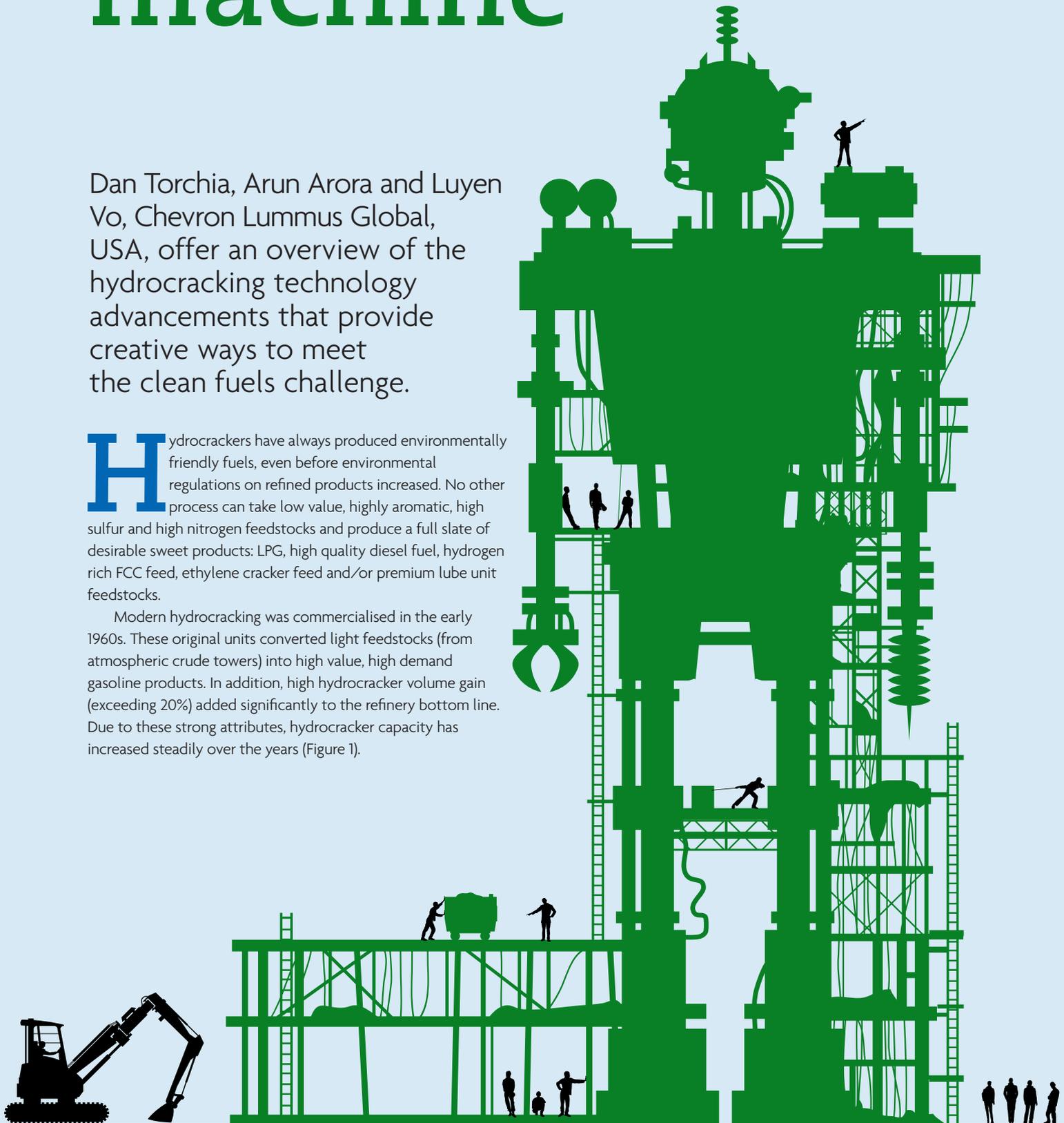


Clean, green, hydrocracking machine

Dan Torchia, Arun Arora and Luyen Vo, Chevron Lummus Global, USA, offer an overview of the hydrocracking technology advancements that provide creative ways to meet the clean fuels challenge.

Hydrocrackers have always produced environmentally friendly fuels, even before environmental regulations on refined products increased. No other process can take low value, highly aromatic, high sulfur and high nitrogen feedstocks and produce a full slate of desirable sweet products: LPG, high quality diesel fuel, hydrogen rich FCC feed, ethylene cracker feed and/or premium lube unit feedstocks.

Modern hydrocracking was commercialised in the early 1960s. These original units converted light feedstocks (from atmospheric crude towers) into high value, high demand gasoline products. In addition, high hydrocracker volume gain (exceeding 20%) added significantly to the refinery bottom line. Due to these strong attributes, hydrocracker capacity has increased steadily over the years (Figure 1).



Increased environmental regulations on gasoline and diesel have made hydrocracking an essential process, resulting in ever greater increases in worldwide capacity. The most recent grassroots hydrocrackers were designed to maximise the production of middle distillates from increasingly difficult feedstocks such as FCC light cycle oil (LCO), heavy vacuum gas oils (HVGO) and heavy coker gas oils (HCGO). Like their predecessors, most modern hydrocrackers produce high value, environmentally friendly distillate products, including massive volumes of ultra low sulfur diesel (ULSD), even with progressively more demanding feedstocks (Table 1).

Early generation hydrocrackers had capacities of approximately 10 000 bpd, while many new units today exceed 100 000 bpd.

Catalyst advancements

Ongoing market growth, ever increasing operating severities and the design of very large units has propelled Chevron Lummus Global (CLG) towards an ambitious catalyst development programme, especially over the last decade.

Each new catalyst lowers the reactor temperature required to achieve target conversion (extends run length), while

maintaining the product slate or, conversely, improves the product yield structure at target activity and run length. With improvements to catalyst formulations and raw material quality (both amorphous and zeolitic), CLG's latest line of ISOCRACKING® catalysts can enhance selectivity for a full range of applications, and also exhibit increased activity and stability for processing increasingly difficult feedstocks. These catalyst developments demonstrate high stability in processing heavy and cracked feeds with nitrogen contents exceeding 3000 ppmw.

Along with optimum catalyst design, catalyst life cycles can be extended by improving reactor operation. CLG's ISOMIX®-e reactor internals enhance reactor operation by thoroughly mixing and uniformly distributing gas and liquid across the reactor bed, while also allowing for complete wetting of the catalyst. This results in even temperature distribution (low radial ΔTs) and maximum catalyst utilisation across the reactor bed, improving cycle length and operating stability. With its unique truss system structure to support the reactor internals, catalyst volume can be increased allowing for longer cycles, higher throughput and faster turnarounds, all with minimal capital investment. This combination of linked catalyst and hardware design is essential for the reliable production of maximum clean fuels today.

Process advancements

The growing demand for middle distillates, a declining market for high sulfur fuel oil, and increasingly stringent environmental regulations are putting refineries, especially those with lower Nelson complexity index, under immense margin pressures and even forcing many to shut down. This recent trend has led to grassroots projects for distillate oriented conversion technologies. Very few (if any) refineries have their conversion strategy focused on FCC technology, and many FCC units are operating in low severity distillate mode or occasionally being converted to a propylene producer.

Table 1. Hydrocrackers: then and now

	1960s	2000s
Average unit size (bpd)	10 – 20 000	50 – 60 000+
Feed S (wt%)	0.5 – 1.0	2.0 – 3.0
Feed N (ppmw)	500 – 1000	2000+
Feed % cracked	10 – 20	25 – 70
Primary product	Naphtha/Jet	Jet/Diesel
Naphtha S (ppmw)	0.5 – 10	0.5 – 5
Diesel S (ppmw)	100 – 500	5 – 10

Table 2. Comparison of hydrocracker flow schemes

	Single stage once through	SSREC	TSREC and optimum conversion	Single stage reverse sequence
Capacity restrictions for single train, fresh feed basis (bpd)	65 – 70 000	<50 000	65 – 70 000	50 – 55 000
Maximum commercial conversion (%)	80	97 – 99	100 for TSREC and 70 – 80% for OPC	100
Segregated reaction zones	No	No	Yes	Yes
NH ₃ and H ₂ S inhibition effect on cracking and aromatic saturation	Yes	Yes	No	No
Middle distillate selectivity at maximum conversion	Base – – – (80% conversion)	Base – – (99% conversion)	Base (100% conversion)	Base – (100% conversion)
Operating pressure for same run length at maximum conversion	Base ++	Base +	Base	Base
Feed flexibility at design capacity	Very poor (conversion)	Moderate (PPC, overall conversion)	Very good (shift conversion, PPC in 2 nd stage)	Very good (change conversion, RCP, PPC in 2 nd stage)
Product flexibility	None except final distillation	Moderate (change RCP or PPC)	Very good (change conversion, RCP, PPC in 2 nd stage)	Very good (change conversion, RCP, PPC in 2 nd stage)
Total installed cost at maximum conversion	Base + at 80%	Base +++ for >60 MBD Base + for 30 – 40 MBD Base – for <30 MBD	Base	Base –

Hydrocracking offers greater flexibility to process opportunity crudes while producing premium grade clean fuels, which improve refinery margins. Thus, in the last decade alone, more than 90 hydrocracking units have been licensed worldwide. Many new refineries and refinery expansions are targeting operating capacities of 400 000 bpd or higher: which in many cases increases average hydrocracker capacity beyond the conventional 65 000 bpd single train capacity to 70 000 bpd. CLG has designed several units ranging 70 000 – 140 000 bpd; one of these is currently in precommissioning, one is under construction, and others are in the advanced engineering stages.

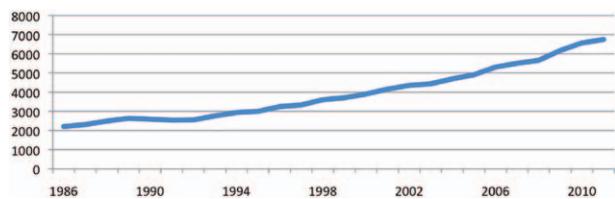


Figure 1. Worldwide hydrocracking capacity (million bpd). Source: Oil & Gas Journal Annual Refining Surveys, 1986 – 2011.

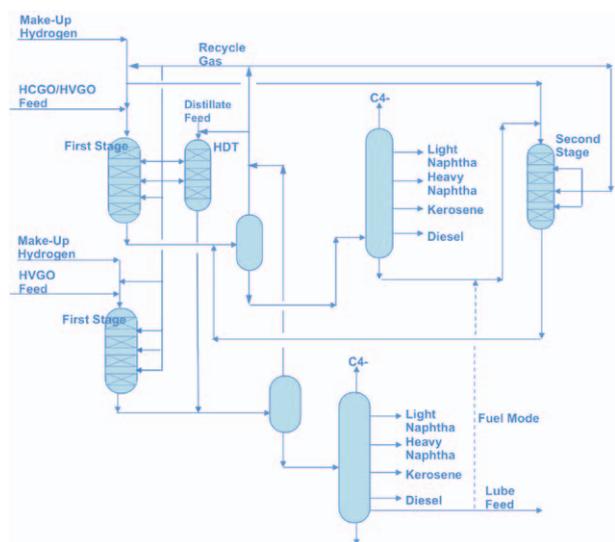


Figure 2. Scheme one, process flow.

	Mid distillates in fuel mode	UCO in lube mode
Yield (%)	93 (Summer); 88 (Winter)	12
S (ppmw)	<6	<10
N (ppmw)	<1	<2
Pour point (°C)	-13 (Summer); -30* (Winter)	-
Cetane index	>53 (Summer); >48 (Winter)	-
Waxy (VI)	-	>140
Run length	36 months	36 months

*The unit is designed to produce a certain amount of Arctic Diesel with a pour point <-45 °C by lowering the recycle cut point (RCP) to second stage

Recent commercial experience shows that most of the high conversion, world scale units processing difficult feedstocks have opted for the two stage recycle (TSREC) process configuration. These units generally feed high nitrogen VGO and coker gas oils while maximising middle distillates production. The flexibility to independently adjust stage one and stage two conversion based on feed quality and product requirements is simply not possible in single stage recycle (SSREC) configurations. For example, for poor quality and/or more refractory feeds, it may be beneficial to reduce stage one conversion to the minimum required to meet the nitrogen target for stage two feed, resulting in a lower catalyst deactivation rate in stage one. This shifts the load to stage two, where the increased severity can be handled because it operates in an NH₃ and H₂S free atmosphere, and has a significantly reduced deactivation rate. In addition, the TSREC process flow scheme also offers:

- The capability to increase conversion in stage one (up to 60%) for processing simpler feeds to maximise the yield of middle distillates.
- Minimum product quality giveaway by optimising conversion in stage one and stage two.
- Up to 10% lower hydrogen consumption compared to SSREC configuration (higher selectivity).
- Lower total installed cost compared to SSREC configuration due to smaller reactors.

CLG has over 30 operational TSREC hydrocracking units with capacity ranging 20 000 – 60 000 bpd. Table 2 presents a summary evaluation of the various processing schemes. This evaluation of hydrocracking shows that, at higher conversion levels (over 80%) and at higher capacities (over 50 000 bpd), TSREC is the most economically attractive configuration.

Clean fuels from heavy feedstocks

Two innovative hydrocracking schemes for clean fuels production are presented as follows:

- Scheme one presents a modified TSREC scheme to process refractory feeds such as HCGO and HVGO. The objective is to maximise diesel with severe cold flow property specifications, along with providing the flexibility to produce feed for group III lube base oils production.
- Scheme two presents CLG's latest patented scheme for residue hydrocracking, called LC-MAX. This technology will permit refiners to convert over 85% of the vacuum residue to VGOs and lighter material, even while processing the most difficult feeds. The process is particularly attractive when a refiner has an existing delayed coking unit that requires debottlenecking or when tightening margins require the refiner to process opportunity crudes.

Scheme one

Produce clean fuels and group III base oils while processing cracked feedstock

This processing scheme is designed for HVGO from West Siberian and Sakhalin crudes, and HCGO to maximise the production of Euro V diesel. This also offers an option to produce feed for the group III lubes (Figure 2). The unit is integrated with a

hydrotreating unit to upgrade distillates using the CLG patented split feed injection technology. HVGO and HCGO are processed in parallel first stage reactor systems with a shared second stage. When the unit operates in fuels mode, the unconverted oil (UCO) from the VGO section is mixed with UCO from the HCGO section and hydrocracked to extinction in the common second stage. In base oil production mode, the UCO bleed is fed to the lube oil unit.

The catalyst system selected for the reactor processing as much as 65% HCGO was primarily Ni-Mo hydrotreating, followed by one of CLG's latest high activity middle distillate selective hydrocracking catalysts. The reactor processing HVGO is loaded with high middle distillate selective hydrocracking catalyst. The catalyst system is tailored for increasing the viscosity index (VI) of the UCO to a level where, after CLG licensed ISODEWAXING technology is applied, group III base oils can be produced. The second stage is loaded with a high distillate selective, high hydrogenation function, second stage catalyst. Table 3 provides the key performance parameters for this scheme.

Scheme two

Clean fuels from residue hydrocracking utilising the LC-MAX process

This scheme offers an advantage over conventional LC-FINING (Table 4) by offering conversion levels of 85+%, even for very difficult residuum. Whole vacuum residue is processed in the first reaction stage and UCO from the first stage is deasphalted in the solvent deasphalting unit (SDA) to remove heavy asphaltenes. The intermediate step of removing asphaltenes offers large savings in hydrogen consumption, which would otherwise have been used to saturate and crack these difficult molecules. Clean deasphalted oil (DAO) from the SDA step is

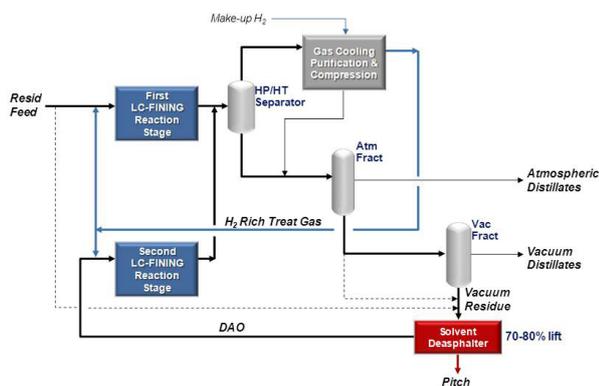


Figure 3. LC-MAX simplified flow scheme.

Table 4. Comparison of LC-FINING with LC-MAX			
	Stand alone LC-FINING	LC-MAX first stage	LC-MAX second stage
Flow rate	Base	Base	0.4 Base
Reactor temperature (°C)	Base	+10	+28
Reactor volume	Base	0.45 Base	0.35 Base
Chemical H ₂ coins	Base	0.7 Base	0.4 Base
Catalyst addition rate	Base	0.75 Base	0.13 Base

hydrocracked at much higher reaction rate in the second stage. Improved reaction rates in the second stage greatly reduce the required reactor size and catalyst addition rate (Table 4). With the second stage now available to achieve conversion at higher reaction rates, first stage conversion can be limited to 48 – 60% to limit sediment formation. Limiting conversion in the first stage also permits operation at relatively high space velocity, thereby offering savings in the reactor size.

Furthermore, by processing DAO, the second stage processing operates at 80 – 95% conversion with negligible sediment formation. This reduced sedimentation also increases the operating factor by minimising the risk of back end equipment fouling. The pitch from the SDA can be fed to a coker, burned in a gasifier, fed to a pelletiser, blended to make bunker fuel or burned as a fuel with cutter stock. A recent study for a refiner with a 40 000 bpd LC-MAX unit showed that 165 tpd of hydrogen or 165 MW of power can be generated by feeding pitch to a gasifier.

The VGO and lighter products from the LC-MAX process can be upgraded within the same high pressure loop as the LC-MAX process using the integrated hydroprocessing concept first commercialised by CLG for a major refiner in Canada, and again in Northern Europe. The basic process flow for this scheme is illustrated in Figure 3.

Trend towards cleaner fuels

The global push towards clean fuels is in full swing as more and more countries impress stricter policies onto fuels in order to reduce their carbon footprint. Over the next 20 years the global energy demand is expected to rise by almost 40%, with most of this demand growth occurring in developing countries such as China and India. Coupled with this demand will be an even greater drive to reduce carbon emissions with cleaner fuels, as well as a bigger push to increase the blending targets for biofuels and renewable fuels into the fuels market. In essence, it will be increasingly more difficult to meet clean fuels requirements.

With the majority of emissions coming from on road vehicles, the mandates around clean fuels and emissions reduction also impact the lubricants market, where formulators are now required to produce engine oils and transmission fluids with lower volatility and enhanced oxidation stability, as well as contributing to better fuel economy. Formulators have had to shift from group I to more group II/III base oils in order to meet these requirements. Group I base oils are traditionally produced by solvent refining, whereas group II/III base oils are produced using an all hydroprocessing route that utilises hydrocracking to meet viscosity index, sulfur and aromatics requirements. As such, CLG hydrocracking and hydroprocessing technology is favourably positioned for both clean fuels and high quality base oils.

With the projected rise in energy demand and continued trend towards cleaner fuels, global hydroprocessing capacity is expected to increase to meet the challenge. In the long term, refiners must continue to look for creative ways to boost refining margins with low value feedstocks while meeting the changing clean fuels requirements. CLG's innovative and cost effective hydroprocessing technology solutions are expected to continue to deliver clean fuels to the marketplace for the foreseeable future.