[COMMENT NUMBER ONE: This needs to be part of the emissions section to explain how we get from the reference case to the strategies.]

Direct Cost of Emissions Reduction Strategies

Introduction

The Integrated Assessment provides insight into how air pollutants affect the ecosystem, what the effect of reducing specific air pollutants may be on the ecosystem, and the estimated costs of reducing those emissions. SAMI has addressed the direct cost analysis by estimating the cost of the emission management strategies in the years 2010 and 2040, including the following examples:

- installing and operating a scrubber on a coal-fired boiler,
- mass transit alternatives that would reduce the vehicle miles traveled,
- new practices in animal operations that reduce ammonia emissions.

Cost estimates were developed for the A1 and A2 reference strategies as well as all the B-group alternative reduction strategies. All cost estimates are calculated as total annualized cost in 2010 and 2040 and expressed in year 2000 dollars. The annualized costs cover all cost components including capital, operating, and fuel and are generally presented in three ways:

- the aggregate total cost of each strategy in the year 2010 and in the year 2040,
- the cost of the reduction of a specific pollutant in each strategy and separated by source sector. (performed for NO_x, SO_2, NH_3 VOC and PM_{10}, because those are the pollutants for which reduction strategies were developed and/or modeled.)
- the dollar per ton cost of specific pollutant reduction in each strategy.

The reader can combine these values with the results from the effects assessment to gain insight into the environmental benefit that can flow from the expenditures on emission reductions.

Developing cost estimates on a 20 to 50 year timeframe is a highly uncertain activity. Because the sector controls are very different, costs were developed as point estimates for the Utility and Industrial sectors and as a range of costs associated with emission reductions for the Highway Vehicle, Area and Non-Road Source Sectors. The cost estimates are useful in making broad comparisons between alternative strategies. It would be overreaching to use them as anything more than rough estimates of project costs.

Total Annualized Costs

Total annualized strategy costs are presented in Figure 8.1. Both the low end and high end of the cost estimate is presented there. The range in the total annualized costs results from a range of estimates being developed for the Highway Vehicle, Area, and Non-Road sectors. Single value estimates were developed for the other sectors (Utility and Industrial point sources). It is expected that the best estimate is somewhere between those values. The annualized costs developed for 2010 represent the difference in cost from a 1990 baseline for controls in place in

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the year 2010. Likewise, the annualized cost for 2040 is the difference in cost from a 1990 baseline for controls in place in the year 2040. These are not total accumulated costs, but annualized costs that combine intermittent capital costs and annual operation and maintenance charges into a stream of equal annual payments over a given period, using standard techniques. [There is no need to justify standard operating procedure.]

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Deleted: costs. In the same way that the emission inventory was presented in tons of pollutant reduced per year, the costs have been calculated on an annual basis. While for certain sectors it would be relatively easy to calculate a total cost, for sectors like highway vehicle were the

Deleted: assumptions include the introduction of and penetration into the market of automobiles with new technology, the multi-year costs are almost impossible to calculate. Because meaningful accumulated costs could not be calculated for some of the sectors it was not calculated for any of them.

[INSERT FIGURE 8.1: TOTAL STRATEGY COST FOR ALL SECTORS]

The A1 and A2 reference strategies are projected to cost $4 billion per year and $6 billion per year respectively in 2010 and $10 billion per year and $12 billion per year respectively in the year 2040. All costs for the reference strategies were point estimates - there were very specific controls in the Highway Vehicle sector and no controls assumed in the Non-Road and Area sectors in these strategies. The B-group strategies all have a range of estimated costs. The B1 strategy cost estimate ranges from $10 to $14 billion per year in 2010 and from $24 to $43 billion per year in 2040. The B2 strategy cost estimate ranges from $13 to $22 billion per year in 2010 and $34 to $60 billion per year in 2040. The largest jump in cost is between the B2 and B3 strategies. The B3 strategy cost estimate ranges from $33 to $61 billion per year in 2010 and from $61 to $110 per year in 2040. Both the cost and the range are significantly higher for the B3 strategy because this strategies calls for very high emission reductions regardless of technical or practical concerns. Thus, it is not surprising that the associated costs would be high or that it would be difficult to estimate those costs with precision. The distribution of the costs among the source sectors is discussed in the Key Findings Section.

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Cost estimate development

Overarching assumptions

The development of these cost estimates involved the calculation of costs for specific control methods in each of the source sectors. The following overarching assumptions were made in the development of these costs:

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- Costs are in annualized Year 2000 dollars and are direct costs only.
- Costs represent changes in annualized costs of control measures in place in 2010 and 2040, from a 1990 baseline, but not total accumulated costs. Where costs include capital costs, those costs have be amortized over a 15 year period at a 7% discount rate, resulting in a carry charge rate of 15% which includes property tax, insurance and administrative costs.
- NOx controls for B strategies assume regional trading (modeled separately for utility and industrial point sources).
- Highway Vehicle, Area and Non-road sectors have a range of costs represented by the high and low ends of the control measure costs.

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Utility Sector

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Determining costs for the

Determining the Utility sector costs involved developing costs for controls on existing units and developing costs for new units of specific technoloty and fuel types. Controls designed to reduce

NOx and SO2 were considered independently and calculated using cost formulas that included the capital costs and the operation and maintenance costs amortized over 15 years. In 2010 all the cost was associated with retrofit controls on coal-fired boilers. There was no new unplanned generation capacity needed to meet electricity demand in 2010 based on the assumed electricity demand growth. However, it was recognized that increased demand would eventually necessitate the building of currently unplanned power plants. SAMI assumed that these plants would include a mix of pulverized coal, natural gas, and coal gasification plants in specific ratios. In the A2 and B1 strategies for 2040 it was assumed that the new generation would be represented by a weighted average of : 20% pulverized coal, 40% natural gas combined-cycle, and 40% integrated gasification combined-cycle (IGCC). In both the B2 and B3 strategies for 2040 it was assumed that the percentages would be 0, 50, 50, respectively. It was assumed in the B1 and B2 strategies that large coal fired units that reached 65 years of age if not already controlled, would add NOx and/or SO2 control technology to meet specified emission limits. In the B3 strategy it was assumed that these units would be replaced or re-powered with a mix of generation represented by 50% natural gas and 50% IGCC like the assumption for new facilities. (Figure 8.2 and 8.3.) Thus the cost for 2010 is entirely based on the installation of additional control technologies. While the majority of the costs for 2040 are based on the difference between the cost of new fuel types and the standard coal-fired plant (do not know what this sentence is saying). All of these costs were estimated for the future based on assumptions regarding future markets (what kind of markets?). It was because there were known fixed starting points from which to estimate these costs, that they were estimated with a single point instead of a range (another sentence who's meaning is unclear so I don't know how to fix it).

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[INSERT FIGURES 8.2 AND 8.3]

Industrial Sector

Development of the Industrial sector costs were similar to the utility section costs, except there were many more smaller combustion sources. As a result of the number of smaller sources other costs like the cost of continuos emission monitors (CEMS) which are the same regardless of the size of the unit became significant and were also included.

Highway Vehicle Sector

Determining the Highway Vehicle sector costs involved determining costs associated with meeting the Tier II emission standards, increasing the numbers of zero emission vehicles (ZEVs), reducing the growth of light duty vehicle miles traveled (VMT), meeting the 2007 heavy duty vehicle emission standards, transferring freight from truck to rail and reducing sulfur limits. Developing costs for these emission reduction strategies was a very different exercise than the development of point source emission reduction costs. Costs were developed as costs per mile, cost per gallon of gasoline, or cost per vehicle depending on which metric was appropriate and then converted into a total cost. In many situations costs were extrapolated from limited case studies that provided the only information available about the cost of such activities. The cost of reducing the growth of VMT is such a case. A variety of approaches exist to reduce VMT with a variety of costs and effectiveness. From these it was determined that the cost of VMT reduction could range from 6 to 35 cents per mile - these values were used in establishing the range of

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VMT reduction costs and contribute to the vast range in Highway Vehicle sector costs. Likewise, a range of ZEV costs were calculated using existing ZEV or near-ZEV vehicles. Figure 8.4 illustrates all the costs associate with the 2040 B3 strategy (the strategy with the most stringent reductions). Clearly the greatest costs and the greatest uncertainty are associated with VMT reduction and ZEVs.

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[INSERT FIGURE 8.4]

Nonroad Engine Sector

Calculating Non-Road sector costs is similar to calculating highway vehicle sector costs. Like with highway vehicles the large range (?)of cost involve efforts to convert to ZEV. Specific case studies like airport baggage tractors were used to estimate cost across all airport equipment. Case studies were also used to estimate cost of emission reductions in train, planes, boats, and other non-road mobile sources. Costs associated with lowering sulfur concentrations in gasoline and diesel fuel were assumed to be the same as for highway fuels.

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Area Sector

The area sector captures all the emissions not captured in the other sectors, so it contains a variety of very different emissions and control approaches for which costs were estimated. In most cases the A2 reference strategy and the B1 strategy involved emission reductions at levels that had been considered or experimented with, so there was some existing data. The B3 strategy and in some cases the B2 strategy involved levels of control that have not been tried and for which the costs are highly speculative. The Energy Information Administration's *Annual Energy Outlook 2001* was the source of the background information for combustion costs.

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Key findings of TOTAL cost estimates

[INSERT FIGURES 8.5 AND 8.6]

2010

Deeper analysis of these total annualized costs can be done by examining each year individually, separating the costs of each strategy by source sector (the stacked bar in Figure 8.5 and 8.6), and representing the high and low end of the cost estimate range . At the low end of the range the Utility and Highway Vehicle sectors contribute most to the cost of air emissions reduction, except in B3 where costs are significant for all sectors. Costs for most sectors approximately double between B2 and B3, except Non-Road which has a ten times increase and the Area source which has twenty times increase. Although not visible in the scale of the graphic, there is a cost savings in the Area Source sector in the B1 strategy as a result of fuel switching from oil to natural gas. At the high end of the cost range, the Highway Vehicle and Area sectors account for most of the costs, remembering that these two sectors have a range of costs in the analysis while the Utility sector does not. The Utility, Area and Non-Road sectors have greatest increase from B2 to B3. The Area source sector becomes largest cost contributor in the B3 strategy. These

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costs are associated with emission reductions of greater than or equal to 75% across the six major pollutants of NOx, SO2, VOC, NH3, PM10 and PM2.5.

[INSERT FIGURES 8.7 AND 8.8]

2040 Likewise the 2040 cost estimates can be examined from analogous graphs (Figure 9.7 and 9.8). In general, costs are about double the cost in 2010, except there is little change of cost between 2010 and 2040 for the industrial sector. As in 2010, Utility and Highway Vehicle sectors account for most of the costs in 2040, except in the B3 strategy where the Area source costs are very large. A majority of the costs and cost uncertainties in the Highway Vehicle sector is from LD VMT reductions and LD ZEV. Non-Road costs are insignificant except in the B3 strategy where it accounts for about 10% of the total. Examining the difference between the upper end and lower end of the cost range yields the following observations:

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- At the low end of the cost range, Highway and Area sources account for most of increase from B1 to B2,
- Utility, Area and Non-Road sectors have the greatest increase from B2 to B3,
- At the high end of the range the Highway Vehicle sector accounts for most of the total cost in B1 and B2,
- And at the high end, the Area source sector accounts for the highest percentage of cost in the B3 strategy.

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COST PER POLLUTANT

While the proceeding analysis offered some information about the overall comparative costs of strategies and sectors it did not distinguish the costs in terms of the type of pollutant controlled. Another analysis performed provided both total annualized cost per pollutant and then using the A2 level of control as the starting point, calculated the cost per ton of pollutant removed. In order to do this analysis, assumptions were made to allocate costs of certain control measures to specific pollutants. The allocation assumptions that were made are:

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Utility and Industrial Sectors:
existing units--costs allocated to SO2 or NOx reductions depending on control measure (e.g., SCR costs allocated to NOx, scrubber costs allocated to SO2)
new units--costs allocated to SO2 or NOx in proportion to the percentage reduction in emission rates for a given strategy

Highway Vehicles: costs associated with light-duty ZEV or VMT control measures evenly split between VOC and NOx; light duty Tier 2 and heavy duty vehicle control measure costs allocated to NOx

Non-Road: ZEV costs for gasoline lawn & garden, recreational vehicles, and recreational marine vessels assigned to VOC; other ZEV controls, aircraft controls, and 2007 diesel highway engine standards assigned to NOx; reduced fuel sulfur levels assigned to SO2

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Area source controls:

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Costs assigned to NOx: natural gas combustion sources; miscellaneous burning; residential wood
Costs assigned to SO2: coal and oil combustion sources
Costs assigned to VOC: chemical and allied products; solvent use; storage and transport
Costs assigned to PM: fugitive road dust; agricultural crops & livestock; managed burning
Costs assigned to NH3: fertilizers (and animal waste)

The per pollutant reductions and costs can be seen in Figures 8.9-8.11

[INSERT FIGURES 8.9-8.11 (ACTUALLY THEY ARE TABLES)]

[INSERT FIGURE 8.12-8.14]

Results SO2

Figure 8.12 shows the total cost of SO2 removal by sector for the A2, B1 and B3 strategies. The highway vehicle sector does not appear because there are no controls for SO2 implemented in that sector. In the A2 reference strategy additional SO2 controls are only applicable to the Utility sector. The greatest total annualized costs are experienced in the Utility sector, as are the greatest reductions (Table 8.9). To consider the cost per ton of SO2 removed examine Figure 8.13 [drop figure 8.13 and renumber the figures, also correct the original Figure 8.14 to have the correct numbers]. The cost per ton of SO2 removed in the Industrial Sector is five to six times greater than in the Utility sector. The Industrial sector costs are higher than utility due to negative economies of scale involved with smaller industrial boilers. Area source reductions are gained through fuel switching and this analysis indicates that there would be a cost savings associated with this control method. The Area source sector only accounts for approximately 10% of the emission reductions under any given strategy, roughly equivalent to the Industrial sector. The tons of SO2 reduced by each sector are represented by the number above each bar and can be compared to the number above the black bar, which is the tons reduced by all sectors combined. This value was used to calculate an average removal cost for all sectors. The Non-Road and then the Utility sectors have next lowest per ton costs. The range of costs for SO2 is very small so it is represented as one cost [I do not understand the immediately preceeding sentence].

[INSERT FIGURE 8.15]

The analysis shows the same pattern of costs in 2040 for SO2 reductions as was seen in 2010; potential cost savings in the Area sector, extremely high Industrial costs. A greater percentage of the SO2 reduction come from the Area sector in 2040, where a 75% reduction in SO2 is dictated by each of the 2040 strategies (B1, B2 and B3). The amount of SO2 being reduced in the Utility sector goes up in each subsequent strategy as does the cost per ton.

Results NOx

[The Figures and Tables are confusing to follow. The columns in the Tables need to be described and the last three columns needed to be explained how calculated. Some of the numbers in original Figure 8.14 do not appear to be correct] The total cost per sector for NOx reduction and the per ton costs are shown in Figures 8.14 and 8.15). The relative size of the

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total cost by sector is dependent on the range (low or high end) being viewed. At the low end of the range of Highway, Non-Road, and Area costs, the Utility costs are higher than the some of the other sectors. At the high end of the range of Highway, Non-Road, and Area costs, the Utility and Industrial costs are relatively low in comparison. For example, the Highway Vehicle sector costs are less than the Utility and Industrial in the B1 strategy at the low end of the range, but at the high end of the range it is two to five times more than the utility and industrial sectors.

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[INSERT FIGURES 8.16 AND 8.17]

Results NH3

All of the ammonia reductions and all of the costs are associated with animal operations and fertilizer production and use in the Area sector. Figure 8.18 shows the comparison in cost between the B1 strategy and the B3 strategy. The cost of the B3 strategy is significantly greater and has a large range. The B3 strategy calls for levels of ammonia reduction which may not be achievable and for which it is extremely difficult to estimate cost.

[INSERT FIGURE 8.18]

Uncertainty Analysis

Estimating the cost of emission reductions 20 to 50 years in the future is a difficult and uncertain process. However there are aspects of the analysis which are more certain than others. Utility costs for the B-group strategies in 2010 is the most certain aspect of this analysis ranking a [the table says 6] out of 10 on a relative uncertainty scale (Table 8.?). The other sectors: Industrial, Highway Vehicle, Non-Road and Area received scores of four, three, two and one respectively. In 2040 all sectors received scores between one and three (Table 8.?). Thus, the estimate of the cost of pollution reduction in the utility sector in 2010 is relatively certain, but all other aspects of the analysis have a high degree of uncertainty. Tables 1,2,and 3 from Chapter IX of the Cost Report illustrate this and also identify the relative significance of the uncertainty by identifying the portion of the total cost associated with each source sector.

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Table VIII-1
Relative Uncertainties of SAMI 2010 Direct Cost Analysis

	Utility	Industry	Highway Vehicles	Nonroad Engines	Area
Strategy Cost Results	+ + + + + +	+ + + +	+ + +	+	+ +

Table VIII-2
Relative Uncertainties of SAMI 2040 Direct Cost Analysis

	Utility	Industry	Highway Vehicles	Nonroad Engines	Area
Strategy Cost Results	+ + +	+ +	+ +	+	+

Table VIII-3
Contribution of Control Costs by Sector to Total Strategy Control Cost (Percent of Total Cost)

Year	Sector	On-the-Books	On-the-Way	Bold with		Bold		Beyond Bold	
				Low	High	Low	High	Low	High
2010	Utility	38	48	51	36	44	25	28	15
	Industry	5	6	15	10	14	8	9	5
	Highway Vehicles	50	42	31	51	34	59	22	32
	Nonroad Engines	6	3	4	3	4	3	12	7
	Area	2	1	-1	0	5	4	29	42
2040	Utility	64	58	33	18	26	15	23	13
	Industry	3	4	6	3	6	3	6	3
	Highway Vehicles	31	36	53	73	54	67	34	39
	Nonroad Engines	2	2	2	2	2	2	11	6
	Area	1	1	5	4	12	14	26	38

The reader can combine these values with the results from the effects assessment to gain insight into the environmental benefit that can flow from the expenditures on emission reductions.

Direct Cost Summary

In summary, the Utility sector costs are more certain than the other sectors, the Nonroad Engine sector is the least certain. Results for 2010 are significantly more certain than 2040. And costs associated with the strategies get less certain as the strategies get more stringent and the technology or methodology for accomplishing that reductions becomes more speculative. The reader can combine these values with the results from the effects assessment to gain insight into the environmental benefit that can flow from the expenditures on emission reductions.

Deleted: These costs are valuable as indicators, but it would be irresponsible to rely heavily on these results in policy making.