This appendix presents a stepwise example of how the mineral processing cost model calcluates the cost of this rulemaking for Option 3 assuming the Modified Prior Treatment baseline for the sector producing titanium and titanium dioxide.[1] The intermediate quantities and cost results presented in this appendix are calculated using the same methodology as used by the cost model. *These quantities and results differ slightly from those found in the cost model printouts due to rounding.*

The appendix is divided into five sections, each of which describes one important facet of the data or calculations used in the cost model. The first section reviews the input data required for cost calculations. The second section shows how the input data are manipulated for use in later cost calculations. The third section presents calculations of treatment costs. The fourth section presents calculations of storage costs. Finally, in the fifth section, the incremental treatment and storage costs are combined, along with recordkeeping costs, to obtain the total incremental sector cost.

G.1. Review of Input Data

This section reviews the five types of input data used to calculate the cost of this rulemaking to the titanium and titanium dioxide mineral processing sector:

1. Waste stream generation rates;
2. Hazardous characteristics;
3. Certainty of recycling;
4. Physical form (i.e. wastewater, waste with 1 to 10 percent solids, solid); and
5. Regulatory classification (i.e. by-product, spent material, sludge).

These data are used to calculated sector costs as described in later sections of this appendix.

G.1.1 Waste Stream Generation Rate and Number of Waste-Producing Facilities

The titanium and titanium dioxide mineral processing sector generates eight waste streams. Exhibit G-1 shows the number of waste producing facilities and the total sector waste stream generation rates for each of these eight waste streams. The number of facilities generating each waste stream varies, ranging from one facility producing scrap milling scrubber water to seven facilities generating waste water treatment plant (WWTP) sludges or solids. EPA obtained data on the generation rate for two of the eight streams (spent surface impoundment solids and WWTP sludges or solids). For the six waste streams for which data were unavailable, EPA estimated a minimum generation rate, an expected generation rate, and a maximum generation rate.

[1] For the purpose of simplicity, this section only describes calculations for the Modified Prior Treatment baseline and Option 3. Calculations for all of the other baselines and options follow the same pattern as described below.

Exhibit G-1
Waste Stream Generation Rates

Titanium Waste Stream	Number of Facilities	Estimated or Reported Generation (mt/yr)		
		Minimum	Expected	Maximum
Pickle Liquor and Wash Water	3	2,200	2,700	3,200
Scrap Milling Scrubber Water	1	4,000	5,000	6,000
Smut from Mg Recovery	2	100	22,000	45,000
Leach Liquor and Sponge Wash Water	2	380,000	480,000	580,000
Spent Surface Impoundment Liquids	7	630	3,400	6,700
Spent Surface Impoundment Solids	7	36,000	36,000	36,000
Waste Acids (Sulfate Process)	2	200	39,000	77,000
WWTP Sludges/Solids	7	420,000	420,000	420,000

G.1.2 Hazardous Characteristics

Each waste stream in the data set is known or suspected to be hazardous for at least one of the four hazardous characteristics:

- Toxicity (i.e., containing on or more of the eight TC Metals);
- Corrosivity;
- Ignitability; and
- Reactivity.

Exhibit G-2 summarizes the status of each of the eight waste streams for the four hazardous characteristic categories, as well as each stream's overall hazard certainty. Four of the waste streams in the sector are known to be hazardous for at least one of the characteristics, as indicated in the far right column by a "Y" (yes) overall hazard certainty classification. The other four streams in the sector are only suspected to be hazardous and are assigned a "Y?" hazard certainty classification in the far right column. For example, leach liquor and sponge wash water is known to be hazardous because it is corrosive, even though the stream is only suspected to be hazardous for chromium and lead, and is not believed to be ignitable or reactive.

Exhibit G-2
Hazardous Characteristics

Titanium Waste Stream	TC Metals								Corr	Ignit	Rctv	Overall Haz?
	As	Ba	Cd	Cr	Pb	Hg	Se	Ag				
Pickle Liquor and Wash Water			Y?	Y?	Y?				Y?	N?	N?	**Y?**
Scrap Milling Scrubber Water			Y?	Y?	Y?		Y?		N?	N?	N?	**Y?**
Smut from Mg Recovery									N?	N?	Y	**Y**
Leach Liquor and Sponge Wash Water				Y?	Y?				Y	N?	N?	**Y**
Spent Surface Impoundment Liquids				Y?	Y?				N?	N?	N?	**Y?**
Spent Surface Impoundment Solids				Y?	Y?				N?	N?	N?	**Y?**
Waste Acids (Sulfate Process)	Y			Y			Y	Y	Y	N	N	**Y**
WWTP Sludges/Solids				Y					N	N	N	**Y**

Y = Known to be hazardous, Y? = suspected to be hazardous

G.1.3 Recycling Status, RCRA Waste Type, and Waste Treatment Type

Exhibit G-3 depicts the recycling status, RCRA waste type, and physical form of each of the waste streams in the titanium sector. Of the eight waste streams in the sector, none are assigned a "Y" (yes) in Exhibit G-3 because none are known to be fully recycled. Two are believed to be fully recycled (Y?). None are assigned a "YS" (yes sometimes) because none are known to be partially recycled, but three are believed to be partially recycled (YS?). Three are assigned "N" (no) because they are known not to be recycled at all (N). Of the five streams that are recycled in some capacity, three are spent materials, one is a by-product, and one is a sludge. Five of the waste streams in the sector are wastewaters, and three waste streams are solids.

Exhibit G-3
Recycling Status

Titanium Waste Stream	Recycling Status	RCRA Waste Type	Physical Form
Pickle Liquor and Wash Water	YS?	Spent Mat'l	Wastewater
Scrap Milling Scrubber Water	YS?	Sludge	Wastewater
Smut from Mg Recovery	Y?	By-Product	Solid
Leach Liquor and Sponge Wash Water	YS?	Spent Mat'l	Wastewater
Spent Surface Impoundment Liquids	Y?	Spent Mat'l	Wastewater
Spent Surface Impoundment Solids	N	NA	Solid
Waste Acids (Sulfate Process)	N	NA	Wastewater
WWTP Sludges/Solids	N	NA	Solid

G.2. Manipulation of Input Data

This section shows how input data described in the previous section are manipulated so that treatment and storage costs can be calculated. The model combines uncertainty about hazard characteristics with uncertainty in generation rates to create a bounded cost analysis, i.e., an expected value case with minimum and maximum value cases providing estimated lower- and upper-bound costs. This section of the appendix helps set the stage for later calculation of expected value costs, upper bound costs, and lower bound costs by calculating the quantity of each waste stream that must be treated and disposed versus recycled in the expected value case, the upper bound case, and the lower bound case.

Manipulation of input data occurs in four steps which are listed here and described in detail later in this section:

1) The estimated or reported generation rate for each of the eight waste streams (from Exhibit G- 1) is divided into a hazardous component and a non-hazardous component;

2) The hazardous portion of each waste stream is divided into a component that is treated and disposed, and a component that is stored prior to recycling;

3) "Model facility" totals are calculated for the treated and disposed waste; and

4) Average facility quantities are calculated for waste stored prior to recycling.

There is a critical difference between "model facility" totals for treated and disposed waste and average facility quantities for waste stored prior to recycling. "Model facility" totals, which are used to model treatment of all waste streams in a sector in a single treatment system at each facility, are calculated on a sector basis while average facility quantities, which are used to calculate storage costs of individual waste streams that must not be commingled, are calculated on an individual waste stream basis.

G.2.1 Estimate Waste Stream Portion Assumed to be Hazardous

As indicated in Exhibit G-2 above, four of the waste streams in the titanium and titanium dioxide mineral processing sector are only suspected to be hazardous (Y?). To apportion this uncertainty over the minimum, expected, and maximum value cases, we multiply the overall waste stream generation rates (minimum, expected, and maximum) for each of the eight waste streams from Exhibit G-1 by the following percentages in Exhibit G-4, to calculate the minimum, expected, and maximum quantities of the waste stream estimated to be both generated and hazardous:

Exhibit G-4
Hazard Certainty Multipliers

Costing Scenario	Hazard Certainty	
	Y?	Y
Minimum	0%	100%
Expected	50%	100%
Maximum	100%	100%

The resulting quantities of waste estimated to be hazardous for each waste stream in the titanium and titanium dioxide sector are shown in Exhibit G-5. The effect of this procedure is to bound the analysis, which is especially important for the four streams that are only suspected to be hazardous. For example, the quantity of pickle liquor and wash water (Y? hazard certainty) assumed to be hazardous in the minimum value case would be 0 mt/yr [i.e., 22,000 mt/yr generated (from Exhibit G-1) x 0% (from Exhibit G-4) = 0 mt/yr], while the expected value case hazardous portion would be 13,500 mt/yr [27,000 mt/yr generated (from Exhibit G-1) x 50% (from Exhibit G-4) = 13,500 mt/yr].[2] In the maximum value case, the entire quantity (32,000 mt/yr) is assumed to be hazardous. For the four titanium waste streams known to be hazardous, the entire generated quantity of those wastes is included in the analysis.

[2] Conversely, note that 22,000 mt/yr of the waste is considered non-hazardous in the minimum value case, while 13,500 mt/yr is considered non-hazardous in the expected value case. The portion of waste that is assumed non-hazardous drops out of the analysis from this point on.

Exhibit G-5
Portion of Waste Assumed to be Hazardous

Titanium Waste Stream	Hazard Certainty	Portion of Waste that is Hazardous (mt/yr)		
		Minimum	Expected	Maximum
Pickle Liquor and Wash Water	Y?	0	1,350	3,200
Scrap Milling Scrubber Water	Y?	0	2,500	6,000
Smut from Mg Recovery	Y	100	22,000	45,000
Leach Liquor and Sponge Wash Water	Y	380,000	480,000	580,000
Spent Surface Impoundment Liquids	Y?	0	1,700	6,700
Spent Surface Impoundment Solids	Y?	0	18,000	36,000
Waste Acids (Sulfate Process)	Y	200	39,000	77,000
WWTP Sludges/Solids	Y?	0	210,000	420,000

G.2.2 Divide Hazardous Quantities Into Portion Treated/Disposed and Portion Stored Prior to Recycling

The hazardous portion of each waste stream (from Exhibit G-5) is then divided into a component of waste that is treated/disposed, and a component that is stored for recycling. To determine these portions, the model applies an appropriate multiplier, depending on its particular recycling status (as indicated in Exhibit G-3 above). The treatment/disposal multipliers are shown in Exhibit G-6, and the recycling multipliers are shown in Exhibit G- 7. Note that in all cases the treatment and disposal multiplier in Exhibit G-6 and the recycling multiplier in Exhibit G-7 sum to 100 percent (i.e., all waste is assumed to be handled in accordance with EPA regulations and either treated and disposed, or stored prior to recycling). The multipliers are applied to the portion of material considered to be hazardous in the minimum, expected, and maximum value cases.

Exhibit G-6
Proportions of Waste Streams Treated and Disposed (in percent)

Baseline or Option	Affected Material	Percent Disposed				
		Recycling Status				
		Y	Y?	YS	YS?	N
No Modified Prior Treatment	All	0	100	60	100	100
Modified Prior Treatment (SL/BP) & MPT	All	0	15	25	80	100
Modified Prior Treatment (SM)	All	0	25	35	85	100
Option 1 from NPT	All	20	100	90	100	100
Option 2 from NPT	Bevill*	100	100	100	100	100
Option 3 from NPT	All	0	30	40	90	100
Option 4 from NPT	All	0	15	25	80	100
Option 1 from MPT & PT (SL/BP)	All	30	65	100	100	100
Option 2 from MPT & PT (SL/BP)	Bevill*	100	100	100	100	100
Option 3 from MPT & PT (SL/BP)	All	0	25	35	85	100
Option 4 from MPT & PT (SL/BP)	All	0	15	25	80	100
Option 1 from PT (SM)	All	30	65	100	100	100
Option 2 from PT (SM)	Bevill*	100	100	100	100	100
Option 3 from PT (SM)	All	0	25	35	85	100
Option 4 from PT (SM)	All	0	15	25	80	100

* For materials recycled through Bevill Units only -- Materials not recycled through Bevill Units are treated and disposed according to Option 3 multipliers.

SL = Sludge, BP = By-Product, SM = Spent Material

Exhibit G-7
Proportions of Waste Streams Stored Prior to Recycling (in percent)

Baseline or Option	Affected Material	Percent Recycled Recycling Status Y	Y?	YS	YS?	N
No Modified Prior Treatment	All	100	0	40	0	0
Modified Prior Treatment (SL/BP) & MPT	All	100	85	75	20	0
Modified Prior Treatment (SM)	All	100	75	65	15	0
Option 1 from NPT	All	80	0	10	0	0
Option 2 from NPT	Bevill*	0	0	0	0	0
Option 3 from NPT	All	100	70	60	10	0
Option 4 from NPT	All	100	85	75	20	0
Option 1 from MPT & PT (SL/BP)	All	70	35	0	0	0
Option 2 from MPT & PT (SL/BP)	Bevill*	0	0	0	0	0
Option 3 from MPT & PT (SL/BP)	All	100	75	65	15	0
Option 4 from MPT & PT (SL/BP)	All	100	85	75	20	0
Option 1 from PT (SM)	All	70	35	0	0	0
Option 2 from PT (SM)	Bevill*	0	0	0	0	0
Option 3 from PT (SM)	All	100	75	65	15	0
Option 4 from PT (SM)	All	100	85	75	20	0

* For materials recycled through Bevill Units only -- Materials not recycled through Bevill Units are stored prior to recycling according to Option 3 multipliers.

SL = Sludge, BP = By-Product, SM = Spent Material

The quantities of waste treated/disposed and the quantities of waste stored prior to recycling for each waste stream in the sector are shown in Exhibit G-8 and G-9, respectively. Quantities reported in Exhibit G-8 and G-9 are calculated by multiplying the portion of waste that is hazardous (Exhibit G-5) by the appropriate treatment/disposal or recycling multipliers (from Exhibit G-6 and G-7). For example, of the 1,350 mt/yr of pickle liquor and wash water assumed to be hazardous in the expected value case of the Modified Prior Treatment baseline, 85 percent of the waste, or approximately 1,150 mt/yr (1,350 mt/yr x 0.85), is sent to treatment/disposal, while 15 percent of the waste, or approximately 200 mt/yr (1,350 mt/yr x 0.15), is stored prior to recycling.

G.2.3 Calculate Total Quantity Treated and Disposed at a "Model Facility"

The cost model assumes that each facility generating waste in the titanium sector builds a single treatment plant to treat all wastes rather than building a separate treatment plant for each waste stream. Therefore to obtain the quantity of waste treated and disposed at a "model facility," the model sums the treated and disposed portion of all eight waste streams by physical form (i.e., wastewaters, wastes with one to ten percent solids, and wastes with more than ten percent solids) and divides by the maximum number of facilities generating waste in the sector, which is two in the minimum value case, and seven in the expected and maximum value cases. The reason why there are only two facilities generating waste in the minimum value case is that there is uncertainty about the hazard characteristics (Y?) of several of the titanium waste streams (see Exhibit G-5). Recall that waste streams that have a Y? hazard certainty classification are considered not hazardous in the minimum value case, 50% hazardous in the expected value case, and 100% hazardous in the maximum value case (see Exhibit G-4). Therefore, the maximum number of facilities generating at least one titanium waste drops to two in the minimum value case, because all of the titanium waste streams generated by more than two facilities have a Y? hazard certainty classification (see Exhibit G-1). For purposes of calculations, it does not matter whether some types of waste are generated at fewer facilities, because the model assumes a single treatment system for all types of waste generated at all facilities. For example, the total wastewater treated/disposed for the pre-rule expected value case is 450,573 mt/yr (which is the sum of the wastewater streams in Exhibit G-10). Dividing by seven, the model facility wastewater treated/disposed for the expected value case is 64,368 mt/yr. Exhibit G-10 presents the model facility waste treated/disposed for the minimum, expected, and maximum value scenarios.

Exhibit G-8
Portion of Hazardous Wastes Generated Treated and Disposed

Waste Stream	Multiplier	Portion of Waste Treated/Disposed (mt/yr)		
		Minimum	Expected	Maximum
Pre-Rule				
Pickle Liquor and Wash Water	0.80	0	1,080	2,560
Scrap Milling Scrubber Water	0.80	0	2,000	4,800
Smut from Mg Recovery	0.15	15	3,300	6,750
Leach Liquor and Sponge Wash Water	0.80	304,000	384,000	464,000
Spent Surface Impoundment Liquids	0.15	0	255	1,005
Spent Surface Impoundment Solids	1	0	18,000	36,000
Waste Acids (Sulfate Process)	1	200	39,000	77,000
WWTP Sludges/Solids	1	0	210,000	420,000
Post-Rule				
Pickle Liquor and Wash Water	0.85	0	1,148	2,720
Scrap Milling Scrubber Water	0.85	0	2,125	5,100
Smut from Mg Recovery	0.25	25	5,500	11,250
Leach Liquor and Sponge Wash Water	0.85	323,000	408,000	493,000
Spent Surface Impoundment Liquids	0.25	0	425	1,675
Spent Surface Impoundment Solids	1	0	18,000	36,000
Waste Acids (Sulfate Process)	1	200	39,000	77,000
WWTP Sludges/Solids	1	0	210,000	420,000

Exhibit G-9
Portion of Hazardous Wastes Generated that is Stored Prior to Recycling

Waste Stream	Multiplier	Portion of Waste Stored Prior to Recycling (mt/yr)		
		Minimum	Expected	Maximum
Pre-Rule				
Pickle Liquor and Wash Water	0.20	0	270	640
Scrap Milling Scrubber Water	0.20	0	500	1,200
Smut from Mg Recovery	0.85	85	18,700	38,250
Leach Liquor and Sponge Wash Water	0.20	76,000	96,000	116,000
Spent Surface Impoundment Liquids	0.85	0	1,445	5,695
Spent Surface Impoundment Solids	0	0	0	0
Waste Acids (Sulfate Process)	0	0	0	0
WWTP Sludges/Solids	0	0	0	0
Post-Rule				
Pickle Liquor and Wash Water	0.15	0	203	480
Scrap Milling Scrubber Water	0.15	0	375	900
Smut from Mg Recovery	0.75	75	16,500	33,750
Leach Liquor and Sponge Wash Water	0.15	57,000	72,000	87,000
Spent Surface Impoundment Liquids	0.75	0	1,275	5,025
Spent Surface Impoundment Solids	0	0	0	0
Waste Acids (Sulfate Process)	0	0	0	0
WWTP Sludges/Solids	0	0	0	0

Exhibit G-10
Model Facility Quantity of Waste Treated/Disposed

Baseline/Option	Model Facility Waste Treated/Disposed (mt/yr)								
	Minimum			Expected			Maximum		
	Waste-waters	1-10% Solids	Solids	Waste-waters	1-10% Solids	Solids	Waste-waters	1-10% Solids	Solids
Pre-Rule	152,100	0	8	60,905	0	33,043	78,481	0	66,107
Post-Rule	161,100	0	13	64,385	0	33,357	82,785	0	66,750

G.2.4 Calculation of Average Quantity Recycled

Since recycling costs are specific to each waste stream in the sector, the cost model does not calculate model facility totals for recycling. Rather, it calculates an average facility total by dividing the portion of each waste stream that is stored prior to recycling (from Exhibit G-9) by the number of facilities that generate each waste (from Exhibit G-1). Exhibit G-11 shows the results of this calculation.

Exhibit G-11
Average Facility Quantities Stored Prior to Recycling

Waste Stream	Number of Facilities	Average Facility Waste Stored Prior to Recycling (mt/yr)		
		Minimum	Expected	Maximum
Pre-Rule				
Pickle Liquor and Wash Water	3	0	90	213
Scrap Milling Scrubber Water	1	0	500	1,200
Smut from Mg Recovery	2	43	9,350	19,125
Leach Liquor and Sponge Wash Water	2	38,000	48,000	58,000
Spent Surface Impoundment Liquids	7	0	206	814
Spent Surface Impoundment Solids	7	0	0	0
Waste Acids (Sulfate Process)	2	0	0	0
WWTP Sludges/Solids	7	0	0	0
Post-Rule				
Pickle Liquor and Wash Water	3	0	68	160
Scrap Milling Scrubber Water	1	0	375	900
Smut from Mg Recovery	2	38	8,250	16,875
Leach Liquor and Sponge Wash Water	2	28,500	36,000	43,500
Spent Surface Impoundment Liquids	7	0	182	718
Spent Surface Impoundment Solids	7	0	0	0
Waste Acids (Sulfate Process)	2	0	0	0
WWTP Sludges/Solids	7	0	0	0

G.3. Treatment Cost Calculations

This section of the appendix explains how the cost model calculates the total incremental treatment cost incurred by the titanium and titanium dioxide mineral processing sector.

The model first determines if the treated and disposed waste quantities from Exhibit G-10 are large enough to warrant on-site treatment. Next the model calculates neutralization, dewatering, stabilization, and disposal costs. The model then annualizes capital and closure costs and calculates a total sector treatment cost. Finally, the model calculates the total titanium sector incremental treatment cost. All treatment and disposal calculations are performed using the “model facility” quantities calculated in the last section of this document.

G.3.1 Determination of On-Site versus Off-Site Treatment

The model assumes that low-volume wastes ($\leq$ 879 mt/yr solids or $\leq$ 350 mt/yr liquids) will be sent off-site for treatment and disposal. All wastes generated in the titanium sector are assumed to be treated on-site, because both wastewaters and solids are generated in quantities above the low-volume threshold in all three costing scenarios (see Exhibit G-10).

G.3.2 Neutralization and Precipitation Costs

Five of the eight titanium waste streams are wastewaters and therefore require neutralization, precipitation, dewatering, and stabilization prior to disposal. (The other three streams are solids and do not require neutralization, precipitation, and dewatering.) The model uses four equations to determine the neutralization cost for wastewaters:[3]

- Surge Tank Costs ($/yr) = $4 \times 10^{-8} Q_n^2 + 0.1175 Q_n + 3{,}680$
- Capital Costs ($) = $36{,}131 + 151.95\, Q_n^{0.5}$
- O&M Costs ($/yr) = $-206{,}719 + 36{,}594 \ln Q_n$
- Closure Costs ($) = $6{,}361 + 10^{-3} Q_n$

In all four of the above equations, Q_n (the amount of waste requiring neutralization) equals the sum of wastewaters and waste streams with one to ten percent solids requiring treatment. Using the pre-rule expected value case as an example, the model facility quantity of wastewater requiring treatment is 60,905 mt/yr, and the quantity of wastes with one to ten percent solids content is 0 mt/yr (see Exhibit G-10). Therefore, neutralization surge tank storage costs equal $10,985, neutralization capital costs equal $73,631, neutralization O&M costs equal $196,440 per year, and neutralization closure costs equal $6,422. Exhibit G-12 shows the neutralization costs for the titanium and titanium dioxide sector.

Exhibit G-12
Neutralization Costs

Baseline/Option Costs	Neutralization Costs		
	Minimum	Expected	Maximum
Pre-Rule			
- Surge ($/yr)	22,477	10,985	13,148
- Capital ($)	95,392	73,631	78,699
- O&M ($/yr)	229,931	196,440	205,718
- Closure ($)	6,513	6,422	6,439
Post-Rule			
- Surge ($/yr)	23,713	11,411	13,681
- Capital ($)	97,214	74,687	79,851
- O&M ($/yr)	232,148	198,473	207,672
- Closure ($)	6,523	6,425	6,444

The model uses two equations to determine the precipitation cost for wastewaters:[4]

- Capital Costs ($) = $3{,}613 + 15.195\, Q_p^{0.5}$
- O&M Costs ($/yr) = $826.48 + 0.3465\, Q_p$

In the above equations, Q_p (the amount of waste requiring precipitation) equals the sum of wastewaters and waste streams with one to ten percent solids requiring treatment. Using the pre-rule expected value case as an example, the model facility quantity of wastewater requiring treatment is 60,905 mt/yr, and the quantity of wastes with one to ten percent solids content is 0 mt/yr (see Exhibit G-

[3] Equations from Exhibit D-1, Appendix D.

[4] EPA assumes that neutralization and precipitation occur within the same unit, therefore, precipitation closure costs are included in the neutralization closure cost equation.

10). Therefore, precipitation capital costs equal $7,363, and precipitation O&M costs equal $21,930 per year. Exhibit G-13 shows the precipitation costs for the titanium and titanium dioxide sector.

Exhibit G-13
Precipitation Costs

Baseline/Option Costs	Precipitation Costs		
	Minimum	Expected	Maximum
Pre-Rule			
- Capital ($)	9,539	7,363	7,870
- O&M ($/yr)	53,529	21,930	28,020
Post-Rule			
- Capital ($)	9,721	7,469	7,985
- O&M ($/yr)	56,821	23,136	29,511

G.3.3 Dewatering and Stabilization Costs

Neutralization operations produce a slurry which must be dewatered, stabilized, and disposed. About 15 percent of the quantity introduced into the neutralization operation leaves as this slurry. Therefore, in the following equations, Q_{dw}, the amount of material requiring dewatering, is 15 percent of the sum of the quantity of wastewaters and wastes with a solids content of 1 to 10 percent requiring treatment:[5]

- Capital Costs ($) = $95,354 + 664.48\ Q_{dw}^{0.5}$
- O&M Costs ($/yr) = $12,219 + 286.86\ Q_{dw}^{0.5}$

For example, in the post-rule expected value case, Q_{dw} is equal to 9,658 mt/yr [(64,385 mt/yr wastewaters plus 0 mt/yr wastes with a solids content of 1 to 10 percent (from Exhibit G-10)) x 0.15]. Therefore, the capital cost associated with dewatering 9,658 mt/yr waste is $160,655, and the O&M cost is $40,410 per year.

Dewatering produces a sludge which needs to be stabilized and disposed. The dewatered sludge, equal to about 15 percent of the mass entering dewatering, is combined with the solid waste streams requiring stabilization and disposal in the following equations:[6]

- Capital Costs ($) = $207.93\ Q_s^{0.78}$
- O&M Costs ($/yr) = $87,839 + 52.16\ Q_s$
- Closure Costs ($) = $9,806 + 0.19\ Q_s$

In these equations therefore, the quantity requiring stabilization, Q_s, is 2.25 percent[7] of the sum of the original quantity of wastewaters and wastes with a solids content of 1 to 10 percent requiring treatment, added to the entire quantity of solid waste requiring treatment. For example, in the post-rule expected value case, Q_s is equal to 34,806 mt/yr [1,449 mt/yr wastewaters and wastes with 1 to 10 percent solids ((64,385 mt/yr + 0 mt/yr, from Exhibit G-10, * 0.0225) plus 33,357 mt/yr solids (from Exhibit G-10)]. Therefore, the capital cost associated with stabilizing 34,806 mt/yr waste is $725,110, the O&M

[5] Equations obtained from Case A, Exhibit D-2, Appendix D.

[6] Equations obtained from Case B, Exhibit D-2, Appendix D.

[7] This is equal to 15 percent of the quantity entering dewatering, which is 15 percent of the original quantity requiring treatment.

cost is $1,903,302 per year, and the closure cost is $16,419. Exhibit G-14 shows the dewatering and stabilization costs for the titanium and titanium dioxide sector.

Exhibit G-14
Dewatering and Stabilization Costs

Baseline/Option Costs	Dewatering and Stabilization Costs					
	Minimum		Expected		Maximum	
	Dewatering	Stabilization	Dewatering	Stabilization	Dewatering	Stabilization
Pre-Rule						
- Capital ($)	195,721	118,979	158,866	718,728	167,450	1,220,787
- O&M ($/yr)	55,548	266,761	39,637	1,882,840	43,343	3,628,085
- Closure ($)	NA	10,458	NA	16,345	NA	22,702
Post-Rule						
- Capital ($)	198,808	124,857	160,655	725,110	169,400	1,231,154
- O&M ($/yr)	56,881	278,171	40,410	1,903,302	44,185	3,666,676
- Closure ($)	NA	10,499	NA	16,419	NA	22,842

G.3.4 Disposal Costs

After neutralization, precipitation, dewatering, and/or stabilization, stabilized residues from titanium sector wastes are disposed of in a pile. The cost of disposal in a pile is described by the following equation:[8]

- Pile Costs ($/yr) = 1.8703 Q_{ds} + 12,308

In the above equation, Q_{ds}, the quantity being disposed, is equal to 155 percent of the mass entering stabilization from dewatering added to 175 percent of the solid wastes entering stabilization. Alternatively Q_{ds} is the sum of [1.55 x (0.0225 x (quantity of wastewaters and wastes with a 1 to 10 percent solids content requiring treatment)] and [1.75 x (quantity of solids requiring treatment)]. For example, in the expected value case of Option 3, Q_{ds} is equal to 60,621 mt/yr [(1,449 mt/yr x 1.55) plus (33,357 mt/yr x 1.75)]. Therefore, the cost of disposal in a pile is equal to $130,717. Exhibit G-15 depicts the disposal costs for the sector.

Exhibit G-15
Disposal Costs

Baseline/Option Costs	Disposal Costs		
	Minimum	Expected	Maximum
Pre-Rule	22,255	124,431	233,797
Post-Rule	22,859	125,686	236,182

[8] Equation obtained from Exhibit D-21.

G.3.5 Annualization of Costs and Calculation of Total Sector Treatment Costs

Because capital and closure costs are one-time costs, they are annualized so that total annualized titanium sector incremental treatment costs may be calculated. The model annualizes the titanium sector capital costs by multiplying them by a capital recovery factor (CRF) of 0.09439.[9] Closure costs, which are assumed to be incurred after 20 years of operation (i.e., in year 21), are reduced to present value and then annualized using the CRF. The annualization process and the calculation of total neutralization, precipitation, dewatering, and stabilization costs are accomplished using the following formula:[10]

- Annualized Cost = (Capital Costs)(CRF) + O&M Costs + (Closure Costs)(CRF)/(1.07^{21})

Using the above formula, the model combines the capital, O&M, and closure costs to obtain total annualized neutralization, precipitation, dewatering, and stabilization costs for the titanium sector.[11] For example, the pre-rule annualized stabilizationn cost in the titanium and titanium dioxide sector equals ($718,728 x 0.09439) + $1,882,840 + (($16,345 x 0.09439) / 1.07^{21}), or $1,951,053. The disposal cost function is already annualized. Exhibit G-16 presents the total annualized neutralization, precipitation, dewatering, stabilization, and disposal costs for the titanium sector.

Exhibit G-16
Annualized Neutralization, Precipitation, Dewatering, Stabilization, and Disposal Costs (Modified Prior Treatment Baseline and Option 3)

Baseline/Option Costs ($)	Costing Scenario		
	Minimum	Expected	Maximum
Pre-Rule			
- Neutralization	261,531	214,521	226,441
- Precipitation	54,429	22,625	28,763
- Dewatering	74,022	54,632	59,149
- Stabilization	278,230	1,951,053	3,743,833
- Disposal	22,255	124,431	233,797
Total	**690,467**	**2,367,262**	**4,291,983**
Post-Rule			
- Neutralization	265,186	217,080	229,012
- Precipitation	57,739	23,841	30,265
- Dewatering	75,646	55,574	60,175
- Stabilization	290,196	1,972,119	3,783,405
- Disposal	22,859	125,686	236,182
Total	**711,626**	**2,394,300**	**4,339,039**

Total titanium sector pre- and post-rule treatment costs are calculated by summing the annualized neutralization, precipitation, dewatering, stabilization, and disposal costs from Exhibit G-16 and multiplying the sum by the maximum number of facilities in the titanium sector (two in the minimum value case, seven in the expected and maximum value cases). Therefore, the total titanium sector

[9] Derivation of the CRF may be found on page D-2 of Appendix D.

[10] For more information, see pages D-1 and D-2 of Appendix D.

[11] Surge tank costs are also added to the annualized capital, O&M, and annualized closure costs in the calculation of the total annualized neutralization cost.

expected value case pre-rule treatment cost in this example is equal to (($214,521 + $22,625 + $54,632 + $1,951,053 + $124,431 = $2,372,235) x 7), or **$16,570,834**. Similarly, the total titanium sector expected value case post-rule treatment cost in this example is equal to (($217,080 + $23,841 + $55,574 + $1,972,119 + $125,686 = $2,399,311) x 7), or **$16,760,100**.

G.3.6 Total Sector Incremental Treatment Cost

The total titanium sector incremental treatment cost is calculated by subtracting the pre-rule total sector treatment cost from the post-rule total sector treatment cost. In this example, the total titanium sector incremental treatment cost is **$42,318** in the minimum value case, **$189,266** in the expected value case, and **$329,392** in the maximum value case.

G.4. Storage Cost Calculations

This section of the appendix calculates the total sector incremental storage cost incurred by the titanium and titanium dioxide mineral processing sector. This process involves four steps: (1) the appropriate storage unit for each waste stream is selected; (2) the average facility storage cost is calculated for each waste stream; (3) a total sector storage cost is calculated; and (4) a total sector incremental storage cost is calculated. Note that until the total sector storage cost is calculated at the end of this section, all calculations in this section are performed on an average facility basis.

G.4.1 Storage Unit and Cost Equation Determination

Depending on the quantity of recyclable waste generated and the physical form of the waste (liquid or solid), wastes that require storage prior to recycling can be stored in a variety of storage units. EPA developed individual cost equations for each type of storage unit and used these cost equations to determine the range of quantities over which each type of unit is the least costly storage unit available. Exhibit G-17 shows these cost functions for the various storage units available for use in the Modified Prior Treatment baseline and Option 3, as well as the range of quantities for which that unit would be employed.[12] In each of these equations, Q is the annual quantity requiring storage prior to recycling.

[12] For a full list of storage unit functions, refer to Exhibit D-21.

Exhibit G-17
Storage Cost Equations

Modified Prior Treatment Baseline			
Waste Type	**Storage Unit**	**Quantity Range (mt/yr)**	**Cost Equation**
Liquid	Drum	0 - 220	$Y = -0.0074\ Q^2 + 9.4798\ Q + 189.34$
	Tank	220 - 500	$Y = -9x10^{-7}\ Q^2 + 0.55\ Q + 1{,}795.7$
	Unlined S.I.	≥ 500	Y = 1,000
Solid	Drum	0 - 200	Y = 24.589 Q + 132.23
	Roll-Off	200 - 935	$Y = -0.0022\ Q^2 + 29.272\ Q + 4{,}840.9$
	Unlined Pile	≥ 935	Y = 4.0207 Q + 26,271
Option 3 (PT)			
Waste Type	**Storage Unit**	**Quantity Range (mt/yr)**	**Cost Equation**
Liquid	Drum	0 - 220	$Y = -0.0074\ Q^2 + 9.4798\ Q + 189.34$
	Tank	220 - 1 million	$Y = -9x10^{-7}\ Q^2 + 0.55\ Q + 1{,}795.7$
	Lined S.I.	> 1 million	Y = 0.0704 Q + 1,955.1
Solid	Drum	0 - 200	Y = 24.589 Q + 132.23
	Roll-Off	200 - 1343.1	$Y = -0.0022\ Q^2 + 29.272\ Q + 4{,}840.9$
	Building	1343.1 - 45,000	$Y = 0.00002\ Q^2 + 3.2395\ Q + 35{,}800$
	Lined Pile	> 45,000	Y = 4.0924 Q + 27,676

SL = Sludge, BP = By-Product, SM = Spent Material

Exhibit G-18 shows the storage units used in the minimum, expected, and maximum value cases for the eight waste streams generated in the titanium sector. For example, scrap milling scrubber water is stored in an unlined surface impoundment in the pre-rule maximum value case because it is a liquid waste (a wastewater), classified as a sludge, and the quantity stored prior to recycling (1200 mt/yr) exceeds the threshold quantity of 500 mt/yr needed to store liquids in an unlined surface impoundment.

G.4.2 Storage Costs

Exhibit G-19 shows the storage costs for each of the eight titanium waste streams. Exhibit G-19 is created by plugging the quantity of waste stored prior to recycling (Exhibit G-11) into the appropriate cost function from Exhibit G-17. For example, leach liquor and sponge wash water is stored in a tank in all three costing scenarios under Option 3. Therefore the cost equation for the minimum, expected, and maximum value case are as follows:

- Cost = $-9x10^{-7}\ Q^2 + 0.55\ Q + 1{,}795.7$

Inserting 28,500 mt/yr, 36,000 mt/yr, and 43,500 mt/yr into the minimum, expected, and maximum cost equations, respectively, yields a storage cost of $16,740 in the minimum value case, $20,429 in the expected value case, and $24,018 in the maximum value case.

Exhibit G-18
Storage Units Used in the Modified Prior Treatment Baseline and Option 3

Titanium Waste Stream	Storage Unit		
	Minimum	Expected	Maximum
Pre-Rule			
Pickle Liquor and Wash Water	Not Recycled	Drum	Drum
Scrap Milling Scrubber Water	Not Recycled	Unlined S.I.	Unlined S.I.
Smut from Mg Recovery	Drum	Unlined Pile	Unlined Pile
Leach Liquor and Sponge Wash Water	Unlined S.I.	Unlined S.I.	Unlined S.I.
Spent Surface Impoundment Liquids	Not Recycled	Drum	Unlined S.I.
Spent Surface Impoundment Solids	Not Recycled	Not Recycled	Not Recycled
Waste Acids (Sulfate Process)	Not Recycled	Not Recycled	Not Recycled
WWTP Sludges/Solids	Not Recycled	Not Recycled	Not Recycled
Post-Rule			
Pickle Liquor and Wash Water	Not Recycled	Drum	Drum
Scrap Milling Scrubber Water	Not Recycled	Tank	Tank
Smut from Mg Recovery	Drum	Building	Building
Leach Liquor and Sponge Wash Water	Tank	Tank	Tank
Spent Surface Impoundment Liquids	Not Recycled	Drum	Tank
Spent Surface Impoundment Solids	Not Recycled	Not Recycled	Not Recycled
Waste Acids (Sulfate Process)	Not Recycled	Not Recycled	Not Recycled
WWTP Sludges/Solids	Not Recycled	Not Recycled	Not Recycled

Exhibit G-19
Average Facility Storage Costs

Titanium Waste Stream	Average Facility Storage Cost ($)		
	Minimum	Expected	Maximum
Modified Prior Treatment Baseline			
Pickle Liquor and Wash Water	Not Recycled	983	1,873
Scrap Milling Scrubber Water	Not Recycled	1,000	1,000
Smut from Mg Recovery	1,190	63,865	103,167
Leach Liquor and Sponge Wash Water	1,000	1,000	1,000
Spent Surface Impoundment Liquids	Not Recycled	1,828	1,000
Spent Surface Impoundment Solids	Not Recycled	Not Recycled	Not Recycled
Waste Acids (Sulfate Process)	Not Recycled	Not Recycled	Not Recycled
WWTP Sludges/Solids	Not Recycled	Not Recycled	Not Recycled
Option 3 (PT)			
Pickle Liquor and Wash Water	Not Recycled	780	1,517
Scrap Milling Scrubber Water	Not Recycled	2,002	2,290
Smut from Mg Recovery	1,067	63,887	96,162
Leach Liquor and Sponge Wash Water	16,740	20,429	24,018
Spent Surface Impoundment Liquids	Not Recycled	1,670	2,190
Spent Surface Impoundment Solids	Not Recycled	Not Recycled	Not Recycled
Waste Acids (Sulfate Process)	Not Recycled	Not Recycled	Not Recycled
WWTP Sludges/Solids	Not Recycled	Not Recycled	Not Recycled

G.4.3 Total Sector Storage Cost

To obtain a total sector storage cost, pre-rule (Modified Prior Treatment baseline) and post-rule (Option 3) total sector storage costs must be calculated for each waste stream and summed. Total sector pre- and post-rule storage costs are calculated by multiplying the minimum, expected, and maximum average facility storage cost for each titanium waste stream (Exhibit G-19) by the number of facilities generating the waste stream. Using leach liquor and sponge wash water as an example, the Option 3 total sector storage cost is $42,792 ($21,396 x 2 facilities) in the minimum value case, $52,244 ($26,122 x 2 facilities) in the expected value case, and $60,916 (30,458 x 2 facilities) in the maximum value case. Exhibit G-20 shows the total sector storage cost for each waste stream and the total sector storage cost for the entire sector.

Exhibit G-20
Total Sector Storage Costs

Baseline or Option	Number of Facilities	Storage Cost ($)		
		Minimum	Expected	Maximum
Modified Prior Treatment Baseline	-			
Pickle Liquor and Wash Water	3	0	2,949	5,619
Scrap Milling Scrubber Water	1	0	1,000	1,000
Smut from Mg Recovery	2	2,380	127,730	206,334
Leach Liquor and Sponge Wash Water	2	2,000	2,000	2,000
Spent Surface Impoundment Liquids	7	0	12,796	7,000
Spent Surface Impoundment Solids	7	0	0	0
Waste Acids (Sulfate Process)	2	0	0	0
WWTP Sludges/Solids	7	0	0	0
Pre-Rule Total Sector		**4,380**	**146,475**	**221,953**
Option 3 (PT)	-			
Pickle Liquor and Wash Water	3	0	2,340	4,551
Scrap Milling Scrubber Water	1	0	2,002	2,290
Smut from Mg Recovery	2	2,134	127,774	192,324
Leach Liquor and Sponge Wash Water	2	33,480	40,858	48,036
Spent Surface Impoundment Liquids	7	0	11,690	15,330
Spent Surface Impoundment Solids	7	0	0	0
Waste Acids (Sulfate Process)	2	0	0	0
WWTP Sludges/Solids	7	0	0	0
Post-Rule Total Sector		**35,614**	**184,664**	**262,531**

G.4.4 Total Sector Incremental Storage Cost

The total titanium sector incremental storage cost is calculated by subtracting the pre-rule total sector storage cost from the post-rule total sector storage cost. In this example (where the pre-rule scenario is the Modified Prior Treatment baseline, and the post-rule scenario is Option 3), the total titanium sector incremental storage cost is **$31,234** in the minimum value case, **$38,189** in the expected value case, and **$40,578** in the maximum value case.[13]

[13] In the minimum value case, there is a saving in storage cost due to a slight decrease in the amount of material recycled.

G.5. Incremental Cost Calculations

This section of the appendix shows how the model calculates the total incremental cost of the rulemaking for the titanium sector. The total incremental cost is calculated by adding the total sector incremental treatment cost (calculated in Section G.3), the total sector incremental storage cost (calculated in Section G.4), and a recordkeeping cost of $1,411 per facility generating waste in the sector. The recordkeeping cost of $1,411 per facility translates to a total sector recordkeeping cost of $2,822 ($1,411 x 2 facilities) in the minimum value case, and $9,877 ($1,411 x 7 facilities) in the expected and maximum value cases. Thus, for the titanium and titanium dioxide sector, the incremental cost of this rulemaking is equal to **$76,374** ($42,318 incremental treatment cost + $31,234 incremental storage cost + $2,822 recordkeeping cost) in the minimum value case, **$237,232** ($189,266 incremental treatment cost + $38,189 incremental storage cost + $9,877 recordkeeping cost) in the expected value case, and **$379,847** ($329,392 incremental treatment cost + $40,578 incremental storage cost + $9,877 recordkeeping cost) in the maximum value case.

The total cost incurred by an average facility in this sector is $38,248 in the minimum value case, $33,943 in the expected value case, and $54,375 in the maximum value case. Average facility costs are calculated by dividing the total sector incremental cost by the maximum number of facilities in this sector. Note that in this example the *average* facility cost in the minimum value case ($38,248) is larger than the average facility cost in the expected value case ($33,943). This is due to the fact that there are only two facilities producing waste in the minimum value case, and seven facilities producing waste in the expected and maximum value cases. This results in a higher average facility cost because the *total* sector incremental cost is divided by two rather than seven.