## Appendix A. Unit Process Maps

### *Applendix A.1. Model Overview*

This model was created using unit processes developed by NETL and modeled in the GaBi 6.0 LCA modeling software package. All of the unit processes utilized to create this model are publicly available on the NETL website, with the exception of those noted explicitly below, which are available from PE International. The model can be re-created utilizing the GaBi 6.0 software or by utilizing a spreadsheet to perform the scaling calculations between the individual unit processes.

### *Applendix A.2. Model Connectivity and Unit Process Links*

The structure of LCA models in GaBi uses a tiered approach, which means that there are different groups of processes, known as plans, which are combined to create the model. To aid in the connectivity of various plans used in this model, the following naming convention will be utilized in the figure headings throughout the remainder of this section. The main plan will be referred to as the top-level plan, and all subsequent plans will be referred to as second-, third-, etc. level plans. An example of this tiered-nature of the model structure is shown in Figure A1.

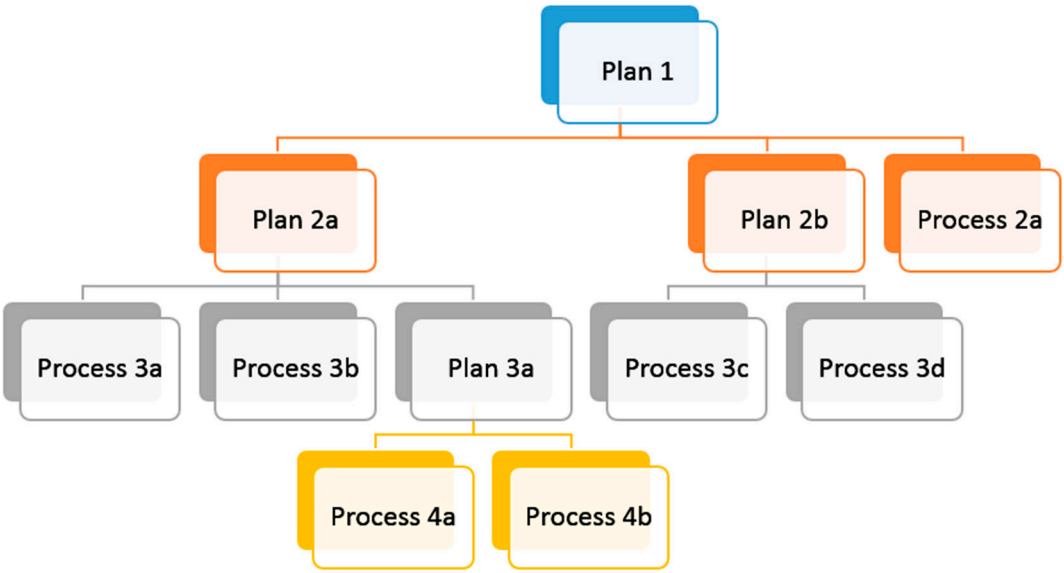


**Figure A1.** Tiered Modeling Approach.

Table A1 demonstrates the relationships between the tiers of plans used in the construction of the model. The figures in this section illustrate the connectivity of the various processes and plans.

**Table A1.** Parent/Child Plan Connections for Coal Exports.

| Figure | Plan Name | Parent Plans | Child Plans |
|---|---|---|---|
| A-2 | Coal Exports | None | 1. Surface Coal Mine—Coal Exports—Construction<br>2. Surface Coal Mine—Coal Exports—Overburden Removal<br>3. Surface Coal Mine—Coal Exports—Coal Extraction<br>4. Surface Coal Mine—Coal Exports—Mine Reclamation<br>5. Coal Cleaning<br>6. Rail Transport |

| | | | |
|---|---|---|---|
| | | | 7. Truck Transport<br>8. Barge Transport<br>9. U.S.: Marine Coal Terminal<br>10. Ocean Freighter Transport<br>11. U.S.: Marine Coal Terminal<br>12. PPFM CTG Model—Modified for Coal Exports<br>13. Fly Ash Disposal<br>14. $CO_2$ Pipeline—No Compression<br>15. Saline Aquifer Sequestration |
| A-3 | Surface Coal Mine—Coal Exports—Construction | Coal Exports | 1. Surface Mine Commissioning/ Decommissioning<br>2. Assembly: Surface Coal Mine, Construction |
| A-4 | Surface Mine Commissioning/ Decommissioning | Surface Coal Mine—Coal Exports—Construction | None |
| A-5 | Assembly: Surface Coal Mine, Construction | Surface Coal Mine—Coal Exports—Construction | 1. Blasthole Drill, Construction<br>2. Coal Loading Silo, Construction<br>3. Conveyer System, Construction<br>4. Coal Loader, Construction<br>5. Dragline, Construction<br>6. Mining Truck, Construction<br>7. Electric Shovel, Construction<br>8. Coal Crusher, Construction |
| A-6 | Blasthole Drill, Construction | Assembly: Surface Coal Mine, Construction | None |
| A-7 | Coal Loading Silo, Construction | Assembly: Surface Coal Mine, Construction | None |
| A-8 | Conveyer System, Construction | Assembly: Surface Coal Mine, Construction | None |
| A-9 | Coal Loader, Construction | Assembly: Surface Coal Mine, Construction | None |
| A-10 | Dragline, Construction | Assembly: Surface Coal Mine, Construction | None |
| A-11 | Mining Truck, Construction | Assembly: Surface Coal Mine, Construction | None |
| A-12 | Electric Shovel, Construction | Assembly: Surface Coal Mine, Construction | None |
| A-13 | Coal Crusher, Construction | Assembly: Surface Coal Mine, Construction | None |
| A-14 | Surface Coal Mine—Coal Exports—Overburden Removal | Coal Exports | None |
| A-15 | Surface Coal Mine—Coal Exports—Coal Extraction | Coal Exports | None |
| A-16 | Surface Coal Mine—Coal Exports—Mine Reclamation | Coal Exports | None |
| A-17 | Coal Cleaning | Coal Exports | None |
| A-18 | Rail Transport | Coal Exports | None |
| A-19 | Truck Transport | Coal Exports | None |
| A-20 | Barge Transport | Coal Exports | None |
| A-21 | Ocean Freighter Transport | Coal Exports | None |
| A-22 | PPFM CTG Model—Modified for Coal Exports | Coal Exports | 1. SCPC Power Plant, Construction<br>2. Ammonia Production, No $CO_2$ Capture |
| A-23 | SCPC Power Plant, Construction | PPFM CTG Model | None |
| A-24 | Ammonia Production, No $CO_2$ Capture | PPFM CTG Model | None |
| A-25 | Fly Ash Disposal | Coal Exports | None |
| A-25 | $CO_2$ Pipeline—No Compression | Coal Exports | 1. $CO_2$ Pipeline Construction |
| A-26 | $CO_2$ Pipeline Construction | $CO_2$ Pipeline—No Compression | None |
| A-27 | Saline Aquifer Sequestration | Coal Exports | See NETL's saline aquifer LCA (NETL, 2013) |

The following section includes screenshots of the GaBi plans followed by a table of the unit processes included in the corresponding plan. Table A2 gives an example of the tables. The "Unit Process" column provides the name of the unit process as it is called in the GaBi model as well as the name of the unit process as it can be found on the NETL LCA website [1].

To find the complete documentation of each unit process, either open the hyperlink provided OR go to the NETL LCA website and search for the files with the corresponding name.

The majority of NETL unit processes are parameterized. The parameter values are utilized within calculations in the unit process to determine the input and output values for that corresponding process. In addition to allowing for the assessment of uncertainty and sensitivity in the overall model results, parameters also make unit processes flexible. For example, the distance parameter in the cargo train transport unit process can be adjusted as necessary to meet the requirements for a particular study. Unit processes posted on the NETL website are prepopulated with default parameter values. For this study, some parameter values were altered to accurately model the desired scenarios. These values are detailed in Table A3 with the corresponding unit process. To match the results presented in this study, it is important that the parameter values are tuned accordingly.

**Table A2.** Example Appendix table.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| NETL Unit Process Library Name | Brief Description of Unit Process or Plan | # | #/#### |

*Applendix A.3. NETL Conventions for Modeling Fuel Combustion*

NETL utilizes a special convention related to the modeling of petroleum fuel combustion emissions (e.g., diesel). When a fuel is combusted, there is typically a set of three processes: (1) cradle-to-gate production of the fuel; (2) combustion of that fuel in a specified piece of equipment (e.g., reciprocating engine, mobile source, etc.); and (3) a process that includes parameters to scale the amount of combusted fuel required to meet the demands of the system (e.g., cargo train transport, tug and barge transport). The flow that moves between processes 2 and 3 is a flow of combusted fuel and is used only for the purposes of scaling all of the processes in the system to the functional unit. For example, the rail transport process includes parameters that are used to calculate the required combusted fuel input (e.g., distance and fuel efficiency). Given those values, that rail transport process demands the corresponding amount of combusted fuel. As discussed above, those combustion emissions are contained and accounted for in a separate unit process.

**Table A3.** Coal Exports Model Parameter Values and Applicable Unit Processes.

| Parameter 1 | Parameter 2 | Export Location | | | Applicable Unit Process |
|---|---|---|---|---|---|
| | | PRB | Australia | Indonesia | |
| Coal Mine Methane (scf/ton) | Low Value<br>Expected Value<br>High Value | 0.8<br>8.0<br>38.7 | 34.3<br>42.9<br>54.4 | 27.9 | Coal Mine Methane Emissions |
| Diesel Scalar | Low Value<br>Expected Value<br>High Value | 1 | 1 | 2<br>3<br>4 | Surface Coal Mining—Overburden Removal, Extraction, and Reclamation |
| Mine Electricity Switch | N/A | 1 | 1 | 0 | Surface Coal Mining—Overburden Removal, Extraction, and Reclamation; See Tables S4 for Grid Mixes |
| Strip Ratio | Low Value<br>Expected Value<br>High Value | 2<br>3<br>4 | 8<br>9<br>10 | 3<br>5.5<br>8 | Surface Coal Mining—Overburden Removal, Extraction, and Reclamation |
| Coal Cleaning Switch | N/A | 0 | 1 | 0 | Logic block; no associated UP |
| Sulfur Concentration of Diesel Fuel (ppm) | N/A | 15 | 10 | 3500 | Combustion of Diesel |
| Rail Distance (km) | Low Value<br>Expected Value<br>High Value | 1900<br>2000<br>2100 | 150<br>225<br>300 | N/A | Cargo, Train Transport |
| Truck Distance (km) | Low Value<br>Expected Value<br>High Value | N/A | N/A | 44<br>79<br>114 | Tractor-tanker transport |
| River Barge Distance (km) | Low Value<br>Expected Value<br>High Value | N/A | N/A | 100<br>250<br>450 | Tug and Barge Transport |
| Ocean Distance (km) L/H are ±10% | To Japan<br>To Korea<br>To Taiwan | 7892<br>8451<br>9904 | 8075<br>8558<br>7888 | 4683<br>4380<br>2997 | Ocean Freighter Transport |
| Coal Type | Low Value<br>Expected Value<br>High Value | Spring Creek<br>Decker<br>North Antelope | Hunter Valley | Adaro, Mulia<br>Modeled Separately | PPFM—Power Plant Flexible Model |

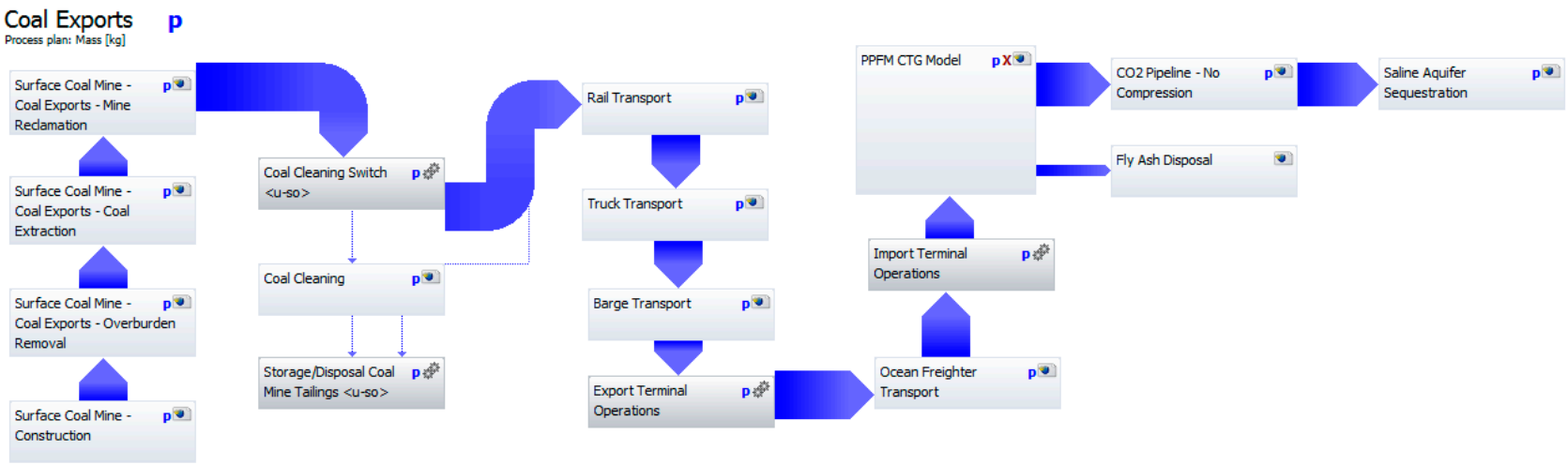


**Figure A2.** Coal Exports—Top-Level Plan.

**Table A4.** Coal Exports.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Storage/Disposal Coal Mine Tailings | This unit process provides a summary of relevant input and output flows associated with disposing or storing coal mine tailings in an impoundment (pond), piles (landfill), or backfill. | 1 | June 2014 |
| Marine Coal Terminal | This unit process provides a summary of relevant input and output flows associated with the processing of coal at a marine bulk terminal. Inputs to this unit process includes coal. Outputs include air emissions. | 1 | May 2015 |

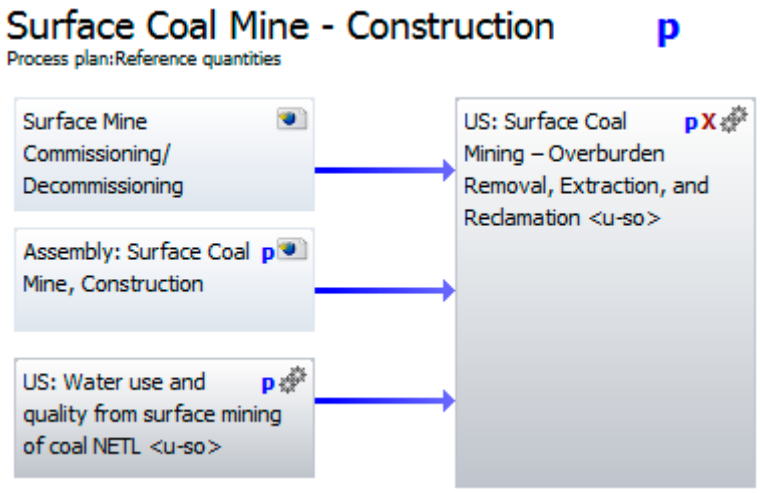


**Figure A3.** Surface Coal Mine—Construction—Second-Level Plan.

**Table A5.** Surface coal mine—Construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Water use and quality from surface mining of coal | This unit process provides a summary of water consumption and quality associated with surface mining of coal. The data are representative of subbituminous coal from the Powder River Basin. | 2 | July 2013 |
| Surface Coal Mining—Overburden Removal, Extraction, and Reclamation | This unit process provides a summary of relevant input and output flows associated with the extraction of coal from a surface mine. This includes the amount of electricity and fuel required to power equipment and the direct particulate matter and volatile organic compound emissions from operating equipment and using explosives. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 1 | August 2015 |

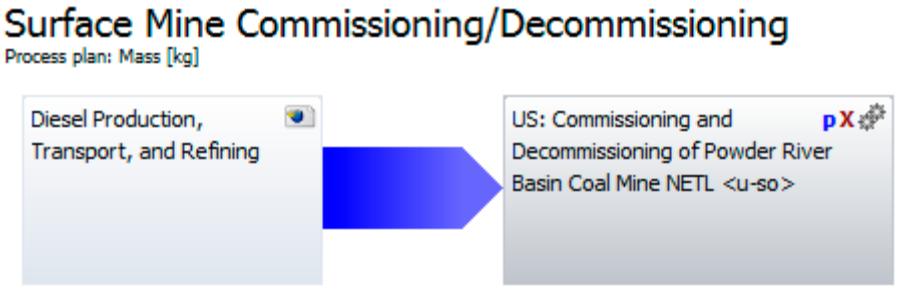


**Figure A4.** Surface mine commissioning/decommissioning—Third-level plan.

**Table A6.** Surface mine commissioning/decommissioning.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Commissioning and Decommissioning of Powder River Basin Coal Mine | This unit process provides a summary of relevant input and output flows associated with the commissioning (installation and opening) and decommissioning (closing and removal) of a surface mine for Powder River Basin subbituminous coal. Relevant input and output flows include diesel requirements for machinery and associated combustion emissions. | 1 | Junuary 2010 |
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. All inputs and outputs are normalized per kg of diesel. | 2 | September 2011 |

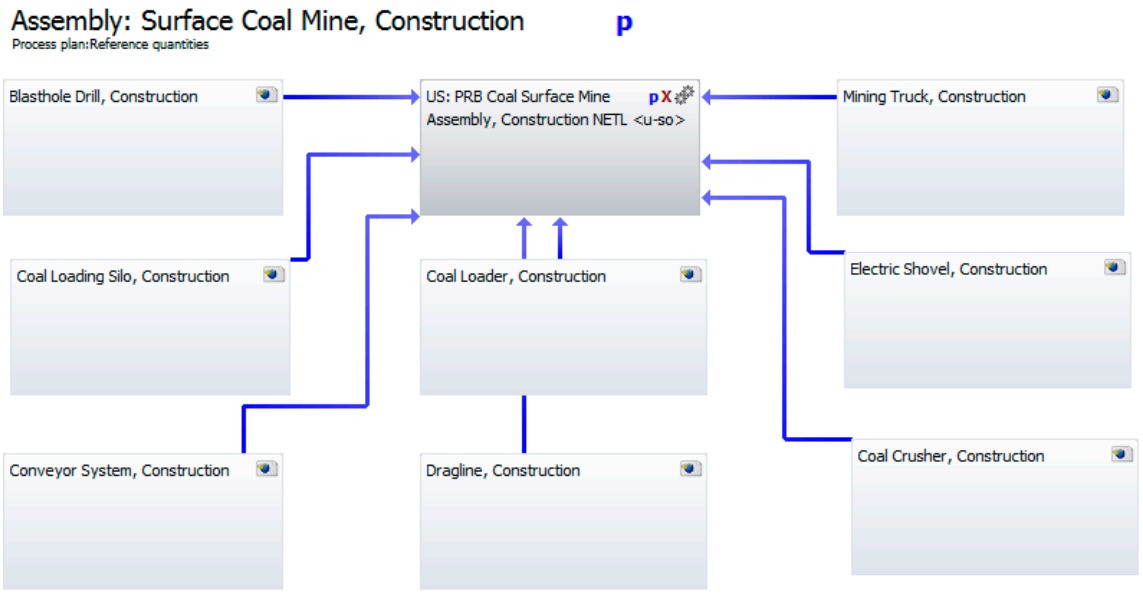


**Figure A5.** Assembly: Surface coal mine, construction—Third-level plan.

**Table A7.** Assembly: Surface Coal Mine, Construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| PRB Coal Surface Mine Assembly, Construction | This unit process provides a summary of the quantities of each piece of equipment required to extract and produce coal at a large surface mine in the Powder River Basin region. The number of each piece of equipment is based on equipment life expectancy, length of the study period, and amount of coal produced. The construction data for individual pieces of equipment is evaluated in the child plans listed below. All inputs and outputs are normalized per 1 piece of Powder River Basin coal surface mine per kg of coal produced. | 1 | February 2010 |

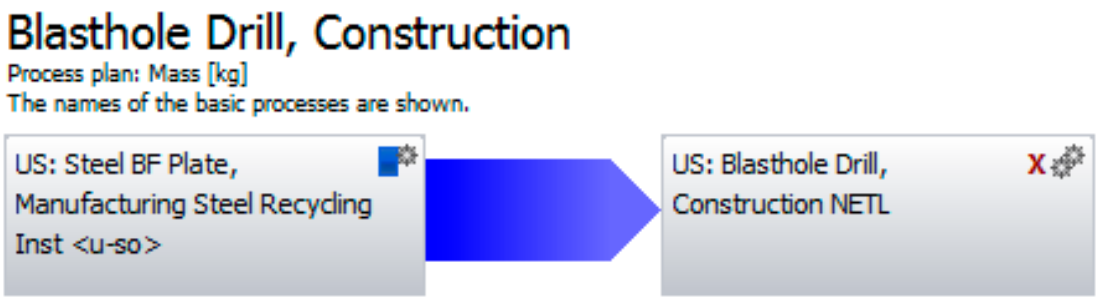


**Figure A6.** Blasthole drill, construction—Fourth-level plan.

**Table A8.** Blasthole drill, construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Steel Blast Furnace (BF) Plate, Manufacturing | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| Blasthole Drill, 250,000 lbs, Construction | This unit process provides a summary of the amount of steel plate required for the construction of a blasthole drill (e.g., 1 piece [pcs] of blasthole drill, 250,000 lbs). For the purposes of this analysis, the blasthole drill is assumed to be comprised entirely of steel plate, with other materials being negligible. The number of drills required to produce coal on a large surface mine with a dragline is evaluated in PRB Coal Surface Mine Assembly, Construction. All inputs and outputs are normalized per pcs of blasthole drill. | 1 | February 2010 |

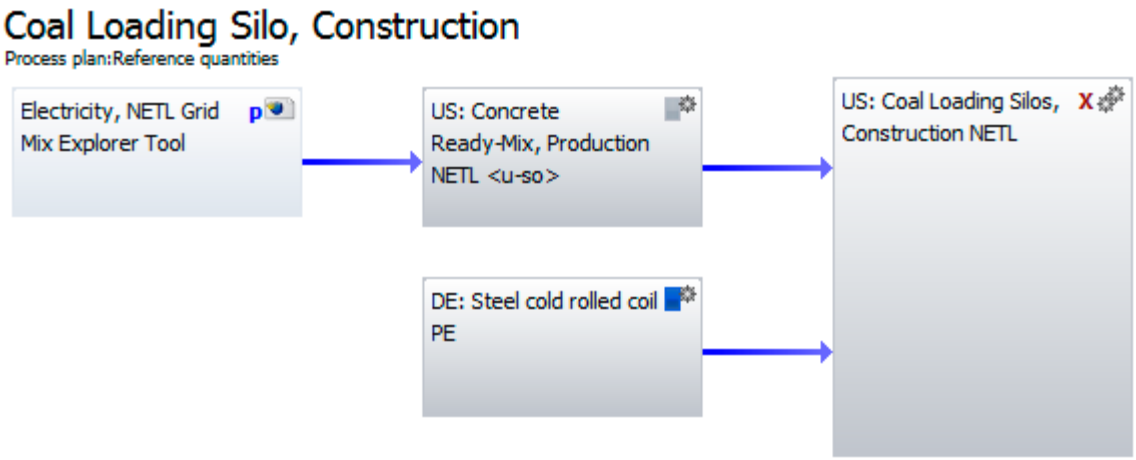


**Figure A7.** Coal loading silo, construction—Fourth-level plan.

**Table A9.** Coal loading silo, construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Steel Cold Rolled Coil | Third-party data available from thinkstep. GUID: E4DECB5D-6711-42AA-86E9-03204B518AC3. Last change: System, 1 November 2012 | N/A | N/A |
| Coal-Loading Silo, 12,000 Tons, Powder River Basin (PRB), Construction | This unit process provides a summary of the amount of steel plate and concrete required for the construction of a loading silo, which holds Powder River Basin sub-bituminous coal, releasing it during train loading. The number of silos required for train loading of Powder River Basin sub-bituminous coal is evaluated in PRB Coal Surface Mine Assembly, Construction. All inputs and outputs are normalized per piece of coal loading silo, 12,000 tons, Powder River Basin | 1 | February 2010 |
| Concrete Ready-Mix, Production | This unit process provides a summary of relevant input and output flows associated with the production of ready-mix concrete. | 1 | June 2013 |

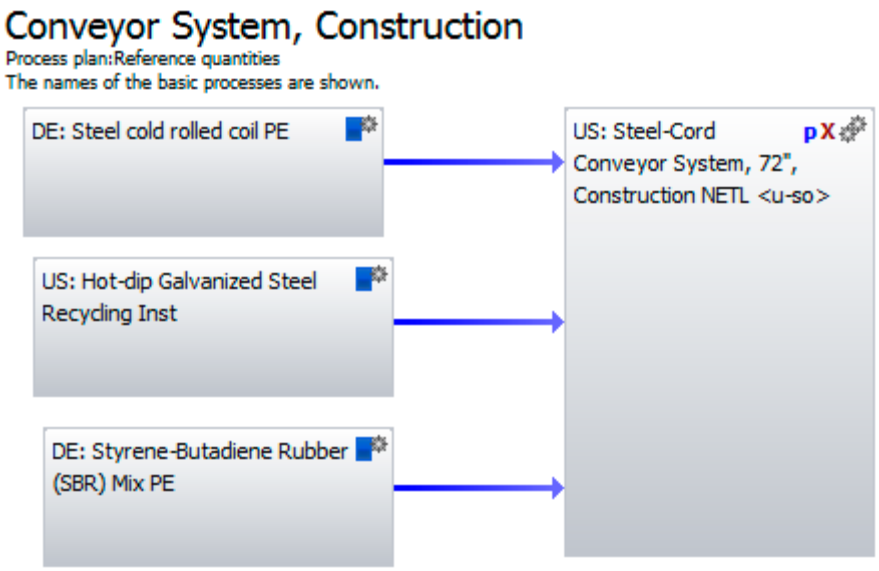


**Figure A8.** Conveyor system, construction—Fourth-level plan.

**Table A10.** Conveyor system, construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Hot-dip Galvanized | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| Styrene-Butadiene Rubber (SBR) Mix | Third-party data available from thinkstep.<br>GUID: 9B317E5C-A721-4912-BB28-06BD6B6FB9F<br>Last change: System, 1 November 2012 | N/A | N/A |
| Steel Cold Rolled Coil | Third-party data available from thinkstep<br>GUID: E4DECB5D-6711-42AA-86E9-03204B518AC3<br>Last change: System, 1 November 2012 | N/A | N/A |
| Steel-Cord Conveyor System, 72", Construction | This unit process provides a summary of the amount of materials required for the construction of a single steel-cord conveyor system, 72" wide, used for the carrying of coal at a Powder River Basin sub-bituminous coal mine. The number of conveyor systems required to transport coal is evaluated in PRB Coal Surface Mine Assembly, Construction. All inputs and outputs are normalized per piece of steel-cord conveyor system, 72". | 1 | January 2010 |

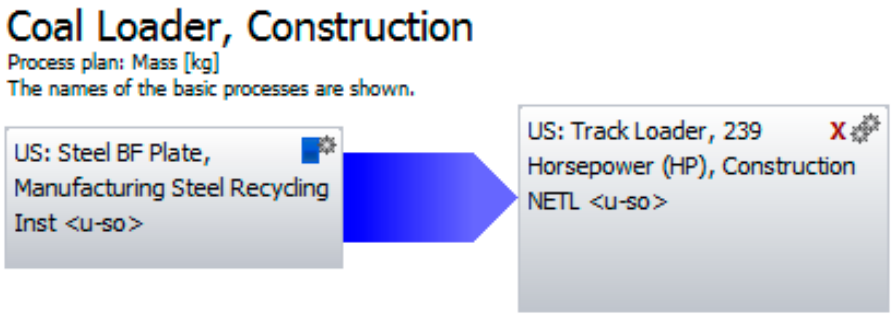


**Figure A9.** Coal loader, construction—Fourth-level plan.

**Table A11.** Coal loader, construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Steel Blast Furnace (BF) Plate, Manufacturing | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| Track Loader, 239 Horsepower (HP), Construction | This unit process provides a summary of the amount of steel required for the construction of a track loader used to scrape and push unconsolidated overburden at a large surface mine. The number of loaders required to scrape and move overburden is evaluated in PRB Coal Surface Mine Assembly, Construction. This unit process provides construction data only for a single loader. | 1 | January 2010 |

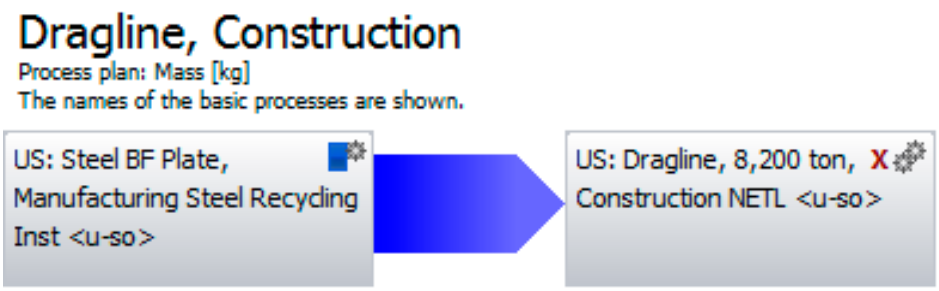


**Figure A10.** Dragline, construction—Fourth-level plan.

**Table A12.** Dragline, construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Steel Blast Furnace (BF) Plate, Manufacturing | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| Dragline, 8200 ton, Construction | This unit process provides a summary of the amount of steel plate required for the construction of a dragline (e.g., 1 piece [pcs] of dragline, 8200 tons). The dragline is assumed to be comprised entirely of steel plate, with other materials being negligible. The number of draglines required to produce coal at a surface mine is evaluated in PRB Coal Surface Mine Assembly, Construction. All inputs and outputs are normalized per pcs of dragline. | 1 | Junuary 2010 |

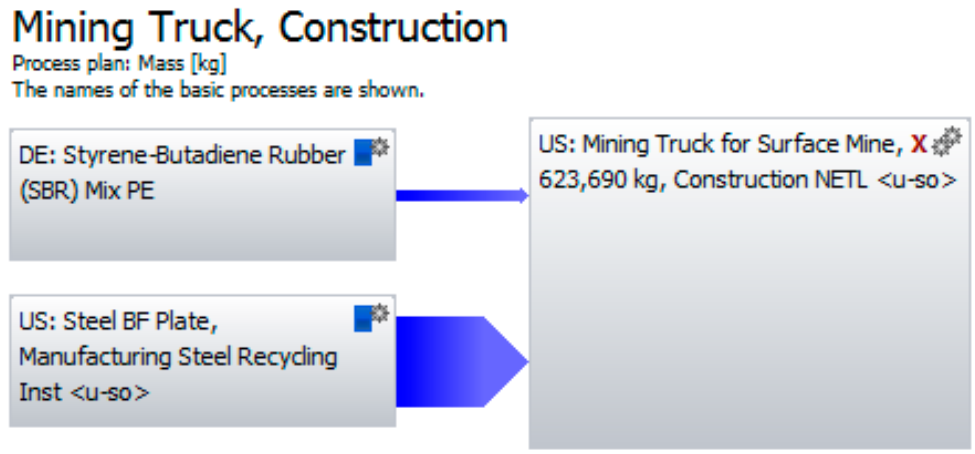


**Figure A11.** Mining truck, construction—Fourth-level plan.

**Table A13.** Mining truck, construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Styrene-Butadiene Rubber (SBR) Mix | Third-party data available from thinkstep.<br>GUID: 9B317E5C-A721-4912-BB28-06BD6B6FB9F<br>Last change: System, 11/1/2012 | N/A | N/A |
| Steel Blast Furnace (BF) Plate, Manufacturing | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| Mining Truck for Surface Mine, 623,690 kg, Construction | This unit process provides a summary of the amount of steel plate and styrene-butadiene-rubber required for the construction of a mining truck (e.g., 1 piece [pcs] of mining truck, 623,690 kg). For the purposes of this analysis, the mining truck is assumed to be comprised of steel plate and styrene-butadiene-rubber, with other materials being negligible. The number of mining trucks required to produce coal is evaluated in PRB Coal Surface Mine Assembly, Construction. All inputs and outputs are normalized per piece of mining truck. | 1 | Junuary 2010 |

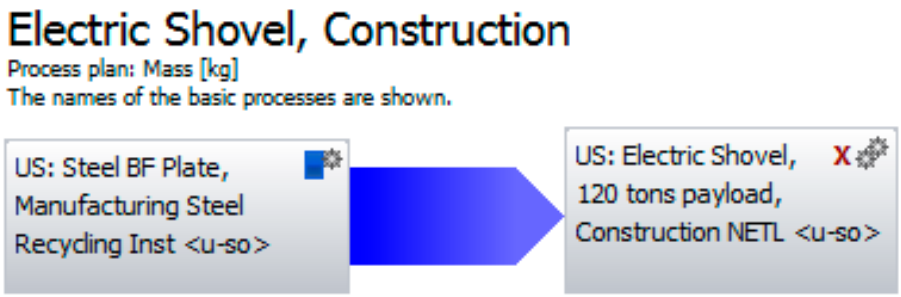


**Figure A12.** Electric shovel, construction—Fourth-level plan.

**Table A14.** Electric shovel, construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Steel Blast Furnace (BF) Plate, Manufacturing | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| Electric Shovel, 120 tons payload, Construction | This unit process provides a summary of the amount of steel required for the construction of an electric shovel (e.g., 1 piece [pcs] of shovel) needed to move overburden and extract coal at a large surface mine, and to load the coal into a truck for transport at the mine site. The electric shovel is assumed to consist entirely of steel plate. The number of shovels required to move overburden and extract coal is evaluated in PRB Coal Surface Mine Assembly, Construction. All inputs and outputs are normalized per pcs of electric shovel, 120 tons payload. | 1 | Junuary 2010 |

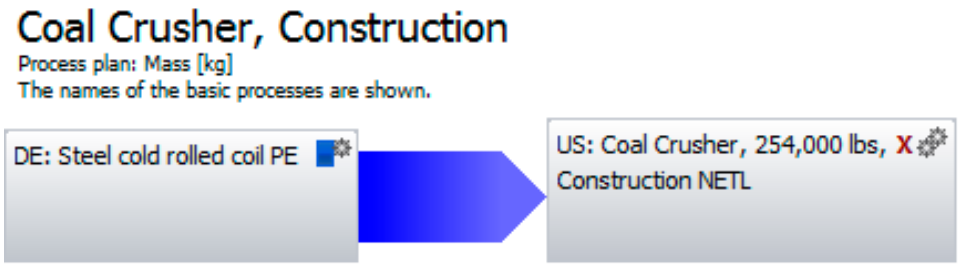


**Figure A13.** Coal Crusher, construction—Fourth-level plan.

**Table A15.** Coal crusher, construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Steel Cold Rolled Coil | Third-party data available from thinkstep.<br>GUID: E4DECB5D-6711-42AA-86E9-03204B518AC3<br>Last change: System, 1 November 2012 | N/A | N/A |
| Coal Crusher, 254,000 lbs, Construction | This unit process provides a summary of the amount of steel required for the construction of a coal crusher (e.g., 1 piece [pcs] of coal crusher, 254,000 lbs). The coal crusher is assumed to be comprised entirely of cold rolled steel, with other materials being negligible. The number of crushers required to produce coal at a surface mine is evaluated in PRB Coal Surface Mine Assembly, Construction. All inputs and outputs are normalized per piece of coal crusher. | 1 | January 2010 |

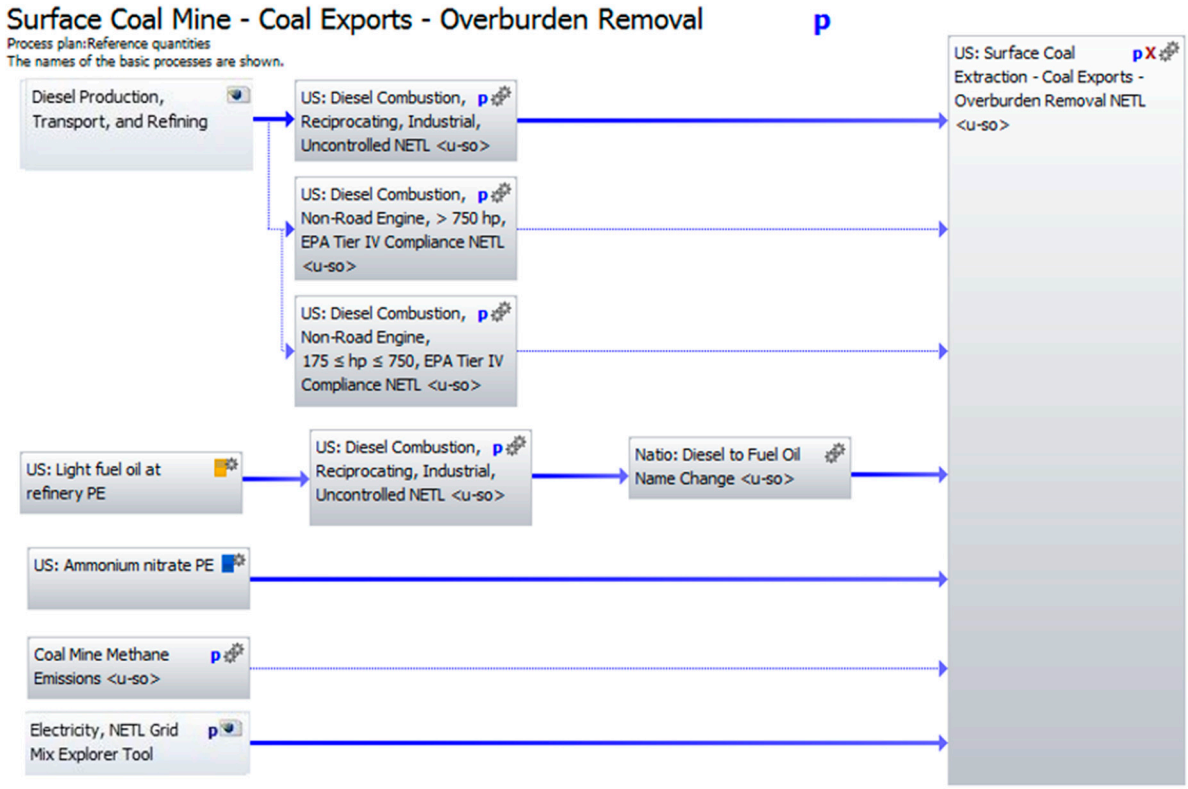


**Figure A14.** Surface coal mine—Coal exports—Overburden removal—Second-level plan.

**Table A16.** Surface coal mine—Coal exports—Overburden removal.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| US: Ammonium nitrate PE | Third-party data available from thinkstep.<br>GUID: CADF4ACF-0724-478B-88DC-08B459EFC5F9<br>Last change: System, 1 November 2012 | N/A | N/A |
| Light Fuel Oil at Refinery | Third-party data available from thinkstep.<br>GUID: 18ED02B4-CF73-44DE-9C3D-D8A234666939<br>Last change: System, 1 November 2012 | N/A | N/A |
| Electricity, NETL Grid Mix Explorer Tool | The goal of the Grid Mix Explorer is to allow the user to customize the makeup of their electricity grid specific to their life cycle case or desired scenario and generate a life cycle inventory for that particular mix of technologies. For this project, mixes in Tables 2–4 were used. | 1 | January 2015 |

| | | | |
|---|---|---|---|
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. All inputs and outputs are normalized per kg of diesel. | 2 | September 2011 |
| Combustion of Diesel (See note about NETL conventions for modeling fuel combustion) | This unit process provides a summary of relevant input and output flows associated with the combustion of diesel utilized for several downstream processes. In this case, the unit process parameter scenario was selected to represent Reciprocating, Industrial, Uncontrolled combustion. For more details, see the unit process DS file. | 2 | March 2014 |
| Diesel to Fuel Oil | Flow name change from "diesel fuel" to "fuel oil" | N/A | N/A |
| Surface Coal Mining—Overburden Removal, Extraction, and Reclamation | This unit process provides a summary of relevant input and output flows associated with the surface mining of coal—overburden removal, extraction, and reclamation. For this plan, the unit process parameter scenario is tuned to represent overburden removal. This includes the amount of electricity and fuel required to power equipment and the direct particulate matter and volatile organic compound emissions from operating equipment and using explosives. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 1 | August 2015 |

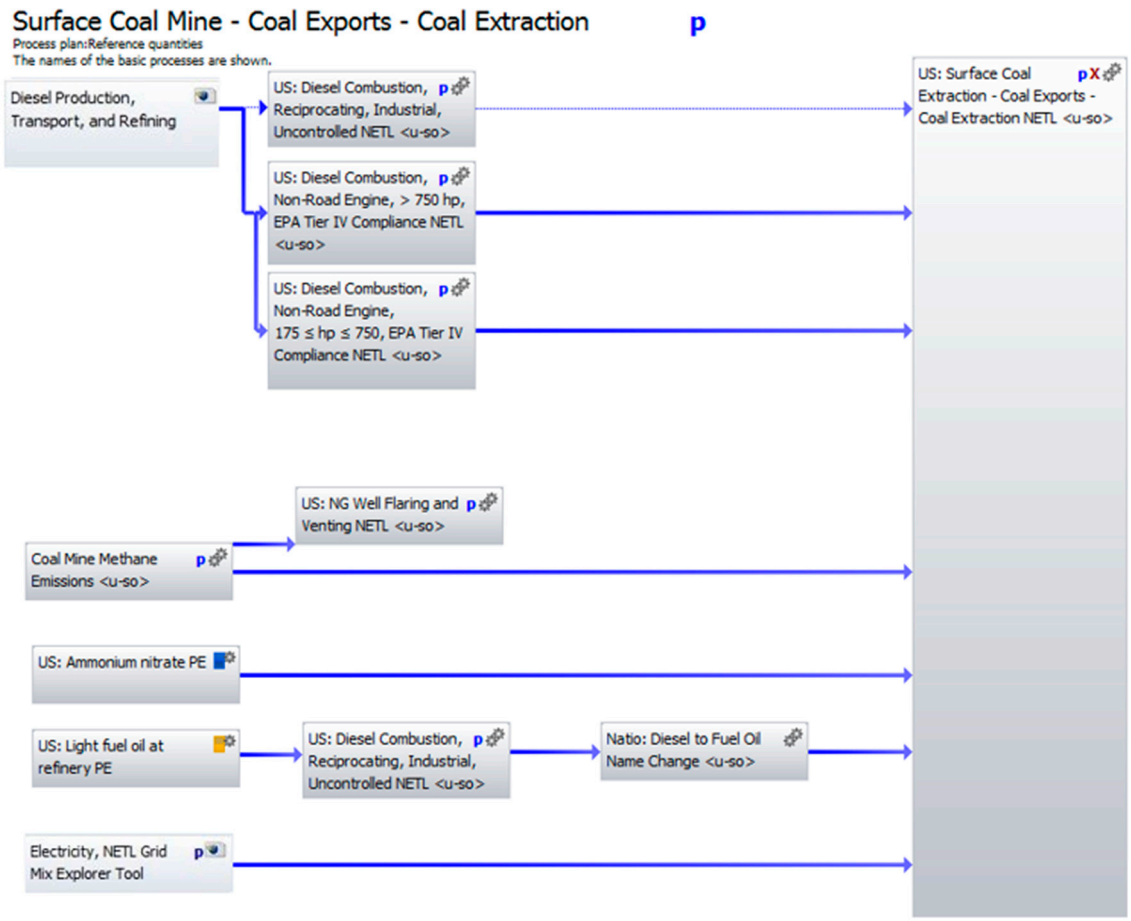


**Figure A15.** Surface coal mine—Coal exports—Coal extraction—Second-level plan.

**Table A17.** Surface Coal Mine—Coal Exports—Coal Extraction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| US: Ammonium nitrate PE | Third-party data available from thinkstep.<br>GUID: CADF4ACF-0724-478B-88DC-08B459EFC5F9<br>Last change: System, 1 November 2012 | N/A | N/A |
| Light Fuel Oil at Refinery | Third-party data available from thinkstep.<br>GUID: 18ED02B4-CF73-44DE-9C3D-D8A234666939<br>Last change: System, 1 November 2012 | N/A | N/A |
| Electricity, NETL Grid Mix Explorer Tool | The goal of the Grid Mix Explorer is to allow the user to customize the makeup of their electricity grid specific to their life cycle case or desired scenario and generate a life cycle inventory for that particular mix of technologies. For this project, mixes in Tables 2–4 were used. | 1 | January 2015 |
| Coal Mine Methane Emissions | This unit process provides a summary of relevant input and output flows associated with coal mine methane emissions. An option is provided to capture a percentage of the total methane produced, but there are no burdens associated with capturing the methane. All vented methane is assumed to be in too low a concentration to be directly flared. The reference flow of this unit process is: 1 kg of extracted coal. | 1 | July 2013 |
| Natural Gas Venting and Flaring | The scope of this unit process covers flaring and venting in support of natural gas extraction activities. In this case, this process is used to approximate the venting and flaring of coal mine methane. The process is based on the reference flow of 1 kg of natural gas, vented or flared. | 2 | May 2011 |
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. All inputs and outputs are normalized per kg of diesel. | 2 | September 2011 |
| Combustion of Diesel (See note about NETL conventions for modeling fuel combustion) | This unit process provides a summary of relevant input and output flows associated with the combustion of diesel utilized for several downstream processes. In this case, the unit process parameter scenario was selected to represent Reciprocating, Industrial, Uncontrolled combustion. For more details, see the unit process DS file. | 2 | March 2014 |
| Diesel to Fuel Oil | Flow name change from “diesel fuel” to “fuel oil” | N/A | N/A |
| Surface Coal Mining—Overburden Removal, Extraction, and Reclamation | This unit process provides a summary of relevant input and output flows associated with the surface mining of coal—overburden removal, extraction, and reclamation. For this plan, the unit process parameter scenario is tuned to represent coal extraction. This includes the amount of electricity and fuel required to power equipment and the direct particulate matter and volatile organic compound emissions from operating equipment and using explosives. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 1 | August 2015 |

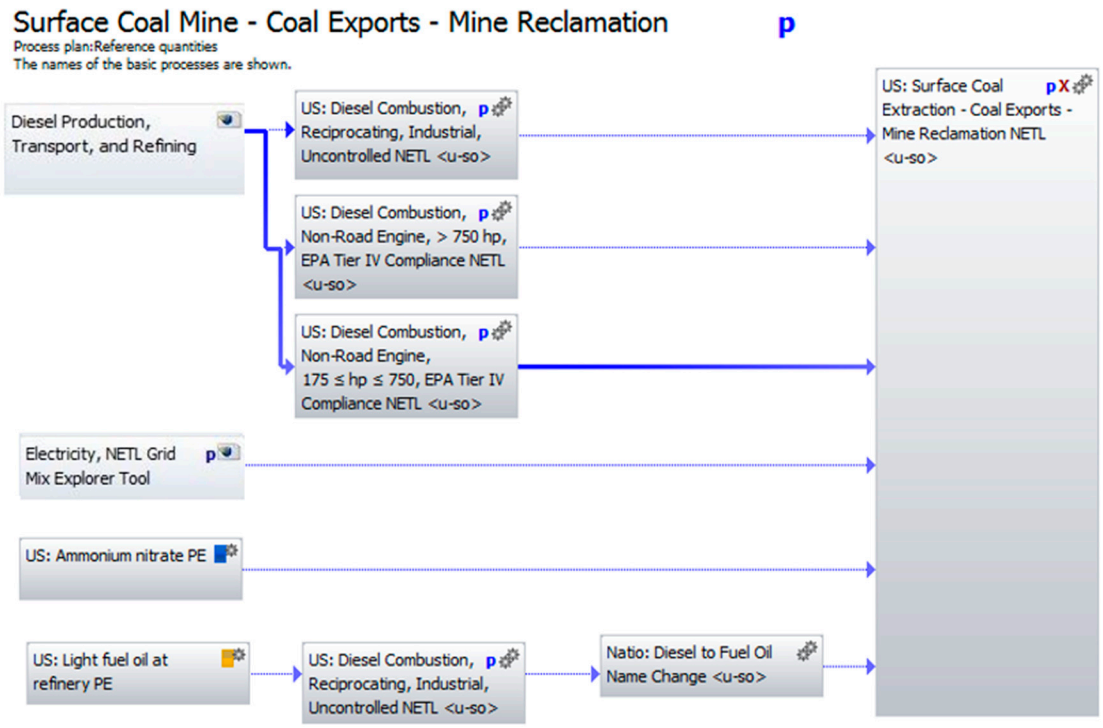


**Figure A16.** Surface Coal Mine—Coal Exports—Mine Reclamation—Second-Level Plan.

**Table A18.** Surface Coal Mine—Coal Exports—Mine Reclamation.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| US: Ammonium nitrate PE | Third-party data available from thinkstep.<br>GUID: CADF4ACF-0724-478B-88DC-08B459EFC5F9<br>Last change: System, 1 November 2012 | N/A | N/A |
| Light Fuel Oil at Refinery | Third-party data available from thinkstep.<br>GUID: 18ED02B4-CF73-44DE-9C3D-D8A234666939<br>Last change: System, 1 November 2012 | N/A | N/A |
| Electricity, NETL Grid Mix Explorer Tool | The goal of the Grid Mix Explorer is to allow the user to customize the makeup of their electricity grid specific to their life cycle case or desired scenario and generate a life cycle inventory for that particular mix of technologies. For this project, mixes in Tables 2–4 were used. | 1 | January 2015 |
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. All inputs and outputs are normalized per kg of diesel. | 2 | September 2011 |
| Combustion of Diesel (See note about NETL conventions for modeling fuel combustion) | This unit process provides a summary of relevant input and output flows associated with the combustion of diesel utilized for several downstream processes. In this case, the unit process parameter scenario was selected to represent Reciprocating, Industrial, Uncontrolled combustion. For more details, see the unit process DS file. | 2 | March 2014 |
| Diesel to Fuel Oil | Flow name change from “diesel fuel” to “fuel oil” | N/A | N/A |
| Surface Coal Mining—Overburden Removal, Extraction, and Reclamation | This unit process provides a summary of relevant input and output flows associated with the surface mining of coal—overburden removal, extraction, and reclamation. For this plan, the unit process parameter scenario is tuned to represent coal extraction. This includes the amount of electricity and fuel required to power equipment and the direct particulate matter and volatile organic compound emissions from operating equipment and using explosives. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 1 | August 2015 |

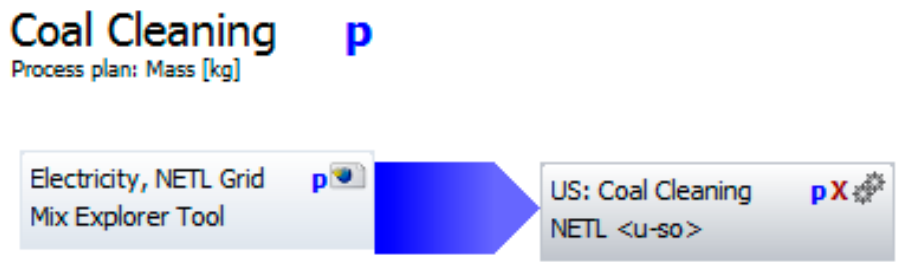


**Figure A17.** Coal cleaning—Second-Level Plan.

**Table A19.** Coal Cleaning.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Electricity, NETL Grid Mix Explorer Tool | The goal of the Grid Mix Explorer is to allow the user to customize the makeup of their electricity grid specific to their life cycle case or desired scenario and generate a life cycle inventory for that particular mix of technologies. For this project, mixes in Tables 2–4 were used. | 1 | January 2015 |
| Coal Cleaning | This unit process provides a summary of relevant input and output flows associated with the amount of electricity required to power equipment used for cleaning coal at underground and surface mines. A centrifuge, flotation machine, screens, and magnetic separator are the pieces of equipment used to clean coal. The process also accounts for the solid wastes that are incurred during the production and processing steps to scale upstream activities for one kg of coal at the entrance to the raw material transport gate. Inputs are electricity, coal, and the water use and quality associated with 1 kg of cleaned coal. All of these items are also adjustable parameters to measure uncertainties. Cleaned coal and the course and fine wastes are the outputs. The unit process is based on the reference flow of one kg of coal. | 2 | July 2013 |

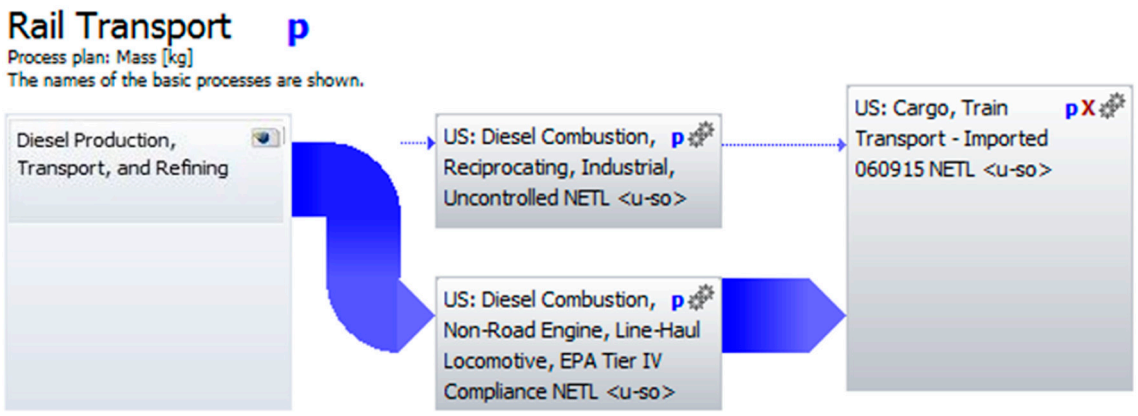


**Figure A18.** Rail Transport—Second-Level Plan.

**Table A20.** Rail Transport.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. Available adjustable parameters and their default values are provided inthis unit process. | 2 | September 2011 |
| Combustion of Diesel (See note about NETL conventions for modeling fuel combustion) | This unit process provides a summary of relevant input and output flows associated with the combustion of diesel utilized for several downstream processes. In this case, the unit process parameter scenario was selected to represent Reciprocating, Industrial, Uncontrolled combustion. For more details, see the unit process DS file. | 2 | March 2014 |
| Cargo, Train Transport | This unit process provides the fuel input to transport generic cargo a given distance by train. The actual combustion of fuel occurs in an upstream process, and because this process is for generic cargo, it does not account for product losses. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 1 | December 2013 |

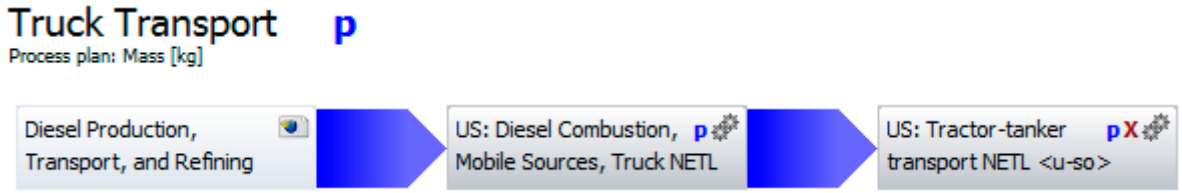


**Figure A19.** Truck Transport—Second-Level Plan.

**Table A21.** Truck Transport.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. Available adjustable parameters and their default values are provided in this unit process. | 2 | September 2011 |
| Combustion of Diesel (See note about NETL conventions for modeling fuel combustion) | This unit process provides a summary of relevant input and output flows associated with the combustion of diesel utilized for several downstream processes. In this case the unit process parameter scenario was selected to represent combustion in a mobile source (truck). For more details, see the unit process DS file. | 2 | March 2014 |
| Tractor-tanker transport | This unit process provides the fuel input to transport generic cargo a given distance by a tractor-tanker. This process was used as a proxy for coal transport via tractor-trailer. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 1 | December 2013 |

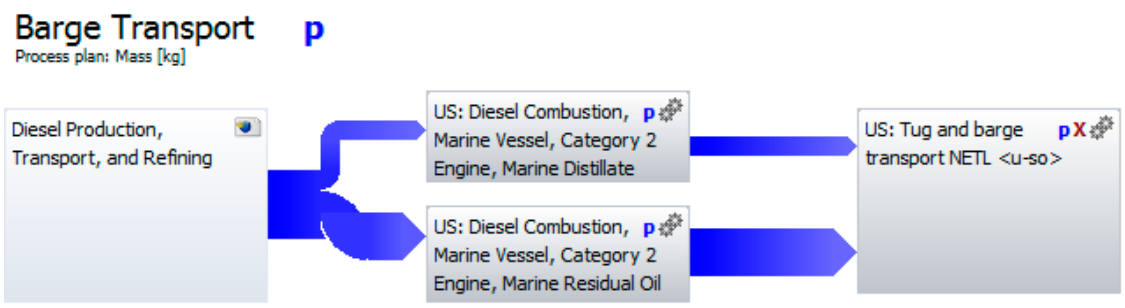


**Figure A20.** Barge Transport—Second-Level Plan.

**Table A22.** Barge Transport.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. Available adjustable parameters and their default values are provided in this unit process. | 2 | September 2011 |
| Combustion of Diesel (See note about NETL conventions for modeling fuel combustion) | This unit process provides a summary of relevant input and output flows associated with the combustion of diesel utilized for several downstream processes. In this case, the process was tuned to represent combustion in a category 2 marine vessel for both marine distillate and marine residual oil. | 2 | March 2014 |
| Tug and Barge Transport | This unit process provides a summary of relevant input and output flows associated with the transport of an unspecified type of cargo by tug and barge. This process can be used regardless of the type of cargo being transported or the location where the transport is taking place. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 1 | November 2013 |

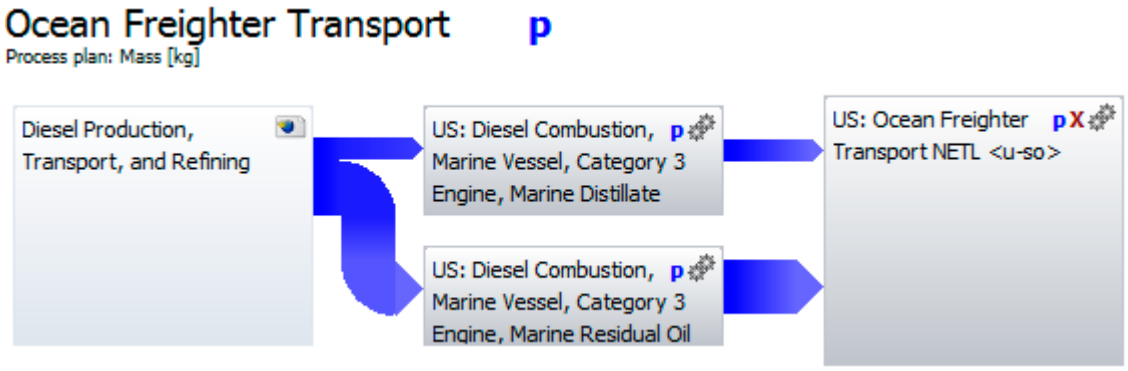


**Figure A21.** Ocean Freighter Transport—Second-Level Plan.

**Table A23.** Ocean Freighter Transport.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. Available adjustable parameters and their default values are provided in this unit process. | 2 | September 2011 |
| Combustion of Diesel (See note about NETL conventions for modeling fuel combustion) | This unit process provides a summary of relevant input and output flows associated with the combustion of diesel utilized for several downstream processes. In this case, the process was tuned to represent combustion in a category 3 marine vessel for both marine distillate and marine residual oil. | 2 | March 2014 |
| Ocean Freighter Transport | This unit process provides a summary of relevant input and output flows associated with the transport of an unspecified type of cargo by ocean freighter. This process can be used regardless of the type of cargo being transported or the location where the transport is taking place. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 2 | July 2010 |

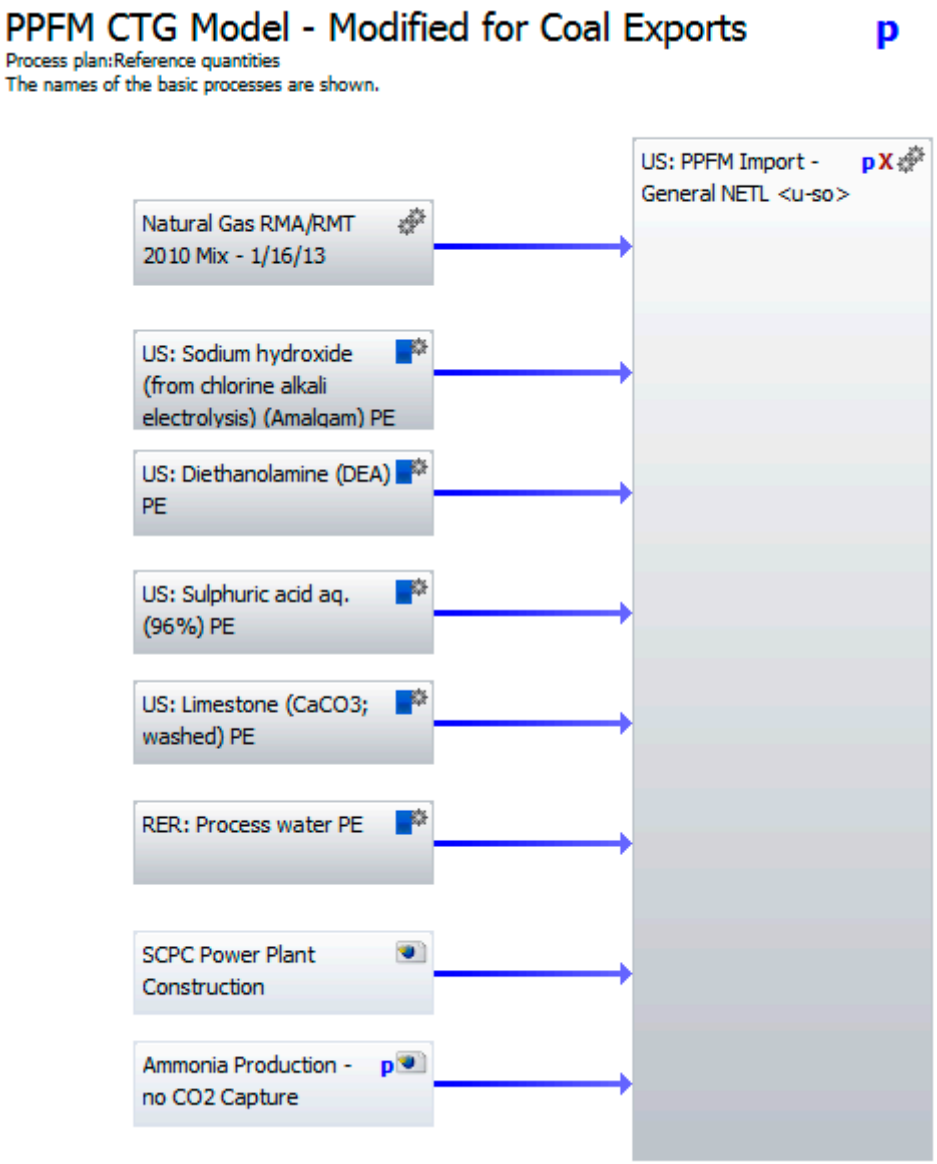


**Figure A22.** PPFM CTG Model—Modified for Coal Exports—Second-level Plan.

**Table A24.** PPFM CTG Model—Modified for Coal Exports.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Natural Gas, U.S. Mix 2010, Extraction and Transport | This unit process provides a summary of relevant input and output flows associated with the extraction and processing of natural gas and its transportation to an energy conversion facility. It includes all inputs for the raw material acquisition and raw material transportation for 1 kg of delivered natural gas proportionally from all extraction methods. | 2 | May 2012 |
| U.S. Sulphuric acid aq. (96%) | Third-party data available from thinkstep.<br>GUID: 1EFF2DA5-68F6-4630-8D80-ADC181B70C13<br>Last change: System, 1 November 2012 | N/A | N/A |
| U.S. Sodium Hydroxide (from chloride alkali electrolysis) | Third-party data available from thinkstep.<br>GUID: C4E097A8-2C08-408A-AAFD-F40A81BA7DE2<br>Last change: System, 1 November 2012 | N/A | N/A |
| U.S. Diethanolamine | Third-party data available from thinkstep.<br>GUID: 894E2AB9-DA97-4357-8DFF-1306AD80D3E6<br>Last change: System, 1 November 2012 | N/A | N/A |
| U.S. Limestone ($CaCO_3$; washed) | Third-party data available from thinkstep.<br>GUID: AC854C76-B419-49FA-A354-AFC0526F6F1E<br>Last change: System, 1 November 2012 | N/A | N/A |
| RER: Process Water PE | Third-party data available from thinkstep.<br>GUID: DB009016-338F-11DD-BD11-0800200C9A66<br>Last change: System, 1 November 2012 | N/A | N/A |
| PPFM—Power Plant Flexible Model | The Power Plant Flexible Model (PPFM) is an Excel-based tool that simulates coal combustion-based power plant electrical output, emissions, materials usage, and costs for a fully-configurable mix of boiler and steam plant types, feedstocks, and emissions control equipment. The technical documentation and user's guide for the model are included in the download package. PPFM is not engineered to be a consumer-level product and requires knowledge of coal combustion power plants and processes to yield reasonable results. | 1 | November 2013 |

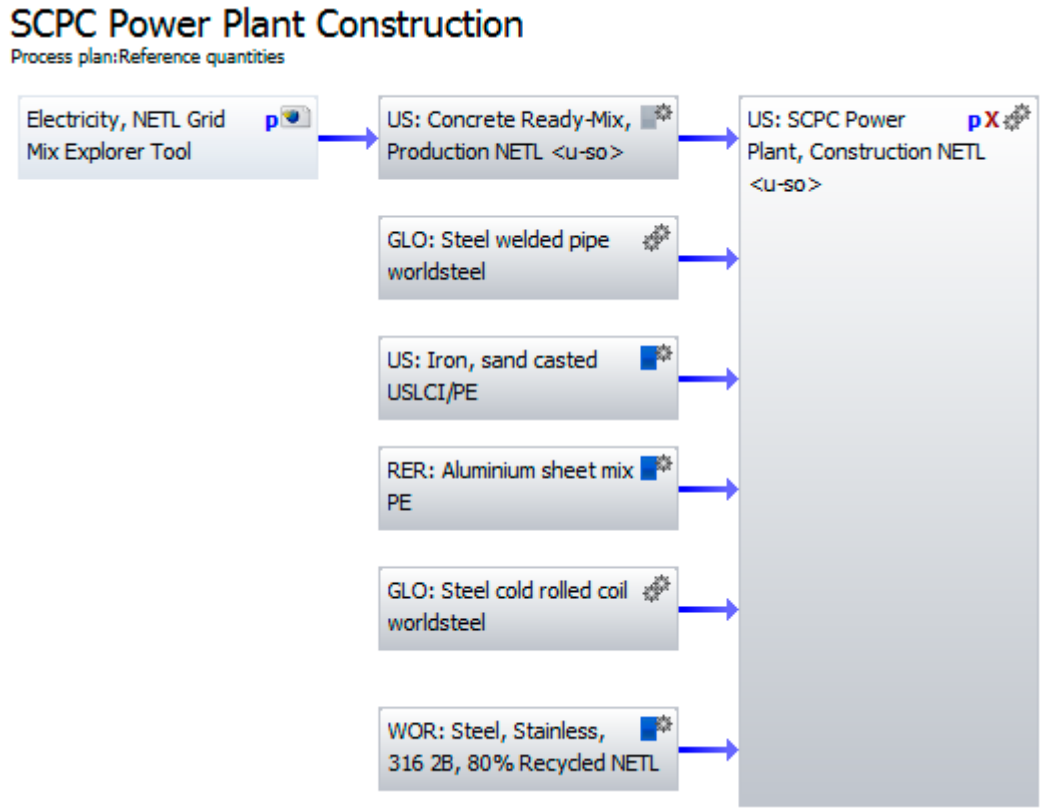


**Figure A23.** SCPC Power Plant, Construction—Third-level Plan.

**Table A25.** SCPC Power Plant, Construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Electricity, NETL Grid Mix Explorer Tool | The goal of the Grid Mix Explorer is to allow the user to customize the makeup of their electricity grid specific to their life cycle case or desired scenario, and generate a life cycle inventory for that particular mix of technologies. For this project, mixes in Tables 2–4 were used. | 1 | June 2012 |
| Concrete Ready-Mix, Production | This unit process provides a summary of relevant input and output flows associated with the production of ready-mix concrete. | 1 | June 2013 |
| Steel BF Welded Pipe, Manufacturing | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| Iron, Sand Casted | Third-party data available from thinkstep.<br>GUID: 1DF2EC0E-DDFC-4454-8DCF-123D758B246C<br>Last change: System, 1 November 2012 | N/A | N/A |
| Aluminum Sheet Mix | Third-party data available from thinkstep.<br>GUID: 84D84DF1-4A0C-4FD8-9857-7A3F8E6FC84C<br>Last change: System, 1 November 2012 | N/A | N/A |
| Steel Cold Rolled Coil | Third-party data available from thinkstep.<br>GUID: 5DB49085-8D9E-4F29-BD70-19C8F39899C0<br>Last change: System, 1 November 2012 | N/A | N/A |
| Stainless Steel 316 2B (80% Recycled), Manufacturing | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| SCPC Power Plant, Construction | This unit process provides a summary of relevant input and output flows associated with the construction of a supercritical pulverized coal power plant. This process can be used for scenarios with and without carbon capture and sequestration. Key inputs include concrete, steel, steel pipe, stainless steel, aluminum, and cast iron. The key output is one 550 MW supercritical pulverized coal power plant power plant. | 2 | September 2011 |

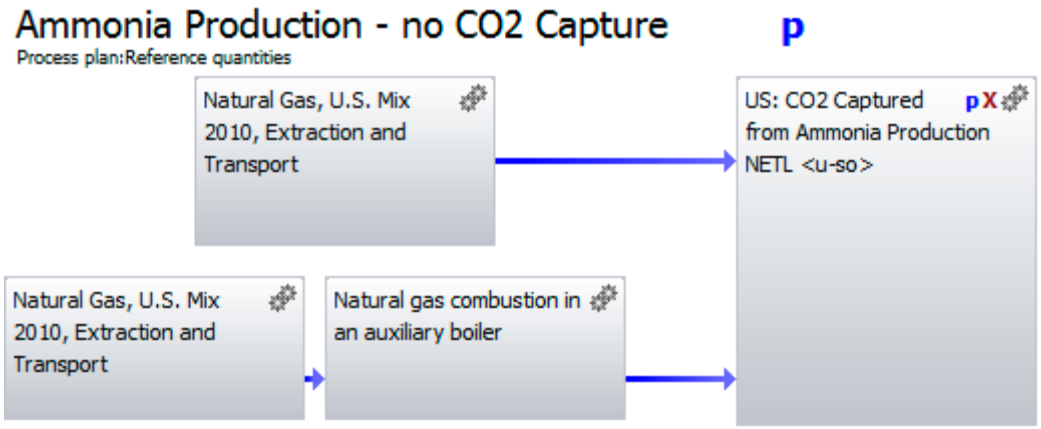


**Figure A24.** Ammonia Production, No $CO_2$ Capture—Third-level Plan.

**Table A2.** Ammonia Production, No $CO_2$ Capture.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Natural Gas, U.S. Mix 2010, Extraction and Transport | This unit process provides a summary of relevant input and output flows associated with the extraction and processing of natural gas and its transportation to an energy conversion facility. All inputs and outputs are normalized per kg of natural gas delivered for the purpose of providing the energy required for steam production. | 2 | May 2012 |
| Natural gas combustion in an auxiliary boiler | This unit process provides a summary of relevant input and output flows associated with the combustion of natural gas in a boiler. The only input to this unit process is natural gas. Air emissions include greenhouse gas emission and criteria air pollutants. All inputs and outputs are normalized per kg of natural gas combustion. | 1 | September 2010 |
| $CO_2$ Captured from Ammonia Production | This unit process provides a summary of relevant input and output flows associated with ammonia production. This process is modified to render captured $CO_2$ an emission, rather than an intermediate flow. | 1 | December 2012 |

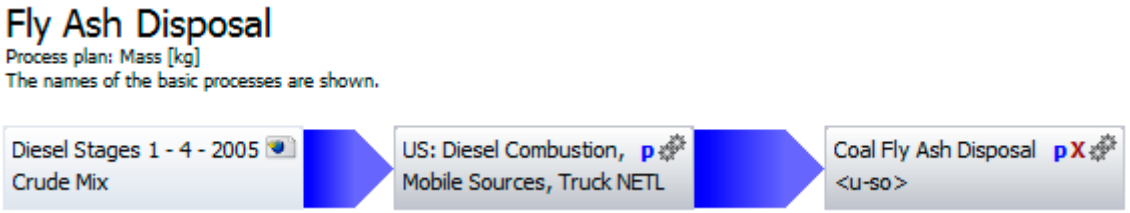


**Figure A25.** Fly Ash Disposal—Second-level Plan.

**Table A27.** Fly Ash Disposal.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Diesel, Production, Transport, and Refining | This unit process provides a summary of relevant input and output flows associated with production of diesel including the production of crude oil, crude oil transportation, and diesel fuel refining/energy conversion. All inputs and outputs are normalized per kg of diesel. | 2 | September 2011 |
| Combustion of Diesel | This unit process provides a summary of relevant input and output flows associated with the combustion of diesel utilized for several downstream processes. In this case, the process was tuned to represent combustion in a mobile source (truck). | 2 | March 2014 |
| Coal Fly Ash Disposal | This unit process provides a summary of relevant input and output flows associated with disposing of fly ash in a landfill. Earth moving equipment, such as bulldozers, compactors, graders, backhoes, and water trucks are the pieces of equipment used to landfill the fly ash. The process also accounts for the air emissions and leachate incurred during and after the landfilling process. The reference flow of this unit process is 1 kg of fly ash, disposal. Combustion emissions are not included in this unit process, but are included in Combustion of Diesel. | 1 | May 2012 |

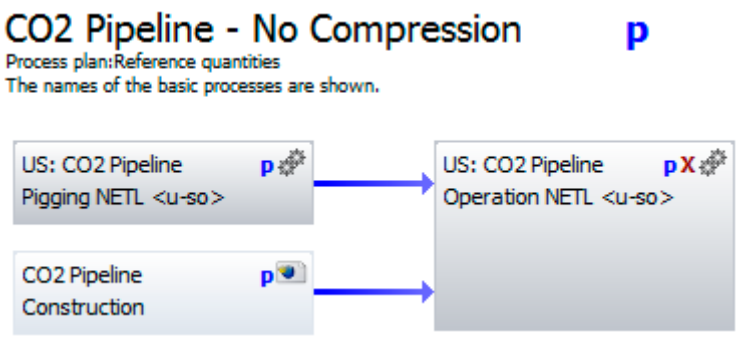


**Figure A26.** $CO_2$ Pipeline—No Compression—Second-level Plan.

**Table A28.** $CO_2$ Pipeline—No Compression.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| $CO_2$ Pipeline Pigging | This unit process provides a summary of relevant input and output flows associated with inspecting $CO_2$ pipelines using "pigs". Emissions are episodic but are levelized according to the amount of $CO_2$ transported between inspection periods. The only emission for this process is $CO_2$ that is released when the pipeline is vented to allow the insertion of the inspection pig. The reference flow of this unit process is 1 kg of transported $CO_2$. | 1 | March 2013 |
| $CO_2$ Pipeline Operation | This unit process provides a summary of relevant input and output flows associated with the operation of a carbon dioxide pipeline that is used for the conveyance of carbon dioxide captured at an energy conversion facility, to a site for sequestration or other use, as relevant. The key emission of this unit process is fugitive $CO_2$ emissionsfrom the pipeline. Compression needed to drive pressurized $CO_2$ through the pipeline is provided by the energy conversion facility, under a separate unit process. | 2 | July 2012 |

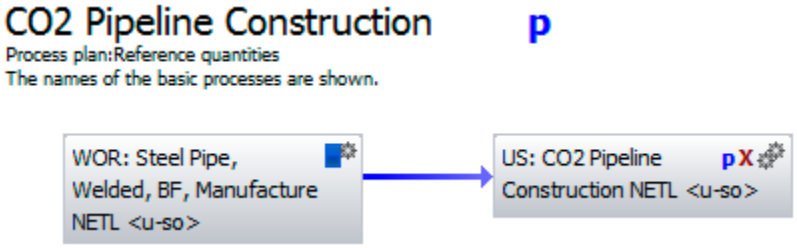


**Figure A27.** $CO_2$ Pipeline Construction—Third-level Plan.

**Table A29.** $CO_2$ Pipeline Construction.

| Unit Process | Notes | Version | Version Date |
|---|---|---|---|
| Steel BF Welded Pipe, Manufacturing | Third-party data available from the Steel Recycling Institute. | N/A | N/A |
| $CO_2$ Pipeline Construction | This unit process provides a summary of relevant input and output flows associated with the construction of a $CO_2$ pipeline. It includes scaling equations based on the relationships between distance, flow rate, and pipeline diameter. It includes parameters for pipeline tortuosity and extra materials for valves and other pipeline equipment. | 1 | October 2012 |
| | The tracked input is steel used for pipeline construction. The reference flow of this unit process is the construction of a $CO_2$ pipeline. | | |

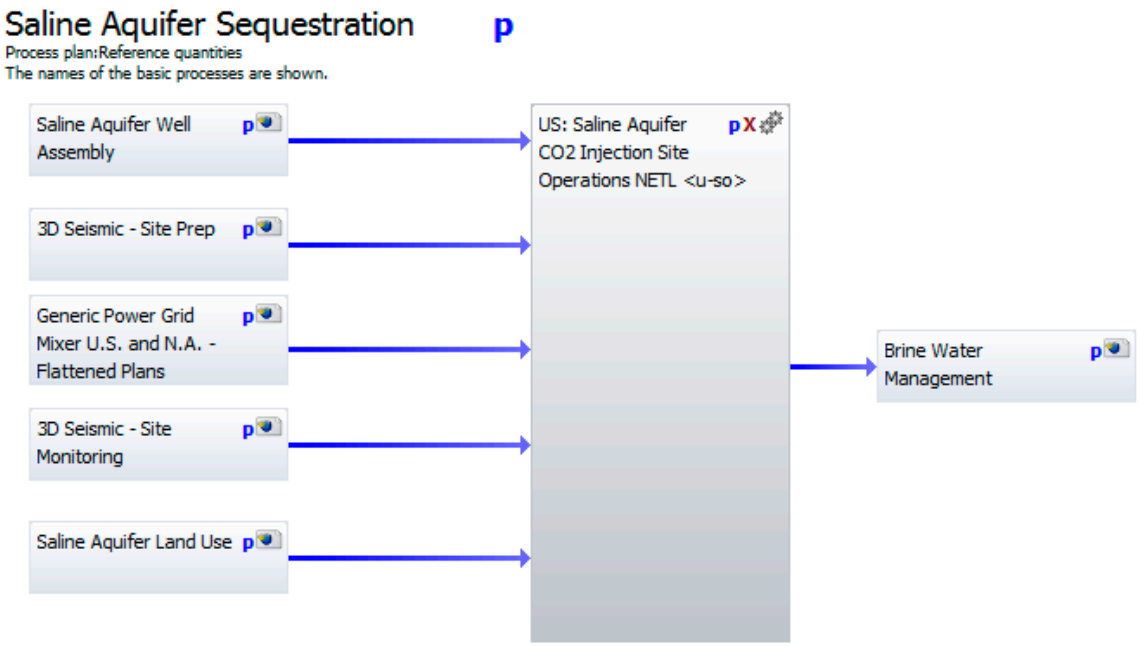


**Figure A28.** Saline Aquifer Sequestration—Second-level Plan [2].

* See NETL's Gate-to-Grave Life Cycle Analysis Model of Saline Aquifer Sequestration of Carbon Dioxide for further details (NETL, 2013).

## References

1. NETL. Unit Process Library. Available online: http://www.netl.doe.gov/research/energy-analysis/life-cycle-analysis/unit-process-library (accessed on 7 July 2016).
2. NETL. *Gate-to-Grave Life Cycle Analysis Model of Saline Aquifer Sequestration of Carbon Dioxide*; DOE/NETL-2013/1600; National Energy Technology Laboratory: Pittsburgh, PA, USA, 2013. Available online: http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Life%20Cycle%20Analysis/GtG-LCA-of-Saline-Aquifer-Sequestration.pdf (accessed on 12 July 2016).