# SUPPLY CHAIN OPTIMIZATION OF PETROLEUM REFINERY COMPLEXES

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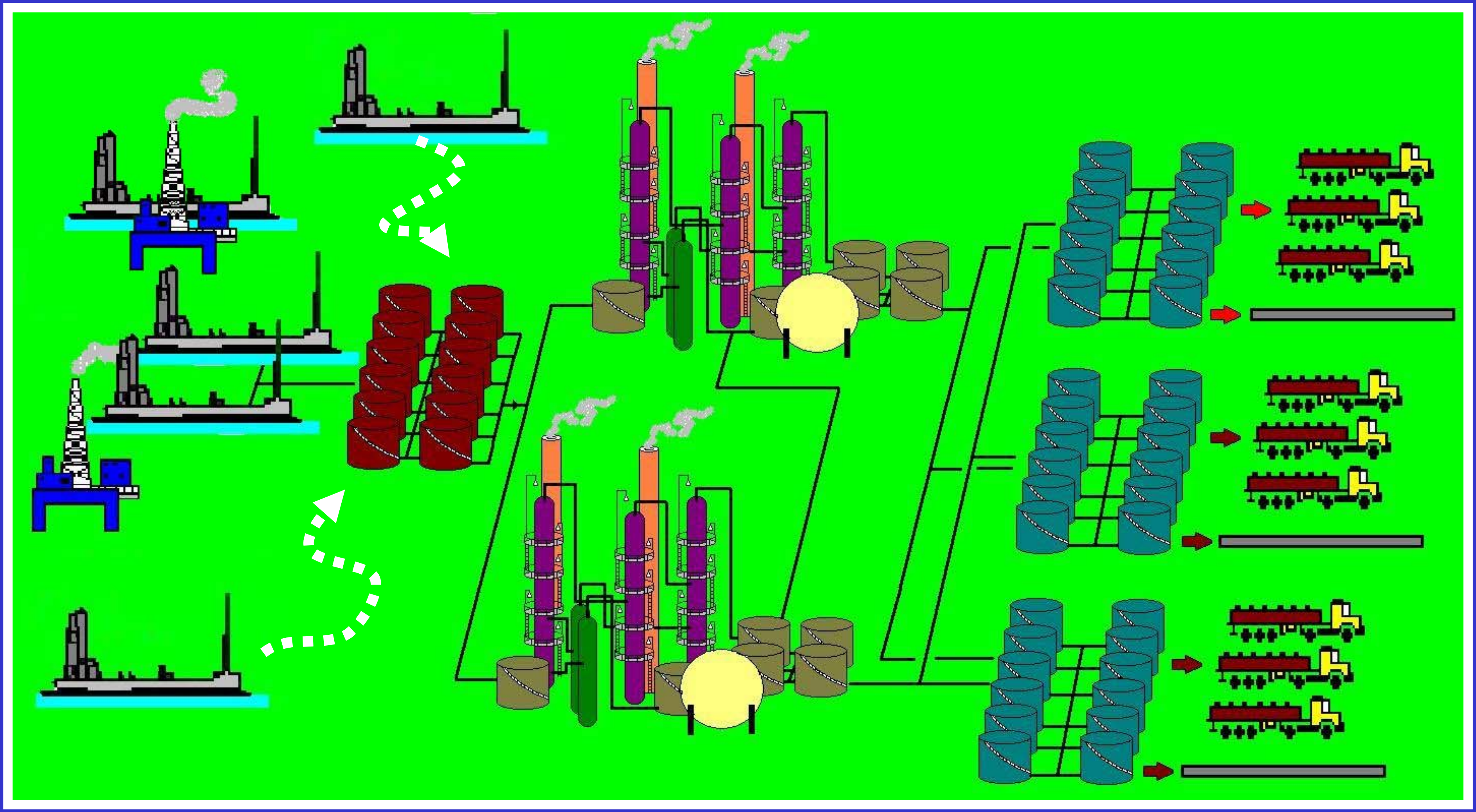
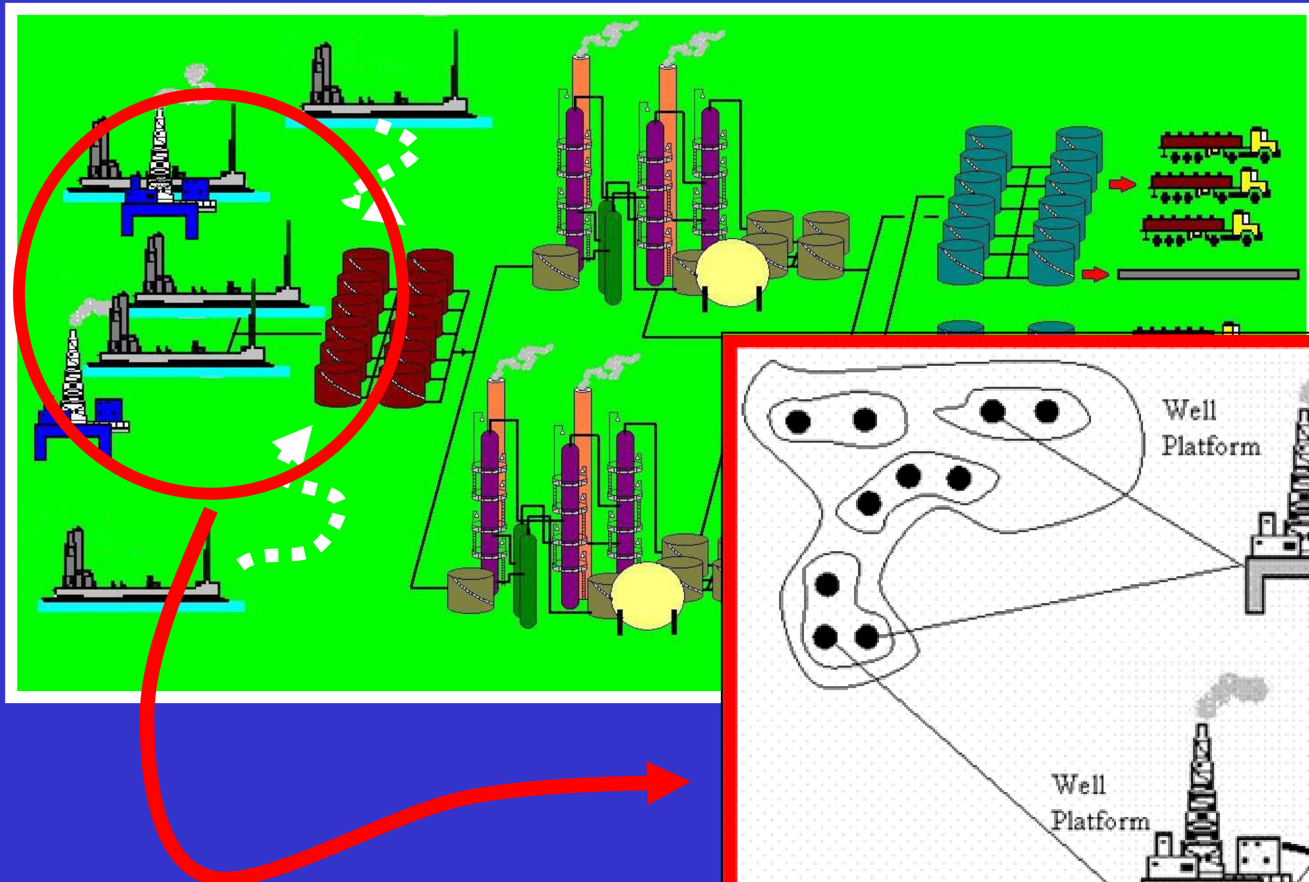
# Outline

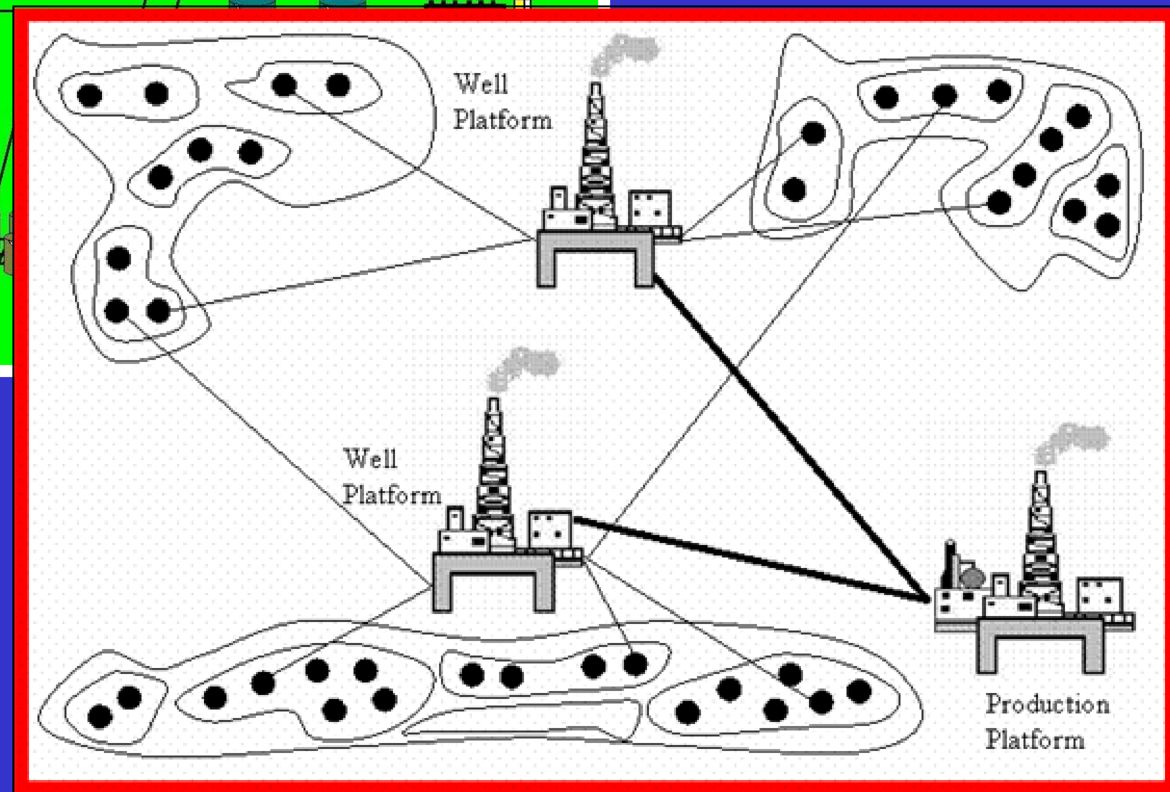
- General Petroleum Supply Chain (PSC)
- Objectives
- Representation of proposed elements
- Real-world PSC - Petrobras
- Results
    - Single refinery
    - PSC
- Conclusions
- Research needs

# General Petroleum Supply Chain





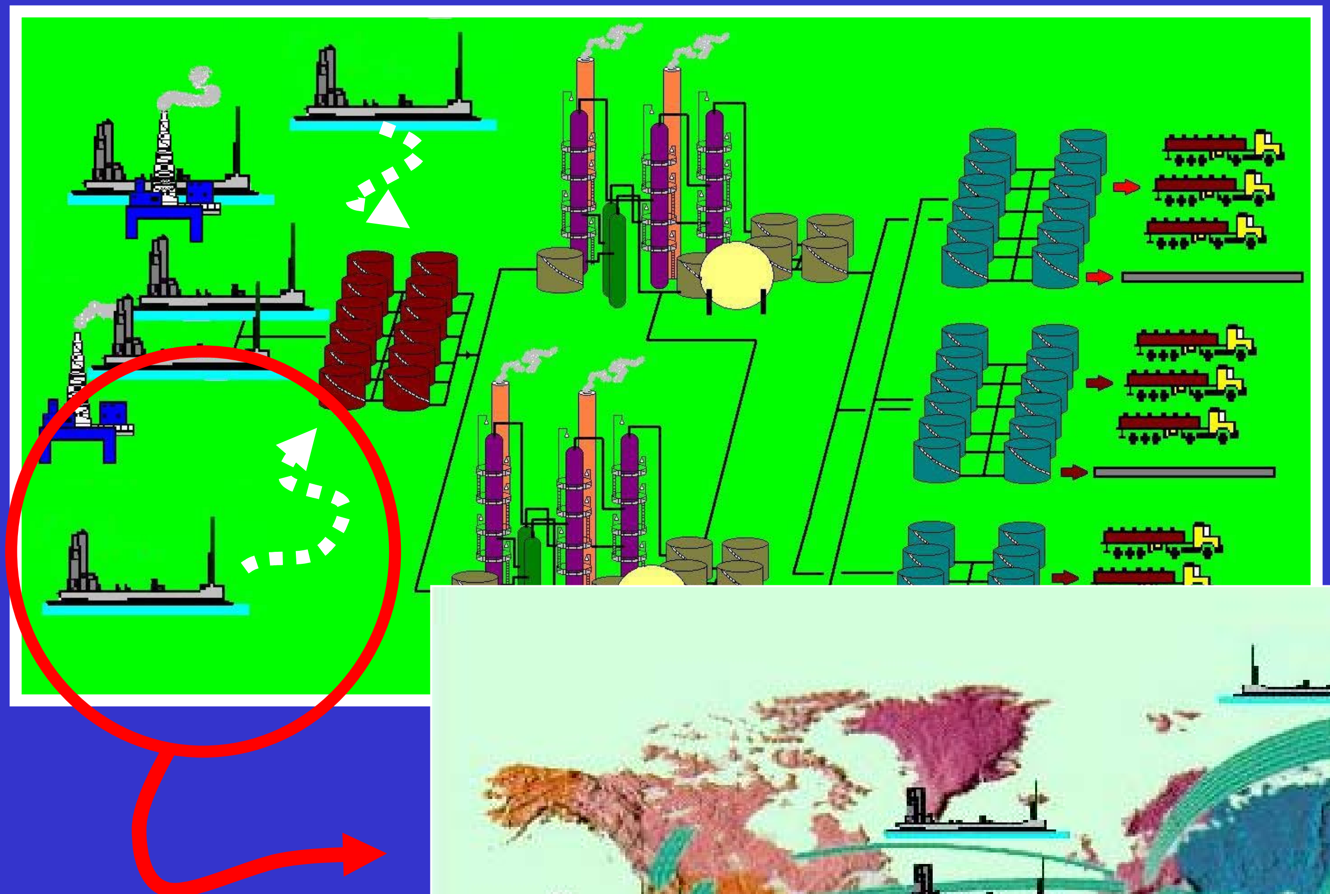
# Oil field Infrastructure




- Iyer *et al*. (1998).
- Van den Heever and Grossmann (2000).
- Van den Heever *et al.* (2000).

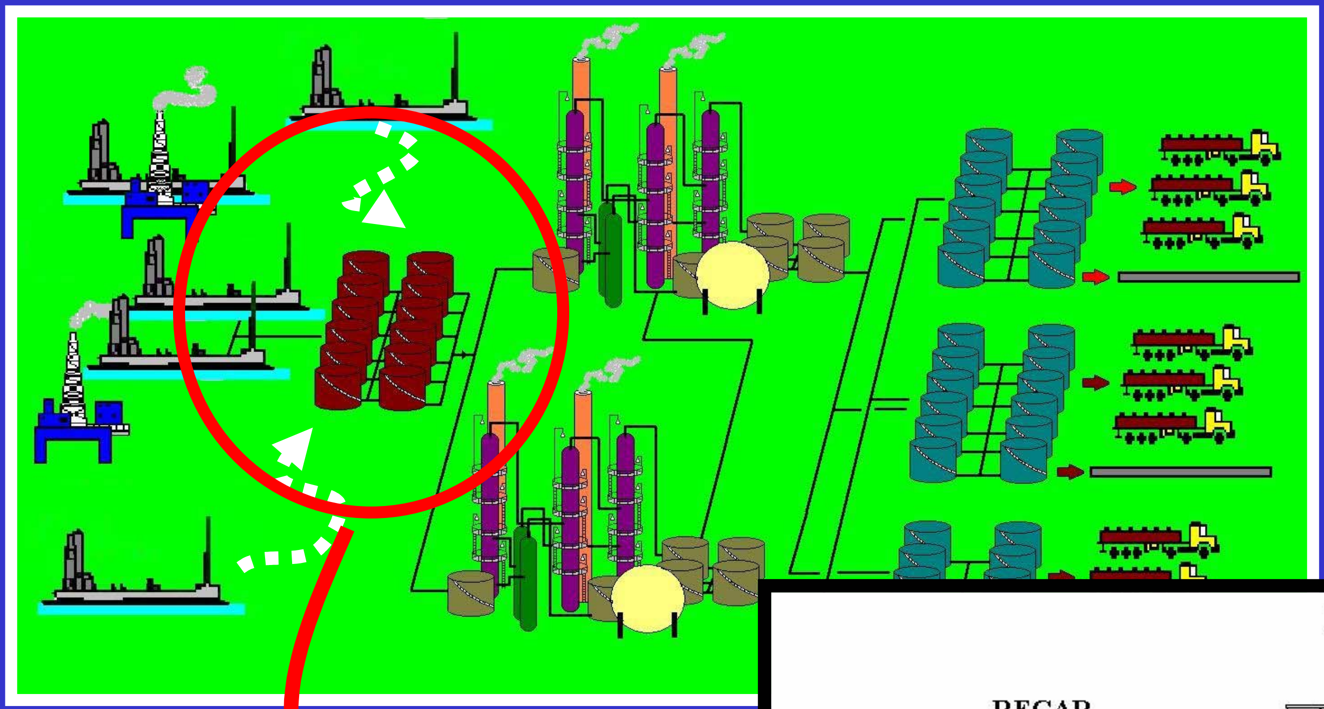
Ierapetritou *et al*. (1999).

- Kosmidis (2002).
- Barnes *et al*. (2002).

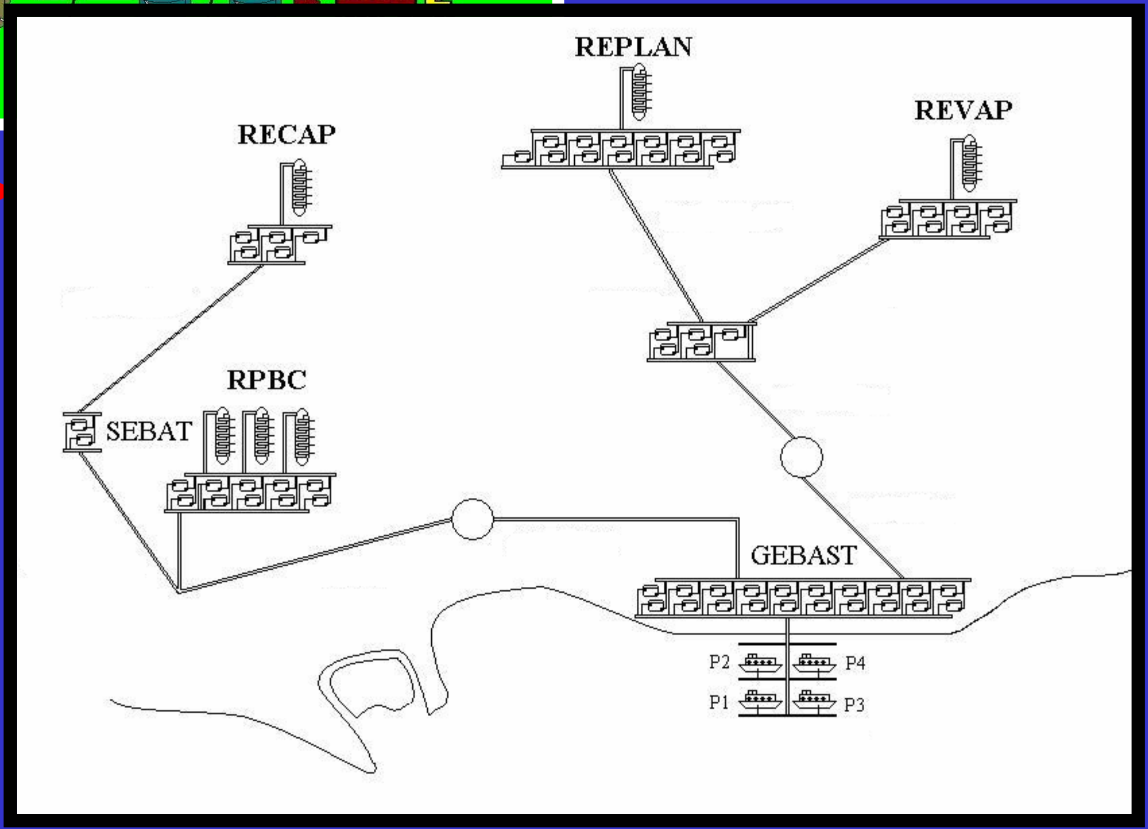


International Petroleum Commerce

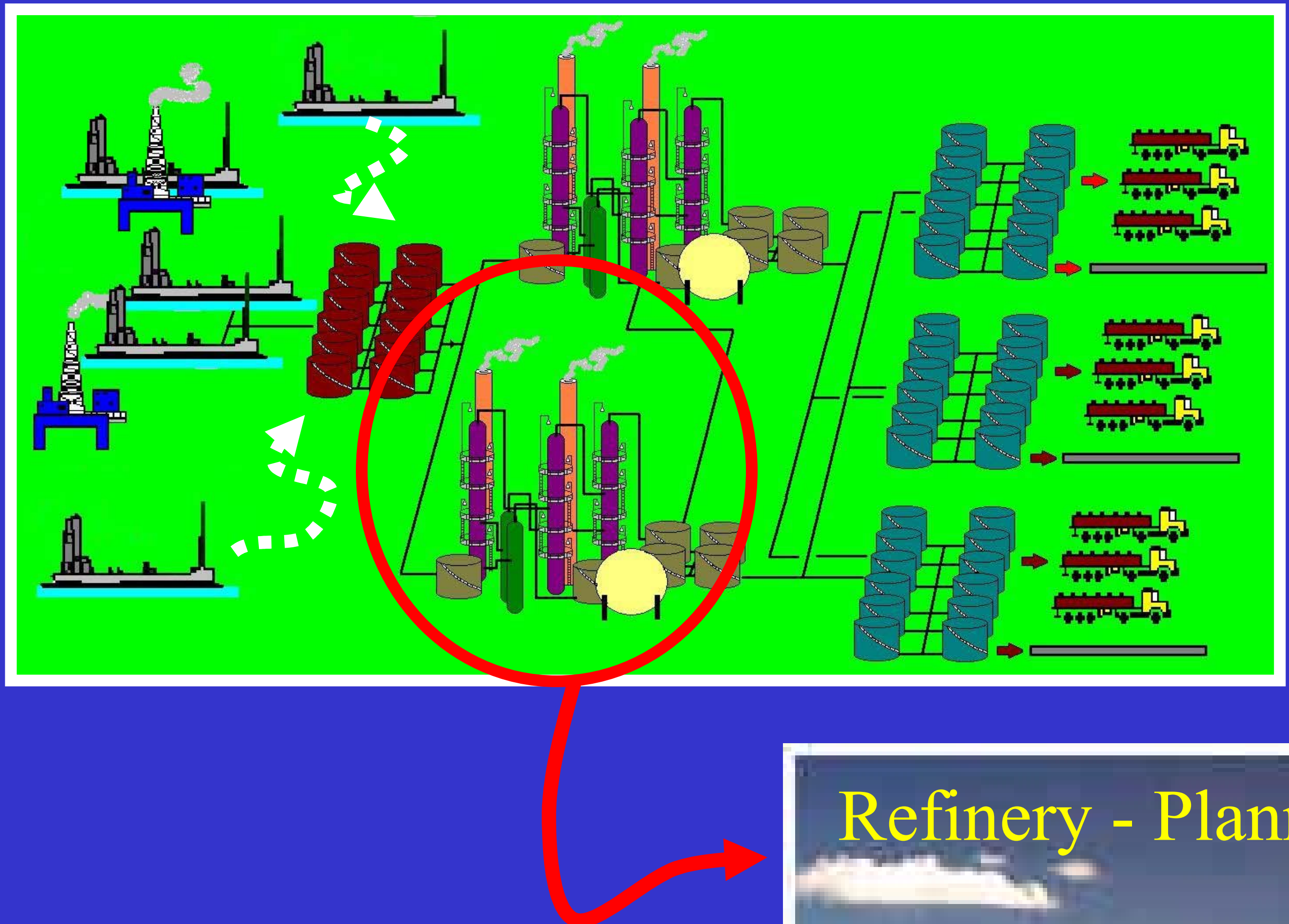
- Operations Research.



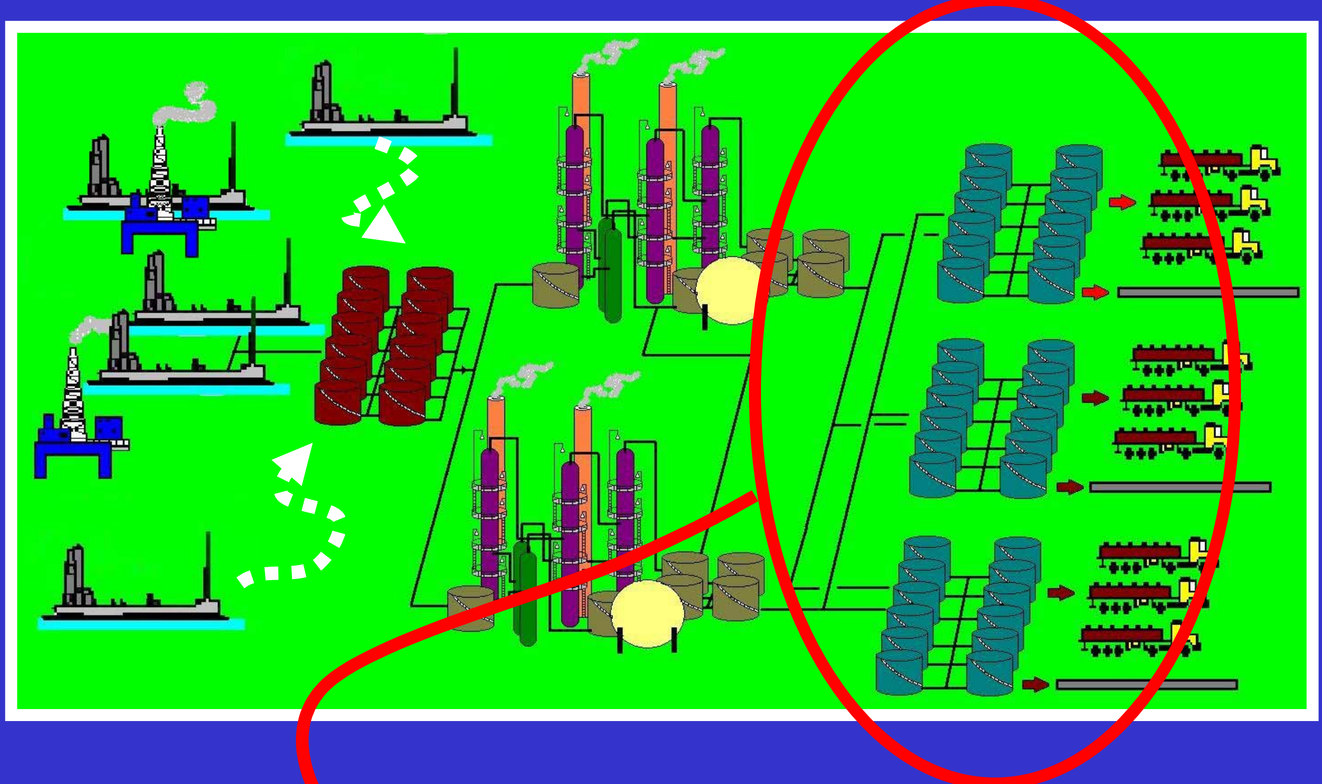
Crude Oil Supply




- Lee *et al.* (1996).
- Pinto *et al.* (2000).
- Más and Pinto (2002).




- Ponnambalam (1992).
- Bok *et al*. (1998).
- Pinto and Moro (2000).



# Distribution



- Ross (2000).
- Iakovou (2001).
- Magatão *et al*. (2002).
- Stebel *et al.* (2002).
- Rejowski and Pinto (2003).

# Objective

Development of an optimization model

that is able to represent

a petroleum supply chain

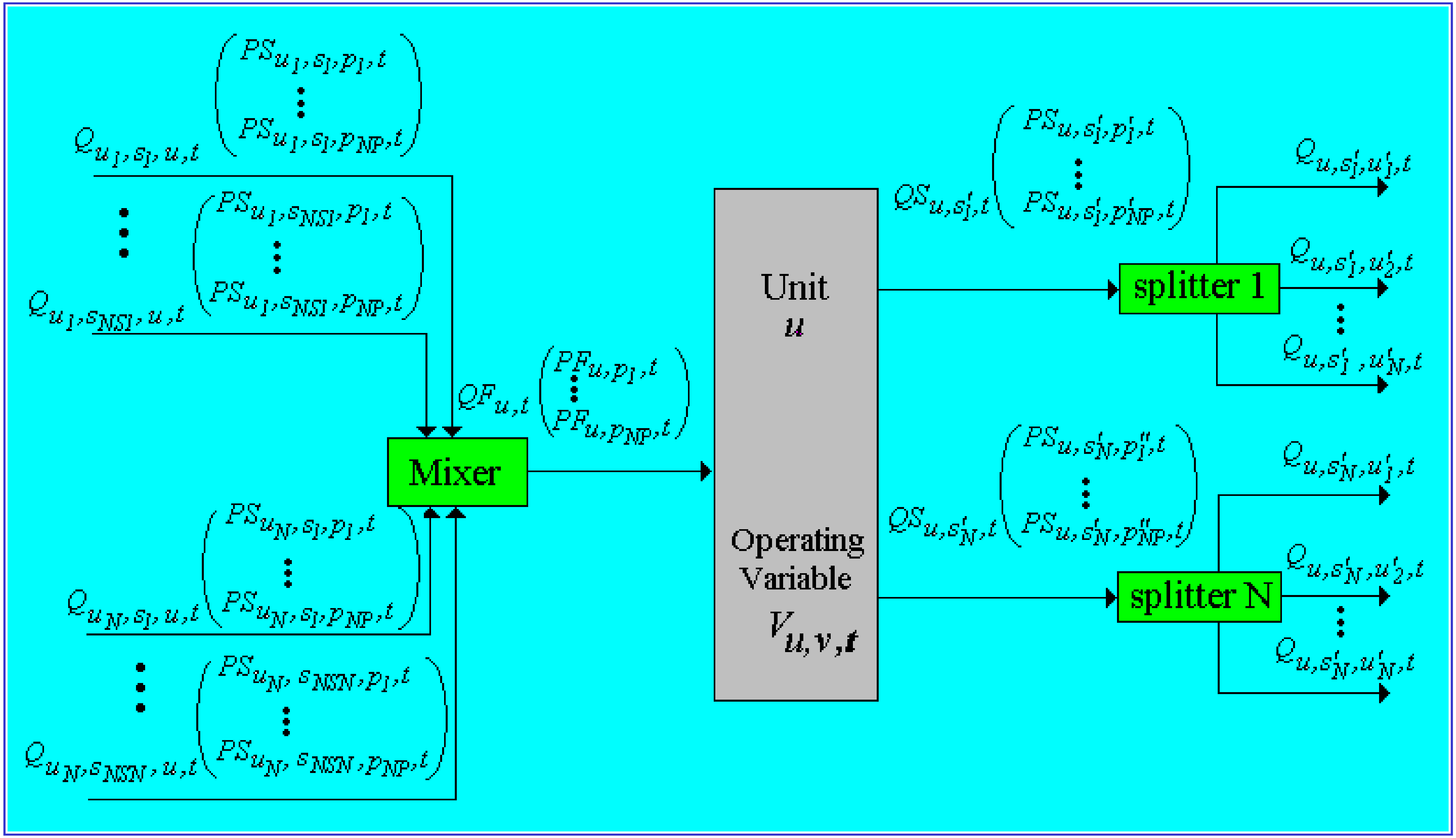
to support the

decision making planning process

of

supply, production and distribution

# Refinery - Processing Unit Model



$$QF_{u,t} = \sum_{(u',s)\in \mathbf{US}_u} Q_{u',s,u,t}$$

$$PF_{u,p,t} = \frac{\sum_{(u',s)\in \mathbf{US}_u} Q_{u',s,u,t}.PS_{u',s,p,t}}{\sum_{(u',s)\in \mathbf{US}_u} Q_{u',s,u,t}}$$

Feed mixing

$$QS_{u,s,t} = QF_{u,t}.f_{u,s}\left(PF_{u,p,t}\right) + \sum_{u\in \mathbf{VO}_u} QGain_{u,s,v}.V_{u,v,t}$$

$$PS_{u,s,p,t} = f_{u,s,p}(PF_{u,p,t} \mid p \in \mathbf{PI}_u, QF_{u,t}, V_{u,v,t} \mid v \in \mathbf{VO}_u)$$

Unit Model

$$QS_{u,s,t} = \sum_{u'\in \mathbf{UO}_{u,s}} Q_{u,s,u',t}$$

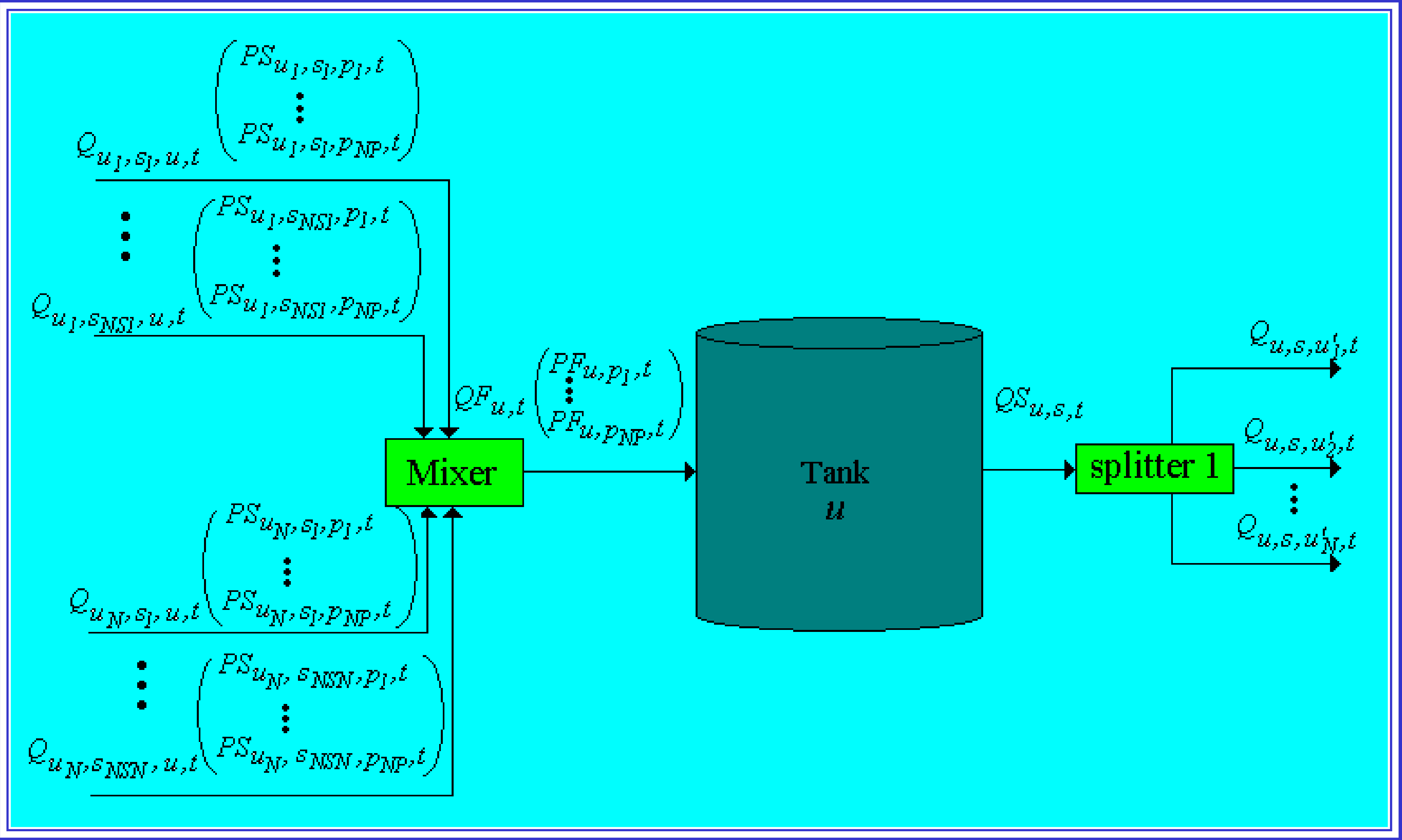
Product splitting stream

$$QF_u^L \le QF_{u,t} \le QF_u^U$$

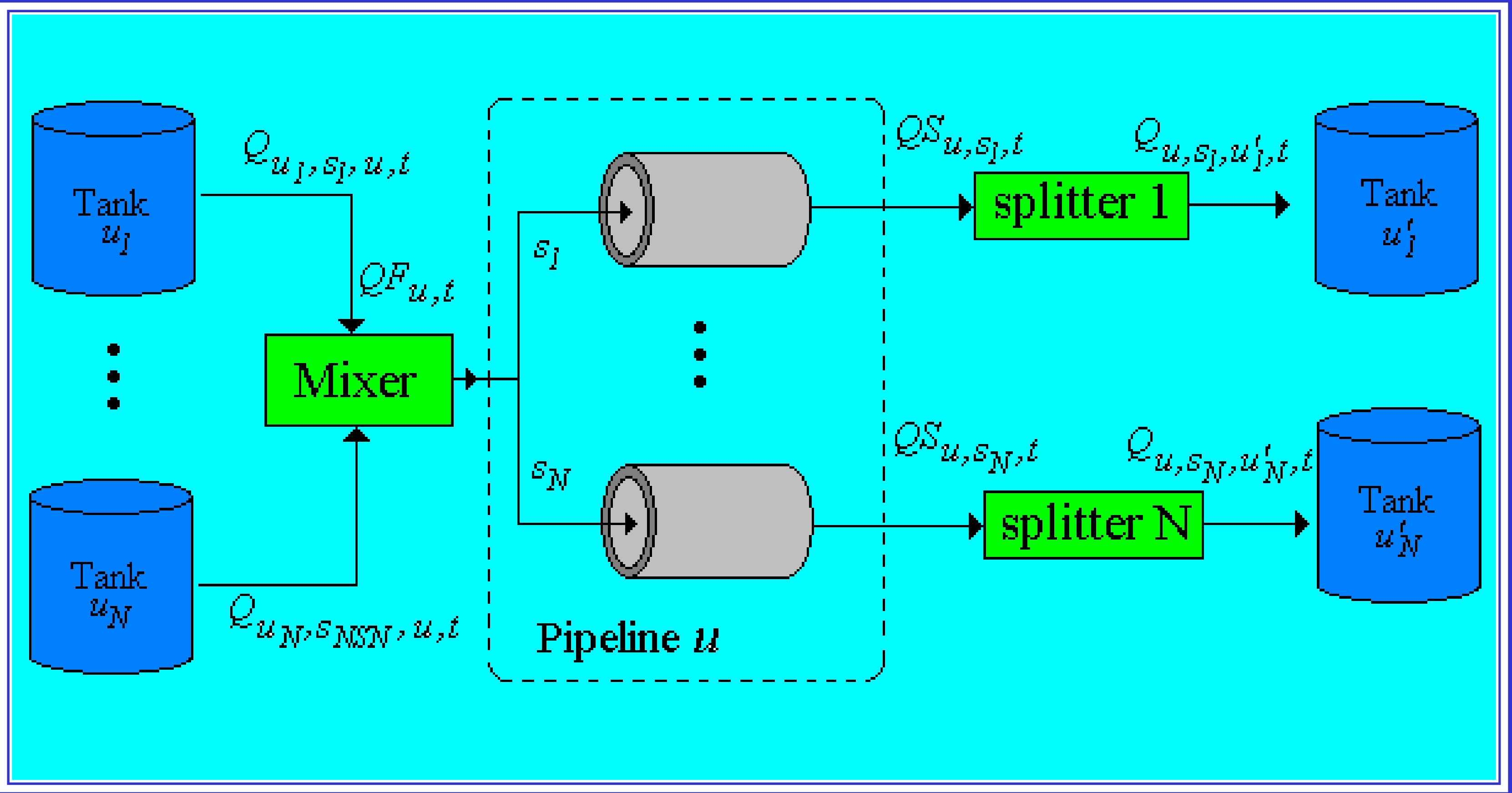
$$V_{u,v}^L \le V_{u,v,t} \le V_{u,v}^U$$

Bounds

# Supply, Distribution – Storage Model



# Supply, Distribution - Pipeline Model




$$QF_{u,t} = \sum_{(u',s)\in \mathbf{US}_u} Q_{u',s,u,t}$$

$$QS_{u,s,t} = Q_{u,s,u',t}$$

$$QS_{u,s,t} = Q_{u',s,u,t}$$

$$QF_{u,t} \leq QF_u^U$$

# Supply Chain Model

## Large Scale MINLP

PSC

$$Max\ \ Z = \sum_{u \in \mathbf{U}_{dem}} \sum_{t \in \mathbf{T}} Cp_{u,t} . \left( QF_{u,t} - Vol_{u,t} \right) - \sum_{u \in \mathbf{U}_{SB}} \sum_{t \in \mathbf{T}} .Cpet_{u,t} .Lot_{u,t}$$

$$- \sum_{u \in \mathbf{U}} \sum_{t \in \mathbf{T}} [\, Cr_u + \sum_{v \in \mathbf{VO}_u} \left( Cv_{u,v} .V_{u,v,t} \right) \,] \, .QF_{u,t} - \sum_{u \in \mathbf{U}_f} \sum_{t \in \mathbf{T}} Cinv_u .Vol_{u,t}$$

$$- \sum_{u \in \mathbf{U}_p} \sum_{t \in \mathbf{T}} Cinv_u .Vol_{u,t} - \sum_{u \in \mathbf{U}_{pipe}} \sum_{t \in \mathbf{T}} Ct_u .QF_{u,t}$$

# Supply Chain Model – cont. from previous slide

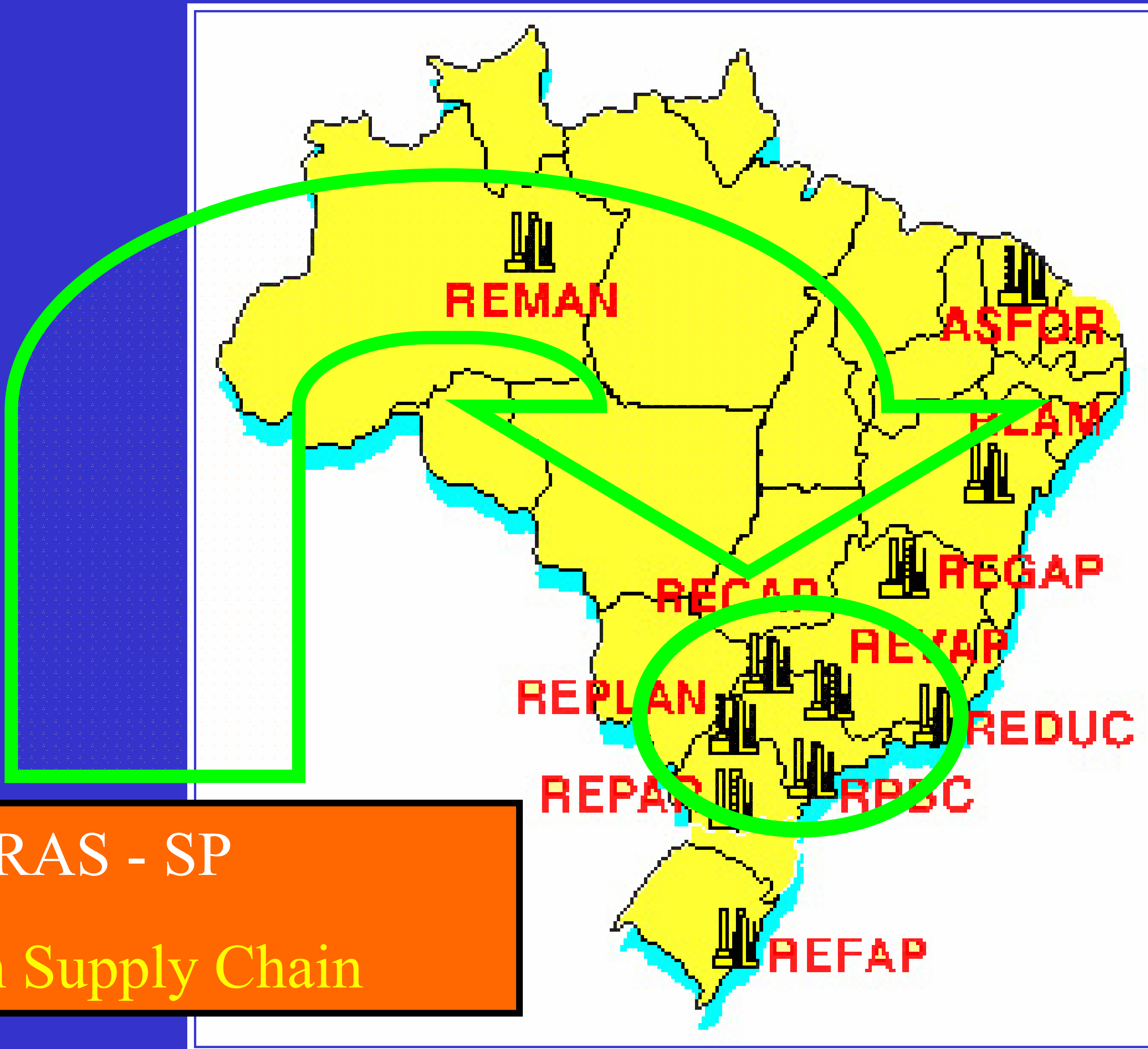
subject to the models of:

- processing units
  - units that compose refinery topology
  - refineries that compose the supply chain

- tank
  - petroleum and product tanks that compose refineries
  - petroleum and product tanks that compose terminals
  - refineries and terminals that compose the supply chain

- pipeline
  - pipeline network for petroleum supply
  - pipeline network for product distribution

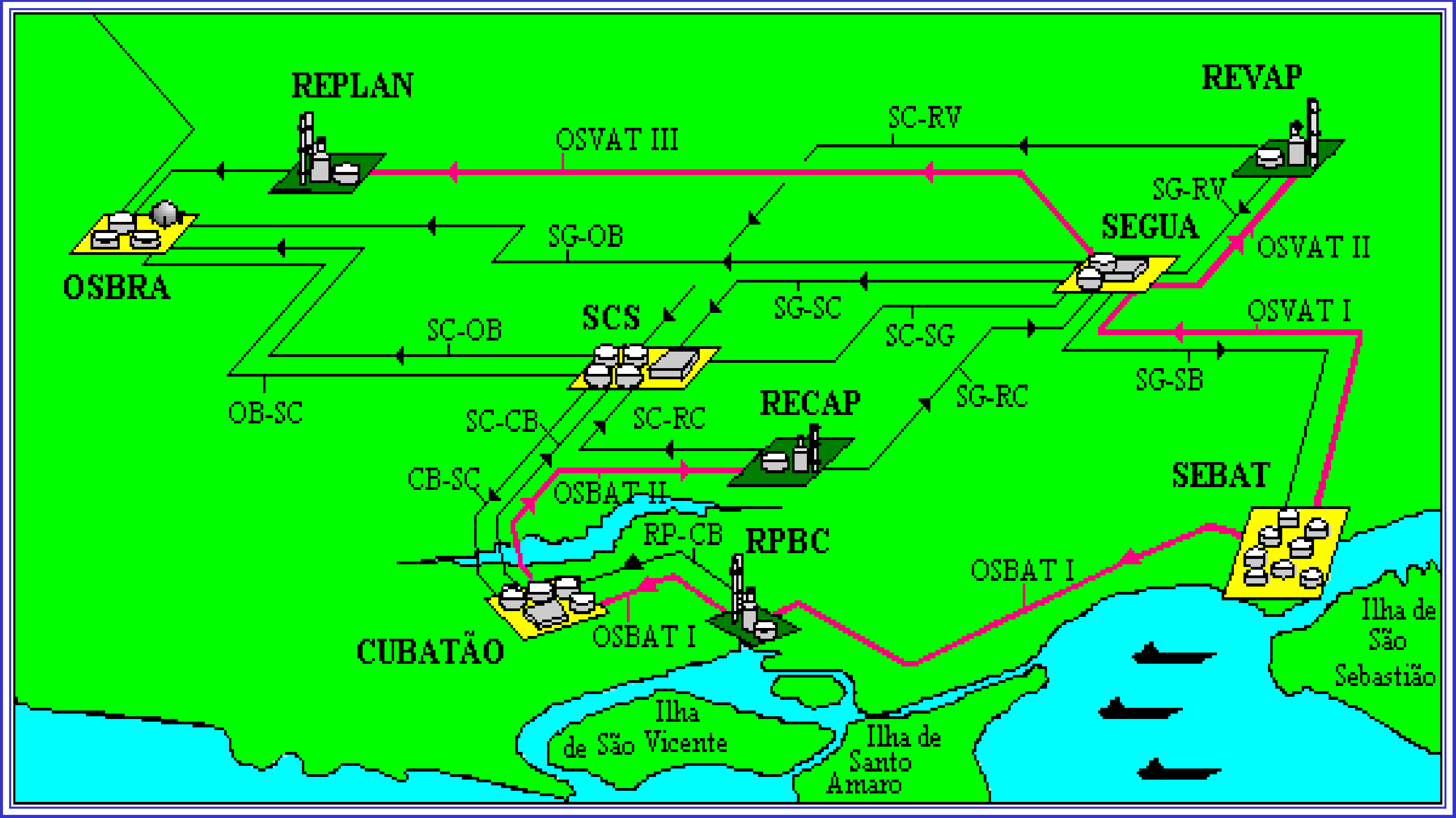
$$QF, QS, Q, Vol, Lot \in \Re^{+} \quad PF, PS, V \in \Re \quad y \in \{0,1\}$$



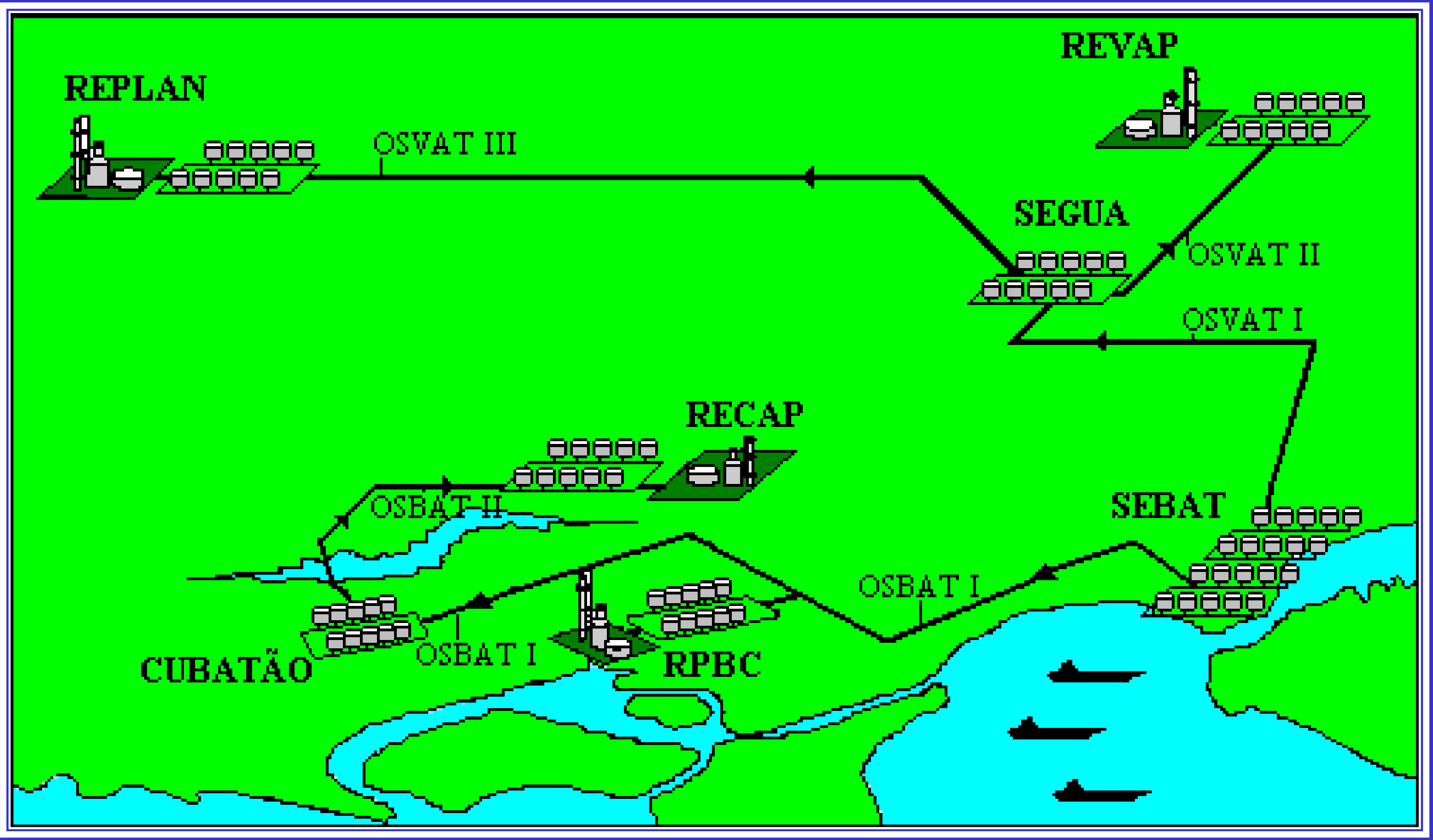

PETROBRAS - SP

Petroleum Supply Chain

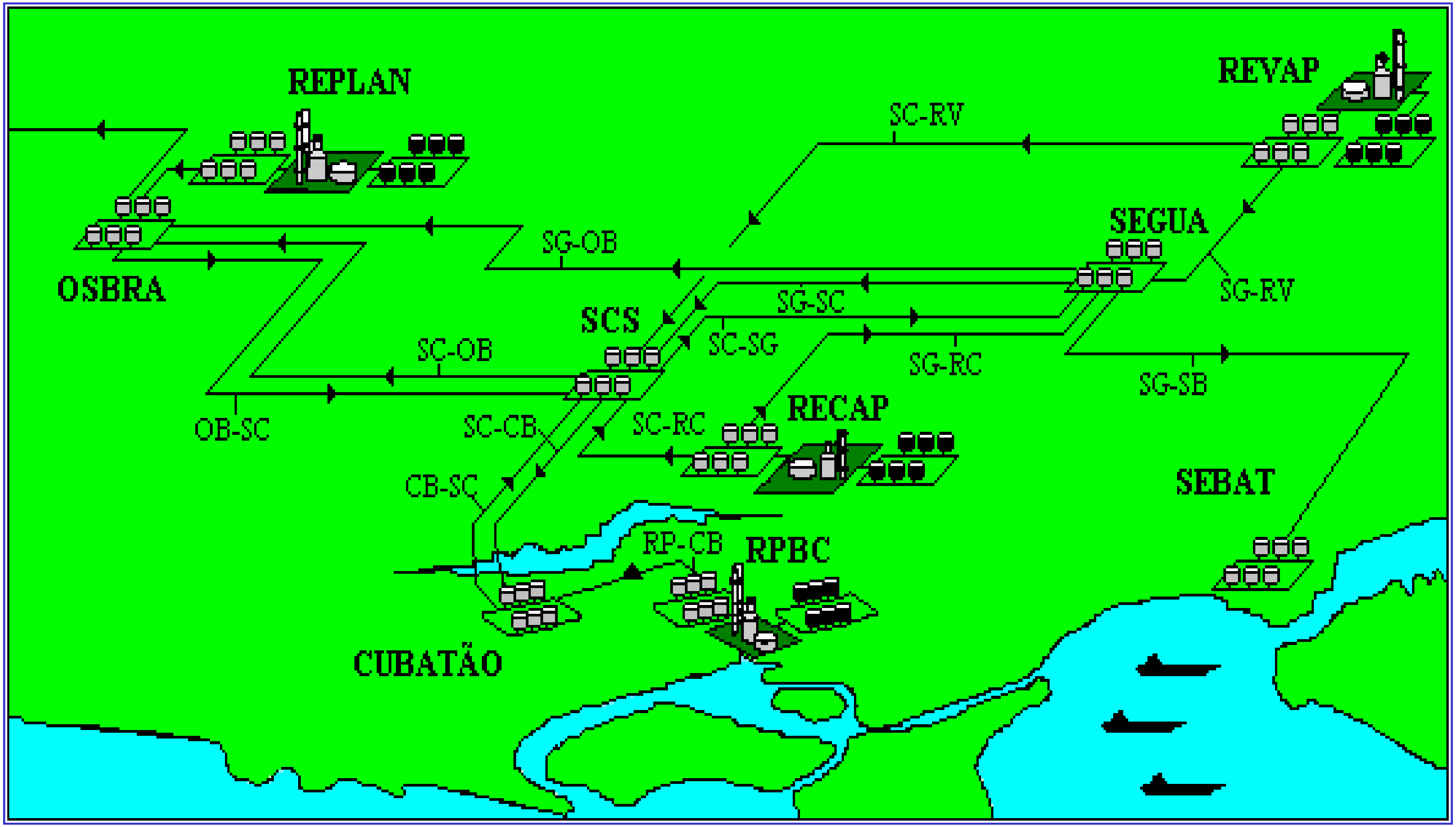
# Supply Chain Components



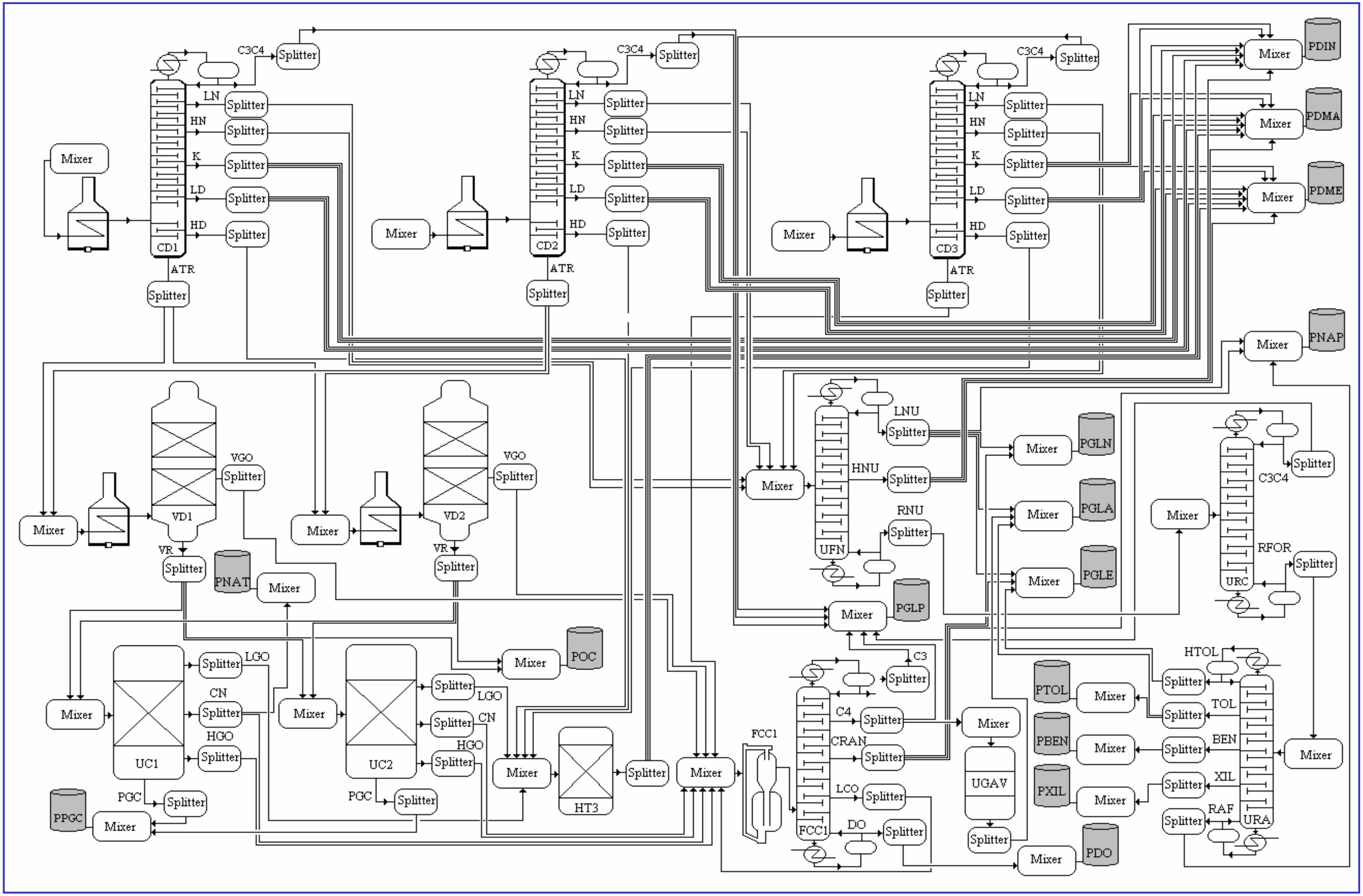
# Petroleum Distribution Overview



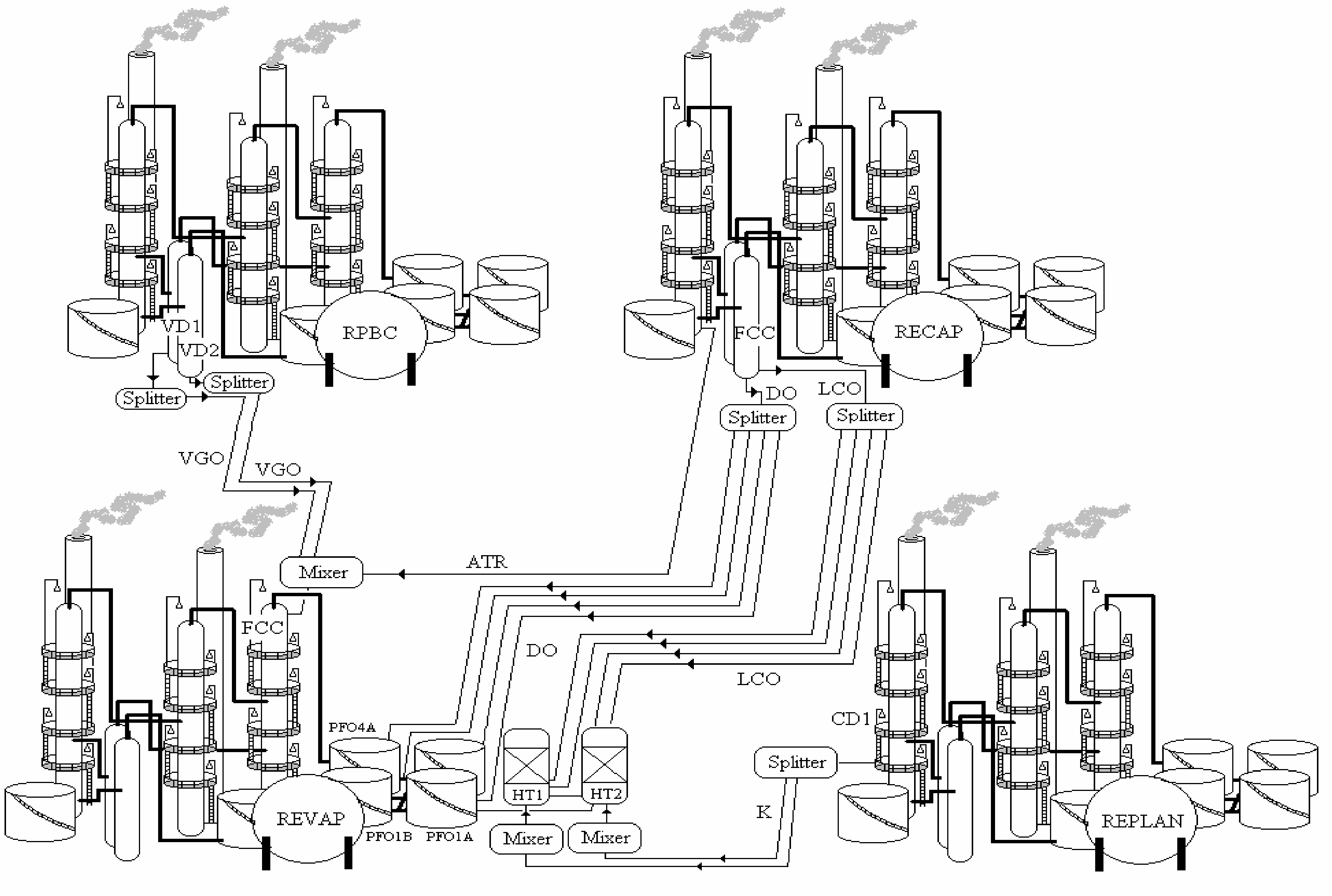
# Product Distribution Overview



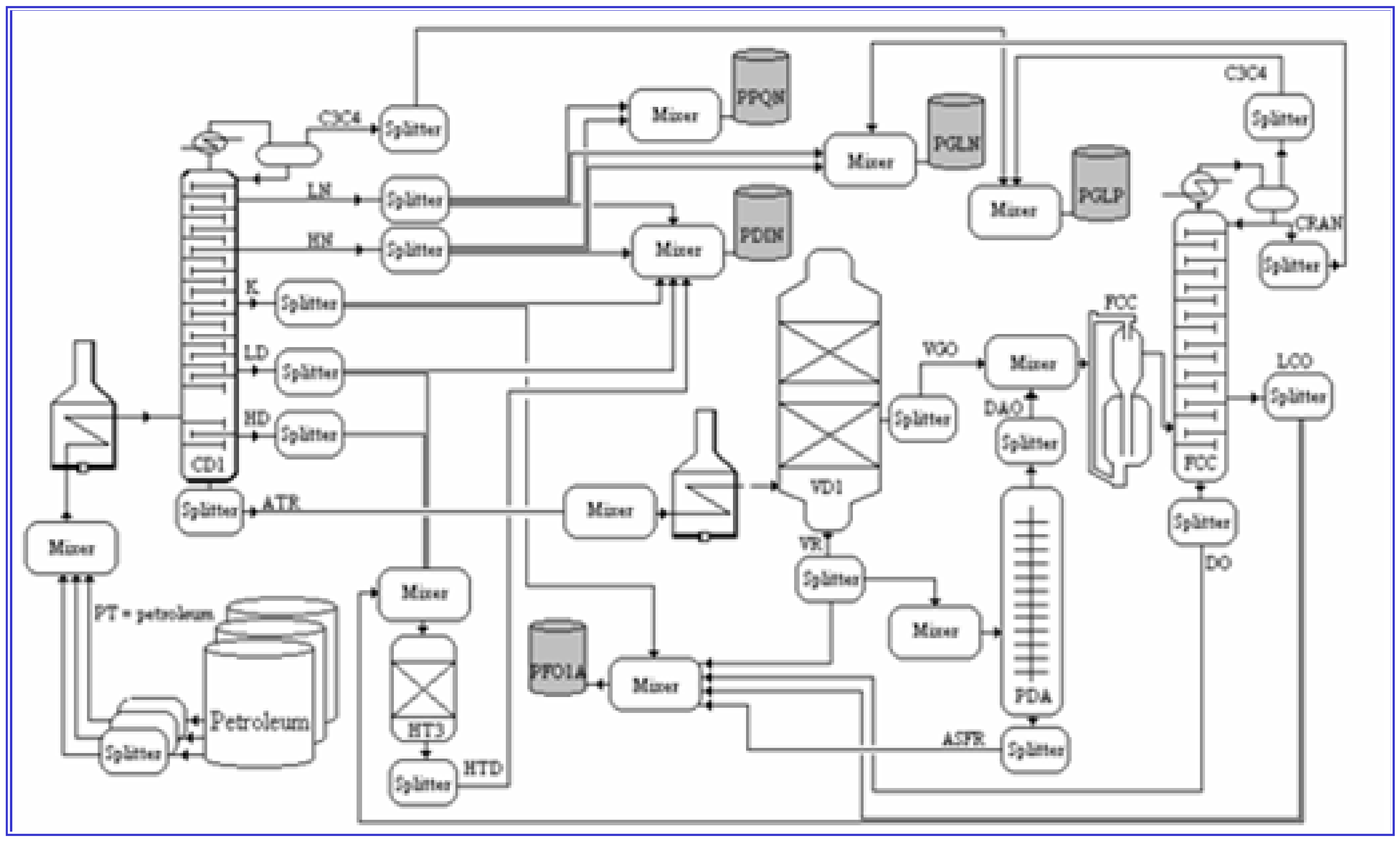
# RPBC flowsheet



# Intermediate connections



# Modeling Example



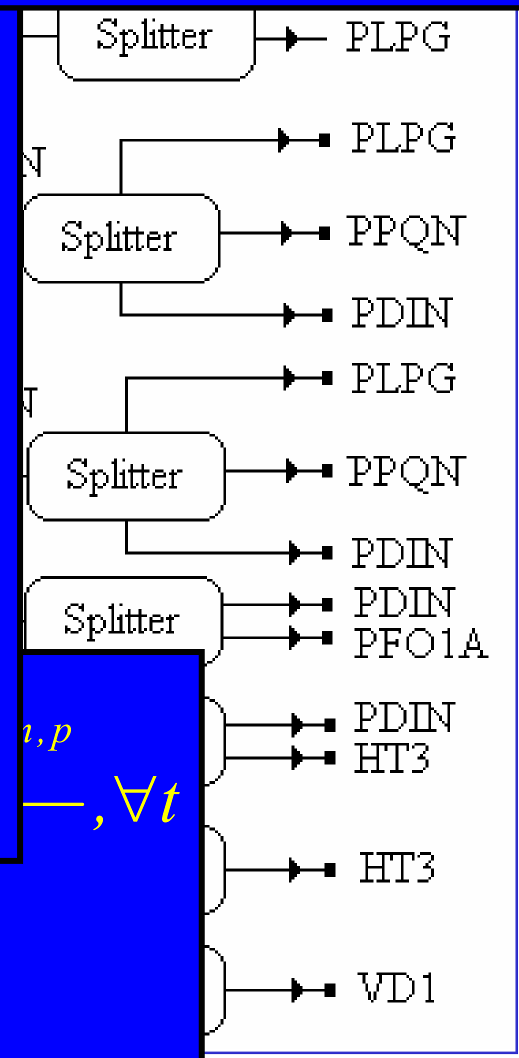
# Tanks and CD1 Model

$$PS_{CD1,s,p,t} = Prop_{CD1,s,p} + PGain_{CD1,s,p}.V_{CD1,V1,t} \qquad \forall, s \in \mathbf{SO}_{CD1}, p \in \mathbf{PO}_{CD1,s}, t$$

$$\ldots Gain_{CD1,s,V_1}.V_{CD1,V_1,t}, \forall t$$

$$QS_{CD1,s,t} = \sum_{u' \in \mathbf{UO}_{CD1,s}} Q_{CD1,s,u',t}$$

$$\left\{ \begin{array}{ccc} C3C4 & \rightarrow & YC3C4 \\ LN & \rightarrow & YLN \\ HN & \rightarrow & YHN \\ K & \rightarrow & YK \\ LD & \rightarrow & YLD \\ HD & \rightarrow & YHD \\ ATR & \rightarrow & YATR \end{array} \right\}$$




$$\ldots_{n,p} \qquad \ldots, \forall t$$

$$\sum_{u' \in \{tank1,2,3\}} Q_{u',petroleum,CD1,t}$$

$$p \in \{YC3C4, YLN, YHN, YK, YLD, YHD, YATR\}$$

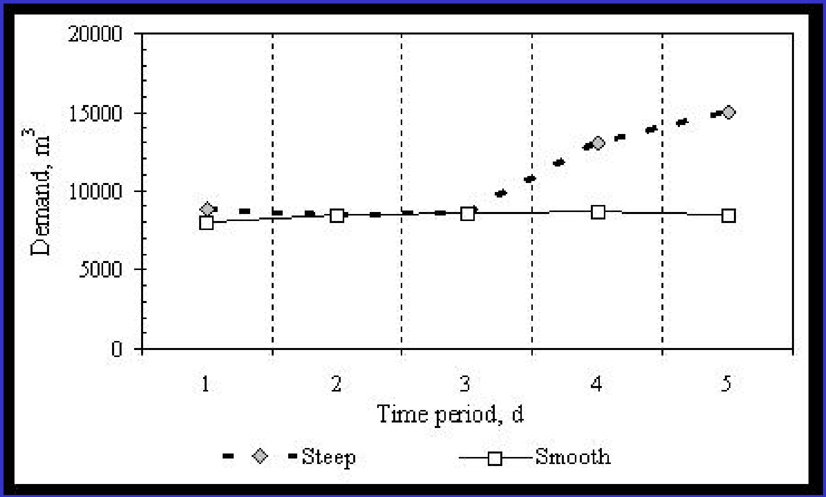
# Refinery Multiperiod Planning – REVAP results

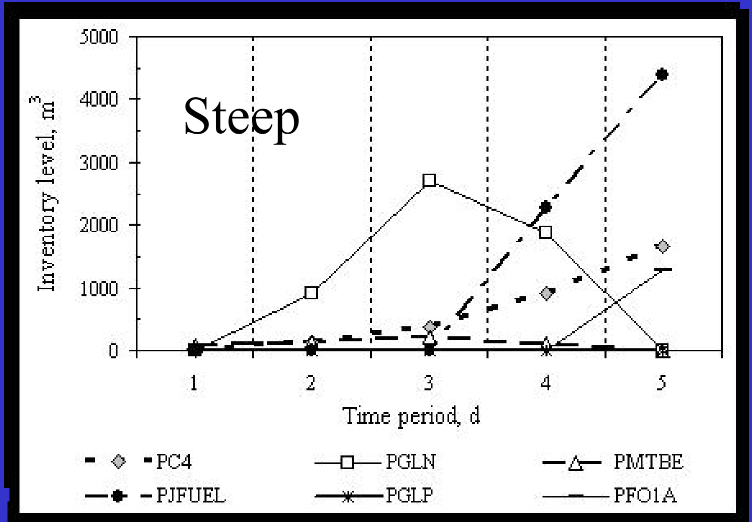
DICOPT

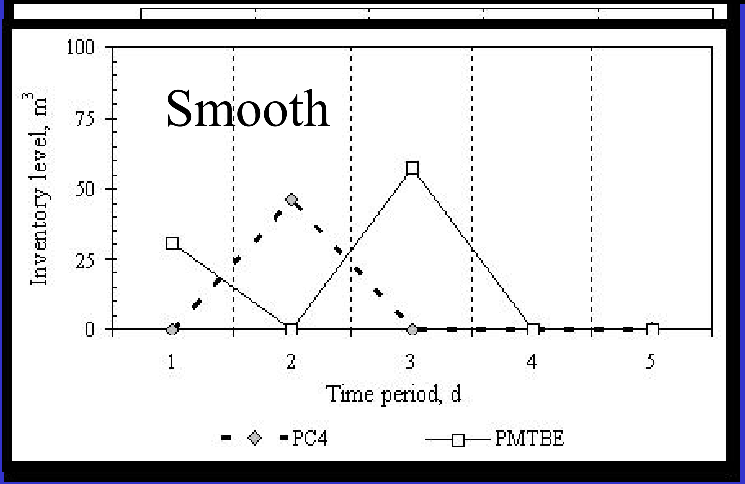
(NLP CONOPT++)

(MIP OSL, CPLEX)

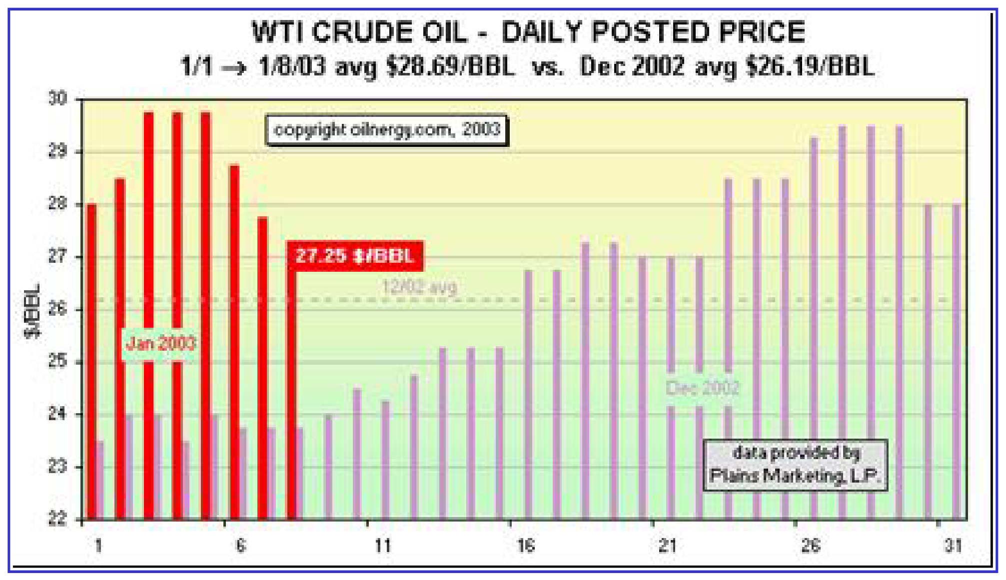
Demand profile - GLN



# Refinery Planning – Model with Uncertainty




Discrete Scenarios

| $c1$ | $c2$ | ..... | $cN$ |
|---|---|---|---|
| P1% | P2% | | PN% |

$$\sum_{c\in C} prob_{c,t} = 1$$

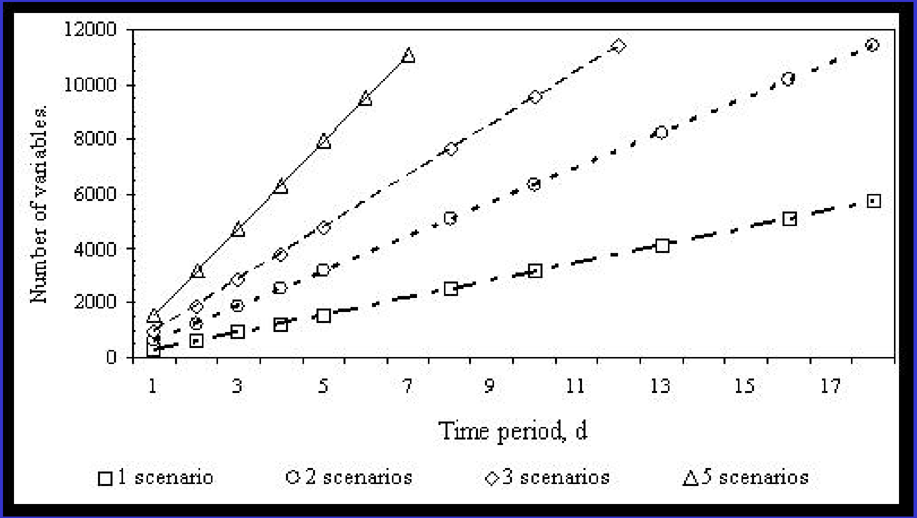
$$Max\ Z = \sum_{c\in \mathbf{C}}\sum_{t\in \mathbf{T}}\left(\sum_{u\in \mathbf{U}_p} prob_{c,t}\, Cp_{u,t,c}\left(QF_{u,t,c} - Vol_{u,t,c}\right)\right) - \sum_{c\in \mathbf{C}}\sum_{t\in \mathbf{T}}\left(\sum_{u\in \mathbf{U}_f}\sum_{s\in \mathbf{SO}} prob_{c,t}\, Cf_{u,t,c}\, QS_{u,s,t,c}\right)$$

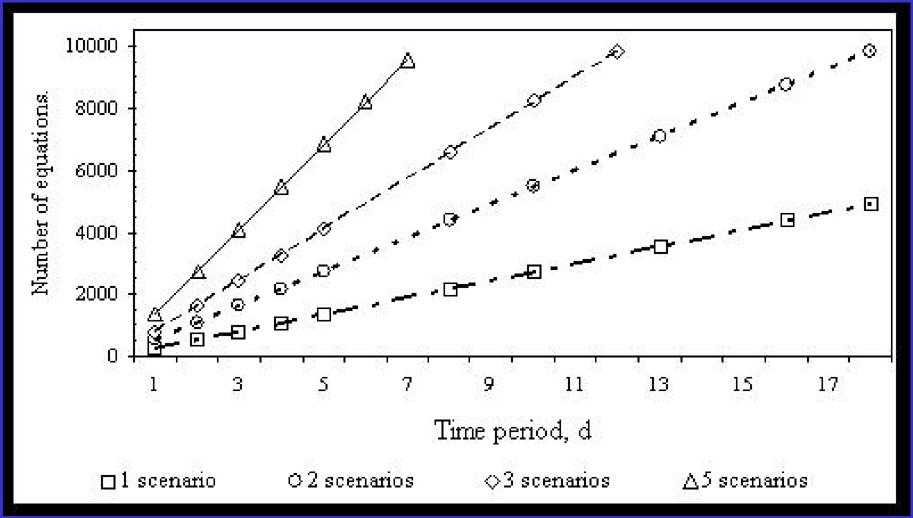
$$-\sum_{c\in \mathbf{C}}\sum_{t\in \mathbf{T}}\left(\sum_{u\in \mathbf{U}_f} Cb_u\, y_{u,t,c}\right) - \sum_{c\in \mathbf{C}}\sum_{t\in \mathbf{T}}\left(\sum_{u\in \mathbf{U}\backslash\{\mathbf{U}_f,\mathbf{U}_p\}}\left[Cr_u + \sum_{v\in \mathbf{VO}_u}\left(Cv_{u,v}.V_{u,v,t}\right)\right] QF_{u,t}\right)$$

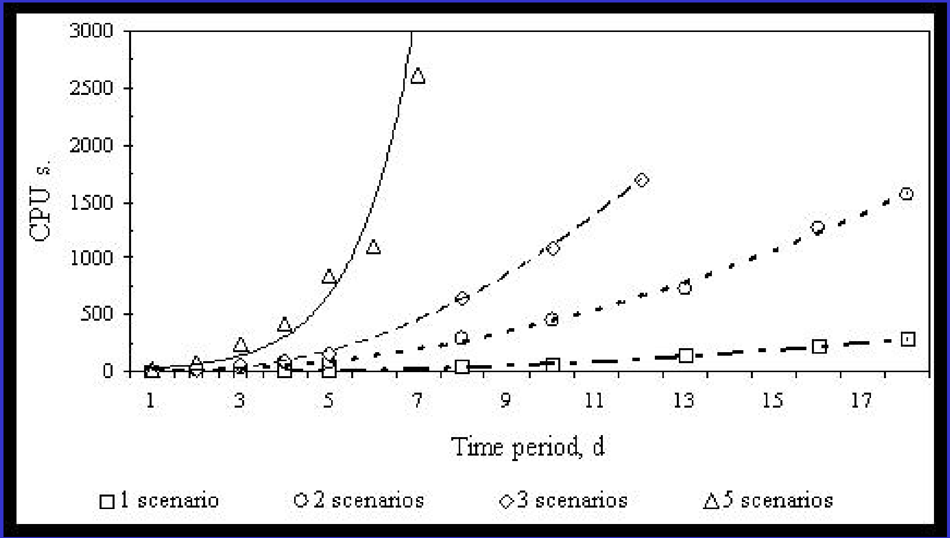
$$-\sum_{t\in \mathbf{T}}\left(\sum_{u\in \mathbf{U}_p} Cinv_{u,t,c}\, Vol_{u,t,c}\right)$$

s.t. refinery constraints

# Planning under Uncertainty - REVAP results



# Supply Chain Example

Cases:

1: Complete model

2: Pre-selection of some suppliers

3: Interruption of pipeline segment SG-RV

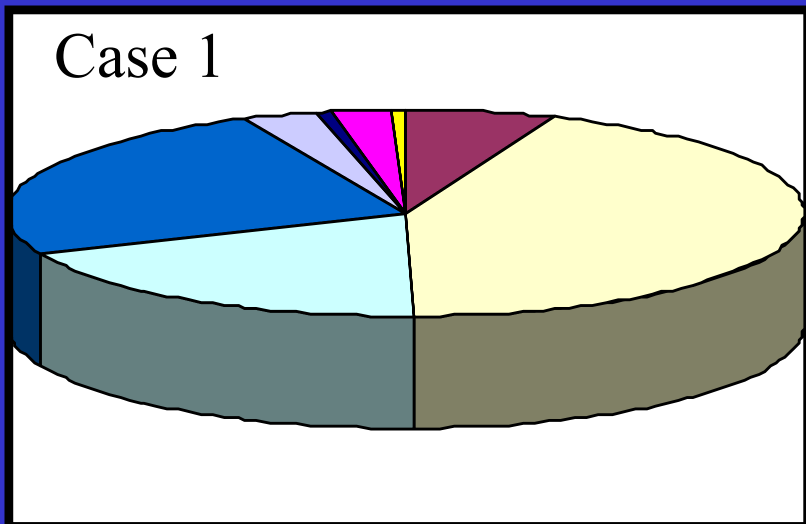
General constraints:

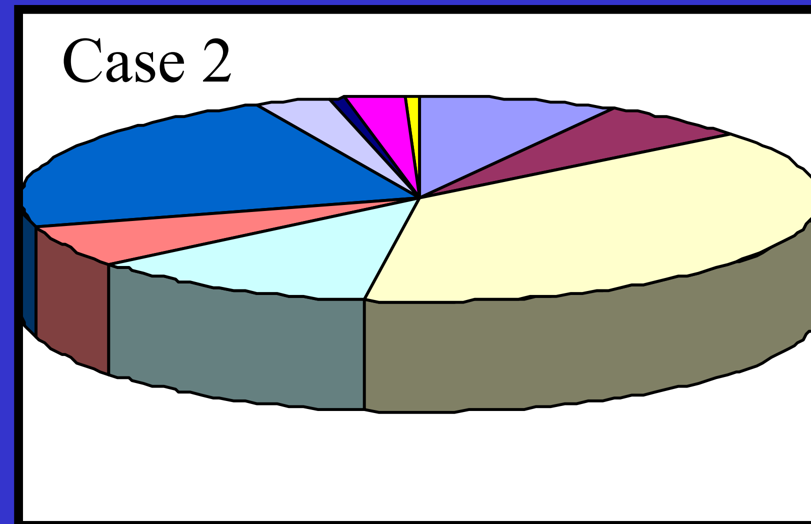
Planning horizon: one / two time periods

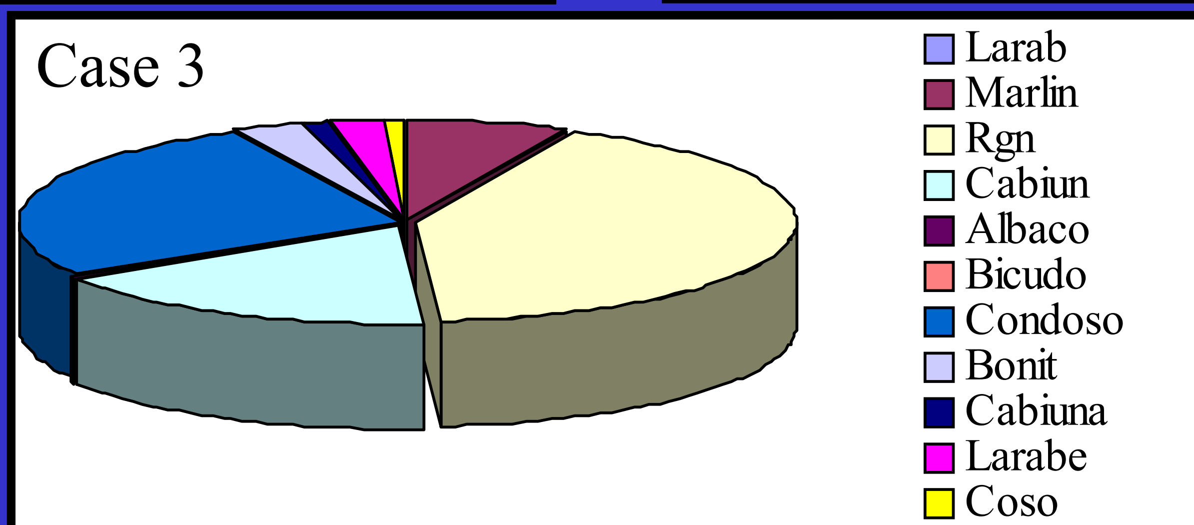
Supply of 20 oil types

Generation of 32 products (6 transported with pipelines)

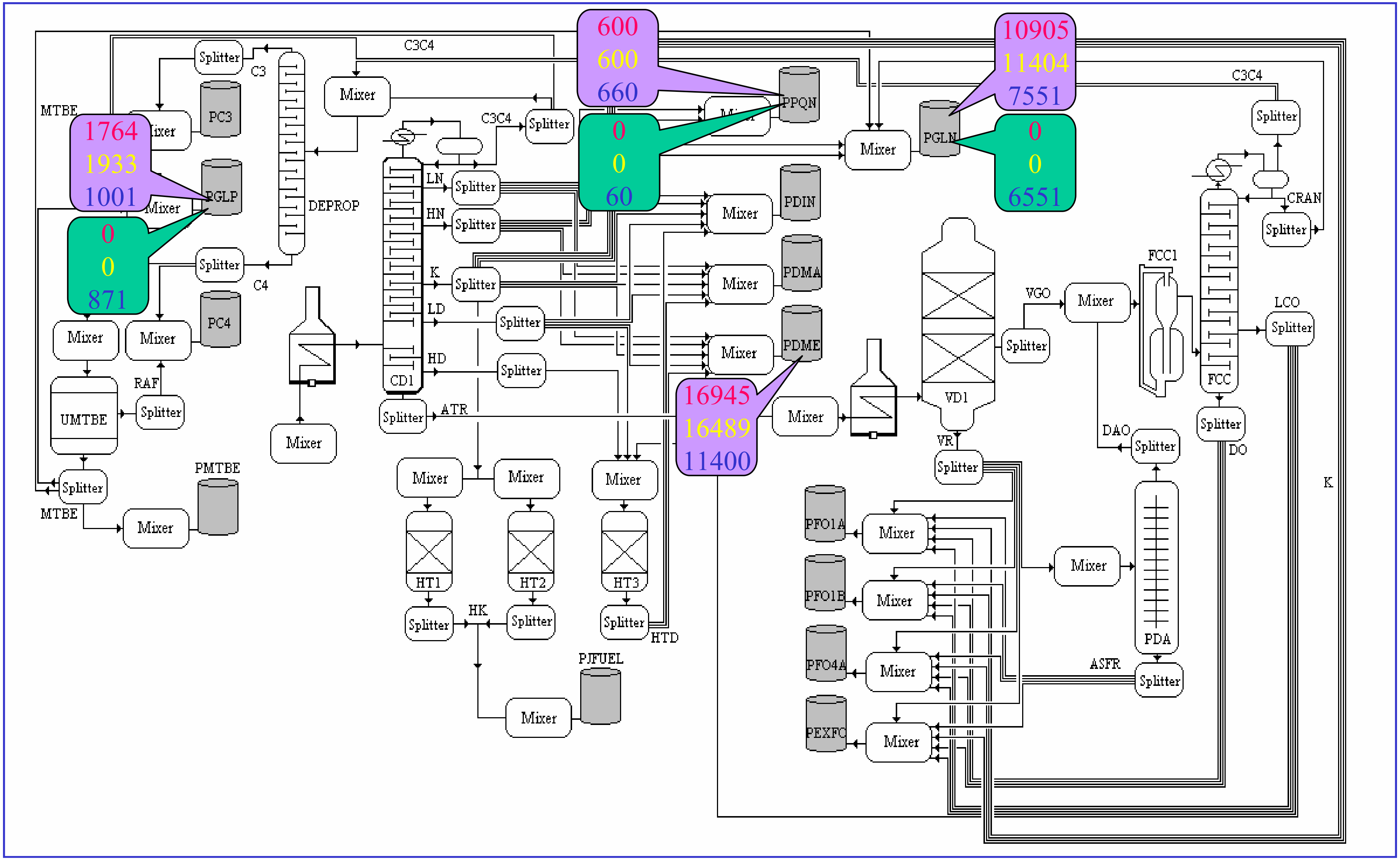
# Supply Chain Example – Petroleum Selection



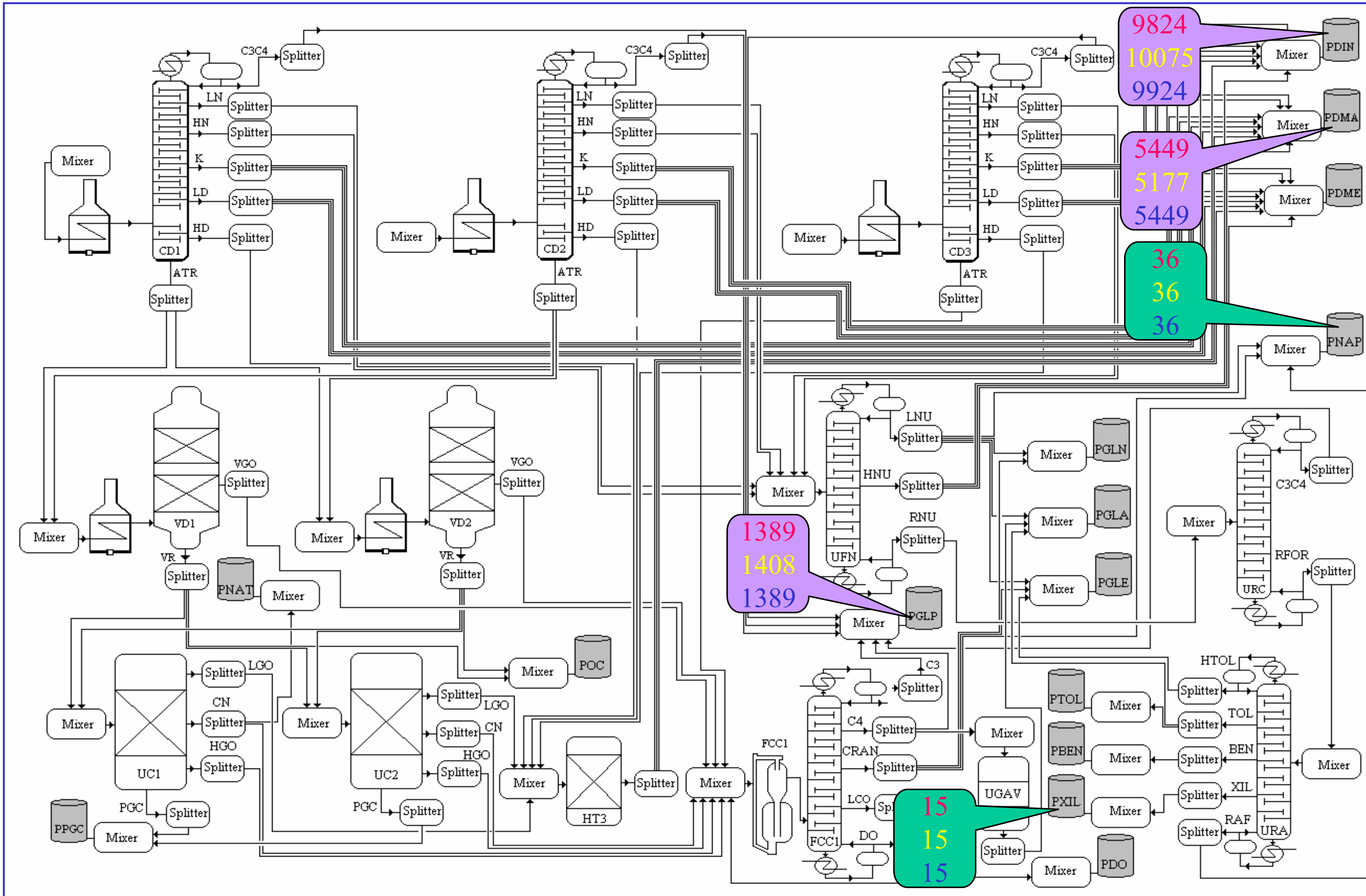



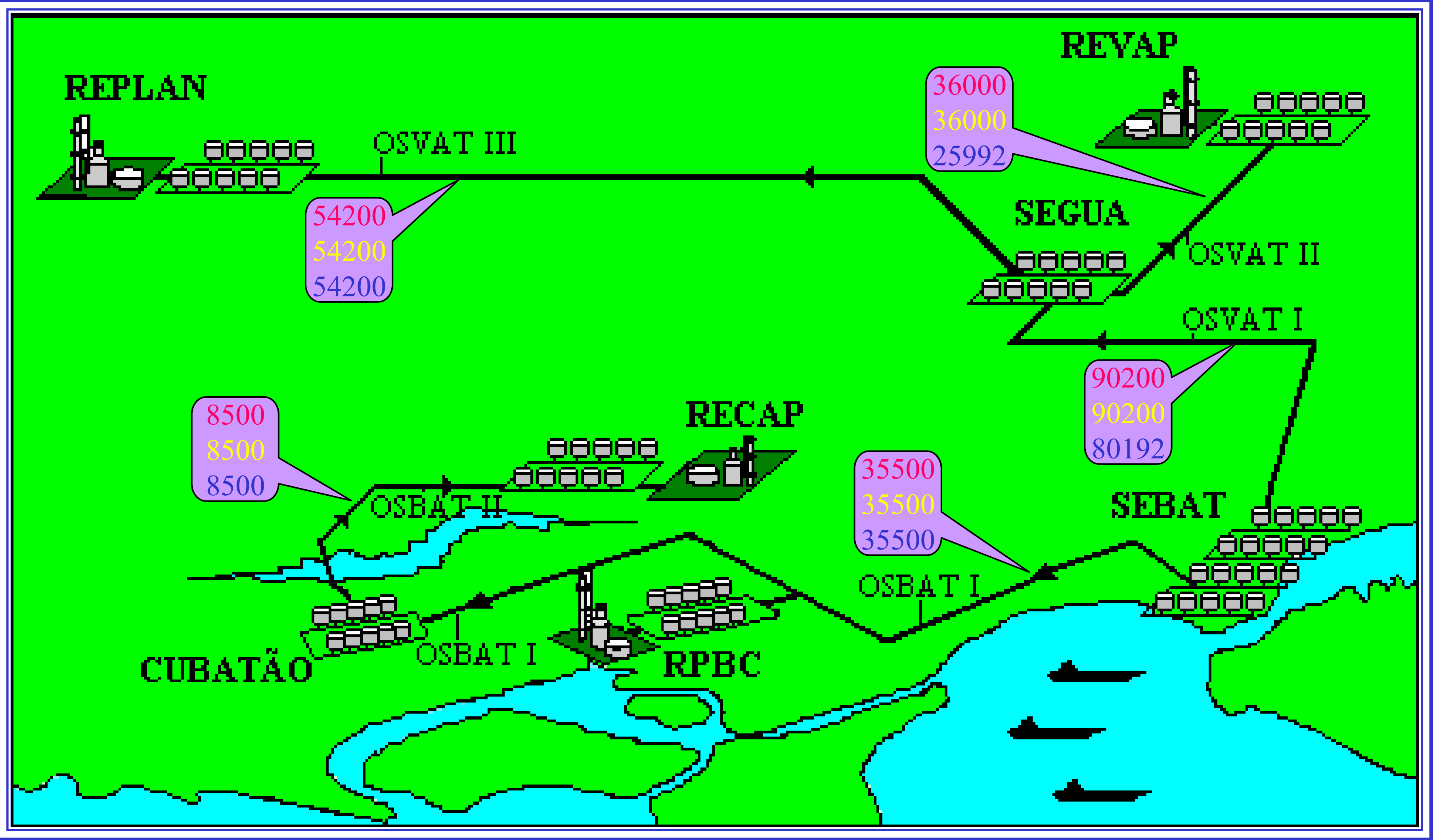
# Supply Chain Example – REVAP



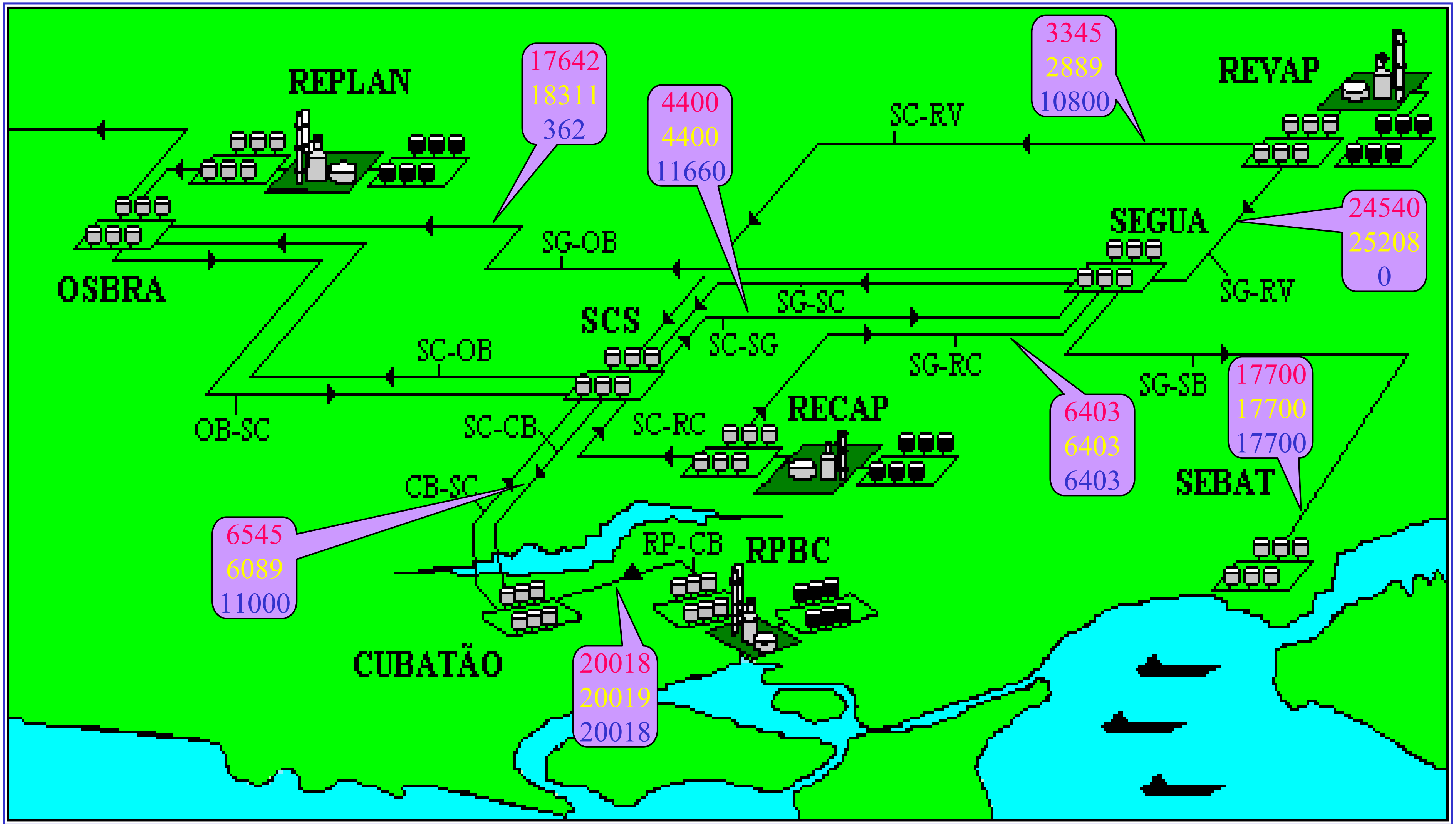
# Supply Chain Example – RPBC



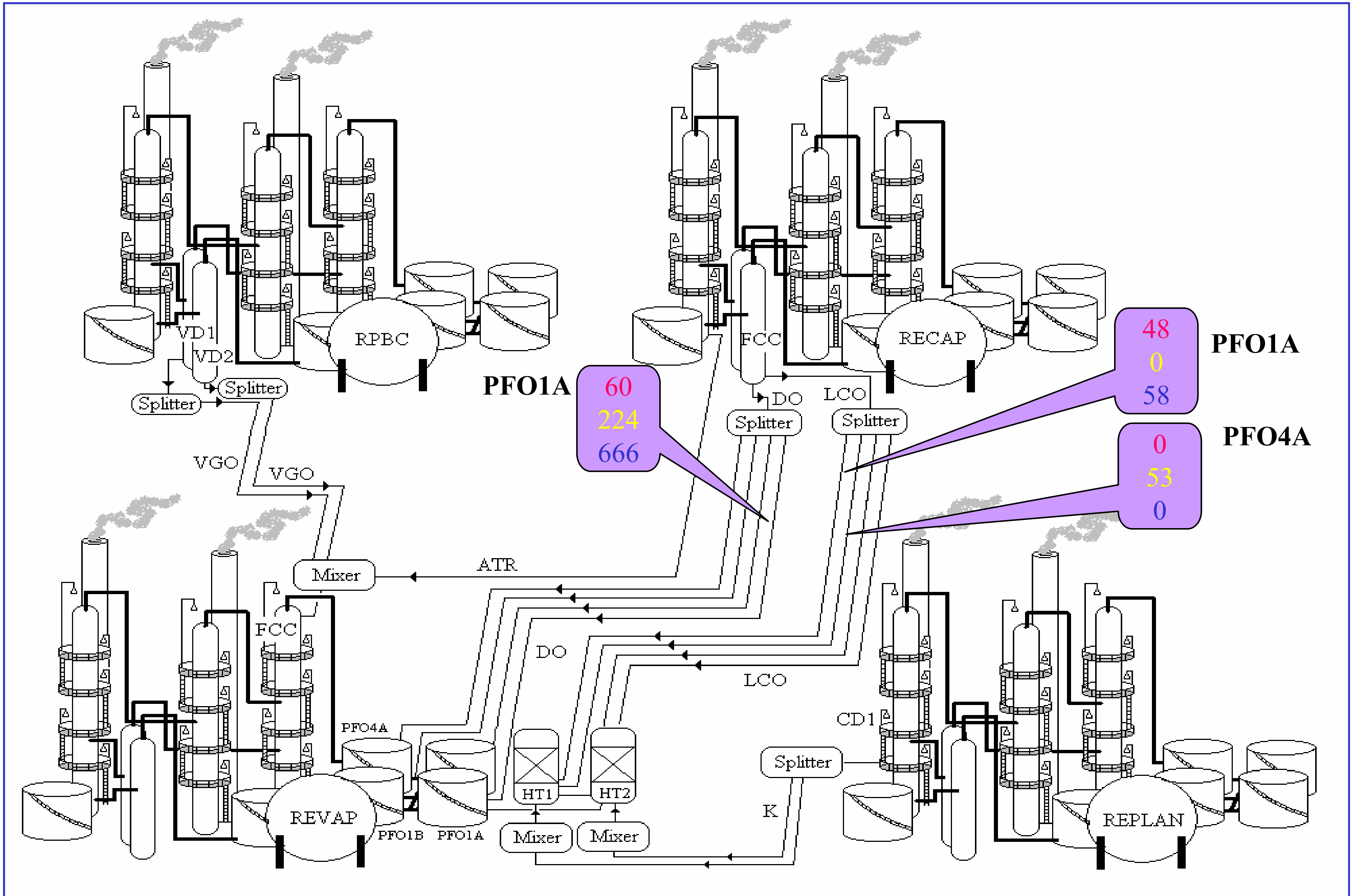
# Supply Chain Example – Oil Supply



# Supply Chain Example – Product Supply



# Supply Chain Example – Intermediate Streams



# Supply Chain Example – Computational Results

| Case | Case 1 | | Case 2 | | Case 3 | |
|---|---|---|---|---|---|---|
| Number of time periods | 1 | 2 | 1 | 2 | 1 | 2 |
| Constraints | 2304 | 4607 | 2306 | 4611 | 2304 | 4607 |
| Variables | 2544 | 5087 | 2544 | 5087 | 2544 | 5087 |
| Discrete variables | 195 | 390 | 195 | 390 | 195 | 390 |
| Solution time (CPU s) | 116.8 | 656.2 | 152 | 915.6 | 157.8 | 2301 |
| Objective Value ($ $x10^6$) | 20.4 | 41.3 | 20.3 | 41.1 | 18.0 | 36.3 |

# Conclusions

- **Mathematical programming**

  -General refinery topology

  -General petroleum supply chain representation

  -Representation of nonlinear properties and multiple periods

  -Non-convex Large-Scale MINLP

- **Real-world applications**

  -General planning trends along multiple periods

  -Analysis of scenarios (discrete probabilities)

  -Intensive computational effort

# Research needs

- **Modeling**
  - ✓Upstream-Downstream Integration
  - ✓Multi country supply chains (royalties, tariffs)
  - ✓Modeling of uncertainties
- **Efficient solution methods**
  - ✓Decomposition (spatial, temporal, functional)
  - ✓Approaches (Lagrangian Relaxation, Cross Decomposition)