

Morrow Pacific: Life Cycle Assessment of a Coal Export Project

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Abstract

Stricter emissions requirements on coal-fired power plants together with low natural gas prices have contributed to a recent decline in the use of coal for electricity generation in the United States. Faced with a shrinking domestic market, many coal companies are taking advantage of a growing coal export market. As a result, U.S. coal exports hit an all-time high in 2012, fueled largely by demand in Asia. The Australian firm Ambre Energy is currently pursuing a permit to develop and operate a coal export project in Oregon that will ship 8.8 million tons of Powder River Basin coal annually to Asian markets via rail, river barge, and ocean vessel. This study uses a hybrid life cycle assessment model to conduct the only environmental life cycle analysis of the project to date. Social and environmental impacts are quantified and monetized to provide a full picture of the project's externalities as a basis for comparison to other energy export alternatives. Findings show that fuel combustion during the three transport phases of the project contributes significant emissions add-ons to the pollution profile of the exported coal. This study highlights the unintended social and environmental consequences of policies intended to reduce air emissions from domestic coal-fired power plants.

1. Introduction

1.1. Background. Stricter emission requirements on coal-fired generation resources and low natural gas prices have together contributed to a recent decline in the domestic use of coal for electricity generation in the United States. The share of electricity generated annually by coal combustion has declined from 49% in 2007 to 42% in 2011¹, a year in which coal was displaced by natural gas as the main source of American electricity for the first time in 29 years². The U.S. Energy Information Administration estimates that coal's share of U.S. electricity generation dropped to 40% in 2012³.

In the face of a declining domestic market, many coal producing companies have turned to a growing coal export market to fill the demand gap. American coal exports in 2011 totaled 107 million tons, the third most all time and a 30% increase over 2010.

Growth in U.S. coal exports has been driven largely by increased demand in Europe and Asia. The two regions received a combined 76% of all U.S. coal exports in 2011, and Asian coal exports have more than tripled since 2009⁴. South Korea received the most U.S. steam coal (coal used for electricity generation) of any country in 2011, and Japanese demand for American coal grew at an average annual rate of 185% in 2010 and 2011⁵.

A growing coal export market has sparked new business interest especially on the American west coast, where inexpensive and low-sulfur Powder River Basin (PRB) coal from Montana and Wyoming can be shipped to Asian markets.

The surface-mined, shallow coal deposits of the PRB produced 42% of all U.S. coal in 2011. With a coal price per BTU that is around half the U.S. average price⁶, Wyoming leads all U.S. states in annual coal production by a significant margin. In 2011, Wyoming originated 433 million tons, or 22%, of all coal produced in the U.S. The two next highest producing states in 2011 were Kentucky and West Virginia, each producing around 5%⁷.

However, Wyoming trails eastern states in production bound for foreign shores. In 2011, the state produced only 4% of total coal exports, while states east of the Mississippi River accounted for a vast majority of the total⁸. With such a small share of US coal exports, it is no surprise that coal traders are showing great interest in developing a PRB coal export project out of a western port. There are currently six proposals on the table for coal export projects in Oregon and Washington alone⁹.

A coal export project with the most likely path to approval is the Morrow Pacific Project (MPP) currently proposed by Ambre Energy. The coal-focused Australian energy developer has invested heavily in Wyoming coal mines and now plans to develop infrastructure to ship 8.8 million tons of PRB coal annually to Asia through two Columbia River ports in Oregon.

The MPP is being proposed at a time when Oregon and Washington's only two coal plants, Boardman and Centralia, have recently announced closures scheduled for 2020. The first leg of the MPP export route would trace that of PRB coal historically shipped to the Boardman coal plant via BNSF and Union Pacific railroads. But at full capacity, it will bring four times more coal through Boardman than historically supplied to the aging coal plant, and then transfer it to a series of water vessels bound for Japan, Taiwan, and South Korea.

The MPP proposal has enflamed many environmental groups in the Pacific Northwest who fear the environmental impacts from its development and operation will far outweigh economic benefits, endanger natural resources, and emit unprecedented levels of air pollution in a region historically reliant on emissions-free hydropower for most its electricity.

The objective of this study is to examine the direct and indirect economic and environmental impacts of the MPP using a hybrid economic input-output environmental life cycle assessment approach.

1.2. Morrow Pacific Project. The MPP will involve shipping of coal in three phases: Rail, Barge, and Ocean-Going Vessel (OGV). Coal first travels via rail approximately 1,000 miles from the PRB in Wyoming to Boardman, Oregon, a small port city in eastern Oregon at Columbia River Mile 268. At the Port of Morrow in Boardman, coal is unloaded from trains into a negative-pressure, air-scrubbing storage facility. Coal is then loaded via closed conveyor system from the storage facility onto covered Columbia River barges roughly 90-feet in length. Barges are then escorted in pairs by assist tugboats 218 miles down the Columbia River (through locks on three Lower Columbia dams unable to accommodate large OGVs) to Port Westward in St. Helens, Oregon. In St. Helens, coal is transferred directly from barges onto Panamax-sized OGVs roughly 150 feet in length using a stationary dry bulk ship loader. OGVs will then travel the remaining 85 river-miles before entering Pacific waters near Astoria, Oregon.

In the first two years of operation, currently scheduled to begin later this year, the MPP will operate at partial capacity of 3.9 million tons of coal per year. At full capacity starting in year 3, the project will ship 8.8 million tons of coal annually requiring up to two open top 125-car trains per day, two barges per day, and two OGVs per week¹⁰. Figure 1 shows a schematic of the three phases involved in the coal export project.

The Army Corps of Engineers, designated permitting agency for the project, has assigned the MPP application to fast-track review. This designation requires Ambre Energy to submit an environmental assessment in place of a more exhaustive environmental impact statement with a public comment period. To date, Ambre Energy has commissioned two studies of the MPP from regional consulting firms: an environmental review¹¹ and an economic impact study¹². The environmental review, available in its entirety on the project's website, considers only impacts related to construction and operation of the storage and conveying terminal at the Port of Morrow in Boardman. The economic impact study, available in a limited summary version on the project's website, considers economic impacts within Oregon borders only.

This study will use a hybrid approach to life cycle assessment (LCA) in order to develop a more complete picture of the environmental impacts resulting from development and operation of the MPP.

2. Method

2.1. Hybrid Input-Output Environmental Life Cycle Assessment Model. The economic and environmental analysis framework chosen for this study borrows from both the traditional Society of Environmental Toxicology and Chemistry/Environmental Protection Agency (SETAC/EPA) process-based approach and the economic input-output (EIO/LCA) model developed at Carnegie Mellon's Green Design Institute¹³. A hybrid model provides benefits from both LCA approaches that together deliver a more complete picture of the economic and environmental impacts associated with the MPP.

Similar hybrid LCA models have been used to calculate the lifecycle economic and environmental impacts associated with coal energy transportation via rail, wire transmission, and gas pipeline (Bergerson et al., 2005)¹⁴ and various sources of electricity generation (Jaramillo et al., 2007)¹⁵.



The advantage of a SETAC/EPA approach to LCA is specificity; its process-based view examines detailed material and energy inputs and environmental outputs to each and every process involved in the production, use, and disposal phases of a product or service over a given time period. The main disadvantage of the SETAC/EPA LCA approach is its large scope; even with the help of computers and LCA-specific software, it is almost always too expensive and time-consuming to conduct a full LCA since products usually have thousands or tens of thousands of direct and indirect inputs. In practice, it is common to draw a tight boundary around categories of inputs and outputs when conducting a SETAC/EPA LCA so as to have a manageable scope. Unfortunately this practice reduces confidence and accuracy in the final representation of total impacts over the life cycle of a product.

Researchers at Carnegie Mellon's Green Design Institute have introduced an alternative to the traditional SETAC/EPA LCA method that simplifies a number of assumptions and uses economy-wide matrix calculations to aggregate total impacts for a product from direct and indirect impacts throughout the supply chain preceding it. Based on the input-output economic models developed by Nobel Prize laureate and economist Wassily Leontief, the EIO/LCA model is a collection of publicly available resource and energy use data coupled with historic economic data collected by the Department of Commerce. Its matrix structure is organized into roughly 500 economic sectors with known relationships between them. The result is a model that provides emissions outputs and economic, energy, and materials inputs for a given increase in demand in the sector of interest.

The EIO/LCA's main advantage is its comprehensiveness; the aggregate nature of the economic data contained in the model allows the user to examine impacts of a product or service stretching throughout the supply chain and throughout the manufacturing, use, and disposal stages. Aggregated economic data is at the same time an inherent weakness of the model; the EIO/LCA method generalizes some industries to fit the entire economy into 500 sectors and assumes a linear relationship between inputs and outputs such that a 10-fold increase in a particular sector output requires a 10-fold increase in all its inputs. These qualities make for a manageable and operational LCA process, but may not provide the level of specificity needed for a regionally or materially unique good or service. A hybrid approach can be employed as in this study to combine the advantages of both LCA methods.

For this analysis, the EIO/LCA model was used to determine sector-specific lifecycle economic and environmental impacts from the capital purchasing and construction phases of the MPP, the maintenance of capital (vessels, buildings, and equipment), and operation of the storage and conveying systems. It was also used to calculate indirect emissions during the three transportation phases (rail, barge, and OGV).

The SETAC/EPA method was used to determine direct emissions during the three transportation phases of the MPP. This consists of direct emissions from combustible fuel during rail, barge, and OGV transportation, as well as particulate matter emission from open top coal cars during the rail transport phase. As in Bergerson et al. (2005)¹⁶, these direct emissions were then added to the aforementioned indirect emissions from the three transportation phases, as well as the emissions during construction, maintenance, and storage and conveying activities—all determined using the EIO/LCA model. The result is a total emissions profile of the MPP.

In determining direct emissions during transportation phases, EPA emissions estimates for specific mobile combustion sources used in product transport (diesel locomotive engines; diesel tow and push boat engines; and OGV fuel oil-powered engines) were used to quantify greenhouse gas emissions (CO₂, CH₄, and N₂O) from operating the trains, barges, and OGVs of the MPP¹⁷. Emission factors from EPA sector-specific (i.e. locomotive, tug and push boats) emissions inventory studies were used to calculate conventional pollutant emissions (SO₂, CO, NO_x, and PM₁₀) from operation of the diesel locomotives¹⁸ and diesel tugboats¹⁹. Estimates of fugitive coal dust and embedded PM₁₀ from open top rail cars in the MPP were taken from Doctor et al. (2001)²⁰ and an industry report by Connell Hatch²¹. Conventional pollutant emissions from OGV operations were calculated using emissions factor outputs from a ship emissions model developed at the National Technical University of Athens Laboratory for Maritime Transport²² in combination with industry-level estimates developed by Maersk Lines²³.

Consistent with the use of hybrid LCA models in other studies²⁴, fatality rates were derived from labor statistics and annual product volumes to quantify probable loss of life during the course of MPP operation.

2.2. Scope Definition. The scope of this life cycle assessment includes the cradle-to-gate impacts of mining of coal through delivery of coal to theoretical port in Busan, South Korea; this includes coal mining, construction of conveying and storage facilities, construction of ship-unloading equipment, construction of OGVs, construction of barges, construction of tugboats, fuel production, rail transportation, barge transportation, marine transportation, and maintenance of vessels, buildings, and equipment. It does not include electricity generation from delivered coal in Asia.

In this study we will quantify the project's lifecycle economic activity (total economic activity, job creation, tax revenue creation, and profits), and report and inventory the project's air pollution (greenhouse gases, and the criteria air pollutants SO₂, CO, NO_x, and PM₁₀). Finally, we will estimate social and environmental externality costs by monetizing the costs of air pollution and anticipated loss of life.

Figure 2 shows the process flow diagram of the MPP and the boundaries of this study. It also indicates the LCA model (EIOLCA or SETAC) used for each project phase and whether the model was used to calculate direct emissions or indirect (i.e. occurring outside the primary sector) emissions. For example, in the river barging phase of the project lifecycle, the SETAC model was used to determine direct emissions associated with the burning of fuel during river barge transport, while the EIOLCA model was used to determine the indirect emissions occurring upstream of the river transport phase, including fuel refining and all of the energy and materials that went into building and maintaining the river barges.

2.3. Basis of Comparison (Functional Unit). The LCA method requires that the product or service being studied is specified in terms of a functional unit. The functional unit is a standardized metric that provides a basis for comparison with an equivalent product or service. Consistent with a fuel delivery comparative LCA of natural gas and coal conducted by the Department of Energy's National Energy Technology Laboratory²⁵, the functional unit chosen for this study is the heat content of the fuel delivered at the South Korean port. In this way, the inventory of air emissions will be reported in

pounds (lbs.) of pollutant per MMBTU of fuel delivered. The Department of Energy study assumes that fuel is delivered to the gate of a power plant, but due to a lack of information on power plant location and energy transport in South Korea, this study’s functional unit will describe fuel delivered to port.

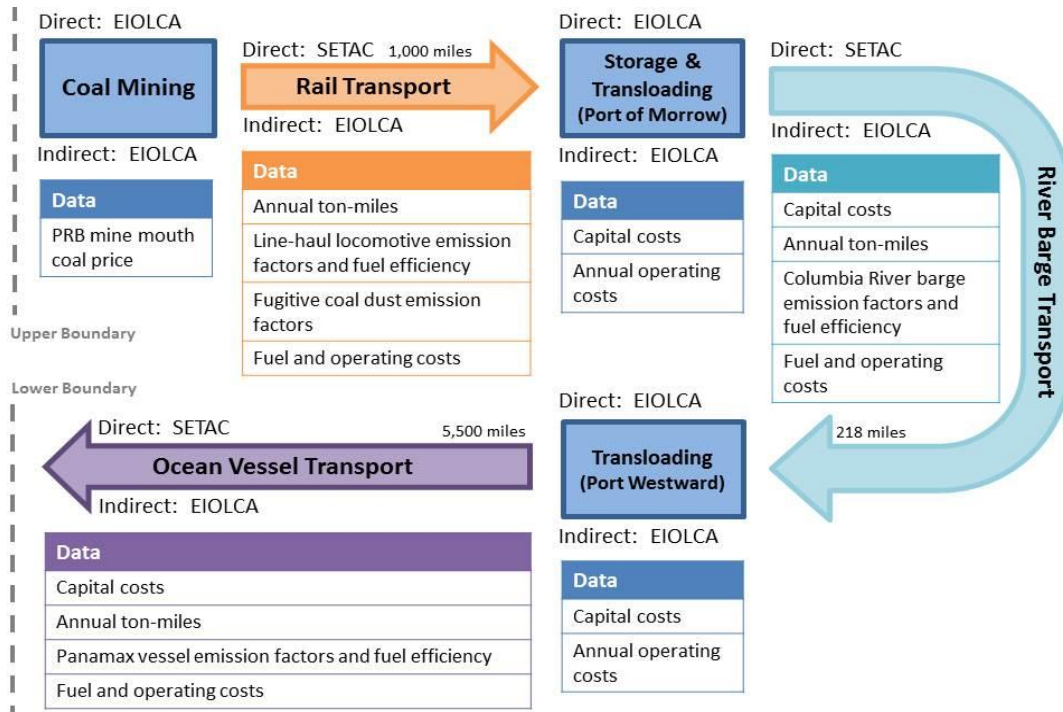


Figure 2. Process Flow Diagram with Model Methodology and Data Requirements

2.4. Data and Assumptions. As the MPP is not currently operational and many financial and operational details have not been publicly disclosed, several assumptions were made in conducting the LCA. In the following tables, Asterisks (*) denote data that was given in Ambre Energy project brochures²⁶, the environmental review by Anderson Perry & Associates²⁷, the economic impact study by ECONorthwest²⁸, or in conversations with a

spokesperson for the MPP from Gard Communications²⁹. All data and assumptions are discussed in detail below. While many of the expenditures below are part of the MPP budget, expenses listed in the following sections are *not necessarily* expenses incurred by Ambre Energy in development of the MPP. Rather, they are better understood as

	Phase 1	Phase 2
Length (years)		2 18
Tons of coal shipped annually	3,900,000	8,800,000 *
Train miles to Boardman		1,000 miles*
Barge miles from Boardman		218 miles*
Panamax miles from St. Helens		5,500 miles
PRB coal energy content		16.74 MMBTU/ton
PRB coal price - mine mouth		0.81 \$/MMBTU
Inflation rate		2.1%
Energy price escalator		3%

Table 1. General Project Assumptions

increases in various sector demands to be used as inputs to the EIO/LCA model.

Table 1 shows a number of general assumptions made during the analysis. Coal volumes shipped annually were provided in Ambre Energy project brochures. Train and barge miles were determined from railroad and river mile information also given in public project documents. In its marketing documents, Ambre Energy also notes that the MPP will operate at partial capacity of 3.9 million tons of coal for the first two years of operation. Beginning in the third year, annual capacity will be ramped to 8.8 million tons and continued indefinitely. For purposes of this analysis, a 20-year project period is assumed.

Rail	Phase 1	Phase 2
Train cars/year	33,125	75,875 *
Ton-miles/year	3,900,000,000	8,800,000,000

Barge	Phase 1	Phase 2
Barge loads/year	1,283	2,933 *
Ton-miles/year	850,200,000	1,918,400,000

OGV	Phase 1	Phase 2
OGV loads/year	58	133 *
Ton-miles/year	21,450,000,000	21,450,000,000

Ambre Energy has not been specific about the destinations for its coal shipments. It has mentioned three possible destinations in several project documents: South Korea, Japan, and Taiwan. To date, no specific ports or allocated amounts have been given. This analysis will assume all coal is shipped to the Port of Busan in South Korea, roughly 5,500 miles by Panamax vessel from St. Helens, Oregon.

PRB coal energy content was calculated from FERC-923 data using a weighted average of the quality of coal delivered to

the Boardman coal plant at the Port of Morrow during 2011³⁰. Average PRB coal prices at the mine mouth were taken from EIA coal receipts³¹. The inflation rate and energy price escalator were derived using the U.S. Department of Energy’s Energy Escalation Rate Calculator Tool³².

Table 2 shows the coal transport volume assumptions for barge, rail, and OGV. Loads per year are calculated from volume estimates and vessel capacity given in the MPP environmental review. Annual ton-miles reflect mileage estimates given above.

Table 3 lists the breakdown of capital expenditures for the project. Capital expenditures for Columbia River barges reflect a current request for bids by the MPP for the local (Oregon) construction of 20 barges at a total cost of \$70 million³³. The economic impact study indicates that an additional 16 barges will be purchased in phase 2 of the project at a total cost of \$56 million. Cost of the Siwertell dry bulk ship unloader is

<i>Phase</i>	<i># Item</i>	<i>Unit Cost</i>	<i>Total</i>
1	9 OGVs	\$ 32,000,000	\$ 288,000,000
1	20 Barges	\$ 3,500,000	\$ 70,000,000 *
1	1 Siwertell unloader	\$ 40,000,000	\$ 40,000,000 *
1	2 Tug boats	\$ 2,000,000	\$ 4,000,000
1	1 Buildings & Equipment	\$ 42,343,376	\$ 42,343,376 *
2	11 OGVs	\$ 32,000,000	\$ 352,000,000
2	16 barges	\$ 3,500,000	\$ 56,000,000 *
2	3 Tug boats	\$ 2,000,000	\$ 6,000,000
2	1 Buildings & Equip	\$ 33,644,918	\$ 33,644,918 *
TOTAL Capital			\$ 891,988,294

Table 3. Capital Expenses

listed in the economic impact study at a total cost of \$40 million and is purchased in the project's first phase. Building and Equipment capital costs are largely realized at the Port of Morrow dry storage and conveying facility, with the exception of \$1 million to be spent on construction at Port Westward in St. Helens. As noted below and in the economic impact study, these costs are split between phase 1 and 2.

Though the MPP is expected to increase Columbia River barge traffic significantly (by some accounts up to 94%)³⁴, it is not clear that it will add a significant amount of demand in the rail sector. According to the environmental review, the project will travel on existing rail routes reported to have ample capacity to support the proposed new volumes, at least near the Port of Morrow³⁵. But since the environmental review study area only includes the City of Boardman and its immediate surroundings, it is unclear whether significant rail investments will be required. Due to this uncertainty, new rail capital investments are not included in this analysis (though rail fuel and rail operational costs are included in project operating expenses).

MPP project documents do not include information on investments in new OGVs and tugboats. A conversation with a project spokesperson indicated that financial planning for the project is ongoing and no decision on final vessel investments has been made to date. Despite this uncertainty, relatively simple calculations for OGV and barge throughput (considering barge and OGV transit and loading/unloading times) suggest that a minimum of 20 OGVs and 5 barges will be required to keep up with project volumes. These calculations agree with other existing estimates³⁶. Research into market prices for Panamax vessels³⁷ and 3000HP tugboats³⁸ yielded price estimates around \$32 million and \$2 million, respectively. For the analysis, these expenses are split between phase 1 and phase 2 proportionate to project volumes.

Table 4 lists annual operating expenses for the MPP. OGV fuel and total tug operational costs were given as part of the ECONorthwest economic impact study. Storage and Transloading costs were estimated indirectly from cost data also presented in the economic impact study. OGV operations and maintenance costs were derived using data gathered by Drewry Shipping Consultants and researchers at Hofstra University's Department of Global Studies and Geography³⁹. Tug fuel costs were determined using current marine diesel prices and local tugboat fuel efficiency estimates given by the Columbia River Towboat Association⁴⁰. Tug maintenance costs were assumed to be roughly 11% of annual operating costs, the same proportion of operating costs as OGV maintenance costs.

<i>Item</i>	Phase 1	Phase 2
OGV Fuel	\$ 43,640,625	\$ 99,750,000 *
OGV Operations	\$ 41,743,207	\$ 95,413,043
OGV Maintenance	\$ 9,487,092	\$ 21,684,783
Tug Fuel	\$ 5,904,167	\$ 14,290,408
Tug Operations	\$ 20,083,333	\$ 45,109,592 *
Tug Maintenance	\$ 2,887,500	\$ 6,600,000
Storage & Transloading	\$ 27,763,471	\$ 23,530,167 *
Rail Fuel	\$ 16,783,758	\$ 37,871,045
Rail Operations	\$ 55,132,242	\$ 134,283,320
	\$ 223,425,395	\$ 478,532,358

Table 4. Annual Operating Expenses

Rail transportation costs were assumed to be the difference in average price between coal receipts at the Port of Morrow in 2011⁴¹ and coal receipts at the mine mouth⁴², similar to the method used in Bergerson et al. (2005)⁴³. This price estimate would include costs of fuel, capital, maintenance,

operations, and margins by companies involved in the transport. EPA estimates of ton-mile fuel efficiency for Class I Line Haul diesel locomotives were then used in combination with current diesel prices to separate out fuel costs from total rail transportation costs⁴⁴.

2.5. Analysis. Annual project capital and operating expenditures were extrapolated to a 20-year pro forma income statement detailing project volumes, and fixed and variable costs. Dollars were converted to 1997 and 2002 dollars consistent with the basis years of the available EIO/LCA models⁴⁵. The most recent 2002 model was used to estimate all economic and environmental impacts, except conventional air pollutants. The 1997 model was used to estimate conventional air pollutant emissions, as it is the most recent form of the model to contain conventional air pollutant data.

Capital expenditures and operating expenditures were totaled, separated into their appropriate economic sectors, and used as inputs to the EIO/LCA model to determine associated economic and environmental impacts. Cost of coal was used to estimate impacts from coal mining and related upstream activities. Fuel costs were used to estimate impacts from fuel refining and related upstream activities. Storage and Transloading costs were used to estimate impacts from the operation of storage and conveying activities at the MPP ports. Transportation operational costs were used to determine indirect (upstream) impacts from the operation of OGVs, barge, and rail product transport. Figure 3 shows the EIO/LCA sector used for each capital and operating cost category.

<i>EIO/LCA Sector:</i>	Capital Cost Category					Operating Cost Category										
	Barges	OGVs	Unloader	Buildings & Equipment	Tugs	OGV Fuel	OGV Other	OGV Maintenance	Tug Fuel	Tug Other	Tug Maintenance	Buildings & Equipment Maintenance	Coal Storage	Coal	Rail Fuel	Rail Other
336611 - Ship Building and Repair	X	X			X			X			X					
333922 - Material Handling Equipment Manufacturing			X													
237990 - Other Nonresidential Construction				X												
237990 - Other Nonresidential Maintenance												X				
324110 - Petroleum Refining						X			X						X	
483111/483211 - Water Transportation							X			X						
49319 - Other Warehousing & Storage													X			
21211 - Coal Mining														X		
482111 - Line Haul Rail Transportation																X

Figure 3. EIO/LCA Cost Input Sectors

Direct emissions during transport phases were calculated using fuel combustion emission factors and industry estimates of air pollution resulting from fugitive coal dust emissions. Direct emissions from transport operations were then added to all project direct and indirect emissions determined using the EIO/LCA model.

3. Results

3.1. Costs. Figure 4 shows a breakdown of annualized costs by category. Although large when considered upfront, capital costs spread over the life of the project comprise only 7% of total project expenditures on an annual basis. Operations and maintenance costs associated with product transport and coal conveyance comprise the largest class of expenditures at 63%. Fuel costs for rail, barging, and OGVs amount to 30% of total project expenditures.

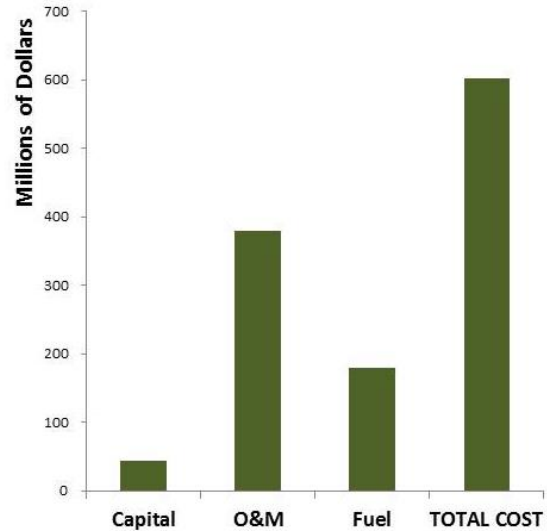


Figure 4. Annualized project costs by cost category

3.2. Economic Benefits. The 20-year project could be expected to create over \$25 billion in direct and indirect economic activity throughout the U.S. economy. It would also directly or indirectly create nearly \$6 billion in total employee compensation (an average of 3,750 \$80,000 FTE on an annual basis), \$742 million in new tax revenue, and roughly \$4.7 billion in profits for all sectors involved.

3.3. Air Emissions. Table 5 shows the amount of air pollutants emitted per functional unit of coal (pounds of pollutant per delivered MMBTU) delivered to port in Busan, South Korea. The table includes functional unit emissions for both greenhouse gases and conventional air pollutants. It also lists the baseline functional unit emissions attributable to coal mining and all upstream activities. These figures represent the functional unit emissions if the power plant was located at the mine mouth and transport was not necessary. The bottom row of the table lists the factors by which the MPP multiplies the mine mouth functional unit emissions through the addition of emissions during its various transport stages.

	SO2	CO	NOx	PM10	CO2e
Total Pounds	480,427,558	187,491,217	641,061,343	962,310,334	141,688,959,106
Total MMBTU	2,782,188,000	2,782,188,000	2,782,188,000	2,782,188,000	2,782,188,000
Total Lbs/MMBTU	0.17	0.07	0.23	0.35	50.93
Mine Mouth Lbs/MMBTU	0.004	0.01	0.005	0.002	7.34
Factor	44x	7x	48x	167x	7x

Table 5. Project Lifecycle Pollutant Emissions per delivered MMBTU

The MPP will emit over 217,000 metric tons of SO₂, 85,000 metric tons of CO, 290,000 metric tons of NO_x, and 436,000 metric tons of PM₁₀ throughout its lifecycle. Figure 5 shows a graphical representation of the functional unit emissions of conventional air pollutants (SO₂, CO, NO_x, and PM₁₀) measured in pounds (lbs.) per delivered MMBTU of coal.

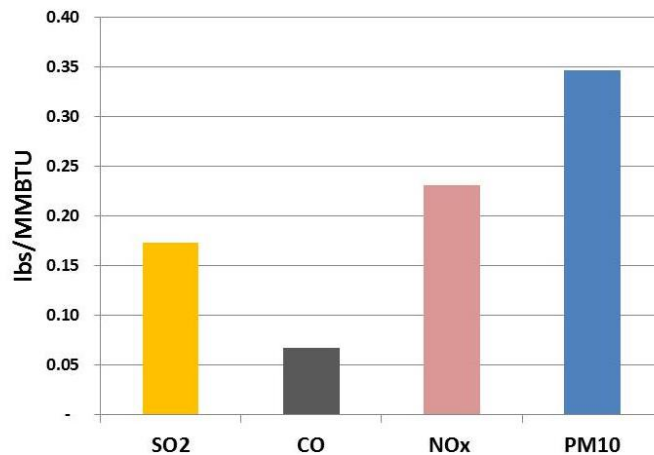


Figure 5. Project Lifecycle Emissions of Conventional Air Pollutants per delivered MMBTU

3.3.1. Conventional Air Pollutants. Figure 6 shows the total lifecycle emissions of conventional air pollutants SO₂, CO, NO_x, and PM₁₀ as a result of the MPP’s operation over a 20 year project life. These figures include all phases of capital manufacturing and construction, coal mining, fuel refining, product transport, and operations and maintenance of buildings, structures, vessels, and transloading and storage equipment, as well as all upstream activities involved in the given sector’s supply chain. The total emissions for each pollutant are shown as an accumulation of the different project phases (the proportion of total emissions created by each phase is also broken down numerically in Table 6).

The project’s OGVs are the largest contributor to emissions of all conventional air pollutants except PM₁₀— for which rail is largely responsible. OGVs emit 62% of the project’s total SO₂ emissions, 28% of CO emissions, and 57% of NO_x emissions.

Rail contributes large amounts of CO and NO_x emissions to the project’s air pollution profile (24% and 12%, respectively) through the combustion of locomotive diesel fuel. But its largest environmental impact is PM₁₀; 94% of the project’s particulate matter is emitted during the rail transport phase. Less than a half percent of total PM₁₀ emissions occur as a result of the combustion of locomotive diesel.

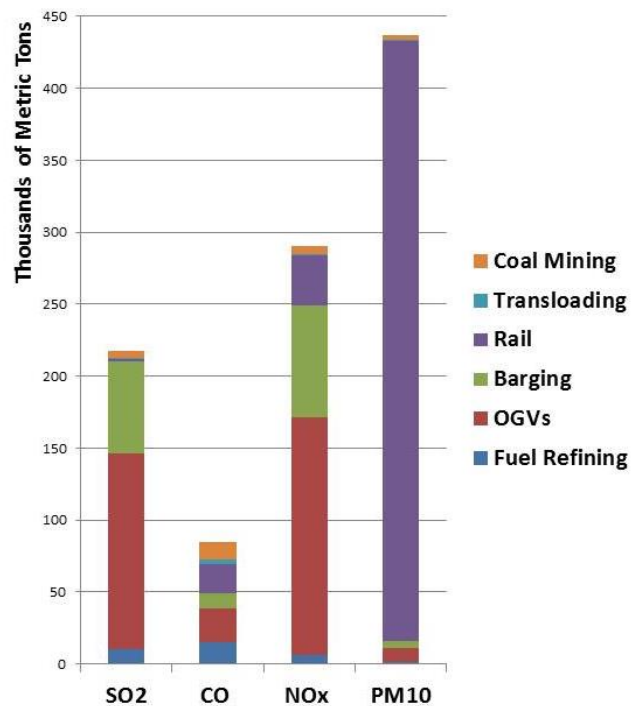


Figure 6. Total lifecycle emissions of conventional air pollutants over a 20-year project life

Rather, it is fugitive coal dust that is responsible for these very large PM10 emissions.

Fugitive coal dust is simply fine particulate coal lost to the general environment as a result of wind tunnel effects sweeping over open top rail cars during transit. Estimates of fugitive coal dust losses differ by distance traveled but can vary from .007%⁴⁶ to 3%⁴⁷ of the total tonnage of the coal load. If the higher figure is correct, the MPP could potentially lose as much as 264,000 tons of coal annually in the form of fugitive coal dust. The fine coal particulate comprising the coal dust ranges in size from a few

micrometers to several hundred, but some industry researchers have estimated that half of fugitive coal dust emissions are classified as PM10⁴⁸. For this study, PM10 emissions were assumed to be half of fugitive coal dust emissions. Total fugitive coal dust emissions were assumed at 0.5% consistent with the study by Doctor et al. (2001)⁴⁹.

Project Phase	SO2	CO	NOx	PM10
Fuel Refining	5%	18%	2%	0%
OGVs	62%	28%	57%	2%
Barging	29%	12%	27%	1%
Rail	1%	24%	12%	96%
Transloading Operations	0%	4%	0%	0%
Coal Mining	2%	15%	2%	1%
TOTAL	100%	100%	100%	100%

Table 6. Proportional project phase contributions to total lifecycle emissions of conventional air pollutants

Emissions of particulate matter from other project phases are assumed to occur only

during combustion of diesel and fuel oil, and not from the release of fugitive coal dust. Both the OGVs and barges are closed containers, and both will be loaded by closed conveyor systems. As mentioned previously, the transloading operation at the Port of Morrow uses a negative air pressure system to store and convey coal to the closed barges, in addition to a wet scrubber system to cleanse air migrating throughout its 300,000-ton capacity coal storage facility. Transloading operations at Port Westward will reportedly use a pneumatic screw Siwertell ship unloader which is expected to release a negligible amount of coal. Transloading and storage operations of the MPP will generally emit a small amount of conventional pollutants throughout the life of the project.

Barging of coal down the Columbia River results in large amounts of SO2, NOx, and CO emissions (29%, 27%, and 12% of total emissions, respectively). Though river transport is energy efficient in comparison to truck and rail, it does not avoid considerable amounts of SO2 and NOx emissions as a result of diesel combustion.

Environmental impacts from activities related to coal mining and fuel refining are significant, though largely overshadowed by the great scale of impacts during transport phases of the project. During the MPP lifecycle, coal mining and fuel refining activities contribute 15% and 18% of total CO emissions, respectively.

3.3.2. Greenhouse Gases. Greenhouse gas emissions (GHG) of varying type are given in Table 7, all measured in metric tons of CO2 equivalent (CO2e) and separated by project phase. In addition to being separated by type of gas, the figures also show the amount of CO2 emitted as a result of indirect inputs to the sector in question (“Indirect CO2” column) and through the combustion or atmospheric release of fossil fuels (“Fossil Fuel CO2” column). These figures include all phases of capital manufacturing and

Project Phase	N2O	HFC/PFCs	CH4	Indirect CO2	Fossil Fuel CO2	TOTAL
Fuel Refining	16,308	28,839	1,873,244	617,609	4,593,786	7,120,368
OGVs	262,997	11,643	173,692	94,898	28,748,984	29,304,538
Barging	123,650	4,140	76,933	33,163	13,545,395	13,789,059
Rail	39,076	6,461	113,623	62,742	4,324,297	4,545,266
Transloading Operations	2,220	2,109	16,937	14,016	217,431	252,756
Coal Mining	21,025	8,864	7,270,273	82,309	1,881,975	9,257,044

Table 7. Project phase contributions to total lifecycle emissions of greenhouse gases (metric tons of CO2e)

construction, coal mining, fuel refining, product transport, and operations and maintenance of buildings, structures, vessels, and transloading and storage equipment. They also include indirect emissions from all input sectors upstream of the sector given.

OGVs are the single largest contributor of global warming potential during the assumed 20-year lifecycle of the project at 46% of total greenhouse gases (see Figure 7 for a percentage-based breakdown of GHG emissions). The vast majority of the CO2e emitted by OGVs is a result of combustion of fuel by the large engines used to propel Panamax vessels. These engines usually run on a type of thick residual oil called fuel oil #6.

Barging activities contribute the second largest amount of global warming potential of any project phase at 22% of total CO2e emissions. Similar to OGVs, most of the CO2e emissions during barging activities occur as a result of combusted fuel, in this case diesel. The coal mining phase contributes the third most CO2e of any phase, at 14%. However, the majority of global warming potential realized as a result of coal mining and related activities results from the release of CH4, or methane, from coalbeds.

Fuel refining activities are responsible for 11% of CO2 equivalent emissions, owing in part to atmospheric release of uncombusted CH4 during the refining process.

Similar to the other transport phases, rail releases the vast majority of its GHGs in the form of CO2 emitted during the diesel combustion process.

Transloading and Storage related activities again contribute little to the GHG profile of the project, contributing less than 1% of total project CO2e emissions.

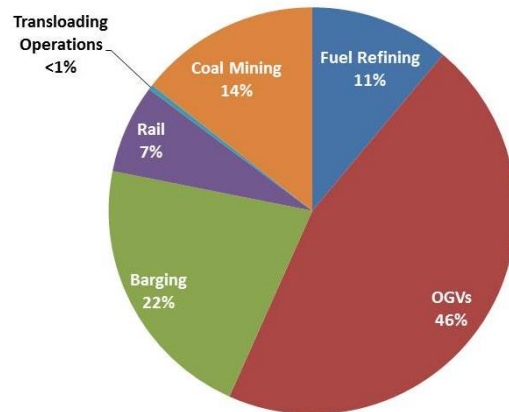
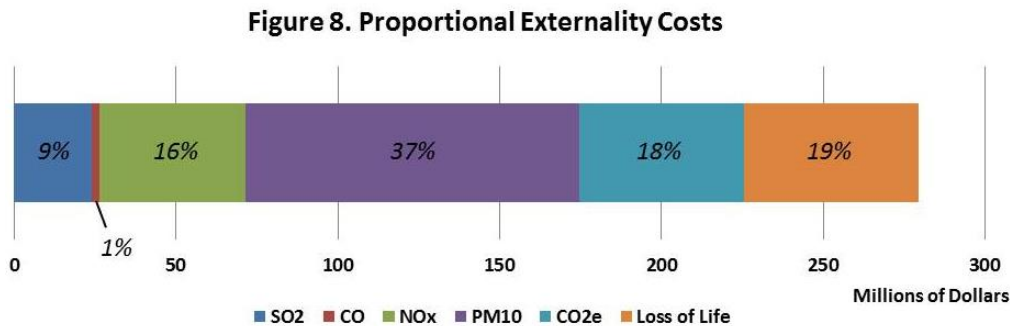


Figure 7. Proportional project phase contributions to total lifecycle emissions of greenhouse gases

3.4. Estimating Externality Costs. In order to evaluate the social and environmental impacts of the MPP, externalities were assigned monetary equivalents and summed. This method, while imprecise, offers insight into the scale of the unintended social and environmental costs when compared to the project’s conventional costs.

Externality costs include the costs of pollution (conventional air pollutants and CO₂) and expected deaths during rail and water vessel transport. If externalities were accounted for in the development of the MPP, they would increase the overall cost of the project by 47%.

The social cost of pollution was calculated using methodology derived from a literature review on determining external costs of air pollution by Matthews et al. (2000)⁵⁰. Costs were determined for each conventional air pollutant and for greenhouse gases (CO₂e), and then tallied. Figure 8 shows a breakdown of the contributions of each externality category to annualized social and environmental costs.



Expected fatalities from the coal mining, rail transportation, and water transportation (OGV and barge) phases were calculated from historical annual fatalities rates in each industry as calculated by the Department of Labor's Mine Safety and Health Administration⁵¹ and the Bureau of Transportation Statistics^{52 53}. For coal mining, state by state fatality data allowed for a fatality rate specific to the Powder River Basin (Montana and Wyoming). Project coal tonnage was compared with historical annual production in the Powder River Basin⁵⁴ to determine a MPP-specific coal mining fatality rate. For rail and water transport, fatality rates were compared to national annual ton-miles of product transport for rail and marine vessel, to determine a fatality rate per project ton-mile⁵⁵. Given product volumes, these calculations indicate that the MPP could directly or indirectly result in 7.27 deaths per year during the rail, barging, OGV, and coal mining phases. This risk was monetized using the current EPA value of a statistical life⁵⁶.

3.5. Impact in the Context of U.S. Coal Plant Closures. The findings of this study indicate that closure of U.S. coal plants may not reduce air pollutant emissions if coal that would otherwise be burned domestically is exported instead. A study comparing the difference in emissions from burning U.S. coal domestically with burning it abroad is naturally complicated by uncertainty with regard to a number of factors, including: destination of exported coal, amounts exported of coal, uses for exported coal (steam versus metallurgical), foreign power plant technology and emissions factors, distance of coal power plants from port destinations, and modes of transportation from port to plant.

However, in the case of the MPP, impending closure of the only two coal plants in the northwestern U.S. creates the conditions for a useful case study on the net emissions flux following a shift from historical domestic coal consumption to coal export.

The MPP takes advantage of existing rail routes historically used to transport PRB coal to the 585 MW Boardman coal plant in Boardman, Oregon and the 1340 MW Centralia Coal Plant in Centralia, Washington. The two plants are the only existing coal-fired generation resources in Oregon and Washington, and both are being closed in 2020 to avoid expensive upgrades required as part of new emissions regulations.

The emissions inventory derived in this study can be used to compare the difference in emissions between exporting the coal as in the MPP and burning the coal domestically at the Boardman and Centralia coal plants. In 2009, the last date for which EPA eGrid has plant level emissions data, Boardman and Centralia together burned roughly 90% of the coal the MPP will ship at full capacity⁵⁷. Using the eGrid emissions data, it is evident that in simply transporting (not transporting *and* burning) the coal as in the MPP, we create 77% of the NOx emissions and 25% of the CO₂e emissions that we would get from the entire lifecycle of the same amount of coal mined, transported, and combusted domestically at Boardman and Centralia for the same time period. And since this 20-year scenario would require the Boardman and Centralia plants to install control technologies requisite with new emissions rules, the added emissions profile is likely to be even larger.

3.5. Uncertainty. The MPP currently exists largely in the form of evolving and changing financial and operational plans. As the project is still in its infancy and has not received required permitting, many of the financial and operational details in this study were estimated to the greatest amount of accuracy possible given the large amount of uncertainty surrounding the project. Results herein will reflect this uncertainty to a large degree, though great care has been taken to estimate unknown details with the aid of the best comparisons available.

In regards to the model used, the EIO/LCA model is continually updated with Department of Commerce economic data, but the most current model uses data from the year 2002. Though project dollars were converted to 2002 dollars using the consumer price index, there is an expected level of imprecision that comes with the use of data from 2002. There is also a level of imprecision involved with the consolidation of the U.S. economy into 500 sectors. Despite these factors, the author believes the EIO/LCA model to be the best method available for considering complete lifecycle economic and environmental impacts of the Morrow Pacific Project.

4. Conclusion

4.1. Discussion. At full capacity, the MPP will ship 8.8 million tons of coal annually. This level of coal exporting will increase the current level of U.S. coal exports by 7%. In so doing, the project will increase the total U.S. greenhouse gas footprint by 0.06%. This number is not insignificant in the context of the average annual growth in U.S. greenhouse gas emissions from 1990 – 2010 reported by the United Nations of 0.4%⁵⁸. MPP contribution of SO₂, NO_x, and PM₁₀ emissions to the total U.S. pollution profile is even more pronounced. Table 8 shows the percentage contribution of the MPP to total U.S. emissions⁵⁹ of SO₂, CO, NO_x, and PM₁₀.

	SO ₂	CO	NO _x	PM ₁₀
2012 U.S. Total (thousands of tons)	5,512	64,678	11,397	21,439
MPP Annual Total (thousands of tons)	12.7	5.0	17.0	25.5
MPP % of National	0.23%	0.01%	0.15%	0.12%

Table 8. Project Contribution to Total United States Emissions of Conventional Air Pollutants

The MPP will bring total direct and indirect economic activity of more than \$25 billion alongside social and environmental externalities measured here to total more than \$5.6 billion, or more than a fifth of total economic activity. While greenhouse gas emissions have the same environmental effect without regard to the geographic location of their emission, conventional air pollutants vary in their relative environmental impact according to the location at which they are emitted. While it is justifiable to assign consistent monetary value to a ton of CO₂e, the monetary impact of a ton of NO_x, SO₂, or PM₁₀ may in actuality vary by location. Consistent with other studies, conventional air pollutants were valued without regard to the location of emission, though this practice may not be perfectly reflective of their environmental impact.

The significant emissions add-on we get from increased coal exporting illustrates unintended consequences of domestic policy meant to reduce emissions from coal. In the face of a global energy market, policymakers will have to think in systems in order to ensure that policies have the effects they are intended to have. LCA studies such as this one can help us to examine the environmental impacts of proposed actions and develop more effective energy and environmental policy.

4.2. Comparative Studies and Further Research. While this project only explores social and environmental externalities in the categories of air emissions and loss of life, there are potentially other significant impacts associated with the MPP including water use and quality (ballast water, water used in locks and dams during transport, water used in coal mining), land use (Port of Morrow facility construction), fish and wildlife (construction on or near water, barging effects on sensitive Columbia River salmon populations), noise, and traffic (rail and river barge). All of these areas are deserving of further research.

This project explores the social and environmental impacts from cradle-to-gate, or from raw material production to port delivery. A next logical step would be to include the lifecycle impacts from electricity generation. This would require more specific information than is currently available, including but not limited to: specific export locations and amounts, amount of coal to be used as steam coal versus metallurgical coal, number of power plant destinations, distances to power plant locations, mode of transport to power plant locations, and power plant efficiency and emission specifications. This information could be used to expand the hybrid LCA analysis, replicating the use of EIOLCA and SETAC LCA models for additional project stages, including electricity generation as in Jaramillo et al (2007)⁶⁰.

The functional unit emissions inventory provided in this study serves as a basis for comparison with other energy export projects. The MPP, though not complete in its publically-available financial and operational information, is currently the most transparent of the six Northwest coal export projects currently being planned. As details develop on additional coal export projects throughout the United States, this study design can be replicated to explore and compare the social and environmental impacts

of all coal export alternatives. In addition, the functional unit chosen for this study was chosen to be compatible with liquefied natural gas (LNG) export projects, therefore providing a basis for comparison with other forms of energy export currently being considered.

This study could also be expanded to answer policy questions surrounding the strategic use of domestic resources. An expanded study could conduct a comparative LCA of coal and natural gas to explore the question of whether it is more environmentally sustainable to export coal and burn natural gas domestically, or to export natural gas and burn coal domestically.

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