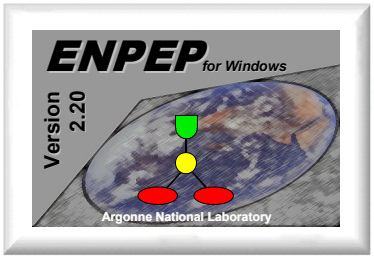
# Overview of the Energy and Power Evaluation Program (ENPEP-BALANCE)

**ENPEP-BALANCE Training Course**
Singapore
December 5-9, 2011

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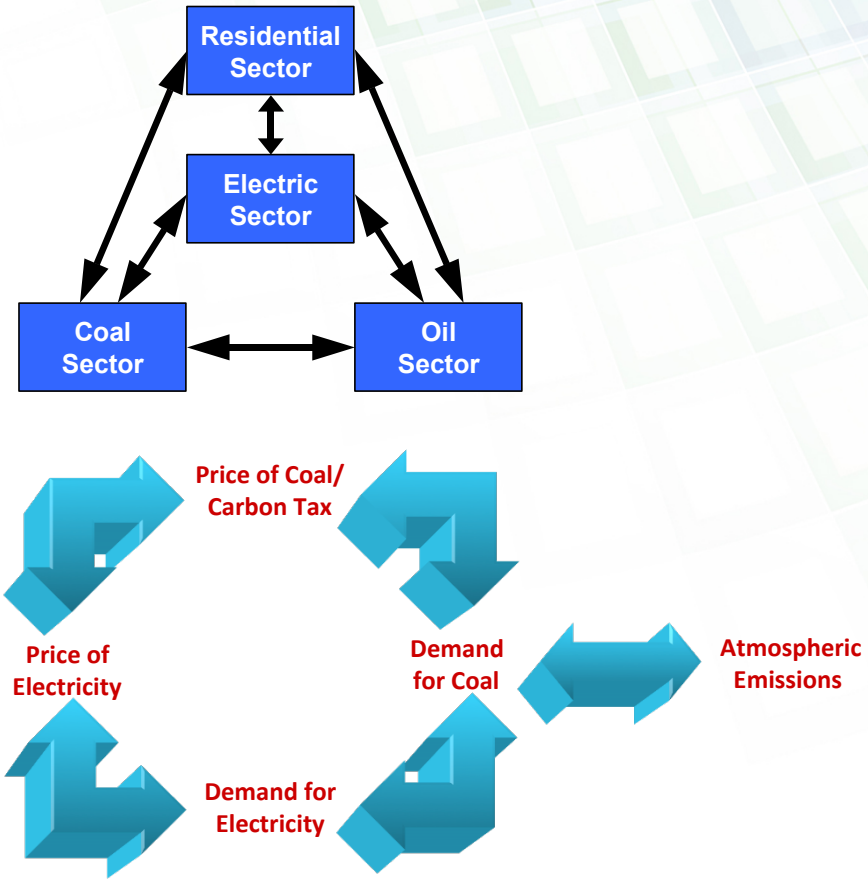
# *ENPEP-BALANCE is Designed to Analyze the Entire Energy System in an Integrated Framework*

- Reveal cross-sectoral effects; provide structure for consistent energy "planning" program

- Integrated framework allows evaluation of feedback effects

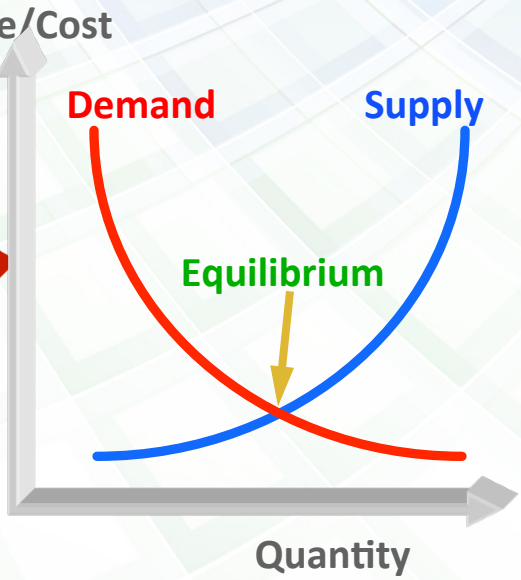


# ENPEP-BALANCE Determines the Equilibrium Supply/ Demand Balance of the Energy System

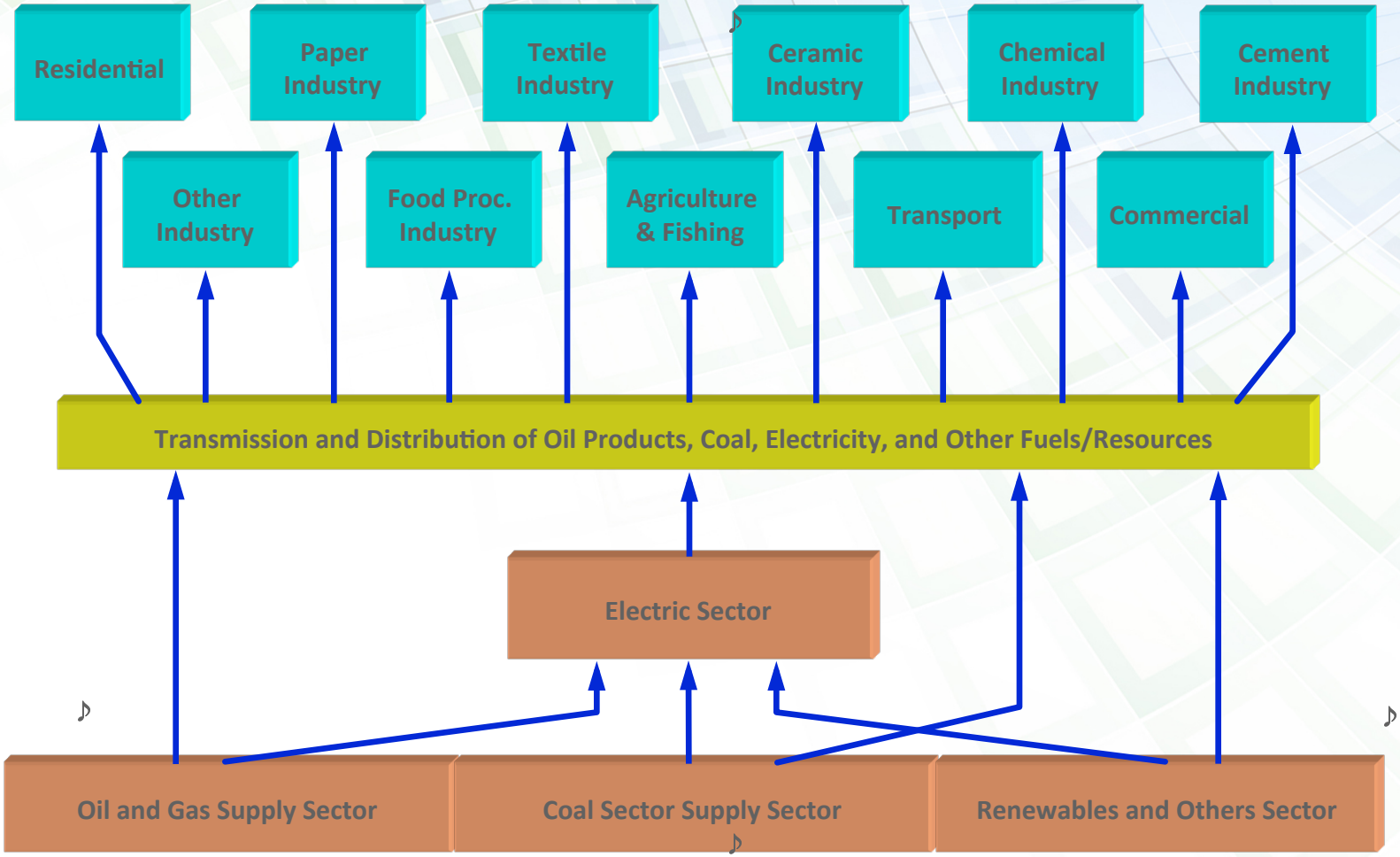
**INPUT**

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

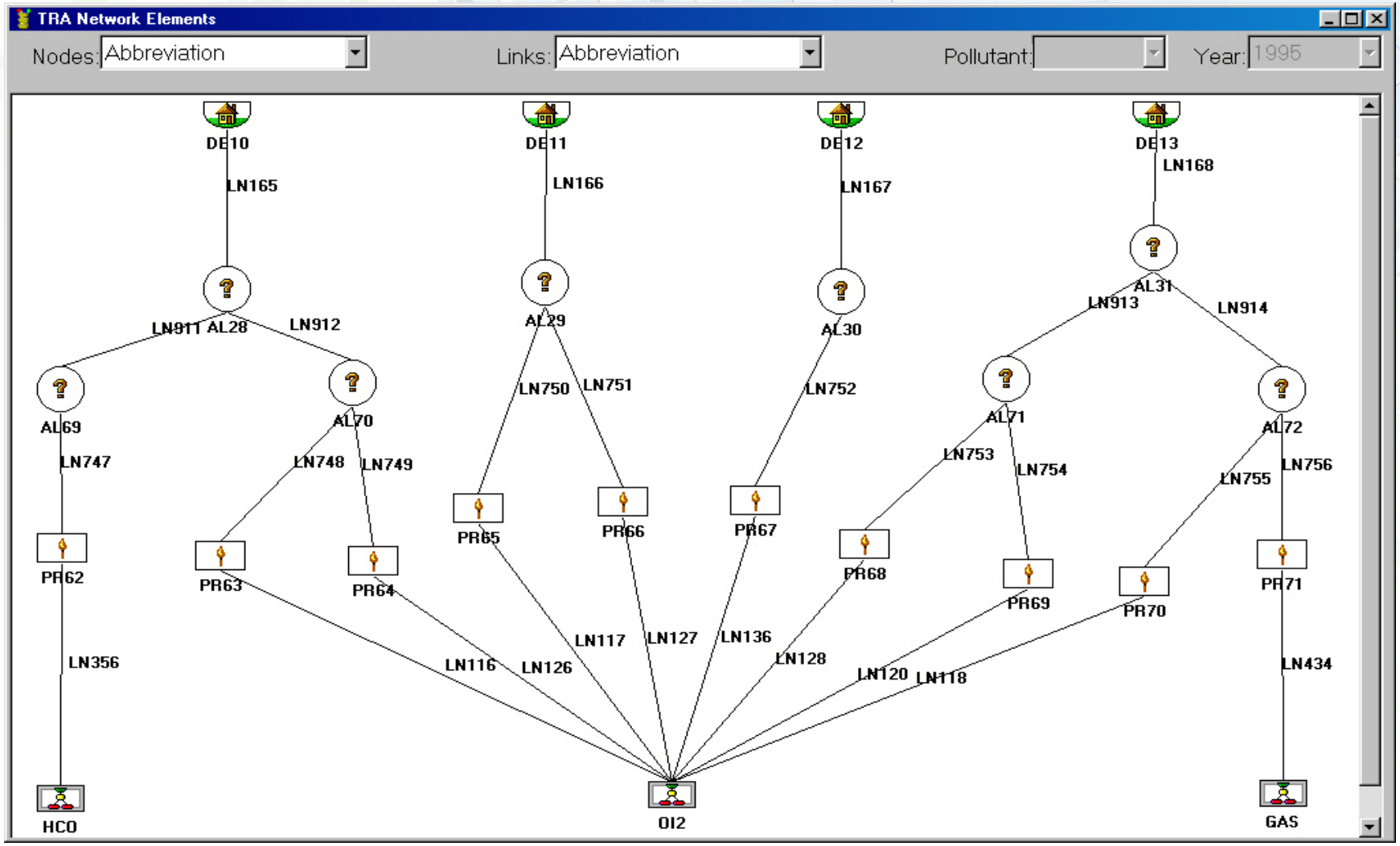

**OUTPUT**



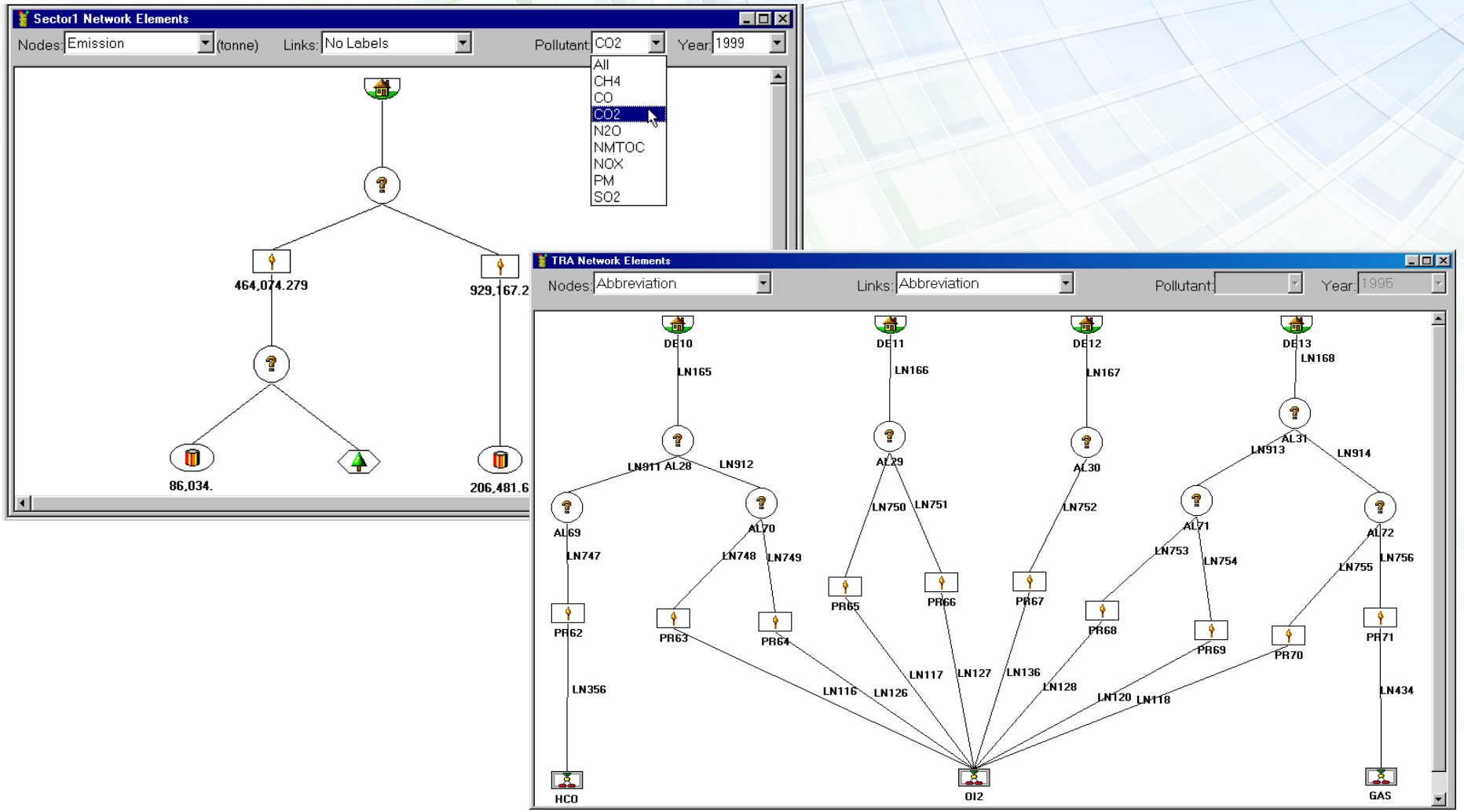
# ENPEP-BALANCE Uses an Energy Network to Simulate Energy Markets



# Networks Consist of Nodes and Links



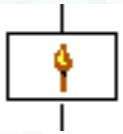
# *Using Nodes and Links, Each Sector is Modeled Differently Depending on Data Availability and Type of Issue Analyzed*



# *The Following Node Types are Available to Model Different Energy Activities*

- Demand

- Conversion Processes



♪Single In-/Output


Multi Output


Multi Input

Transport

- Resource Processes

♪Depletable

Renewable

- Economic Processes


♪Decision/Allocation


Pricing

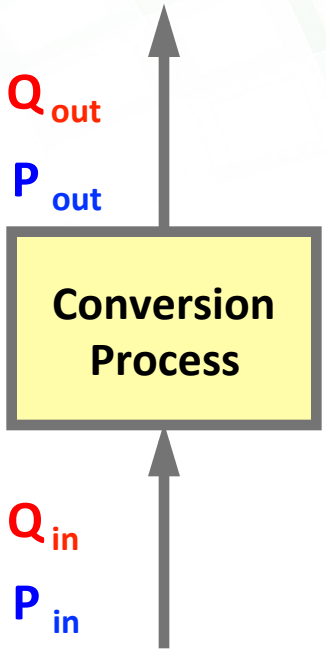
- Electricity Dispatch and Thermal and Hydro Units


♪Central Dispatch

Thermal Unit

Hydro Unit

# *Nodes Are a Series of Simple Sub-Models, Each With a Set of Quantity and Price Equations*




- $Quantity_{output} = f(Quantity_{input})$
  - Example conversion process

    $Q_{out} = Q_{in} \times \gamma$

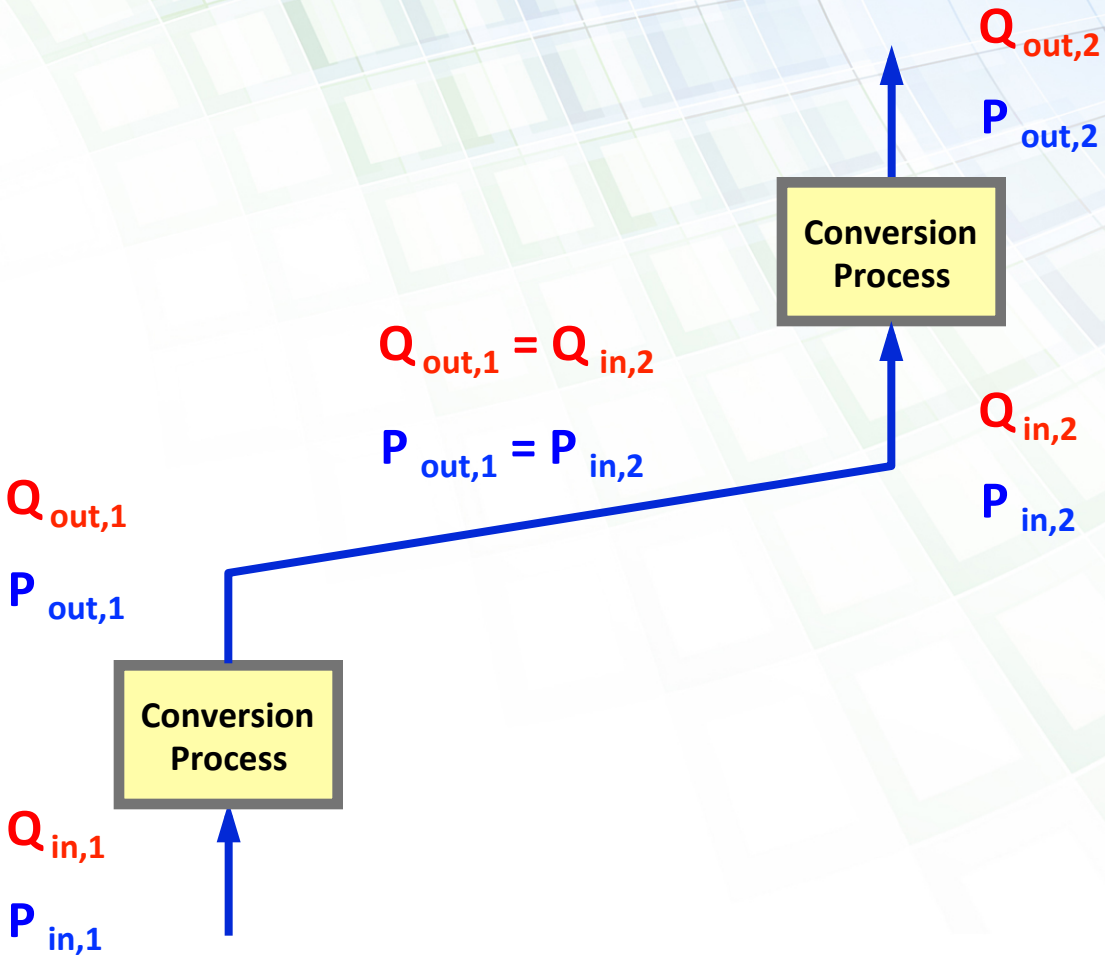
    $\gamma$: **conversion efficiency**

- $Price_{output} = f(Price_{input})$
  - Example conversion process

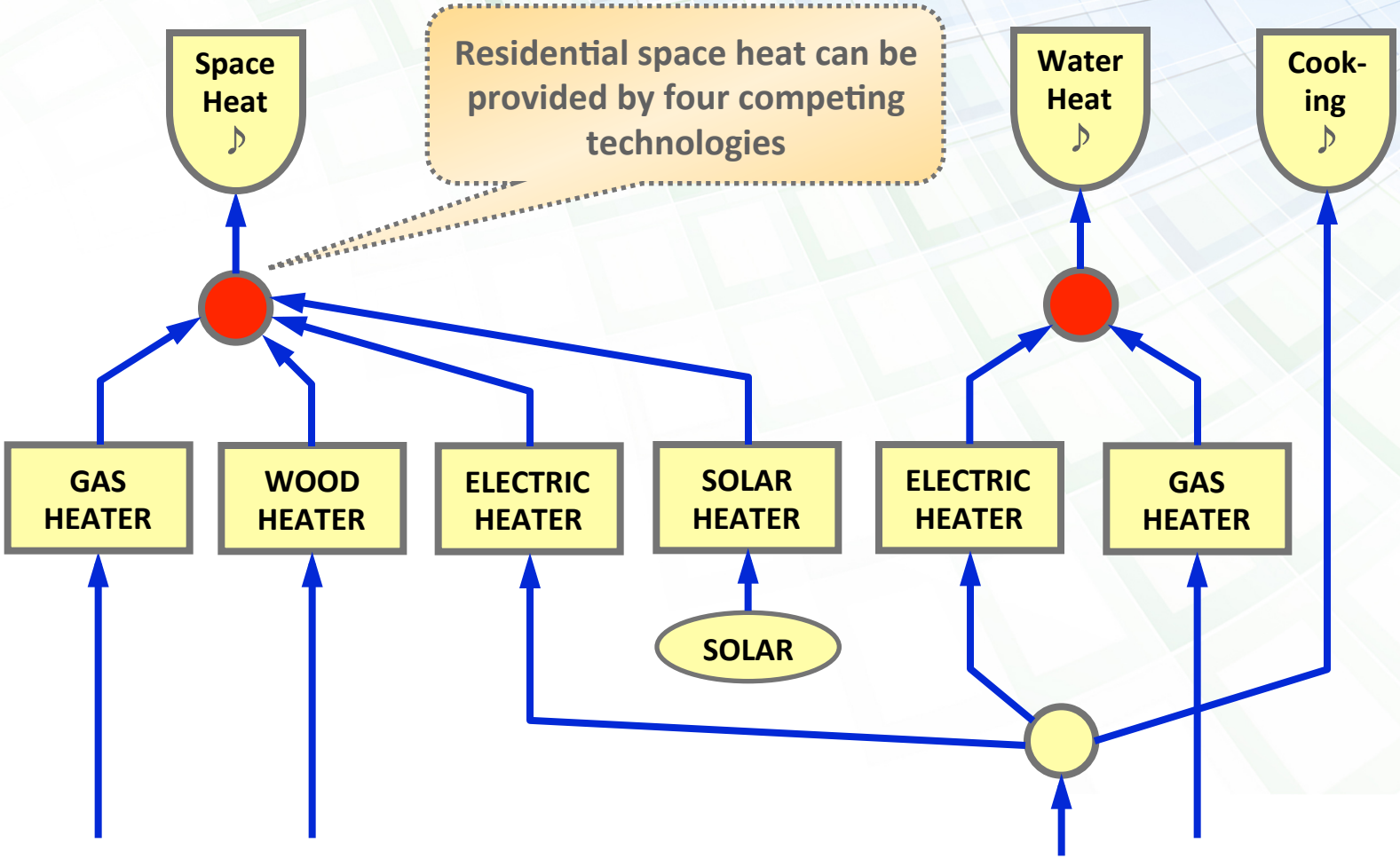
    **Revenue = Cost**

    $Q_{out} \times P_{out} = Q_{in} \times P_{in}$ + O&M + Capital Recovery

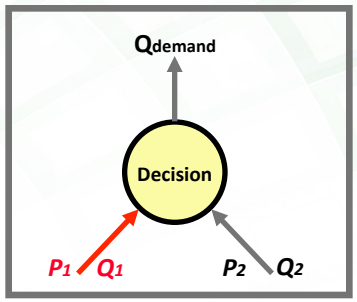
# The Links Connect the Nodes and Pass Information from One Node to Another



# At the Decision Nodes, Fuels and Technologies Compete for Future Market Shares

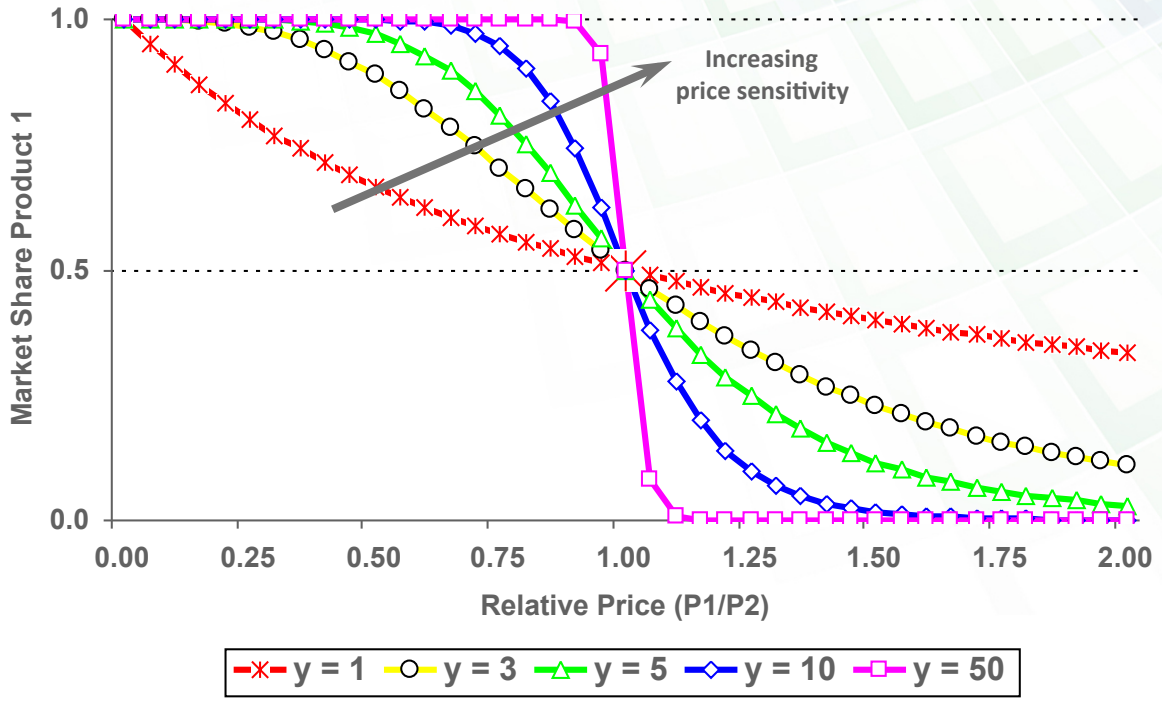


# ENPEP-BALANCE Uses a Logit-Function to Estimate Market Shares of Competing Commodities at the Decision Node



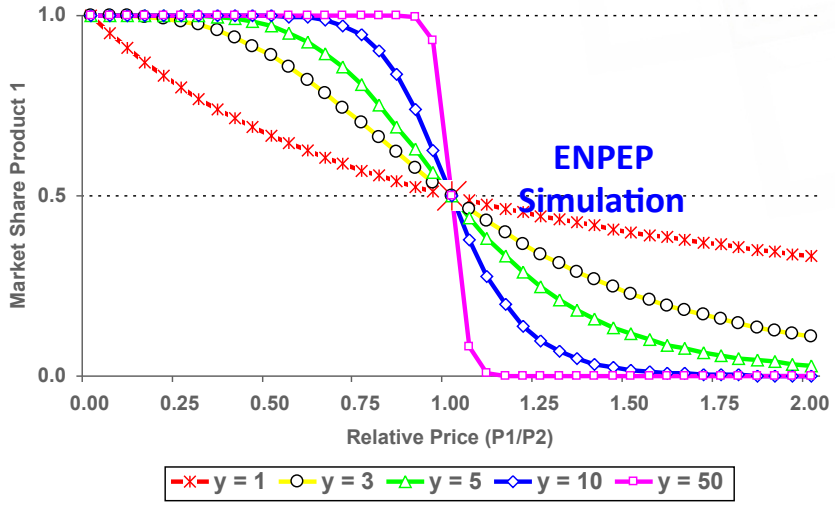

$$MS_1 = \frac{Q_1}{Q_1 + Q_2} = \frac{\left[\frac{1}{P_1 \times PM_1}\right]^{\gamma}}{\left[\frac{1}{P_1 \times PM_1}\right]^{\gamma} + \left[\frac{1}{P_2 \times PM_2}\right]^{\gamma}}$$

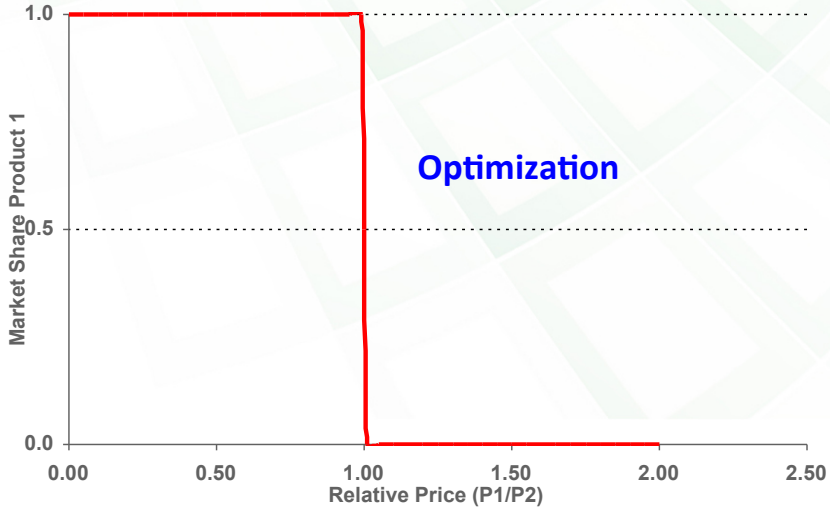
| | |
|---|---|
| $\gamma$ | price sensitivity for this decision process |
| MS: | market share |
| P: | price |
| PM: | premium multiplier |
| Q: | quantity |



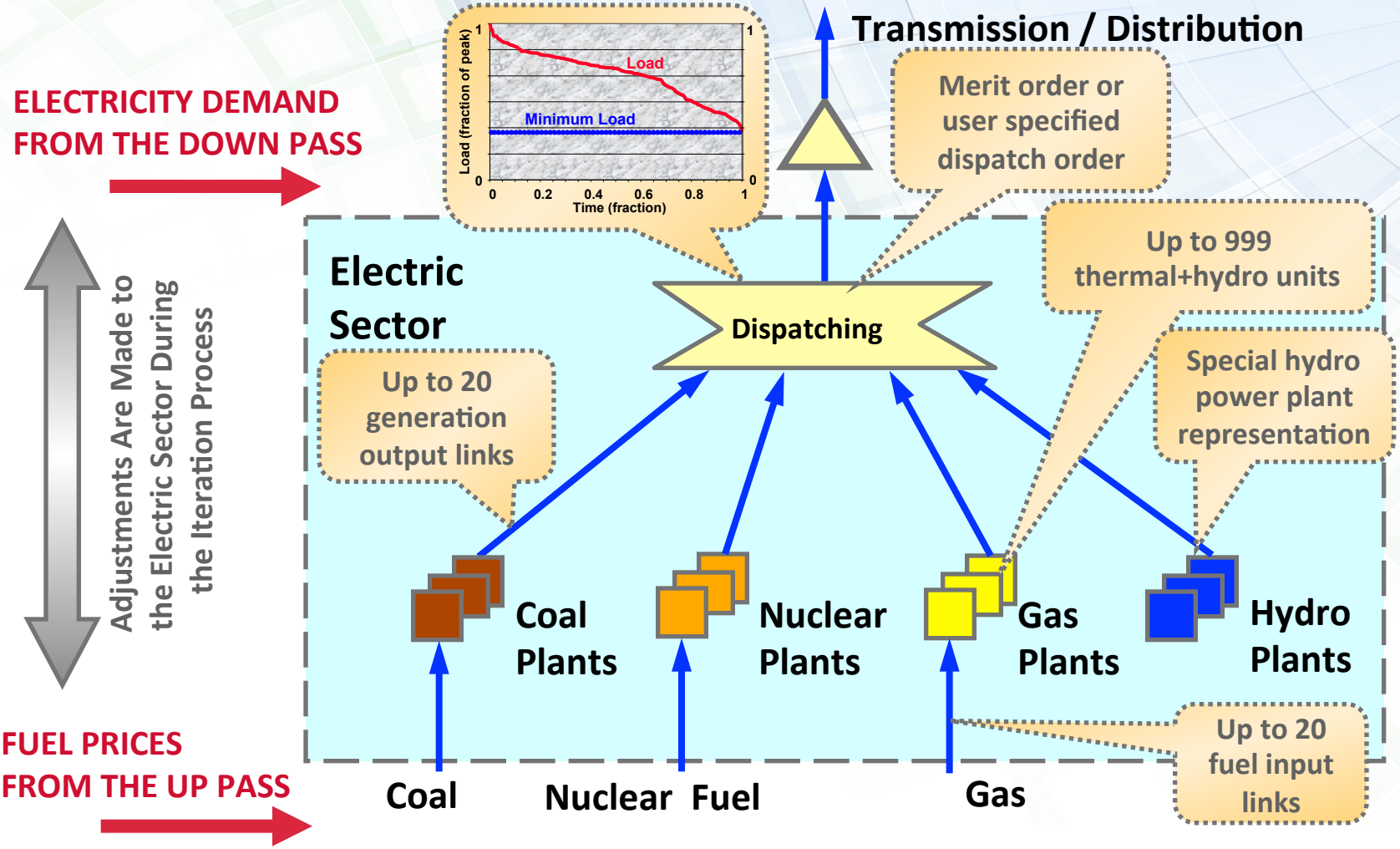
# The ENPEP-BALANCE Nonlinear Equilibrium Algorithm is Based on Decentralized Decision Making

- 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

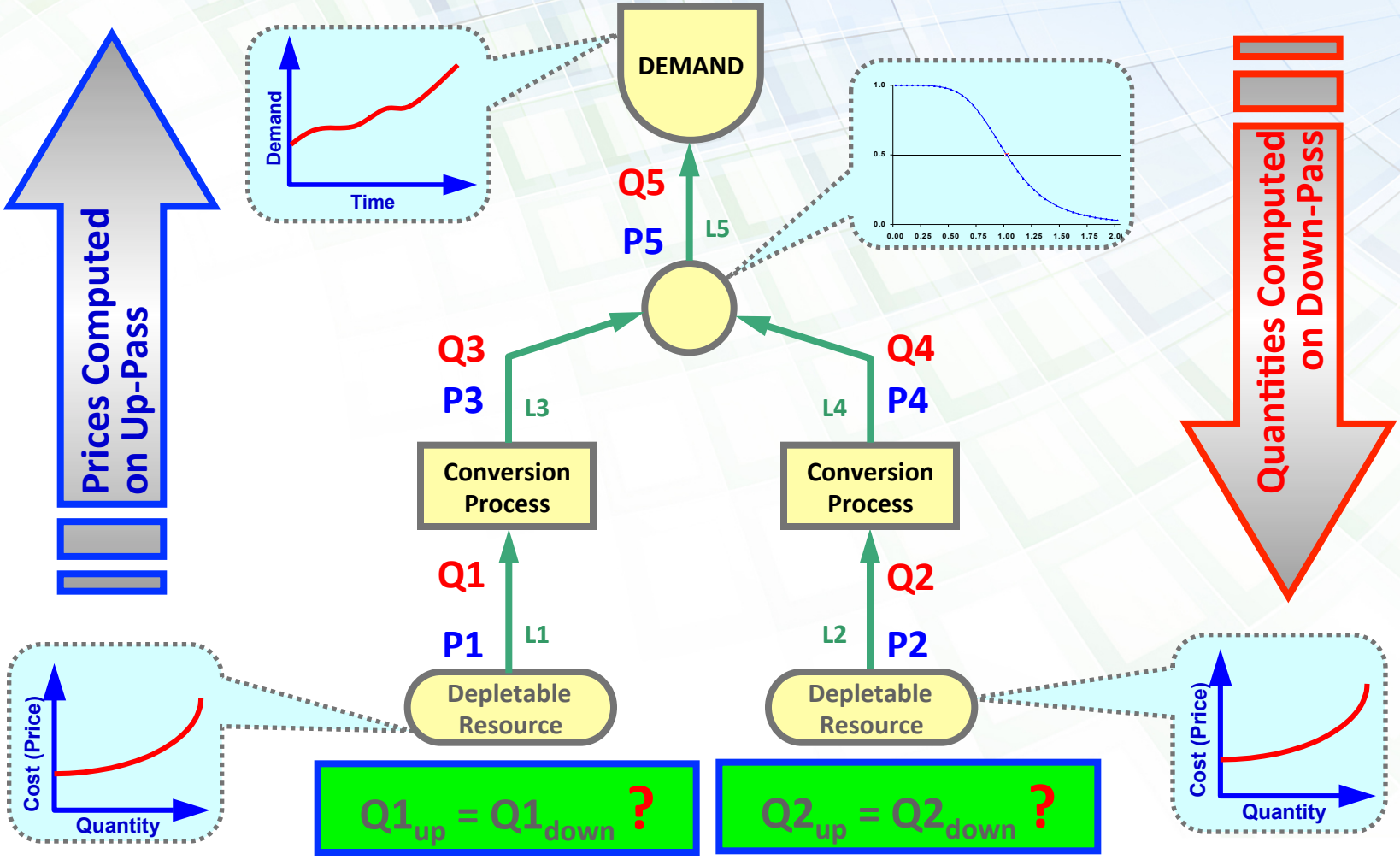


# The Electricity Dispatch Node Handles the Electric Sector in a Special Way



# *ENPEP-BALANCE Uses an Up/Down Pass Sequence and the Jacobi Iterative Technique to Determine the Market Clearing Prices and Quantities (Market Equilibrium)*

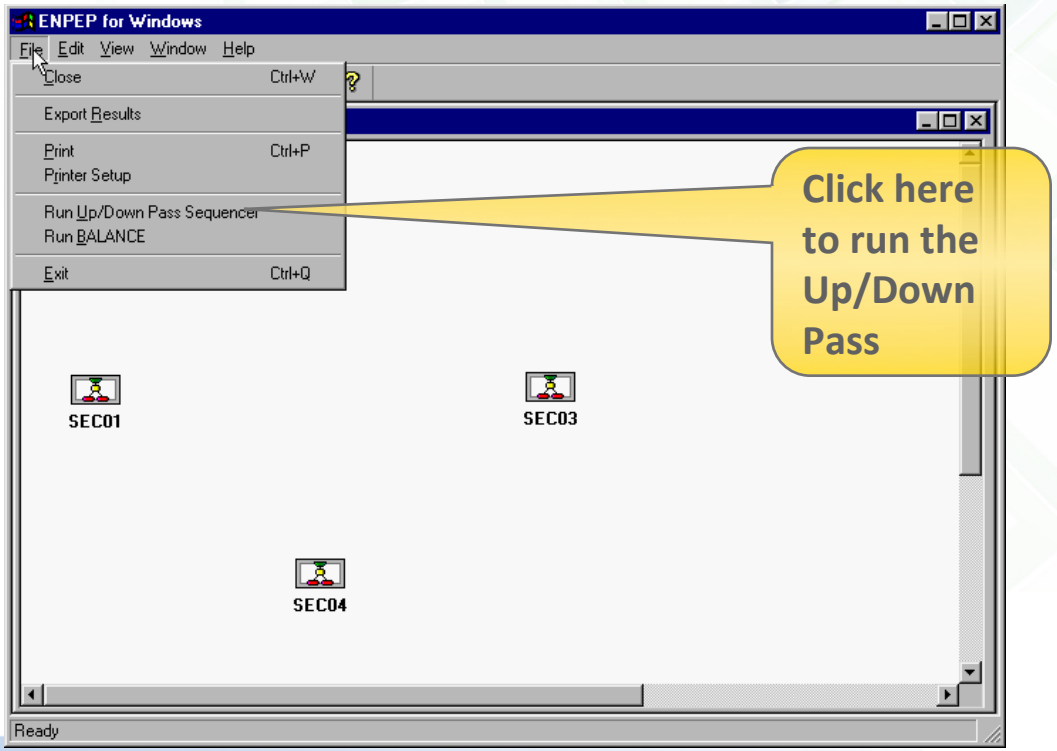


# *The Up-Pass and Down-Pass Determine the Node Visitation Sequence for Calculations (Which Node Comes When)*

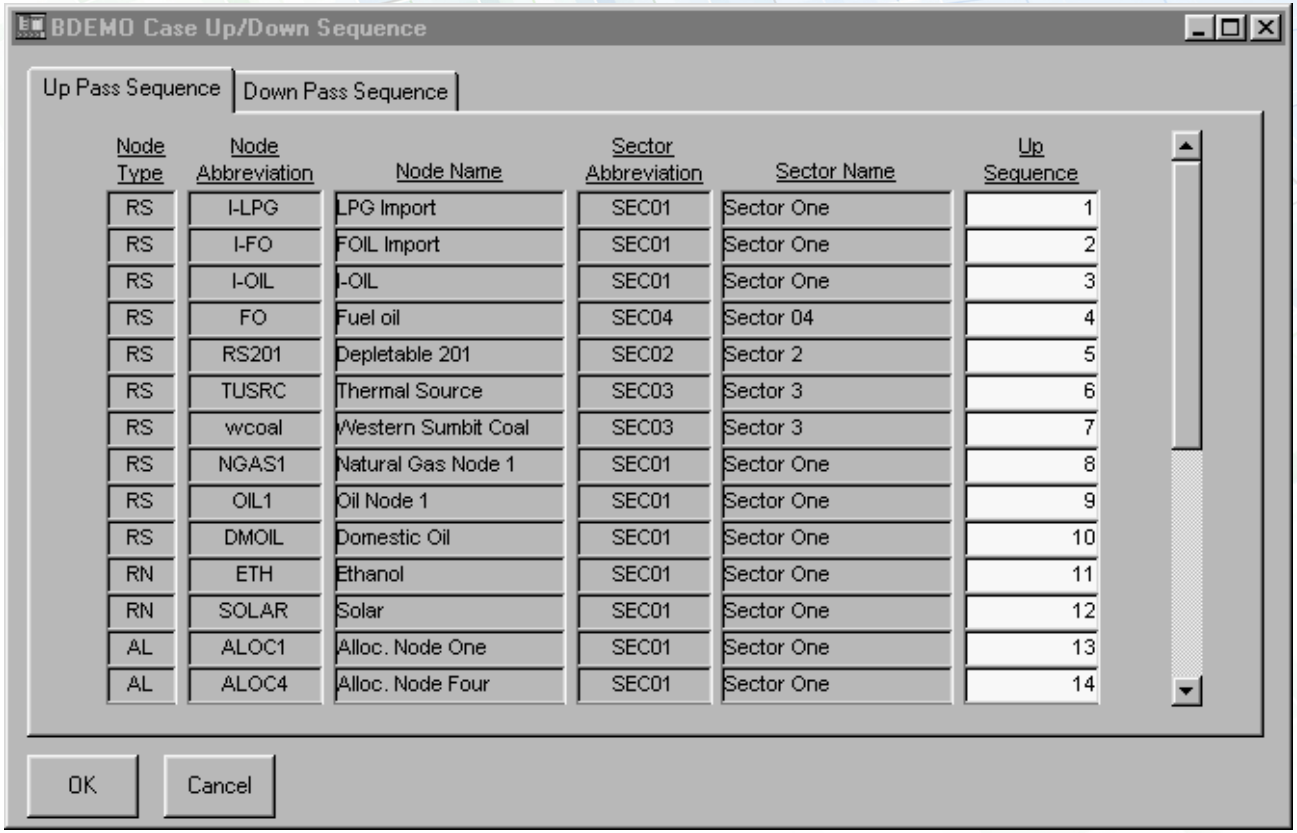
- Up-Pass and Down-Pass Sequences are repeated until convergence is achieved
- **CONVERGENCE IS ACHIEVED WHEN:**
  - Q1 (down) = Q1 (up) +/- Tolerance Level
  - Q2 (down) = Q2 (up) +/- Tolerance Level
  - The final result is a converged solution
  - The solution is in equilibrium across the whole network

# *Execution of the Up and Down-Pass Sequencer in ENPEP-BALANCE*

- Run the Up/Down Pass Sequencer before running ENPEP-BALANCE for the first time
- This will determine the “node visitation sequence”
- Later, the Up/Down Pass must be executed only if there has been a **CHANGE IN THE STRUCTURE** of the energy network
  - Add/delete nodes
  - Add/delete links



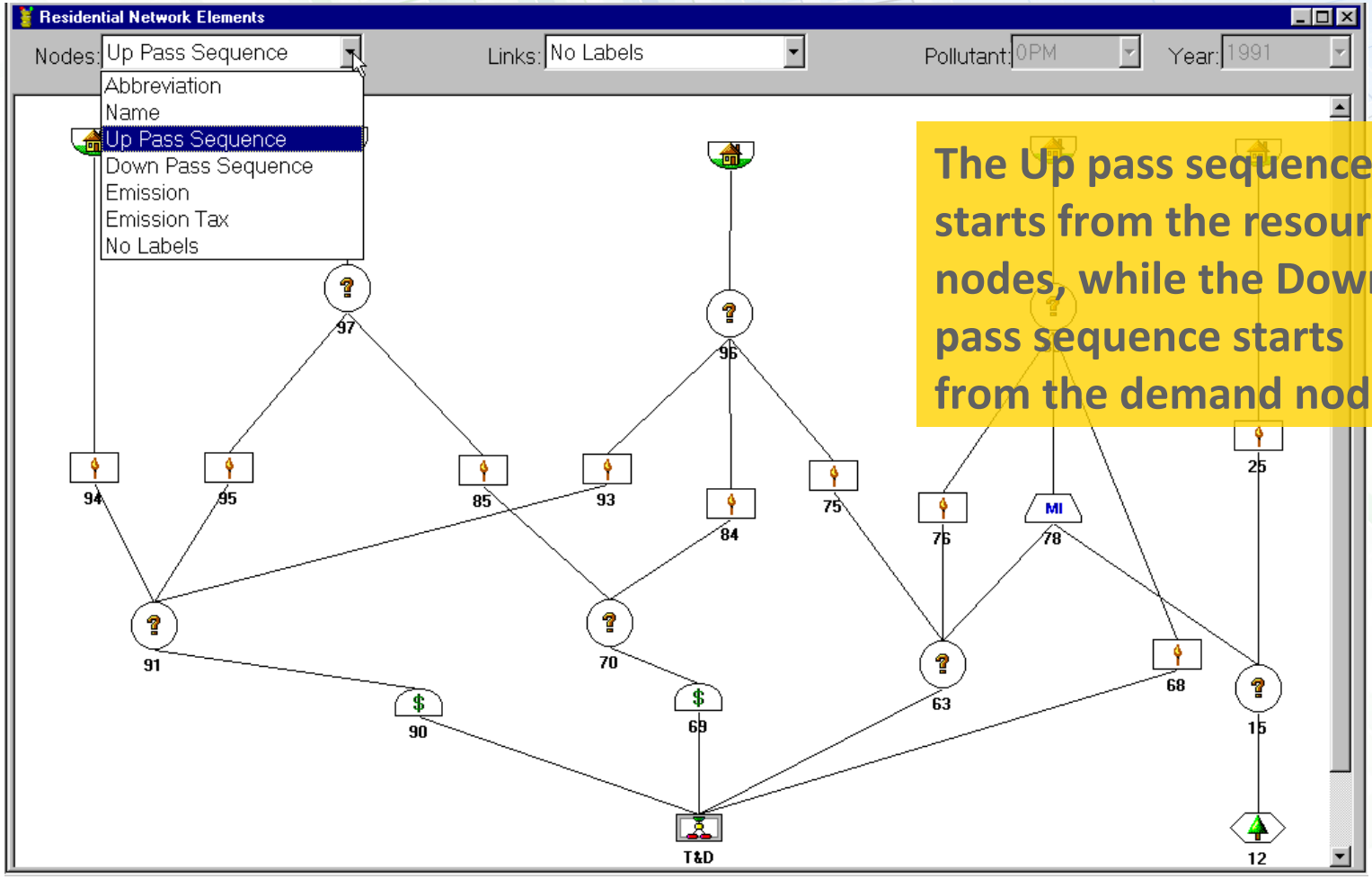
# The Calculated Up/Down Node Visitation Sequence Can Be Viewed in Tabular Form




| Node Type | Node Abbreviation | Node Name | Sector Abbreviation | Sector Name | Up Sequence |
|---|---|---|---|---|---|
| RS | I-LPG | LPG Import | SEC01 | Sector One | 1 |
| RS | I-FO | FOIL Import | SEC01 | Sector One | 2 |
| RS | I-OIL | I-OIL | SEC01 | Sector One | 3 |
| RS | FO | Fuel oil | SEC04 | Sector 04 | 4 |
| RS | RS201 | Depletable 201 | SEC02 | Sector 2 | 5 |
| RS | TUSRC | Thermal Source | SEC03 | Sector 3 | 6 |
| RS | wcoal | Western Sumbit Coal | SEC03 | Sector 3 | 7 |
| RS | NGAS1 | Natural Gas Node 1 | SEC01 | Sector One | 8 |
| RS | OIL1 | Oil Node 1 | SEC01 | Sector One | 9 |
| RS | DMOIL | Domestic Oil | SEC01 | Sector One | 10 |
| RN | ETH | Ethanol | SEC01 | Sector One | 11 |
| RN | SOLAR | Solar | SEC01 | Sector One | 12 |
| AL | ALOC1 | Alloc. Node One | SEC01 | Sector One | 13 |
| AL | ALOC4 | Alloc. Node Four | SEC01 | Sector One | 14 |

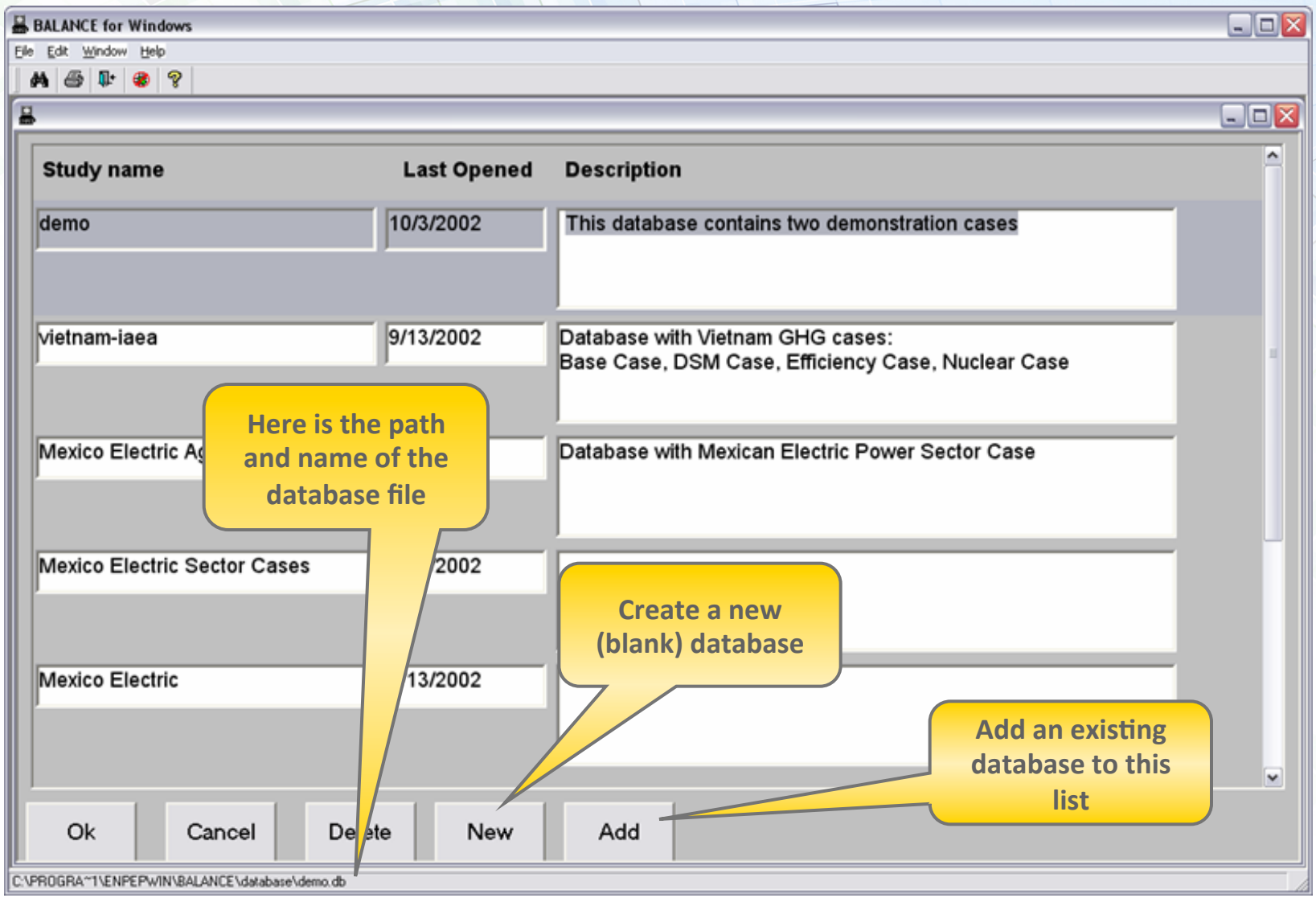
**This screen also allows the user to manually adjust the node visitation sequence, if necessary.**

# The Up/Down Node Visitation Sequence Can Be Viewed Directly in the Network

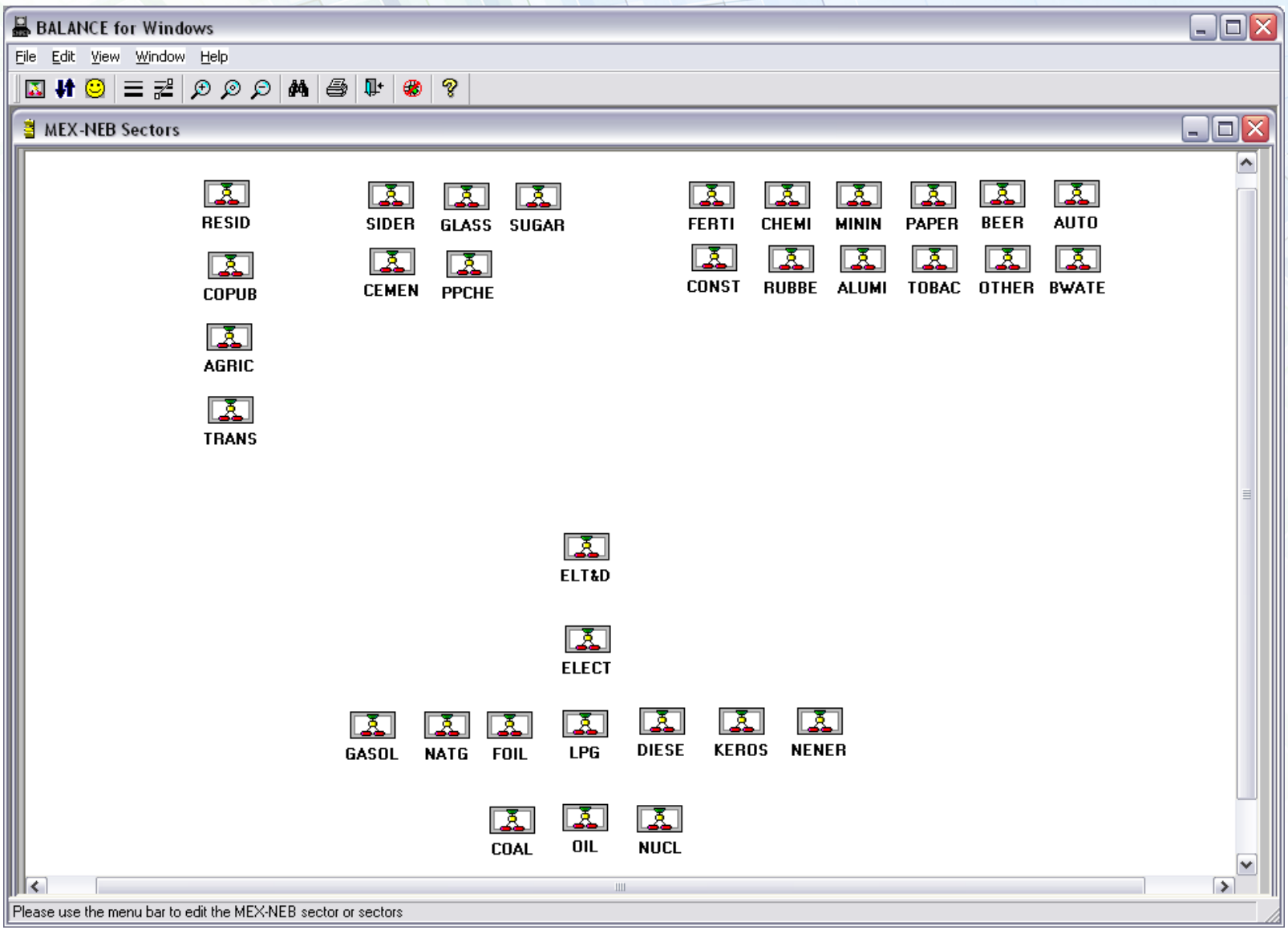



**The Up pass sequence starts from the resource nodes, while the Down pass sequence starts from the demand nodes.**

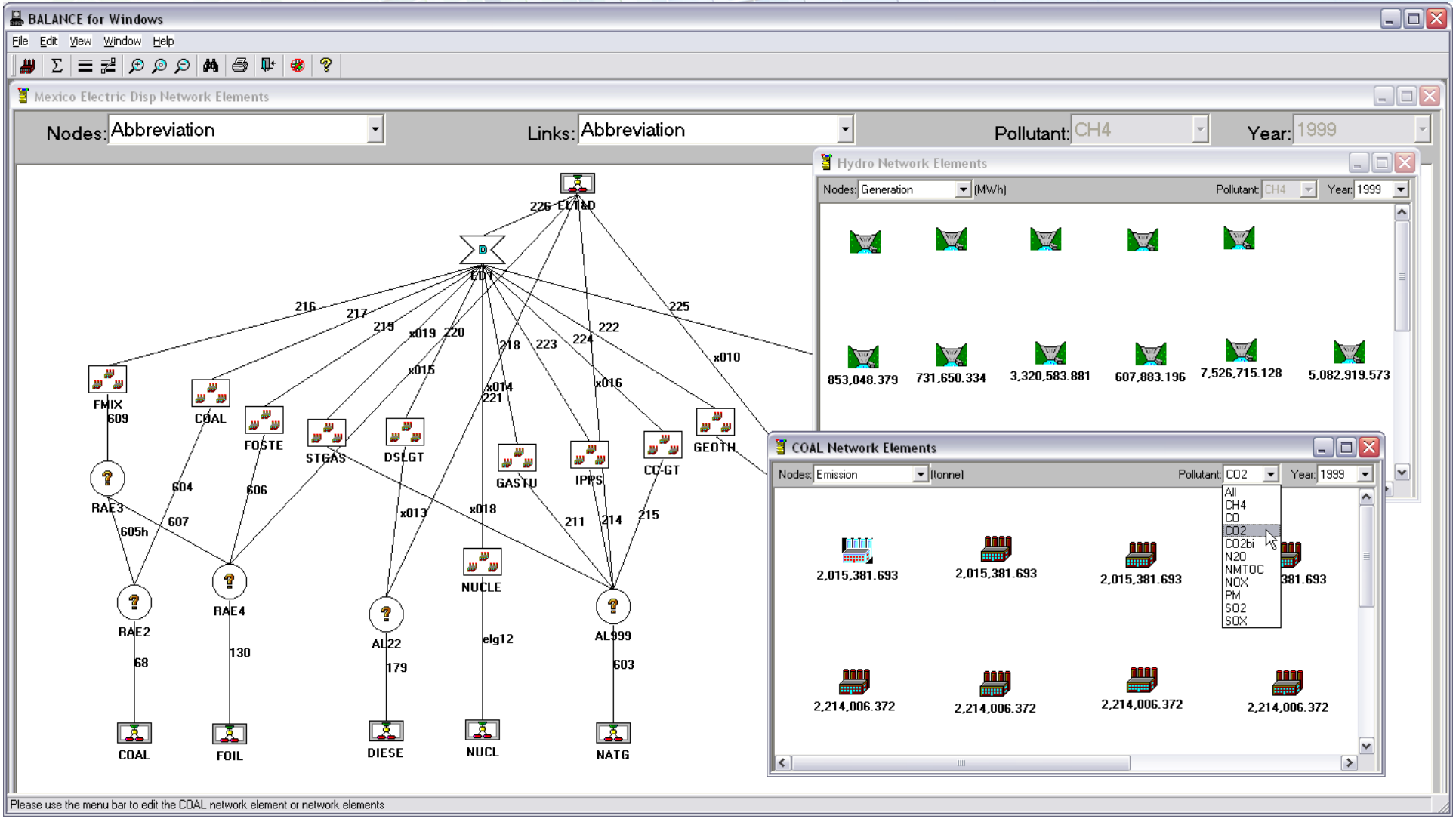
# Each Case Study Can be Stored in a Different Database



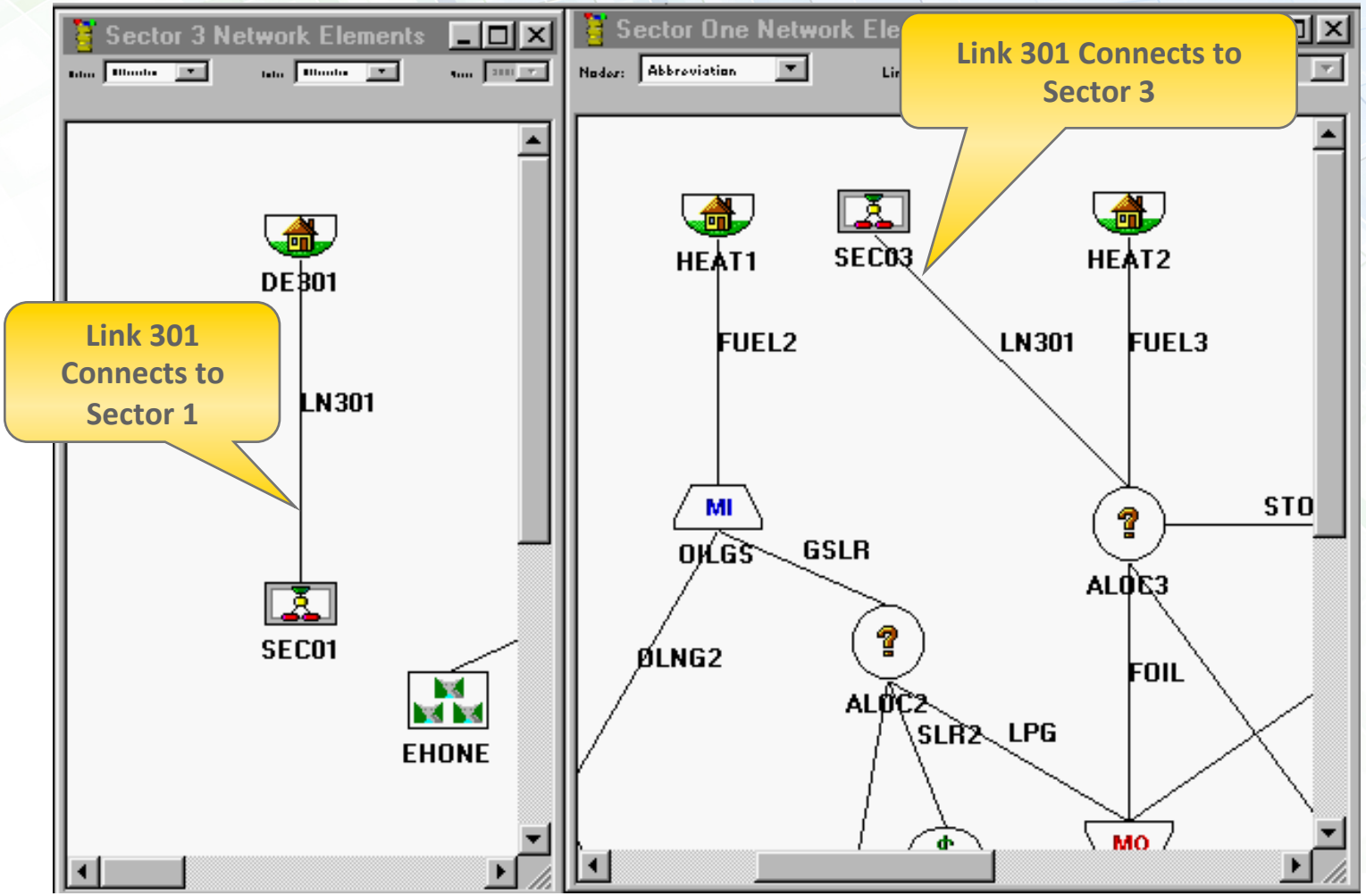
# The First Step in Developing an ENPEP-BALANCE Network is to Define the Sectors Included in Your System



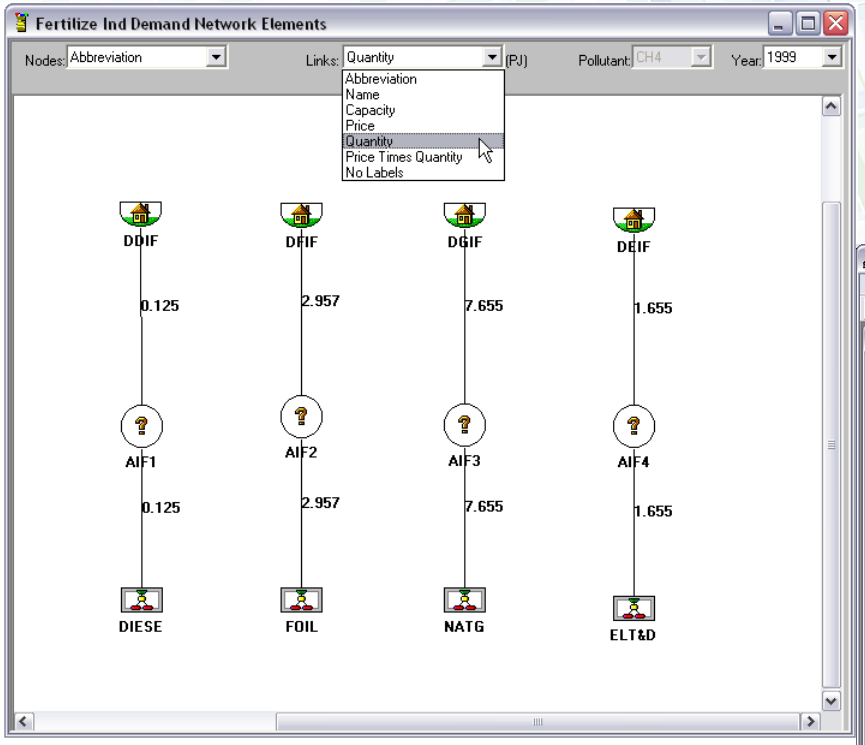
# *Each Sector May be Modeled Differently Depending on Data Availability and Type of Issue Analyzed: Power Sector Can Be Modeled at the Unit Level*

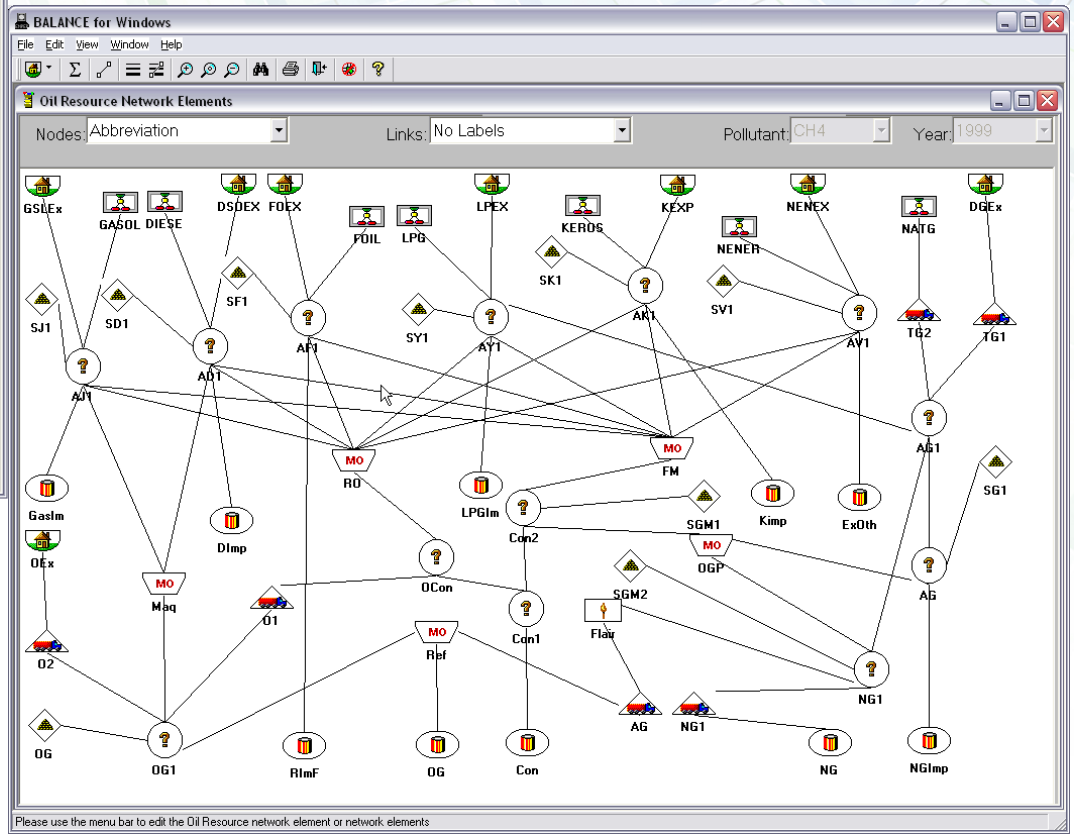


# *Intersectoral Links Can Connect Energy Networks of Different Sectors*

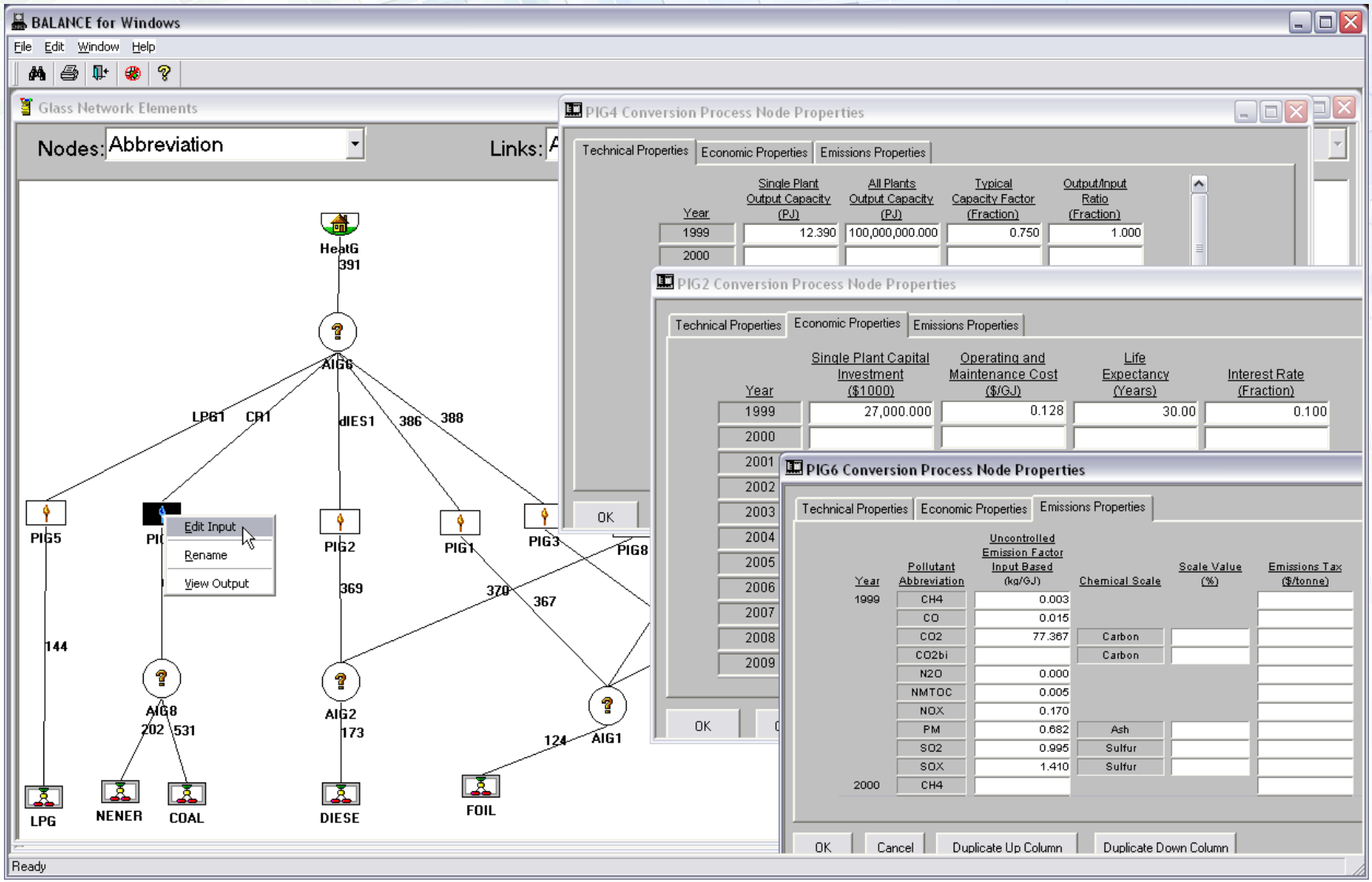


# *The Level of Detail May Vary from Simple to Complex: Example: Simple Fertilizer Industry and More Complex Oil & Gas Sector*

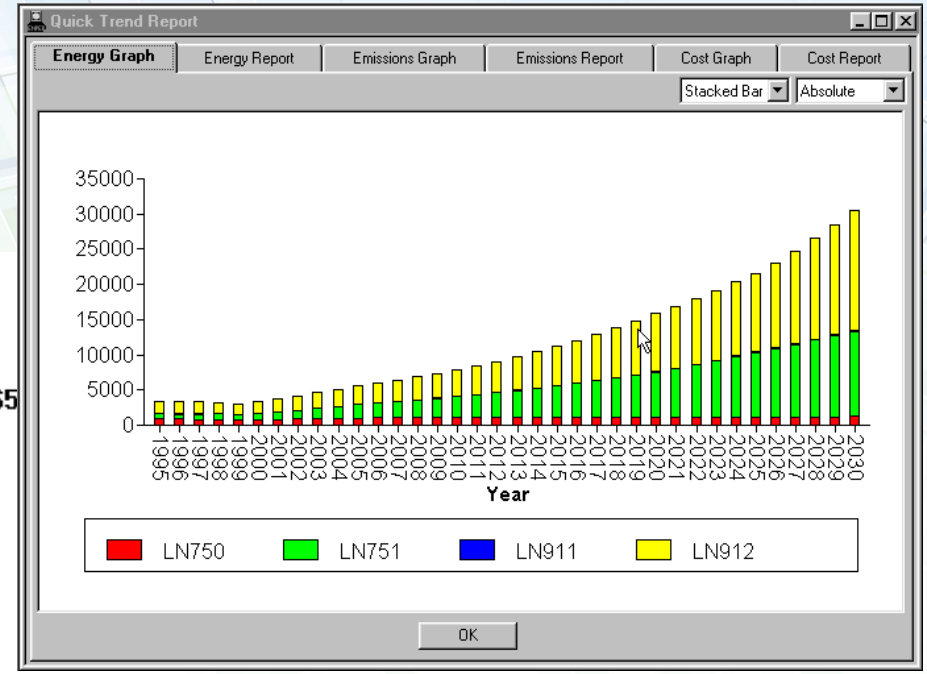


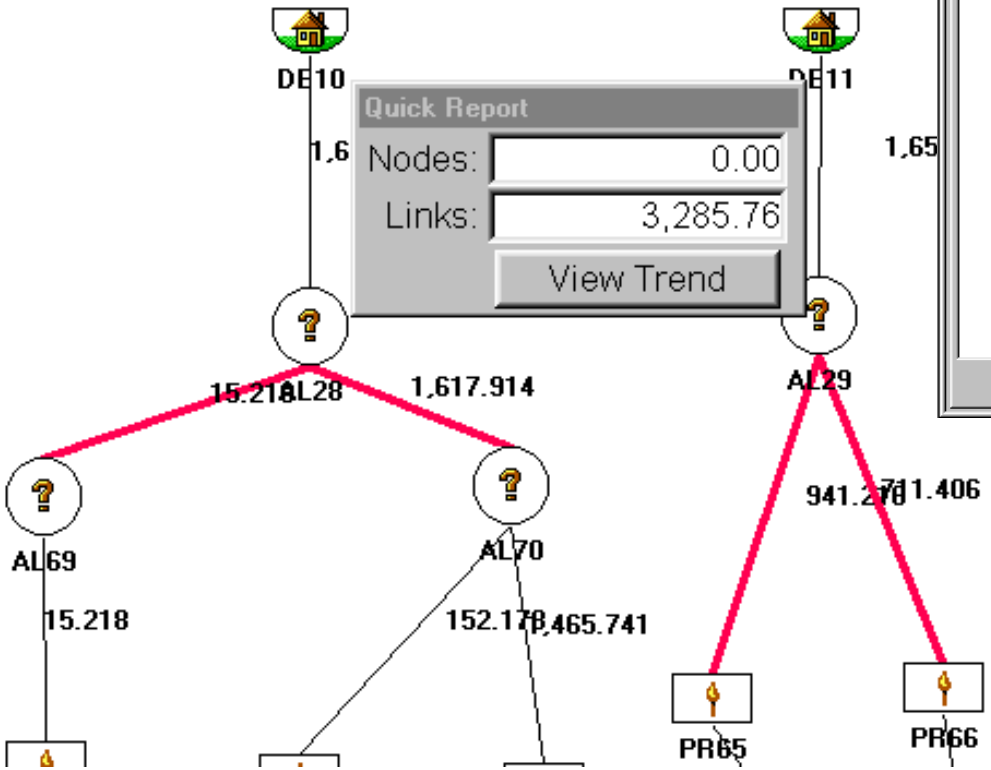



# All Network Elements in ENPEP-BALANCE Can Be Accessed Using a Standardized Simple Menu



# *Results Can be Viewed Interactively for Individual Network Components and the Entire System*

# *ENPEP-BALANCE Uses a Standard Methodology to Determine the Uncontrolled and Controlled Source Emissions*

**Uncontrolled Emissions = Fuel Consumption x Emission Factor x Chemical Scale**

**Controlled Emissions = Uncontrolled Emissions x (100 - Control Efficiency) / 100**

# *Emissions Are Calculated and Reported by Node for any Pollutant the User Specifies*

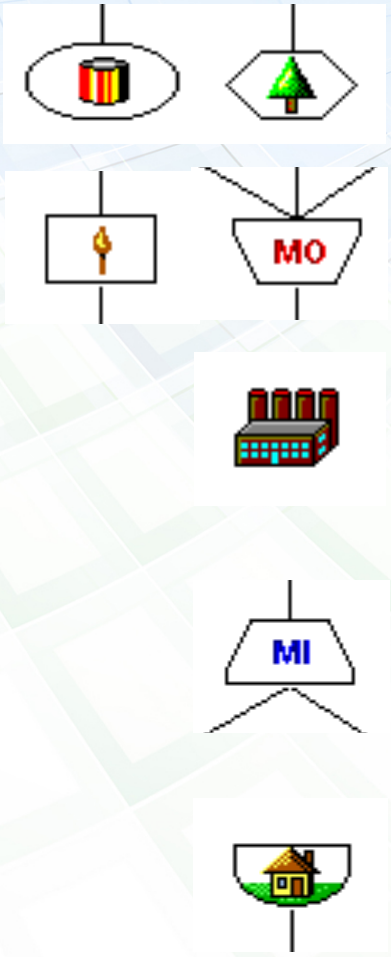
Run Parameters | Pollutants | Pollution Controls | Output Codes | Non-electric Units | Electric Units

| Name | Abbreviation | Chemical Scale |
|---|---|---|
| Methane | CH4 | |
| Carbon Dioxide | CO2 | Carbon |
| Nitrous Oxides | N2O | |
| Non Methane Total Organic Compounds | NMTOC | |
| Nitrogen Oxides | NOX | |
| Particulate Matter Total | PM | Ash |
| Sulfur Dioxide | SO2 | Sulfur |
| Carbon Monoxide | CO | |

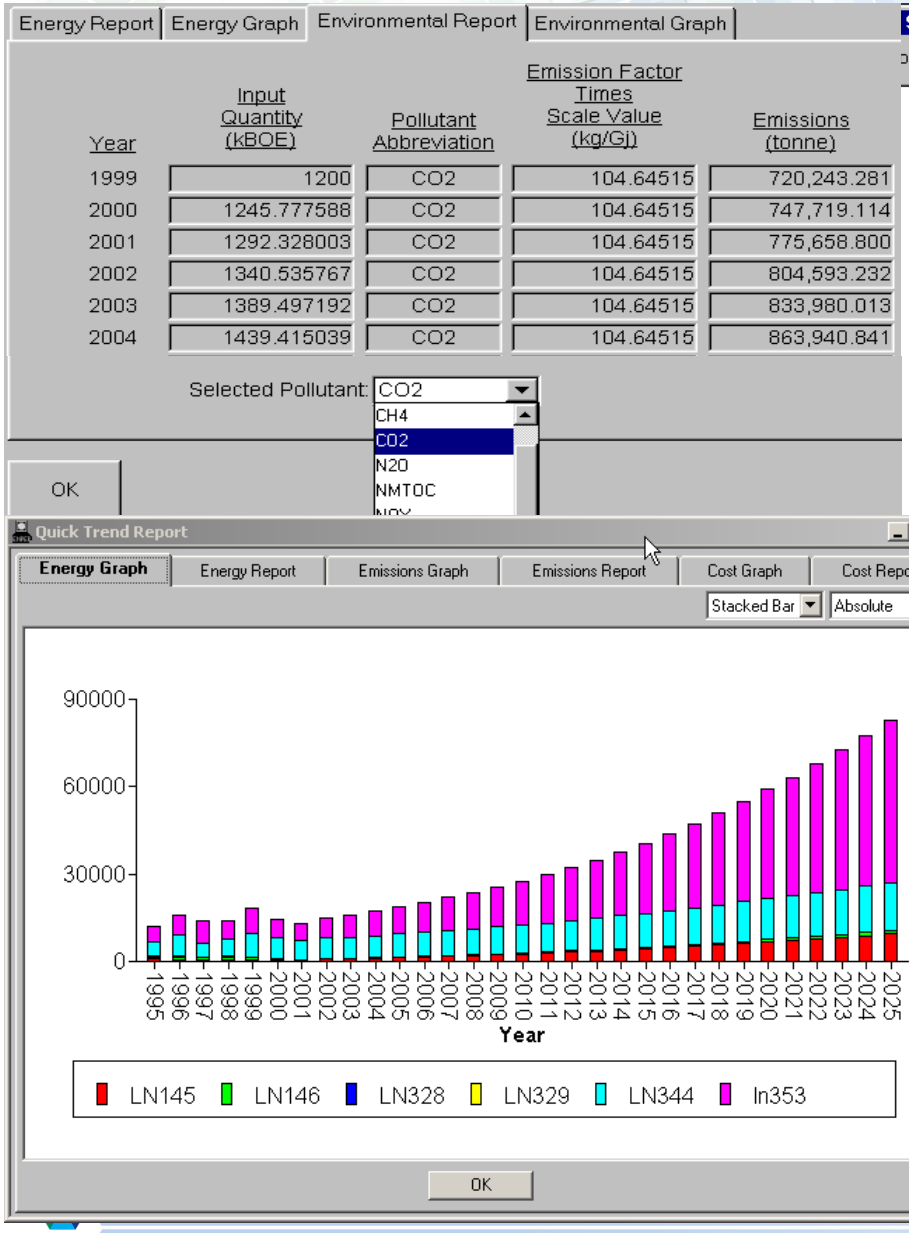
OK | Cancel | Add | Delete

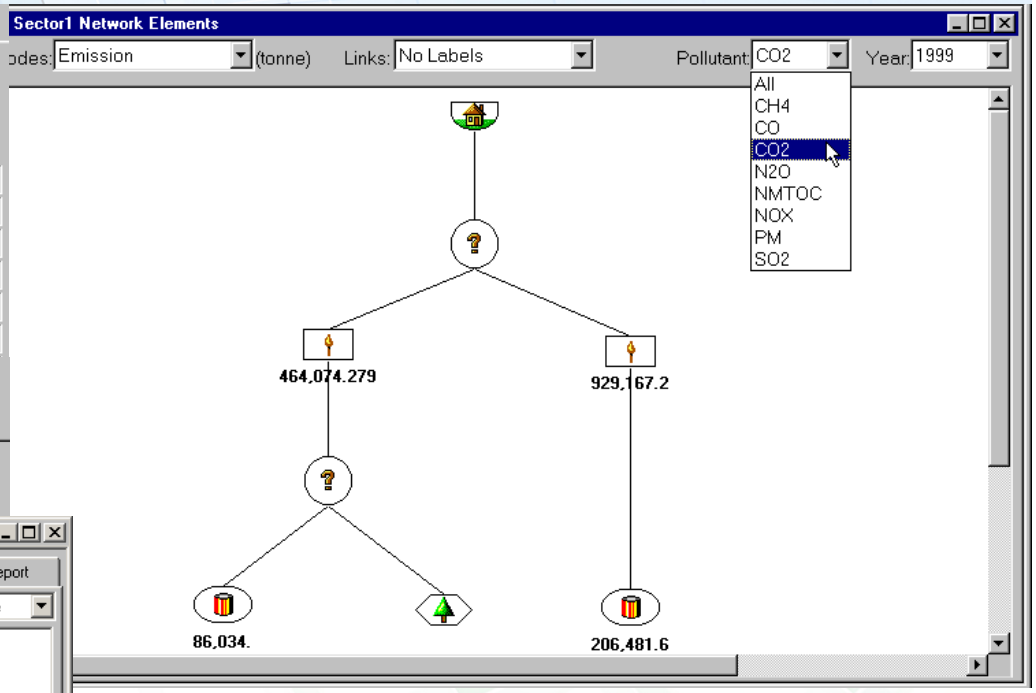
Technical Properties | Economic Properties | Emissions Properties | Control Properties

| Year | Pollutant Abbreviation | Uncontrolled Emission Factor Input Based (kg/Gj) | Chemical Scale | Scale Value (%) | Emissions Tax ($/tonne) |
|---|---|---|---|---|---|
| 1999 | CH4 | 0.001 | | | |
| | CO2 | 1.349 | Carbon | 77.60 | 20.00 |
| | N2O | 0.002 | | | |
| | NMTOC | 0.001 | | | |
| | NOX | 0.399 | | | |
| | PM | 0.184 | Ash | 17.50 | |
| | SO2 | 0.698 | Sulfur | 4.50 | 100.00 |



# *Environmental Results Can be Viewed Directly in the Network, in Tables, Simple Graphs, or Exported to EXCEL*



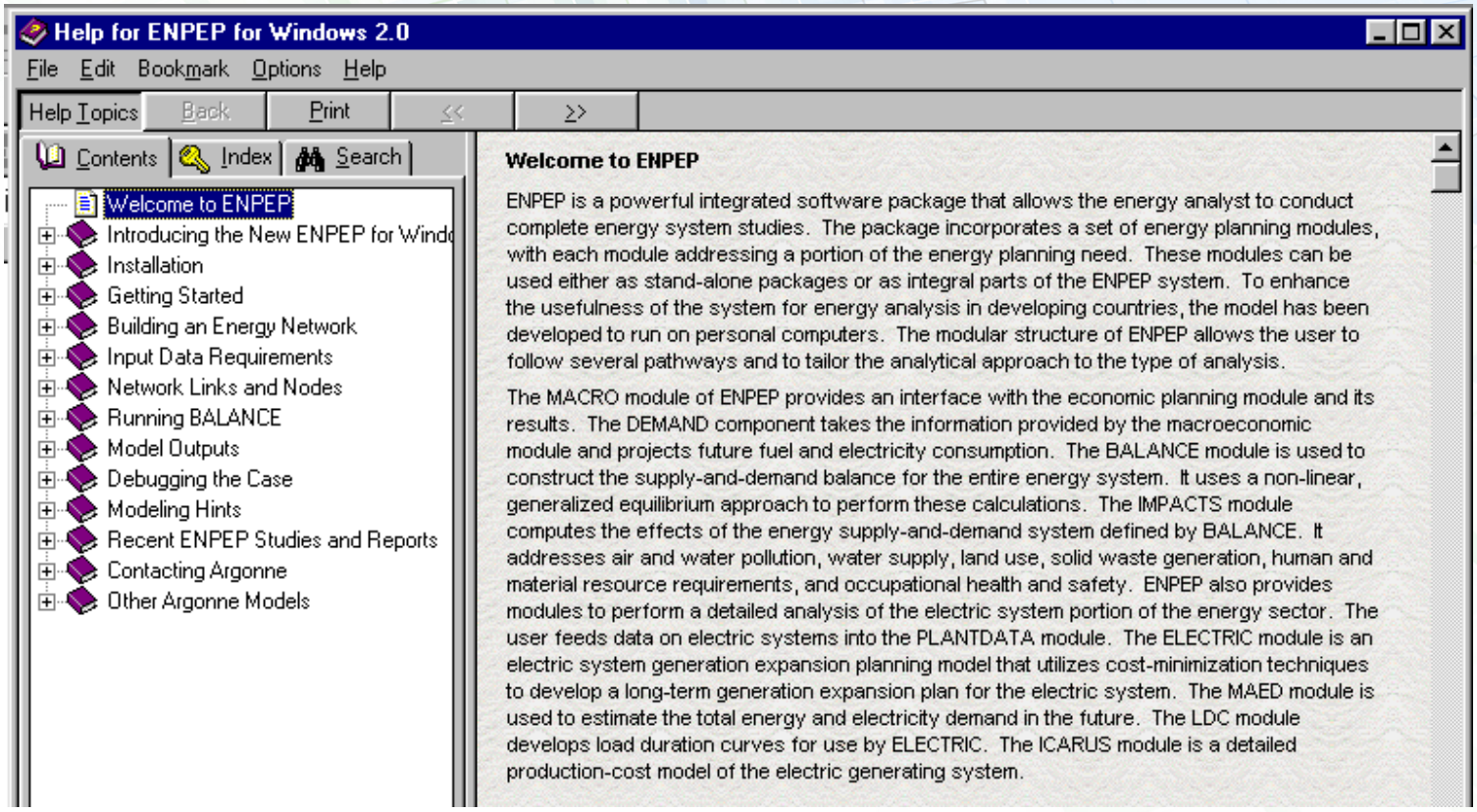







| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | DemoC Export to TXT Nodes emissions | | | | 13-Feb-01 | 11:40 | | |
| 2 | | | | | | | | |
| 3 | Base | Nb of | Nb of | Nb of | | | | |
| 4 | Year | Years | Nodes | Pollutants | Unit | | | |
| 5 | | | | | | | | |
| 6 | 1991 | 30 | 79 | 10 | tonne | | | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | Sector | Node | Type | Pollutant | 1991 | 1992 | 1993 | 1994 |
| 10 | AG | DE23 | DE | 0PM | 1658.296 | 1741.211 | 1822.874 | 1906.544 |
| 11 | AG | DE23 | DE | 1PM10 | 0 | 0 | 0 | 0 |
| 12 | AG | DE23 | DE | 2SO2 | 14.31514 | 15.0309 | 15.73585 | 16.45812 |
| 13 | AG | DE23 | DE | 3NOX | 282.5357 | 296.6624 | 310.5759 | 324.8314 |

# A Help System is Available to Provide Online Support




**Note: The help system is still under construction. Content will change and not all topics may be available at this time.**

# *Energy System Modeling in ENPEP-BALANCE: As with All Models, BALANCE has its Limitations*

- The market share formula needs to be applied carefully to produce realistic results (particularly from transition from 1st to 2nd year)
- The solution is generated year-by-year and is said to be "myopic"
  - However, in today's short-term oriented energy market, this may actually be an advantage
- It is demand-driven
- If not set up in sufficient detail, it can be insensitive to price
- The ease of use in the WINDOWS interface conceals the sub-models!
- Nevertheless, the ENPEP-BALANCE approach is proved to be powerful and useful if applied correctly;
- ENPEP-BALANCE is a tool - and a tool should be used wisely

# *ENPEP-BALANCE is Used by Energy and Environmental Experts Worldwide to Analyze a Variety of Critical Issues*

- Electric system analysis
  - Expansion analysis, demand side management
  - Optimal hydro/thermal dispatch ($, environment)
  - Deregulation, independent power producers, power market studies, interconnection studies, etc.
- Total energy system
  - Overall energy sector development strategies
  - Natural gas market analysis
  - Energy conservation+efficiency
- Environmental analysis
  - Emissions projections for PM, SO2, NOX, etc.
  - Emissions reduction strategies for PM, SO2 and NOX
  - Emissions trading for SO2 and CO2 (cap and trade)
  - GHG mitigation studies and Kyoto Mechanisms
  - Waste generation, land use, water pollution

# Current/Recent ENPEP Applications in South America

**VENEZUELA**
**(WASP, BALANCE, IMPACTS)**
National energy analysis
GHG mitigation analysis

**COLOMBIA**
**(MAED, WASP, BALANCE, IMPACTS, VALORAGUA)**
National energy analysis
Natural gas expansion
Electric system development
Air pollution (PM, SOX, NOX, GHG, etc.)
PM + SOX control cost analysis

**BRAZIL**
**(WASP, BALANCE, VALORAGUA, IMPACTS)**
State energy analysis
State electric system development
Air pollution analysis
Land use analysis
Decision analysis

**PERU**
**(WASP, BALANCE, IMPACTS)**
Load forecasting
Electric system expansion
National energy analysis
Air pollution analysis
GHG mitigation

**URUGUAY**
**(BALANCE, IMPACTS)**
National energy analysis
Market penetration of natural gas
GHG mitigation analysis
FCCC Nat Com (submitted)

# Current/Recent ENPEP Applications in Eastern Europe

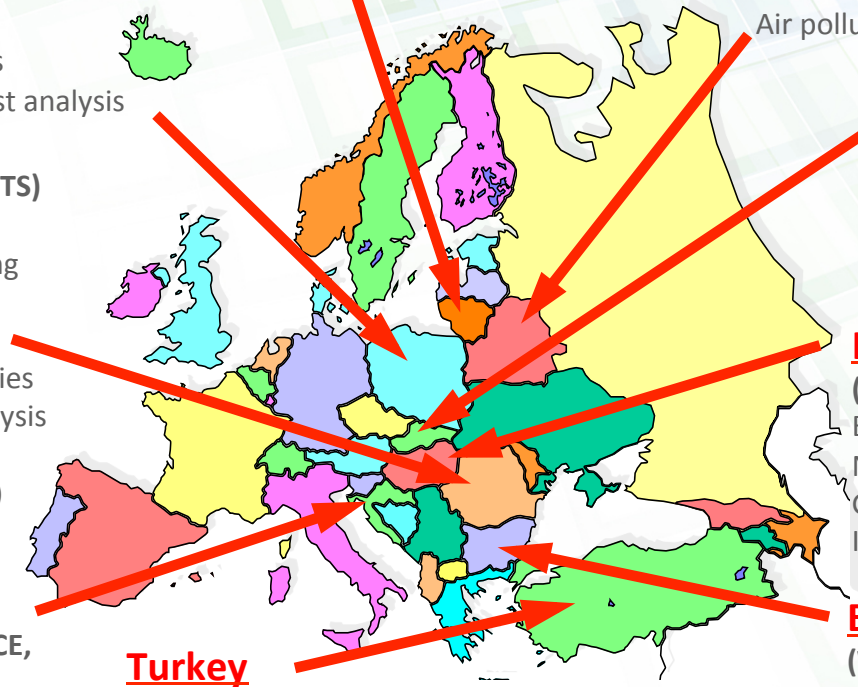
**Poland**
**(MAED, WASP, BALANCE, IMPACTS)**
Deregulated power market analysis
National energy analysis
Air pollution analysis
GHG mitigation analysis
PM and SOX control cost analysis

**Lithuania**
**(WASP, MAED)**
Electric system analysis

**Belarus**
**(WASP, BALANCE, IMPACTS)**
Electric system expansion
National energy analysis
Air pollution analysis

**Slovakia**
**(BALANCE, IMPACTS)**
National energy analysis
GHG mitigation analysis
FCCC Nat Com (submitted)
Joint implementation

**Romania**
**(WASP, BALANCE, IMPACTS)**
National energy analysis
Energy sector restructuring
Natural gas imports
Rehabilitation, IPPs
Removal of energy subsidies
Air & water pollution analysis
GHG mitigation analysis
FCCC NatCom (submitted)
Waste generation



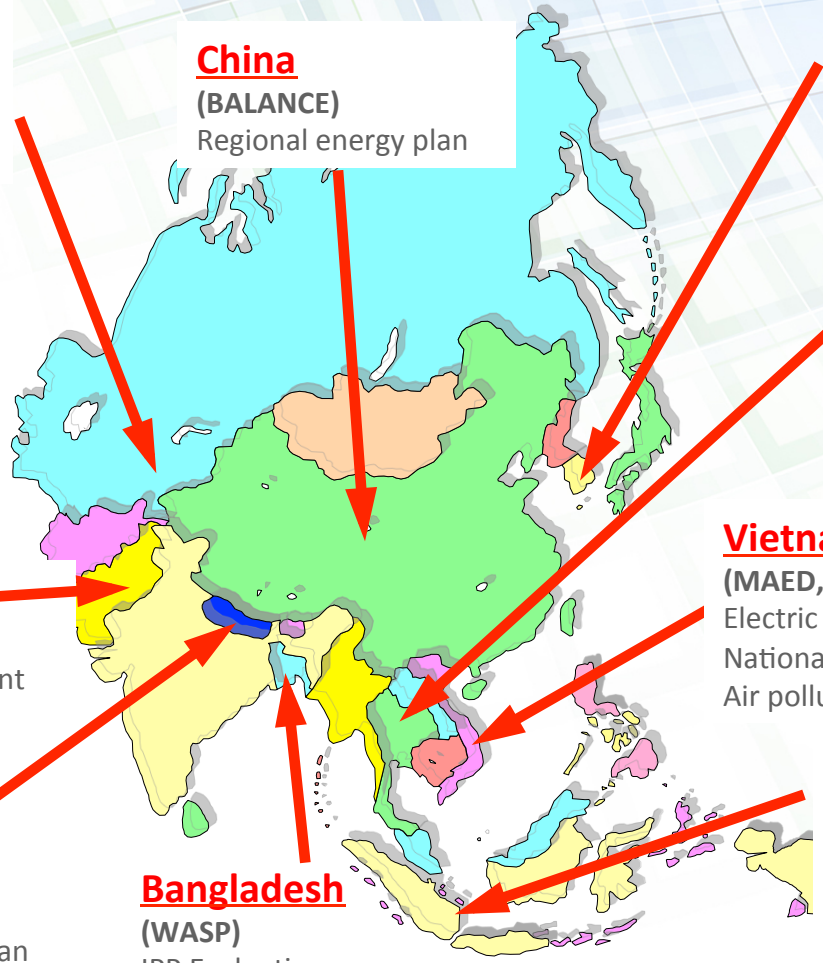
**Hungary**
**(WASP, BALANCE, IMPACTS)**
Electric sector expansion
National energy analysis
GHG mitigation analysis
IPP Bid Evaluation

**Croatia+Balkans**
**(MAED, WASP, BALANCE, IMPACTS)**
National energy plan
Electric system expansion
Air pollution analysis
IPP+Interconnection study

**Turkey**
**(WASP, ICARUS, BALANCE, IMPACTS, etc.)**
National energy plan
Electric sector dispatch and expansion
Privatization, Environmental assessments

**Bulgaria**
**(WASP, BALANCE, IMPACTS)**
National energy plan
Electric system development
GHG mitigation analysis
FCCC Nat Com submitted

# Current/Recent ENPEP Applications in Asia



**Kazakstan**
**(BALANCE, IMPACTS)**
National energy plan
GHG mitigation analysis

**China**
**(BALANCE)**
Regional energy plan

**South Korea**
**(WASP)**
Electric system development
GHG mitigation analysis
FCCC Nat Com (submitted)

**Thailand**
**(BALANCE, IMPACTS)**
National energy plan
GHG mitigation analysis

**Vietnam**
**(MAED, WASP, IMPACTS, BALANCE)**
Electric system development
National energy plan
Air pollution analysis

**Pakistan**
**(WASP)**
Electric system development

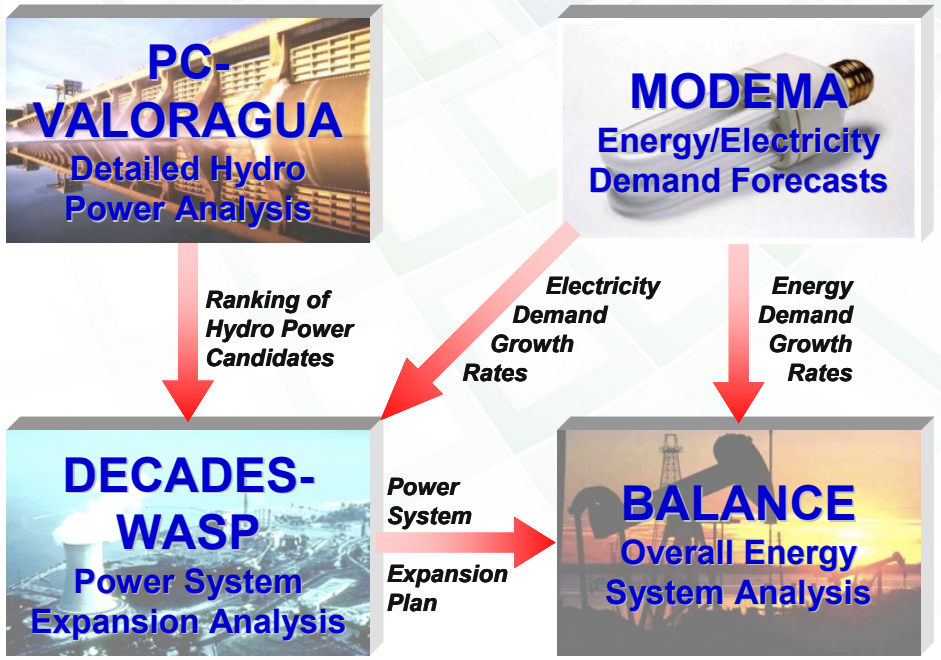
**Indonesia**
**(WASP, BALANCE, IMPACTS)**
Electric system analysis
National energy plan
Air pollution analysis

**Nepal**
**(WASP)**
National energy plan
GHG mitigation analysis

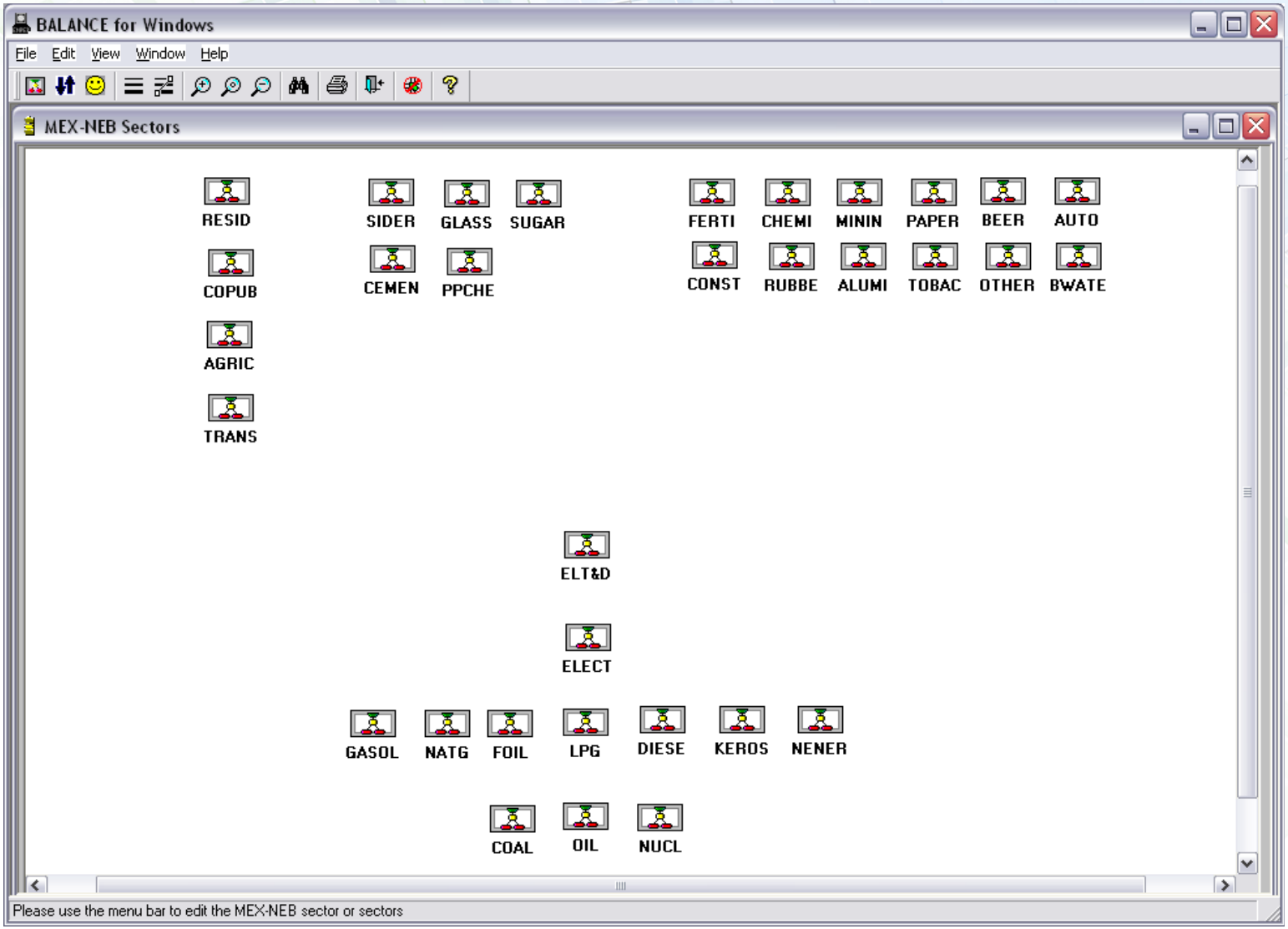
**Bangladesh**
**(WASP)**
IPP Evaluation

# *ENPEP-BALANCE Application in Mexico: Long-term Energy Policy Study*

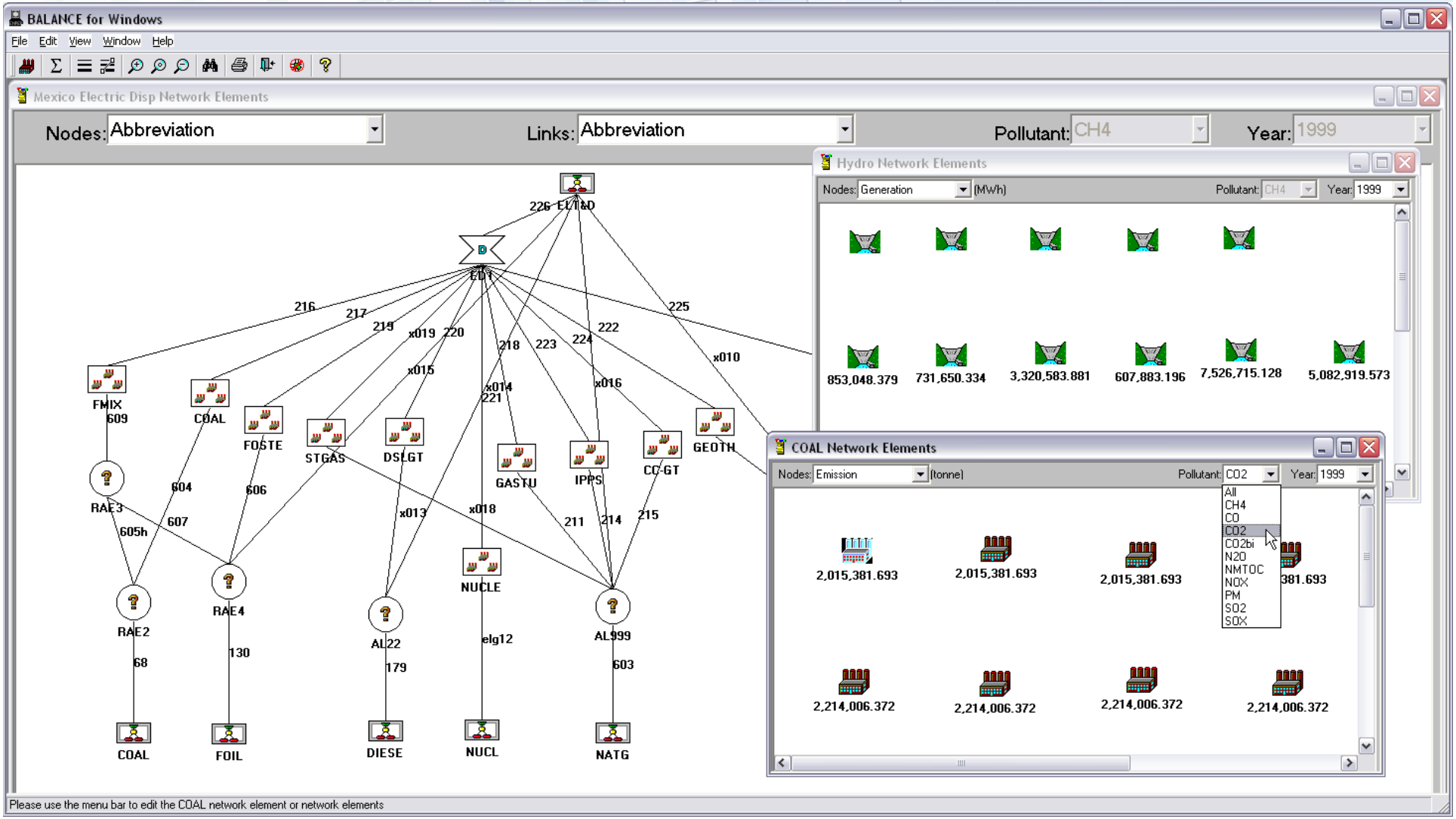
- Study conducted by Mexican team with support from Argonne
- Participating Mexican institutions included SENER, CFE, UNAM, PEMEX, CONAE, IMP, IEE, INE
- Team used mix of models linked together
- Objective was to develop long-term projections of electricity and energy demand and supply, GHG emissions, and emissions of criteria pollutants for 14 power sector scenarios and 4 overall energy scenarios, including renewables (wind and solar)



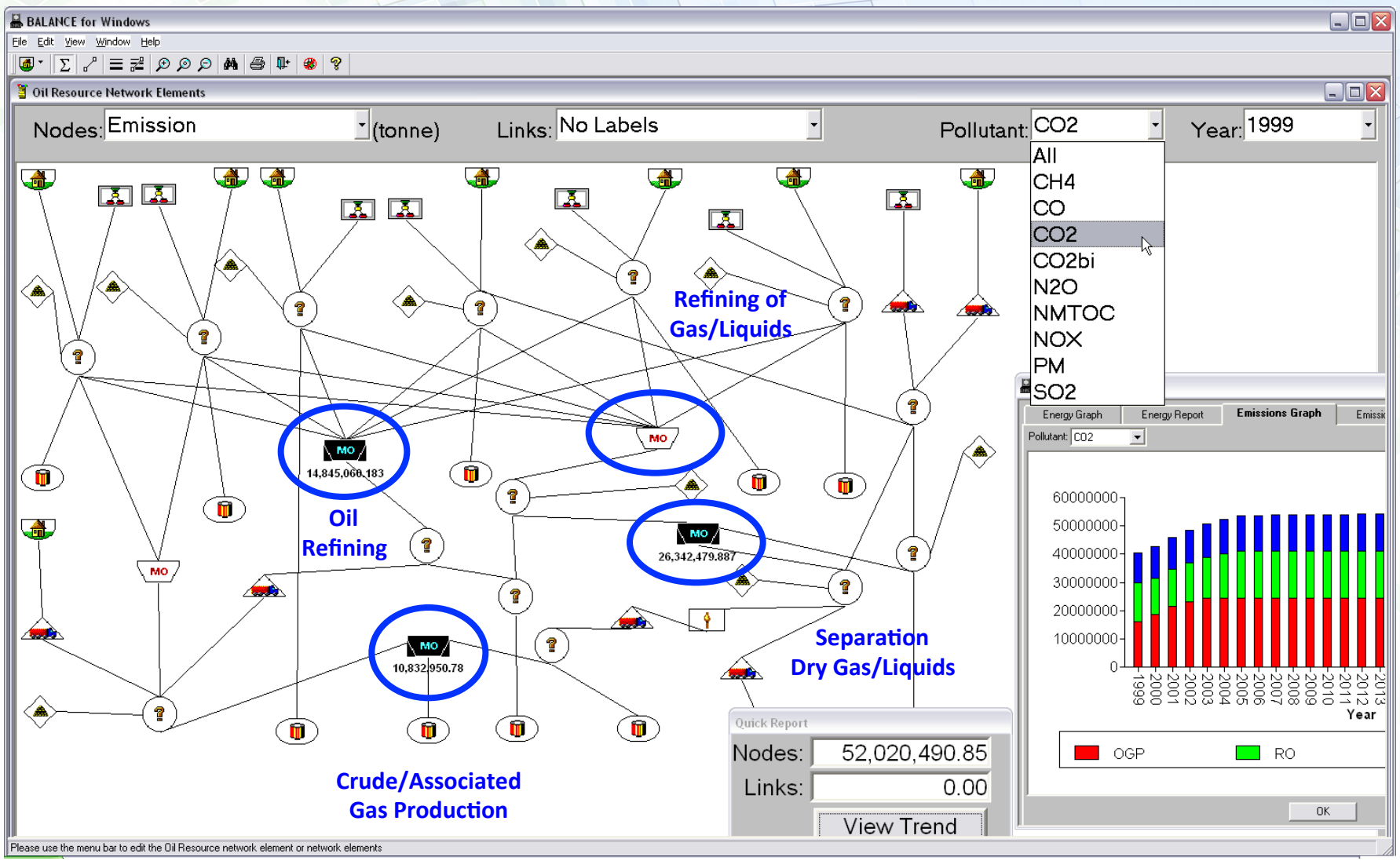
# The Mexican Network Includes 3 Supply Sectors, 9 Conversion and T&D Sectors, and 21 Demand Sectors



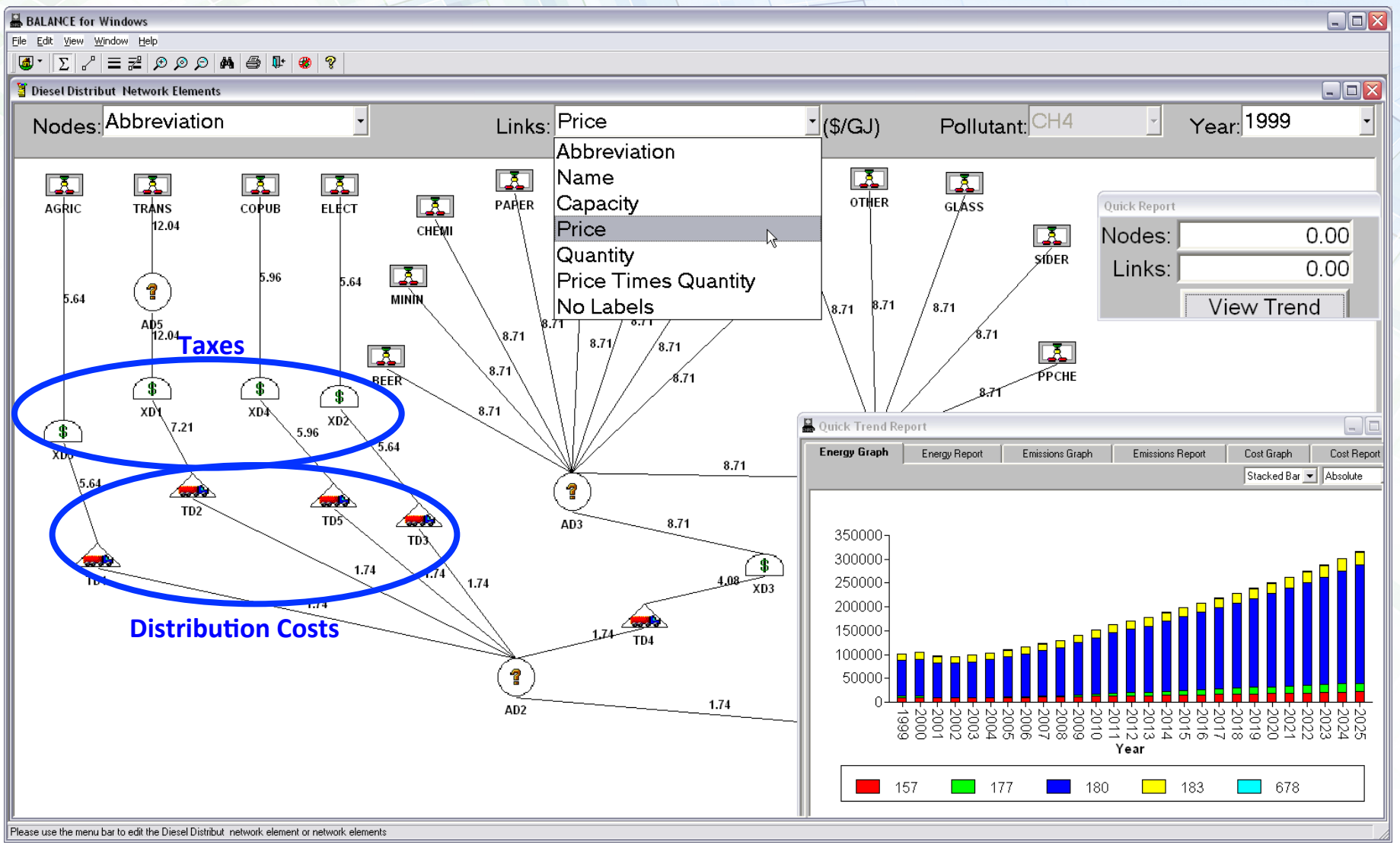
# *Often there is More Information Available for Supply Sectors: Power System (Interconnected) Represented at Unit Level*



# Often there is More Information Available for Supply Sectors: Oil and Gas Production Includes all Major Processes

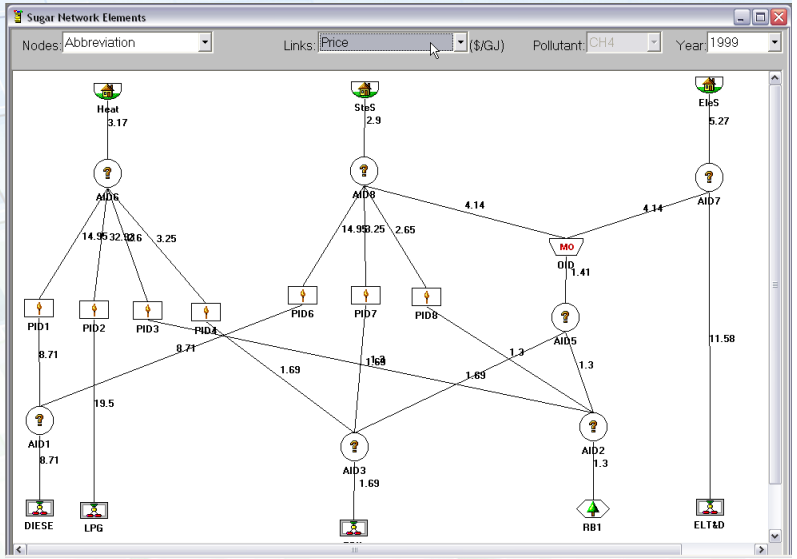


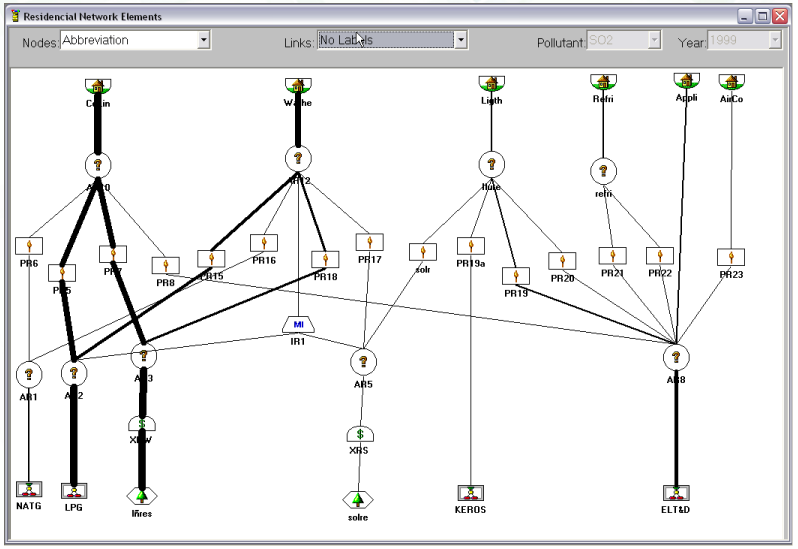
# *Often there is More Information Available for Supply Sectors: T&D Sectors Incorporate Distribution Costs and Taxes*

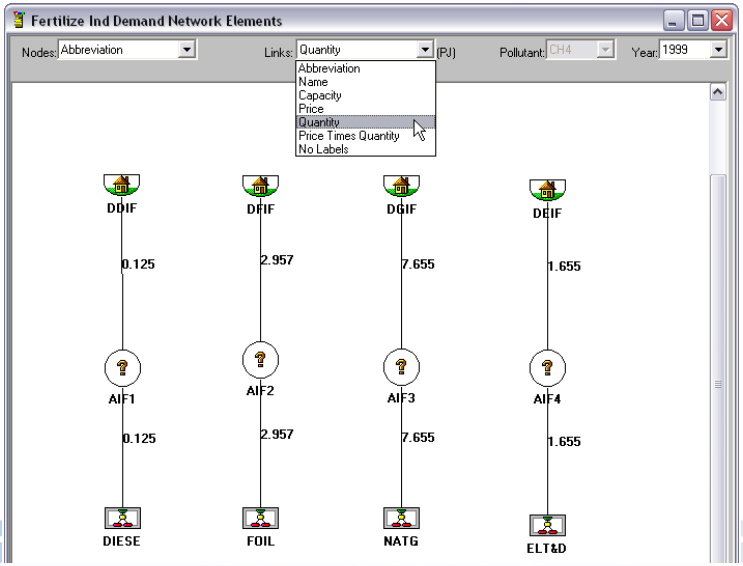


# *The Level of Detail on the Demand Side Varies Widely Across Countries and Within Countries Across Sectors (Mexico)*

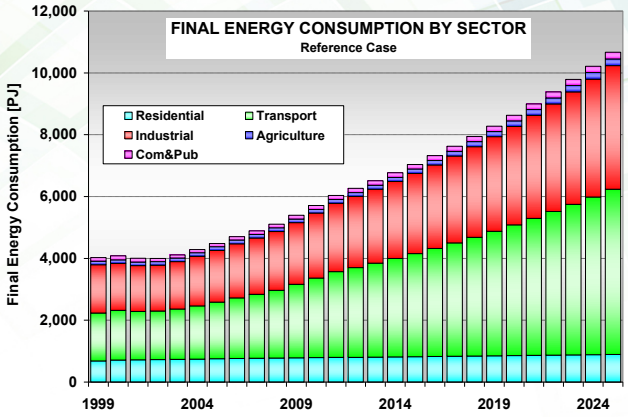
- Detailed Useful Energy Representation
  - Residential
  - Sugar, Cement, Glass, Metallurgical, Petrochemical
- Final Energy Representation
  - Commercial/Public, Agriculture
  - Fertilizer, Construction, Chemical, Rubber, Mining, Aluminum, Paper, Tobacco, Beer, Auto, Bottled Water, Others
- Mix
  -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

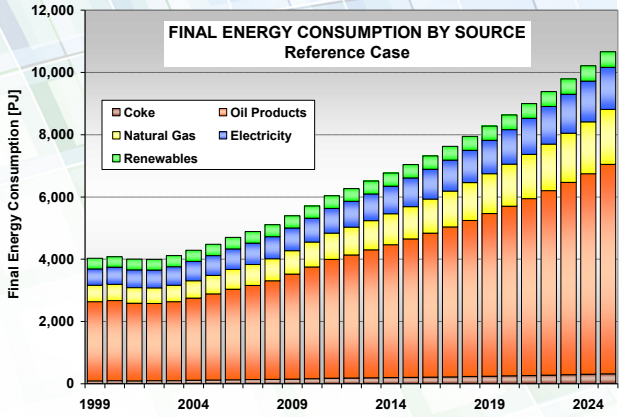


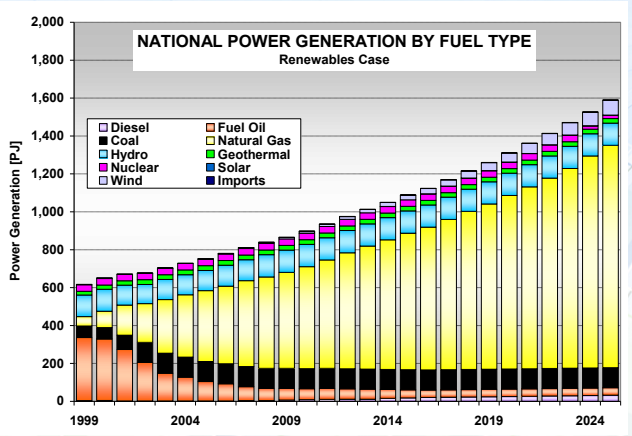



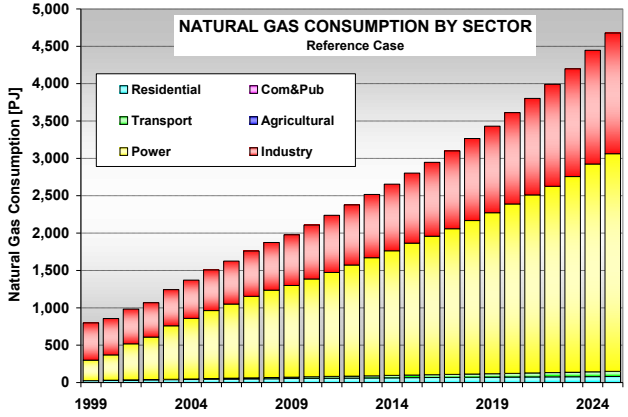



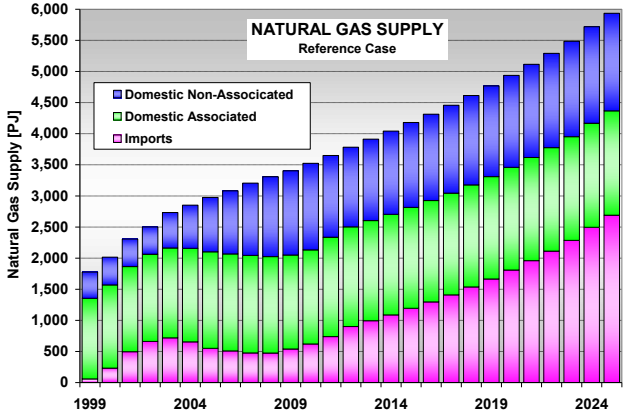
# Mexico Sample Results

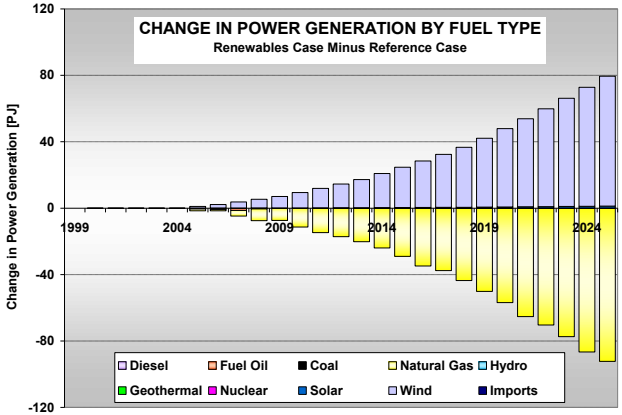


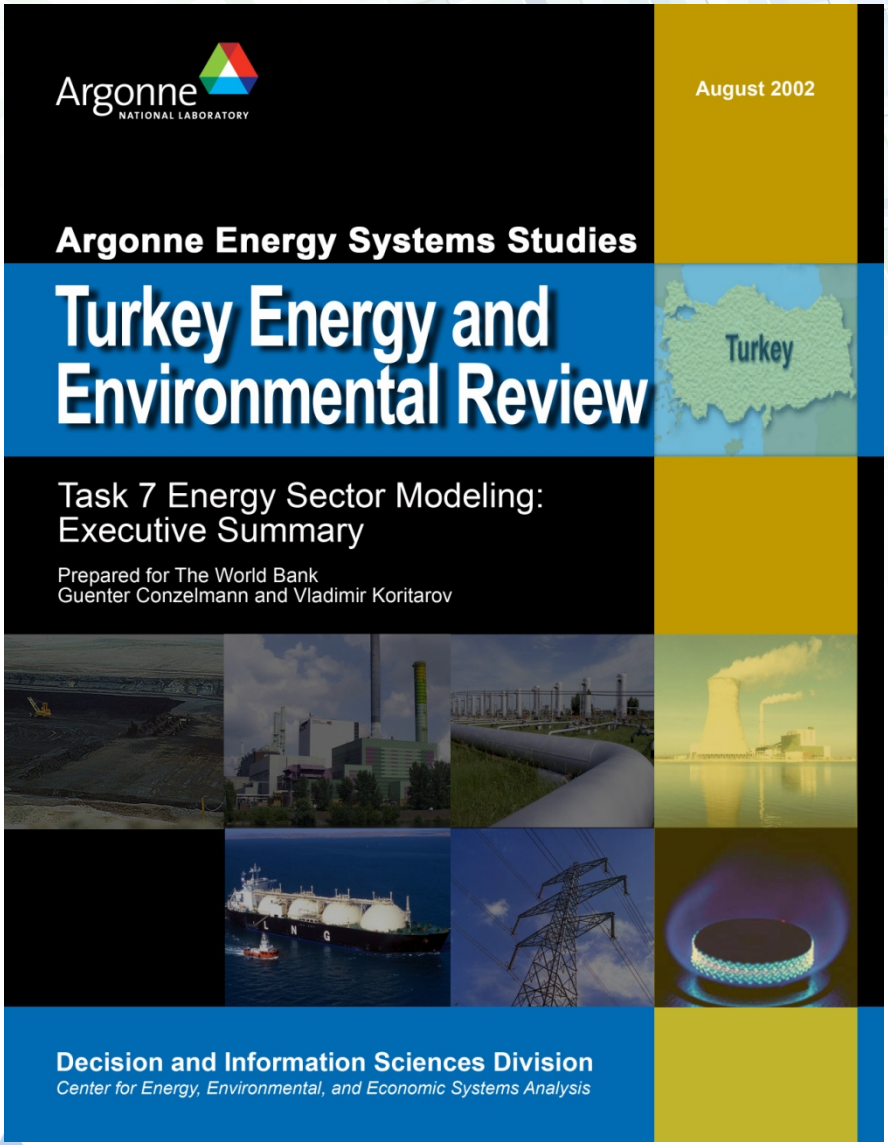



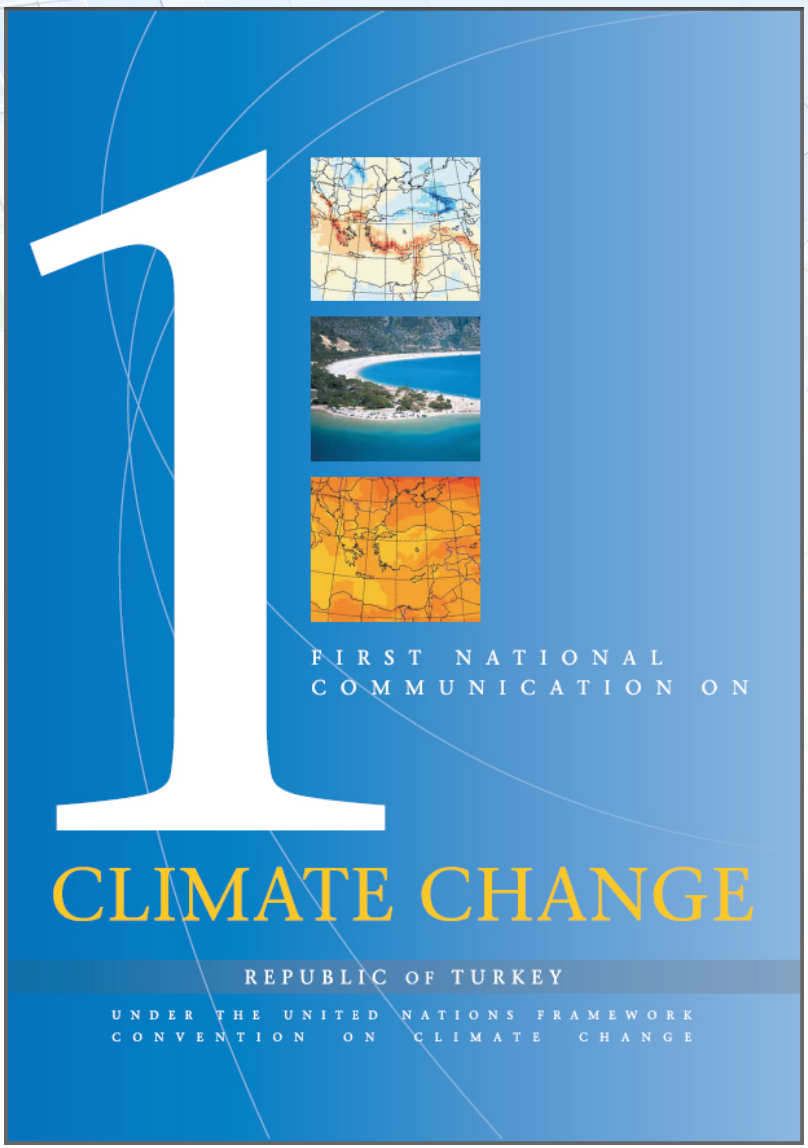



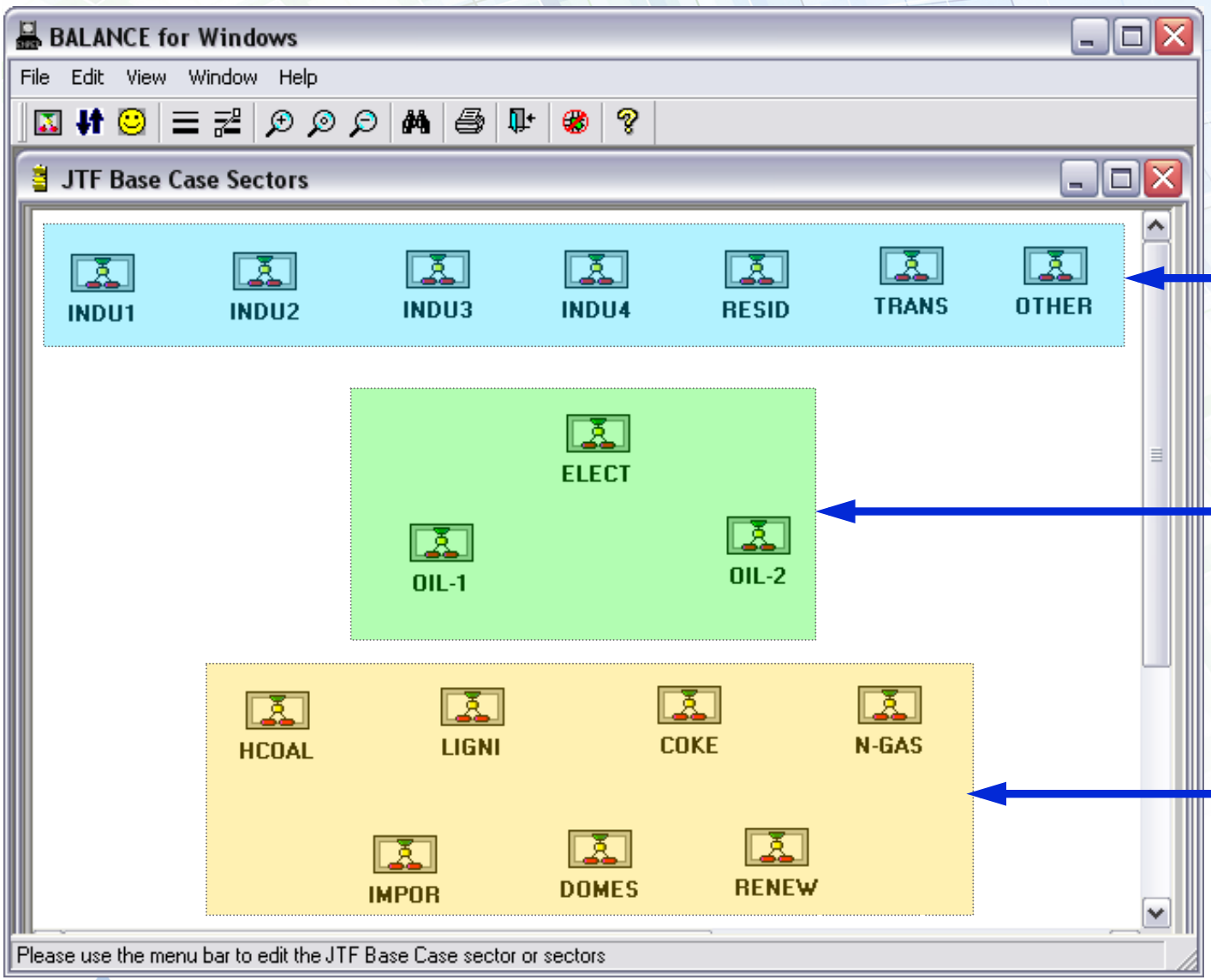



# Two Recent Studies Conducted for Turkey with ENPEP-BALANCE



# *The Model Includes all Energy Forms and All of Turkey's Energy Sectors in an Integrated Framework*

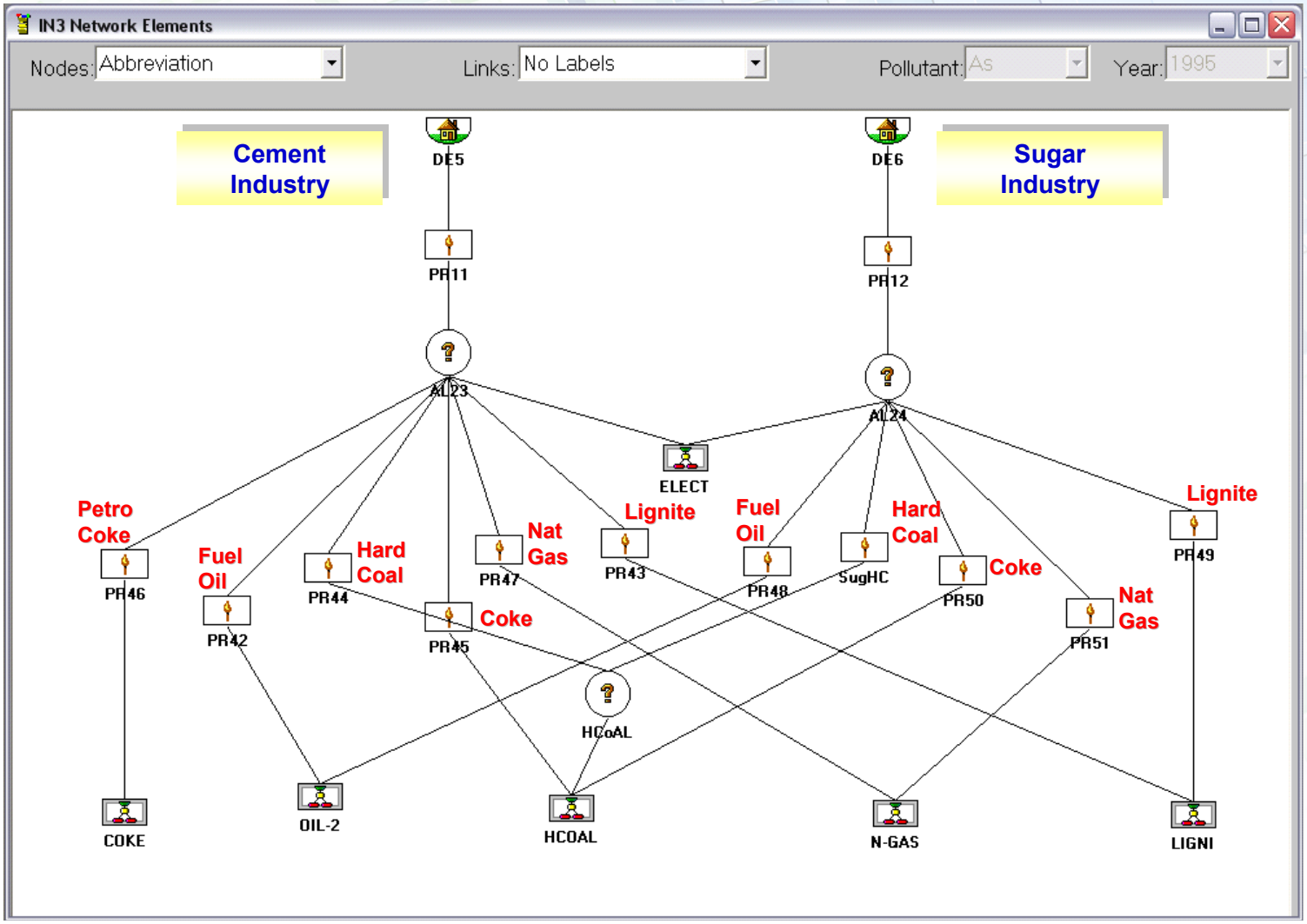



Demand Sectors

Conversion Sectors

Supply Sectors

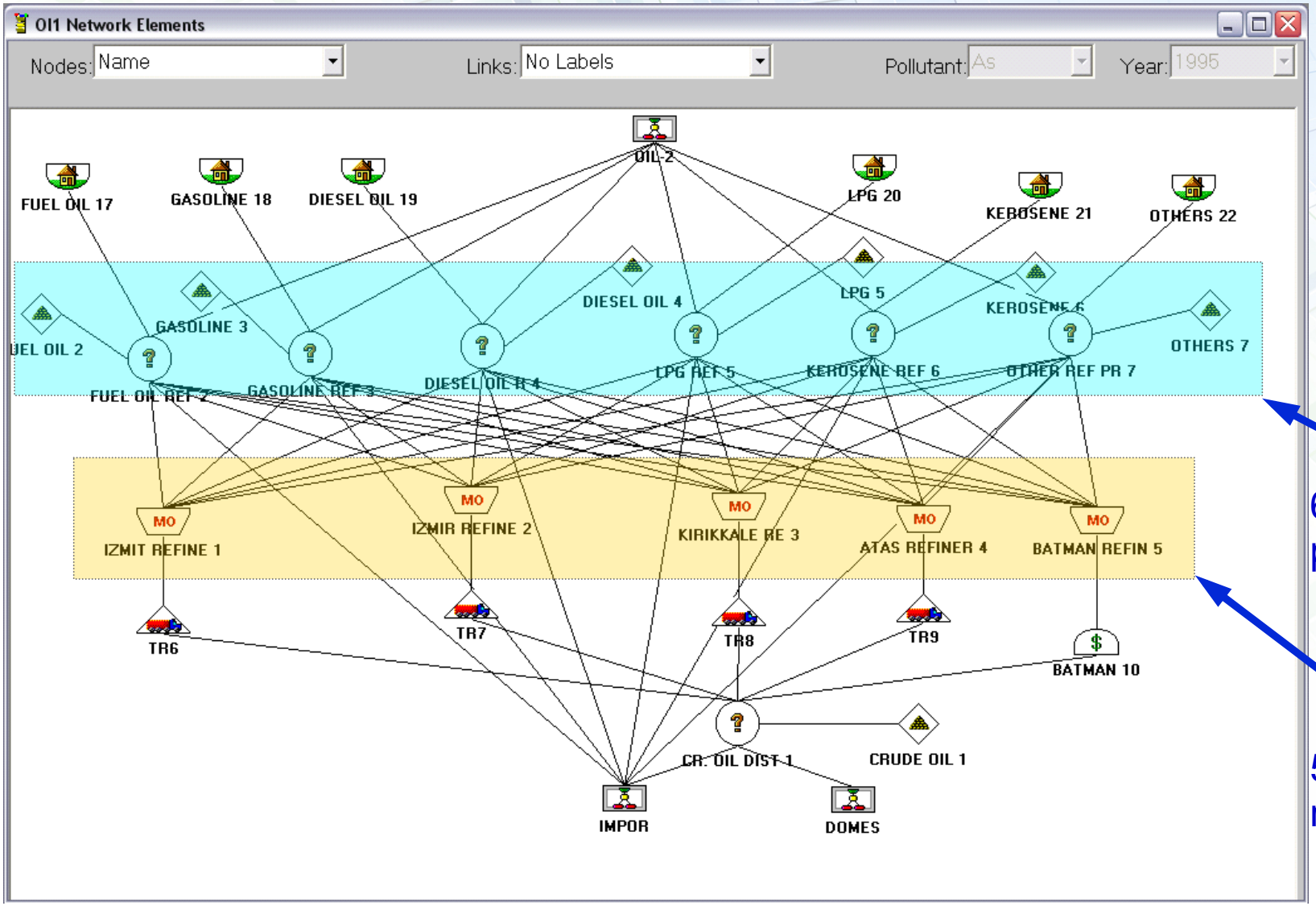
# *Each Sector is Modeled at Different Levels of Detail: Example of Turkish Cement and Sugar Industry*




Other industries included in the Turkish model implementation:

- Iron and steel
- Chemical & petrochemical
- Petrochemical feedstocks
- Fertilizer
- Non-iron metals
- Other

# *Each Sector is Modeled at Different Levels of Detail: Example of Turkish Petroleum Refining*



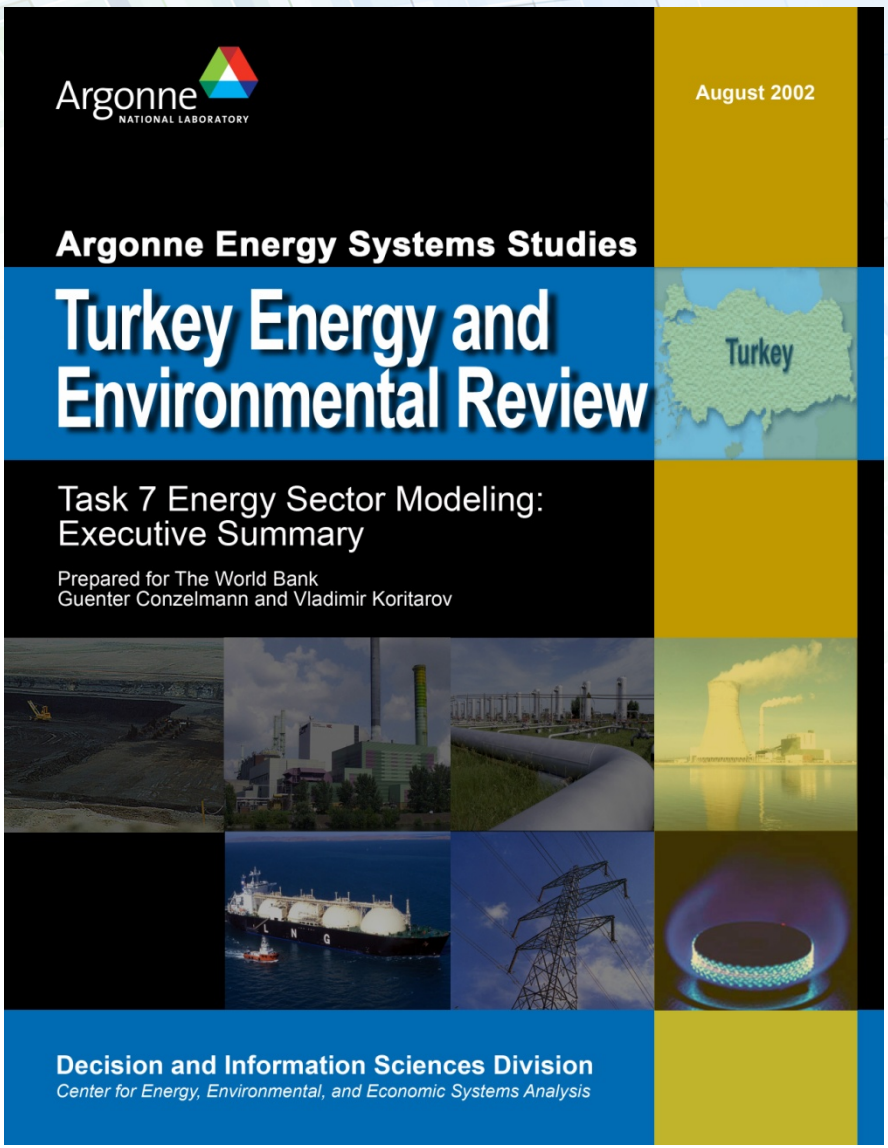

6 different oil products

5 individual refineries

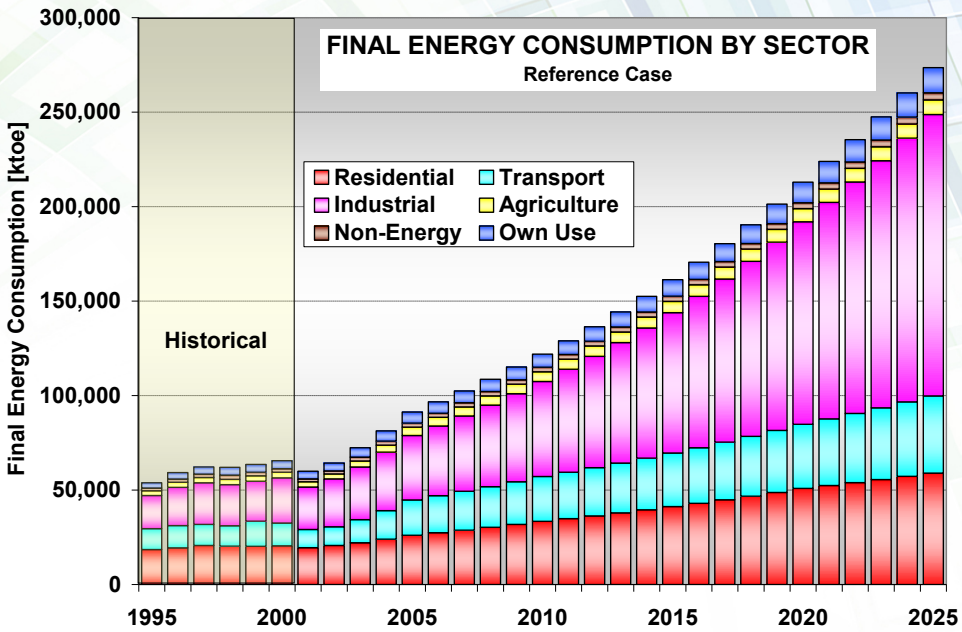
# *Model Results Include Projections of Greenhouse Gases and Other Pollutants*

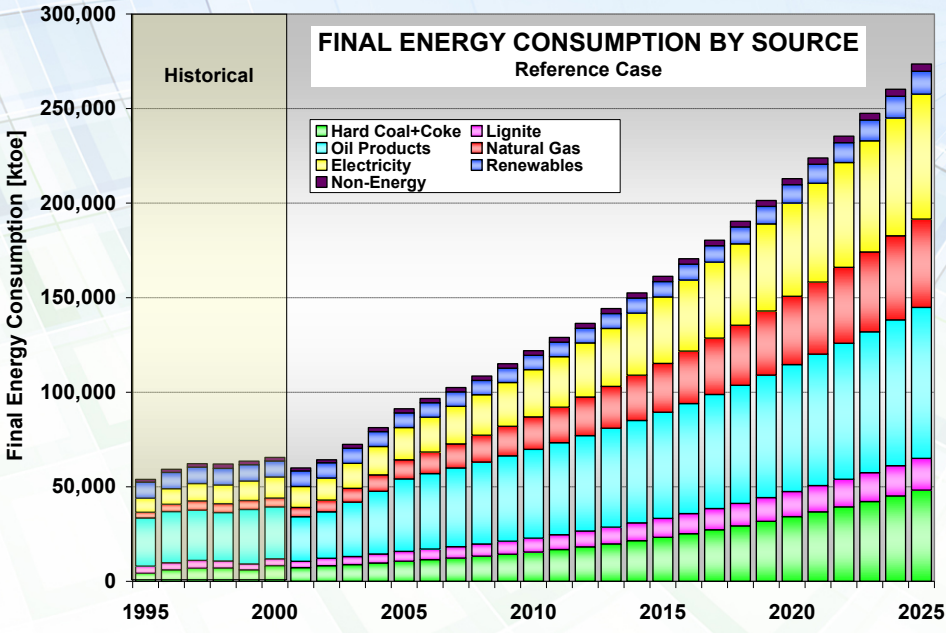
- Greenhouse gases: CO2, CH4, N2O, CO, NMVOC
- Local/regional pollutants: PM, PM10, PM2.5, SO2, NOX, bottom ash, fly ash, total ash
- Air toxics: As, Be, Cd, Cr, Sb, Co, Pb, Mn, Hg, Ni, Se, HCl, HF

# World Bank Energy and Environmental Review



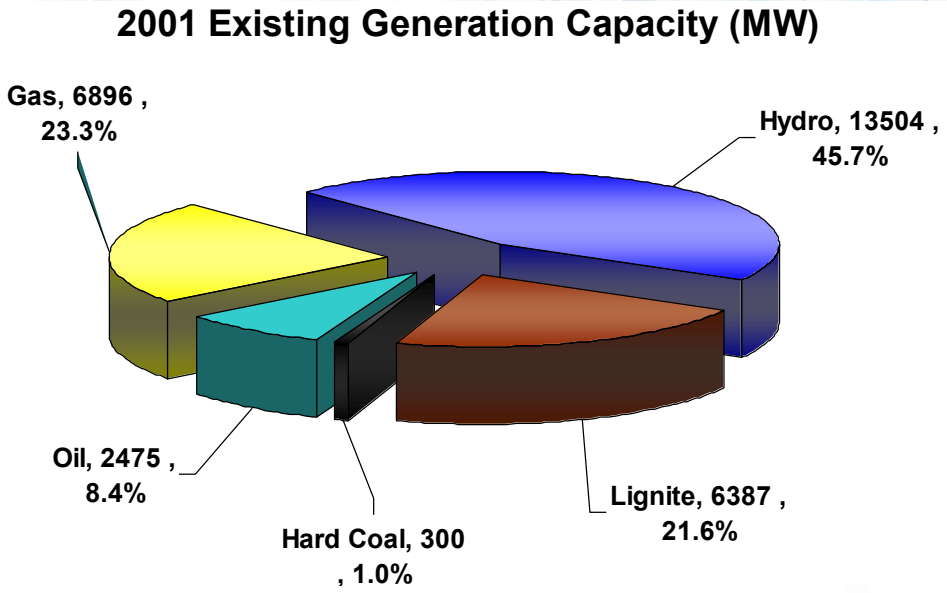
# *Baseline Final Energy Consumption is Projected to Grow from 65.5 mtoe (2000) to 273.5 mtoe (2025)*

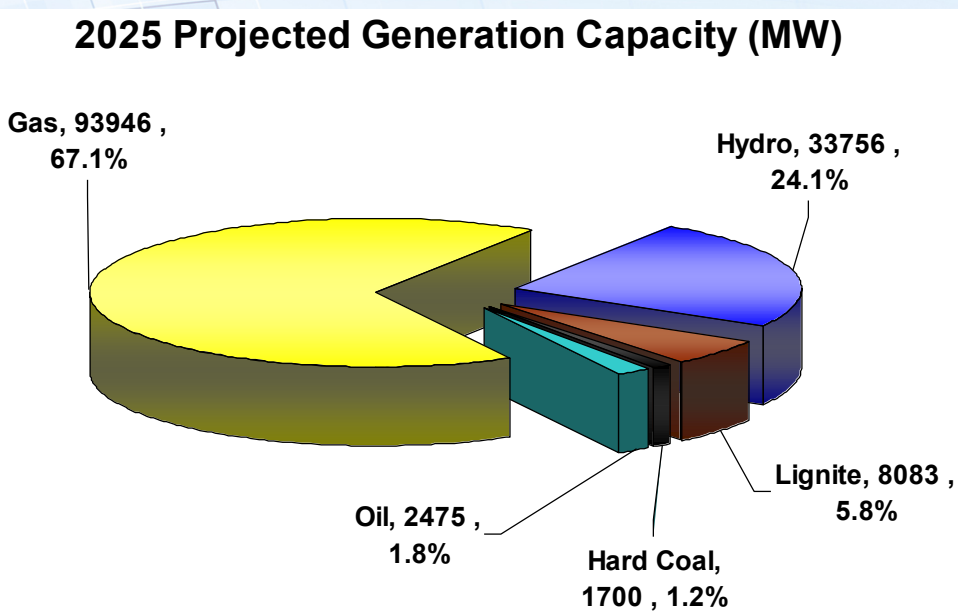


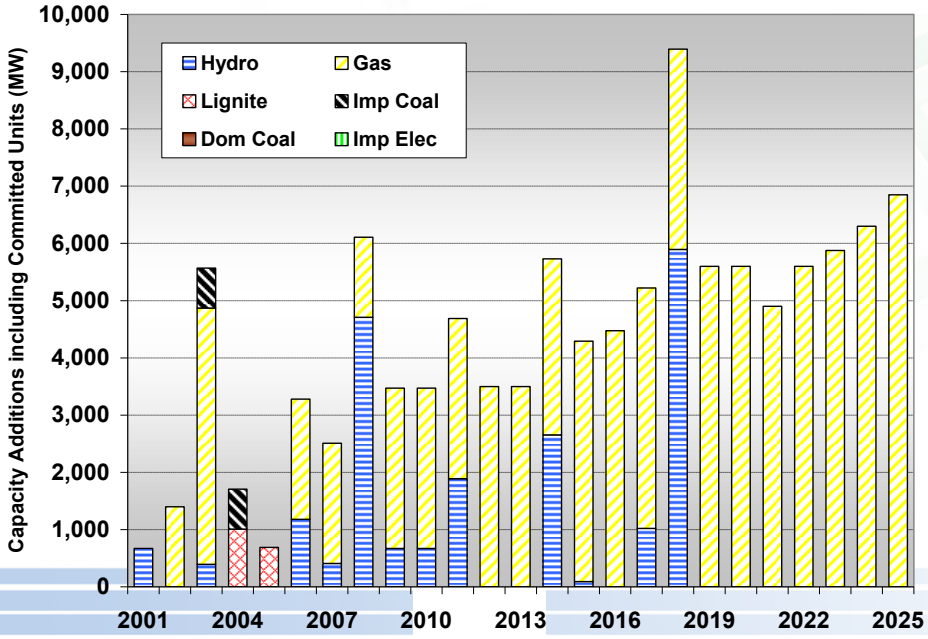




- Average growth rate is 5.9% per year; growth rates vary by sector; e.g., industry (7.6%), transport (5.0%)
- Oil products continue historical decline in market share from 42% to 29% by 2025
- Natural gas grows at 9.6% per year from 4.7 to 46.7 mtoe and captures 17% of the market by 2025 (up from 7% in 2000)
- Electricity grows at 7.4% annually increasing its share from 17% to 24%
- Renewables grow from 8.4 to 12.1 mtoe but their share falls from 13% to 4% mostly due to the decline in non-commercial biomass (wood and wood waste); solar and geothermal energy combined increase fourfold from 2.0 mtoe (2000) to 8.3 mtoe (2025)

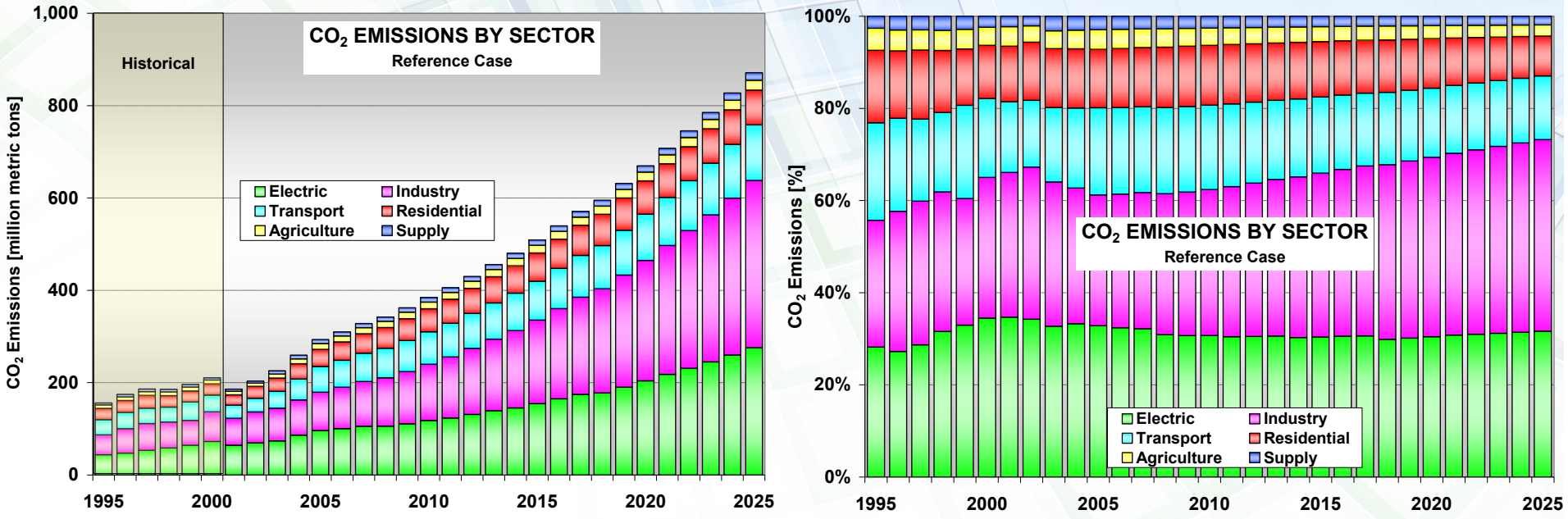
# Baseline Power Sector Expansion is Dominated by Natural-Gas Fired Units



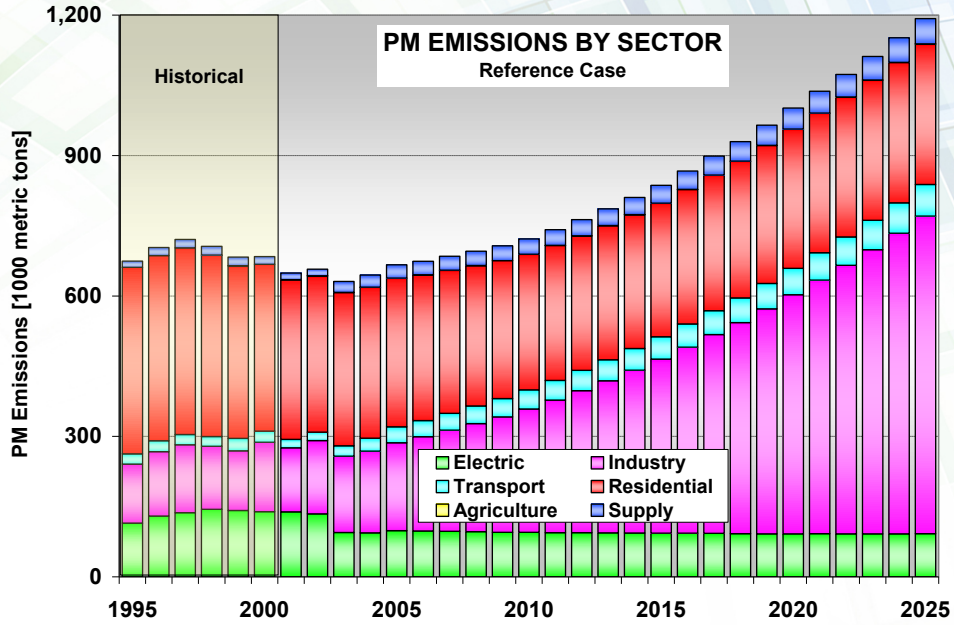



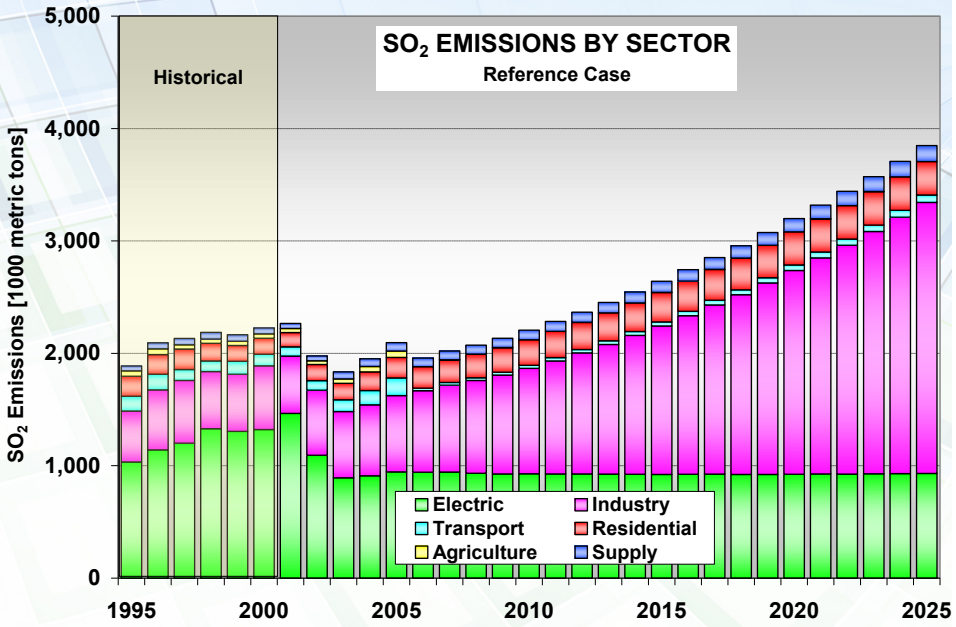
# *Baseline Annual $CO_2$ Emissions are Projected to Grow 5.8% Annually from 211 to 871 million tons*

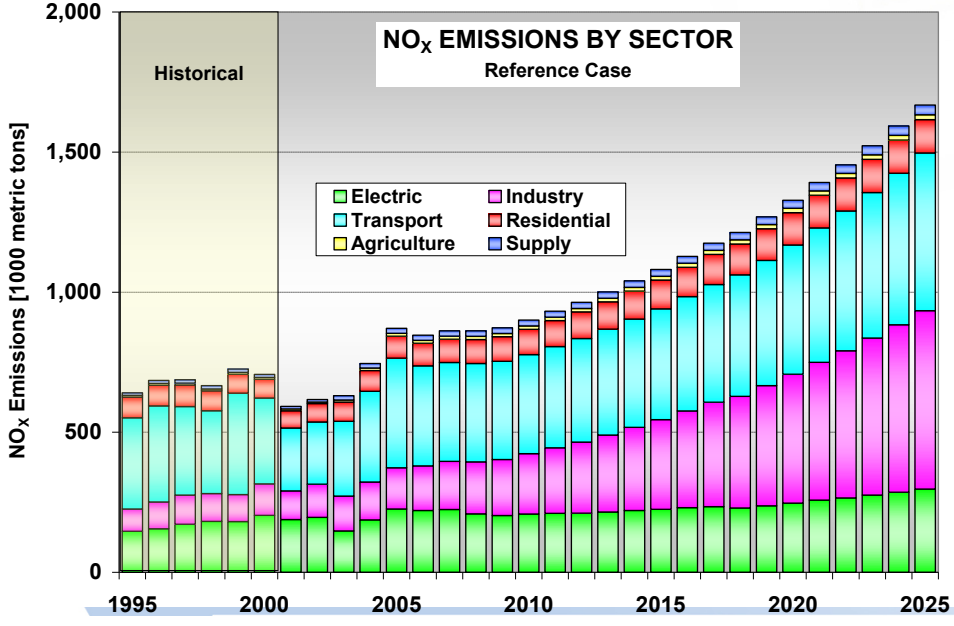


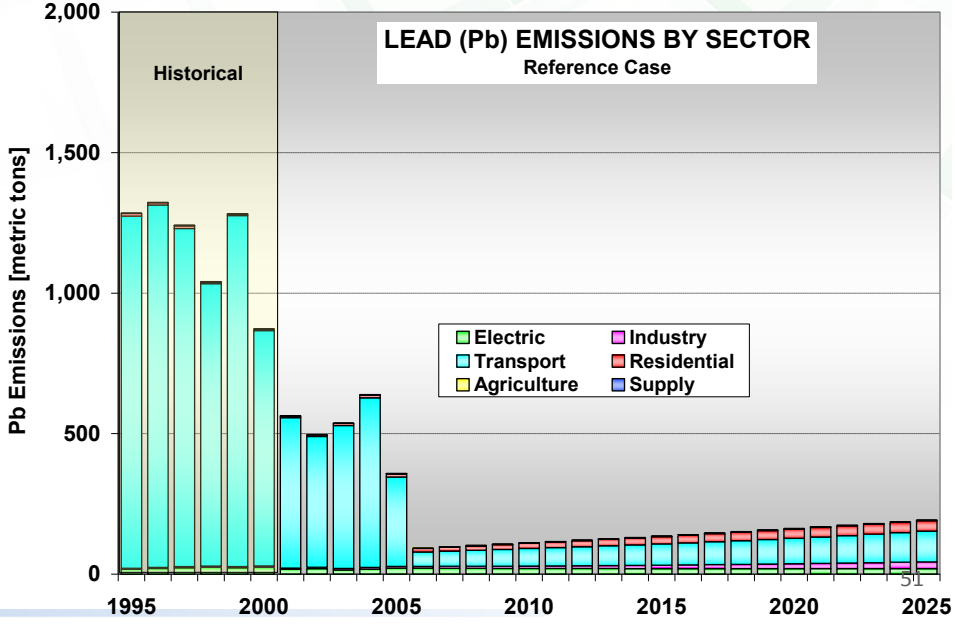

- Industrial $CO_2$ emissions grow by 7.2% per year and account for 42% in 2025 (362.2 mt/yr), up from 30.5% in 2000 (64.4 mt/yr)
  - driven by high growth in industrial final energy as well as continued reliance on solid and liquid fuels which still account for 55% of industrial final energy consumption by 2025, despite the increased penetration of natural gas
- Power sector $CO_2$ emissions grow at a below average rate of 5.5% from 72.7–275.8 million tons, mostly due to increasing reliance on natural gas

# Examples for Other Emissions Results



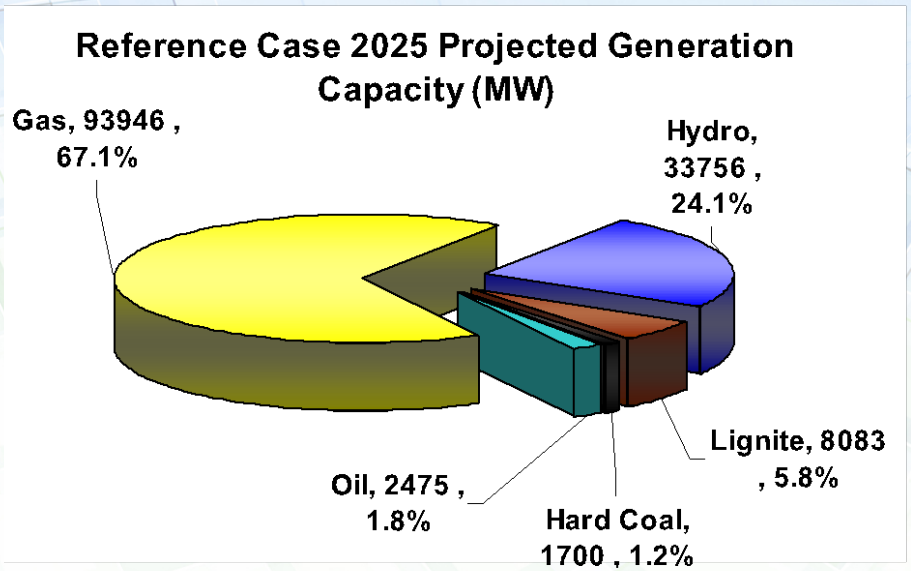
# GHG Mitigation Scenarios

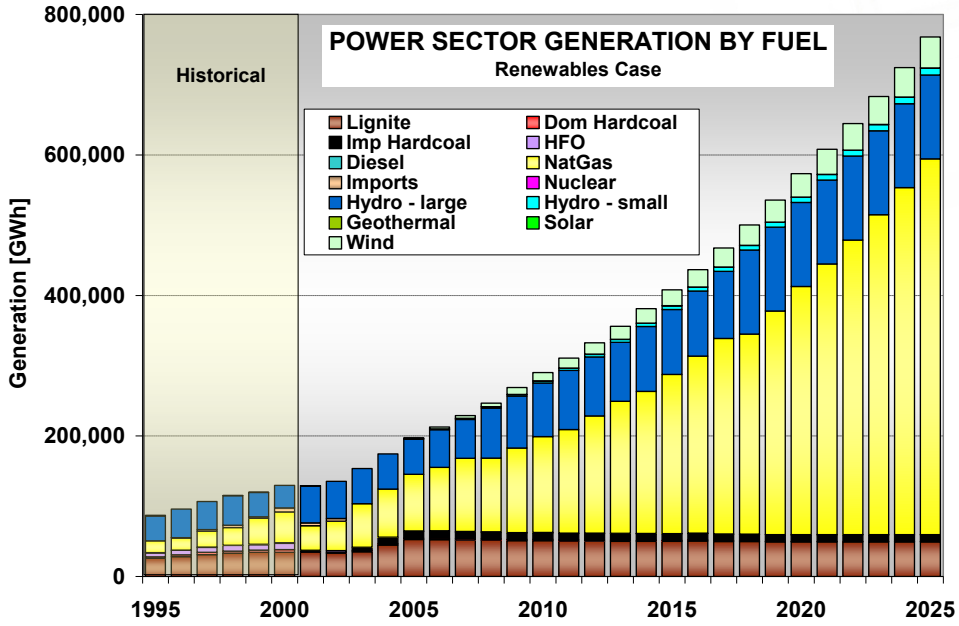
- Technical efficiency improvements of existing power stations
- Clean coal technology (circulating fluidized bed combustion) for power generation
- Constrained gas supply combined with use of new sub-critical and super-critical coal-fired power stations
- Nuclear power
- Increased use of industrial cogeneration
- Expanded use of renewables (wind and mini-hydro)
- $CO_2$ tax of $15 per ton of carbon
- Expanded demand side management in industry and households

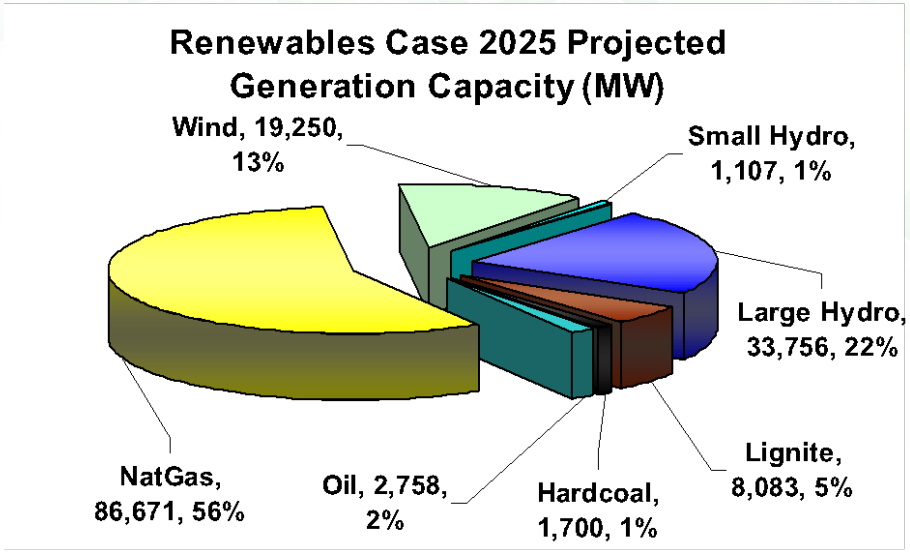
- Local pollution scenarios analyze policies to reduce PM, $SO_2$, and $NO_X$
  - Improving petroleum product quality (reducing S-content in fuel oil)
  - Upgrading existing power stations to meet EU standards on PM and $SO_2$ (2009) and $NO_X$ (2015)
  - Combined case of improved petroleum quality and power station retrofits

# Renewables Scenario

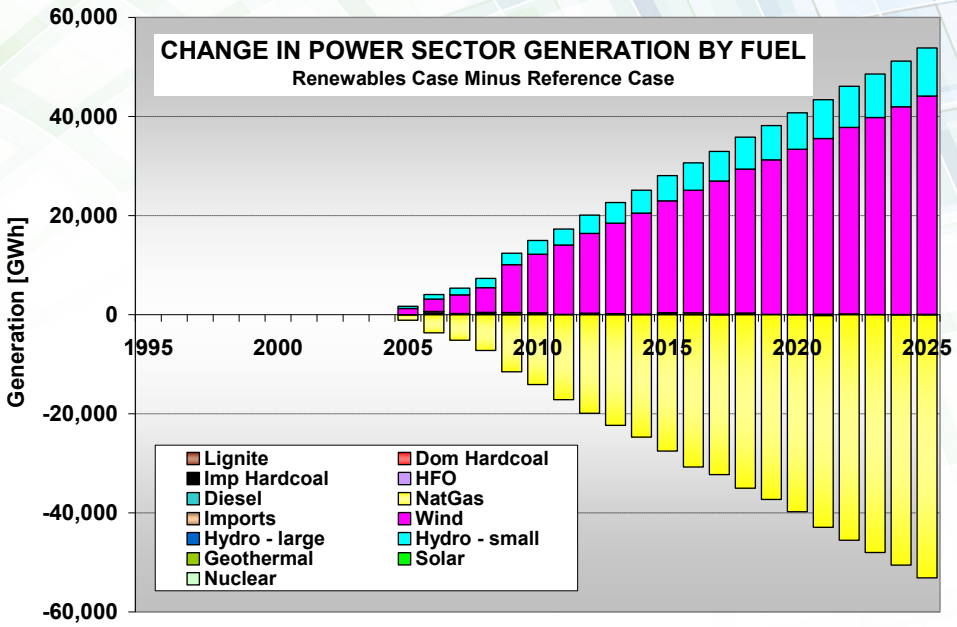
- Assumes start of more aggressive renewables program in 2005 with the goal to have 7% of total electricity production coming from mini-hydro and wind power
- 19,250 MW of wind and 1,107 MW of small hydro will be added to the system
- This replaces a total of 7,250 MW of gas-fired capacity in the power sector over 2000–2025

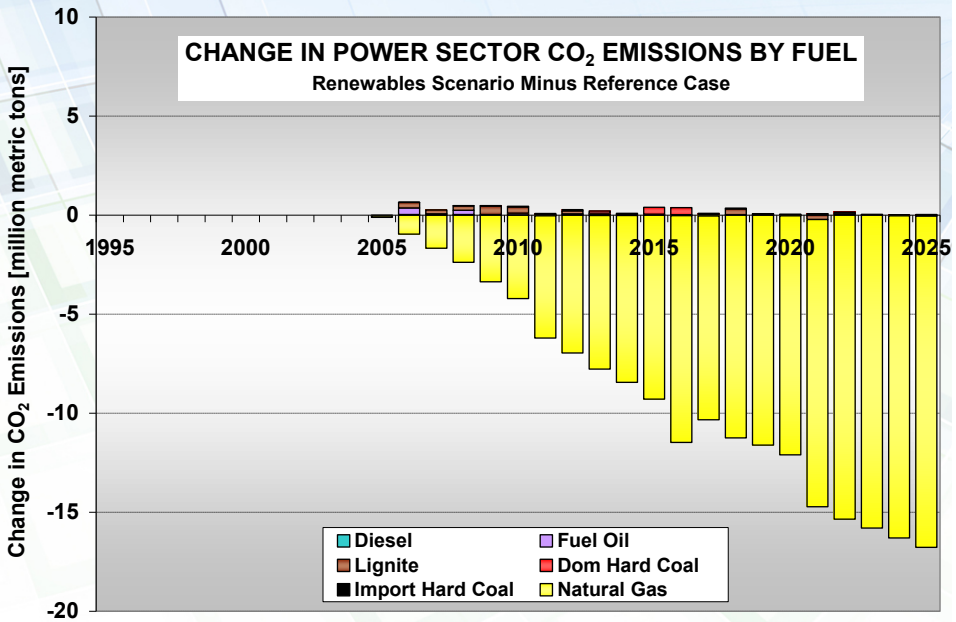


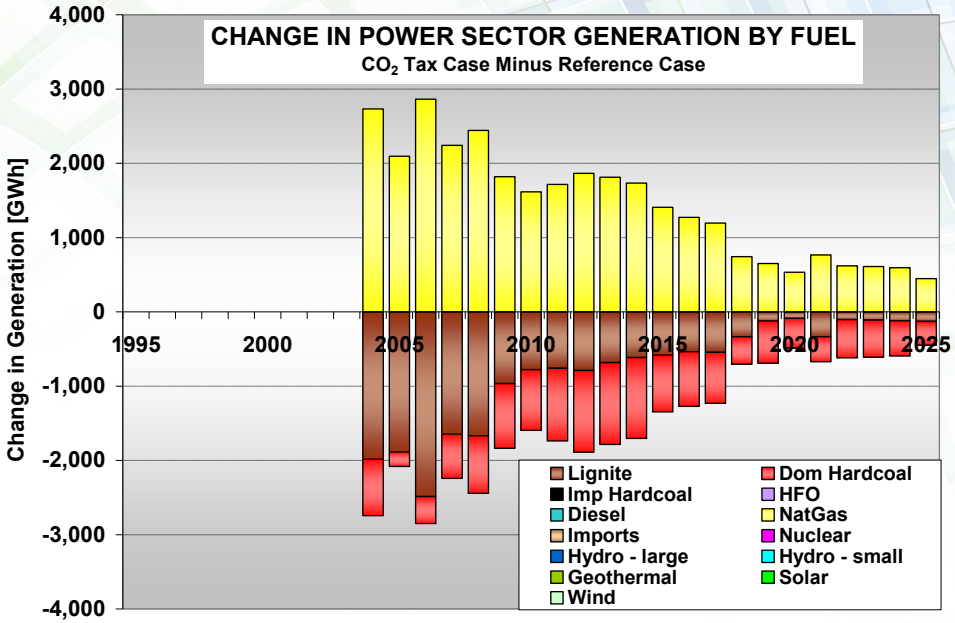
# Renewables Scenario

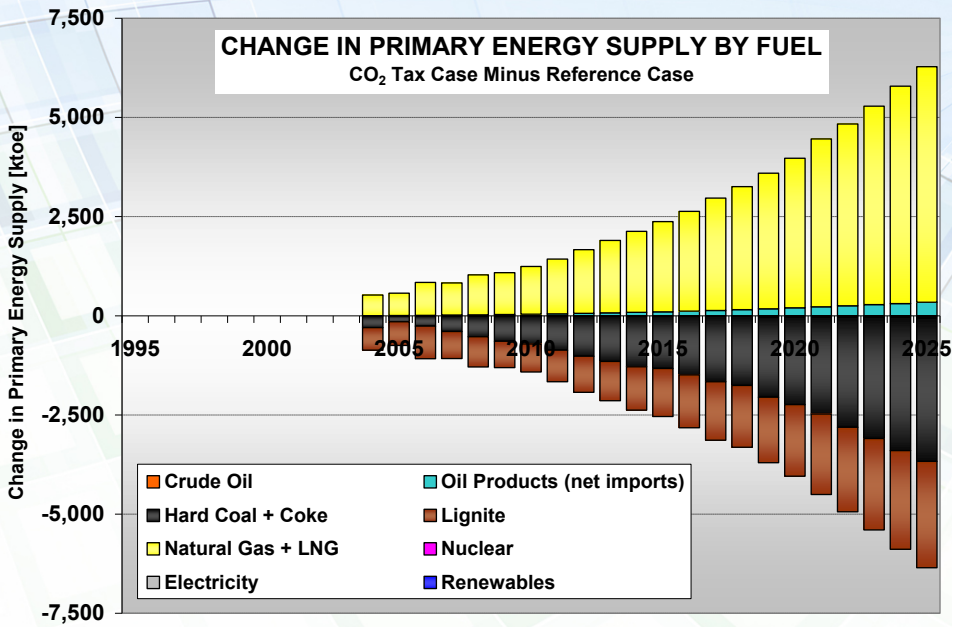


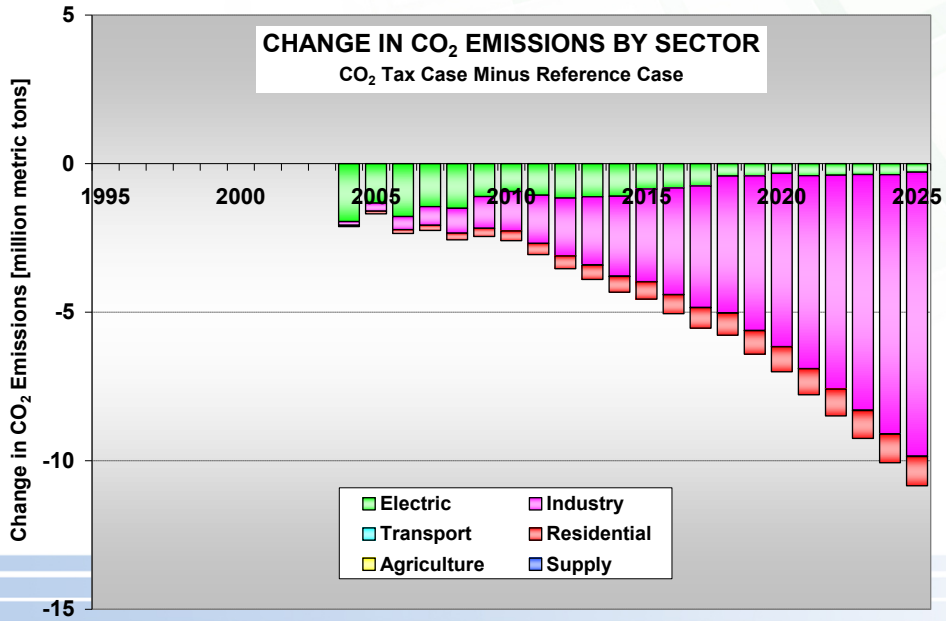




- Wind and mini-hydro displace natural gas-fired generation which limits the emission reduction potential of renewables
- $CO_2$ emissions from power generation are reduced by 16.7 million t/yr (5.9%) by 2025 below the Baseline or Reference Case
- On the national level, emissions reductions are equivalent to a 1.9% cut

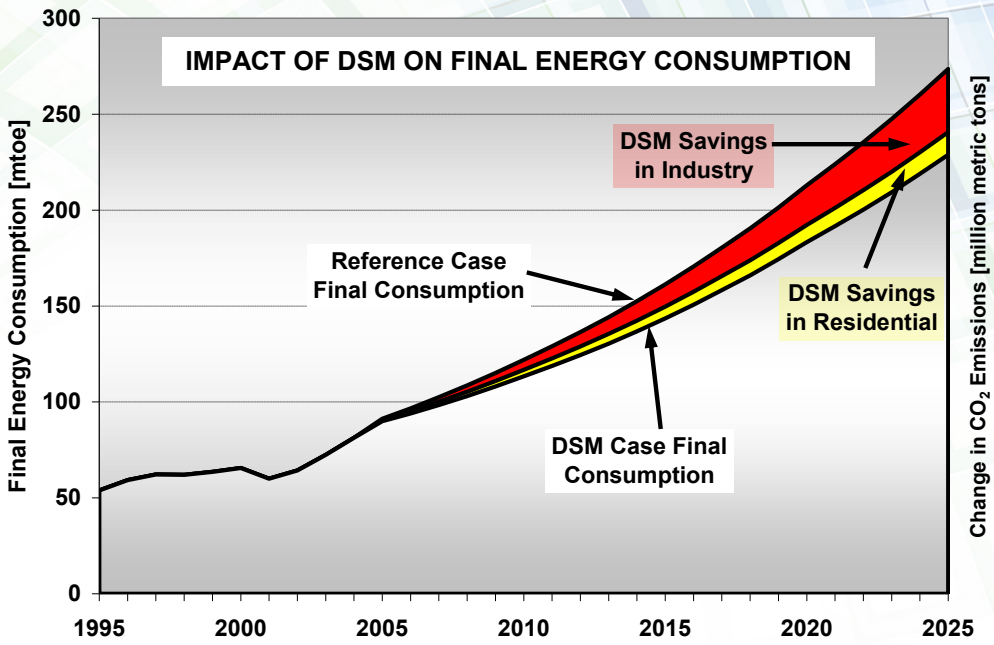
# $CO_2$ Tax Leads to Change in Power Sector Dispatch and a Shift in Overall Fuel Mix

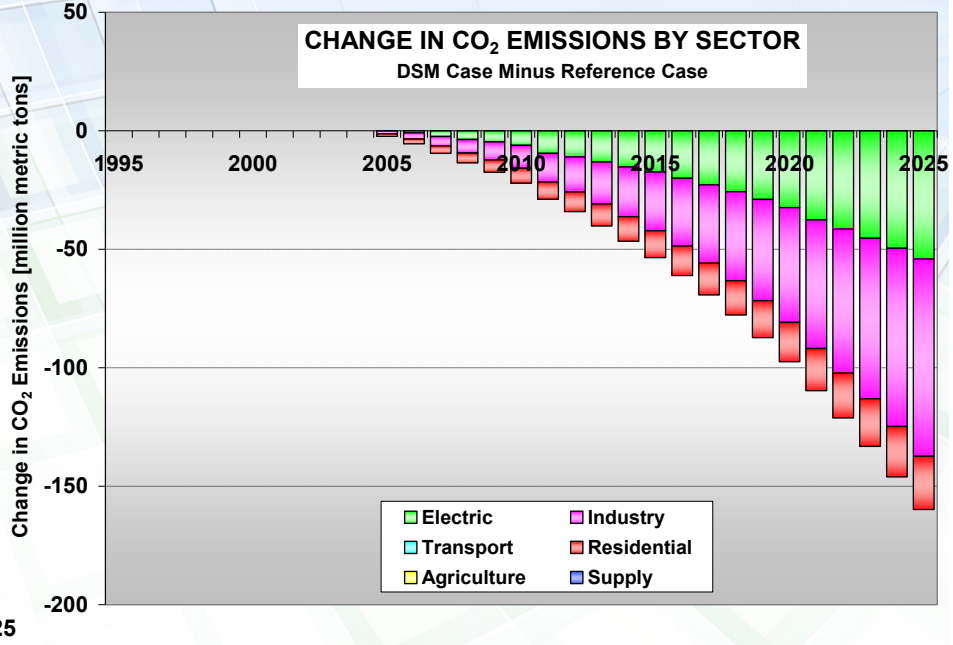


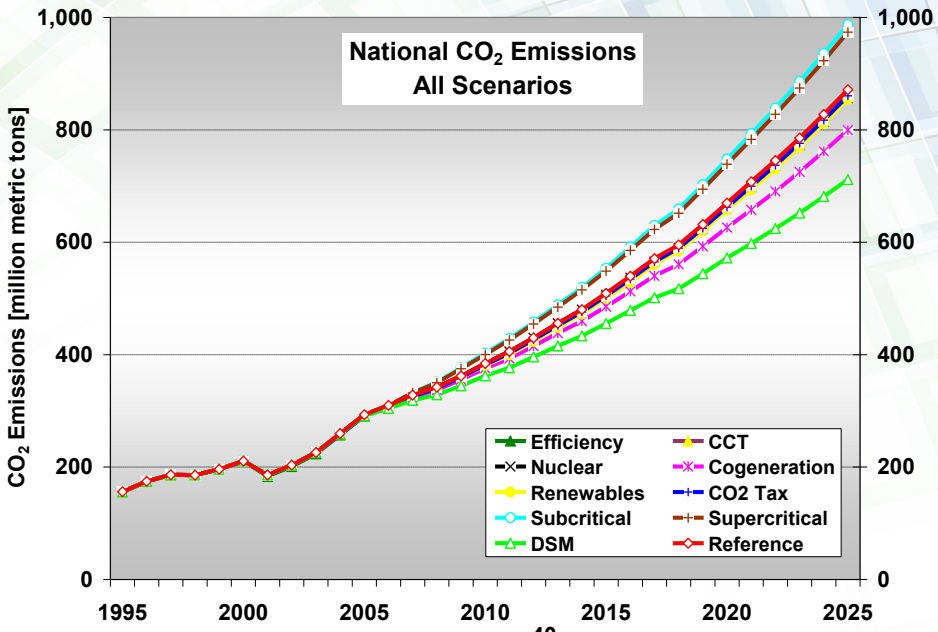
# Demand Side Management (DSM) Scenario

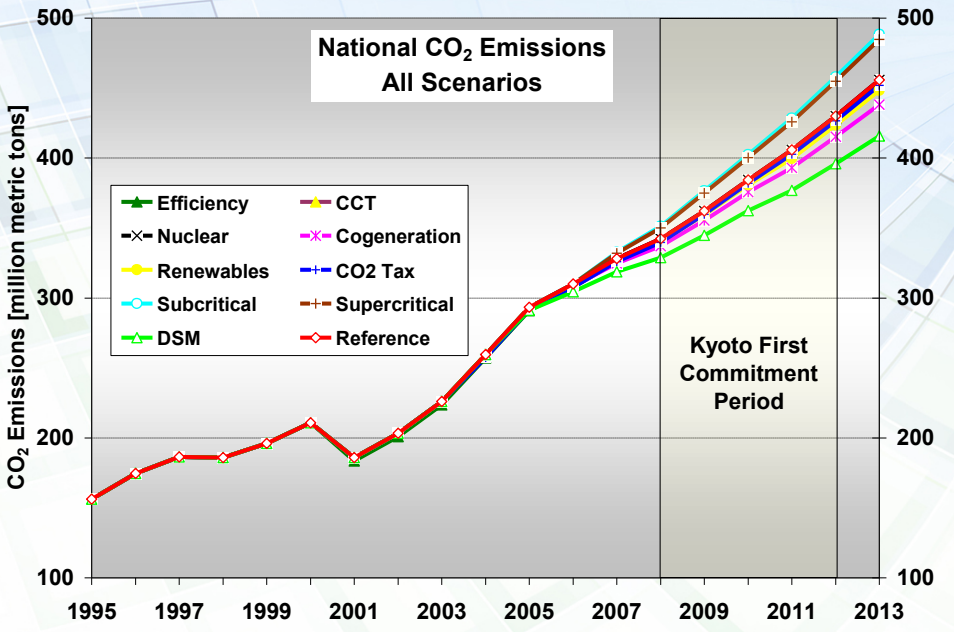


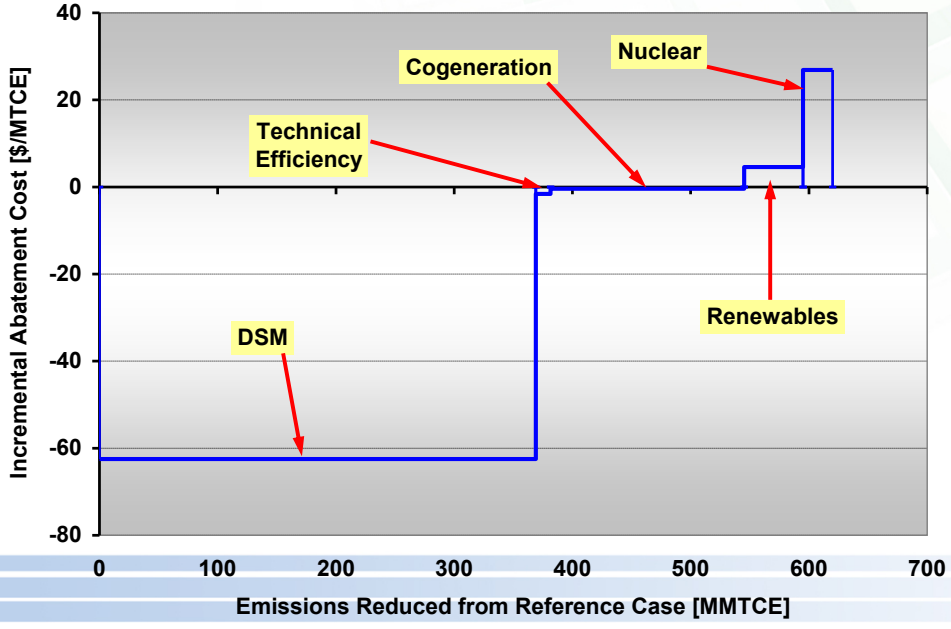




- Total final energy consumption drops by 44.7 mtoe or 16.3%
  - The largest declines are experienced by hard coal and coke with a drop of 24.5%, lignite of 24.3%, and natural gas of 24.2%
  - Electricity falls by 19% while oil products only drop by 6.2% as the transport sector is not affected by the DSM efforts
- By 2025, DSM reduces national $CO_2$ emissions by 160 million tons per year or by 18.3% (23%industry, 30% households, 20% power sector)

# Summary GHG Mitigation Scenarios



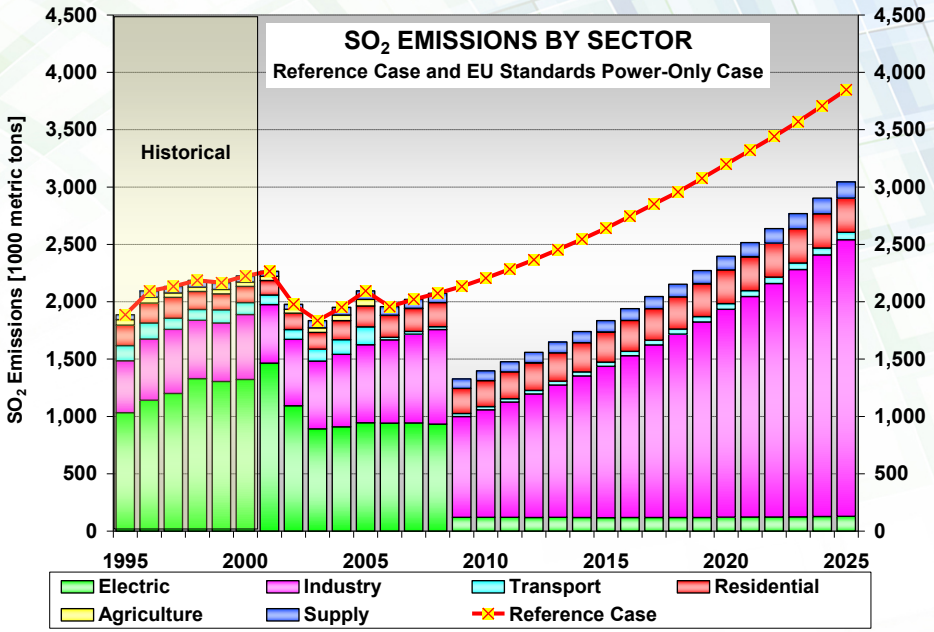



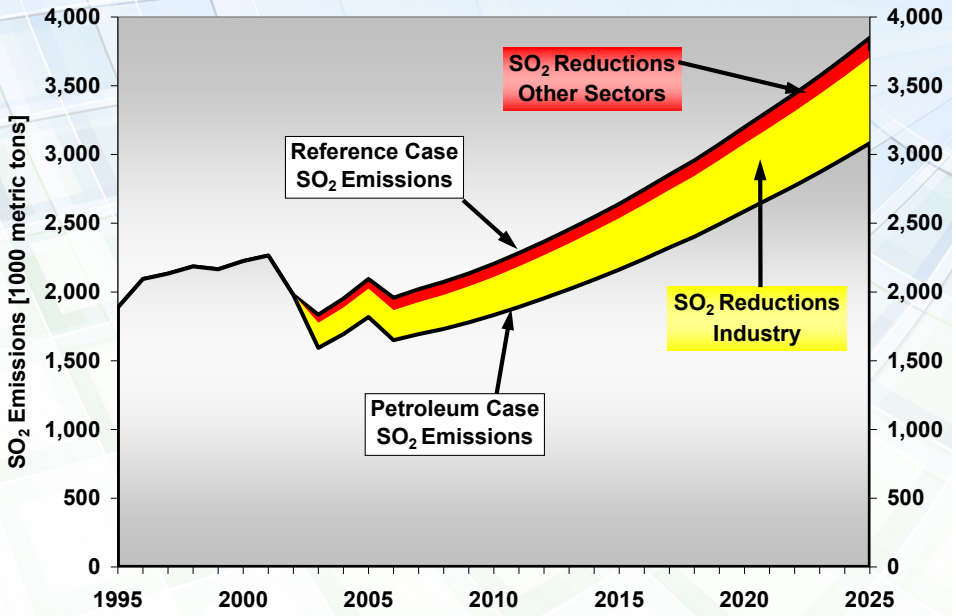
# Summary GHG Mitigation Scenarios

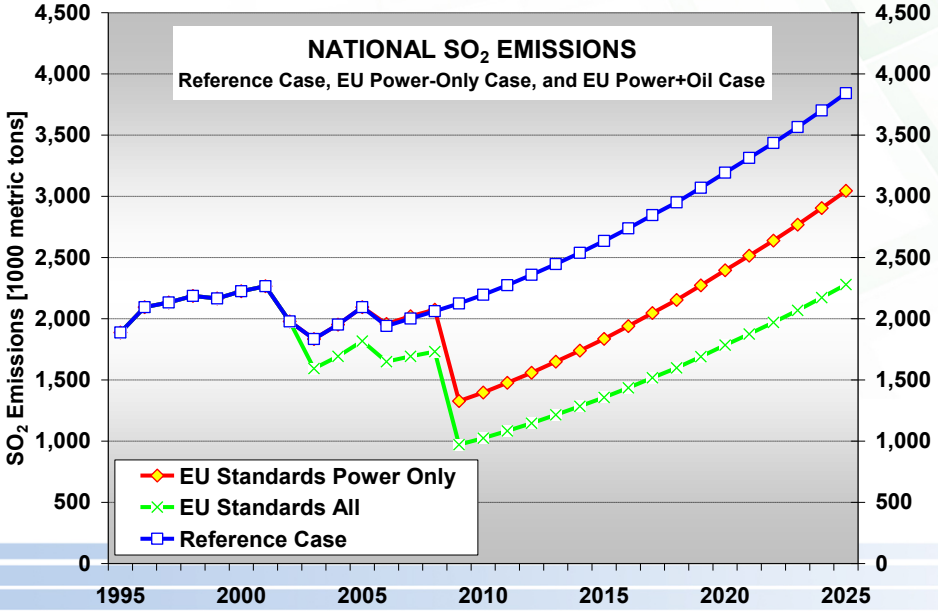
| Scenario | Incremental Cost (million $) | Change in Net Energy Imports (million $) | Cumulative MMTCE Reductions (million tons) | MTCE Cost Effectiveness ($/MTCE) |
|---|---|---|---|---|
| DSM | -23,054.2 | -9,027.4 | 369.03 | -62.5 |
| Technical Efficiency | -19.5 | -48.2 | 12.40 | -1.57 |
| Cogeneration | -63.0 | -915.8 | 163.78 | -0.4 |
| Renewables | 228.6 | -1,493.4 | 49.75 | 4.6 |
| Nuclear | 675.2 | -235.5 | 25.10 | 26.9 |
| Sub-critical Compared to Reference Case; Super-critical Compared to Sub-critical | | | | |
| Constrained Gas Sub-critical | 3,151.2 | -2,218.4 | -289.38 | na |
| Constrained Gas Super-critical | -182.0 | -213.2 | 33.93 | -5.4 |

MMTCE = million metric tons of carbon equivalent (includes $CO_2$, $CH_4$, $N_2O$); MTCE = metric ton of carbon equivalent

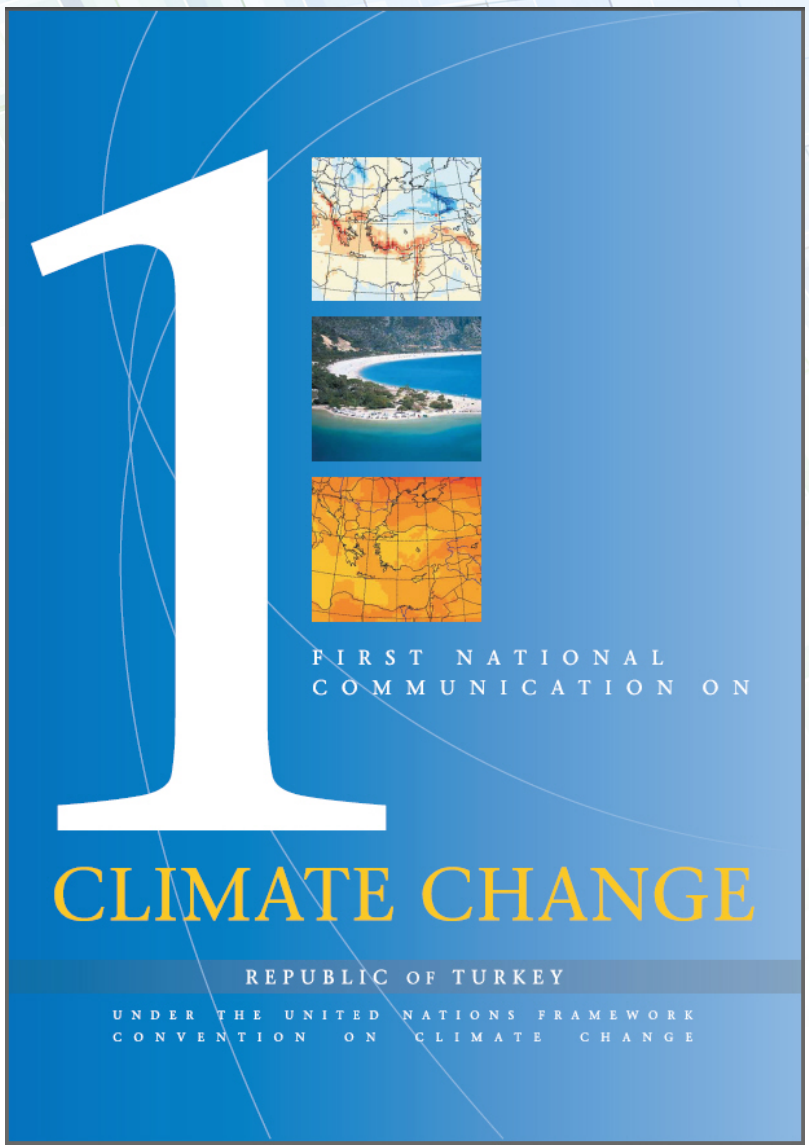
# Examples for Local Pollution Scenario Results



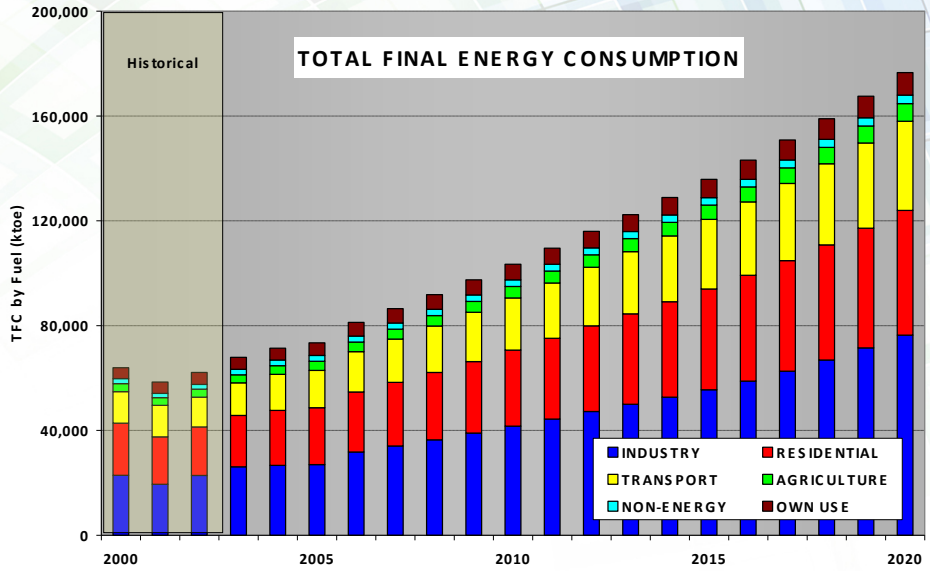



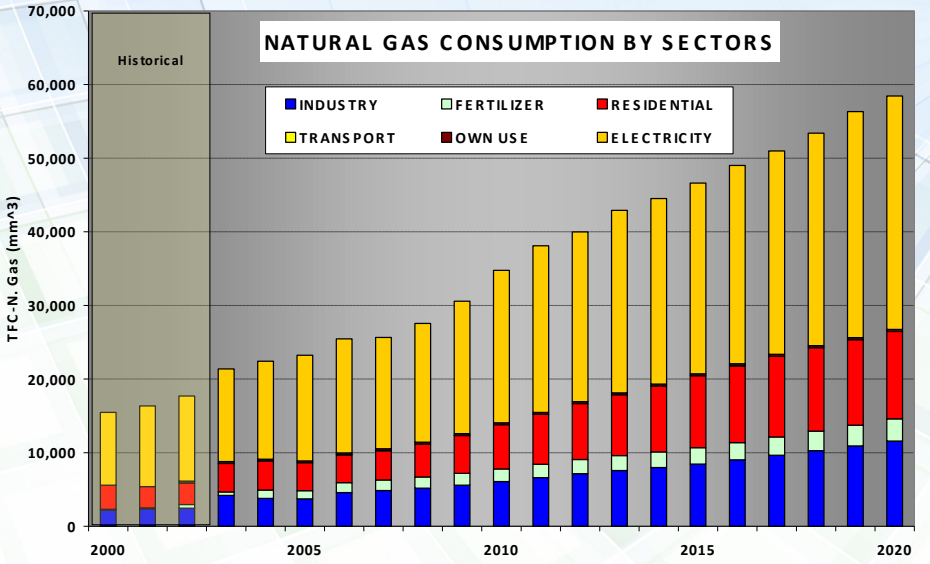



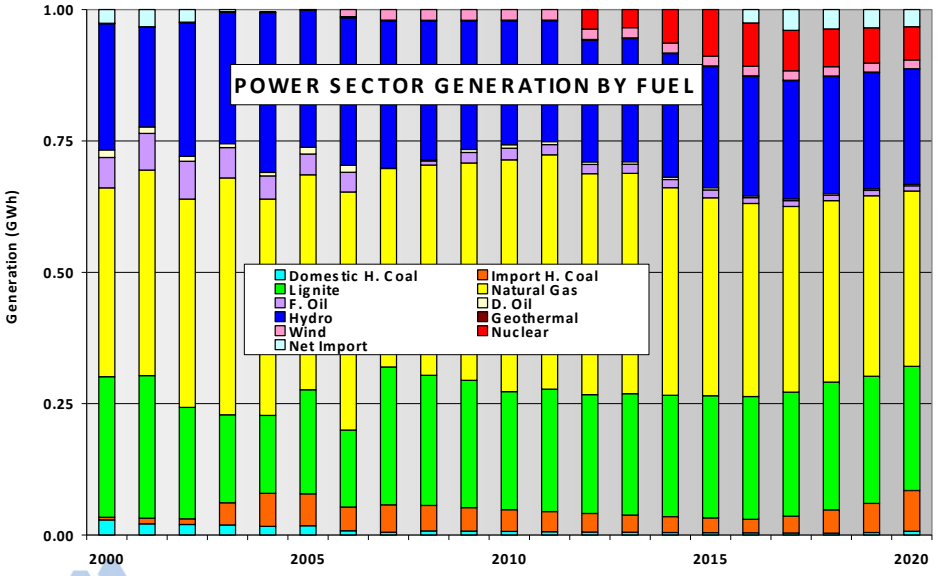
# *Analysis in Support of Turkey's First National Communication*

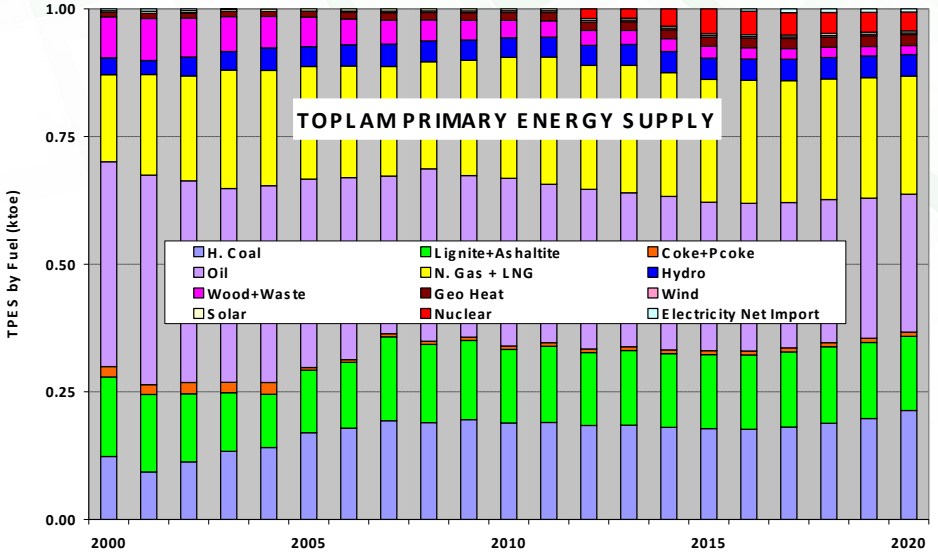


# Examples for UNFCCC Scenario Results

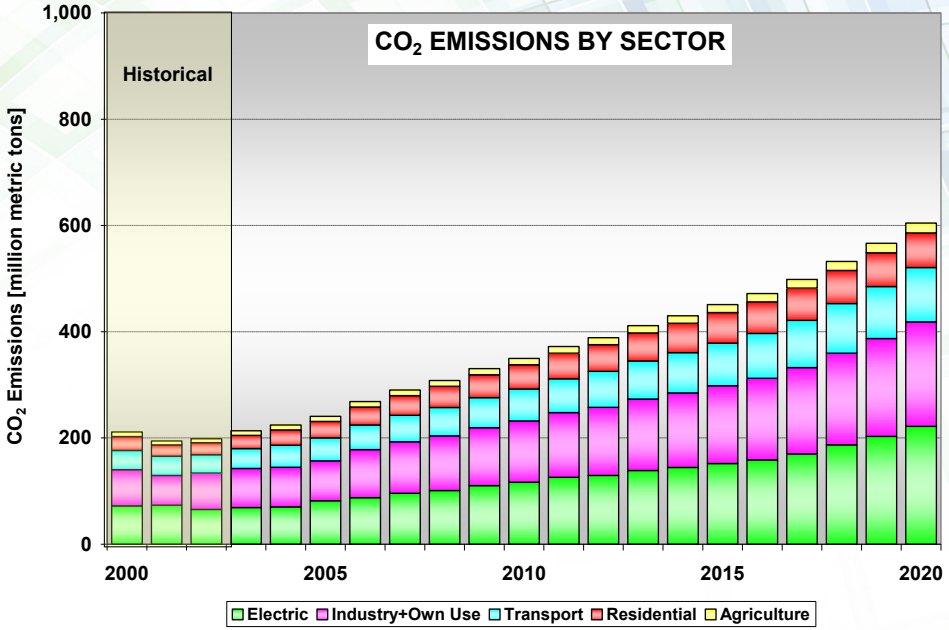


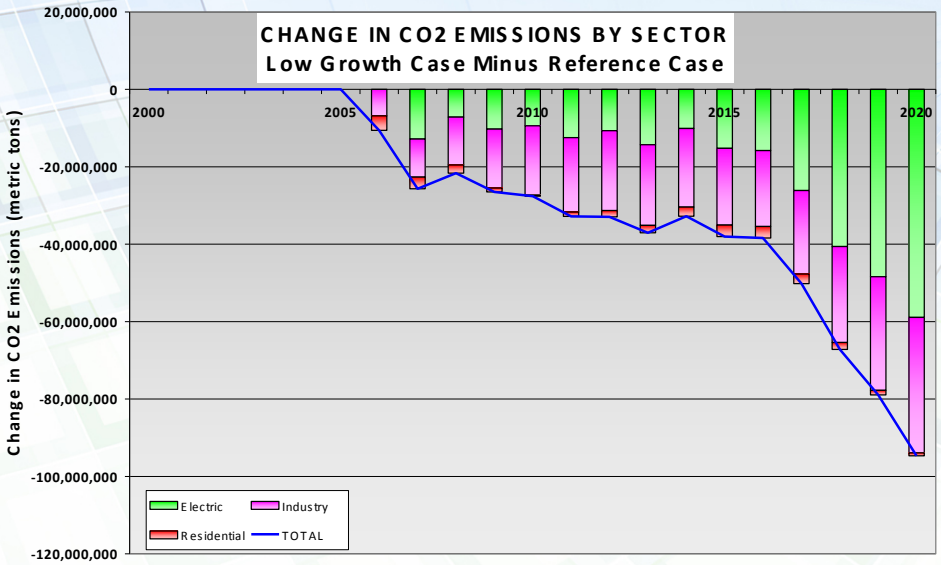



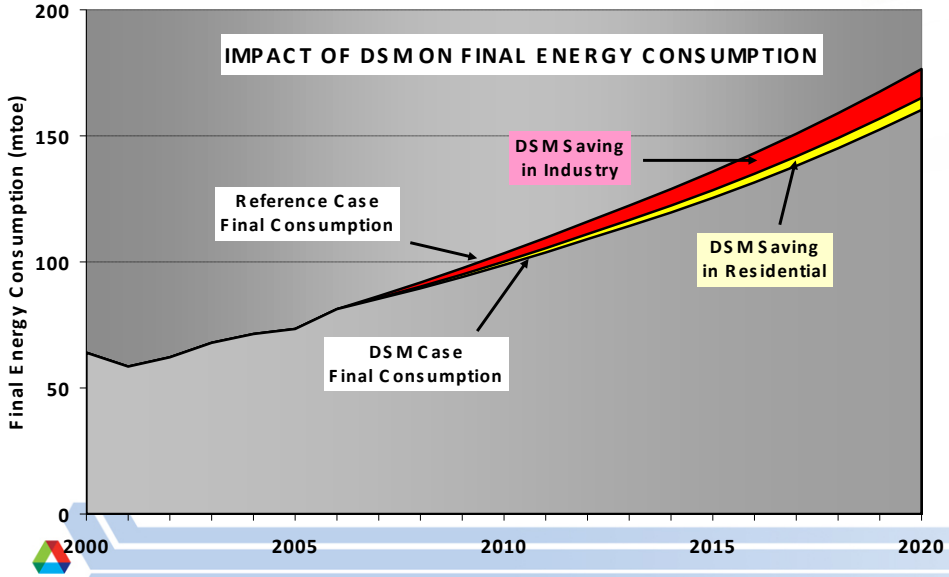



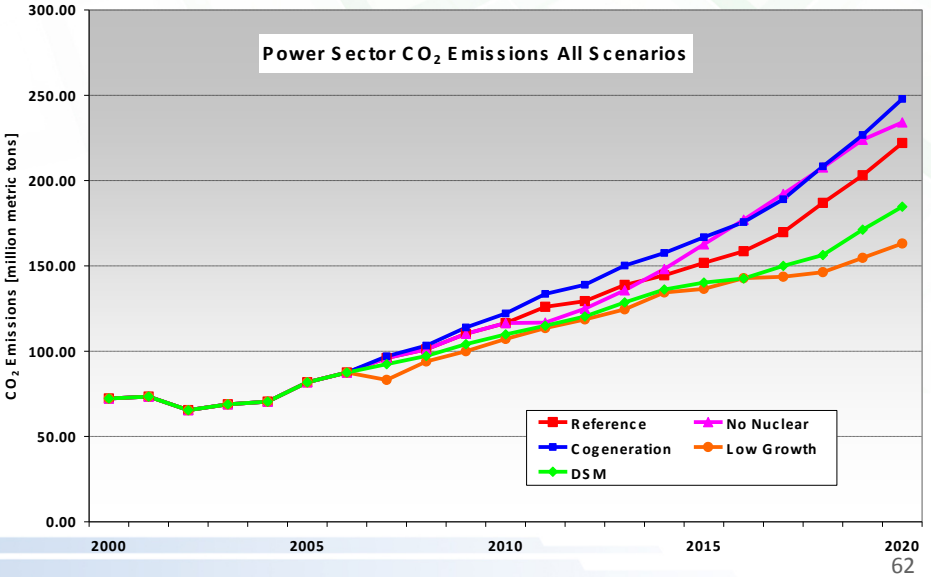



# Examples for UNFCCC Scenario Results



# Information on ENPEP-BALANCE Applications is Available on our Website