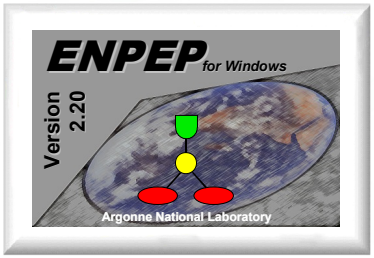
ENPEP-BALANCE: Expanded BALANCE Network with Refinery

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



Guenter CONZELMANN
Center for Energy, Environmental, and Economic Systems Analysis
Decision and Information Sciences Division (DIS)
ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, IL 60439
guenter@anl.gov; ++1-630-252-7173

Refinery Presentation with the BALANCE Module

- Introduction: Refinery Node in BALANCE
  - how to model refineries and other energy facilities of the one-to-several type (one energy input, several energy outputs)

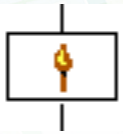
- Example of Network Development (a standard Refinery Case)

The Following Node Types are Available to Construct Cases

- Demand

Refinery node

- Conversion Processes



Single In-/Output

Multi Output

Multi Input

Transport

- Resource Processes

Depletable

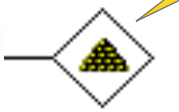
Renewable

Stockpilen ode

- Economic Processes

Decision/Allocation

Pricing



Stockpile

- Electricity Dispatch and Thermal and Hydro Units

Central Dispatch

Thermal Unit

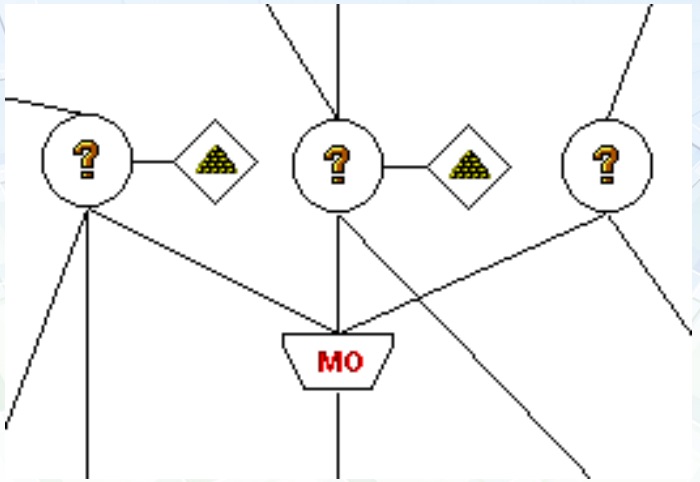
Hydro Unit

Multiple-Output Node (Refinery): Background

- Typically designed for one (several) primary product(s)
  - Refineries: Gasoline (U.S.), also diesel (e.g., Europe)
  - Cogeneration: Steam, with electricity as by-product
  - Which is it in your case?
- Typically, multi-output processes are designed for a specific *"fixed"* output slate (O/I ratios)
  - While there is some flexibility to adjust for seasonal/annual fluctuations, major changes would require major process modifications
  - Example Cogeneration: Designed for a limited-range heat-electricity output mix
  - Example Refinery: Designed to meet a certain mix of refined products
- If the product demand mix changes, there may be over- or under-production (imbalance) of one or more of the outputs
  - Need a way to balance supply/demand
  - Refinery: Use of tank farms/stockpiles to deal with seasonal fluctuations; imports
  - Cogeneration: backup boiler, grid-electricity

Multiple Output Process / Oil Refinery: Technical Properties

- A multiple output node can be used to model any process that has one input and up to 15 outputs that are produced at fixed output ratios
- Examples for multiple output nodes are
  - oil refinery with crude oil as input and gasoline, diesel, fuel oil, LPG, and kerosene as outputs
  - natural gas processing with raw gas as input and dry gas and liquids as outputs
  - co-generation in with biomass as input and electricity and steam as outputs



- ***Output/Input Ratio (O/I)*** represents the conversion efficiency for each of the output products
- The sum of all O/I ratios ***MUST NOT*** exceed 1.0

Technical Properties | Economic Properties | Associated Links

Year	Output Link Abbreviation	Output/Input Ratio	Sizing Link	Single Plant Input Capacity (kBOE)	All Plants Input Capacity (kBOE)	Typical Capacity Factor (Fraction)
2000	DIESL	0.450	DIESL	100.000	1,000.000	1.000
	FOIL	0.200				
	LPG	0.300				
2001	DIESL					
	FOIL					
	LPG					

- If the refinery operates at 5% total losses, the sum of all O/I ratios is 0.95

Multiple Output Process: Technical Properties (cont'd)

- O/I ratios are fixed => for some links, a multiple output node may produce either more or less product than is demanded

Technical Properties | Economic Properties | Associated Links

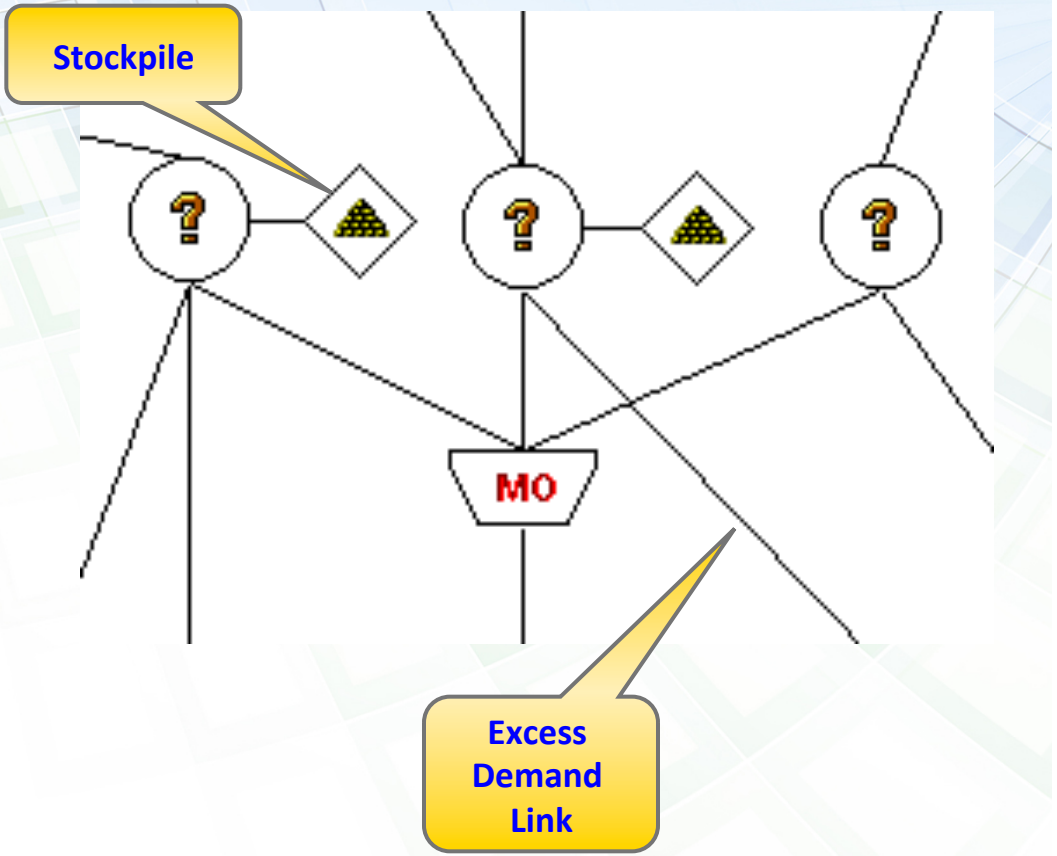
Year	Output Link Abbreviation	Output/Input Ratio	Sizing Link	Single Plant Input Capacity (kBOE)	All Plants Input Capacity (kBOE)	Typical Capacity Factor (Fraction)
2000	DIESL	0.450	DIESL	100.000	1,000.000	1.000
	FOIL	0.200				
	LPG	0.300				
2001	DIESL					
	FOIL					
	LPG					
2002	DIESL					

- This occurs when the mix of product demand does not exactly match the refinery product slate which is assumed to be more or less inflexible

- Node assumes that input requirements are based on the demand requirements of one of the products; this particular product is referred to as the ***Sizing Link*** product (any of the output links, but often gasoline or diesel); the demand for the sizing product is met **EXACTLY** (unless the refinery runs at capacity and cannot keep up with the growth in demand in that particular product)

Multiple Output Process: Technical Properties (cont'd)

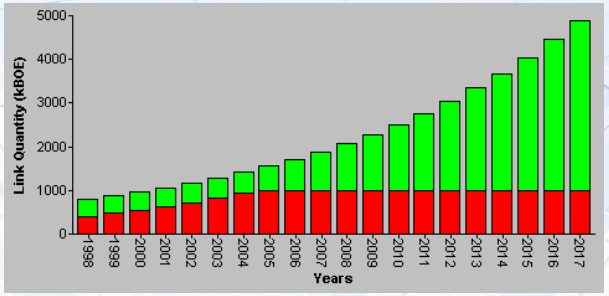
- Demands for the other products may be exceeded or may not be met
- If the quantity of an output product exceeds its demand, it can be stockpiled for possible consumption in the future or exported
- If the refinery output is less than the demand, you need to tell the model where to obtain the remaining supply to make up for the shortfall using an ***Excess Demand Link***



- ***Single Plant Input Capacity*** represents annual physical input limits of ONE unit; the value is used in levelizing investment cost and NPV calculations

Multiple Output Process: Technical Properties (cont'd)

- ***All Plants Input Capacity*** is the maximum input of all the units
  - when this limit is reached, the model will switch to other options to meet the growing demand
  - if other options also reach capacities, the model will issue a warning



- ***Typical Capacity Factor*** represents the fraction of the year this process typically operates; a value of 1.0 equals 8760 hours; used in price calculations and NPV calculations to compute the number of units on-line and total investment costs
- For subsequent years, only enter values when characteristics change

Technical Properties | Economic Properties | Associated Links

Year	Output Link Abbreviation	Output/Input Ratio	Sizing Link	Single Plant Input Capacity (kBOE)	All Plants Input Capacity (kBOE)	Typical Capacity Factor (Fraction)
2000	DIESL	0.450	DIESL	100.000	1,000.000	1.000
	FOIL	0.200				
	LPG	0.300				
2001	DIESL					
	FOIL					

Multiple Output Process: Economic Properties

Technical Properties | Economic Properties | Associated Links

Year	Output Link Abbrev.	Price Ratio	Cost Recovery Link	Price Reference Link	Single Plant Capital Investment ($1000)	Operating and Maintenance Cost ($/BOE)	Life Expectancy (Years)	Interest Rate (Fraction)
2000	DIESL	1.000	☑		10,000.000	10.000	40	0.100
	FOIL	0.900	☐	DIESL				
	LPG	1.100	☐	DIESL				
2001	DIESL		☐					
	FOIL		☐					
	LPG		☐					
2002	DIESL		☐					
	FOIL		☐					

- The ***Cost Recovery Link*** is the output link for which the model performs the price calculations, including the capital cost levelization (typically this link should be the same as the sizing link)
- ***Price Ratio*** allows to specify the price of each output link as either a multiple of the input link price, or a multiple of the price of the cost recovery link
- The price ratio for the cost recovery link should be 1.0
- ***Price Reference Link*** determines whether the price of a specific product is a multiple of the price on the input link (e.g., crude oil) or the price of the cost recovery link (e.g., gasoline)
- ***Single Plant Capital Investment*** represents the capital cost of **ONE** unit; this value is levelized and added to other costs, that is, fuel and O&M cost

Multiple Output Process Economic Properties (cont'd)

- ***Operating and Maintenance Cost (O&M)*** represents the cost of operating and maintaining **EACH** unit of this process; value is per unit of crude input

Technical Properties | Economic Properties | Associated Links

Year	Output Link Abbrev.	Price Ratio	Cost Recovery Link	Price Reference Link	Single Plant Capital Investment ($1000)	Operating and Maintenance Cost ($/BOE)	Life Expectancy (Years)	Interest Rate (Fraction)
2000	DIESL	1.000	☑		10,000.000	10.000	40	0.100
	FOIL	0.900	☐	DIESL				
	LPG	1.100	☐	DIESL				
2001	DIESL		☐					
	FOIL		☐					
	LPG		☐					
2002	DIESL		☐					
	FOIL		☐					

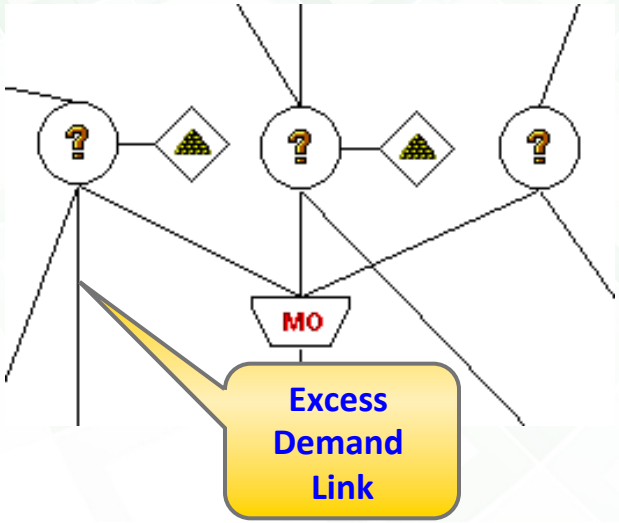
- ***Life Expectancy*** represents the average number of years a typical unit is expected to operate (equals the economic lifetime of the process); the value is used in levelizing the capital investment cost and to determine number of units online in NPV
- ***Interest Rate*** represents the annual interest rate used for levelizing (amortizing) the capital cost of a conversion process (cost of capital); values can be obtained from sources such as the World Bank
- For subsequent years, only enter values when characteristics change

Multiple Output Process Associated Links

- For all non-sizing links, the demand may be exceeded or may not be met by the refinery node
- For links where demand may not be met, the user needs to specify an ***Excess Demand Link***
- Excess demand links are typically import links, but, in general, can be any links in the network
- ***Control Link*** and ***Control Multiplier*** may be used to model some very rare situations, please consult the manual for more details
- *Please make sure that all refinery output links are directly connected to a decision node*

Technical Properties | Economic Properties | Associated Links

Year	Output Link Abbreviation	Excess Demand Link	Control Link	Control Multiplier	Associated Stockpile
2000	DIESL				
	FOIL	FOIL1			STK1
	LPG	LPG1			STK2
2001	DIESL				
	FOIL				STK1
	LPG				STK2



Multiple Output Process Equations

- Quantity equation: conversion from input to output using process output/input ratio (efficiency) for each output product

$$Q_{Out,\,L1} = Q_{In}\ x\ \eta_{L1}$$

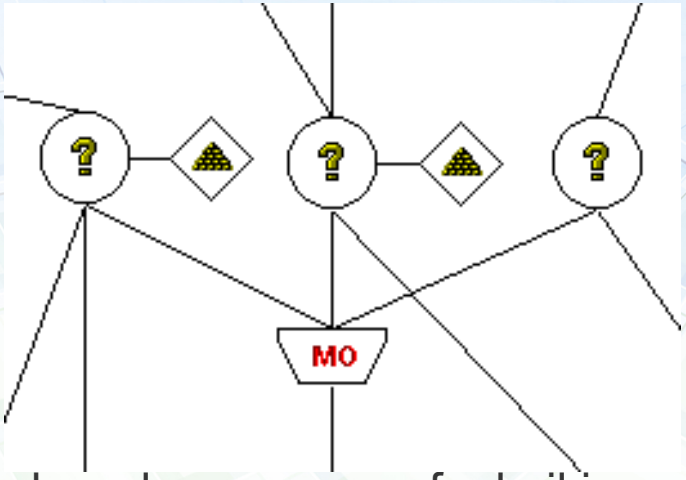
Qin: Energy input
Qout,L1: Energy output on link 1
η_{L1}: Output/input ratio (efficiency) for link 1

- Price equation: varies by the number of output links, example for 4 outputs with link 1 as the cost recovery link

$$P_{Out,L1} = \frac{\left\{\frac{P_{In}}{\eta_{L1}} + \frac{O\&M}{\eta_{L1}} + \left[\frac{TCI\ x\ CRF}{CAP_{single}\ x\ CF\ x\ \eta_{L1}}\right]\right\} x\ (1 + PFF)}{1 + \frac{PR_{L2}\ x\ \eta_{L2}}{\eta_{L1}} + \frac{PR_{L3}\ x\ \eta_{L3}}{\eta_{L1}} + \frac{PR_{L4}\ x\ \eta_{L4}}{\eta_{L1}}}$$

O&M: Operating and Maintenance Costs
TCI: Total Capital Investment
CAPsingle: Single Plant Output Capacity
CF: Capacity factor
CRF: Capital recovery factor
P_{in}: Price of input fuel
PFF: Profit factor
PR_{L2}: Price ratio link 2

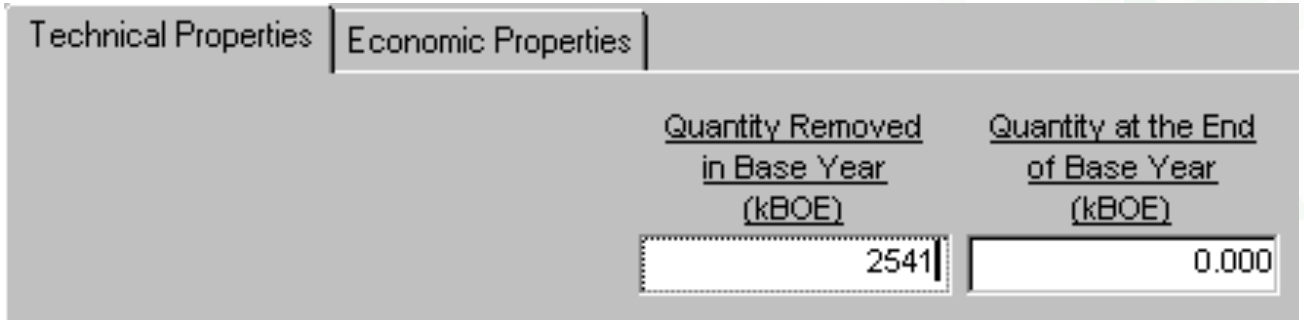
Stockpile Node



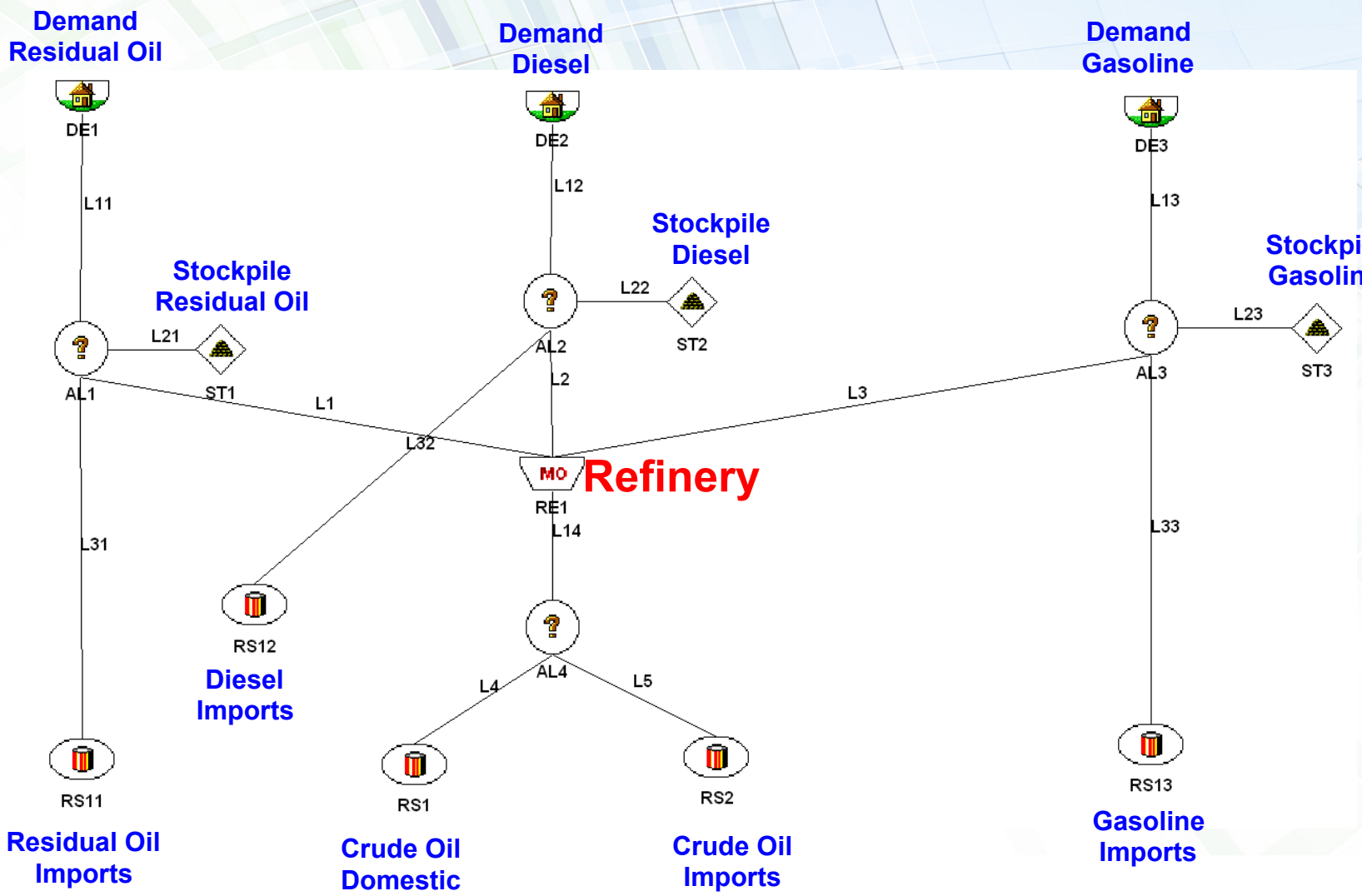
- A stockpile node is used to store the quantity of a particular type of a multiple-output-link product that exceeds its demand
- Stockpiles are used ONLY in conjunction with a multiple-output-link node (such as a refinery) and a decision node
- Example is a stockpile for heavy fuel oil from a refinery that is operated to meet gasoline demand and produces excess fuel oil in certain years
- Node has one link that functions as *both an input link* for filling the stockpile *and an output link* for reducing the stockpile
- However, the link MUST be defined as an **INPUT link to a decision node**, that is, "FROM" stockpile "TO" decision node connected to the same allocation node (no base year split needs to be defined)
- Any excess production of each output product of a multiple-output node is added to the existing amount in a corresponding stockpile each year in the simulation period

Stockpile Node Technical Properties

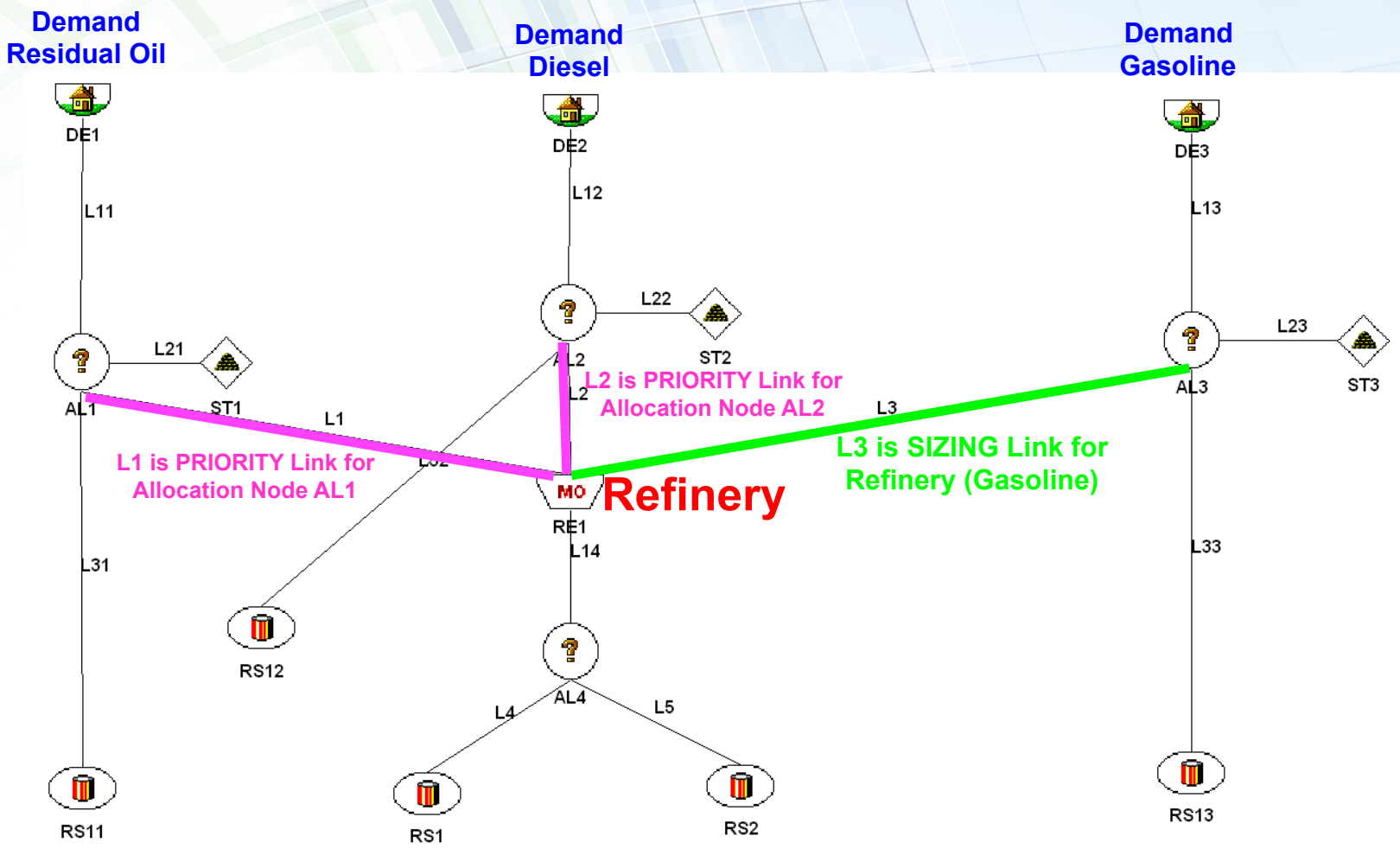
- Each year the decision node inspects the amount in the stockpile and removes as much as possible to meet the demand requirements; thus, the stockpiles are kept empty as possible - this is different from ‘real’ strategic stockpiles where the stocks maybe maintained at a certain level
- Any remaining demand is considered the net demand that the multiple-output process will need to meet
- ***Quantity Removed in Base Year*** represents the amount of a stockpiled product removed in the base year (positive value)
  - This value is negative if there is a flow into, rather than out of, the stockpile
- ***Quantity at End of Base Year*** represents the product amount remaining in the stockpile at the end of the base year
  - This value must be computed as the amount remaining in the stockpile after the product has been removed (or stored if flow is negative) in the base year



Refinery Case: Network Components



Refinery Case: Special Link Definitions



Refinery Case Input Data: Demand Nodes

- Base Year: 2000
- End Year: 2019 (study period = 20 years)
- *Note: You define base year and end year when you create a new case*

Demand Node	Annual Growth Rate (fraction)
DE1 (Residual Oil)	Blank each year (same as 0 each year)
DE2 (Diesel)	0.1 each year (10% growth)
DE3 (Gasoline)	0.05 each year (5% growth)

Refinery Case Input Data: Resource Nodes

Resource Node	Base Year Production (kBOE)	Capacity (kBOE)	Price Growth Rate (Fraction)	Curve Intercept or Base Year Price ($/BOE)	Curve Slope and Curve Quadratic
RS1 (Crude Dom.)	500	999,999	Blank (or 0) each year	30	Both are blank (or 0)
RS2 (Crude Imp)	500	999,999	Blank (or 0) each year	10	Both are blank (or 0)
RS11 (Res Imp)	100	999,999	Blank (or 0) each year	20	Both are blank (or 0)
RS12 (Diesel Imp)	100	999,999	Blank (or 0) each year	35	Both are blank (or 0)
RS13 (Gasoline Imp)	0	999,999	Blank (or 0) each year	40	Both are blank (or 0)

Refinery Case Input Data: Decision-Allocation Nodes

Decision Node	Priority	Premium Multiplier	Base Year Split	Price Sensitivity	Lag Parameter
AL1 (Residual Oil)	From refinery Priority 1 (L1)	All blank	1.0	2.0	1.0
AL2 (Diesel)	From refinery Priority 1(L2)	All blank	1.0	2.0	1.0
AL3 (Gasoline)	No (all blank)	All blank	1.0	2.0	1.0
AL4 (Crude Oil)	No (all blank)	All blank	1.0	2.0	1.0

Refinery Case Input Data: Refinery Node

Output Link	O/I Ratio	Sizing Link	Price Ratio	Cost Recovery Link	Price Reference Link	Excess Demand Link
Residual Oil (L1)	0.2		Blank	YES	Blank	Imp Residual (L31)
Diesel (L2)	0.3		1.5		Residual (L1)	Imp Diesel (L32)
Gasoline (L3)	0.5	YES	1.2		Crude (L14)	Imp Gasoline (L33)

Single Plant Input Capacity = 1000 kBOE
All Plants Input Capacity = 999,999
Typical Capacity Factor = 1.0
Single Plant Capital Investment: 0
O&M cost = 10 $/BOE input

Life expectancy = 40 years
Interest rate = 0.1
Profit factor = 0

ALL STOCKPILES: Leave all fields blank

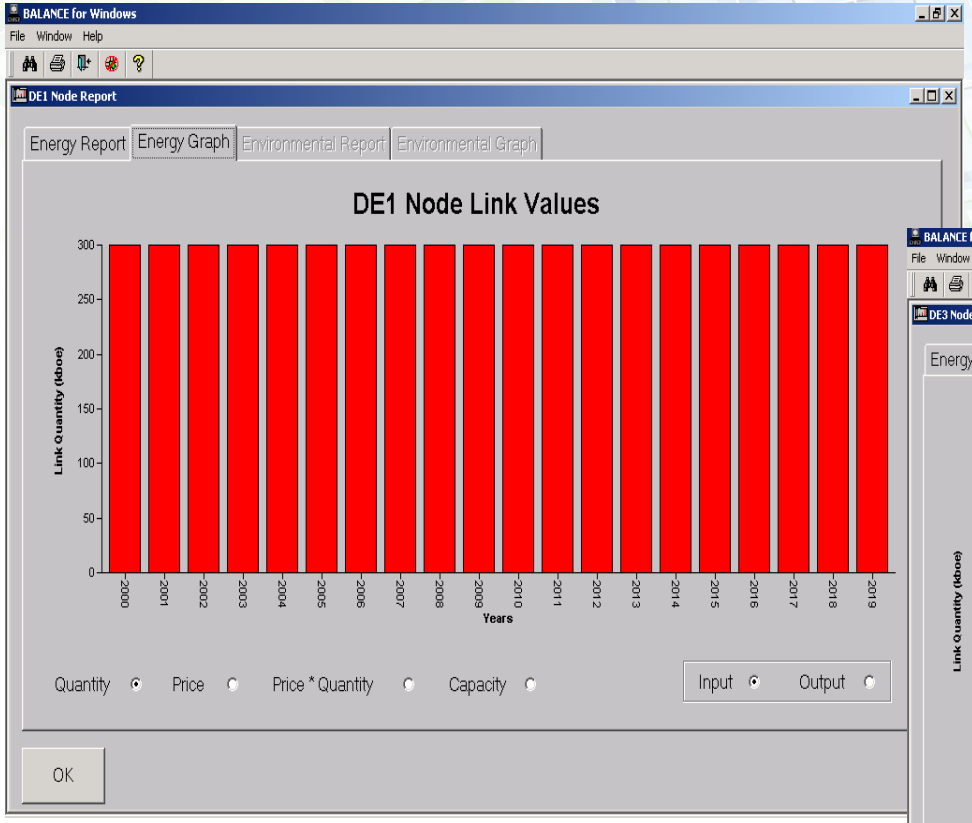
Steps in Developing and Running the REFINERY Case

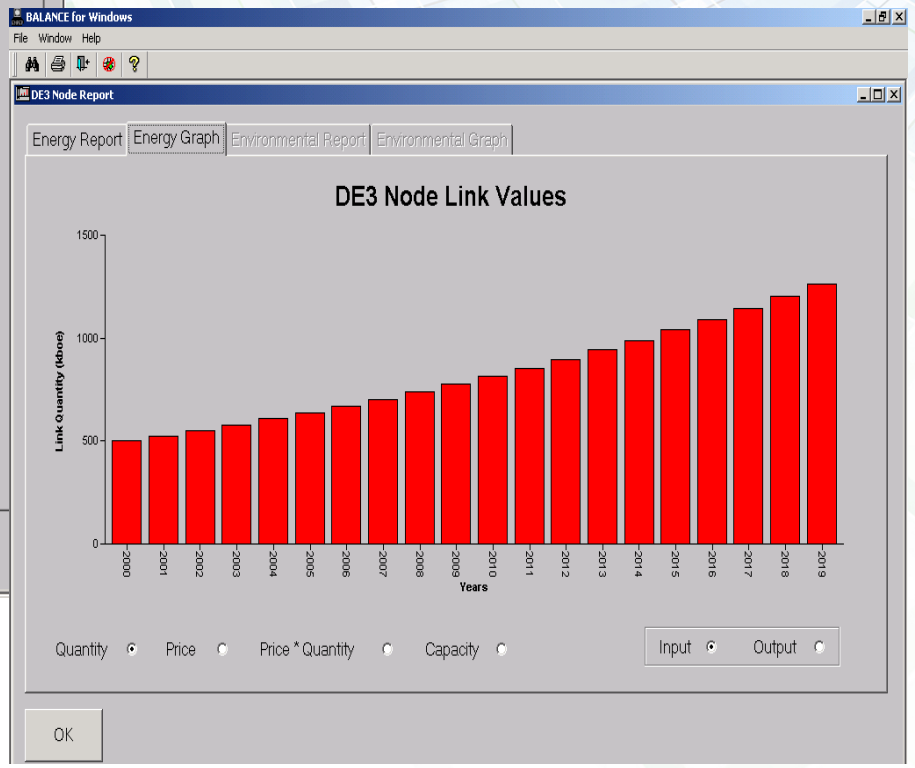
- Network design (done)
- Data definition (done)
- Run the up- and down-pass node visitation sequence
- Run the BALANCE main program
- Analysis of program output
  - Output files
  - Network report
  - Reports/graphs for processes and links

REFINERY Case: Results to Review

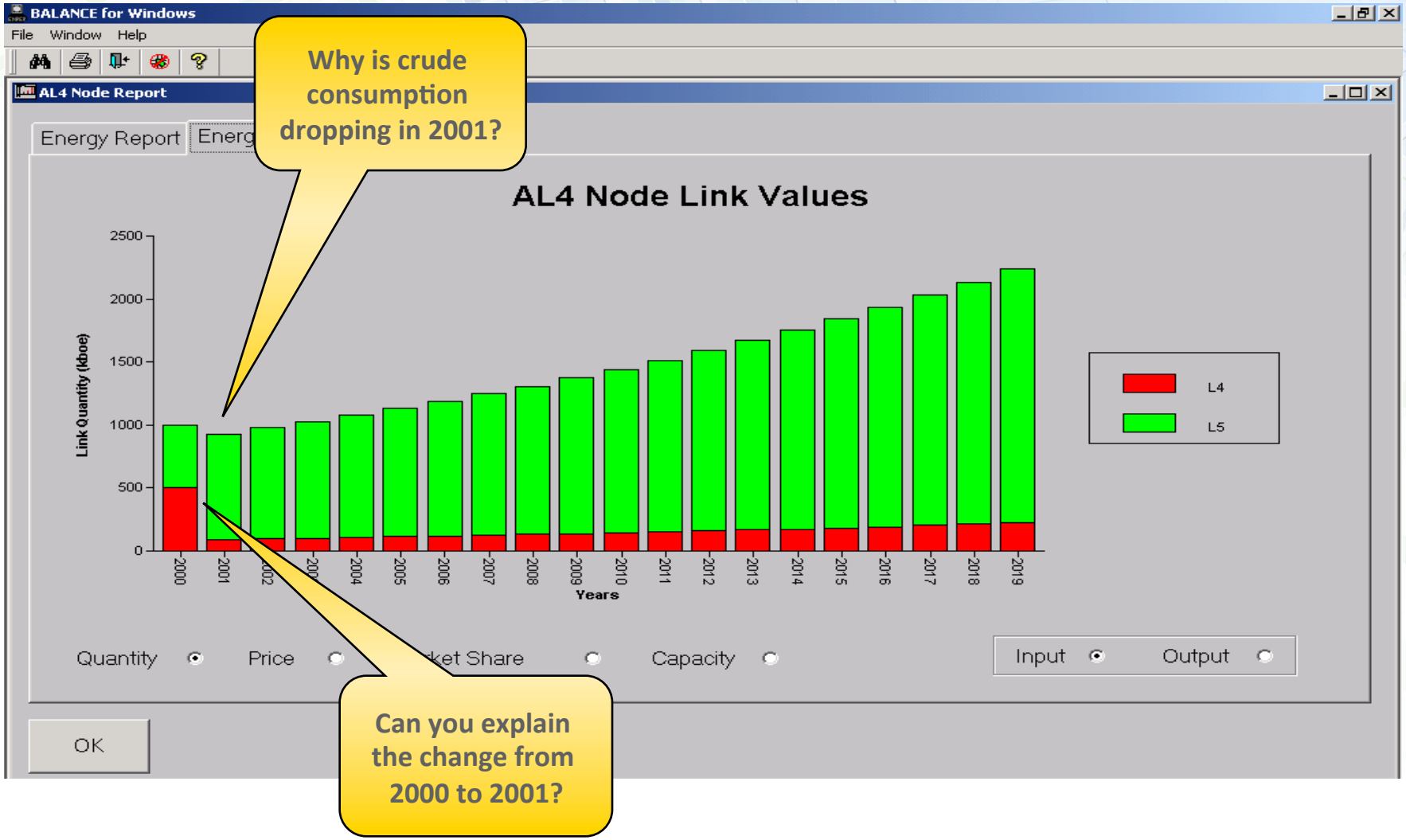
- Demand behavior (residual, diesel, gasoline)
- Resource consumption mix (crude oil)
- Behavior of refinery input and outputs
- Production mixes (refinery vs. imports)
- Resource prices (crude oil)
- Prices of refinery products (residual, diesel, gasoline)
- Prices to the consumer at the demand node (residual, diesel, gasoline)

Demand Behavior (Residual, Diesel, Gasoline)

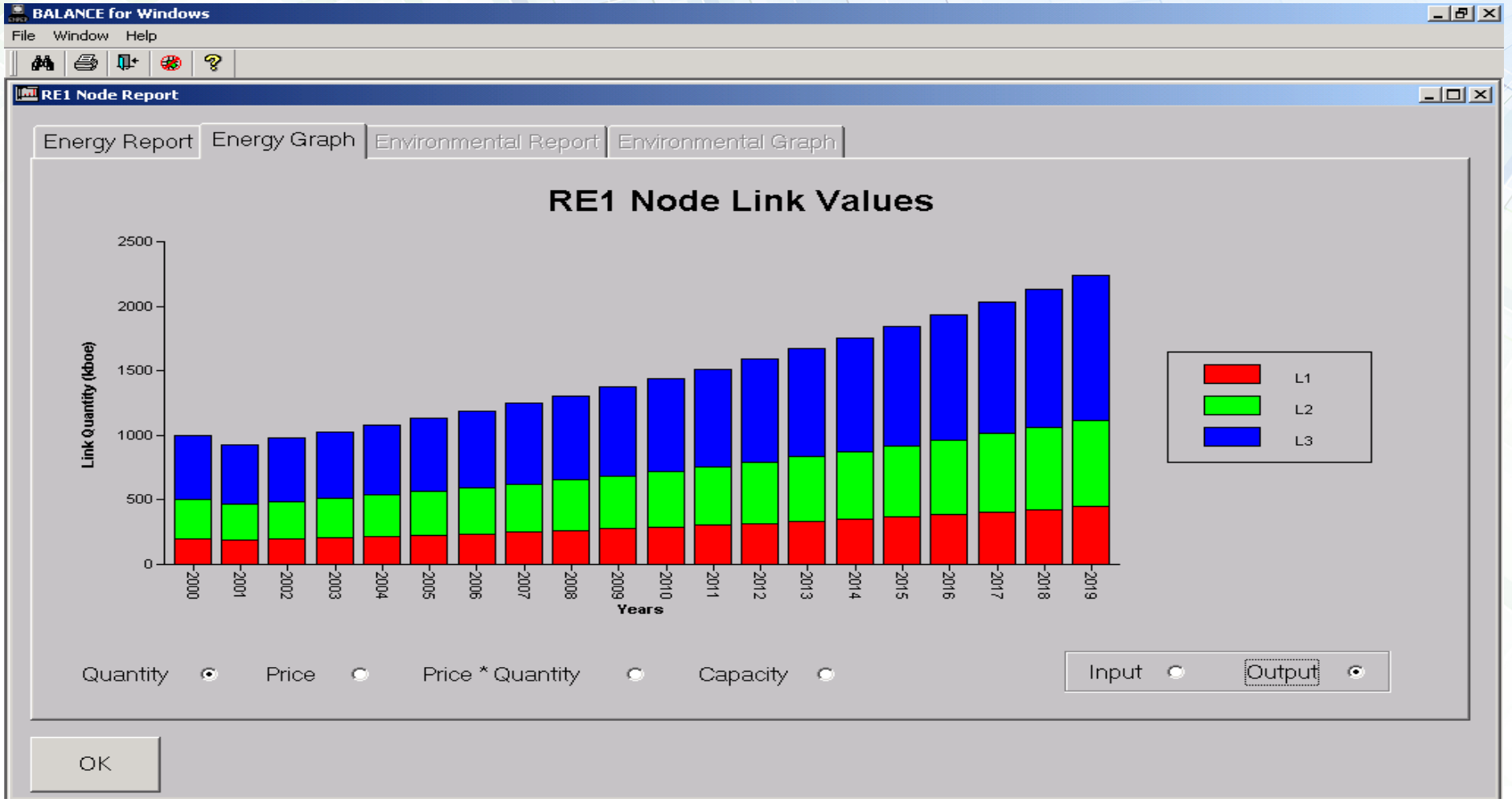




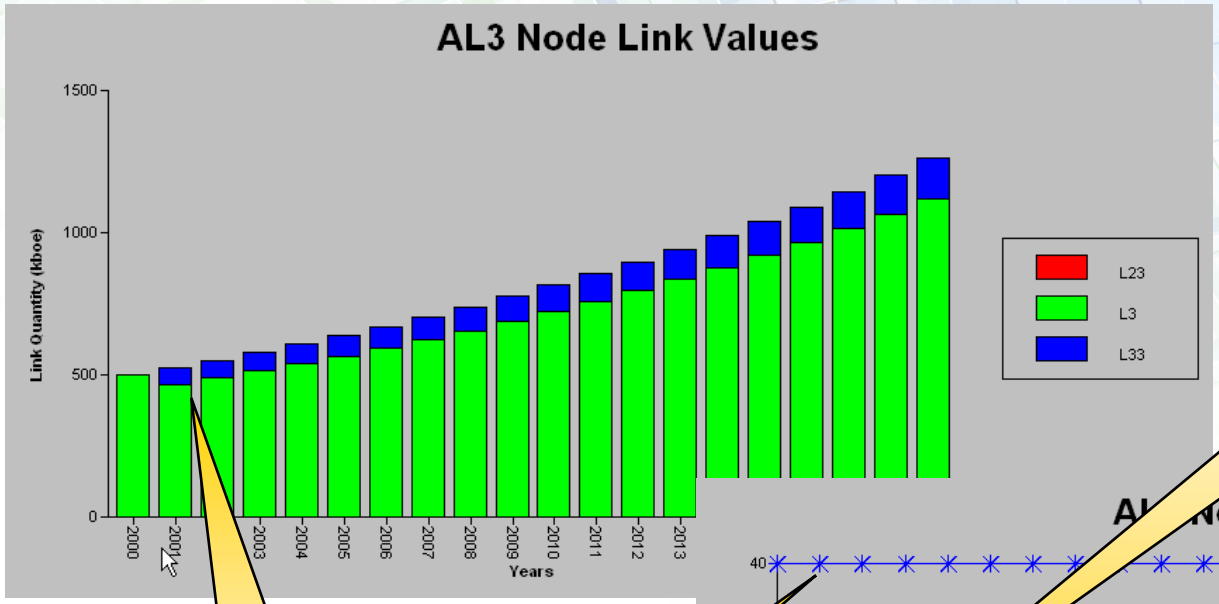
Resource Consumption Mix (Crude Oil)



Behavior of Refinery Input and Outputs

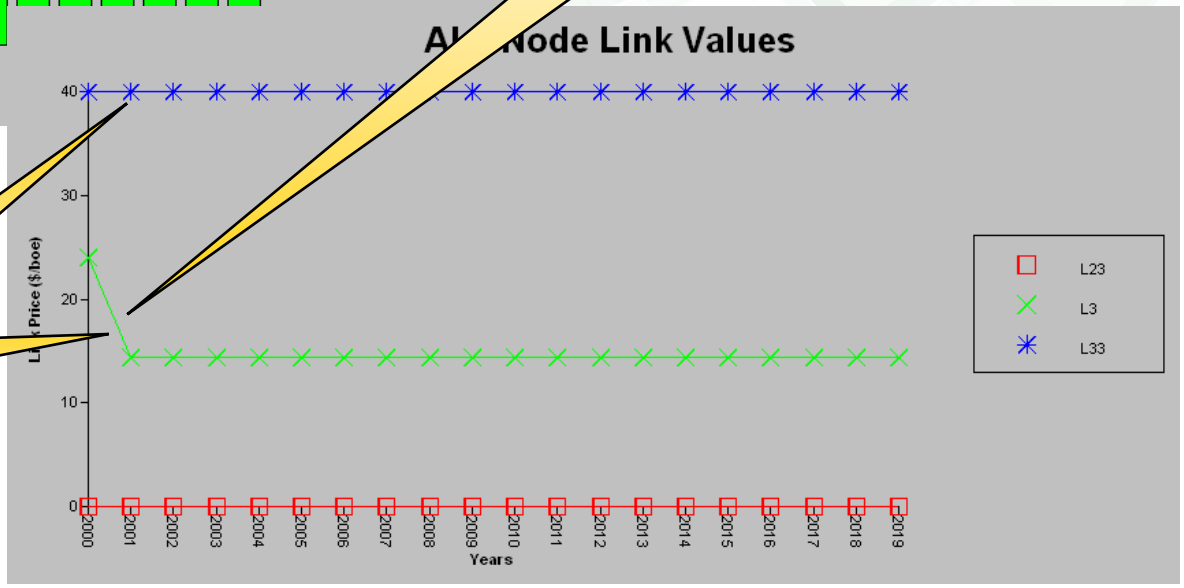


Production Mixes (Refinery vs. Imports) – Gasoline (Sizing)

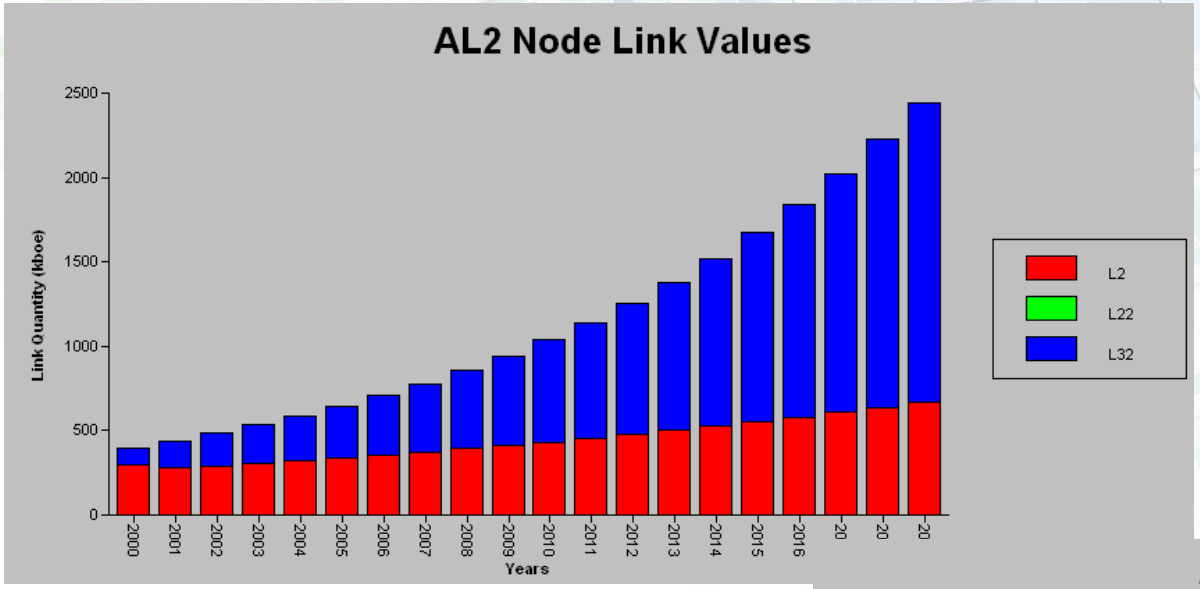


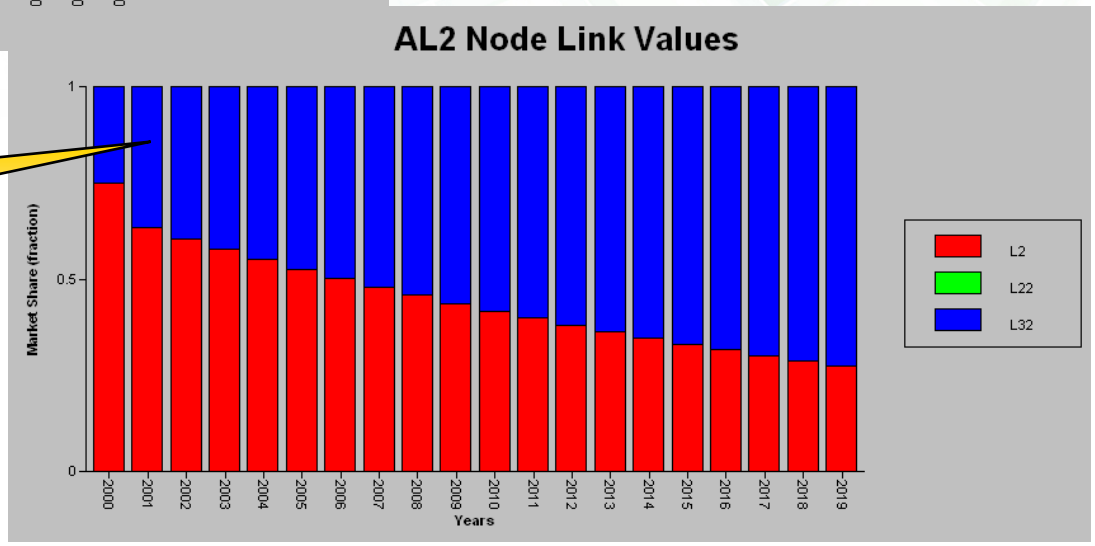
Can you explain the 2001 drop in price of refined gasoline (green)?

Why is it taking import gasoline (blue) if the price is much higher?



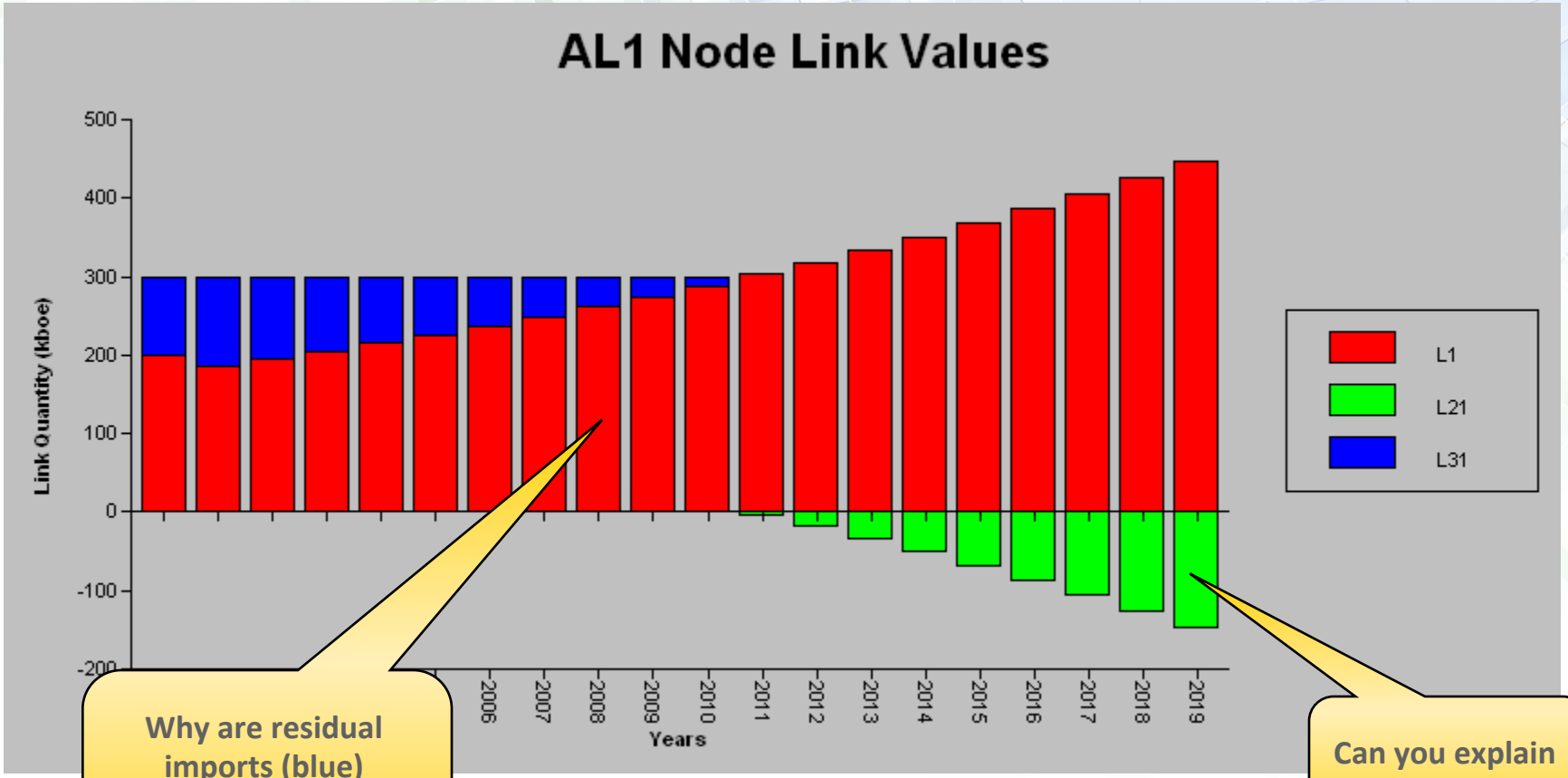
Production Mixes (Refinery vs. Imports) – Diesel Fuel





Why do diesel imports (blue) increase this much?

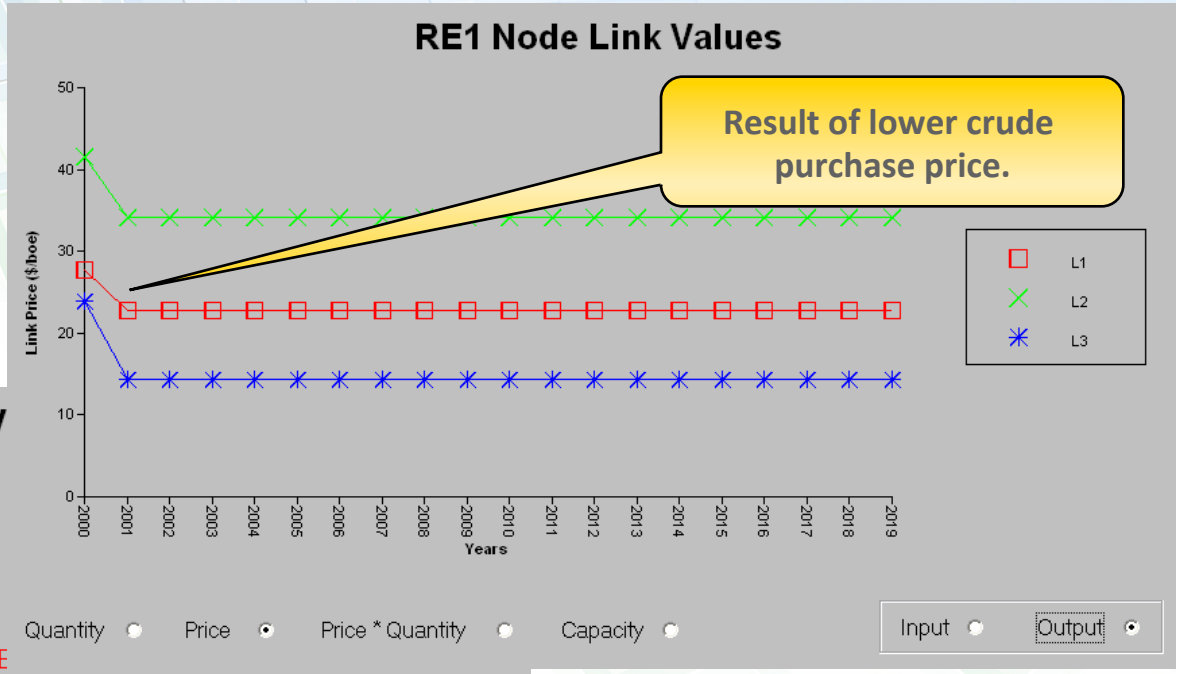
Production Mixes (Refinery vs. Imports) – Residual Oil

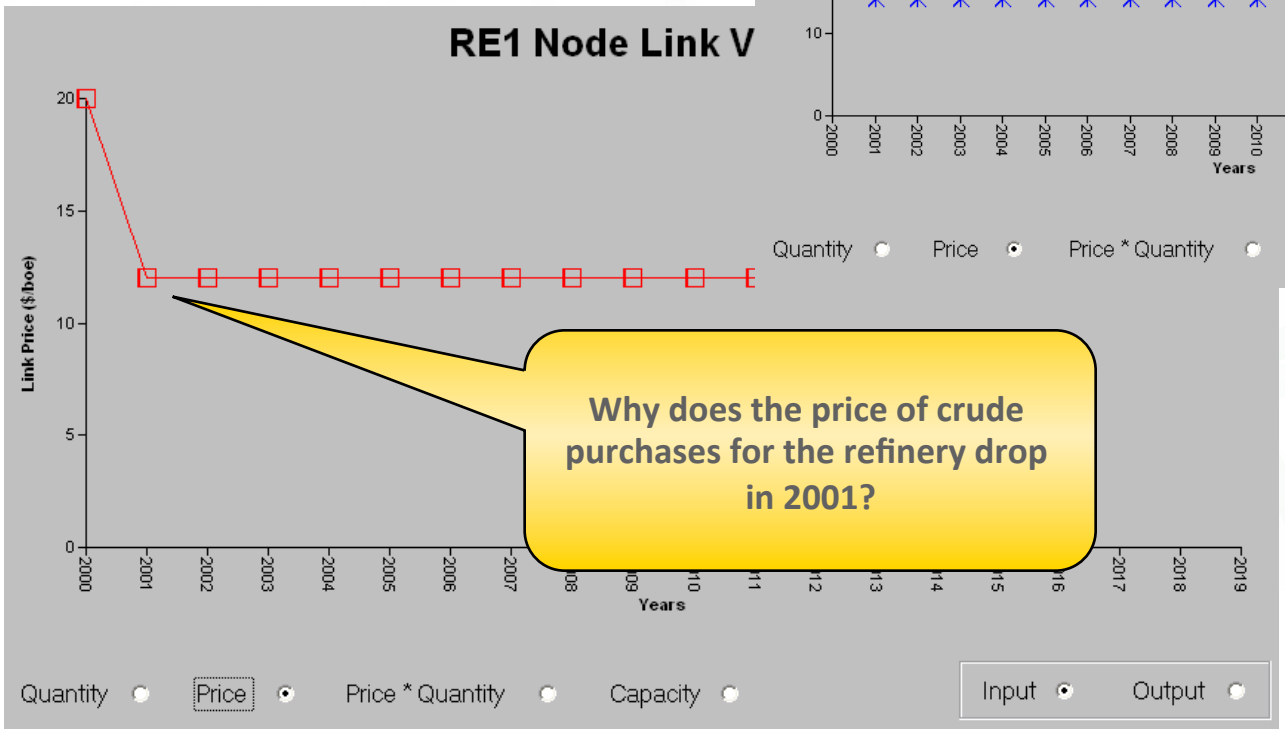


Why are residual imports (blue) displaced by residual from the refinery?

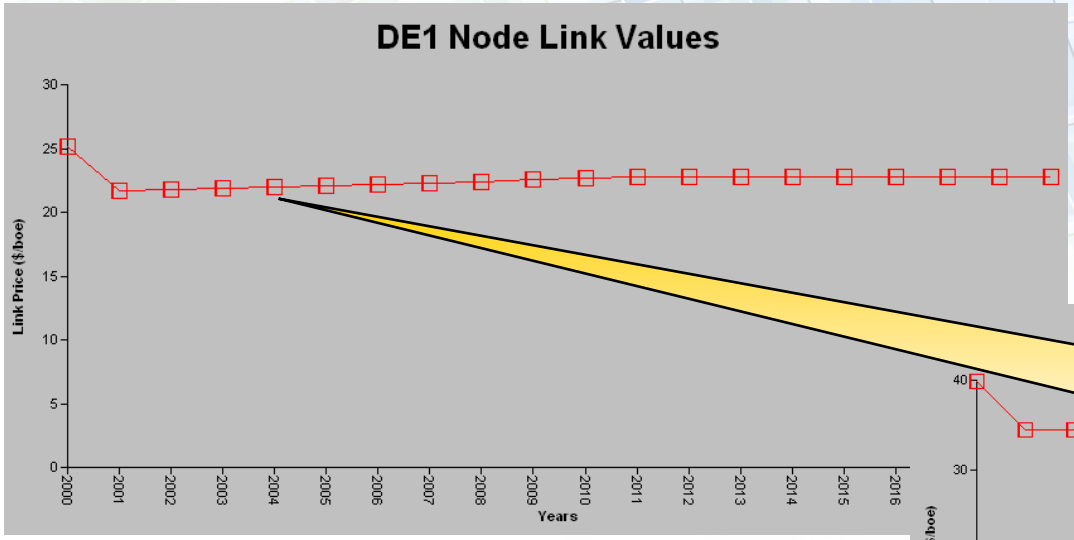
Can you explain this?

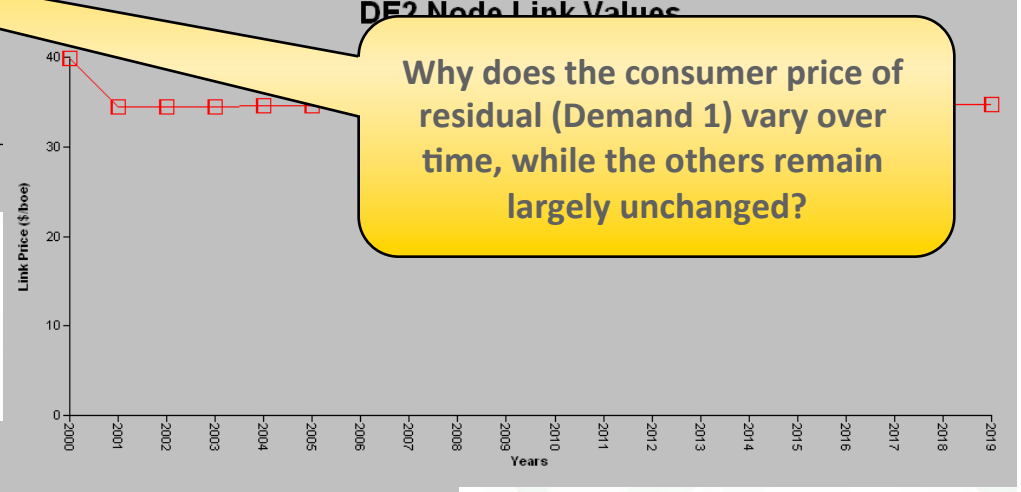
Resource Prices (Crude Oil)



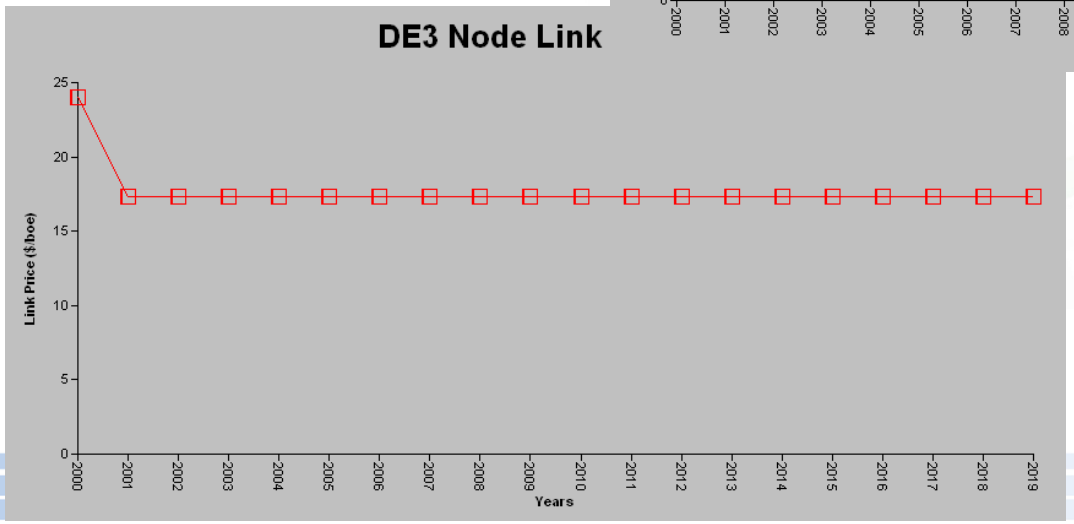


Prices of Final Products (Residual, Diesel, Gasoline)

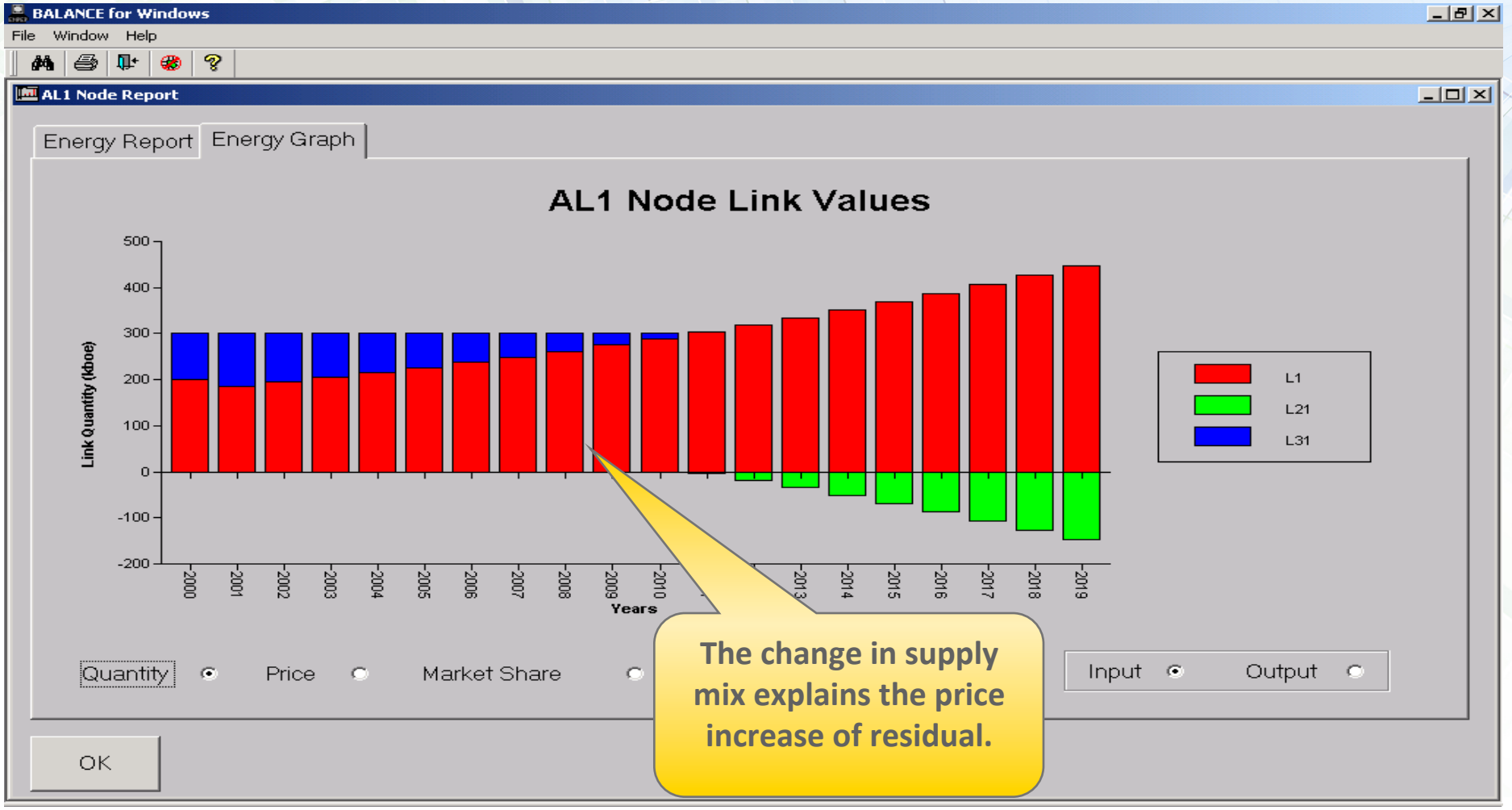




Why does the consumer price of residual (Demand 1) vary over time, while the others remain largely unchanged?



Prices of Final Products (Residual, Diesel, Gasoline)



Exercises for Training

- Case 1: Design and run the refinery base case
- Case 2: Change price sensitivities from 2 to 10 at all decision nodes
- Case 3: Change the lag parameter from 1.0 to 0.5 at all decision nodes
- Case 4: Change refinery capacity to 1500 kboe (all plants capacity) in 2010
- Case 5: Change energy resource prices as follows
  - Price growth rates: 1%/yr for RS1, 6%/yr for RS2, no change on imported products
- Case 6: Change energy resource prices as follows
  - Supply curves: no change on imported products, RS1 linear slope = 0.01; RS2 quadratic = 0.00002
- Case 7: Introduce constraint on imported crude oil (RS2): 1500 kBOE (2005); 1200 kBOE (2010); 1000 kBOE (2015)
- Case 8: Change the output sizing link to residual oil
- Case 9: Introduce a declining demand for gasoline, e.g. -0.05/year every year

Note: All variations are based on Case 1
Make a copy of Case 1, Open the Case, Close the Case, and Rename the Case to Case X. Then open the case, make the input changes, and run the case.