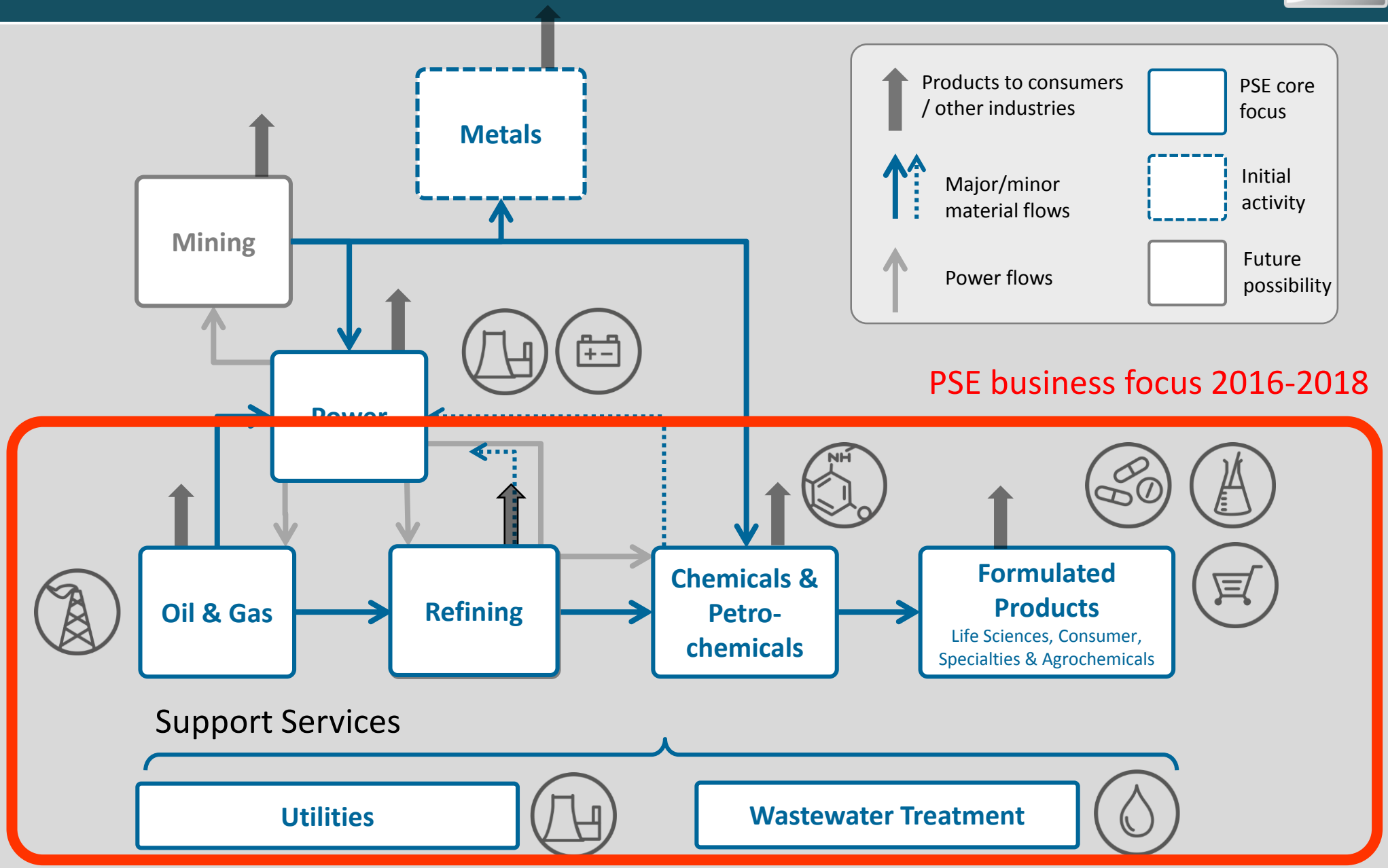
ADVANCED PROCESS MODELLING FORUM
LONDON
20–21 APRIL 2016

Refining

Advanced Real-time Refinery Monitoring & Optimisation

K.S Kumar – Bharat Petroleum Corporation Limited, India
Charles Brand – PSE, UK

PSE's market: the process industries value chain



Bharat Petroleum

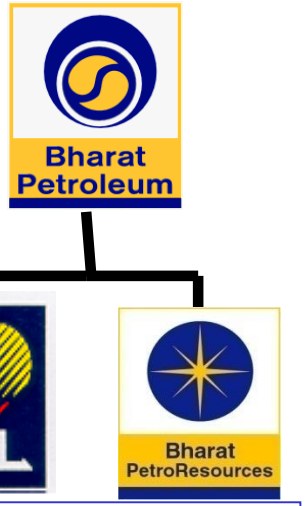
BPCL Corporate Overview

Bharat Petroleum

Corporate Overview

- **Bharat Petroleum Corporation Ltd. (BPCL) was formed in 1976 consequent upon passing of the Burmah Shell Acquisition Act by Parliament**
- **BPCL's market share among PSUs is 23.29 % as on 31st March 2015**
- **BPCL ranked 757 on Forbes Global 2000 list in 2015, a significant leap from 1045 rank in 2014.**

BPCL group



Major JVs

Bharat Oman Refineries Ltd
Petronet LNG Ltd
Indraprastha Gas Ltd
Central UP Gas Ltd
Maharashtra Natural Gas Ltd
Sabarmati Gas Ltd
Petronet CCK Ltd
Delhi Aviation Fuel facility Pvt Ltd
Matrix Bharat Marine Services Pte Ltd.
Bharat Star Services Ltd
Bharat Renewable Energy

Installed Refining

- 12 MMTPA in Mumbai (Bharat Petroleum)
- 9.5 MMTPA in Kochi (Bharat Petroleum)
- 6 MMTPA in Bina, 50% holding (Bharat Oman Refineries Limited)
- 3 MMTPA in Numaligarh, 61.65 % holding (NRL)

BPCL's group share in overall refining capacity in India 14.1 % (out of 225 MMTPA)

Group Share in Marketing 23.29 %

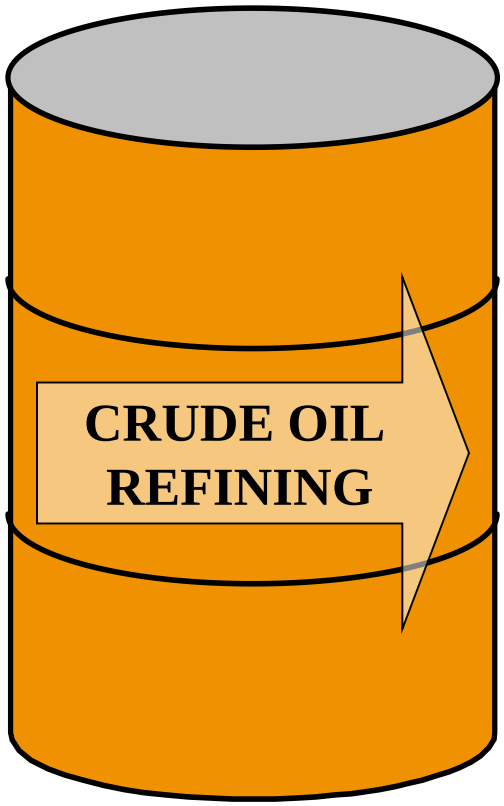
Strong Workforce 12360

Bharat Petroleum

Refining Process & Refining economics

Bharat Petroleum

Crude oil to products



Lt Distillate

Middle Distillate

Heavy ends

Main Products

C3-C4 LPG

C5-C10 PETROL

C9-C16 KERO

C14-C24 HSD

>C22 FO

Decreasing Boiling Point (deg C)

0

100

200

300

400

500

Main process - simple distillation

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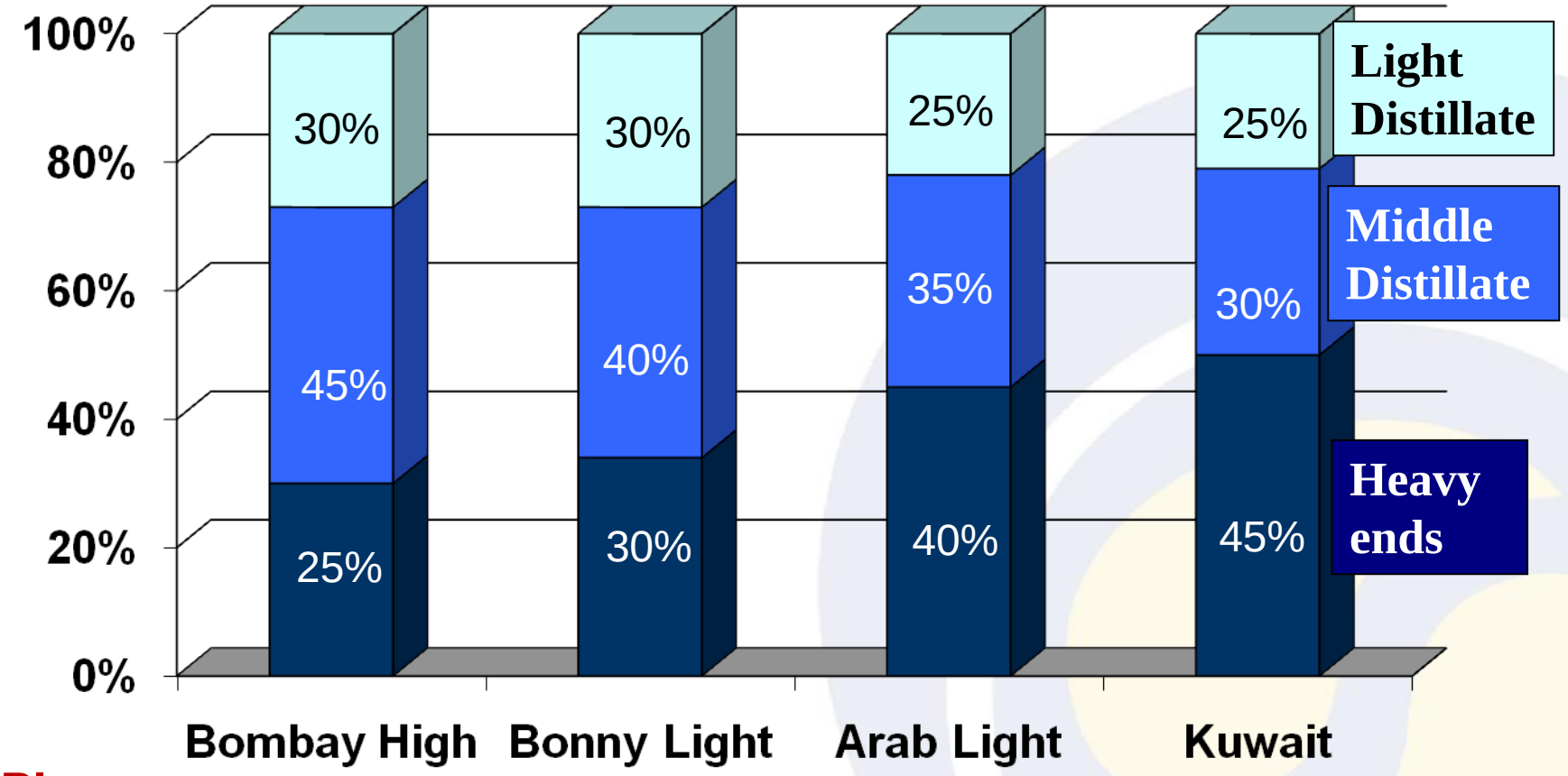
Different crude – different yields



	Bombay High	Bonny Light	Arab Light	Kuwait
° API	40	33.6	34.2	31.0
% Sulfur	0.17	0.18	1.9	2.7

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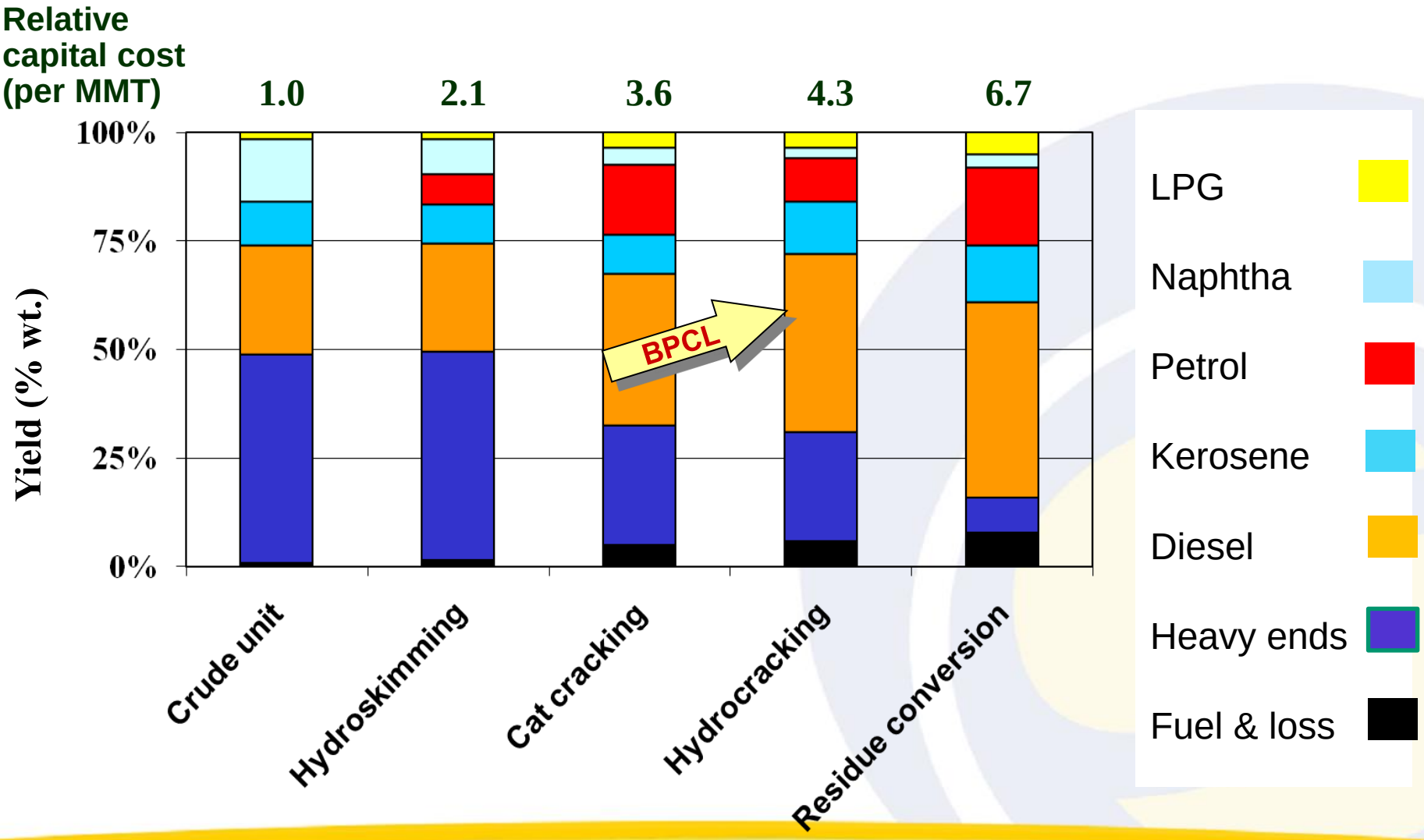
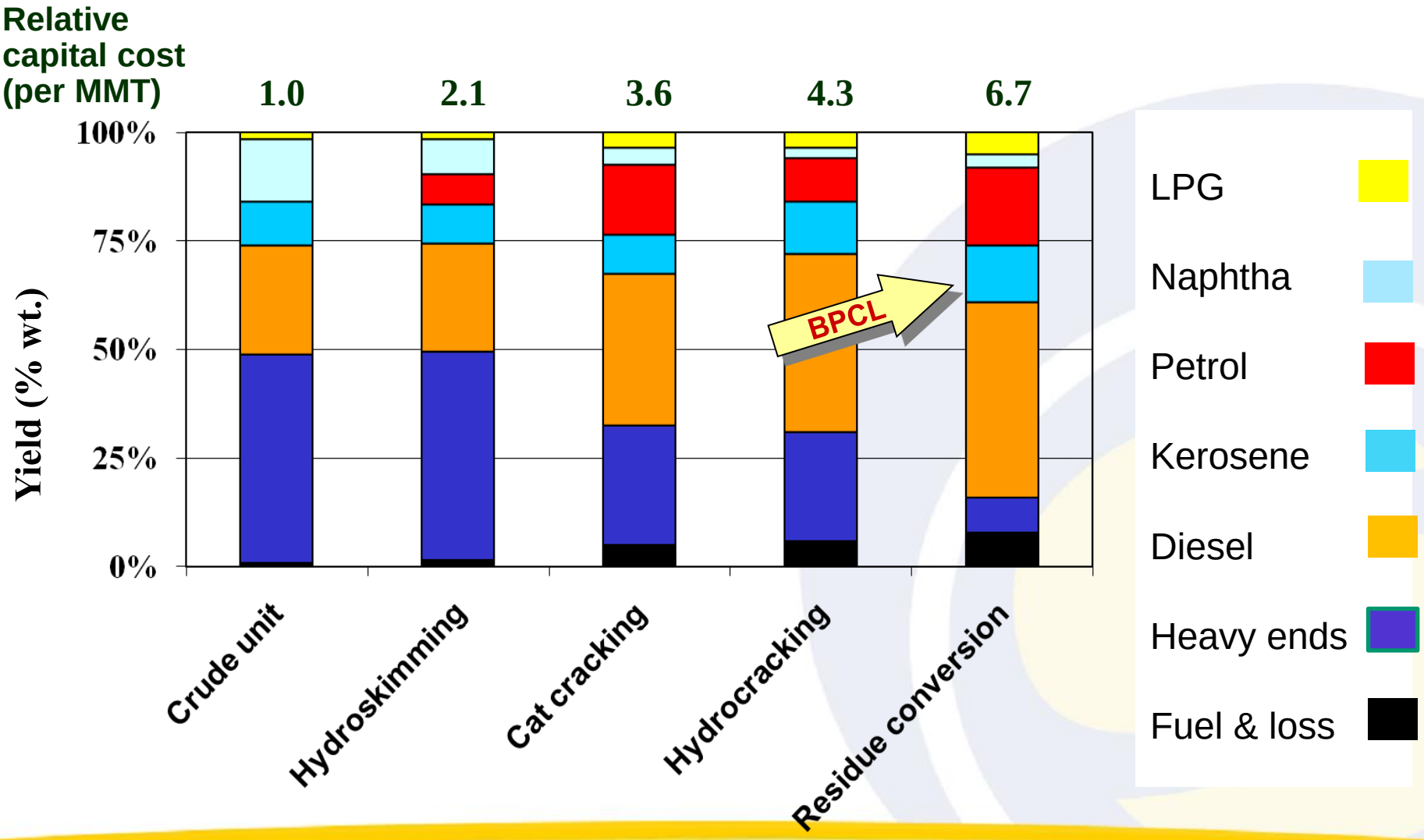
Yields are dependent on Refinery configuration



Bharat Petroleum

Yields are dependent on Refinery configuration



Bharat Petroleum

Mumbai Refinery History & Growth

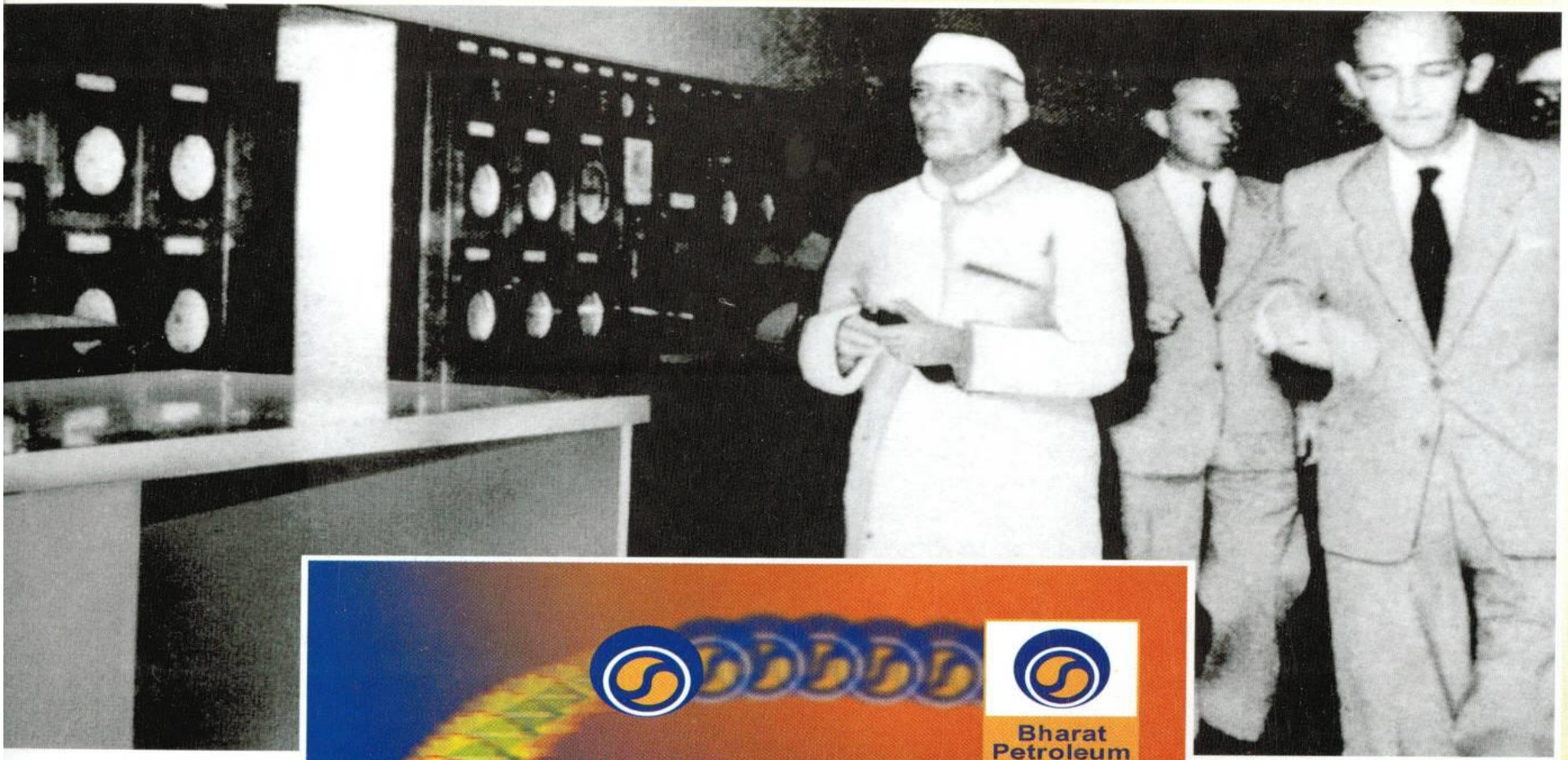
Bharat

View of the Refinery - 1957

General view of the Refinery from the Administration Building.

Historical Events

PANDIT NEHRUJI'S VISIT TO MR



TRANSITION
FROM BSR TO BPCL

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Refinery Growth

1955-76

Crude unit
Cracking unit
Bitumen unit
Vacuum unit -I
Platformer unit
3 No. Boilers
Solvent unit

7 units

1990

Crude unit-revamped
Cracking unit
Bitumen Unit
Vacuum unit-I revamped
Aromatics unit-revamped
3 No. Boilers
Crude Unit II
New solvent unit
Cracking unit – II
High Vacuum unit
Amine treating unit - I
Sulfur recovery unit

12 units

2006 onwards till Nov 2015

Crude unit 1
Cracking unit –I revamped
Bitumen unit-revamped
Vacuum unit-I
3 No. Boilers-revamped
New solvent unit
Cracking unit – II -revamped
High Vacuum unit-revamped
Aromatics unit -revamped
Amine treating unit – I & II
New Sulfur recovery unit - I & II
MTBE
Crude unit – II
CDU/VDU 3
DHDS unit - revamped
Hydrocracker - revamped
NHDS
Captive Power Plant - (3)
HGU – I & II
LOBS
CCG Splitter
NHT & CCR

25 units

Capacity expansions
Technology up-gradation
Value added products
Product quality / environment

Bharat Petroleum

Refinery Growth

1955-76

Crude unit
Cracking unit
Bitumen unit
Vacuum unit -I
Platformer unit
3 No. Boilers
Solvent unit

7 units

1990

Crude unit-revamped
Cracking unit
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Cracking unit – II
High Vacuum unit
Amine treating unit - I
Sulfur recovery unit

12 units

Capacity expansions
Technology up-gradation
Value added products
Product quality / environment

Dec 2015

~~Crude unit 1~~
Cracking unit –I revamped
Bitumen unit-revamped
~~Vacuum unit~~-I
3 No. Boilers-revamped
New solvent unit
Cracking unit – II -revamped
~~High Vacuum unit-revamped~~
Aromatics unit -revamped
Amine treating unit – I & II
New Sulfur recovery unit - I & II
MTBE
~~Crude unit – II~~
CDU/VDU 3
DHDS unit - revamped
Hydrocracker - revamped
NHDS
Captive Power Plant - (3)
HGU – I & II
LOBS
CCG Splitter
NHT & CCR

CDU-4 Commissioned in Dec 2015

22 units

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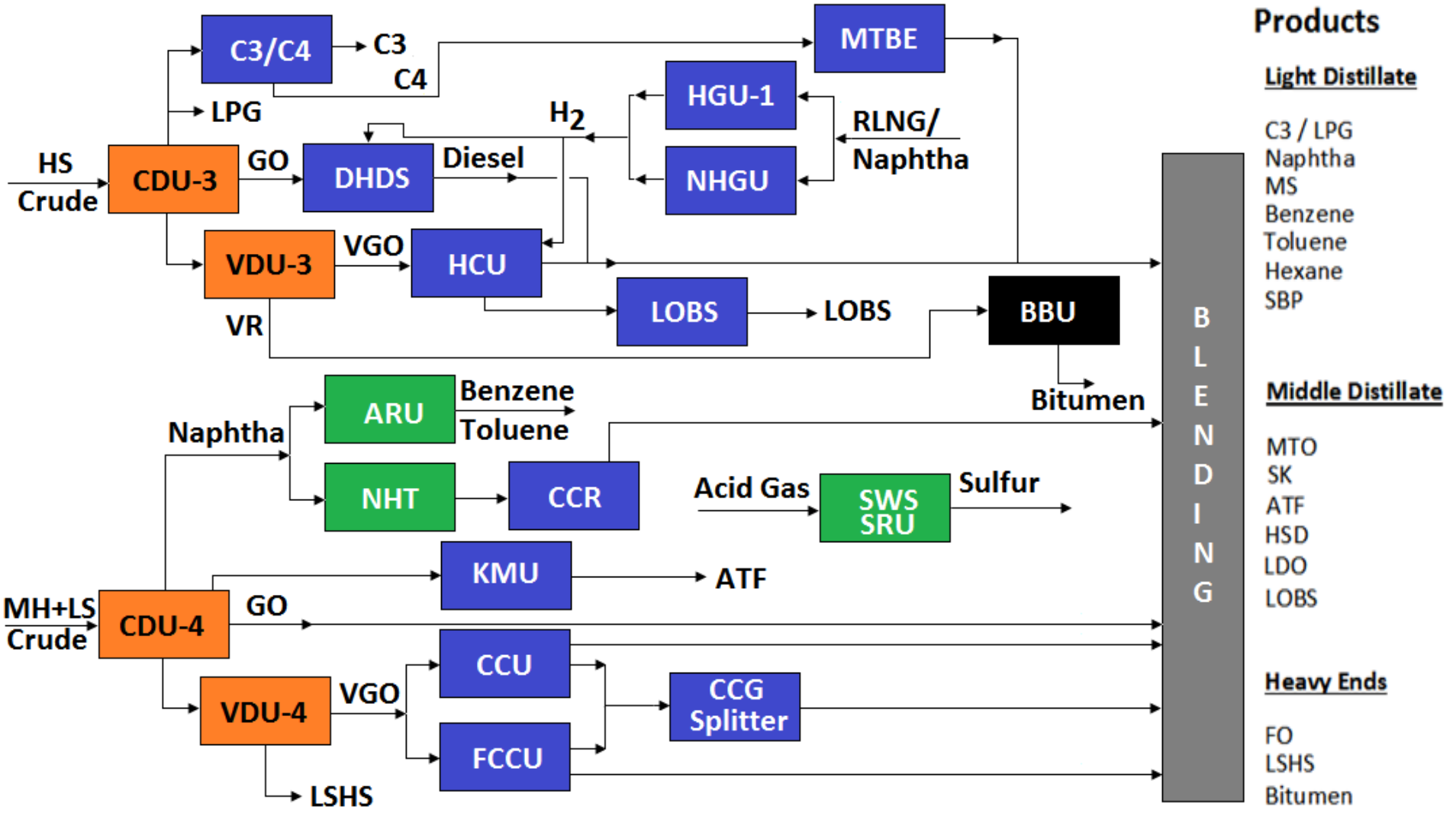
REFINERY CONFIGURATION & PRODUCT PORTFOLIO



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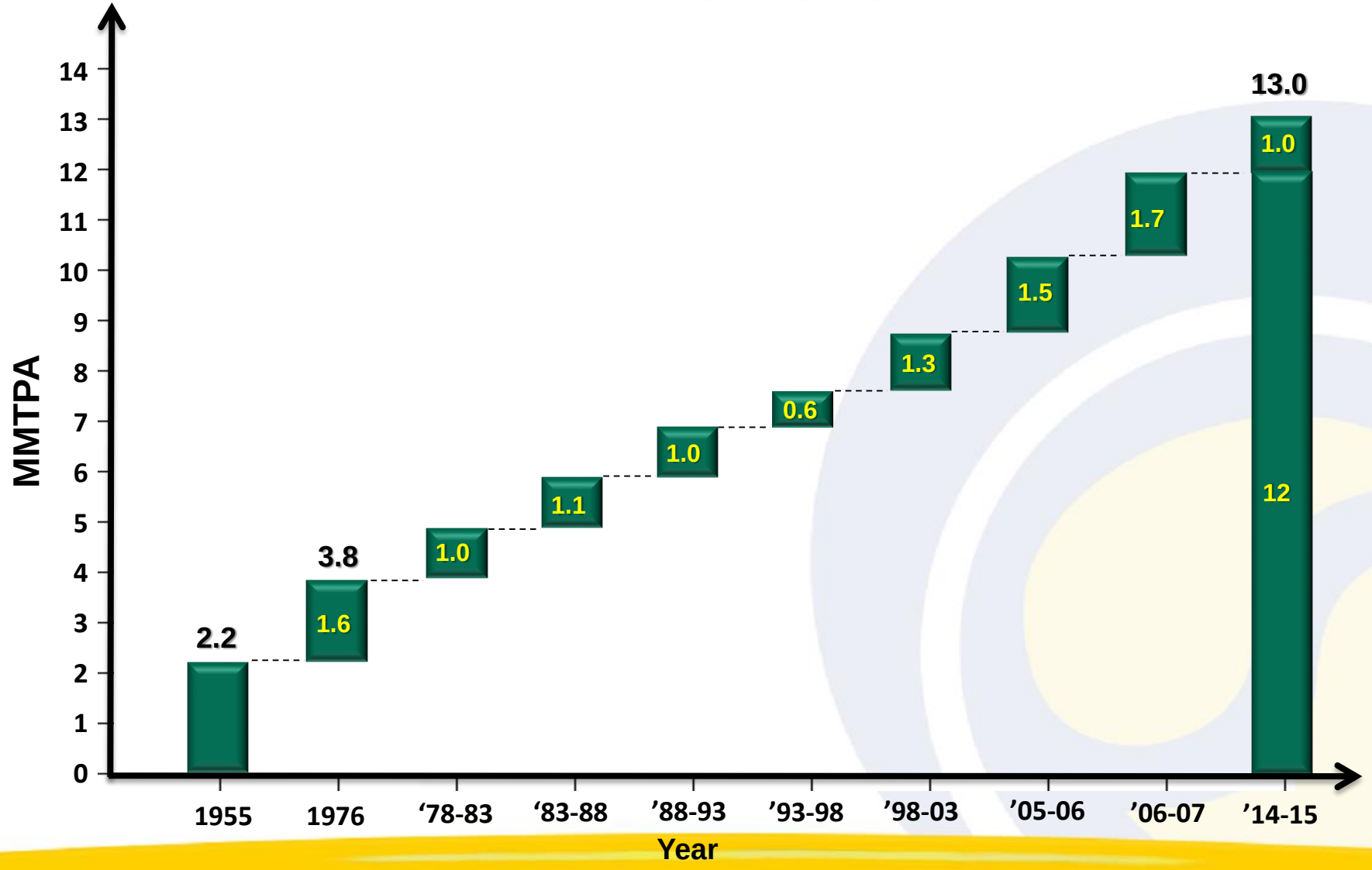
Increased Crude Processing 1976-2015



Bharat

View of the Refinery - 2016

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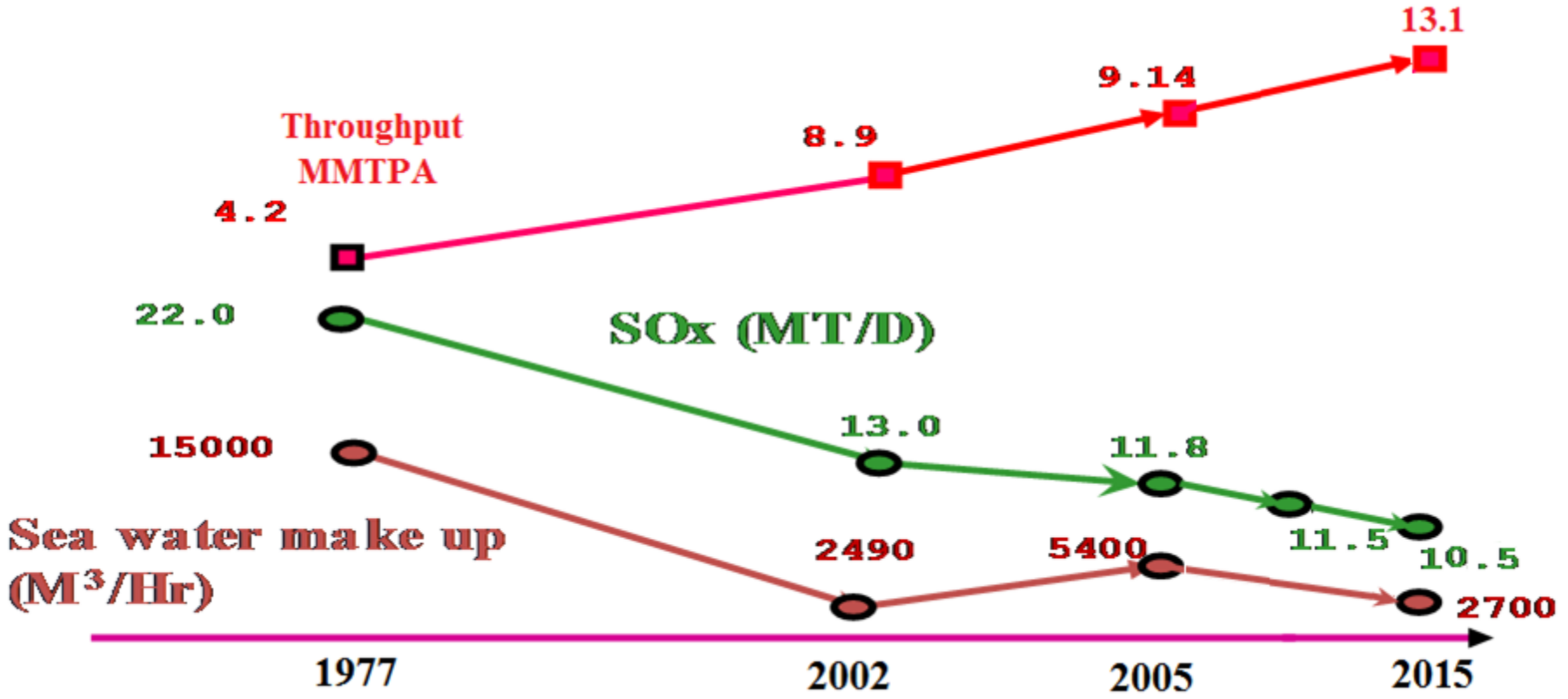
Environment Neutral Operation



Bharat Petroleum

Corporate Social Responsibility

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Other CSR Initiatives

Balvadi at Washala

Project *UTKARSH*

Bharat Petroleum

Other CSR Initiatives

Medical Camps

Tree Plantation

Bharat Petroleum

Other CSR Initiatives

Distributing Fishing nets

Woman empowerment

ARRMO – introduction

Motivation

- Challenges
  - Many refineries switch crude feedstock regularly
  - Significant potential profit loss during the transition
    - off-spec products, giveaway, flaring, throughput limitation …

- Existing technology
  - Relies on (pseudo) steady-state operation
    - start off with potential error of 1-3 %
  - Unable to handle dynamic optimisation transition
    - several hours of off-spec operation

→ Potential significant benefit in having online, real-time
  - steady-state optimisation with state estimation
  - dynamic optimisation

The project

InnovateUK announcement

Main FCO website

Foreign & Commonwealth Office

Blogs home | About our blogs | All bloggers | About the team | A

FCO Blogs > Science & Innovation Network, India > Health and disease > Deputy Prir

Deputy Prime Minister announces new UK-India partnerships to tackle some of the world's biggest problems

August 27, 2014

During a trade mission to India this we
Nick Clegg, announced a series of nev
and Indian scientists which will look to
issues facing the two countries. From
the weather, the new partnerships will cement the position of both countries in the vanguard of scientific research. You can see more photos from the visit on Flickr.

Mr Clegg also met PM Modi in Delhi

He announced four projects that have won a share of over £1.7 million funding from the UK's innovation agency, the Technology Strategy Board and the Indian Department of Science and Technology to create new commercial technology in the health and energy sectors. The four projects successfully bid for funding from the UK-India Joint Industrial Research and Development Programme.

The successful partnerships are:

- GBIT in India and Oxitec Ltd in the UK: Research on sustainable prevention of dengue fever, a mosquito-born disease which threatens 40% of the world's population.
- Lifecare Innovations in India and Wockhardt Ltd/University of Central Lancashire in the UK: improving the treatment for the life-threatening tropical disease Leishmaniasis.
- Chogen Powers Ltd in India and GeoCapita Ltd/University of Glasgow in the UK: research into improving the process for generating power from biofuels.
- Bharat Petroleum Corporation/Gyan Data in India and Process Systems Enterprise Ltd in the UK: to improve efficiency and yields in oil refineries.

We, the UK Science and Innovation Network-India are very pleased to

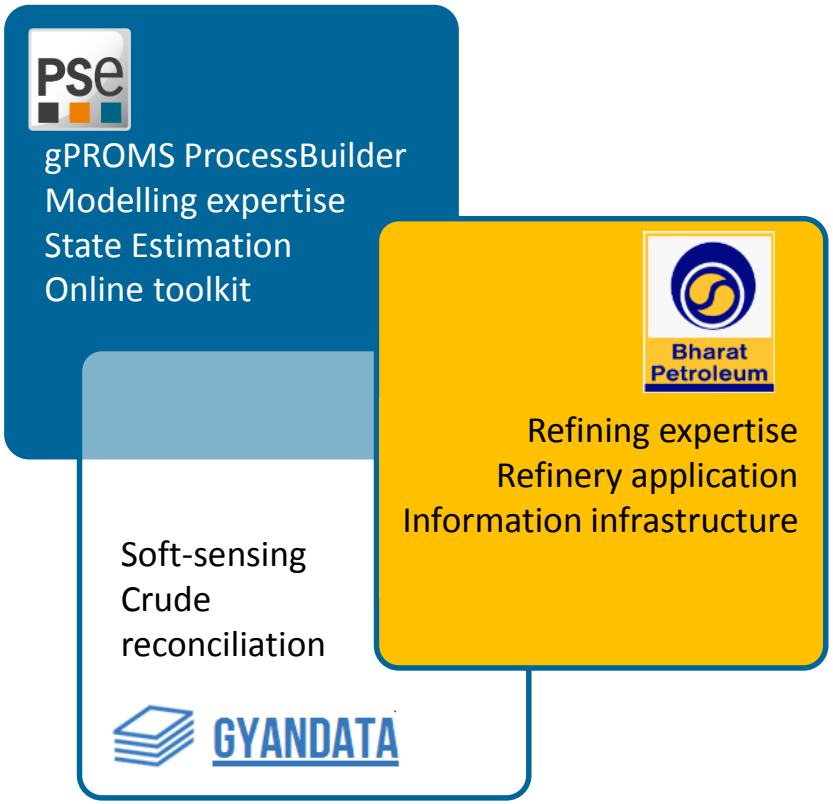
- Bharat Petroleum Corporation/Gyan Data in India and Process Systems Enterprise Ltd in the UK: to improve efficiency and yields in oil refineries.

partnership between both TSB and DST that led to the announcement of the UK-India Collaborative Industrial R&D Programme. We have been working closely with the TSB to establish opportunities for UK-India Innovation collaboration and this call is the first step in that direction.

- http://blogs.fco.gov.uk/science-innovation-network-india/2014/08/27/deputy-prime-minister-announces-new-uk-india-partnerships-to-tackle-some-of-the-worlds-biggest-problems/

Basics

- R&D project
  - Total £1m+, Rs10 Crore
  - Funded by InnovateUK (was TSB) & GITA (Indian R&D) + partners
  - 24 months – Feb 2015 – Jan 2017
- Objective
  - Advance the **science and application** of **real-time dynamic optimisation** for **crude transition**, taking into account (many) product constraints

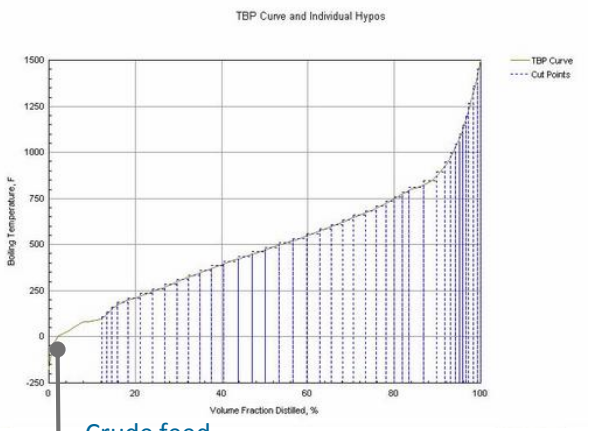


ARRMO description

Physical scope

Architecture

Physical scope – schematic overview



Crude feed

Preheat train 1

Desalter

Preflash

Preheat train 2

Pumparound

CDU
C-101

1
10
11
20
22
25
30
32
37
39
44
46
51
52
57

AFC

To Naphtha stabiliser

HN

LK

HK

B

LGO

MP steam

HGO

MP steam

OH
Vapour

VD

LLVGO (PA)

LVGO

HVGO

B

Vacuum
slops

B

MP steam

VR

'Generic' schematic for illustration

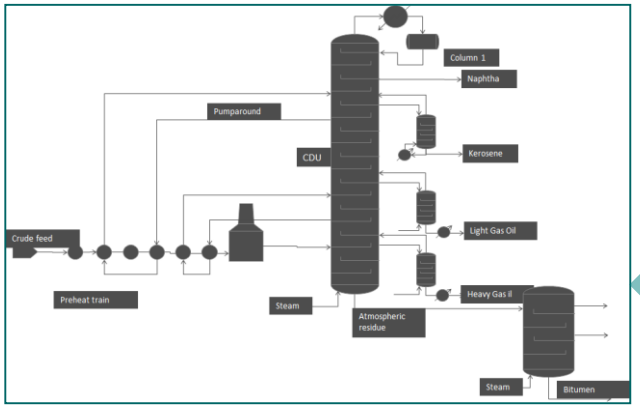
From crude inlet

To product properties

ARRMO – fit with existing infrastructure

Advanced Real-time Refinery Monitoring & Optimisation

Plant



Plant measurements and controls

DCS

APC

APC setpoints

Periodic plant measurements (via IP.21)

Info
Advice
Alarms

Crude Definition File

Product info specs,prices min/max demands

Cost info Crude & utility costs

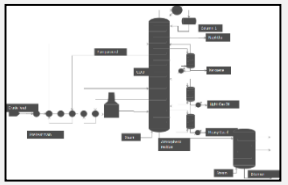
ARRMO

Advanced Real-Time Refinery Monitoring & Optimisation

State Estimator

Crude Assessor

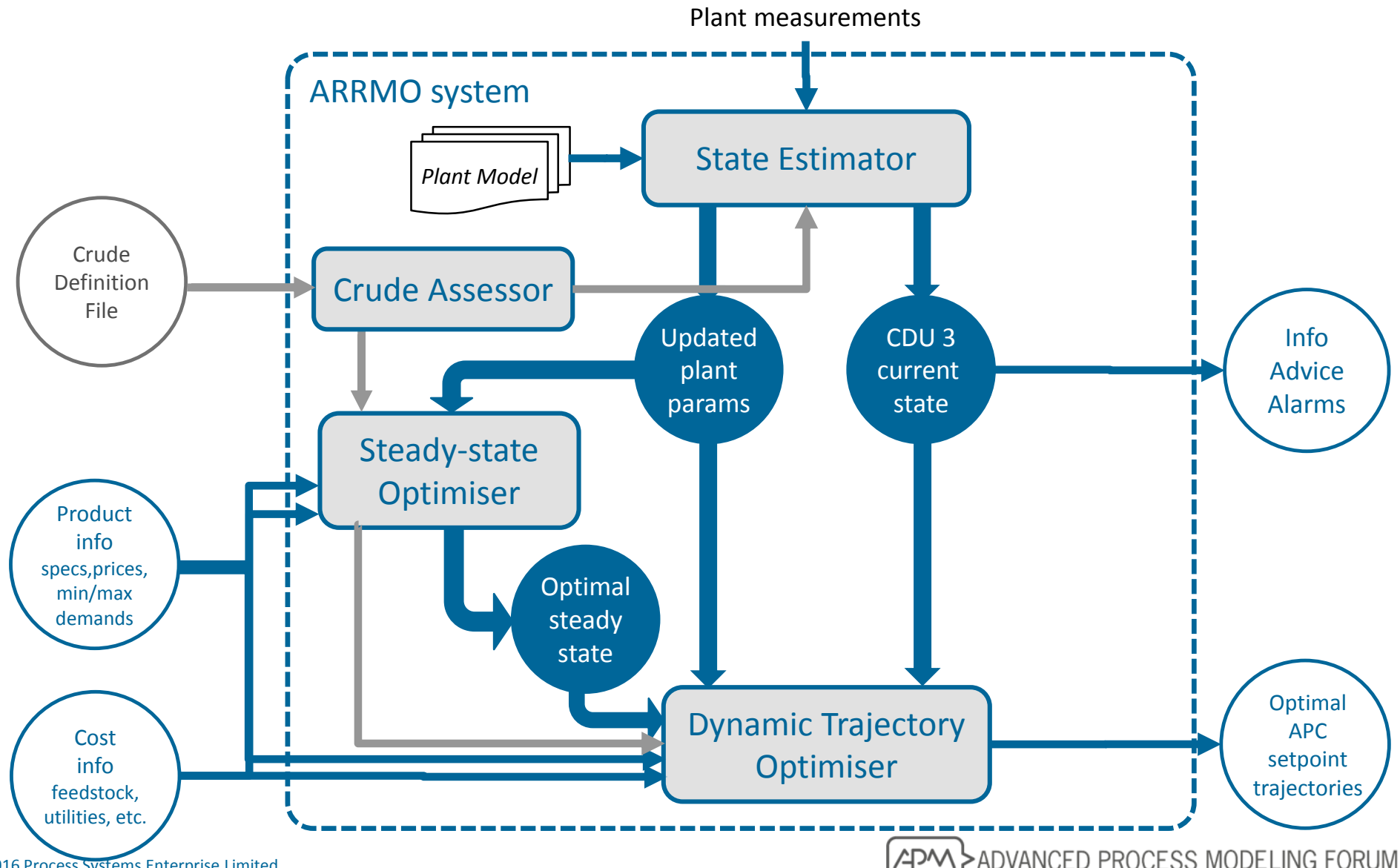
Plant model



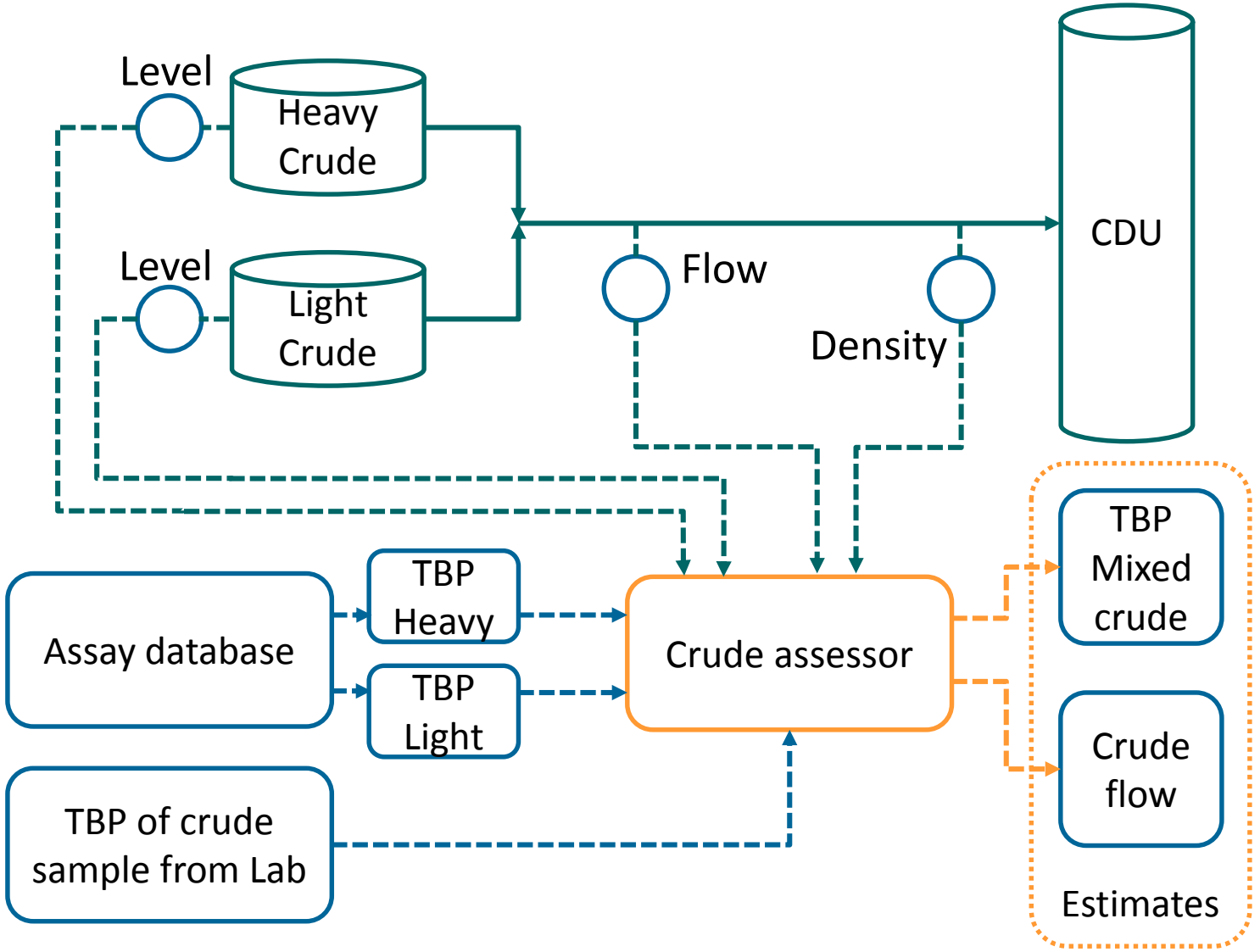
Optimisation framework

ARRMO framework

Advanced Real-time Refinery Monitoring & Optimisation



Crude assessor



Work packages

WP 1
Develop User Requirements Specification, Technical Specification, Project Plan

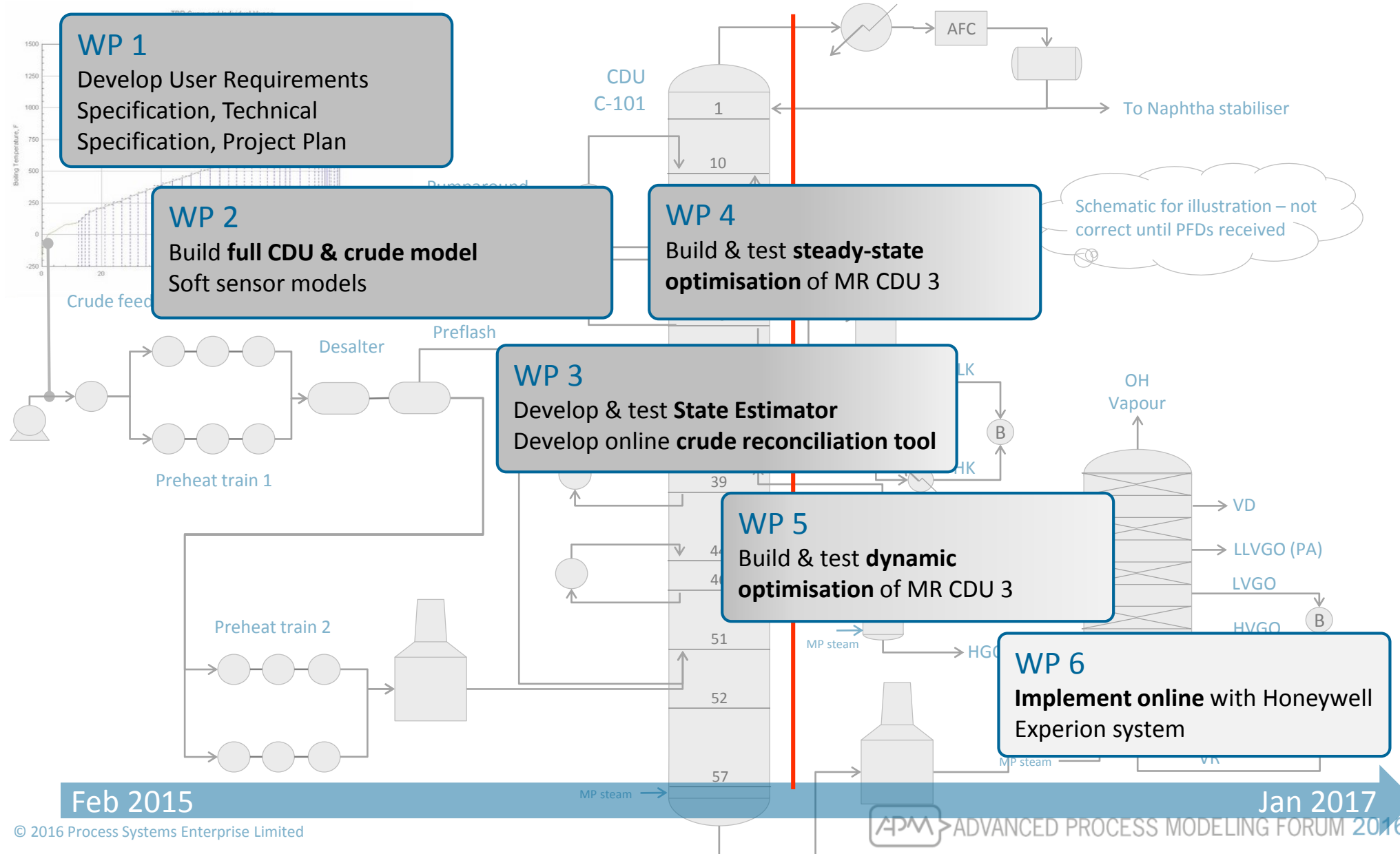
WP 2
Build **full CDU & crude model**
Soft sensor models

WP 3
Develop & test **State Estimator**
Develop online **crude reconciliation tool**

WP 4
Build & test **steady-state optimisation** of MR CDU 3

WP 5
Build & test **dynamic optimisation** of MR CDU 3

WP 6
Implement online with Honeywell Experion system

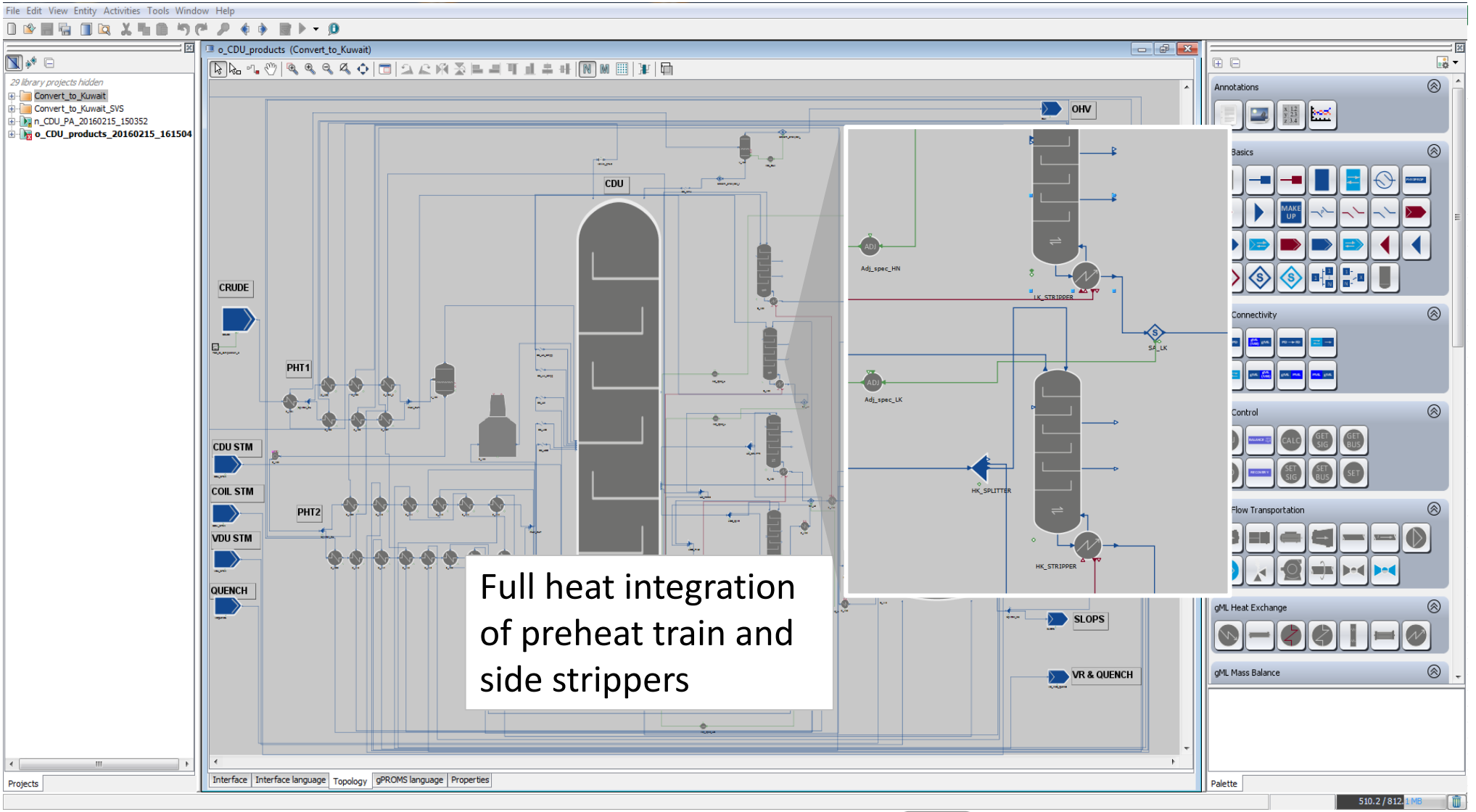


Current status

Validation against existing data

ARRMO model – integrated refinery CDU

Implemented in gPROMS ProcessBuilder

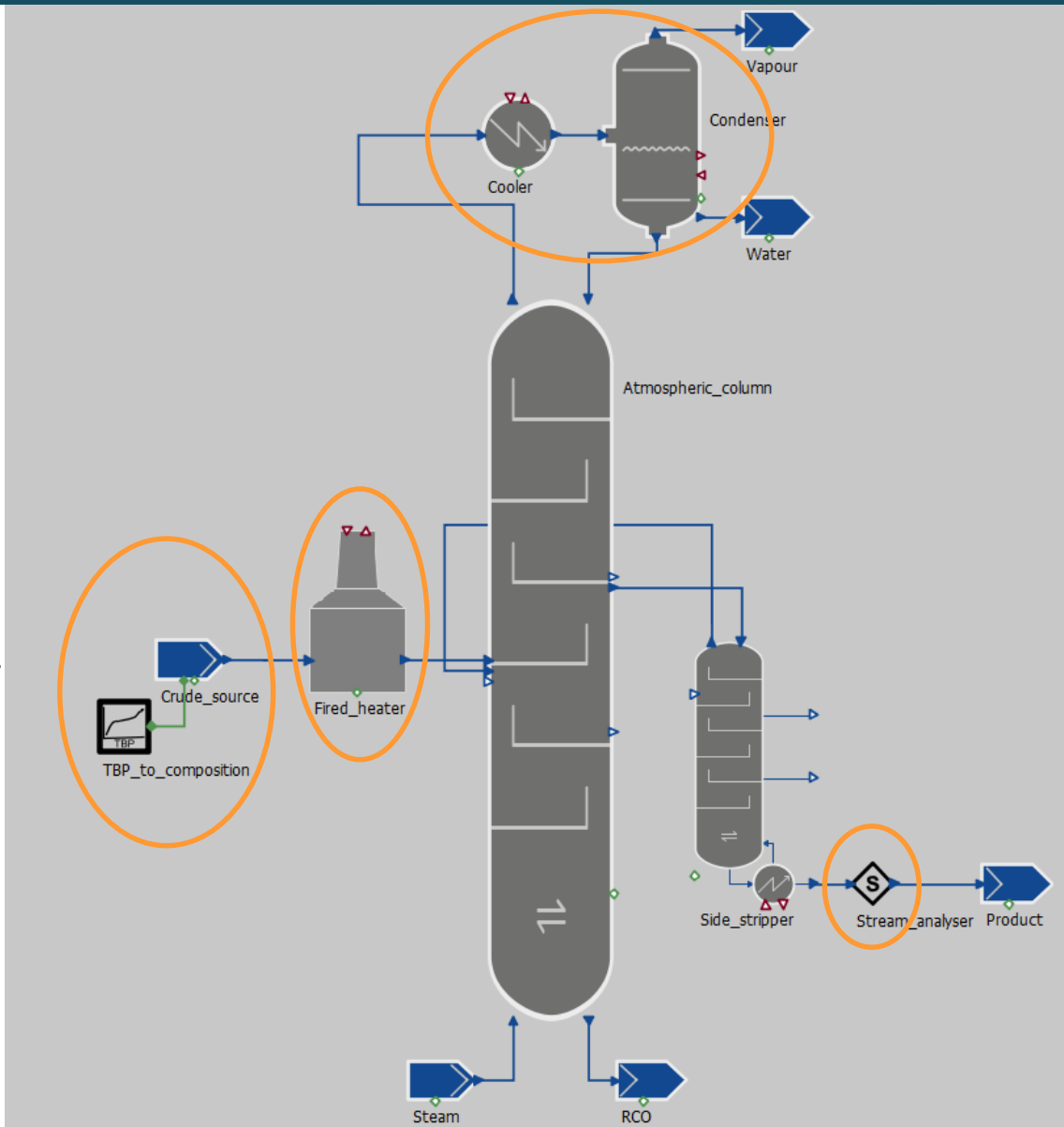


Full heat integration of preheat train and side strippers

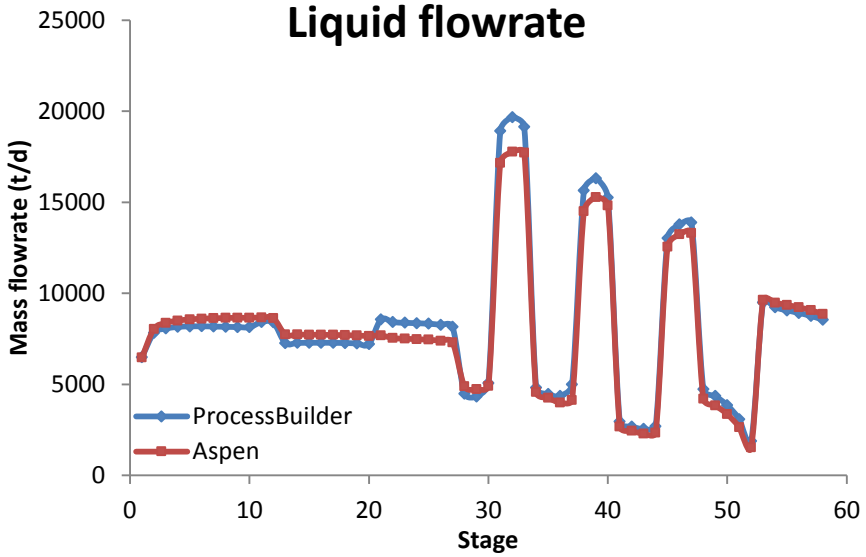
New gPROMS model library: Refining

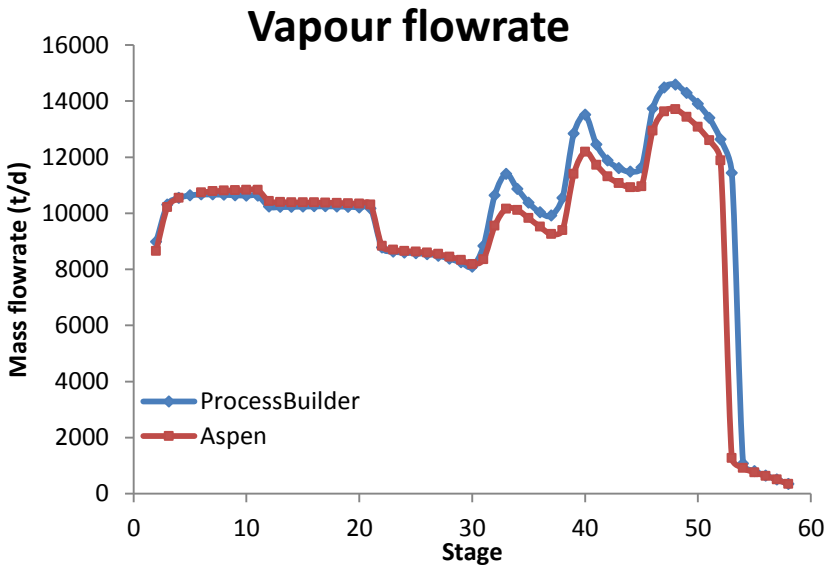
NB. Most units required for CDU/VDU modelling already covered by existing ProcessBuilder libraries

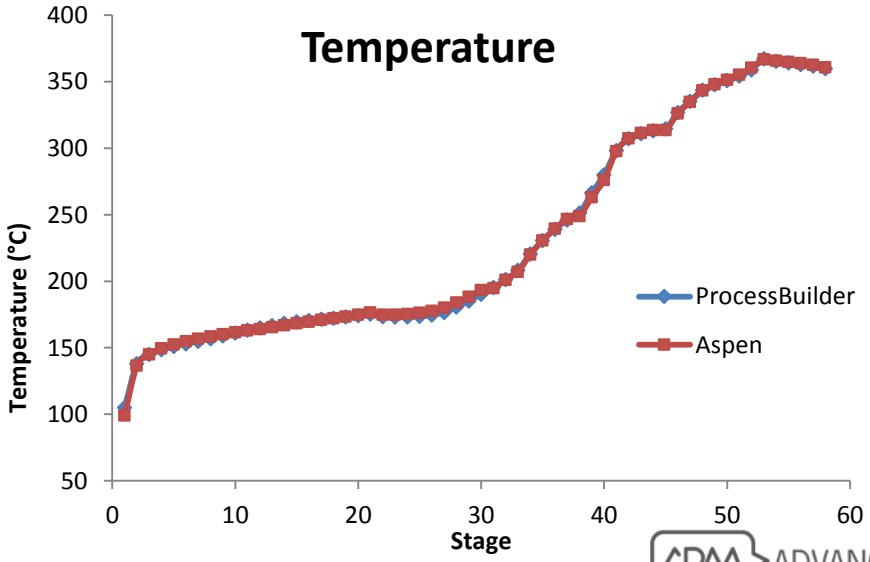
- Crude feed source
  - TBP specification
- Fired heater
- Overhead system
- Product analyser
  - Distillation curves
    - TBP
    - ASTM D86-D1160
  - Properties
    - Watson characterisation factor
    - Flash point, Freeze point
    - Pour point, Aniline point
    - Smoke point, Cloud point
    - Cetane index
    - Reid vapour pressure



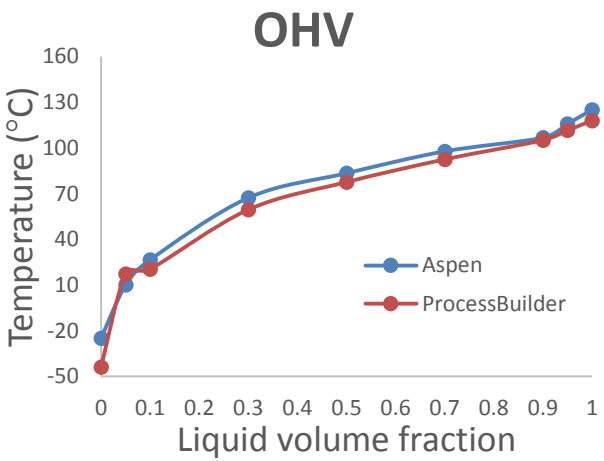
Column profiles – CDU

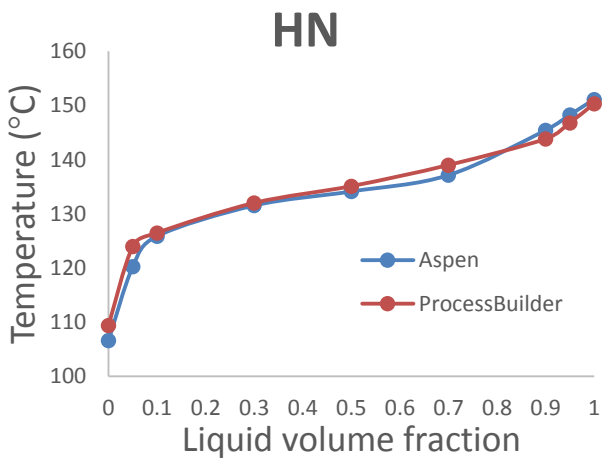


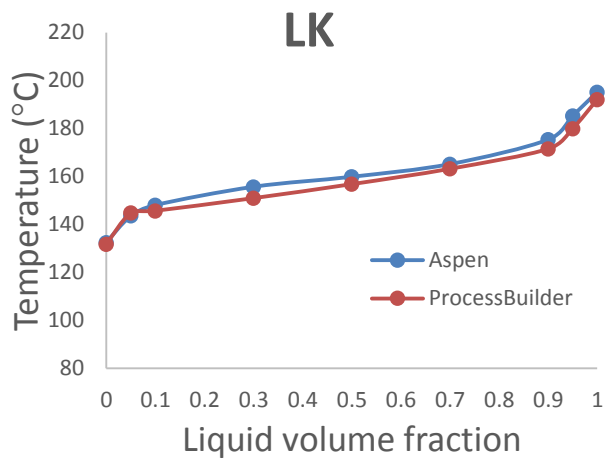


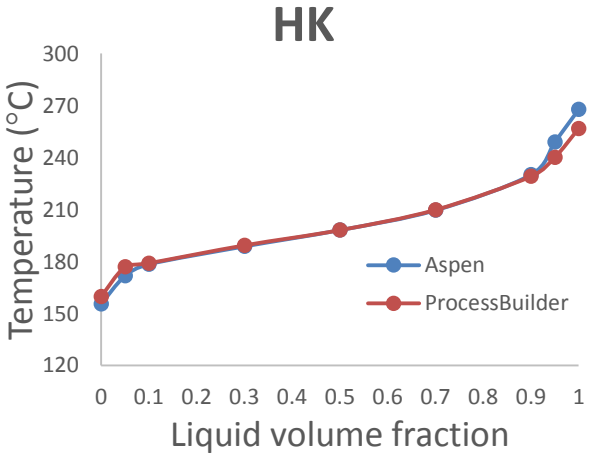


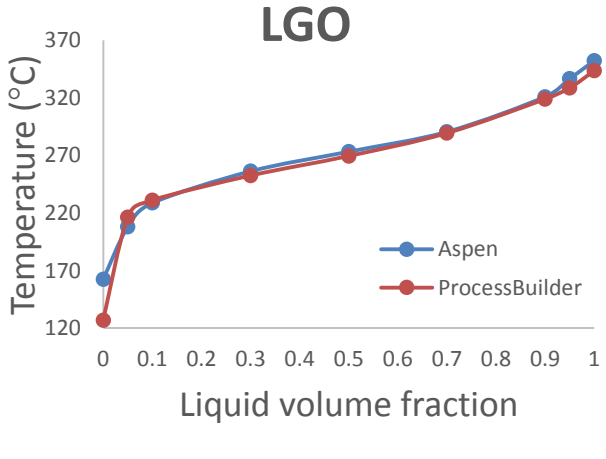
CDU – ASTM D86 / D1160

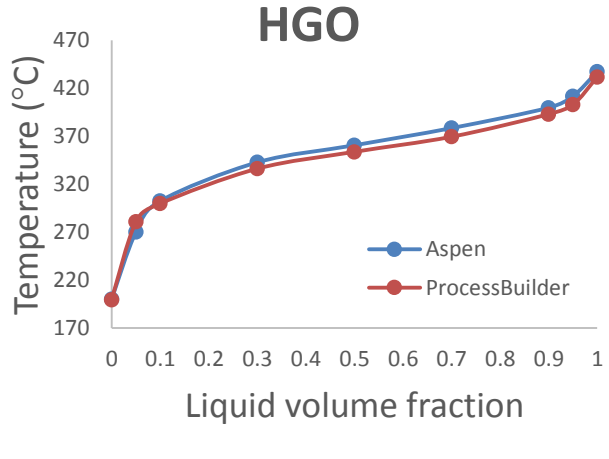




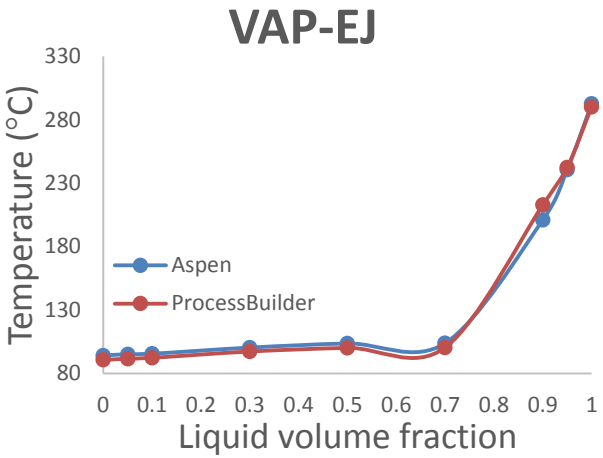


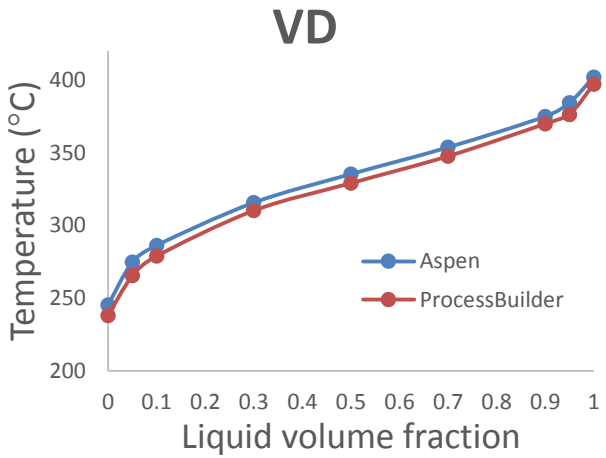


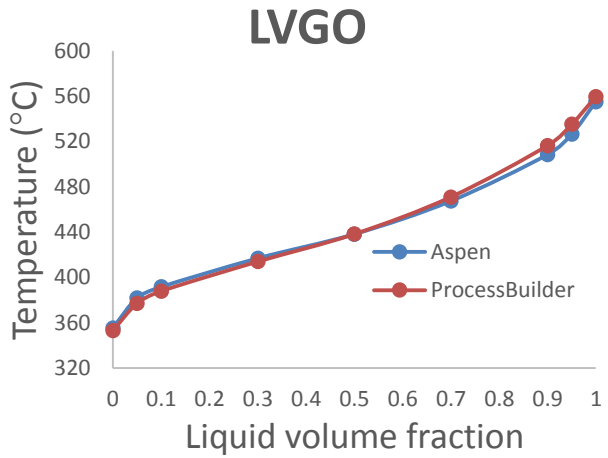


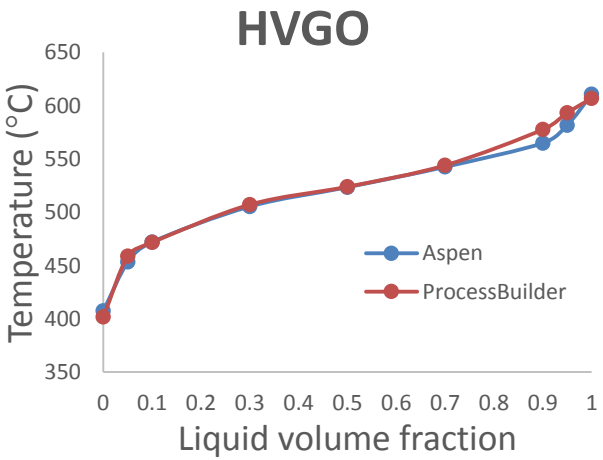


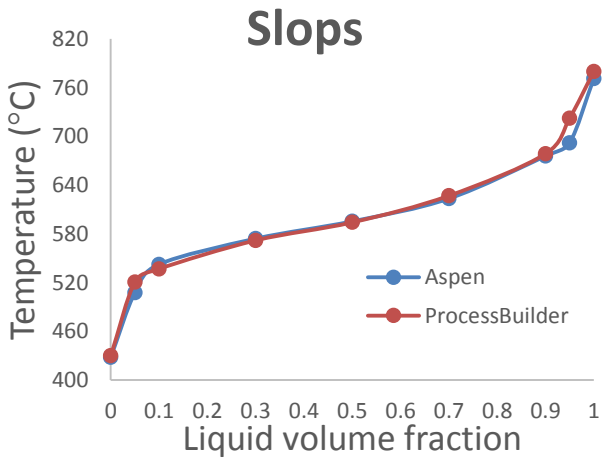
VDU – ASTM D1160

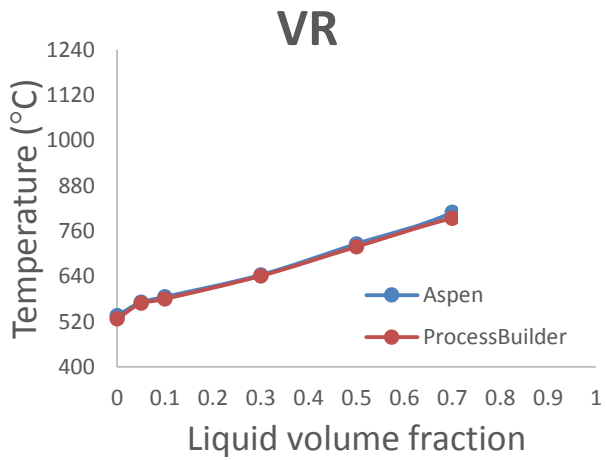








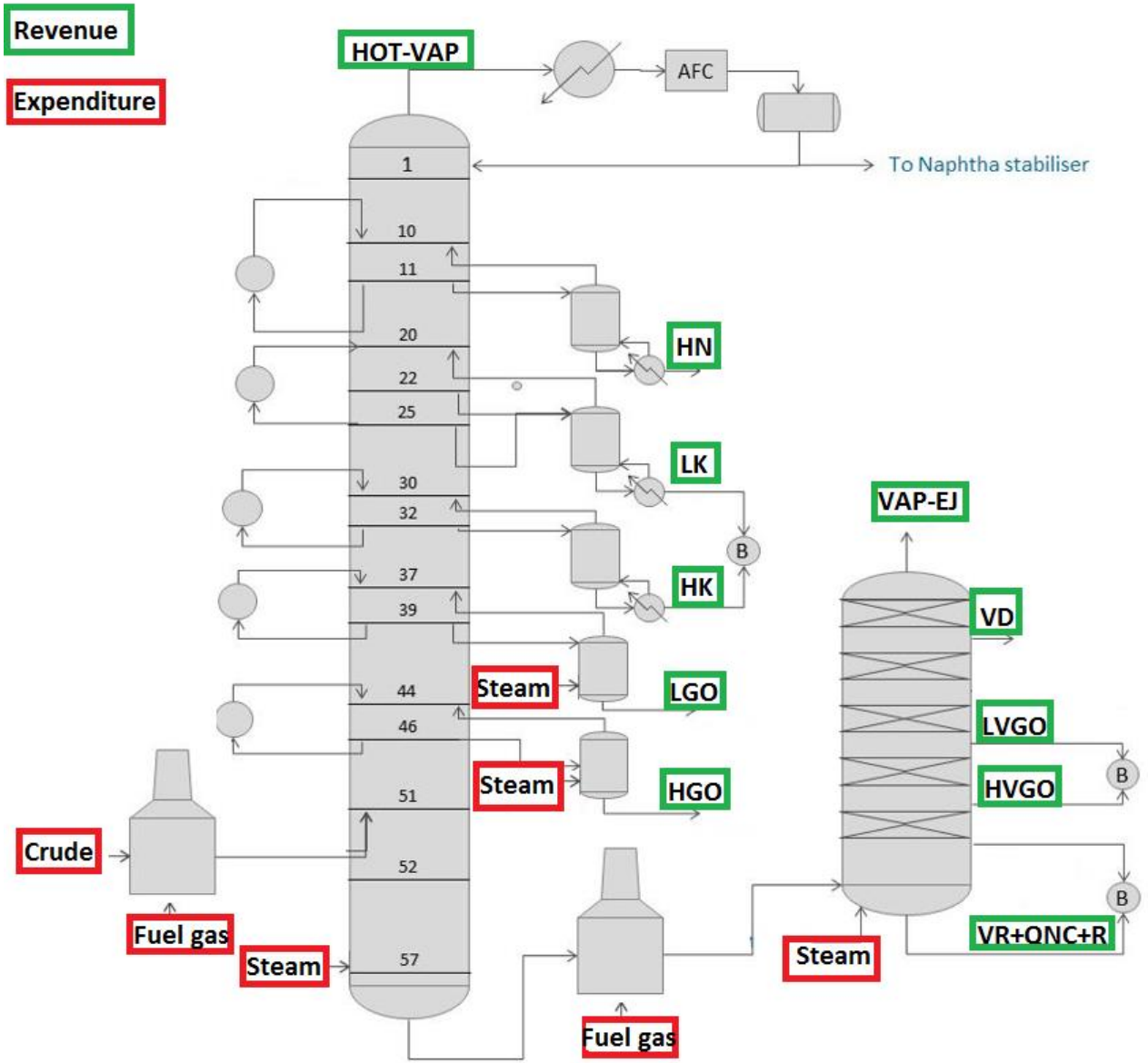




Steady-state optimisation

Preliminary analysis

Objective function: Economic performance



Objective

$$\boldsymbol{Profit = Product\ Revenue - Crude\ Costs - Utility\ Costs}$$

$$Product\ Revenue = \sum_{i=1}^{i=Product\ N} Flowrate_i \times Price_i$$

$$Crude\ Cost = Crude\ Consumption \times Crude\ Price$$

$$Utility\ Costs = Steam\ Consumption \times Steam\ Price + Fuel\ Consumption \times Fuel\ Price$$

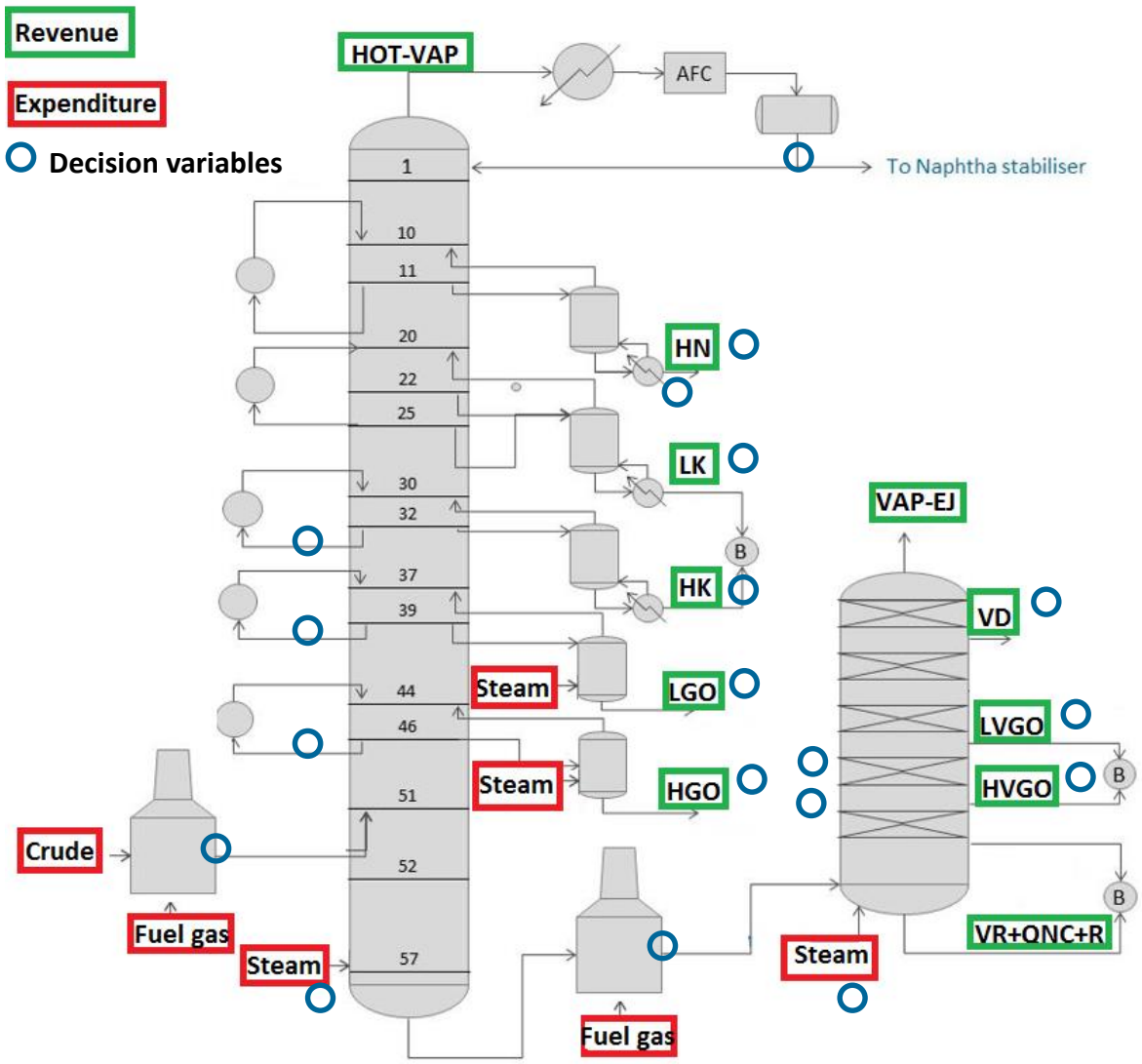
Pricing information

Stream	Value (US$ / t)
OHV	[redacted]
HN	[redacted]
LK	[redacted]
HK	[redacted]
LGO	[redacted]
HGO	[redacted]
VAP-EJ	[redacted]
VD	[redacted]
VGO	[redacted]
Slops	[redacted]
VR	[redacted]

Stream	Value (US$ / t)
Crude	[redacted]
Fuel gas	[redacted]
Steam	[redacted]

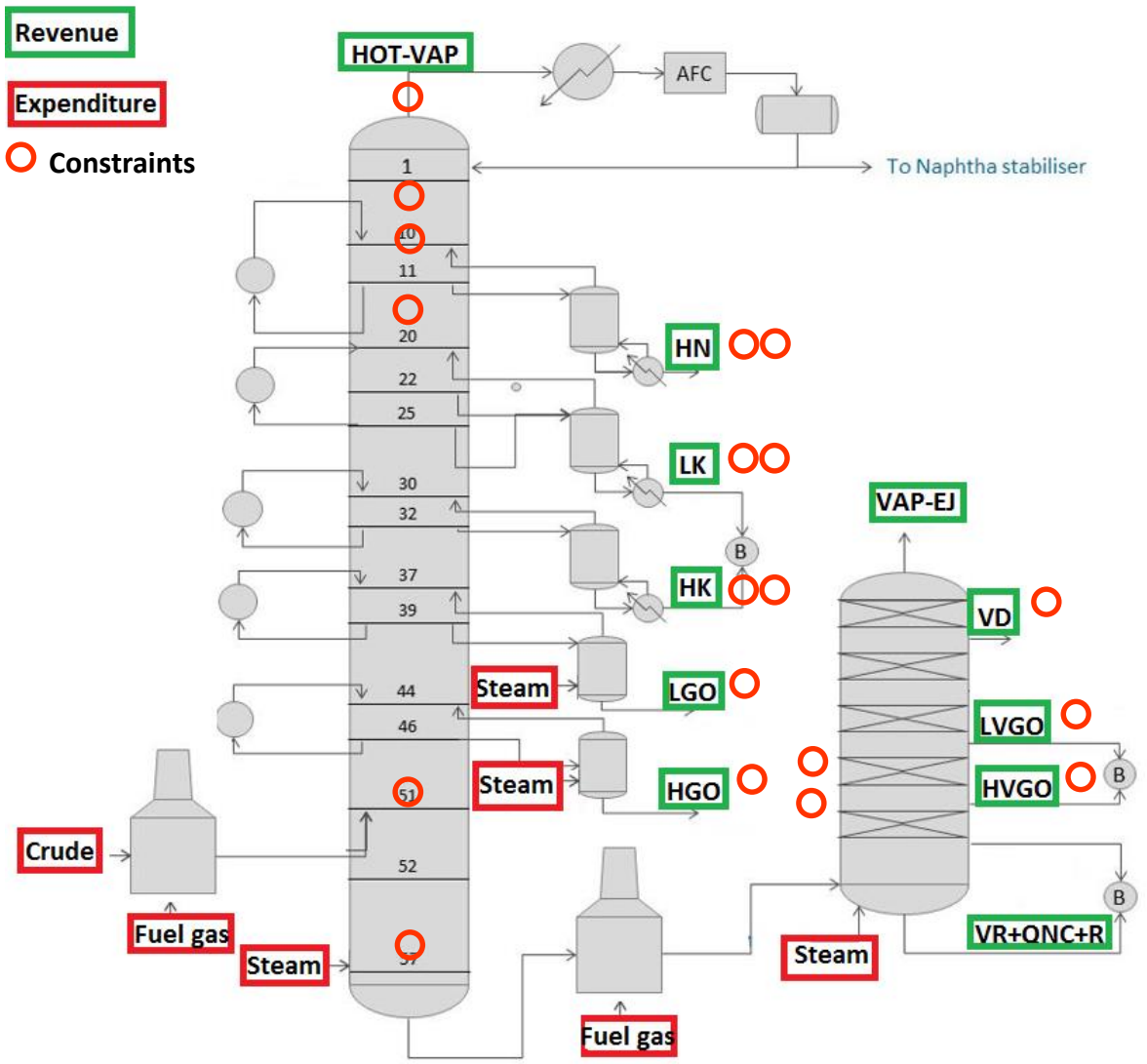
Decision variables

- CDU
  - Reflux ratio
  - Furnace temperature
  - Pumparound fractions
    - HK, LGO, HGO
  - Stripping steam SS_1 / RCO flowrate
  - Yields
    - HN, LK, HK, LGO, HGO
- VDU
  - Furnace temperature T_2
  - Pumparound fractions
    - LVGO, HVGO
  - Slops recycle fraction
  - Stripping steam SS_4 / VR flowrate
  - Yields
    - VD, LVGO, HVGO



Constraints

- Various product constraints
  - ASTMs (5%, 95%)
  - Flash Point, Freeze Point …
- Process/equipment constraints
  - Liquid, vapour flowrates
- Many more possible
  - All API quality constraints
  - Almost any variable



Preliminary results

- Product revenues
  - Economics very much favour HN and HK v LK and HGO
- Costs
  - Steam increased, fuel gas decreased
- **Overall increase in profit of $79.5K / day**
- NEXT STEP – meeting of stakeholders to analyse / verify optimisation results

Overall

		% change
Product revenue	▲	1.29
Utility costs	▲	0.07
Crude costs		0.00

Product revenue – CDU

Revenue		% change	% total
OHV	▲	3.47	17.22
HN	▲	20.00	3.90
LK	▼	-20.00	3.18
HK	▲	19.72	11.72
LGO	▼	-6.00	17.07
HGO	▼	-40.00	1.80

Product revenue – VDU

Revenue		% change	% total
VAP-EJ	▼	-30.04	0.23
VD	▲	18.05	5.04
VGO	▲	12.71	24.64
Slops	▼	-71.43	0.05
VR	▼	-12.32	15.15

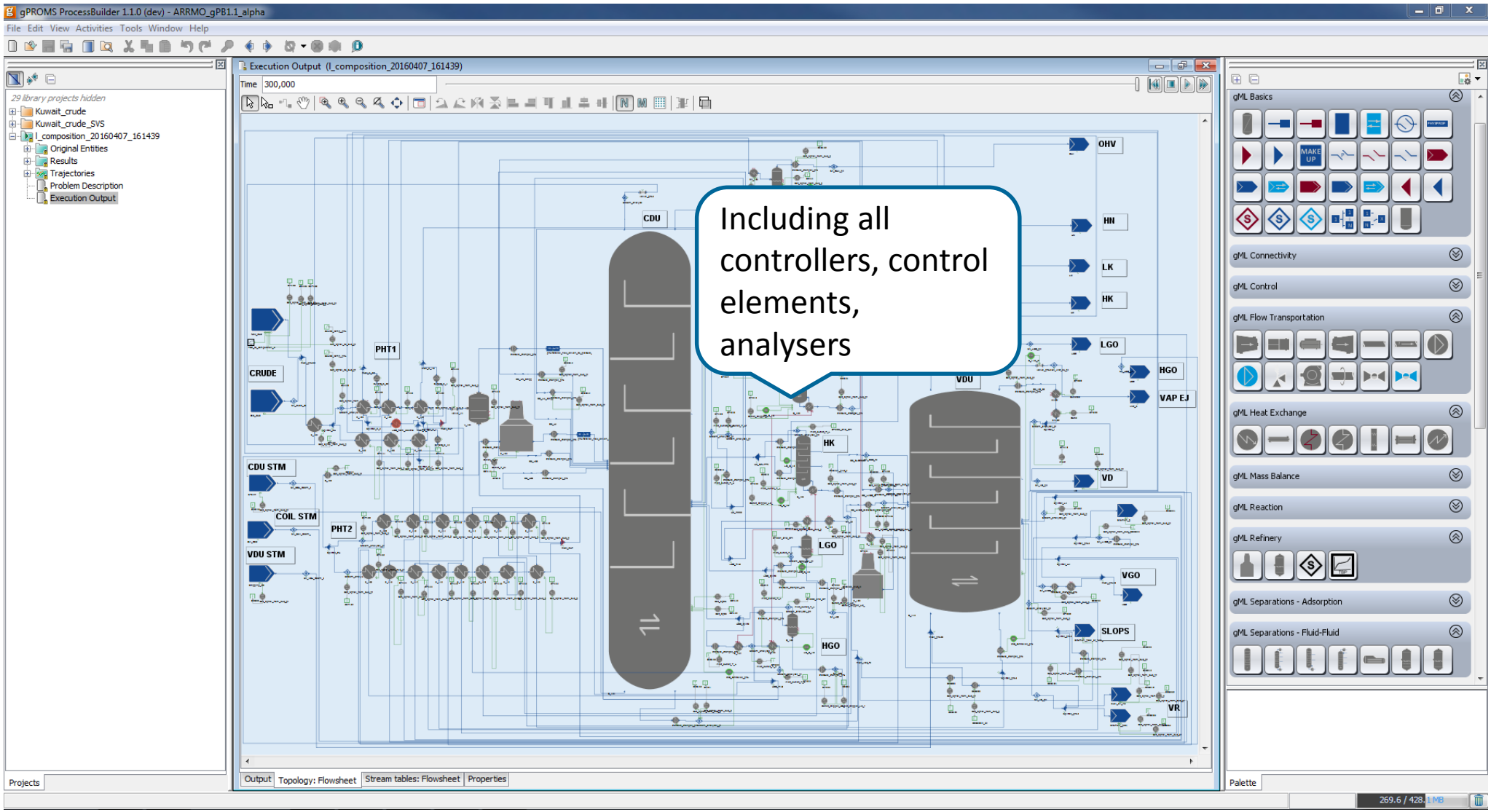
Costs

Cost		% change
Steam	▲	17.05
Fuel gas	▼	-2.48

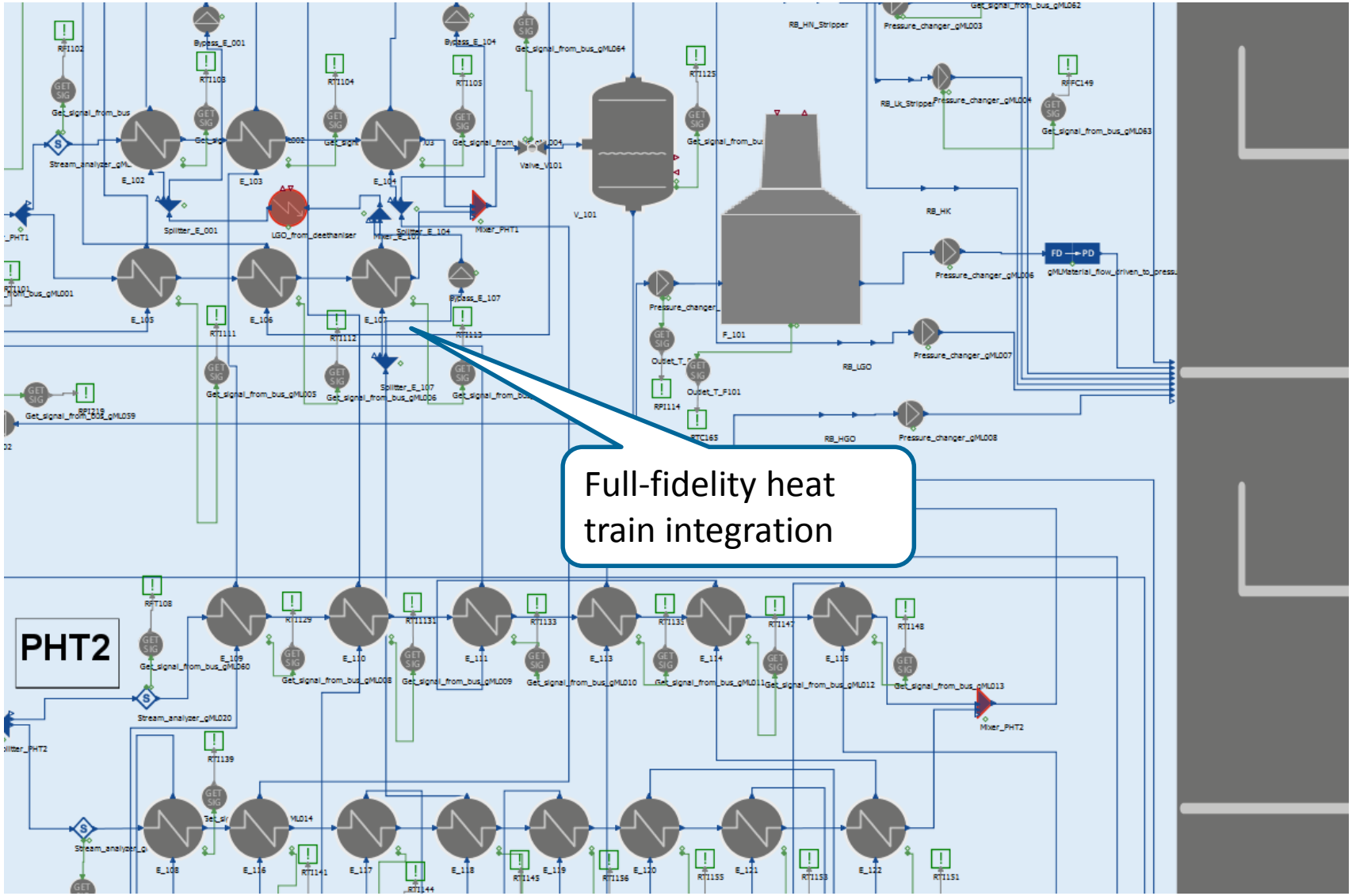
Dynamic simulation

Dynamic flowsheet

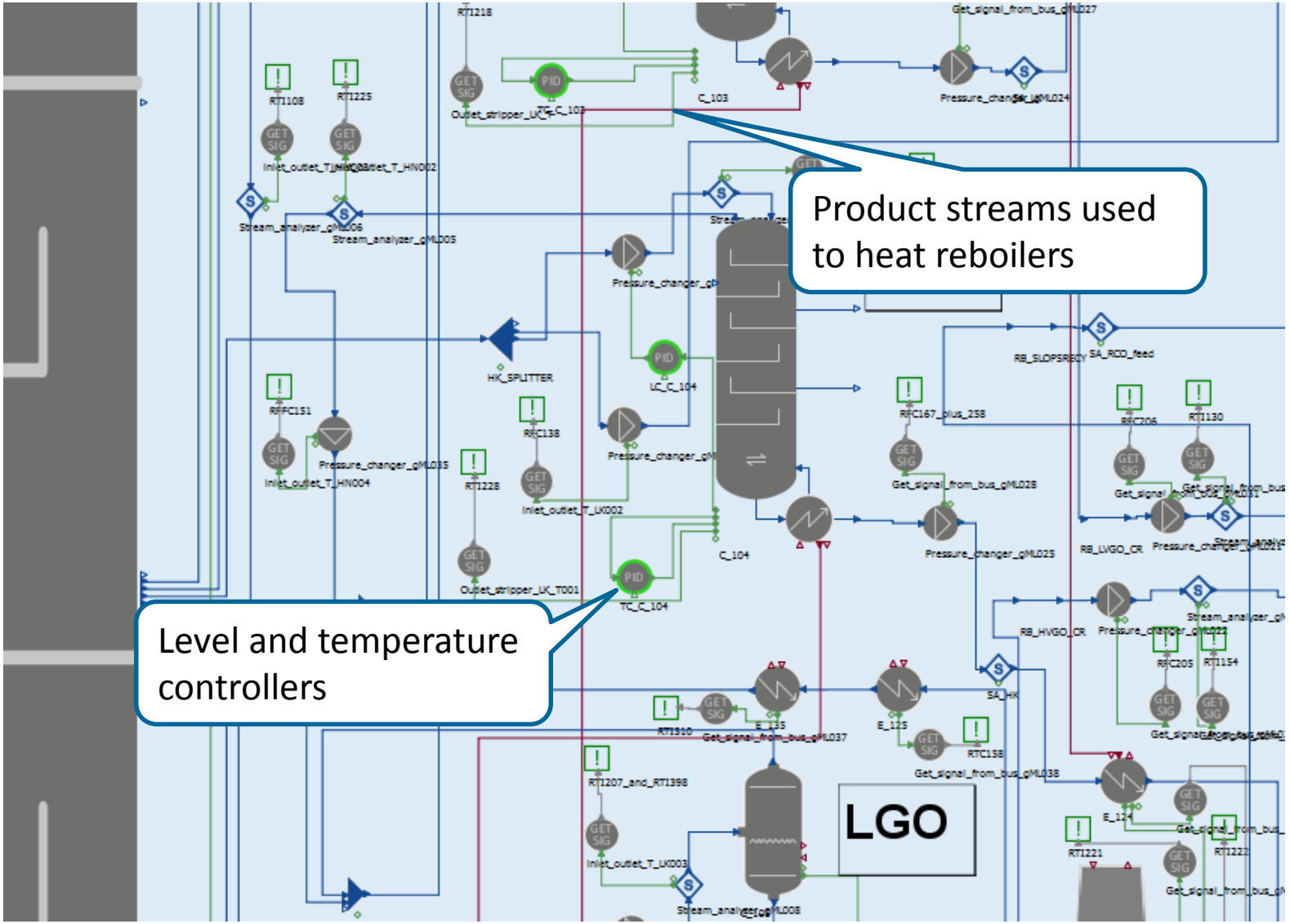
With controllers, analysers



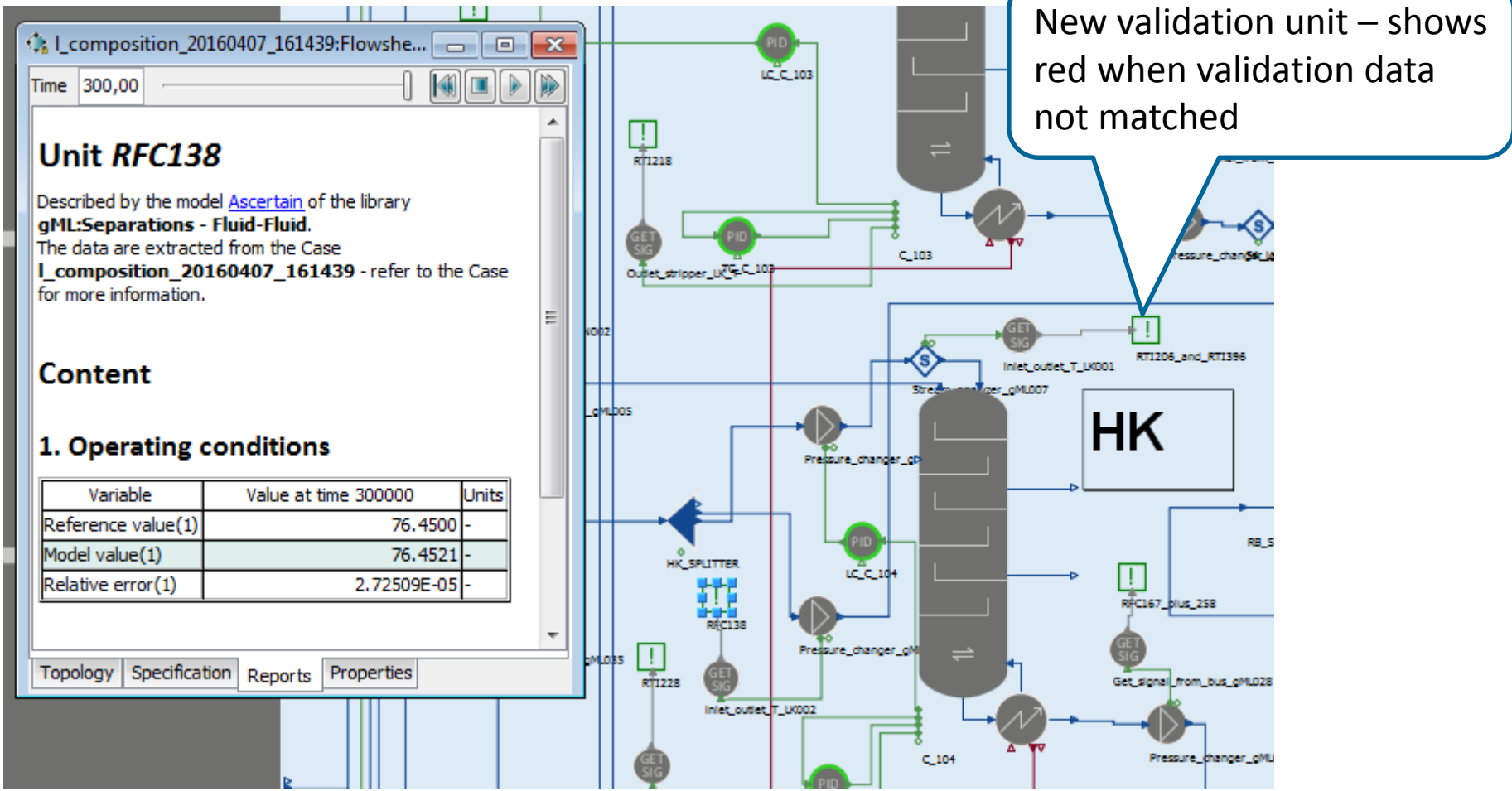
Complete heat integration



Complex pumparounds and side-strippers topology

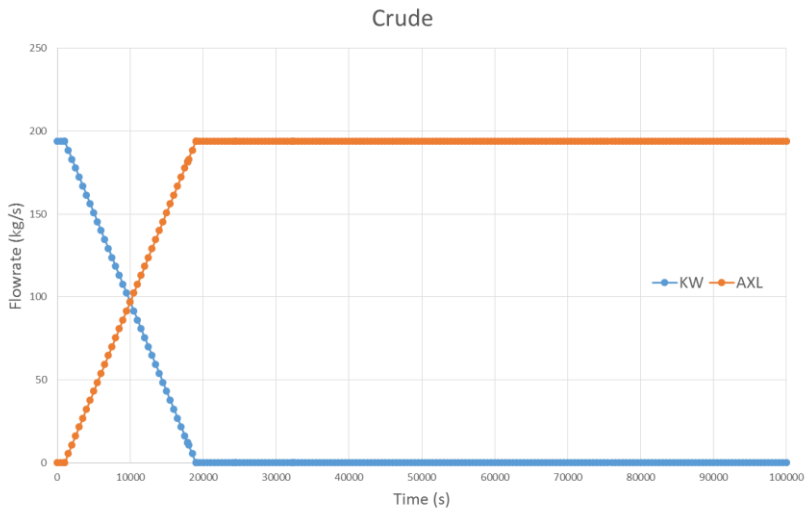


Flowsheet validation and sensor models

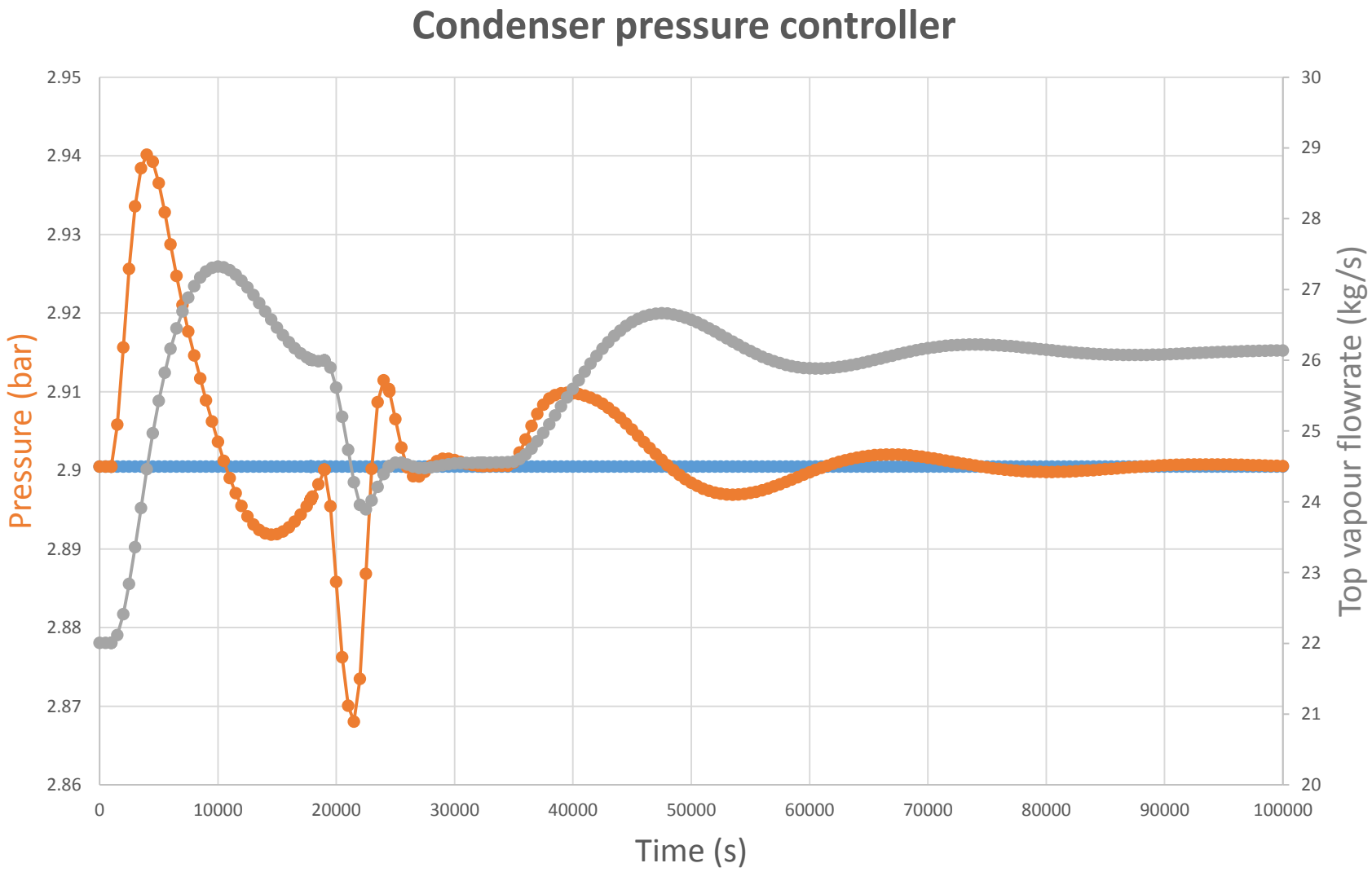


Crude changeover

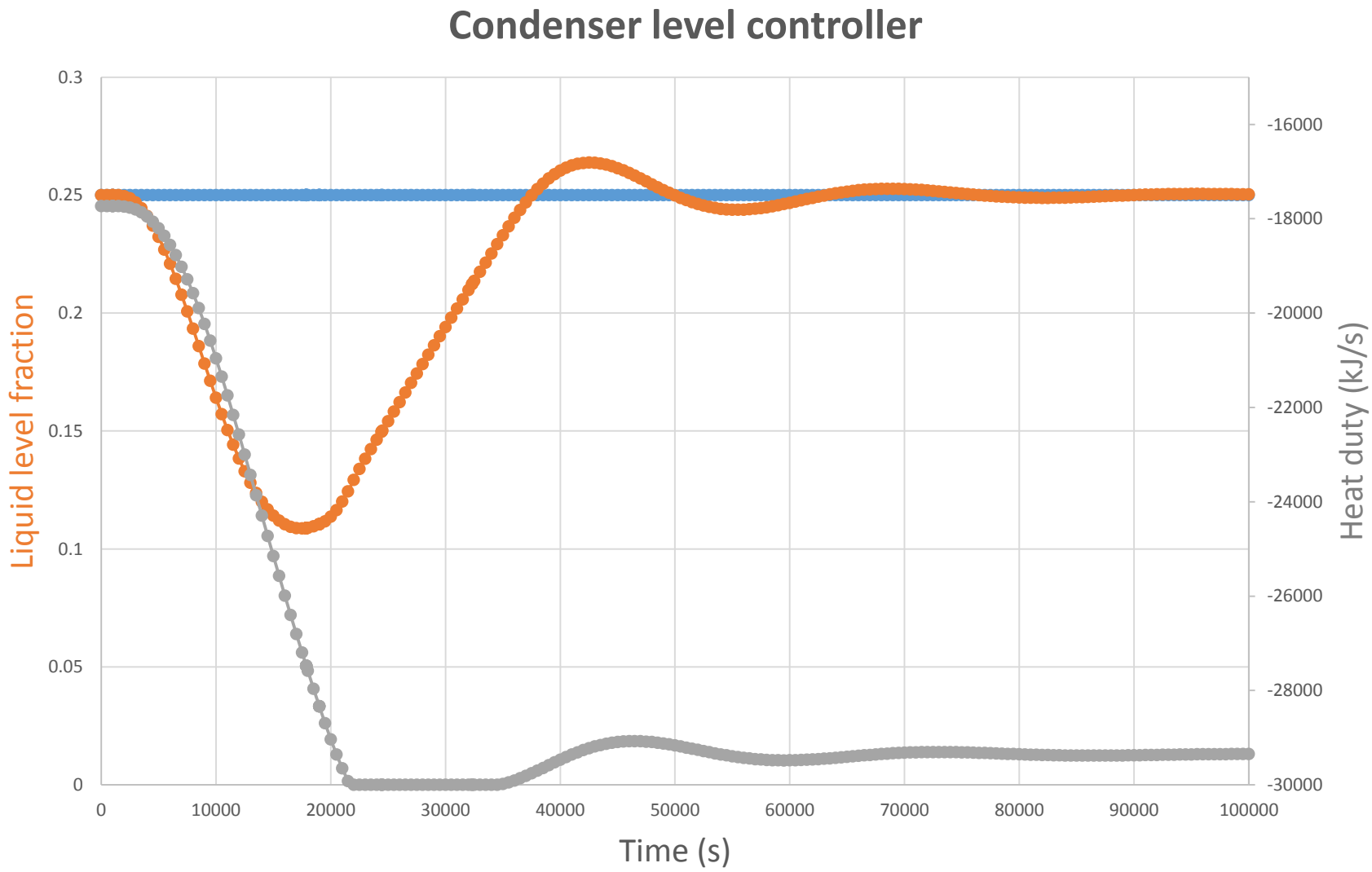
- Change feed from Kuwait crude to Arabian light
- Changeover occurs over 5 hours
- Observe the behaviour of the system
- 14 controllers in total
- 127 sensors/tags: flowrate, pressure or temperature



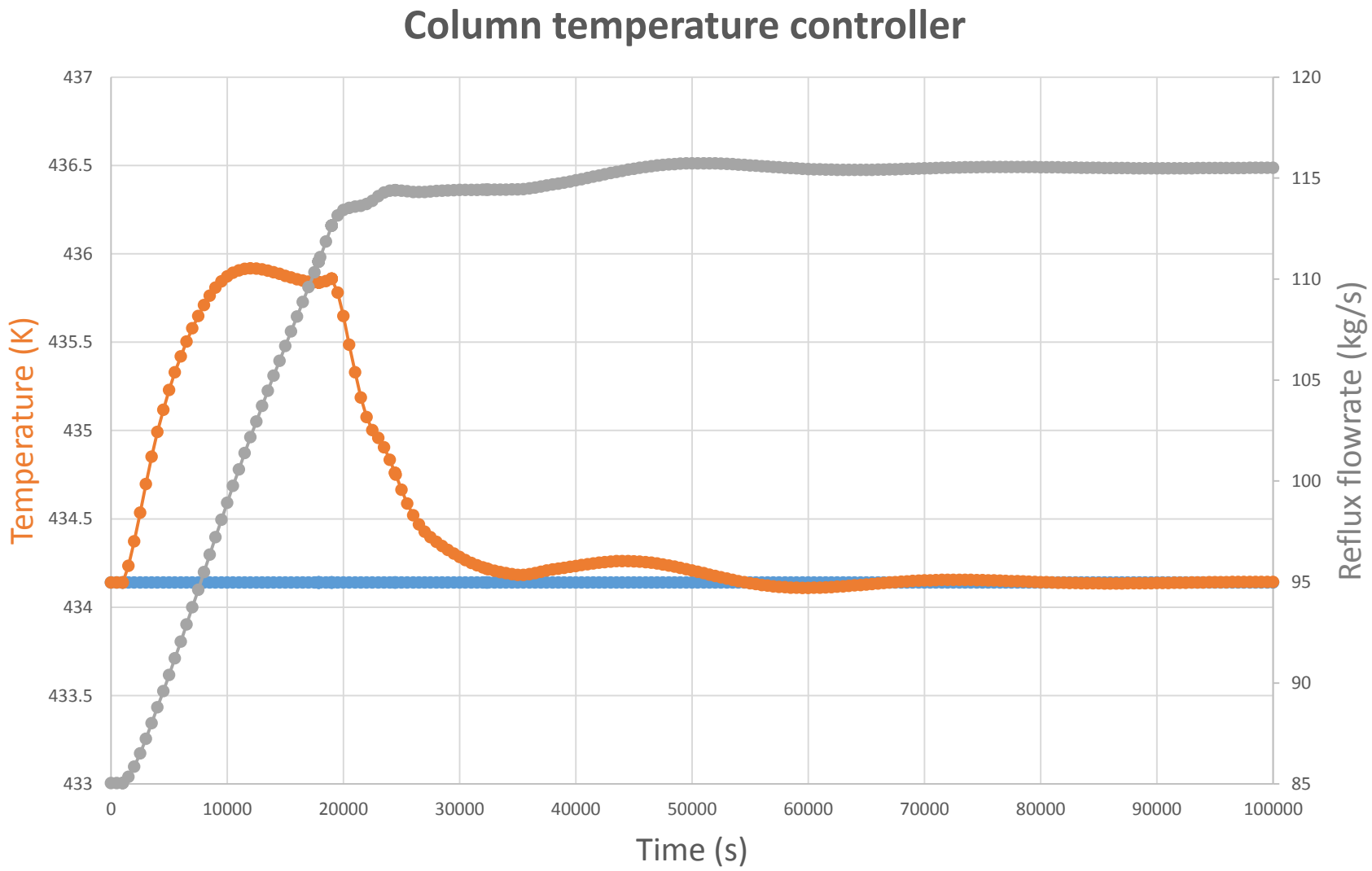
Condenser pressure



Condenser liquid level



Column temperature (stage 7, controlled by reflux)

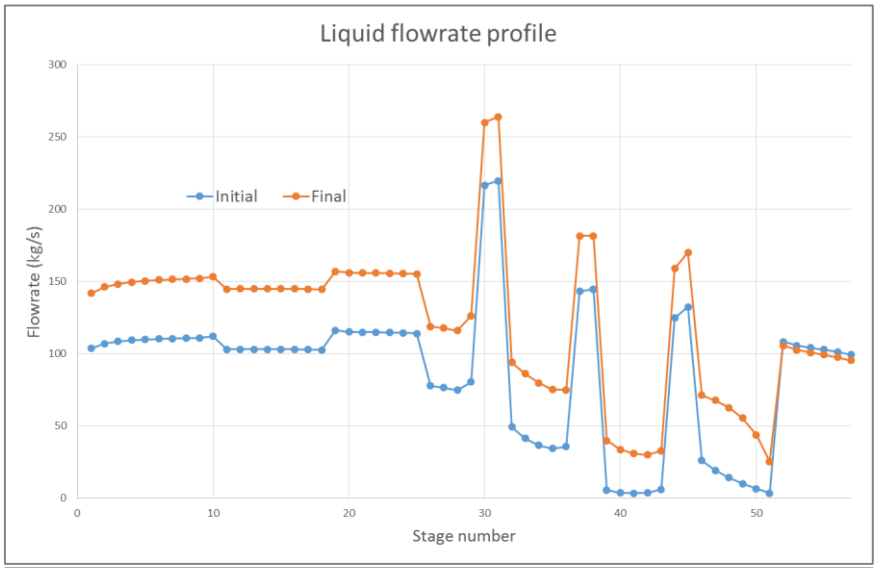


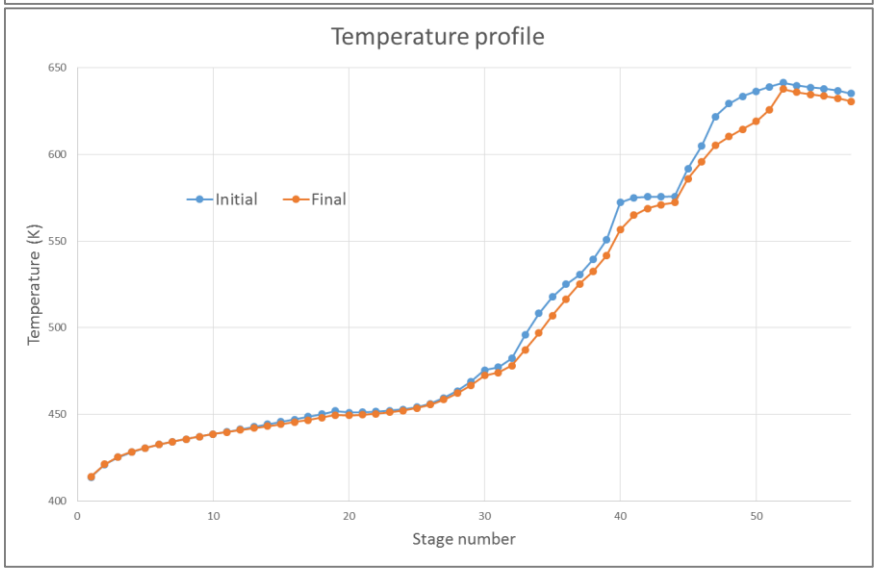
Column internals

- Check operation
- Liquid and temperature profiles

Statistics

- Number of equations
  - Algebraic: 163857
  - Differential: 5178
- gPROMS Model Pruning algorithm automatically eliminates 116222 variables
- Computation time: 3h for 3 days

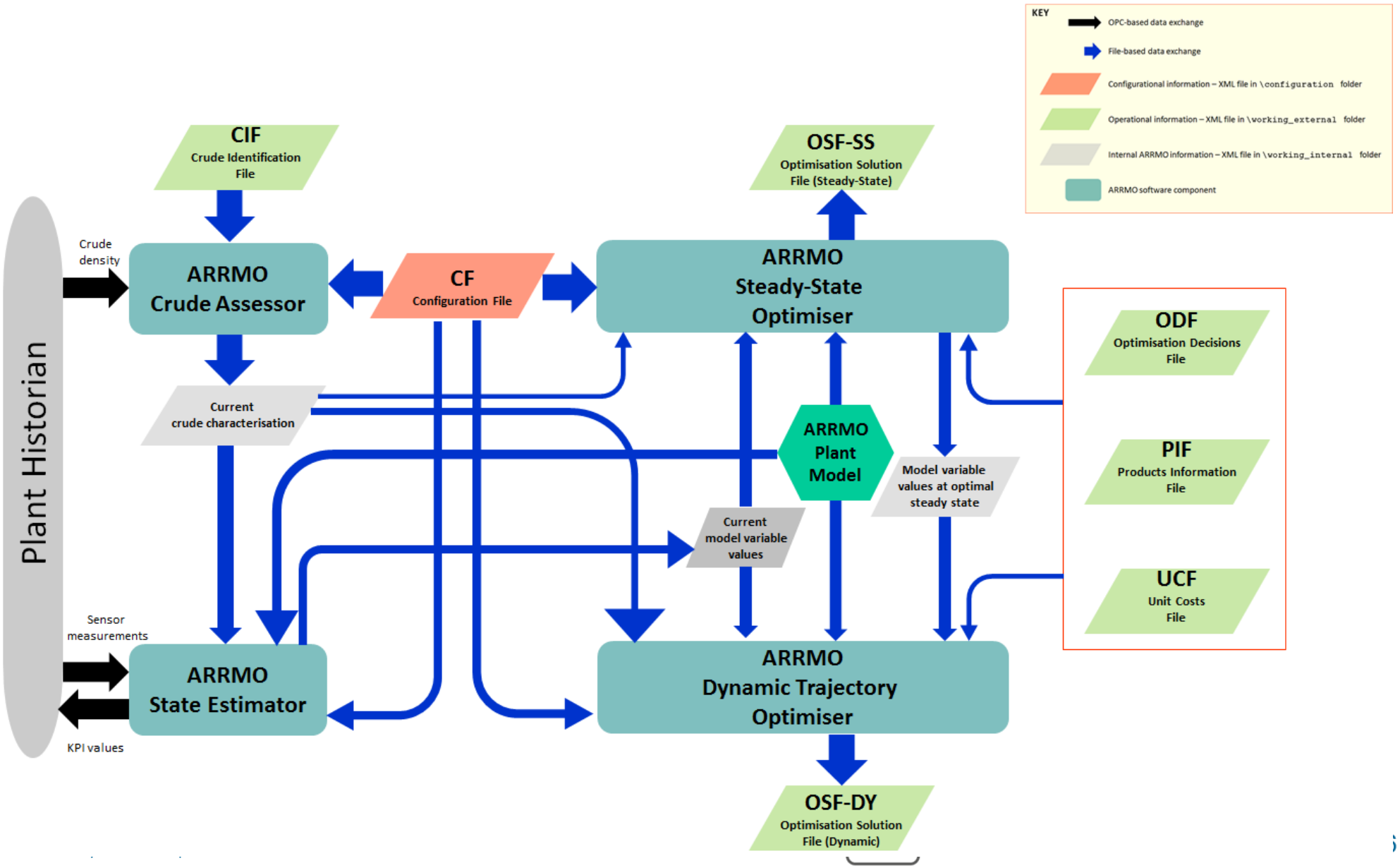




Current work & next steps

ARRMO software architecture

Original design (ARRMO Technical Specification, Nov 2015)

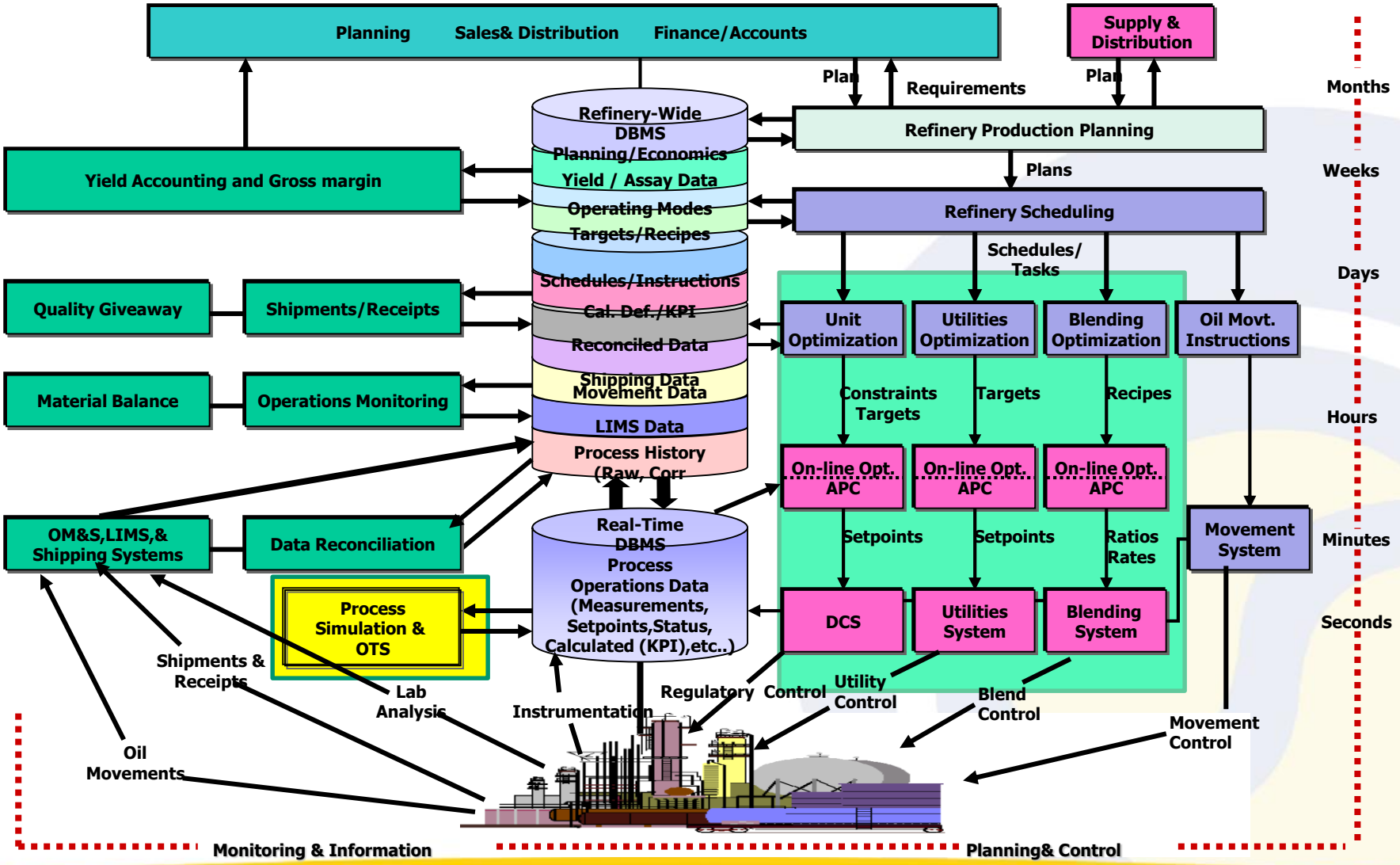


Next steps

- April – June 2016
  - Develop and test components
    - Crude Assessor, Optimisers, State Estimator, etc.
- July – December 2016
  - Develop and test the interface
  - Assemble and implement full system
  - Test real scenarios in open loop mode
  - Gain operations feedback
- December 2016-January 2017
  - Wrap-up
- Present at various conferences
  - From Q3 2016
  - Petrotech New Delhi Dec 2016

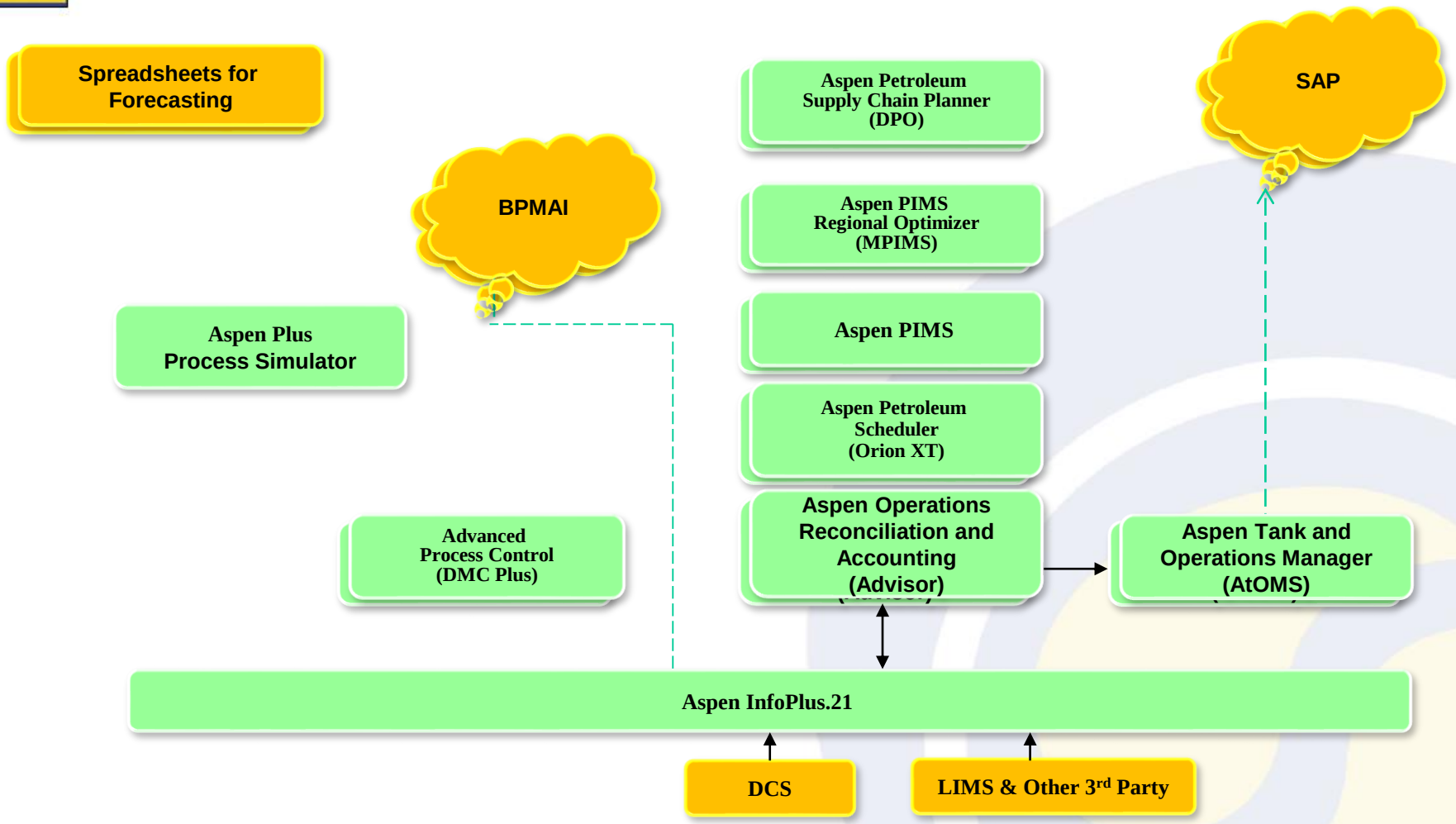
Bharat Petroleum

BPCL Refinery Broad Process & Linkages : Landscape – Real Time Optimization – 2000 to 2020



Bharat Petroleum

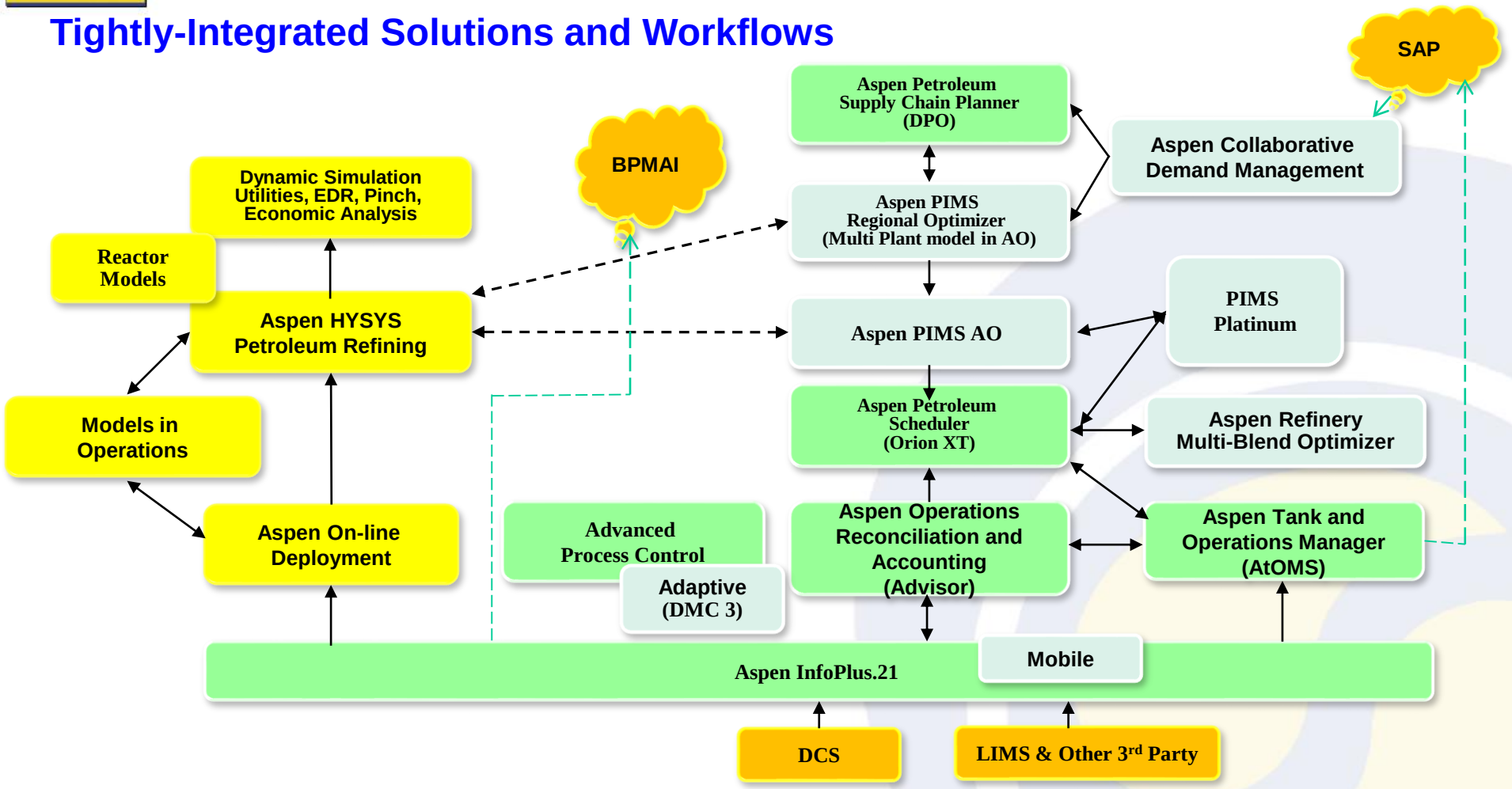
As-Is Solution Map– Mumbai - 2015



Bharat Petroleum

To-Be Solution – Mumbai

Tightly-Integrated Solutions and Workflows



3rd Party | Existing Aspen Tools, Suite | New or Added aspenONE AES | New or Added aspenONE MSC

Bharat Petroleum

Challenges in implementation

- Crude estimation
- Instrumentation in the plant
- Connection between the model and the plant
- Interface to DCS and APC

- Impact of the finished product specifications (environment constraints)

- Conclusion
  - The success of the project is relying on the good communication between the simulation team and the operators on the plant

February 2015

@ BPCL Mumbai Refinery, March 2016

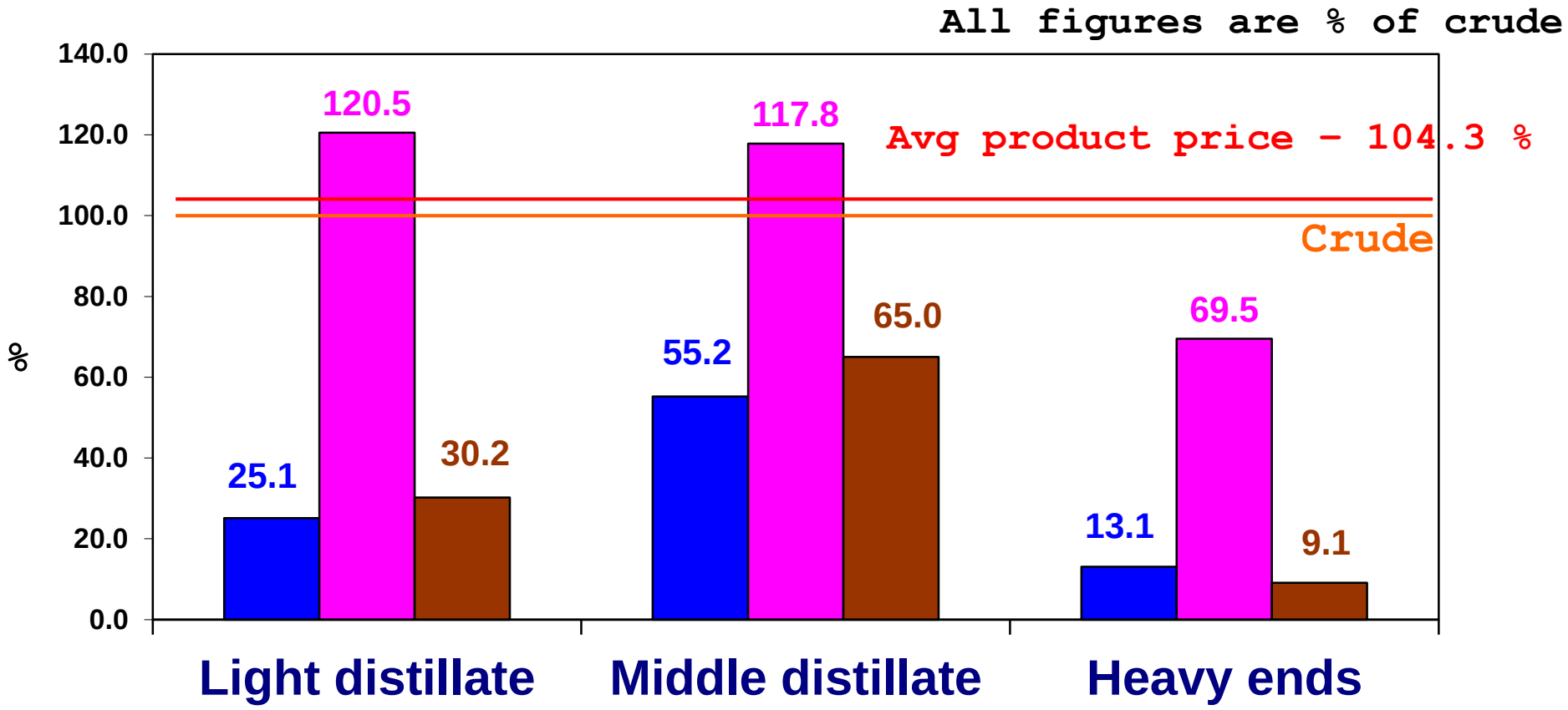
Thank you

Bharat Petroleum

Energising lives

Typical Refinery economics

Mumbai Refinery 2014-15



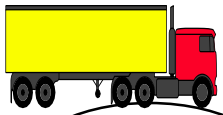
Improving yield of value added products is the mantra of any Refinery

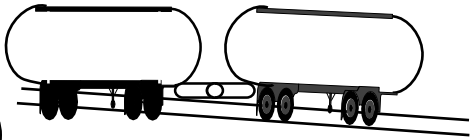
Quality & Process Improvements

Journey on the path of Business Excellence .....

Bharat Petroleum

Logistic Linkages

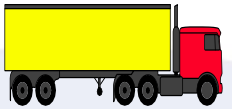




RLNG/ BHAG

Uran

Loading facilities



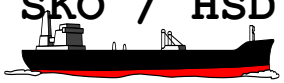
Jetty

LPG

MS /HSD /FO SKO/NAPHTHA

MKTG. Installations

CRUDE / MS/ SKO / HSD



REFINERY

12″ P/L

Pirpau Jetty

NAPHTHA/ LABFS / LSHS

Direct Customers/ Wadilube

ATF

LOBS

CRUDE / GAS

ONGC

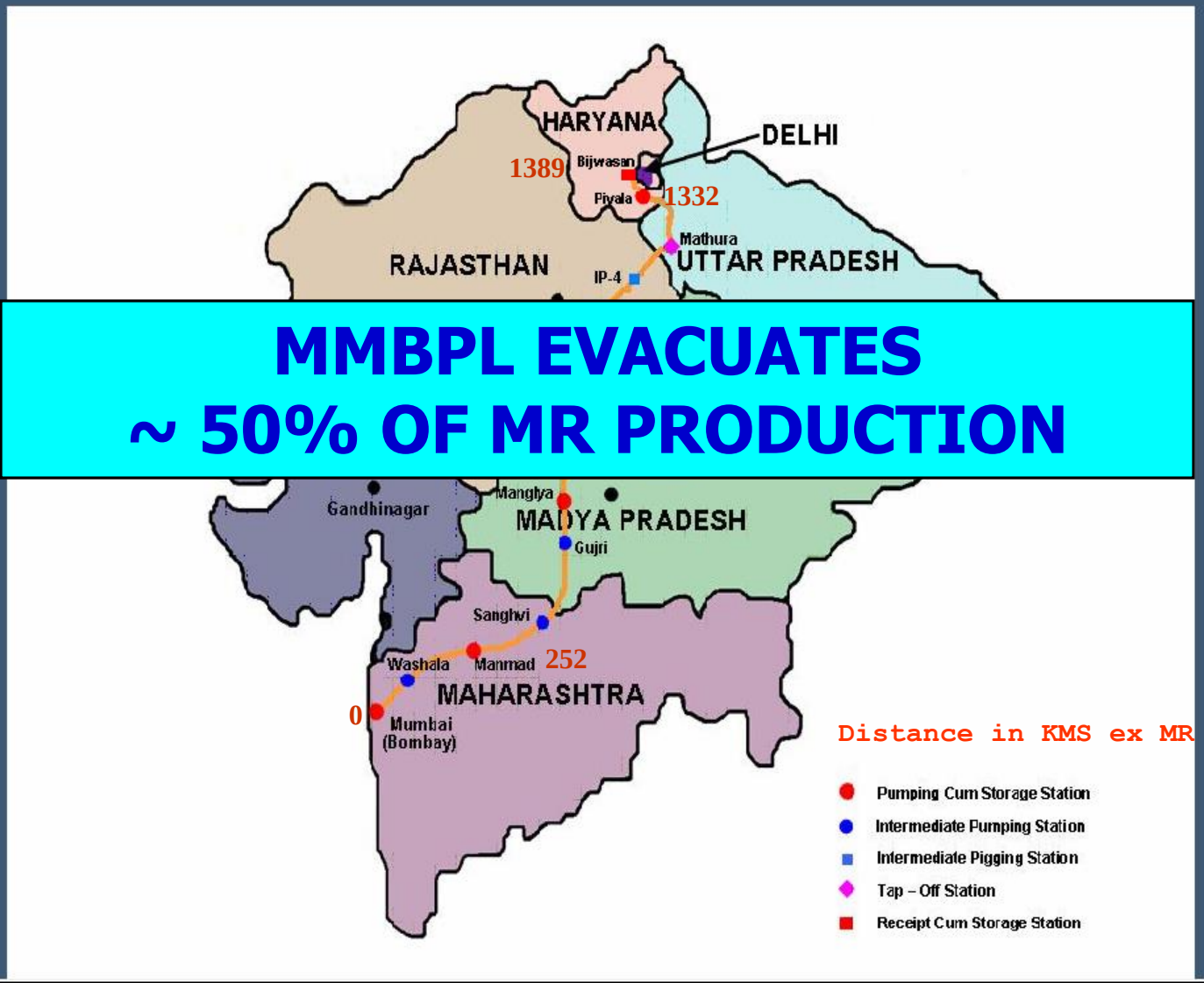
MS/HSD/SK

MMBPL (Pipeline)

Aviation Station

MMBPL ROUTE MAP

Mumbai-Manmad-Manglya-Bijwasan PipeLine

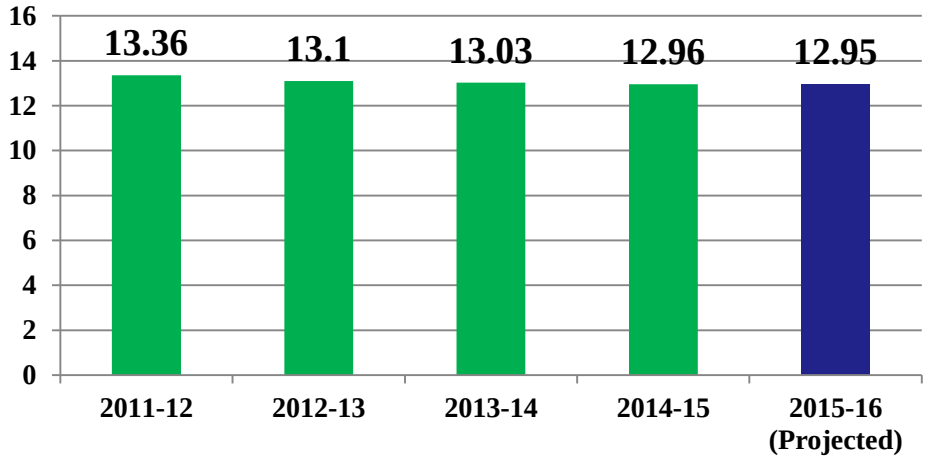


MMBPL EVACUATES
~ 50% OF MR PRODUCTION

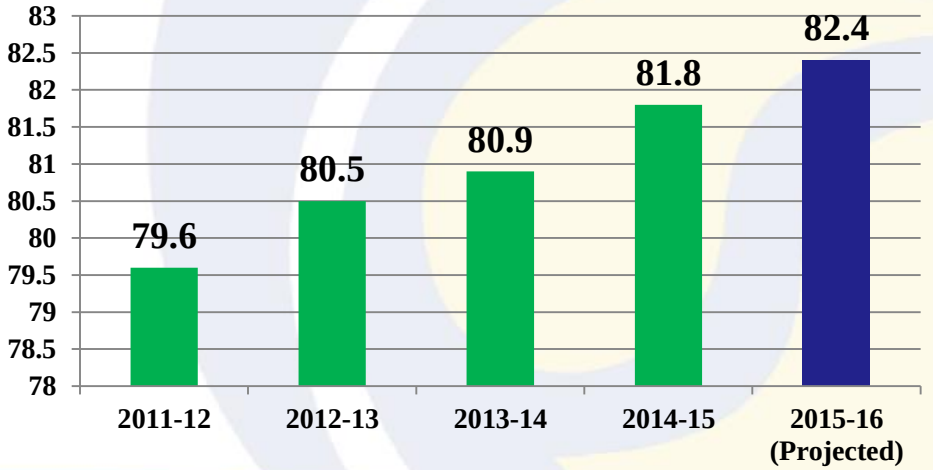
Bharat Petroleum

Physical performance

Crude Throughput (MMTPA)



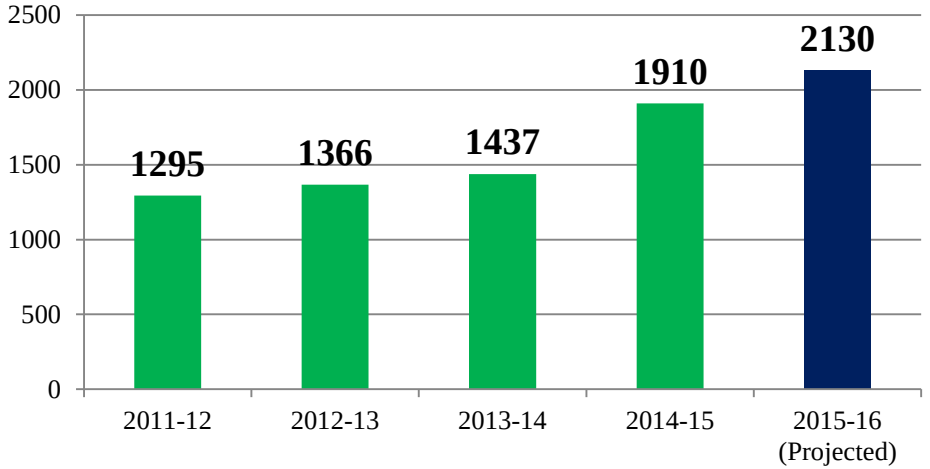
Distillate Yield (% wt on crude)



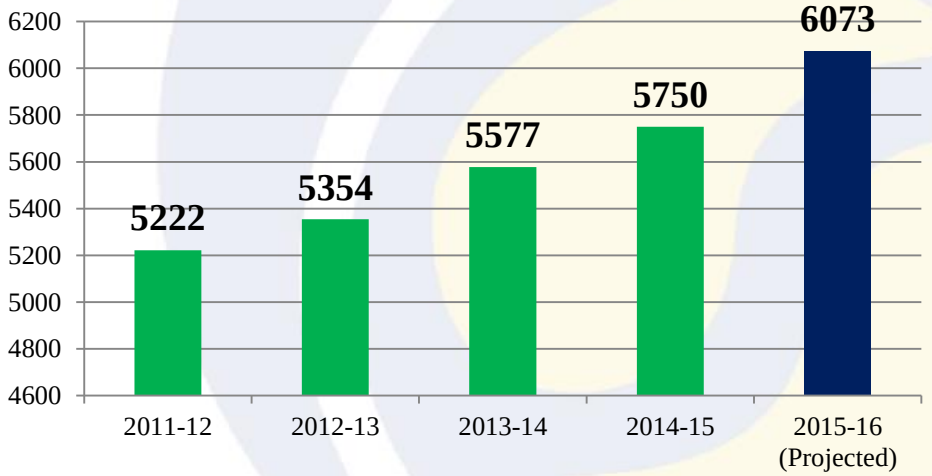
Bharat Petroleum

Physical performance (contd)

MS Production (TMTPA)



HSD Production (TMTPA)



Results

Decision variables

- CDU
  - Reflux ratio
  - Furnace temperature
  - Pumparound fractions
    - HK, LGO, HGO
  - Stripping steam SS_1 / RCO flowrate
  - Yields
    - HN, LK, HK, LGO, HGO
- VDU
  - Furnace temperature T_2
  - Pumparound fractions
    - LVGO, HVGO
  - Slops recycle fraction
  - Stripping steam SS_4 / VR flowrate
  - Yields
    - VD, LVGO, HVGO

	Unit	Final Value	Initial Guess	Lower Bound	Upper Bound	% change	
Reflux ratio R1	kg/kg	[redacted]	[redacted]	[redacted]	[redacted]	-10.0	▼
Reflux ratio R_2	kg/kg	[redacted]	[redacted]	[redacted]	[redacted]	10.0	▲
Furnace temperature T_1	K	[redacted]	[redacted]	642.65	646.65	-0.3	▼
Furnace temperature T_2	K	[redacted]	[redacted]	683.15	690.15	0.4	▲
HK pumparound fraction	kg/kg	[redacted]	[redacted]	[redacted]	[redacted]	20.0	▲
LGO pumparound fraction	kg/kg	[redacted]	[redacted]	0.3958	0.5278	-3.6	▼
HGO pumparound fraction	kg/kg	[redacted]	[redacted]	[redacted]	[redacted]	20.0	▲
LVGO pumparound fraction	kg/kg	[redacted]	[redacted]	[redacted]	[redacted]	20.0	▲
HVGO pumparound fraction	kg/kg	[redacted]	[redacted]	[redacted]	[redacted]	-10.0	▼
Slops recycle fraction	kg/kg	[redacted]	[redacted]	0.5	0.95	15.2	▲
Stripping steam SS_1 / RCO flowrate	kg/kg	[redacted]	[redacted]	0.011	0.02	27.4	▲
Stripping steam SS_4 / VR flowrate	kg/kg	[redacted]	[redacted]	0.0051	0.0096	29.7	▲
HN yield	kg/kg	[redacted]	[redacted]	0.024	0.0321	20.2	▲
LK yield	kg/kg	[redacted]	[redacted]	[redacted]	[redacted]	-20.0	▼
HK yield	kg/kg	[redacted]	[redacted]	0.0802	0.1202	19.8	
LGO yield	kg/kg	[redacted]	[redacted]	0.1779	0.2271	-6.0	▼
HGO yield	kg/kg	[redacted]	[redacted]	0.0209	0.0365	0.0	
VD yield	kg/kg	[redacted]	[redacted]	0.0374	0.0534	18.2	▲
LVGO yield	kg/kg	[redacted]	[redacted]	0.1754	0.2505	11.1	▲
HVGO yield	kg/kg	[redacted]	[redacted]	[redacted]	[redacted]	20.0	▲

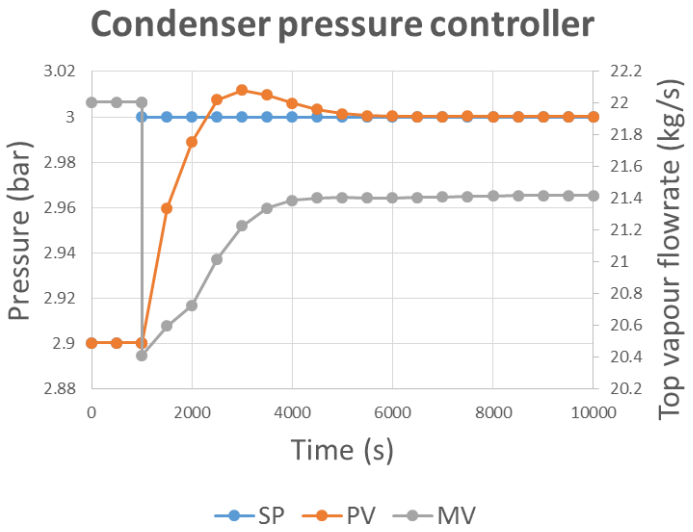
Results
Constraints

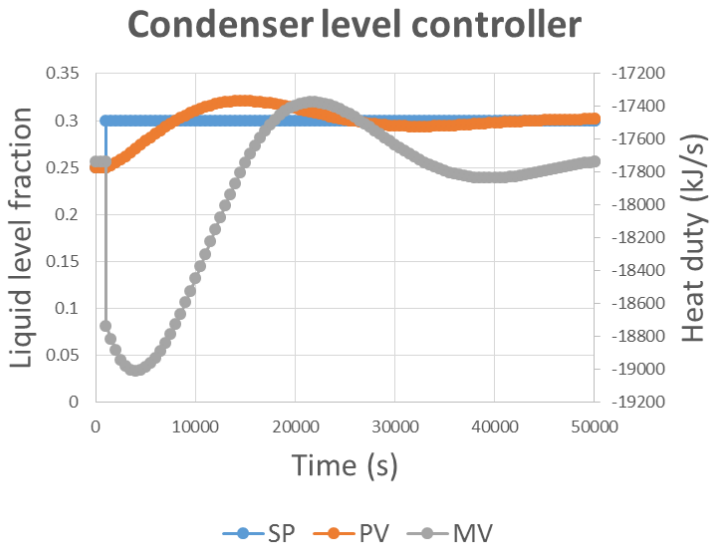
- Various product constraints
  - ASTMs (5%, 95%)
  - Flash Point, Freeze Point …
- Process/equipment constraints
  - Liquid, vapour flowrates
- Many more possible
  - All API quality constraints
  - Almost any variable

Stream	Variable	Unit	Lower Bound	Upper Bound	Final Value
OHV	D86 95%	C	0.00	125.00	[redacted]
HN	D86 5%	C	120.64	[redacted]	[redacted]
HN	D86 95%	C	143.59	149.59	[redacted]
LK	Flash	C	29.22	300.00	[redacted]
LK	Freeze	C	-273.00	-50.00	[redacted]
HK	Flash	C	52.02	300.00	[redacted]
HK	Freeze	C	-273.00	-39.67	[redacted]
LGO	D86 95%	C	327.38	[redacted]	[redacted]
HGO	D1160 5%	C	272.25	400.00	[redacted]
VD	D86 95%	C	352.24	[redacted]	[redacted]
VGO	D1160 95%	C	551.39	800.00	[redacted]
Liquid flow st 51 CDU	Molar flowrate	kmol/hr	50	1.00E+30	[redacted]
vapour flow st 57 CDU	Molar flowrate	kmol/hr	50	1.00E+30	[redacted]
Liquid flow st 6 VDU	Molar flowrate	kmol/hr	50	1.00E+30	[redacted]
Liquid flow st 10 VDU	Molar flowrate	kmol/hr	50	1.00E+30	[redacted]
Vapour flow st 16 VDU	Molar flowrate	kmol/hr	50	1.00E+30	[redacted]

Pressure, level control

- Pressure in the condenser is controlled via the top vapour flowrate
- Step change from 2.9 to 3 bar
- Level fraction in the condenser is controlled via the cooling duty
- Step change from 0.25 to 0.3

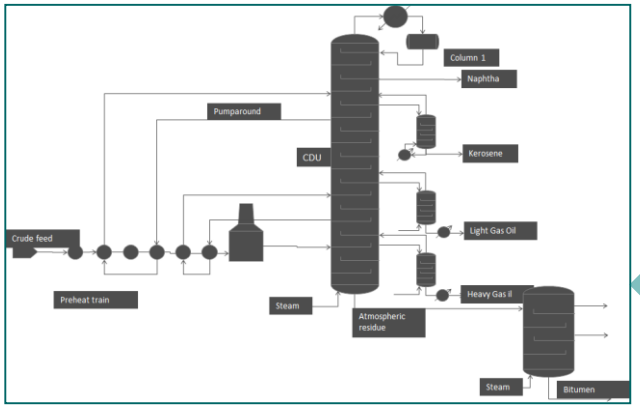




ARRMO overview

Advanced Real-time Refinery Monitoring & Optimisation

Plant



Plant measurements and controls

DCS

APC

APC setpoints

Periodic plant measurements (via IP.21)

Info
Advice
Alarms

Crude Definition File

Product info specs,prices min/max demands

Cost info Crude & utility costs

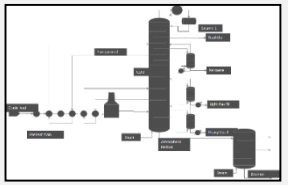
ARRMO

Advanced Real-Time Refinery Monitoring & Optimisation

State Estimator

Crude Assessor

Plant model



Optimisation framework