MSAR® Technology Overview
Quadrise Fuels International plc ("QFI") is a UK-listed company with world-leading expertise and technology for producing commercial emulsion fuel (a synthetic fuel oil, MSAR®) directly from extra-heavy oil and refinery residuals:

- many of the QFI team were previously responsible for commercialising BP and PDVSA’s Orimulsion® business, along with downstream specialists from oil companies (ExxonMobil, Shell, ConocoPhillips), power utilities and marine (GE Alstom, Maersk, DNV-GL & VPS).
- the proprietary chemicals and associated RDI support for MSAR® are supplied exclusively by AkzoNobel Surface Chemistry globally.
- QFI clients include A.P. Møller - Mærsk, Cepsa, YTL PowerSeraya and several majors in Oil & Utilities that include Saudi Arabian conglomerates.

Quadrise licenses & supplies MSAR® technology, additives & services to produce a stable ‘Oil-in-Water’ emulsion fuel from the heaviest oil residuals.

**How it works:**
Tiny droplets of extra-viscous heavy hydrocarbons are dispersed in water & chemicals in a modular in-line blending unit using proven proprietary processes and additives. MSAR® systems can be installed in <12months.

**Key benefits:**
✓ Water & chemicals replace premium diluents in the fuel oil pool.
✓ Significant value is added at the refinery.
✓ MSAR® viscosity is lower than HFO.
✓ MSAR® can be handled & transported using existing HFO infrastructure.

MSAR® provides refiners with low-cost, rapidly deployed upgrading solutions for residuals blended to HFO.

**Key benefits:**
✓ Provides a stable, lower cost synthetic HFO.
✓ MSAR® provides enhanced combustion:
  ✓ High carbon conversion = lower PM/Soot.
  ✓ Water reduces NOx by 20-50%.

MSAR® delivers HFO consumers tangible cost savings & environmental benefits.

**MSAR® = Multiphase Superfine Atomised Residue**
70% of extra-viscous heavy residue droplets (5-10 microns) dispersed in ~29% water and <1% stabilising chemicals.
Global MSAR® Projects

QFI is currently developing commercial MSAR® projects with global oil majors, power utilities & shipping companies. Focussing on the Marine and Power applications for HFO, QFI is jointly working on projects with the world’s largest container shipping company, and the largest oil company and oil-fired utility in the Kingdom of Saudi Arabia respectively.

Marine

MSAR® is proven in Wärtsilä 4-stroke diesel engines, and through a joint development with Mærsk and the OEMs, MSAR® is undergoing final commercial OEM “LONO” approvals for use in 2-stoke diesel propulsion engines using HFO/MGO.

Modular Manufacturing Units

(“MMU” – 6KBPD MSAR®)

Designed for Marine & Power MSAR®

Refinery – Marine MSAR® Case Study:

A 6KBPD MSAR® system was installed within a Cepsa 240KBPD refinery in Spain within 9 months from NTP to commissioning. The unit supplied cargoes of MSAR® made from visbreaker residue to a Maersk container vessel in commercial service. MSAR® production & Mærsk vessel testing has concluded & the interim vessel inspection has been completed. The Interim “Letter Of No Objection” from Wärtsilä, the engine manufacturer, was received June 2017; No detrimental effects. Quadrise managed the refinery integration, production & QC.

Power

Refueling of HFO thermal boilers with emulsion fuel is proven, with over 60 million tons of Orimulsion® consumed in steam boilers (100-700MWe) on base-load by major utilities globally.

MSAR® is a second generation fuel, offering enhancements to stability, combustion & emissions. QFI is at the FEED stage of a project with a major oil company in Saudi Arabia to operate a MSAR® system within a major refinery to blend vacuum/visbroken residue to MSAR® to supply a 400MWe boiler at a major utility via sea tanker.

Key benefits to KSA:

✓ Improve downstream profits
✓ Lowers cost of oil-fired utility generation
✓ Lowers NOx & PM emissions & ash-disposal costs
Illustrative MSAR® Refinery Scheme

The MSAR® production process is proven and simple:

- Refinery Residue is taken from Unit rundown (via a tie-in), or optionally from imported residue streams, at typically under 200°C, ideally at the required viscosity for emulsification (typically <1000cSt) and before any diluent hydrocarbons are added (to maximise value)...

- Water, derived from refinery process or waste-water sources (included treated sour water) for power, or demineralised for marine MSAR®, together with...

- Proprietary surfactants (one for power, two for marine), acid (normally formic, to activate the surfactants) and a polymer to enhance the stability of the MSAR® are added via...

- An in-line high-speed colloid mill in the MSAR® Manufacturing Unit (MMU) under pressure to produce a high phase ratio (typically ~70% hydrocarbon) oil-in-water emulsion, that is immediately cooled, producing a super-stable oil-in-water fuel...

- Typically ranging from 150-300cSt at 50°C - that can be easily adjusted by manipulating the water content via the MMU DCS to meet user / OEM requirements...

- Conventional H₂S inhibitors can be added to the residue or MSAR® to meet 2ppm requirements...

- MSAR® can be stored in existing HFO tanks at ambient conditions (no steam heating required) and exported by utilising existing logistics systems where refinery configurations allow.

MSAR® systems can be deployed in <12 months.

- The MSAR® system is designed to be modular and scalable.
- The refinery plot area required is also minimal (<100m²/KBPD)
- Each MMU is designed for 6KBPD MSAR® (4.2KBPD Residue) and is capable of producing both Marine or Power MSAR®.
- The system is designed both for continuous or batch operation.
Case Study: Vacuum Residue cut with LCO for 380cSt HFO vs MSAR®

### Economic Fundamentals:

- When a refinery produces heavy fuel oil (HFO), middle distillates are downgraded to the fuel oil pool to dilute residues to mainly control viscosity.

- MSAR® technology significantly improves the refinery middle distillate yield and margin by releasing high value distillates from the fuel oil pool, as they are no longer required as cutter stock to control viscosity.

- Budget Capex for 1 MMU is ~$5M, with payback of 12 months, even if only half of the Margin generated in the above case went to the refinery.

- The Margin is a function of the Gasoil / Fuel Oil spread, which is forecast to significantly widen prior to 2020, as a result of the IMO decision, further strengthening MSAR® economics.
  - The Margin increases as the Spread increase.
  - The sensitivity of the Margin generated as a function of the Spread is shown on the right.

<table>
<thead>
<tr>
<th>MSAR® production from 1 x MSAR® Unit</th>
<th>= 1000 mt/d</th>
<th>= 350,000mt/yr</th>
<th>% Resid in MSAR®</th>
<th>= 70%</th>
<th>= 245,000mt/yr</th>
<th>Residue p.a.</th>
</tr>
</thead>
</table>

**Market Prices**

<table>
<thead>
<tr>
<th>Refinery Fuel Oil Blend Assumed</th>
<th>Gasoil, 0.1wt% S</th>
<th>508</th>
<th>HFO 3.5% S</th>
<th>274</th>
<th>CAL 18 (Mitsui 19/04/17) FOB MED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery Fuel Oil Blend Assumed</td>
<td>$/mt</td>
<td>Viscosity, cSt@50°C</td>
<td>wt %</td>
<td>mt/yr</td>
<td>Comments</td>
</tr>
<tr>
<td>Heavy Fuel Oil, 3.5wt% S</td>
<td>274</td>
<td>380</td>
<td>100%</td>
<td>432,627</td>
<td>Gasoil / Fuel Oil spread = $234/mt</td>
</tr>
<tr>
<td>made from... Cutter Stock (LCO)</td>
<td>432</td>
<td>6.5</td>
<td>43.4%</td>
<td>187,627</td>
<td>$/t value assumed is 85% of Gasoil</td>
</tr>
<tr>
<td>and... Refinery Residue</td>
<td>153</td>
<td>890,000</td>
<td>56.6%</td>
<td>245,000</td>
<td>Netback value (HFO &amp; LCO $/t and blend ratio)</td>
</tr>
</tbody>
</table>

**Step 1... Derive the value of the residue per ton on a netback Basis, i.e. value of HFO less the cost of distillates (LCO)**

<table>
<thead>
<tr>
<th>MSAR® Blend Economics</th>
<th>$/mt</th>
<th>Ratio (wt%)</th>
<th>$/mt of MSAR®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery Residue</td>
<td>153</td>
<td>x 70%</td>
<td>107</td>
</tr>
<tr>
<td>OPEX (Water 29%, Additives 1%, etc)</td>
<td>30</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>MSAR® Cost of Production</td>
<td>=</td>
<td>137</td>
<td></td>
</tr>
</tbody>
</table>

**Step 2... Calculate the cost of MSAR*/t = (Residue + water + additives)**

**Step 3... Adjust MSAR® value for lower NCV and compare fuel savings “like for like” vs HFO.**

<table>
<thead>
<tr>
<th>Assumptions: HFO NCV = 40.8 GJ/mt</th>
<th>Resid NCV (GJ/mt) = 39.5 GJ/mt</th>
<th>therefore...</th>
<th>MSAR® NCV = 27.1 GJ/mt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of MSAR® on HFO basis = 40.8 / 27.1</td>
<td>x $137/mt</td>
<td>= $68/mt HFO</td>
<td>MSAR® cost normalised for NCV (HFO equiv.)</td>
</tr>
<tr>
<td>Margin for MSAR® vs HFO (normalised for NCV) = 274 - 206</td>
<td>= $68/mt HFO</td>
<td>25% Discount vs HFO. ($/mt to be shared)</td>
<td></td>
</tr>
<tr>
<td>(=$68/mt HFO x 27.1 / 40.8)</td>
<td>= $45/mt MSAR®</td>
<td>x 350,000mt/yr MSAR®</td>
<td>= $16 million/yr</td>
</tr>
</tbody>
</table>

**Step 4... Calculate MSAR® Margin (to be shared)**

**Margin Sensitivity, $/million/yr, vs [FO-00] spread**

1 MMU: 245mt/yr of Resid + 350mt/yr MSAR®
The Quadrise team were previously responsible for commercialising the Orimulsion® business, with sales of over 60 million tons globally. End-user buy-in is of paramount importance to MSAR® projects with major consumers (the largest container line & global oil-fired utility).

Key benefits to end-users:
- Lower cost HFO alternative (price set by refinery).
- MSAR® provides enhanced combustion:
  - High carbon conversion = less Ash & Soot.
  - Water reduces NOx by 20-50%.

Fuel handling considerations for MSAR® vs HFO:
- Avoid static exposure to extreme temperatures.
- Minimise potential “shear” risks (...or formulate).
- Limit contamination with regular fuels if possible.

Marine MSAR® has so far been tested on:

2-stroke: ME

2-stroke: RT Flex

4-stroke: V32/46/64

Marine MSAR® engine tests carried out by:

Marine MSAR® vessel and LONO trials with:

Conversion from HFO to MSAR®:
- MSAR® is formulated to meet end-user requirements.
- Fuel specifications are similar to HFO (ISO8217) with minor adjustments to allow for water and droplet size.

<table>
<thead>
<tr>
<th>Marine MSAR® specifications</th>
<th>Value</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrize Quadri® fuel booster</td>
<td>MSAR®</td>
<td>HFO</td>
</tr>
<tr>
<td>Estimation equipment</td>
<td>Modern Refinery</td>
<td>Mature Refinery</td>
</tr>
<tr>
<td>MSAR® Digital Link, µs</td>
<td>75</td>
<td>Modern Refinery</td>
</tr>
<tr>
<td>Cetane Number (ISO 3816-1)</td>
<td>Modern Refinery</td>
<td></td>
</tr>
<tr>
<td>Burner No. (1, 2, 3, 4)</td>
<td>20</td>
<td>Modern Refinery</td>
</tr>
<tr>
<td>Burner Heat Ratio, %</td>
<td>7</td>
<td>Modern Refinery</td>
</tr>
</tbody>
</table>

MSAR® specifications

Part One - Emission Specifications

- Quadrize can supply: analyser equipment
- Modern Refinery: 75 µs
- Cetane Number: 20
- Burner Heat Ratio: 7%

Fuel handling considerations for MSAR® vs HFO:

- Avoid static exposure to extreme temperatures.
- Minimise potential “shear” risks (...or formulate).
- Limit contamination with regular fuels if possible.

Marine MSAR® has so far been tested on:

2-stroke: ME

2-stroke: RT Flex

4-stroke: V32/46/64

Marine MSAR® engine tests carried out by:

Marine MSAR® vessel and LONO trials with:

Conversion from HFO to MSAR®:
- MSAR® is formulated to meet end-user requirements.
- Fuel specifications are similar to HFO (ISO8217) with minor adjustments to allow for water and droplet size.

Marine Bunker Fuel Users – Conversion to MSAR® Fuel

Marine MSAR® engine tests carried out by:

Marine MSAR® vessel and LONO trials with:

Conversion from HFO to MSAR®:
- MSAR® is formulated to meet end-user requirements.
- Fuel specifications are similar to HFO (ISO8217) with minor adjustments to allow for water and droplet size.

MSAR® performance is similar to burning natural gas.
- The impact of using a water-based fuel is well understood in the marine diesel engine environment.
- Compatible with marine vessel flue gas scrubbers.

Considerations for Marine MSAR® vs HFO:

- Segregated storage & changeover, cross contamination with MDO/MGO or HFO.
- Visible emissions - steam.
- Injection timing for slow speed engines – electronic common rail preferred.
- Class approval.
- Marine MSAR® discount and availability.

Marine MSAR® engine tests carried out by:

Marine MSAR® vessel and LONO trials with:
Thermal plant references for oil-in-water emulsion fuel use:

<table>
<thead>
<tr>
<th>Country</th>
<th>Plant Name</th>
<th>Dates</th>
<th>Boiler Design Fuel</th>
<th>Boiler Rating (MW)</th>
<th>Orimulsion(^{\text{\textregistered}}) Consumption (million tonnes) Per year</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>Power Seraya Stage I</td>
<td>04-06</td>
<td>HFO</td>
<td>1x210</td>
<td>1.5 2.5</td>
<td></td>
</tr>
<tr>
<td>Guatemala</td>
<td>Constellation Energy Planta Azuana</td>
<td>04-06</td>
<td>HFO</td>
<td>150 Diesel</td>
<td>0.3 2.0</td>
<td></td>
</tr>
<tr>
<td>South Korea</td>
<td>DOSPO Tossugum</td>
<td>03-06</td>
<td>HFO</td>
<td>2x200</td>
<td>1.9 2.0</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>GEPF Nanhai A8(^{\text{\textregistered}})</td>
<td>01-06</td>
<td>HFO</td>
<td>420 + 100</td>
<td>0.5 3.5</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>GEPF Heng Tun(^{\text{\textregistered}})</td>
<td>01-06</td>
<td>HFO</td>
<td>200</td>
<td>0.2 0.9</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>GEPF Huang Pu(^{\text{\textregistered}})</td>
<td>01-06</td>
<td>HFO</td>
<td>500</td>
<td>0.1 0.6</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>ENEL Flume Santa 3, 4</td>
<td>09-04</td>
<td>Coal, HFO</td>
<td>2x320</td>
<td>1.1 4.0</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>ENEL Brindisi Sud 1,2,3,4</td>
<td>08-05</td>
<td>Coal, HFO</td>
<td>4x660</td>
<td>1.4 8.0</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>ENEL Rostermama</td>
<td>08-02</td>
<td>Coal, HFO</td>
<td>770</td>
<td>0.1 0.7</td>
<td></td>
</tr>
<tr>
<td>Barbados</td>
<td>Aracruz Cement</td>
<td>07-06</td>
<td>HFO</td>
<td>1x120</td>
<td>0.2 0.6</td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>SI Power Aosta S</td>
<td>95-03</td>
<td>Coal, HFO</td>
<td>640</td>
<td>1.4 6.1</td>
<td></td>
</tr>
<tr>
<td>Lithuania</td>
<td>LE Urtuus Elektro</td>
<td>95-06</td>
<td>HFO</td>
<td>150+1xDiesel</td>
<td>0.2 0.7</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>Hokkaido Electric Shikotsu</td>
<td>97-06</td>
<td>Orimulsion(^{\text{\textregistered}})</td>
<td>350</td>
<td>0.2 0.8</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>Kansai Electric Osaka 4</td>
<td>94-06</td>
<td>HFO</td>
<td>350</td>
<td>0.2 1.4</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>Kanto-Kuwaishi 1</td>
<td>91-06</td>
<td>Coal, HFO</td>
<td>9x15</td>
<td>0.4 6.0</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>Kanto-Kuwaishi 2</td>
<td>94-06</td>
<td>HFO</td>
<td>15x15 + Steam</td>
<td>0.4 6.0</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>NB Power Dollhaouse 1</td>
<td>94-06</td>
<td>HFO</td>
<td>105</td>
<td>0.8 7.0</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>NB Power Dollhaouse 2</td>
<td>94-06</td>
<td>Coal</td>
<td>215</td>
<td>1.2 7.0</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>PowerGen Warwick</td>
<td>93-06</td>
<td>HFO</td>
<td>500</td>
<td>1.2 5.2</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>PowerGen Richmond</td>
<td>93-06</td>
<td>Coal</td>
<td>3x120</td>
<td>0.3 1.7</td>
<td></td>
</tr>
</tbody>
</table>

Key benefits to end-users:
- ✓ Lower cost HFO alternative (price set by refinery).
- ✓ MSAR\(^{\text{\textregistered}}\) provides enhanced combustion:
  - High carbon conversion = less Ash & Soot.
  - Water reduces NO\(_x\) by 20-50%.

Fuel handling considerations for MSAR\(^{\text{\textregistered}}\) vs HFO:
- ✓ Avoid static exposure to extreme temperatures.
- ✓ Minimise potential “shear” risks (…or formulate).
- ✓ Limit contamination with regular fuels if possible.

Example fuel handling modifications at a thermal power plant:

- Existing offloading systems used; ideally HFO removed (e.g. by compressed air) before emulsion delivery, residual emulsion flushed into Main tank.
- Atomiser tips replaced with larger-ported units.
- Flame characteristics similar, but cooler and shorter.
- Water in fuel increases flue gas mass by 3-5%wt.
- But excess air can be reduced, reducing gas wt by 3-5%.
The phased investigation and business model typically follows the development pathways below.

Should the MSAR® concept be of interest to client the recommended next steps are as follows:

- Joint presentation of this MSAR® proposal and the MSAR® concept to client senior management and experts.
- Signature of a bilateral non-disclosure agreement.
- Joint investigation of the MSAR® concept with client:
  - Preliminary screening tests of refinery process streams (drum samples of VR & water) at QRF (UK visit).
  - Feasibility study of MSAR® installation (pilot and commercial phases) at client facilities.
  - Site visits to MSAR® production system at Cepsa (Spain) and Quadrise HQ & RDI facilities (UK).
  - Joint presentation of the MSAR® concept to 3rd party stakeholders, review of facilities.
  - Joint preparation of MSAR® Techno-Economic study (cost estimate +/-30%) to client senior management.
- Subject to the above, agreement to proceed to pilot / commercial phase with potential deployment in under 12 months.

**Fast-Track Project Implementation In <12 Months**

Quadrise look forward to working with your team in the near future to discuss this opportunity in more detail!
MSAR® References

Cepsa Refinery – Maersk Marine Project:
System commissioned in June ’16. Operated over 9 months to obtain Wärtsilä Interim LONO. The Quality Control Plan was developed in conjunction with Cepsa & Maersk and is supported by an on-site Quadrise Laboratory and QRI in the UK.

Power MSAR® commercial demonstration – Sweden
340MWe Karshamn Unit 3 Powerplant (CON) with EU APC
~1000mt MSAR® successfully tested
Up to 50% NOx reduction demonstrated

Power MSAR® commercial demonstration – Lithuania
4X8/D Pilot MSAR® facility installed in 200kW/D refinery (~3 months)
140kW (≥22000 mt) MSAR® produced 24x7 by Quadrise
Confirmed to the refinery technoeconomic benefits of MSAR®
MSAR fuel shipped ~300km by conventional rail (6000 mt loads)
Confirmed 600MW base load power & Alstom APC operations
Independently verified by European Bank (EBRD) consultants
Commercialisation deferred due to low Russian gas pricing (refinery is a potential supplier for marine fuel however)

Power MSAR® commercial demonstration – Canada
400kW/D MSAR® production system installed at Deer Creek for oil-field steam raising using extra-heavuy crude as feedstock in a DSTG boiler.
逾20,000 bbls produced and consumed over a 6-month period. Commercialisation deferred due to slump in US natural gas prices vs crude oil.

MOU with YTL
PowerSeraya (Singapore)
• Former Orimulsion® user
• 750MWe = 1.8M mt/a
• Investigation into MSAR® refinery supply options

Quadrise is providing extensive Operational Support & QC covering from VBR supply, through production, MSAR® loading at the jetty, spills planning and follow up on the vessel.

Use of the MSAR® ore as fuel at our petrochemical plant has demonstrated the fuel is compatible with modern infrastructure and is suitable for long-term operation at their site under existing fuel specifications. The site is located near major oil for industrial facilities and has access to a suitable infrastructure for transport and storage of the MSAR® fuel.