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High Conversion of Vacuum Residue

Opportunities and Challenges

Jan Steegstra
Director, Technology Marketing
Chevron Lummus Global

A Chevron and McDermott Joint Venture

Cost of Doing Nothing Post 2020

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- For a 300,000 bpsd refinery post 2020, the opportunity cost of Not Upgrading the VR will be over $ 500 million/year!
- Blending to produce ULSFO will permit refinery to continue operation; high value ULSD or FCC feed at several times the volume of VR (6 to 9 times) will be needed to make 0.5 wt.% Sulfur FO for high sulfur Middle Eastern VR
- Sweet Crudes will cost at least $2/bbl more or roughly a $220 million/year penalty! Limited supply and refiner has to change product pattern.

Market Pressures Driving Residue Upgrading Solutions to High Conversion

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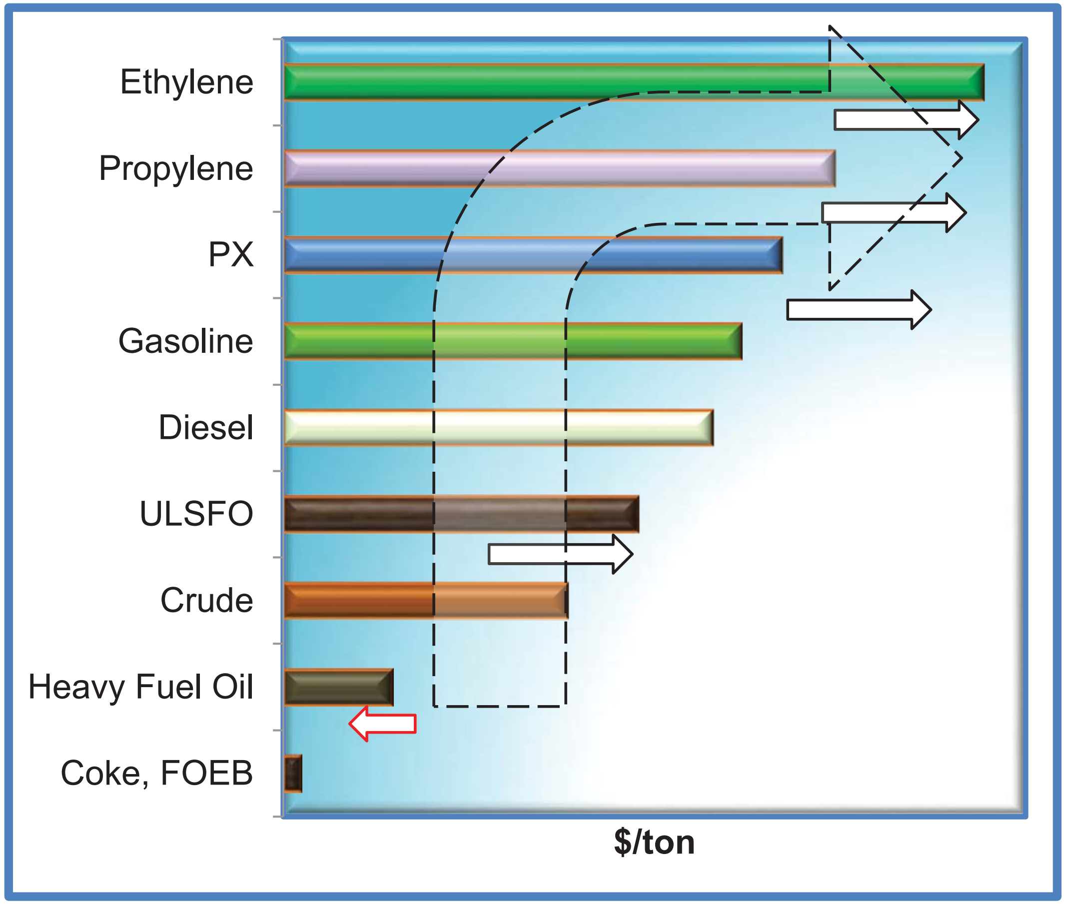
- Worldwide transportation fuel demand is increasing relative to heavy fuel oil or coke.
- Petchem demand > Transportation Fuels>> HSFO
- Relative product prices support high conversion of residue
- Push for more Chemicals Production from Crude to increase margins



Challenge is to find high conversion solutions based on proven low risk technologies

Which Residue Upgrading Approach to Take?

- **Coking**
  - Full Conversion
  - High feed flexibility
  - Doesn't make LSFO
  - Lower liquid yields and Coke disposition

- **Residue Hydrotreating**
  - Can make LSFO
  - Feedstock considerations
  - Combine with RFCC to make gasoline

- **Residue Hydrocracking**
  - 60 - 97+ % conversion
  - Feed flexibility
  - Highest liquid yields
  - LSFO possibilities

Residue Conversion High Conversion Solutions Are All Available through CLG/MDR

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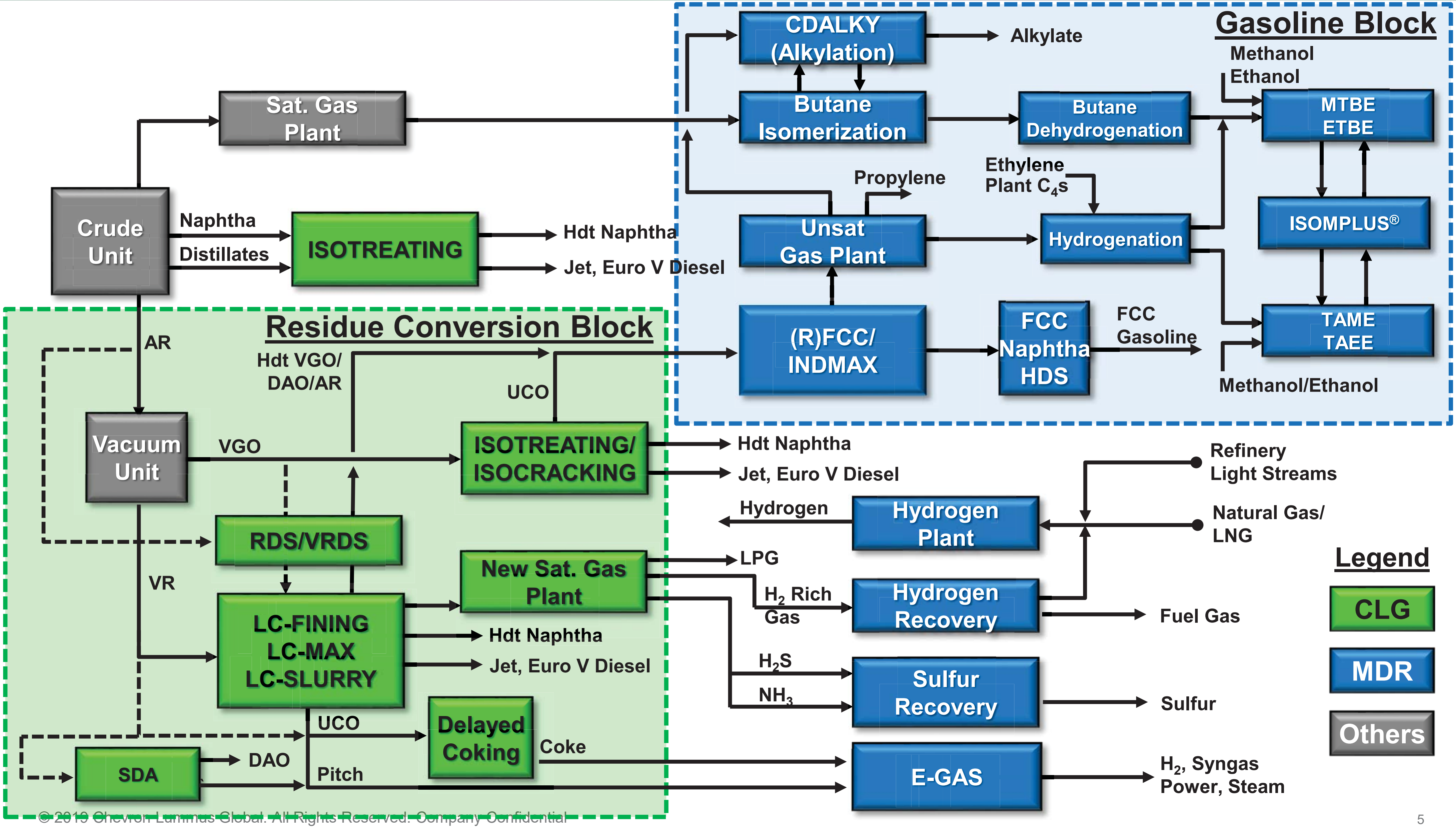

Highest Boiling Fragments Are Very Polar and Very Rich in HPNA

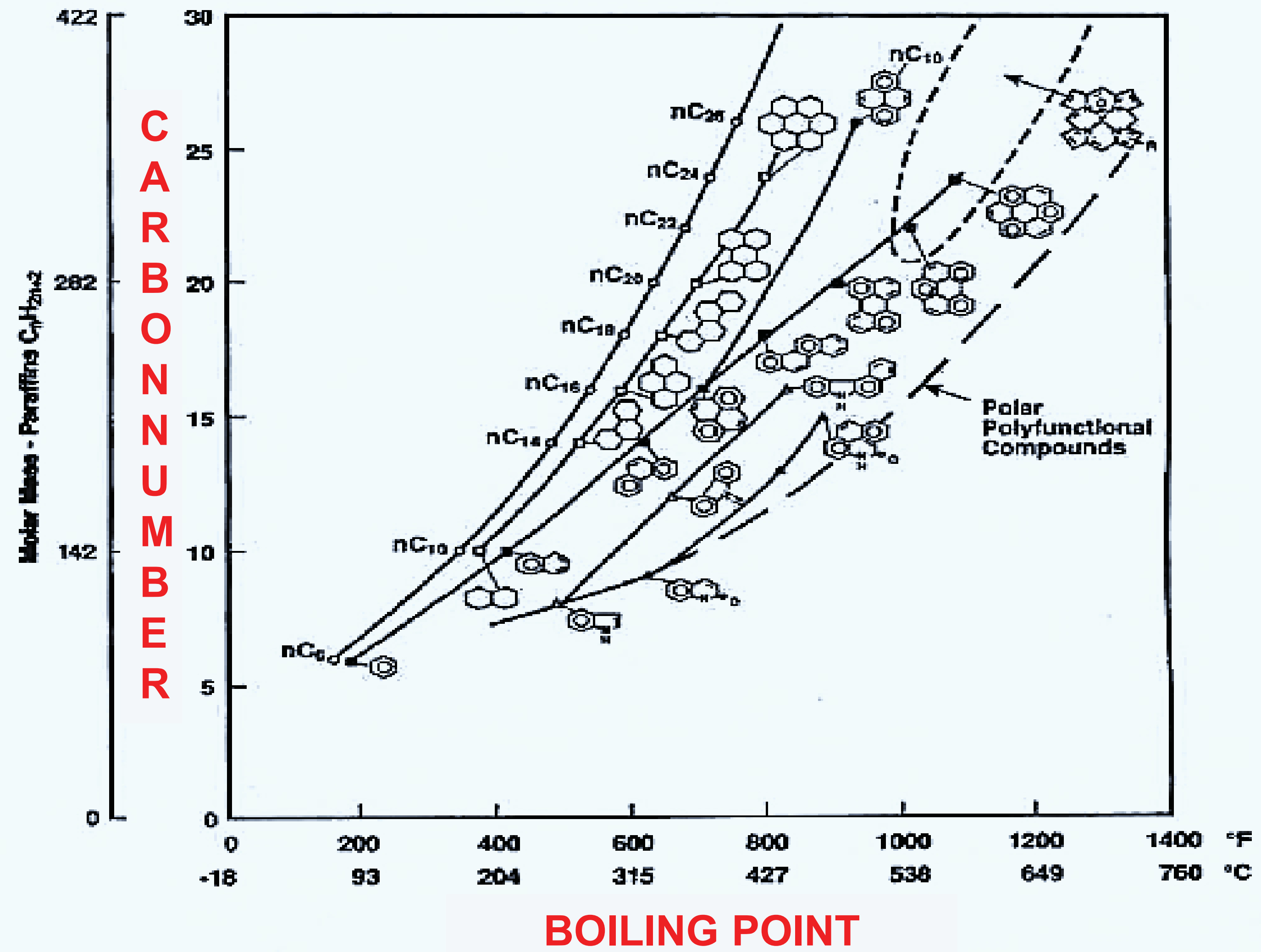

Figure 2.7 The effect of molecular weight and structure on boiling point.

Courtesy: Irvin A. Wiehe

CCR to Diesel – Hydrogen Consumption

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- CCR has ~ 3.8 wt % hydrogen
- Euro V Diesel requires 14.5 wt % hydrogen to meet S.G. specifications; Petrochemical Naphtha has 15.5 wt.% Hydrogen.
- In order to convert 25 wt % CCR in VR to Diesel or Naphtha, we will require an increment of 10.7 to 11.7 wt % hydrogen! This will not be economically viable under most scenarios.
- Smart CCR conversion is key to residue hydrocracking

Robust LC-FINING Ebullated Bed Residue Hydrocracking Technology Platform

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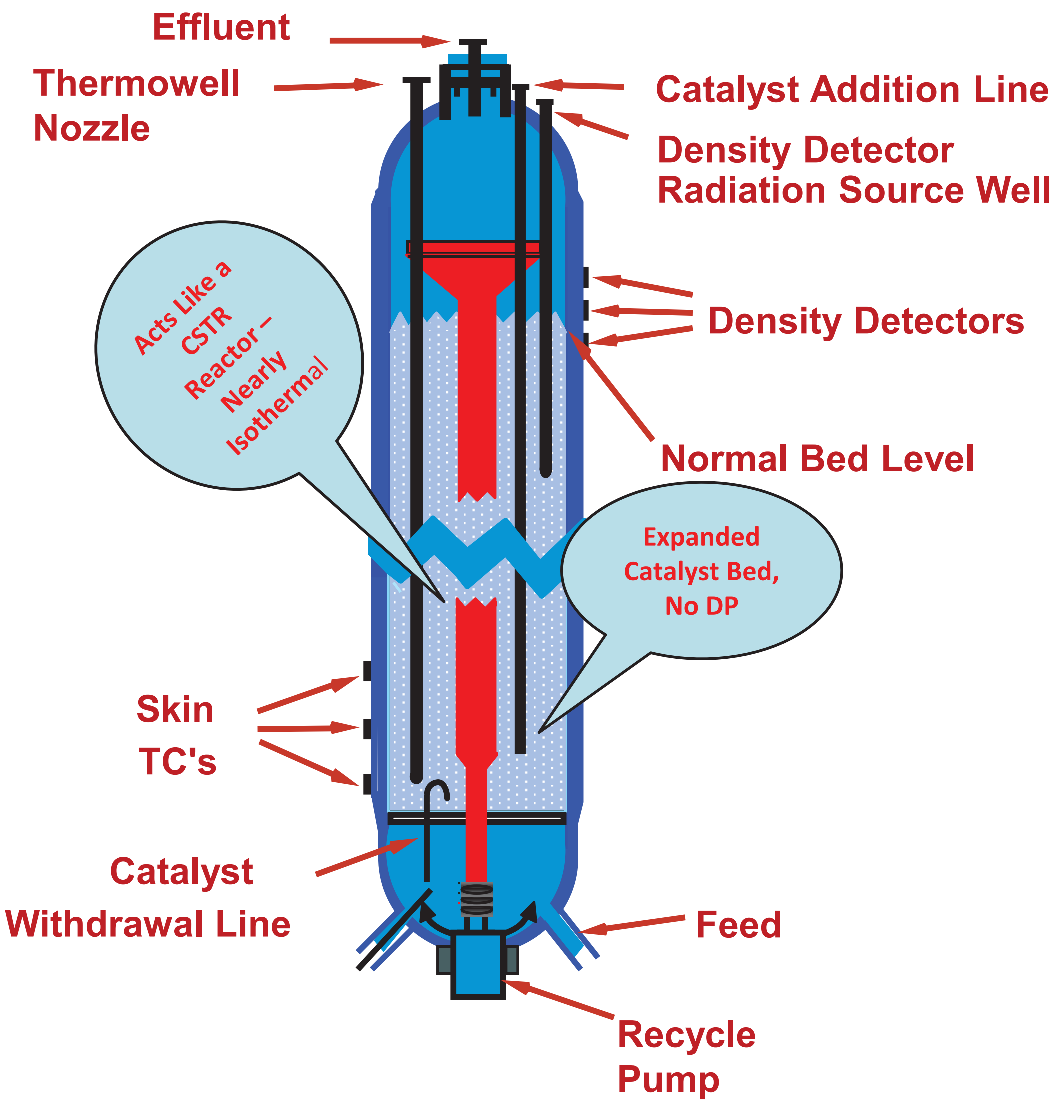
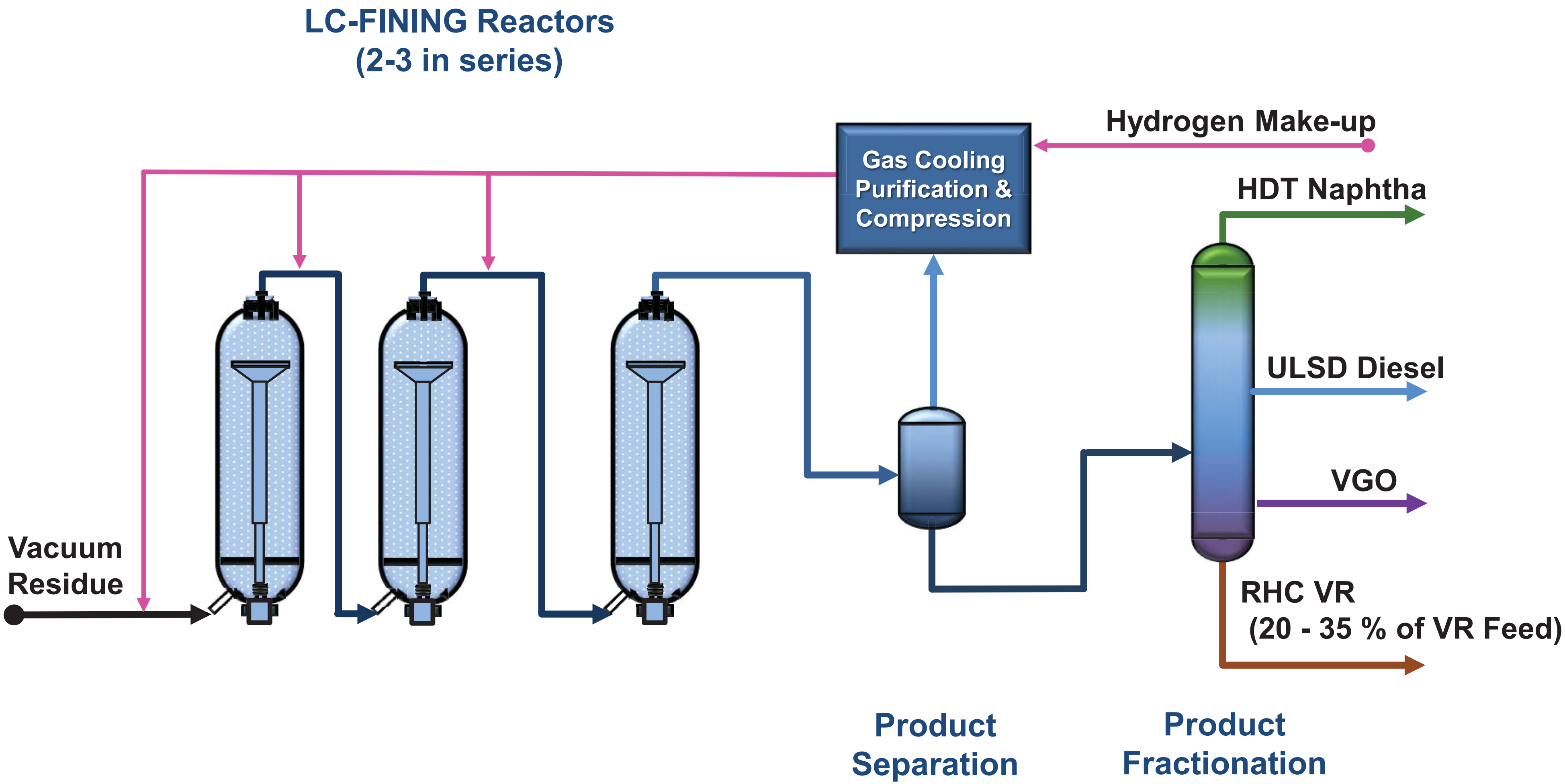


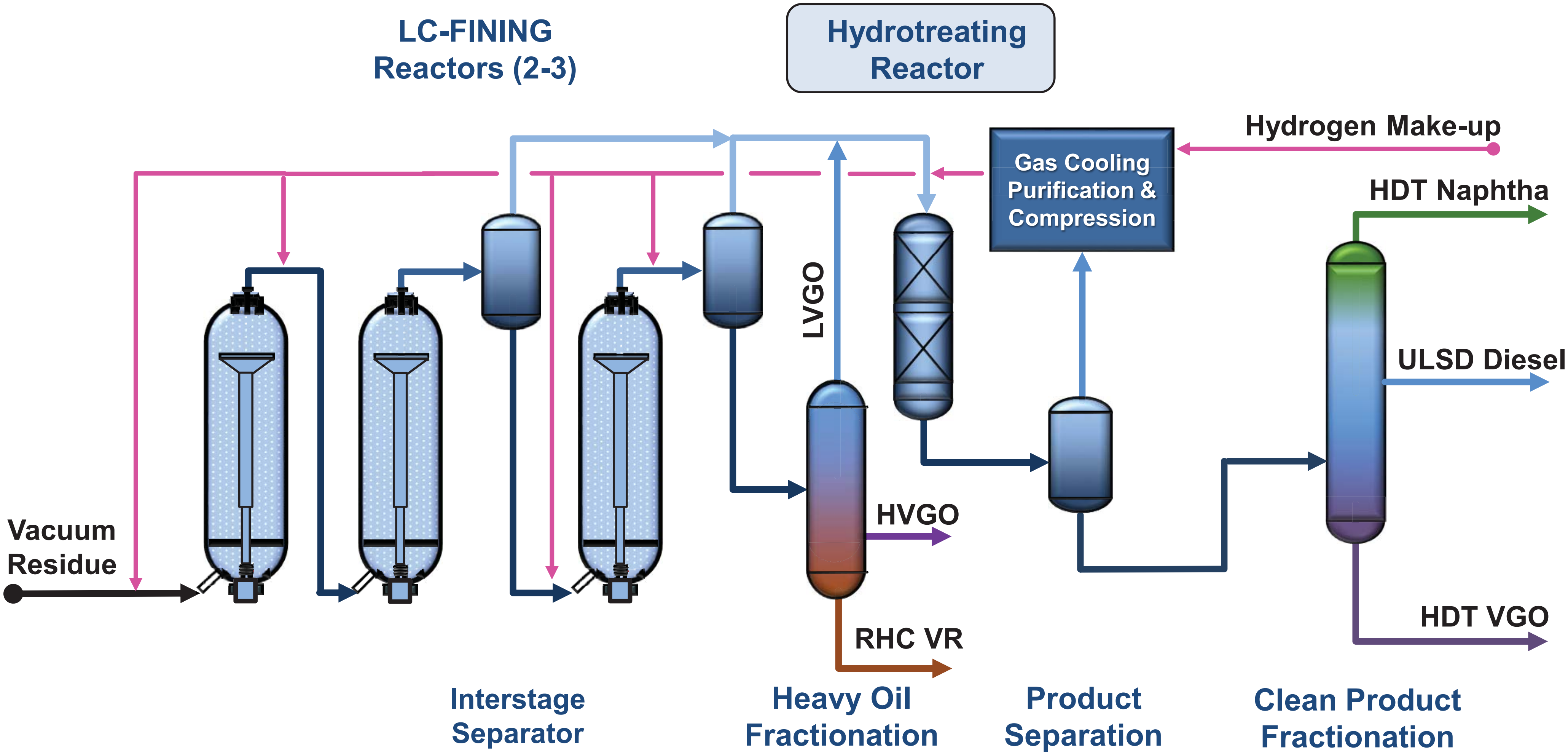
Reactor Temperature	410 - 440 °C (770 - 824 °F)
Reactor Pressure	110 - 180 bar (1600 - 2600 psig)
Resid Conversion	55 - 80 %
Hydrogen P.P.	75 - 125 bar (1100 - 1800 psi)
Chem H_2 Consumption	135 - 300 Nm^3/m^3 (800 - 1780 SCFB)
Desulfurization	60 - 85 %
CCR Reduction	40 - 70 %
Demetallization	65 - 88 %

LC-FINING
Typical Simplified Flow Scheme



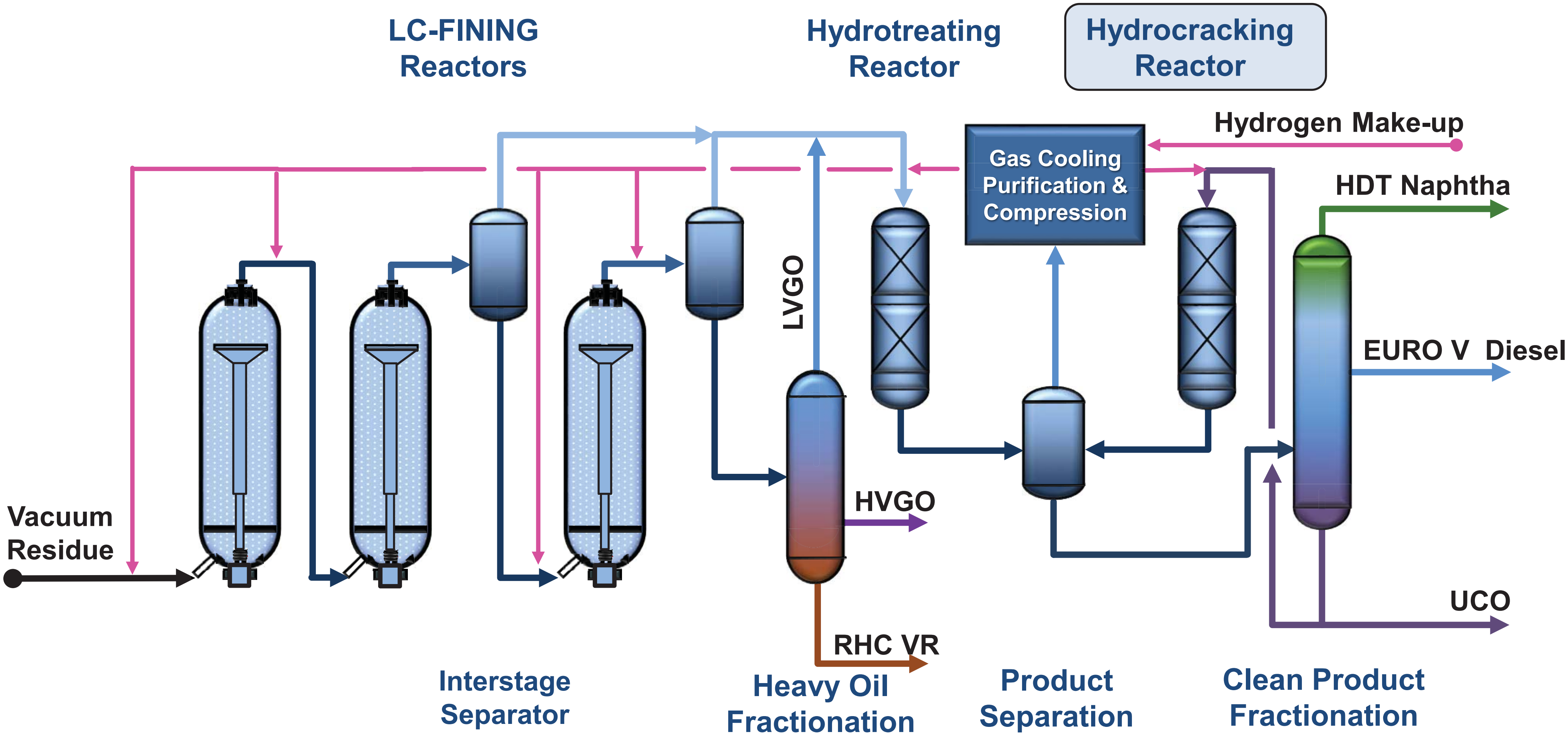
Can result in significant HSFO reduction and LSFO production with certain feeds

LC-FINING with Integrated Hydrotreating Produces Clean High Quality Products



Hydrotreating costs reduced 40 - 50 %

LC-FINING with Integrated Two-Stage Hydrocracking Maximizes High Value Distillates



Key is a "clean" second-stage and VGO End Point Control

Shell Canada

Neste Porvoo, LC-FINING With Integrated ISOCRACKING Facility to Make Euro V Compliant Naphtha and Diesel

The GS Caltex LC-FINING Unit

Residue Hydrocracking Challenges

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- Conversion restricted by the nature of feed
- Sediment formation rises rapidly at higher conversions; conversion often limited by back-end fouling
- Full reactor potential (capital utilization) often restricted by sediment in UCO
- Hydrogen is wasted in hydrogenation and hydrocracking of heavy asphaltenes
- Selectivity to liquid decreases at high temperature required for conversion. Hydrogen wasted in making low value C_4- material.

LC-MAX – Block Flow Diagram

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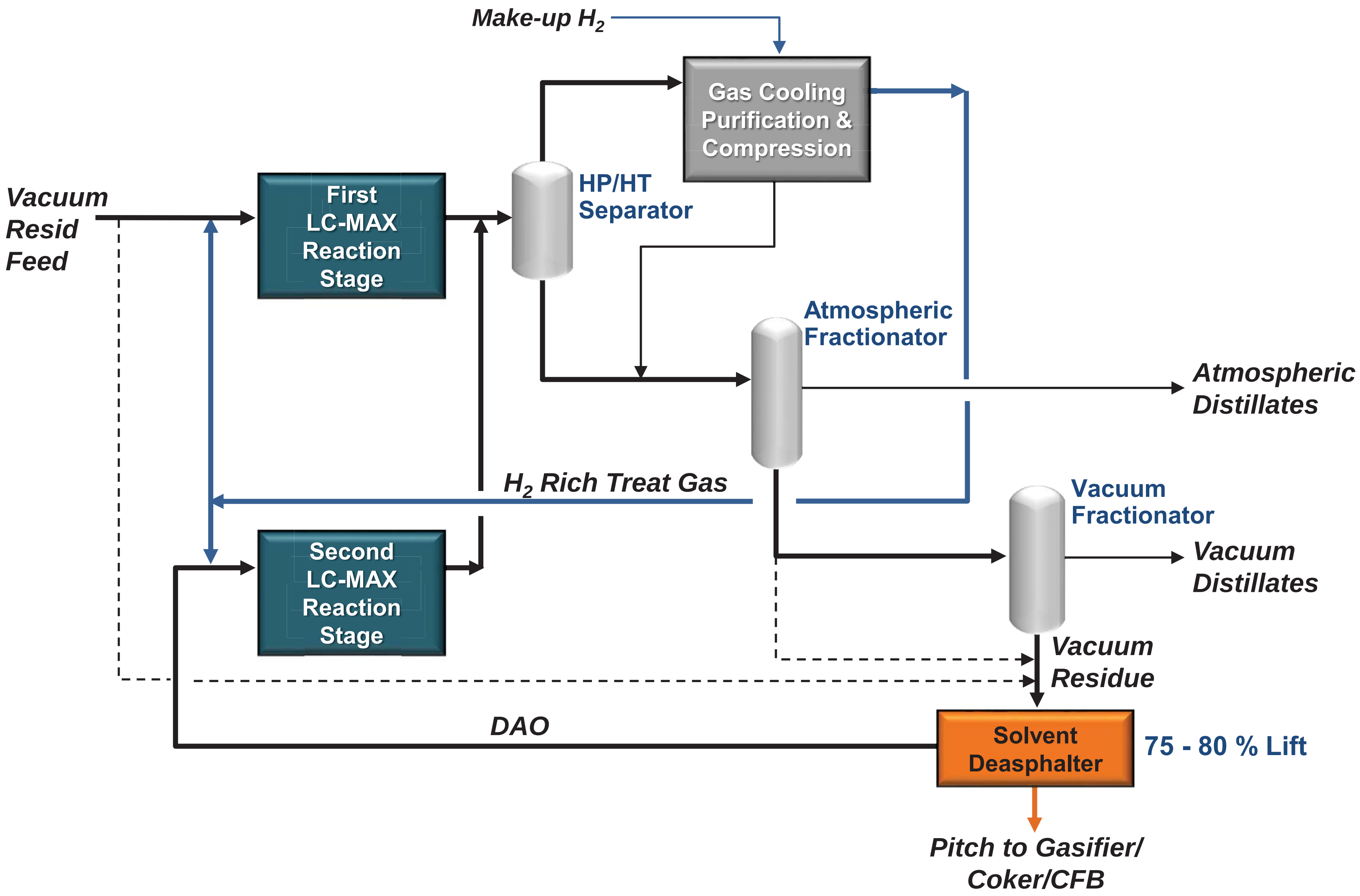


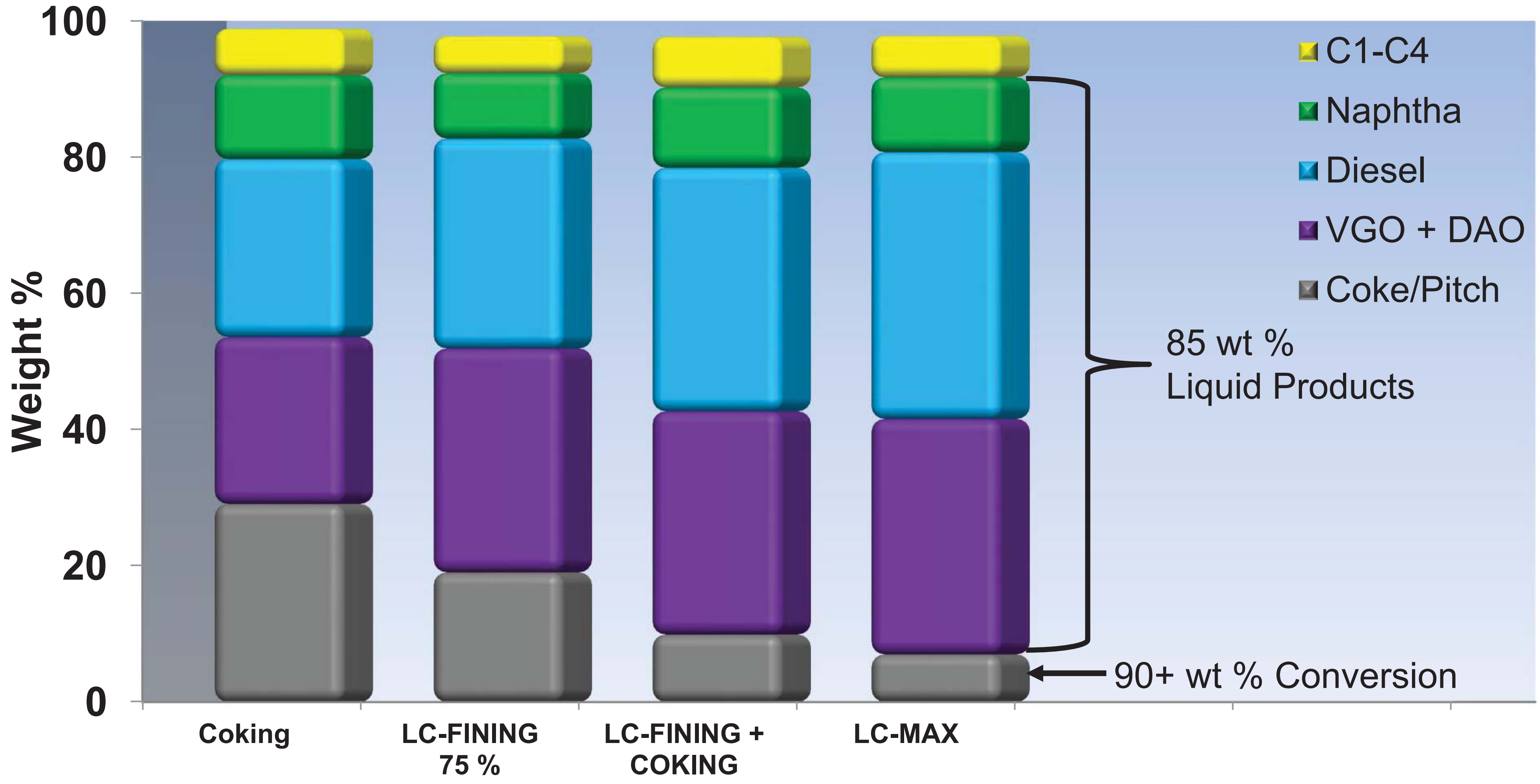
LC-MAX – Process Features

- 90 %+ 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 *(hydroconversion of heavy asphaltenes produces 4-ring HPNA that are very difficult to upgrade)*

LC-MAX vs. LC-FINING for Ural VR

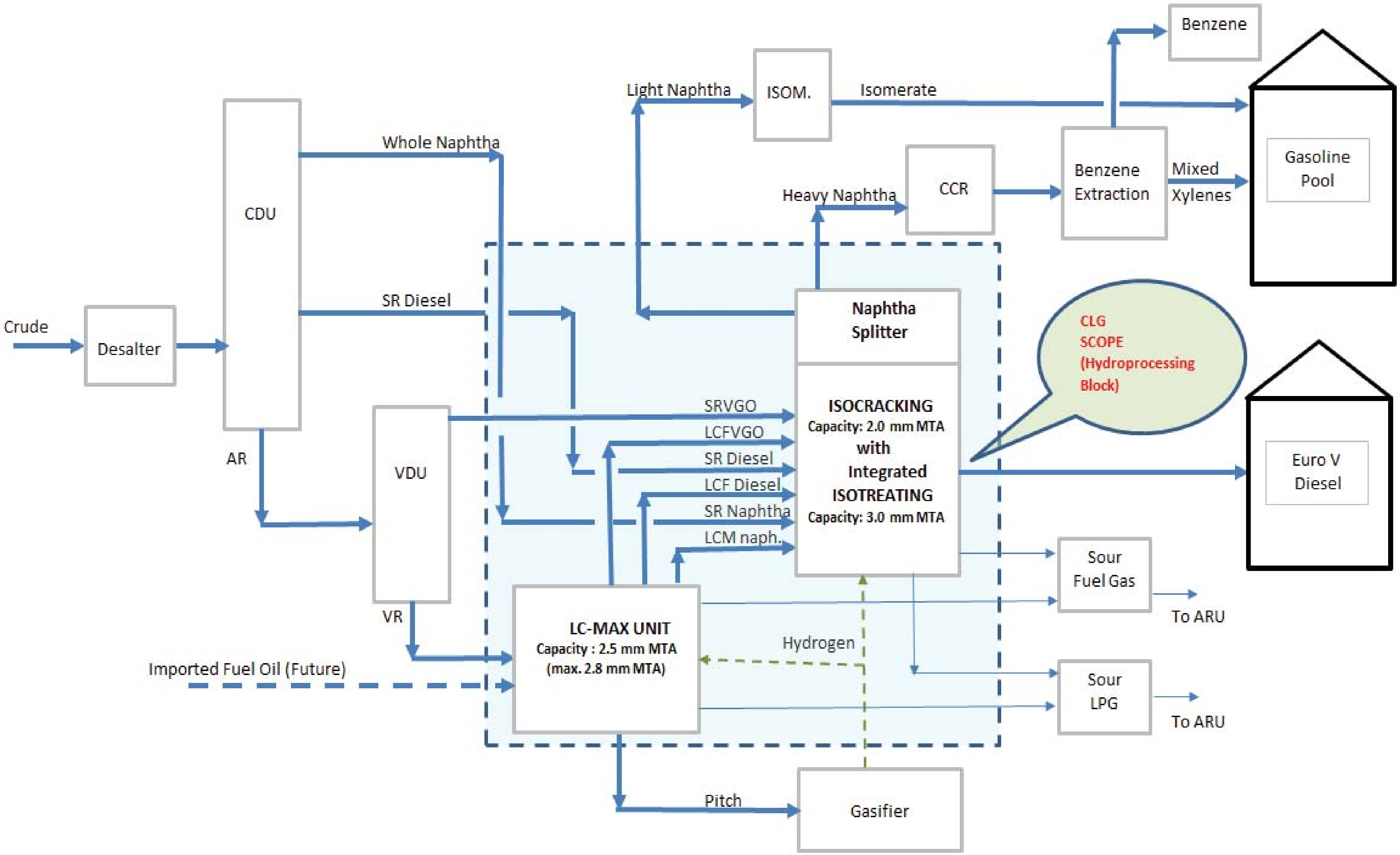
	LC-FINING	LC-MAX
Conversion, %	63	88 - 92
Feed Flexibility	Good	Excellent
Reactor Volume	Base	0.9 x Base
Chemical Hydrogen	Base	Base x 1.15 for 20 % Higher Conversion
Catalyst Addition Rate	Base	Base x 0.88
Bottoms Product	LSFO	Coker Feed, Gasifier Feed
Fractionation Section Fouling	Base	<< Base
Unconverted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

Significant Yield Increase With LC-MAX



Liquids:	Base	+10.3	+17.3	+21.7

A New Complex With LC-MAX



LC-LSFO TO MEET IMO 2020

What is LC-LSFO?

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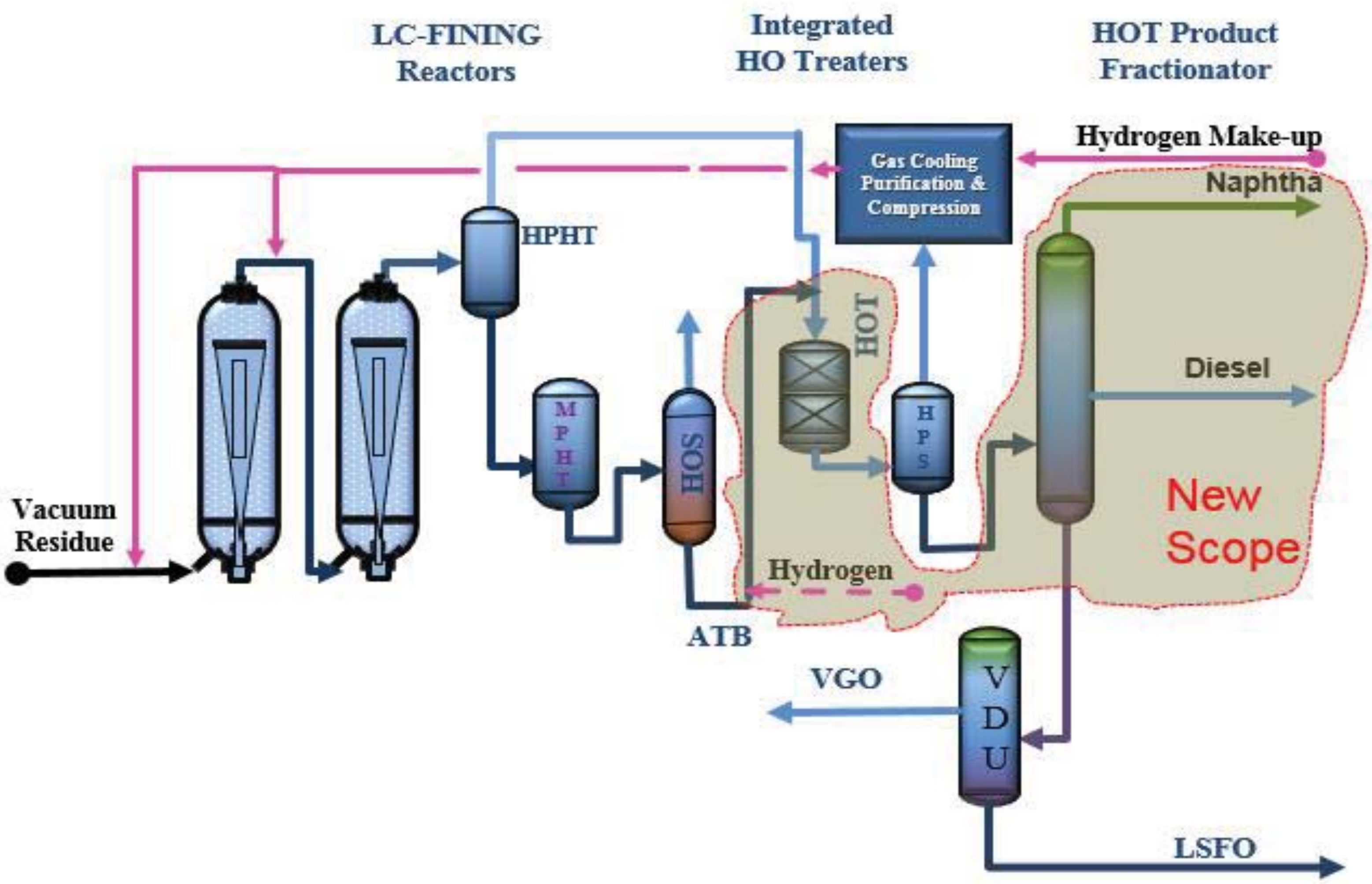
- A Process for upgrading LC-FINING High Sulfur Unconverted Oil to Low Sulfur Unconverted Oil
- LC-LSFO objective is to produce low sulfur oil from LC-FINING Unconverted Oil
- LC-LSFO is suitable for LC-FINING ATB (Atmospheric Tower Bottom) or heavier VTB (Vacuum Tower Bottom).
- LC-LSFO treated residue can meet 0.5 wt % sulfur and blended to Low Sulfur Fuel Oil.

LC-LSFO Flow Scheme



Minimum modification required as recycle gas flow increase is negligible

- LC-FINING flow scheme remains unchanged
- Add new filtration on ATB or VTB
- Add new HOT Reactor, Furnace, HP Feed Pump, HPHT, MPHT, Product Stripper or Product Fractionator

LC-SLURRY
Increased Conversion With Difficult Feeds

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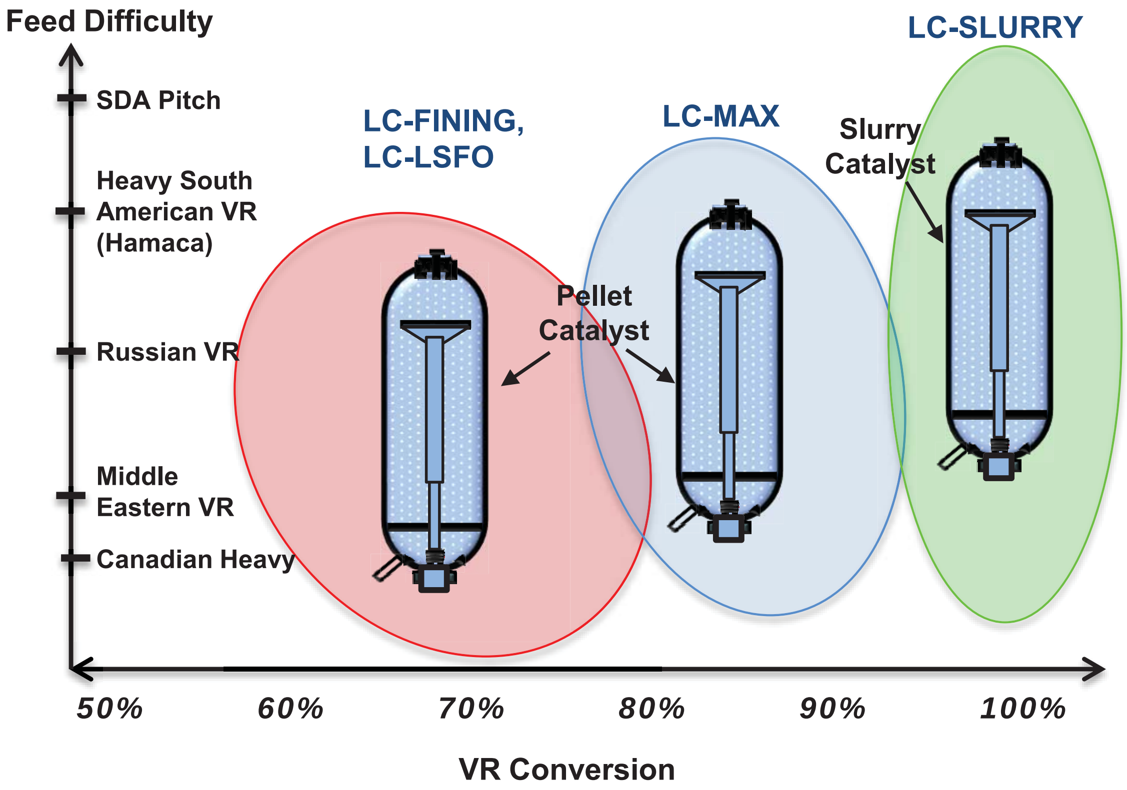

- Near 100 % conversion of heavy oils / SDA tar to high-value products
  - 115 % liquid yield
  - Over 80 vol % Euro V diesel (after VGO HC)
- Unique high activity catalyst
  - Recovered in the process
  - Eliminates fouling concerns associated with other catalyst or additive systems
- Based on LC-FINING platform
  - Commercially proven and reliable
  - Optimal reactor configuration

The Early Years of Slurry Hydrocracking Development

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- **1978-1984** Chevron started slurry hydrocracking work in late ‘70’s. Simple Fe-based Additives tested followed by Mo-based Additives. Technology used Bubble Reactors. Parallel work on Coal Liquefaction carried by both Chevron and Lummus. Oil shock of 1979 and a period of high oil prices led to decision to build **16 TPD demo plant** in Richmond refinery in 1984. Unit ran for 6 months and generated a lot of data. Shutdown to secure tax credits for Chevron that funded work.
- **1984 –** Chevron merges with Gulf. Gulf Research had developed high activity Mo.-catalyst.
- **1985-1991** : Modern Slurry Hydrocracking Research (1980-1985): Chevron Activated Slurry Hydrocracking **(CASH)**
  - Used special Mo.-catalyst (nano catalyst)
  - Conversion achieved 95 - 99 %.
  - Work stopped because of severe budget constraints in refining industry
- **1999-2001** Chevron acquires partial ownership of AOSP Project Edmonton Canada. AOSP (Shell Canada) builds large LC-FINING unit. Chevron sees advantage of LC-FINING platform compared to Bubble Reactor Platform.
- **2001 –** Chevron merges with Texaco. Chevron acquires Texaco ultra-heavy oil fields. Decision to develop slurry hydrocracking for upgrader of ultra-heavy Vacuum Residue.
- **2002 –** Scale-up Risk of Reactor Technology Evaluated. Texaco and Chevron experience with EB Technology leads to selection of Liquid Circulation (LC-FINING) Platform instead of Slurry Bubble Column for all future work.

Intense R&D and Commercialization

- **2003 –** Slurry Hydrocracking Research Program restarted with intense focus on Upstream Upgrading. Scale-up of catalyst synthesis, resid hydrocracking, solids separation and metals recovery. Name Changed to Vacuum Residue Slurry Hydrocracking **(VRSH)** to reflect new catalyst and process platform
  - Extensive Work on Very Heavy VR feedstocks (e.g. Hamaca & Maya)
  - Integrated HDT, first commercialized in LC-FINING units, used for High Quality Products
- **2005 –** Decision to construct 600 TPD-protype in Pascagoula Refinery. Project funded through Engineering and Procurement.
- **2007** – Large pilot plant RU-87 (175 kg/day) commissioned in Richmond to supplement smaller pilot plants (RU-85 and RU-86). Earlier VRSH testing carried out in Lummus' large pilot facilities in Bloomfield.
- **2008-2009** Large Catalyst Deoiling Plant built in Richmond. Large Scale Catalyst Synthesis and Metals Recovery Demonstrated
- **2010** – Chevron cancels construction of prototype because of sharp drop in Crude Oil prices and explosive growth of light shale oil crude oil. Upstream interest lost.
- **2012** – Research effort restarted with focus on downstream applications (for refineries). Bimetallic Catalyst developed. Very long runs with most difficult feeds demonstrated. Next generation catalysts developed.
- **2015** – VRSH rolled into CLG for licensing. Name changed to LC-SLURRY
- **2016** – Major Oil Companies express interest in LC-SLURRY. CLG licenses first LC-SLURRY unit to Beowulf / Preem who had earlier evaluated VCC for nearly two years.

CLG Licenses the first LC-SLURRY Unit For Beowulf / Preem in Sweden. This 2.5 MM MTA unit will produce Euro V Diesel and LSFO (< 0.5 wt.% Sulfur).

LC-SLURRY
Optimal Flow Scheme for Slurry Hydrocracking

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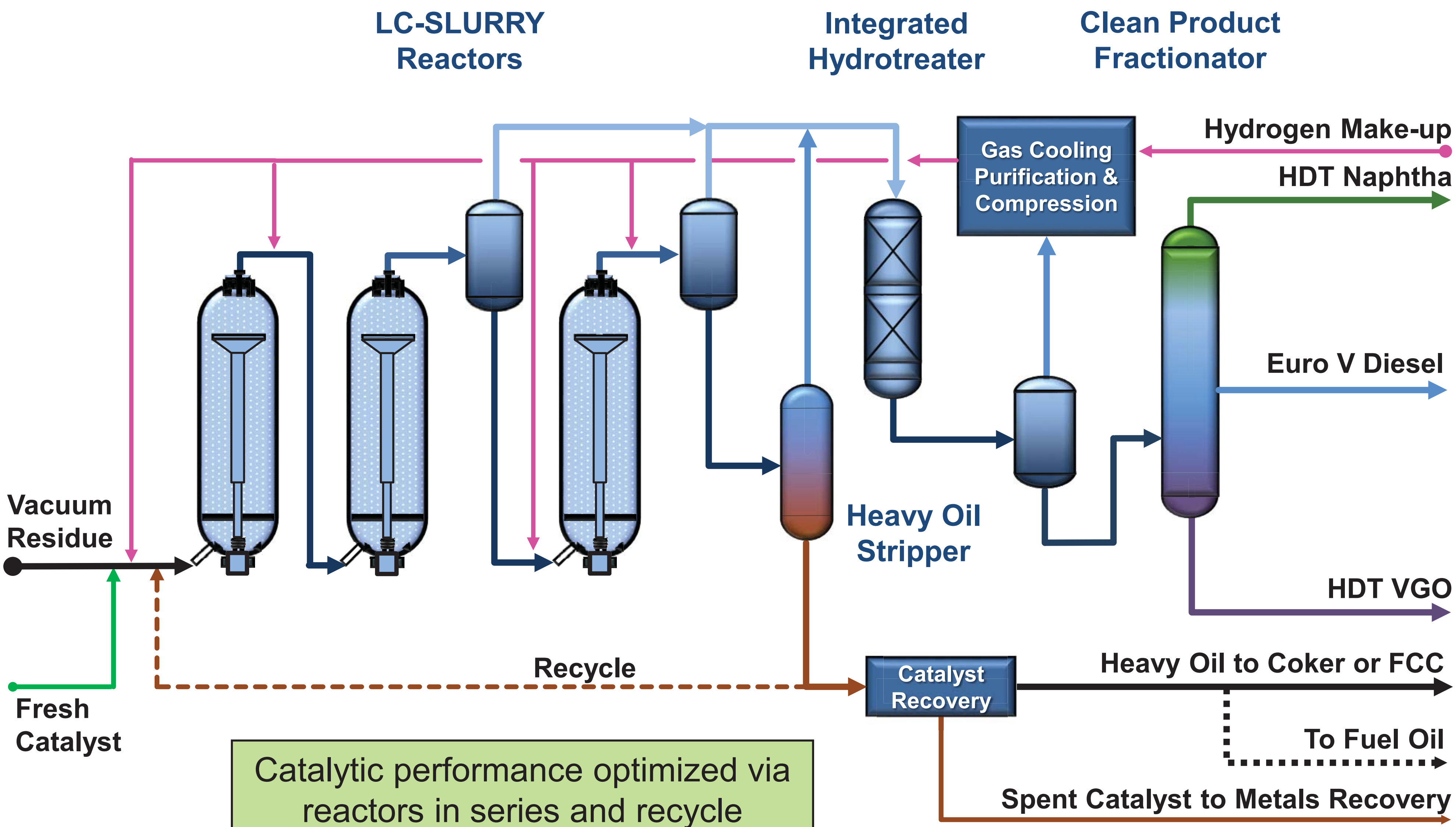

Catalytic performance optimized via reactors in series and recycle

What is LC-SLURRY?

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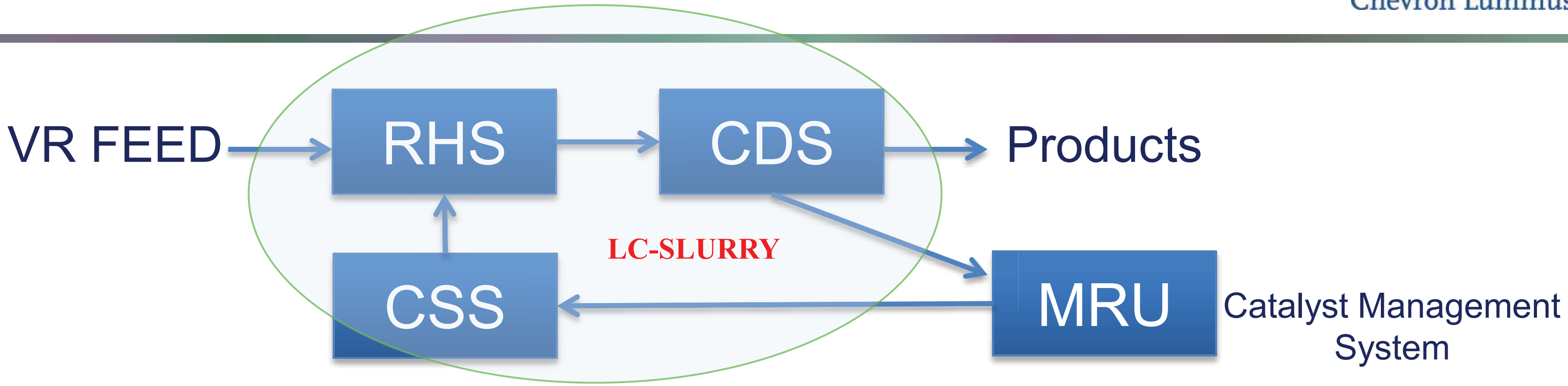

Unit	Description
RHS – Residue Hydrocracking Section	Slurry resid hydrocracking unit • Achieves full (97 % +) VR conversion • Uses ISOSLURRY catalyst • Based on LC-FINING reactor platform
CDS – Catalyst Deoiling Section	Process to separate spent VRSH catalyst from the unconverted oil
CSS – Catalyst Synthesis Section	Prepares ISOSLURRY catalyst from Ni and Mo Salts
MRU – Metals Recovery Unit	Process to recover metals from spent ISOSLURRY catalyst (outside facility- not part of plant)

LC-SLURRY
Maximizes Valuable Products

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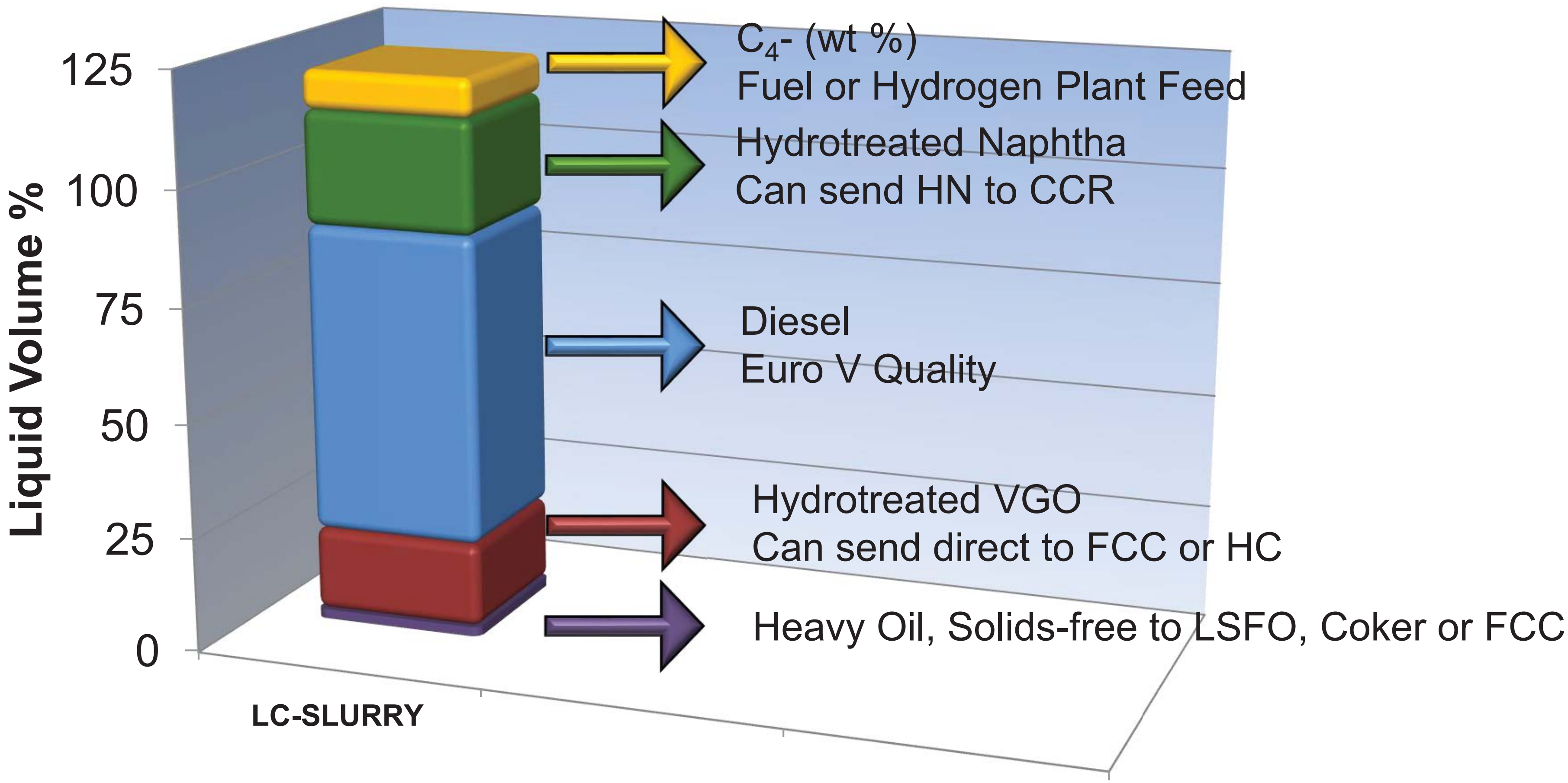

Zero residue is produced!

LC-SLURRY – Makes Over 81 Vol % Diesel After VGO HC and Heavy Oil Processing

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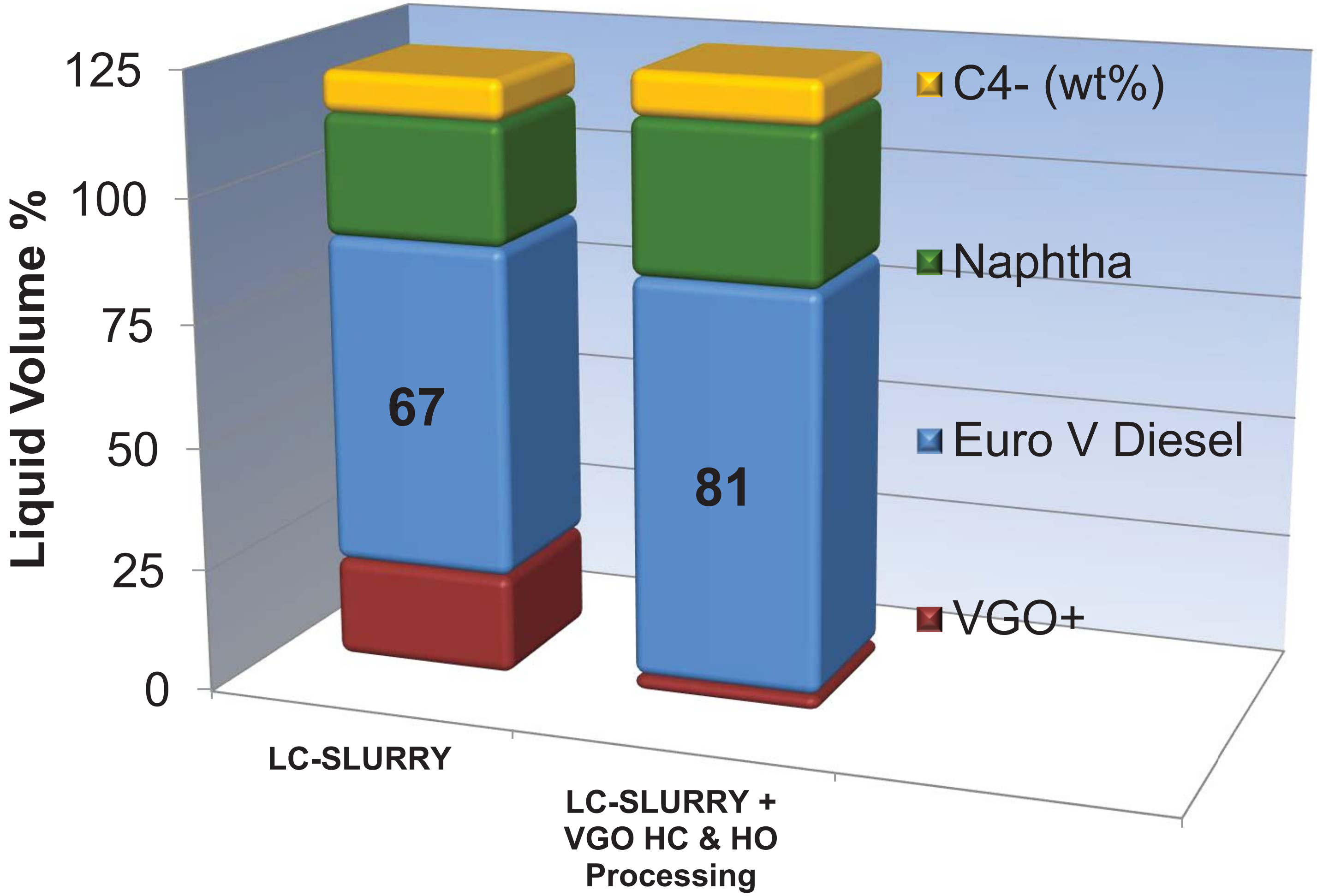

LC-SLURRY
Differentiated by Several Key Components

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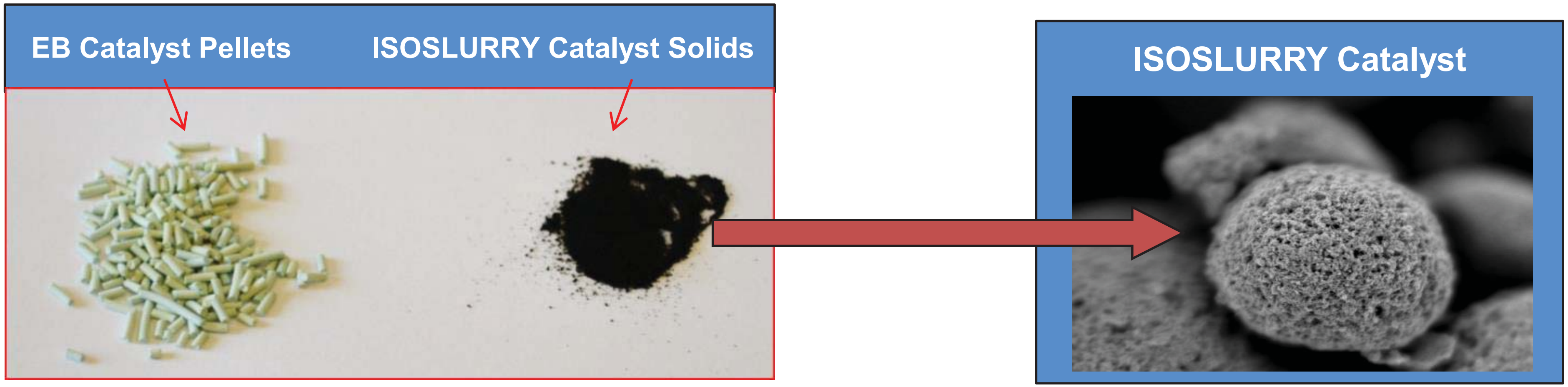
- **ISOSLURRY™ Catalyst**
  - Highly active, ultra-fine, proprietary bimetallic catalyst
  - Produced and activated ex-situ
- **Hydrocracking Section**
  - LC-FINING proven reactor platform
  - Multi-stage reactor system
- **Hydroprocessing Section**
  - In-line hydrotreating removes contaminants
  - Additional hydroprocessing can increase Euro V Diesel production and allow heavy oil product to be blended to LSFO or processed in Coker / FCC
- **Catalyst / Oil Separation**
  - Re-adapted, proven technology effectively recovers the catalyst from bottoms oil
  - Enables use of bottoms stream for coker feed, fuel oil etc.
  - Spent catalyst rich in metals and suitable for metals recovery

ISOSLURRY™ Catalyst Designed for Superior Performance

- Based on residue hydroprocessing catalyst know-how
- Unique and optimized properties
- Highly active nickel moly-based catalyst
- Excellent access to reactive sites
- Produced ex-situ to ensure high quality

- Catalyst quality and dosage
  - Keeps the system clean
  - Suppresses coke formation
  - Improves bottom oil quality
  - Allows very high conversion with reliable operation



LC-SLURRY
Upgrades the Most Difficult Molecules

- MCR/CCR conversion tracks VR conversion
  - Avoids instability issues
  - Avoids large coke make
  - 94 % HDMCR and 97 % VR conversion on SDA tar
- Catalyst quality and dosage
  - Keeps the system clean
  - Suppresses coke formation
  - Improves bottom oil quality
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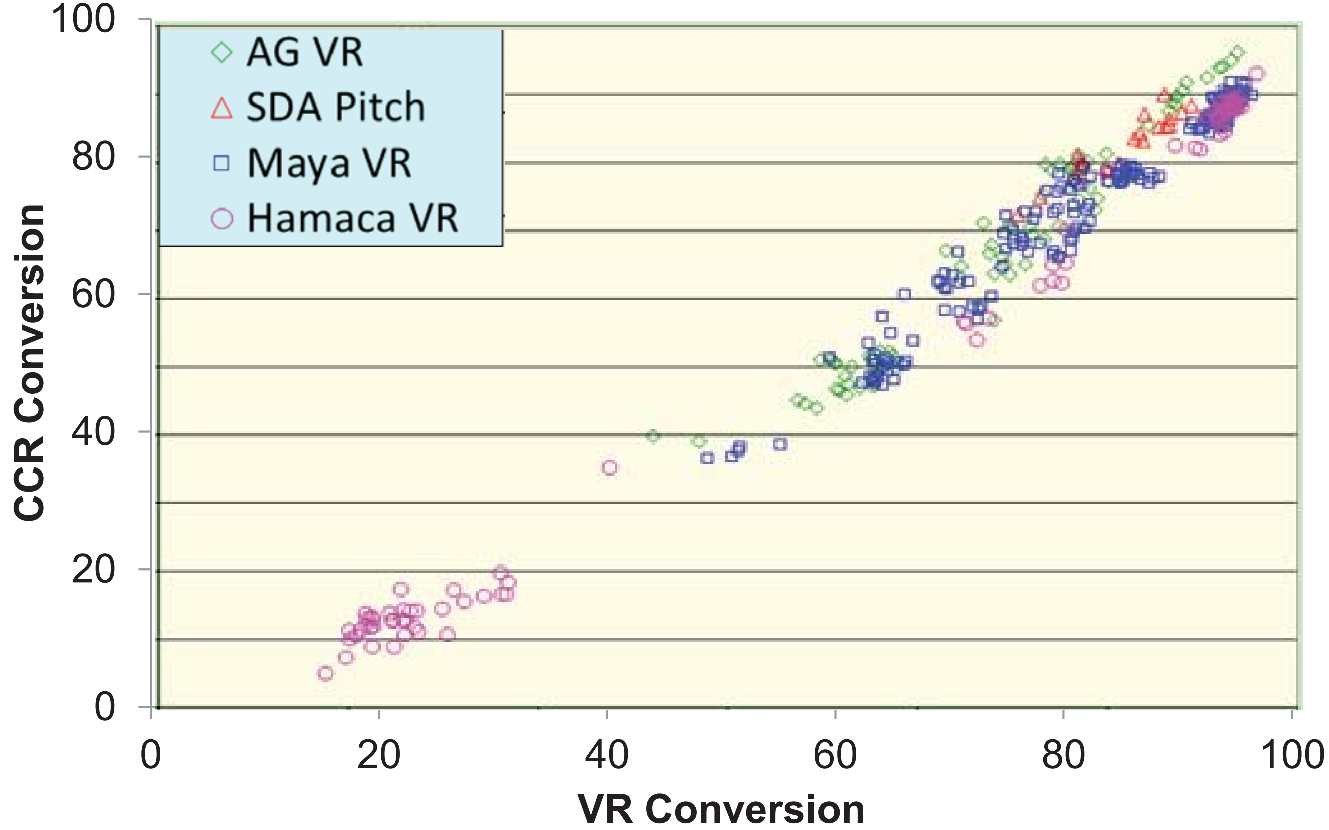

CLG Offers All Residue Upgrading Technologies

- Commercially Proven
- High Liquid Yields
- Meets or Exceeds Future Specifications
- Maximizes Feed and Product Flexibility
- Low or Zero Residue