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In The Name Of God

Upgrading Process of Heavy Oil

CORPORATIVE PLANING DIRECTORATE
(Consumption Affairs)

Spring 1387

Contents

What is the Heavy Oil ?

From the Standpoint of Properties

Heavy Oil is **High Heating Value**,

but **High Viscous** Oil such as Residues

from CDU and VDU.

(Especially **High-Sulfur and High-Metal Fuel Oil** Case)

Heavy Oil Upgrading Process

What is the Heavy Oil ?

From the Standpoint of Properties

Properties		Results
High Heating Value	⇒	Good Fuel (used only for Fuel)
High Sulfur Content	⇒	Air Pollution (Acid Rain,Oxidant etc)
High Viscosity (High Pour Point)	⇒	Heating (during Transport,Storage etc) Mal Atomizing
High Metal Content	⇒	Corrosion Catalyst Poisonous

What do the Upgrading Processes mean?

Heavy Oil

High Sulfur, high Metal, high Heating Value and high Viscous as Residues from CDU and VDU

High MW & Low H/C ratio

Light Oil

To change the Heavy Oil to the High Quality Light Products

(Especially Lighter Fractions, low Sulfur and low Metal Products are good).

Low MW & High H/C ratio

What do the Upgrading Processes mean?

From the Standpoint of Properties

Properties	Before Processing	After Processing
High Heating Value	Good Fuel (used only for Fuel)	Various Products (not only for Fuel but also Petrochemical feed etc)
High Sulfur Content	Air Pollution (Acid Rain,Oxidant etc)	Low Sulfur
High Viscosity (High Pour Point)	Heating (during Transport,Storage etc) Mal Atomizing	Low Viscocity (Lighter Fractions) not Necessary more Heating Good Atomizing
High Metal Content	Corrosion Catalyst Poisonous	Low Metal Products less Corrosive/Poisonous

1. Introduction:

Key for Heavy Oil Upgrading Process Selection

1.1 Introduction

- Gasoline/Middle distillate market demand is increasing.
- New regulations for protecting environment is getting severe.
- Crude oil properties is getting heavier.
- Sulfur contents in crude is also getting heavier.
- Purchasing light sweet crude oil is expensive.

→ What can we do now ?

Install Heavy Oil Upgrading Process in Refinery.

1.2 Introduction: Key Point

- There are many different types of Heavy Oil upgrading technology available to meet the refinery's needs.
- By adding upgrading process in refinery, capital cost & revenue is increasing, but profitability is not necessarily improved.

Key Point :

How to produce light oil products efficiently and economically from Heavy Oil.

→ **How to optimize the Refinery Configuration?**

1.3 Primary Factors for Upgrading Process Selection

- Price Spread between Light and Heavy Crude
- Price Spread between Crude and Residue
- Products Demand & Specification

  Fuel Oil or Gasoline/Gas Oil ?
  Motor Gasoline or Gas Oil ?
  Export use or Domestic use ?
  Spec. Change due to Environmental Regulation?
  Marketability of Coke/Pitch?

- Feed Properties

  SpGr, Sulfur, Metals, UOPK($\sqrt[3]{(T_b/S)}$)

Heavy Oil Upgrading Process

1.4 Primary Factors for Upgrading Process Selection

- Process Configuration of Existing Plant
- Operation Flexibility for Max./ Min. Product Rates

→ High Flexibility is required ?

- Technology of Heavy Oil Upgrading Process

→ To meet the Needs?

Well-Proven ?

- Hydrogen & Electric Power's Price & Consumption
- Economics

→ Maximize Profitability ?

Maximum Allowable Capital Cost ?

2. Features of Heavy Oil Upgrading Processes

Technology Improve in Heavy Oil Upgrading Processes

1. Producing more efficient catalysts
2. Upgrading catalytic processes from fixed bed to fluidized bed.
3. Making spare batch reactores to keep process work continously.
4. Using a wider range of feeds in new processes.
5. producing new products .
6. Increasing the yield and efficiency of processes.

Classification of Residue Upgrading

1. Hydrogen Addition type

Hydrogen is added to heavy oil

(Hydrogen, Catalyst, High Temperature & Pressure)

2. Carbon Rejection type

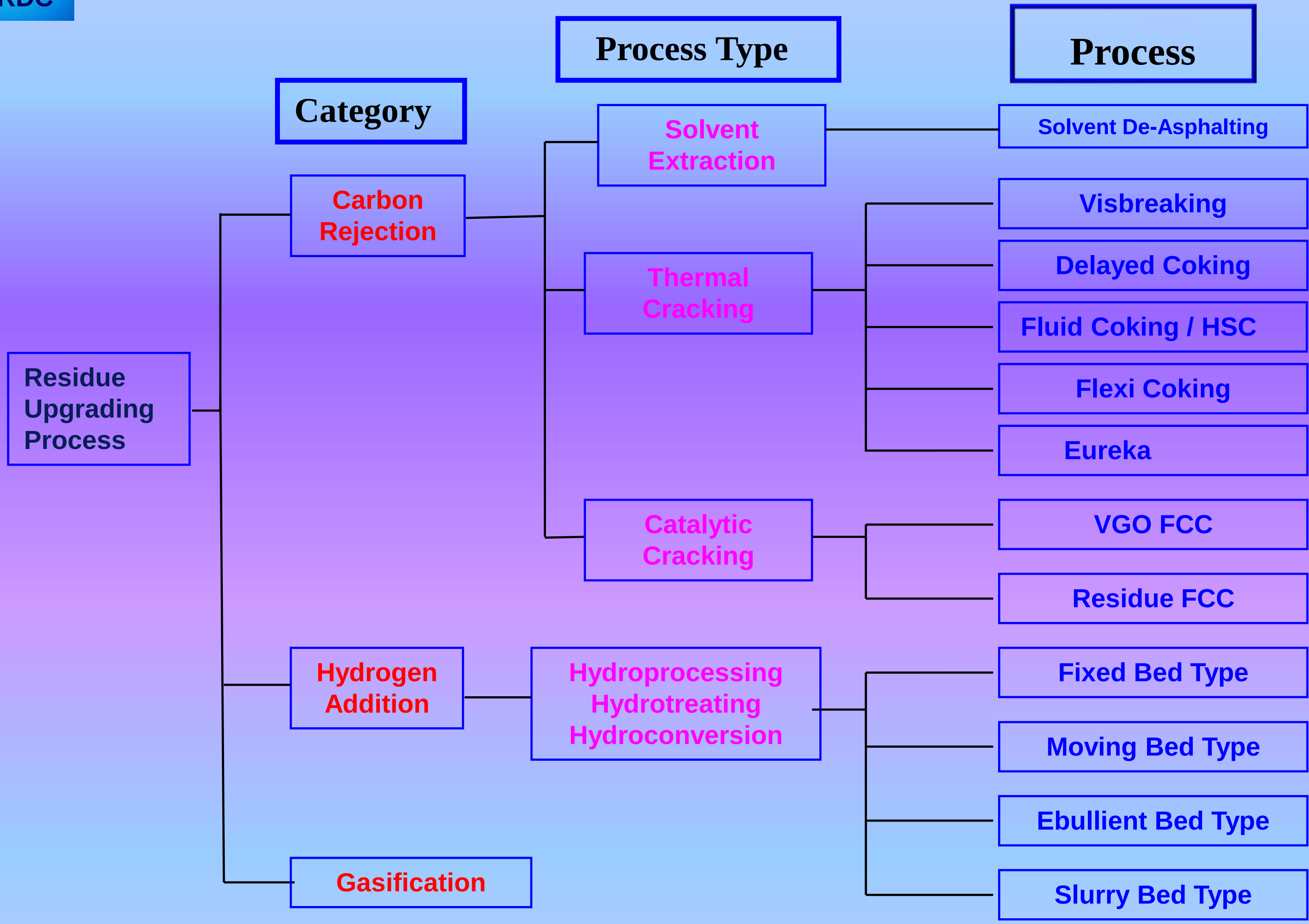
Carbon is removed from heavy oil

3. Gasification type

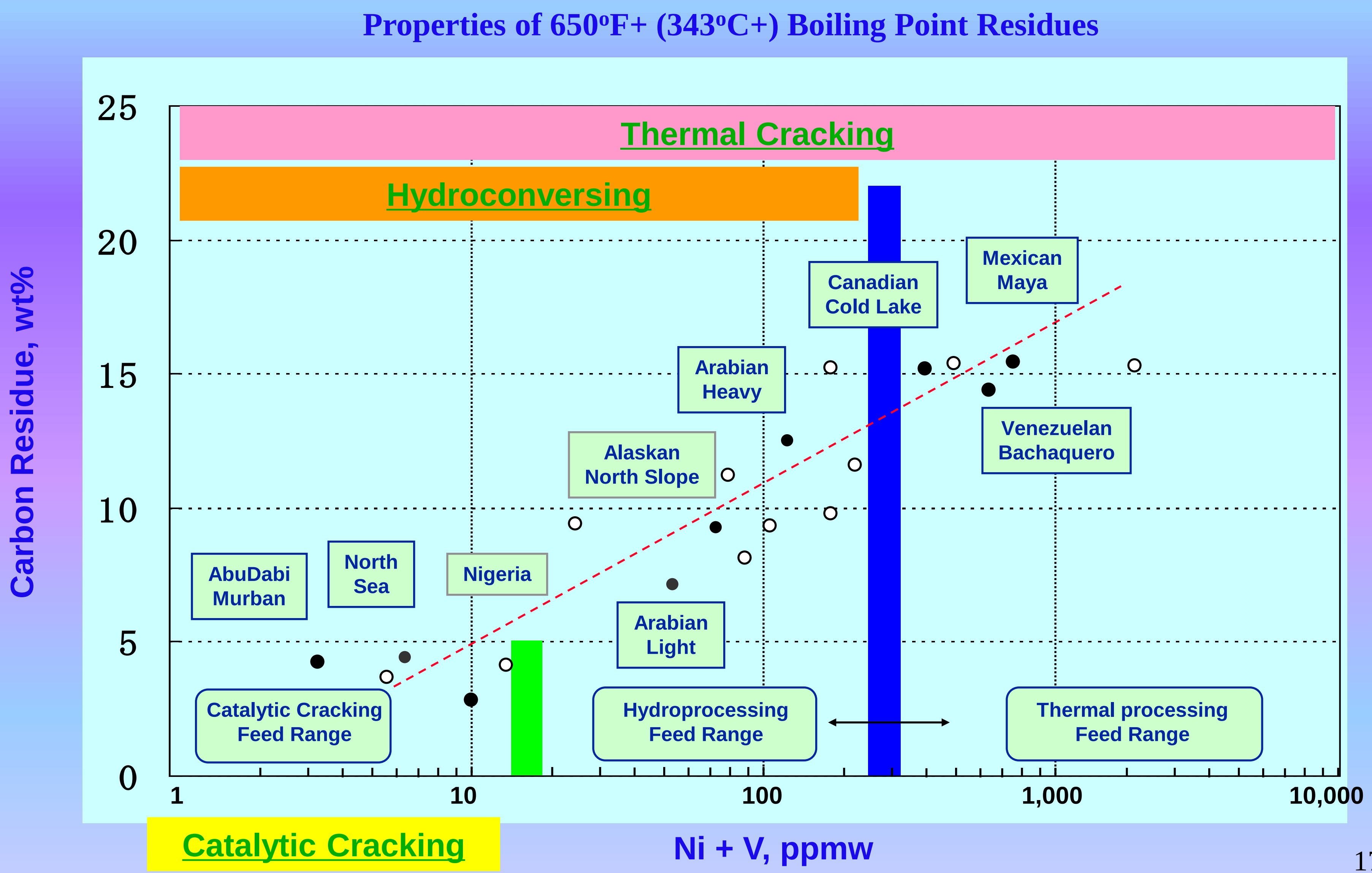
Heavy oil is converted to produce hydrogen (H2) and carbon monoxide (CO) in the partially oxidation.

The overall processing employs combinations of carbon rejection and hydrogen addition steps.

Classification of Heavy Oil Upgrading Processes



2.2 Feed Limitation for Heavy Oil Upgrading Processes



2.3 Features of Thermal Cracking Process

Merit:

- Thermal cracking process can handle heavy oils that are not easily processed due to their impurities (Metal, Sulfur, CCR, Nitrogen content).
- Lower Investment Cost
- Easy Operation

Demerit:

- Low Octane Gasoline Product
- Low Stability Products
- Low Value Gas (C_1,C_2)
- Limited Coke Market

2.4 Features of Catalytic Cracking Process

Merit:

- Catalytic cracking process can produce high Octane Gasoline material.
- Catalytic cracking process also produce high value gases (Propylene, Ethylene).
- HP/MP Steam Generation

Demerit:

- Feed Limitation: Pre-Treating Unit is required to eliminate Impurities (Metal, Sulfur, CCR, Nitrogen content).
- High Operating Cost (Expensive Catalyst)
- High Investment Cost
- Difficult Operation

2.5 Features of Solvent Extraction Process

Merit:

- Solvent Extraction process can handle heavy oils that are not easily processed due to their impurities (Metal, Sulfur, CCR, Nitrogen content).
- Solvent Extraction process can produce De-Asphalted Oil (DAO) with easy operation.
- Low Investment Cost

Demerit:

- Low Value Pitch (High Sulfur, High Viscosity)
- High Operating Pressure

2.6 Features of Hydroprocessing Process

Merit:

- Hydroprocessing process can produce high Quality Products.
- Hydroprocessing process can remove Asphaltene from heavy oil together with Metal, Nitrogen and Sulfur.
- High Operation Flexibility

Demerit:

- Higher Operating Cost (Catalyst & Hydrogen)
- Higher Operating Pressure
- Higher Investment Cost
- Low Value Pitch or LS fuel oil

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Heavy Oil Upgrading Process

2.7 Comparison of Each Categories of Process

	Hydrogen Addition		Carbon Rejection		
	Hydrocracking	Hydroconver-ting	Catalytic Cracking	Solvent Extraction	Thermal Cracking
Feed	HGO/VGO	AR/VR	VGO~AR	AR/VR	AR~VR
PreTreating	Required	-	(Required)	-	-
Product Quality	Excellent	Excellent	Good	Good	Low
Main Product	Middle Dist.	Middle Dist	High Octane Gasoline, Propylene	DAO	Low Octane Gasoline Distillate
By-Product	LS Fuel Oil	Low Value Pitch	Slurry Oil	High Sulfur Pitch	HS Fuel Oil or Coke
Investment Cost	High (Rx, Comp'r)	High (Rx, Comp'r)	High (Boiler)	Low	Low
Operation Cost	High (Cat.,H2)	High (Cat.,H2)	High (Cat.)	Low	Low

Gasification

Dirty Feedstock (Heavy Oil) → Gasifier ⇄ Carbon Extractor

Gasifier → Scrubber → Gas Cooler → Gas Purifier → Clean Product (Syngas)

Heavy Oil Upgrading Process

2.8 Classification of Commercial Thermal Cracking Process

Thermal Cracking

Processes	Commercial Process / Licenser
Visbreaking	Coil type: Foster Wheeler/UOP Soaker type: Shell/ABB Lummus
Delayed Coking	Foster Wheeler/UOP, ABB Lummus, Conoco/Bechtel
Fluid Coking	Exxon Mobil
Flexi Coking	
Eureka / HSC	Eureka: Kureha/ Chiyoda/ Fuji Oil HSC(High-conversion Soaker Cracking):Toyo Engineering & Mitsui Kozan Chemicals

2.9 Classification of Commercial Catalytic Cracking Process

	Processes	Commercial Process / Licenser
Catalytic Cracking	VGO FCC	UOP, Exxon/Mobil, Shell, Kellogg BR, Axens, Stone&Webster, ABB Lummus
	Residue FCC	RCC: UOP R2R: Axens/Stone&Webster LRFCC: Shell HOC(Heavy Oil Cracking): Kellogg BR Flexicracking: Exxon/Mobil DCC: Stone&Webster

Why FCC/RFCC is installed in Refinery ?

⇒ Utilizing Value-less Heavy Oil Feedstock.

⇒ Production of 40-55 wt% Gasoline Yield.

⇒ Prduction of Propylene & Butylenes.

⇒ No Use of Hydrogen.

Heavy Oil Upgrading Process

2.10 Classification of Commercial Hydroprocessing Process

Hydroprocessing	Processes	Commercial Process / Licenser
Hydroprocessing (Hydrotreating/ Hydroconversion)	Fixed Bed Type	RCD Unibon: UOP RDS/VRDS: Chevron HYVAHL: Axens Residfining: Exxon/Mobil Unicraking: UOP MAK-LCO: Kellogg BR
	Moving Bed Type	OCR(Onstream Catalyst Replacement): Chevron HYCON: Shell
	Ebullated Bed Type	H-Oil: Axens LC-Fining:ABB Lummus/Amoco Oil T-Star: Axens
	Slurry Bed type	VCC(Veba Combi Cracking): Veba Oel Microcat RC: Exxon/Mobil (HC)3: Aostra/ARC

Hydrotreating process

Following are representative reactions, which occur in hydrotreating process.

- Hydrocracking
- Hydrodesulfurization
- Hydrodenitrification
- Hydrodemetallization
- Saturation of aromatics
- Olefin hydrogenations

- **All the reactions are <u>exothermic</u>.**

Hydroprocessing Process

H-OIL PROCESS

- The H-Oil process was developed by HRI and commercialized by HRI and City Service, but now it is licensed by IFP.
- The H-Oil Process is a unique, catalytic process for hydrogenation of residue and heavy oils in an ebullated bed reactor to produce upgraded petroleum products.
- The purpose of the unit is quite same as the Chevron OCR/VRDS Process.
- The ebullated-bed reactor was designed to overcome problems encountered with a fixed-bed reactor.
- Temperature : 400-450° C and Pressure: 180-220 kg/cm2G

WHAT IS OCR?

- OCR, or Onstream Catalyst Replacement, is a counter-current, moving-bed technology that removes metals from feedstocks for fixed-bed residuum hydrotreating reactors.
- In the OCR reactor residuum and hydrogen flow upward through the reactor and the catalyst flows downward.
- This process removes the metals from previously uneconomical feeds for further downstream conversion.
- OCR's ability to efficiently remove metals enables refiners to process more difficult feeds or achieve deeper desulfurization.

2.11 Classification of Commercial Solvent Extraction Process

Commercial Process / Licenser

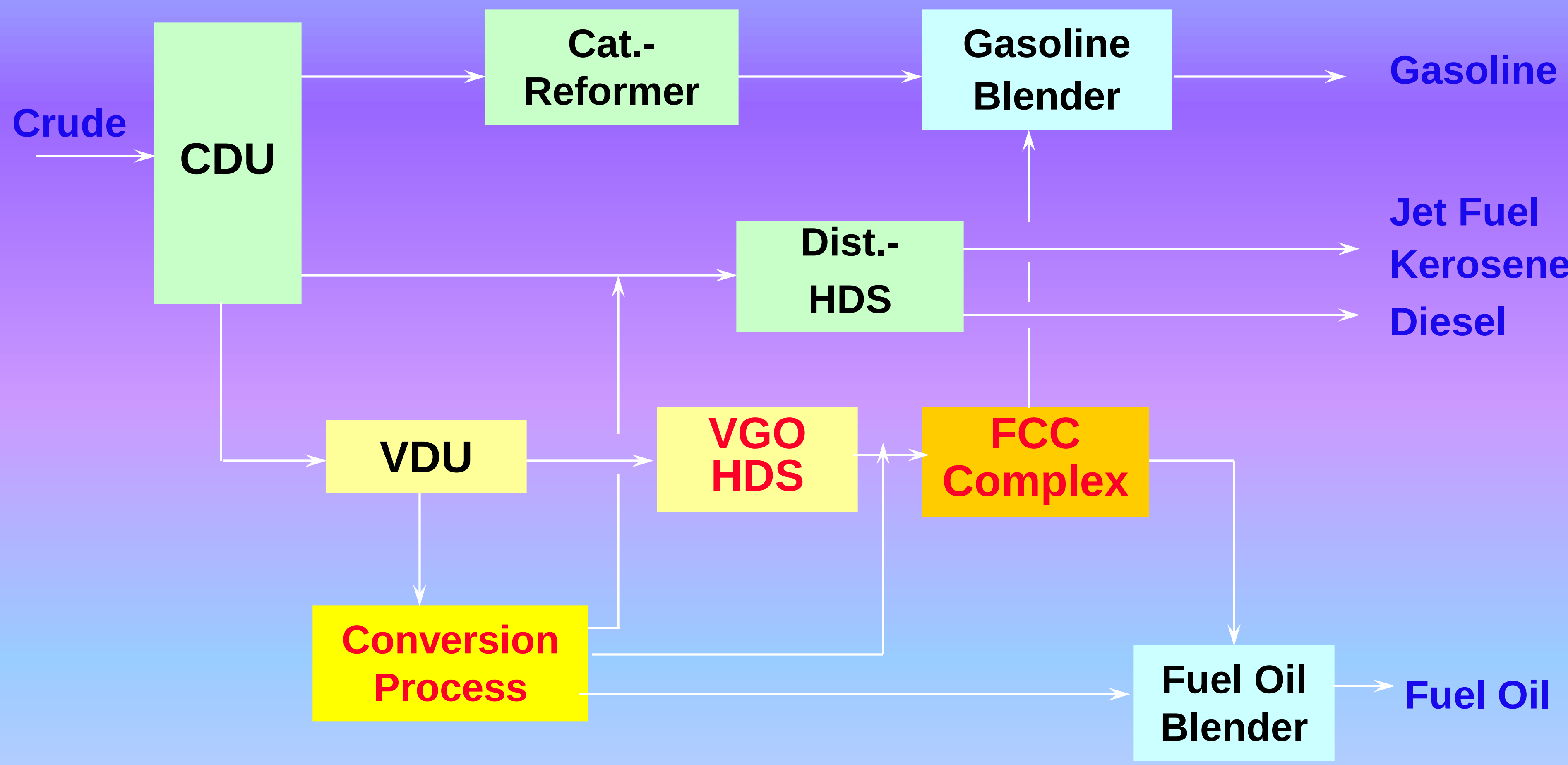
Solvent Extraction

- SDA (Solvent Deasphalting): Foster Wheeler/UOP
- DEMEX: UOP
- ROSE: Kellogg BR
- SOLVAHL: Shell

3. Feasibility Study for Typical Model Case

Heavy Oil Upgrading Process

3.1 Process Configuration for Typical Refinery



3.2 Feasibility Study Case Definitions

Candidate Process :

Most often selected (well-proven) Technologies

- Residue Hydrocracking (Hydroconversion)
- VR-HDS / Residue FCC (Catalytic Cracking)
- SDA (Solvent Extraction)
- Visbreaking (Thermal Cracking)
- Delayed Coking (Thermal Cracking)

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3.3 Comparison of Candidate Processes

	Residue Hydrocraking	Residue FCC	SDA	Visbreaking	Delayed Coking
Operation Type	Continuous	Continuous	Continuous	Continuous	Semi-Batch
Pressure,psig	1000~2500	10~35	300~600	140~350	15~100
Temperature, deg.F	770~840	900~970	120~450	840~930	900~950
Yields, vol%(wt%)					
Naphtha	7~10	50~60	-	7	14
Gas Oil	55~70	12~20	30~65	17	55
Residue	25~40	6~10	35~70	75	(30)
(Condition)	(Liquid)	(Liquid)	(Liquid)	(Liquid)	(Solid)
Investment Cost	High	High	Low	Low	Middle

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Heavy Oil Upgrading Process

3.4 Feasibility Study Case Definitions

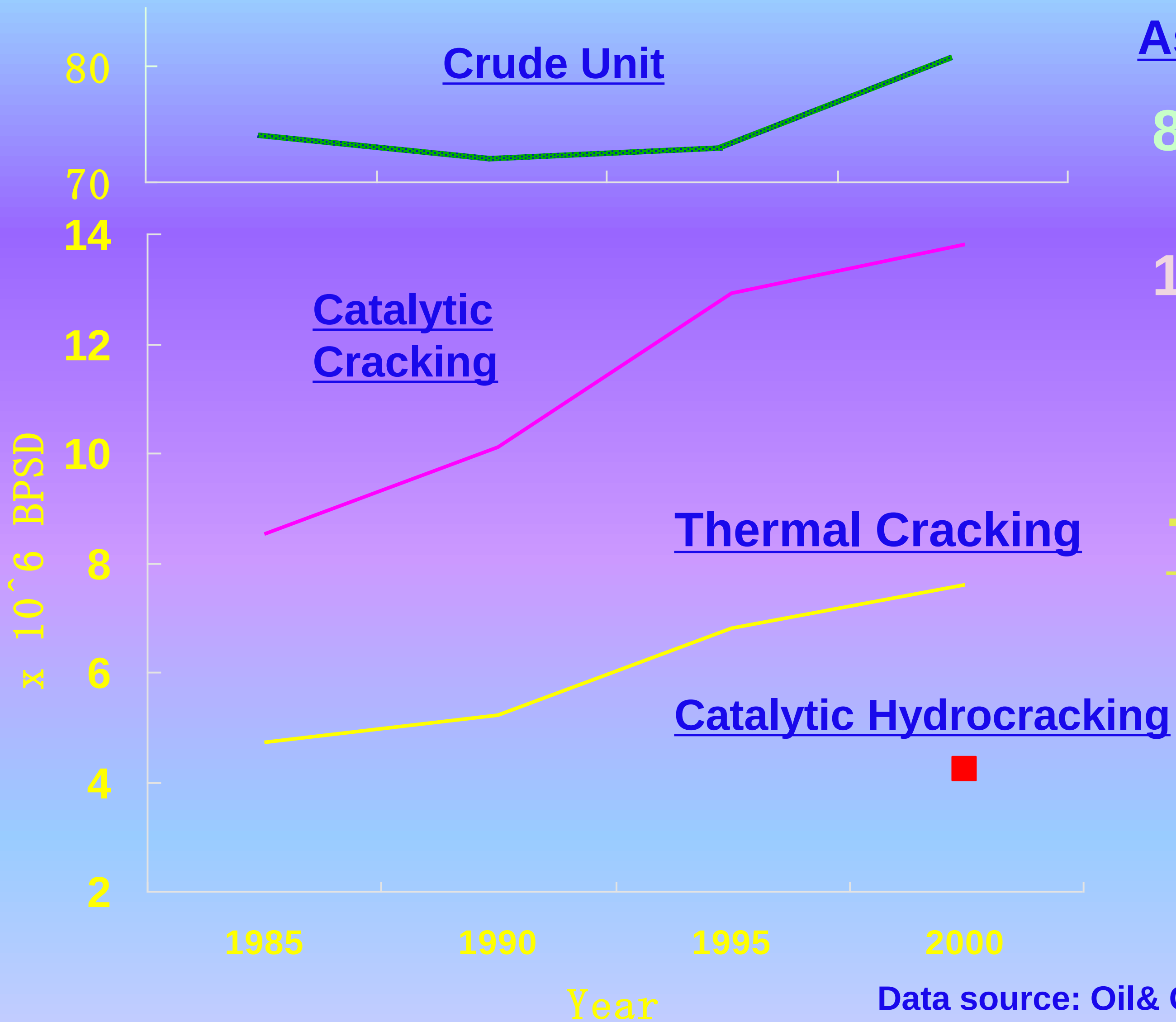
Main Process Units for Study Cases

Case Description	Base	R-HCR	VRDS/RFCC	SDA	Visb.	Delayed Coker
CDU	■	■	■	■	■	■
VDU		■	■	■	■	■
Cat.Reformer	■	■	■	■	■	■
Dist. HDS	■	■	■	■	■	■
VGO FCC		■		■	■	■
Alkylation		■	■	■	■	■
Residue HCR		■				
VRDS / RFCC			■			
SDA				■		
Visbreaking					■	
Delayed Coking						■

4. Process Configuration in Existing Domestic Refinery

Heavy Oil Upgrading Process

4.1 Trend of Major Heavy Oil Upgrading Process in the World



As of January 1.2003

81,877,646 BPSD

14,195,514 BPSD

7,871,204 BPSD

4,437,289 BPSD

Data source: Oil& Gas Journal / Dec.23,2002

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Heavy Oil Upgrading Process

4.2 Capacity of Heavy Oil Upgrading Process in the World

	Thermal Cracking			Solvent Extraction			Hydroprocessing			Catalytic Cracking		
	No of Units	Capacity MBPSD	% of Crude	No of Units	Capacity MBPSD	% of Crude	No of Units	Capacity MBPSD	% of Crude	No of Units	Capacity MBPSD	% of Crude
United States	72	1, 989	13. 0	14	260	1. 7	13	610	4. 0	12	630	4. 1
Japan	5	85	1. 7	1	16	0. 3	17	605	12. 5	8	250	5. 2
Europe	136	2, 792	10. 7	1	13	0. 0	8	176	0. 7	4	214	0. 8
Rest of World	122	2, 866	10. 5	6	103	0. 4	28	1, 000	3. 6	24	736	2. 7
Total World	335	7, 732	10. 5	22	392	0. 5	66	2, 391	3. 2	48	1, 830	2. 5

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4.3 Total Capacity of Heavy Oil Upgrading Process in the World

Total Capacity of Heavy Upgrading Processes

	No of Units	Capacity MBPSD	% of Crude
United States	111	3,489	22.8
Japan	31	956	19.7
Europe	149	3,195	12.2
Rest of World	180	4,705	17.2
Total World	471	12,345	16.7

5. Summary

5.1 Summary

Key Point:

- How to produce light oil products efficiently and economically from Heavy Oil.
- How to optimize the Refinery Configuration.

Primary Factors:

- Price Spread between Light and Heavy Crude
- Price Spread between Crude and Residue
- Products Demand & Specification
- Feed Properties
- Process Configuration of Existing Plant
- Operation Flexibility
- Technology of Heavy Oil Upgrading Process

5.2 Summary

As per the Feasibility Study of Typical Model case and Consideration for Recent Trend on Heavy Oil Upgrading Technologies,

Following Application seems to be reasonable for Modernized Green Project.

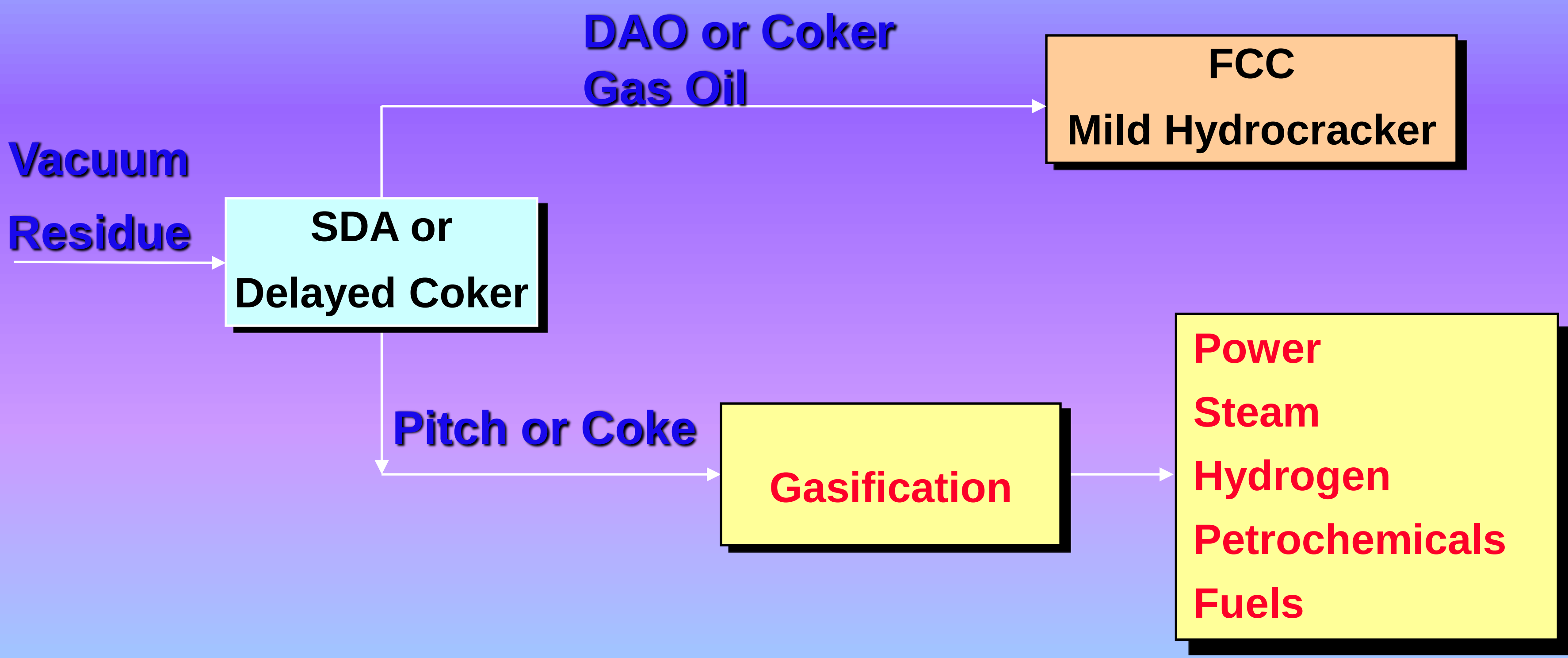
(1) Provision of SDA or Delayed Coker to produce more Middle Distillate and minimize Residual Fuel Oil

(2) Introduction of MHC Technologies to produce more high Quality Middle Distillates

(3) Provision of IGCC (Integrated Gasification Combined Cycle) towards Zero Residual Fuel Oil.

5.3 Summary

Application towards Zero Residual Fuel Oil Production

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