It is impossible to improve air quality, and in particular to reduce air pollution caused by the transportation sector, without reducing the sulphur content of fuels. Sulphur is a naturally occurring part of crude oil and must be removed during the refining process. Despite this removal, some sulphur remains in finished products, including both gasoline and diesel fuel. When these fuels are burned, sulphur dioxide (SO2) and sulphate particulate matter are emitted. Reduction in the sulphur content of transport fuels will immediately reduce the emissions of these sulphur pollutants. As the sulphur levels decline to very low levels, the benefits can increase to help reduce the total pollutant levels being emitted.

Because of its direct pollutant impact, high sulphur levels prevents the adoption of major pollution control technologies from being used in today's vehicles. Sulphur causes fouling of conventional and advanced vehicle emissions control technologies, which in turn affects the control of other pollutants, like carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). Reduction in sulphur levels in fuels helps reduce emissions from existing vehicles and allows the use of more advanced technologies in new vehicles.

**BENEFITS ON VEHICLE EMISSIONS**

As developing countries achieve global phase-out of leaded gasoline, the use of low sulphur gasoline and diesel fuels will become the norm. This will enable the introduction of cleaner vehicles and technology that can help further reduce transport-related air pollution. Figure 1 demonstrates the general progression of clean fuel and vehicle technology development implemented over time to reduce emissions.

Reduction of sulphur enables advanced vehicle exhaust after-treatment technologies to work at their optimum efficiencies. For traditional vehicle technologies, sulphur is the most important parameter for emission reductions, especially for sulphur dioxide, PM and nitrogen oxides. Sulphur removal can immediately reduce the emissions levels from current vehicles and is a necessary step to using improved catalytic systems, filters (for diesel fuel engines) and other advanced technologies capable of eliminating most vehicles exhaust emissions. Since vehicles and fuels must work together as a system, the greatest benefits are achieved when lower sulphur fuels combine with appropriate vehicle emissions control technologies.

Studies indicate the degree of required reduction in sulphur levels varies around the world. In the industrialized countries where vehicles soon will have to follow the most advanced emission limitations for NOx and CO, ultra-low sulphur fuels at 10 ppm have been requested by the automobile industry. In general, the next step for countries that have finalized the phase-out of leaded gasoline is reducing sulphur levels in gasoline and diesel fuel. Although the timeline is different for every country, the drive is to reduce sulphur in gasoline and diesel to 50 ppm (or below) by the end of this decade. Figure 2 (page 3) illustrates the range of gasoline sulphur limits across the globe.

**SULPHUR REMOVAL PROCESSES**

Crude oil quality is the main indicator of how much sulphur is present in the feed used by the refinery and how that refinery operates processing units. Sulphur is (Continued on p.3)
An Interview with Cal Hodge, President – A 2nd Opinion, Inc.

Mr. Hodge graduated from the University of Kansas with a B.S.Ch.E. degree. Before founding A 2nd Opinion, Inc. (A2O) in 1998 he worked for Amoco, The Pace Consultants and Valero Energy. During his career automotive pollution decreased 99% due to changes in fuel quality and vehicle technology. He became involved with today’s cleaner burning gasoline in the eighties when he noticed the properties that make gasoline burn cleaner are the same properties he controlled in the sixties to improve customer satisfaction with unleaded premium. At A2O, Mr. Hodge uses his experience to assist clients with regulatory, clean fuels, economic and strategic issues. You may contact him via email at A2ndOpinionInc@aol.com.

Q: Could you briefly tell us about the role that sulfur reduction in transportation fuels has had in reducing vehicle emissions?
A2O: During my career motor vehicle emissions in the United States have decreased 99%. The first 90% was done by removing lead from gasoline. The last 9% came from sulfur removal. The diesel powered SUV I am driving today emits less than 1% of the pollution that the 1967 Volkswagen Beetle that I bought during my senior year at the University of Kansas. Sulfur removal made the catalytic converter more effective on gasoline powered vehicles. Sulfur removal made clean diesel vehicles possible.

Q: Refinery processes and technologies have advanced considerably to remove sulfur from fuels, but sometimes with octane loss. In what ways do refiners achieve octane replacement?
A2O: First let me remind you that the octane loss is less than was expected when desulfurizing gasoline was first proposed and that desulfurizing diesel fuel tends to increase its cetane. In the United States where leaking underground storage tanks (LUST) and lawyers prevent the use of ethers and where the use of aromatics cannot increase, refiners have, despite its tendency to increase emissions of both VOC’s and NOx, turned to bioethanol. Some of the butylenes that had been used to make MTBE have been converted to alkylate, isooctene and/or isooctane which are used to offset ethanols’ VOC emissions by replacing some more volatile light hydrocarbons. Removing sulfur has helped offset ethanol’s NOx emissions. Outside the U.S. where LUST and lawyers do not appear to be problems, ethers are the best octane replacement option. Converting ethanol, regardless of source, to ethers tends to eliminate its tendency to increase NOx and VOC emissions and expands gasoline supply more than direct blending. The ether, with the oxygen atom hidden between carbon atoms, seems to perform more like a clean burning branched chain paraffinic hydrocarbon in gasoline engines that have evolved to use hydrocarbon based fuels.

Q: Transportation fuel demand continues to have dramatic growth in certain areas of the world. What challenges do you see for the refinery industry in meeting this demand?
A2O: Over the last forty years the refining industry has been a non-profit organization. Typically there has been one or two good years that caused refiners to expand followed by several bad years after too many expanded. The key challenge is to get ready before rather than after the good years. I have never known anyone smart enough to do that. So to fill in the valleys, I challenge the industry to globalize and tighten transportation fuel standards to both improve air quality and potential profits.

Q: Auto fuel policy, like the auto industry's World-Wide Fuel Charter, is moving to ever stricter quality parameters. What do you think are the key advances being made and looking forward?
A2O: Now that the auto industry knows how to make clean burning gasoline and diesel powered vehicles if the fuels do not contain sulfur or lead, there is no excuse for not requiring all motor vehicles, even motor scooters and cycles, to be clean burning and for the fuels to be lead and sulfur free. Worldwide. No one should add lead to gasoline. 15 to 30 ppm sulfur at the pump should be considered lead free. I also would like to see at least 87 octane gasoline and 50 cetane diesel. Worldwide. Tighter fuel standards are good for the refining industry because they eliminate surpluses of usable product. Tighter vehicle emissions standards are good for the auto industry because they create new vehicle sales.

Q: With crude oil prices at historical high levels, what impacts do you believe this has on refinery operations and ability to continue to achieve sulfur reductions and other fuel quality requirements?
A2O: Refineries use energy to convert crude oil to usable refined products. To make the products meet today’s standards requires more energy. If crude costs more, energy costs more. Therefore apparent margins must increase. Unfortunately profits don’t. The other big risk is that the higher the crude price the more it can fall. Because refineries buy crude before they sell products, margins can go negative when prices are falling. To mitigate the price risk, refiners tend to sell future product as they buy today’s crude which decreases margins or to minimize inventories which causes bigger price spikes when disruptions occur. Lower net margins (profits) means refiners have less cash to use to upgrade product quality and price spikes create political problems.

Q: How is biofuels policy and increasing use of renewable fuels impacting fuels production and use?
A2O: Most renewable fuels require some sort of government policy intervention such as subsidies or mandates to make them viable in today’s market. When mandates and/or subsidies are applied to spec-

(Continued on p.3)
removed, to varying degrees, during the refining of crude oil into automotive fuel and other products. Refiners and technology companies have worked to improve the catalysts and process units to better manage sulphur content in feeds and gain efficiencies for sulphur removal. Sulfur reduction is important for refineries for several reasons:

- Many catalysts in reformer units are sensitive to the sulphur levels in the feed
- Air pollution control standards that apply to the refinery or process units
- SO₂ emission from the hydrogenation of sulphur-containing coke

Sulphur in gasoline comes predominantly from three sources: FCC (fluid catalytic cracker) gasoline, coker naphtha, and straight-run naphtha. In many cases, more than 90% of the sulphur in gasoline pool comes from the FCC gasoline output. To achieve lower sulphur levels in the finished gasoline product, the refiner must make a lower-sulphur FCC gasoline.

Several different processes are used to reduce the sulphur level in the FCC feed. One process is hydrot-... (Continued on p.5)

Sulphur Reduction - The Key to Lower Vehicle Emissions

- Organosulphur content will poison the hydrocracking catalyst
- Most sulphur compounds are corrosive.

Biotechnical innovations are also underway. At least three companies are genetically modifying microbes to eat essentially the same fermentable biomass feedstocks as used to make bioethanol and excrete hydrocarbons that boil in the gasoline, jet fuel and diesel fuel boiling ranges. Being hydrocarbons, the products are going to be fully compatible with the existing infrastructures.

Figure 2 – Gasoline Sulphur Limits

Source: International Fuel Quality Center, April 2008

Note: Where available/applicable, sulfur levels are based on early implementation of lower sulfur gasoline.
North African Program Advances Gasoline Lead Phase-out & Sulphur Reduction

Delegates from Algeria, Morocco and Tunisia met at the Tunis International Center of Environmental Technologies (CITET) in August to review progress in phasing out leaded gasoline, and discuss strategies on reductions in fuel sulphur levels. The initial session examined technical issues on leaded gasoline phase-out, including refining technologies, vehicle benefits of unleaded fuels, and case examples of other country’s experiences with phase-out. The remainder of the sessions involved national strategies being implemented by the three countries to move to unleaded gasoline and low sulphur fuels. The meeting was organized by the Tunisian Ministry of Environment and Sustainable Development, with coordination also provided by the U.N. Environmental Programme – Partnership for Clean Fuels and Vehicles (PCFV), Asian Clean Fuels Association (ACFA), International Petroleum Industry Environmental Conservation Association (IPIECA), and African Refining Association (ARA).

Moroccan officials announced that they would be phasing out leaded gasoline and moving to 50 ppm sulphur level in fuels at the end of 2008. Tunisian representatives similarly announced that leaded gasoline phase-out at the end of the year and the start of a national program to reduce fuel sulphur levels to at least 350 ppm. Algeria plans to upgrade its four refineries to meet Euro-equivalent standards for lead, benzene, sulphur and aromatics content, and expects to complete the phase out of leaded gasoline by 2013. Public education programs will take place in each country with the help of external organizations, to help ensure implementation of the strategies. Other major understandings coming out of the meeting include:

• proposed standardization of fuel specifications, and vehicle and air quality standards
• exchange of information and the development of a regional plan on the environment and health issues, encompassing the northwestern African region
• economic feasibility analysis and incentives for further improvements in fuel quality
• investigation of other clean energy and renewable fuels options for the region.

Mr. Habib Dimassi, principal assistant to the Minister of Environment and Sustainable Development welcomed the meeting participants. Mr. Clarence Woo, Executive Director of the Asian Clean Fuels Association and Mr. Rob Cox, representing the International Petroleum Industry Environmental Conservation Association (IPIECA), gave introductory remarks about the program and stressed the importance of improving fuel quality and implementing advance vehicle emissions controls for the region.

His Excellency Nadhir Hamada, Tunisia Minister of Environment and Sustainable Development, provide a keynote address to the delegates. He briefly summarized the progress being made to improve air quality and efforts to reduce emissions from all sectors, including transportation.

Mr. Rob Cox, representing IPIECA, presented the principal techniques applied to fuel quality improvements. He reviewed the options available to refiners, such as reforming, isomerization, and alkylation, and use of high quality blendstocks such as MTBE and alcohols. Mr. Cox concluded that each fuel producer needs to evaluate their refinery operations to select the most suitable and economic products for meeting clean fuel needs.

Ms Rajah Mazouzi, from the Tunisia Ministry for Public Health, demonstrated the health impacts due to high sulphur emissions and the benefits from reductions in sulphur levels (Figure 4). She described how sulphur reductions help to lower CO, HC, and NOx emissions from gasoline and diesel powered engines.

The representatives of Algeria, Morocco and Tunisia gave detailed presentations about current work taking place to tighten specifications on fuels and vehicle emissions standards. They examined refinery modernization and process changes to provide clean fuels to the marketplace.

Following the technical reviews and presentations, the delegates worked on principal recommendations and action plans to continue the improvements achieved to date. Based on the success of this program, it was agreed that a follow-up meeting would be conducted in the North African region to address regional and national action plans for the improvement of air quality and promotion of clean fuels. Additional details on the event can be found at: http://www.unep.org/pcfv/meetings/Northafricanmeeting.asp

North African Program Advances Gasoline Lead Phase-out & Sulphur Reduction

Source: CITET Workshop, 2008
Sulphur Reduction - The Key to Lower Vehicle Emissions

(continued from p3)  

Because sulphur in the FCC gasoline so strongly depends on the sulphur content of the feed, moderately severe feed hydrotreating results in less sulphur in the gasoline than from other desulphurization methods. Feed hydrotreating has other benefits – it also improves feed quality by reducing metal content, nitrogen content and other contaminants. The down side is that the investment required for an FCC feed hydrotreating system is several times more expensive than other options.

Because most of the sulphur in FCC gasoline resides in the high boiling fraction of the gasoline, the simplest method to reduce gasoline-sulphur content is to cut the gasoline so that the heaviest portion (10 to 15%) is transferred from the gasoline to the distillate fraction. This approach solves the sulphur problem when FCC gasoline requirements are not too severe and the sulphur in the full-range FCC gasoline is not too high.

Most sulfur-reduction approaches result in some octane loss in FCC gasoline. Recracking the heavy FCC gasoline by recycling it to the catalytic cracker reduces the sulfur in FCC gasoline while actually increasing RON and MON. Gasoline produced from reacracking is highly aromatic (virtually no olefins remain), helping to increase octane index. Recracking the heavy-gasoline, however, results in a significant loss in gasoline volume. Depending on the configuration of the refinery and product slate produced, the refiner may look to other high octane process units, such as oxygenate-ether, like MTBE, or alkylate.

POLICY CONSIDERATIONS FOR FUEL SULPHUR REDUCTIONS

Decisions makers need to consider a number of factors when developing strategies and programs for reducing sulphur levels in fuels. These factors must be integrated into the overall effort to lower vehicle emissions and improve air quality. Obviously, the unique conditions and situation for a given country will greatly influence how fuel sulphur reduction can be take place. The key considerations for sulphur reductions include:

- Current sulphur levels in the fuel
- Existing vehicle fleet and level of emission control technologies generally used
- Vehicle emission standards and phase-in of any stricter requirements
- Vehicle maintenance levels and ability to retro-fit
- Vehicle use patterns
- Fuel refining, distribution, retail structure and capabilities to provide reduced sulphur fuels to the marketplace.

Broader considerations, such as fuel supply and security, economics, market competitiveness, environmental factors, and consumer education and acceptance will also come into play for any fuel quality strategy. Stakeholders, from fuel producers/suppliers, auto and engine manufacturers, local, state and national government officials, regulatory agencies, and public interest and community groups need to be full engaged for implementation to be successful. Figure 3 illustrates the interdependence of issues when planning and implementing reduction of sulphur levels in motor fuels.

In developing countries, the strategies to devising a specific “road map” for fuel quality improvements generally involve short-term actions, such as stricter requirements for areas where the worst air quality exists, followed by longer-term efforts, like regional harmonization of standards. The strategy must also consider whether sulphur levels should be lowered incrementally over time or should be done in one major step. As noted previously, the motor fuels and the vehicles need to be viewed as one system.

In the European Union, North America, Japan and Korea, fuel quality changes and sulphur reductions have occurred in line with introduction of stricter emission standards and new vehicle technologies. As a result, ultra-low sulphur standards exist in these regions (see Figure 2). Developing countries dealing with serious air quality challenges can benefit from the experiences in these other regions. Organizations like ACFA and the UNEP Partnership for Clean Fuels and Vehicles, have developed guidance tools for lower sulphur fuels strategies.

The phase-down of fuel sulphur levels has become the priority for many countries during this decade and into the next. And the public health benefits can be immediately realized with the improvements in air quality.

Figure 3 – Interdependent Factors to Sulphur Reductions

Source: IPIECA, 2006
RUSSIA DELAYS EURO-3 IMPLEMENTATION
The Russian government recently decided to postpone the switch to Euro-3 equivalent fuels standards by two years, due to concerns that domestic refiners would be unable to meet the previous deadline of January 2009. Russian oil companies had indicated that they would be unable to make the necessary upgrades and meet the investment levels required to achieve the standard by January 2009. The standard will now officially take effect in 2011. About 50% of motor fuels produced by Russian refiners comply with the Euro-2 equivalent standard. While most refiners are expected to be ready to transition to the Euro-3 gasoline standard during 2009 and fully reach requirements over the two years, a large scale modernization would be needed for further fuel quality improvements to meet the Euro-4 equivalent standards. As a result of this decision, the Russian government is seeking opportunities to shore up domestic production of petroleum fuels, including consideration of building a new refinery to serve its domestic market.

HONG KONG BAD AIR DAYS INCREASES HEALTH RISKS
A multi-year health study of impoverished people in Hong Kong shows a greater risk of death when air quality is bad in the territory. The study, lead by the University of Hong Kong’s School of Public Health, and published in the journal Environmental Health Perspectives, found that most deaths occurred a day after the air pollution index showed a rise. The researchers found that more deaths occurred in poor neighborhoods just after air quality declined significantly. This occurrence was not observed in richer neighborhoods. The researchers were able to examine over 215,000 deaths from respiratory and cardiovascular causes. Date on districts lived in, income levels, marital status and other markers were used and compared to air pollution readings in the territory. The research is look further into explaining why poorer people were more susceptible to these increases in air pollution.

INDIA ISSUES NEW VEHICLE EMISSIONS STANDARDS
The Indian Ministry of Shipping, Road Transport and Highways has issued notification of amendments to most Indian emissions standards for road and off-road vehicles. The notification shows Type Approval limits, Conformity of Production limits, durability requirements, Deterioration Factors, reference and commercial fuel specifications and, for light-duty vehicles, OBD Threshold Limit Values. The notification from the Gazette of India is on the Department of Road Transport & Highways website: http://morth.nic.in/writereddata/sub-linkimages/GE522774676141.pdf.

The main requirements for 2-and 3-wheelers with gasoline engines are shown below.

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<th>CO</th>
<th>HC</th>
<th>NOx</th>
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<td>0.10</td>
<td>0.08</td>
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<tr>
<td>Category N1 &amp; N</td>
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<td>0.08</td>
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<tr>
<td>RW ≤ 1305</td>
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<tr>
<td>1305 &lt; RW ≤ 1760</td>
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<td>1760 &lt; RW</td>
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For 2 and 3-wheelers, the Bharat Stage III emissions limits, applicable from 1 April 2010 will be g/km

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<tr>
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<th>HC</th>
<th>PM</th>
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<tbody>
<tr>
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<td>1.0</td>
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</tr>
<tr>
<td>1.25</td>
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</tr>
</tbody>
</table>

For light-duty vehicles, Bharat Stage IV will apply from 1 April 2010 for the National Capital Region, Mumbai, Kolkata, Pune, Chennai, Bangalore, Hyderabad, Ahmedabad, Surat, Kanpur and Agra.

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