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Mexico's Long-Term Energy Outlook: Results of a Detailed Energy Supply and Demand Simulation

Analysis Conducted by a Team of Analysts from:

Secretaría de Energía (SENER)
Universidad Nacional Autónoma de México (UNAM)
Comisión Nacional de Ahorro de Energía (CCONAE)
Instituto Mexicano del Petróleo (IMP)
Instituto de Investigaciones Eléctricas (IIE)
Instituto Nacional de Ecología (INE)
Petróleo de México (PEMEX)
Comisión Federal de Electricidad (CFE)
Argonne National Laboratory (ANL)

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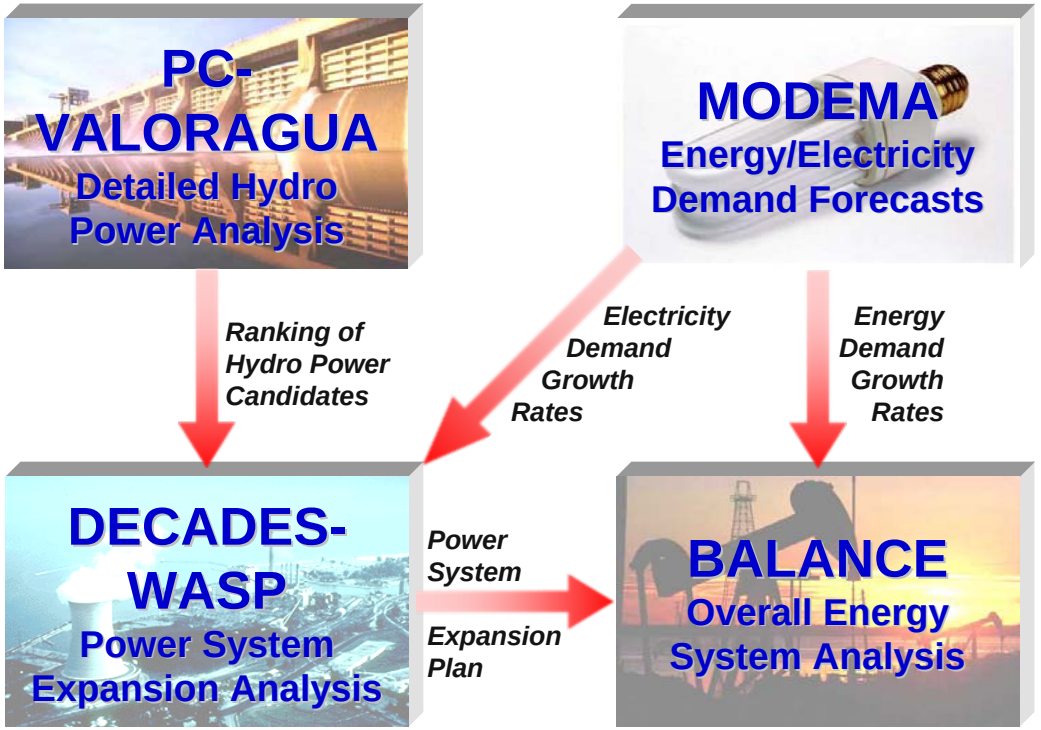
The Study Team Used a Set of Analytical Tools to Conduct the Analysis

- *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

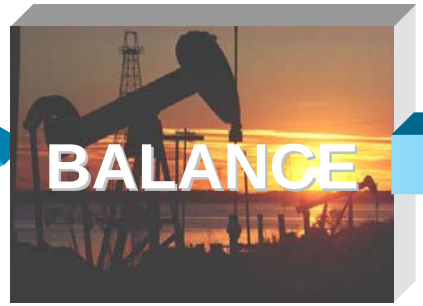


- *ENPEP-BALANCE* to study total energy system issues including all fuels and all sectors

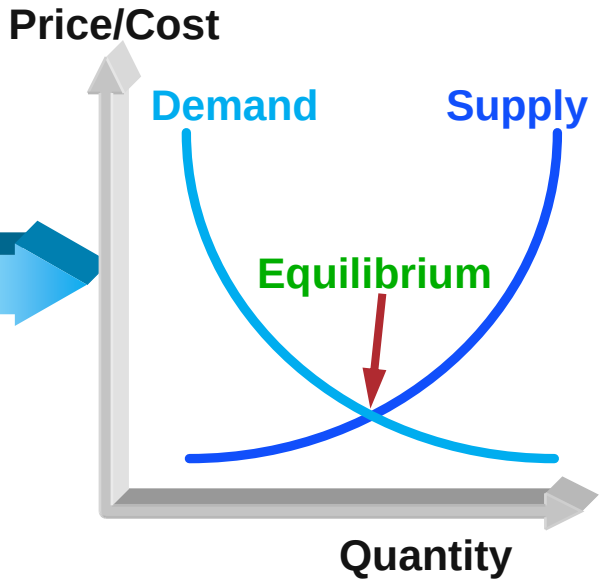
ENPEP-BALANCE Determines the Equilibrium Supply-Demand Balance of the Entire Energy System

INPUT

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

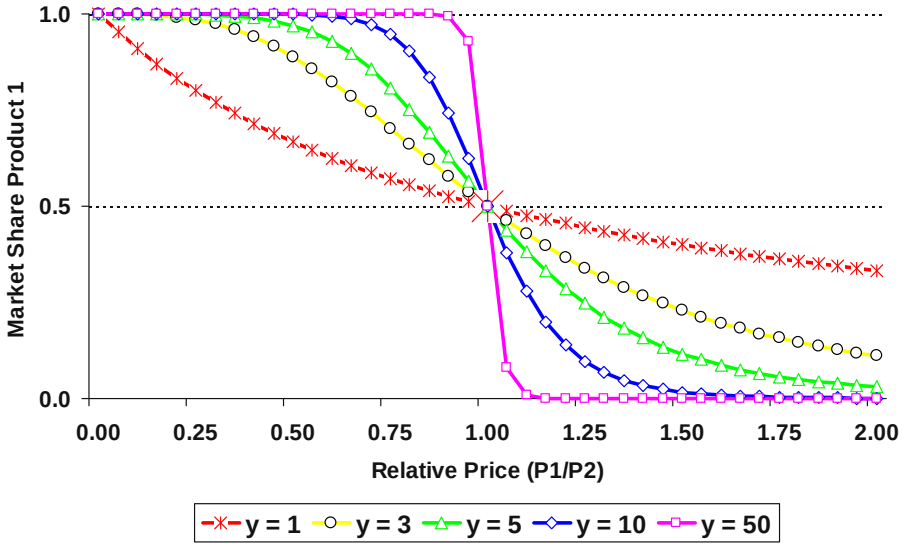


OUTPUT



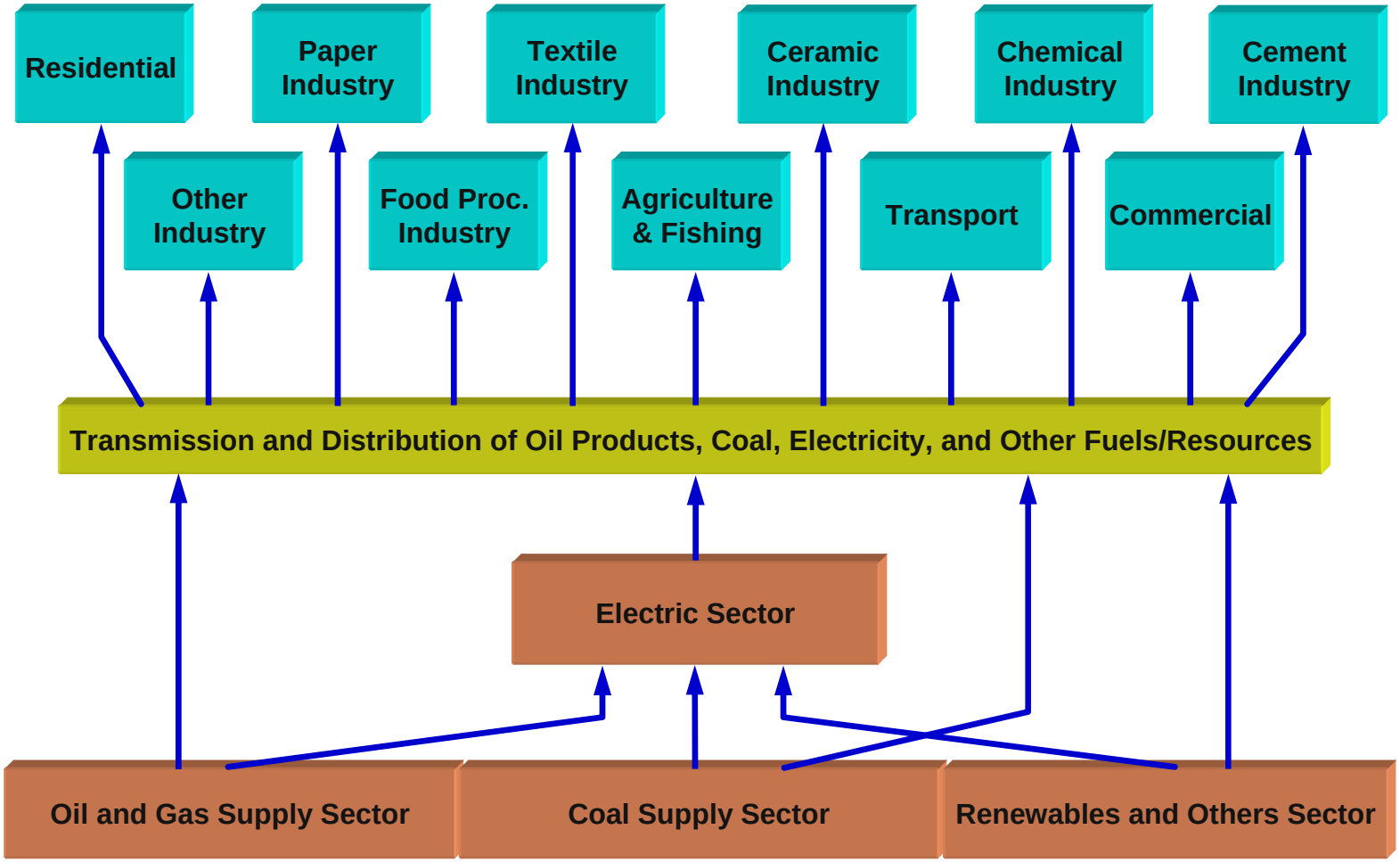
ENPEP-BALANCE Uses a Logit Function to Estimate Market Shares of Different Technologies or Fuels

- 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

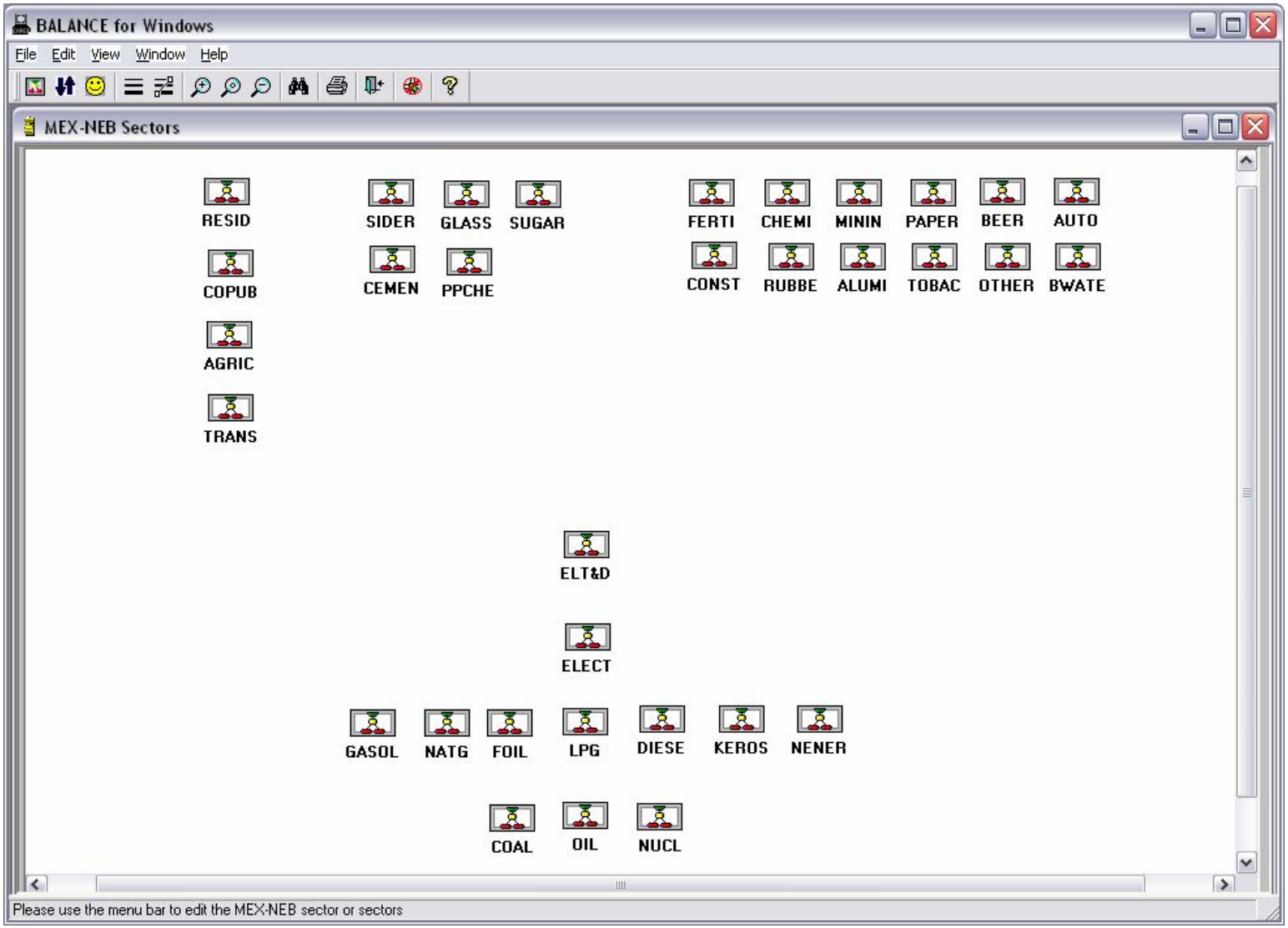


- No single person or organization controls all energy prices and decisions on energy use
- All decision makers optimize their energy choices based on their own needs and desires

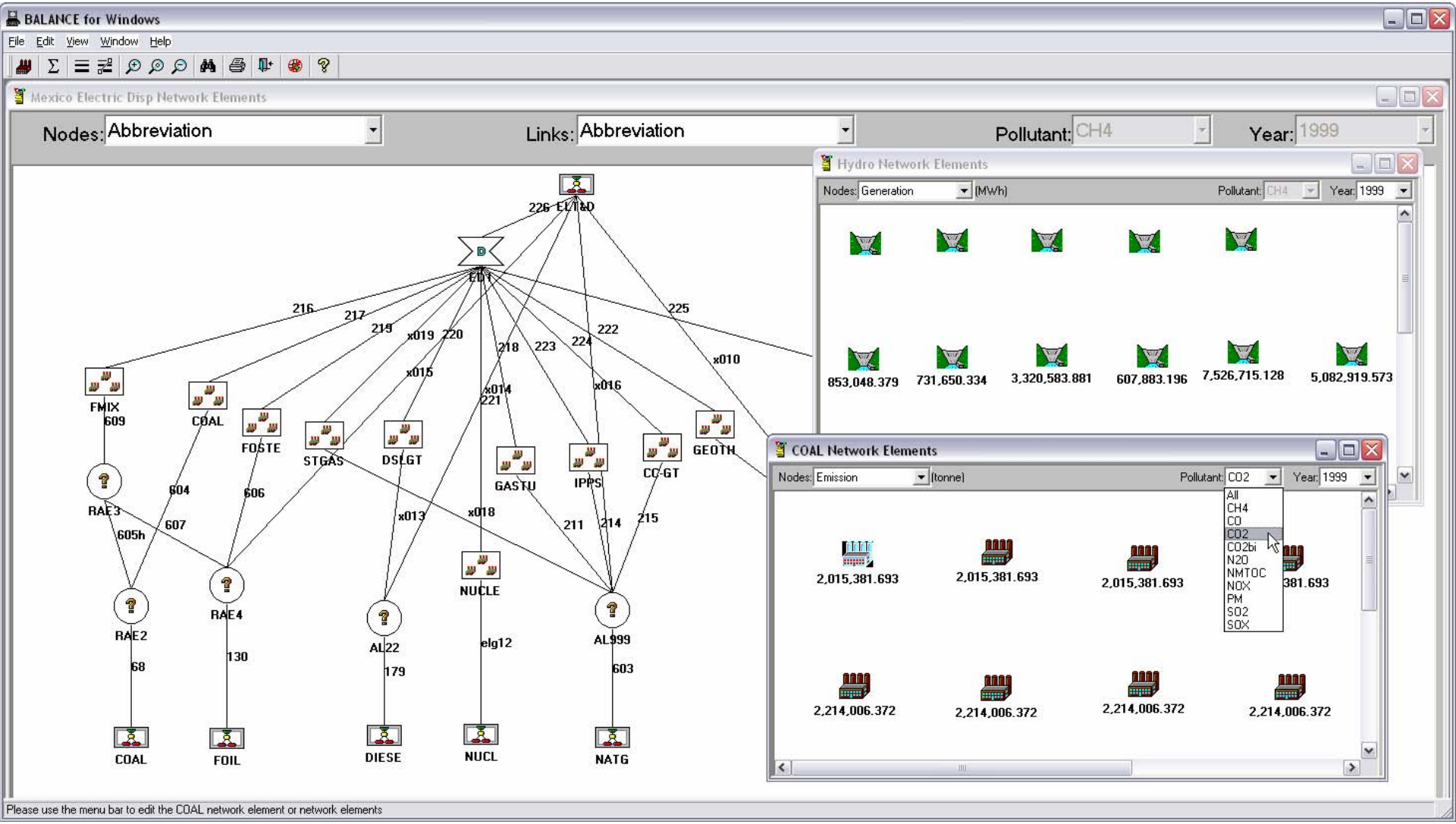
BALANCE Integrates the Analysis and Uses an Energy Network to Simulate Energy Markets



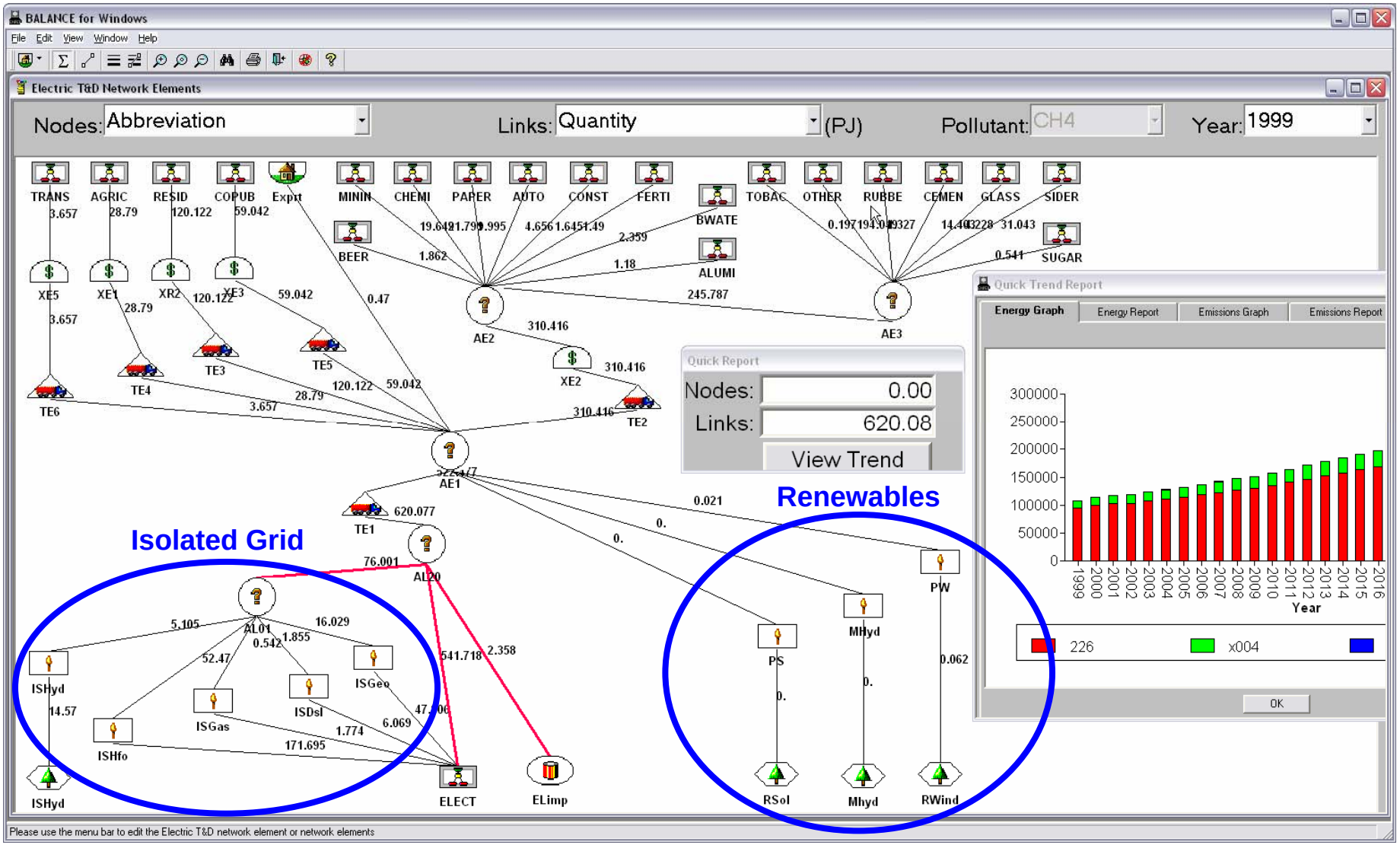
The Mexican Network Configuration Includes 3 Supply Sectors, 9 Conversion and T&D Sectors, and 21 Demand Sectors



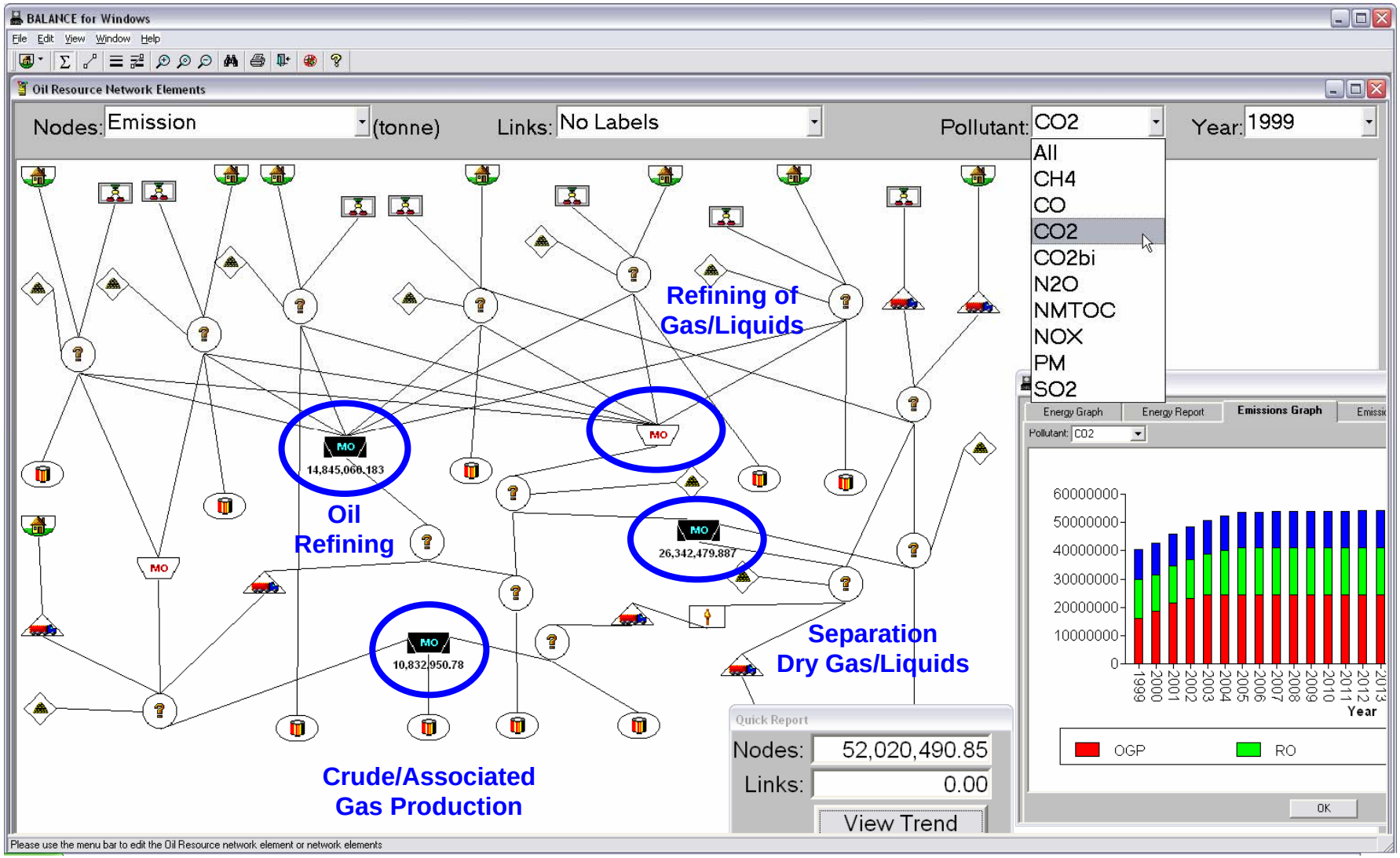
The Team Modeled Each Sector at Different Levels of Detail: Mexico's Interconnected Power System is Represented at the Unit Level



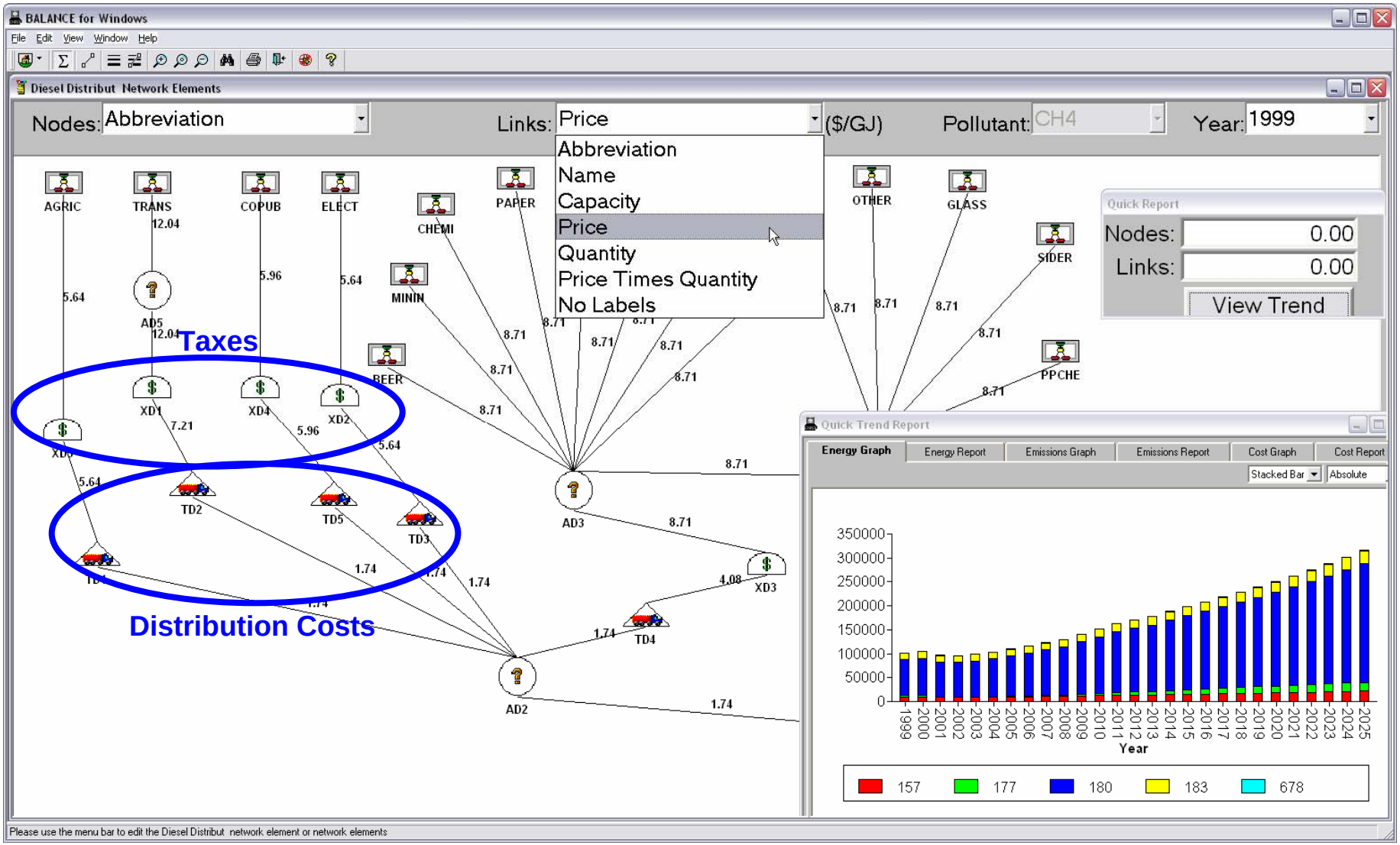
The Isolated Power System is Modeled as Aggregated Fuel Groups (Same for Renewables)



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

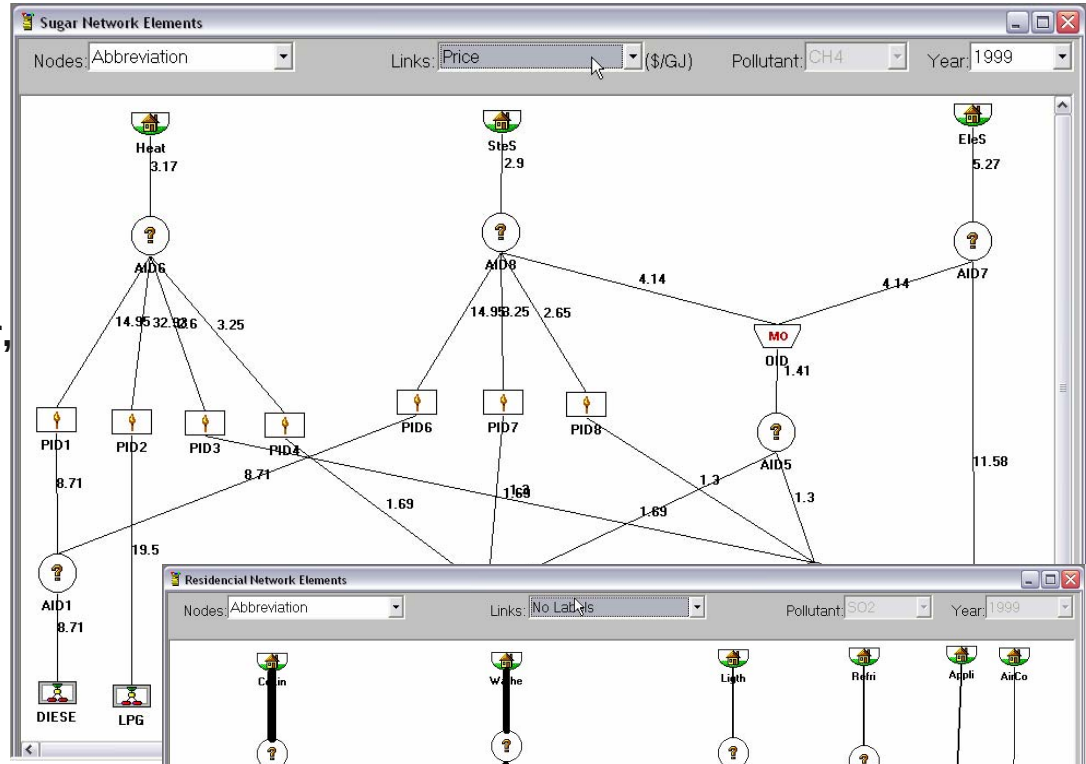


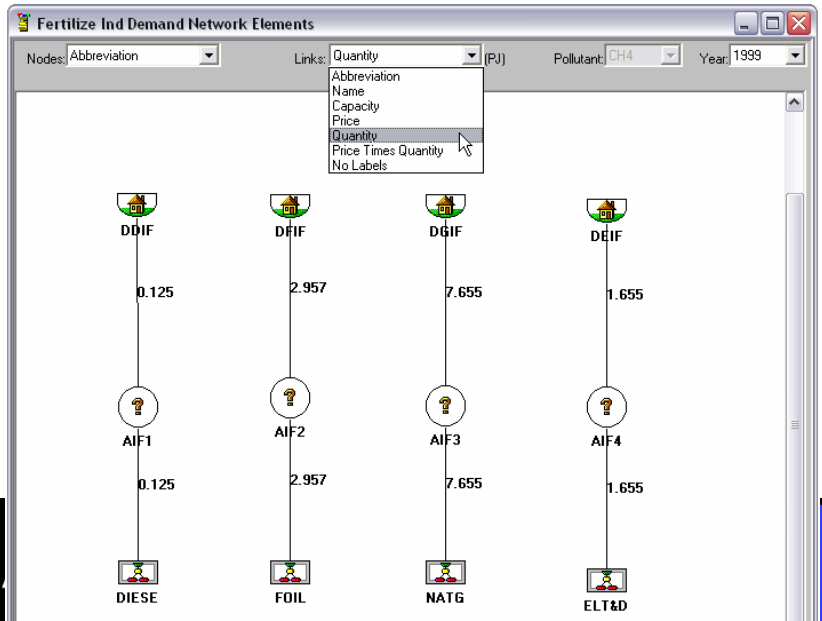
T&D Sectors Incorporate Distribution Costs and Taxes

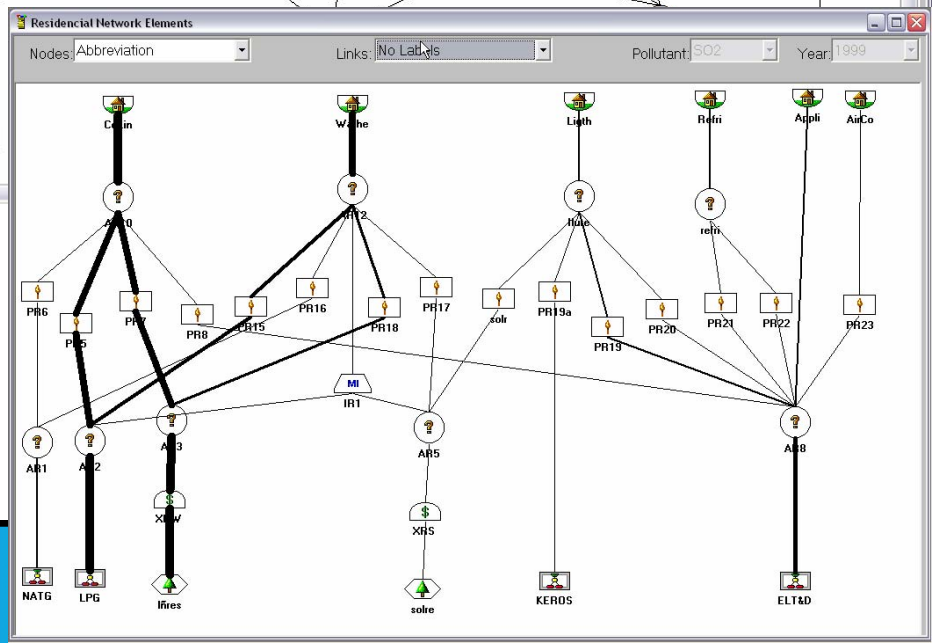


The Level of Detail on the Demand Side Varies with Data Availability

- **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





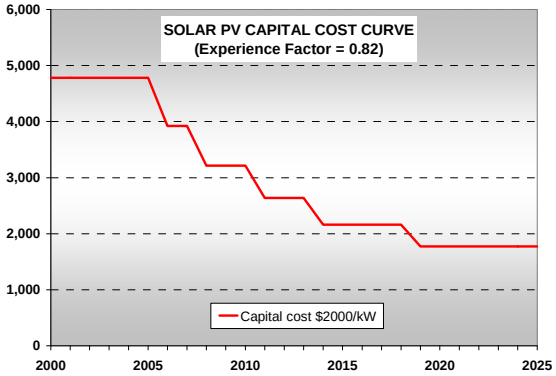


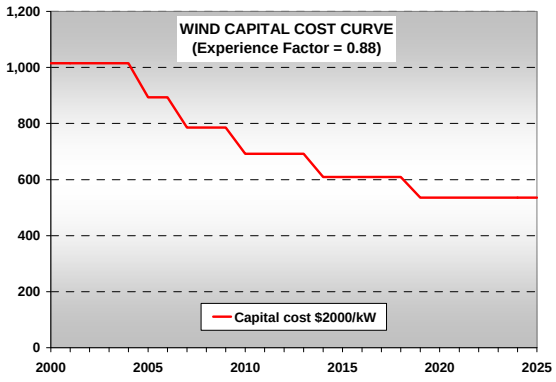
For the Power Sector, the Team Analyzed a Total of 14 Scenarios

- 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

The Following 4 Scenarios were Analyzed for the Entire Energy System

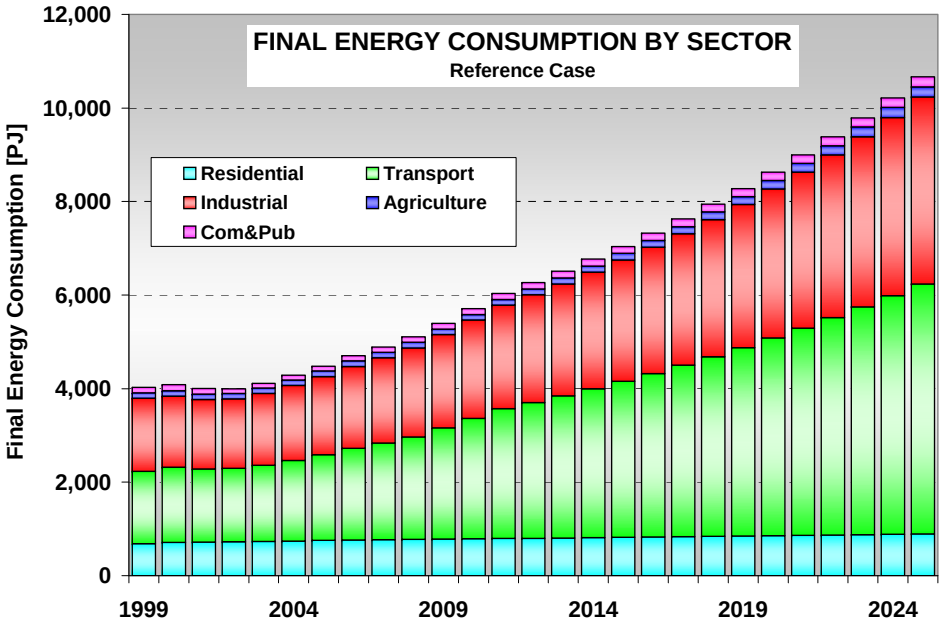
- Reference Case
  - Study period is 1999 to 2025
  - No limitation on gas supply
  - Power sector expansion options include nuclear, combined cycles, gas turbines, imported coal, and hydro
  - GDP grows at 4.5% (2002-2011) and 3.5% until 2025; population growth rate drops from 1.33% (2000-2010) to 1.02% (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

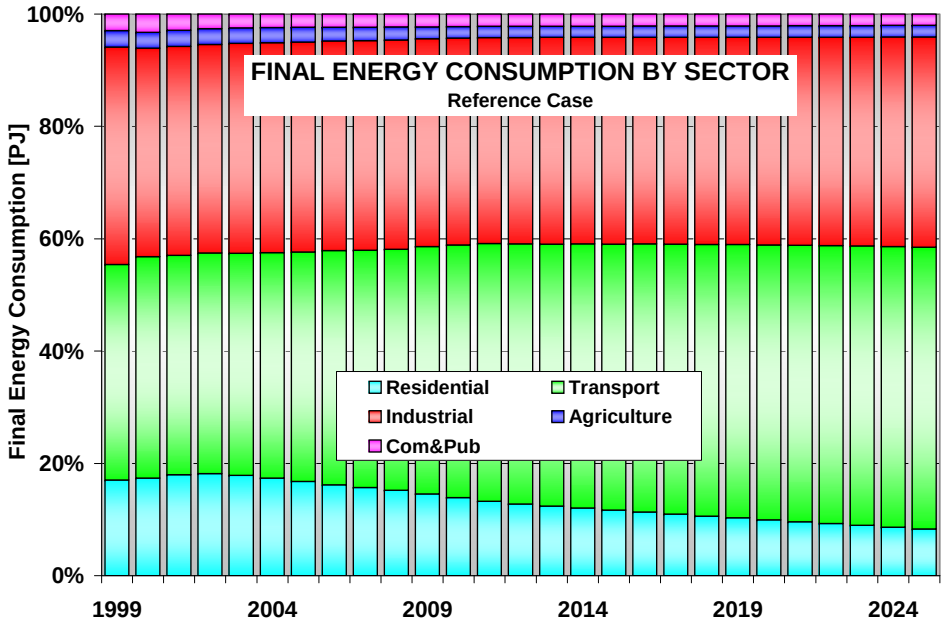




Reference Case: Final Energy Consumption is Projected to Grow from 4,030 to 10,700 PJ with Transportation Growing the Fastest

- 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

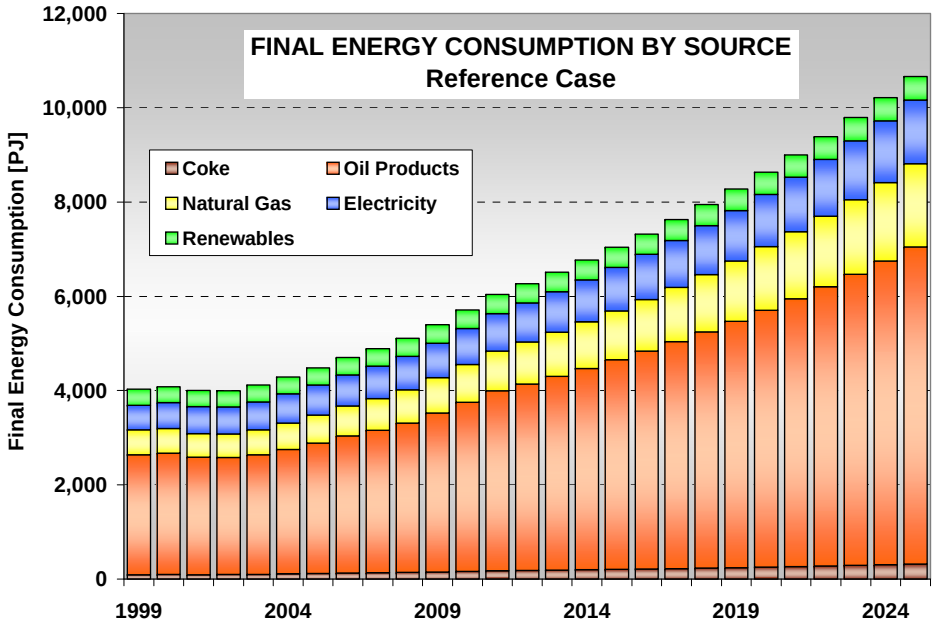


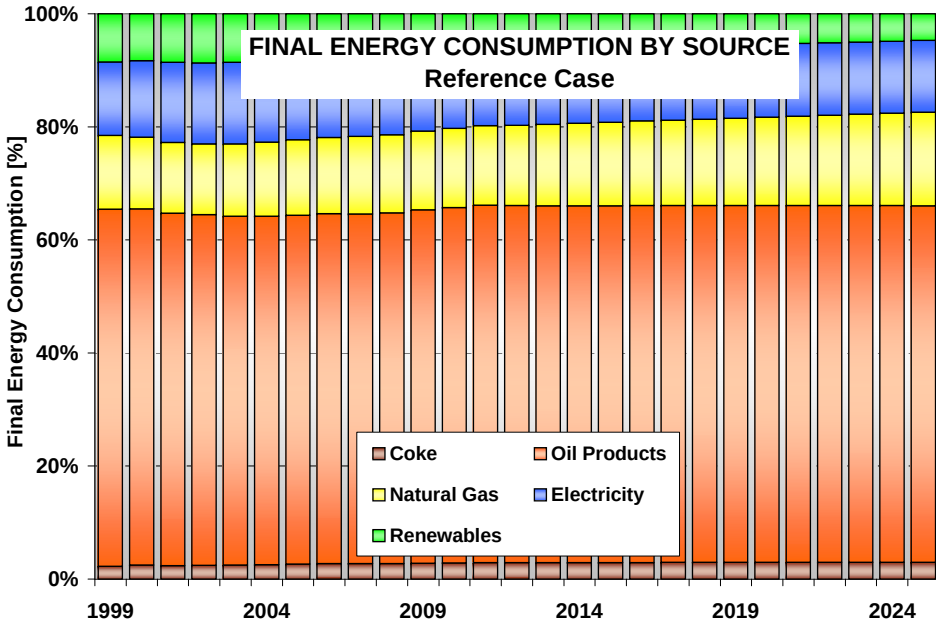


Reference Case: Oil Products will Continue to Dominate Final Energy Consumption

- 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%

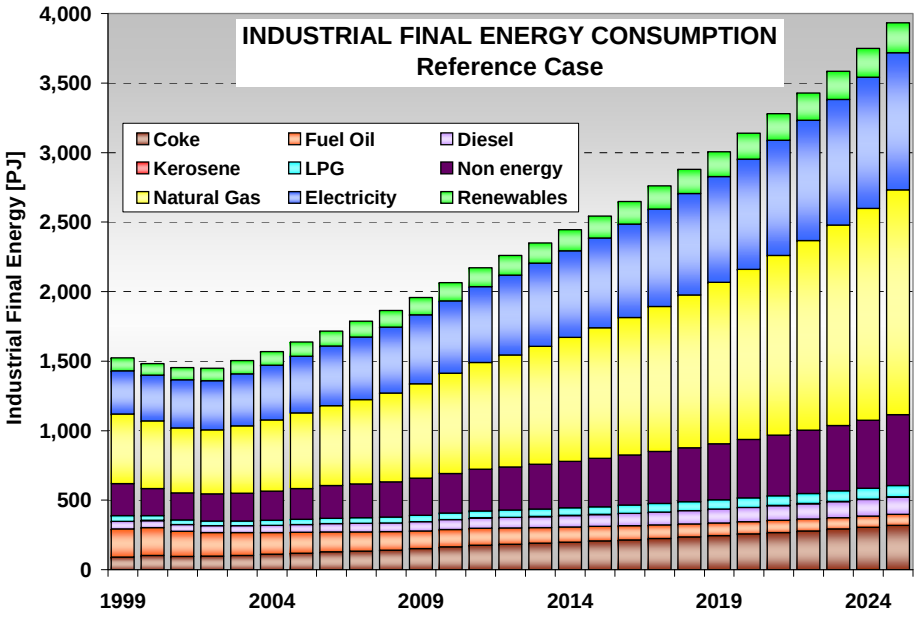


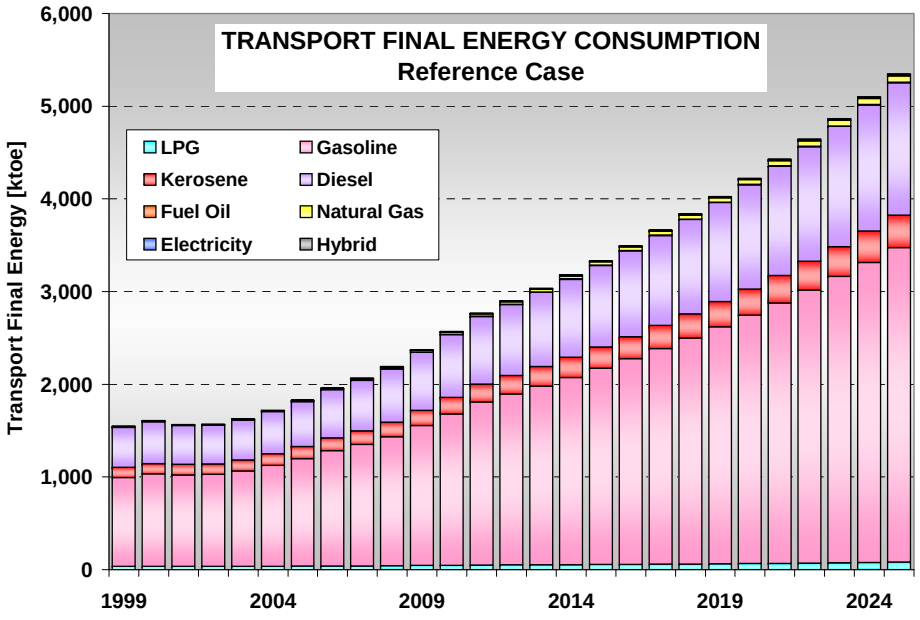


Reference Case: Industrial and Transport Consumption

- 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%

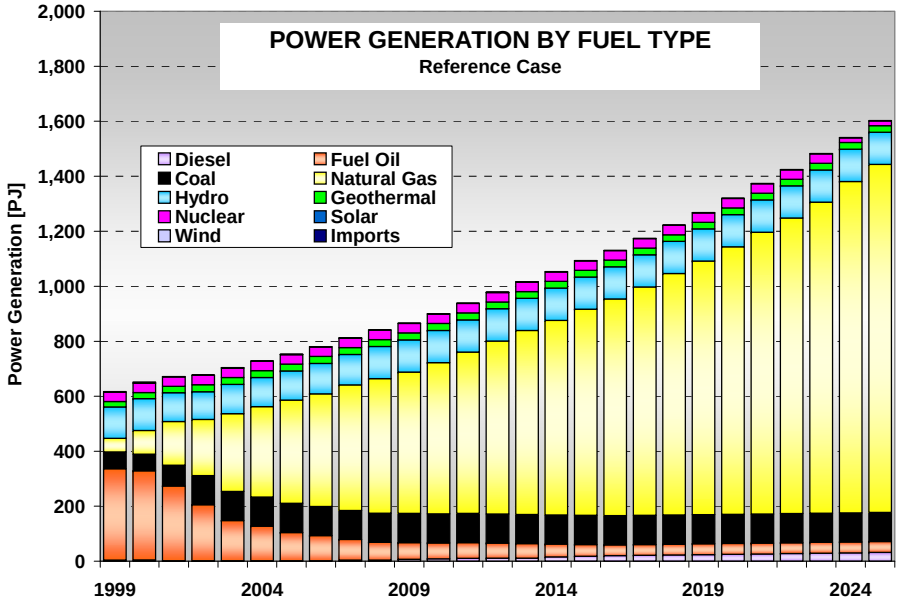
- Transport sector final consumption grows at 4.9% from 1,547 PJ to 5,349 PJ; fuel shares change very little: gasoline and diesel combined account for 90% of total transport consumption

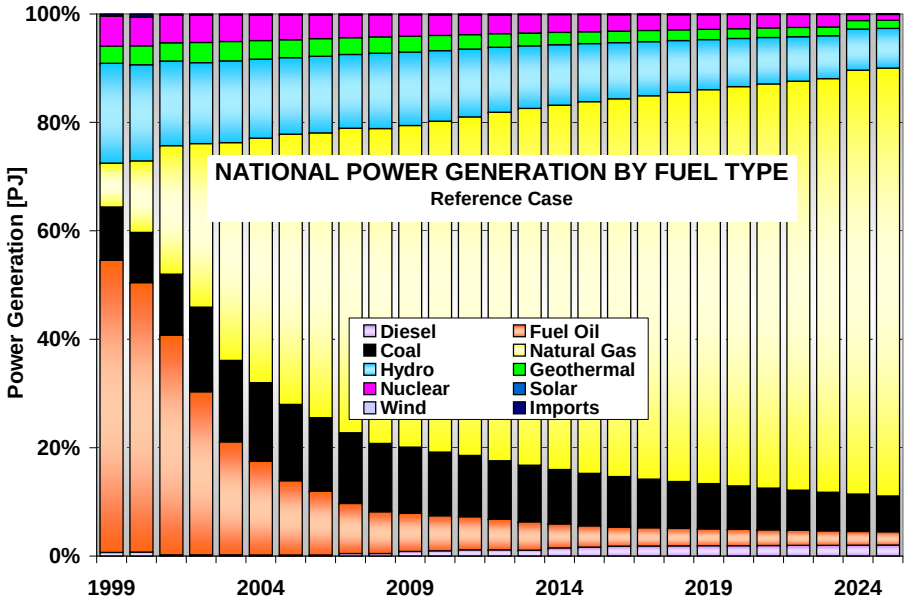




Reference Case: Power Generation will be Dominated by Natural Gas, while Fuel Oil Declines Due to Retirements

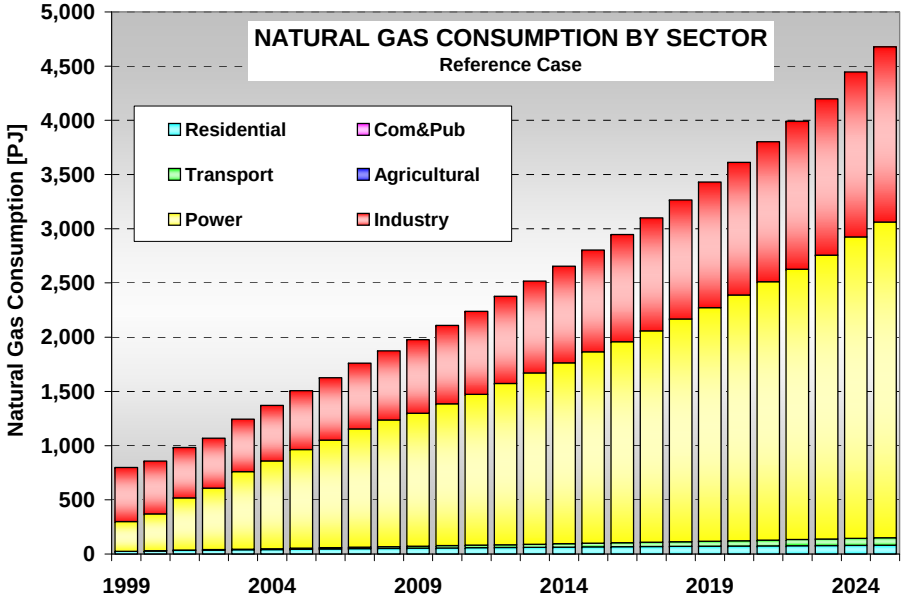
- Natural gas-fired generation increases from 50 PJ to 1,265 PJ (out of 1,603 PJ total) in 2025; natural gas generation share increases from 8% to 79%
- Fuel oil-fired generation decreases from 333 PJ to 39 PJ in 2025; fuel oil generation share decreases from 54% to 2.5%
- Generation from renewables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

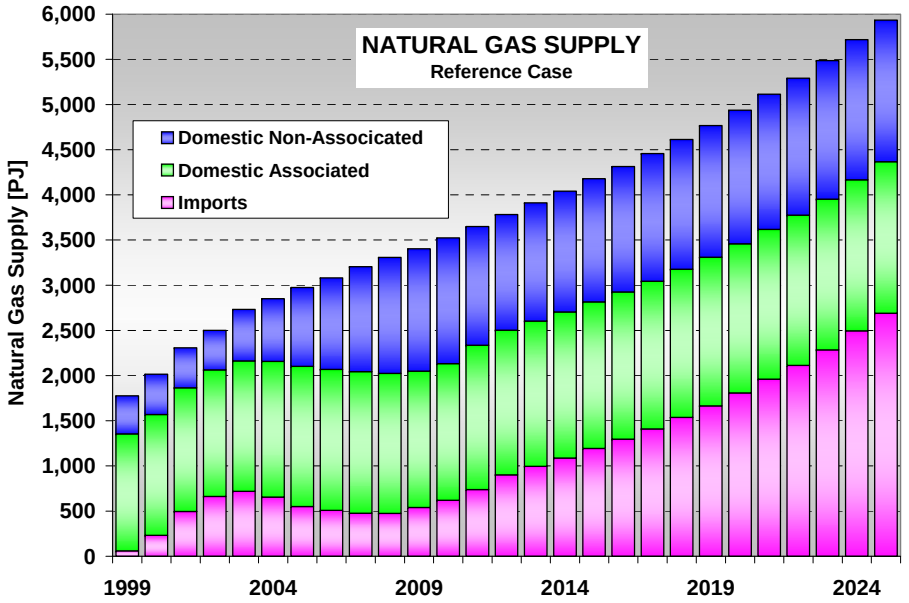




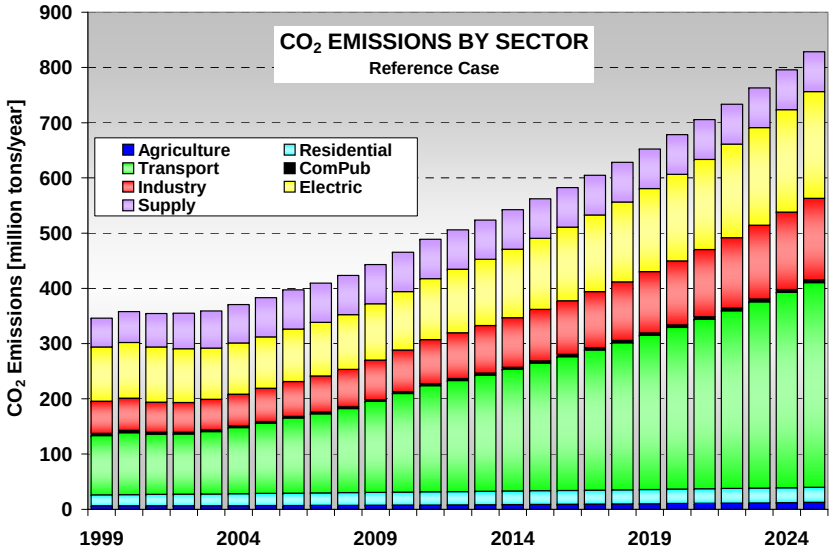
Reference Case: Natural Gas Consumption is Primarily Driven by Power Generation leading to a Near-Term and Long-Term Need for Natural Gas Imports

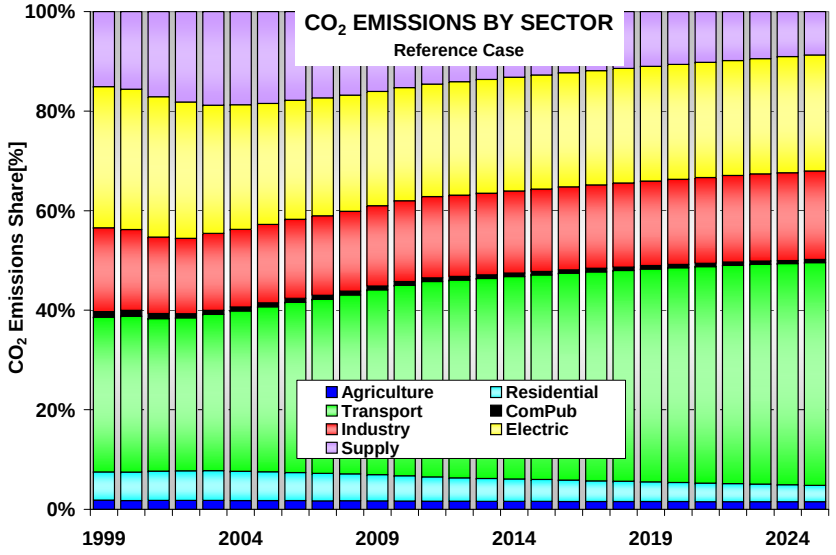
- In 1999, industry accounts for 63% of natural gas consumption while power generation accounts for 34%; By 2025, the shares will change to 35% industry and 62% power generation
- Because the domestic gas production is assumed to be constant for the first 4 years (as given in the latest *Gas Prospectiva*), 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

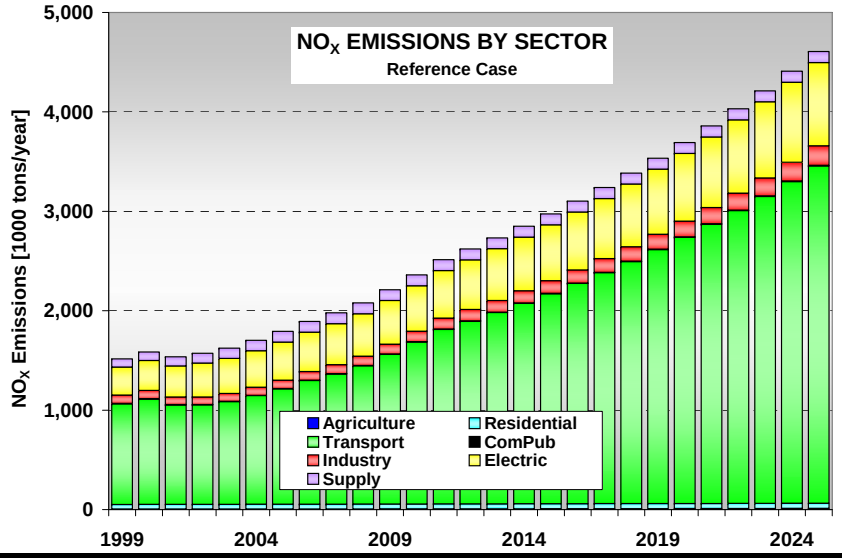


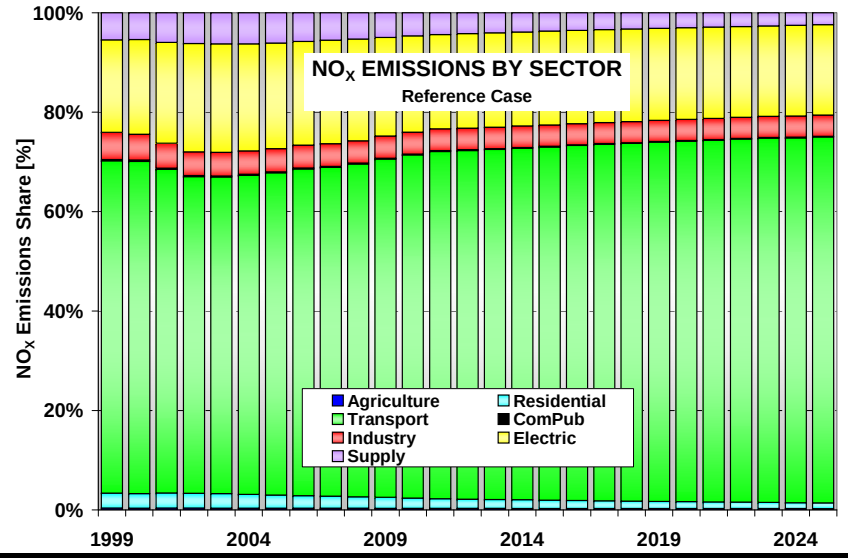


Reference Case Emissions by Sector:
CO_2 will Increase from 346 to 828 million tons/year
NO_X will Increase from 1.5 to 4.6 million tons/year

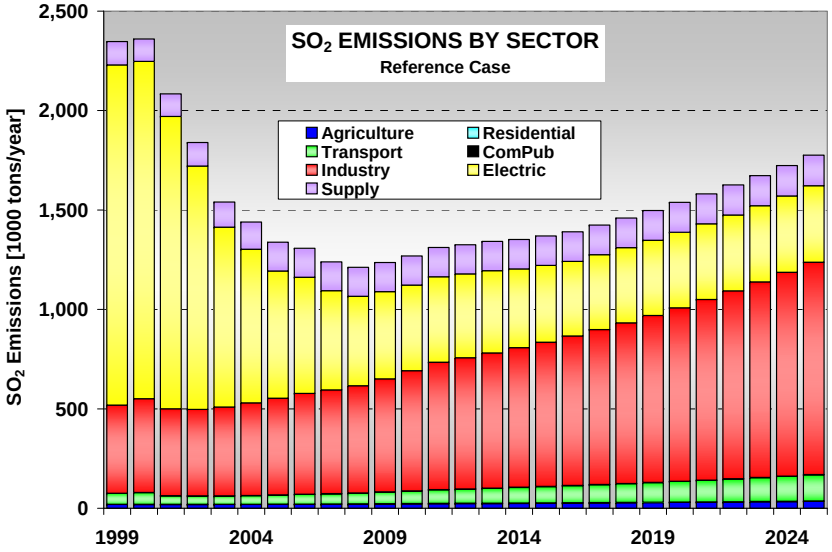


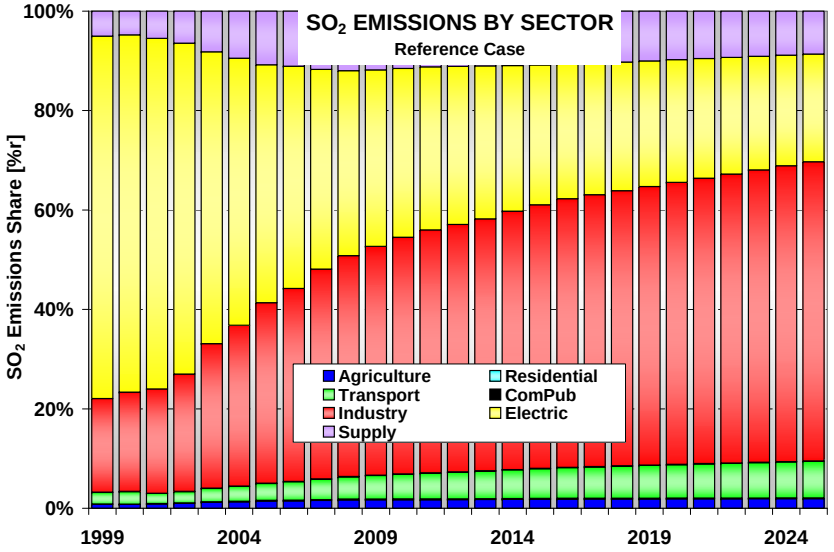


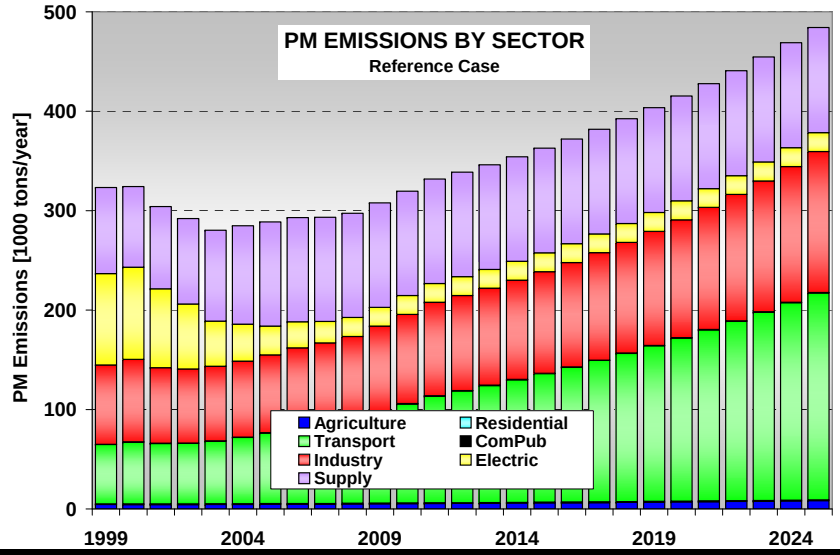


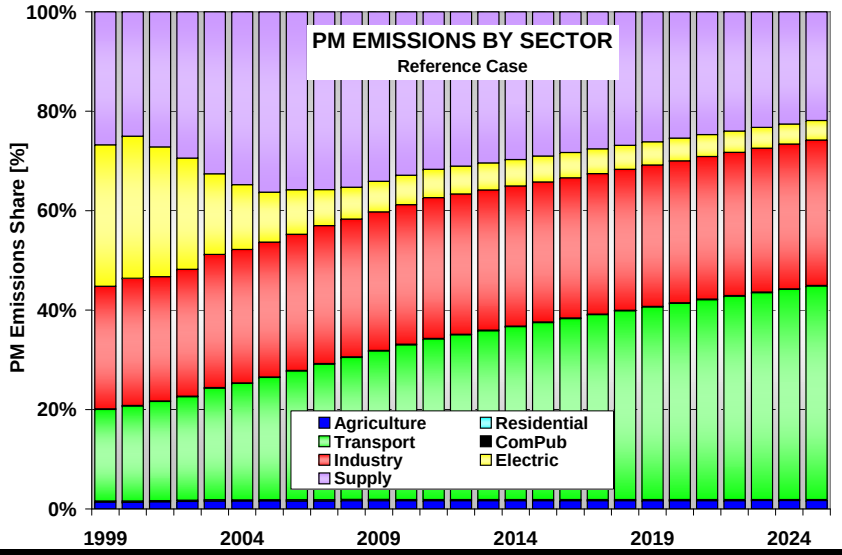


Reference Case Emissions by Sector:
SO_2 will Decrease from 2.3 to 1.8 million tons/year
PM will Increase from 323 to 484 ktons/year



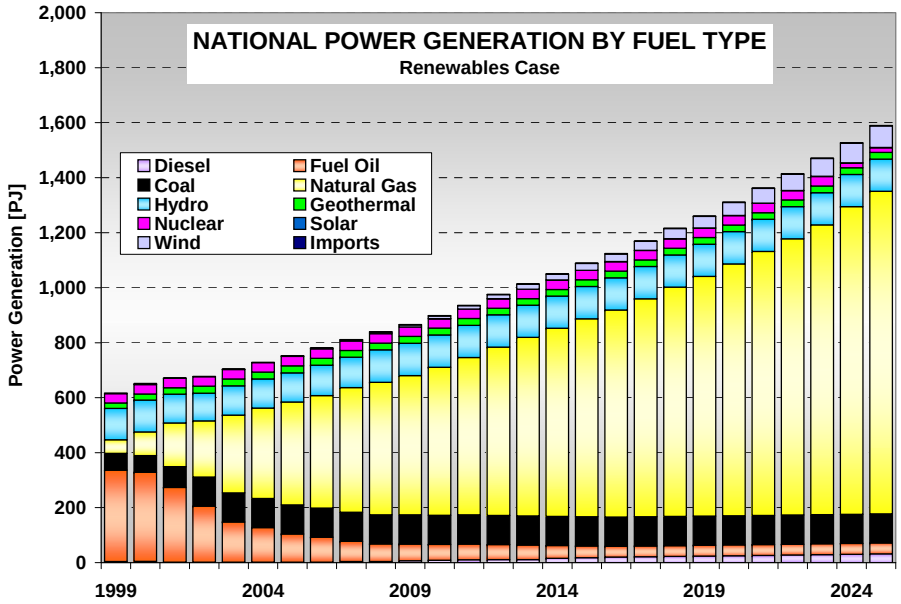


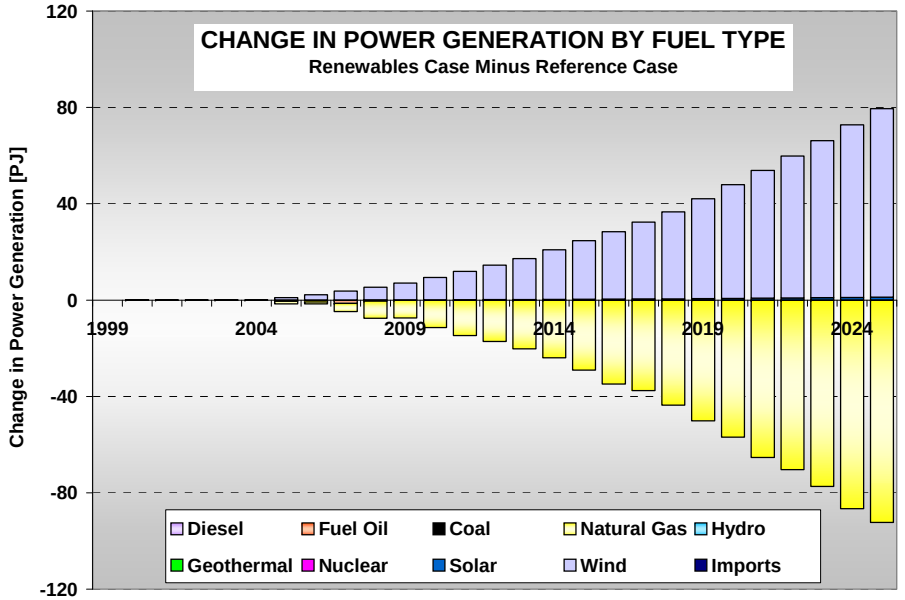




Renewable Scenario: Wind will Replace Gas-Fired Generation and will be the Dominating Renewable Power Generation Resource

- 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

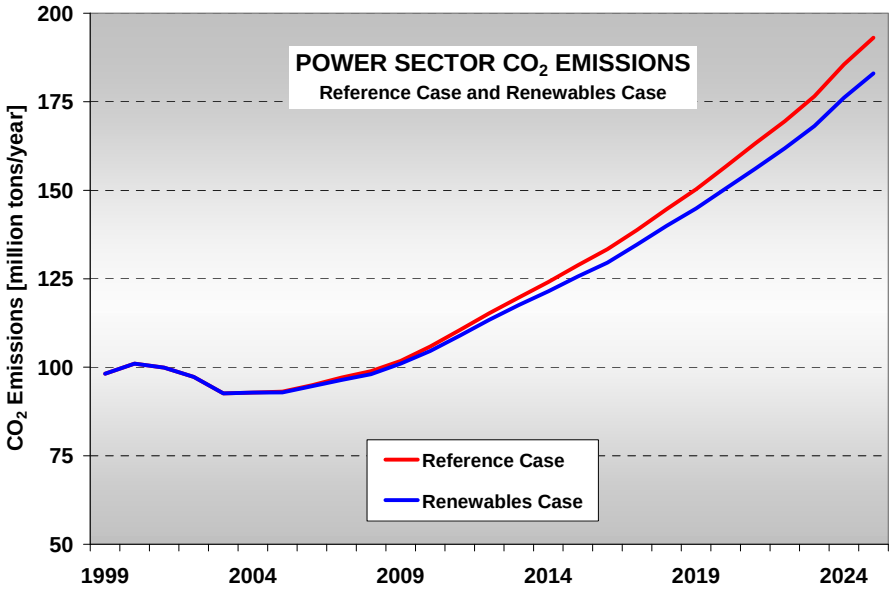


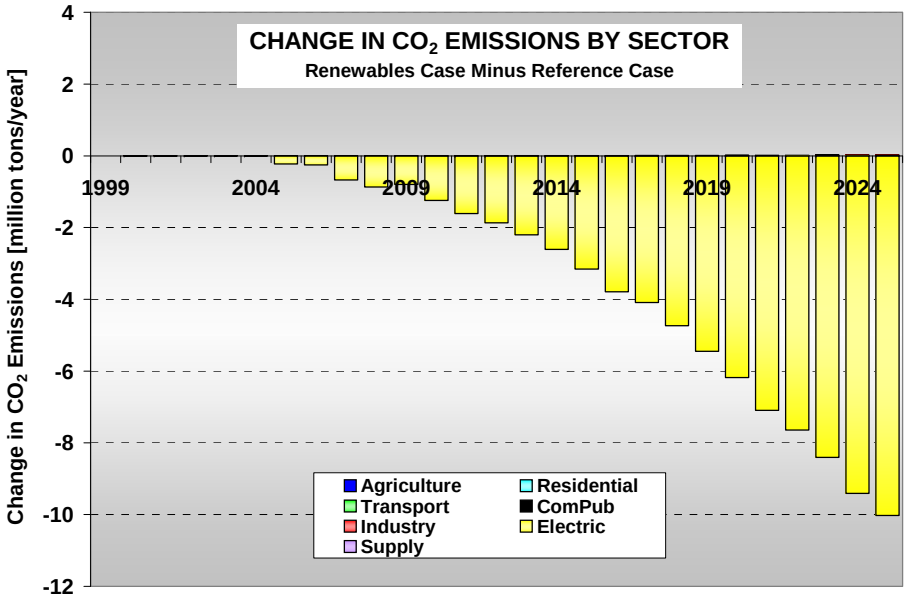


Renewable Scenario: Emission Reductions Are Somewhat Limited as Renewables Replace Gas

- 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





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*