IsoTherming® Hydroprocessing Technology – A Low Cost Revamp Solution

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Synopsis

The demand for most finished fuel products is expected to exceed pre-pandemic levels by mid-2022. The sustained demand and lack of investment in Latin American refining assets may pose a substantial threat to many refiners in the region if investments for improving fuel quality and quantity are not made. Utilization has been historically low in the region throughout the last couple of years, and it is forecasted to remain this way leaving the region's refiners dependent on imports to meet the increasingly stringent fuel regulations. Increasing challenges are foreseen with importing finished fuel products given the global refining rationalization that occurred as a direct result of the pandemic.

The IsoTherming® hydroprocessing technology is a commercially proven solution that enables refiners to reduce sulfur in finished products to ultra-low levels with low capital investment while maximizing the energy efficiency of the unit. By significantly reducing the need for both fuel gas and steam, the IsoTherming® technology is not only the most energy efficient hydroprocessing technology, but also the most environmentally friendly through its lower carbon dioxide generation compared to conventional trickle bed hydroprocessing. The core of the IsoTherming® technology is the ability to provide the hydrogen necessary for the reactions using a liquid stream rather than a recycle gas system. The reactor feed is saturated with hydrogen, which eliminates the need for a recycle gas compressor.

This paper describes the principles of the IsoTherming® technology and highlights the energy efficiency, versatility and robustness of the process. Two recent revamp case studies will be showcased that demonstrate the benefits of the IsoTherming® technology specifically in the areas of energy efficiency and margin improvement through maximizing the ability to process difficult feedstocks.

In addition to increasingly strict regulations on fuel specifications, requiring investment, such as sulfur and cetane, refiners in this region are also under pressure to look for ways to comply with the pressure to produce products from renewable feedstocks. The IsoTherming® technology is well suited to provide refiners with a cost-effective option for co-processing renewable feedstocks in the existing hydrotreater units. The IsoTherming® technology is uniquely advantaged to manage the high heat of reaction that comes with processing these renewable components which has proven to be a challenge to those operating hydroprocessing units with the traditional trickle bed technology. A discussion of co-processing renewable components and its impact on unit design and operation will be included in the paper.

Introduction

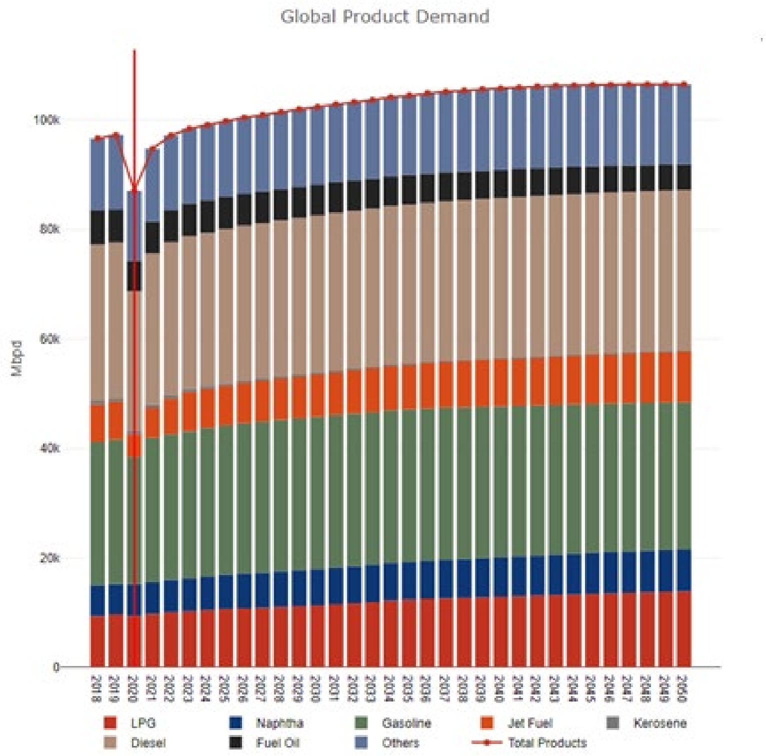
Latin American Demand for Fuel Products

Latin America is projected to see growth in demand for finished products through 2050 driven by both population growth and improvement in the standard of living. The current Latin American refineries will be challenged to produce the necessary products due to an aging refining fleet that is coming off a recent run of lower than normal utilization rates. Although this region already experiences low run rates due to weak economics and lack of investment, the onset of the COVID-19 pandemic further depressed utilization when demand plummeted, and companies struggled with storage constraints. During the last two years, North America has experienced refinery rationalization, with additional streamlining to come, however surviving refiners are enjoying high margins thanks in part to the continued flow of products from the U.S. to Latin America. By mid-2020 U.S. Gulf Coast refiners saw levels of finished fuel exports to Latin America increase as pandemic lockdowns in Latin America began to ease which is on par with the yearly exported volumes from the two years prior to the pandemic (2018, 2019). In total, over 1 million barrels of finished distillate range products (diesel, jet fuel, kerosene) were exported to Latin America from the U.S. in 2020, which kept U.S. refining utilization rates above 70% for the full year. The flow from the U.S. to Latin America is expected to remain at this high level for the foreseeable future unless investment is made in this region's existing refining assets.

From a global perspective, the demand for most finished fuel products is expected to exceed pre-pandemic levels by mid-2022 as can be seen by Figure 1.

Figure 1

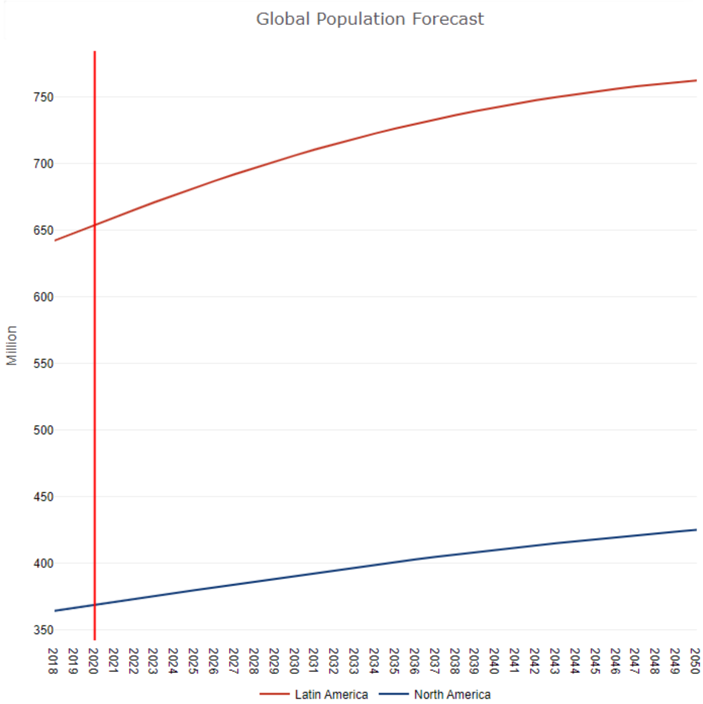
Global Product Demand, Stratas Advisors December 2021



While North America will see product demand peak within the next 15 years, a different story will unfold in the southern hemisphere. As Figure 2 shows, the Latin American population is projected to increase steadily and at a faster rate than the North American population through 2050 bringing economic growth to the region.

Figure 2

Latin America vs. North America Population Forecast, Stratas Advisors December 2021

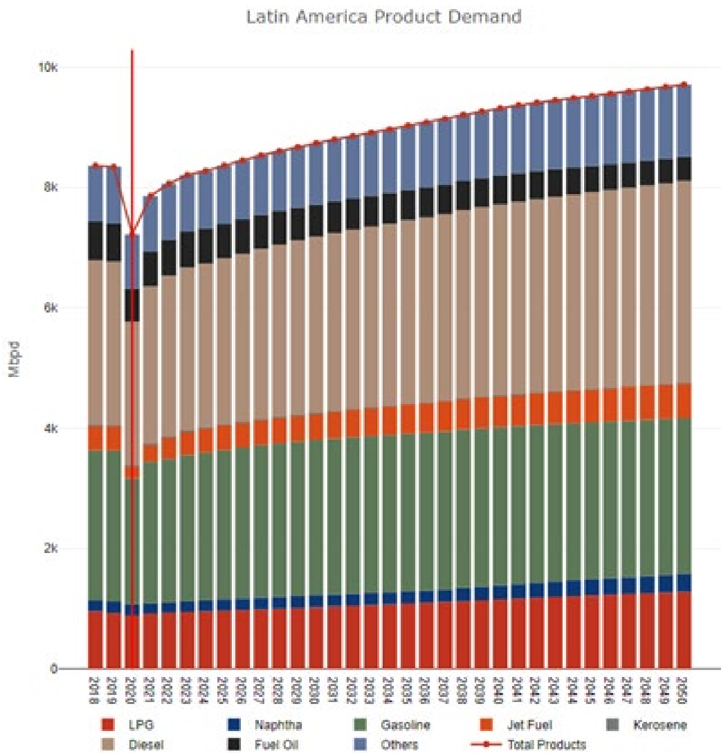


Much of that population growth will be concentrated around urban centers rather than historically rural areas. This demographic will require access to passenger vehicles for personal use as well as movement of goods and people, thus propelling the demand for finished fuel products to continue to increase through 2050.

Figure 3 illustrates the projected growth in finished fuel products, which is estimated to be 1.8 million bpsd between 2021 and 2050, a 0.73% compound annual growth rate (CAGR) for this period.

Figure 3

Latin America Product Demand, Stratas Advisors December 2021



Looking deeper into the distillate range products, significant growth in demand is expected for both jet fuel and diesel. Although air travel has not fully returned to pre-pandemic levels, major airlines are continuing to increase connectivity, frequently announcing new international routes added to their portfolio. Figure 3 shows an estimated growth of jet fuel demand in Latin America around 300 thousand bpsd between 2021 and 2050, which is a 2.44% CAGR.

Diesel, which is currently the most widely consumed refining product in the world, will be an important piece of Latin America's economic development. Without diesel, transportation of goods, agriculture and other sectors will all be negatively impacted. Figure 3 shows an estimated growth in diesel demand of 750 thousand bpsd between 2021 and 2050, which is 0.87% CAGR.

The growth rates of both jet fuel and diesel outpace projected global growth rates of 1.85% CAGR and 0.21% CAGR, respectively, further illustrating the impact that the Latin America region will have on the global fuel market in the coming years.

While it is now obvious that there will be an increase in demand for quantity of refined distillate products, it is worth noting that Latin America will also see an increase in demand for higher quality products in the coming years. While some parts of the world, such as North America and western Europe, have been producing fuels compliant with the strictest specifications for quite some time, Latin America is somewhat scattered when it comes to regulations on fuel quality. To date, the region has not taken a holistic approach and instead has taken a country by country approach leading to some countries, like Chile, investing in their assets and producing Euro V compliant fuels for many years already, while other countries, like Argentina and Peru have announced regulations but implementation has not yet occurred.

Figure 4

Sulfur Limits for On-Road Diesel, Stratas Advisors April 2021

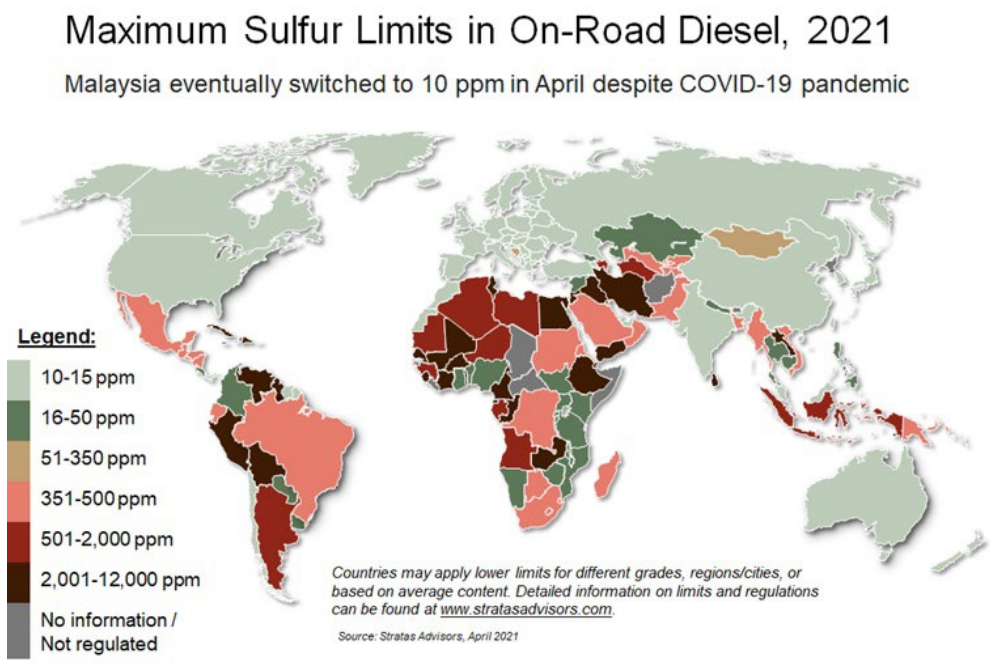
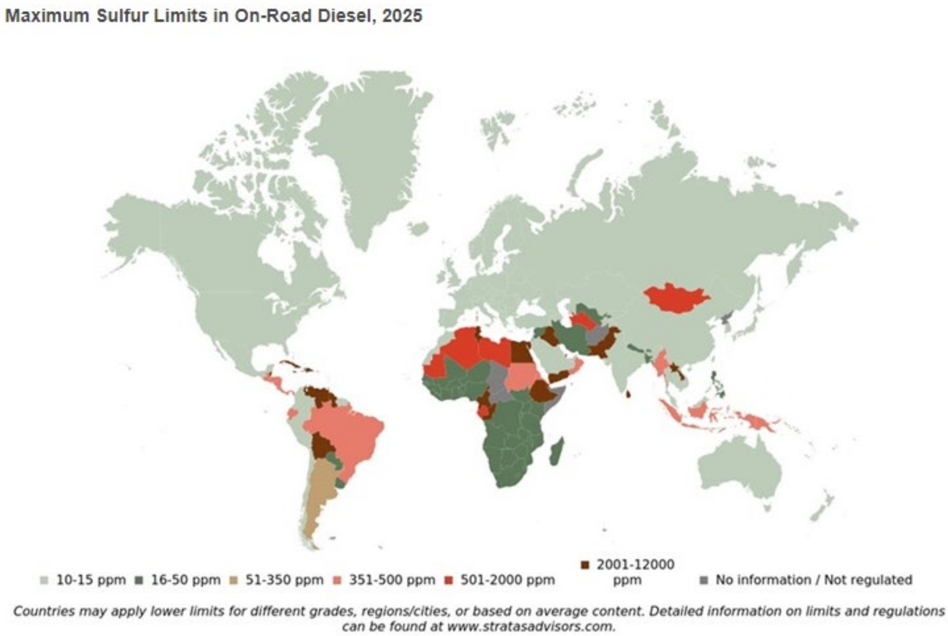


Figure 4 illustrates that the majority of Latin America does not currently have a maximum specification of 10-15 ppm sulfur content in on-road diesel similar to much of the industrialized world, including two of the world's top 10 markets for consumption of on-road diesel (Brazil at #4 and Mexico at #10).

As can be expected by such a growing market, there is pressure on the Latin American region to clean up fuel quality to conform with the world's agenda of clean energy. Currently, numerous countries in the region, including but not limited to Peru, Argentina and Colombia all have proposed regulations to reduce national sulfur limits for on-road diesel. In addition to limiting sulfur content, some countries are expanding regulations to other product properties such as cetane, modeling the Euro VI specification of a minimum cetane number of 51, helping with quicker ignition and a reduction in harmful NOx emissions.

Figure 5

Projected Sulfur Limits for On-Road Diesel in 2025, Stratas Advisors October 2021



Coupling the rising demand for finished fuels with the impending environmental regulations in much of the Latin American region, refiners will need to evaluate options for upgrading or adding to their hydrotreating assets to meet these requirements. In the current economic and political environment in the region, having a low capital cost option for doing so is critical, otherwise imports from the United States Gulf Coast will be required in large quantities to serve this region.

Introduction to the IsoTherming® Hydroprocessing Technology

The IsoTherming® hydroprocessing technology is a commercially proven process that provides refiners worldwide a more economical means to produce today's transportation fuels. Implementing the IsoTherming® technology enables refiners to not only produce high-quality, low-sulfur fuels compliant with local environmental regulations, but also decrease energy consumption and operating costs when compared with historical trickle bed hydroprocessing technologies. The proven reliability and operational flexibility of the technology also enables refiners to meet business sustainability and social responsibility objectives.

Figure 6

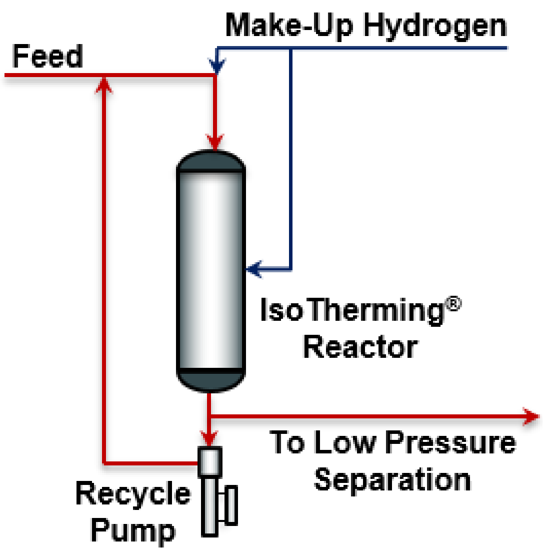
IsoTherming® Reactor in Commercial Service

The fundamental principle of the IsoTherming® technology is the ability to provide the hydrogen necessary for the chemical reactions using a liquid stream, rather than a including recycle gas system. The reactor feed is saturated with hydrogen, which eliminates the need for a recycle gas compressor and amine absorber. To satisfy hydrogen requirements within the reactor, additional hydrogen can be added by means of an external liquid recycle stream and/or inter-bed hydrogen injection. Feed types that have low hydrogen demand, such as kerosene, do not require an external recycle stream to satisfy hydrogen availability requirements.

Operating the reactor liquid-full also acts as a heat sink for the exothermic reactions. Thus, the reactor operates closer to isothermal conditions, which reduces uncontrolled cracking reactions and lowers light ends make.

Figure 7

IsoTherming® Reaction Zone



The type of hydroprocessing application, product objectives and chemical hydrogen requirements dictate optimal reactor design considerations that include, but are not limited to, number of catalyst beds and recycle ratio. The IsoTherming® reactor design is robust and has been commercially proven to successfully provide over 160% percent of design chemical hydrogen consumption while processing fluctuating feedstocks. This flexibility allows refiners the ability to process a wide variety of feeds to maximize refinery profits.

The IsoTherming® technology currently has 29 licenses comprised of 24 grassroots units and 5 revamp units. There have been 16 commercial installations of the technology. Applications for the IsoTherming® technology, whether grassroots or revamp, include:

- ✓ Kerosene Hydrotreating
- ✓ Transmix Hydrotreating
- ✓ Diesel Hydrotreating
- ✓ FCC Feed Hydrotreating
- ✓ Mild Hydrocracking
- ✓ Dewaxing
- ✓ Gas-To-Liquid (GTL) Upgrading
- ✓ Heavy Oil Upgrading

Reduced Operating Expenses

By eliminating the hydrogen gas compressor and its ancillary recycle loop equipment, significant maintenance and operating cost savings can be realized. The IsoTherming® process does not require heating large quantities of recycle gas in the charge heater providing additional fuel gas consumption savings. Overall, the IsoTherming® technology has consistently demonstrated a 40-60% utility savings over trickle bed technology including:

Table 1

Utility Savings Associated with the IsoTherming® Technology

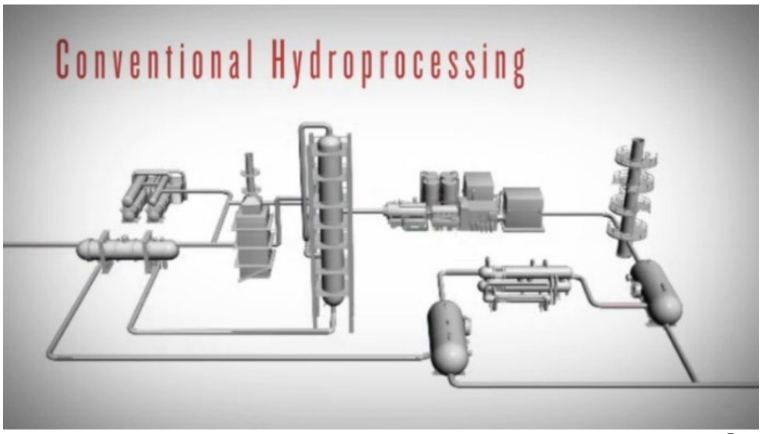
Fuel Gas	Power	Energy Recovery
30 - 60% Reduction	30 - 40% Reduction	30 - 50% Increase
• No need to heat large quantities of recycle gas • Lower heater firing rates in normal operation • Lower greenhouse gas emissions	• Eliminates the electrical requirements of a recycle gas compressor	• Optimized heat integration allows for maximum steam generation • Power generation possible with minimum high-pressure operating requirements

Capital Cost Advantages

The IsoTherming® technology has demonstrated significant capital cost advantages. This advantage is particularly pronounced in hydroprocessing revamps and low hydrogen consumption applications. For grassroots units, capital cost savings over 30-50% have been achieved dependent upon the application under consideration and global economic factors.

Figure 8

Layout of Conventional Trickle Bed Hydroprocessing Unit

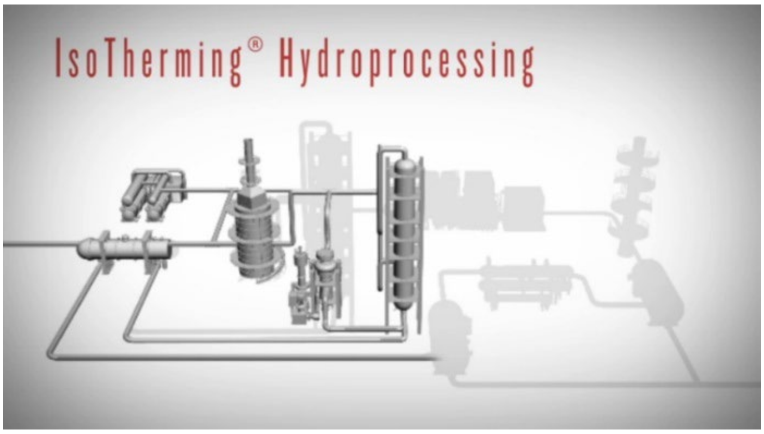


Revamps of existing trickle bed hydrotreaters with the IsoTherming® technology can offer refiners an extreme capital cost savings if bottlenecks exist with the unit in high pressure sections such as the feed heater or recycle gas compressor loop. Two case studies are included in the following sections of this paper to illustrate this is greater detail.

As mentioned, the IsoTherming® technology process configuration does not require heating recycle gas. As such, the feed/effluent exchanger heat duty requirements are reduced, which contributes to a significant reduction in high pressure heat exchanger shells that are required when comparing to an equivalent trickle bed design. Furthermore, separation of hydrocarbon and gas in order to recover the recycle gas is not required with the IsoTherming® process. Consequently, the IsoTherming® process does not require high- or low-pressure separation vessels and air coolers for the reactor effluent before entering the stripper or fractionator.

Figure 9

Layout of IsoTherming® Hydroprocessing Unit



For projects with low hydrogen consumption, the ability to supply the hydrogen through feed saturation without requiring a recycle pump results in even fewer pieces of high-pressure equipment resulting in lower capital costs.

Increased Catalyst Life

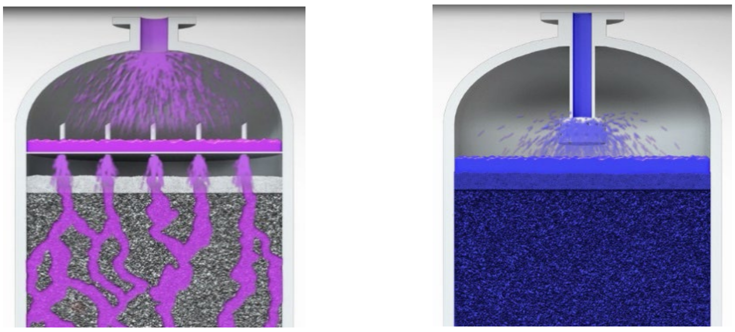
Within a liquid-full reactor, the IsoTherming® technology ensures the catalyst is completely wetted thus drawing the heat of reaction away from the catalyst surface and minimizing local hot spots. In addition, even liquid flow throughout the catalyst bed results in a uniform radial temperature profile. The liquid flow regime within the reactor minimizes light ends generation and catalyst deactivation due to reduced coke formation.

The IsoTherming® reactors achieve target sulfur product specifications with lower catalyst deactivation rates when compared to trickle bed reactors in similar service, even with significant variability in feed quality and feed flowrate. These claims are further supported commercially by several operating Vacuum Gas Oil units that have experienced catalyst life in excess of 4 years.

Figure 10

Comparison of Trickle Bed vs IsoTherming Flow Regime

Trickle Bed Flow Regime IsoTherming® Reactor Flow Regime



These benefits indicate that the IsoTherming® technology is well suited to provide the Latin American region with a low cost, high benefit solution for upgrading their refining fleet to meet anticipated demand in the years to come. The following case studies will detail exactly how the IsoTherming® technology has proven its value to two refineries through revamps of their existing hydroprocessing units.

Development

Case Study #1 – Refinery A

The first case study detailed is for Refinery A, located in Western Europe. Refinery A has an existing trickle bed diesel hydrotreater that lacks a recycle gas compressor. This unit currently produces ultra-low sulfur diesel with poor cycle length. Even at reduced throughput rates, current cycle length ranges from 12-14 months. Additionally, Refinery A is currently very limited on processing any cracked feedstock in this unit, forcing them to send nearly all cracked feedstock to the other high-pressure diesel hydrotreater unit in the refinery.

Evaluation by catalyst suppliers has concluded that a catalyst upgrade by itself could not achieve the desired product and operating targets due to unit constraints. Therefore, Refinery A chose to evaluate the option of a unit revamp for their low-pressure diesel hydrotreater unit.

Refinery A extensively studied the revamp solution with the current trickle bed technology and compared to a revamp solution offered by Elessent Clean Technologies with the IsoTherming® technology. The trickle bed revamp was considerably more expensive with less benefit than what could be achieved with the IsoTherming® technology. A full conversion of the unit to liquid phase with the IsoTherming® technology will provide the customer not only extended cycle length, but a return to nameplate capacity and the ability to process cracked feedstock. A summary of the key benefits can be seen in Table 2.

Table 2

Refinery A – Current Operation vs IsoTherming® Revamp

Parameter	Current	IsoTherming® Revamp
Capacity	149 Sm^3/hr	205 Sm^3/hr (↑ 38%)
% Cracked Feedstock	0%	8.1%
Feed Density @ 20°C, kg/m^3	860	909 (+ 49 points)
LHSV hr^{-1}	0.34	0.78
Cycle Length	12-14 months	36 months (↑ 3x)
Recycle Hydrogen	Once thru	Recycle Pump

Refinery A's desired feed blend to the unit under discussion is shown in Table 3.

Table 3

Refinery A – Revamp Feed Basis

Parameter	Blended Feed
Capacity	205 Sm^3/hr
Density @ 20°C, kg/m^3	909
Distillation, °C / °F	
IBP	197 / 387
50%	343 / 649
95%	374 / 705
EBP	383 / 721
Sulfur, wppm	11,000
Nitrogen, wppm	902
Bromine Number, g/100g	3.3
Mono Aromatics, wt%	18.0
Poly Aromatic, wt%	24.9
Total Aromatics, wt%	42.9

The blended feedstock is combination of straight run gas oil (SRGO), vacuum diesel (VD), unifiner gas oil, light cycle oil (LCO) and light vacuum gas oil (LVGO). The blend not only has high nitrogen content but the characterization of the nitrogen and polyaromatic species that will be seen in such a distillation range make for an especially challenging operation. The objectives for the revamp with this blended feed are as follows:

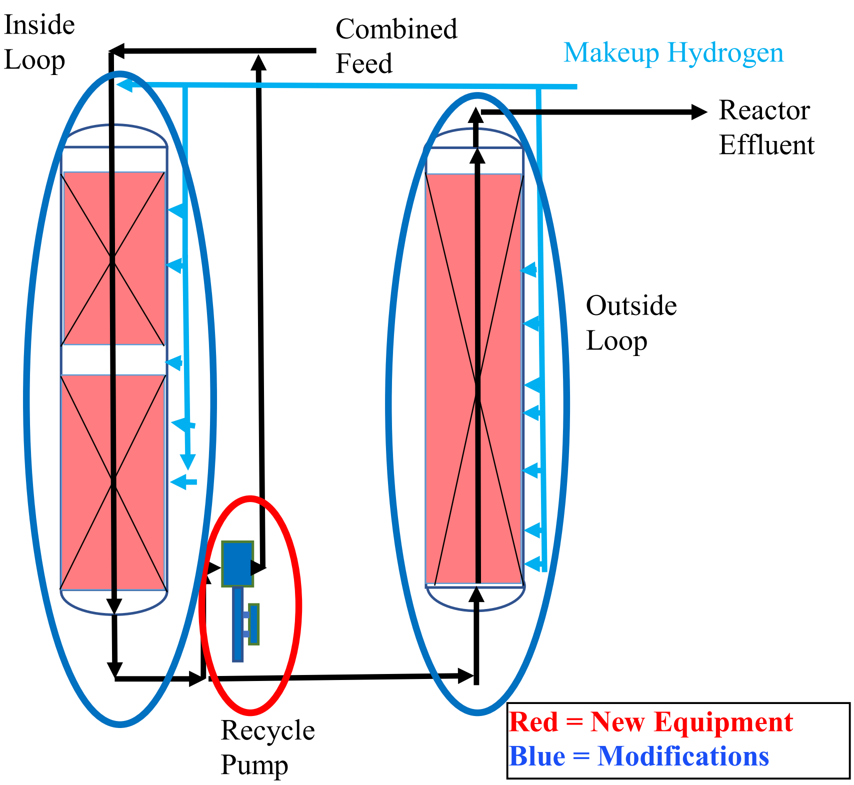
- Maximum diesel product sulfur of 7 wppm
- Minimum density shift of 25 kg/m^3
- Minimum diesel flash point of 60°C
- Diesel product ASTM Color not greater than 2

In the unit's current operating state, although the unit achieves sulfur specification at the reduced capacity, density shift is much less than the refinery objective, and the unit produces high ASTM colored diesel due to the temperature requirement for meeting the sulfur specification.

Figure 11 illustrates the modifications to the unit's reaction zone after revamp with the IsoTherming® technology.

Figure 11

Refinery A Revamp Reaction Zone



Refinery A's current unit has two equal sized reactors operating in series, each containing two catalyst beds. The revamp solution does not add any additional catalyst volume and converts both reactors (continuing to operate in series) to the liquid phase IsoTherming® technology by replacing the internals with proprietary IsoTherming® reactor internals. Additionally, a recycle pump is added allowing the first reactor to operate with a liquid recycle (designated as inside loop) and the second reactor will operate in a once-through, upflow mode (designated as outside loop).

Utilizing this configuration allows the first reactor to operate with a high hydrogen partial pressure and low temperature rise which is key for the refinery's density shift objective as well as the cycle length extension. The second reactor performs the final desulfurization to meet the refinery's sulfur specification.

A summary of operating conditions at both start-of-run (SOR) and end-of-run (EOR) is shown in Table 4.

Table 4

Refinery A – Revamp Reaction Zone Conditions

Parameter	SOR	EOR
Reactor 1 Inlet Temperature, °C / °F	350 / 651	365
Reactor 1 Temperature Rise, °C / °F	17 / 63	13 / 55
Reactor 1 Inlet Pressure, $kg/cm^2(g)$ / psi(g)	66.3 / 943	66.3 / 943
Overall Reaction Zone Pressure Drop, kg/cm^2 / psi	3.7 / 53	5.0 / 71
Overall Active Catalyst LHSV, hr^{-1}	0.78	0.78
Overall Chemical Hydrogen Consumption, Nm^3/m^3 / scf/bbl	107.8 / 604	96.8 / 542
Cycle Length, months	36	

The reactor inlet temperature is selected to maximize the amount of hydrodentirogenation achieved in the first reactor, which is critical for achieving the extension in cycle length. Although there is high hydrogen consumption in the system due to the polyaromatic content, the large volume of liquid recycle in the first reactor (inside loop) significantly reduces the temperature rise, also benefitting cycle length. By bringing the unit back up to its nameplate capacity of 205 Sm^3/hr (30,945 bpsd), the active catalyst liquid hourly space velocity (LHSV) is raised to an equivalent 0.78 hr^{-1} overall. Even with the increase in operating capacity the pressure drop is much lower throughout the system due to the liquid full operation of the IsoTherming® technology. This provides higher hydrogen partial pressure in the reactor, benefitting reaction kinetics and allowing for the use of nickel molybdenum (NiMo) catalyst as the active catalyst. The current operation is limited to the use of cobalt molybdenum (CoMo) catalyst as the active catalyst due to the hydrogen partial pressure and high temperature requirements. NiMo is essential to the treatment of this feedstock for an extended cycle length due to its superior hydrodenitrogenation performance.

A summary of the feedstock and expected product properties at SOR and EOR conditions is shown in Table 5, which demonstrates that all objectives are met:

Table 5

Refinery A – Revamp Feed and Diesel Product Properties

Parameter	Blended Feed	SOR Diesel Product	EOR Diesel Product
Capacity	205 Sm^3/hr	209 Sm^3/hr	208 Sm^3/hr
Density @ 20°C, kg/m^3	909	875	881

Distillation, °C / °F			
IBP	197 / 387	147 / 297	154 / 309
50%	343 / 649	319 / 606	324 / 615
95%	374 / 705	361 / 682	364 / 687
EBP	383 / 721	377 / 711	378 / 712
Sulfur, wppm	11000	≤7	≤7
Nitrogen, wppm	902	≤2	≤2
Bromine Number, g/100g	3.3	0.1	0.1
Mono Aromatics, wt%	18.0		
Poly Aromatic, wt%	24.9	≤10	≤10
Total Aromatics, wt%	42.9		

Below is a comprehensive list of the proposed changes to the unit equipment:

New Equipment:

- New reactor recycle pump and warehouse spare
- Diesel product coalescer
- Vacuum drying tower
- Water wash pump
- Reactor effluent / medium pressure (MP) steam generator[1]
- Reactor effluent / MP steam superheater[1]
- Reactor vent / MP steam generator[1]
- Hot diesel feed / stripper bottoms exchanger[1]
- Feed / 1st reactor effluent exchanger[1]

Modified Equipment:

- Replace both reactors internals with IsoTherming® internals and Hydrogen Injection Devices (HIDs)
- Retraying the bottom portion of the stripper
- Larger impeller and driver for feed pump
- Diesel product pump – repurposed to vacuum drying tower bottoms

Decommissioned:

- Water wash pump
- Water injection pump

[1]This piece of equipment was added after a cost / benefit analysis

Feedback from Refinery A indicated that the proposed trickle bed revamp solution was much more capital cost intensive and included a much longer list of new equipment including a new recycle gas compressor (and associated high pressure auxiliary equipment such as amine absorber and heat exchangers). Even with a new recycle gas compressor the trickle bed technology was unable to offer the same extension in cycle length at the nameplate capacity as the IsoTherming® technology, and additional catalyst volume or reduced feedstock rates were required to meet a similar cycle length.

Not only is this revamp solution with the IsoTherming® technology a low capital cost endeavor, but it has additional operating efficiency benefits for Refinery A. The feedstock under review has a very high hydrogen consumption and thus a high heat release. Due to the extremely energy efficient nature of the IsoTherming® technology coupled with this high heat release, the feed fired heater is only required to operate at minimum operation rates outside of start-up conditions. Even at this minimum rate, there is surplus heat after pre-heating the feed. Therefore, a cost / benefit analysis was conducted, and it was deemed economical to utilize the excess heat of reaction to produce medium pressure steam in the unit. Table 6 quantifies the high-pressure energy savings expected post-revamp with the IsoTherming® technology compared to current trickle bed operation:

Table 6

Refinery A – Utility Comparison IsoTherming® Revamp vs. Current Operation

Parameter	Trickle Bed	IsoTherming®
Normal Operating Charge Heater Duty, MMkcal/hr	4.936	1.780
% Savings	-	64%
Fuel Gas, kg/hr	414	149
Fuel Gas Value, $/yr[1]	$ (1,233,224)	$ (444,711)
Steam Produced, kg/hr	0	10,281
Steam Value, $/yr[2]	$	$ 891,035
Annual Net Value of Utility Consumption / Production	$ (1,233,224)	$446,324

[1] Based on a Fuel Gas Value $/MMkcal of 29.7 USD

[2] Based on Steam Value $/1000 kg of $10.3 USD

Based on the assumed cost values of fuel gas and steam, the revamp saves Refinery A $1.7 MM USD ($51 USD / barrel of feedstock) annually in high pressure utilities alone. Additional savings are also expected from low pressure utilities.

This revamp solution is not only attractive from a capital and operating cost standpoint, but it lowers the carbon footprint of the refinery due to the reduction in combustion of fuel gas from the fired heater. Based on the normal operating duties shown in the above table, the reduction of CO_2 emissions is equivalent to the removal of over 1,200 light passenger vehicles annually (based on heat content of propane of 139 MMBtu and 4.6 metric tonnes CO_2 emissions / year from a single light passenger vehicle). Support for the revamp of Refinery A's diesel hydrotreater unit with the IsoTherming® technology continues in anticipation of a 2025 start-up date.

Case Study #2 – Refinery B

The second case study is for Refinery B, located in Latin America. Refinery B has an existing trickle bed diesel hydrotreater with an approximate capacity of 212 Sm^3/hr (32,000) bpsd that has been operational for less than 7 years. This hydrotreater currently produces a diesel product with a maximum sulfur content of 50 ppm and achieves a cycle length of approximately 3 years. The refinery is investigating options for upgrading the product quality produced from this unit to comply with an impending regulation implementing Euro VI diesel quality. An evaluation by the incumbent licensor determined that additional catalyst volume (a new additional reactor) would be required to meet the Euro VI specification, and even with the additional catalyst volume, a reduction in catalyst cycle length to 2 years should be expected.

Elessent Clean Technologies worked closely with Refinery B to evaluate multiple revamp scenarios involving a range of capacity increases as well as varying LCO content. A comparison of the final revamp conditions compared to current operation is presented in Table 7.

Table 7

Refinery B –Current Operation vs IsoTherming® Revamp

Parameter	Current	IsoTherming® Revamp
Capacity	212 Sm^3/hr	298 Sm^3/hr (↑ 40%)
% LCO	16 vol%	14 vol%
Product Sulfur	50 ppm	≤ 10 ppm
LHSV hr^{-1}	1.1	1.1
Cycle Length	36 months	36 months
Catalyst System	CoMo	NiMo

It was determined that additional catalyst volume would be required in order to produce Euro VI compliant diesel with the conversion to the IsoTherming® technology. The refinery desired to minimize fuel oil production and thus maximize the processing of LCO in the revamped unit. The final revamp capacity includes all of the available LCO from the refinery and also increases the capacity of the unit to allow for Refinery B to import off spec product and upgrade it for compliance with the Euro VI specification. In expanding the capacity of the unit, Refinery B has significantly increased the profitability of a regulatory driven project for minimal additional capital cost, which will be discussed in the next sections.

Refinery B's desired feed blend to the unit under discussion is shown in Table 8.

Table 8

Refinery B – Revamp Feed Basis

Parameter	Blended Feed
Capacity	298 Sm^3/hr
Density @ 15°C, kg/m^3	857
Distillation, °C / °F	

IBP	55 / 131
50%	282 / 540
95%	385 / 725
EBP	416 / 781
Sulfur， wppm	2298
Nitrogen， wppm	275
Bromine Number, g/100g	2.0
Mono Aromatics, wt%	16.1
Poly Aromatic, wt%	15.3
Total Aromatics, wt%	31.4

The blended feedstock is combination of eight streams: two straight run diesel (SRD) cuts, straight run naphtha (SRN), two light vacuum gas oil (LVGO) cuts, two straight run kerosene (SRK) cuts and light cycle oil (LCO). Although the total nitrogen content is not extremely high it should be noted the nitrogen species expected are high in molecular weight and low in reactivity based on the distillation of that stream. Additionally, the aromatic content in this distillation range will be challenging due to reactivity and their saturation is imperative to meet the cetane specification as part of the Euro VI product quality.

The specific Euro VI product quality specifications that must be met as part of the revamp are as follows:

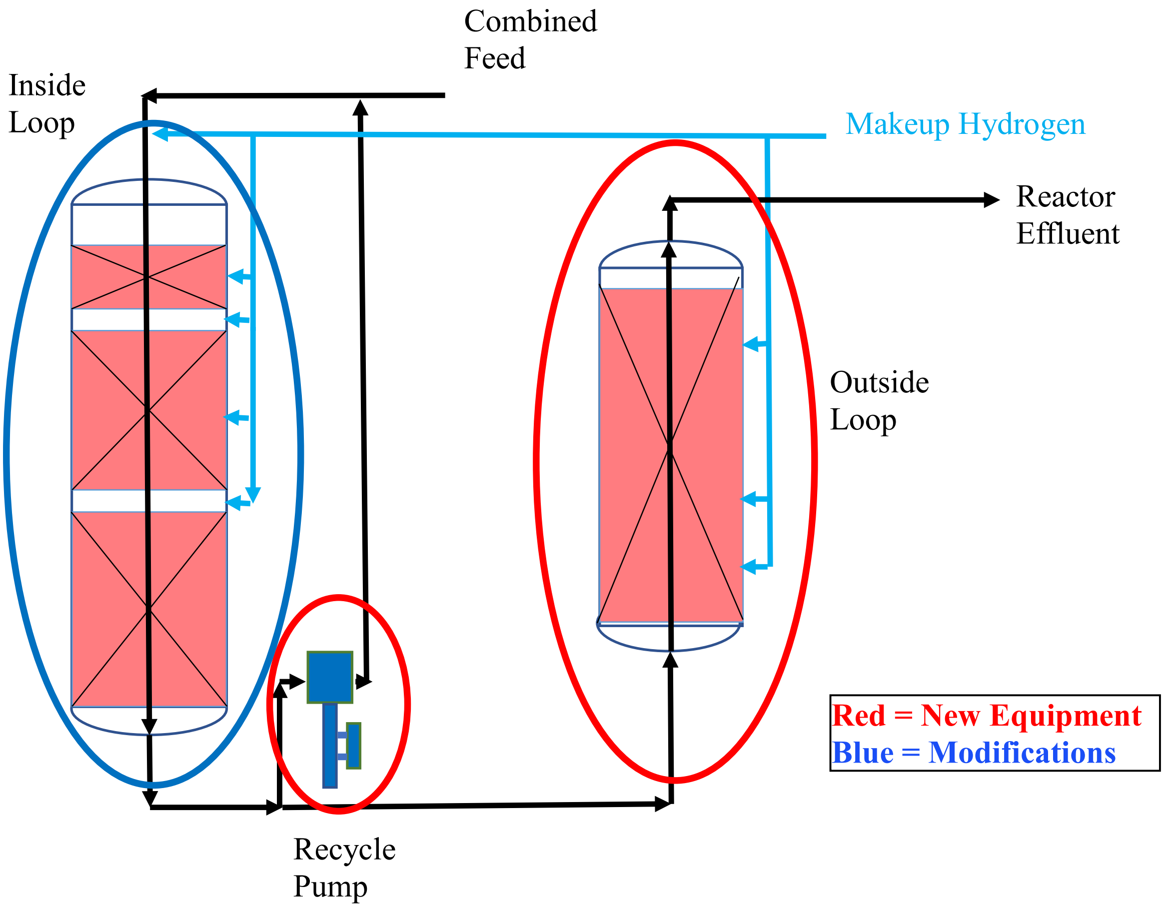
- Maximum diesel product sulfur of 10 wppm
- Diesel density @15 °C 820 – 845 kg/m3
- Maximum diesel polyaromatics content 8 wt%
- Minimum diesel cetane number 51
- Minimum diesel cetane index 46

Refinery B has successfully produced diesel with less than 10 ppm sulfur content, however the polyaromatics and cetane specifications were not achieved. Additionally, the operating conditions required to achieve 10 ppm sulfur indicated cycle length would be severely reduced from the typical 3 years when operating at these conditions, thus the requirement for the trickle bed revamp scenario is to add additional catalyst volume.

Figure 12 illustrates the reactor section of the unit with the revamp to the IsoTherming® Technology.

Figure 12

Refinery B Revamp Reaction Zone



Refinery B's unit currently has a single reactor with three catalyst beds. The existing reactor internals will be replaced with proprietary IsoTherming® reactor internals. Additionally, a new reactor will be added to operate in series with the existing reactor. A new reactor recycle pump will be added and the existing reactor will operate with recycle (inside loop) while the new reactor will operate as a once through upflow reactor (outside loop). Not shown in the above picture is a new heat exchanger that will be added between the two reactors to allow for independent temperature control.

Similar to the revamp proposed to Refinery A, utilizing this configuration allows the first reactor to operate with a high hydrogen partial pressure and low temperature rise, which is critical for meeting the cetane specification. A summary of operating conditions at both start-of-run (SOR) and end-of-run (EOR) is shown in Table 9.

Table 9

Refinery B – Revamp Reaction Zone Conditions

Parameter	SOR	EOR
Reactor 1 Inlet Temperature, °C / °F	357 / 675	372 / 702
Reactor 1 Temperature Rise, °C / °F	5.3 / 8.6	4.5 / 7.9
Reactor 1 Inlet Pressure, kg/cm^2(g) / psi(g)	64.0 / 943	64.0 / 943

Overall Reaction Zone Pressure Drop, kg/cm^2 / psi	6.3 / 90	8.2 / 116
Overall Active Catalyst LHSV, hr^{-1}	1.1	1.1
Overall Chemical Hydrogen Consumption, Nm^3/m^3 / scf/bbl	43.0 / 241	39.3 / 220
Cycle Length, months	36	

As can be seen from the above table, although additional catalyst volume is being added for the revamp, the active catalyst LHSV is staying constant with current operation. Reactor 1 will perform the majority of the hydrodenitrogenation at the conditions shown above. The second reactor will have independent temperature control with the addition of the new inter-reactor heat exchanger, allowing the refinery the flexibility to tune its operating temperature while in operation to meet the cetane and polyaromatics specifications for the duration of the cycle length.

The current operation of the unit is limited by pressure drop issues within auxiliary equipment in the recycle gas loop, thus the current reactor inlet pressure is nearly 10 $kg/cm^2(g)$ below design pressure. As the IsoTherming® technology does not utilize this high-pressure auxiliary equipment in this same service, after the revamp Refinery B will again see the operation return to the design inlet pressure of 64 $kg/cm^2(g)$, thus paving the way for use of NiMo catalyst – critical for meeting the full suite of Euro VI specifications.

A summary of the feedstock and expected product properties at SOR and EOR conditions is shown in Table 10, which demonstrates all objectives are met.

Table 10

Refinery B – Revamp Feed and Diesel Product Properties

Parameter	Blended Feed	SOR Diesel Product	EOR Diesel Product
Capacity	298 Sm^3/hr	292 Sm^3/hr	291 Sm^3/hr
Density @ 15°C, kg/m^3	857	844	845
Distillation, °C / °F			
IBP	59 / 138	81 / 178	89 / 192
50%	282 / 540	279 / 534	281 / 538
95%	385 / 725	382 / 720	384 / 723
EBP	416 / 781	413 / 775	414 / 777
Sulfur，wppm	2298	≤10	≤10
Nitrogen，wppm	275	≤2	≤2
Bromine Number, g/100g	2.0	0.1	0.1
Mono Aromatics, wt%	16.1		
Poly Aromatic, wt%	15.3	≤8	≤8

Total Aromatics, wt%	31.4

Below is a comprehensive list of the proposed changes to the unit equipment:

New Equipment:

- New reactor
- New reactor recycle pump
- Reactor effluent / MP steam generator[1]
- Hot low-pressure separator[1]

Modified Equipment:

- Replace existing reactor internals with IsoTherming® internals and HIDs
- Retraying the top portion of the stripper

[1] This piece of equipment was added after a cost / benefit analysis

Feedback from Refinery B indicated the alternate trickle bed revamp solution to meet the refinery objectives came with a much higher capital cost to achieve the objectives even without the capacity increase. Not only is a second reactor required, but costly modifications to the recycle gas compressor would be required to allow for the increase in hydrogen consumption associated with processing all of the available LCO within the refinery. Additional investment would also be required to restore the reactor inlet pressure back to its design pressure through resolving the pressure drop issue in the recycle gas compressor auxiliary equipment. Even with this investment, a revamp with the IsoTherming® technology offers the refinery to maintain its current 3-year cycle length which could not be matched by the trickle bed technology solution.

Similar to the revamp for Refinery A, the revamp offering for Refinery B has significant operating cost savings associated with it. The current feed heater design duty is 14.2 MMkcal / hr, but as can be seen in the below table, the IsoTherming® technology requires significantly less duty out of the heater, even with the capacity expansion. An estimate was completed of the required trickle bed fired heater duty at the revamp capacity and feed basis, and it is estimated that trickle bed would require a fired heater duty nearly 4x the requirement of the IsoTherming® technology. Therefore, investment would need to be made in the feed heater for trickle bed technology to achieve the capacity expansion that the IsoTherming® technology offers Refinery B.

A comparison of the high-pressure utility savings of the revamp with the IsoTherming® technology compared to what would be required by trickle bed technology at the expansion feed rate is shown in Table 11.

Table 11
Refinery B – Utility Comparison IsoTherming Revamp vs. Current Operation

Parameter	Trickle Bed	IsoTherming®
Normal Operating Charge Heater Duty, MMkcal/hr	22.7	6.132
% Savings	-	73%

Fuel Gas, kg/hr	2034	549
Fuel Gas Value, \$/yr[1]	\$ (5,671,790)	\$ (1,531,967)
Steam Produced, kg/hr	0	3,770
Steam Value, \$/yr[2]	\$-	\$ 326,729
Annual Net Value of Utility Consumption / Production	\$ (5,671,790)	\$ (1,205,238)

[1] Based on a Fuel Gas Value of \$/MMkcal \$29.7 USD

[2] Based on Steam Value \$/1000 kg of \$10.3 USD

Based on the assumed cost values of fuel gas and steam, the revamp saves Refinery B \$4.5 MM USD (\$99 USD / barrel of feedstock) annually in high pressure utilities alone. Additional savings are also expected from low pressure utilities.

Similar to the Refinery A revamp, this revamp solution is not only attractive from a capital and operating cost standpoint, but it also lowers the carbon footprint of the refinery due to the reduction in fuel gas combustion from the fired heater. Based on the current normal operating duty and capacity of the feed heater, the reduction of CO_2 emissions, even at 1.5x current capacity, is equivalent to the removal of over 2,700 light passenger vehicles annually (based on heat content of propane of 139 MMBTU and 4.6 metric tonnes CO_2 emissions / year from a single light passenger vehicle). Refinery B continues to evaluate the revamp project to comply with an impending regulation effective in 2024.

Renewables Processing

Latin America is one of the largest global markets for biofuels with Argentina and Brazil as the two leading countries for demand. Latin America's percent share of global biofuel demand is much greater than its percent share of global energy demand, showing that the region is a step ahead in terms of decarbonizing transportation. Some countries in Latin America have current mandates regarding renewable fuels while it is being considered by others within the region. Whether mandated or not, renewable fuel production in likely on the mind of all refiners in this region. The IsoTherming® technology is well suited to assist refiners in their production of renewable distillate range products. The liquid full technology is uniquely positioned to handle the high hydrogen consumption and temperature rise that are associated with processing lipid-based feedstocks – whether in conjunction with a petroleum derived feedstock or in a stand-alone unit. The capital cost savings, energy efficiency and sustained catalyst life highlighted in the above case studies will also be apparent in a renewable processing application.

Conclusions

Elessent Clean Technologies continuously optimizes its liquid-full IsoTherming® reactor design and unit configuration to process increasingly severe feedstocks at a lower capital cost. Elessent is also actively identifying and evaluating opportunities for the IsoTherming® technology in new and emerging markets and applications. Elessent licenses the IsoTherming® technology and offers products and services that support its customers throughout the life of the unit. With licensed commercial units worldwide, the IsoTherming® technology is an innovative and commercially proven technology that is changing the way refiners are looking at hydroprocessing. This commercially proven technology can provide Latin American refiners an attractive option for meeting current and future demand for greater amounts of cleaner fuel at the lowest capital cost.

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