Developing Strategies to Meet the Latest Clean Fuels Specifications

With the current trends for tighter specifications for both gasoline and diesel, it is important that every refiner has a long-term strategy for meeting these new goals.

Depending on whether the refinery is a simple hydroskimming or complex conversion refinery the solution will probably be unique. It will probably require a mixture of getting the best out of existing hydrotreatment and associated facilities and adding some new processes. Many of the technologies for upgrading both gasoline and diesel to meet ultra low sulfur levels will be licensed, rather than open art. In addition, the offsite facilities will need to be uprated to enable the handling of these higher specification products and the integration within the refinery will need to be reviewed, as the solutions will not be a simple end of pipe type.

In today's business climate it will be important to maximize return on investment, taking into account upgrades such as, energy savings, to assist in the financing. Last year, in this conference, we looked at cost-effective revamps, this year we will specifically focus on strategy development for meeting clean fuel legislation, but still maximizing effectiveness of capital.

In developing an upgraded refinery scheme the key skills required in developing a strategy include:

- **Licensors evaluation and selection**: A good knowledge of available technologies is required, to allow their suitability to be assessed for the refinery, and the impact on refinery, octane/cetane balances, hydrogen, sulfur handling, etc. to be evaluated.

- **Licensor evaluation procedure**: This needs to be done in a structured manner to get the best results and the evaluator needs to be independent of licensed technologies, but knowledgeable about them.

- **Cost, constructability & revamp issues**: When establishing a strategy for the future, It is important to have a practical scheme, with realistic costs. The cost estimating must include all peripheral equipment, with the impact on offsite and utilities and other process units taken fully into account. This work needs to be undertaken by an organization that has these necessary skills and will often lead to the need for contractor to do this type of work, rather than a consultant or licensor, who will typically have limited accurate costing abilities

- **Economic evaluation**: The final step is to look at the viability and robustness to change of the selected options and it is here that a well thought out, innovative revamp can provide a winning solution

This paper looks at the development of product specification and describes the steps needed to develop a Clean Fuels Strategy for a particular refinery. In particular the paper looks at:

- The development of clean fuels in Europe

- The current and future development of clean fuels in Asia
- Development of a long term refining strategy required for production of clean fuels

Clean Fuel Specifications in Europe

First of all we will look at the development of clean fuels in Europe and see if there are any lessons that can be learnt for the subsequent development in Asia.

The European Union currently comprises of 15 member states. Each of the member states has it's own refining and petroleum product supply issues. The member states have widely varying opinions and commitments on most subjects that come up within the EU. For example the Northern states including Germany and Scandinavian countries have generally been quicker in developing improvements in petroleum product qualities. Countries in Southern Europe, particularly the Mediterranean countries are not quite so advanced in clean fuels initiatives.

The European Commission is responsible for setting product specifications in Europe. The many interested parties debated the future specifications for a long time, before finally in July 1998, the EU Commission produced an agreement setting out the key gasoline and diesel product specifications for 2000 and 2005. The following are some of the key parties involved in the debate on the development of the EU specifications:

- European Parliament – The members of parliament from the member states contain a wide cross section of opinions, including some members who provide a significant push to speed up the clean fuel development process.
- Auto Industry – The auto industry have grouped together to coordinate the views of the car manufacturer's regarding the development of engine technology and tail pipe clean up systems.
- CONCAWE – This organization was founded in 1963 by a group of major oil companies in Europe. CONCAWE provides technical input to the development of health, safety and environmental issues, including the cost benefit analysis of clean fuels legislation.

The EU Commission agreements normally allow some flexibility for certain counties to implement changes in fuel specifications at different times due to national requirements. Some countries will look to introduce cleaner fuels earlier than EU requirements. This has been achieved through tax incentive schemes within each country. Taxes are not harmonised throughout the EU. Some countries are allowed "Derogation", which means they are given longer time frames to implement new fuel specifications.

The European Auto and Refining industries have joined together to jointly research the transport fuels issues. The EU has used the results of the Auto/Oil research program to define future product specifications. The Auto/Oil 1 program was used for the proposed year 2000 specs, Auto Oil 2 program is now doing further research which will be used to define 2005 specs.

Auto Oil 1 has been a good example of how to achieve a scientific basis for defining measures to meet air quality targets. The program not only showed the importance of vehicle technology and fuel quality on their own, but also demonstrated the importance of their interactions. A

major outcome for current and future debate on both engine technology and fuel quality is that fuels and vehicle technology need to be developed together as a single system.

In addition to the EU product specifications there is also the development of a World Fuel Charter. The charter is a worldwide agreement between the major motor manufacturers in the US, Europe and Japan to set common fuel standards. The charter sets out three grades of fuel. The third grade is an “Advanced Fuel Spec”. This charter clearly shows the type of fuel that Auto manufacturers would like to see and the ultimate goal of zero sulphur fuels.

So what are the key specifications currently in use and proposed for Europe?:

Specification	**Euro Gasoline 2000 EN 228**	**Euro Gasoline 2005 (possible)**	**World Wide Fuel Charter Category 3 (possible)**
Sulphur Max PPM wt	150	50	30
Benzene Max Vol%	1.0	1.0	1.0
Aromatics Max Vol%	42	35	35
Olefins Max Vol%	18		10
Density Kg/m^3			715

The specifications for 2005 are not yet agreed. The following are possible additional requirements:

- Sulphur reduction to lower than 50 ppm wt
- Olefins reduction from 18 vol% to 10 vol%

A summary of the key parameters in the on road diesel specification is:

Specification	Euro Diesel 2000 EN 590	Euro Diesel 2005 (possible)	World Wide Fuel Charter Category 3 (possible)
Sulphur Max PPM wt	350 (50)	50	30
Density, kg/m^3	820 - 845	820 - 845	820 - 840
Cetane Number	>51	>51	>55
Cetane Index			>52
Aromatics, wt%			<15
PNA, wt%	<11	?	<2
T95 ^oC	<360		<340

Impact on European Refining

In this section of the paper we will look at how the European Refiners have adapted refineries in line with the changing product specifications. This is very much an ongoing process with the refiners now developing strategies for the introduction of cleaner fuels in 2005. In some countries refiners are considering introducing cleaner fuels sooner to take advantage of tax breaks.

The primary areas of interest to date have been the impacts on the gasoline and diesel pools and the ability of the refiner to manage the hydrogen balance for any new refinery configuration.

Impact on the Gasoline pool

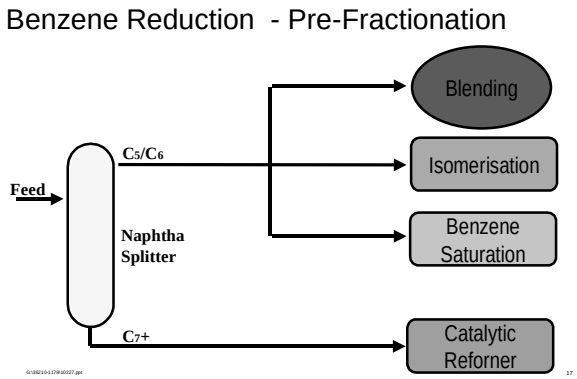
Looking at gasoline first the three main changes in gasoline specifications have been:

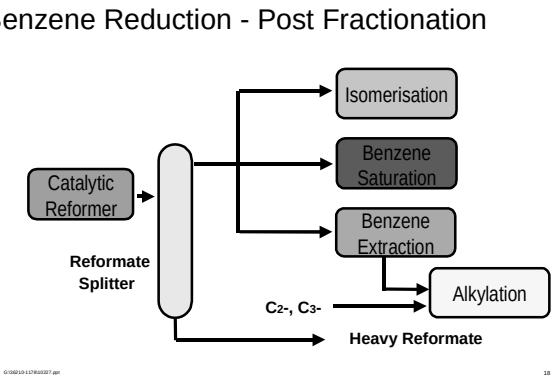
- Lead phase out
- Reduction in benzene
- Progressive reduction in sulfur

The increase in octane, required as a result of lead phase out, has involved refineries investing in a wide range of octane boosting processes, including Isomerisation, Reforming, Alkylation, MTBE and so on.

The primary source of benzene in the gasoline pool is the reformate stream and has clearly been the first target for most refineries when reviewing benzene reduction options. The reduction in benzene has generally been considered to be a choice between pre fractionation of benzene or benzene pre-cursors from the reformer feed or post fractionation of reformate. The options for benzene reduction by these methods are presented in the schemes below.

Benzene Reduction

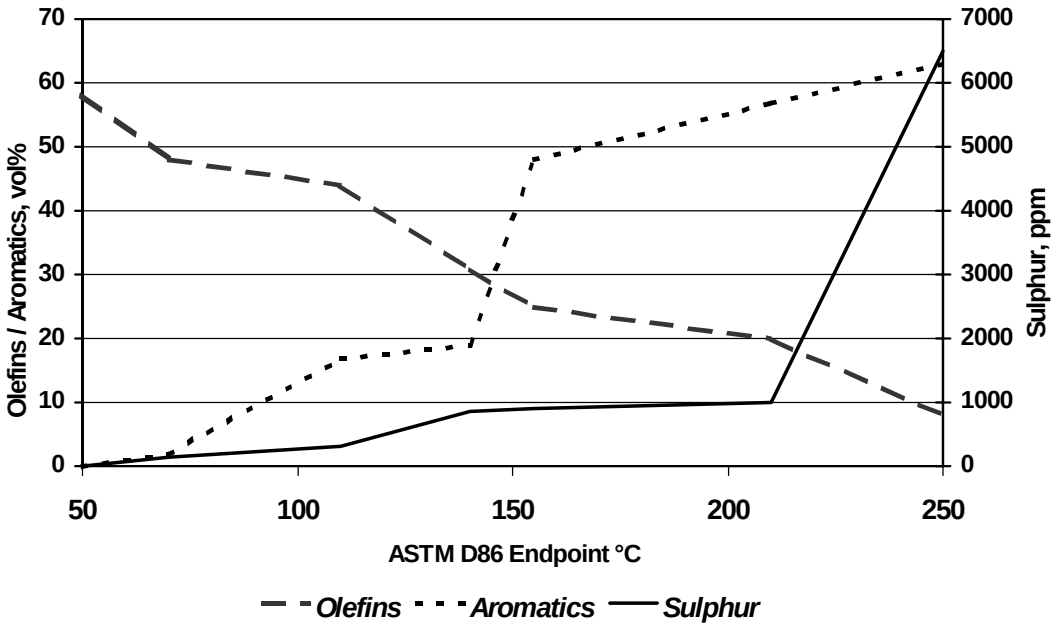




Foster Wheeler has completed a number of benzene reduction projects in Europe. These projects have involved both pre and post fractionation schemes. A number of refineries have opted to extract a benzene rich stream from the reformate product. The benzene rich stream is then sold for use as a petrochemical feedstock.

The primary source of sulfur in the gasoline pool in Europe is the FCC naphtha. Thus any strategy for gasoline sulfur reduction must focus on FCC naphtha. The key properties of this stream are presented in the chart below.

FCC Naphtha Composition



The sulfur content of the FCC naphtha increases sharply with increasing boiling range. In broad terms, about half of the total sulfur in the cut is found in the final 10% of the boiling range. Clearly in order to achieve a significant impact on gasoline sulfur, the focus needs to be on the heavier fractions of the FCC naphtha.

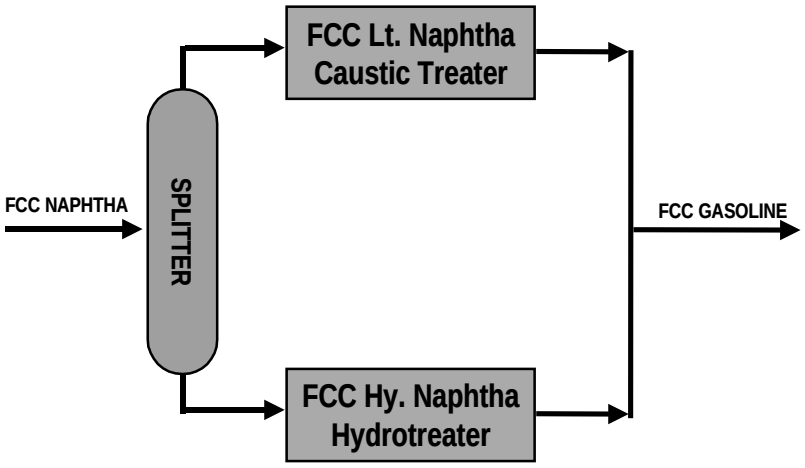
The olefin distribution, as illustrated above, supports this focus particularly if hydrotreatment is to be considered. Olefins provide much of the superior octane qualities of FCC naphtha. Hydrotreatment saturates these olefins, and destroys octane and for the heavier part of the FCC naphtha, minimizes the potential octane loss.

There is a degree of similarity between reviewing the options for benzene and sulphur reduction. The benzene reduction considered pre or post fractionation of Cat Reformer feed or product. The options for sulfur reduction of FCC naphtha are often considered to be pre or post FCC treatment schemes.

FCC feed pretreatment involves hydrotreating the whole FCC feed stream. This is relatively expensive compared to the post treating options and therefore has not been the solution favored by the majority of European refineries to date. For those refineries that have invested in FCC feed hydrotreating then they get the benefit of increased yields across the FCC, cleaner products not only for gasoline but also the LCO/DCO products, and reduced emissions from the FCC Regenerator flue. Some industry analysts consider there will be an increase in the number of FCC feed hydrotreaters in Europe in the near future.

Many of the projects that Foster Wheeler has been involved with have been based around splitting the FCC naphtha into two and three cuts and processing the separate FCC naphtha streams as required. Generally the heavy cut will be hydrotreated and lighter cuts may be routed to an extractive caustic treatment process. A typical FCC naphtha-processing scheme is presented below.

FCC naphtha separation and treatment



There are many technology options and Licensors in the FCC post treatment market each claiming an advantage of some description over rival technology providers. Some Refiners will need assistance in developing tailored solutions for their particular refinery.

Impact on the Diesel Pool

The on road diesel specification has been reduced to 500 ppm Sulfur in 1996 and then reduced further to 350 ppm Sulfur in 2000. Future specification reduction to 50 ppm and possible down

to as low as 10 ppm is currently being discussed. Consequently there has been a large increase in distillate hydrotreating in Europe throughout the mid to late 90's.

The potential changes to the diesel specifications in 2005 are most likely to be more stringent than those adopted for 2000. Specifically increases in Cetane No, reductions in density, 95% ASTM and Poly Aromatic Hydrocarbons.

Impact on Hydrogen Systems

The requirement to produce cleaner fuels has meant the refineries need more hydrogen available for hydro-processing. In addition the reduction in benzene specification in gasoline has resulted in a reduction in catalytic reformer severity and lowering in the amount of hydrogen available. The additional hydrogen demand is met by maximizing hydrogen recovery from various refinery off gas streams and from hydrogen production units.

New techniques have been developed for the analysis of hydrogen networks in refineries. Hydrogen Pinch methods have been developed based on the familiar approaches used for many years in the energy field. These new methods look at minimizing the hydrogen required from a hydrogen production plant. Foster Wheeler is currently very active in all aspects of providing tailored hydrogen solutions for refineries including:

- Studies on ways to recover hydrogen through compression and purification of refinery streams.
- Providing competitive hydrogen production units integrated with the specific needs of the refinery

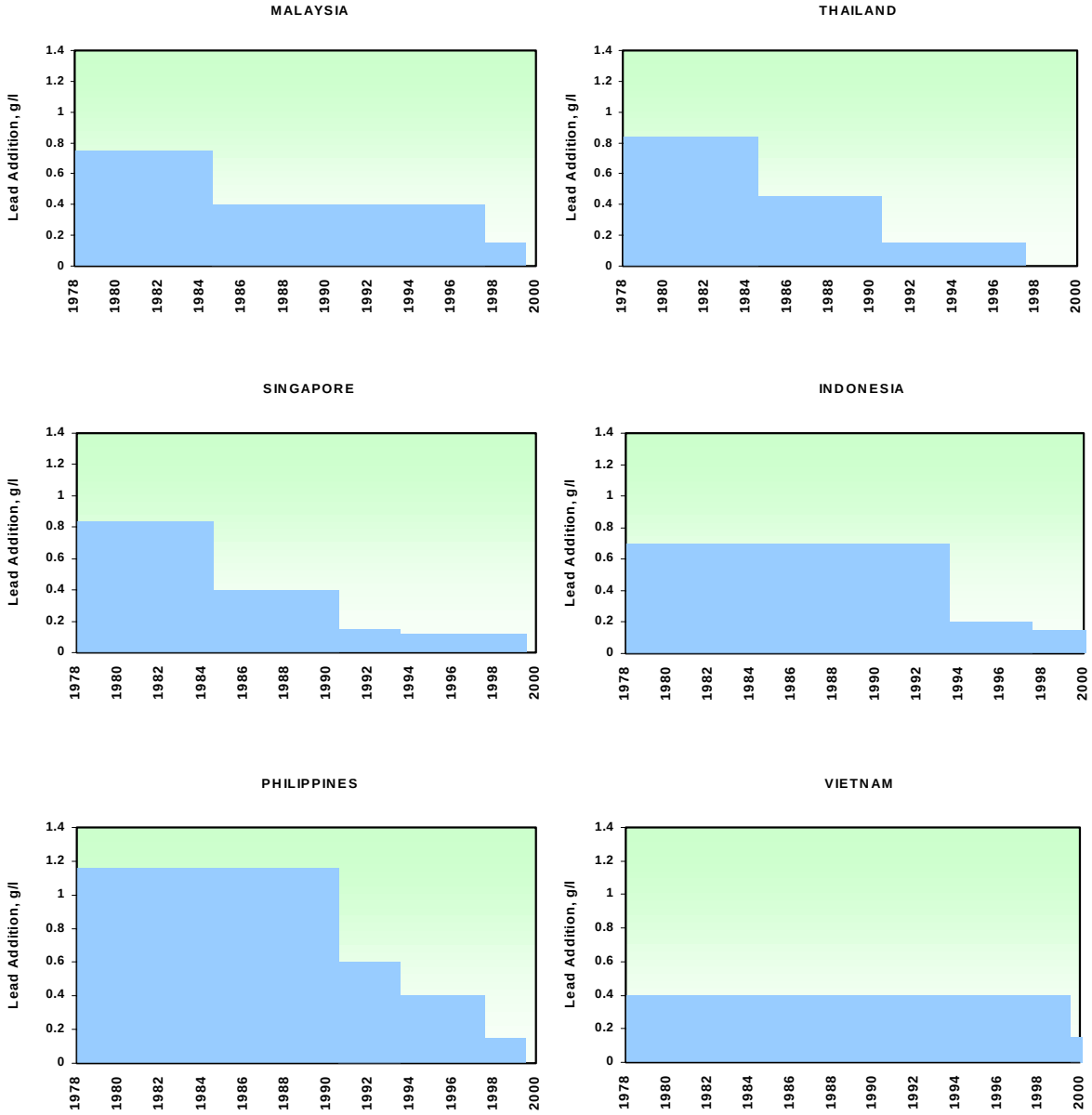
Increasingly refiners are looking "over the fence" in order to reduce the cost of hydrogen supply. The required hydrogen could be supplied by a lower cost base producer, a plant supplying others or from a third party prepared to invest on the basis of build, own, operate (BOO) long term supply agreement. Foster Wheeler has an alliance with BOC to develop BOO projects.

Clean Fuels Specifications in Asia

Product specifications in Asia are changing very rapidly as the regions populace becomes increasingly concerned about the air they breathe and the water they drink. Acute pollution levels in major cities are leading to a number of measures designed to improve air quality.

Moves towards 'clean fuels' specifications as legislated in Europe over the past ten years are already well underway in many countries in the region:

Lead Phase-Out in Asia



Over the past twenty years, lead addition to gasoline has gradually reduced in response to pollution control requirements. In the run up to 2005, it is expected that lead addition to gasoline will be completely phased out in all countries.

The graphs above further illustrate the diverse nature of fuels specifications in the region, with each country opting to follow its own timetable for implementation of clean fuels legislation. However, some convergence of product specifications towards an ASEAN standard is expected as the requirements of motor manufacturers for cleaner fuels dictate the qualities produced. Already, all incremental growth in gasoline demand is for unleaded, as a direct result of the catalytic converters fitted to new cars.

The current domestic gasoline specifications in the ASEAN region are:

Specification	Malaysia	Thailand	Singapore	Indonesia	Philippines	Vietnam
RON	93/97	92/97	97	94	93	92
PB, g/l	0.0	0.0	0.0	0.15	0.0	0.0
Sulphur Max wt%	0.1	0.1		0.2		0.05
Benzene Max Vol%	-	3.5	-	-	6.0	5.0
Aromatics Max Vol%	-	50	-	-	45	-
Olefins Max Vol%	10	-	-	-	-	-

The current diesel quality specifications in the ASEAN region are:

Specification	Malaysia	Thailand	Singapore	Indonesia	Philippines	Vietnam
Sulphur Max wt%	0.05	0.05	0.5	0.5	0.5	0.3
Density, kg/m^3	-	820-890	860 max	820-870		860 max
Cetane Number	50	-	-	45		-
Cetane Index	-	48	48	48		45
Aromatics, wt%	-	-	-	-		-
PNA, wt%	-	-	-	-		-
T90°C	370	338	370	-		370
T95 ^oC	-	-	-	-		-

The paper will now look at the moves towards clean fuels made by countries in the region, which result in the current specifications shown above. Predictions for further improvements in fuels quality will also be considered.

Malaysia – Refineries produce gasoline and diesel for both the domestic and export markets. As the rest of Asia moves towards cleaner fuels specifications, Malaysia will need to produce higher quality export gasoline and diesel. Domestically, the end of 2000 saw the end of leaded gasoline phase-out, accompanied by an increase in production of premium, 97 RON gasoline.

Thailand - Only cars fitted with catalytic converters have been sold in Thailand since 1993 and unleaded gasoline has been used for both regular and premium grades since 1996. Thailand has introduced restrictions on the benzene and aromatics content of gasoline, although tighter specifications are anticipated in years to come. Thailand has recently moved to 500 ppm diesel sulphur specification.

Indonesia – The Government of Indonesia are looking to complete lead phase out by the end of 2002. This will require the import of high octane blending components until such times that the Indonesian refineries can be upgraded to provide the incremental octane requirements.

Philippines - The Philippine Clean Air Act was signed into law in 1999. The CAA includes the phase-out of leaded gasoline throughout the country by the middle of 2000. The program began with the restriction that only unleaded fuels can be sold in the Metro Manila area from early 2000 onwards. The act also covers a reduction in the aromatics content of gasoline from 45 to 35 vol% by 2003, a reduction in the benzene content of gasoline from 6.0 to 2.0 vol% by 2003 and a reduction in the sulfur content of diesel fuels from 0.5 to 0.05 wt% by 2004.

Vietnam - Vietnam currently imports all refined products from other ASEAN countries. The VietRoss refinery project currently being developed at Dung Quat by PetroVietnam/Zarubezneft joint venture will produce transport fuels for the domestic market. Vietnam product demand is increasing. The new refinery will not meet the domestic demand. The requirement of the motor manufacturers and an increasingly environmentally concerned populace is likely to dictate the production of high quality transport fuels from future Vietnamese refineries.

South Korea - issued tight gasoline specifications in 1997, resulting in a rapid reduction in sulfur, benzene and aromatics content to European Auto-Oil 1 levels by the end of 2000. Japan has a very similar program in place.

In India, unleaded gasoline is fast becoming the main brand used. Reductions in sulfur and benzene content are also being implemented. In 1998, China pledged to phase out leaded gasoline from all major cities.

Strategy Development

A clean fuels strategy should be developed in the same way as any other investment decision making process. The steps involved in the strategy development are typically:

- Define the refinery objectives
- Develop a wide range of ideas for possible solutions to meet the objectives: this could include holding brainstorming sessions with refinery, licensors and contractors personnel

- Develop selected options for further consideration
- Cost the options and assess the economic viability for forwarding to refinery management
- Recommend a strategy and agree a way forward. This may include an investment roadmap

Refinery Objectives

The refinery objectives typically involve producing clean fuels at the lowest possible cost, at the same time giving the best return on investment. Some typical strategies to achieve that are presented below.

There are important considerations to be made when setting the refinery objectives. For example the implementation of a clean fuels strategy could be based on minimum investment to meet the most immediate changes to product specifications and to keep pre-investment for the future to an absolute minimum. This strategy may well cost more in the long run. Examples of where this may apply include:

- Sizing of hydrogen production units for current or future needs
- Providing plot space for additional reactors to improve hydrotreating space velocities or provision of plot space for future naphtha splitting columns on CDU or FCC units

Alternatively the refiner may be prepared to invest for the future.

Typical Refining Strategies

Refiners clean fuels strategies can be developed in many ways, taking into account the different aspects pertinent to the particular refiner. The lessons learnt from the development in Europe can be carried forward into the Asian refining industry. The strategies have typically included some or all of the following different elements:

- Reviewing the target product markets – For example the production of a benzene cut from the reformate stream as a feedstock to petrochemical producers.
- Crude substitution – Many of the Asian refineries process a mix of local sweet crude and imported Middle East crude. A strategy would be to consider changing the ratio of local sweet to imported sour crude processed.
- Maximizing use of the existing facilities – Many of the European refineries have developed refinery configurations that re-use existing, possibly redundant, hydrotreating capacity. Other schemes have looked at the potential for processing streams in blocked operation in hydrotreaters, producing greater flexibility in the blending options available. Such a strategy would lead to greater investment in offsites than specifically on new process units.
- Product swapping – Some of the European refining groups have increased the amount of product swapping between refineries within their own companies or by processing arrangements with neighboring refineries. The objective of such transactions is again to maximize the product revenues and avoid unnecessary investment in upgrading facilities by taking advantage of refinery synergies.
- Concentration of investments on a larger scale – A development of the refinery product swapping scenario for a large, possibly national oil company in Asia, would be to consider

shipping intermediate products from one refinery to another and concentrating investment in a single large scale upgrading unit.

There are many different approaches that can be considered in developing clean fuels strategies from crude supply, refinery processing to product marketing. The strategies described above can be considered to be either marketing led or technology led solutions.

Consultants can assist refiners to develop market led solutions by working with the refiner's product marketing teams to look at various supply issues including looking at alternative and possibly cheaper supply options. Foster Wheeler has been involved in several projects, which have developed LP models to look at different supply options from more than one refinery location. This approach can be used to consider developing product swap arrangements and further developed to look at the swapping of refinery intermediate products.

Foster Wheeler has been involved in many technology led studies in the USA, Europe and the Middle East which have been directed at meeting the challenges set by clean fuels legislation while at the same time examining opportunities for profit enhancement. These studies have examined different aspects of this problem, including:

- *Refinery Planning* – economic studies to evaluate the processing options for a given refinery. These studies can cover potential changes to feedstock qualities and product specifications and assess the potential impact of changes to process units (via revamp or addition) and product blending options.

- *Revamp Options* – innovative design studies directed at making the most effective use of existing process plant to meet new product specifications and to maximize throughput.

- *Hydrogen Management* – studies to determine the optimum use of hydrogen within the refinery covering production, recovery and purification options, import and export opportunities.

- *Energy Efficiency* – studies aimed at improving energy efficiency within a process unit or complex.

- *Technology Evaluation* – independent evaluation studies to compare available technologies (licensed or not) for a particular application.

This paper focuses on the refinery processing solution, particularly the selection of processing routes and evaluation of different technologies available.

Technology Evaluation

The technologies associated with clean fuels, such as deep desulphurisation and dearomatisation, continue to develop. These processes are becoming more intensive as sulfur content, for example, is driven ever downwards. Margins for error in process design and operational control are being squeezed as a result. Note that it is invariably the last fraction which is the most difficult to remove! Consequently, suppliers of the competing technologies are tending to retain closer control over the design process, not only to protect their know-how but also to safeguard their performance guarantees. They are doing this by keeping the basic design work in-house and hence the industry is seeing a trend back towards the provision of

licensed technology packages in clean fuels hydroprocessing, whether for new units or for revamps.

For process evaluation purposes (new units or revamps), refiners may prefer to use contractors who have no commercial links with suppliers or licensors of the applicable technologies. In the field of clean fuels, technologies can include hydrotreating and dearomatisation, hydrocracking, fluid catalytic cracking, catalytic reforming, and alkylation. At the same time, it is important that the selected contractor maintains open relationships with technology suppliers in order to keep abreast of developments and opportunities. This should enable independent and informed advice to be offered to a client, and unbiased analysis of the applicable processing routes to be provided. A proven ability to work effectively with licensors during basic design is also important

Licensor evaluation and selection

Foster Wheeler experience of evaluating licensors has typically been based on the following objectives:

- Conceptual review of licensor technology available for an investment to meet a specific specification e.g. review of the numerous options for FCC Naphtha desulphurisation.
- Licensor evaluation and selection as part of a larger project development, such as the development of a major expansion or grass roots refinery.

Typically licensor evaluations will consider the technical and commercial aspects of the licensor's technology offering and, depending on the scope of evaluation required, will address the following questions:

Commercial Terms

- Process guarantees & liabilities
- Licensor royalties
- Licensor support costs both at the design and operating stages
- Engineering design schedules
- Catalyst cost - first fill and regeneration

Technology

- Process data including product yields and product qualities
- Catalyst/Chemicals/Utility requirements
- Technology features/Innovative nature of design
- Process flexibility/reliability/operability
- Safety and environmental aspects
- Number of operating plants/relevant experience
- Operating plant performance data
- Technical support service offered including training
- Technical development program – potential enhancements to the process currently on offer

The various stages involved in a full licensor evaluation are:

- Compile a list of potential licensors and agree which licensors are to be evaluated
- Prepare a duty specification for the process. A clear and consistent statement of requirements is essential so that all licensors are able to submit their proposals on the same basis and to the same standard
- Liaise with licensors to promote understanding and to ensure a timely submission of the data. Visits to licensors, or video conference meetings arranged as necessary
- Agree a licensor evaluation procedure
- Perform a full technical and commercial evaluation of each licensor's proposal according to the procedure. Clarification to be sought as required
- Where appropriate, coordinate visits to similar operating units so that the evaluation may benefit from actual operating data
- Prepare a Licensor Evaluation Report and subsequently assist the client with final licensor selection. Assist in the negotiation of the various formal agreements
- Subsequent to license award, provide a comprehensive licensor coordination service during front-end process design and subsequent engineering design

When the licensor evaluation is part of a technology evaluation, the contractor will normally only produce a licensor evaluation report. In this case the refiner or contractor will negotiate the licensor contract as part of the next stage of project development after the refinery management has approved the clean fuels strategy.

The contractor will use the licensor information to integrate the proposed new plant into the refinery configuration. This will typically include:

- Specifying and costing changes to existing process units
- Defining the offsites and utility requirements to support the new and revamped process unit configuration
- Establishing the plot space requirements and piping tie in locations

The contractor scope of work will be sufficient to establish the approximate capital and operating costs for each of the options to be considered.

Strategy Approval and Implementation

The next step in the strategy development is to assess the economics of both market and technology led options, and develops a coherent proposal for management review. The recommended solution must provide the best solution for the set of refinery objectives defined by the refinery management. However the proposed solution should also present the basis on which the recommendation has been developed and possible future scenarios which may affect the investment decision.

Once the refinery management has approved the clean fuels strategy, then the refinery projects staff can proceed with the implementation of the strategy.

For those strategies based on investment in new or revamped process units, then the refinery project staff and contractor can proceed with the development of the basic design and licensor contractor negotiation.

Summary

This paper has looked at the development of clean fuels in Europe and highlighted the need for the oil industry to work together with the auto manufacturers to develop a phased implementation in changes to the fuel specifications.

The paper then discusses the impact of the EU 2000 and proposed EU 2005 specifications on the refineries and described the typical changes that have been made by the European refineries to meet the new specifications. In particular each refinery has many technology options. Technology providers are each claiming some form of advantage over rival technologies. Some refiners need assistance in developing tailored solutions for their particular refinery.

Product specifications in Asia are also changing rapidly as the regions populace become increasingly concerned with the quality of the air, particularly in the major cities in the region. There is a worldwide trend to convergence in product specifications through the world fuel charter, however the timeframe for harmonization is many years.

There is a move right across Asia to phase out lead in gasoline. This is complete in many countries. Several countries are looking to complete the transition in the next 2/3 years.

The development of clean fuels is an ongoing debate in each country and will continue for the foreseeable future. It is clear that each country will develop new product specifications but the timing of the introduction of new specifications will vary across the region. The continuing economic improvement in the region will help the overall development.

The development of clean fuels strategies will be a key issue for refiners over the next 10 years. Contractors who maintain open relationships with technology suppliers can play an important role in advising refiners on how to implement a clean fuels strategy and provide an unbiased analysis of the applicable processing routes available.