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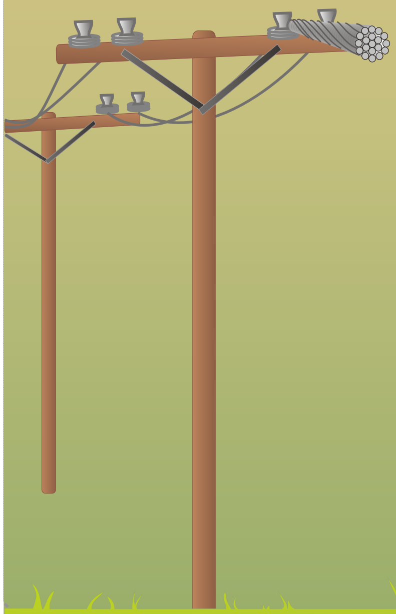
Life Cycle Assessment (LCA) of overhead versus underground primary power distribution systems in Southern California



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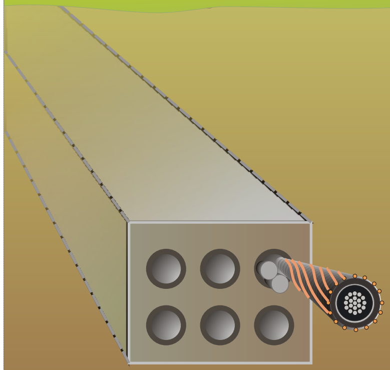

Faculty Advisor: Roland Geyer
Client: Southern California Edison

Life Cycle Assessment (LCA) of Overhead versus Underground Primary Power Distribution Systems in Southern California

March 20, 2009

As authors of this Group Project Report, we are proud to archive it on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Donald Bren School of Environmental Science & Management.

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The mission of the Donald Bren School of Environmental Science & Management is to produce professionals with unrivaled skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technical decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. It is a three-quarter project in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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Roland Geyer, Advisor

Project Abstract

High electrical power demand has spurred discussion on the trade-offs between overhead and underground power distribution systems. Many regions in the United States, European Union, and Australia are considering revising the protocol for new power distribution installations and/or conversion of existing infrastructure to underground mode. Studies generally concur that underground distribution is much more costly to install, but may improve reliability and decrease maintenance costs. Recently, a few comparative environmental assessments of overhead and underground cable production have been conducted. However, current literature lacks a full investigation of the life cycle environmental impacts of both distribution methods, including all infrastructure components. This project thus examines the difference between the potential environmental impacts of overhead and underground primary power distribution systems. It is based on a full Life Cycle Assessment (LCA), which has been conducted using LCA software GaBi 4.3, which draws from a wide range of data sources. The analysis incorporates detailed information on the use phase, including installation, maintenance, and decommissioning of cable and associated infrastructural components. The study is also specific to Southern California Edison, one of the largest electric utility suppliers in the United States. The results cover a wide range of environmental concerns, such as climate change, photochemical smog, acidification, and toxicity.

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1. Summary

High electrical power demand has spurred discussion on the trade-offs between overhead and underground power distribution systems. Many regions in the United States, European Union, and Australia are considering revising the protocol for new power distribution installations and/or conversion of existing infrastructure to underground mode. Studies generally concur that underground distribution is much more costly to install, but may improve reliability and decrease maintenance costs. Recently, a few comparative environmental assessments of overhead and underground cable production have been conducted. However, current literature lacks a full investigation of the life cycle environmental impacts of both distribution methods, including all infrastructure components. This project thus examines the difference between the potential environmental impacts of overhead and underground primary power distribution systems. It is based on a full Life Cycle Assessment (LCA), which has been conducted using LCA software GaBi 4.3, which draws from a wide range of data sources. The analysis incorporates detailed information on the use phase, including installation, maintenance, and decommissioning of cable and associated infrastructural components. The study is also specific to Southern California Edison, one of the largest electric utility suppliers in the United States. The results cover a wide range of environmental concerns, such as climate change, photochemical smog, acidification, and toxicity.

2. Introduction

This analysis uses Life Cycle Assessment (LCA) methodology to assess and compare potential environmental impacts of overhead and underground primary power distribution systems in Southern California. The results support decision-makers in managing the expansion or conversion of the electrical grid.

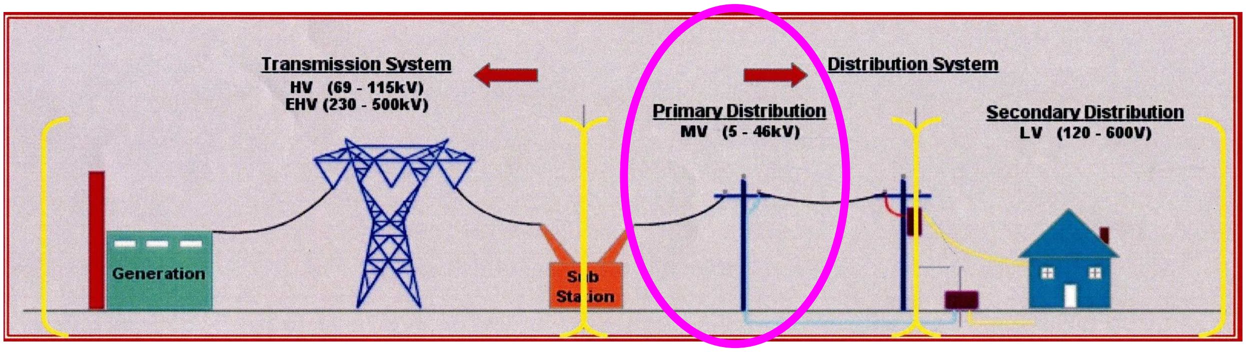
High electrical power demand has spurred discussion on the trade-offs between overhead and underground power distribution systems. Projections affirm that the supply and demand side of electricity service will face imbalance without procurement of additional resources and efficient use of current resources (1-4). The policy debate is fueled from overhead systems creating a potential hazard for vehicle collisions, visual obstruction, and increased damage in fires (5-7). The California Public Utilities Commission's Rule 20 provides undergrounding conversion funds from ratepayer fees and gives priority to congested, civic, and scenic areas (8). Likewise, other areas within the United States (US), the European Union (EU), and Australia are considering the requirement that new power distribution be installed underground and that existing overhead infrastructure be converted for aesthetic and safety purposes (5-7).

There are many factors that contribute to the tradeoff between overhead and underground power distribution. The most widely discussed factors in literature are: aesthetics, safety, cost, and reliability. Underground systems are concealed, thus they increase nearby property values and the aesthetics of the area. Also, underground systems reduce the possibility for live-wire contacts and vehicle accidents from collisions with utility poles (9). Although installation of underground distribution presents a substantial initial investment, costing four to twenty times more than overhead systems, it may improve reliability and decrease maintenance costs (6, 7, 10). While underground systems may improve reliability due to fewer outages, the time required to repair an outage event is considerably longer than for overhead systems (5-7, 10). Thus, the topic of reliability is very contentious and depends significantly on the location of the electrical product system. The above factors have been extensively discussed in literature, but very few studies focus on the environmental impacts of electrical distribution systems. A few LCA studies have examined the environmental impact of different components of the power grid infrastructure (11-14). No LCA has investigated the entire infrastructure, as well as the cables, for overhead and underground primary power distribution for the purpose of analyzing and comparing potential environmental impacts.

In 2008, Southern California Edison (SCE), one of the largest utility companies in the US, commissioned the Donald Bren School of Environmental Science and Management to investigate the life cycle of both overhead and underground power delivery systems. SCE delivers power to 13 million people in a 50,000 square-mile service area, which is considered one of the most rapidly developing areas in the US (15). SCE's load-growth for 2008-2017 is estimated at 2.22 percent per year (615 megawatts per year) system-wide (16). This growth will require 564 new distribution circuits of various length, or roughly 56 circuits per year (16).

Figure 1 depicts the process of electricity delivery. The transmission system delivers high voltage (HV) electricity from the generation site to substations. At the substations, the HV electricity is stepped down to medium voltage (MV) levels. Primary power distribution delivers electricity from the substations to secondary distribution. At this point, the voltage is stepped down again to low voltage (LV), which is consumed by facilities and households. Figure 1 shows the voltage ranges for the power delivery stages described above.

Figure 1. Electricity Delivery System



Focusing on SCE’s service area, this study chose to evaluate cables and infrastructure associated with primary power distribution (Circled area in Figure 1). An advantage of choosing the distribution system for this study, as compared to a transmission system, is that it is located in densely populated areas and comprises approximately ninety percent of SCE’s electrical line length (16). Long distance transmission lines are often through rural and sparsely populated areas, whereas distribution lines deliver power amongst neighborhoods, towns, and in urban centers. It is this urban and suburban area of power delivery where the majority of stakeholders are involved in the discussion of choosing between overhead and underground systems. This study provides a basis for more informed decision-making in electricity grid planning and management by adding a new dimension into the discussion, namely environmental impacts of each system drawn from a full comparative LCA.

3. Methods and Data

Life Cycle Assessment methodology was used to examine the cradle-to-grave environmental impacts of overhead versus underground primary power distribution systems in Southern California. LCA is a suitable tool to evaluate the potential impacts of an electricity distribution system. LCAs have been performed on various electrical components, many focusing on the cable itself (11, 12, 14). The terminology and framework of the methodology has been developed and standardized by the Society of Environmental Toxicology and Chemistry (SETAC) and the International Organization for Standardization (ISO 14040/14044) (17).

3.1 Scope and System Boundaries

Scope: Four spatial and temporal factors determine the scope and boundaries of this study. First, the study focuses on primary (MV) distribution. Primary distribution comprises the majority of SCE’s electrical line length and its planning and management involve many stakeholders. Thus, focusing on primary distribution addresses much of the debate between power delivery methods. Second, a distance of one mile was selected as the unit of comparison to capture all significant infrastructural components of each power delivery system. Third, data for the analysis was compiled in collaboration with SCE and their specific upstream supply chain and downstream waste management companies. SCE has fairly comprehensive environmental programs and practices in place. Investigating overhead and underground primary power distribution services, as provided by SCE, compares these systems in a relatively eco-efficient setting. Finally, the study focuses only on those materials and associated processes that are used in current SCE installations. For instance, many utility poles were previously treated with creosote, a coal-tar derivative, and are still in use as part of existing infrastructure. However, SCE has shifted to using pentachlorophenol (PCP) treated poles and thus, only impacts from PCP treated poles were analyzed in this study. In summary, the scope of this comparative LCA project is to focus on one mile of MV distribution based on data that are SCE-specific and uses only current installation information.

System Boundaries: Environmental impacts associated with the physical and human capital (i.e. the production and maintenance of buildings and vehicles, labor, and associated resources) were not included in the model. It is not viable to allocate and differentiate these capital impacts between overhead and underground systems. Moreover, the impacts would not affect the results of the comparison significantly and thus, they were assumed to be negligible.

Functional Unit: To compare the two power delivery methods, the following functional unit was defined for the system boundaries: one circuit mile of power line for the delivery of MV power over one year, including infrastructural components. The cables compared were selected based on their high-purchase volume and comparable capacity for power delivery. For the chosen cables in a MV distribution system, an overhead electrical circuit requires four cables (three phases and one neutral); while an underground circuit requires only three cables, each includes a copper concentric neutral. The supporting infrastructural components associated with the cables chosen were modeled. The primary components and processes required to model each power delivery method from cradle to grave are itemized in Table 1.

In summary, the study’s scope and system boundaries ensure a comparable and representative functional unit that covers the life cycle environmental impacts of typical, MV power delivery systems in Southern California.

Table 1. LCA System Boundaries

Materials Required for a Circuit Mile (c mile)			
Infrastructure Component	**Material**	**Mass**	**Unit**
OVERHEAD			
Cable (4 cables)	Aluminum	3,020	kg / c mile
	Steel, galvanized	474	kg / c mile
Cable Reel (1.85 reels)	Steel, galvanized	336	kg / c mile
Utility Poles (25) **Crossarms** (30)	Wood	9,071	kg / c mile
	Pentachlorophenol (PCP)	266	kg / c mile
Insulators (100)	Polyethylene (PE)	91	kg / c mile
Steel Castings	Steel, galvanized	420	kg / c mile
UNDERGROUND			
Cable (3 cables)	Aluminum	6,734	kg / c mile
	Copper	2,278	kg / c mile
	Polyethylene (PE)	7,408	kg / c mile
Cable Reels (3.96 reels)	Steel, galvanized	2,278	kg / c mile
Vault (5.2) **and Duct** (1)	Concrete	1,096,593	kg / c mile
Steel Rebar for Vault	Steel	15,910	kg / c mile
Conduit (6)	Polyvinyl chloride (PVC)	66,986	kg / c mile

Processes Included		
	Overhead Product System	**Underground Product System**
Production	Production of all listed components	Production of all listed components
Installation	Pole hole digging Aerial lifting Cable pulling	Trench excavation Placing vaults Concrete mix & pour Cable pulling
Maintenance	Tree trimming Scheduled maintenance	Vault water pumping Scheduled maintenance
Decommissioning	Pole pulling Cable pulling Aerial lifting	Cable pulling Excavation Concrete crushing
End of Life Management	Cable recycling Reel reuse Pole assembly landfill	Cable recycling Reel reuse Vault & duct landfill Conduit landfill
Transportation	All required within and between listed processes	

3.2 Parameterization

Several factors in each product system are associated with significant uncertainty (Table 2). These factors were parameterized in the model to facilitate sensitivity analysis and examine the associated range of results. Including a wide range of estimated values and modeling all associated scenarios ensures the validity of the comparative results between overhead and underground. The sensitivity analysis indicates that the overall results do not vary significantly and are robust.

Table 2. Parameterized Factors for Cable Product Systems

Parameter	Baseline Scenario Value	Range	Unit	Source
OVERHEAD (OH)				
Cable Lifetime	40	30 - 50	Years	*Short TA. (2004)*
Infrastructure Capacity	1	1, 2, 4	Number of Circuits	*Hughes M. (2008)*
PCP Leaching to Soil	0	0-100	% of PCP Mass Leaching to Soil	n/a
Recycling Rate (Including Collection and Recovery)	0.94	± 2%	Fraction of OH Cable Mass Recovered	*EPA (2008); own calculations. See Table 5.*
UNDERGROUND (UG)				
Cable Lifetime	30	20 - 40	Years	*Short TA. (2004)*
Infrastructure Capacity	1	1, 4, 6	Number of Circuits	*Hughes M. (2008)*
Recycling Rate (Including Collection and Recovery)	0.84	± 13%	Fraction of UG Cable Mass Recovered	*EPA (2008); own calculations. See Table 5.*
Infrastructure Lifetime	125	100 -150	Years	*Hughes M. (2008)*

3.3 Reference Flows

The period of one year was chosen to compare environmental impacts of the two power delivery systems to maximize the usefulness of the results for managers. Lifetimes of various components of the electricity distribution infrastructure differ considerably. To estimate the environmental impacts of each system for one year, impacts associated with production and end of life (EOL) phases of each component were divided by their respective lifetimes. In the use phase, impacts from installation and decommissioning were scaled down to one year also using the lifetimes of the installed components. Likewise, the impacts from maintenance of each system are distributed evenly throughout the lifetime of the system. Thus, only one year of maintenance was modeled to estimate the associated environmental impacts for one mile of circuit.

Table 3 illustrates the conversion of the functional unit masses to the reference flow masses for a baseline scenario. Functional unit masses are masses of materials per circuit mile. Reference flow masses are masses of materials needed to represent the impacts of the life cycle over one year.

Table 3. Functional Unit Mass to Reference Flow Mass Conversion (Baseline Scenario)

Component	Calculation of Reference Flow Mass*	Reference Flow Mass	Unit
OVERHEAD (OH)			
Cable	OHCableMass*(1+OHReliability)/OHCableLifetime	100.77	kg / cmile·yr
Cable Reel	OHReelMass*(1+OHReliability)/OHCableLifetime	9.70	kg / cmile·yr
Pole Mass	(PoleMass-PCPLeachingMass)/PoleLifetime /OHCapacity	186.74	kg / cmile·yr
PCP Leaching	PCPLeachingMass/PoleLifetime	0.00	kg / cmile·yr
Insulators	InsulatorMass/PoleLifetime	1.81	kg / cmile·yr
Steel Castings	SteelCastMass/PoleLifetime	8.39	kg / cmile·yr
UNDERGROUND (UG)			
Cable	UGCableMass*(1+UGReliability)/UGCableLifetime	578.42	kg / cmile·yr
Cable Reel	UG ReelMass*(1+UGReliability)/UGCableLifetime	80.23	kg / cmile·yr
Reinforced Concrete	ConcreteMass/UGInfrastructureLifetime/UGCapacity	8900.03	kg / cmile·yr
PVC Conduits	PVCMass/UGCapacity/UGInfrastructureLifetime	535.89	kg / cmile·yr

*Blue represents parameters of the model

OHReliability – the fraction of the cable mass that is replaced due to failure events per year.
UGReliability – the fraction of the cable mass that is replaced due to failure events per year.
PoleLifetime – average time of Utility Pole use.

3.4 Life Cycle Inventory

Data Collection and Modeling: In the Life Cycle Inventory (LCI), the practitioners used GaBi 4.3 LCA software to model each product system. GaBi 4.3 is a tool that balances complex process networks and connects inventory data with environmental impact categories. The software also includes a collection of proprietary industry inventories for basic materials and processes. The GaBi 4.3 software structure supports compliance with ISO 14040/44 guidelines for LCA (17).

The inventory data was gathered in collaboration with SCE and their primary suppliers and contractors. SCE specific data was collected using the following methods: site visits, on-site measurements, and personal communications. Site visits included the cable supplier’s manufacturing facilities, SCE service centers, SCE warehouses, and waste management facilities. These methods facilitated measurement, calculation, or defensible estimation of SCE-specific values for production, installation, maintenance, decommissioning, and waste management processes. Remaining processes were modeled using LCA databases, including PE International’s GaBi 4.3 database, the ECOINVENT database (Swiss Centre for Life Cycle Inventories), and literature sources. The following diagrams (Figures 2 and 3) are schematic representations of the specificity used in the model.

Figure 2. Overhead System Flow Diagram

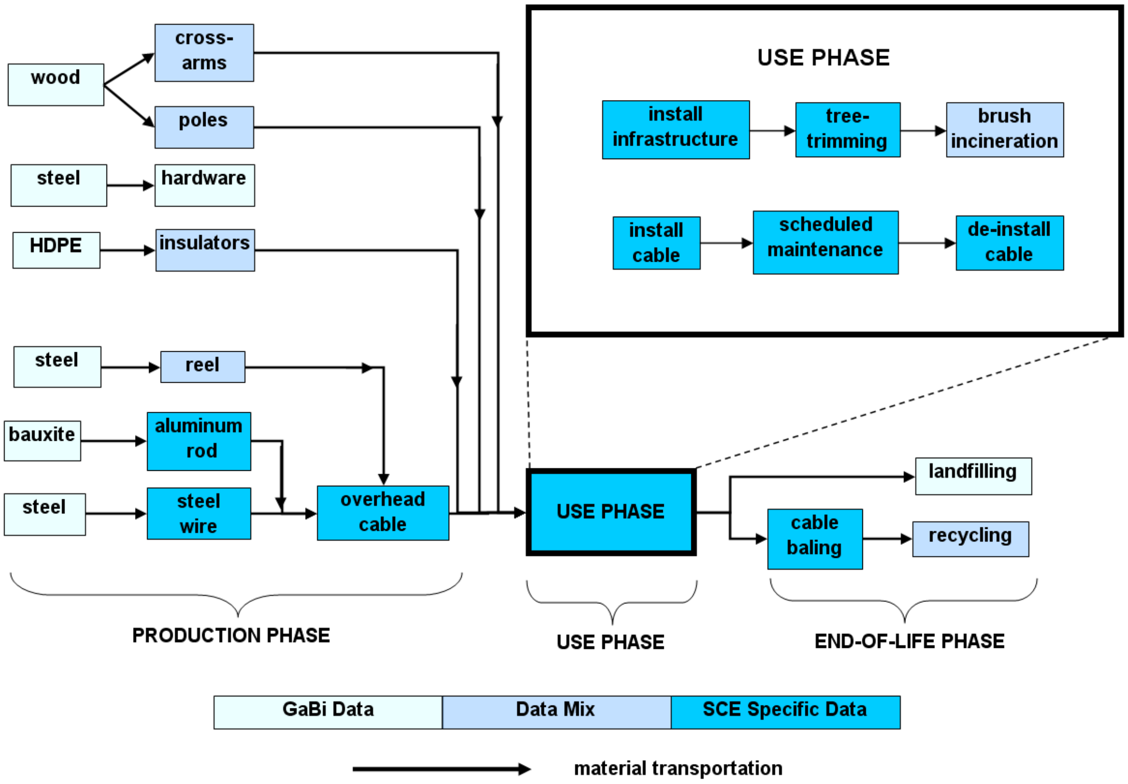
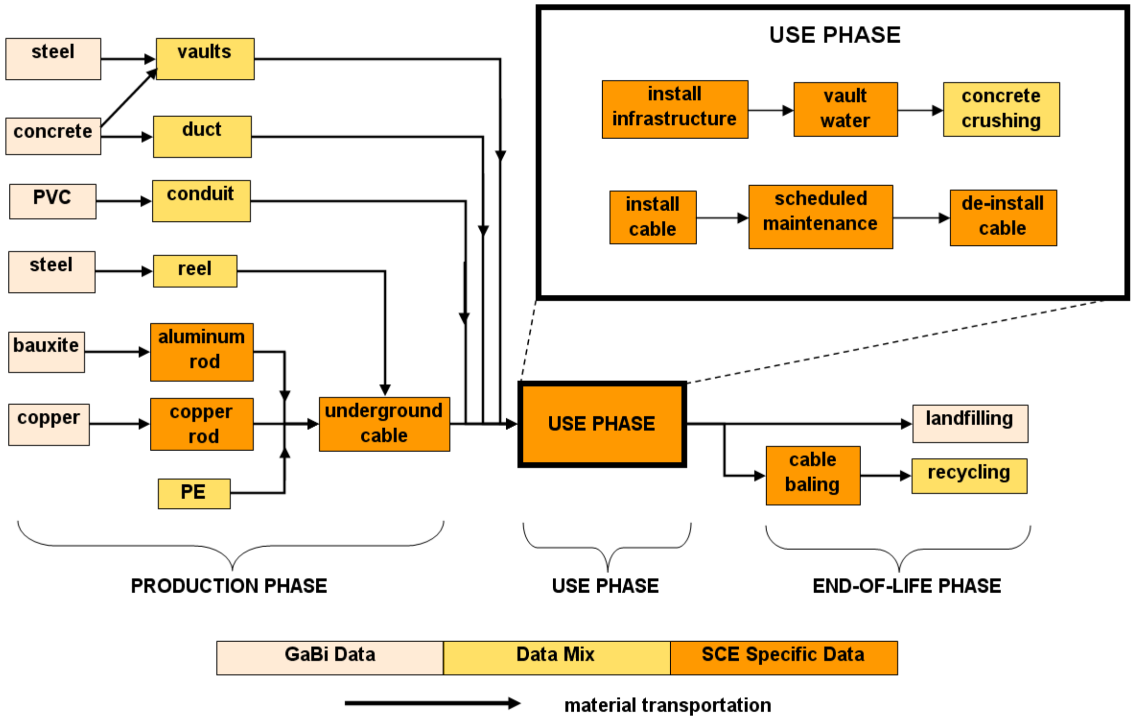


Figure 3. Underground System Flow Diagram



Within the model, practitioners followed standard LCI methodology. However, some specific aspects should be discussed.

In the production phase, cable production was modeled incorporating the most specific data. The data needed for material and energy requirements for cable production were compiled in close collaboration with SCE's primary cable supplier. This primary data were subsequently modeled by the practitioners in the software and includes aluminum and copper rod production, wire drawing, stranding and testing, and cable extrusion. The remaining processes of cable production, namely raw materials supplied to the cable production, were modeled using industry averages from the GaBi 4.3 software and the Ecoinvent database.

The use phase of each product system, including installation, maintenance, and decommissioning, was modeled almost entirely with data calculated from information obtained during communication with SCE specialists. The bulk of use-phase processes involve diesel-fueled utility vehicles. Inventory for installation, maintenance, and decommissioning processes included both distances driven by utility vehicles and the engine idling time used for work (e.g., hydraulics and auxiliary work, digging, and pumping).

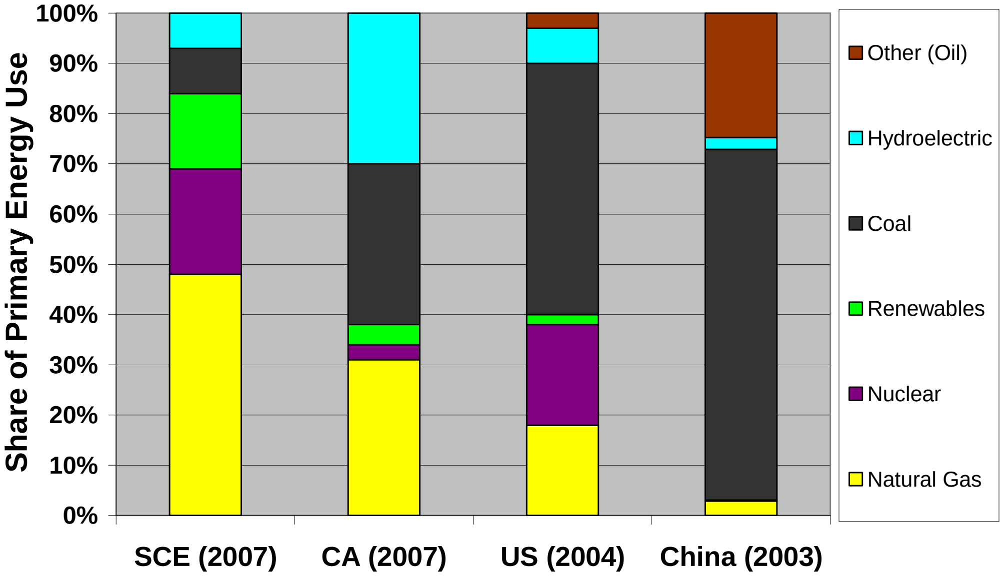
The standard requirements for the installation, maintenance, and decommissioning of each system were modeled. The diesel fuel consumption from driving and idling during these activities were calculated given average vehicle types, distances, and project durations for SCE. For the overhead system, installation processes include digging holes for poles, setting poles, and stringing the cable; which requires a digger, a cable dolly, an aerial bucket lift, and a cable puller. These same types of vehicles are required to decommission the system. To install the underground system the following activities are typically required: digging the trench, placing vaults and conduits, mixing and pouring concrete, filling the remaining space with backfill, and pulling the cable. The vehicle types needed for these activities are a trencher, a dump truck, a crane, a cable dolly, a cable puller, and a concrete mixer vehicle. Decommissioning for underground requires the same vehicle types except that the concrete mixer is replaced with a machine to crush concrete. Modeling of maintenance accounts for impacts from transportation, replacement of the cable sections due to the failure events, tree trimming for the overhead system and pumping vault water out of the underground infrastructure.

Cables decommissioned from the Southern California Edison service area are sorted and baled by SCE's waste management contractor. The bales are then shipped to China for recycling. Data required for cable sorting, packaging, and chopping processes in the EOL phase were gathered in close collaboration with SCE's cable waste management facility and recycling rates were parameterized in the model using a range of values. Subsequently, the data was modeled by the practitioners in the software.

Due to the potentially high impact of transportation processes on the comparison results, specific attention was paid to modeling transportation. Transport of materials was modeled using data specific to each trip including: payload capacity and utilization ratio of the vehicle; distance traveled and distance percentage in town, out of town, and on the highway; proportion of sulfur in diesel fuel and emissions standard of the vehicle. For example, the travel path between specific SCE supply chain facilities and the SCE warehouses and service centers to which the materials are delivered was determined using Google maps. These maps were used to ascertain the distance between facility addresses as well as the distance percentages in town, out of town, and on the highway. Specific distances were not available for steel and concrete raw materials in the production of pre-cast underground vaults. In these cases, local production distances and parameters were assumed (i.e., within 100 kilometers and travel conditions similar to those of the service area).

For an accurate representation of the energy used within Southern California, energy inputs required for the use phase were specific to the SCE utility power profile. Energy inputs required for the Production and EOL phases used a US average profile mix except for cable recycling which occurs in China and thus, uses average China profile mix. The comparison in energy mix profiles used between modeled phases as well as the California mix are illustrated in Figure 4.

Figure 4. Energy Portfolio Comparison



Allocation: Allocation is avoided in the model by using the avoided burden method. This method assumes that the amount of material recycled replaces the same amount of primary product, and therefore the recycling credits are assigned to the primary producer. Producing primary material may then be seen as a process that produces recyclable material. Credits are given to primary material production for reuse and recycling of materials.

In the product systems, the steel reels are reused with some loss each year. Reel reuse is reflected by crediting impacts from the entire reel production process. The portion that is lost from the product system is assumed to be recycled into secondary steel. The recycling of this smaller portion of the reel is reflected by crediting impacts to the primary production of steel.

Though the cables are recycled, the recovery rates for cables are uncertain. A range of values was considered to account for this uncertainty. The high value of the recovery rate is 95 percent and is quoted from the Bureau of International Recycling (11). This high value is appropriate when the cable materials do not change their inherent properties through the recycling process.

The recycling infrastructure in China has a higher potential for material loss or changes in material properties (downgrading) than in developed countries. The fact that the recycling occurs in China is one reason to consider a lower value of recovery rate. Another aspect to consider is that, while overhead cables are comprised solely of metals, underground cables contain both metals and high density polyethylene and thus, require additional EOL processing. This increase in material complexity presents a higher likelihood for material loss and downgrading through the recycling process. A devaluation factor was calculated for each cable product to reflect the possible lower rates of recovery in these system boundaries. This factor accounts for the possible limitations in recycling the product as a whole and/or in the further use of the secondary material. A preferred method to determine devaluation is from long-term price averages of primary and secondary materials because prices are assumed to best describe the value of a material over the whole material cascade (18). Devaluation factors were first calculated for each material in the cable products using long-term price ratios. This is similar to the method for calculating the Recyclability Index (RI) of a material as proposed by Villalba, et al. (19). Material devaluation factors related to the cable composition were then multiplied to obtain a devaluation factor for each cable product. This resulting product devaluation factor was than used as the low value of cable recovery given for each cable product, 91.19 percent for overhead and 72.75 percent for underground (Table 4).

Table 4. Calculation of Low Range Recycling Rate for Cables

	Average Value in \$/kg for Raw Materials (as cited in 19)			
	Steel	**Aluminum**	**Copper**	**High Density Polyethylene**
Secondary Material (V_{SM})	0.29	0.65	0.90	0.93
Primary Material (V_{PM})	0.29	1.59	1.77	1.10
Product Recycling Rate (RR) Based on Raw Materials' Recycling Indices (RIs)				
Recycling Index ($RI = V_{SM} / V_{PM}$)	1.0000	0.9119	0.9435	0.8454
Low Range RR for OH Cable	$= RI_{steel} * RI_{aluminum} =$ **0.9119**			
Low Range RR for UG Cable	$= RI_{aluminum} * RI_{copper} * RI_{HDPE} =$ **0.7275**			

3.5 Assumption & Limitations

A few assumptions were made in the model inventory in order to simplify the comparative analysis. First, the system boundaries for this study did not include the transformers required for both product systems. Transformers would be required at the same locations whether the power delivery system is overhead or underground and would perform the same voltage conversions. However, there are some differences in the design between underground and overhead transformers, which were not analyzed in this study.

Second, components encompassing the functional unit were estimated for one mile of straight circuit with no topographical barriers and no obstacles for installation (e.g., roads, hard rocks, hills, corners, etc). In many cases, geological, terrain, and land use conditions will affect the quantity of infrastructural components needed and energy required for installation, which may significantly change the relative impact of the two systems. For example, assuming no obstacles implies that the underground system does not require landscaping or re-pavement at the surface after installation.

Third, the truck transportation process inventories were based on EU, rather than US, diesel fuel emission standards. While the current US regulation for *new* diesel vehicles is comparable to EU Euro 5 emission standards, diesel vehicles currently in use in the US are older and the majority are below this standard. Therefore, it was estimated that the EU Euro 4 diesel fuel emission standards is the most suitable, conservative assumption for our analysis (20, 21).

Fourth and fifth, land-use issues (e.g. right-of-way, land use change) and the effect of electromagnetic fields (EMFs) were not considered in this study due to their complexity. Both of these topics are quite controversial and there are many competing claims about the possible harm caused by them (9, 22-24). While the potential harm by EMFs is still an open question, EMF concentrations around primary power distribution are mainly defined by the distance from the power line. Thus, using underground primary power delivery systems result in higher EMF exposure for power consumers and general public.

Additionally, due to the complexity of the issue, this study did not include the comparison of power losses between the two cable systems. Power loss is related to the cable’s impedance. Impedance in alternating currents will affect the voltage drop along the length of the circuit. Impedance is a function of several factors including: cable separation, conductor size, neutral/shield resistance, and proximity to other cables and ground wires (25).

Finally, the SCE cable supply chain already minimizes material waste in the cable production process and SCE’s recycling programs recover nearly all of the materials within the utility’s sphere of control. This level of industry efficiency in the studied supply chain should be considered when comparing opportunities in other utilities supply chains and systems.

3.6 Impact Assessment

After inserting all inventory data and parameterization factors into the model, the process network and flows were balanced by the software. Flows from the inventory analysis were than classified into impact categories and specific indicators were calculated for each category. Impact categories were selected based on their relevance to the project goal and scope (Table 5). The absolute values of the impact indicators are measured in different units and are not directly comparable. Therefore, they are normalized using overall environmental loads for the US according to the latest normalization factors developed by the Center for Environmental Studies (CML) at Lieden University in the Netherlands. Normalization puts the indicator results into a broader context and gives the environmental impact profile for each product system in common dimensions. “Hot spot” analysis was then used to isolate processes contributing most significantly to the overall impacts for each product system.

Table 5. Selected Impact Categories

Category	Indicator
Abiotic Depletion (AD)	kg Sb eq.
Acidification Potential (AP)	kg SO2 eq.
Eutrophication Potential (EP)	Kg PO4- eq.
Freshwater Aquatic Ecotoxicity Potential (FAEP)	kg DCB eq.
Global Warming Potential (GWP) –100 years	kg CO2 eq.
Human Toxicity Potential (HTP)	kg DCB eq.
Photochemical Ozone Creation Potential (POCP)	kg ethylene eq.
Terrestric Ecotoxicity Potential (TEP)	kg DCB eq.

4. Results & Discussion

4.1 Technical Analysis

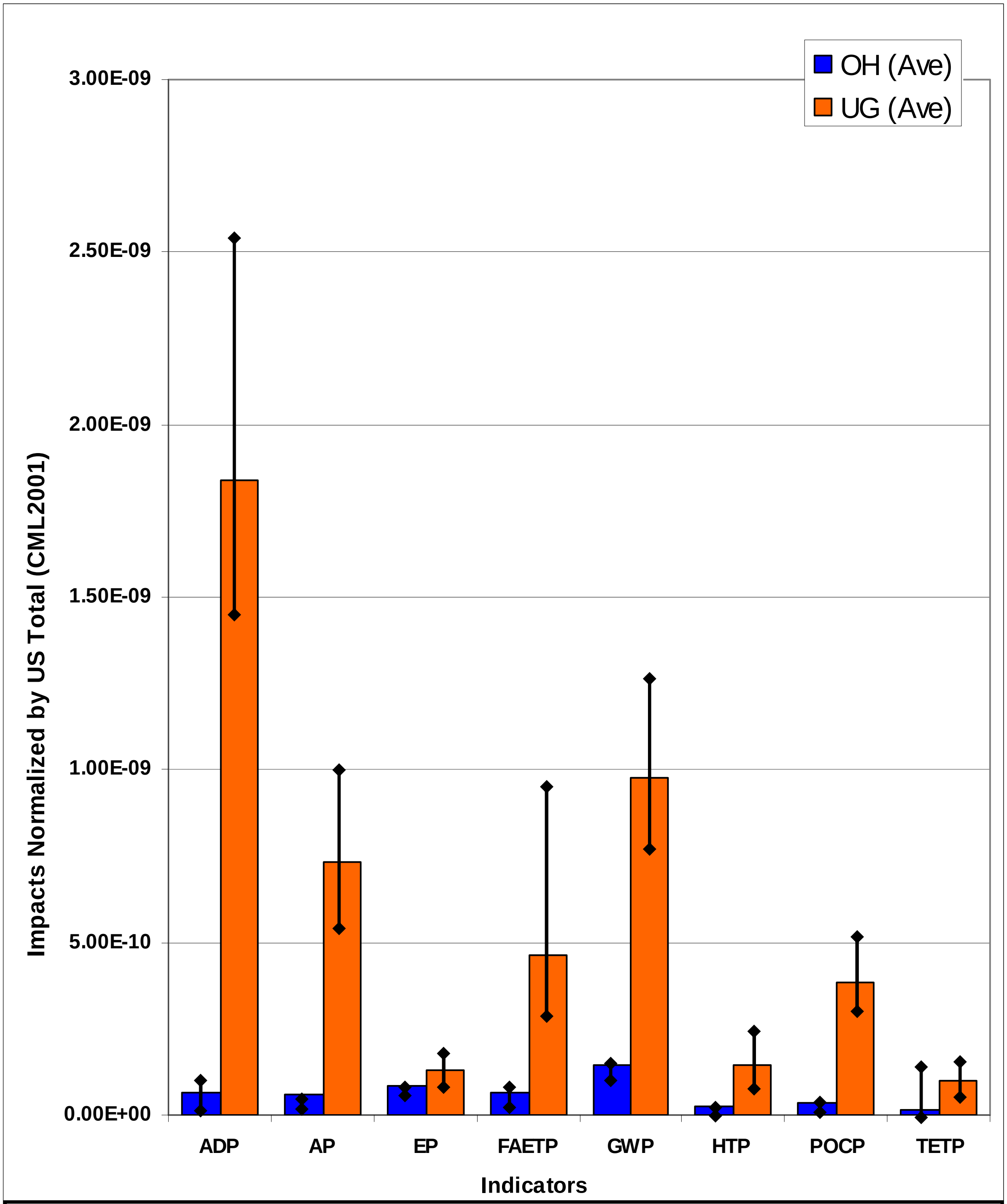
Overall Comparison and Sensitivity Analysis: The results comparison shows that the underground system has more environmental impact potential than the overhead system in all categories and most scenarios (Figure 5). As will be discussed shortly, this difference is primarily due to the higher material intensity for underground cables. The baseline scenario values shown in Table 2 were modeled, resulting in the average environmental impact results depicted in Figure 5.

The sensitivity analysis accounts for uncertainties in the parameterized factors for each system. In Figure 5, the error bars indicate the highest and lowest ends of impacts in all modeled scenarios. As described in Table 2, the factors included in the scenarios are infrastructure lifetime for underground, chemical leaching from the overhead treated wooden utility poles, and cable lifetimes and recycling rates for each system. The sensitivity analysis suggests that the cable lifetimes are the most significant parameterized factors affecting the net environmental impacts. As can be seen in Figure 5, potential environmental impacts of the underground primary distribution system are considerably higher for all impact indicators. However, scenario analysis suggests that there are two impact indicators in which the overhead system may potentially have higher environmental impacts than the underground system.

For the overhead system, the Terrestric Ecotoxicity Potential (TETP) impacts are significantly increased if 100 percent of the pentachlorophenol (PCP) wood treatment chemical leaches into the soil around the utility pole. The fate and transport of PCP leaching from wooden utility poles is not well understood and highly dependent on soil type (27). Therefore, a range of zero to 100 percent leaching was selected to capture all possible scenarios. It is important to note, however, that 100 percent leaching is a conservative estimate and, according to literature, somewhat unlikely (27, 28). Accounting for 100 percent PCP leaching brings the impacts of the overhead system in the TETP category into overlap with the TETP range for the underground system. When a majority of the PCP leaches into the soil, the TETP impact for the overhead system is higher than the TETP impact in the underground baseline scenario. However, the underground ‘worst-case scenario’ still has higher environmental impacts in all indicators.

Impact values between the two systems are relatively close in the Eutrophication Potential (EP) indicator and the ranges are narrow. For the baseline scenario, the underground system has higher impacts than the overhead system. However, there is some overlap as the ‘worst-case scenario’ for the overhead system has higher impact than the ‘best-case’ scenario for the underground.

Figure 5. Overhead vs. Underground: Overall Comparison and Sensitivity Analysis

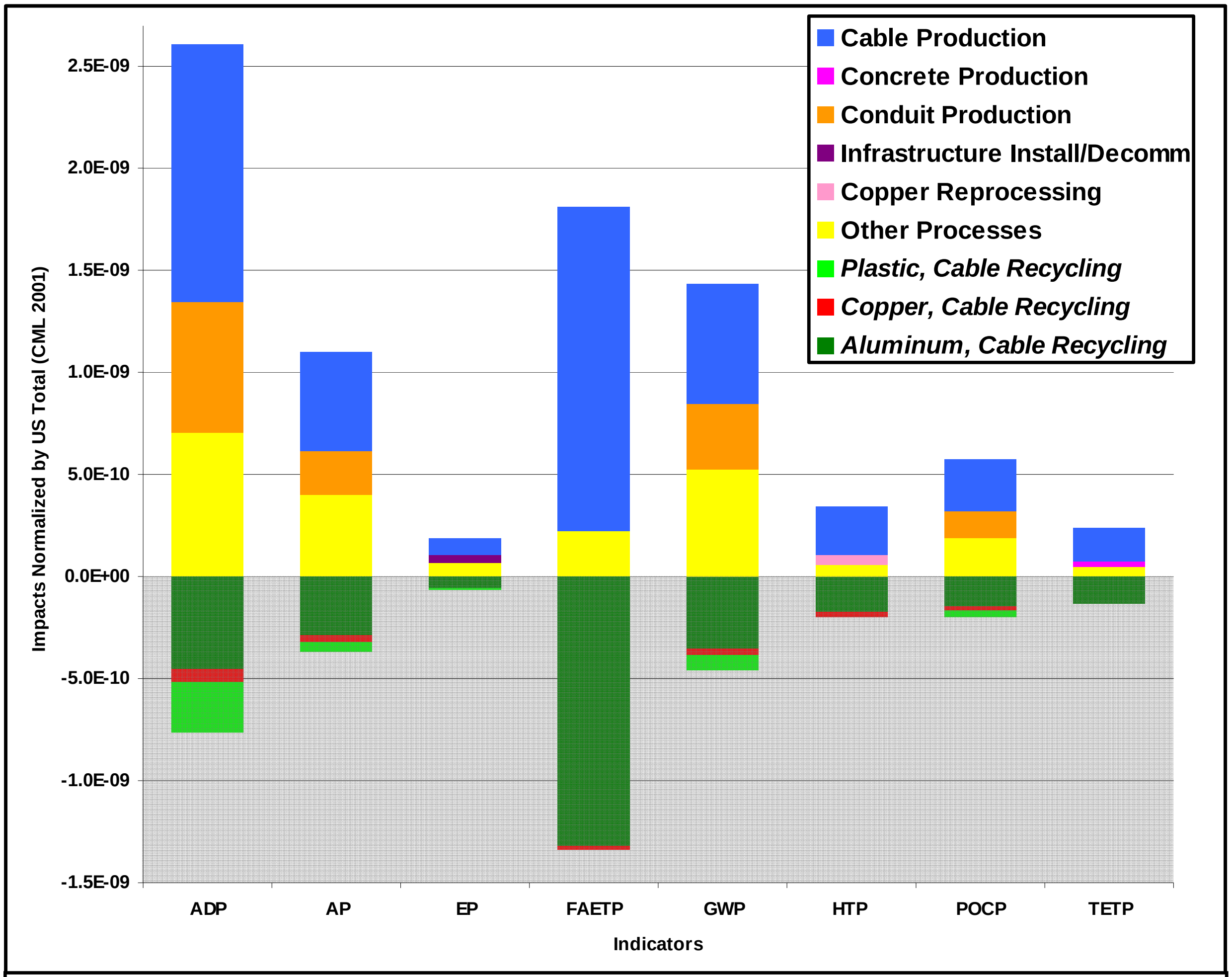


ADP: Abiotic Depletion Potential
AP: Acidification Potential
EP: Eutrophication Potential
FAETP: Freshwater Aquatic Ecotoxicity Potential
GWP: Global Warming Potential (100 years)
HTP: Human Toxicity Potential (inf.)
POCP: Photochemical Ozone Creation Pot.
TETP: Terrestric Ecotoxicity Potential

Hotspot Analysis—Underground System: Cable production is the process dominating the environmental impacts in the underground system across all eight indicators (Figure 6). Within cable production, it is the cradle-to-gate process of liquid aluminum production that is responsible for the majority of impacts, especially in Abiotic Depletion Potential (ADP). The “aluminium, primary, liquid at plant” process inventory in the Ecoinvent database includes the electrolysis step of aluminum production. This step is the most energy consuming of aluminum production. As of 2008, electricity use at an aluminum electrolysis plant is approximately 15.6 kWh/kg liquid aluminum, as compared to electricity consumption for primary copper production, which is 0.55 kWh/kg copper (29). The mining and resource extraction processes of cradle-to-gate aluminum production also contribute significantly to ADP and Freshwater Aquatic Ecotoxicity Potential (FAETP) impacts.

The next highest contribution in this system is the cradle-to-gate production of the polyvinyl chloride (PVC) required for the cable conduits. The high impacts in ADP, Photochemical Ozone Creation Potential (POCP), and Global Warming Potential (GWP) reflect this process’ requirement of petroleum as feedstock and subsequent creation of smog and greenhouse gases, respectively. Installation and decommissioning of the concrete infrastructure for the underground system contributes significantly to the EP impact indicator.

Figure 6. Underground Hotspot Analysis, Contributing ≥ 25% of Net Impacts
***Main credits shown in grey**



ADP: Acidification Potential
EP: Eutrophication Potential
GWP: Global Warming Potential (100 years)
POCP: Photochemical Ozone Creation Potential

ADP: Abiotic Depletion Potential
FAETP: Freshwater Aquatic Ecotoxicity Potential
HTP: Human Toxicity Potential (inf.)
TETP: Terrestric Ecotoxicity Potential (inf.)

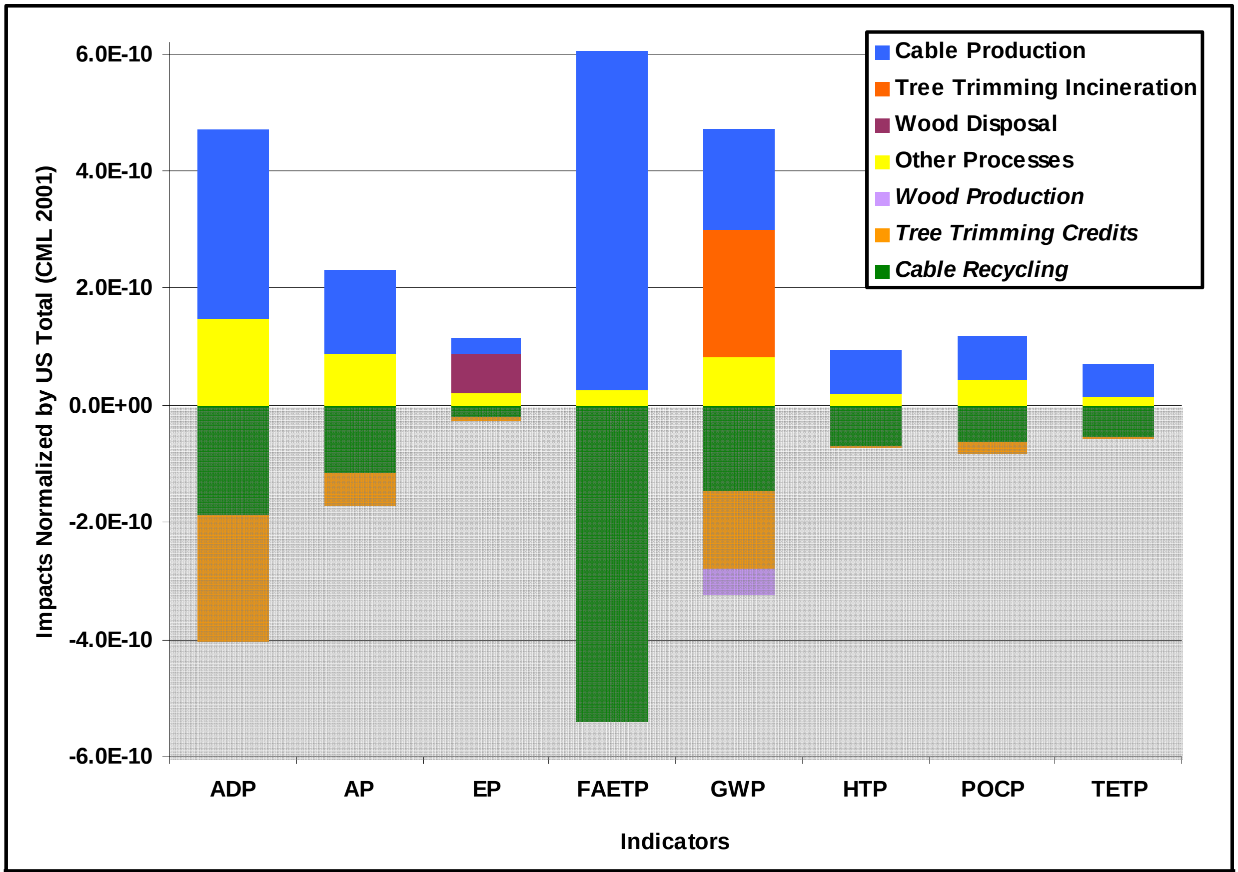
Hotspot Analysis—Overhead System: In the overhead system, production of the cable again dominates environmental impact indicators (Figure 7). The overhead cable modeled is comprised of mostly aluminum. Thus, the primary liquid aluminum production at plant is responsible for 60-99 percent of the impacts from cable production across all indicators. The amount of aluminum required for overhead cable is less than half that of underground as seen in Table 1. This lower material intensity is the reason the associated impacts in the overhead system are an order of magnitude smaller than in the underground system.

Another process included in the overhead cable production impact for the ADP indicator is natural gas production, which is used to keep the metal molten at the aluminum rod plant. Even though aluminum is a dominant contributor to all indicators, the methods employed by SCE's main supplier of cable are very efficient. The primary aluminum is produced adjacent to the aluminum rod plant; therefore the aluminum can be kept molten up to the rod rolling stage. As a result, less natural gas is required in this facility relative to the amount of natural gas needed for an ordinary metal refinery. In other words, ingot is not purchased and re-melted as can be the case for refined metal products.

The majority of GWP impacts in the overhead system result from the incineration of tree trimmings during the use phase. However, in the studied utility, the incineration process also generates heat and electricity that is utilized within the SCE service area and thus, credited to the use phase as "*Tree Trimming Credits*" (Figure 7). The magnitude of these credits compensates total use phase impacts in the ADP, FEATP, Human Toxicity Potential (HTP), and TETP indicators. Composting or mulching tree trimmings would reduce the pulse of greenhouse gas emissions relative to incineration, but would not result in the generation of heat and electricity to be utilized by SCE. In other words, composting or mulching tree trimmings would reduce GWP impacts, but not result in ADP, FEATP, HTP, and TETP indicator credits.

Finally, landfilling of the wooden utility poles and the resulting nutrient runoff contributes most to the EP indicator in the overhead system.

Figure 7. Overhead Hotspot Analysis, Contributing ≥ 25% of Net Impacts
***Main credits shown in grey**

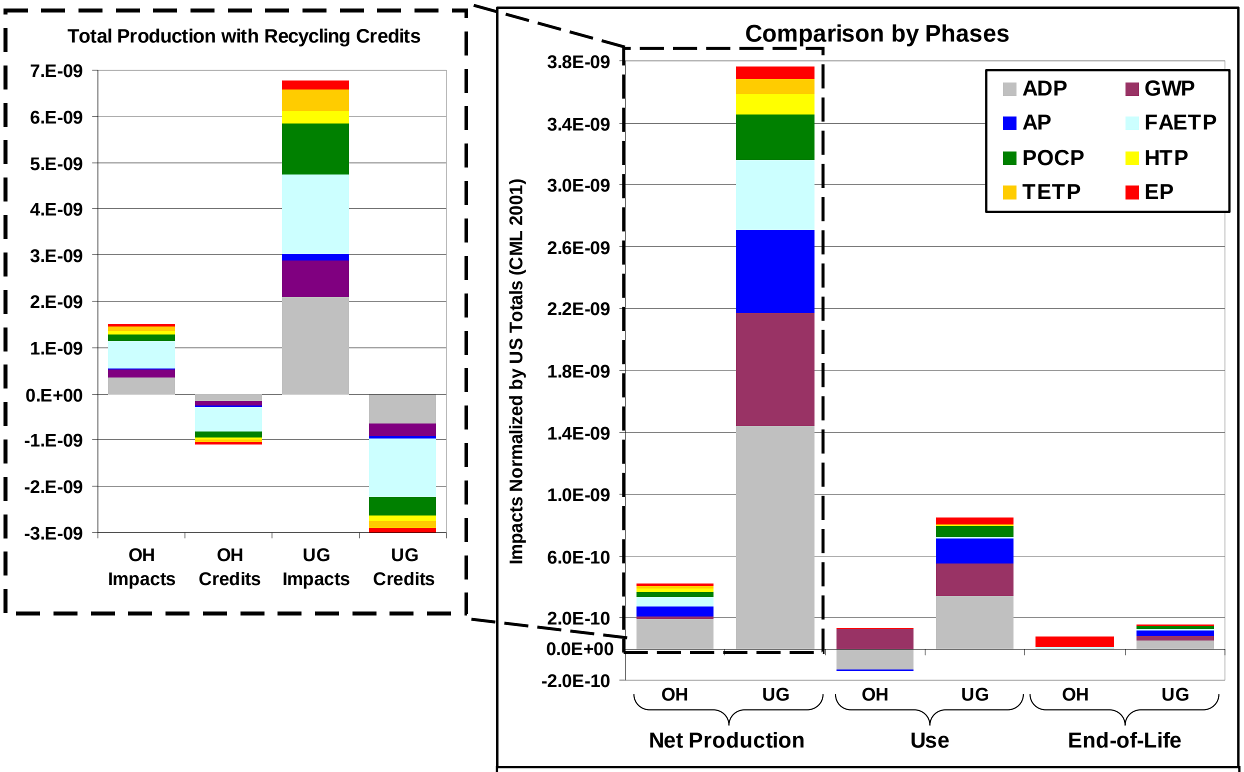


ADP: Acidification Potential
EP: Eutrophication Potential
GWP: Global Warming Potential (100 years)
POCP: Photochemical Ozone Creation Potential

ADP: Abiotic Depletion Potential
FAETP: Freshwater Aquatic Ecotoxicity Potential
HTP: Human Toxicity Potential (inf.)
TETP: Terrestric Ecotoxicity Potential (inf.)

Impacts by phases: Analyzing environmental impacts by phases shows that the EOL phase contributes the least to net impacts. Credits associated with recycling cable materials in the EOL phases are attributed to primary production (i.e., the production phase). Even with these credits attributed, the net production impacts contribute the largest share to overall environmental impacts in both systems (Figure 8).

Figure 8. Environmental Impacts by Phases



ADP: Acidification Potential
EP: Eutrophication Potential
GWP: Global Warming Potential (100 years)
POCP: Photochemical Ozone Creation Potential

ADP: Abiotic Depletion Potential
FAETP: Freshwater Aquatic Ecotoxicity Potential
HTP: Human Toxicity Potential (inf.)
TETP: Terrestric Ecotoxicity Potential (inf.)

4.2 Recommendations

First, the larger environmental impacts of an underground system should be considered in the decision-making process regarding primary power distribution. It must be noted, though, that there is limited flexibility in material selection for cable production due to their physical property requirements and associated economic issues. Placing power delivery systems underground requires additional cable materials. Firstly, the conductor must be protected from mechanical damage and thus, requires insulating material (i.e., high density polyethylene in this study). Also, when enclosed in tight configuration, heat from the cable does not easily dissipate as it does in open air. Temperature increase in the underground cable would not only pose the risk of melting the plastic insulation layer(s), but would also decrease the conductive properties of the cable. To ensure a safe temperature range for the underground system, the electrical current density must be decreased. This decrease is achieved by using conductors with larger cross-sectional areas. In other words, a larger mass of aluminum conductor is needed for the underground cable to have the same power delivery capacity as the smaller bare metal overhead cable. In brief, high material intensity of the underground cable is driven by physical conditions, so it is inevitable that delivering primary power underground places higher pressures on the environment.

Second, because the production phase of each system’s life cycle contributes the largest to overall environmental impacts, SCE and other electrical utilities must look to Green Supply Chain Management in order to reduce overall life cycle impacts for either system.

Third, the model reflects that SCE vehicle fleets use low-sulfur diesel fuel as is required in California. Still, within the utility’s corporate boundaries, impacts are dominated by diesel fuel production for, and fuel emissions during, the installation, maintenance, and decommissioning of the cable systems. Thus, management and logistics of the service vehicle fleet should be a major consideration in reducing the overall environmental impacts of the use phase in both overhead and underground systems.

Finally, the developed model and ‘hot spot’ analysis may be used to investigate alternatives for materials, and component and process design.

4.3 Further Research

This model provides an opportunity to test different scenarios associated with management solutions. Some of these scenarios would require additional process inventories. For example, in order to assess potential improvements in vehicle fleet management, additional inventories for hybrid electric vehicles, flexible-fuel vehicles, and biofuels would be necessary.

Next, environmental impacts resulting from physical and human capital were assumed to be negligible and were excluded from the analysis because they would not significantly affect the comparative study results. However, including these impacts into the model using Hybrid LCA methodology could more accurately capture overall environmental impacts of either system.

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Appendix 1.
Material Inventory Calculations: Overhead Infrastructure & Cable

Product Summary

Reference Flow Masses for OH System
Functional Unit = one circuit mile
Default Timeframe = 1 year

# of cables OH	4	#
# of poles	25	#
# of crossarms	30	#
# of insulators	100	#
# of castings	30	#
# of steel reels	1.854258121	#

Materials

cable wire mass, aluminum alloy 1350	3,020.2486	kg
cable wire mass, coated steel (high-grade zinc-coated)	474.3373	kg
OH cables circuit, total mass	3,494.5859	kg
steel flange, total mass	244.0049	kg
steel drum, total mass	92.4261	kg
steel reel, total mass	336.4309	kg
steel reel with cable, total mass	3,831.0169	kg
avoided burden steel reel, total mass	272.5091	kg
welding seam length for reels	10.6534	m
surface area of zinc coating	101.7997	m^2
wooden utility poles, total mass	8,626.9744	kg
wooden crossarm, total mass	443.6110	kg
PCP for poles treatment, total mass	261.8903	kg
PCP for crossarms treatment, total mass	4.4930	kg
PCP for wood accessories, total mass	266.3833	kg
total wood mass treated with PCP	9,336.9687	kg
PE insulators, total mass	90.7185	kg
pole hardware, steel castings (galvanized steel)	419.5729	kg

Product: 336.4 kcmil, 18/1, ACSR "Merlin", Bare Aluminum, MV

Producer: Southwire®,	One Southwire Drive
http://www.southwire.com/	Carrollton, GA 30119

Product Choice Basis: This cable type was chosen based on high purchase volume by SCE. Moreover, this cable type has a comparable ampacity with the highly used underground cable.

Summary

distance (length of circuit)	1	mile
# of cables per circuit	4	#
total cable mass per circuit mile	3,494.5859	kg
total Al mass per circuit mile	3,020.2486	kg
total steel mass per circuit mile	474.3373	kg

Calculations

conversions and constants

1 pound	0.45359237	kg
1 foot	0.000189394	mile

Stock Description (1)

336.4-18/1 ACSR MERLIN

Total Feet	5,998,894	ft
Total Dollars	3,160,560	$
Total Pounds	2,188,302	lbs
Total Aluminum	1,891,273	lbs
Total Copper	0	lbs
Total Steel	297,029	lbs
Total Compound	2,188,302	lbs

	1 cable		**1 cable**		**1 circuit**
	lbs/foot	**%**	**kg/foot**	**kg/mile**	**kg/mille**
Total cable mass	0.3648	100.0000	0.1655	873.6465	3,494.5859
total aluminum	0.3153	86.4265	0.1430	755.0621	3,020.2486
total steel	0.0495	13.5735	0.0225	118.5843	474.3373

Calculate Replacement Mass from Failures

number of OH failure events per year (2)	0.9	mile
length replacement section per 1 event (3)	225	ft
	0.042613636	miles
length replacement per year per mile of OH cable	0.038352273	miles
length replacement per year per mile of OH circuit	0.153409091	miles
mass OH cable per circuit mile	3,494.5859	kg
mass OH cable replacement per circuit mile per year	536.1012502	kg
	0.153409091	fraction
	15.34090906	%

Source:

1. Southwire, Personal Communication
2. Short, TA. (2004) Electrical Power Distribution Systems Handbook, pg. 97, CRC Press
3. Assume replacement section is average length between poles.

Product: Steel Reel SW Designation S-77

Producer: Southwire®,	One Southwire Drive
http://www.southwire.com/	Carrollton, GA 30119

Product Choice Basis: This reel is used for the overhead cable (336.4 kcmil, 18/1, ACSR "Merlin") according to Southwire and SCE inventory records.

Summary

length of cable per circuit mile	21,120.0000	ft
reels per circuit mile	1.8543	#
total reel mass per circuit mile	336.4309	kg
total flange mass per circuit mile	244.0049	kg
total drum mass per circuit mile	92.4261	kg
total combined reel and cable mass per circuit mile	3,831.0169	kg
total reel mass returned per circuit mile	272.5091	kg
total welding seam length per circuit mile	10.6534	m

Calculations

conversions and constants

1 pound	0.45359237	kg
1 cubic inch	1.63871E-05	m^3
1 inch	0.0254	m
1 mile	5280	ft
pi	3.141592654	

estimate mass fraction of reel parts by surface area

*surface area = (2*pi*radius^2)+(2*pi*radius*height)*

flange radius (1)	33.0000	in
flange height (1)	3.0000	in
total surface area of one flange	7,464.4241	in^2
total surface area of two flanges	14,928.8483	in^2
drum radius (1)	18.0000	in
drum height (1)	32.0000	in
total surface area of drum	5,654.8668	in^2
total surface area of reel	20,583.7151	in^2
two flanges surface area fraction of total	0.7253	
drum surface area of total	0.2747	

calculate twice length drum circumference

*circumference = 2*pi*radius*

welding seam length (in) per reel	226.1947	in
welding seam length (m) per reel	5.7453	m
welding seam length per circuit mile	10.6534	m

calculate mass parts per circuit mile		
S-77 mass per reel (1)	400.0000	lbs
	181.4369	kg
total length OH Merlin cable per circuit mile	21,120.0000	ft
length OH Merlin per S-77 steel reel (2)	11,390.0000	ft
S-77 steel reels per circuit mile	1.8543	#
mass S-77 steel reels per circuit mile	336.4309	kg
mass flange steel per circuit mile	244.0049	kg
mass drum steel per circuit mile	92.4261	kg

calculate mass of steel reel for avoided burden		
reel shrinkage rate (2003) (2)	26	%
reel shrinkage rate (2004) (2)	17	%
reel shrinkage rate (2005) (2)	14	%
average shrinkage rate	19	%
average fraction of steel reels returned	0.81	
mass of reels returned (avoided burden) per circuit mile	272.5090568	kg

Sources:

(1) Southwire, Reel Specification Sheet:
http://www.southwire.com/Southwire/StaticFiles/Text/62-2ReelData.pdf

(2) Southwire Personal Communication

Product: Zinc coating for steel products (wire and pole hardware)

Producer: Unknown (use average data as contained in Gabi, no transportation modeled)
Product Choice Basis: OH Merlin cable spec sheets from Southwire designate a zinc-coated steel core and the hardware will need protection from weathering)

Summary

area of zinc coating for steel core per circuit mile	70.2200	m^2
area of zinc coating for pole hardware per circuit mile	6.9555	m^2
area of zinc coating for steel reel per circuit mile	24.6242	m^2
total area of zinc coating for steel products per circuit mile	101.7997	m^2

Calculations

conversions and constants

1 ft	0.3048	m
1 inch	0.0254	m
1 mile	5280	ft
pi	3.141592654	
1 square inch	0.00064516	m^2

estimate surface area for zinc coating of cable parts

estimate surface area for zinc coating of steel core

*surface area = (2*pi*radius^2)+(2*pi*radius*height)*

length (ft) of steel core per circuit mile	21,120.0000	ft
length (m) of steel core per circuit mile	6,437.3760	m
steel core diameter, in. (1)	0.1367	in
steel core diameter, m	0.0035	m
surface area of steel core per circuit mile	70.2200	m^2
mass steel core per circuit mile	474.3373	kg
surface area of steel core per kilogram steel core	0.1480	m^2

estimate surface area for zinc coating of pole hardware

estimated surface area of zinc coating of 5/8's bolts per circuit mile

5/8 in bolts needed per pole (2)	1.0000	#
number of poles per circuit mile (2)	25.0000	#

*surface area = (2*pi*radius^2)+(2*pi*radius*length)*

length (in.) of 5/8 in. bolts for v-braces (3)	14.0000	in
length (m) of 5/8 in. bolts for v-braces	0.3556	m
diameter (in.) of 5/8 in. bolts for v-braces (3)	0.6250	in
diameter (m) of 5/8 in. bolts for v-braces	0.0159	m
surface area of zinc coating of 5/8 in. bolts for v-braces	0.0181	m^2
surface area of zinc coating of 5/8 in. bolts for v-braces per circuit mile	0.4533	m^2

estimated surface area of zinc coating for v-braces per circuit mile

v-braces needed per pole (2)	1.0000	#
number of poles per circuit mile (2)	25.0000	#

*surface area = (2*w*l)+(2*w*h)+(2*l*h)*2 ***

**Multiplied by 2 to account for both sides of the V as a rectangular prism

width (in) of v-braces (3)	0.25	in
width (m) of v-braces	0.00635	m
length (in) of v-braces (3)	30.0000	in
length (m) of v-braces	0.7620	m
height (in) of v-braces (3)	1.5000	in
height (m) of v-braces	0.0381	m
surface area of zinc coating for v-braces	0.1365	m^2
surface area of zinc coating of v-braces per circuit mile	3.4113	m^2

estimate surface area for zinc coating of 1/2 in bolts for v-braces per circuit mile

bolts needed per pole (2)	3.0000	#
number of poles per circuit mile (2)	25.0000	#

*surface area = (2*pi*radius^2)+(2*pi*radius*length)*

length (in) of 1/2 in. bolts for v-braces (2)	5.7500	in
length (m) of 1/2 in. bolts for v-braces	0.1461	m
diameter (in) of 1/2 in. bolts for v-braces (2)	0.5000	in
diameter (m) of 1/2 in. bolts for v-braces	0.0127	m
surface area of zinc coating of bolts for v-braces	0.0061	m^2
surface area of zinc coating of 1/2 in. bolts for v-braces per circuit mile	0.4560	m^2

estimated surface area for zinc coating of insulator pins per circuit mile

number of insulators per pole (2)	4.0000	#
number of poles per circuit mile (2)	25.0000	#

*surface area = (2*pi*radius^2)+(2*pi*radius*length)*

length (in) of 1/2 in. bolts for v-braces (3)	12.5000	in
length (m) of 1/2 in. bolts for v-braces (3)	0.3175	m
diameter (in) of 1/2 in. bolts for v-braces (3)	1.0000	in
diameter (m) of 1/2 in. bolts for v-braces	0.0254	m
surface area of zinc coating of insulator pins	0.0263	m^2
surface area of zinc coating of insulator pins per circuit mile	2.6349	m^2

Total estimated surface area for zinc coating of pole hardware

per circuit mile	6.9555	m^2
per kg of steel castings	0.016577487	m^2

Calculate zinc coating area for OH reel

total surface area (in^2) of each OH reel	20583.71507	in^2
total surface area (m^2) of each OH reel	13.27978961	m^2
coating area per kg of reel	0.073192311	m^2
total surface area of OH reel per circuit mile	24.62415774	m^2

Sources:

(1) Southwire, Overhead Specification Sheet: 336.4 kcmil, 18/1, ACSR "Merlin"
(2) SCE Service Center Site Visit, Valencia, CA
(3) Kortick: http://kortick.com/new_catalog_pages/Z/ZBE3.html

Product: Class 2 Douglas Fir Utility Pole

Producer: McFarland Cascade,
http://www.ldm.com/corporate_info.htm#contact_us Eugene, OR,
Product Choice Basis: SCE’s main pole supplier

Summary

poles per circuit mile	25.0000	#
mass Douglas Fir per circuit mile	8,626.9744	kg
mass treated utility pole per circuit mile	8,888.8647	kg
mass treated pole	355.5546	kg
Mass treated wood (pole and crossarm)	370.4914	kg

Calculations

conversions and constants		
1 pound	0.45359237	kg
1 inch	0.0254	m
1 mile	5280	ft
1 inch	0.083333333	ft
pi	3.141592654	
1 cubic foot	0.028316847	m^3
estimate number of poles per circuit mile		
type of wood most often used for SCE utility poles (1)	Douglas Fir	
average distance between poles for Merlin circuit (2)	225.0000	ft
average poles per mile of circuit	23.4667	#
modeled poles per mile of circuit	25.0000	#
calculate volume of Class 2 pole		
*frustum volume= (pi*h/3)*(R^2+R*r+r^2)*		
*circumference = 2*pi*radius*		
type of pole most often used for SCE Merlin circuit (2)	Class 2	
Class 2 pole height (h) (2)	45.0000	ft
Class 2 ground line circumference, in. (2)	40.5000	in
Class 2 ground line circumference, ft.	3.3750	ft
Class 2 top circumference, in. (2)	25.0000	in
Class 2 top circumference, ft.	2.0833	ft
ground line radius (R)	0.5371	ft
top radius (r)	0.3316	ft
volume of each Class 2 pole	27.1703	ft^3
sawn timber volume from Gabi pole production	0.7694	m^3
calculate mass of poles per circuit mile (3)		
density of Douglas Fir poles	28.0000	lbs/ft^3
mass (lbs) of wood per pole	760.7689	lbs
mass (kg) of wood per pole	345.0790	kg
mass of pole wood per circuit mile	8,626.9744	kg
density (kg/ft^3) of Douglas fir wood	12.7006	kg/ft^3

density (kg/m^3) of Douglas fir wood	448.5170	kg/m^3
calculate mass of treated utility pole per circuit mile		
sawn timber volume from Gabi pole production	0.7694	m^3
mass of untreated pole	345.0790	kg
PCP mass per pole	10.4756	kg
treated utility pole mass	355.5546	kg
treated utility pole mass per circuit mile	8,888.8647	kg
pole height underground	8.0000	ft

Sources:

1. SCE Wood Specialist, Personal Communication
2. SCE Service Center Site Visit, Valencia, CA
3. Graham, R.D., Helsing, G.G. (Feb. 1979). Wood Pole Maintenance Manual: inspection and supplemental treatment of douglas-fir and western red cedar poles. Oregon: Oregon State University, Forest Research Lab.

Product: Douglas Fir Crossarms

Producer: BROOKS Manufacturing Co.,	2120 Pacific Street
http://www.brooksmfg.com/	Bellingham, WA 98229

Product Choice Basis: SCE's main crossarms supplier

Summary

crossarms per circuit mile	30.0000	#
mass Douglas Fir per circuit mile	443.6110	kg

Calculations

conversions and constants		
1 pound	0.45359237	kg
1 inch	0.0254	m
1 mile	5280	ft
1 inch	0.083333333	ft
1 cubic feet	0.028316847	m^3
pi	3.141592654	
1 cubic foot	0.028316847	m^3
estimate number of crossarms per circuit mile		
type of wood most often used for Brooks crossarms (1)	Douglas Fir	
number of poles per circuit mile	25.0000	#
number of crossarms per pole (2)	1.0000	#
modeled crossarms per circuit mile (2)	30.0000	#
calculate volume of average size crossarm		
*rectangular volume = length*width*height*		
crossarm length (2)	10.0000	ft
common crossarm widths (3)	3.5000	in
common crossarm widths (3)	3.7500	in
average crossarm width (in) modeled	3.6250	in
average crossarm width (ft) modeled	0.3021	ft
common crossarm heights (3)	4.5000	in
common crossarm heights (3)	4.7500	in
average crossarm height (in) modeled	4.6250	in
average crossarm height (ft) modeled	0.3854	ft
crossarm volume (ft^3)	1.1643	ft^3
crossarm volume (m^3)	0.0330	m^3
calculate mass of crossarm per circuit mile		
density of Douglas Fir poles (4)	28.0000	lbs/ft^3
mass (lbs) of wood per crossarm	32.5998	lbs
mass (kg) of wood per crossarm	14.7870	kg
mass of crossarm wood per circuit mile	443.6110	kg
density (kg/ft^3) of Douglas fir wood	12.7006	kg/ft^3
density (kg/m^3) of Douglas fir wood	448.5170	kg/m^3

calculate mass of treated crossarm per circuit mile		
sawn timber volume from Gabi crossarm production	0.0330	m^3
mass of untreated crossarm	14.7870	kg
PCP mass per crossarm	0.1498	kg
treated crossarm mass	14.9368	kg
treated crossarm mass per circuit mile	448.1040	kg

Sources:

(1) Brooks Manufacturing Website, http://www.brooksmfg.com/
(2) SCE Service Center Site Visit, Valencia, CA
(3) Cox Industries, Incorporated: http://www.coxwood.com/pdf/CrossArm_Brochure.pdf.
(4) Graham, R.D., Helsing, G.G. (Feb. 1979). Wood Pole Maintenance Manual: inspection and supplemental treatment of douglas-fir and western red cedar poles. Oregon: Oregon State University, Forest Research Lab.

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Product: **Pentachlorophenol (PCP) Wood Preservative**

Producer: Unknown (use average data as contained in Gabi, no transportation modeled)
Product Choice Basis: This is the main wood preservative used for SCE wood products by McFarland Cascades & Brooks Manufacturing.

Summary

mass PCP for utility poles per circuit mile	261.8903	kg
mass PCP for crossarms per circuit mile	4.4930	kg
total mass PCP required for wood accessories per circuit mile	266.3833	kg

Calculations

conversions and constants		
1 pound	0.45359237	kg
1 US gallon	3785.41178	cm^3
calculate PCP needed for utility poles		
retention for PCP in Douglas Fir (1)	0.85	lbs/ft^3
volume of Class 2 utility pole	27.1703	ft^3
mass (lbs) of PCP per Class 2 Douglas Fir utility pole	23.0948	lbs
mass (kg) of PCP per Class 2 Douglas Fir utility pole	10.4756	kg
utility poles per circuit mile	25.0000	#
mass (lbs) of PCP required for poles per circuit mile	577.3693	lbs
mass (kg) of PCP required for poles per circuit mile	261.8903	kg
calculate PCP needed for crossarms		
preservative mix used per crossarm (2)	0.4000	gallons
PCP fraction in preservative mix (2)	0.0500	
PCP volume (gallons) used per crossarm	0.0200	gallons
PCP volume (cm^3) used per crossarm	75.7082	cm^3
density of PCP @ 22C (3)	1.97822	g/cm^3
mass (g) of PCP per crossarm	149.7675	g
mass (kg) of PCP per crossarm	0.1498	kg
crossarms per circuit mile	30.0000	#
mass of PCP required for crossarms per circuit mile	4.4930	kg
total mass PCP for wood accessories per circuit mile	266.3833	kg
total mass PCP leaching from poles in use phase		
low value PCP concentration surrounding pole	328.0000	mg/kg soil
high value PCP concentration surrounding pole	1,060.0000	mg/kg soil

Sources:

(1) SCE Wood Specialist, Personal Communication & McFarland Cascade Retention Tables: http://www.ldm.com/products.htm
(2) Shannon Terrell, Brooks Manufacturing. Personal Communication. December 29, 2008.
(3) CRC Handbook of Chemistry & Physics

Product: Hendrix HPI-15VT Polyethylene Insulator

Producer: Hendrix Wire & Cable Inc.,	53 Old Wilton Rd.,
http://www.hendrix-wc.com/hendrix/contact.htm	Milford, NH 03055

Product Choice Basis: SCE’s main insulator supplier

Summary

Insulators per circuit mile	100.0000	#
Insulator PE mass per circuit mile	90.7185	kg

Calculations

Conversions and Constants

1 pound	0.45359237	kg
number of poles per circuit mile	25.0000	#
number of insulators per pole	4.0000	#
modeled number of insulators per circuit mile	100.0000	#

Calculate mass of insulators per circuit mile

type of insulators used (1)	Polymer HPI-15VT	
mass (lbs) of polymer per insulator (1)	2.0000	lbs
mass (kg) of polymer per insulator	0.9072	kg
mass of polymer insulators per circuit mile	90.7185	kg

Source:

(1) SCE Service Center Site Visit, Valencia, CA

Product: Steel Castings Utility Pole Hardware

Producer: Kortick Manufacturing,
http://www.kortick.com/contact.html

2230 Davis Court,
Hayward, CA 94545

Product Choice Basis: SCE’s main pole hardware supplier

Summary

mass 5/8's bolts per circuit mile	34.0194	kg
mass v-braces per circuit mile	136.0777	kg
mass of bolts for v-braces per circuit mile	68.0389	kg
mass insulator pins per circuit mile	181.4369	kg
total mass of steel castings per circuit mile	419.5729	kg

Calculations

conversions and constants

1 pound	0.45359237	kg

calculate mass of 5/8's bolts per circuit mile

mass of bolts needed per pole (1)	3	lbs
number of poles per circuit mile	25.0000	#
Mass (lbs) of bolts needed per circuit mile	75.0000	lbs
mass (kg) of bolts needed per circuit mile	34.0194	kg

calculate mass of v-braces per circuit mile

v-braces needed per pole (1)	1.0000	
mass of steel per v-brace (1)	12.0000	lbs
mass (lbs) of v-brace steel per circuit mile	300.0000	lbs
mass (kg) of v-brace steel per circuit mile	136.0777	kg

calculate mass of 1/2 in. bolts for v-braces per circuit mile

mass per bolt (1)	2.0000	lbs
bolts needed per pole (1)	3.0000	#
Mass (lbs) bolts per circuit mile	150.0000	lbs
mass (kg) bolts per circuit mile	68.0389	kg

calculate mass of insulator pins per circuit mile

mass per pin (1)	4.0000	lbs
pins needed per pole (1)	4.0000	#
Mass (lbs) pins per circuit mile	400.0000	lbs
mass (kg) pins per circuit mile	181.4369	kg

calculate total mass steel casting needed per circuit mile	419.5729	kg
calculate total mass steel casting needed per pole	16.7829	kg

Source:

(1) SCE Service Center Site Visit, Valencia, CA

Appendix 2.
Material Inventory Calculations: Underground Infrastructure & Cable

Product Summary

Reference Flow Masses for UD System
Functional Unit = one circuit mile
Default Timeframe = 1 year

# of cables UD	3	#
# of vaults	5.28	#
# of conduit cylinders	6	#
# of steel reels	3.96	#
# of ducts	1	#

Materials		
cable wire mass, aluminum alloy 1350	6734.061272	kg
cable wire mass, copper neutral	2277.957876	kg
cable compound mass, polyethylene	7407.729932	kg
cable wire mass, total	16419.74908	kg
steel flange, total mass	1698.767453	kg
steel drum, total mass	578.8468425	kg
steel reel, total mass	2277.614296	kg
steel reel with cable, total mass	18697.36338	kg
avoided burden steel reel, total mass	1,905.6040	kg
welding seam length for reels	26.5435	m
surface area of zinc coating	107.4393	m^2
vault concrete, total mass	106,065.8310	kg
vault steel rebar reinforcing, total mass	15,909.8747	kg
total reinforced vault mass per circuit mile	121,975.7057	kg
concrete duct, total mass	990,527.6628	kg
combined vault and duct concrete, total mass	1,096,593.4938	kg
total duct & vaults mass	1,112,503.3685	kg
PVC conduit, total mass	66,985.7787	kg
total volume for digging energy used	1,313.6852	m^3

Product: 1000mcm AL 17kV 220 mil single conductor UD Aluminum with Copper concentric, MV

Producer: Southwire®, http://www.southwire.com One Southwire Drive Carrollton, GA 30119
Product Choice Basis: This cable type was chosen based on high purchase volume by SCE. Moreover, this cable type has a comparable ampacity with highly used overhead cable.

Summary

distance (length of circuit)	1	mile
# of cables per circuit	3	#
total cable mass per circuit mile	16,419.7491	kg
total Al mass per circuit mile	6,734.0613	kg
total copper mass per circuit mile	2,277.9579	kg
total PE mass per circuit mile	7,407.7299	kg
combined Al & PE mass per circuit mile	14,141.7912	kg

Calculations

conversions and constants

1 pound	0.45359237	kg
1 foot	0.000189394	mile

Stock Description (1)

1000-61 MB AL 17KV 220MILS 15X12 POLYJKT/SCE

Total Feet	10,375,069	ft
Total Dollars	49,320,947	$
Total Pounds	23,710,275	lbs
Total Alum Pounds	9,724,049	lbs
Total Copper Pounds	3,289,393	lbs
Total Steel	0	lbs
Total Compound	10,696,833	lbs

	1 cable		**1 cable**		**3 cables**
	lbs/foot	**%**	**kg/foot**	**kg/mile**	**kg/mille**
Total Cable Mass	2.2853	100.0000	1.0366	5,473.2497	16,419.7491
Total Aluminum	0.9373	41.0120	0.4251	2,244.6871	6,734.0613
Total Copper	0.3170	13.8733	0.1438	759.3193	2,277.9579
Total PE Compound	1.0310	45.1148	0.4677	2,469.2433	7,407.7299

Calculate Replacement Mass from Failures

number of UD failure events per year (2)	0.1	mile
length (ft) replacement section per 1 event (3)	1000	ft
length (mi) replacement section per 1 event	0.189393939	miles
length replacement per year per mile of UD cable	0.018939394	miles
length replacement per year per mile of UD circuit	0.056818182	miles
mass UD cable per circuit mile	16,419.7491	kg/mile
mass UD cable replacement per circuit mile per year	932.9402867	kg

Source:

(1) Short, TA. (2004) Electrical Power Distribution Systems Handbook, pg. 97, CRC Press
(2) Short, TA. (2004) Electrical Power Distribution Systems Handbook, pg. 97, CRC Press
(3) Assume replacement length is average distance between two vaults.

Product: Steel Reel SW Designation S-300

Producer: Southwire®,	One Southwire Drive
http://www.southwire.com/	Carrollton, GA 30119

Product Choice Basis: This reel is used for the 1000mcm 17kV UD cable according to Southwire and SCE inventory records.

Summary

length of cable per circuit mile	15,840.0000	ft
reels per circuit mile	3.9600	#
total reel mass per circuit mile	2,277.6143	kg
total flange mass per circuit mile	1,698.7675	kg
total drum mass per circuit mile	578.8468	kg
total combined reel and cable mass per circuit mile	18,697.3634	kg
total reel mass returned per circuit mile	1,905.6040	kg
total welding seam area per circuit mile	26.5435	m
total area of zinc coating for steel products per circuit mile	107.4393	m^2

Calculations

conversions and constants

1 pound	0.45359237	kg
1 cubic inch	1.63871E-05	m^3
1 inch	0.0254	m
1 mile	5280	ft
1 square inch	0.00064516	m^2
pi	3.141592654	

estimate mass fraction of reel parts by surface area

*surface area = (2*pi*radius^2)+(2*pi*radius*height)*

flange radius (1)	48.0000	in
flange height (1)	4.0000	in
total surface area of one flange	15,682.8305	in^2
total surface area of two flanges	31,365.6611	in^2
drum radius (1)	21.0000	in
drum height (1)	60.0000	in
total surface area of drum	10,687.6982	in^2
total surface area of reel	42,053.3593	in^2
two flanges surface area fraction of total	0.7459	
drum surface area of total	0.2541	

calculate twice length drum circumference

*circumference = 2*pi*radius*

welding seam length (in) per reel	263.8938	in
welding seam length (m) per reel	6.7029	m
welding seam length per circuit mile	26.5435	m

calculate mass parts per circuit mile		
S-300 mass (lbs) per reel (1)	1,268.0000	lbs
S-300 mass (kg) per reel	575.1551	kg
total length UD 17 kV cable per circuit mile	15,840.0000	ft
length UD 17 kV per S-300 steel reel (2)	4,000.0000	ft
S-300 steel reels per circuit mile	3.9600	#
mass S-300 steel reels per circuit mile	2,277.6143	kg
mass flange steel per circuit mile	1,698.7675	kg
mass drum steel per circuit mile	578.8468	kg

calculate mass of steel reel for avoided burden		
reel shrinkage rate (2003) (2)	10	%
reel shrinkage rate (2004) (2)	14	%
reel shrinkage rate (2005) (2)	25	%
average shrinkage rate	16.33333333	%
average fraction of steel reels returned	0.836666667	
mass of reels returned (avoided burden) per circuit mile	1905.603961	kg

calculate surface area of zinc coating required		
total surface area (in^2) of each UD reel	42,053.3593	in^2
total surface area (m^2) of each UD reel	27.13114526	m^2
total surface area of UD reel per circuit mile	107.4393352	m^2

Sources:

(1) Southwire, Reel Specification Sheet:
http://www.southwire.com/Southwire/StaticFiles/Text/62-2ReelData.pdf

(2) Southwire, Personal Communication

Product: 7’x14’ Edison Precast Vault

Producer: Jensen Precast-Fontana,
http://www.jensenprecast.com/locations/Fontana
Product Choice Basis: SCE UD vault supplier

14221 San Bernardino Ave
Fontana, CA 92335-5232

Summary

vaults per circuit mile	5.2800	#
mass vault concrete per circuit mile	106,065.8310	kg
mass of (vault) steel rebar per circuit mile	15,909.8747	kg
total vault mass per circuit mile	121,975.7057	kg
mass duct & vault **concrete** per circuit mile	1,096,593.4938	kg
total mass of duct & vault materials per circuit mile	1,112,503.3685	kg

Calculations

conversions and constants		
1 pound	0.45359237	kg
1 mile	5280	ft
1 inch	0.0254	m
1 foot	0.3048	m
number of vaults per circuit mile		
average distance between vaults for UD circuit (1)	1,000.0000	ft
average vaults per circuit mile	5.2800	#
modeled vaults per circuit mile	5.2800	#
calculate mass of precast vaults materials based on average volumetric steel-to-concrete ratio		
mass per vault = 0.15 (concrete mass) + (concrete mass)		
type of vault most often used for SCE 17kV UD circuit (1)	7x14	ft
mass (lbs) each 7x14 vault (2)	50,930.0000	lbs
mass (kg) each 7x14 vault	23,101.4594	kg
volumetric fraction steel rebar per vault (3)	0.1500	
mass of concrete per vault	20,088.2256	kg
mass of steel rebar per vault	3,013.2338	kg
calculate mass of vault concrete per circuit mile		
mass of vault concrete per circuit mile	106,065.8310	kg
density reinforced concrete (4)	2,400.0000	kg/m^3
volume of vault concrete per circuit mile	44.1941	m^3
calculate mass of (vault) steel rebar per circuit mile	15,909.8747	kg

Sources:

(1) SCE Service Center Site Visit, Valencia, CA
(2) Jensen, Vault Specification Sheet: http://www.jensenprecast.com/products/pdf/utilitystructures%5Cutilityco%5Cso.%20cal.%20edison/k714-fv96-11.pdf
(3) Liu, Dalin, “Tests on high-strength rectangular concrete-filled steel hollow section stub columns,” in *Journal of Constructional Steel Research* (2005) 61: 902-911.
(4) The Physics Factbook: http://hypertextbook.com/facts/1999/KatrinaJones.shtml

Product: Concrete Duct

Producer: Unknown

Product Choice Basis: Assumed a local cement supplier for distance calculations.

Summary

ducts per circuit mile	1.0000	#
mass duct concrete per circuit mile	990,527.6628	kg
mass duct & vault **concrete** per circuit mile	1,096,593.4938	kg
total mass of duct & vault materials per circuit mile	1,112,503.3685	kg

Calculations

conversions and constants		
1 pound	0.45359237	kg
1 mile	5280	ft
1 inch	0.0254	m
1 foot	0.3048	m

calculate mass of duct concrete per circuit mile

*cubic volume = length * height * width*

cubic duct = cubic volume - cylinder volume

number of concrete ducts per circuit mile (1)	1.0000	#
length per vault (2)	14.0000	ft
total length of vaults per circuit mile	73.9200	ft
length (ft) of each concrete duct remaining per mile	5,206.0800	ft
length (m) of each concrete duct remaining per mile	1,586.8132	m
height (in) of each concrete duct (1)	19.0000	in
height (m) of each concrete duct	0.4826	m
width (in) of each concrete duct (1)	25.0000	in
width (m) of each concrete duct	0.6350	m
volume of each concrete parallelepiped	486.2805	m^3
volume of PVC cylindrical conduits (total) per circuit mile	73.5606	m^3
volume of concrete duct per circuit mile	412.7199	m^3
density of concrete (3)	2,400.0000	kg/m^3
mass of concrete duct per circuit mile	990,527.6628	kg

combined mass of vault and duct concrete per circuit mile	1,096,593.4938	kg
combined mass of vaults and ducts per circuit mile	1,112,503.3685	kg

Sources:

(1) SCE Service Center Site Visit, Valencia, CA

(2) Jensen, Vault Specification Sheet: http://www.jensenprecast.com/products/pdf/utilitystructures%5Cutilityco%5Cso.%20cal.%20edison/k714-fv96-11.pdf

(3) The Physics Factbook: http://hypertextbook.com/facts/1999/KatrinaJones.shtml

Product: PVC 5-inch DB-100 UD Conduit

Producer: Carlon & PW Eagle	Carlon: Cleveland, OH PW Eagle: Perris, CA

Product Choice Basis: This product is the most commonly used material to encase the cable for underground and the selected producers are SCE's most common suppliers.

Summary

conduits per circuit mile	6.0000	#
mass conduit PVC per circuit mile	66,985.7787	kg

Calculations

conversions and constants		
1 pound	0.45359237	kg
1 inch	0.0254	m
pi	3.141592654	
estimate mass fraction of reel parts by surface area		
*hollow cylinder volume = pi*h*((R^2)-(r^2))*		
conduits per circuit mile (1)	6.0000	#
length of each conduit per mile (h)	1,586.8132	m
conduit outer diameter (R), in (1)	5.5030	in
conduit outer diameter (R), m	0.1398	m
conduit inner diameter (r), in (1)	5.1450	in
conduit inner diameter (r), m	0.1307	m
volume per hollow conduit cylinder	12.2601	m^3
density (g/cm^3) PVC conduit (2)	0.9106	g/cm^3
density (kg/cm^3) PVC conduit	0.0009	kg/cm^3
density (kg/m^3) PVC conduit (2)	910.6200	kg/m^3
mass per hollow conduit cylinder	11,164.2964	kg
mass PVC conduit per circuit mile	66,985.7787	kg
total volume hollow conduit per circuit mile	73.5606	m^3

Sources:

1. SCE Service Center Site Visit, Valencia, CA.
2. CRC Handbook of Chemistry & Physics, 2008.

Mass: Excavation Volume

Producer: N/A

Product Choice Basis: Calculated the volume of dirt removed to install the duct, conduit, and vaults and partially doubled this amount to refill the leftover space above the duct.

Summary

volume removed for vaults	117.2182	m^3
volume removed for ducts	486.2805	m^3
volume replaced on ducts	710.1865	m^3
total volume for digging energy used	1,313.6852	m^3

Calculations

conversions and constants		
1 pound	0.45359237	kg
1 mile	1609.344	m
1 inch	0.0254	m
1 foot	0.3048	m
1 cubic foot	0.028316847	m^3
volume removed for vaults		
vault length (1)	7.0000	ft
vault width (1)	14.0000	ft
vault depth (1)	8.0000	ft
Volume (ft^3) removed for each vault	784.0000	ft^3
volume (m^3) removed for each vault	22.2004	m^3
volume removed for vaults per circuit mile	117.2182	m^3
volume removed for ducts		
length (ft) of each concrete duct remaining per mile	5,206.0800	ft
length (m) of each concrete duct remaining per mile	1,586.8132	m
height (in) of each concrete duct (2)	19.0000	in
height (m) of each concrete duct	0.4826	m
width (in) of each concrete duct (2)	25.0000	in
width (m) of each concrete duct	0.6350	m
volume of each concrete cube	486.2805	m^3
total volume removed for ducts & vaults per circuit mile	603.4986	m^3
dirt replaced on top of duct		
depth (ft) replaced (2)	3.0000	ft
depth (m) replaced	0.9144	m
width (in) replaced	19.0000	in
width (m) replaced	0.4826	m
length (mile) replace	1.0000	mile
length (m) replace	1,609.3440	m
volume to replace	710.1865	m^3
total volume to model energy used digging	1,313.6852	m^3

Sources:

1. (1) Jensen, Vault Specification Sheet
2. (2) SCE Service Center Site Visit, Valencia, CA

Appendix 3.
Process Inventory Calculations

Process: Aluminum Rod

Process name	Al Rod Alloy 1350
Producer	Southwire®, One Southwire Drive, Carrollton, Ga. 30119 USA, (770) 832-4242, http://www.southwire.com/
Process choice base	Al Rod is the precursor for Al wire

Summary

natural gas energy for melting Al ingot per kilogram Al	1.7936	MJ
electric power for rolling per kilogram Al	0.6349	MJ
mass water for cooling per kilogram Al	1.0000	kg
mass chlorine gas for metal cleaning per kg Al	0.0004	kg

Calculations

conversions and constants		
1 metric ton	1000	kg
1 therm	105.5056	MJ
1 kilowatt hour	3.6	MJ
density of water	1	g/cm^3
1 liter	1000	cm^3
1 US short ton	0.90718474	ton
calculate rod production requirements per kg Al		
natural gas energy for melting Al ingot per ton Al (1)	17.0000	therms
	1,793.5952	MJ
natural gas energy for melting Al ingot per kilogram Al	1.7936	MJ
electric power for rolling per ton Al (1)	160.0000	kWh
	576.0000	MJ
electric power for rolling per ton Al	634.9313	MJ
electric power for rolling per kilogram Al	0.6349	MJ
volume water for cooling per ton Al (1)	1,000.0000	L
volume water for cooling per kilogram Al	1.0000	L
	1,000.0000	cm^3
mass water for cooling per kilogram Al	1,000.0000	g
	1.0000	kg
mass chlorine gas for metal cleaning per ton Al (2)	360.0000	g
	0.3600	kg
mass chlorine gas for metal cleaning per kg Al	0.0004	kg

Source:

(1) Southwire, Personal Communication

(2) UNIDO, Conceptual Design Study of Aluminum Wire Drawing and Stranded Wire Production, Vienna, 1989, pg. 33.

Process: Aluminum Wire

Process name	Al Wire Alloy 1350 Drawing, Stranding & Testing
Producer	Southwire®, One Southwire Drive, Carrollton, Ga. 30119 USA, (770) 832-4242, http://www.southwire.com/
Process choice base	Al Wire is the core of the UD cable

Summary

energy required per kilogram Al	1.0151	MJ
	3,065.7943	MJ

Calculations

conversions and constants		
1 kilowatt hour	3.6	MJ
1 pound	0.45359237	kg
calculate energy requirements per kg Al		
energy required per pound Al (1)	0.1279	kWh
	0.4604	MJ
energy required per kilogram Al	1.0151	MJ

Source:

(1) Southwire, Personal Communication

Process: Copper Rod

Process name	Cu Rod
Producer	Southwire®, One Southwire Drive, Carrollton, Ga. 30119 USA, (770) 832-4242, http://www.southwire.com/
Process choice base	Cu Rod is the precursor for Cu wire

Summary

natural gas energy for melting Cu ingot per kilogram Cu	0.0014	MJ
electric power for rolling per kilogram Cu	0.2592	MJ
mass water for cooling per kilogram Cu	1.0000	kg
mass IPA for metal cleaning per kg Cu	0.0904	kg

Calculations

conversions and constants		
1 metric ton	1000	kg
1 kilocalorie	0.004148	MJ
1 kilowatt hour	3.6	MJ
density of water	1	g/cm^3
1 liter	1000	cm^3
1 US short ton	0.90718474	ton
calculate rod production requirements per kg Cu		
natural gas energy for melting Cu ingot per ton Cu (1)	330.0000	kcal
	1.3688	MJ
natural gas energy for melting Cu ingot per kilogram Cu (1)	0.0014	MJ
electric power for rolling per ton Cu	72.0000	kWh
	259.2000	MJ
electric power for rolling per kilogram Cu	0.2592	MJ
volume water for cooling per ton Cu (1)	1,000.0000	L
volume water for cooling per kilogram Cu	1.0000	L
	1,000.0000	cm^3
mass water for cooling per kilogram Cu	1,000.0000	g
	1.0000	kg
volume IPA for metal cleaning per ton Cu	115.0000	L
density IPA (2)	0.00078600	kg/L
mass IPA for metal cleaning per kg Cu	0.0904	kg

Source:

(1) Southwire, Personal Communication
(2) Density of IPA, http://en.wikipedia.org/wiki/Isopropyl_alcohol

Process: Copper Wire

Process name	Cu Wire Drawing, Stranding & Testing
Producer	Southwire®, One Southwire Drive, Carrollton, Ga. 30119 USA, (770) 832-4242, http://www.southwire.com/
Process choice base	Cu Wire is the neutral for the UD cable

Summary

energy required per kilogram Cu	0.5714	MJ

Calculations

conversions and constants		
1 kilowatt hour	3.6	MJ
1 pound	0.45359237	kg
calculate energy requirements per kg Al		
energy required per pound Cu (1)	0.0720	kWh
	0.2592	MJ
energy required per kilogram Cu	0.5714	MJ

Source:

(1) Southwire, Personal Communication

Process: Cable Extrusion

Process name	Triple Extrusion with Maillefer Extrusion Machine Model MEH 60-30D
Producer	Southwire®, One Southwire Drive, Carrollton, Ga. 30119 USA, (770) 832-4242, http://www.southwire.com
Process choice base	This process is used to produce the UD cable.

Summary

distance (length of circuit)	1	mile
# of cables per circuit	3	#
total cable mass per circuit mile	16,419.7491	kg
total Al mass per circuit mile	6,734.0613	kg
total copper mass per circuit mile	2,277.9579	kg
total PE mass per circuit mile	7,407.7299	kg
length of cable per circuit mile	15,840.00	ft
PE scrap per circuit length	30.79244203	kg
energy consumed per circuit length	1390.757143	MJ

Calculations

conversions and constants

1 pound	0.45359237	kg
1 foot	0.000189394	mile
1 foot	0.3048	meters
1 electrical horsepower (1)	746	W
Min Nominal Efficiency 145hp electrical Motor (2)	92.4%	

material inventory

length of cable extruded per circuit mile	15,840	ft
production run (3)	175000	ft
production runs per circuit length	0.090514286	#
PE scrap per production run (3)	750	lbs
	340.1942775	kg
PE scrap per circuit length	30.79244203	kg

energy inventory (*using 145-hp AC motor)*

Maillefer extrusion (model MEH 60-30D) motor (4)	145	hp
	108170	Watt
Motor max power	108170	J/s
	97353000	J/hr
	97.353	MJ/hr
energy consumed by motor	105.3603896	MJ/hr
energy consumed per circuit length	1390.757143	MJ

Source:

(1) Horsepower conversions, Wikipedia: http://en.wikipedia.org/wiki/Horsepower]

(2) Engineering Toolbox: http://www.engineeringtoolbox.com/electrical-motor-efficiency-d_655.html

(3) Southwire, Personal Communication

(4) Schut JH. (2009). K 2004 Wrap-Up: Extrusion: Extruder Outputs Rise, Downstream Units Gain Flexibility, Plastics Technology, URL: http://www.ptonline.com/articles/200501fa3.html.

Process: Cable Baling

Process name	Cable Baling Machine Energy Requirements (HRB-1035W-BR 200T Baler)
Producer	Alpert & Alpert Metals
Process choice base	Cable Baling Machine used by the company

Summary

energy required for baling	0.0147710	MJ/kg

Calculations

conversions and constants

1 kilograms	2.20462262	pounds
1 kilowatt	1000	Watt
1 ton	2000	kilograms

Energy required for baling

average baling power consumption (1)	201	kilowatts
average baling power consumption	201000	Watt
	201000	J/sec
	723600000	J/hour
	723.6	MJ/hour
processing capacity (2)	45	bales/hour
mass of each bale (2)	2400	lbs
	1088.621689	kg
processing capacity	48987.976	kg/hour
	2.04132E-05	hour/kg
	0.014770972	MJ/kg

Source:

1. (1) Power Requirements for HRB-1035W-BR 200T, Harris Waste Management Group Incorporated, 315 W 12th Avenue, Cordele, GA 31015, Phone: 229-273-2500, Fax: 229-273-8791.
2. (2) Personal Communication with A. Greg Tellier, Director of Ferrous & Utilities, Alpert & Alpert Iron & Metal, Incorporated.

Process: Cable Chopping

Process name	Cable Chopping Machine Energy Requirements (ELDAN Super Chopper SC2118-II)
Producer	China cable chopping facility contracted by Alpert & Alpert Metals
Process choice base	Metal content ensures cable recycling, selected widely used cable chopper model with capacity appropriate to one of 6-7 large cable chopping facilities in China

Summary

energy required for chopping	0.0193	MJ/kg

Calculations

Conversion factors and constants		
1 kilowatt	1000	Watt
average engine utilization rate	75%	
1 ton	2000	kilograms
Energy required for cable chopping		
chopper engine (2 * 250kW engines) (1)	500	kilowatts
chopper engine (2 * 250kW engines)	500000	Watt
engine max power	500000	J/sec
engine average power	375000	J/sec
	1350000000	J/hour
	1350	MJ/hour
processing capacity (1)	35	tons/hour
	0.028571429	hours/ton
energy per cable mass	38.57142857	MJ/ton
	0.019285714	MJ/kg

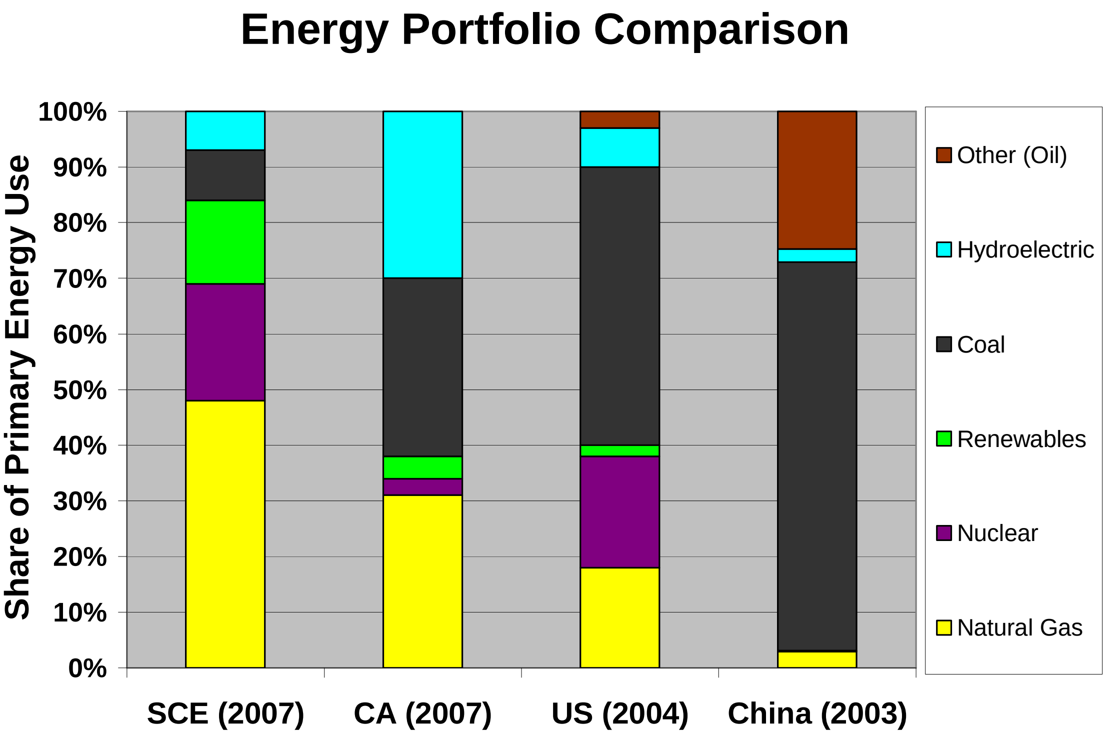
Source:

(1) Eldan twin-rotor Super Chopper SC2118-II specifications, Eldan Recycling A/S: http://www.waste-management-world.com/display_article/308174/123/ARCH/none/none/1/Product-news/

Appendix 4.
Energy Input Inventory

Energy Portfolio Comparison

	Percentage Total Generation			
	SCE 2007 (1)	CA 2007 (1)	US 2004 (2)	China 2003 (3)
Natural Gas	48	31	18	2.9
Nuclear	21	3	20	0.2
Renewables	15	4	2	0
Coal	9	32	50	69.8
Hydroelectric	7	30	7	2.4
Other (Oil)	0	0	3	24.7
Total	100	100	100	100



Source:

1. Power Content Labels, California Energy Commission, Contact: 1-800-555-7794, http://www.energy.ca.gov/consumer.
2. Energy Information Administrator's Electric Power Annual, November 2005.
3. Energy in China: Transportation, Electric Power & Fuel Markets, Asia Pacific Energy Research Centre, 2004.

Appendix 5.
Use Phase Transportation Distance Calculations

Central SCE Warehouse Selection

Summary

warehouse locations	Alhambra, CA***** Irwindale, CA San Clemente, CA Santa Ana, CA Ventura, CA Westminster, CA

*****Chosen central SCE warehouse location based on distances from SCE service area boundaries

Map of 6 SCE Warehouses & Chosen Central Warehouse

Source:
1. (1) SCE, Personal Communication
2. (2) Google Maps

SCE Service Center Locations

Summary

service center locations	*approximate distance from central SCE warehouse (km)*
Avalon, CA	
Barstow, CA	
Bishop, CA*	440
Blythe, CA*	350
Cathedral City, CA	
Compton, CA**	34
Fontana, CA	
Fullerton, CA	
Goleta, CA*	180
Irvine, CA	
Lancaster, CA	
Long Beach, CA	
Monrovia, CA**	17
Monterey Park, CA**	6
Ontario, CA	
Redlands, CA	
Ridgecrest, CA*	248
Rimforest, CA	
San Dimas, CA	
San Jacinto, CA**	38
Santa Ana, CA	
Santa Fe Springs, CA**	28
Santa Monica, CA**	40
Shaver Lake, CA*	438
Tehachapi, CA	
Thousand Oaks, CA	
Torrance, CA	
Tulare, CA*	288
Valencia, CA	
Ventura, CA	
Victorville, CA	
Wofford Heights, CA	

*6 furthest SCE Service Centers from **c**hosen central SCE warehouse in Alhambra, CA

******6 closest SCE Service Centers from chosen central SCE warehouse in Alhambra, CA

Source:

1. SCE, Personal Communication
2. Google Maps

Calculation of Distance from SCE Central Warehouse to Generic SCE Service Center and/or Generic SCE Installation Site

Summary

distance from SCE central warehouse to generic SCE service center and/or generic SCE installation site	175.5	km

Calculations

calculate average distance from Alhambra, CA to 6 furthest SCE service centers

(440km + 350km + 180km + 248km + 438km + 288km) / 6 = 324 km

calculate average distance from Alhambra, CA to 6 closet SCE service centers

(34km + 17km + 6km + 38km + 28km + 40km) / 6 = 27 km

calculate distance from SCE central warehouse to SCE service center and/or generic SCE installation site

(324km + 27km) / 2 = 175.5 km

Calculation of Distance from Generic SCE Service Center to Generic SCE Installation Site

Summary

distance from generic SCE service center to generic SCE installation site	31.6	km

Calculations

conversions and constants

1 mile	1.6	km

calculate distance from generic SCE service center to generic SCE installation site

area of SCE service center	50,000	mi^2
number of SCE service centers	32	#
approximate area per SCE service center	1,562.5	mi^2
approximate side length of square area per SCE service center	39.5	mi
	63.2	km

assuming generic SCE service center is at center of associated square area, average driving distance to everywhere within the square is ½ of the approximate side length:

approximate distance from generic SCE service center to generic SCE installation site	31.6	km

Source:

(1) SCE, Personal Communication
(2) SCE service area size: http://www.sce.com/AboutSCE/CompanyOverview/

Calculation of Use Phase Roadway Percentages - Distance from SCE Central Warehouse to Generic SCE Service Center and/or Generic SCE Installation Site

Summary		
% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%

Source:

(1) GaBi 4.3 averages

Calculation of Use Phase Roadway Percentages - Distance from Generic SCE Service Center to Generic SCE Installation Site

Summary		
% on motorway (traveling at 82 km/hr)	10	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	75	%

Source:

(1) Google Maps

Appendix 6.
Transportation Parameters Inventory

All Phases:
Proportion of Sulfur in Diesel Fuel for All Transportation Parameters Modeled

Summary

proportion of sulfur in diesel fuel	15	ppm

Source:

1. EPA: http://www.epa.gov/fedrgstr/EPA-AIR/2006/May/Day-01/a3930.htm
2. Google Maps

All Phases:
Payload Utilization Ratio for All Truck Transportation Parameters Modeled

Summary

Payload utilization ratios were calculated based on vehicle total capacities and mass of cargo – scaled appropriately based on number of trips made full/empty, etc.

Production Phase:
Truck Trailer Transport of Wooden Crossarms from Bellingham, WA to SCE Warehouse in Alhambra, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 32t total cap. / 22t payload / Euro 4
start location	Bellingham, WA
end location	Alhambra, CA

Calculations

% on motorway (traveling at 82 km/hr)	97	%
% outside of town (traveling at 70 km/hr)	2	%
% within town (traveling at 27 km/hr)	1	%
total distance traveled	1,992	km
payload utilization ratio	82	%

Source:

1. Brooks Manufacturing Company, Personal Communication
2. Google Maps
3. GaBi 4.3

Production Phase:
Truck Transport of Polyethylene (PE) Insulators from Milford, NH to SCE Warehouse in Alhambra, CA

Summary

GaBi 4.3 transportation selection	Truck from 32t total cap. / 24.7t payload / Euro 4
start location	Milford, NH
end location	Alhambra, CA

Calculations

% on motorway (traveling at 82 km/hr)	98	%
% outside of town (traveling at 70 km/hr)	1	%
% within town (traveling at 27 km/hr)	1	%
total distance traveled	4,706	km
payload utilization ratio	75	%

Source:
(1) Hendrix Wire & Cable, Inc., Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of Steel Castings from Hayward, CA to SCE Warehouse in Alhambra, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28 - 34 t total cap./ 22 t payload / Euro 4
start location	Hayward, CA
end location	Alhambra, CA

Calculations

% on motorway (traveling at 82 km/hr)	96	%
% outside of town (traveling at 70 km/hr)	3	%
% within town (traveling at 27 km/hr)	1	%
total distance traveled	609	km
payload utilization ratio	85	%

Source:
(1) Kortick Manufacturing, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase: Truck Transport of Aluminum Ingot within Southwire - Hawesville, KY

Summary

GaBi 4.3 transportation selection	Truck 7.5t - 12t total cap. / 5t payload / Euro 3 (local)
start location	Hawesville, KY
end location	Hawesville, KY

Calculations

% on motorway (traveling at 82 km/hr)	0	%
% outside of town (traveling at 70 km/hr)	0	%
% within town (traveling at 27 km/hr)	100	%
total distance traveled	.46	km
payload utilization ratio	5	%

Source:

(1) Southwire Company, Personal Communication
(2) GaBi 4.3

Production Phase: Truck Trailer Transport of OH Aluminum Wire from Hawesville, KY to Flora, IL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22 t payload / Euro 4
start location	Hawesville, KY
end location	Flora, IL

Calculations

% on motorway (traveling at 82 km/hr)	48	%
% outside of town (traveling at 70 km/hr)	46	%
% within town (traveling at 27 km/hr)	6	%
total distance traveled	254.28	km
payload utilization ratio	85	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of Steel Wire from Niles, MI to Flora, IL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Niles, MI
end location	Flora, IL

Calculations

% on motorway (traveling at 82 km/hr)	80	%
% outside of town (traveling at 70 km/hr)	16	%
% within town (traveling at 27 km/hr)	4	%
total distance traveled	490.4	km
payload utilization ratio	85	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of Steel Billet from Decatur, AL/Birmingham, AL to Hartselle, AL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Decatur, AL & Birmingham, AL
end location	Hartselle, AL

Calculations

% on motorway (traveling at 82 km/hr)	85	%
% outside of town (traveling at 70 km/hr)	10	%
% within town (traveling at 27 km/hr)	5	%
total distance traveled	72.45	km
payload utilization ratio	85	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase: Truck Trailer Transport of Steel Sheet from Decatur, AL/Birmingham, AL to Hartselle, AL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Decatur, AL & Birmingham, AL
end location	Hartselle, AL

Calculations

% on motorway (traveling at 82 km/hr)	85	%
% outside of town (traveling at 70 km/hr)	10	%
% within town (traveling at 27 km/hr)	5	%
total distance traveled	72.45	km
payload utilization ratio	85	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase: Truck Trailer Transport of OH Steel Reel from Hartselle, AL to Flora, IL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Hartselle, AL
end location	Flora, IL

Calculations

% on motorway (traveling at 82 km/hr)	70	%
% outside of town (traveling at 70 km/hr)	20	%
% within town (traveling at 27 km/hr)	10	%
total distance traveled	595	km
payload utilization ratio	7.578	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of OH Cable on Steel Reel from Flora, IL to Distributor in Villa Rica, GA to Southwire - Rancho Cucamonga, CA to SCE Warehouse – Alhambra, CA to Generic SCE Service Center

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Flora, IL → Villa Rica, GA → Rancho Cucamonga, CA
end location	Rancho Cucamonga, CA → Alhambra, CA → generic SCE service center

Calculations

% on motorway (traveling at 82 km/hr)	85	%
% outside of town (traveling at 70 km/hr)	10	%
% within town (traveling at 27 km/hr)	5	%
total distance traveled	3,867.68	km
payload utilization ratio	85	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of Wooden Utility Pole from Eugene, OR to Alhambra, CA

Summary

GaBi 4.3 transportation selection	Truck trailer > 34 - 40t total cap. / 27t payload / Euro 4
start location	Eugene, OR
end location	Alhambra, CA

Calculations

% on motorway (traveling at 82 km/hr)	98	%
% outside of town (traveling at 70 km/hr)	1	%
% within town (traveling at 27 km/hr)	1	%
total distance traveled	1,381	km
payload utilization ratio	85	%

Source:

(1) McFarland-Cascade, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Rail Transport of Wooden Utility Pole from Eugene, OR to Alhambra, CA

Summary

GaBi 4.3 transportation selection	Rail transport cargo - Diesel
start location	Eugene, OR
end location	Alhambra, CA

Calculations

total distance traveled	1,381	km
payload utilization ratio	60	%

Source:

1. McFarland-Cascade, Personal Communication
2. Google Maps
3. GaBi 4.3

Production Phase:
Boat Transport of Copper Cathode from Top 10 Global Copper Mines to Panama City, FL

Summary

GaBi 4.3 transportation selection	Bulk commodity carrier (average) / ocean ELCD
start location	Top 10 global copper mine locations
end location	Panama City, FL

Calculations

total distance traveled	9,390.38	km
dead weight tons	105,000	tons

Source:

1. Global Info Mine: http://www.infomine.com/commodities/copper.asp
2. Port-to-port distances: http://www.maritimechain.com/port/port_distance.asp
3. GaBi 4.3

Production Phase:
Truck Trailer Transport of Copper Cathode from Panama City, FL to Carrollton, GA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Panama City, FL
end location	Carrollton, GA

Calculations

% on motorway (traveling at 82 km/hr)	84	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	1	%
total distance traveled	445.8	km
payload utilization ratio	90.7	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Transport of Copper Rod within Southwire – Carrollton, GA

Summary

GaBi 4.3 transportation selection	Truck from 32t total cap. / 24.7t payload / Euro 4
start location	Carrollton, GA
end location	Carrollton, GA

Calculations

% on motorway (traveling at 82 km/hr)	0	%
% outside of town (traveling at 70 km/hr)	0	%
% within town (traveling at 27 km/hr)	100	%
total distance traveled	0.55	km
payload utilization ratio	91.8	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of Copper Wire from Carrollton, GA to Heflin, AL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Carrollton, GA
end location	Heflin, AL

Calculations

% on motorway (traveling at 82 km/hr)	58	%
% outside of town (traveling at 70 km/hr)	7	%
% within town (traveling at 27 km/hr)	35	%
total distance traveled	72.7	km
payload utilization ratio	91	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of UG Aluminum Wire from Hawesville, KY to Heflin, AL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22 t payload / Euro 4
start location	Hawesville, KY
end location	Heflin, AL

Calculations

% on motorway (traveling at 82 km/hr)	61	%
% outside of town (traveling at 70 km/hr)	34	%
% within town (traveling at 27 km/hr)	5	%
total distance traveled	613.18	km
payload utilization ratio	85	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase: Rail Transport of PE from Sea Drift, TX to Carrollton, GA

Summary

GaBi 4.3 transportation selection	Rail transport cargo - Diesel
start location	Sea Drift, TX
end location	Carrollton, GA

Calculations

total distance traveled	1,475.77	km
payload utilization ratio	60	%

Source:

(1) Southwire, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase: Truck Trailer Transport of PE from Carrollton, GA to Heflin, AL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22 t payload / Euro 4
start location	Carrollton, GA
end location	Heflin, AL

Calculations

% on motorway (traveling at 82 km/hr)	58	%
% outside of town (traveling at 70 km/hr)	7	%
% within town (traveling at 27 km/hr)	35	%
total distance traveled	72.7	km
payload utilization ratio	85	%

Source:

(1) Southwire Company, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of UG Steel Reel from Hartselle, AL to Heflin, AL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Hartselle, AL
end location	Heflin, AL

Calculations

% on motorway (traveling at 82 km/hr)	86	%
% outside of town (traveling at 70 km/hr)	8	%
% within town (traveling at 27 km/hr)	6	%
total distance traveled	231	km
payload utilization ratio	7.686	%

Source:

1. Southwire Company, Personal Communication
2. Google Maps
3. GaBi 4.3

Production Phase:
Rail Transport of UG Cable on Steel Reel from Heflin, AL to Southwire – Rancho Cucamonga, CA

Summary

GaBi 4.3 transportation selection	Rail transport cargo - Diesel
start location	Heflin, AL
end location	Rancho Cucamonga, CA

Calculations

total distance traveled	3,316.9	km
payload utilization ratio	60	%

Source:

1. Southwire, Personal Communication
2. Google Maps
3. GaBi 4.3

Production Phase:
Truck Trailer Transport of UG Cable and Steel Reel from Southwire – Rancho Cucamonga, CA to SCE Warehouse – Alhambra, CA to Generic SCE Service Center

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Rancho Cucamonga, CA → Alhambra, CA
end location	Generic SCE service center

Calculations

% on motorway (traveling at 82 km/hr)	91	%
% outside of town (traveling at 70 km/hr)	0	%
% within town (traveling at 27 km/hr)	9	%
total distance traveled	233.5	km
payload utilization ratio	85	%

Source:

1. Southwire Company, Personal Communication
2. Google Maps
3. GaBi 4.3

Production Phase:
Truck Trailer Transport of Polyvinyl Chloride (PVC) Conduit from Perris, CA & Cleveland, OH to Alhambra, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22 t payload / Euro 4
start location	Perris, CA & Cleveland, OH
end location	Alhambra, CA

Calculations

% on motorway (traveling at 82 km/hr)	92.5	%
% outside of town (traveling at 70 km/hr)	5.25	%
% within town (traveling at 27 km/hr)	2.25	%
total distance traveled	1,919.45	km
payload utilization ratio	85	%

Source:

1. Carlon, Personal Communication
2. PW Eagle, Inc., Personal Communication
3. Google Maps
4. GaBi 4.3

Production Phase:
Truck Trailer Transport of Reinforced Concrete Vaults from San Marcos, CA & Fontana, CA to SCE Warehouse – Alhambra, CA to Generic SCE Service Center to SCE Generic Installation Site

Summary

GaBi 4.3 transportation selection	Truck trailer 34t - 40t total cap / 27t payload / Euro 4
start location	San Marcos, CA & Fontana, CA → Alhambra, CA
end location	Generic SCE service center → SCE generic installation site

Calculations

% on motorway (traveling at 82 km/hr)	30	%
% outside of town (traveling at 70 km/hr)	40	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	287.4	km
payload utilization ratio	85	%

Source:
(1) Jensen Precast, Personal Communication
(2) Google Maps
(3) GaBi 4.3

Production Phase:
Truck Trailer Transport of Cement from Cement Plant to Generic SCE Installation Site

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22 t payload / Euro 4
start location	Generic southern California cement plant
end location	Generic SCE installation site

Calculations

% on motorway (traveling at 82 km/hr)	0	%
% outside of town (traveling at 70 km/hr)	50	%
% within town (traveling at 27 km/hr)	50	%
total distance traveled	64.37	km
payload utilization ratio	42.5	%

Source:
(1) Independent research
(2) Google Maps
(3) GaBi 4.3

Use Phase:
Truck Trailer Transport of OH Cable on Steel Reel from Generic SCE Service Center to Generic SCE Installation Site

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE service center
end location	Generic SCE installation site

Calculations

% on motorway (traveling at 82 km/hr)	10	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	75	%
total distance traveled	127.12	km
payload utilization ratio	42.5	%

Source:
1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Use Phase:
Truck Transport of Wooden Crossarms from Generic SCE Service Center to Generic SCE Installation Site

Summary

GaBi 4.3 transportation selection	Truck up to 7.5t total cap. / 3.3t payload / Euro 4
start location	Generic SCE service center
end location	Generic SCE installation site

Calculations

% on motorway (traveling at 82 km/hr)	10	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	75	%
total distance traveled	190.68	km
payload utilization ratio	16.35	%

Source:
1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Use Phase:
Truck Transport of PE Insulators from Generic SCE Service Center to Generic SCE Installation Site

Summary

GaBi 4.3 transportation selection	Truck up to 7.5t total cap. / 3.3t payload / Euro 4
start location	Generic SCE service center
end location	Generic SCE installation site

Calculations

% on motorway (traveling at 82 km/hr)	10	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	75	%
total distance traveled	190.68	km
payload utilization ratio	16.35	%

Source:
1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Use Phase:
Truck Transport of Steel Castings from Generic SCE Service Center to Generic SCE Installation Site

Summary

GaBi 4.3 transportation selection	Truck up to 7.5t total cap. / 3.3t payload / Euro 4
start location	Generic SCE service center
end location	Generic SCE installation site

Calculations

% on motorway (traveling at 82 km/hr)	10	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	75	%
total distance traveled	190.68	km
payload utilization ratio	16.35	%

Source:
1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Use Phase:
Truck Trailer Transport of Wooden Utility Poles from SCE Warehouse – Alhambra, CA to Generic SCE Installation Site

Summary

GaBi 4.3 transportation selection	Truck trailer > 34t - 40t total cap. / 27t payload / Euro 4
start location	Alhambra, CA
end location	Generic SCE installation site

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	175.5	km
payload utilization ratio	80	%

Source:
1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Use Phase:
Truck Trailer Transport of OH Cable Scrap from Generic SCE Installation Site to Alpert & Alpert – Long Beach, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE installation site
end location	Long Beach, CA

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	217.9	km
payload utilization ratio	85	%

Source:
1. SCE, Personal Communication
2. Alpert & Alpert Iron & Metal, Inc., Personal Communication
3. Google Maps
4. GaBi 4.3

Use Phase:
Truck Trailer Transport of PE Insulators from Generic SCE Installation Site to Alpert & Alpert – Long Beach, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE installation site
end location	Long Beach, CA

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	217.9	km
payload utilization ratio	85	%

Source:

(1) SCE, Personal Communication
(2) Alpert & Alpert Iron & Metal, Inc., Personal Communication
(3) Google Maps
(4) GaBi 4.3

Use Phase:
Truck Trailer Transport of Wooden Utility Poles & Crossarms from Generic SCE Installation Site to Alpert & Alpert – Long Beach, CA

Summary

GaBi 4.3 transportation selection	Truck trailer > 34t - 40t total cap. / 27t payload / Euro 4
start location	Generic SCE installation site
end location	Long Beach, CA

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	217.9	km
payload utilization ratio	85	%

Source:

(1) SCE, Personal Communication
(2) Alpert & Alpert Iron & Metal, Inc., Personal Communication
(3) Google Maps
(4) GaBi 4.3

Use Phase:
Truck Trailer Transport of Steel Castings from Generic SCE Installation Site to Alpert & Alpert – Long Beach, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE installation site
end location	Long Beach, CA

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	217.9	km
payload utilization ratio	85	%

Source:

(1) SCE, Personal Communication
(2) Alpert & Alpert Iron & Metal, Inc., Personal Communication
(3) Google Maps
(4) GaBi 4.3

Use Phase:
Truck Trailer Transport of Empty OH Steel Reel from Generic SCE Service Center to SCE Warehouse – Alhambra, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE installation site
end location	Long Beach, CA

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	175.5	km
payload utilization ratio	7.578	%

Source:

(1) SCE, Personal Communication
(2) Southwire, Personal Communication
(3) Google Maps
(4) GaBi 4.3

Use Phase:
Truck Trailer Transport of Tree Trimming Wastes from Generic SCE Installation Site to Incinerator – Coachella, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE installation site
end location	Coachella, CA

Calculations

% on motorway (traveling at 82 km/hr)	92	%
% outside of town (traveling at 70 km/hr)	7	%
% within town (traveling at 27 km/hr)	1	%
total distance traveled	391.4	km
payload utilization ratio	85	%

Source:

1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Use Phase:
Truck Trailer Transport of UG Cable on Steel Reel from Generic SCE Service Center to Generic SCE Installation Site

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE service center
end location	Generic SCE installation site

Calculations

% on motorway (traveling at 82 km/hr)	10	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	75	%
total distance traveled	63.56	km
payload utilization ratio	42.5	%

Source:

1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Use Phase:
Truck Trailer Transport of PVC Conduit from SCE Warehouse – Alhambra, CA to Generic SCE Installation Site

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Alhambra, CA
end location	Generic SCE installation site

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	175.5	km
payload utilization ratio	85	%

Source:
1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Use Phase:
Truck Trailer Transport of UG Cable Scrap from Generic SCE Installation Site to Alpert & Alpert – Long Beach, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE installation site
end location	Long Beach, CA

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	217.9	km
payload utilization ratio	85	%

Source:
1. SCE, Personal Communication
2. Alpert & Alpert Iron & Metal, Inc., Personal Communication
3. Google Maps
4. GaBi 4.3

Use Phase:
Truck Trailer Transport of Empty UG Steel Reel from Generic SCE Installation Site to SCE Warehouse – Alhambra, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Generic SCE installation site
end location	Alhambra, CA

Calculations

% on motorway (traveling at 82 km/hr)	27	%
% outside of town (traveling at 70 km/hr)	43	%
% within town (traveling at 27 km/hr)	30	%
total distance traveled	175.5	km
payload utilization ratio	7.686	%

Source:

1. SCE, Personal Communication
2. Southwire Company, Personal Communication
3. Google Maps
4. GaBi 4.3

EOL Phase:
Truck Trailer Transport of OH Empty Steel Reels from SCE Warehouse – Alhambra, CA to Southwire – Flora, IL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Alhambra, CA
end location	Flora, IL

Calculations

% on motorway (traveling at 82 km/hr)	96	%
% outside of town (traveling at 70 km/hr)	4	%
% within town (traveling at 27 km/hr)	0	%
total distance traveled	3,089	km
payload utilization ratio	7.578	%

Source:

1. Southwire Company, Personal Communication
2. Google Maps
3. GaBi 4.3

EOL Phase:
Truck Trailer Transport of Bailed Cable Scrap from Alpert & Alpert – Long Beach, CA to Port of Los Angeles, CA

Summary

GaBi 4.3 transportation selection	Truck trailer > 34t - 40t total cap. / 27t payload / Euro 4
start location	Long Beach, CA
end location	Port of Los Angeles, CA

Calculations

% on motorway (traveling at 82 km/hr)	25	%
% outside of town (traveling at 70 km/hr)	12.5	%
% within town (traveling at 27 km/hr)	62.5	%
total distance traveled	8	km
payload utilization ratio	100	%

Source:

(1) Alpert & Alpert Iron & Metal, Inc., Personal Communication
(2) Google Maps
(3) GaBi 4.3

EOL Phase:
Boat Transport of Bailed Cable Scrap from Port of Los Angeles, CA to China

Summary

GaBi 4.3 transportation selection	Bulk commodity carrier (average) / ocean ELCD
start location	Port of Los Angeles, CA
end location	China

Calculations

total distance traveled	10,758.27	km
dead weight tons	105,000	tons

Source:

(1) Port-to-port distances: http://www.maritimechain.com/port/port_distance.asp
(2) SCE, Personal Communication
(3) GaBi 4.3

EOL Phase:
Truck Trailer Transport of Wooden Utility Poles, Crossarms, Steel Castings, and PE Insulators from Alpert & Alpert – Long Beach, CA to Landfill - Puente Hills, CA & Landfill – Simi Valley, CA

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap. / 22t payload / Euro 4
start location	Long Beach, CA
end location	Puente Hills, CA & Simi Valley, CA

Calculations

% on motorway (traveling at 82 km/hr)	93.45	%
% outside of town (traveling at 70 km/hr)	2.05	%
% within town (traveling at 27 km/hr)	4.5	%
total distance traveled	71.1	km
payload utilization ratio	21.765	%

Source:
1. Alpert & Alpert Iron & Metal, Inc., Personal Communication
2. Google Maps
3. GaBi 4.3

EOL Phase:
Truck Trailer Transport of Empty UG Steel Reels from SCE Warehouse – Alhambra, CA to Southwire – Heflin, AL

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Alhambra, CA
end location	Heflin, AL

Calculations

% on motorway (traveling at 82 km/hr)	97	%
% outside of town (traveling at 70 km/hr)	1	%
% within town (traveling at 27 km/hr)	2	%
total distance traveled	3,368	km
payload utilization ratio	7.686	%

Source:
1. Southwire Company, Personal Communication
2. Google Maps
3. GaBi 4.3

EOL Phase:
Truck Trailer Transport of Concrete Vaults & Ducts from Generic SCE Installation Site to Landfill

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Alhambra, CA
end location	Southern California landfill

Calculations

% on motorway (traveling at 82 km/hr)	10	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	75	%
total distance traveled	26.12	km
payload utilization ratio	85	%

Source:
1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

EOL Phase:
Truck Trailer Transport of PVC Conduit from Generic SCE Installation Site to Landfill

Summary

GaBi 4.3 transportation selection	Truck trailer 28t - 34t total cap./ 22t payload / Euro 4
start location	Alhambra, CA
end location	Generic southern California landfill

Calculations

% on motorway (traveling at 82 km/hr)	10	%
% outside of town (traveling at 70 km/hr)	15	%
% within town (traveling at 27 km/hr)	75	%
total distance traveled	26.12	km
payload utilization ratio	85	%

Source:
1. SCE, Personal Communication
2. Google Maps
3. GaBi 4.3

Appendix 7.
Use Phase Utility Vehicle Distance & Auxiliary Energy Consumption

OVERHEAD	diesel consumed (kg)	dummy cargo weight (kg)	% total cargo for sub process	GaBi vehicle selected
Maintenance activities				
Tree trims incineration	GaBi process	GaBi process	N/A	GaBi process
Tree trimming	19.553	10,102	1.00	truck 20-26 t total cap./17.3 t payload/Euro 4
Scheduled maintenance	10.385	2,775	0.27	solo truck 7.5 t total cap./3.3 t payload/Euro 3
Cable installation/decommissioning				
Rope pulling	284.215	170,950	16.93	truck-trailer 28-34 t total cap./22 t payload/Euro 4
Aerial lifting	587.423	303,643	30.08	truck 20-26 t total cap./17.3 t payload/Euro 4
Infrastructure installation/decommissioning				
Pole assembly installation/decommissioning	926.669	522,080	51.71	truck 20-26 t total cap./22 t payload/Euro 4
Excavation (see mass calculations for volume)	GaBi process	GaBi process	N/A	GaBi process
Total for Overhead	1,828.245	1,009,550	100.00	

UNDERGROUND	diesel consumed (kg)	dummy cargo weight (kg)	% total cargo for sub process	GaBi vehicle selected
Maintenance activities				
Pumping vault water	1.798	484	0.06	Up to 7.5 t total cap./3.3 t payload/Euro 3
Scheduled maintenance	13.847	3,741	0.44	Up to 7.5 t total cap./3.3 t payload/Euro 3
Cable installation/decommissioning				
Cable puller driving	58.040	35,980	4.19	truck trailer, 34-40 t total cap/27 t payload/Euro 4
Make-up crew driving	110.790	29,680	3.46	Solo truck up to 7.5t total cap./3.3t payload/Euro3 (short-distance)
Cable puller idling	985.019	592,495	69.01	truck trailer 28-34 t total cap./22 t payload/Euro 4
Infrastructure installation/decommissioning				
Excavation (see mass calculations for volume)	GaBi process	GaBi process	N/A	GaBi process
Placing vaults & laying duct	326.074	196,135	22.85	truck trailer 28-34 t total cap./22 t payload/Euro 4
Total for Underground	1,495.568	858,515	100.00	

Assumptions:

- Utilization ratio of engine during idle work is 75%
- Efficiency of internal combustion engine is 37%
- Installation idling diesel consumption is equal to de-installation diesel consumption (except in Overhead: pole installation energy greater than pole decommission energy and in Underground: concrete truck mixer for installation, crusher for decommissioning)
- Emission profile of engine for water pumping is approximately the same as one of the maintenance truck (3.3 payload)
- Average emission profile of all big trucks for infrastructure installation is same as of the truck trailer 28 - 34 t total cap. / 22 t payload / Euro 4

Process: Overhead installation and decommissioning idling energy Summary

Producer	Southern California Edison and/or contractors
Process choice base	The sub-processes were selected based on interviews with SCE engineers and on literature values

OH Installation Summary

Process	Vehicle	# Vehicles	Process Time	Total Hours	Fuel Notes	fuel use idling rate (gal/hr)	total fuel needed (gallons)	(kg)	Truck type in GaBi	Cargo, kg (w/default parameters)
infrastructure										
assemble poles	Man power	none	3 days	24		N/A			N/A	
dig pole holes & set poles	derrick digger	2	3 days	48	PTO	4 (1)	192	617.7792	20-26 t total cap./ 17.3 t payload/ Euro 4	522,079.87
remove poles decommissioning	derrick digger	1	3 days	24	PTO	4 (1)	96	308.8896		
cable										
string wire	double aerial lift	2	2 days	32	auxiliary	2 (2)	128	411.8528	truck 20-26 t total cap./17.3 t payload/Euro 4	303,643.203
	OH cable dolly	1	2 hrs	2	auxiliary	2.2215	4.4429	14.2,955	solo truck up to 7.5t total cap./3.3t payload/Euro3 (short-distance)	170,950
	OH Rope Puller	1	4-6 hrs	6	auxiliary	max 180 hp (75% utilization)		244.8717	truck-trailer 28-34 t total cap./22 t payload/Euro 4	

Sources:

(1) Vincent Jacobo, Jr., General Foreman, Single Conductor Foreman, SCE, Personal Communication

(2) Steve Van Sickle, Assistant Equipment Supervisor, King County Department of Transportation, Seattle Times, July 29, 2008. URL: http://www.discovery.org/a/6431.

Process: Overhead Rope Pulling Idling Energy

Calculations

Conversion factors and constants

1 horsepower	745.6999	Watt
average engine utilization rate (1)	75%	
internal combustion engine efficiency (2)	0.37	
Average diesel energy efficiency (3)	48	MJ/kg
Average diesel density (4)	0.85	kg/liter
1 gallon equals	3.785411784	liters
density diesel fuel per gallon	3.217600021	kg

Cable

OH Rope Puller

truck engine (5)	180	HP
	134,225.98	Watt
engine max power	134,225.98	J/sec
engine average power	100,669.49	J/sec
	362,410,151.40	J/hour
	362.41	MJ/hour
	2,174.46	MJ of energy /installation
	5,876.92	kg diesel/installation
	122.44	kg diesel/installation

Cable dolly

see separate tab-cable dolly calculations

Infrastructure

See above

Sources:

1. (1) Mark Bryant, Engine Expert, Personal Communication
2. (2) Physics in an automotive engine, http://mb-soft.com/public2/engine.html.
3. (3) Fuel efficiency, http://en.wikipedia.org/wiki/Fuel_efficiency.
4. (4) Diesel, http://en.wikipedia.org/wiki/Diesel.
5. (5) CP165 Drum Puller Spec Sheet, Conductors Stringing Equipment, TSE International, Inc.

Process: Overhead Maintenance Idling Energy

Producer: Southern California Edison and/or contractors
Process choice base:
The sub-processes were selected based on interviews with SCE engineers and on literature values

OH Maintenance

Summary

infrastructure

no

cable

tree trimming

vehicle type	1 aerial lift truck	
vehicle fuel consumption	1	GPH
mass idle diesel consumed trimming per mile per year	4.468180855	kg
mass tree trimmings per circuit mile (per year)	612.7298	kg

Process name: Tree trimmings along OH distribution lines
Producer: Asplundh Contract Tree Trimming Service
Process choice base: SCE subcontracts all line tree maintenance to Asplundh

Calculations

conversions and constants

1 US short ton	0.90718474	ton
1 liter	0.264172052	gallons
average motorway velocity (1)	82	km/hr
average town velocity (1)	27	km/hr
average outside town velocity (1)	70	km/hr

calculate mass of green waste per circuit mile

mass of green waste per crew (2)	2.5	ton
	2.26796185	ton
	2,267.9619	kg
tree trimming crews for SCE service area total (2)	186.0000	#
mass of green waste, SCE service area total	421,840.9041	kg
trimming frequency per crew, per week (2)	2.0000	#
mass of green waste, SCE area per week	843,681.8082	kg
mass of green waste, SCE area per year (3)	43,871,454.0264	kg
length of OH line in SCE service area, total (4)	71,600.0000	miles
mass of green waste per OH mile per year	612.7298	kg

estimate distance driven per circuit mile

total length OH line in SCE service area (4)	71,600.0000	miles
total number of 2-man crews in SCE service area	186.0000	#
number of 2-man crews per OH circuit mile	0.0026	#
distance driven per 2-man crew	765.1600	km/week
	39,788.3200	km/year
distance driven per OH circuit mile per year	103.3607	km/year

estimate time needed to drive each day

average distance from Asplundh to SCE service line (5)	175.4000	km
fraction motorway (6)	0.2700	
fraction town (6)	0.3000	
fraction outside town (6)	0.4300	
average velocity during Asplundh to SCE service line	60.3400	km/hr
average driving time from Asplundh to SCE service line	2.9069	hr
total driving time empty per day (round trip) (7)	5.8137	hr
average distance from SCE service line to staging (8)	31.7800	km
fraction motorway (9)	0.75	
fraction town (9)	0.1	
fraction outside town (9)	0.15	
average velocity during SCE service line to staging	74.7	km/hr
total driving time full from SCE service line to staging	0.425435074	hr

estimate time needed to trim each day

total driving time empty per day	5.8137	hr
total driving time full per day	0.425435074	hr
total working hours per day	8	hr
total trimming time per day	1.7608	hr

calculate fuel needed for trimming per circuit mile per year

aerial lift truck average idle fuel consumption rate (10)	1	gallon/hr
total trimming time per day per truck	1.7608	hr
fuel consumed trimming per day per truck	1.760842686	gallons
fuel consumed trimming per day all trucks	327.5167395	gallons
fuel consumed trimming per week all trucks	655.0334791	gallons
fuel consumed trimming per year all trucks	34061.74091	gallons
fuel consumed trimming per mile per year	0.475722638	gallons
average density diesel fuel per liter (11)	0.85	kg
average density diesel fuel per gallon	3.217600021	kg
mass diesel consumed trimming per mile per year	1.530685171	kg

Source:

(1) GaBi 4.3 LCA Software transportation process default averages
(2) SCE Personal Communication
(3) Assume trimming events each week of the year (52 weeks/year)
(4) SCE Service Area Facts, ,Southern California Edison Backgrounder Contact: Corporate Communications: 626-302-2255, www.edisonnews.com
(5) Assume nearest Asplundh company station (downtown Los Angeles) and average distance from an SCE warehouse to an installation site
(6) Using same parameters as average SCE warehouse to installation site distance
(7) Assume no load from Asplundh station to SCE service line as well as return to Asplundh station from staging point (each of these trips approximately equal).
(8) Assume same as average distance from installation site to SCE service center.
(9) Using same parameters as average installation site to SCE service center distance.
(10) Slotkin RM, CEO, Odyne Corporation, 2008: http://www.greencarcongress.com/2007/05/odyne_shifts_pl.html
(11) Average density of diesel fuel: http://en.wikipedia.org/wiki/Diesel

Process: Overhead Service Vehicle Driving Energy

Producer	Southern California Edison and/or contractors
Process choice base	The sub-processes were selected based on interviews with SCE engineers and on literature values

Cargo	**Mode**	**Type Chosen in GaBi**	**Start**	**End**	**% Motorway**	**% Rural**	**% City**	**% Auslast**	**Distance (km)**	**Nutzlast (tons)**	**ppm Schwefel**	**DIESEL CONSUMED (modeled in GaBi)**
Digger Derrick driving for pole installation/decommissioning	Truck	20 - 26 t total cap./ 17.3 t payload/ Euro 4	SCE Service Center	Installation Site	10	15	75	85	190.68	17.3	15	83.869
Scheduled line maintenance driving	Solo truck	7.5 t total cap./ 3.3 t payload/ Euro 3	SCE Service Center	Installation Site	10	15	75	85	95.34	3.3	15	10.385
Tree trimming lift truck driving	Truck	20 - 26 t total cap./ 17.3 t payload/ Euro 4	Asplundh (L.A., CA)	Installation Site	10	15	75	85	103.36	17.3	15	15.085
Rope Pulling fraction for double aerial lift truck in cable installation/decommissioning	Truck	20 - 26 t total cap./ 7.3 t payload/ Euro 4	SCE Service Center	Installation Site	10	15	75	85	508.48	17.3	15	39.343
Aerial Lifting fraction for double aerial lift truck in cable installation/decommissioning	Truck	21 - 26 t total cap./ 17.3 t payload/ Euro 4	SCE Service Center	Installation Site	10	15	75	85		17.3	15	175.57

Process: Underground Installation and Decommissioning Idling Energy Summary

Producer: Southern California Edison and/or contractors

Process choice base: The sub-processes were selected based on interviews with SCE engineers and on literature values

UD Installation Summary

Process	Vehicle	# Vehicles	Process Time	Total Hours	Fuel Notes	fuel use idling rate	total fuel needed		Truck type in GaBi	Dummy Cargo, kg (w/ default parameters)
						(gal/hr)	(gallons)	(kg)		
cable										
roll cable to dollies & scrap (clean off) excess cable	UD cable dolly	2	4 hrs	8	auxiliary	2.2215	17.772	57.182	truck trailer 28-34 t total cap./ 22 t payload/Euro 4	592,495
UDG cable puller	3-axle pull truck	1	1 day	16	diesel	max 240 hp (75% utilization)		435.327		
infrastructure										
concrete mixing and pouring	Concrete truck	1	1day	8.25 (1)	diesel	max 300 hp (75% utilization)		280.582	truck trailer 28-34 t total cap./22 t payload/Euro 5	196,135
placing vaults	crane lifter	1	.5 hrs each	2.64 (2)	diesel			45.492		

Source:

(1) Wade Smith, Contractor/Bidder for Cement & Grading Construction, Personal Communication

(2) Sauter E. (2007). TechTalk: Lifting, setting and bracing, Technical Article from Concrete Monthly, http://www.concretemonthly.com/monthly/art.php?2841.

Process: Underground Installation/Decommissioning Idling Energy

Calculations

Conversion factors and constants

1 Mechanical Horsepower	745.699872	Watt
average engine utilization rate (1)	75%	
internal combustion engine efficiency (2)	0.37	
Average diesel energy efficiency (3)	48	MJ/kg
Average diesel density (4)	0.85	kg/liter
1 gallon equals	3.785411784	liters

cable

Underground cable puller

LH46 20,000 LB PULLER

truck engine (5)	240	HP
	178967.9693	Watt
engine max power	178967.9693	J/sec
engine average power	134225.977	J/sec
	483213517.1	J/hour
	483.2135171	MJ/hour
average engine energy output	10.06694827	kg/hr
average fuel consumption	27.2079683	kg/hr
	435.3274928	kg diesel/installation

Cable dolly

see separate tab-cable dolly calculations

infrastructure

concrete mixing and pouring

truck engine (6)	300	HP
	223709.9616	Watt
engine max power	223709.9616	J/sec
engine average power	167782.4712	J/sec
	604016896.3	J/hour
	604.0168963	MJ/hour
average engine energy output	12.58368534	kg/hr
average fuel consumption (7)	34.00996038	kg diesel/installation
	280.5821731	kg diesel/installation

Crane (vaults placement)

truck engine (8)	152	HP
	113346.3805	Watt
engine max power	113346.3805	J/sec
engine average power	85009.78541	J/sec
	306035227.5	J/hour
	306.0352275	MJ/hour
average engine energy output	6.375733906	kg/hr
average fuel consumption	17.23171326	kg/hr
	45.491723	kg diesel/installation

Sources:

(1) Mark Bryant, Engine Expert, Personal Communication
(2) Physics in an automotive engine, http://mb-soft.com/public2/engine.html.
(3) Fuel efficiency, http://en.wikipedia.org/wiki/Fuel_efficiency.
(4) Diesel, http://en.wikipedia.org/wiki/Diesel.
(5) Morpac Industries, LH 46 20,000 LB Puller Spec Sheet.
(6) Champion Materials, 1996 Advance FD4000 Mixer Spec Sheet.
(7) Based on 8.25 hours of idling per Wade Smith, Contractor for Cement and Grading Construction.
(8) Link-Belt, FRC 8030 II Series 30-ton Rough Terrain Crane Spec Sheet.

Process: Underground Maintenance Idling Energy

Producer: Southern California Edison and/or contractors
Process choice base: The sub-processes were selected based on interviews with SCE engineers and on literature values

Infrastructure

none

Cable

truck type in GaBi	**DIESEL CONSUMED**
Up to 7.5 t total cap. / 3.3 t payload / Euro 3	1.797994887

Pumping (Vault water)

engine model (1)	Honda EM 3800	
time to pump one vault (2)	30 min	
# of vaults per mile	5.28	
frequency of scheduled visits (2)	once in 3 years	
pumping time		
for 1 mile	2.64	hours
for 1 mile for 1 year	0.88	hours
fuel consumption (diesel) (1)		
per hour	0.635	gallons/hour
per 1 mile and 1 year	0.5588	gallons/mile/year
	2.115288103	liters/mile year
	1.797994887	kg/mile/year

conversion factors and constants		
Average diesel density	0.85	kg/liter
gallon equals	3.78541178	liters

Source:
(1) Honda EM3800 Model Generator Spec Sheet.
(2) SCE Engineer, Personal Communication

Process: Underground Service Vehicle Driving Energy

Producer: Southern California Edison and/or contractors

Process choice base: The sub-processes were selected based on interviews with SCE engineers and on literature values

Cargo	Mode	Type Chosen in GaBi	Start	End	% Motor-way	% Rural	% City	% Auslast	Distance (km)	Nutzlast (tons)	ppm Schwefel	DIESEL CONSUMED (modeled in GaBi)
3-axle material truck for cable pulling	Truck-trailer	34-40 t total cap./27 t payload/ Euro 4	SCE Service Center	Installation Site	10	15	75	85	63.56	3.3	15	29.02
Make-up Crew (2 Vans & 1 Truck, 1.5 days-all)	Solo truck	Solo truck up to 7.5t total cap./ 3.3t payload / Euro3 (short-distance)	SCE Service Center	Installation Site	10	15	75	85	127.12	3.3	15	13.847
Make-up Crew (2 Vans & 1 Truck, 1.5 days-all)	Solo truck	Solo truck up to 7.5t total cap./ 3.3t payload / Euro3 (short-distance)	SCE Service Center	Installation Site	10	15	75	85	381.36	3.3	15	41.548
Maintenance truck for pumping vault water	Solo truck	Up to 7.5 t total cap. / 3.3 t payload / Euro 3	SCE Service Center	Installation Site	10	15	75	85	21.186	3.3	15	13.84726

Process: Cable Dolly Idling Energy

Producer: Southern California Edison and/or contractors
The sub-processes were selected based on interviews with SCE engineers and on literature values

Reel dolly fuel consumption

24,000# LINE PULL: Engine Model 3015D

Conversion factors and constants

1 liter	0.264172052	US gallons
BSFC constant (1)	9549.27	
diesel density (2)	850	g/L

calculate dolly fuel consumption rate

with BSFC = fuel rate/power (g/kWh)
*and kW = rpm*Tq / 9549.27 (rpm*Nm)*

reel dolly motor rated RPM (3)	3000	rpm
reel dolly peak torque (3)	96	Nm
reel dolly BSFC (3)	237	(g/kWh)
power	30.15937344	(rpm*Nm)
fuel rate	7147.771505	g/h
	8.409142947	L/h
	2.221460548	gallons/h

The BSFC Calculation *(in metric units)*

(Brake Specific Fuel Consumption)

To calculate BSFC, use the formula **BSFC = Fuel rate / Power:**
***Fuel rate** is the fuel consumption in grams per hour (g/hr)
***Power** is the power produced in Kilowatts where **kW = w * Tq / 9549.27**
w is the engine speed in rpm
Tq is the engine torque in Newton meters (N·m)

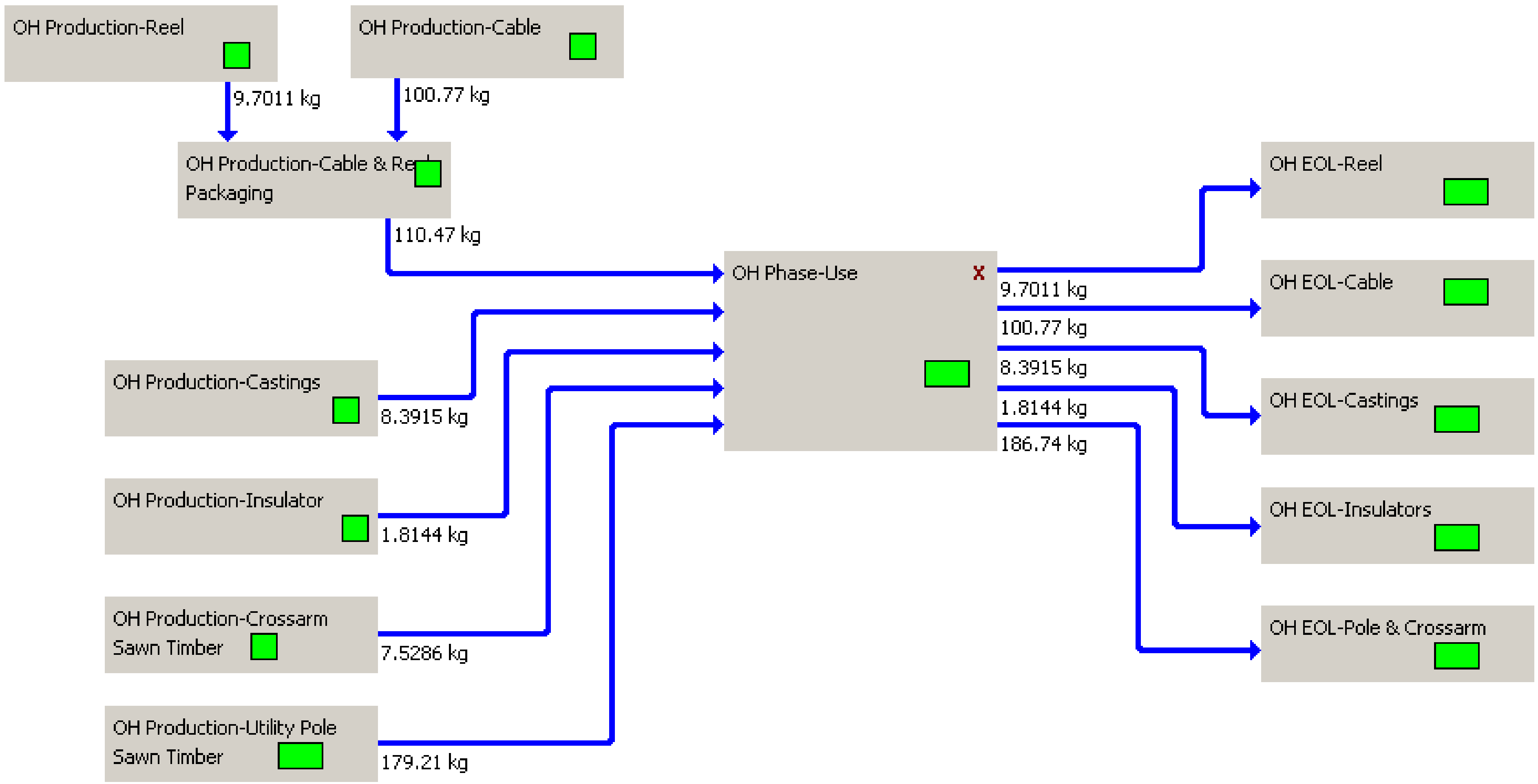
The resulting units of BSFC are g/(kW·h)

Source:

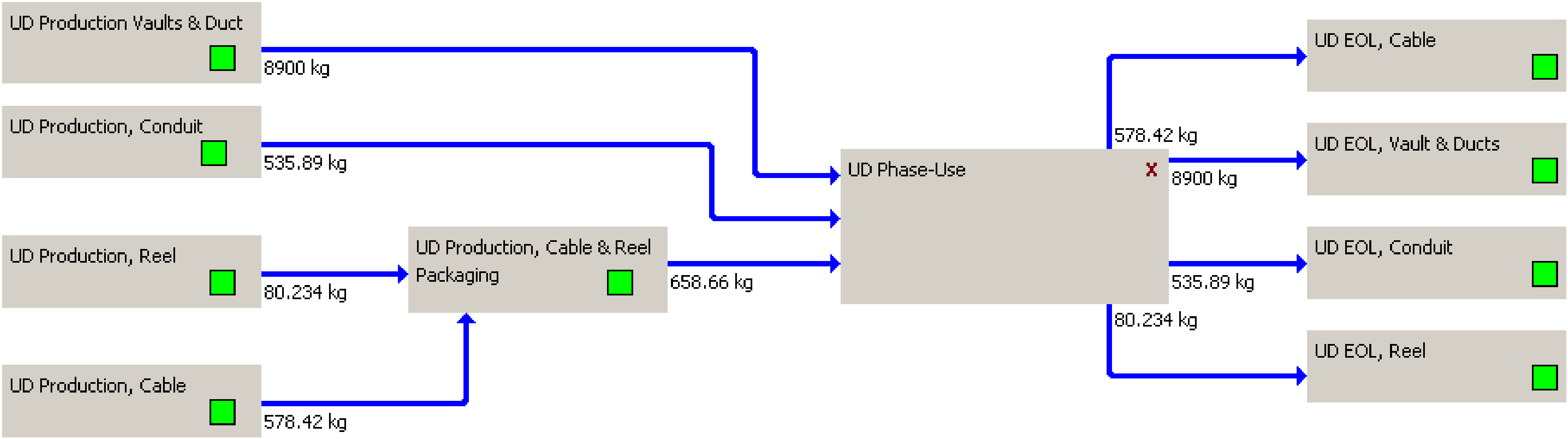
(1) Brake specific fuel consumption, http://en.wikipedia.org/wiki/Brake_specific_fuel_consumption.
(2) Diesel, http://en.wikipedia.org/wiki/Diesel.
(3) Hogg & Davis, Inc. HYDAA 985 24,000# Line Pull Cable Dolly Spec Sheet

Appendix 8.
Inventory Model in GaBi 4.3 Software

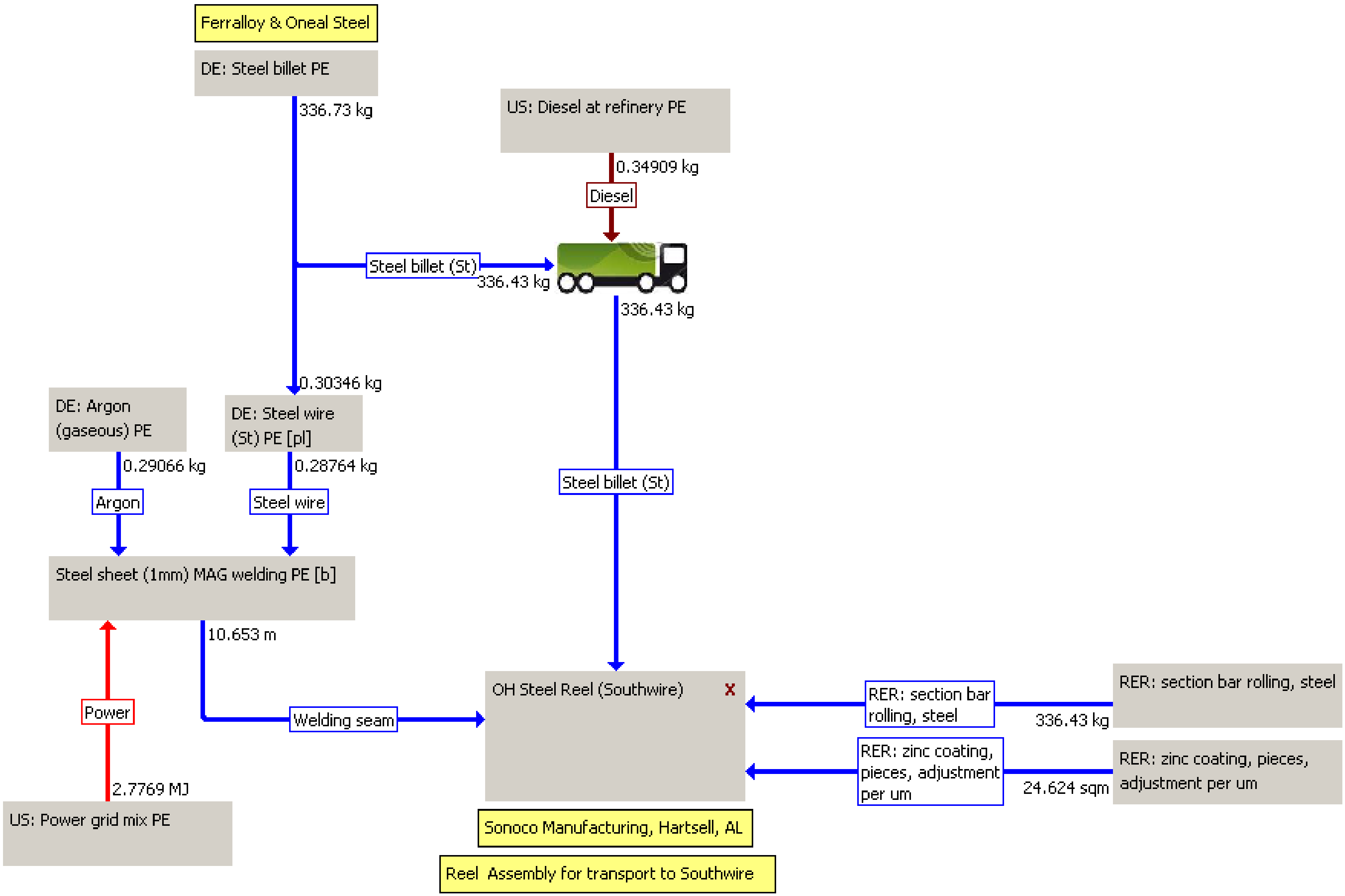
Model: Overhead Life Cycle



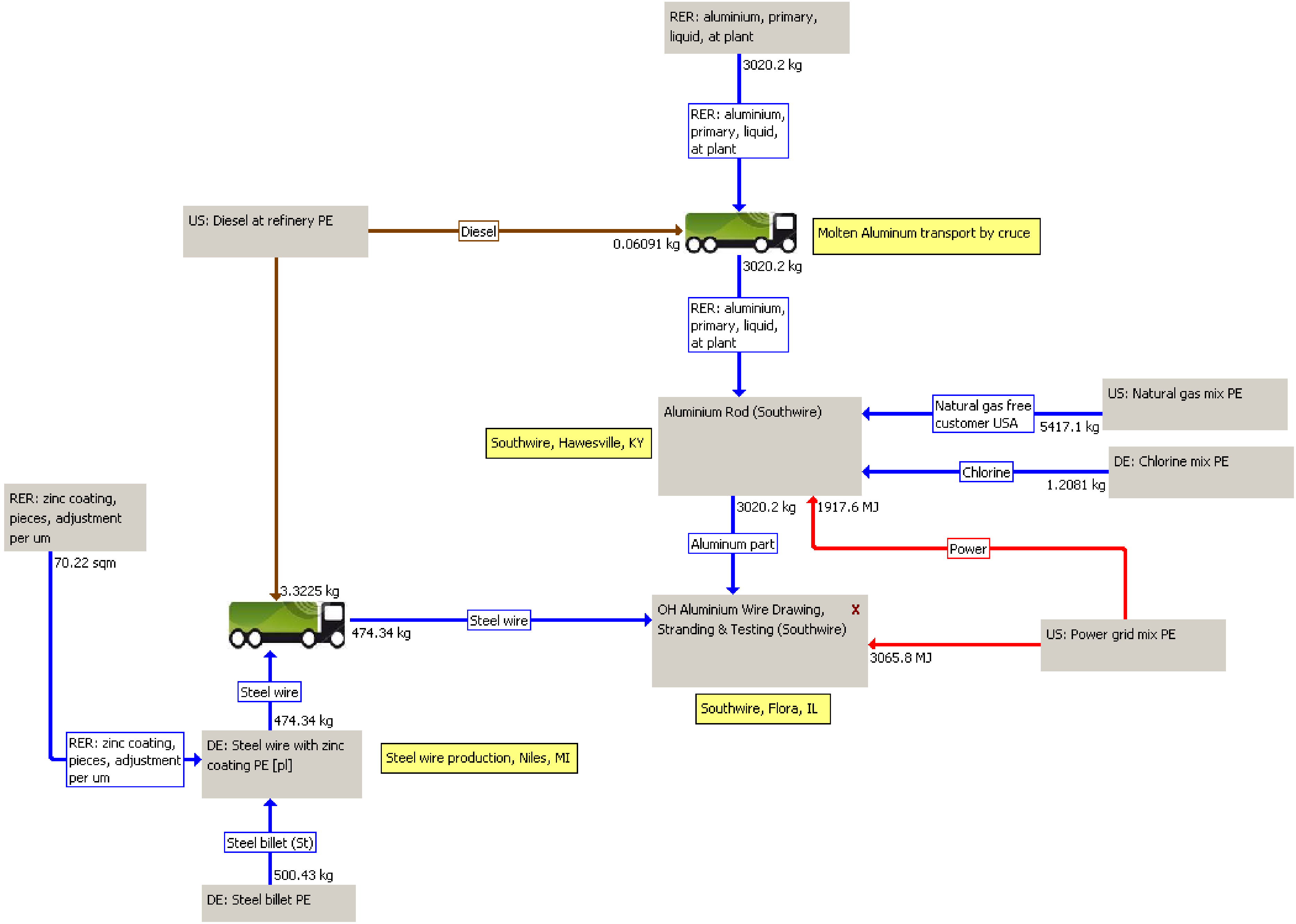
Model: Underground Life Cycle



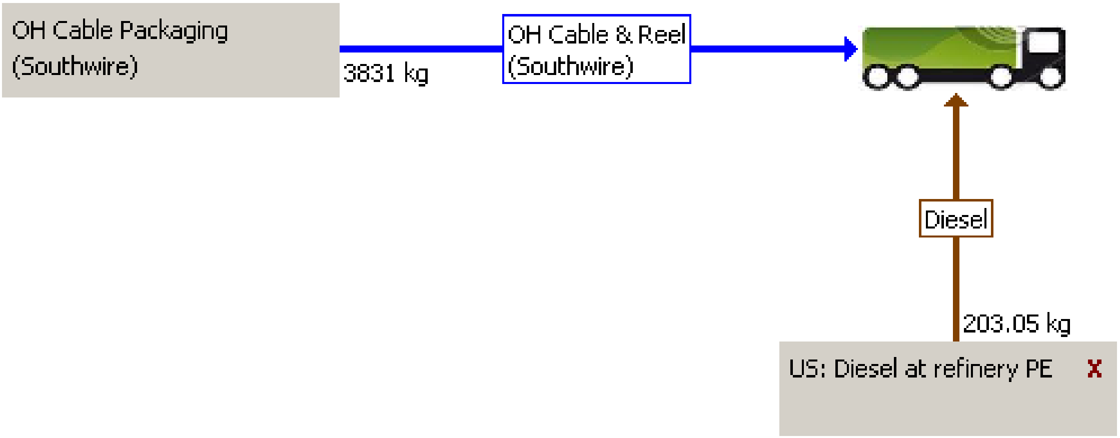
Overhead Production: Steel Reel



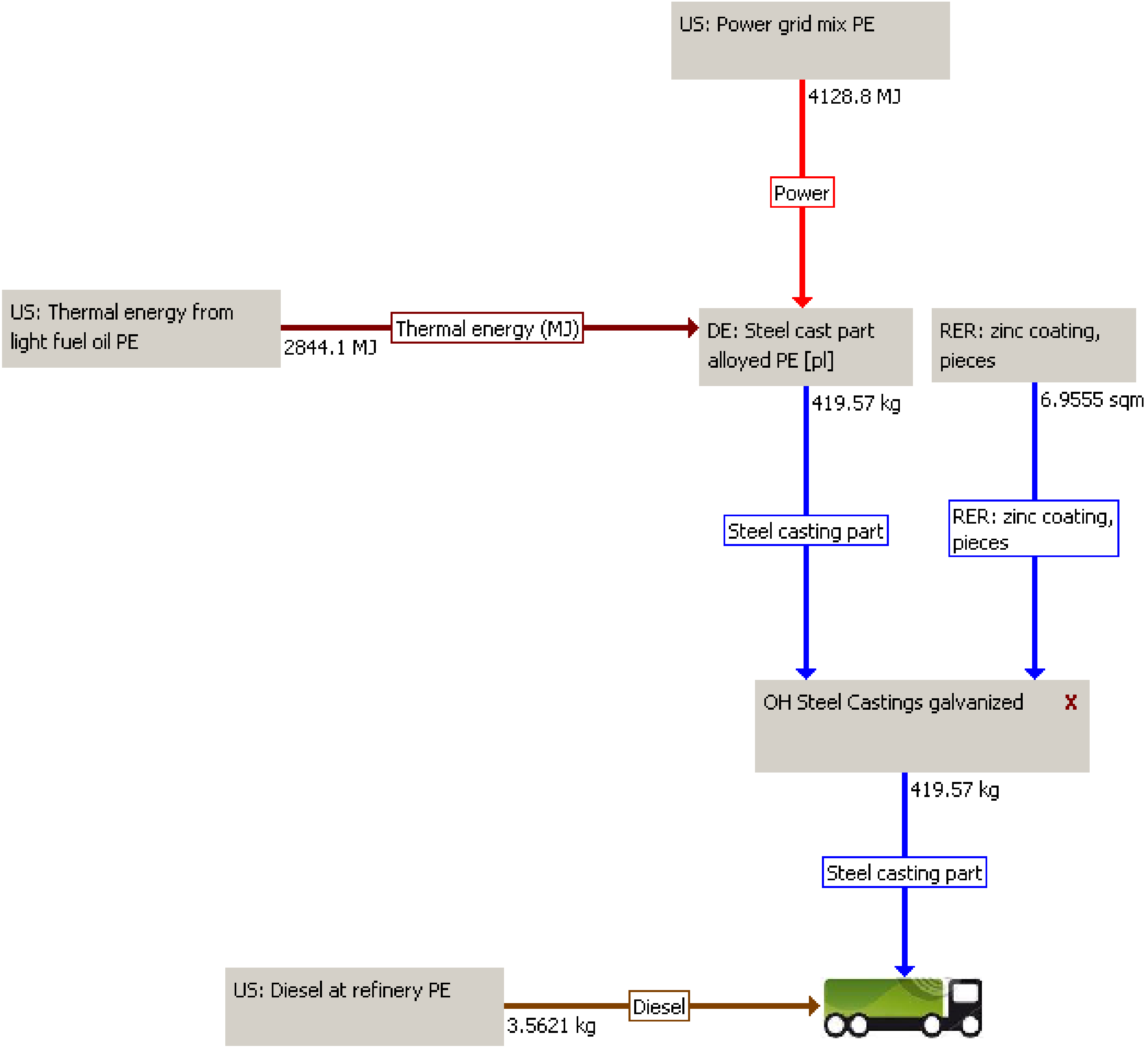
Overhead Production: Cable



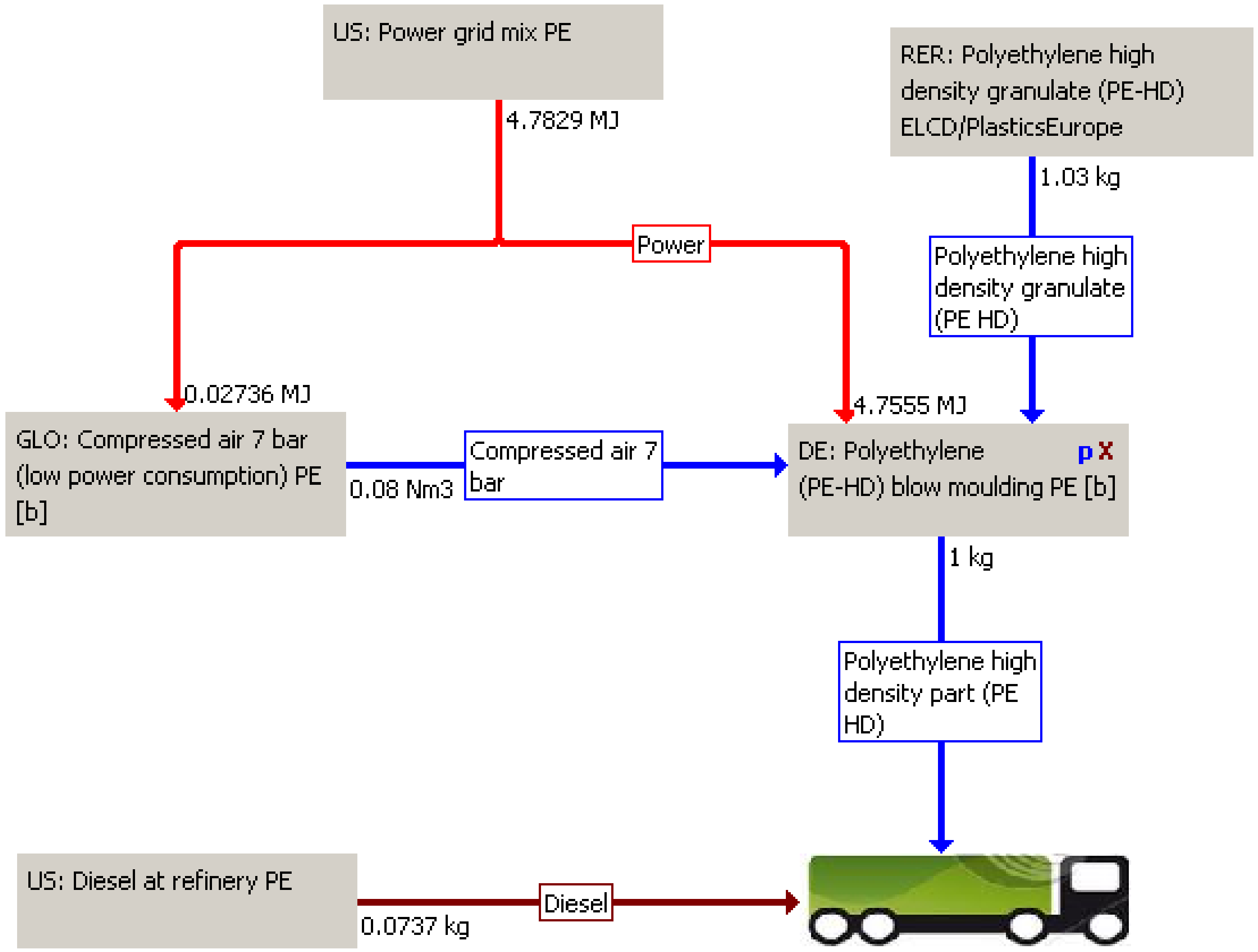
Overhead Production: Cable & Reel Packaging



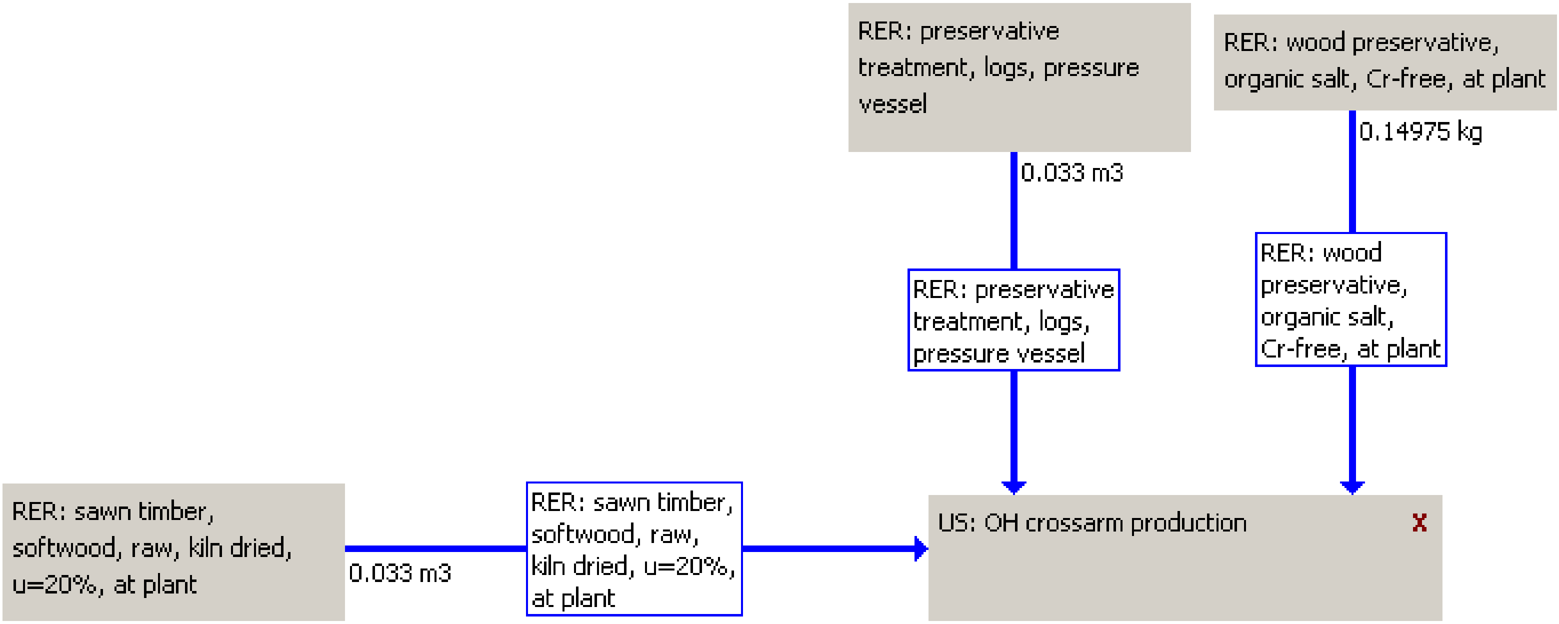
Overhead Production: Castings



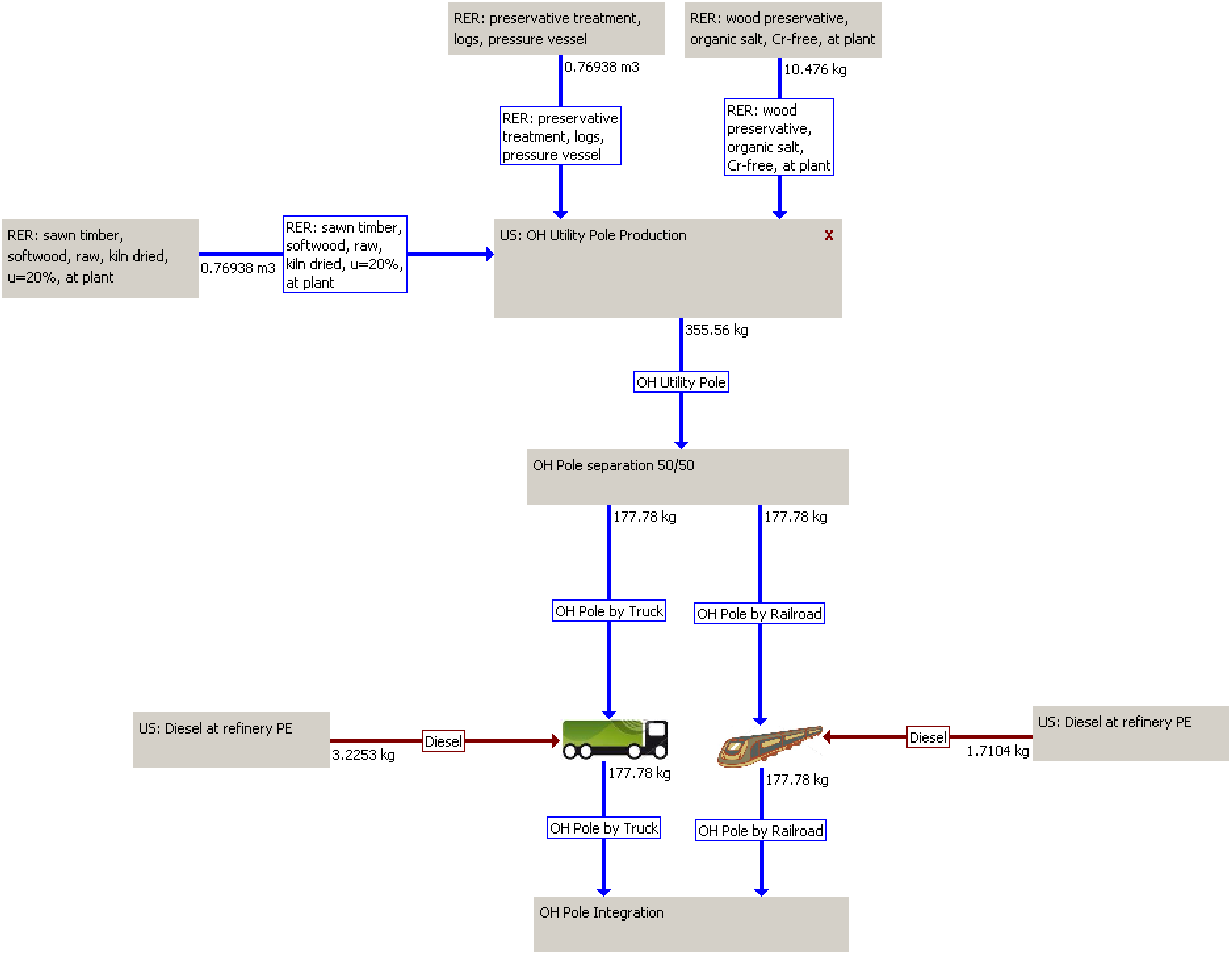
Overhead Production: Insulator



Overhead Production: Crossarm



Overhead Production: Utility Pole



RER: preservative treatment, logs, pressure vessel

0.76938 m3

RER: preservative treatment, logs, pressure vessel

RER: wood preservative, organic salt, Cr-free, at plant

10.476 kg

RER: wood preservative, organic salt, Cr-free, at plant

RER: sawn timber, softwood, raw, kiln dried, u=20%, at plant

0.76938 m3

RER: sawn timber, softwood, raw, kiln dried, u=20%, at plant

US: OH Utility Pole Production

X

355.56 kg

OH Utility Pole

OH Pole separation 50/50

177.78 kg

177.78 kg

OH Pole by Truck

OH Pole by Railroad

US: Diesel at refinery PE

3.2253 kg

Diesel

US: Diesel at refinery PE

1.7104 kg

Diesel

177.78 kg

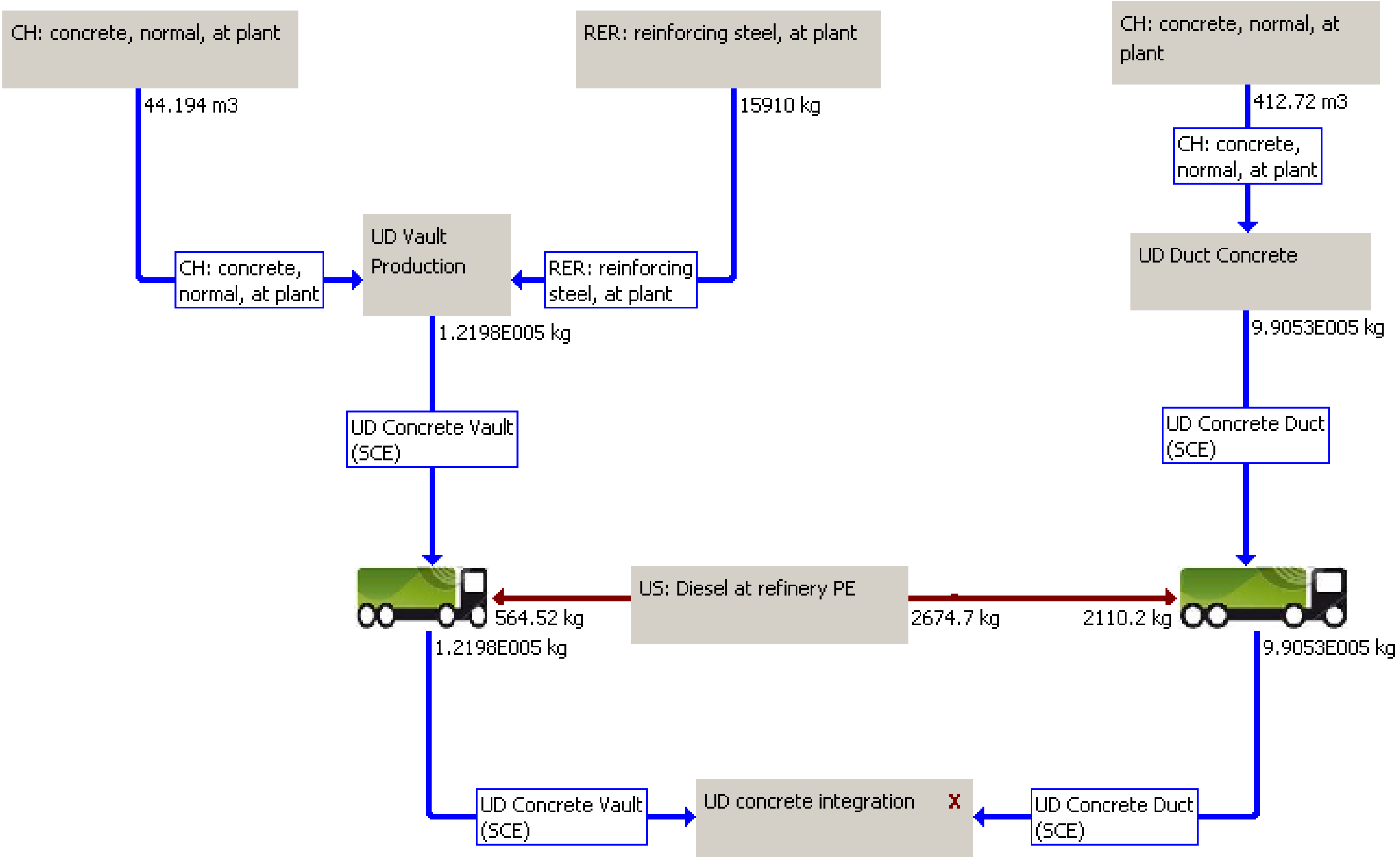
177.78 kg

OH Pole by Truck

OH Pole by Railroad

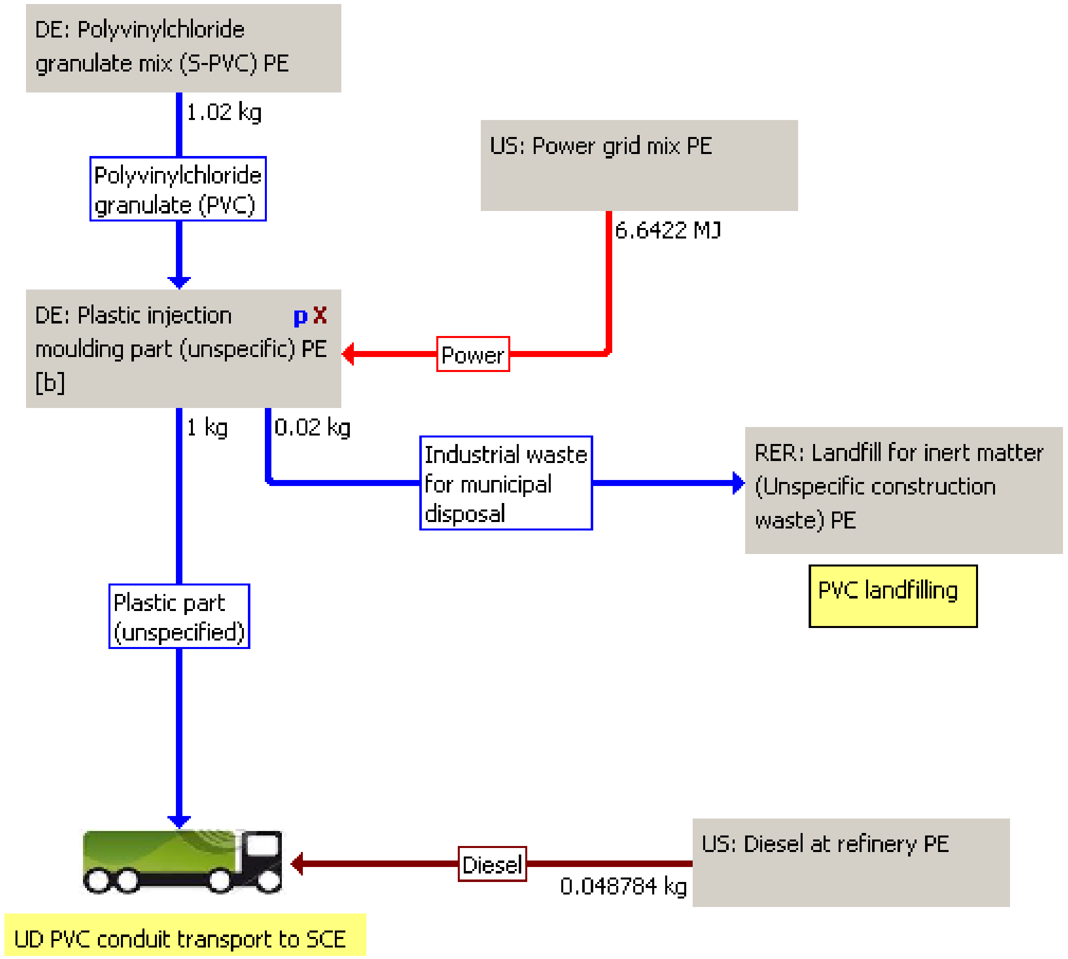
OH Pole Integration

Underground Production: Vaults & Ducts

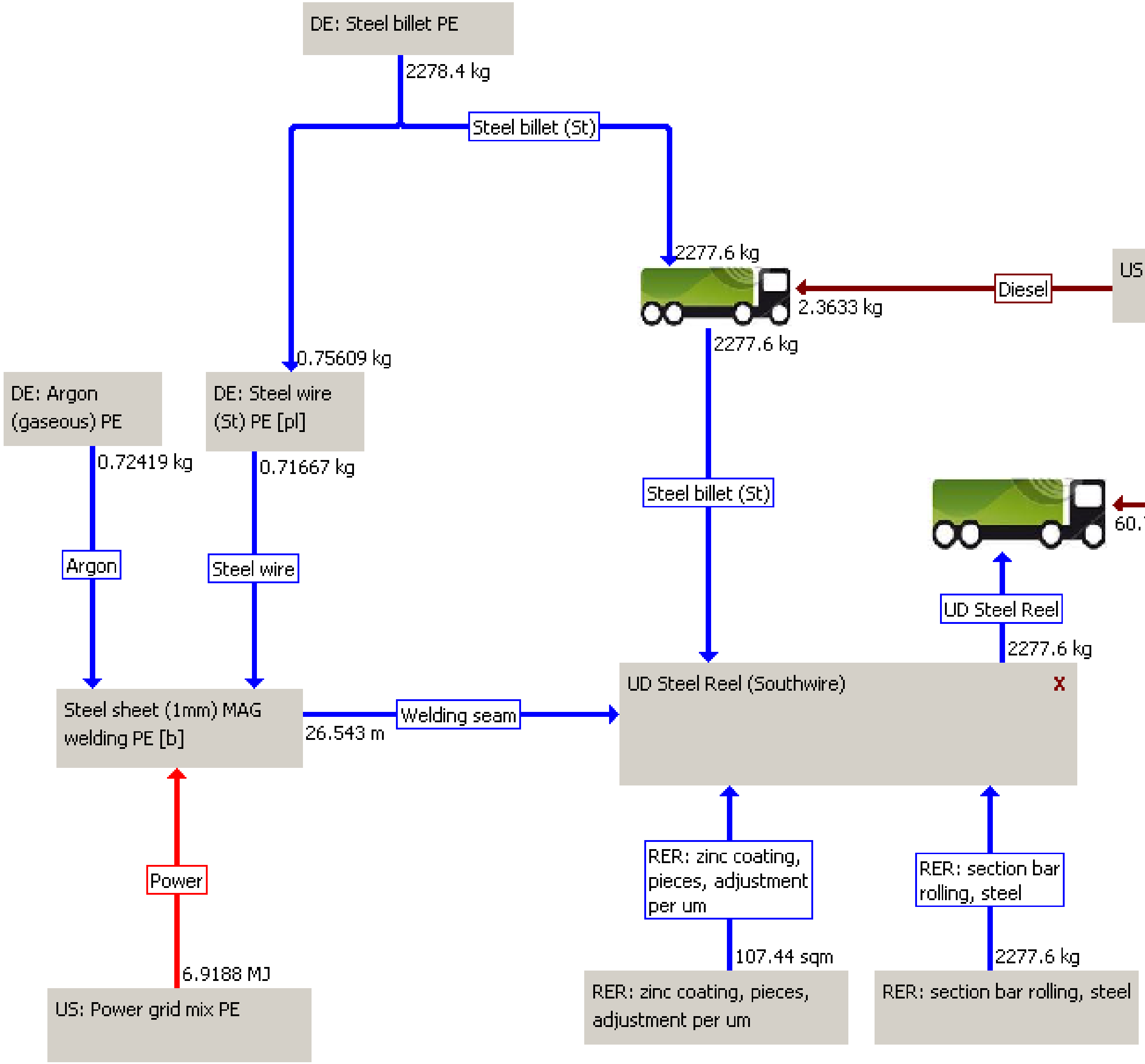


UD concrete integration (Vaults & ducts) go directly to installation site.

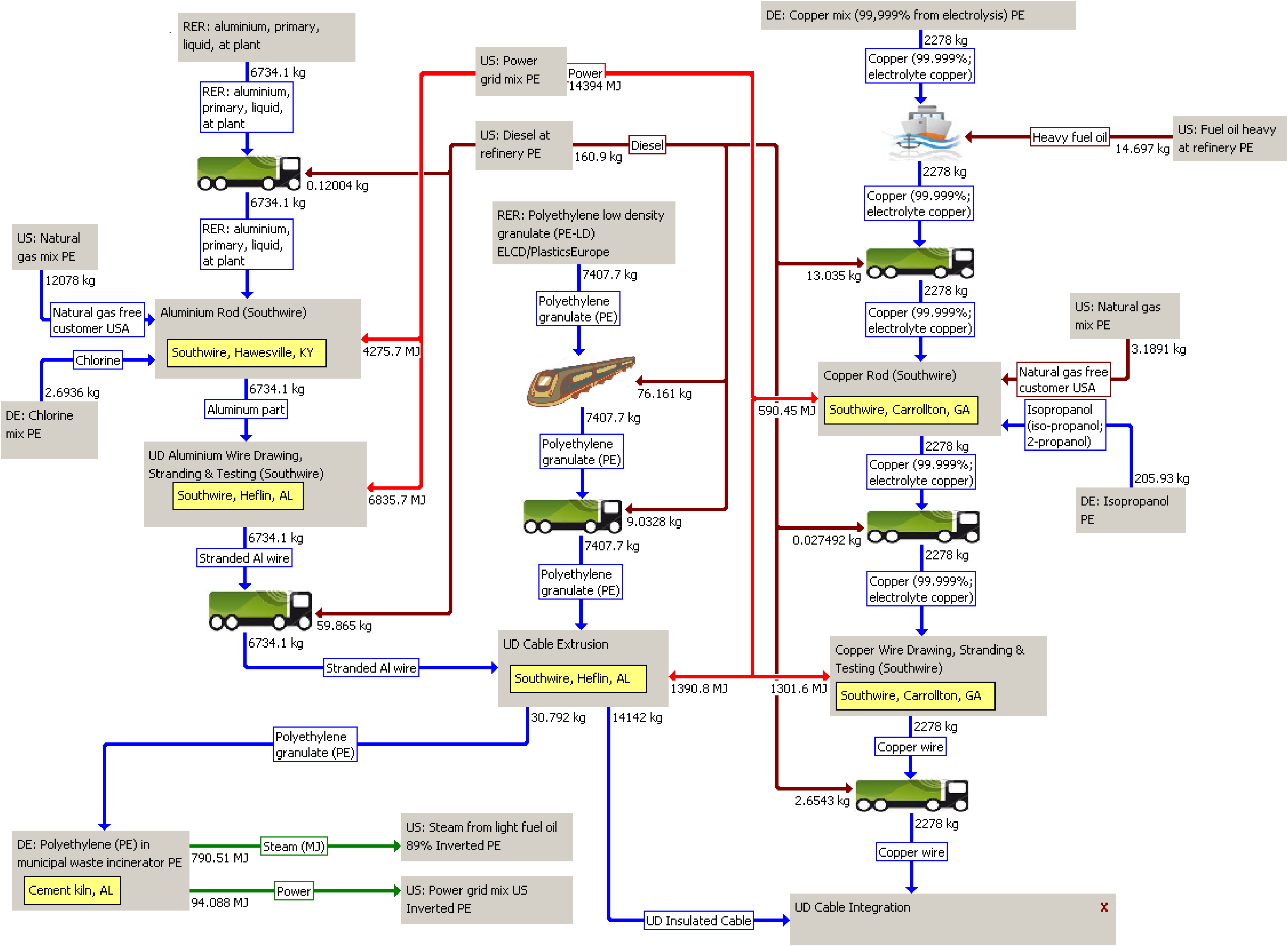
Underground Production: Conduit



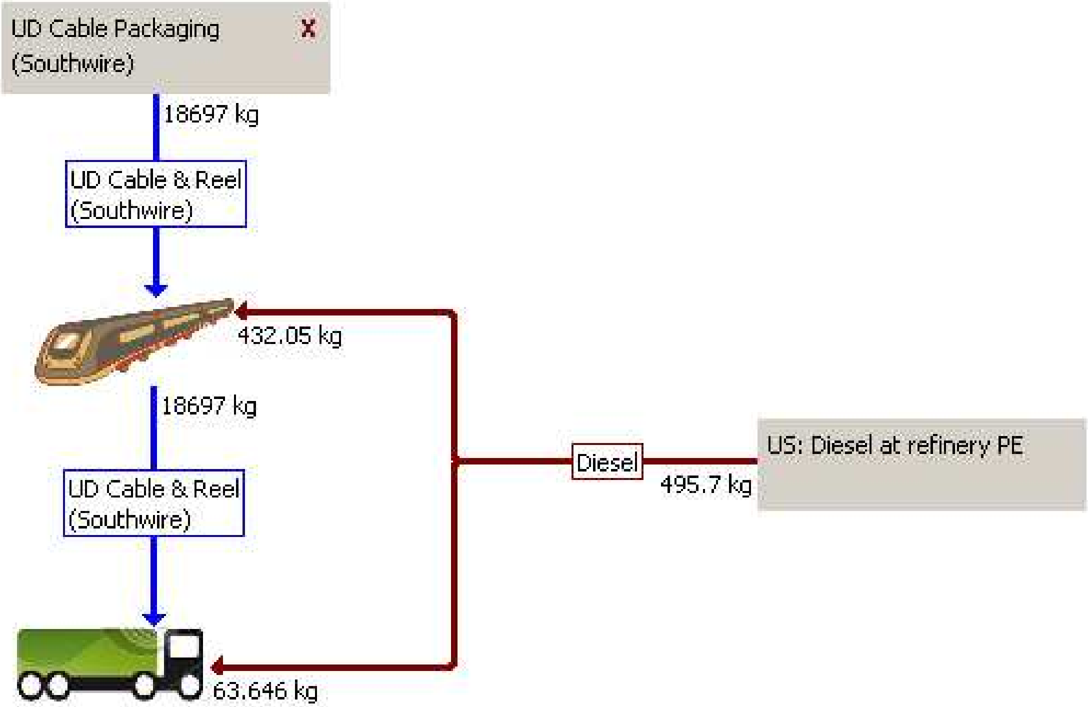
Underground Production: Steel Reel



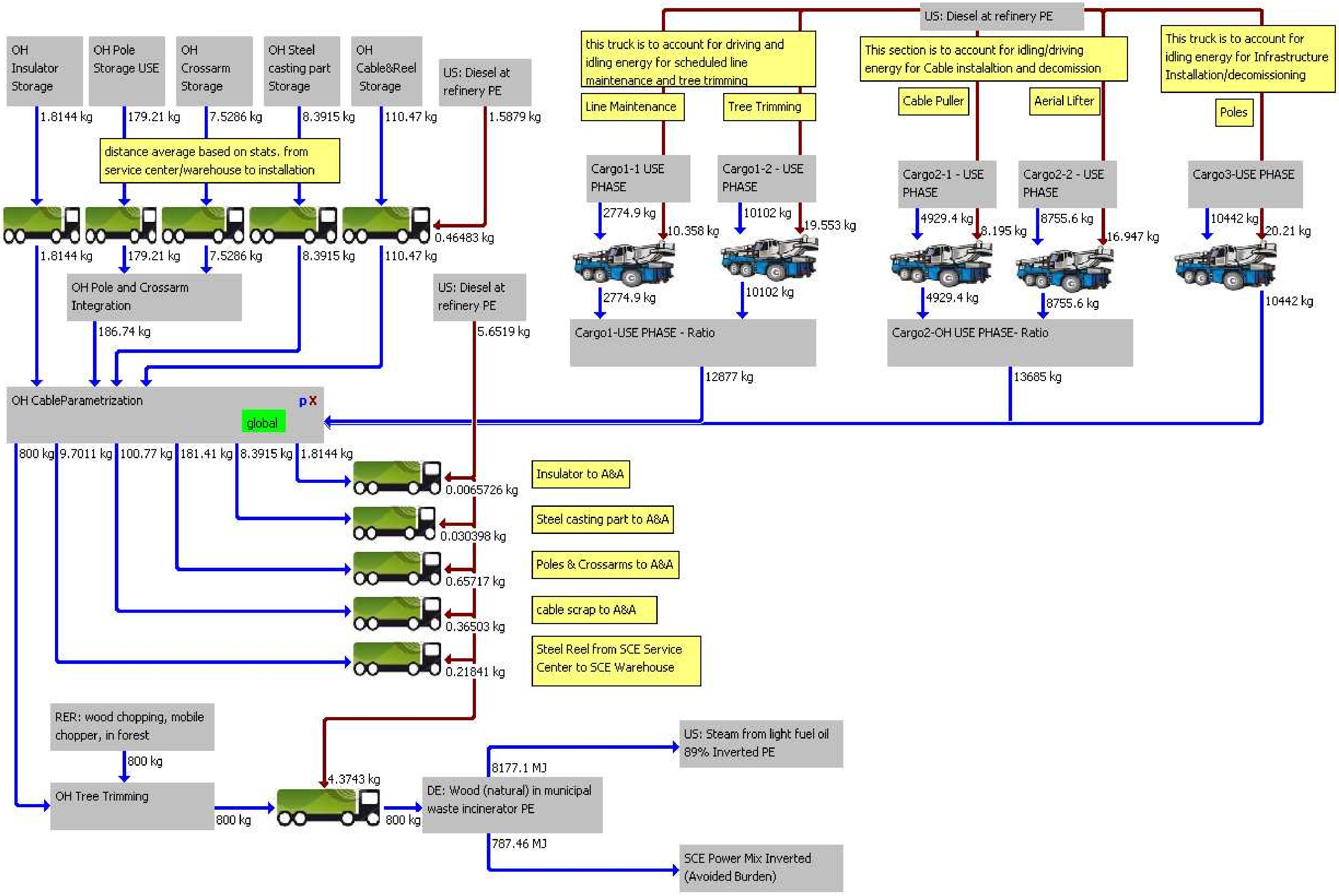
Underground Production: Cable



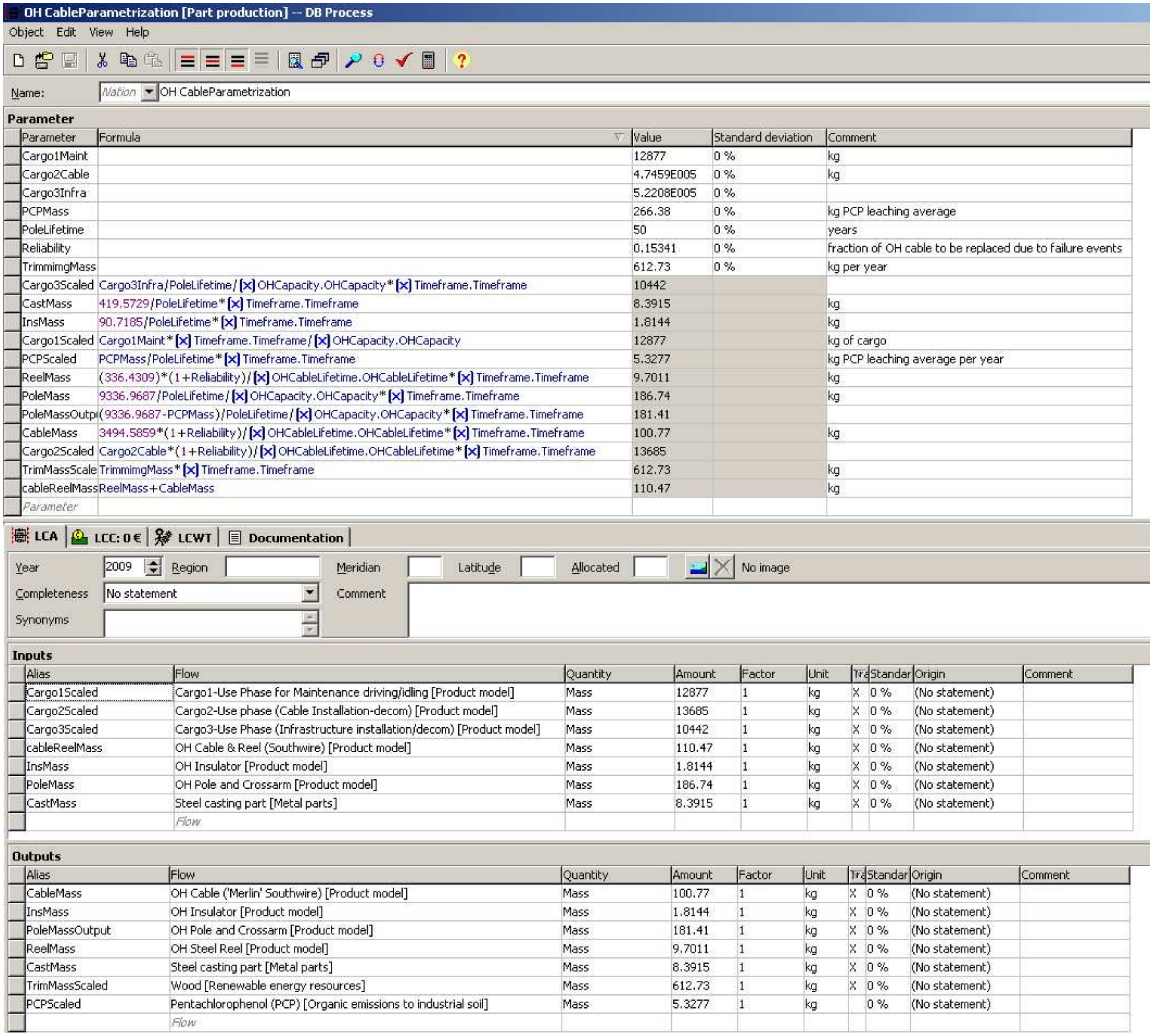
Underground Production: Cable & Reel Packaging



Overhead Use Phase



Overhead Use Phase: Parameterized Installation Process



Name: Nation OH CableParametrization

Parameter

Parameter	Formula	Value	Standard deviation	Comment
Cargo1Maint		12877	0 %	kg
Cargo2Cable		4.7459E005	0 %	kg
Cargo3Infra		5.2208E005	0 %	
PCPMass		266.38	0 %	kg PCP leaching average
PoleLifetime		50	0 %	years
Reliability		0.15341	0 %	fraction of OH cable to be replaced due to failure events
TrimmimgMass		612.73	0 %	kg per year
Cargo3Scaled	Cargo3Infra/PoleLifetime/[x] OHCapacity.OHCapacity*[x] Timeframe.Timeframe	10442		
CastMass	419.5729/PoleLifetime*[x] Timeframe.Timeframe	8.3915		kg
InsMass	90.7185/PoleLifetime*[x] Timeframe.Timeframe	1.8144		kg
Cargo1Scaled	Cargo1Maint*[x] Timeframe.Timeframe/[x] OHCapacity.OHCapacity	12877		kg of cargo
PCPScaled	PCPMass/PoleLifetime*[x] Timeframe.Timeframe	5.3277		kg PCP leaching average per year
ReelMass	(336.4309)*(1+Reliability)/[x] OHCableLifetime.OHCableLifetime*[x] Timeframe.Timeframe	9.7011		kg
PoleMass	9336.9687/PoleLifetime/[x] OHCapacity.OHCapacity*[x] Timeframe.Timeframe	186.74		kg
PoleMassOutp	(9336.9687-PCPMass)/PoleLifetime/[x] OHCapacity.OHCapacity*[x] Timeframe.Timeframe	181.41		
CableMass	3494.5859*(1+Reliability)/[x] OHCableLifetime.OHCableLifetime*[x] Timeframe.Timeframe	100.77		kg
Cargo2Scaled	Cargo2Cable*(1+Reliability)/[x] OHCableLifetime.OHCableLifetime*[x] Timeframe.Timeframe	13685		
TrimMassScale	TrimmimgMass*[x] Timeframe.Timeframe	612.73		kg
cableReelMass	ReelMass+CableMass	110.47		kg
Parameter				

Year 2009 Region Meridian Latitude Allocated No image

Completeness No statement

Comment

Synonyms

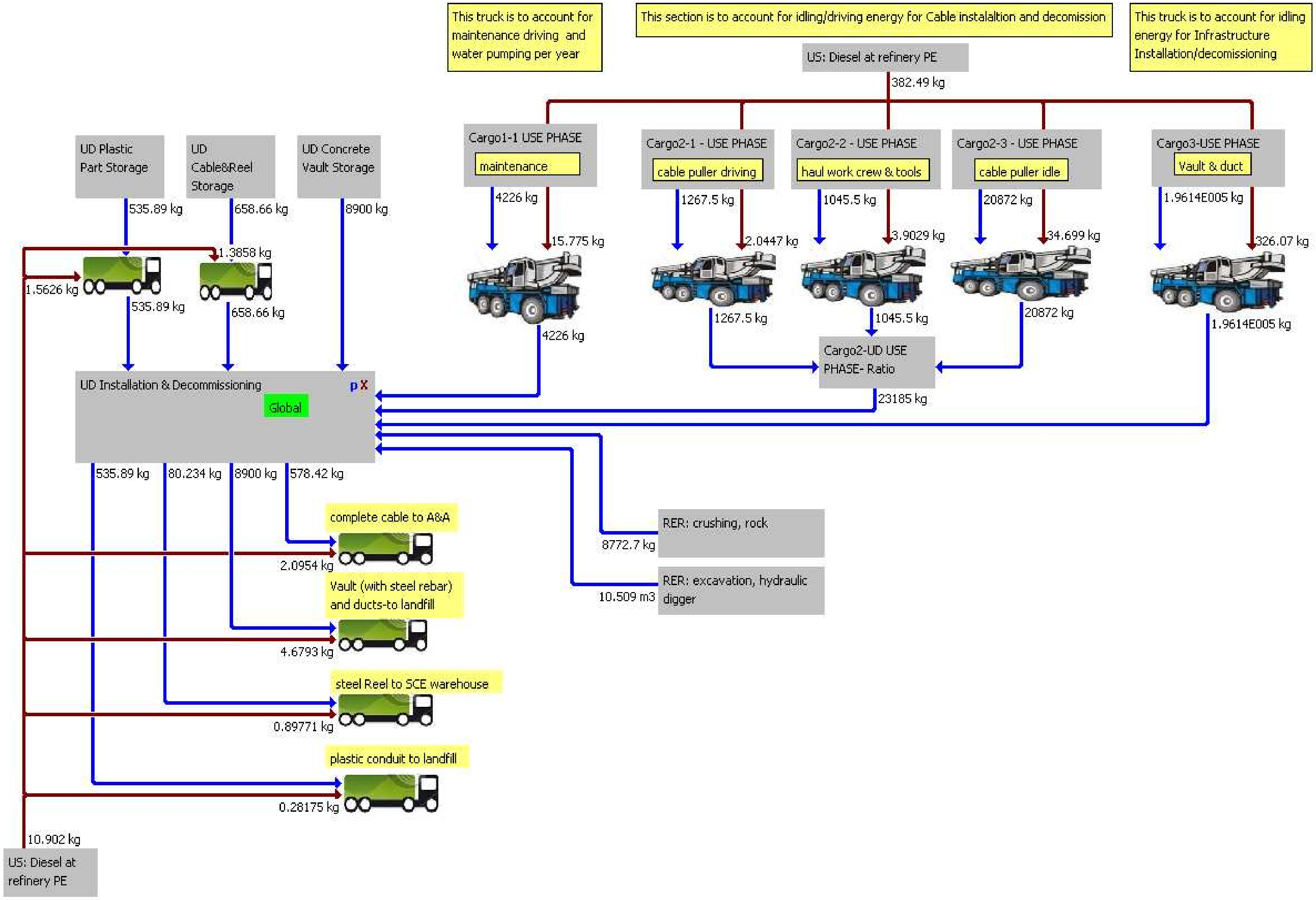
Inputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tra	Standar	Origin	Comment
Cargo1Scaled	Cargo1-Use Phase for Maintenance driving/idling [Product model]	Mass	12877	1	kg	X	0 %	(No statement)	
Cargo2Scaled	Cargo2-Use phase (Cable Installation-decom) [Product model]	Mass	13685	1	kg	X	0 %	(No statement)	
Cargo3Scaled	Cargo3-Use Phase (Infrastructure installation/decom) [Product model]	Mass	10442	1	kg	X	0 %	(No statement)	
cableReelMass	OH Cable & Reel (Southwire) [Product model]	Mass	110.47	1	kg	X	0 %	(No statement)	
InsMass	OH Insulator [Product model]	Mass	1.8144	1	kg	X	0 %	(No statement)	
PoleMass	OH Pole and Crossarm [Product model]	Mass	186.74	1	kg	X	0 %	(No statement)	
CastMass	Steel casting part [Metal parts]	Mass	8.3915	1	kg	X	0 %	(No statement)	
	Flow								

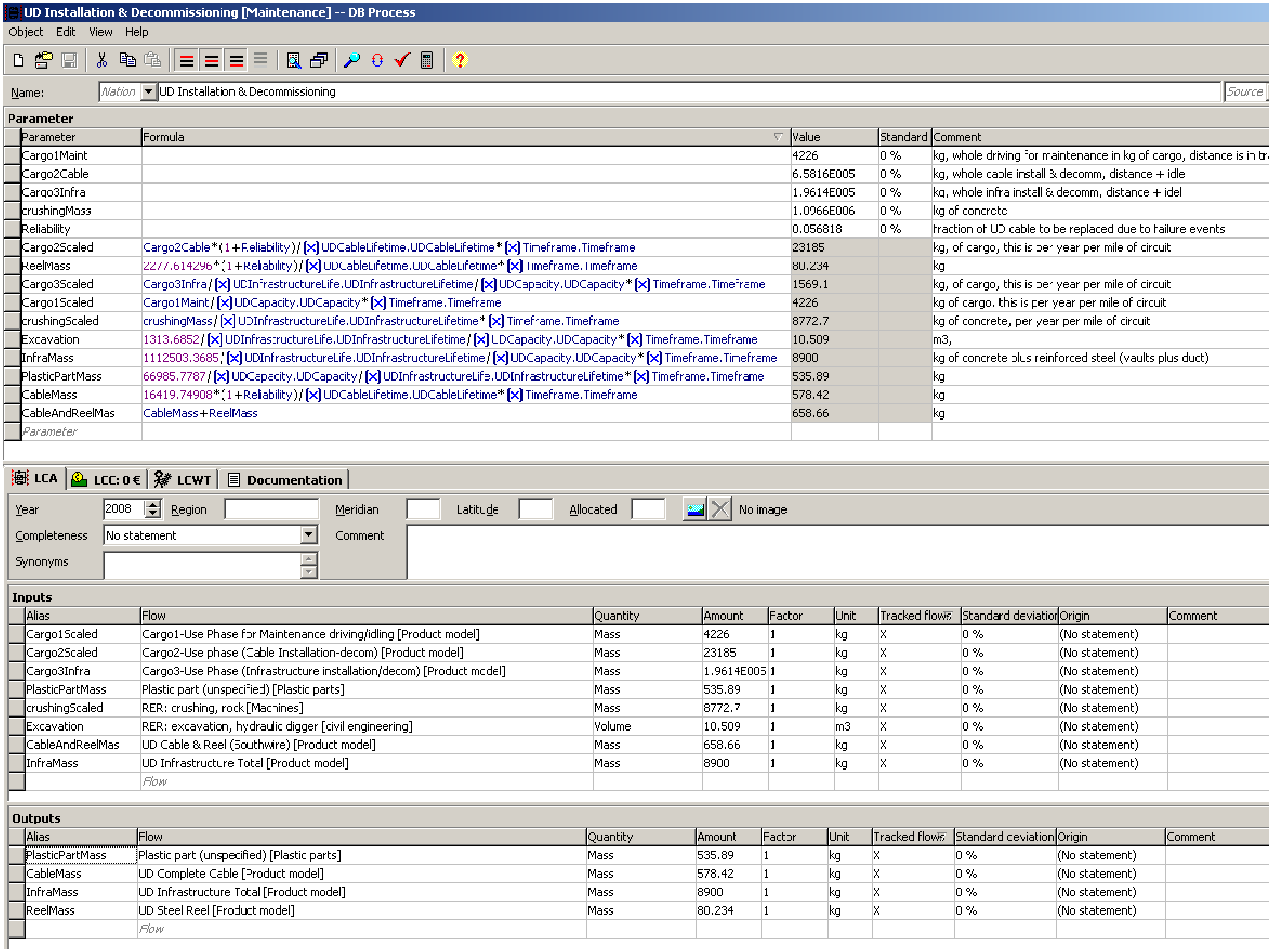
Outputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tra	Standar	Origin	Comment
CableMass	OH Cable ('Merlin' Southwire) [Product model]	Mass	100.77	1	kg	X	0 %	(No statement)	
InsMass	OH Insulator [Product model]	Mass	1.8144	1	kg	X	0 %	(No statement)	
PoleMassOutput	OH Pole and Crossarm [Product model]	Mass	181.41	1	kg	X	0 %	(No statement)	
ReelMass	OH Steel Reel [Product model]	Mass	9.7011	1	kg	X	0 %	(No statement)	
CastMass	Steel casting part [Metal parts]	Mass	8.3915	1	kg	X	0 %	(No statement)	
TrimMassScaled	Wood [Renewable energy resources]	Mass	612.73	1	kg	X	0 %	(No statement)	
PCPScaled	Pentachlorophenol (PCP) [Organic emissions to industrial soil]	Mass	5.3277	1	kg		0 %	(No statement)	
	Flow								

Underground Use Phase



Underground Parameterized Installation Process



Name: Nation UD Installation & Decommissioning Source

Parameter

Parameter	Formula	Value	Standard	Comment
Cargo1Maint		4226	0 %	kg, whole driving for maintenance in kg of cargo, distance is in tr
Cargo2Cable		6.5816E005	0 %	kg, whole cable install & decomm, distance + idle
Cargo3Infra		1.9614E005	0 %	kg, whole infra install & decomm, distance + idel
crushingMass		1.0966E006	0 %	kg of concrete
Reliability		0.056818	0 %	fraction of UD cable to be replaced due to failure events
Cargo2Scaled	Cargo2Cable*(1+Reliability)/ [x] UDCableLifetime.UDCableLifetime* [x] Timeframe.Timeframe	23185		kg, of cargo, this is per year per mile of circuit
ReelMass	2277.614296*(1+Reliability)/ [x] UDCableLifetime.UDCableLifetime* [x] Timeframe.Timeframe	80.234		kg
Cargo3Scaled	Cargo3Infra/ [x] UDInfrastructureLife.UDInfrastructureLifetime/ [x] UDCapacity.UDCapacity* [x] Timeframe.Timeframe	1569.1		kg, of cargo, this is per year per mile of circuit
Cargo1Scaled	Cargo1Maint/ [x] UDCapacity.UDCapacity* [x] Timeframe.Timeframe	4226		kg of cargo. this is per year per mile of circuit
crushingScaled	crushingMass/ [x] UDInfrastructureLife.UDInfrastructureLifetime* [x] Timeframe.Timeframe	8772.7		kg of concrete, per year per mile of circuit
Excavation	1313.6852/ [x] UDInfrastructureLife.UDInfrastructureLifetime/ [x] UDCapacity.UDCapacity* [x] Timeframe.Timeframe	10.509		m3,
InfraMass	1112503.3685/ [x] UDInfrastructureLife.UDInfrastructureLifetime/ [x] UDCapacity.UDCapacity* [x] Timeframe.Timeframe	8900		kg of concrete plus reinforced steel (vaults plus duct)
PlasticPartMass	66985.7787/ [x] UDCapacity.UDCapacity/ [x] UDInfrastructureLife.UDInfrastructureLifetime* [x] Timeframe.Timeframe	535.89		kg
CableMass	16419.74908*(1+Reliability)/ [x] UDCableLifetime.UDCableLifetime* [x] Timeframe.Timeframe	578.42		kg
CableAndReelMas	CableMass+ReelMass	658.66		kg
Parameter				

Year	2008	Region		Meridian		Latitude	
Allocated		No image					
Completeness	No statement	Comment					
Synonyms							

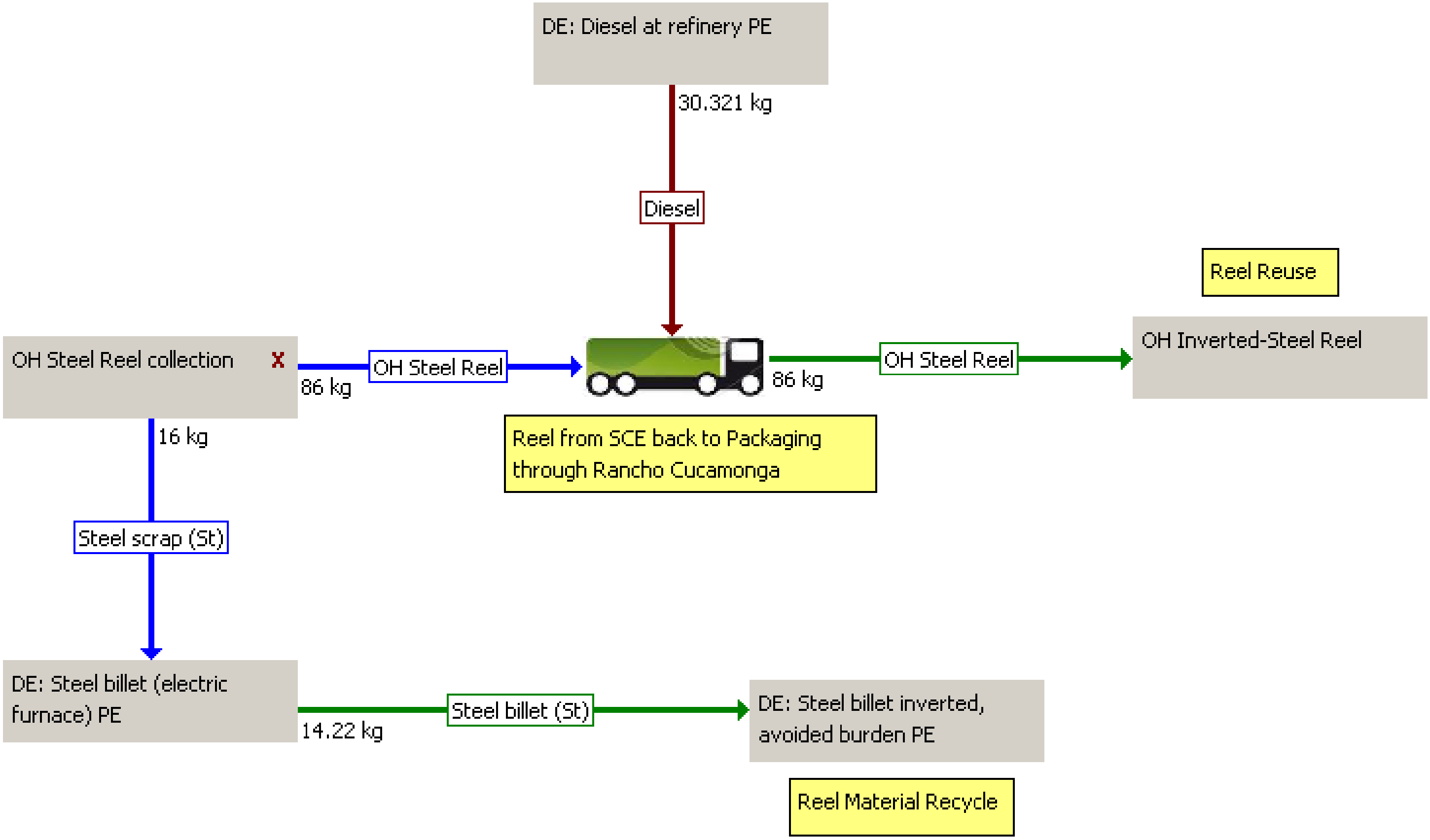
Inputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked flows	Standard deviation	Origin	Comment
Cargo1Scaled	Cargo1-Use Phase for Maintenance driving/idling [Product model]	Mass	4226	1	kg	X	0 %	(No statement)	
Cargo2Scaled	Cargo2-Use phase (Cable Installation-decom) [Product model]	Mass	23185	1	kg	X	0 %	(No statement)	
Cargo3Infra	Cargo3-Use Phase (Infrastructure installation/decom) [Product model]	Mass	1.9614E005	1	kg	X	0 %	(No statement)	
PlasticPartMass	Plastic part (unspecified) [Plastic parts]	Mass	535.89	1	kg	X	0 %	(No statement)	
crushingScaled	RER: crushing, rock [Machines]	Mass	8772.7	1	kg	X	0 %	(No statement)	
Excavation	RER: excavation, hydraulic digger [civil engineering]	Volume	10.509	1	m3	X	0 %	(No statement)	
CableAndReelMas	UD Cable & Reel (Southwire) [Product model]	Mass	658.66	1	kg	X	0 %	(No statement)	
InfraMass	UD Infrastructure Total [Product model]	Mass	8900	1	kg	X	0 %	(No statement)	
	Flow								

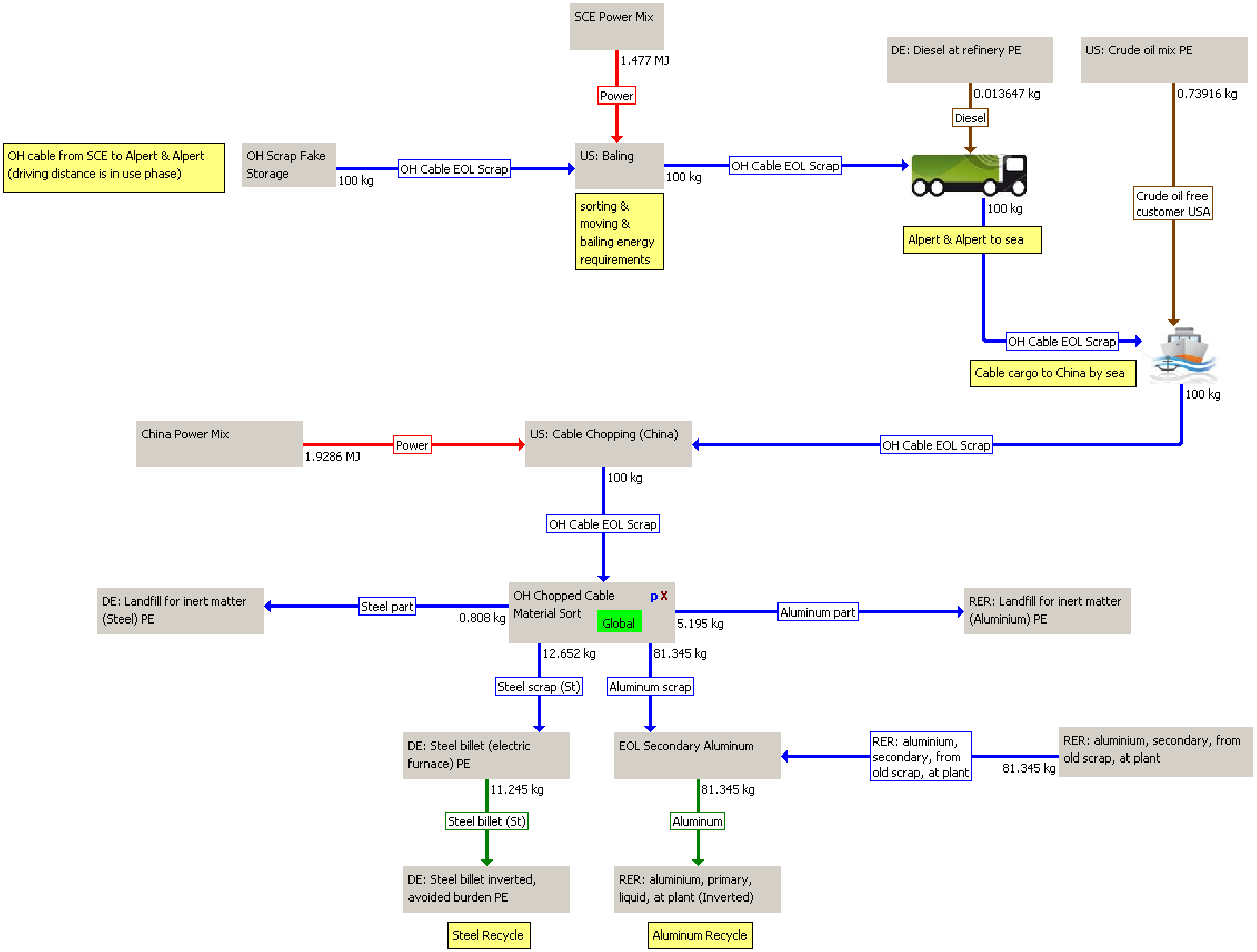
Outputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked flows	Standard deviation	Origin	Comment
PlasticPartMass	Plastic part (unspecified) [Plastic parts]	Mass	535.89	1	kg	X	0 %	(No statement)	
CableMass	UD Complete Cable [Product model]	Mass	578.42	1	kg	X	0 %	(No statement)	
InfraMass	UD Infrastructure Total [Product model]	Mass	8900	1	kg	X	0 %	(No statement)	
ReelMass	UD Steel Reel [Product model]	Mass	80.234	1	kg	X	0 %	(No statement)	
	Flow								

Overhead EOL: Steel Reel



Overhead EOL: Cable



SCE Power Mix

1.477 MJ

Power

OH cable from SCE to Alpert & Alpert (driving distance is in use phase)

OH Scrap Fake Storage

100 kg

OH Cable EOL Scrap

US: Baling

sorting & moving & bailing energy requirements

100 kg

OH Cable EOL Scrap

DE: Diesel at refinery PE

0.013647 kg

Diesel

100 kg

Alpert & Alpert to sea

US: Crude oil mix PE

0.73916 kg

Crude oil free customer USA

OH Cable EOL Scrap

Cable cargo to China by sea

100 kg

China Power Mix

1.9286 MJ

Power

US: Cable Chopping (China)

OH Cable EOL Scrap

100 kg

OH Cable EOL Scrap

DE: Landfill for inert matter (Steel) PE

Steel part

0.808 kg

OH Chopped Cable Material Sort

p X

Global

5.195 kg

Aluminum part

RER: Landfill for inert matter (Aluminium) PE

12.652 kg

Steel scrap (St)

81.345 kg

Aluminum scrap

DE: Steel billet (electric furnace) PE

EOL Secondary Aluminum

RER: aluminium, secondary, from old scrap, at plant

81.345 kg

RER: aluminium, secondary, from old scrap, at plant

11.245 kg

Steel billet (St)

81.345 kg

Aluminum

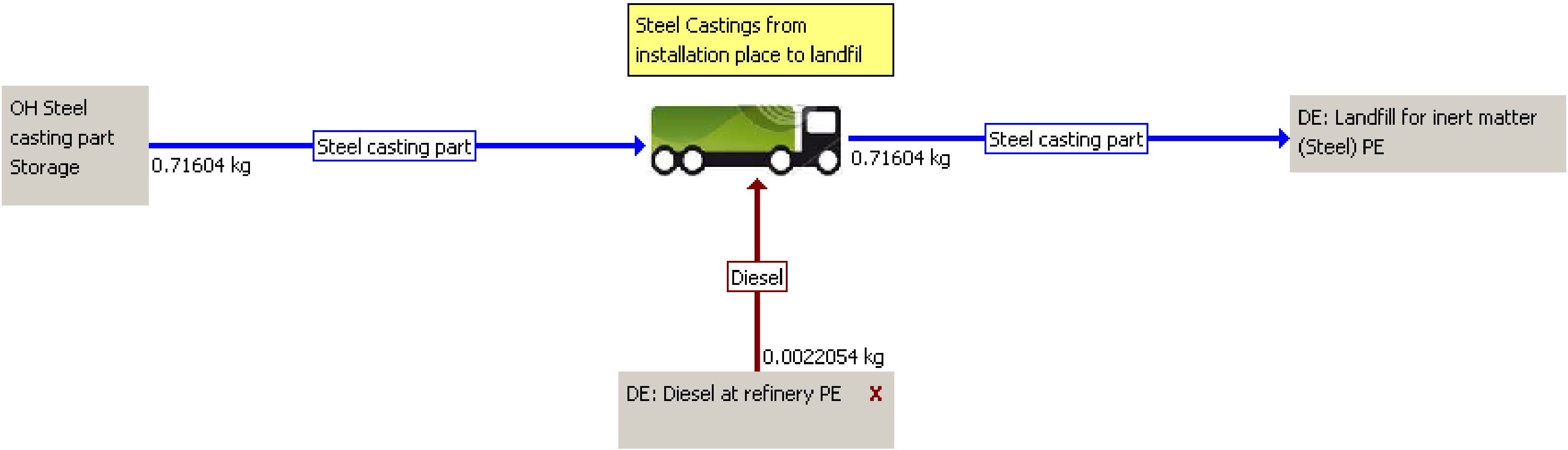
DE: Steel billet inverted, avoided burden PE

RER: aluminium, primary, liquid, at plant (Inverted)

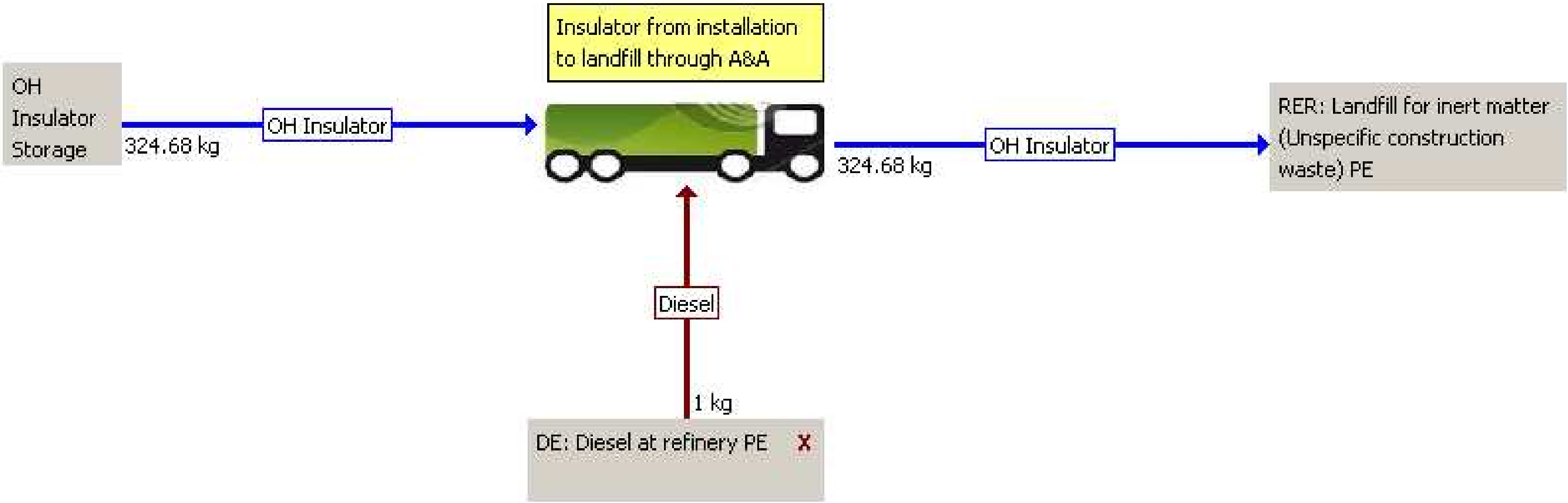
Steel Recycle

Aluminum Recycle

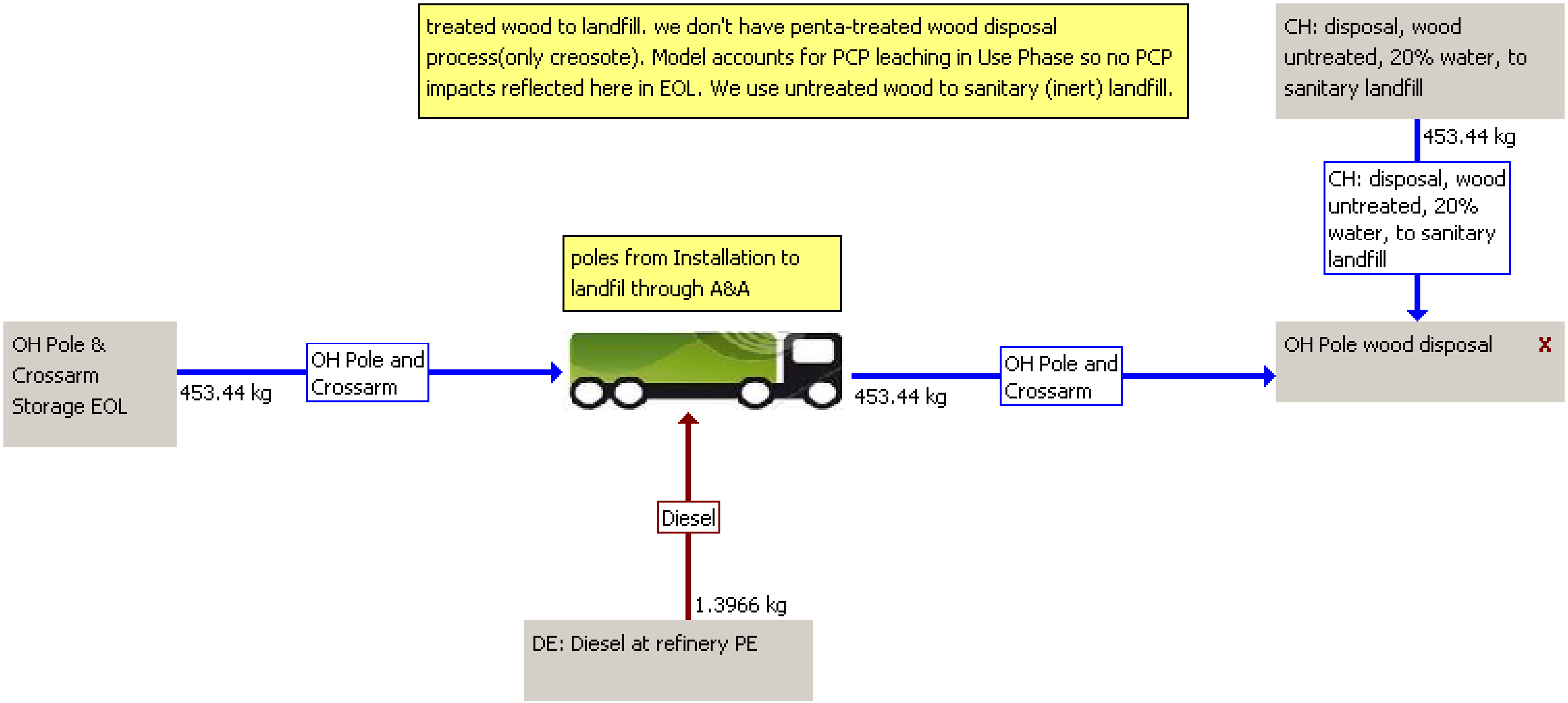
Overhead EOL: Castings



Overhead EOL: Insulator



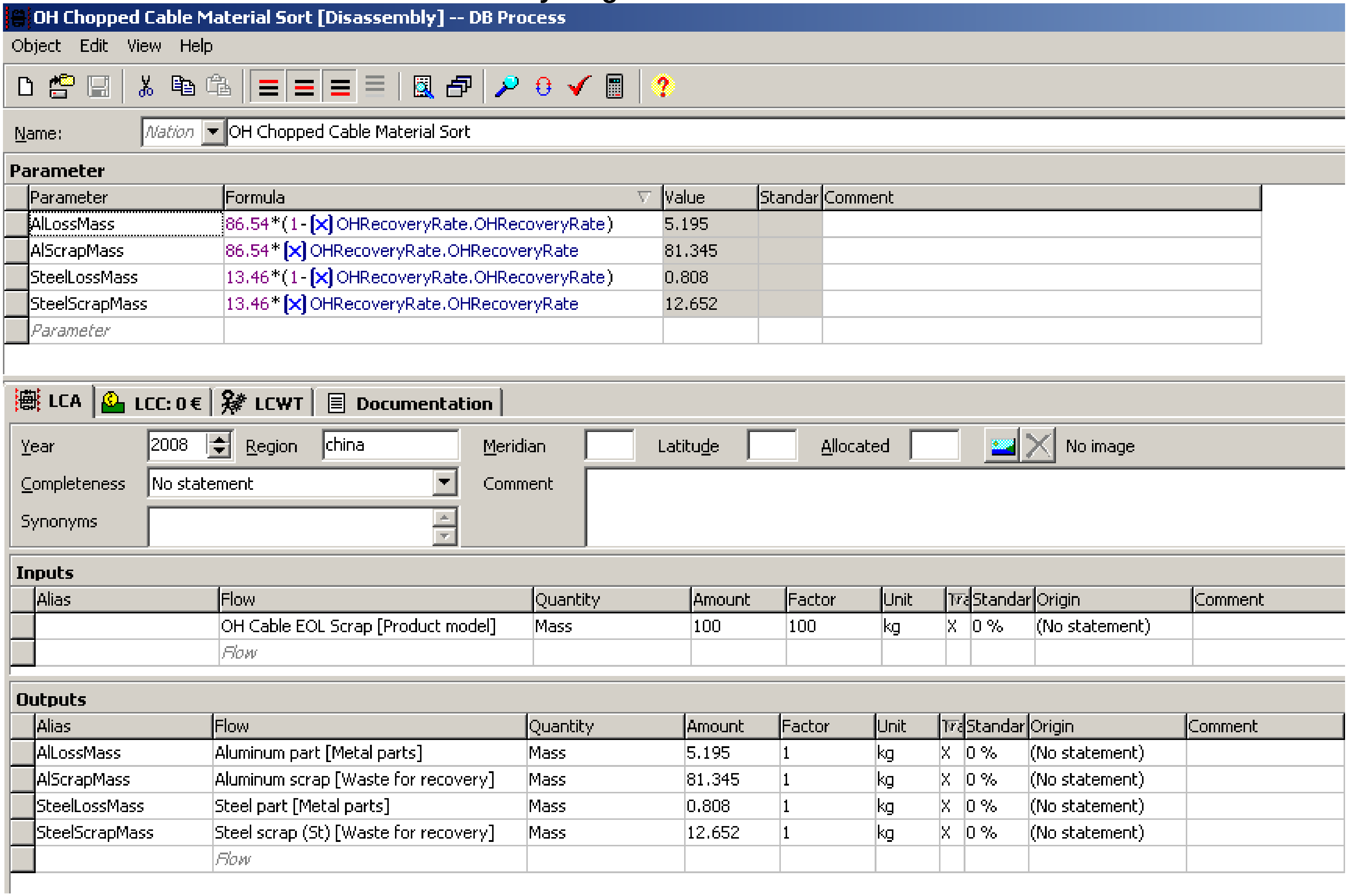
Overhead Pole & Crossarm



treated wood to landfill. we don't have penta-treated wood disposal process(only creosote). Model accounts for PCP leaching in Use Phase so no PCP impacts reflected here in EOL. We use untreated wood to sanitary (inert) landfill.

poles from Installation to landfil through A&A

Overhead EOL: Parameterized Cable Recycling Process



Name: *Nation* OH Chopped Cable Material Sort

Parameter

Parameter	Formula	Value	Standar	Comment
AlLossMass	86.54*(1-[x] OHRecoveryRate.OHRecoveryRate)	5.195		
AlScrapMass	86.54*[x] OHRecoveryRate.OHRecoveryRate	81.345		
SteelLossMass	13.46*(1-[x] OHRecoveryRate.OHRecoveryRate)	0.808		
SteelScrapMass	13.46*[x] OHRecoveryRate.OHRecoveryRate	12.652		
Parameter				

Year 2008
Region china
Meridian
Latitude
Allocated
No image
Completeness No statement
Comment
Synonyms

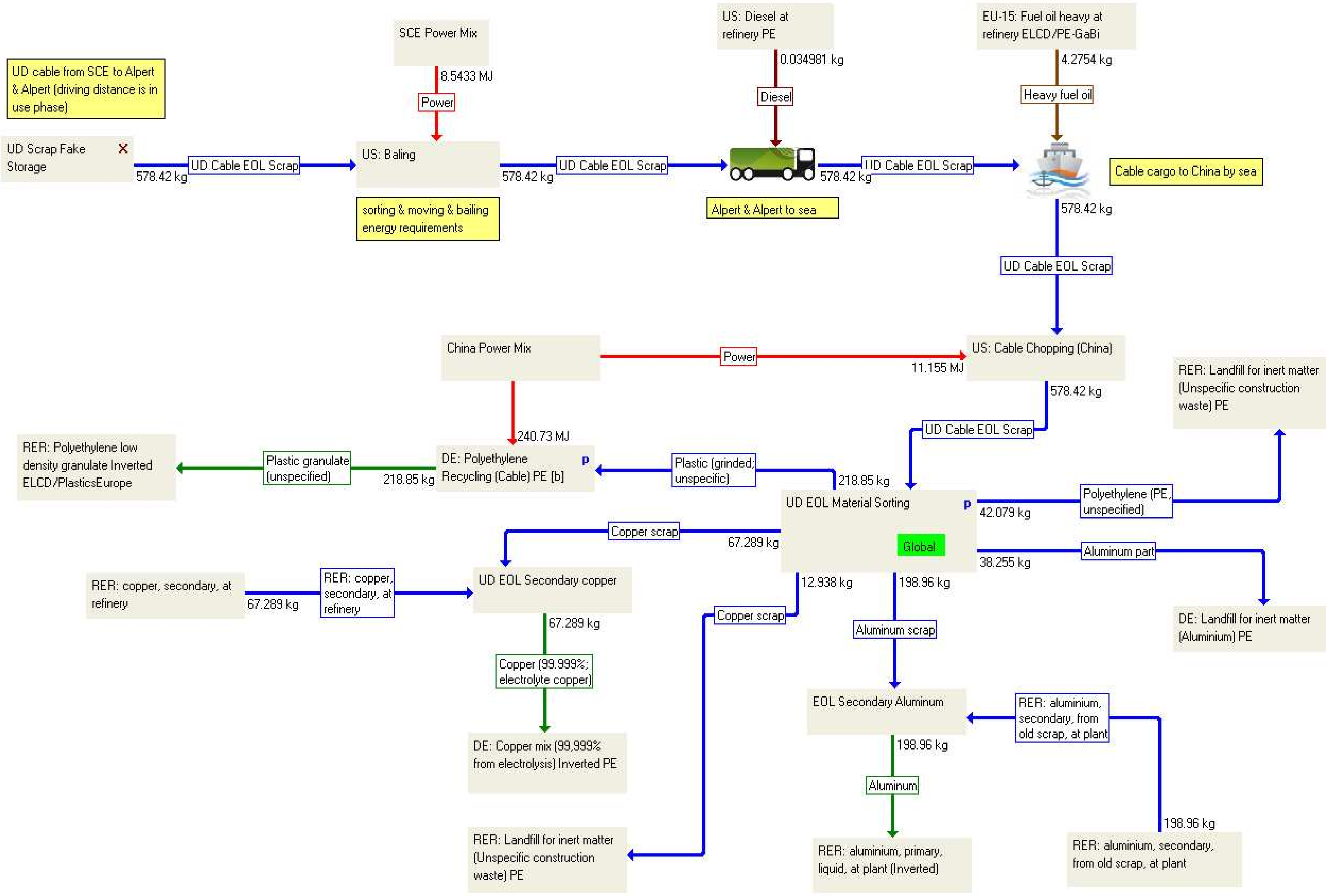
Inputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tra	Standar	Origin	Comment
	OH Cable EOL Scrap [Product model]	Mass	100	100	kg	X	0 %	(No statement)	
	Flow								

Outputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tra	Standar	Origin	Comment
AlLossMass	Aluminum part [Metal parts]	Mass	5.195	1	kg	X	0 %	(No statement)	
AlScrapMass	Aluminum scrap [Waste for recovery]	Mass	81.345	1	kg	X	0 %	(No statement)	
SteelLossMass	Steel part [Metal parts]	Mass	0.808	1	kg	X	0 %	(No statement)	
SteelScrapMass	Steel scrap (St) [Waste for recovery]	Mass	12.652	1	kg	X	0 %	(No statement)	
	Flow								

Underground EOL: Cable



UD cable from SCE to Alpert & Alpert (driving distance is in use phase)

SCE Power Mix

8.5433 MJ

Power

US: Diesel at refinery PE

0.034981 kg

Diesel

EU-15: Fuel oil heavy at refinery ELCD/PE-GaBi

4.2754 kg

Heavy fuel oil

UD Scrap Fake Storage

578.42 kg

UD Cable EOL Scrap

US: Baling

578.42 kg

UD Cable EOL Scrap

578.42 kg

UD Cable EOL Scrap

Cable cargo to China by sea

sorting & moving & bailing energy requirements

Alpert & Alpert to sea

578.42 kg

UD Cable EOL Scrap

China Power Mix

Power

11.155 MJ

US: Cable Chopping (China)

578.42 kg

RER: Landfill for inert matter (Unspecific construction waste) PE

UD Cable EOL Scrap

240.73 MJ

RER: Polyethylene low density granulate Inverted ELCD/PlasticsEurope

Plastic granulate (unspecified)

218.85 kg

DE: Polyethylene Recycling (Cable) PE [b]

p

Plastic (grinded; unspecific)

218.85 kg

UD EOL Material Sorting

p

Global

42.079 kg

Polyethylene (PE, unspecified)

Copper scrap

67.289 kg

38.255 kg

Aluminum part

RER: copper, secondary, at refinery

67.289 kg

RER: copper, secondary, at refinery

UD EOL Secondary copper

12.938 kg

198.96 kg

DE: Landfill for inert matter (Aluminium) PE

Copper scrap

Aluminum scrap

67.289 kg

Copper (99.999%; electrolyte copper)

EOL Secondary Aluminum

RER: aluminium, secondary, from old scrap, at plant

DE: Copper mix (99.999% from electrolysis) Inverted PE

198.96 kg

Aluminum

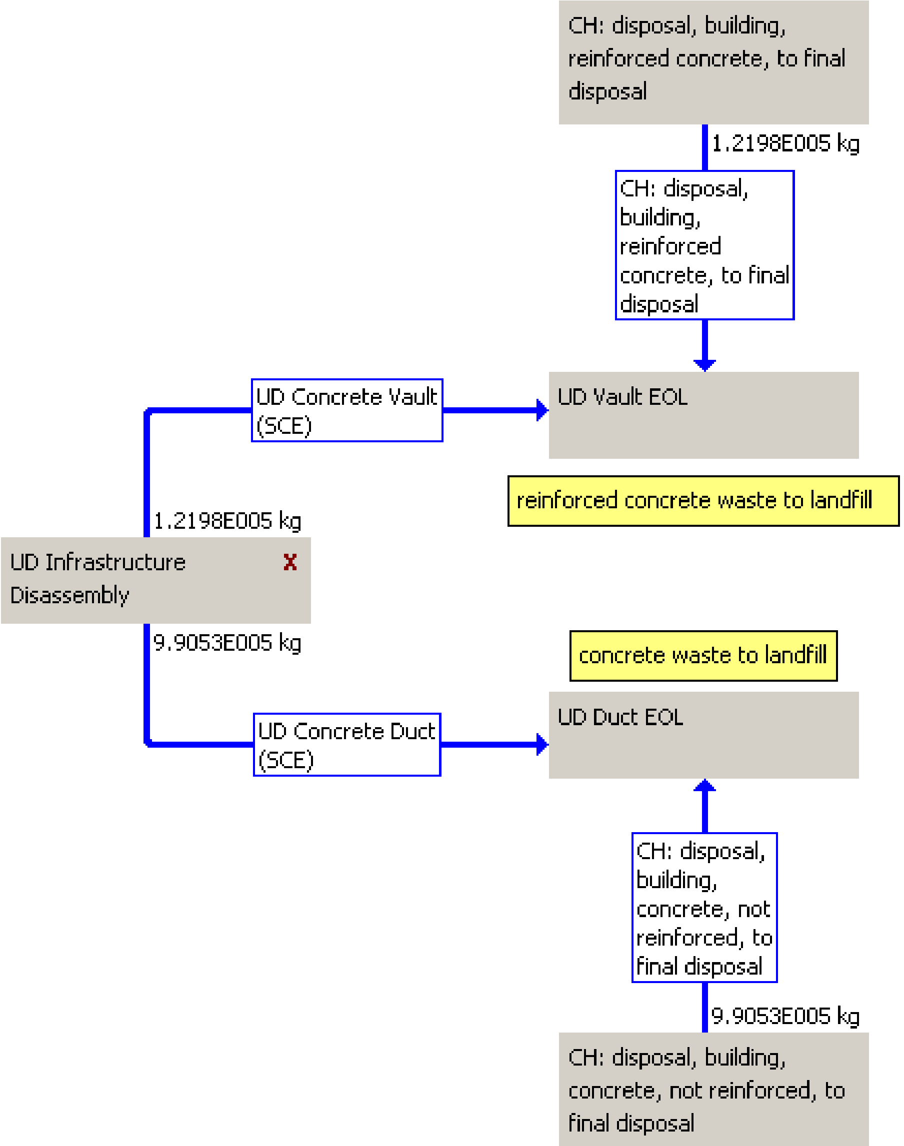
198.96 kg

RER: Landfill for inert matter (Unspecific construction waste) PE

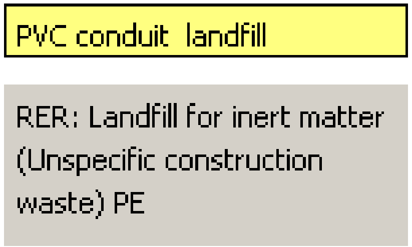
RER: aluminium, primary, liquid, at plant (Inverted)

RER: aluminium, secondary, from old scrap, at plant

Underground EOL: Concrete



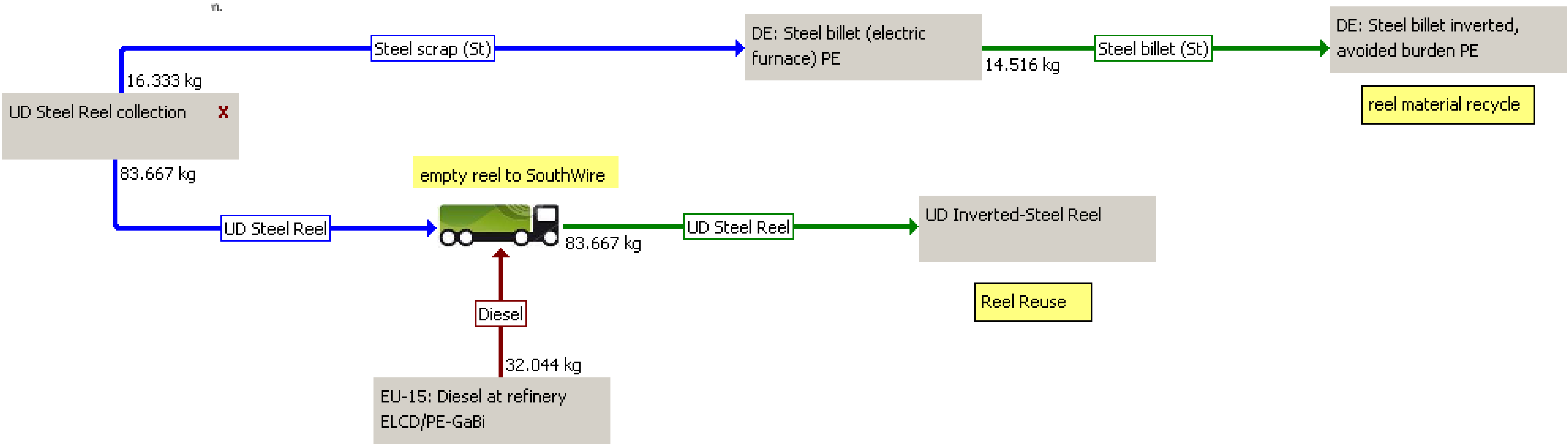
Underground EOL: Insulator



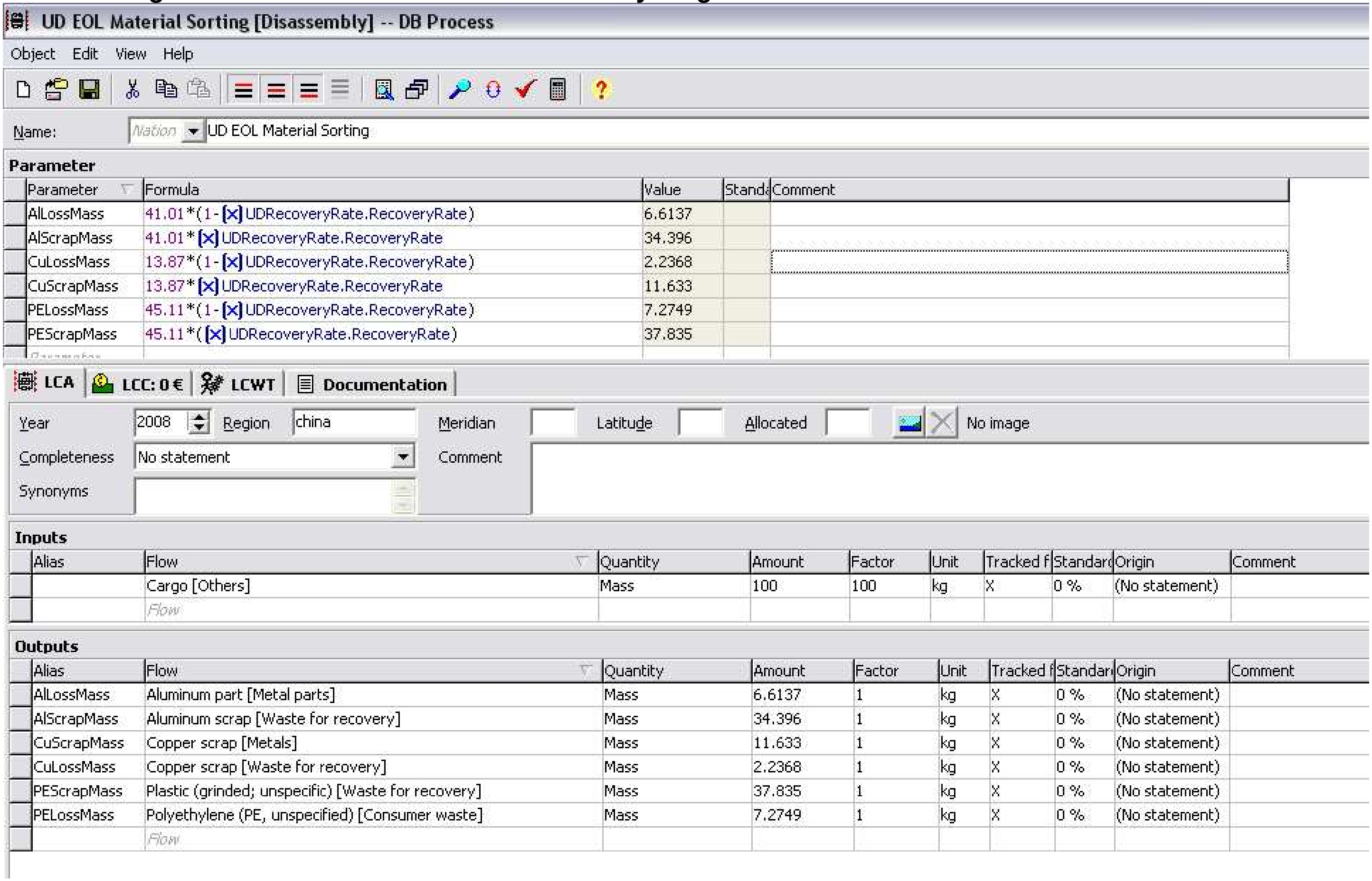
PVC conduit landfill

RER: Landfill for inert matter (Unspecific construction waste) PE

Underground EOL: Steel Reel



Underground EOL: Parameterized Cable Recycling Process



Name: UD EOL Material Sorting

Parameter

Parameter	Formula	Value	Stand	Comment
AlLossMass	41.01*(1-[x] UDRecoveryRate.RecoveryRate)	6.6137		
AlScrapMass	41.01*[x] UDRecoveryRate.RecoveryRate	34.396		
CuLossMass	13.87*(1-[x] UDRecoveryRate.RecoveryRate)	2.2368		
CuScrapMass	13.87*[x] UDRecoveryRate.RecoveryRate	11.633		
PELossMass	45.11*(1-[x] UDRecoveryRate.RecoveryRate)	7.2749		
PEScrapMass	45.11*([x] UDRecoveryRate.RecoveryRate)	37.835		

Year: 2008
Region: china
Meridian:
Latitude:
Allocated:
Completeness: No statement
Comment:
Synonyms:

Inputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked f	Standar	Origin	Comment
	Cargo [Others]	Mass	100	100	kg	X	0 %	(No statement)	

Outputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked f	Standar	Origin	Comment
AlLossMass	Aluminum part [Metal parts]	Mass	6.6137	1	kg	X	0 %	(No statement)	
AlScrapMass	Aluminum scrap [Waste for recovery]	Mass	34.396	1	kg	X	0 %	(No statement)	
CuScrapMass	Copper scrap [Metals]	Mass	11.633	1	kg	X	0 %	(No statement)	
CuLossMass	Copper scrap [Waste for recovery]	Mass	2.2368	1	kg	X	0 %	(No statement)	
PEScrapMass	Plastic (grinded; unspecific) [Waste for recovery]	Mass	37.835	1	kg	X	0 %	(No statement)	
PELossMass	Polyethylene (PE, unspecified) [Consumer waste]	Mass	7.2749	1	kg	X	0 %	(No statement)	