of wind farms
- Solar power will only increase to 1.2 PJ of generation (0.1% of total generation); this is equivalent to 195 MW of installed PV capacity
- The combined renewables are able to decrease natural gas imports by up to 178 PJ or 6.6% of natural gas imports

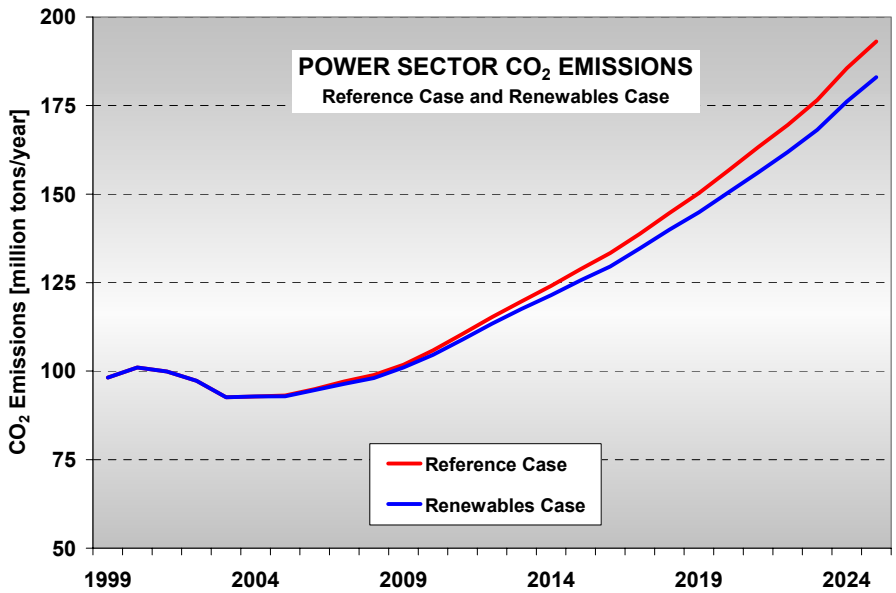


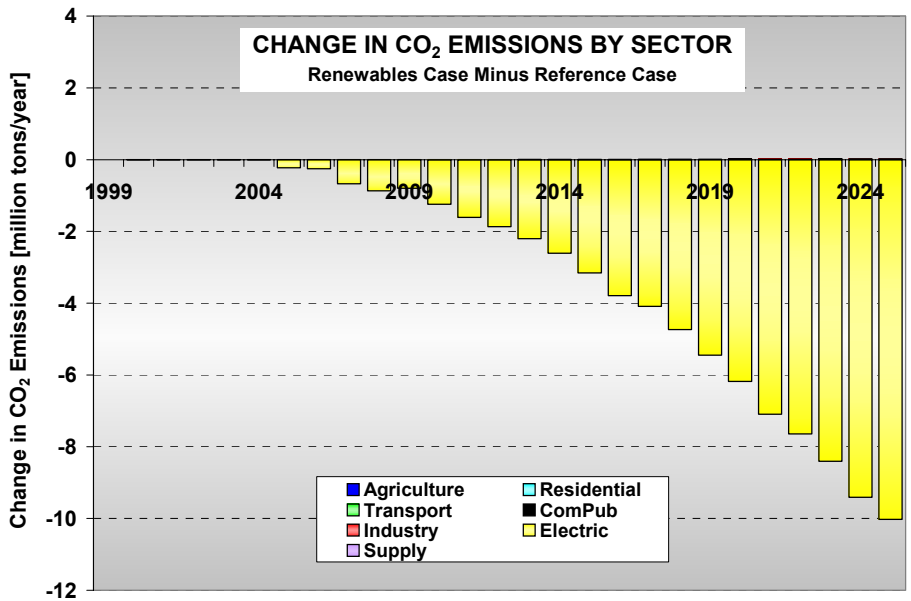


Renewable Scenario: Emission Reductions Are Somewhat Limited as Renewables Replace Gas

- The effect on CO_2 emissions is a reduction of up to 10.0 million tons (2025) equivalent to a 5.2% reduction of power sector emissions

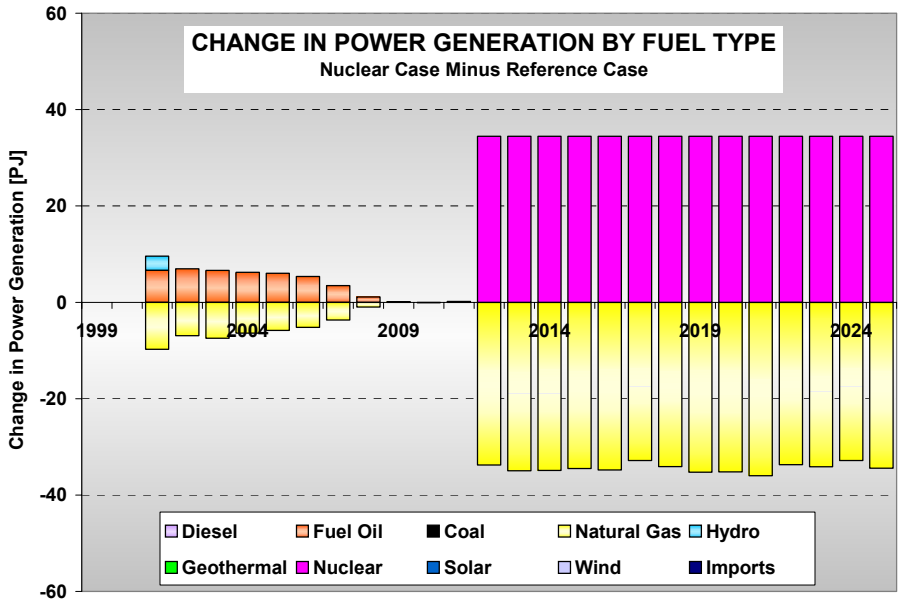
- Co-benefits are limited to reductions in NO_X of up to 43,400 tons (2025) or 5.2% of power sector NO_X emissions

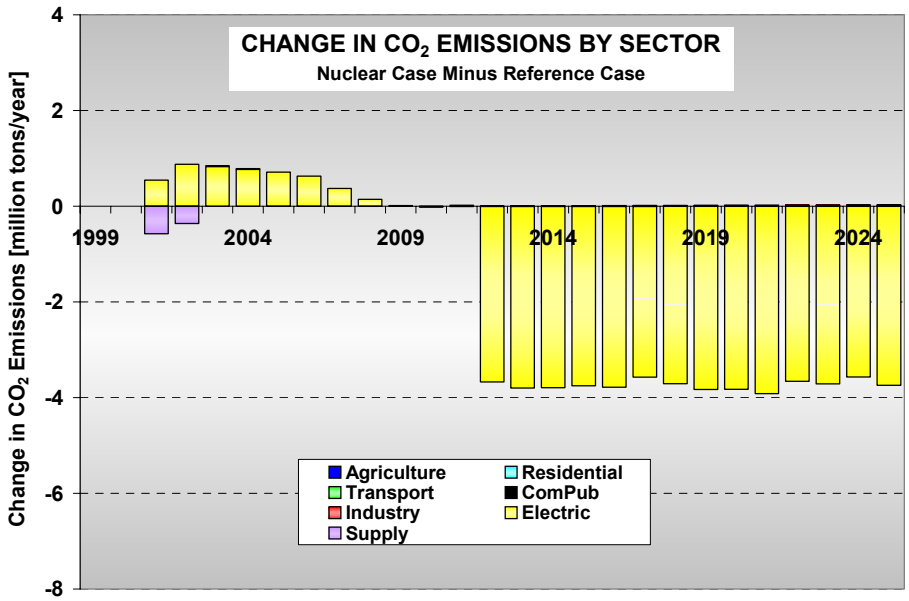




Nuclear Scenario: The Additional Nuclear Unit Replaces Gas Generation and Leads to Lower Emissions

- Because of the large capacity of the nuclear unit, the expansion schedule is slightly affected starting in 2001; this leads to a small increase in fuel oil generation and a decline in gas generation between 2001 and 2011
- In 2012, nuclear generation will increase by 34 PJ; by 2025 this is equivalent to 3.2% of total generation (up from 1.1% in the Reference Case)
- CO_2 Emissions are slightly increased in the early years but then noticeable decreased starting in 2012 (3.6 – 3.9 million tons) equal to a 2% reduction in power sector emissions





Summary of Results

- **Reference Case**
  - The transport sector will become the largest energy consuming sector
  - Oil products continue to dominate final consumption
  - Natural gas will be the primary fuel of choice for power generation which will lead to a near-term and long-term need for additional gas imports
  - CO_2, NO_X, and PM emissions will increase while SO_2 emissions will decline
- **Alternative Scenarios**
  - Limiting natural gas availability to the power sector can substantially decrease gas imports, leading to significantly higher coal imports for power generation and higher emissions
    - Total incremental economic system cost is US$ 2.26 billion
    - CO_2, SO_2, NO_X, and PM all increase noticeably despite assumed pollution controls
  - Renewables reduce gas generation and gas imports while lowering emissions
    - Total incremental economic system cost is US$ 416 million
    - Total cumulative CO_2 reductions are 82.2 million tons at a cost of $5.1/ton CO_2
  - Nuclear power also leads to lower gas imports and lower emissions
    - Total incremental economic system cost is US$ 240 million
    - Total cumulative CO_2 reductions are 48.1 million tons at a cost of $5.0/ton CO_2