Optimal Model-Based Production Planning for Refinery Operation

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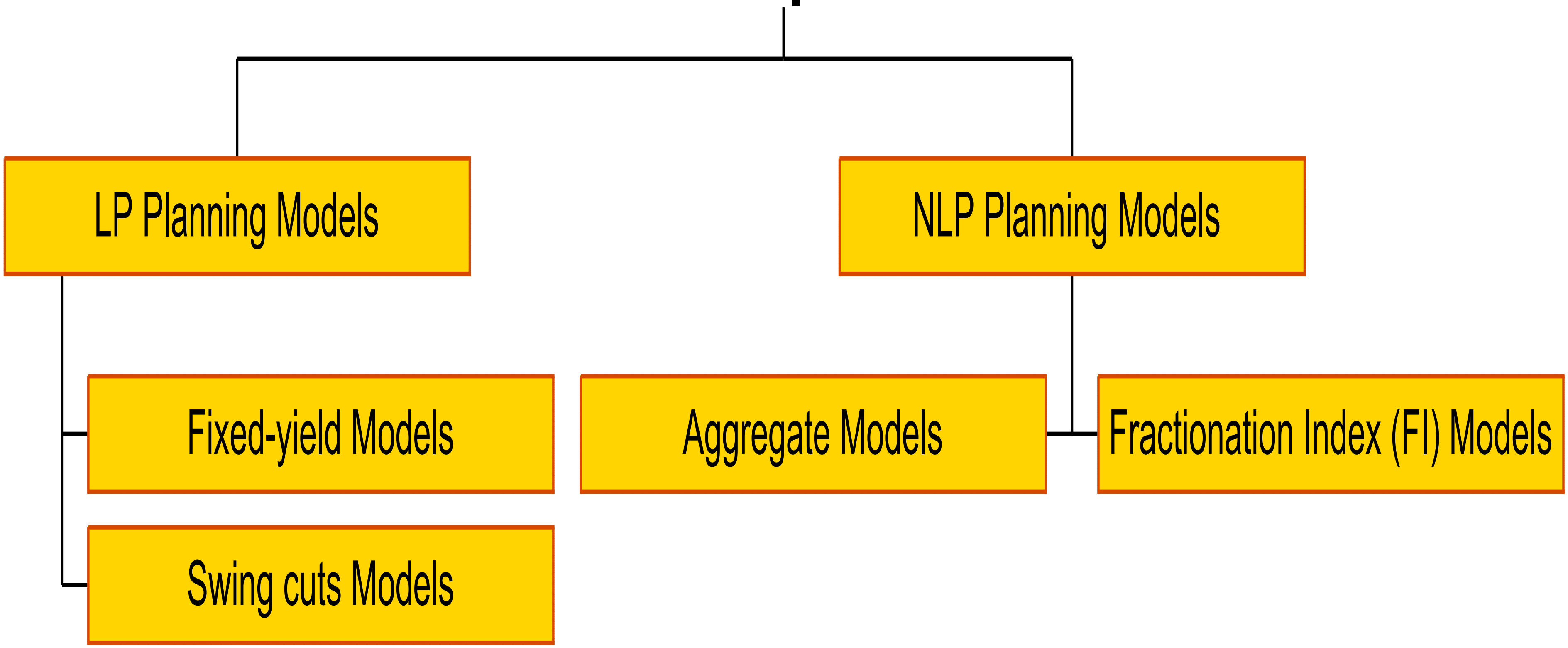
Outline

- Introduction
- Refinery Planning Model Development
  - LP Planning Models
  - NLP Planning Models
    - FI Model
    - Aggregate Model
- Conclusion & Future work

Introduction

- Refinery production planning models
  - Optimizing refinery operation
    - Crude selection
  - Maximizing profit; minimizing cost
  - LP-based, linear process unit equations
- Current Project
  - Collaboration with BP Refining Technology
  - Goal: develop a refinery planning model with nonlinear process unit equations, and integrated scheduling elements

Refinery Planning Model Development



LP Refinery Planning Models

- **Fixed yield models**:
  - Linear equation for calculating process unit yield $F_{outlet} = a_{unit,feed,outlet} * F_{feed}$
  - Models are robust and simple, but limited
- **Swing cut models**:
  - Uses existing LP tools
  - Optimizing the crude cut size

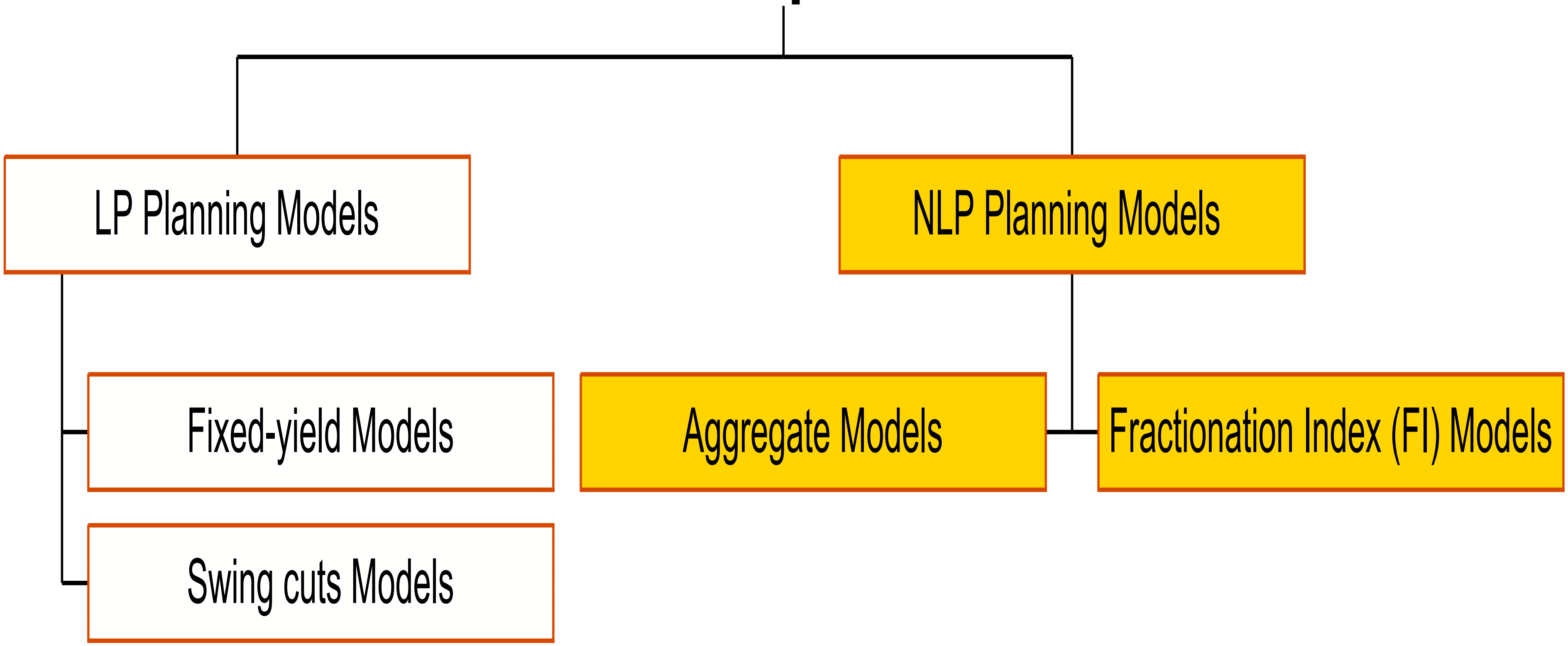
$$F_{outlet} = a_{CDU,feed} * F_{feed} + b_{CDU,outlet,front} + b_{CDU,outlet,back}$$

LP Refinery Planning Model Example

- **Example**
  - Complex refinery configuration
    - Processing 2 crude oils & importing heavy naphtha
  - Swing cut model
    - Offers lower net cost & different feed quantities
    - Shows benefits of better equations

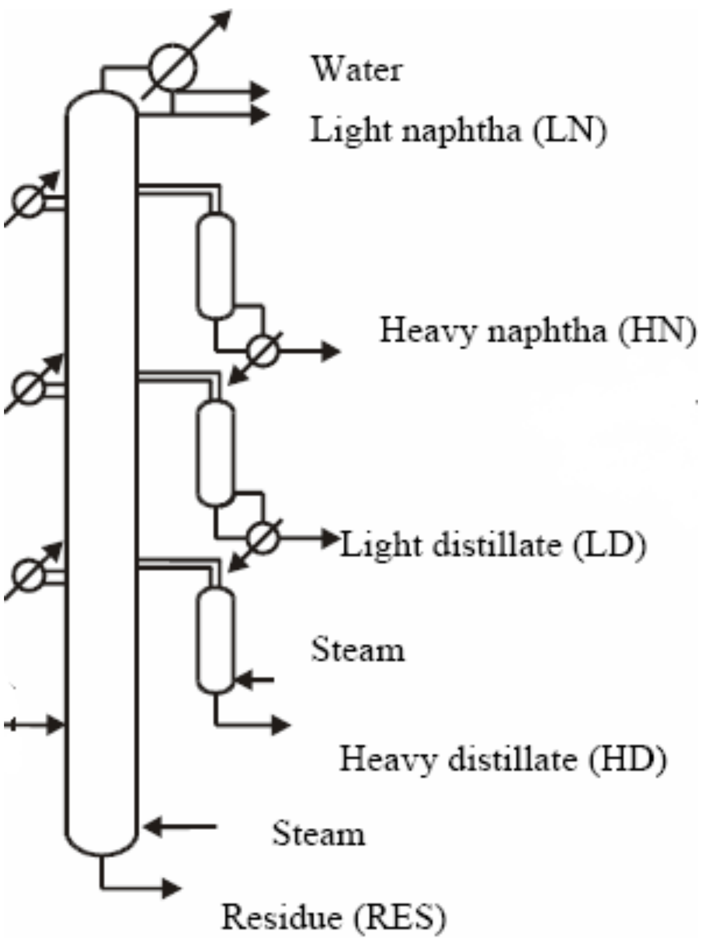
		Fixed yield	Swing cut
Crude Feedstock	**Crude1 (lighter)**	**142**	**0**
	Crude2 (heavier)	**289**	**469**
Other Feedstock	**Heavy Naphtha**	13	9
Refinery Production	**Fuel Gas**	13	17
	LPG	18	20
	Light Naphtha	6	6
	Premium Gasoline	20	20
	Reg. Gasoline	80	92
	Gas Oil	163	170
	Fuel Oil	148	160
	Net Cost	**89663**	**85714**

Refinery Planning Model Development

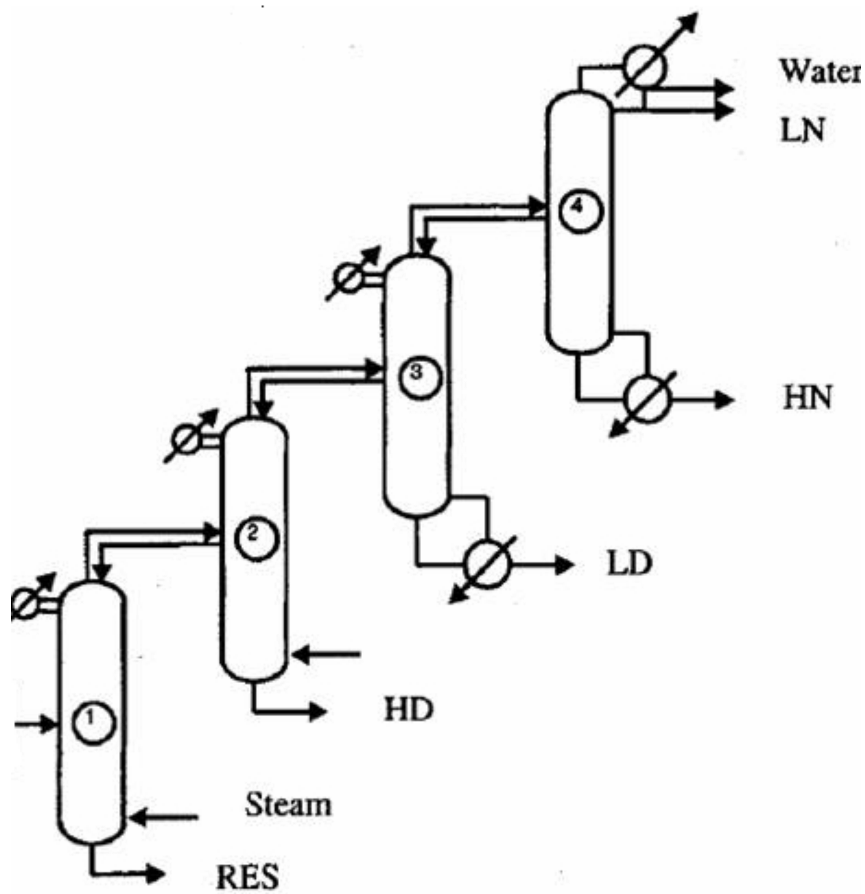


- Focus on the front end of the refinery
  - Crude distillation unit (CDU)

CDU & Cascaded Columns



Typical Crude Distillation Column
(Gadalla et al, 2003)

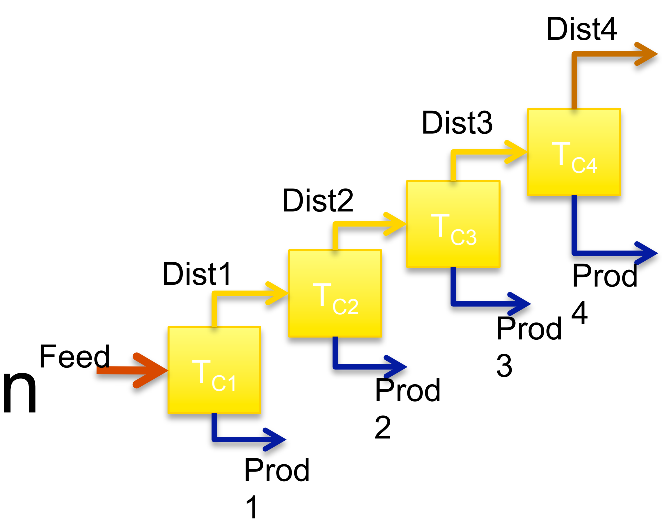


Cascaded Columns Representation of a Crude Distillation Column
(Gadalla et al, 2003)

NLP Refinery Planning Models

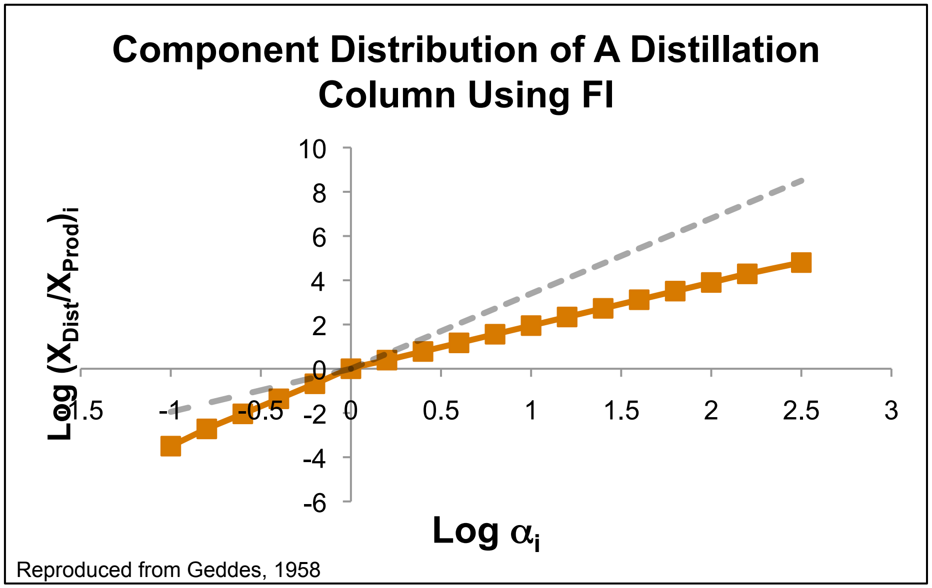
- **FI model**
  - CDU is a series of separation units
    - Cut point temperature is the separation temperature
  - Based on Geddes' fractionation index method (Geddes 1958)
    - FI replaces N_{min} in Fenske equation

$$\left(\frac{Dist}{Prod}\right)_{i,j} = \left(\alpha_{i/ref}\right)_j^{FI}\left(\frac{Dist}{Prod}\right)_{ref,j}, i \in comp, j \in stage$$



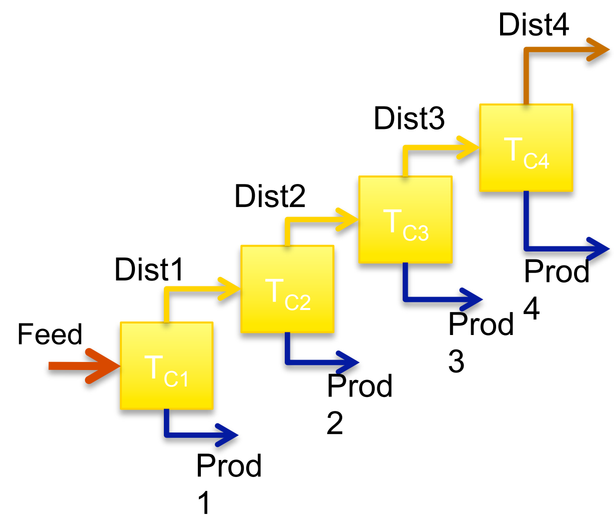
NLP Refinery Planning Models

- **FI model**
  - Feature
    - Represents fractionation power
    - Single or double FI values per column
    - Value dependent on choice of temperature & reference component
  - For CDU
    - Each sep unit have 2 values
    - Flash zone displays different trend
    - Model is crude-independent



NLP Refinery Planning Models

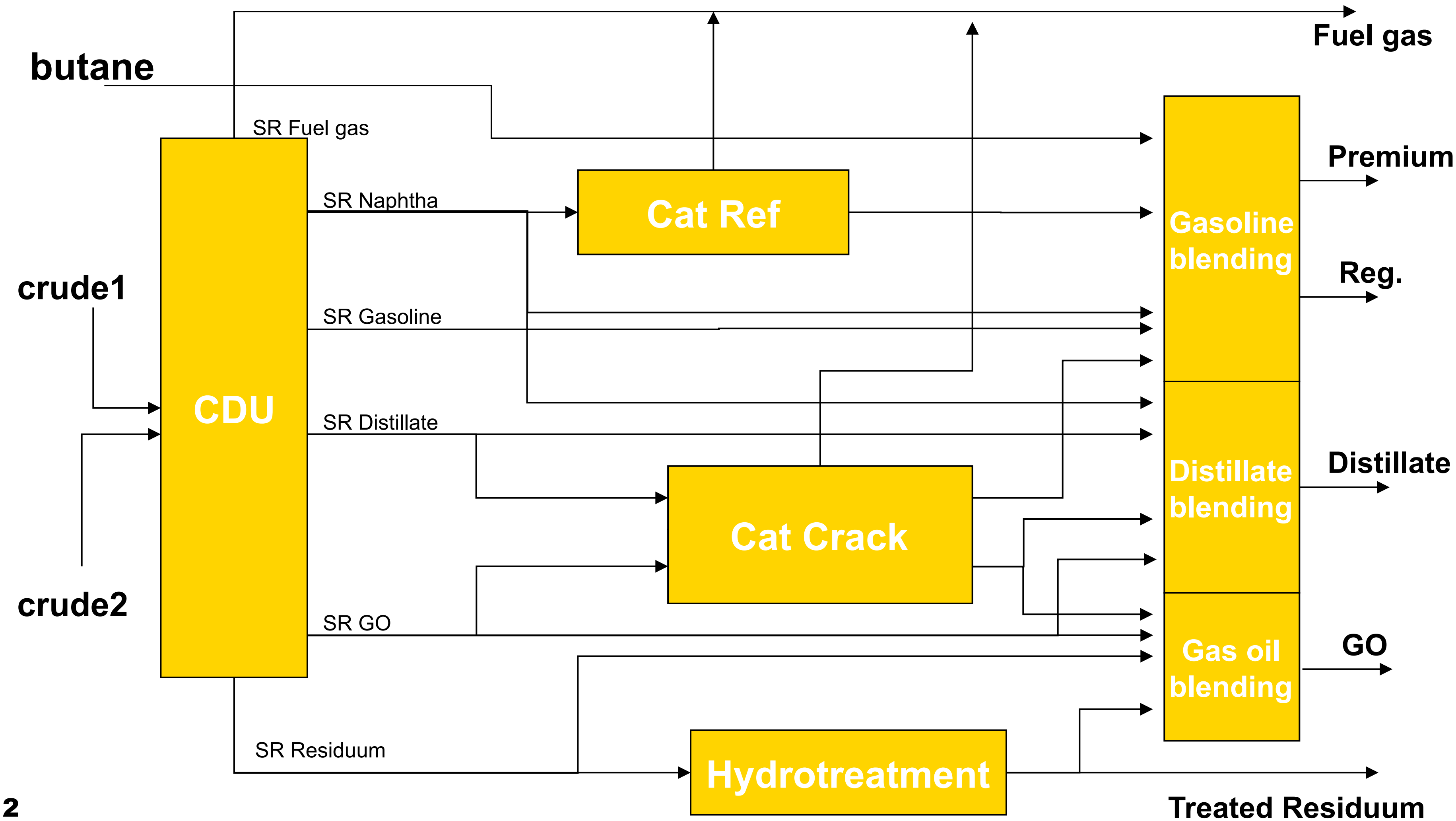
- **FI model**
  - FI model example
    - Venezuelan crude
    - 40 Pseudo-components, 4 cuts
    - 4 runs: Maximizing naphtha (N), heavy naphtha (HN), light distillate (LD), heavy distillate (HD)
    - Cut-point temperature and product quantities reflect the different business objectives
    - Stats
      - Equations: 562
      - Variables: 568
      - Solver: CONOPT



	Cut point temperature					
Run	Gas OH	Naphtha	H Naphtha	L Dist.	H Dist;	B. Residue
Max Naphtha		272.7	417.0	426.4	526.8	595.3
Max H Naph.		272.7	386.2	487.8	526.8	595.3
Max L Dist.		272.7	386.2	398.3	606.0	631.1
Max H Dist.		272.7	386.2	398.3	526.8	650.5
	Product					
Max Naphtha	6.2	112.9	35.1	68.6	16.5	60.7
Max H Naph.	6.2	107.4	53.0	56.1	16.6	60.7
Max L Dist.	6.2	111.5	10.7	95.0	16.0	60.5
Max H Dist.	6.2	111.5	10.7	94.0	16.9	60.5

Problem Statement

Typical Refinery Configuration *(Adapted from Aronofsky, 1978)*



Problem Statement

- Information Given
  - Refinery configuration: Process units
  - Feedstock & Final Product
- Objective
  - Select crude oils and quantities to process
    - Minimize cost
    - single period time horizon

NLP Refinery Planning Models

- **FI Model in the planning model**
  - Processing 2 crude oils:
    - Crude 1 (mid continent) & Crude 2 (W. Texas)
  - Results
    - Economics

	Fixed Y	Swing C	FI
Cost	771.93	748.09	717.01

    - Feedstock results

Feedstock	Fixed Y	Swing C	FI
crude1	89.72	78.06	41.92
crude2	0.00	21.94	58.08

NLP Refinery Planning Models

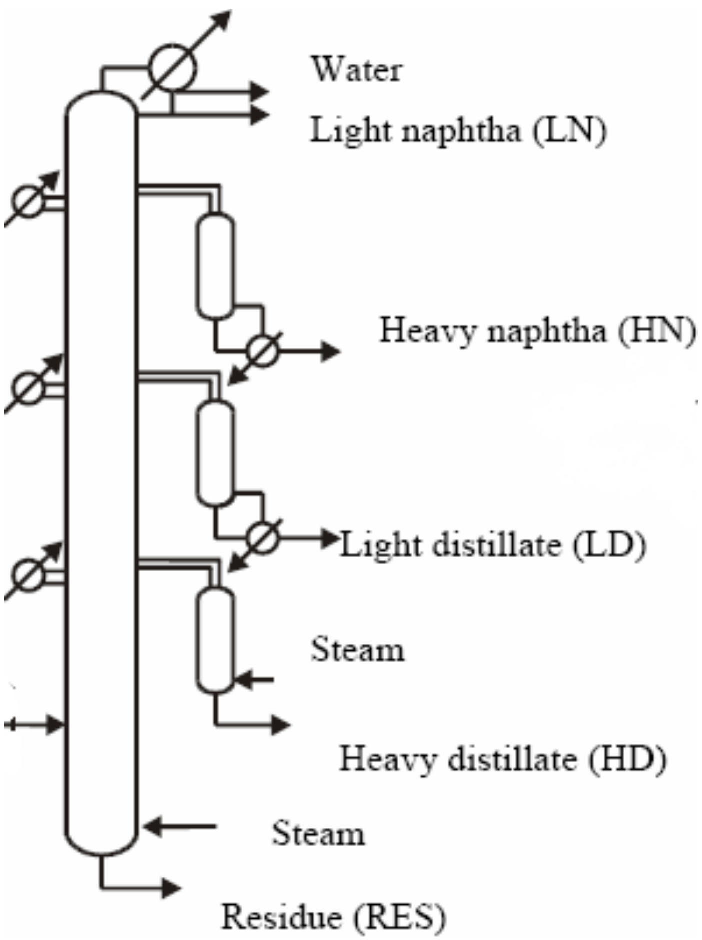
- **FI Model in the planning model**
  - Results
    - Products
      - Increased reg. gasoline
      - Different fuel oil rates and treated residue

Prodcut	Fixed Y	Swing C	FI
Fuel gas	7.7	7.8	8.7
Premium gasoline	0.0	0.0	0.0
Regular gasoline	48.1	44.2	52.7
Distillate	0.0	0.0	0.0
Fuel oil	41.0	43.6	17.0
H.Treated Residue	0.0	0.0	21.9

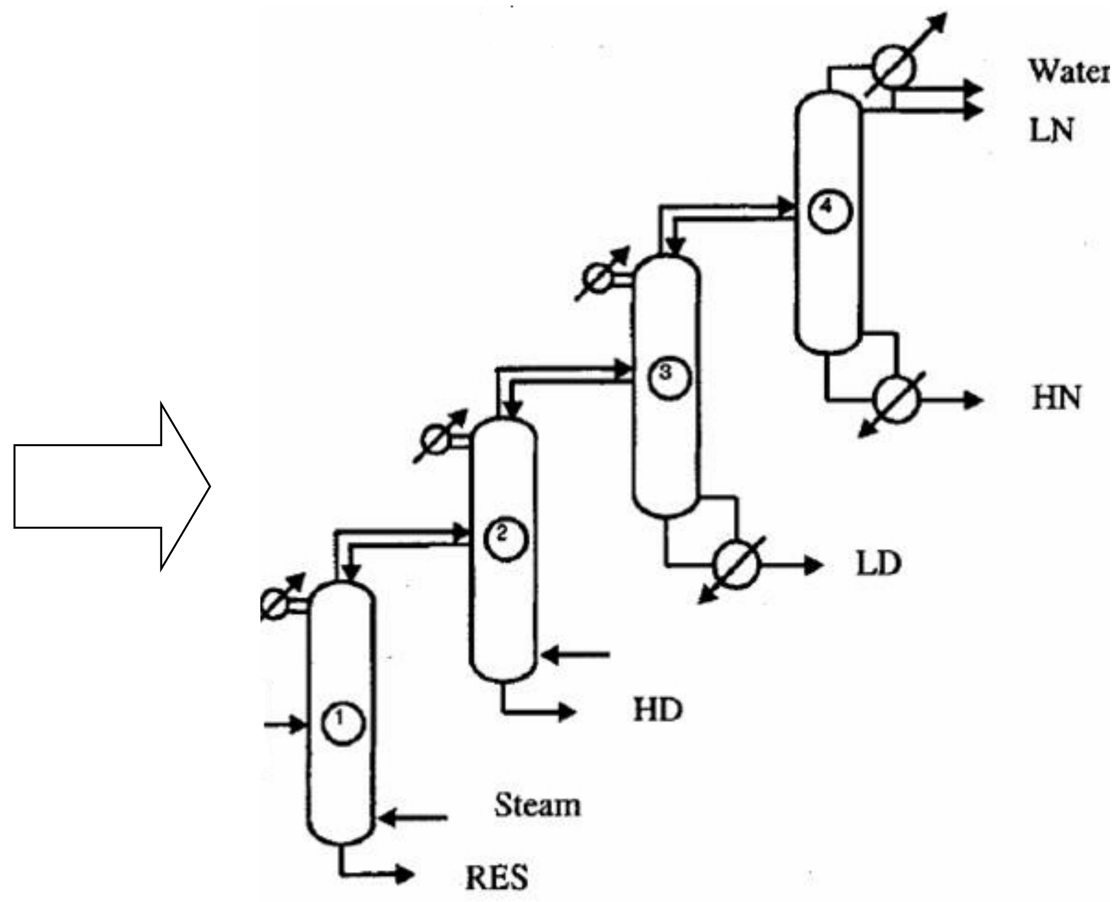
    - Model statistics

Feedstock	Fixed Y	Swing C	FI
Equations	155	163	1289
Variables	184	200	1334
Time sec	0.13	0.13	1.56

CDU & Cascaded Columns



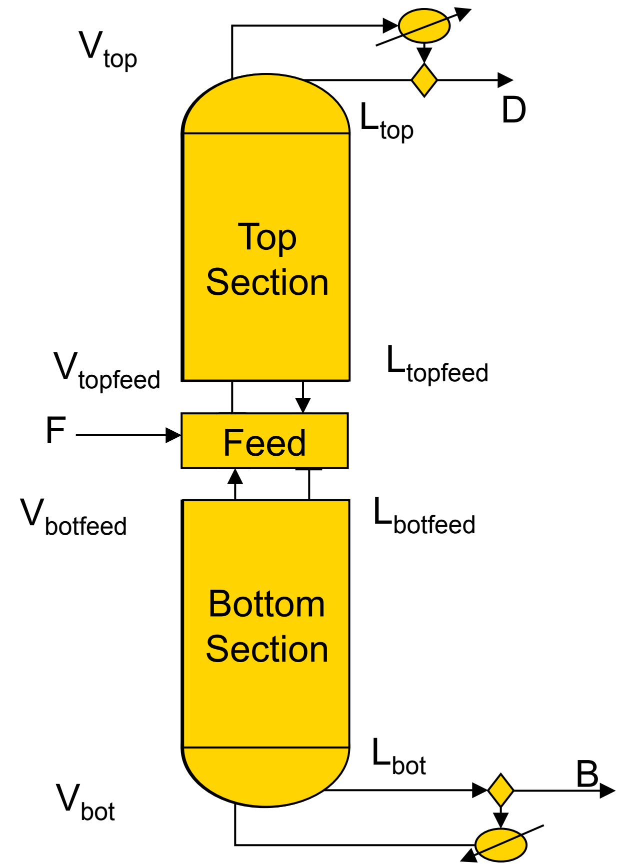
Typical Crude Distillation Column
(Gadalla et al, 2003)



Cascaded Columns Representation of a Crude Distillation Column
(Gadalla et al, 2003)

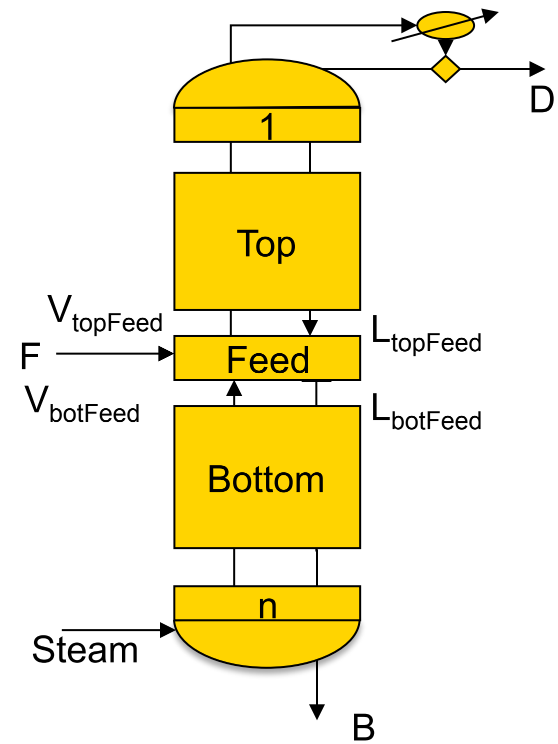
NLP Refinery Planning Models

- **Aggregate model**
  - More detailed modeling
  - Conventional distillation
  - Based on work of Caballero & Grossmann, 1999
  - integrated heat and mass exchangers
  - sections around the feed location
    - Assuming equimolal flow in each section
  - Nonlinearity in equilibrium constant
  - Single & cascaded columns arrangements
    - Model is robust
    - Results in good agreement with rigorous calculation



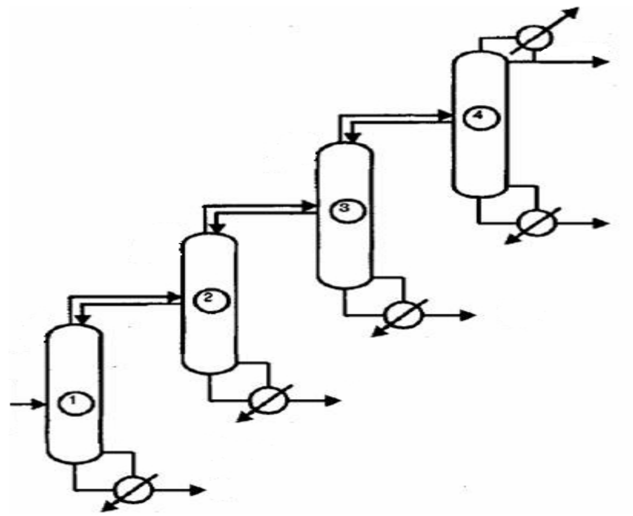
NLP Refinery Planning Models

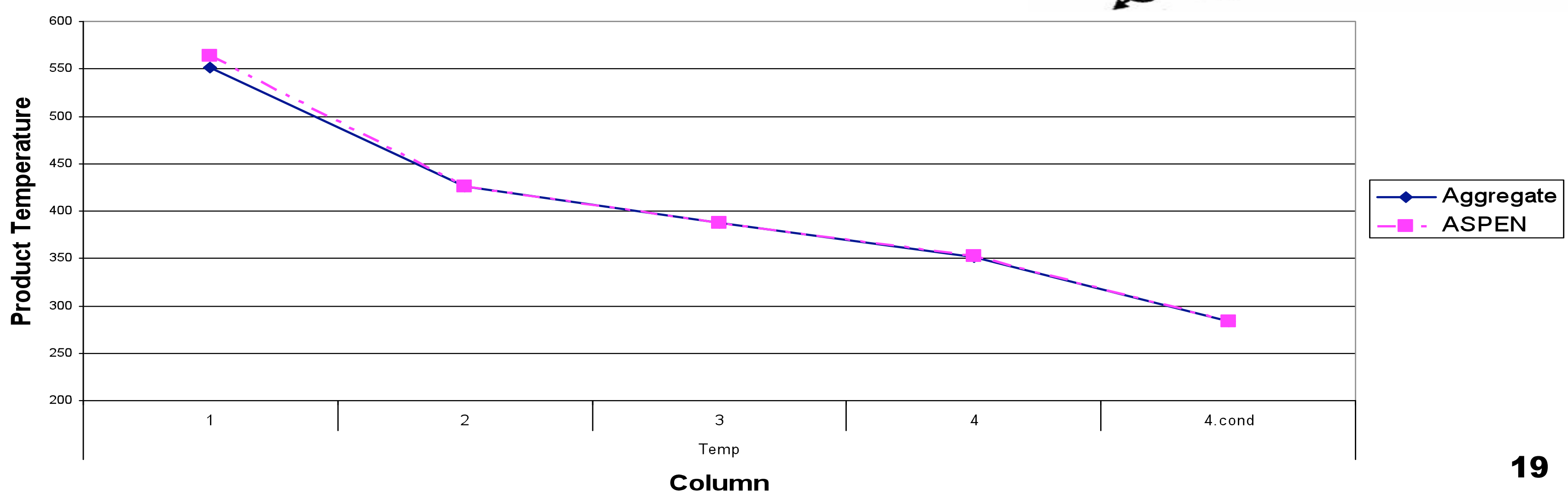
- **Aggregate model**
  - Steam distillation
  - Modified aggregate model
    - 3 Equilibrium stages
    - 2 multi-stage sections
    - Assuming non-equimolal flow in each section
  - Nonlinearity in equilibrium constant
  - Single & cascaded columns arrangements
    - Model is robust
    - Results show predicted temperature peak at the feed stage



NLP Refinery Planning Models

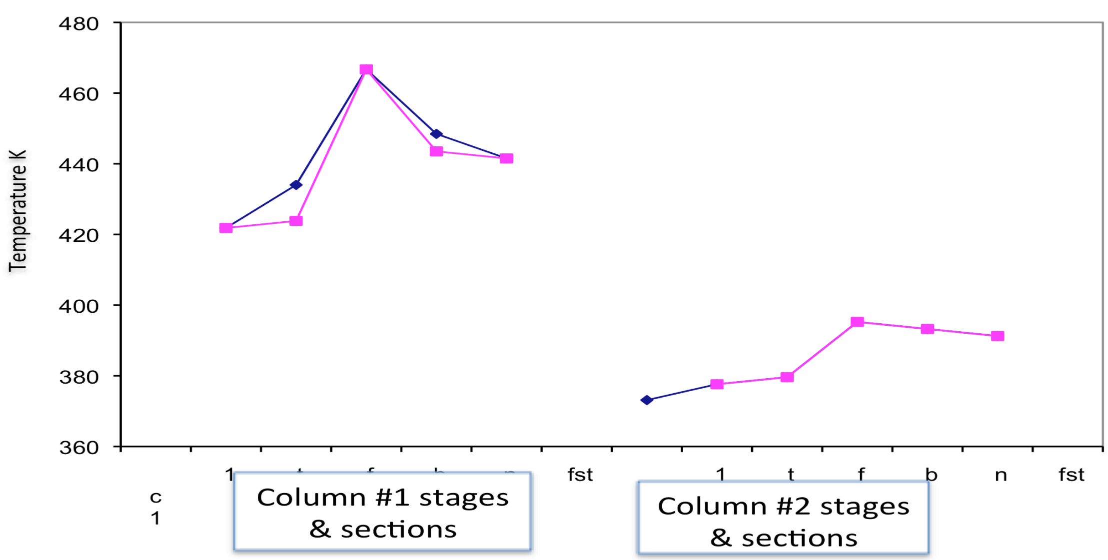
- **Aggregate model**
  - Conventional distillation example
    - 4 columns
    - Feed: 18 components (C3-C20)
    - Results: product temperature matching simulation results

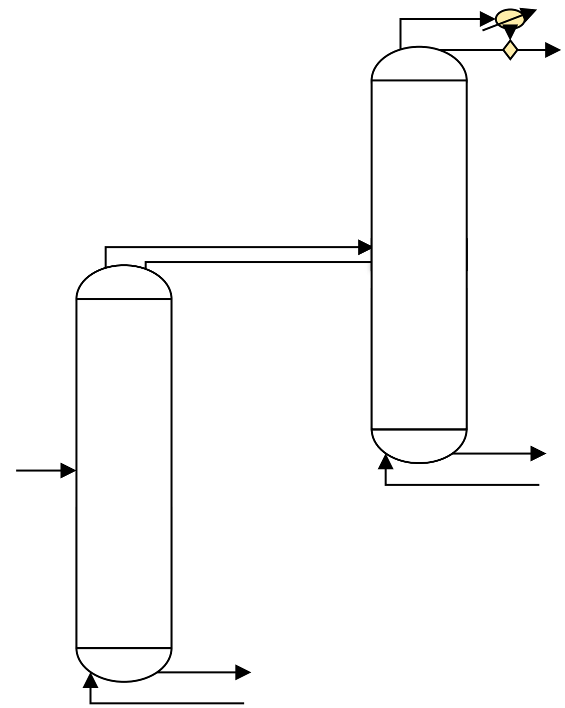




NLP Refinery Planning Models

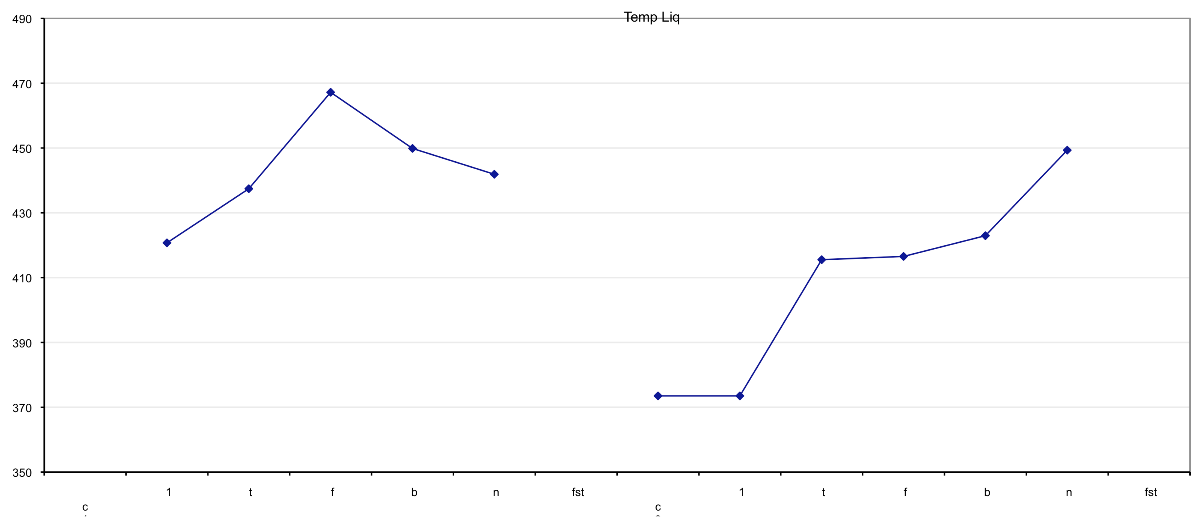
- **Aggregate model**
  - Steam distillation example
    - 2 columns, both with steam distillation
    - Feed: 4 components
    - Results: temperature trend successfully predicted for both columns

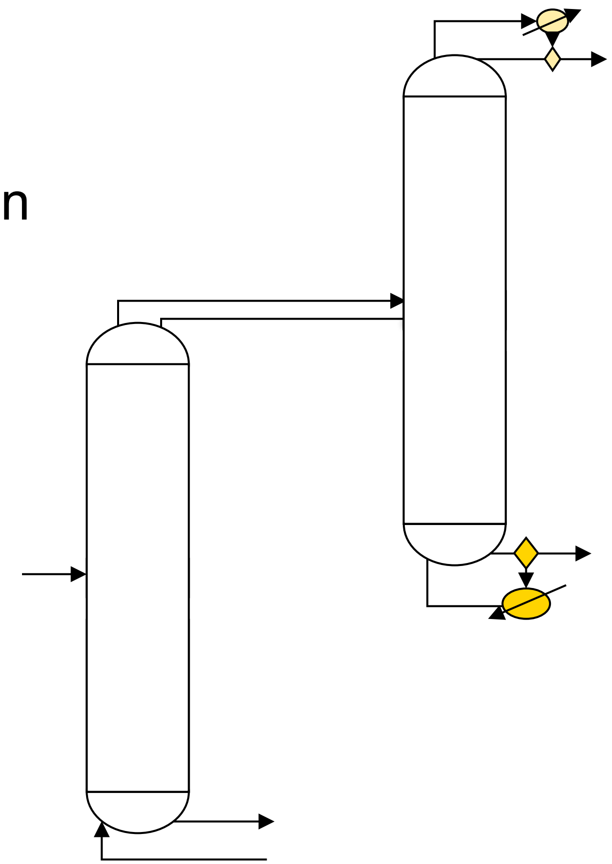




NLP Refinery Planning Models

- **Aggregate Model**
  - Mixed-type distillation cascade
    - Combines conventional and steam distillation
      - Similar to CDU
    - Extension of the previous problem





Conclusion & Future work

- NLP FI model
  - More runs using the FI model
    - More crude oils: 5+
    - Improve crude blending calculations
- NLP Aggregate model
  - Improve steam stripping equations
  - Investigate better initialization scheme and additional constraints
- Extend the model to multi-period
- NLP models
  - Assess the benefit of the different modeling approaches in terms of accuracy, robustness & simplicity
  - Upgrade process model for other important units
- Add scheduling elements