



**Maximising distillate yields and refinery economics –
An alternative solution to conventional fuel oil production or residue conversion**

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Abstract

For the past two decades refiners have adjusted, at considerable expense, to an increasingly demanding legislative regime regarding specifications for transportation fuels. This wave of unproductive capital expenditure may continue as refiners gear up over the next decade to handle similar requirements for environmentally driven expenditure associated with fuel oil.

A new low-capital cost means of processing heavy, viscous residues was demonstrated on a commercial scale at the 200,000BPD Orlen Lietuva Refinery in Mazeikiai during the latter half of 2008. Production of over 20,000MT of oil-in-water emulsion fuel from visbreaker residue using MSAR[®] technology resulted in an alternative liquid fuel available for sale at a discount to conventional heavy fuel oil (HFO), and competitive with natural gas. The price advantage enables long-term off-take contracts for emulsion fuel to be obtained from major energy consumers, whilst generating a price for the refiner's residue in excess of its intrinsic value in HFO.

Future applications include lower cost bunker fuel, which could subsidise on-board sulphur dioxide scrubbing to meet new maritime regulations, whilst avoiding major hydro-processing expenditure to produce low sulphur HFO.

The paper provides an overview of the technology application and its relative economics, its fit with refinery operations including upgrading plans, examples of emulsion properties from a variety of global refinery residues and summary results of the commercial scale Lithuanian demonstration.

MSAR[®] refinery technology development

Commencing 1990 British Petroleum (BP) and Petroleos de Venezuela (PDVSA) successfully established a 6.5 million tonne per annum market for their proprietary emulsion fuel Orimulsion[®] consisting of 70% 8° API Orinoco bitumen and 30% water. Orimulsion[®] was exported as a boiler fuel for power generation and by 2006 over 60 million tonnes had been shipped to customers worldwide. Demand outstripped supply by over 300% (please refer to Appendix 1 for further details).

In parallel to the Orimulsion[®] progress, a group of former BP experts were developing an alternative low-capex emulsion technology MSAR[®] (Multi-phase Superfine Atomised Residue) in conjunction with AkzoNobel. This modular technology, based primarily on refinery residue feedstock was ideally placed to fill the void created by the politically motivated decision to cease Orimulsion production in 2006.

The MSAR[®] solution differs from Orimulsion[®] in that it is scalable to lower throughputs (as low as 4,000BPD versus 100,000BPD) making on-site refinery emulsion fuel manufacture a reality utilising viscous low-value residues.

The technology is available to refiners from Quadrisse Fuels International (QFI) under sub-licence from AkzoNobel. Alternatively QFI will procure refinery residue at a price above its intrinsic fuel oil blending value and process this into MSAR[®] emulsion fuel on a BOO basis for sale to energy consumers.

Refinery integration of MSAR[®]

From a refiner's perspective, MSAR[®] offers a solution to the dilemma surrounding conventional heavy fuel oil (HFO) production: HFO is sold at a discount to crude, generally consuming valuable diluents and reducing the refinery profitability (Figure 1).

Figure 1. – The refiner's dilemma

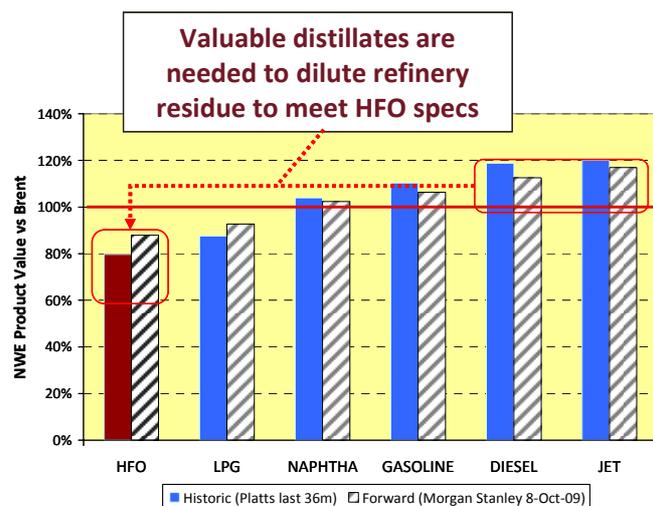
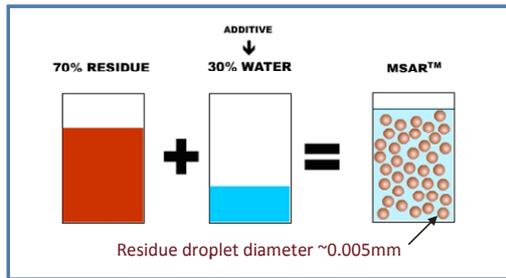


Figure 2. – MSAR[®] overview



MSAR[®] technology blends the refinery residue directly with water and a surfactant package under pressure in a colloid mill to produce a stable emulsion fuel that behaves like heavy fuel oil (Fig 2).

The MSAR[®] solution can be integrated into existing refinery and HFO infrastructure (Figure 3). Hot

refinery residue is slip-streamed (or the whole stream is diverted) from the residue run-down system after maximum process heat has been recovered, but before high value cutter stock is added (Figure 4). Residue viscosities of up to 100,000cSt (standard unit) and 60,000,000cSt (high-temperature unit) measured at 100°C can be handled, without impacting the quality of the emulsion fuel.

Water for the emulsification process can be derived from a number of sources including natural reserves, standard utility water, oil-contaminated waste water or stripped sour water streams. The MSAR[®] systems can either be supplied as skid-built modules (typically 4,000BPD residue each) or as components for stick-assembly.

The ‘value add’ of MSAR[®] over HFO production is that no diluents are needed to produce a transportable product. Therefore providing the resulting emulsion fuel can be sold at a price in excess of the net-back¹ residue value in HFO (Figure 5 overleaf) plus the MSAR[®] production cost, the refinery profitability can be significantly enhanced. To illustrate an example², assuming a 200,000BPD refinery displaces 1 million tonnes of HFO sales (~50% of

Figure 3. – Conventional HFO production

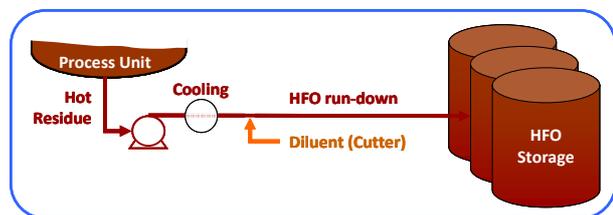
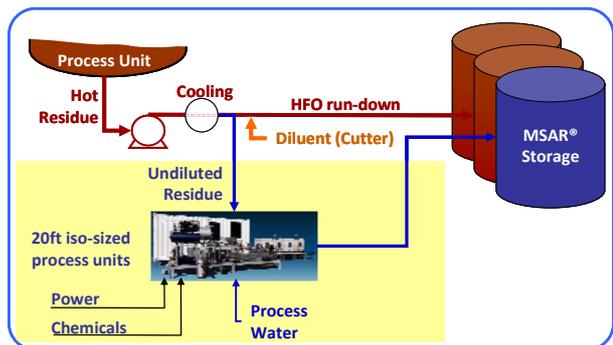


Figure 4. – MSAR[®] system integration

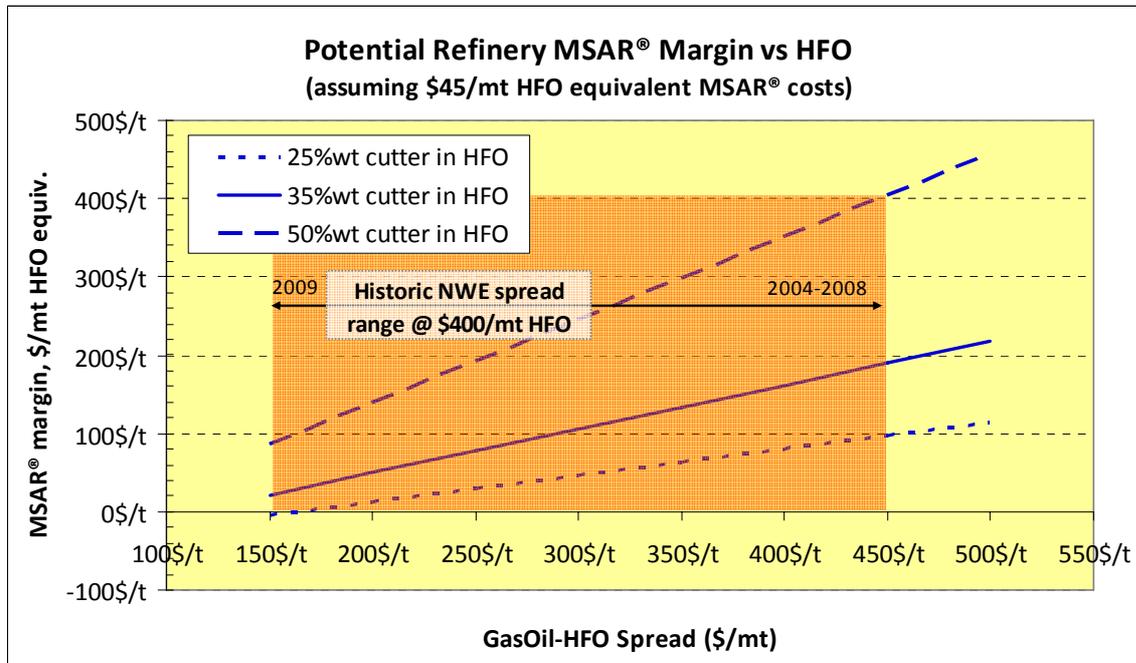


¹ The residue value is a function of the HFO value less the value of distillate products needed to meet viscosity specifications. Higher % distillates in HFO or a greater Gasoil-HFO \$ spread, result in a lower residue value and a greater margin available for MSAR[®] production.

² Assuming 35%wt cutter in the HFO, with HFO at \$400/MT and Cutter at \$600/MT respectively. Capex estimate includes MSAR[®] production system and allowance for tie-ins, assuming shared use of HFO handling facilities.

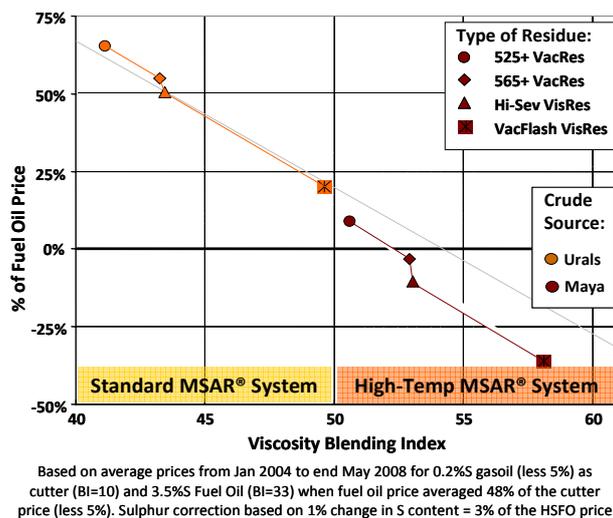
the total available HFO) with MSAR[®], the uplift potential is \$50 million per year or \$0.75/BBL crude processed for an estimated capital expenditure of \$15 million. This uplift potential may need to be shared with the consumer to guarantee regular off-take.

Figure 5 – MSAR[®] uplift potential over HFO



The profit potential increases when heavier crudes are processed or refining process conditions are more severe (Figure 6), due to the higher spread between the residue value and the energy equivalent value as a fuel. Further enhancements to refinery operations can therefore be considered when producing MSAR[®].

Figure 6 – Residue netback value in HFO



Operational enhancements applicable with MSAR[®]

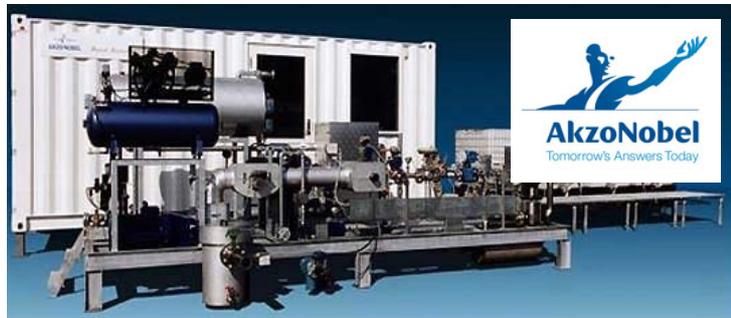
The MSAR[®] process is relatively insensitive to increased residue viscosity/density (e.g. from increased severity operations) or stability issues experienced during conventional fuel oil blending. Therefore during MSAR[®] production, conventional enhancements to operations that were previously uneconomic or operationally problematic during HFO production can be re-evaluated as follows:

Process	Enhancement	Overview
Vacuum distillation	Increasing vacuum distillation unit VGO/residue cut-points	During HFO production, marginal vacuum gasoil (VGO) is a relatively economic fuel oil blending component. The economic incentive to cut deeper and recover marginal VGO drops off significantly as the VGO quality diminishes. During MSAR [®] production no viscosity blend-stock is required and marginal VGO can therefore be diverted to secondary processing to realise a higher return.
Visbreaking	Recovery of visbreaker light-ends to the distillate pool	Where visbreaker distillates are currently routed to HFO production for viscosity control, these products can potentially be diverted to secondary distillate processing. The undiluted visbreaker residue can be sent to MSAR [®] production.
	Increasing visbreaker severity	Severity of visbreaker operation is generally limited by the stability requirement of the blended fuel oil and the extent of fouling and coke lay-down in the visbreaker heater. The former requirement means that the stability of the residue must be sufficient to ensure that the finished fuel resulting from blending with diluents (that are less aromatic than the residue) is stable and that asphaltene flocculation does not occur. Where the residue is made into MSAR [®] , blend stability is not an issue and severity may be increased, subject to acceptable levels of heater fouling and coke deposition. In the absence of any other constraint, a limit on residue stability is recommended (equivalent to a p-value of 1.05 using the Shell methodology). Some operational modifications, such as increasing steam injection or re-cycling heavy distillates from the visbreaker fractionator, may help mitigate coking tendency and enhance yield while some relatively low-cost options to increase heater capacity might be implemented in certain instances.

Process	Enhancement	Overview
Visbreaking (Cont'd)	Vacuum-recovery of visbreaker VGO	A vacuum flasher is a relatively low capital cost addition to a refinery with a visbreaker. This recovers a major part of the visbroken vacuum gasoil (VVGO) to be used as additional cracker feed. Just as the economics of deep-cut VDU (in the absence of a visbreaker) are enhanced by routing the residue to MSAR [®] manufacture, so are the economics of vacuum flashing visbreaker residue. Although marginal VVGO is of poorer quality than marginal VGO, during MSAR [®] manufacture it becomes economic to dig deeper, as the distillates and VVGO has a higher intrinsic value than HFO.
Solvent de-asphalting	Production of MSAR[®] rather than HFO using SDA residue	The precipitated asphalt product from SDA is generally a difficult stream to blend to HFO because of its extremely high viscosity. Processing to MSAR [®] (using a high temperature unit), either using 100% SDA residue or a partial blend (to provide 10-20% volatile components to enhance combustion) yields an extremely competitive and readily transportable fuel.

MSAR[®] technology leverages equipment perfected over 20 years for road emulsion applications. MSAR[®] systems can be installed within 6-12 months, when utilising existing fuel oil supply infrastructure. Over 100 emulsion production units have been supplied worldwide by AkzoNobel to date.

Figure 7 – The MSAR[®] manufacturing module



The refiner is thus provided with a modular, low-capex, short lead-time uplift pathway. The MSAR[®] option is especially relevant in today's climate of high project costs and extended delivery schedules which increase risk and negatively impact conventional upgrading process economics. The potential capital payback period is low enough for MSAR[®] also to be considered as an interim value adding residue disposal solution pending the planning, approval, financing and implementation of major upgrading schemes that may have been suspended in the current economic climate.

Commercialisation of MSAR[®] technology

The first large-scale commercial demonstration of MSAR[®] technology was on Orlen Lietuva's 200,000BPD Mažeikiai refinery. The MSAR[®] produced was sold to the 1,800MWe AB Lietuvos Elektrinė thermal power plant, some 300KM from the refinery by rail.

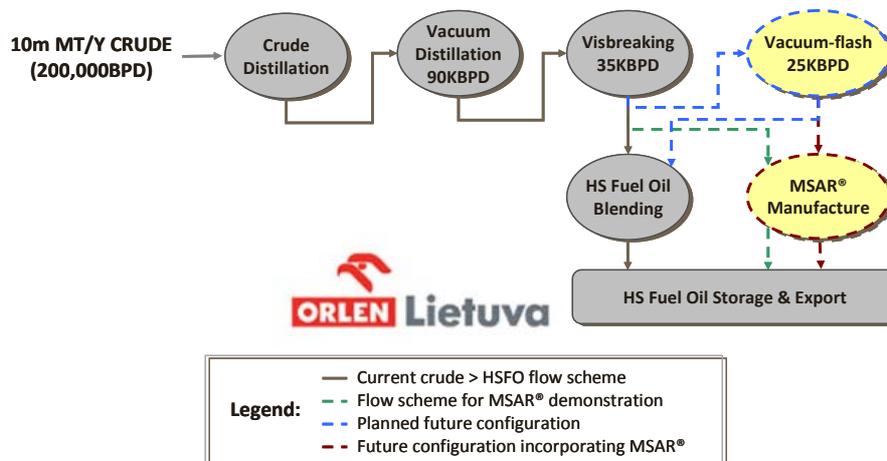


Orlen Lietuva refinery integration of MSAR[®]

Integration options for MSAR[®] technology were reviewed with the refinery in the context of their future modernisation plans.

It became apparent that there was significant potential for MSAR[®] to add value around the existing visbreaker and that this could be substantially enhanced by the future addition of a low capital cost vacuum flasher unit:

Figure 8 – MSAR[®] integration at Orlen Lietuva



Early in 2008 commercial agreements were reached with both the refinery and the power plant to carry out a demonstration of MSAR[®] technology. Over 20,000MT (120,000BBL) of MSAR[®] were to be manufactured at the refinery for supply to the power plant via the state railway, AB Lietuvos Geležinkeliai. Binding agreements were put in place and QFI financed and managed the MSAR[®] installation and emulsion production operations, and were buyer and seller of the refinery residue and MSAR[®] fuel respectively.



A temporary MSAR[®] production facility was installed within the refinery compound, using an existing non-hazardous plot area of less than 250m². Utilities for the manufacture of MSAR[®] were supplied from the refinery systems.

MSAR[®] product was pumped to an existing HFO tank and stored before being exported by rail. MSAR[®] export utilised the existing refinery HFO rail loading system, batching MSAR[®] along with conventional HFO dispatch. In total 8 block trains (50 x 60MT wagons) were loaded and over 20,000MT of MSAR[®] exported from the refinery to the power plant.

MSAR[®] product was formulated to replicate Orimulsion[®] where possible and to maintain detailed fuel quality specifications during recommended storage and handling for 3 months.

Figure 9 – Comparable specifications of Orimulsion[®] and MSAR[®] in Lithuania (Saybolt)

Typical (Average) Specifications for Orimulsion[®] and MSAR[®]			
Characteristics:	Orimulsion [®] (400 Spec.)	MSAR [®] (Urals VBR)	Analytical Method or Equipment
Water Content, % w/w	30	30	ASTM D-4006
Mean droplet Size, Microns	20	9	Malvern Particle Sizer
Droplets > 150 Microns, % w/w	0.5	1.0	Sieve Test
Apparent Viscosity @ 20s ⁻¹ , cP	200 @ 30°C	200 @ 50°C	Coaxial Cylinder Viscometer
Gross Calorific Value, MJ/Kg	30	30	ASTM D-240
Net Calorific Value, MJ/Kg	28	28	ASTM D-240, Calculated
Sulphur, % w/w	2.8	1.9	ASTM D-1552
Sodium, ppm	10	30	Atomic Absorption
Vanadium, ppm	320	180	Atomic Absorption
Nickel, ppm	70	50	Atomic Absorption
Magnesium, ppm	5	111	Atomic Absorption
Ash, % w/w	0.10	0.12	ASTM D-482

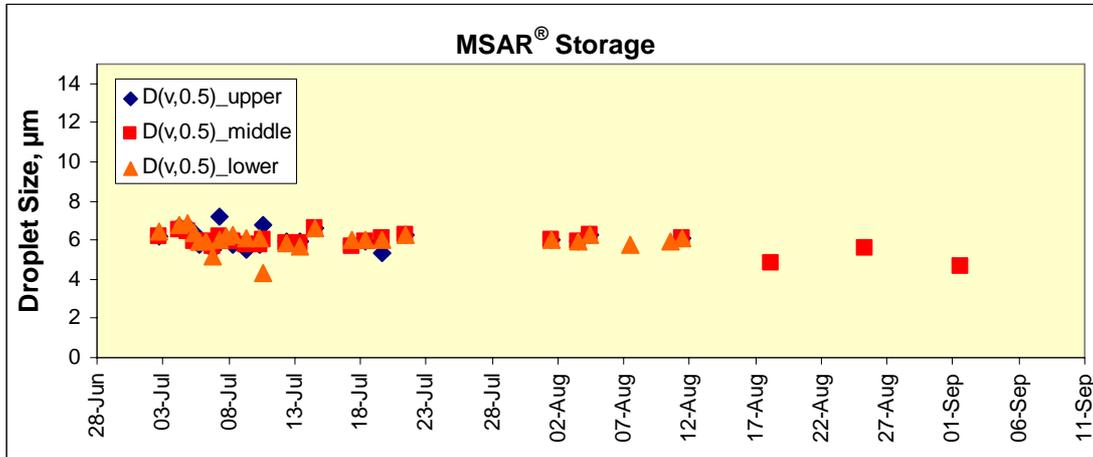
During the demonstration the viscosity of the supplied visbreaker residue varied by up to 500cSt (at 100°C), with the refinery processing predominantly Urals-derived crude or 50/50 blends of Urals with heavy North Sea crudes. It was observed that variations in MSAR[®] production viscosity due to operational variations upstream could be readily compensated for by minor adjustments in the MSAR[®] manufacturing system parameters.



Besides these adjustments for viscosity control, all other parameters (in terms of MSAR[®] droplet size characteristics, determined stability, etc) remained within expectations and specification, demonstrating the stability and reliability of the process and resulting fuel. The quality of MSAR[®] in storage was closely monitored (Figure 10 overleaf). Through

progressive adjustments in the MSAR[®] formulation, quality parameters remained constant during the site storage of MSAR[®] demonstrating the high stability of the fuel over time.

Figure 10: Variation in MSAR[®] oil droplet size in refinery storage



MSAR[®] was fired at the power plant on the 300MWe Unit 7 installed with pollution abatement systems to meet EU new plant standards. The main period of the combustion testing was completed in September 2008. MSAR[®] firing proved extremely satisfactory; achieving flame stability at both low and high load operations. A visual inspection of the boiler internals concluded that the levels of fouling were within expectations and acceptable.

Overall, MSAR[®] emulsion fuel performance was fully EU compliant when the flue gas abatement equipment was in operation and met all the expectations of the parties. It was concluded that additional optimisation when firing MSAR[®] would be necessary after the new Alstom systems had been fully commissioned on HFO during 2009. These MSAR[®] tests are tentatively scheduled for Q1 2010, prior to the commencement of commercial supplies.

Commercial discussions are ongoing between the parties to conclude agreements for the commercial MSAR[®] facilities required to provide an economic base-load energy alternative for Lithuania from 2010 onwards.

Similar refinery and power-plant alignments have been identified globally for MSAR[®] technology implementation and are at various stages of development with National Oil Companies, Oil Majors and Private Developers.

MSAR[®] and future HFO market issues

The existing marine sink for high sulphur HFO is set to disappear in terms of new sulphur specifications issued by the IMO. Refiners face the difficult choice of revamping their facilities to meet HFO specifications, opting out of the HFO market altogether by installation of residue destruction facilities, or relying on consumers to solve the sulphur issue.

MSAR[®] for some may be an innovative value adding solution which can be implemented at a relatively low cost. To appreciate the MSAR[®] potential it is necessary to have an understanding of the bulk fuel oil markets and where and how MSAR[®] might be a viable substitute. Emulsion fuel cannot (as yet) be treated as a tradable commodity and therefore potential energy consumers need to be aligned with the candidate producer, in much the same way as the initiation of the LNG and Orimulsion[®] supply chains.

For an MSAR[®] project to be viable, the following mutual interests need to be served:

- **For the refinery:**
 - sustainable profitability (net of new costs) over current HFO production and sales
 - potentially an anchor customer for emulsion off-take to justify the initial investment
- **For the consumer:**
 - sustainable fuel savings over other primary energy sources (net of new costs)
 - secure and reliable supplies
 - negligible impact to current plant performance (e.g. maximum load, efficiency)
 - reliable operations on emulsion fuel (boiler and flue gas clean-up equipment)
 - environmental compliance to stringent standards with respect to emissions

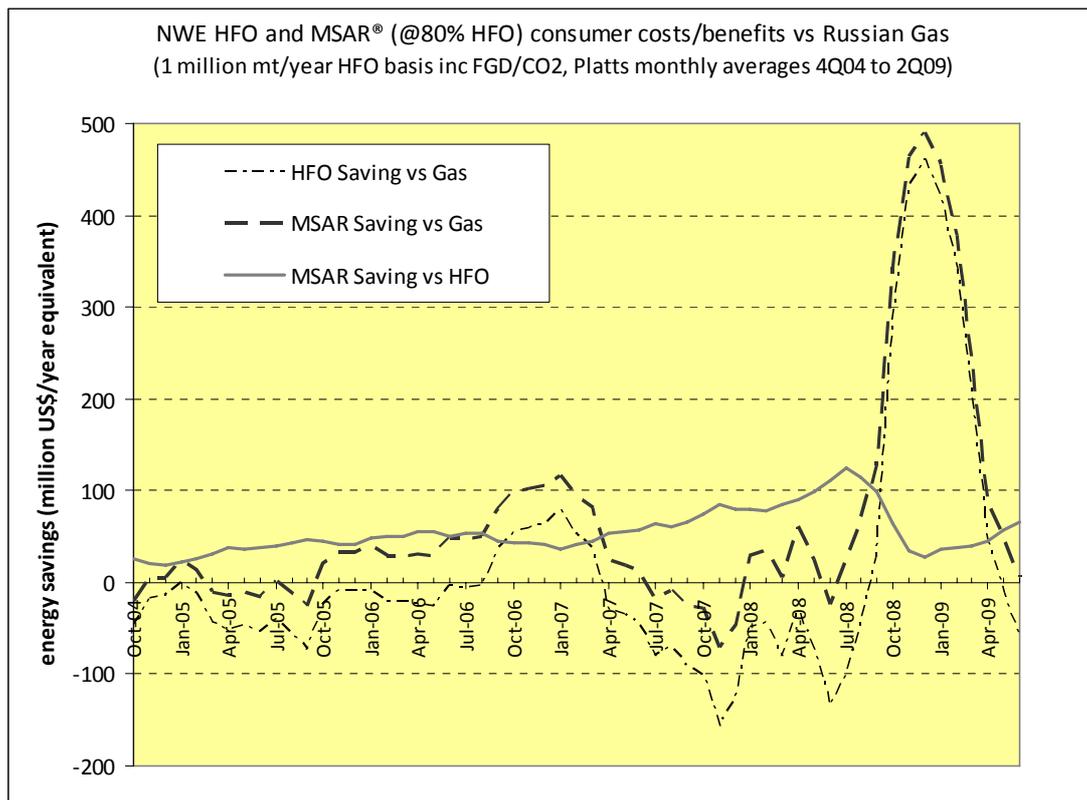
MSAR[®] boiler fuel substitution

Applicable markets for potential HFO/crude substitution include Central and South America, the Middle East and Asia where oil use is still predominant (over 180 million tonnes per annum in 2007 according to the IEA) and where even a 5% energy saving could equate to \$20 million per annum for a 600MWe base-load power plant (consuming 1 million tonnes of HFO equivalent annually) at current HFO market prices.

A less obvious application for MSAR[®] is the potential substitution of natural gas in units designed for dual or multiple fuels. This is applicable in regions where the formula price for

natural gas or LNG is linked to oil products. Furthermore the increased environmental burden from MSAR[®] use needs to be accounted for, as it does with HFO. Where circumstances allow (e.g. use of low-sulphur hydrocarbons or selection of units equipped with flue gas desulphurisation) then the price advantage of a residue-based HFO-replacement offers an interesting alternative to natural gas, even accounting for the incremental cost of oil-based operations, flue gas desulphurisation (FGD) and carbon dioxide. Using the example below (Figure 11) for HFO or MSAR[®] consumption in a NWE-based thermal boiler versus Russian gas the net energy savings versus gas for the period equate to \$65 million per annum for MSAR[®] (assuming a sales price at 80% of HFO), compared with \$10 million for HFO (i.e. a \$55 million annual MSAR[®] consumer benefit over HFO). The price advantage with MSAR[®] could potentially subsidise the installation of new flue gas abatement systems.

Figure 11 – Potential variable cost savings using MSAR[®] and HFO versus Natural Gas

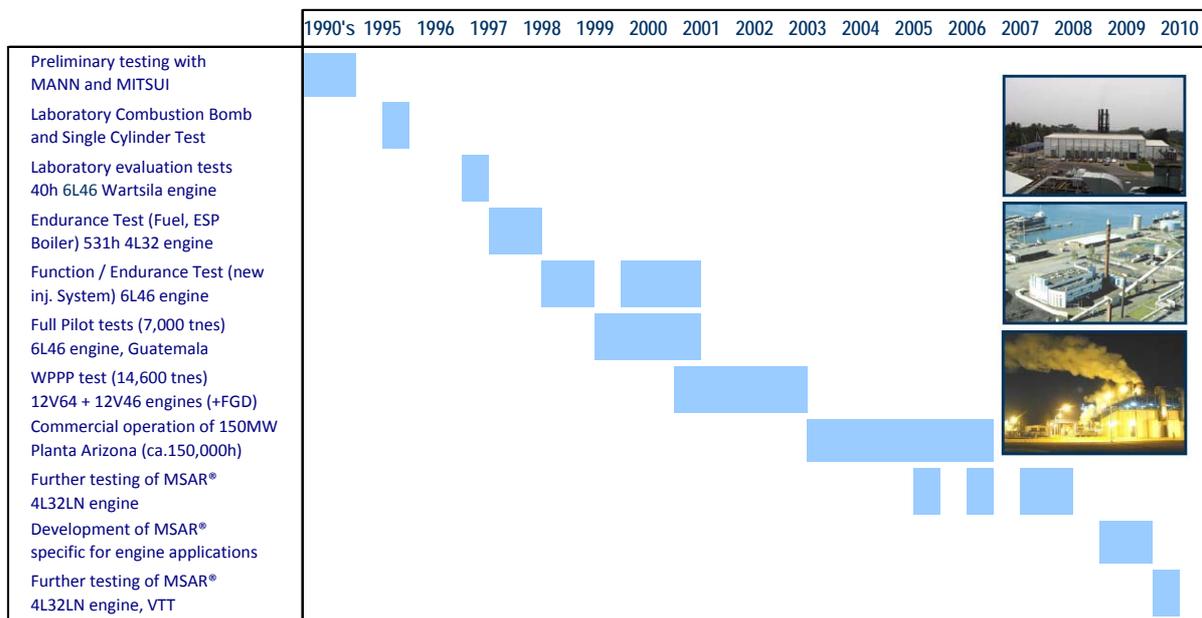


With respect to general base-load boiler and flue-gas cleanup operations with MSAR[®] there is a wealth of experience available from the 60 million tonnes of Orimulsion[®] consumed in boilers ranging from 50MWth to over 700MWe (please refer to Appendix 2 for further details and Appendix 3 for general recommendations for consumers looking to switch to MSAR[®]).

HFO/bunker fuel substitution by MSAR[®] in diesel engines (power and marine)

Orimulsion[®] was specifically precluded from being supplied to the bunker market by BP and PDVSA to avoid internal conflict with oil trading divisions, hence the principle application of emulsion fuel in diesel engines to date has been for power generation, predominantly using Wärtsilä medium speed 4-stroke engines. As a result of the successful testing programme, a 150MWe Wärtsilä Orimulsion[®]-fuelled power plant complete with FGD was installed in Guatemala in 2004, financed by the World Bank.

Figure 12 – Emulsion fuel development on diesel engines



Since commencement of the MSAR[®] business, the Wärtsilä research and development has been repeated using different hydrocarbon types on their pilot engine in Finland. The performance of MSAR[®] in Wärtsilä tests has been similar to Orimulsion[®] (e.g. lower NOx versus HFO), and further improvements to the fuel pre-treatment system operations have been experienced with MSAR[®] reducing retrofit and operating costs.

Development work continues on a new formulation of MSAR[®] with a reduced water content that will enable existing Wärtsilä engines to be converted from HFO to MSAR[®] without any significant modifications to the fuel feed design, negating the 90% maximum load constraint previously experienced with 70:30 oil-in-water emulsions (such as Orimulsion[®]).

The design and operation of modern flue-gas abatement systems has also been fully tested by Wärtsilä, their associated OEMs and the World Bank who have all concluded that emulsion fuel operations are similar to, or better than operations when using HFO.

Given the successful testing of MSAR[®] in diesel power plants, opportunity exists to apply this experience to the marine sector where >170 million tonnes/year of bunker fuel is consumed.

The proposed IMO specifications for bunker fuel and the expansion of the Special Emissions Control Areas (SECAs) are subjects of considerable debate within the refining and maritime communities as is the future use of bunker fuel oil or marine distillates to meet prospective IMO and SECA standards. The application of ship-borne scrubbing equipment is (in our view) a technically and economically viable alternative to distillate substitution to meet the forthcoming sulphur standards. The introduction of a lower-cost bunker fuel alternative could provide a means of subsidising the scrubbing equipment and simultaneously increasing the owner's profitability.

Figure 13 – Scrubber performance (emulsion & marine)

	Fuel	Region/ Supplier	Process	Oil %S content	SO ₂ Scrubber Efficiency	%S HFO equiv.
Emulsion Fuelled Power Plants (examples)	Orimulsion [®]	Canada	Wet-limestone	4.0%	93%	0.28%
	Orimulsion [®]		Wet-limestone	4.0%	95%	0.20%
	Orimulsion [®]	Japan	Wet-limestone	4.0%	94%	0.24%
	Orimulsion [®]		Wet-limestone	4.0%	93%	0.28%
	Orimulsion [®]	Italy	Wet-limestone	4.0%	96%	0.16%
	Orimulsion [®]		Wet-limestone	4.0%	95%	0.20%
	Orimulsion [®]	Guatemala	Wet-limestone	4.0%	>90%	<0.41%
	Orimulsion [®]	Denmark	Wet-limestone	4.0%	>99%	<0.04%
	MSAR [®]	Lithuania	Wet-limestone	3.0%	>97%	<0.08%
Marine Scrubbers	HFO	Wärtsilä	NaOH	3.4%	>99%	<0.03%
	HFO	EcoSpec	Sea-water	2.0%	93%	0.14%
	HFO	Krystallon	Sea-water	3.5%	>99%	<0.04%

However the introduction of emulsion fuel to this market segment is not without its challenges, namely:

- Performance testing on marine diesels and scrubbing equipment with MSAR[®] is required, at pilot and commercial scale
- Bunker fuel segregation is required (HFO and MSAR[®] should not be mixed), complicating logistics
- MSAR[®] energy content is lower than HFO, hence the vessel range or cargo capacity of existing vessels is reduced
- Potential environmental impact with MSAR[®] needs to be fully assessed (updating existing spill contingency plans)

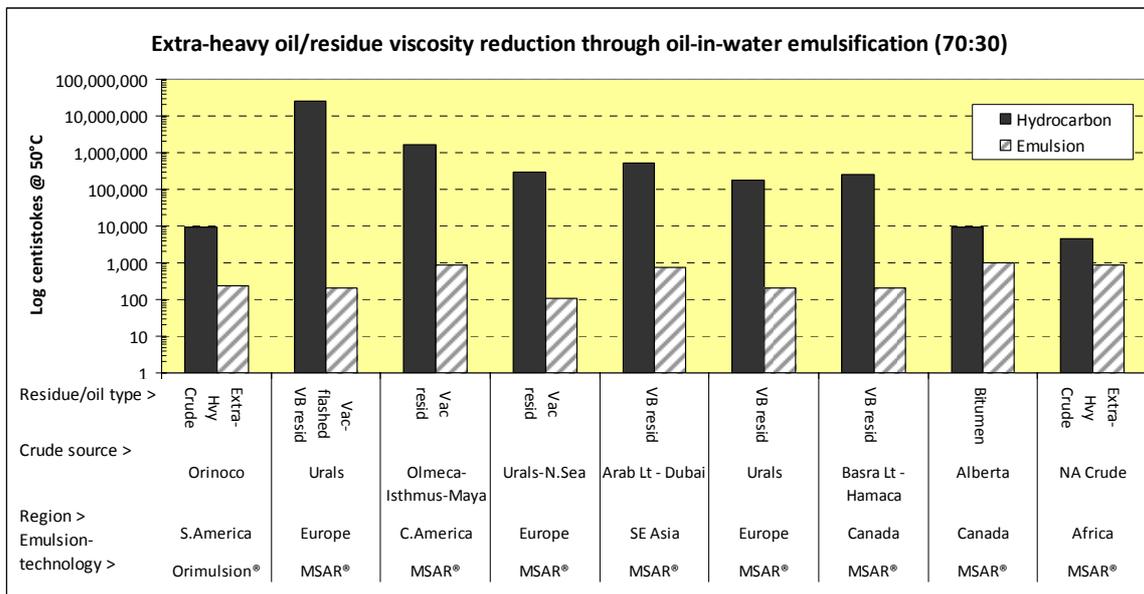
However, given the proven record of emulsion fuel in the boiler and diesel engine power sectors we believe that a parallel techno-economic solution will be compelling for refiners and consumers alike over the longer term. In the meantime QFI is actively seeking OEM and industry partners for a joint development and implementation plan commencing in 2010.

Emulsion feedstock and fuel characteristics

Experience with MSAR[®] technology has shown that a different solution is required for residue emulsions when compared with asphalt, extra-heavy crude or fuel oil emulsions. This is due to the more stringent standards required for fuel consumption and long-term static/dynamic stability - requirements that were the cornerstone of the global Orimulsion[®] business.

The MSAR[®] fuel formulation is generally bespoke for each application and is resolved by testing a sample of approximately 400kg of refinery residue at the AkzoNobel laboratories. The optimum emulsion fuel is determined at laboratory scale, then pilot testing is completed in a flow loop to determine fuel stability prior to any commitments being made to a potential client. To date a number of refinery residues from a variety of crudes and processing units have been successfully emulsified using MSAR[®] technology (please refer to Figure 14 below and Appendix 4 for further details).

Figure 14 – Examples of refinery residues and resulting emulsion fuel viscosities

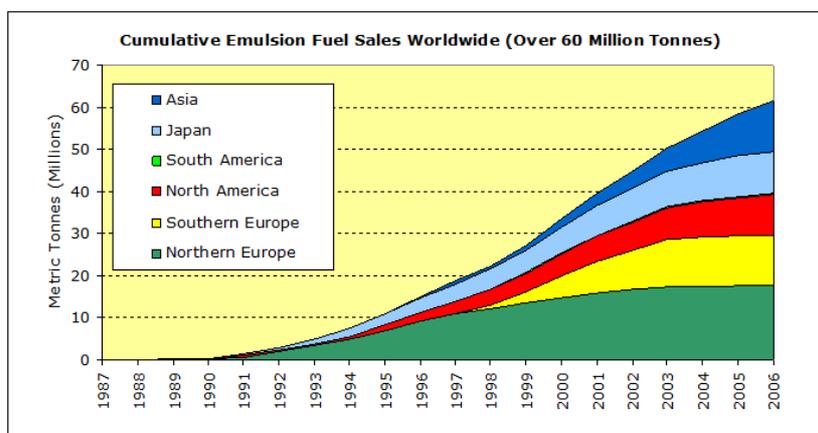


Appendix 1 – Orimulsion®

Commencing 1990 British Petroleum (BP) and Petroleos de Venezuela (PDVSA) successfully established a 6.5 million tonne per annum market for their proprietary emulsion fuel Orimulsion® – a 70% bitumen in 30% water emulsion. The product, manufactured from 8° API Orinoco bitumen was exported world-wide as a boiler fuel for power generation.

By 2003 Orimulsion® contracts with major electricity generating companies in North and Central America, Europe and Asia. Orimulsion® consumers were fully compliant in meeting stringent environmental standards including the EU Large Combustion Plant Directive with further endorsement from the US Environmental Protection Agency³. Beyond conventional thermal boilers, the commercial success of Orimulsion® at a World Bank funded 150MWe Wärtsilä diesel generator plant in Guatemala had opened new horizons. By 2006 over 60 million tonnes of the Orimulsion® had been shipped to customers worldwide and demand outstripped supply by over 300%.

Figure 15 - Commercial emulsion fuel sales to 2006



PDVSA did not capitalise on this commercial success however. Orimulsion® was precluded by PDVSA from entering the bunker market so as to protect their oil trading business, and in 2004 became a political target for the newly elected government. The final blow was for PDVSA to renege on its long-term supply commitments⁴. Production of Orimulsion® ceased in December 2006.

³ <http://www.epa.gov/nrmrl/pubs/600r01056/600r01056.htm>

⁴ Oil & Gas Journal, September 22, 2008 volume 106, issue 36

Appendix 2 – Major Emulsion Fuel Consumers

Baseload Orimulsion® Consumers Installed with Flue Gas Desulphurisation Equipment

Country	Plant Name	Dates Start-End	Boiler Design Fuel	Boiler Rating MWe	Orimulsion® [million tonnes]	
					Per year	Total
Japan	Kashima-Kita 1	91-06	HFO	95+Steam	0,4	6,0
	Kashima-Kita 2	94-06	HFO	125+Steam		
	Kansai Electric Osaka 4	94-05	HFO	156	0,2	1,4
	Hokaido Electric Shiriuchi	97-06	Ori®	350	0,2	0,8
Canada	NB Power Dalhousie 1/2	94-06	HFO/Coal	105/215	0,8	7,0
Denmark	SK Power Asnæs 5	95-03	Coal, HFO	640	1,4	6,1
Guatemala	Constellation Energy, P.Arizona	04-06	HFO	150 Diesel	0,3	1,0
Germany	RWE Ibbenbueren ⁽¹⁾	98-02	Coal, HFO	770	0,03	0,2
Italy	ENEL Brindisi Sud 1,2,3,4 ⁽³⁾	98-05	Coal, HFO	2x660	1,4	8,0
	ENEL Fiume Santo 3, 4	99-04	Coal, HFO	2x320	1,1	4,0
South Korea	KOSPO Youngnam	03-06	HFO	2x200	1,0	2,0
Singapore	Power Seraya Stage I	04-06	HFO	3x250	1,5	2,5
China	GEPB Nanhai A ⁽²⁾	01-06	HFO	400	0,5	3,0
	GEPB Nanhai B ⁽²⁾	01-06	HFO	100	0,1	0,6
	GEPB Heng Yun ⁽²⁾	01-06	HFO	200	0,15	0,9
	GEPB Huang Pu ⁽²⁾	01-06	HFO	500	0,1	0,6
Notes:	(1) Orimulsion® was used as a start-up and combustion support fuel for coal (2) Orimulsion® was co-fired with HFO (3) Orimulsion® was co-fired with coal					

Appendix 3 – MSAR[®] conversion overview for consumers

Only minor modifications are required to convert an HFO system to MSAR[®]. The fuel can be stored and handled at ambient conditions and normally combusted with only minimal preheat (50-60°C versus 80-120°C for HFO).

Heating of storage tanks will not typically be required, except in very cold regions. Only coarse (~ 740µm) suction filters are required and it is generally recommended that high pressure pumps are retrofitted with variable speed drives for flow control. Steam to heat exchangers should be low pressure (<4 bar) and desuperheated to minimise localised over-heating. When operating with MSAR[®], significant mixing with other oil-based products should be avoided, as should freezing or over-heating (>80°C). Excessive shear (such as the potential turbulence from a instantaneous pressure drop of >6 bar over orifices or control valves) should also be avoided. As a direct HFO substitute it may be used locally or transported by road, rail, pipeline or sea.

Burner nozzles will need to be re-sized, due to the higher emulsion fuel flow required (resulting from the lower calorific value versus HFO).

Typical MSAR[®] conversion recommendations:

- Pipeline pressure drops assessed for revised fuel properties and flow rates
- Fuel heating systems (where needed) converted to hot-water (e.g. storage tank coils), low-pressure steam (e.g. fuel pre-heaters) or electrical self-limiting (e.g. pipe steam tracing)
- Fuel pumping systems evaluated for required capacity and (where needed) converted to variable speed drive from high-pressure spill-back control. Suction filter baskets are evaluated
- Fuel flow measurements systems evaluated and (where needed) replaced with non-intrusive flow metering (e.g. Coriolis meters)
- Burner nozzles replaced with appropriate and larger capacity designs
- Boiler configurations and fan capacities assessed for change in flue gas properties
- Flue gas treatment systems reviewed using revised fuel properties versus environment limits

MSAR[®] environmental impact

MSAR[®] is pre-atomised (~5 microns) and can be burned at very low-levels of excess oxygen whilst achieving virtually complete carbon burnout and reduced NO_x emissions.

Emissions of sulphur dioxides will be similar to direct firing of the residue, i.e. marginally higher than the equivalent HFO due to the absence of diluents. Conventional abatement equipment designed for HFO combustion is generally suitable for MSAR[®].

Figure 16 – Emulsion fuel NO_x emissions versus limits

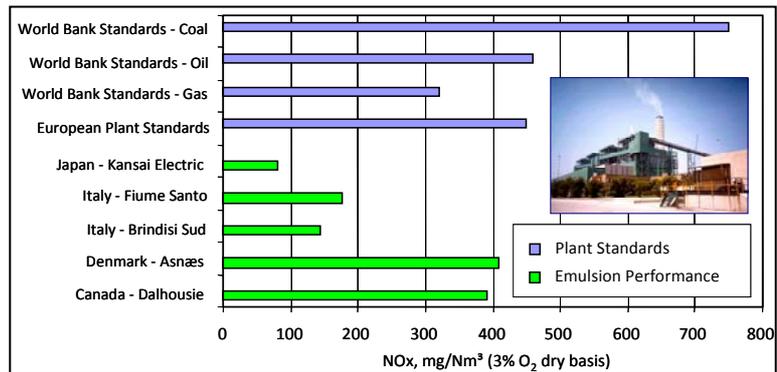
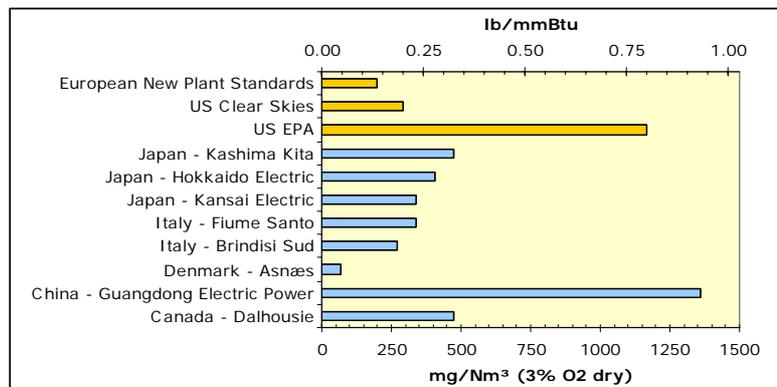


Figure 17 – Emulsion fuel SO₂ emissions versus limits



MSAR[®] environmental summary:

- CO₂ emissions comparable with HFO and lower than direct-residue, coal and pet-coke use
- SO₂ emissions marginally higher than HFO, captured using conventional flue gas scrubbing processes
- SO₃ emissions lower than residue firing and similar to, or lower than HFO
- Reduced NO_x (by typically >20%) versus HFO due to water content and efficient combustion
- Reduced particulate emissions (complete carbon burnout versus HFO and hot residue)
- Reduced mass of combustion ash produced (near-zero carbon)
- Ash is suitable for treatment / metals recovery
- Global experience with major OEM suppliers (e.g. Alstom, MHI, IHI, Babcock etc)

Appendix 4 – Extra-Heavy Oils & Residues and Resulting Emulsion Fuel Properties

Product	Orimulsion®	MSAR®	MSAR®	MSAR®
Source	S.America	Europe	C.America	Europe
Crude diet	Orinoco	Urals	Olmecca-Isthmus-Maya	Urals-N.Sea
Residue	Extra-Hvy Crude	Vac-flashed VB resid	Vac resid	Vac resid

Hydrocarbon Properties	<i>Units</i>				
Density at 15 degC	<i>kg/m³</i>	1018	1060	1021	1033
Viscosity (100 degC)	<i>cSt</i>	250	30,500	5900	2070
Viscosity (50 degC)	<i>cSt</i>	9181	25,490,869	1,690,917	299,930
Shell V50 blending index		39.2	48.3	45.8	43.9
Ash	<i>% (mass)</i>	0.12	0.15	0.10	0.05
Sulphur	<i>% (mass)</i>	4.04	3.00	4.10	1.77

Emulsion Fuel Properties	<i>Units</i>				
Density at 15 degC	<i>kg/m³</i>	1009	N/D	N/D	1023
Water content	<i>% (mass)</i>	29.0	29.6	29.4	29.6
Viscosity (50 degC / 20 s ⁻¹)	<i>cSt</i>	230	200	865	107
Shell V50 blending index		31.7	31.3	34.9	29.5
Droplet Size	<i>microns</i>	15	7	4	4
Ash	<i>% (mass)</i>	0.07	N/D	N/D	0.05
Sulphur	<i>% (mass)</i>	2.85	N/D	N/D	1.18
LHV	<i>MJ/kg</i>	27.8	N/D	N/D	27.7

Product	MSAR®	MSAR®	MSAR®	MSAR®
Source	SE Asia	Europe	Canada	Canada
Crude diet	Arab Lt - Dubai	Urals	Basra Lt - Hamaca	Alberta
Residue	VB resid	VB resid	VB resid	Bitumen

Hydrocarbon Properties	<i>Units</i>				
Density at 15 degC	<i>kg/m³</i>	1040	1046	1060	1013
Viscosity (100 degC)	<i>cSt</i>	2900	1500	1,877	250
Viscosity (50 degC)	<i>cSt</i>	523,335	176,240	255,113	9,181
Shell V50 blending index		44.6	43.3	43.8	39.2
Ash	<i>% (mass)</i>	N/D	0.07	0.10	0.05
Sulphur	<i>% (mass)</i>	5.00	2.67	4.98	4.28

Emulsion Fuel Properties	<i>Units</i>				
Density at 15 degC	<i>kg/m³</i>	N/D	1030	1041	1008
Water content	<i>% (mass)</i>	29.6	29.8	30.0	29.6
Viscosity (50 degC / 20 s ⁻¹)	<i>cSt</i>	757	201	200	970
Shell V50 blending index		34.6	31.3	31.3	35.1
Droplet Size	<i>microns</i>	6	10	7	4
Ash	<i>% (mass)</i>	N/D	0.11	N/D	0.05
Sulphur	<i>% (mass)</i>	N/D	1.92	N/D	3.07
LHV	<i>MJ/kg</i>	N/D	28.9	N/D	26.9