ENPEP-BALANCE: System Economic Cost Calculations

ENPEP-BALANCE Training Course
Singapore
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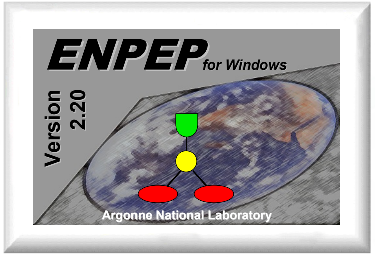

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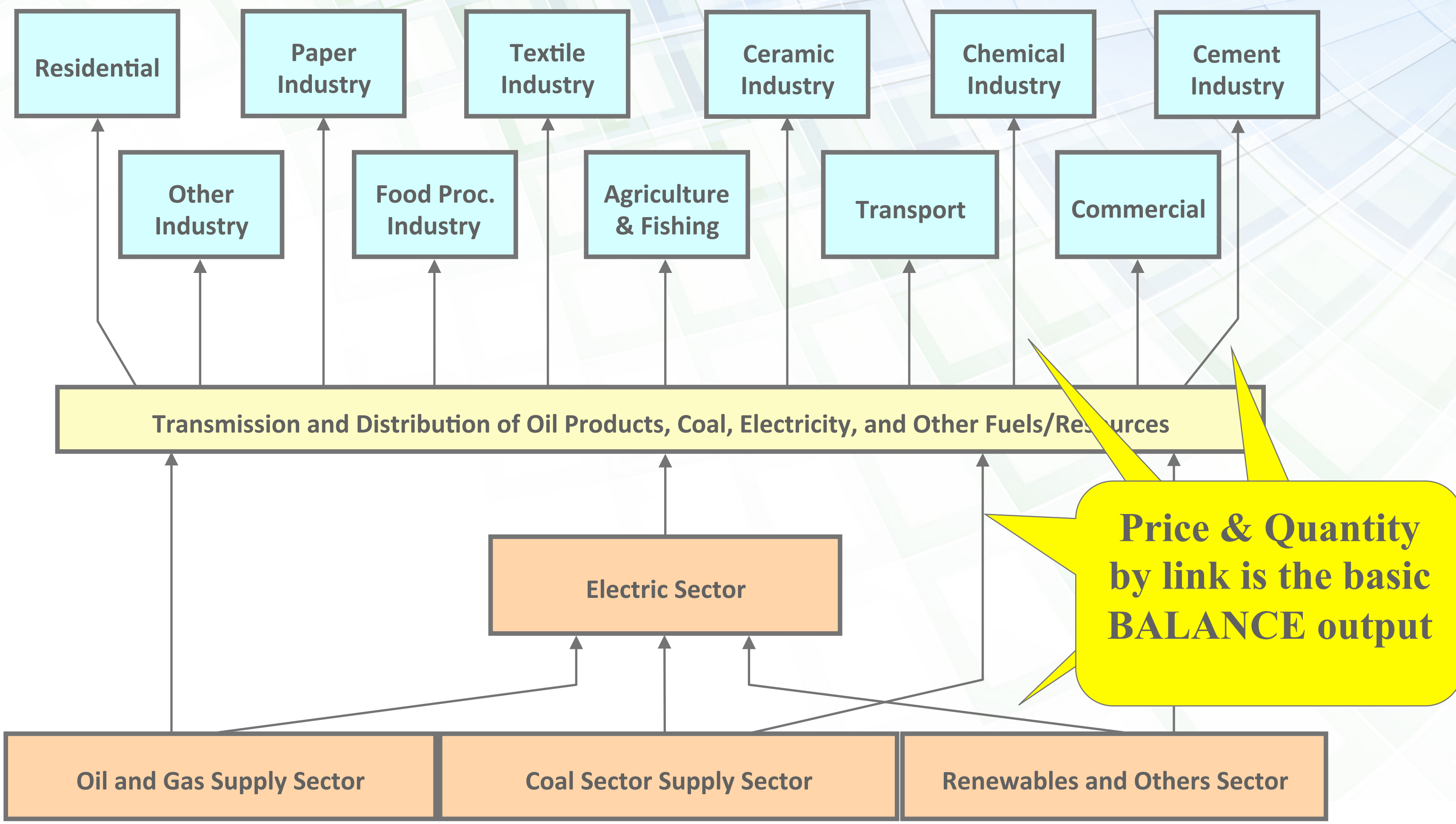
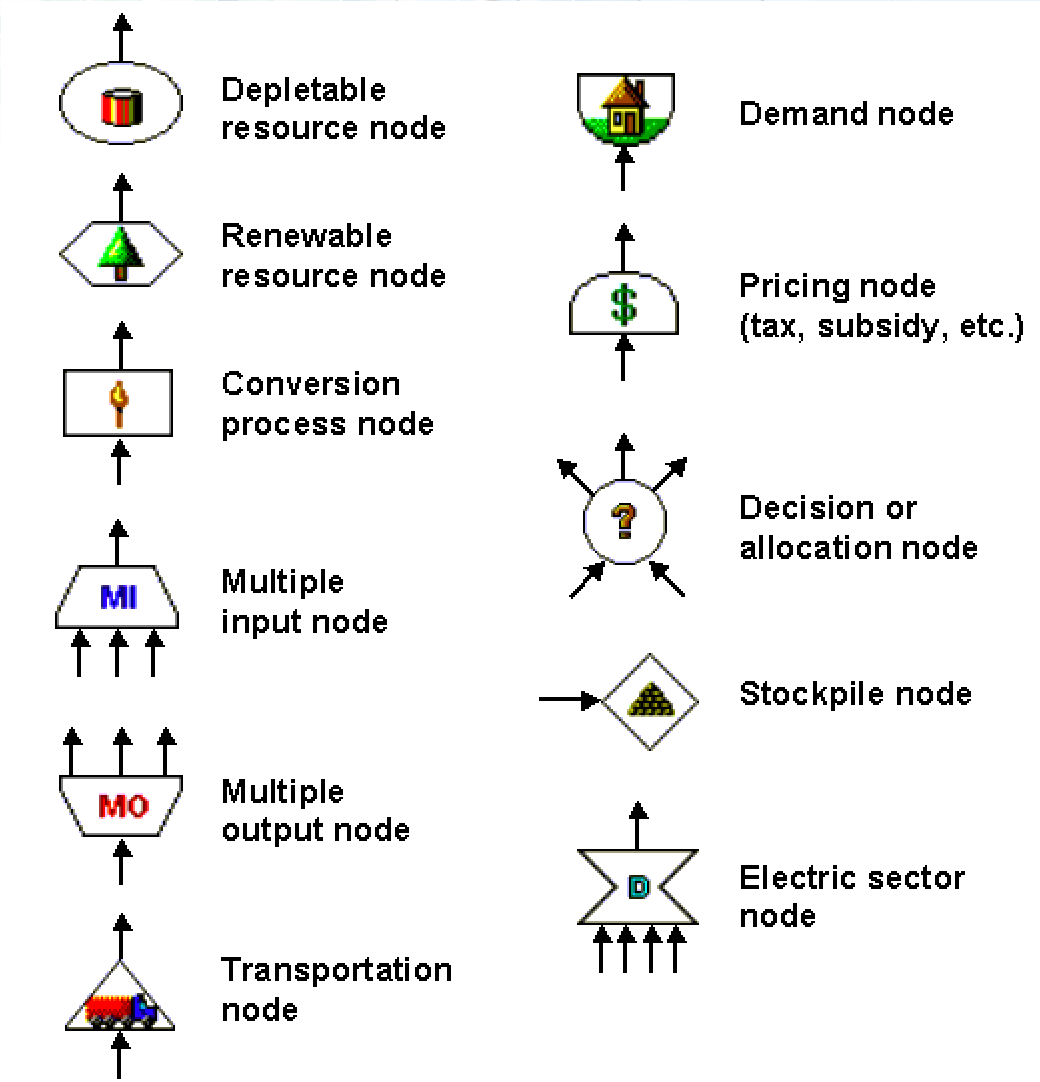
ENPEP-BALANCE Uses an Energy Network to Simulate Energy Markets



Methodology of Economic Cost Calculations

- Annual economic costs are computed from ENPEP-BALANCE input and output data for both network nodes and electric sector supply technologies
- For resources, resource costs (or fuel costs) are considered
- For technologies, new capital and O&M expenditures are considered
- When computing economic costs past investments are not considered
  - Base year costs are considered to be sunk investments
  - This differs from financial costs which include payments to capital
- Retiring & replacing an existing technology
  - Base year ages of technology (unknown in BALANCE) are assumed to be evenly distributed in the range between 0 and LIFETIME
  - This assumption is simplistic but the user can override its consequences

Every BALANCE Node is Specific in Terms of System Costs



Cost Calculations: Depletable Resource Node

- BALANCE uses a quadratic supply curve of energy production costs to determine the market price that the module assigns to the single output link of the depletable resource node:

$$Pt = A(\sum Q) \times (1 + Rt) + B \times Qt + C \times (Qt)2$$

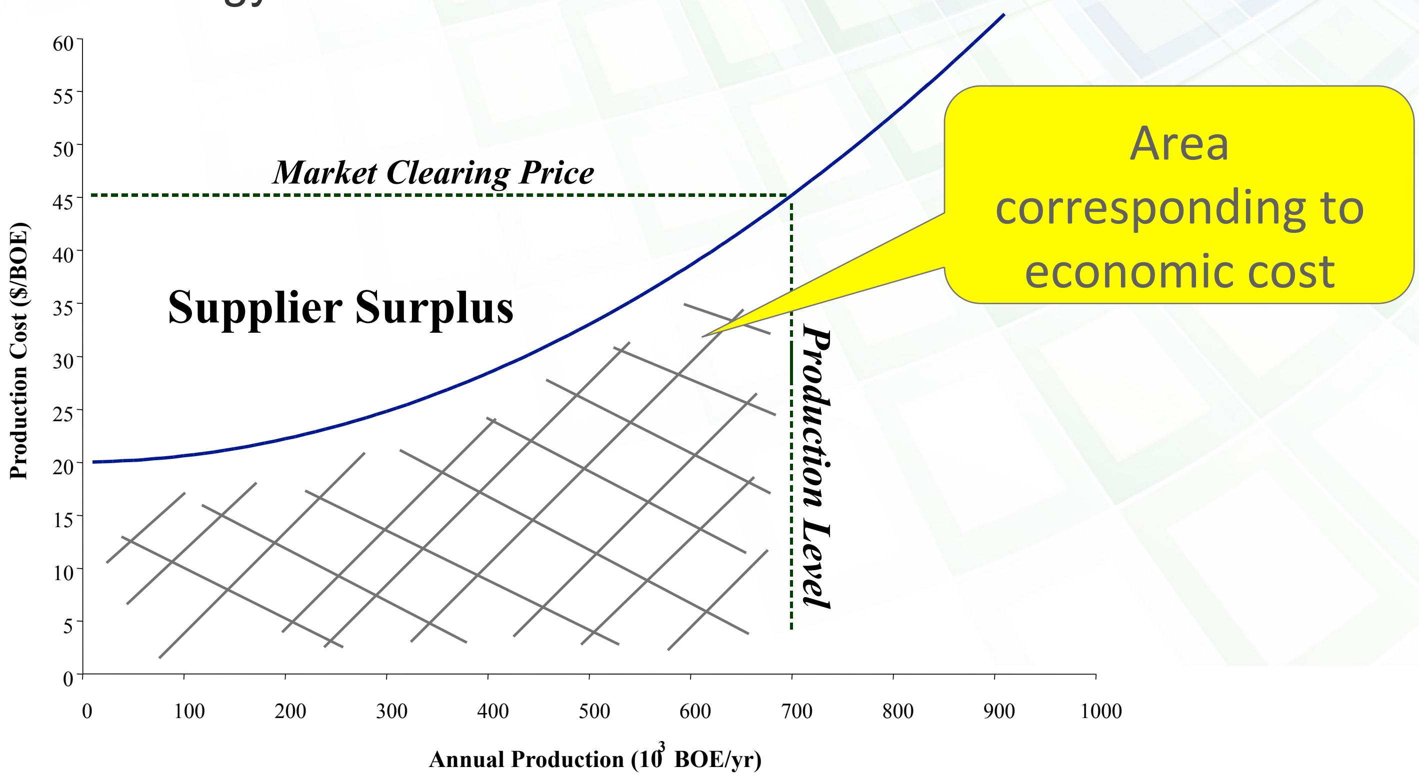
- BALANCE assumes that all suppliers will receive the end-of-year marginal cost for all energy sales. Therefore, total annual revenues for suppliers equals the market price times the quantity of energy sold or imported in a year:

$$Revenue = Pt \times Qt$$

- The total annual economic cost for extracting an energy resource is the area under the supply curve from zero production to the total annual production, i.e., the cost is not equivalent to the supplier revenue

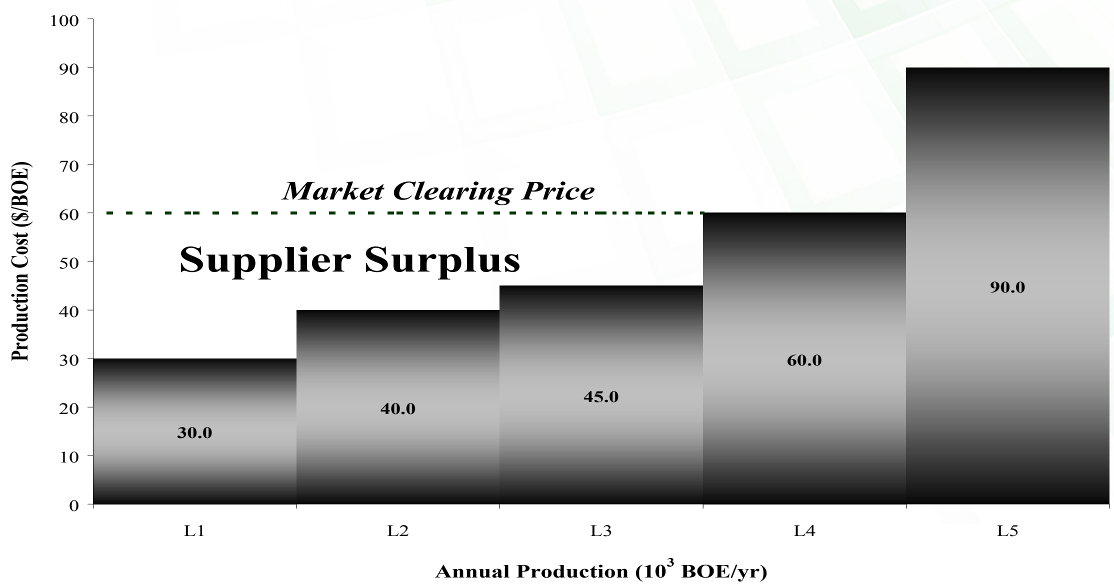
Calculations: Depletable Resource Node

- In network calculations, BALANCE uses a financial approach and assumes that suppliers receive the market clearing price
- Thus, there is a difference between economic resource extraction costs and supplier revenues based on the market clearing price
- The supplier surplus is the economic rent or money received by energy producers that is above the cost of energy extraction



Cost calculations: *Renewable Resource Node*

- The renewable resource node represents production costs as a step function:
  - *cost = C1 if Qt <= L1*
  - *cost = C2 if L1 < Qt <= L2*
  - *cost = C3 if L2 < Qt <= L3*
  - *…*
- Otherwise, the same basis economic principles that were applied to depletable resource nodes pertain to renewable resource nodes



Cost calculations: Simple Conversion Node

- The economic costs for a single input/single output node include only incremental cost components that are required for the conversion process
  - New capital expenditures
  - O&M costs
- There is not a separate economic cost calculation for energy consumption (fuel input) in the conversion process
  - These costs are accounted for in the depletable and renewable resource nodes
  - The more efficient a conversion process, the less fuel it consumes and, therefore, the lower the economic costs (accounted for in the resource nodes)
- BALANCE input data are sufficient to calculate variable costs
- However, for capital costs there is a problem…

Cost Calculations: Simple Conversion Node

- The market price used in BALANCE can include past investments (amortization of previous expenses)
  - However, past investments are **not** considered to be part of economic costs; only new expenditures are considered
  - Base year capital cost data are ignored in economic cost calculations

- For conversion processes, BALANCE does not know the **age distribution** of the units existing in the base year
  - Lifetime is defined (not age)
  - Additional assumptions are needed

- For conversion processes, BALANCE knows energy flows starting from the base year

- The number of operating units can be estimated from energy flows, unit capacity, and unit capacity factor

Cost calculations: Simple Conversion Node

- The most important assumptions related to the age estimate are:
  - The number of units in the base year is estimated based on the entered unit capacity and capacity factor (rounded up):

    N = energy_flow (base year) / CAP / CF

  - The units existing in the base year are assumed to have been constructed uniformly over time (the unit life is known):

    LIFE = 10 years, N = 20 units => **2 units / year** were constructed in the past

  - Based on the age estimate for existing units, their retirement schedule is calculated
  - New units coming on line are estimated using a) the demand for energy in the current year and b) known number of units existing in the previous year

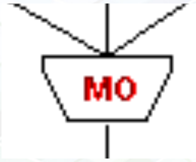
    Nnew (t) = energy_flow (t) / CAP / CF – Nold(t-1)

  - After a new unit enters the system, its age is calculated year by year;
  - A salvage value is calculated for all new units if it operates beyond the end of the simulation period

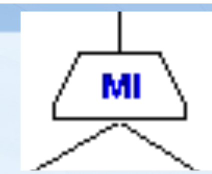
Cost Calculations: Simple Conversion Node

- **<u>Important consequence</u>**: typical unit capacity, typical unit capacity factor, and unit lifetime are critical for cost calculations; if economic costs are to be estimated, these parameters must be defined very carefully

- Similarly, O&M & capital costs must be defined accurately
  - Amortization of capital into O&M costs is possible from the viewpoint of price calculations, but not from the viewpoint of economic costs



Cost Calculations: Multi-input & Multi-output Node



- For cost calculations, there is no principal difference between the simple conversion process and complex conversion processes (multi-input and multi-output)

- The costs are:
  - Variable O&M costs (no fixed costs for conversion processes)
  - Capital O&M costs

- Past investments are not considered (including the base year)

- The number and age of existing units are estimated similar to the simple conversion process
  - Includes energy flows from the network, the capacity of single unit, and the unit capacity factor

Cost Calculations: Stockpile Node

- Normally, the annual amount of energy processed at a node exactly matches the demand for an energy product up to its annual production
  - The only exception is at the single input/multiple output (i.e., refinery) node
  - The refinery production level is based on the demand for only one of the output products (OSL). When the production of the other refined products exceeds the demand for the product, the excess is stored at a stockpile node
  - If not sent to exports, products remain in the stockpile until the next year
- BALANCE stockpiles are not ‘real’ stockpiles – they are a modeling convention designed for refineries
  - Accordingly, there are no capital expenses or O&M costs associated with a stockpile node
  - Actual stockpile costs if any should be calculated separately or included in the cost parameters of the refinery
- However, in reality the stockpiling of an energy product does affect economic costs
  - When an energy product is stockpiled, costs are incurred in the year when it was produced, but benefits will not occur until sometime in the future
  - The time value of money (NPV) is involved
  - If the production of the stockpiled product were delayed until the time of consumption, the economic cost would be lower in the NPV calculation

Cost Calculations: Decision Node

- In BALANCE, there are no costs associated with making choices at a decision node. The node only determines the supply structure for a given demand based on a market simulation algorithm

- However, BALANCE inputs for decision nodes have a potentially large influence on total economic costs:
  - Example 1: when a priority is placed on a product it satisfies the entire energy demand within the production limits of the energy product. The market share of the priority product is maximized regardless of the market price or the economic cost of production. When the priority product has a high economic cost of production relative to alternative supplies, it places a burden on the economic system

  - Example 2: if the lag parameter is set to zero, the market share typically remains constant regardless of the price of competing products. This insensitivity to market prices often results in a misalignment between energy supply resources and consumption levels. A rigid infrastructure that does not change in response to economic price signals can be very expensive

Cost Calculations: Decision Node (cont'd)

– Example 3: The price sensitivity is an important market share parameter that influences energy consumption patterns. When the parameter is set to a high value (e.g., 15), there are typically large differences in the market shares among the competing products. On the other hand, a small value assigned to the price sensitivity results in relatively small differences among the market shares. In general, the higher the price sensitivity the lower the economic cost when market prices reflect the marginal economic cost of energy production

– Example 4: The set of premium multipliers that are entered into BALANCE influence the market shares of energy alternatives by effectively raising (i.e., multiplier greater than 1.0) or lowering (i.e., multiplier less than 1.0) the price of competing energy products in the market share equation. This distorts the usual economic signals and can result in a higher system costs

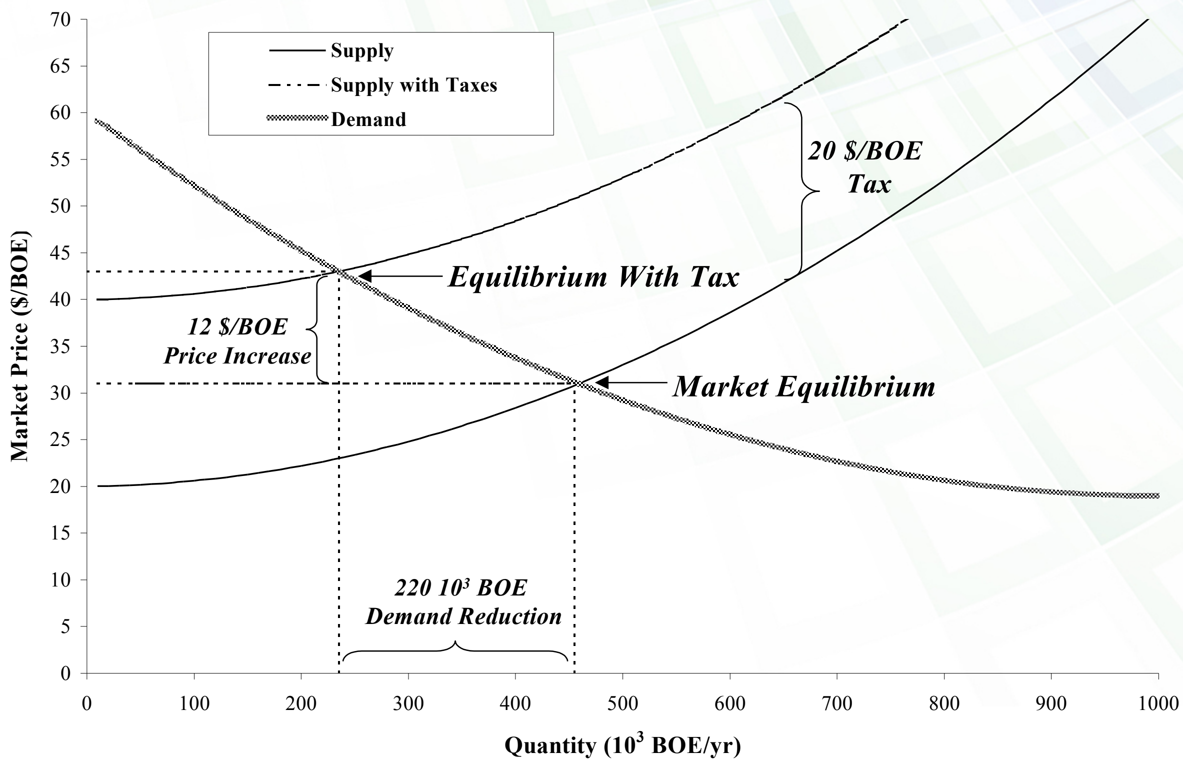
- **Conclusion**: the energy system simulated by the BALANCE market share algorithm produces a result that is not necessarily the least-cost development strategy in terms of economic cost. With economic costs one can study reasons and implications of the difference between the market behavior and the least-cost development path

Cost Calculations: Pricing Nodes and Emission Tax

- A pricing policy node models either the market price increase resulting from taxation or the decrease in price when costs are subsidized
- The price output from a policy node therefore does not reflect the economic cost of bringing an energy product to the market in terms of labor and material expenditures
- By changing the relative market prices for energy products both taxes and subsidies affect the economics of the energy system
- Economic costs are affected since taxes and subsidies shift production from products that have high taxes to products that have either lower taxes or are subsidized
- Taxes can be used to reflex externalities

Cost Calculations: Pricing Nodes and Emission Tax

- The BALANCE module also includes emission taxes at several types of nodes. As transfer payments, these taxes are not included as economic costs
- To the extent that these taxes reflect actual costs to society that are not captured by the marketplace, these emission taxes may reflect economic costs (external costs)



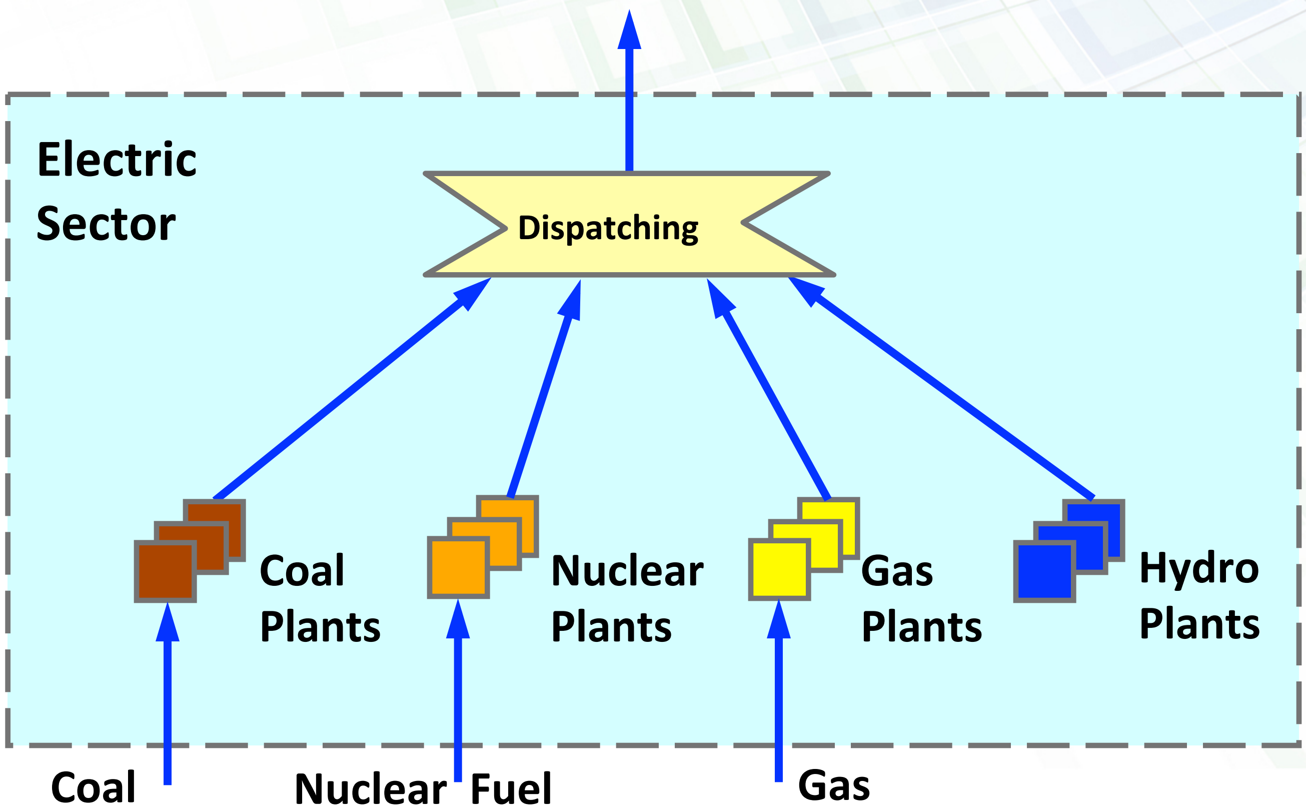
Cost Calculations: Demand Nodes

- Demand nodes model the demand for either final or useful energy
  - There is one input link into this node and there are no output links
  - There are no costs associated with this node

- Demand growth rates are often used to model sectoral shifts in the economy over time and the impact of energy efficiency measures on energy consumption and costs
  - When the economy moves toward industries and activities that are less energy intensive, resource extraction and energy imports typically decrease and the total economic cost of energy is reduced
  - Also through product quality improvements the value added per unit of output increases. Through this mechanism economies can reduce energy consumption while increasing the gross national product. This feature <u>is captured</u> by the current methodology

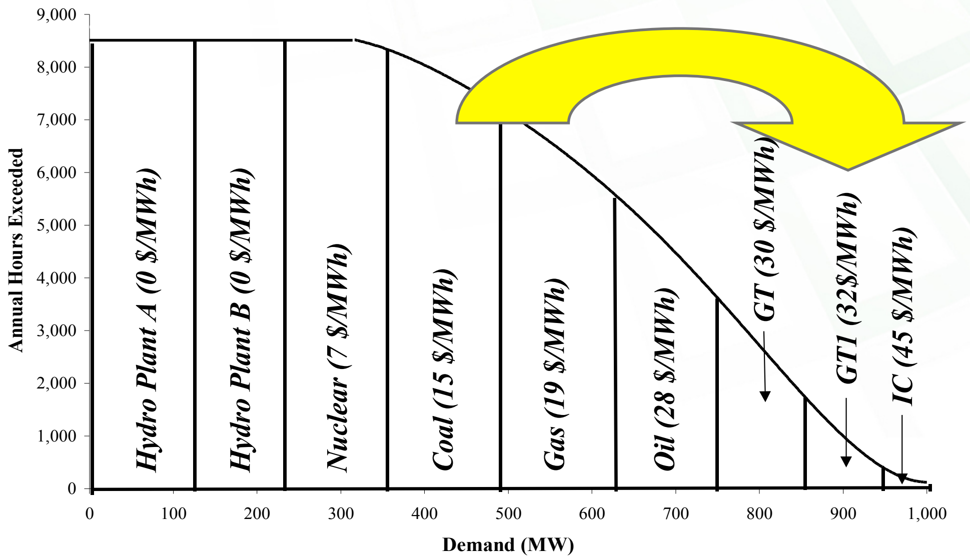
Cost Calculations: Electric Sector Nodes

- Two issues should be considered for the electric sector (with dispatch):
  - The dispatch pattern and its impact on economic costs
  - Cost parameters of power units (thermal and hydro)



Cost Calculations: Electric Sector Dispatch

- All hydropower resources are loaded first and an economic dispatch order enters thermal units into the LDC (in accordance with the sum of fuel costs & variable O&M costs)
- When the market prices for fuels reflect economic costs, the default loading order normally results in the lowest total economic cost for the sector
- However, the loading order can be adjusted according to model inputs. It typically increases generation from more expensive units and decreases generation from units with lower costs. Consequently, reordering the dispatch typically increases economic costs. This reordering of units may be necessary to account for technical limitations or reliability considerations that are not directly modeled by BALANCE



Cost Calculations: Electric Sector

- Economic cost calculations for power units are similar to those for conversion processes, but they are extended and more straightforward because the BALANCE cost data fit better to the task
- The costs are:
  - Fixed O&M costs (defined in BALANCE data)
  - Variable O&M costs (defined in BALANCE data)
  - Capital costs (defined in BALANCE data)
  - Costs of unit conversions (refurbishment etc. – also defined)
- Past investments are not considered (base year included)
- The number and age of existing units do not have to be estimated – they are part of BALANCE data for the electric sector

- When entering refurbishment costs (after the base year), remember that such costs are at present treated as cumulative costs, not as incremental costs

Net Present Value (NPV) Calculation

- All annual economic costs over time are discounted to the base year using an NPV equation
  - The NPV calculation accounts for the time value of money whereby a dollar spent today has a higher economic value than a dollar expenditure in the future
- The computation of the NPV is based on a user input value for the real discount rate
  - Capital costs are incurred at the beginning of a year
  - Fuel and O&M costs are assumed to occur in the middle of a year

$$
\begin{aligned}
NPV = & \sum_{dn} \sum_{y} DEC_{dn,y} * (1 + DR)^{[1/(y-by)]} + \sum_{rn} \sum_{y} REC_{rn,y} * (1 + DR)^{[1/(y-by)]} + \\
& + \sum_{cp} \sum_{y} TCC_{cp,y} * (1 + DR)^{[1/(y-by)]} + \sum_{cp} \sum_{y} TVC_{cp,y} * (1 + DR)^{[1/(y-by)]} + \\
& + \sum_{u} \sum_{y} TPVC_{u,y} * (1 + DR)^{[1/(y-by)]} + \sum_{u} \sum_{y} TPCC_{u,y} * (1 + DR)^{[1/(y-by)]} + \\
& + \sum_{u} \sum_{y} TPFC_{u,y} * (1 + DR)^{[1/(y-by)]} + \sum_{y} UEC_{y} * (1 + DR)^{[1/(y-by)]} - \\
& - \sum_{cp} \sum_{y} SV_{cp,y} - \sum_{u} \sum_{y} PSV_{u,y}
\end{aligned}
$$

Methodology of Cost Calculations - Summary

The table below shows a summary of different types of network elements and the components that are calculated by the economic cost methodology described:

Node/Power Plant Type	Capital	Fixed O&M	Variable O&M	Fuel & Energy	Unserved Energy	Salvage Value
Depletable Resource				✔		
Renewable Resource				✔		
Single Input/ Single Output	✔		✔			✔
Single Input/Multiple Output	✔		✔			✔
Multiple Input/Single Output	✔		✔			✔
Pricing Policy						
Decision						
Demand						
Stockpile						
Hydropower Unit	✔	✔				✔
Thermal Unit	✔	✔	✔			✔
Thermal Unit Conversions	✔	✔	✔			✔

Methodology of Cost Calculations

A detailed methodology document provides a description of the approach to the calculation of system costs:

IAEA Working Material

METHODOLOGY FOR COMPUTING ECONOMIC COSTS OF AN ENERGY SYSTEM WITH THE BALANCE MODULE OF ENPEP

Software Implementation

- The BALANCE algorithm (BAL.exe) produces information necessary for the calculation of economic costs. It produces three additional output files for every BALANCE run
  - EconResource.out (cost information for resource nodes),
  - EconProcess.out (cost information for conversion nodes),
  - EconElectric.out (cost information for the ELECTRIC sub-module of BALANCE)

- As output, a new file, NPV.out is generated. It contains annual values of all economic costs for every process and for every simulation year in addition to the corresponding NPVs

- You will need to import the NPV.out file into Excel to analyze system costs

A Clean Excel Sheet is Created; First Part is for Resources, Second Part for Processes

Microsoft Excel - NPV.out

File Edit View Insert Format Tools Data Window Help

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	A	B	C	D	E	F	G	H	I	J	K	L
1	YEAR	SECTOR	NODE	TYPE	CAPITAL	RESOURC	FIXEDOM	VARAIBLE	SALVAGE	ECONOMI	UNSERVE	NPV
2					$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
3	1998	SEC1	Coal	RS	0	5000	0	0	0	0	0	4767.31
4	1998	SEC1	Oil	RS	0	10000	0	0	0	0	0	9534.63
5	1999	SEC1	Coal	RS	0	5000	0	0	0	0	0	4333.92
6	1999	SEC1	Oil	RS	0	10000	0	0	0	0	0	8667.84
7	2000	SEC1	Coal	RS	0	5000	0	0	0	0	0	3939.93
8	2000	SEC1	Oil	RS	0	10000	0	0	0	0	0	7879.86
9	2001	SEC1	Coal	RS	0	5000	0	0	0	0	0	3581.75
10	2001	SEC1	Oil	RS	0	10000	0	0	0	0	0	7163.51
11	2002	SEC1	Coal	RS	0	5000	0	0	0	0	0	3256.14
12	2002	SEC1	Oil	RS	0	10000	0	0	0	0	0	6512.28
13	2003	SEC1	Coal	RS	0	5000	0	0	0	0	0	2960.13
14	2003	SEC1	Oil	RS	0	10000	0	0	0	0	0	5920.25
15	2004	SEC1	Coal	RS	0	5000	0	0	0	0	0	2691.02
16	2004	SEC1	Oil	RS	0	10000	0	0	0	0	0	5382.05
17	2005	SEC1	Coal	RS	0	5000	0	0	0	0	0	2446.39
18	2005	SEC1	Oil	RS	0	10000	0	0	0	0	0	4892.77
19	2006	SEC1	Coal	RS	0	5000	0	0	0	0	0	2223.99