Chevron Lummus Global

Residue Hydrocracking Solutions For Refinery Sustainability

RefComm Galveston
April 29 - May 3, 2019

Dan Gillis - Director, Technology
Chevron Lummus Global

A Chevron and McDermott Joint Venture

Presentation Topics

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- CLG Background
- Future Market Requirements
- LC-FINING
- Technology Advances
- Case Study

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A Chevron and McDermott 50:50 Joint Venture

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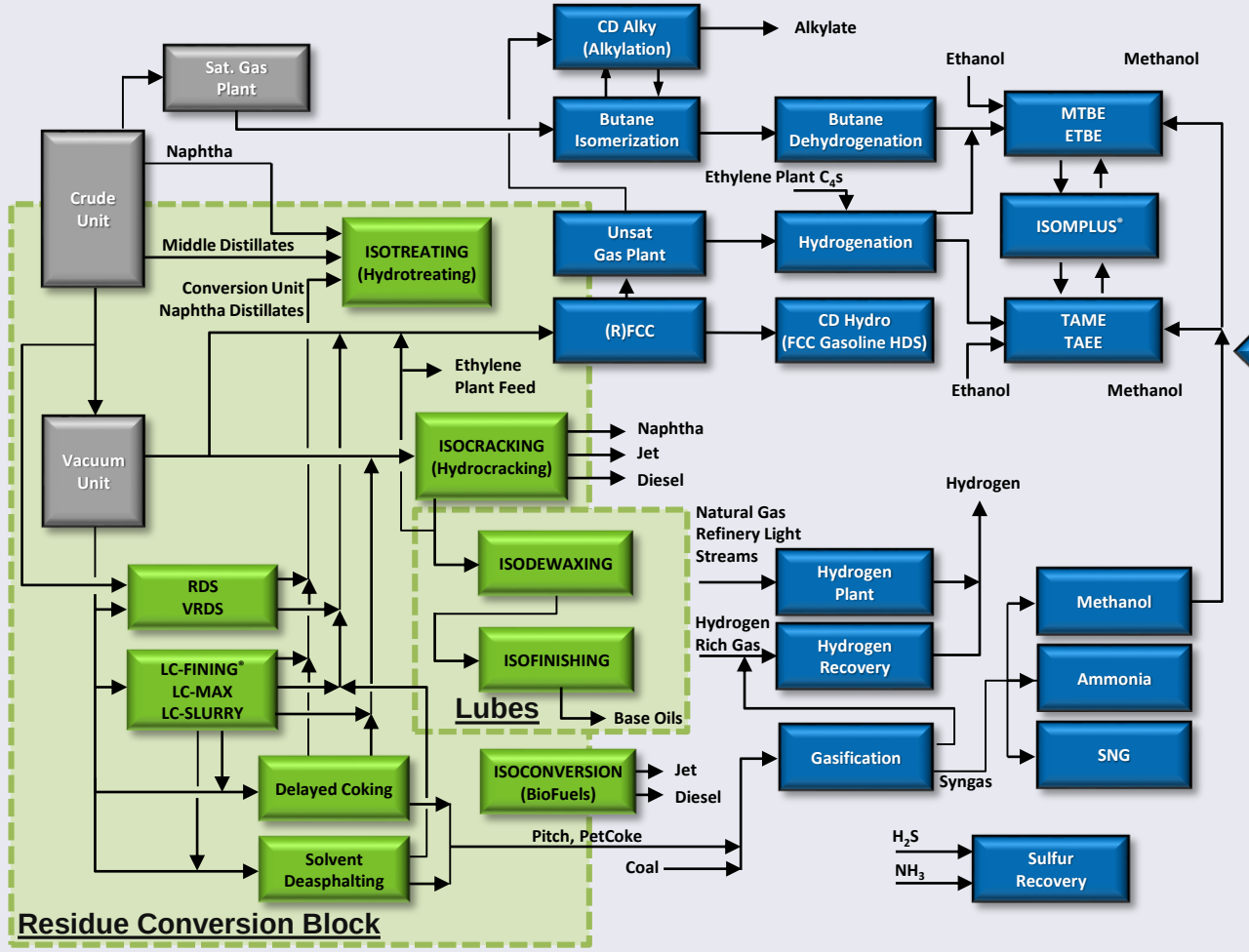
License a wide array of Hydroprocessing and Heavy Oil Upgrading Technologies



Compliment Lummus Technology Portfolio

- CLG Technologies
- Other Lummus Technologies
- Open Art Technologies

Addressing IMO 2020 and crude to chemicals objectives with innovative solutions

Operational Excellence Through Chevron

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One of the world's leading refiners

- High level of hydroprocessing
- Operates >100 high-pressure hydroprocessing reactors
- In USA operates 6 ISOCRACKING units
- Operate 4 Delayed Cokers

CLG Benefits as:

- Part of Chevron Hydroprocessing Best Practice Network
- Draws on Chevron's operating expertise

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Entire Project Support from McDermott

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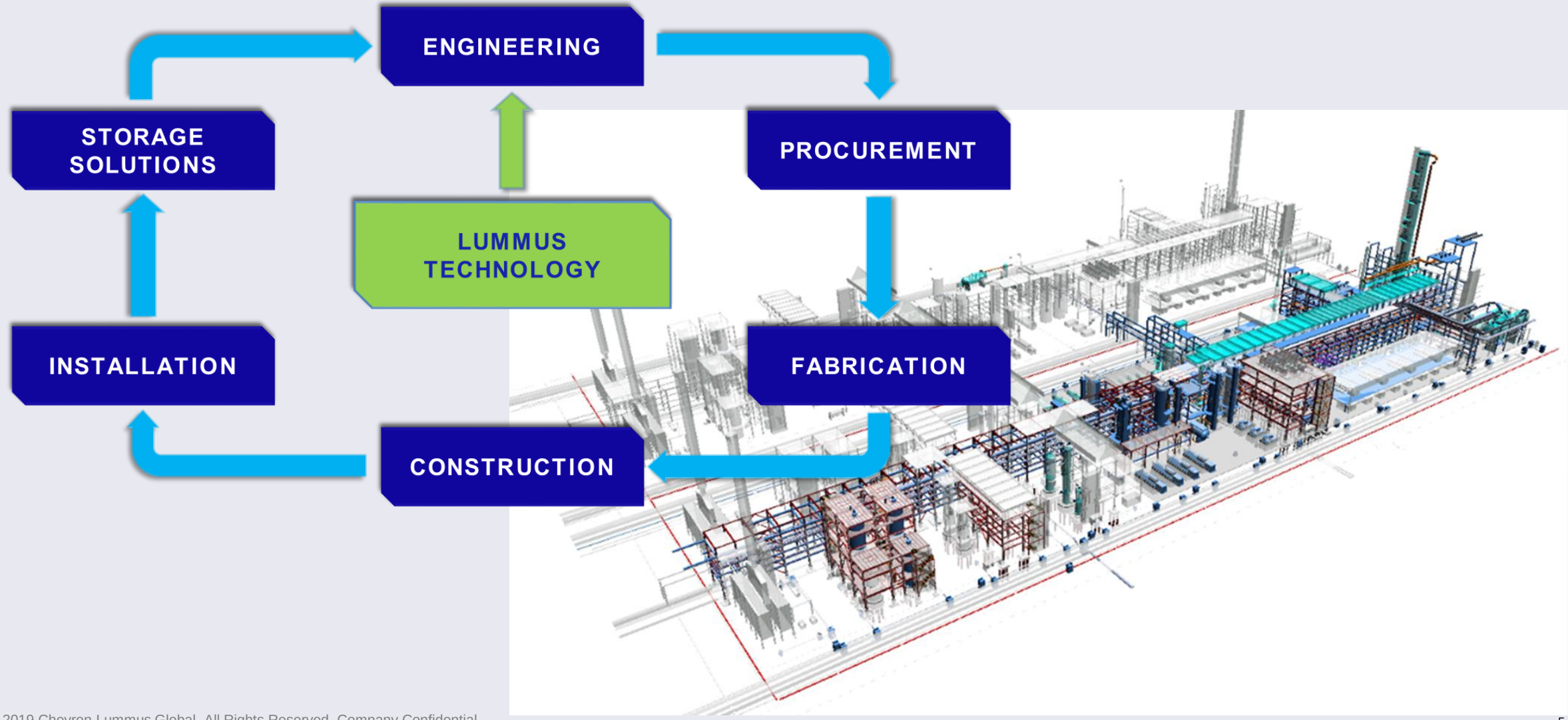

Market Pressures Driving Residue Upgrading Solutions to High Conversion

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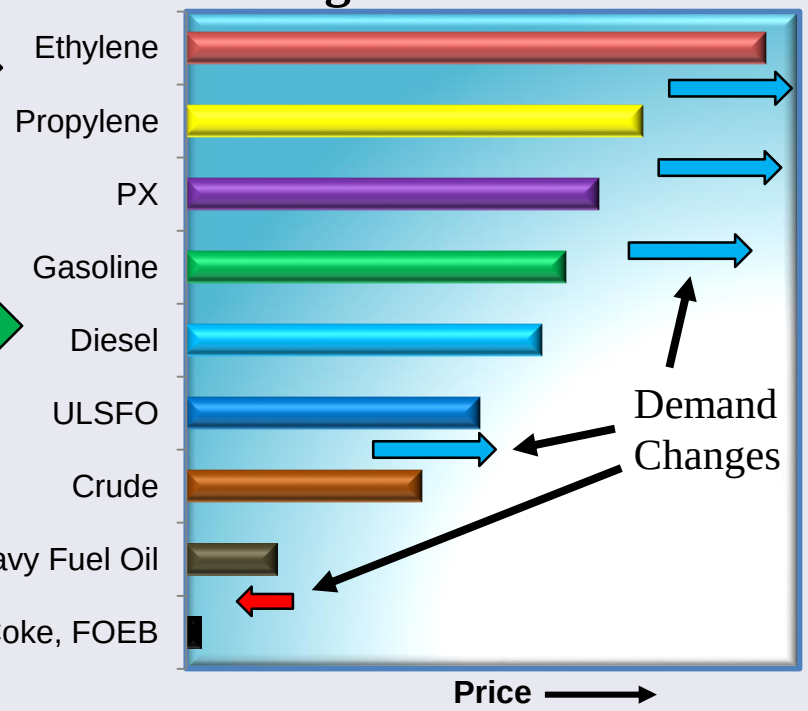
Demand higher for PetChem than for transportation fuels

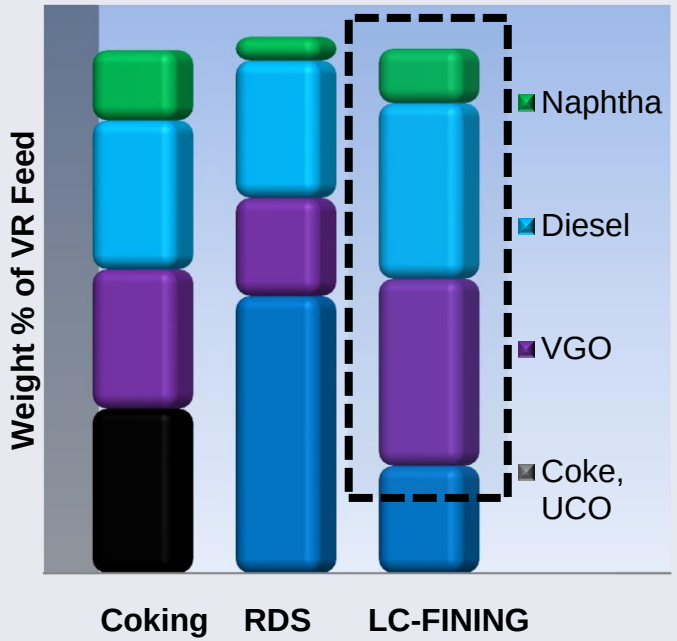
Transportation fuels & LSFO strong demand

Weak demand for HSFO and Coke

Relative prices support higher conversion



Residue Hydrocracking maximizes cracker feed stocks



Residue Hydrocracking is best fitted to meet all requirements

Crude Oil to Chemicals: Optimal Refinery – Steam Cracker Complex

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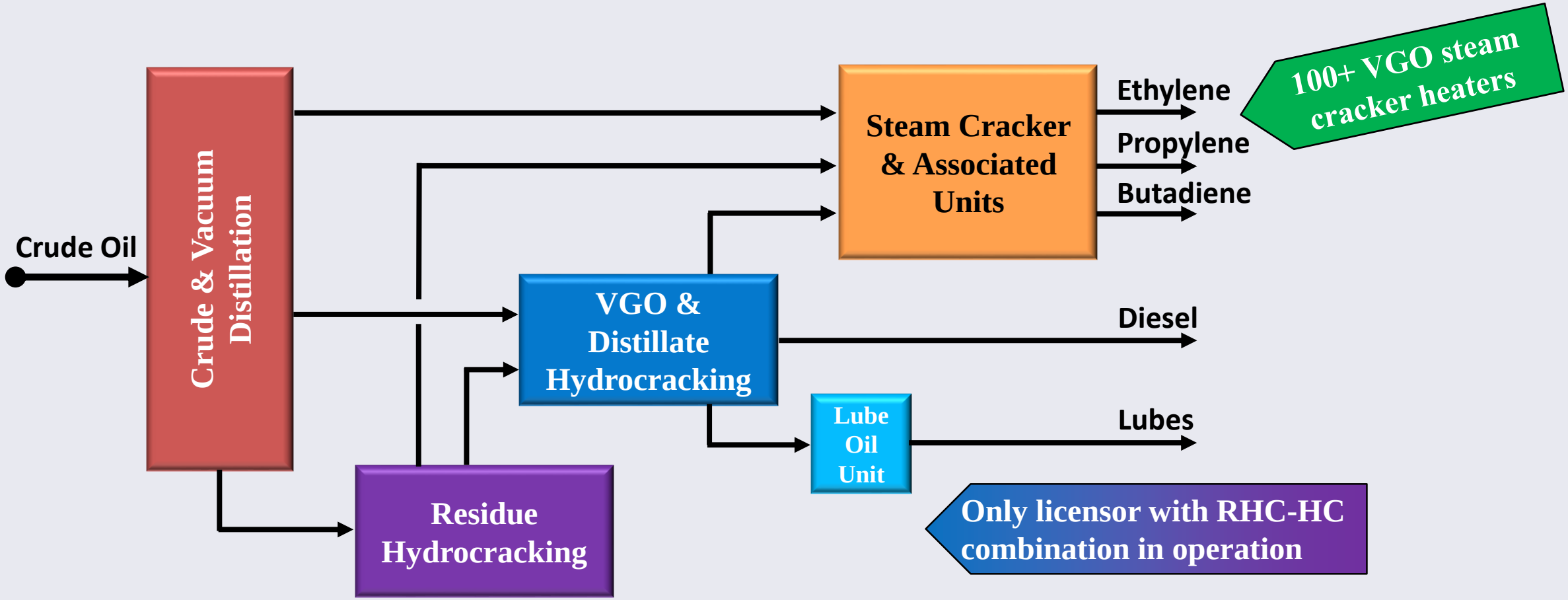

Only McDermott can provide all technologies and offer overall complex guarantees – Chemical yields, on-stream factor

Crude Oil to Chemicals:
Optimal Refinery - Petrochemicals Complex

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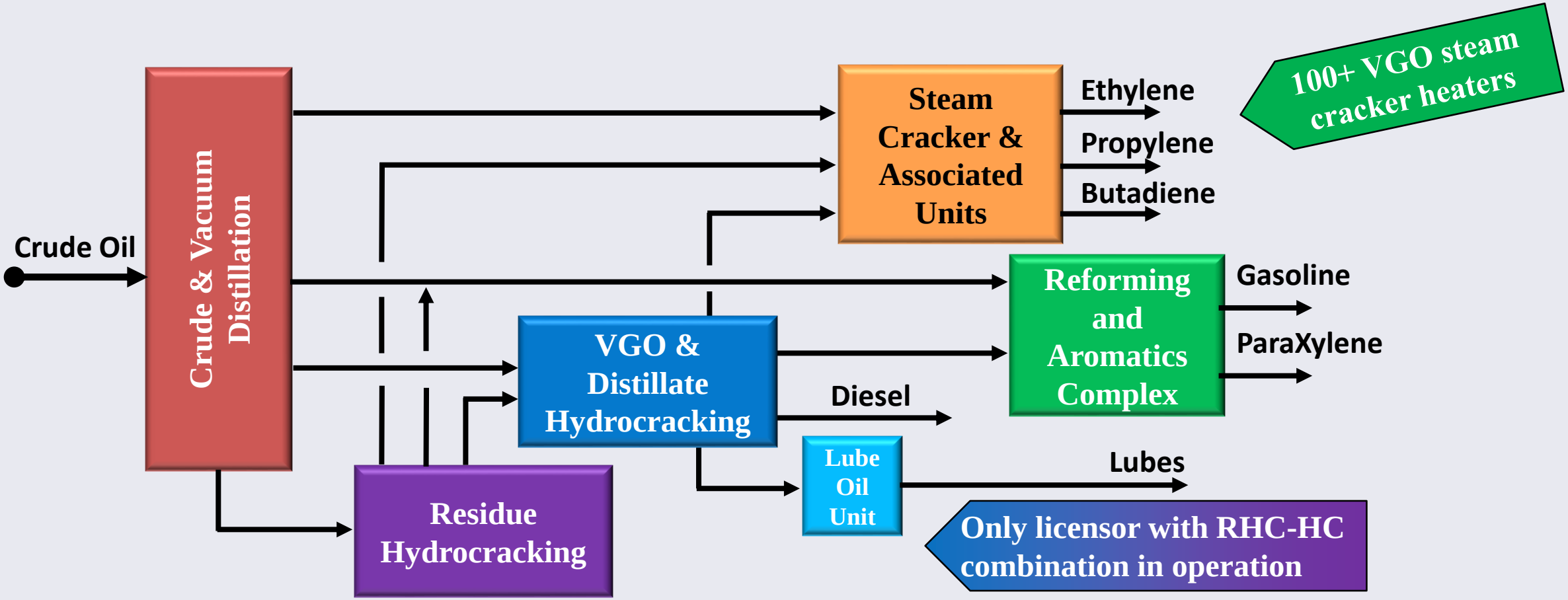

Only McDermott can provide all technologies and offer overall complex guarantees – Chemical yields, on-stream factor

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THE SOLUTION TO MAXIMIZING CONVERSION TO HIGH-VALUE PRODUCTS

THE LC-FINING™ PLATFORM

Robust LC-FINING™ Ebullated Bed Residue Hydrocracking Technology Platform

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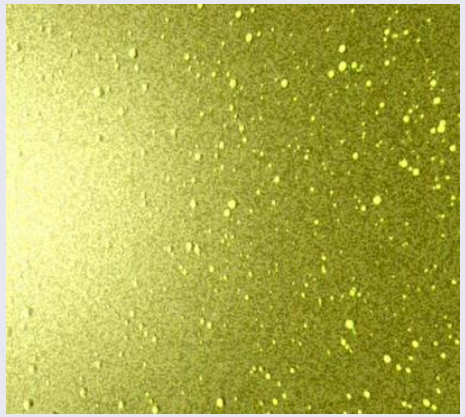
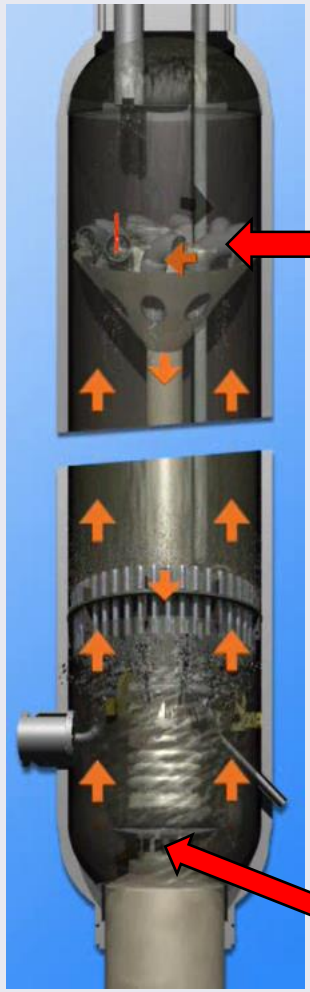
Reactor Features

- Upflow Reactor
- Low pressure drop
- Recycle pump backmixes and expands single catalyst bed
- Nearly isothermal
- Catalyst can be added and withdrawn on line



Gas Bubbling Up in Expanded Catalyst Bed



LC-FINING™ Residue Hydrocracking Meets Future Product Demands

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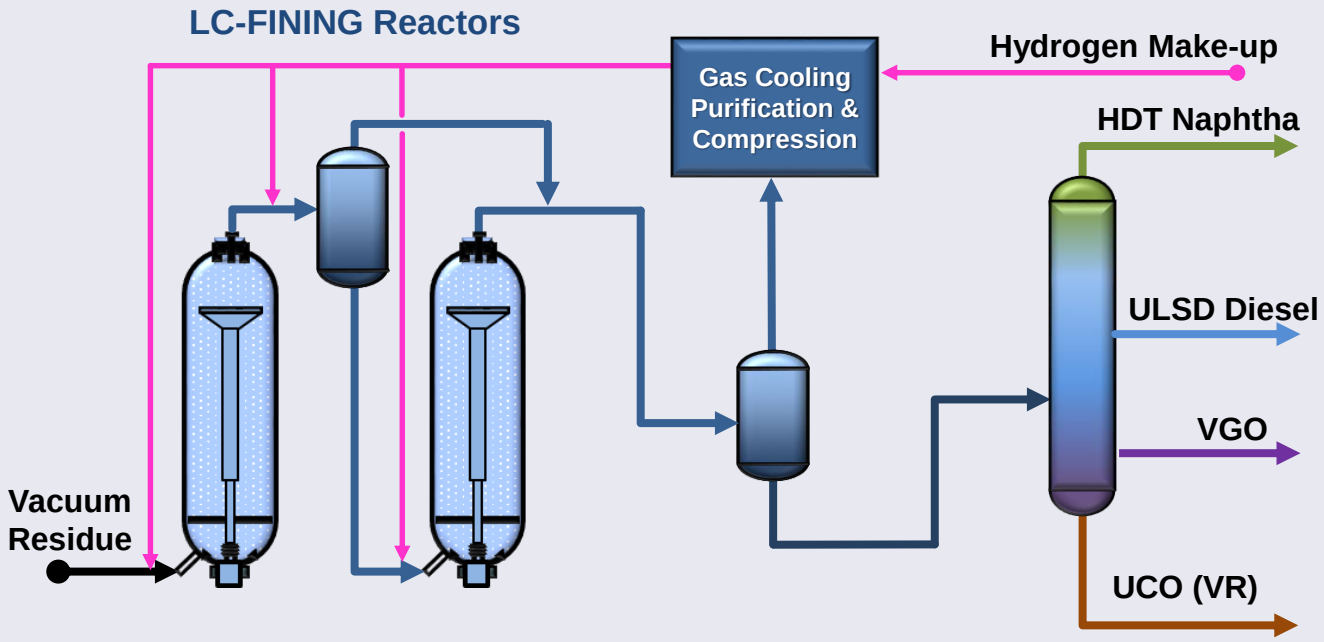
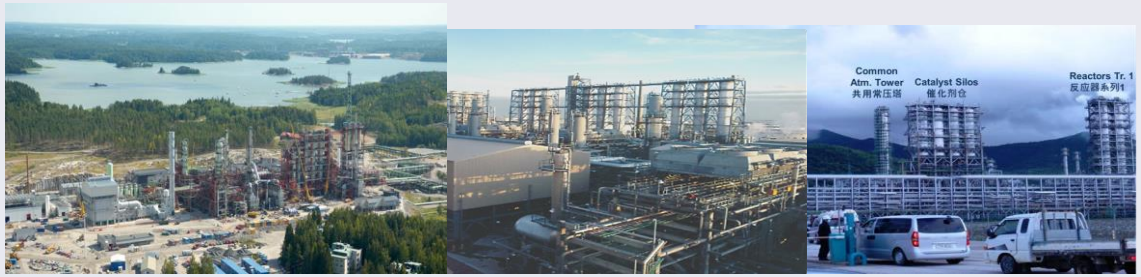


Reactor Temperature	410–440°C (770-824°F)
Reactor Pressure	110–180 bar (1600-2600 psig)
Resid Conversion	55–85%
Desulfurization	60–85%
CCR Reduction	40–70%
Demetallization	65–88%

High Pressures and Temperatures

High Conversion and contaminant removal

Extensive Commercial Experiences



LC-FINING™
Product Separation and Fractionation System

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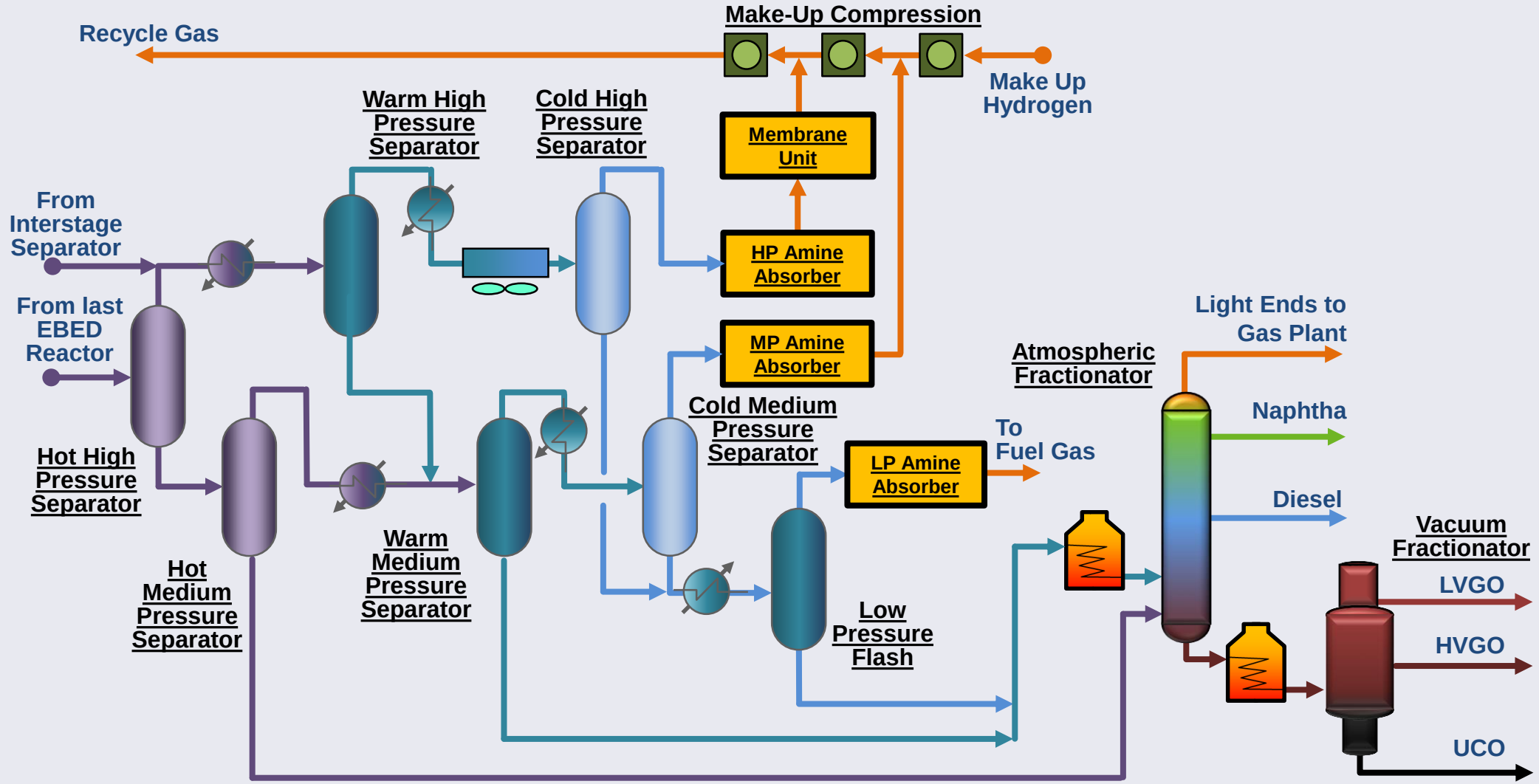

LC-FINING™ Reliability Enhanced by Design Features and Best Practices

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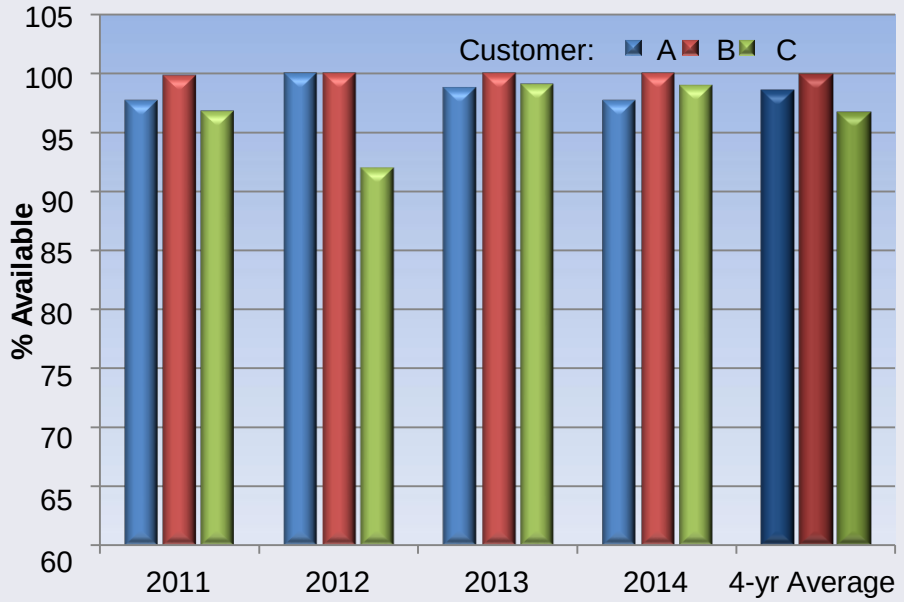
Customer Performances:

- A 96%+ on-stream factor
- B ran for 42 months straight from first day of oil in
- C has 3 units with typically 4 years between turnarounds



Reliability and High Operating Factors are Absolutely Essential!

Whole Refinery Operation will Ride on Residue Upgrading Unit!

LC-FINING™ Commercialization of Innovations

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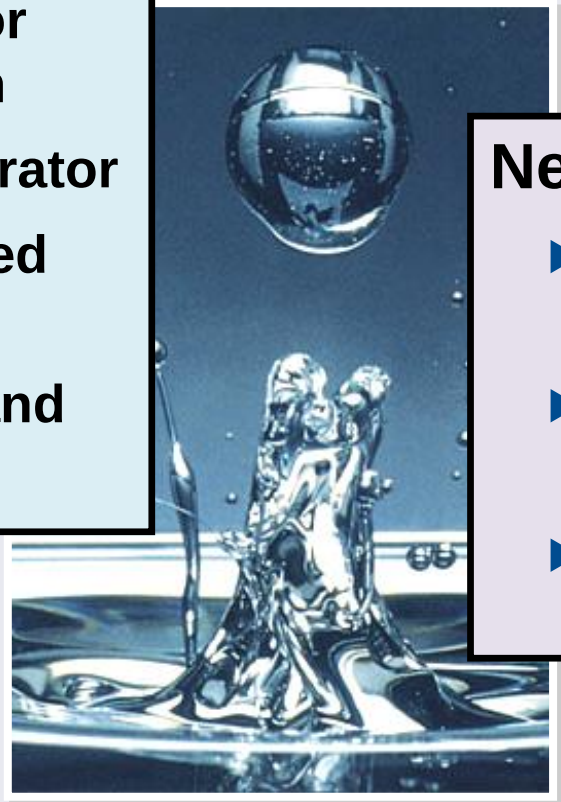
Innovations

- PSA and Membranes for recycle gas purification
- Interstage reactor separator
- Close coupled integrated hydrotreating
- Combined LC-FINING and hydrocracking



New applications

- LC-MAX for 90+% conversion
- LC-LSFO to make IMO 2020 ULSFO
- LC-SLURRY for full conversion

Lowers Costs and Increases Benefits

LC-FINING™ with Integrated Hydrotreating Produces Clean High Quality Products

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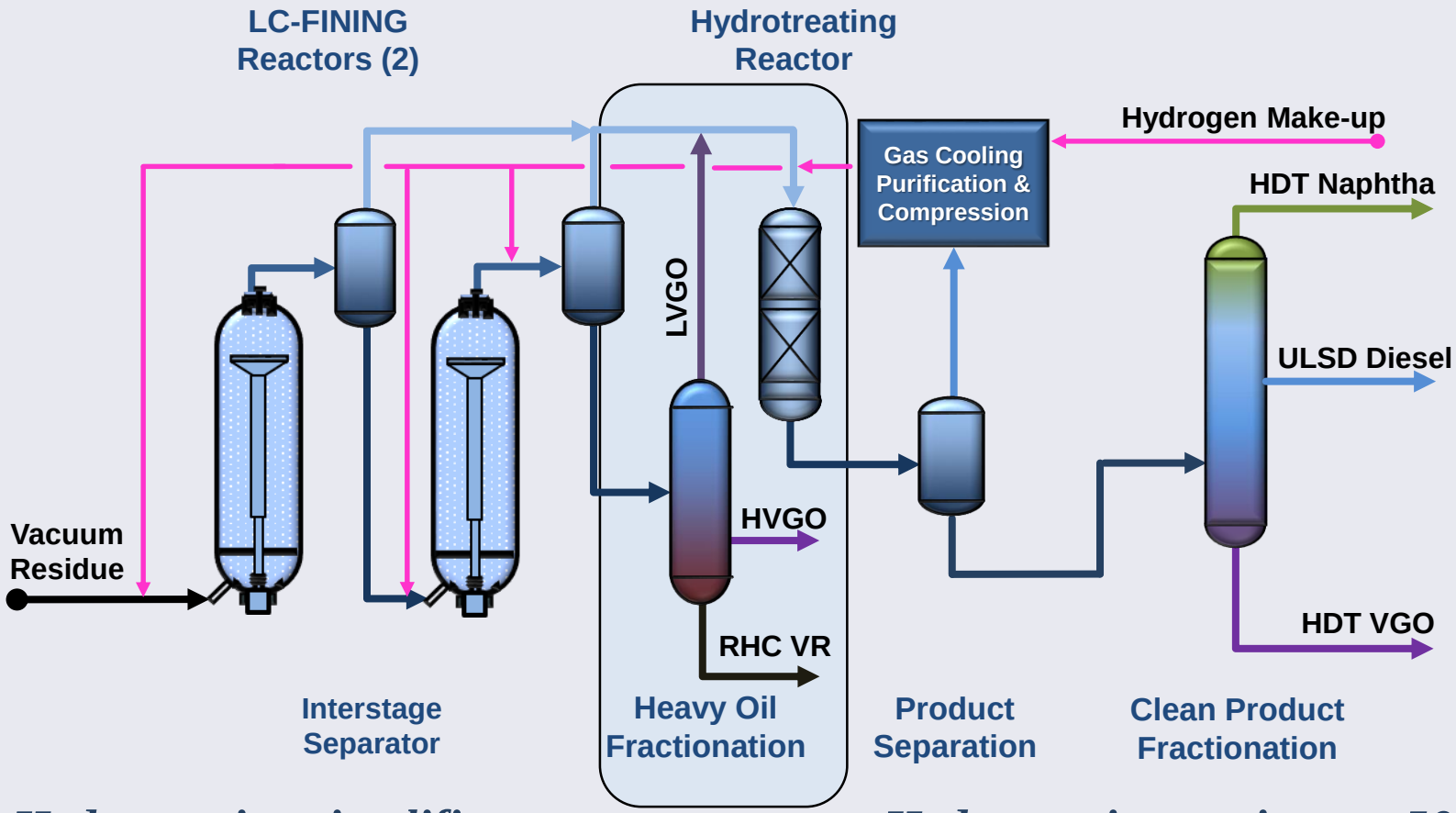

Integrating Hydrotreating simplifies fractionation and produces clean products

Hydrotreating equipment 50% of stand alone unit, 60-70% of standalone cost

LC-FINING™ with Integrated Two-Stage Hydrocracking Maximizes Distillates

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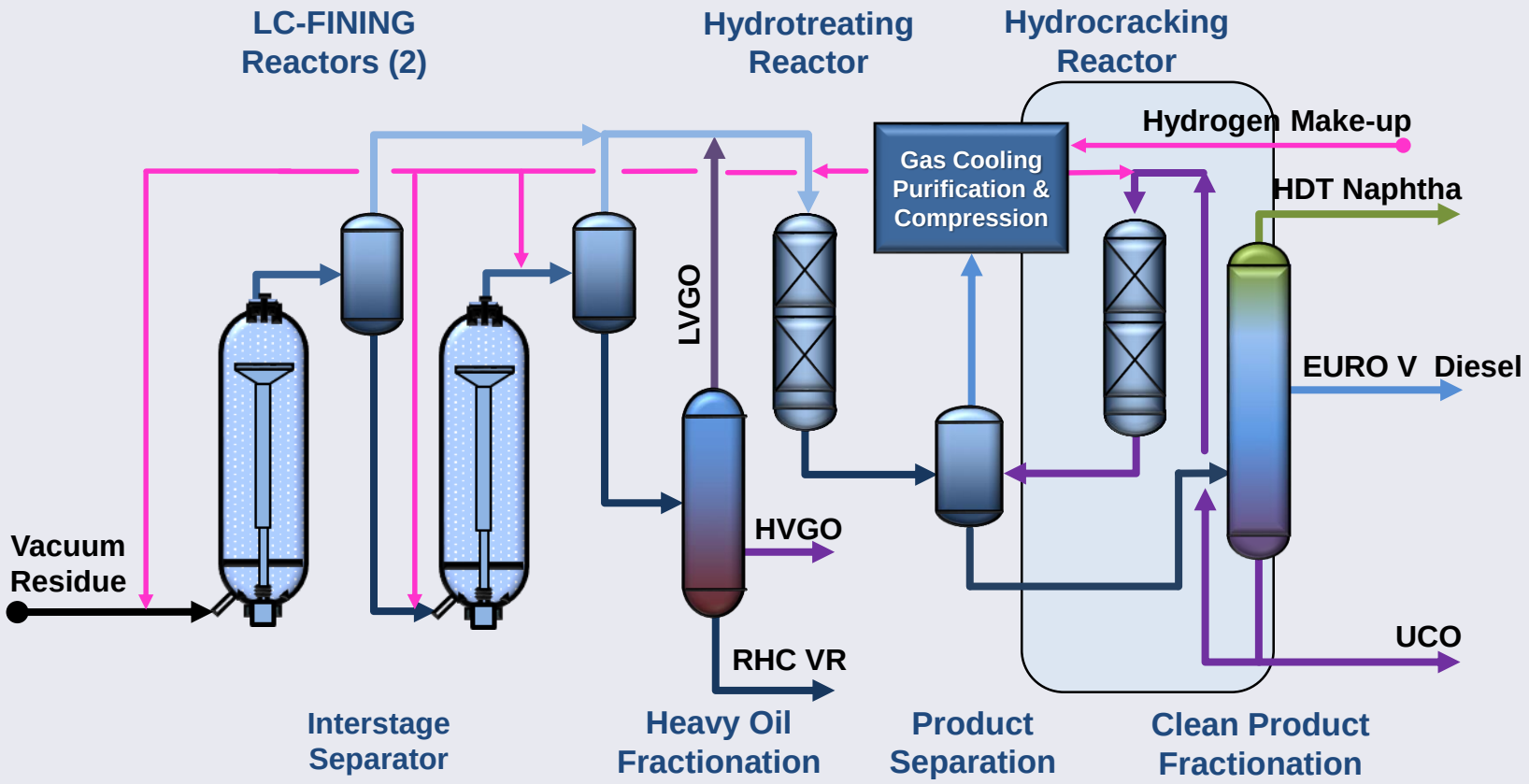

Key is a "clean" second-stage for Selective Cracking to Euro V Diesel

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WHY IS CONVERSION LIMITED IN RESIDUE HYDROCRACKING?

Asphaltenes and CCR in Vacuum Residue

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565°C+

- ***CCR ~ 24%.***
- ***Hydrogen Content : 10 wt.%***
- ***Asphaltenes : 15 wt.%***

700°C+

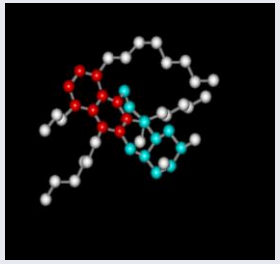
- ***CCR ~ 38%.***
- ***Hydrogen Content : 9.2 wt.%***
- ***Asphaltenes : 56 wt.%***

***Arab Heavy VR**

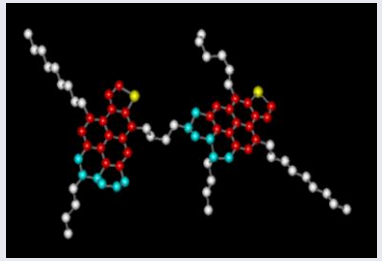
As we push conversion we have to convert more and more difficult type of asphaltenes!

What Do We Know About Asphaltenes?

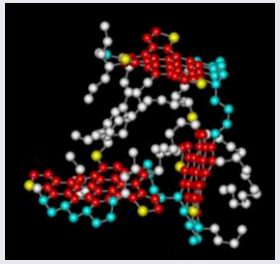
- Asphaltenes can be of many different types – good, bad and really ugly!



Good



Bad



Really Ugly

- CLG has developed proprietary methods to identify types
- Allows us to know at what conversion level the converted, heaviest asphaltenic cores will drop out of solution (sediment formation)
- Defines the maximum conversion without serious reactor & downstream equipment fouling

CLG large database of commercial data used to set conversion limits for each unit

Managing Sediment Formation is the Key to High Conversion in Residue Hydrocracking

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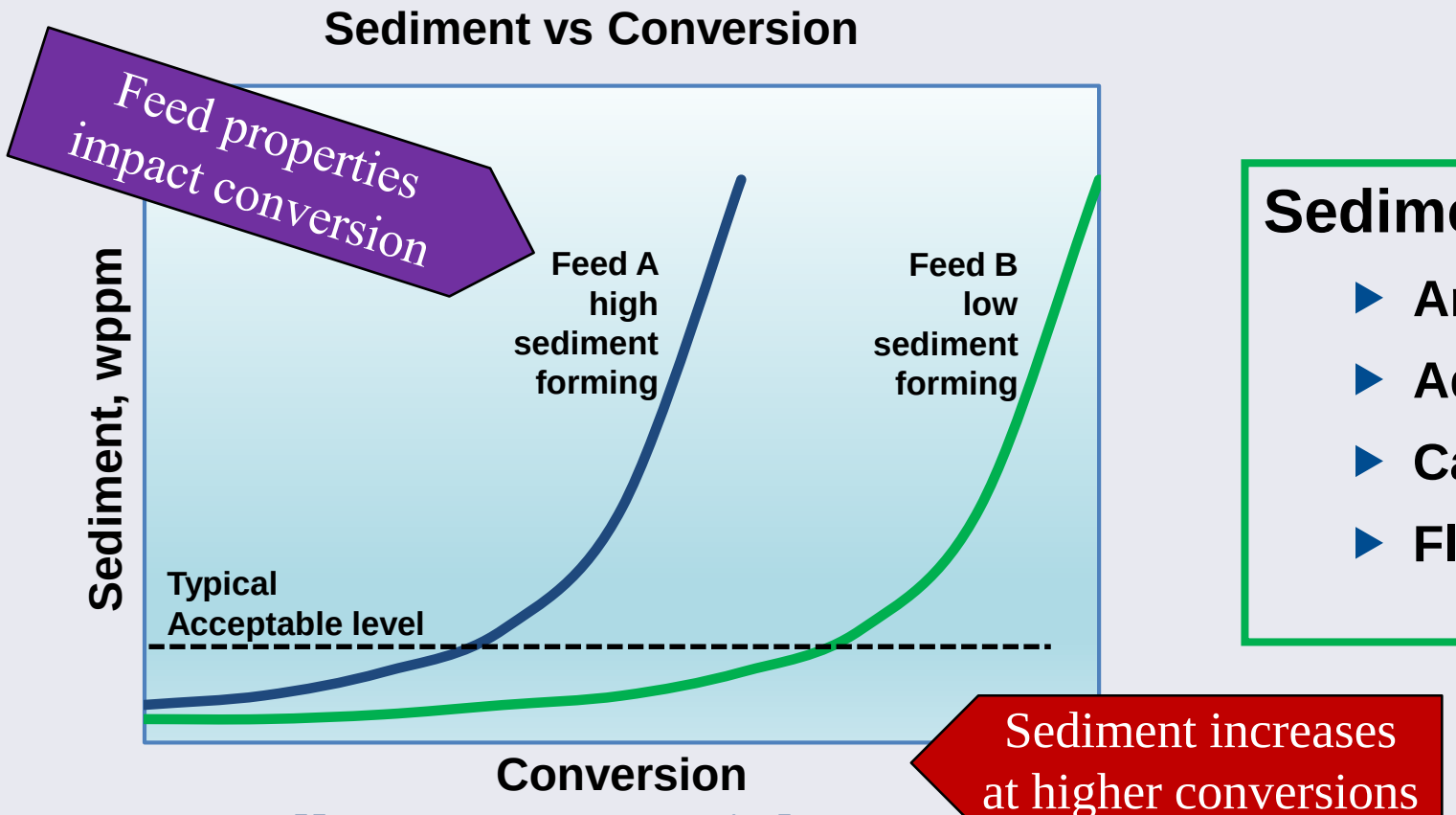

Sediment reduction options:

- Aromatic diluents
- Additives / co-catalysts?
- Catalyst advances
- Flow scheme solutions

Full reactor potential not realized by sediment in UCO

Aromatic Diluents Improve Solvency and Reduce Sediment

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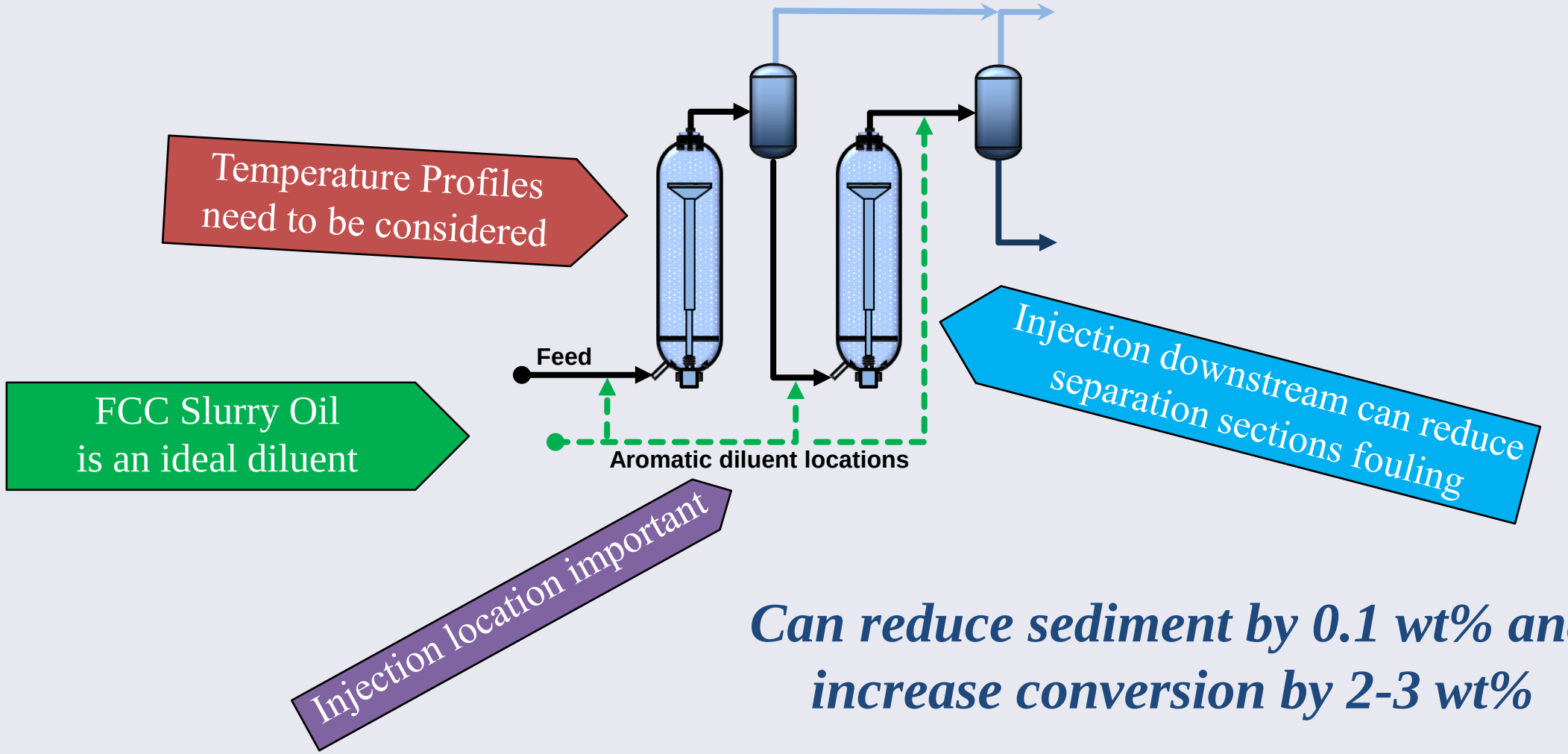

Can reduce sediment by 0.1 wt% and increase conversion by 2-3 wt%

Soluble Molybdenum Co-Catalyst Benefits?

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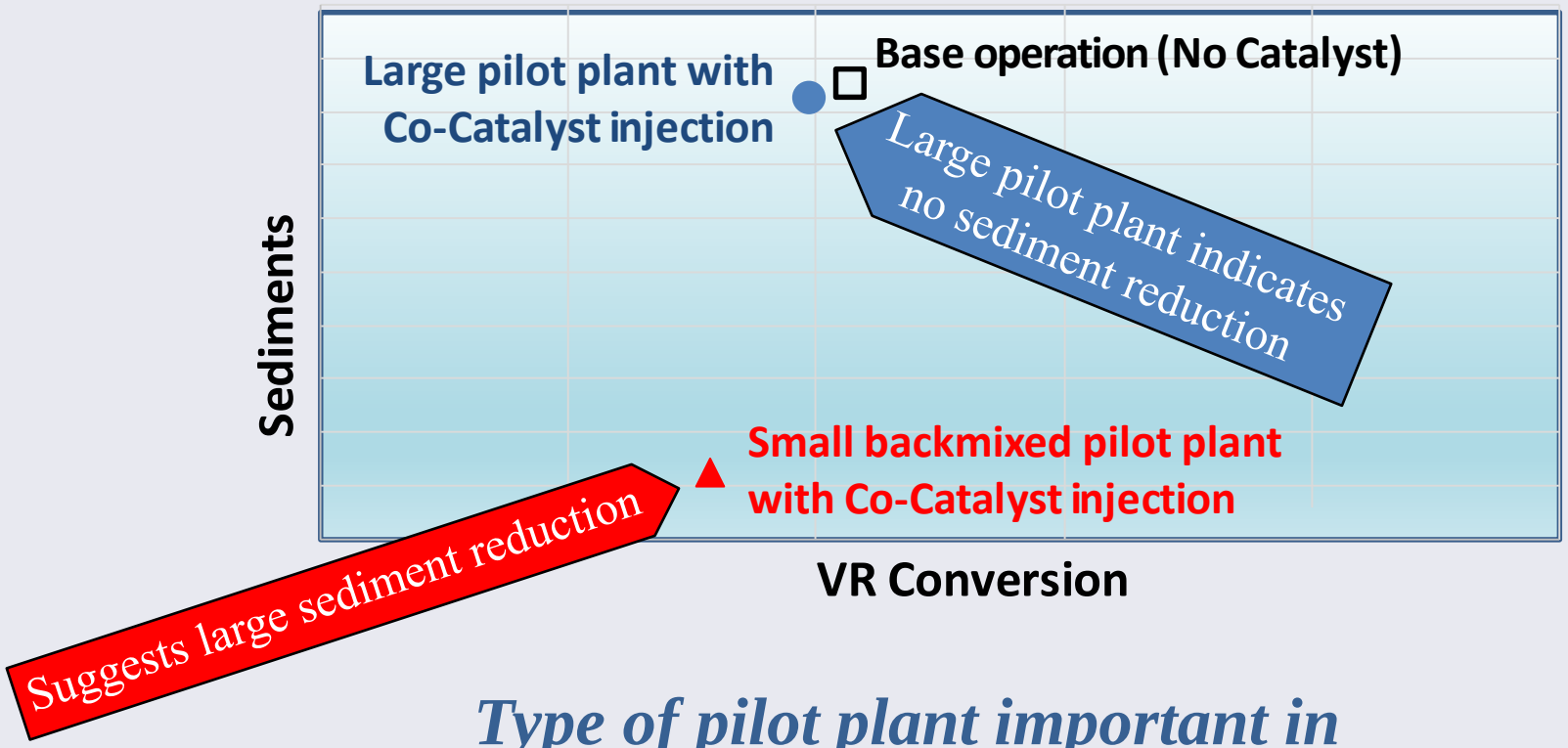

Type of pilot plant important in determining benefits

Several units have seen severe fouling under reactor distribution grid when using co-catalyst

A Comparison of Two LC-Fining Units and their EB Reactor Reliability

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- Unit A and Unit B are both LC-Fining Units.
- Unit A and Unit B were commissioned within 3 years of one another, and so have incorporated very similar equipment technology.
- Both Units have been designed with 3 Reactors in series.
- Both Units have been designed to process a similar feed, with similar conversion targets.
- Both Units have been designed with very similar Space Rates.

A Comparison of Two LC-Fining Units and their EB Reactor Reliability

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- Unit A has been working very closely with CLG and their catalyst supplier:
  - Several CLG recommended LC-Fining Reactor internal modifications have been performed.
  - They now operate with a dual solid catalyst system.
  - Conversion now exceeds design values.
- Unit A has achieved a 4 year run length on their 1st Reactor with one exception since the initial plant start up
  - This exception involved opening all of the LC-Fining Reactors while necessary repairs were carried out elsewhere in the plant during their 3rd run cycle.

EB Reactor Run Lengths
A Comparison

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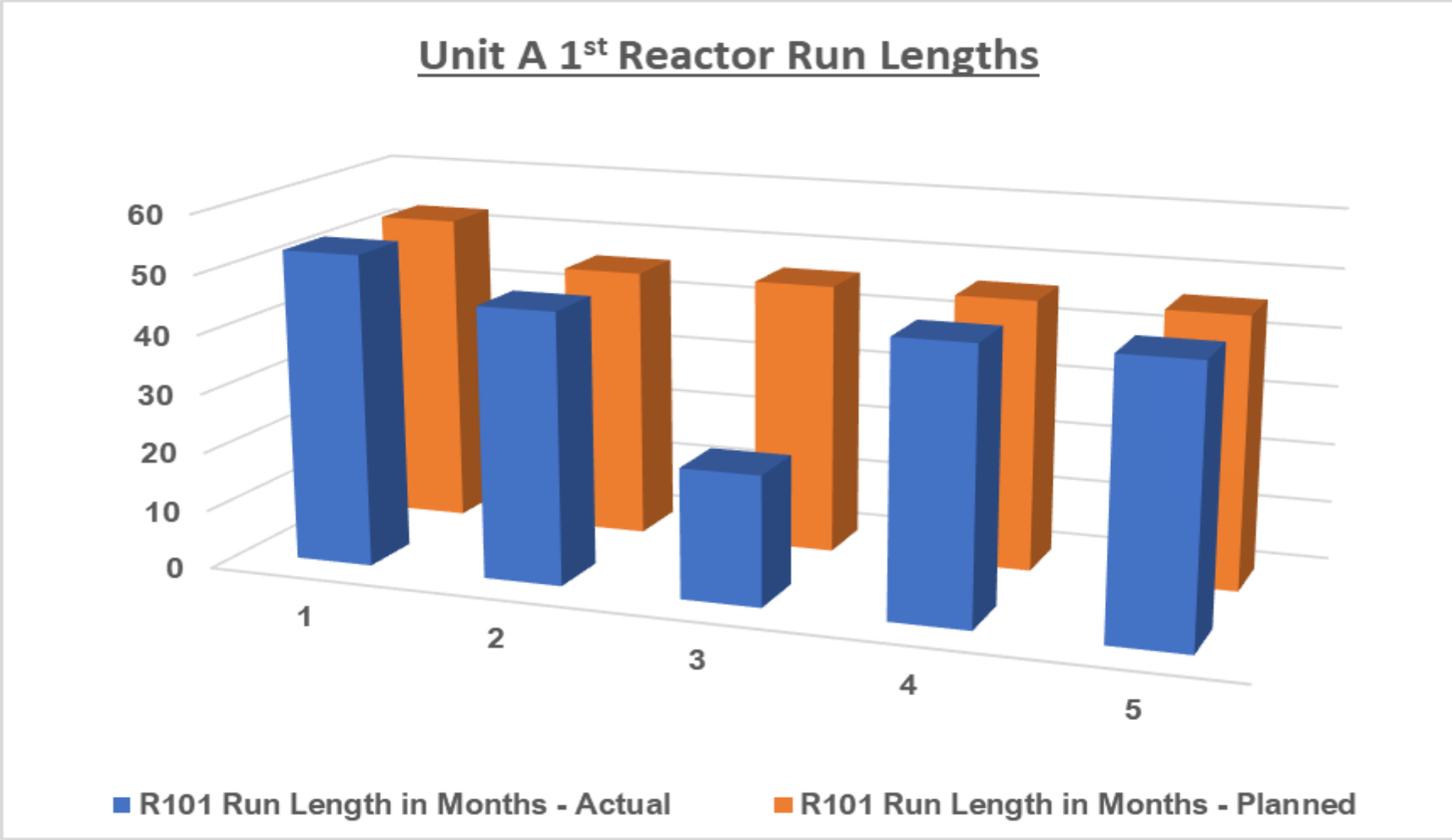

A Comparison of Two LC-Fining Units and their EB Reactor Reliability

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- Unit B operates with a single solid catalyst system.
  - Plant modifications are now underway to allow operation of a dual solid catalyst system
- During the first 3 out of 4 unit runs Unit B achieved their target run length of 3+ years.
  - Their first run was cut in half due to an 8+ hr site wide power failure which required all 3 LC-Fining Reactors be cleaned.
  - During run 6, 7, 8 & 9 under grid fouling in the 1st LC-Fining Reactor necessitated a SD for cleaning after approx. 1 year of operation.
  - During run 6, 7, 8 & 9 Unit B injected organo-moly into their feed stream.

A Comparison of Two LC-Fining Units and their EB Reactor Reliability

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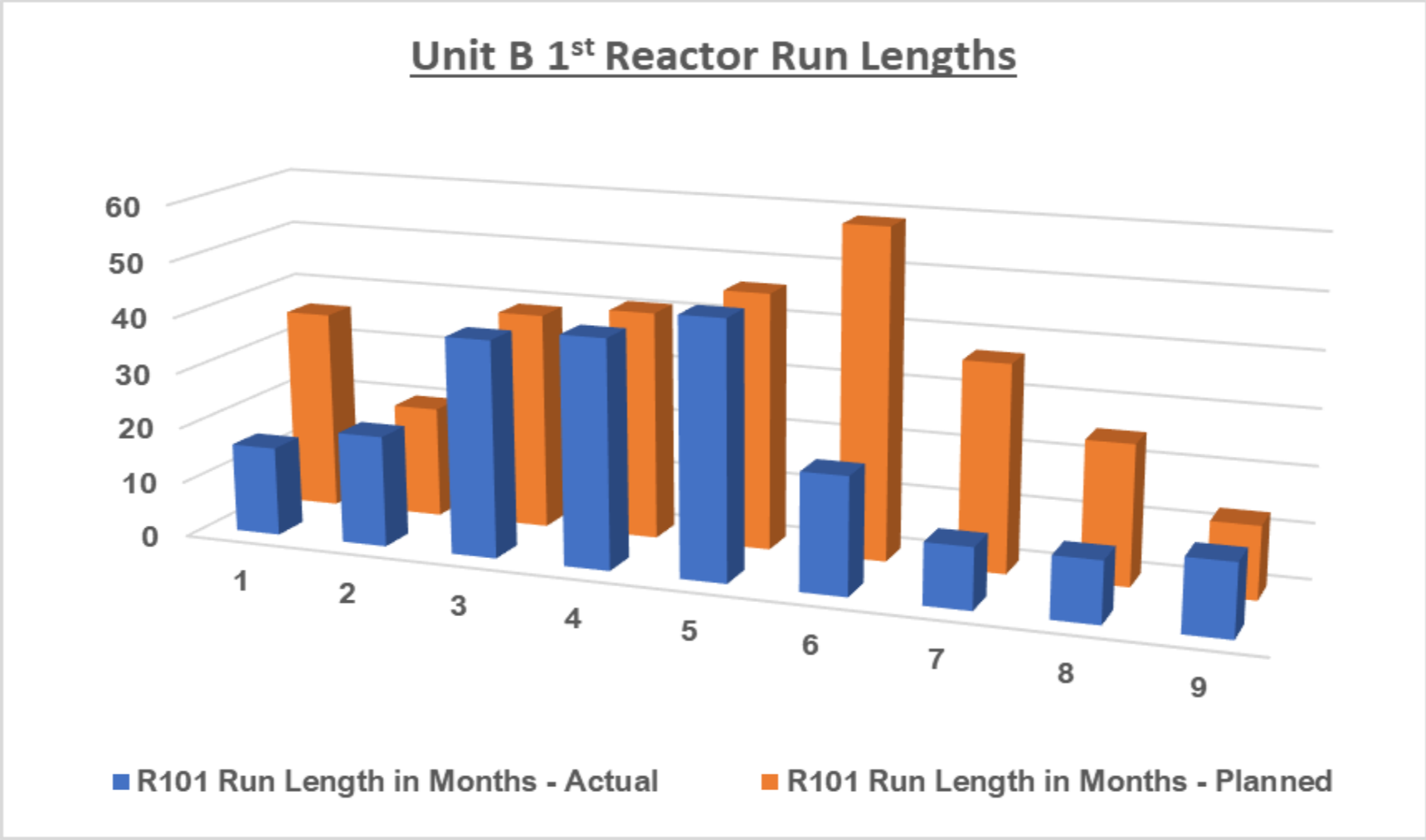

A Comparison of Two LC-Fining Units and their EB Reactor Reliability

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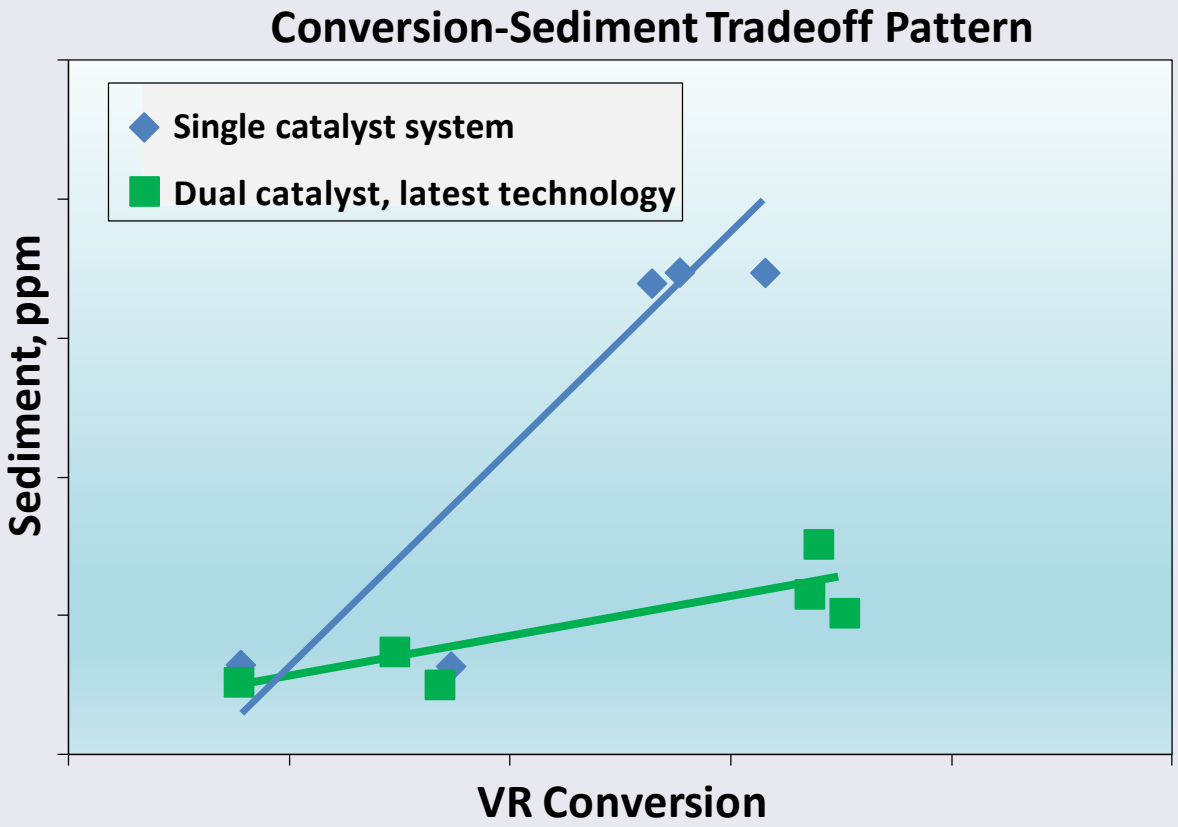
- CLG has been working closely with two of our licensees who have chose to inject organo-moly into their feed.
- Both of these units have experienced severe under grid fouling in the 1st LC-Fining Reactor.
- Extensive analysis of the under grid fouling deposits shows them to contain a high percentage of moly, but little to no alumina.
- A third LC-Fining unit which has processed feed containing naturally occurring organic Moly has also experienced severe under grid fouling in the 1st LC-Fining Reactor.

Catalyst Advances Allow Higher Conversion



Higher Conversion obtained with:

- Advanced catalyst formulations
- Dual catalyst system
- Optimized operating conditions

LC-FINING™ Flow Scheme Solutions increase Residue Hydrocracking Performances

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Option:

- Processing LC-FINING UCO in a Delayed Coker
- Modifying Feedstock such as with an upfront SDA
- Selective conversion of feedstock components
- Converting low value UCO into high value LSFO or FCC feed
- Utilizing advanced micron sized catalysts

Solution Examples:

- Marathon LC-FINING UCO is processed in a coking unit with overall conversion >88%
- Neste Oil SDA unit on part of LC-FINING feed boosts conversion
- LC-MAX flow scheme to obtain >93% conversion - selected for several new units
- Integration of CLG LC-FINING + RDS technologies
- LC-SLURRY advanced slurry hydrocracking to maximize high value products

CLG LC-FINING™ plus Coking

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More Feed Flexibility

Increased liquid yields

Combined Liquids

Feed

Hydrogen

Unconverted Bottoms

Coke

Better hydrogen utilization

Less and higher-quality coke

Combination results in high conversion (88-90%)

LC-FINING™ + Coking Increases Liquid Yields and Produces High-Value Coke

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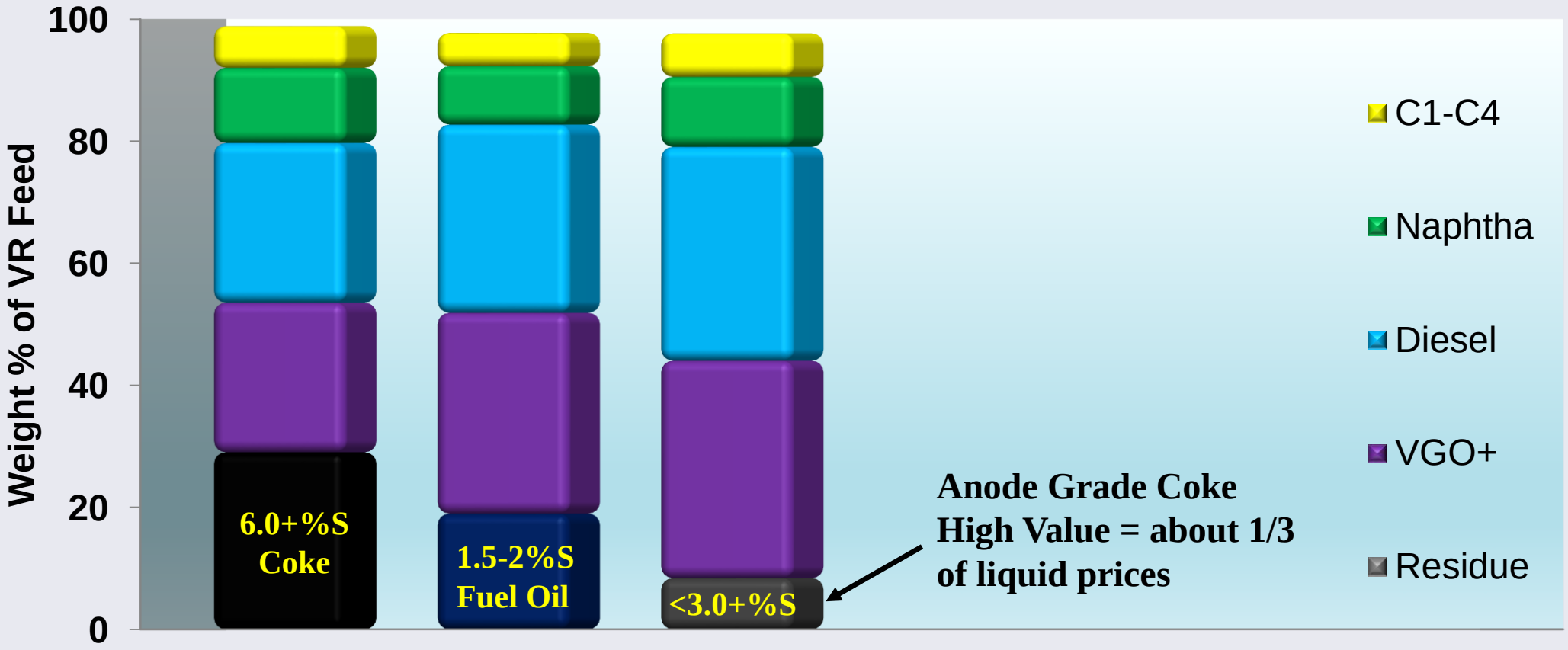

CLG LC-MAX®
for High-Conversion and High-Quality products

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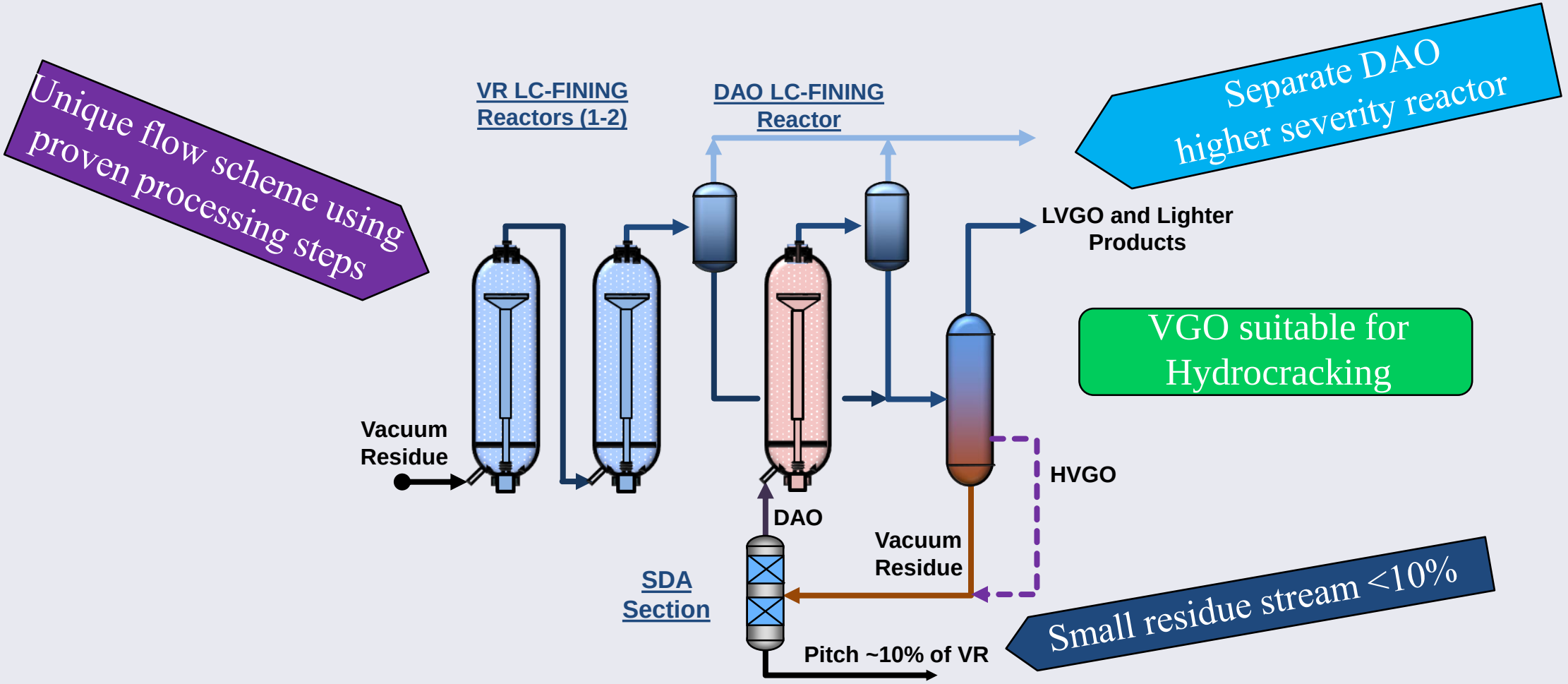

High conversion with high liquid selectivity in one process

LC-MAX® – Process Features

- 93%+ conversion for difficult crudes
- Fully integrated two-stage process
- Whole VR is hydrocracked in a first reaction stage
- Stage 1 UCO is deasphalted to remove heavy asphaltenes
- DAO is hydrocracked in Stage 2 (much higher rate constant and cleaner operation)
- Hydrogen not wasted in hydroconversion of difficult heavy asphaltenes
- Avoids production of 4-ring HPNA that are very difficult to upgrade

Processing Urals VR	LC-FINING	LC-MAX
Conversion, %	63	88-92
Feed Flexibility	Good	Excellent
Reactor Volume	Base	0.9 x Base
Chemical Hydrogen	Base	Base x 1.15 for 20% Higher Conversion
Catalyst Addition Rate	Base	Base x 0.88
Bottoms Product	LSFO	Coker Feed, Gasifier Feed
Fractionation Section Fouling	Base	<< Base

CLG LC-MAX® -G
for High-Conversion and FCC based refineries

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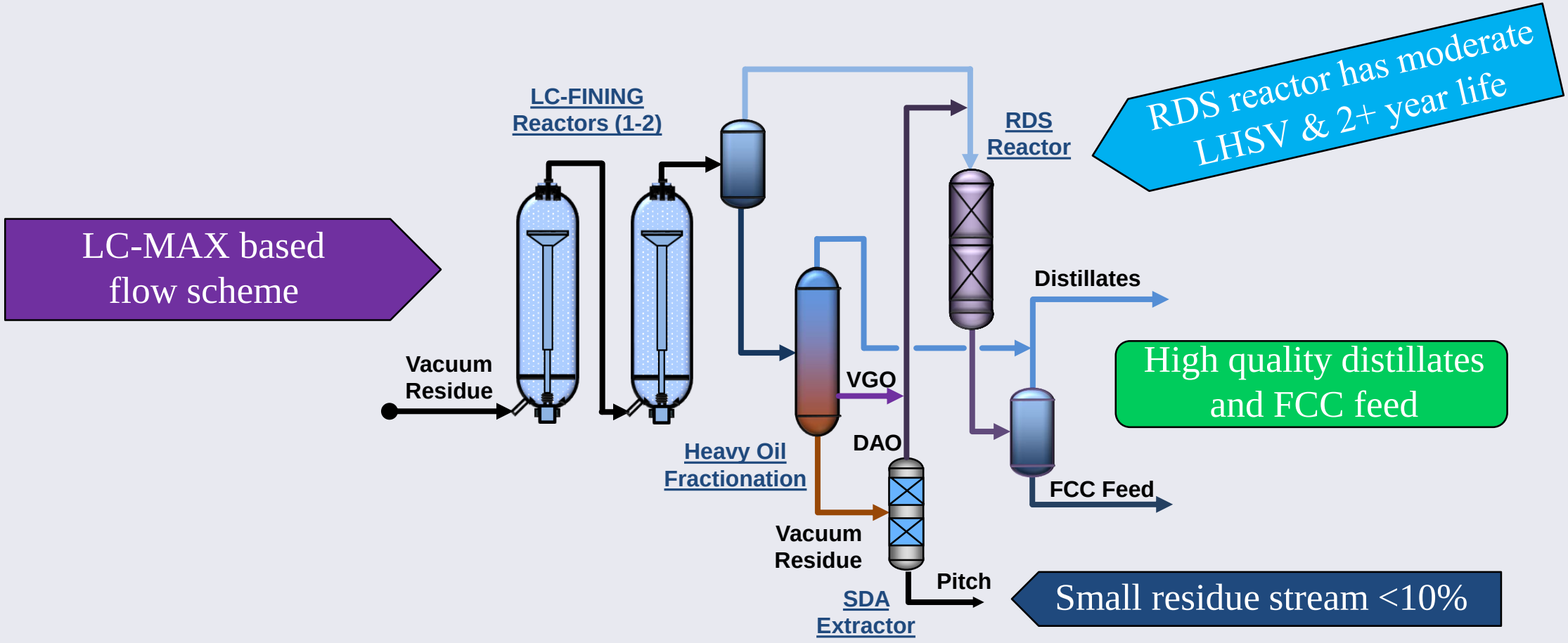

High conversion to high-quality FCC feed

LC-MAX® Achieves High Liquid Yields and has Yield Selectivity Options

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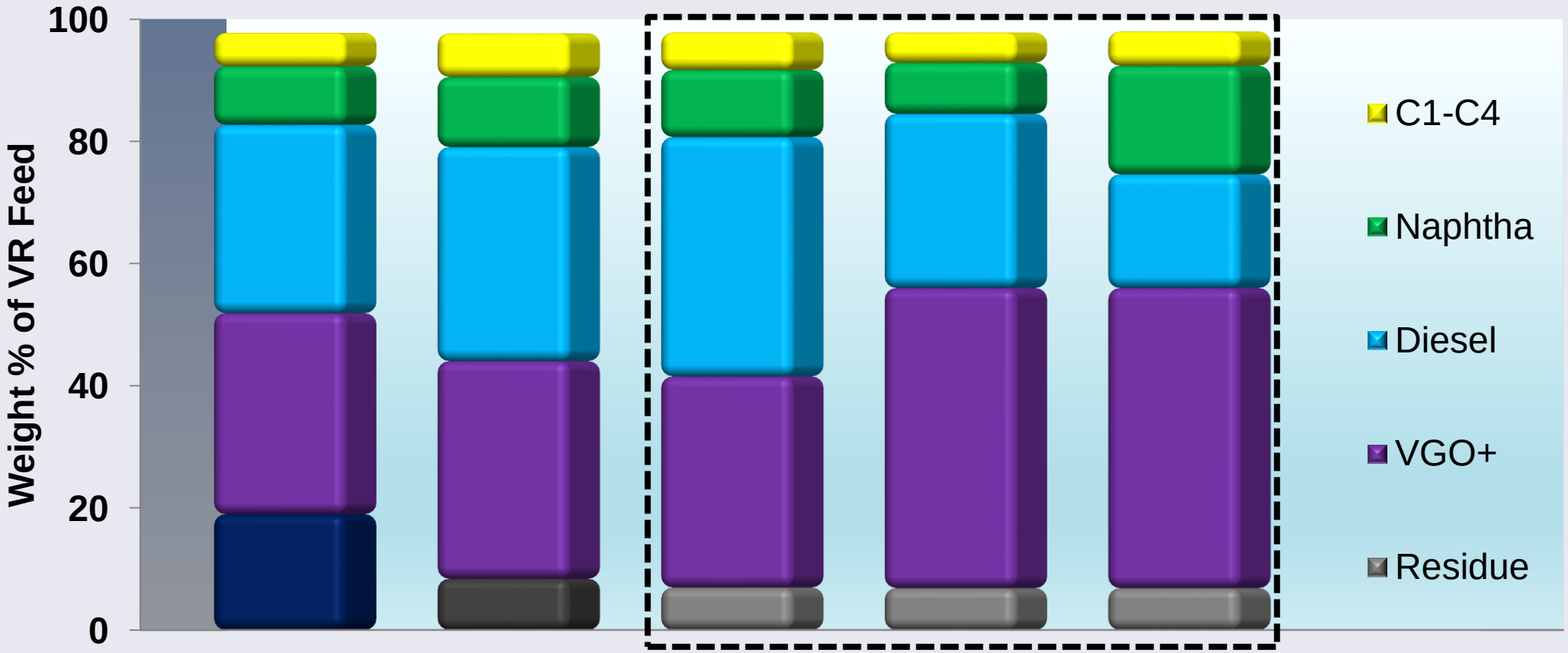
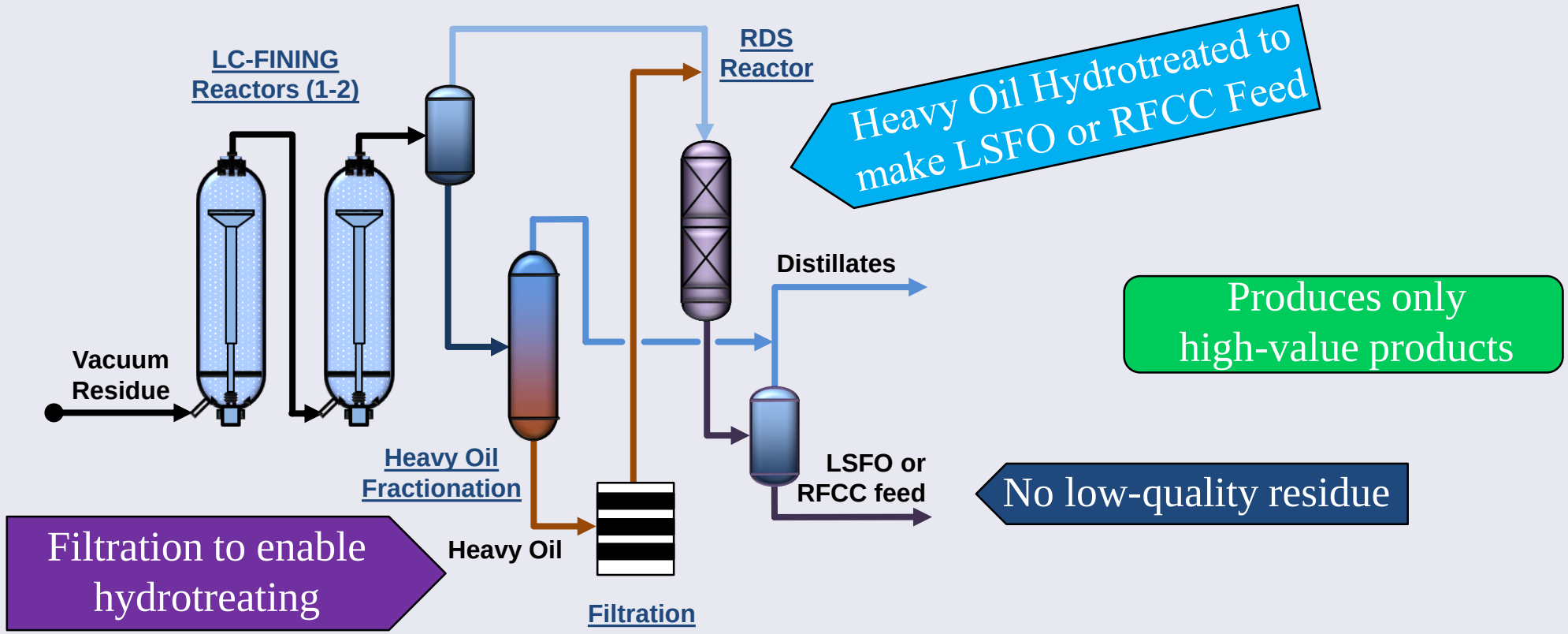


IDHC = Integrated Distillate Hydrocracking

CLG LC-LSFO™ (LC-FINING plus RDS) for Conversion and LSFO production



Great solution for customers wanting conversion plus LSFO

CLG LC-SLURRY™ for Full Conversion to High-Quality Products

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LC-FINING based platform

Unique high activity ISOSLURRY™ Catalyst

Integrated Hydrotreating assures high-quality products

Heavy Oil is catalyst free and suitable for further processing

Full conversion with highest liquid yields and product values

LC-FINING™ Liquid Yields Increase Significantly with Flow Scheme and Catalyst Advances

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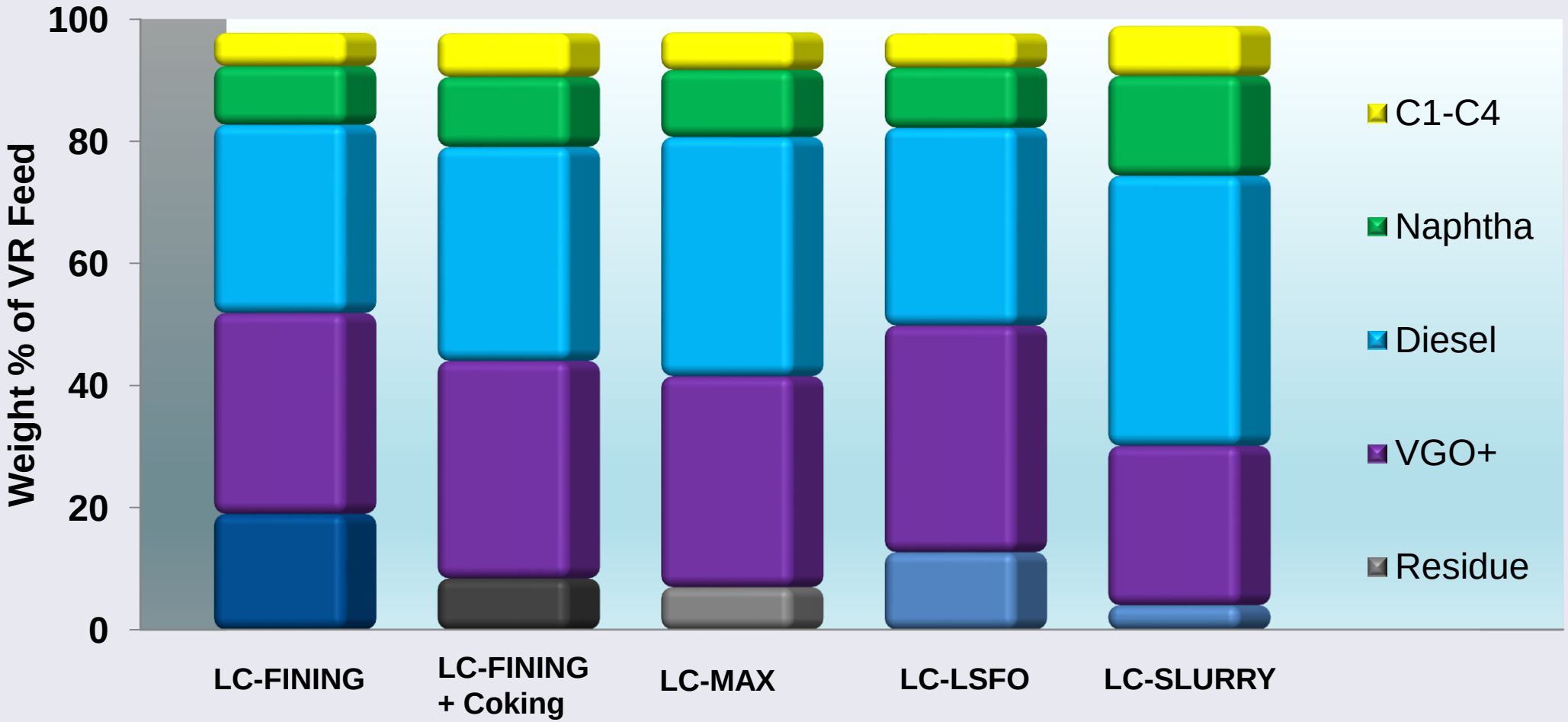

Residue Hydrocracking Options Case Study

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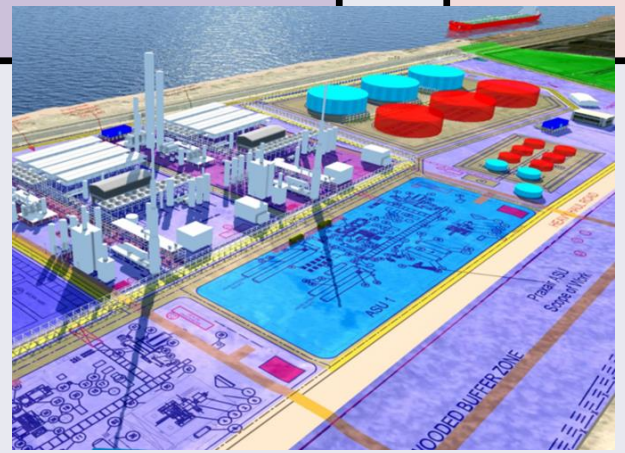
Existing refinery basis:

- 300,000 BPD,
- Arab light crude
- VGO HC, FCC, and visbreaking conversion units
- Produces transportation fuels and HSFO

Evaluated impact and benefit of:

- Residue hydrocracking alternates
- Aromatics complex
  – make Para-Xylene
- Steam cracker
  – make Ethylene and derivatives



Feed and Product Pricing Basis

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Assumptions:

- 2020+ scenario with HSFO sold as if at distressed prices
- Availability of Natural Gas by pipeline
- Gasoline desired over distillates
- Coke/Pitch assumed low in value

Feed stocks	$/MT
Arab Light Crude, $/bbl	70.8
Natural Gas	158
($/MSCF)	(3.50)
Methanol	365

Product	$/MT
LPG	665
Finished Butadiene	1079
Finished Ethylene	1296
Propylene PG	1021
Benzene	798
Para Xylene	923
Euro V 95 RON Gasoline	847
Jet A1	757
Euro V Diesel	794
HSFO	200
LSFO	692
Coke/Pitch	50
Sulfur	70

Residue Conversion Addition Impact on Refinery Yields

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Process:	LC-FINING	LC-MAX	LC-LSFO	LC-SLURRY
High Value Products Increase	16.3% + 6.7% MSFO	21.1%	18.2% + 4.5% LSFO	21.1% + 1.5% LSFO
Residue S, wt%	<2.0	4.3	<0.5	<0.5

Residue Conversion Addition Economic Benefits

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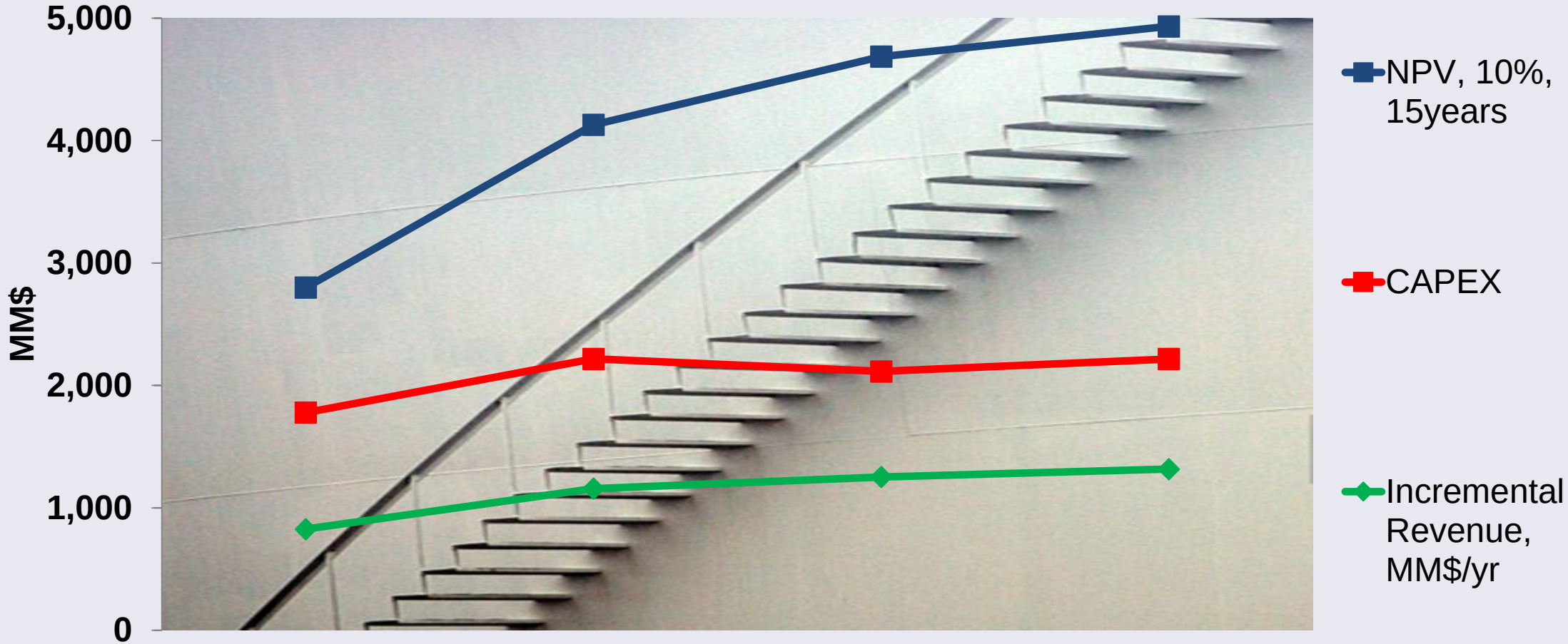

Process:	LC-FINING	LC-MAX	LC-LSFO	LC-SLURRY
Profitability Index	2.6	2.9	3.2	3.2

LC-LSFO™ and Petrochemical Options Impact on Refinery Yields

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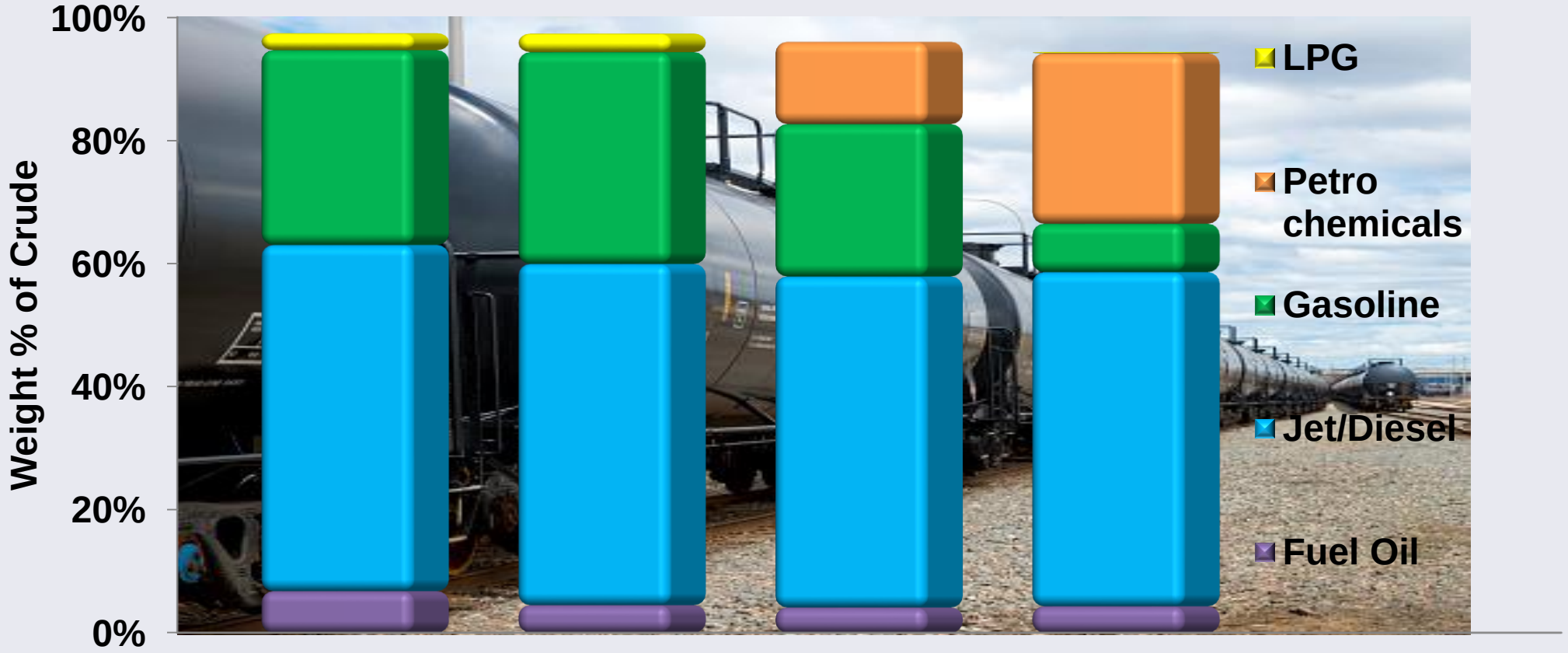

Process:	LC-FINING	LC-LSFO	LC-LSFO + Cracker	LC-LSFO + Cracker + PX
High Value Products Increase	16.3% + 6.7% MSFO	18.2% + 4.5% LSFO	20.2% + 4.1% LSFO	18.2% + 4.3% LSFO
Residue S, wt%	<2.0	<0.5	<0.5	<0.5

LC-LSFO™ and Petrochemical Options Economic Benefits

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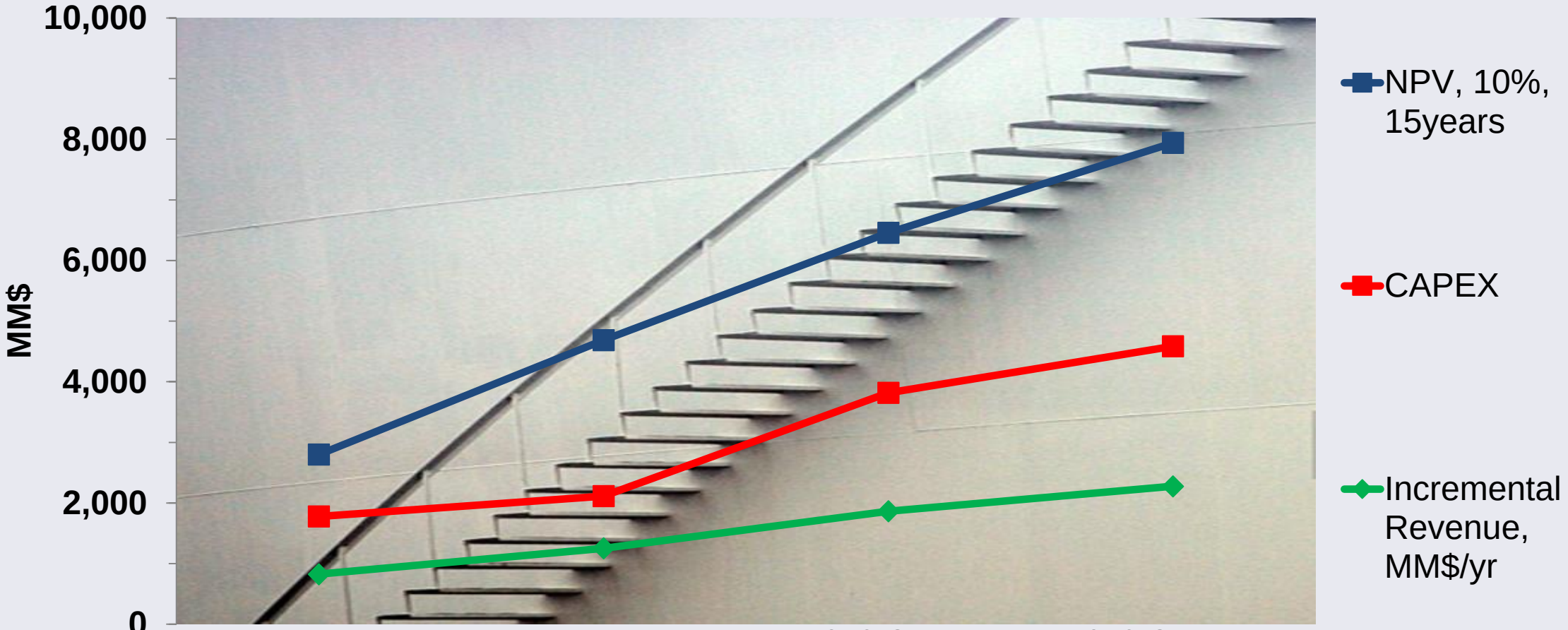
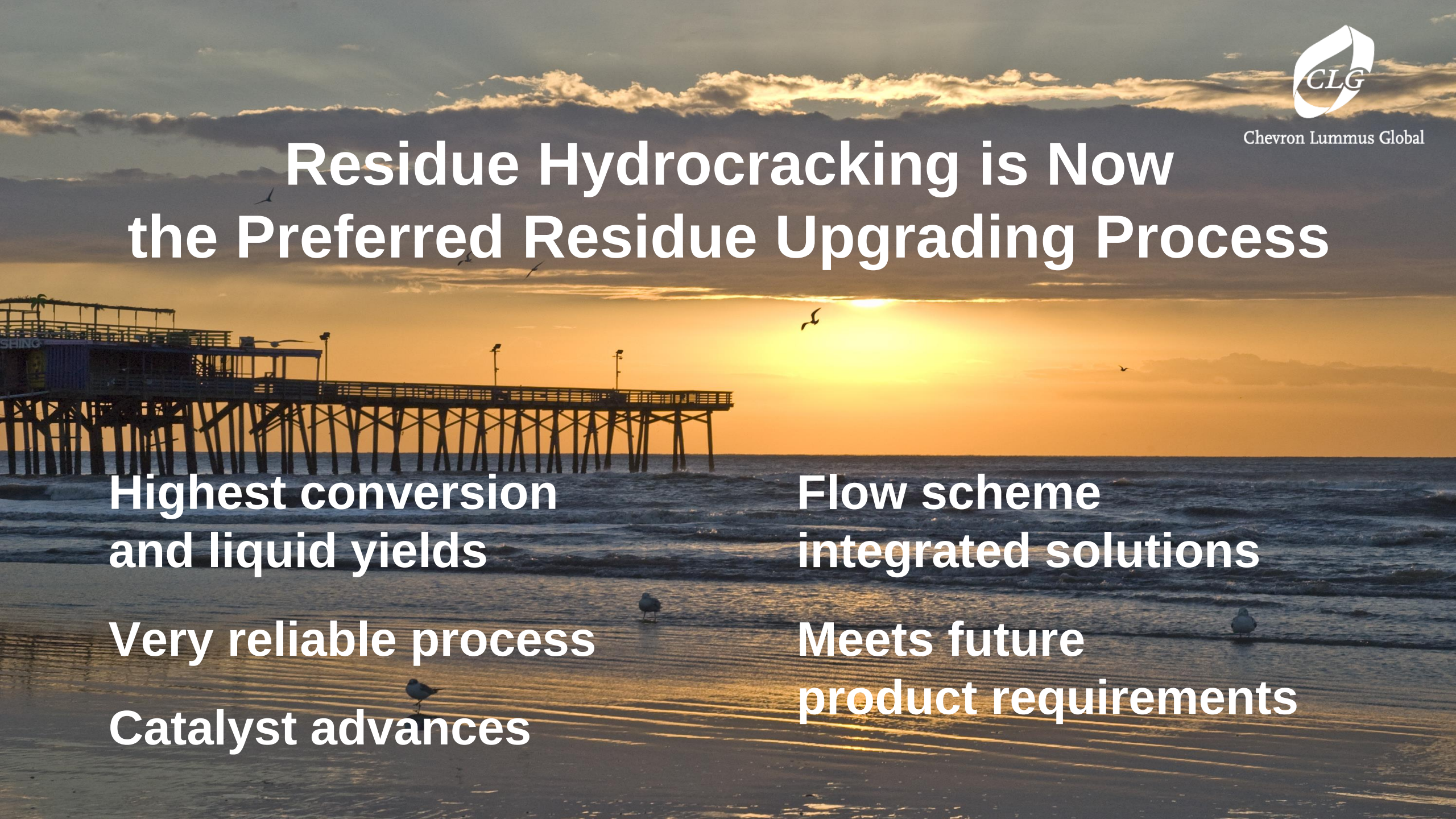


Process:	LC-FINING	LC-LSFO	LC-LSFO + Cracker	LC-LSFO + Cracker + PX
Profitability Index	2.6	3.2	2.7	2.7



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Residue Hydrocracking is Now the Preferred Residue Upgrading Process

- Highest conversion and liquid yields
- Very reliable process
- Catalyst advances
- Flow scheme integrated solutions
- Meets future product requirements