Cost-benefit Analyses of Lowering Sulfur Levels in Transportation Fuels

In the U.S. and Europe extensive cost-benefit analyses have been done to determine the net benefit of moving to near zero sulfur fuels for transportation, and lately for non-road purposes as well. In the face of steadily increasing vehicle miles traveled, the challenge of meeting air quality goals and protecting human health has required the development and adoption of more and more advanced mobile source emissions standards, requiring in turn stringent fuel standards. Under a variety of assumptions, analyses have consistently found that the benefits outweigh the costs of lowering the sulfur levels in fuels. And benefits may be even greater when sulfur levels are reduced from a higher baseline.

Human health benefits have dominated in cost-benefit analyses performed in support of upcoming mobile source regulations in the U.S.. The benefits associated with rules setting more stringent emissions and fuel standards for passenger and heavy-duty vehicles and non-road engines, are expected to be 5-40 times greater than costs. In the European cost-benefit analysis, fuel standards were evaluated separately from more stringent emissions standards. Still, the benefits continue to be positive down to near-zero sulfur levels, primarily as a result of reduced costs associated with expected increases in fuel economy

Other countries are considering or are adopting similar standards, along a similar timeframe to the U.S. and Europe. A less extensive cost-benefit analysis has been completed for Mexico and, based upon this and additional evidence, the government and national oil industry there have agreed to adopt U.S. standards with a time lag of only six months to a year. Other cost studies for Asia and China have been generally in line with U.S. and European findings and offer approximately upper and lower bound estimates for the costs associated with producing lower sulfur fuels in this region. This paper will discuss the nature of the costs and benefits included in these types of analyses and then will provide a brief synopsis of the findings of each study.

Costs and Benefits

Cost-benefit analyses vary a great deal depending upon where the boundaries of analysis are drawn, what assumptions are used, and what is the focus of analysis. Studies in both the U.S. and Europe have consistently found that the benefits of reducing sulfur in transportation fuels far outweigh the costs, regardless of the very different assumptions used. The U.S. Environmental Protection Agency (EPA) treats fuels and vehicles as a system in their analyses, weighing the benefits associated with improved air quality against the costs associated with both refinery upgrades and advanced vehicle technologies. In contrast, a recent analysis for the European Union (EU) investigated only the shift in sulfur levels, assuming new emissions standards were a separate issue. Air quality benefits played a less important role in this analysis, which focused more on increased fuel economy resulting from design modifications made possible with near-zero sulfur fuels.

In order to avoid doing a computationally intensive multi-year analysis of the benefits of proposed regulations, EPA simplified its cost-benefit methodology to instead consider a single year in the future. This provides a snapshot of benefits and costs when the vehicle fleet is assumed to be fully turned over and consists almost entirely of vehicles and fuels meeting the proposed standards. In all three rules, EPA has assumed that 2030 is a representative year in which to compare costs and benefits. EPA's cost-benefit methodology includes four basic steps:

1. Calculation of the impact of standards on emissions inventories.
2. Air quality modeling to determine changes in ambient concentrations of ozone and particulate matter that will result from the changes in the precursor emissions.
3. Benefits analysis to determine the changes in human health and welfare that will result from changes in ambient concentrations. Benefits are monetized
4. Comparison of the costs of the standards to the monetized benefits.

The first step requires development of a baseline emissions inventory. Emissions inventories are calculated at the county level using a mobile source model capable of predicting grams per mile emissions from vehicles and engines, according to type and model year. The baseline can be developed using knowledge of vehicle miles traveled (VMT), broken down by engine type and model year. Nationwide emissions inventories are generated from available data for the year 2030. Two inventories are prepared, one baseline and another incorporating the emissions benefits of the rule being considered.

In the second step, EPA uses a number of three-dimensional grid-based Eulerian air quality models to estimate ozone and particulate concentrations and deposition over large spatial scales. Comparing model results for the baseline emissions inventory and the changed inventory provides an estimate the number of people that will benefit from different levels of air quality improvements.

Using epidemiological studies, EPA is able to assign a particular health endpoint with the modeled change in concentration. (The heavy-duty rule includes the following example: a 10 $\mu g/m^3$ decrease in daily $PM_{2.5}$ levels might decrease hospital admissions by three percent.) Each health endpoint is monetized based upon willingess-to-pay and contingent valuation studies and total benefits of the rule being considered are summed for the year 2030. Many benefits are not quantifiable, particularly welfare benefits such as damage to forests and reduction in visibility.

In the final step, annual program costs are estimated and compared with the benefits. Costs are dominated by fuel quality improvements, including refinery upgrades, higher operating costs, and increased distribution costs. Advanced vehicle technologies add a small incremental cost, typically less than a quarter of total costs. Decreased maintenance costs and increased fuel economy are subtracted out of costs.

Many cost benefit analyses skip the air quality modeling step because it is very labor intensive. Simple cost per ton ratios, averaged over urban and rural populations, have been developed by many different agencies as a simple factor for the quantification of benefits if emissions reductions are known. In most analyses, benefits are dominated by reduced mortality and illness associated with the up to 95% reduction in particulate matter (PM) emissions from new diesel vehicles, assuming new vehicle standards are included in the analysis. When new vehicle standards are not considered, reductions in PM emissions from existing diesel vehicles due to low sulfur fuels may still be significant. Emissions reductions can range from 5% to more than 15%, depending on the change in sulfur levels and the technology and upkeep of the vehicle. Respirable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) are associated with premature mortality, as well as bronchitis, cardiovascular and pulmonary diseases, and asthma. Recent studies demonstrating health effects at very low concentrations suggest that there is no lower threshold for these impacts and that substantial benefits will continue to be accrued as ambient concentrations continue to be reduced (Brunekreef and Holgate 2002).

Advanced vehicle technologies contingent upon use of low sulfur fuel also reduce emissions of ozone precursors and other direct pollutant emissions from new gasoline and diesel vehicles. When used in existing vehicles with catalytic controls, low sulfur gasoline will increase the efficiency of the catalyst. Although these benefits are widespread and very important, they are often ignored in cost-benefit analysis because quantification requires extensive modeling. In addition, these tend to be associated with chronic illness rather than death, thereby reducing the monetary benefit that is assigned. Other often unquantified benefits include increased visibility, reduced environmental harm, and material and crop damage.

Maintenance costs and impacts on fuel efficiency can enter into either the cost or benefit side of the equation. The European Commission assumed that advanced technologies contingent upon near zero sulfur fuels would increase fuel economy, providing a significant benefit. Reducing sulfur levels in fuel will tend to reduce maintenance costs but, unless care is taken to ensure adequate lubricity of diesel fuel, maintenance costs can increase for diesel vehicles at near zero sulfur levels.

United States

The U.S. EPA has performed cost-benefit analyses for recent rulings setting fuel and vehicle emissions standards for on-road and non-road vehicles. The Tier 2 standards set stringent emissions standards for passenger vehicles and required sulfur levels in gasoline to be reduced from current levels of 300-350 ppm to an average of 30 ppm sulfur, with a maximum of 80 ppm. The Heavy-duty Engine and Vehicle Standards reduced heavy-duty truck emissions by up to 95% and required sulfur levels in diesel fuel to be reduced from current levels of 500 ppm to a maximum of 15 ppm. The most recent ruling required nonroad diesel fuel to be reduced from existing levels of approximately 3,000 ppm sulfur to 15 ppm in 2010. The lower sulfur fuel will allow nonroad diesel vehicles and equipment to meet new standards, which require emissions to be reduced by over 90%. The 40 to 1 ratio of benefits to costs was significantly higher for the nonroad rule than for previous programs.

Table 1. U.S. Benefits & Costs in 2030

Regulation	**Benefits** (billions)	**Costs** (billions)	**Net** (billions)	**Ratio**
Tier 2 (EPA 1999)	25	5.3	20	5:1
Heavy-duty diesel (EPA 2000)	70	4.3	66	16:1
Non-road (EPA 2004)	83	2.0	81	40:1
Total	178	12	167	15:1

Reducing sulfur levels in gasoline and diesel are integral parts of meeting the new emissions standards associated with each of these rulings and thus in achieving the expected benefits. EPA found that average costs to meet the new, phased-in 30 ppm sulfur standard for gasoline will be over 0.50¢ per liter in 2004 but will decline to less than 0.45¢ per liter in 2010, as lower cost technology becomes more viable (EPA 1999). On the other hand, the costs of meeting the new 15 ppm standard for on-road diesel are expected to start at a national average of 1.1¢ per liter and increase to 1.3¢ per liter in 2010, as smaller refineries are required to also meet the standards (EPA 2000). Current non-road fuels in the U.S. can have sulfur levels as high as 3,000 ppm. The regulatory impact analysis for the non-road rule estimates that the average price for non-road fuel could increase by approximately 1.8¢ per liter, with increases of up to 3.4¢ per liter in certain parts of the country (EPA 2004).

Reduction in premature mortality due to reduced PM levels was the dominant benefit in each case. This was a greater benefit for the heavy-duty standard, which will result in significant reductions in direct PM emissions. But the benefit was also significant for Tier 2, due to a reduction in NO_x and SO_x emissions, both of which result in secondary PM formation. For many health endpoints, the non-road rule almost doubles the benefits predicted by the two other rules combined. By 2030, 26,000 fewer annual incidents of premature mortality are predicted due to these three rules. Cost-benefit analyses for the three rules also predict annual avoided incidences of 13,000 cases of chronic bronchitis, more than 38,000 cases of acute bronchitis, 19,000 hospital admissions from respiratory and cardiovascular causes, more than 3 million lost work days and 21 million restricted activity days. The studies also predict $5.2 billion in damages from reduced visibility. Agricultural crop damage is not monetized for the non-road rule but $1 billion in benefits are estimated for the other two rules. Unquantified benefits include reduced environmental harm and material damage.

U.S. EPA projected each analysis out to the year 2030 and net benefits for these three studies were $167 billion (see Table 1). Several aspects of the analysis, including the timeframe, introduced considerable uncertainty into the final numbers. Yet, because many benefits were not monetized, one can still assume that the final numbers are an underestimate. In fact, one plausible alternative to EPA's benefit analysis for the heavy-duty standards found over 150% increase in total benefits, which would make the net benefit of the rulings $270 billion (EPA 2000).

Canada

Environment Canada convened a government working group in 1997 to recommend appropriate sulfur levels in gasoline and diesel. The group analyzed costs and non-monetized health benefits of lowering sulfur in gasoline. Throughout Canada the average sulfur level in gasoline was 360 ppm in 1997. In certain regions, however, such as Ontario and the Prairies, sulfur levels in gasoline were over 500 ppm.

Health benefits of reducing sulfur levels to 30 ppm (without the additional benefit of more stringent vehicle emissions standards) were considered to be significant. Over a 20-year period of analysis, over 2,000 premature deaths were expected to be avoided, along with more than 90,000 cases of bronchitis in children, 1.6 million restricted activity days, and 11 million acute asthma days. The methodology used was considered likely to underestimate benefits and Health Canada predicted that potential benefits could be an order of magnitude higher than estimates.

Capital costs required for Canada's 17 refineries to achieve this reduction in sulfur levels was expected to be $1.2 billion U.S. (1.8 billion in Canadian dollars) and operating costs were expected to increase by $80 million U.S. annually. About 0.7 cents U.S. per liter were expected to be recovered from consumers, threatening the viability of up to 4 refineries. There was expected to be a higher potential to recover compliance costs from consumers if standards were matched between the U.S. and Canada, reducing the threat to refinery viability.

European Union

In contrast to EPA studies, the most recent study of the Directorate-General Environment (2001) of the European Union looked only at the shift from 50 to 10 ppm sulfur fuels, assuming all vehicle emissions standards remained constant. Greenhouse gas emissions were the primary concern of the analysis, rather than absolute health benefits. In this context the primary benefit was increased fuel economy of new models taking advantage of near-zero sulfur fuel to achieve modest 2-3% increases in fuel efficiency. Gasoline and diesel fuels were considered together, with diesel expected to achieve lower efficiency gains (2%) at higher costs (0.3-1.0 U.S. cents per liter) but with smaller increases in CO_2 emissions from refineries. The primary air quality benefits was a 5% reduction in PM from diesel vehicles, only a small portion of the quantified monetary benefits but a significant impact, especially considering the relatively small change in sulfur levels.

The costs of lowering fuel sulfur levels from a maximum of 50 ppm to a maximum of 10 ppm were expected to range from 0.11 to 0.29¢ per liter for gasoline and from 0.29 to 0.61¢ per liter for diesel, with a possible price premium for diesel that could reach as high as 0.90¢ per liter (Birch and Ulivieri 2000). These estimates are consistent with other studies by Concawe, Ford, the Federal Republic of Germany, and the Netherlands Government, reported by the European Conference of Ministers of Transport (2000).

Monetary benefits were predicted for seven different scenarios, ranging from a full introduction to a phase-in of near-zero sulfur fuel over the timeframe of 2005 to 2011, with the benefit analysis stretched out to 2020. The benefits in the year 2020 were typically two to three times greater than the costs and the net present value of the benefits of the various scenarios (including both gasoline and diesel) ranged from $1.7 to $3.2 billion U.S. (Directorate-General Environment 2001).

While the analysis by the Directorate-General predicted only moderate air quality benefits from existing vehicles for this incremental decrease in sulfur levels, the actual air quality benefits associated with recent reductions in sulfur levels in Europe have been dramatic. A study in Denmark, one year after the level of sulfur in diesel fuel was reduced from 500 ppm to 50 ppm, revealed a significant decrease in ultrafine particle concentrations in the ambient air. The study related the drop in ambient particle number concentration to a 56% reduction in average particle emissions from diesel vehicles (Wåhlin et al. 2000).

Tax incentives for lower sulfur levels have been used to accelerate the transition to low and near zero sulfur fuels in many European countries, including Switzerland, Germany, Sweden, Denmark, Finland, the United Kingdom, Norway, the Netherlands, and the Czech Republic (Olivastri and Williamson 2000). Some examples include:

- As of January 2004, the Swiss government has levied a tax of 2.4 cents per liter on motor fuels with sulfur content above 10 ppm (IEA).
- Beginning in November 2001, the Federal Government of Germany levied an additional tax of 1.9¢ per liter on fuels with sulfur levels above 50 ppm. The threshold was decreased to 10 ppm in January 2003, prompting a speedy market shift toward near zero sulfur fuels well ahead of EU regulations (Germany 2004).
- Sweden first introduced an environmental tax on sulfur in diesel in 1991, with adjustments in 1992 and 1996, which lead to a 95% market share for 10 ppm sulfur diesel in urban areas by 1999. The three largest cities in Sweden set strict standards for heavy duty diesel vehicles traveling within their borders, resulting in widespread retrofits for these vehicles (Erlandsson 2000).
- Denmark and Finland have both had success in moving the market completely from 500 ppm to 50 ppm sulfur diesel with the introduction of tax differentials amounting to approximately 2-3 US cents/liter. In consultation with refiners, the government of Denmark found that a tax incentive of 0.09 DDK/liter (1 US cent/liter) would result in 100% market penetration. The government reduced tax by this amount for ULSD and increased tax by this amount for high sulfur diesel, resulting in a differential of twice the recommended amount. The incentive was introduced on June 30, 1999 and full market penetration was achieved literally overnight, by July 1, 1999 (Olivastri and Williamson 2000). The tax incentive in Finland was designed to be revenue neutral and did not decrease government revenues significantly.
- The United Kingdom (UK) introduced a stepped reduction in tax for near zero sulfur diesel. The duty for near zero sulfur diesel was reduced by 1 pence/liter (2 US cents/liter) in 1997, with an additional pence added each year up to 3 pence/liter (5 US cents/liter) in 1999. With the original incentive level, a small supply of near zero sulfur diesel was made available in urban areas. Once the incentive reached 2 pence/liter (3 US cents/liter), the supply took off, reaching almost 100% penetration just 2 years after the original incentive introduction. Incentives for clean fuels were accompanied by reduced pollution concessions for trucks and buses meeting certified emissions standards, providing a substantial incentive for vehicle manufacturers and operators to invest in advanced pollution control technology (Olivastri and Williamson 2000). In 2000, the UK introduced a 1 pence/liter tax differential for near zero gasoline.

These case studies demonstrate that tax incentives for clean fuels can be effectively used to spur the introduction of clean fuels over a fairly short time frame, especially if measures are introduced in consultation with refiners. Measures can be designed to be revenue neutral with minimal cost to the government. Because distribution of two grades of highway diesel fuel may lead to additional costs and obstacles, it is preferable to stimulate a complete and rapid market shift for this fuel, and in this regard it is important to get the price right. Indeed, in this case it may actually be more efficient to be on the conservative side, especially when setting the differential as an additional tax on higher sulfur products and when regulatory measures will overrule the tax incentives after some period of time.

Mexico

A set of informal cost-benefit analyses were performed for a recent conference on clean fuel and vehicle standards in Mexico. Three methods were used to arrive at an estimate of benefits. All three estimates required a prediction of emissions change between a with and without near zero sulfur fuel in the year 2030. In this analysis, it was assumed that there had been complete turnover of the fleet with vehicles capable of meeting stringent emissions standards, contingent upon near zero sulfur fuel availability. Because vehicle standards were not in question, costs consisted only of refinery upgrades and were based upon Pemex analysis of investment needs.

The three methods included:

1. The first method scaled the benefits from U.S. EPA findings for the heavy-duty rule. The tons of emissions reduced were compared to the tons reduced in the U.S. by the heavy-duty rule. Overall health benefits were calculated by comparing the ratio of tons reduced in urban areas of Mexico to tons reduced in urban areas of the U.S.. The benefits were adjusted to account for population, a different rate of population growth, gross domestic product (GDP) – which was adjusted for purchasing power parity, and GDP growth.
2. The second method used the average benefit values developed by EPA. The average cost per ton for SO_2, NO_x, and PM emissions was $16,000, $10,000, and $143,000 respectively. These values are based primarily upon health benefits and are averaged over urban and rural populations. In this analysis, predicted emissions reductions were multiplied by costs per ton to derive a nationwide benefit.
3. The final method used measured data of speciated ambient concentrations of PM for Mexico City, along with emissions estimates at the time of the measurement campaign to develop a Mexico City-specific ratio of ambient concentration to emissions. The tons reduced for the City could then be directly translated into an ambient concentration reduction. This was then multiplied by the monetized value for health benefits per concentration change that had been developed by Evans et al. (2002) in their chapter, "Health Benefits of Air Pollution Control," in *Air Quality in the Mexico Megacity*. The value developed by Evans et al. was scaled up to account for a more recent value of statistical life used by EPA and the addition of purchasing parity to GDP. This approach was only possible for Mexico City; average benefit values from the second method were used for the rest of the country.

Findings from these three methods, weighed against total investment costs and annualized investment cost expected for the year 2030, are included in Table 2.

Table 2. Benefits and costs for Mexico, using a variety of estimation methods

		Mexico City	Rest of country	Nationwide
Benefits in billions of US$ (health only)	Method 1	22		
	Method 2	2.5	7.2	9.7
	Method 3	4.8	7.2	12
Costs in billions of US$ (fuel only)	Total investment	3.3		
	High cost	0.3	1.1	1.4
	Low cost	0.1	0.5	0.6
Ratio (benefit:cost)	High over low	48	14	370
	Low over high	8	7	3
Net Benefit in billions of US$	High minus low	4.7	6.7	21
	Low minus high	2.2	6.1	6.4

Even weighing the benefits for a single year against the total investment required yields a net benefit of US$ 6 billion for the year 2030. Using the more appropriate annualized costs, the annual net benefit ranges from US$ 8 billion to US$ 21 billion. Cost estimates for reducing sulfur in gasoline, from an average of 350 ppm to an average of 30 ppm, range from 0.50 to 1.4 cents per liter. For diesel fuel, a reduction of sulfur from an average of 370 ppm to a cap of 15 ppm would incur incremental costs of 1.1 to 1.3 cents per liter.

The benefits are likely to be largest for Mexico City, where high ambient concentrations of particulate matter are closely linked to premature mortality, along with other chronic and debilitating health impacts. In Mexico City, widespread use of advanced diesel vehicles will result in an almost 30% reduction of fine particle concentrations. This level of improvement in air quality is expected to result in roughly 4,000 fewer premature deaths each year in Mexico City alone. Monetizing these and other health benefits using values developed specifically for Mexico, this translates into US$ 3-5 billion in annual health benefits for Mexico City alone.

Nationally, clean fuels and vehicles will offer even more significant emissions reductions. Advanced diesel vehicles will reduce direct particulate matter emissions by 150 tons each day nationwide, only 17 tons of which are emitted in Mexico City. Nitrogen oxides and sulfur oxides, both precursors for particulate matter, will be reduced by 60 and 70 tons per day throughout the country. The nationwide benefits range from US$ 10-22 billion.

Cost Studies for China and Asia

In 2001-2002, the Energy Foundation funded a study to explore China's refining options in light of changing gasoline and diesel fuel specifications. Lawrence Berkeley Lab in California and Trans-Energy Research Associates, Inc., in Seattle, Washington were awarded a contract to provide a thorough background on China's oil market and refining sector. China Petrochemical Consulting Corporation (CPCC) in Beijing participated as a technical resource providing data on a wide range of Chinese oil market and refining issues.

Although Chinese refining has expanded enormously and has many plans on the books for continued investment, the current and planned refinery configuration appear to be insufficient to meet growing domestic demand for clean fuels, especially lower sulfur levels. The team built and employed a linear program model of the Chinese refining sector and used scenario analysis to test the ability of the Chinese refining sector to produce fuels meeting European standards, EURO 2, 3, 4 and 5, in 2005, 2008 and 2010. Twelve scenarios were developed, varying by the year in which standards are met, fuel quality (in many scenarios a portion of the fuels are of higher quality, most likely to be used as urban fuels), and fuel volume.

The study allocated capital costs to gasoline and diesel, and calculated that reformulating diesel in the year 2010 would add around 0.85 cents per liter capital cost to the refining sector, rising to around 0.98 cents per liter under the EURO 5 scenario. Gasoline costs were around 0.40 cents per liter across the board (Trans-Energy 2002). In general, the results showed some cost savings when China's major metropolitan areas went to the new specifications first and rural areas followed, but the differences were not terribly significant. Capital costs by scenario for gasoline and diesel appear in Table 2. While these costs appear well within the tolerances seen in the US, the study noted that the costs pertained to equipment costs at the refinery only, and that distribution and operating costs would add to the total.

Table 2. China Refining Scenarios (Trans-Energy 2002)

Scenario	Year	Euro	Gasoline		Diesel		Total cost (¢/l)
			sulfur (ppm)	cost (¢/l)	sulfur (ppm)	cost (¢/l)	
1	2000	--	1000/800	--	2000	--	--
2	2005	2	500	0.21	500	0.50	0.74
3	2005	2 & 3	500/150	0.24	500/350	0.53	0.74
4	2005	3	150	0.29	350	0.53	0.85
5	2005	2 & 4	500/50	0.24	500/50	0.53	0.77
6	2008	3 & 4	150/50	0.37	350/50	0.71	1.1
7	2010	3	150	0.40	350	0.85	1.2
8	2010	3 & 4	150/50	0.40	350/50	0.85	1.2
9	2010	3 & 4	150/50	0.40	350/50	0.85	1.2
10	2010	3 & 5	150/20	0.40	350/30	0.85	1.2
11	2010	4	50	0.40	50	0.85	1.3
12	2010	5	20	0.40	30	1.0	1.4

While the China study attempts to model the lowest-cost investment scenario for China to reach a range of low-sulfur fuel goals, a study commissioned by the Asian Development Bank (ADB), looking only at low sulfur diesel, represents more of a highest-cost scenario. The study includes twelve Asian countries with dramatically different refining capacity and demand as well as varying degrees of current refinery investment and desulfurization capacity. The study has a somewhat detailed starting point for the countries under consideration but, from there, a single type of refinery upgrade is applied across the board to achieve each decreasing sulfur level. Other simplifications also contribute to what appears to be a significantly higher incremental and capital cost outcome than is elsewhere predicted, a result that is especially dramatic when the outcomes for China from the two studies are compared.

The Asia study looks at the cost of reducing the entire diesel pool, including diesel used for industrial, off-road, and rail applications. Recently promulgated standards in the U.S. and the E.U. suggest that, in order to meet air quality goals, low sulfur limits will ultimately be necessary for all these applications, yet the China study above demonstrates the significant cost reductions that can be gained with an optimization approach to target sulfur levels for on-road transportation fuels. The ADB study does include a single example of a blending study for Singapore, which determines that, although the crude streams of the gas oil pool range from 2,400 to 3,900 ppm sulfur, the capacity currently exists in that country to produce significant quantities diesel fuel with sulfur levels of 50 ppm, which could be used for on-road applications (Enstrat 2003).

Another important simplification of the Asia study is that diesel demand is held static even though, as mentioned in the introduction and cited as primary motivator for the study, the size of vehicle fleets in some of the countries considered is doubling every five to seven years. This again contrasts sharply with the China study, which allows for optimization over time as increasing demand requires that new refining units are built.

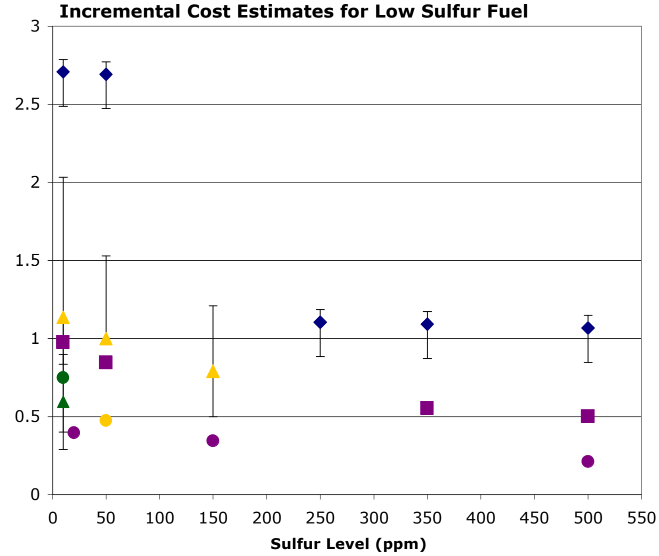
The ADB study estimates that costs associated with lowering sulfur levels in diesel fuel are roughly constant, at around 1.1 cents per liter, for product levels ranging from 3,000 to 250 ppm sulfur. There is a gap in sulfur levels considered, from 250 to 50 ppm, over which costs more than double. At around 2.7 cents per liter, costs are again roughly constant for 10 ppm and 50 ppm sulfur diesel fuel, increasing by less than 1% to up to 9%, depending upon the country (Enstrat 2003).

In exploring the price gap between 250 and 50 ppm sulfur, this study finds that one type of technology is the most efficient alternative for achieving the lowest sulfur limits and another technology type is least costly for meeting higher limits. For each case, above and below 250 ppm, the study finds that investing directly in more efficient technology from the outset is less costly than moving through a range of intermediate technologies. The study states, "[these findings] reinforce the desirability of avoiding intermediate sulfur specification levels, which may be achieved through the deployment of relatively less advanced refining technologies, which may become ineffective or partly obsolete if subsequently stricter sulfur limits are going to be mandated" (Enstrat 2003).

Conclusion

The refining industry has recently made a great deal of progress towards developing more economical processes to remove sulfur from gasoline and diesel fuel. At the same time, refineries throughout the world have demonstrated that low-sulfur fuels can be affordably produced with current technology. Low-sulfur fuels are already in use or required in many parts of the world. In addition, as the global demand for low-sulfur fuels increases, new technologies are emerging that promise to lower substantially the cost of desulfurization. Emerging and more affordable technologies are typically not fully considered in cost studies, with the result that many of the studies below may overestimate the actual capital and ongoing costs of wide-scale refinery upgrades to reduce sulfur levels. This reflects the tendency of projections to overestimate costs of future technologies, demonstrated by a study comparing past projections to actual costs for fuel and vehicle regulation in the U.S.[1] (Anderson and Sherwood, 2002).

Figure 1
Incremental Cost Estimates for Low Sulfur Fuel



The costs of achieving low-sulfur levels depend primarily on the current state of refining equipment being used. However, once the initial investment is made for refinery upgrades there may be very little price difference as sulfur levels decline, even to low and near-zero levels. Figure 1 provides an overview of the estimated incremental costs for reducing sulfur in gasoline and diesel from most of the studies discussed above. The quoted incremental costs for low or near-zero sulfur diesel refining range from roughly 0.53-2.6¢ per liter, although most costs fell within the 0.53-1.3¢ per liter range. For gasoline the costs range from 0.26-1.3 cents per liter and the vast majority of estimates are lower than 0.53¢ per liter.

To date, there has not been an analysis of the benefits that would result from the transition to world class vehicle and fuel standards in China. Depending on data availability, China could use one of the methodologies outlined for Mexico to estimate the health benefits of these policies. Determining the emissions reductions expected and the vehicle costs would require analysis of the size of the vehicle fleet and average distances driven by different types of vehicles. Refinery costs could be estimated using the ADB commissioned study and the Trans-Energy study as upper and lower bounds.

As the vehicle population continues to grow, the economy expands, and more and more people flock to the cities, the potential public health benefits of achieving stringent fuel and vehicle emissions standards in China are great. Indeed, a tremendous health cost accrues and a number of lives are lost with each year of delay.

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1. The study found that actual costs were consistently much lower (or in a few cases within range) than the expected values, providing a reminder of the strong tendency to overestimate forecasts of new technology costs.

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