Impacts of a Snake River Drawdown on Energy Consumption and Environmental Emissions in Transporting Eastern Washington Wheat and Barley

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by

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and

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EWITS Research Reports: Background and Purpose

This report is the twenty third of a series of reports prepared from the Eastern Washington Intermodal Transportation Study (EWITS). The reports prepared as a part of this study provide information to help shape the multimodal network necessary for the efficient movement of both freight and people into the next century.

EWITS is a six-year study funded jointly by the Federal government and the Washington State Department of Transportation as a part of the Intermodal Surface Transportation Efficiency Act of 1991. Dr. Ken Casavant of Washington State University is Director of the study. A state-level Steering Committee provides overall direction pertaining to the design and implementation of the project. The Steering Committee includes Jerry Lenzi, Regional Administrator (WSDOT, Eastern Region); Tom Green (WSDOT, South Central Region); Don Senn (WSDOT, North Central Region); Charles Howard (WSDOT, Planning Manager), and Jay Weber (Douglas County Commissioner). Pat Patterson represents the Washington State Transportation Commission on the Steering Committee. An Advisory Committee with representation from a broad range of transportation interest groups also provides guidance to the study. The following are key goals and objectives for the Eastern Washington Intermodal Transportation Study:

- *Facilitate existing regional and statewide transportation planning efforts.*
- *Forecast future freight and passenger transportation service needs for eastern Washington.*
- *Identify gaps in eastern Washington's current transportation infrastructure.*
- *Pinpoint transportation system improvement options critical to economic competitiveness and mobility within eastern Washington.*

For additional information about the Eastern Washington Intermodal Transportation Study or this report, please contact Ken Casavant at the following address:

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Executive Summary

The ability to transport agricultural products efficiently and cost effectively is important for Washington producers. However, environmental concerns also play roles in transportation decision-making processes. Freight transportation involves both the use of energy and the production of diesel engine emissions. Transportation of wheat and barley in eastern Washington is dependent on truck, rail, barge, and intermodal combinations. A drawdown of the Snake River to aid the migration of anadromous fish will change the availability of barge for transporting wheat and barley above the Tri-Cites, Washington. This will have effects not only on costs of transportation to grain producers, but also on fuel consumption and emissions output as truck and rail respond to the changing grain transportation needs.

Objectives

The purpose of this report is to update energy intensity coefficients and investigate impacts of selected policy on energy usage[1] and emissions[2] output for the eastern Washington agricultural transportation sector by examining the effects of a Snake River drawdown on energy usage and emissions. Specific objectives include:

- Identifying trends in energy intensity and emissions factors for barge, rail, and truck through a review of literature;

- Calculating the energy used and emissions created by each mode in the base case scenario for wheat and barley transport;

- Calculating the energy used and emissions created by each mode in the case of no barge availability above the Tri-Cities for wheat and barley due to a drawdown of the Snake River;

- Summarizing the consequences of a modal shift due to a Snake River drawdown in terms of energy consumption, environmental impacts, transportation corridors, and impacts on producers, consumers, and policy makers.

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[1] Energy intensity in this report is measured in Btu's per ton-mile, the number of Btu's required to move one ton of mass one mile. A Btu is a British thermal unit which is the amount of energy required to raise the temperature of one pound of water one degree Fahrenheit (F) at or near 39.2 degrees F (Statistical Abstract of the United States, 1994). One million Btu's is approximately equivalent to 8 gallons of gasoline or 1.2 days of US energy consumption per capita, in 1984 (Information Please Almanac, 1995).

[2] Mobile source emissions are those emissions created by diesel or gasoline engines used in freight and passenger vehicles on land, water, or in the air. Mobile source emissions also include emissions from recreational vehicles such as boats and small engines such as lawnmowers.

Review of Literature

Energy Intensity Literature

A review of the energy intensity literature revealed that energy intensity (consumption) for truck, rail, and barge has decreased since the 1970's. Truck energy intensity declined the least (8.8%), despite federal legislation mandating improvements in newly built diesel truck engines, because tonnage per truckload and the number of loaded back hauls also declined during the same period. Rail energy usage improved the most (46.2%) of the three modes, due to more efficient locomotive technology and increased tonnage per carload. Rail energy intensity was slightly lower than barge in 1995, the year of most recent data. On average, barge is more fuel-efficient than rail. Barge energy usage improved 31.3% since 1970, but tons per trip have declined, causing a slow down in energy conservation (Greene and Fan, 1995).

The most recent energy coefficients, used in this study, for each mode are from the Transportation Energy Data Book: Edition 17, published by the Oak Ridge National Laboratory and edited by Stacy C. Davis (Table i).

Table i--Energy Intensity Coefficients for Truck, Rail, and Barge Used in this Study

Mode	Btu's per Ton-Mile
Truck	551
Rail	372
Barge	374

Source: Davis, 1997

Mobile Source Emissions Literature

The literature on emissions from mobile sources, which includes freight transportation vehicles, indicated that emissions have also declined since the 1970's. For instance, the level of hydrocarbons in truck emissions, per gallon of fuel, decreased 32% from trucks made pre-1963 to trucks produced in 1997 and later. Carbon monoxide levels decreased 20% and nitrous oxides fell by 49% for the same group of trucks (Environmental Protection Agency, 1985). The components of diesel emission are hydrocarbons (HC), carbon monoxide (CO), nitrous oxides (NOx), particulate matter (PM), and sulfur oxides (SOx) (Environmental Protection Agency, 1985). Data for emissions output came from various sources and are detailed in Table ii.

Table ii--Emissions Coefficients Used in this Study for Truck, Rail, and Barge, Pounds per 1000 Gallons of Diesel Fuel

Mode	HC	CO	NOx	PM	SOx
3 Axle Truck*	212	23	93	14	5
5 Axle Truck*	212	23	93	16	6
Rail#	22	59	564	15	36
Barge^	19	57	419	9	75

Source: * Environment Protection Agency, 1992
Environment Protection Agency, 1992 (SOx) and Environment Protection Agency, 1997 (HC, CO, NOx, PM)
^ Pera, 1996

Data and Methodology

The data used in this study are the result of a 1998 transportation cost study, using a Geographical Information Systems (GIS) database and a General Algebraic Modeling System (GAMS) optimization framework (Jessup, 1998). The GIS/GAMS model measured minimum distance, least cost routes, and modes used to transport wheat and barley for two transportation scenarios. The first scenario has barge available along the Snake River ports. The second scenario examines the effects of no barge availability above the Tri-Cities in Washington, due to a drawdown of the river to aid anadromous fish migration.

The GIS/GAMS results for each scenario consist of routes (mileage), modes, and tonnage of wheat or barley. This information is inventoried and organized to identify ton-miles of wheat and barley. Ton-miles are also sorted by mode of transport. For example, if 1000 tons of wheat traveled 200 miles by rail, then 200,000 ton-miles are attributed to the rail mode. The energy required and emissions produced to move 200,000 ton-miles by rail is found by multiplying the energy intensity or emissions coefficient for rail by 200,000 ton-miles. Calculations are made for each mode in the base case scenario of barge availability on the Snake River and then for the no barge case. Comparisons across scenarios are made to determine energy usage and emissions composition changes if a drawdown of the Snake River occurs.

Energy Intensity and Emissions Output Impacts

The energy consumption for the movement of wheat increases by 1.5% in terms of Btu's when barge is not available. This amounts to approximately 9.5 billion Btu's or the amount of energy consumed by 9500 people in one day, measured at the 1984 energy consumption rate (Information Please Almanac, 1995). Total emissions output for wheat movement increases by 4%, with a significant decrease in sulfur oxide components. As for the movement of barley, overall Btu usage (energy) increases by 41% and overall emission levels increase by 24%. The change in energy usage represents 23 billion Btu's or the energy required to fuel the activities of 23,000 people for one day at 1984 energy consumption rates (Information Please Almanac, 1995).

Most of the movement of wheat and barley, which would have gone by barge, is transported by rail. This becomes the case because rail is more cost (rate) effective than truck. Fortunately, rail is also more fuel efficient (a 1995 literature review revealed rail to be slightly more efficient than barge, but on average, barge is more fuel efficient than truck) and comparable in emission output to truck and barge. This, combined with the high-energy intensity of truck, causes the rather slight increases in fuel consumption and emissions output when barge is not available. One possible problem associated with the increased workload of rail in the case of a drawdown is the historical evidence of shortages in rail cars for the shipment of grain in the Pacific Northwest. Transportation planners and producers must address this possible shortage in the event of a planned drawdown of the Snake River (see Jessup, 1998).

Truck usage increases to make up the difference in transportation needs when barging is not possible. Truck requires the most Btu's per ton-mile and produces more hydrocarbons than rail or barge, but does not produce as many NOx compounds. Therefore, increased truck usage would increase fuel consumption, and negate, in part, the energy and emissions efficiency of rail and barge in terms of different emission components. Thus, while a river drawdown may increase shipper costs and change road damage impacts (see Jessup, 1998), it also appears to increase energy consumption and emissions production.

Introduction

The ability to transport agricultural products efficiently and cost effectively is a crucial component to the success of Pacific Northwest (PNW) agricultural producers. In Washington, barge is the most cost effective mode for those producers with nearby access to Snake and Columbia River ports (Jessup, et al.,1996). Otherwise, rail is the next most cost efficient, followed by truck. Intermodal combinations of two or more modes may be the least cost method of transport over any single mode. However, transportation cost is not the only issue to concern producers, consumers, and policy makers in the region.

As people are increasingly becoming aware that economic activity and environmental effects are intricately and inextricably connected, decisions regarding transportation activities must also take into consideration energy use and pollution effects. Transportation is inherently energy intensive, depending greatly on petroleum, and creates emissions which contribute to lower air quality, decreased visual aesthetics, and possibly to a greenhouse effect. A 1996 transportation study revealed that combined, freight and passenger transportation was 96.8% dependent on petroleum as its primary fuel with natural gas at 3% and electricity at 0.2% (Davis, 1997).

Here in the PNW, there is a complete and complementary freight transportation system, which is comprised of truck, rail, and barge. In terms of energy usage, as will be seen, the most energy intensive mode of transport available to PNW producers is truck. After trucks, the next most energy intensive is on average barge and rail, respectively. These three modes vary in the components of their emissions, but tend to correspond in decreasing order of emissions (Lenzi, et al., 1996).

If one or more modes become unavailable to PNW producers, there are predictable consequences in terms of changes in transportation costs, energy consumption, and emissions output. A likely scenario is the loss of navigable river ports along the Snake River if a drawdown of the river occurs to aid anadromous fish migration. Drawdown is a salmon recovery strategy currently being considered and debated in the PNW. While the lock and dam system has aided business and agricultural interests in the region, it has contributed to the demise of many native salmon species. The Snake River Coho became extinct in 1988 and the Snake River Sockeye Salmon was listed in 1990 as an endangered species (Jessup, 1998).

A drawdown of the Snake River would entail lowering the water level to natural levels behind some or all of the four dams (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite) up river from the Tri-Cities. This would result in increased river flow, which provides a more amenable environment for juvenile salmon heading for the ocean and migrating salmon returning up stream to spawn. Producers who once relied on the Snake River barges to transport their grain would have to switch to rail and/or truck (Jessup, 1998). Such a switch would likely affect the use of energy and the composition of emissions output, among other things.

This report addresses the issues of energy intensity and emissions output related to the transportation of wheat and barley in eastern Washington. Two scenarios will be analyzed using data and results from the Graphical Information System (GIS) data base and Generalized Algebraic Modeling System (GAMS) model created by John Ellis and Eric Jessup at Washington State University (Jessup, et al., 1996). The first energy and emissions output scenario is the base case of wheat and barley transportation, where barge is available along the Snake River. The second scenario will be one where barge is eliminated above the Tri-Cities due to a drawdown of the Snake River.

Objectives

The purpose of this report is to continue and update energy intensity and transportation emission research for the eastern Washington agricultural transportation sector and to examine the effects of a Snake River drawdown on energy usage and emissions. Specific objectives are:

Identifying trends in energy intensity and emissions factors for barge, rail, and truck through a review of literature;

Calculating the energy used and emissions created by each mode in the base case scenario for wheat and barley transport;

Calculating the energy used and emissions created by each mode in the case of no barge availability above the Tri-Cities for wheat and barley due to a drawdown of the Snake River;

Summarizing the consequences of a modal shift due to a Snake River drawdown in terms of energy consumption, environmental impacts, transportation corridors, and impacts on producers, consumers, and policy makers.

Review of Literature

A review of the energy intensity[3] and mobile source emissions[4] literature contributes to the general framework of this study. Energy intensity literature provides information regarding the trends of energy usage by freight transportation modes over time, and identifies current usage coefficients. Similarly, the mobile source emissions review provides information on emission levels for the modes in this study. The detailed literature search revealed that more research has been conducted on and more data are available for passenger vehicles and passenger mass transit modes than for freight transportation. Two key sources of information for freight transportation are available. They are the Transportation Energy Databook published by the Oak Ridge National Laboratory and the Procedure for Emission Inventory Preparation Volume IV: Mobile Sources, published by the US Environmental Protection Agency.

Methodology Literature and Applications

Kolb and Wacker (1995) present a framework for calculating energy consumption and emissions levels in an ideal situation where researchers have detailed information regarding modes, routes, and cargo. They note that the use of flat-rate average factors of energy consumption and emissions is misleading, because every movement of cargo is unique in vehicular, weight, modal, infrastructural, pre- and post-trip, shunt, and climatic conditions. Consequently, Kolb and Wacker suggest that the calculations for energy usage and pollution emissions must be calculated for individual trips under a trip's unique conditions and only after numerous reconstructions of realistic commodity movements under different conditions, generalized differentiations may be made according to type of vehicle, weight, and conditions of operation, such as speed and road gradient.

Several of Kolb and Wacker's concerns are particularly relevant to this study. First is the difference in vehicular conditions. This concern is accounted for in several ways in this report. There are two main types of trucks which are primarily used to transport wheat and barley in eastern Washington. These trucks are single unit, 3-axle trucks and combination tractor and trailer, 5-axle units, differentiated by their tare (empty) weights and load weights as explained in a later section of this paper. In this pilot study, we relied on aggregate energy intensity coefficients for trucks but, were able to obtain specific emissions coefficients for the 3-axle and 5-axle trucks operating under average conditions (ambient temperature, road conditions, etc.).

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[3] Energy intensity in this report is measured in Btu's per ton-mile, the number of Btu's required to move one ton of mass one mile. A Btu is a British thermal unit which is the amount of energy required to raise the temperature of one pound of water one degree Fahrenheit (F) at or near 39.2 degrees F (Statistical Abstract of the United States, 1994). One million Btu's is approximately equivalent to 8 gallons of gasoline or 1.2 days of US energy consumption per capita, in 1984 (Information Please Almanac, 1995).

[4] Mobile source emissions are those emissions created by diesel or gasoline engines used in freight and passenger vehicles on land, water, or in the air. Mobile source emissions also include emissions from recreational vehicles such as boats and small engines such as lawnmowers.

For the rail component, fuel efficiency and emissions factors are for Class I rail locomotive configurations. Class I rail information is available in the literature; however, information on branch lines transporting grain from elevators to mainline rail interchanges is not available. This pilot study assumes that branch line and Class I locomotive characteristics are similar in terms of energy usage and emissions (no data or studies could be found to contradict this assumption).

Emissions data for the tugboats, which propel barges along the Columbia and Snake, are taken from a similar study of marine vessel emissions in southern California ports. The California study uses a composite factor of a variety of ships, including several tugs with similar sized engines (Pera, 1996). While, Kolb and Wacker would argue that the use of a composite factor is too inaccurate, such data on each individual tug and its particular load for any unique trip along the Columbia and Snake rivers was proprietary in nature, so again, empirical analysis requires some generalization of the data. The use of a composite factor is appropriate for the purposes of this study.

The second concern is the energy used in pre- and post-trip moves, such as those from the farm to the elevator via farm or commercial trucks. These trips are undertaken no matter the subsequent modes used to transport the grain to their final destinations and therefore, energy use and emissions from pre- and post-trips are ignored in this pilot study.

Finally, the issue of speed and road gradient is important to grain movements by trucks. The allowable grade and, subsequently, speeds at which trucks may safely travel is different among local, state, and interstate roads. More energy is needed to climb rolling and steeper grades on local and state roads than is needed for the flatter interstates. As a result, more fuel is used and more emissions are created by trucks traveling over local and state roads. However, detailed gradient data are seldom available to researchers; this holds for the GIS database and the GAMS model in this study.

Energy Intensity Literature

Work in energy intensities of intermodal transportation by Casavant and Knighten (1981) included a compilation of energy coefficients from various available studies. The consensus of energy intensity coefficients in the literature reviewed by Casavant and Knighten is summarized in Table 1. Current searches for follow-up research revealed few studies and little information. Many of the researchers cited in the Casavant and Knighten bibliography apparently have not continued research in the area of energy intensities since there are no contemporary references to the authors in this area. However, some authors have expanded their research into energy policy and engineering.

One of the most comprehensive studies of energy usage in freight transportation has been conducted by Greene (1996). The energy intensities reported by Greene for barge, rail, and truck are shown in Table 2. He notes that the coefficient for barge is based on 1992 data while the coefficients for rail and truck are based on 1993 data. In this context, a truck is defined as all non- lightweight trucks (two-axle, four-tire trucks), which includes all freight trucks, such as 3-7 axle tractor and trailers, tractor and flatbeds, and dump trucks.

Table 1--Consensus Energy Intensity Coefficients from Research Conducted During the 1970's

Mode	Btu's per Ton-Mile
Barge	500
Rail	750
Truck	2400

Source: Casavant and Knighten, 1981

Greene reports his truck energy coefficient in terms of Btu per vehicle-mile. For comparison purposes, converting the Btu per vehicle-mile expression into a Btu per ton-mile expression, assumes that the typical truck is a 5-axle tractor and trailer configuration that is able to carry a total vehicle weight of 40 tons (80,000 pounds). Greene's Btu per vehicle-mile calculation was converted into a Btu per ton-mile expression as follows:

$$\frac{\text{Btu per Vehicle-Mile}}{\text{Tons per Vehicle}} = \text{Btu per Ton-Mile}$$

$$\frac{22{,}322}{40} = 558$$

Table 2--Energy Intensity Coefficients for 1993 Data Compiled by Greene

Mode	Btu per Ton-Mile
Truck	558
Rail	344
Barge	398

Source: Greene, 1996

Greene and Fan (1995) note that truck energy efficiency has shown only little improvement since 1972 because trucks are carrying fewer tons per trip. The Census of Transportation Truck Inventory and Use Survey (TIUS) shows that the average load carried by combination trucks fell from 16 tons in 1982 to 14.4 tons in 1987. The survey also showed a decline in tonnage carried by single unit trucks. This increase in partial loads and empty back hauls has negated engine energy use improvements due to technological changes in truck transportation and the other modes. Note that if the 16 tons or 14.4 tons is used instead of the 40 tons to calculate the above Btu's per ton-mile for trucks, then the energy intensity of trucks increases.

On the contrary, increased tonnage per carload has caused rail energy use efficiency to increase. An average carload in 1972 was 22 tons, but this average had increased to 36 tons per car by 1992. Given that carload tonnage has increased and rail still consumed less energy, suggests technological improvements helped make rail more efficient as well. Waterborne commerce fuel intensity showed erratic movements, but an overall decline in energy intensity as well (Greene and Fan, 1995).

Ross (1989) published some energy intensity coefficients, which were based on work conducted by the Oak Ridge National Laboratory. In general, Ross found freight activity increasing less rapidly between 1972 and 1985 than before that period. Ross reports that freight energy use measured in vehicles was dominated by highway vehicles, but if measured in ton-miles, then energy use was dominated by non-highway modes. That is highway vehicles use more energy relative to the less energy intensive non-highway vehicles, which transported more tonnage. The most energy intensive mode was heavy trucks, followed by rail, domestic marine, and natural gas pipelines. The energy intensity coefficients compiled by Ross are shown in Table 3.

Table 3--Energy Intensity Coefficients for 1985 Data Compiled by Ross

Mode	Btu per Ton-Mile
Heavy Trucks	3400
Rail	490
Marine (Domestic)	340
Pipeline (Natural Gas)	2100

Source: Ross, 1989

The latest available energy intensity data for freight modes are available from the Transportation Energy Data Book: Edition 17, published by the Oak Ridge National Laboratory (ORNL) and edited by Stacy C. Davis. These are the energy efficiency coefficients used in this study. Tables 4 and 5 summarize the energy efficiency coefficients and trend data published by Davis and the ORNL.

Table 4--Energy Intensity Coefficients for Truck, Rail, and Barge, 1970 to 1995, Btu/Ton-Mile

Year	Truck	Rail	Barge
1970	604	691	545
1971	592	717	506
1972	584	714	522
1973	581	677	576
1974	564	681	483
1975	550	687	549
1976	566	680	468
1977	567	669	458
1978	569	641	383
1979	576	618	457
1980	559	597	358
1981	566	572	360
1982	568	553	310
1983	574	525	319
1984	572	510	346
1985	578	497	446
1986	578	486	463
1987	577	456	402
1988	586	443	361
1989	571	437	403
1990	562	420	388
1991	548	391	386
1992	553	393	398
1993	554	389	389
1994	555	388	369
1995	551	372	374

Source: Davis, 1997

Table 5--Percent Changes in Energy Intensity Coefficients for Truck, Rail, and Barge, 1970-1995

Mode	Period	Percent Change	Average Annual Percent Change
Truck	1970-1995	-8.8	-0.4
	1985-1995	-4.7	-0.5
Rail	1970-1995	-46.16	-2.4
	1985-1995	-25.15	-2.9
Barge	1970-1995	-31.38	-1.5
	1985-1995	-16.14	-1.7

Source: Davis, 1997

Energy intensity for truck, rail, and barge decreased between 1970 and 1995. Truck energy usage fell by nearly 9% between 1970 and 1995. This decrease is small compared to the decrease in energy consumption from rail (46%) and barge (31%) over that same period. As noted earlier, Greene attributes the drastic decline in rail energy usage to the increased weight per carload and strides in improving locomotive technology. The average annual percent improvement in energy efficiency, from 1985 to 1995, for rail is nearly 3%, which is 6 times greater than the change for truck (-0.5%) and nearly twice as great as the change for barge (-1.7%) over the same ten years.

Figure 1 shows the relative changes in energy efficiency trends for each mode. The steep decline in rail energy usage is apparent, as is the much flatter, yet overall declining, trend in truck energy usage. Barge energy usage was more erratic than the other two modes. Efficiency peaked in 1982 and has been increasing, approaching that of rail since 1983. However, the overall trend for barge energy usage is one of improvement.

Figure 1: Energy Intensity Trends for Truck, Rail, and Barge, 1970 to 1995, Btu per Ton-Mile

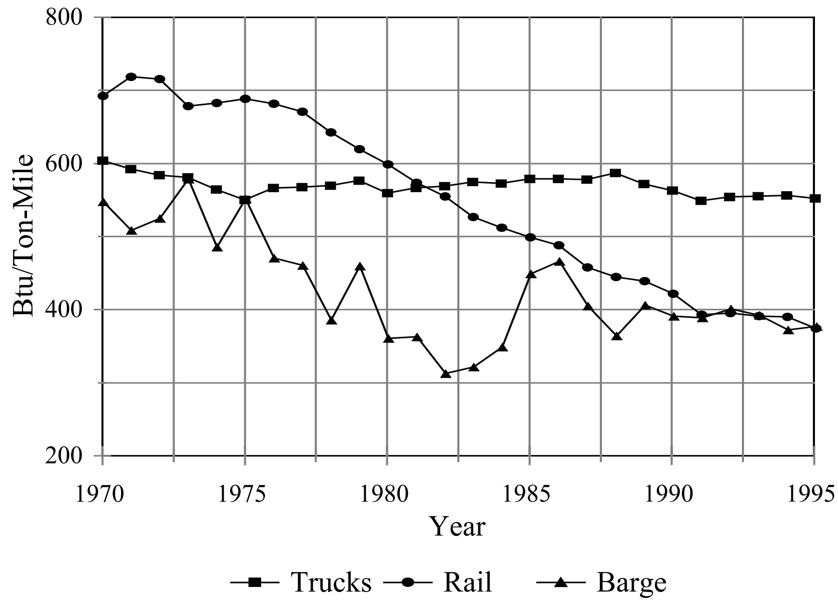


Figure 2: Energy Intensity Trend for Truck, 1970 to 1995, Btu per Ton-Mile

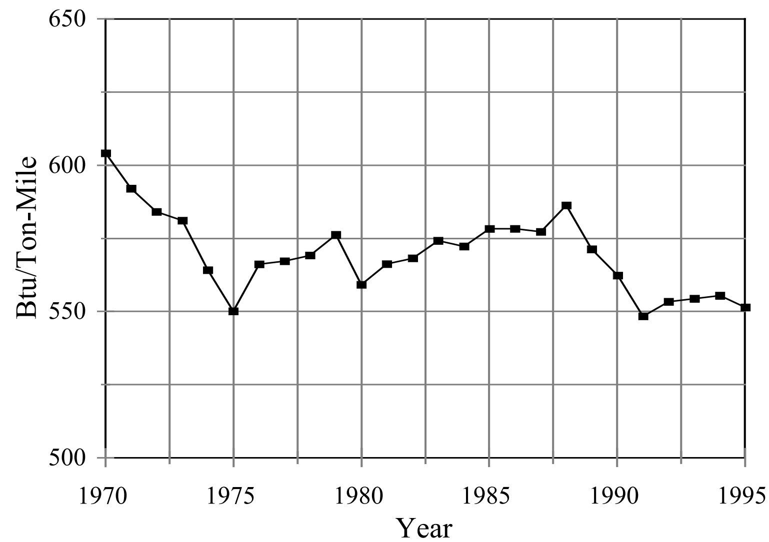


Figure 3: Energy Intensity Trend for Rail, 1970 to 1995, Btu per Ton-Mile

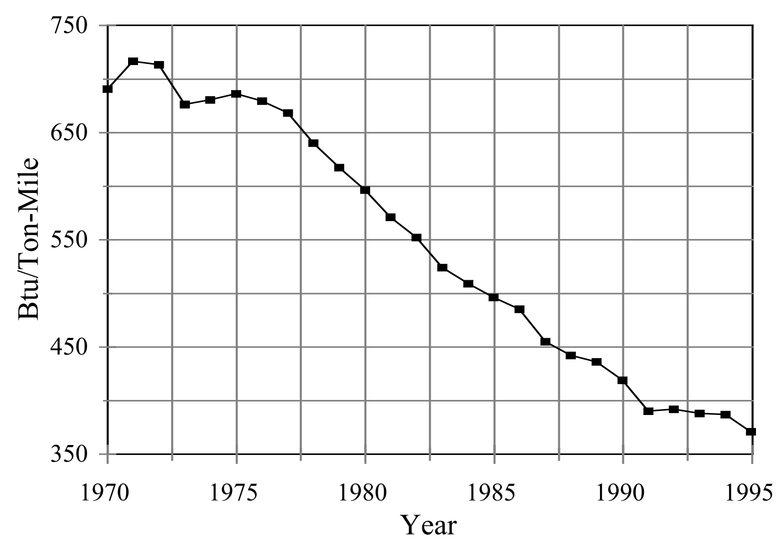
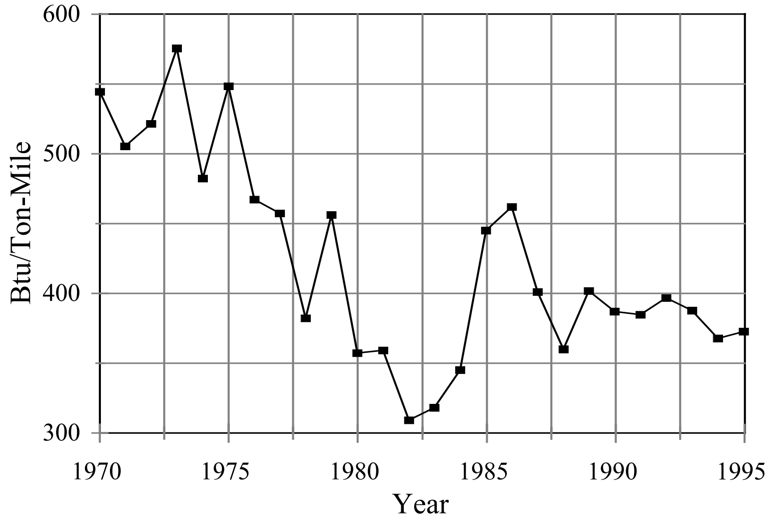


Figure 4: Energy Intensity Trend for Barge, 1970 to 1995, Btu per Ton-Mile



Figures 2-4 show the trends for truck, rail, and barge individually. In Figure 2, truck energy intensity ranges from 604 Btu per ton-mile in 1970 to 551 Btu per ton-mile in 1995. Notable declines occurred in the years 1975 and 1981. Energy intensity remained steady from 1976 to 1988 and appears to be in another period of stability in recent years. Rail energy intensity, in Figure 3, steadily declined from 1975 (687 Btu per ton-mile) to 1991 (391 Btu per ton-mile) and leveled off somewhat between 1991 and 1994 at 390 Btu per ton-mile. Another declining tread may be developing in 1995 when energy intensity fell to 372 Btu per ton-mile. Finally, the barge trend shows wide fluctuations throughout the study period. However, it does seem to have leveled off between 1989 and 1995.

Mobile Source Emissions Literature

Emissions from mobile sources, such as the diesel engines in freight transportation, are usually broken down into 5 components. These components are Nitrous Oxides (NOx), Hydrocarbons (HC), Carbon Monoxide (CO), Particulate Matter (PM), and Sulfur Oxides (SOx). Hydrocarbons are a subset of volatile organic compounds (VOC), which is the emission factor available for truck. Sulfur Oxides include sulfur dioxide (SO_2) and sulfur dioxide is the measure available for the SO components in truck emissions (Environmental Protection Agency, 1992).

As with estimates of energy intensity coefficients, emission factor estimates vary from source to source. Emission factors are even more sensitive to the vehicle and environmental factors pointed out by Kolb and Wacker. For this pilot study, only average emissions factors are used because obtaining such information as the age of a vehicle, odometer reading of a vehicle, possible retro-fitting of engine components, and time spent traveling at different speeds was not attainable.

Trend data, available for some modes, illustrate how technological changes and legislative mandates have caused emissions to change over time. Table 6 contains emission rates for HC, CO, and NOx, from trucks produced between the years pre-1963 and post-1997, measured when the trucks have traveled 50,000 miles. Note that the units associated with the emission level are in grams per mile, which is different from the units used later in this study. Without knowing the fuel efficiency of trucks in each model year, grams per mile cannot be converted to pounds per 1000 miles which is the unit commonly used. However, if the information in Table 6 is treated as relative differences, then the units may be ignored. The level of HC in truck emissions decreased 32% from trucks made pre-1963 to trucks produced in 1997 and later. Carbon monoxide levels decreased 20% and NOx levels decreased by 49% for the same groups of trucks.

The truck emission factors used in this study are based on 1996 data and are derived from an algorithm in Procedures for Emission Inventory Preparation Volume IV: Mobile Sources, a manual published by the US Environmental Protection Agency. The factors are based on the tare (empty) weight of the truck and on average operating conditions for variables such as road condition, ambient temperatures, and age of the vehicle. Tare weights, capacity load weights, and type of trucks of concern in this study may be found in Table 7.

Table 6--Truck Emission Factors for HC, CO, and NOx, Pre-1963 to Post-1997

Model Year	**Emission Level 50,000 Mile (grams per mile)**		
	HC	**CO**	**NOx**
Pre-1963	3.62	10.54	21.94
1963-1965	3.61	10.50	21.85
1966-1968	3.78	10.85	22.67
1969-1971	4.00	11.55	24.06
1972-1974	4.23	12.26	25.53
1975-1979	4.19	11.98	24.77
1980-1981	3.83	10.20	20.50
1982-1984	3.50	9.40	18.88
1985	3.21	9.05	18.23
1986	2.60	8.90	17.90
1987-1992	2.53	8.67	11.44
1993-1996	2.49	8.53	11.23
1997+	2.47	8.41	11.14

Source: US Environmental Protection Agency, 1985

The algorithm calculates two components of emissions differently than the factors used in this study for barge and rail. The algorithm calculates volatile organic compounds (VOC) of which HC is a subset. Therefore, this factor will over estimate the amount of HC from trucks, offering a conservative estimate. For the SOx compounds, the algorithm estimates only SO_2. This will under estimate the sulfur oxide components of truck emissions. All factors are for trucks traveling at the average rate of 40 miles per hour (mph). The truck emission factors are listed in Table 8. The NOx, VOC, and CO components are identical for the smaller 3 axle trucks to the larger 5 axle trucks. The difference in emissions output occurs in the PM and SO_2 components where the large vehicle produces slightly more of both pollutants, 16% more particulate matter and 21% more sulfur oxides.

Table 7--Types of Trucks, Tare Weights, and Load Weights for Trucks Used in this Study

Type of Trucks, Number of Axles	Tare Weight (Tons)	Cargo Weight (Tons)	Total Maximum Loaded Weight (Tons)
Single Unit, 3-axles	8.4	14.1	22.5
Tractor and Trailer 5-axles	13.85	26.15	40

Source: Personal Communication with Denver Tolliver, July 8, 1997

Table 8--Truck Emission Factors Used in this Study, Pounds per 1000 Gallons of Diesel Fuel

Number of Axles	VOC	CO	NOx	PM	SO2
3 axles	212	23	93	14	5
5 axles	212	23	93	16	6

The emission factors for rail have been estimated by EPA. Two sources were found in the review of literature. One source is published in the 1992 edition of the Procedures for Emission Inventory Preparation Volume IV: Mobile Sources. A more recent set of estimates is found in another EPA publication, Technical Highlights Emission Factors for Locomotives, December, 1997. The factors represent locomotive emission rates for unregulated and non-remanufactured locomotives. New emissions control legislation applying to locomotives built after 1973 will lower the emission rates (Environmental Protection Agency, 1985).

The unregulated emissions rates will be used in this study because the cost of tracing the type of locomotive used in each movement of grain would have been prohibitive for this pilot study and, without this information, the unregulated emission factors would provide a more conservative estimate of emissions from locomotives. The locomotive emissions rates are listed in Table 9. Note that the Technical Highlights 1997 values include those for HC, CO, NOx, and PM. There were no SOx estimates for 1997 therefore, the 1992 value from the Procedure for Emissions Inventory Preparation was used.

Table 9--Locomotive Emission Factors Used in this Study, Pounds per 1000 Gallons of Diesel Fuel

HC	CO	NOx	PM	SOx
22	59	564	15	36

Source: US Environmental Protection Agency, Technical Highlights (HC, CO, NOx, PM)
US Environmental Protection Agency, Procedure for Emissions Inventory Preparation (SOx)

Emissions factors for the barge component of this study are taken from a similar study conducted for southern California seaports. The study used the Lloyd's Marine Exhaust Emissions Research Programme estimates for marine engine emission factors. The Lloyd's factors are based on medium speed diesel engines, which adequately represent factors for tugs (Pera, 1996). Note that emissions from the operation of tugs varies with engine age, model, as well as tonnage being transported. This information is not readily available; therefore, composite emission factors are used for this study. Table 10 shows the emission factors used for barge tugs.

Table 10--Barge (Tug boat) Emission Factors Used in this Study, Pounds per 1000 Gallons of Diesel Fuel

HC	CO	NOx	PM	SOx
19	57	419	9	75

Source: Pera, 1996

Data and Methodology

This study examines the energy usage and creation of emissions from the transport of wheat and barley in eastern Washington by truck, rail, and barge. The data for this study comes from the results of a transportation cost study, conducted by Jessup (1998), with a Geographical Information Systems (GIS) database and a General Algebraic Modeling System (GAMS) optimization framework. GIS coverage's of eastern Washington were constructed from Washington State Department of Transportation (WSDOT) data on state, US and Interstate highways, active rail lines, and navigable waterways. Additional road information came from US Bureau of Census Topologically Integrated Geographic Encoding and Referencing (TIGER) files.

Data relating to grain production areas, elevators, and river ports were obtained from the Agricultural Soil and Conservation Service (ASCS) and from an elevator survey sent to each of the over 400 grain elevators in the study area. Data from the ASCS included on-farm storage locations and capacities, acreage, and production estimates within each township. Data from the survey included elevator locations, capacities, handling and storage rates, and modal usage. Response rate for the survey was over 90%, which represent the elevators that handle 96% of the grain volume in eastern Washington.

Transport rates for truck shipments were obtained from the elevator survey. Rail rates were provided by Burlington Northern and Union Pacific and barge rates were provided by the barge companies operating on the Snake and Columbia Rivers.

The above data sources provided the information used by the Generalized Algebraic Modeling System (GAMS) to allocate grain shipments on various modes and routes subject to minimum cost, supply (amount of grain leaving a township cannot exceed the amount produced), demand (sum of all shipments to a final destination must be greater than or equal to grain demanded), and rail and elevator capacity constraints.

According to Jessup (1998), GIS Arc Info and GAMS algorithms are linked by a spreadsheet or database application such as Quattro Pro or Fox Pro. Arc Info determines a set of minimum distance routes from production areas to intermediate destinations such as elevators or river ports. The route information is sent to a database application, which incorporates distance information, and cost information to generate the GAMS input file. GAMS then finds the set of optimal (least cost) routes. The least cost route data are sent back through the database to process and sum the optimal route data for display in Arc Info. Finally, Arc Info generates maps and coverage's to represent the movement of wheat and barley over eastern Washington roads, rail lines, and along the Snake River.

Least cost, minimum distance routes and modes used to transport wheat and barley in 1994 was found by the GIS and GAMS model for two transportation scenarios (Jessup, 1998). The first scenario is one where barge is available along the Snake River ports. The second scenario is one where barge along the Snake River above the Tri-Cities in

Washington is not available due to a drawdown of the river to aid the migration of anadromous fish. Without barge, the other modes below the Tri-Cities will have to transport the grain, which would have gone on barges above the Tri-Cities, thus creating changes in energy usage and emission amounts.

The GIS/GAMS results for each scenario consist of routes (mileage), modes, and tonnage of grain. This information is taken and organized so that ton-miles of wheat and barley are sorted by transport mode. For example, if 1000 tons of wheat traveled 200 miles from a particular elevator to a seaport in Portland by rail, then 200,000 ton-miles are attributed to the rail mode. The energy required to move 200,000 ton-miles by rail is found by multiplying the energy intensity coefficient for rail by 200,000 ton-miles. Similarly, the emissions created by the locomotive is found by multiplying an emissions factor by 200,000 ton-miles. Such calculations are made for each mode in the base case scenario of barge being available on the Snake River and the no barge case. Comparisons across scenarios are made to determine how energy usage and emissions composition change if there is a drawdown of the Snake River.

Results on Energy Intensity and Emissions Output

Wheat

The results in this section are for wheat in both the base and no barge scenarios. From Table 11, it is apparent that rail takes up most of the excess grain, which cannot be transported by barge in the case of a Snake River drawdown. The percent change in ton-miles for rail is nearly 94%. Rail would have to transport nearly twice as much wheat than it does when barge transportation is available. This may pose a rail capacity problem, since a reliable supply of grain rail cars is not always available (this issue is not addressed in this pilot study). Truck ton-miles would increase by 15%. Without the operation of Snake River ports, barge transportation of wheat would decrease by 39%.

The total amount of energy consumed, measured in Btu's for each scenario is detailed in Table 12. Because the Btu measurement is based on ton-miles, it logically follows that the changes in Btu's consumed is proportionate. Rail, having to increase ton-miles of wheat transported by 94%, will also use 94% more energy. Truck used 15% more energy and barge, being restricted along the Snake River, consumes 39% less energy. The net effect is a 1.5% overall increase in energy consumed across the three modes when there is no barge. The increase in energy consumption amounts to 9.5 billion Btu's or the energy consumed by 9500 people in one day, measured at the 1984 energy consumption rate (Information Please Almanac, 1995).

Table 11--Ton-Miles by Mode for Wheat in the Base Case and No Barge Case

Mode	Ton-Miles (Base Case)	Ton-Miles (No Barge Case)	Percent Change in Ton-Miles
Truck	383,528,229	442,849,331	15.47
Rail	281,904,961	545,504,291	93.51
Barge	827,443,923	503,225,117	-39.18

Table 12--Btu per Ton-Mile and Btu's Consumed for Wheat in the Base Case and No Barge Case

Mode	Btu/Ton-Mile	Btu's Consumed (Base Case)	Btu's Consumed (No Barge Case)	Percent Change
Truck	551	211,324,054,179	244,009,981,381	15.47
Rail	372	104,868,645,492	202,927,596,252	93.51
Barge	374	309,464,027,202	188,206,193,758	-39.18
Total Btu's Consumed		625,656,726,873	635,143,771,391	1.52

From the amount of energy consumed, the amount of emissions produced may be derived. There are approximately 140,000 Btu's per one gallon of diesel fuel, so that from the total Btu's consumed, gallons of fuel may be obtained and emission factors are then expressed in pounds per 1000 gallons of diesel fuel. The components of diesel engine emissions are broken down into five groups: nitrous oxides (NOx), HC (hydrocarbons), CO (carbon monoxide), PM (particulate matter), and SOx (sulfur oxides). The total amount of emission components created in the base case and no barge case for the transportation of wheat are listed in Table 13. Tables 14-16 lists the components attributed to truck, rail, and barge, respectively.

Table 13--Total Emissions from Truck, Rail, and Barge for the Transportation of Wheat in the Base Case and the No Barge Case

Emissions Component (lbs)	Base Case	No Barge Case	Percent Change
NOx	1,691,130	1,793,768	6.07
HC	93,196	97,518	4.64
CO	310,571	324,239	4.40
PM	54,728	61,173	11.78
SOx	201,530	163,186	-19.03
Total Emissions	2,351,155	2,439,884	3.78

The total change in emissions due to a loss of barge transportation along the Snake River causes a 4% increase in overall emissions from the transportation of wheat (Table 13). NOx, HC, and CO components of emissions rise slightly at 6%, 5%, and 4%, respectively. Particulate matter increases slightly more, by 12%, which may affect visibility when the fine particulates become airborne. On the other hand, sulfur oxide emissions decreases by 19%.

Breaking down the total emissions into those created by each mode, truck transportation of wheat will create an additional 15%-16% of NOx, HC, Co, PM, and SOx when barge is not available (Table 14). Rail transportation will create an additional 94% of all emission components when its demand for wheat transportation increases without barge availability (Table 15). This is in keeping with the increased share of wheat, which will be moved by rail in the case of no barge. Naturally, if barge is not available above the Tri-Cities, barge emissions will decrease. They decrease by 39%, proportionate to the decrease in tons of wheat transported by barge (Table 16).

Table 14--Emissions Attributed to Truck Transportation of Wheat for the Base Case and No Barge Case

Measure	Base Case	No Barge	Percent Change
NOx (lbs)	320,005	369,501	15.47
HC (lbs)	34,718	40,087	15.47
CO (lbs)	140,380	162,092	15.47
PM (lbs)	23,598	27,332	15.82
SOx (lbs)	8,780	10,180	15.95
Total Emissions	527,481	609,192	15.49

Table 15--Emissions Attributed to Rail Transportation of Wheat for the Base Case and No Barge Case

Measure	Base Case	No Barge	Percent Change
NOx (lbs)	369,287	714,595	93.51
HC (lbs)	15,730	30,439	93.51
CO (lbs)	47,191	91,317	93.51
PM (lbs)	8,989	17,394	93.51
SOx (lbs)	26,966	52,181	93.51
Total Emissions	468,163	905,926	93.51

Table 16--Emissions Attributed to Barge Transportation of Wheat for the Base Case and No Barge Case

Measure	Base Case	No Barge	Percent Change
NOx (lbs)	926,182	563,274	-39.18
HC (lbs)	41,999	25,542	-39.18
CO (lbs)	125,996	76,627	-39.18
PM (lbs)	19,894	12,099	-39.18
SOx (lbs)	165,784	100,825	-39.18
Total Emissions	1,279,855	778,367	-39.18

In summary, there is little change in energy consumption and emissions output when barge is not available to transport wheat along the Snake River. Energy consumption increases slightly, by 1.5%. This results from rail taking on the majority of the grain no longer available to be transported by barge and rail being only slightly more energy efficient (372 Btu/ton-mile) than barge (374 Btu/ton-mile) in 1995. Recall that on average, barge is more fuel-efficient than barge. However, there may be issues of rail capacity since there has been a history of shortages of rail cars available to transport grain.

Emissions output increases by 4% when barge is not available. Rail and barge are comparable in emission levels for HC, CO, and PM. NOx output for rail is about 150 pounds greater, per 1000 gallons of diesel, then barge and 39 pounds less, per 1000 gallons, then barge. Emissions increases are also due to the increase in truck transportation. Truck is higher than rail and barge in HC and PM output.

Barley

A similar examination of energy consumption and emissions output for the transportation of barley is conducted under the scenarios of barge being available along the Snake River and of barge not being available. The changes in Btu usage and emissions for barley transportation are more dramatic than those found for wheat. The amount of barley produced and transported in 1994 is only 9% that of wheat for the same year.

In Table 17, ton-miles of barley shipped by truck increases by 107% when barge is not available. As in the case of wheat, rail takes on most of the ton-miles which would have gone by barge; in this case, rail ton-miles increase by two and one half times. Ton-miles associated with barge decreases by nearly 27%. The changes in Btu consumption for each mode are similar (Table 18). The overall change in Btu consumption across all modes is an increase of 41% when barge is not available. The 41% represents 23 billion Btu's or the energy required to fuel the activities of 23,000 people for one day, given energy consumption rates in 1984 (Information Please Almanac, 1995).

Table 17--Ton-Miles by Mode for Barley in the Base Case and No Barge Case

Mode	Ton-Miles (Base Case)	Ton-Miles (No Barge Case)	Percent Change in Ton-Miles
Truck	52,104,728	108,102,325	107.47
Rail	37,192	93,009	150.08
Barge	76,315,265	55,825,059	-26.85

Table 18--Btu per Ton-Mile and Btu's Consumed for Barley in the Base Case and No Barge Case

Mode	Btu/Ton-Mile	Btu's Consumed (Base Case)	Btu's Consumed (No Barge Case)	Percent Change
Truck	551	28,709,705,128	59,564,381,075	107.47
Rail	372	13,835,424	34,599,348	150.08
Barge	374	28,541,909,110	20,878,572,066	-26.85
Total Btu's Consumed		57,265,449,662	80,477,552,489	40.53

Total emissions from all modes, truck, rail, and barge, increase by a total of 24% when barge is not available. All components of emissions increase, most notably PM, CO, and HC which increased 73%, 57%, and 47%, respectively. NOx emissions increased 19% and SOx emissions fell by 16% (Table 19). Total truck emissions double with all components showing an increase (Table 20). SOx (149%) and PM (137%) increase the most and the remaining components, NOx, HC, and CO increase by approximately 107%.

Total rail emissions increased by 400%. However, in the case of rail, it is more informative to examine the actual number of pounds of emissions than the percent changes (Table 21). The percent changes are large, but the actual pounds are small. For instance, total output increases by 400%, but the actual weight of the pollutant outputs is 62 pounds with barge and 309 pounds without barge. Emission changes for barge are negative overall and for each component (Table 22). Due to less usage of barge on the Snake River, emissions decrease by 27%.

Table 19--Total Emissions from Truck, Rail, and Barge for the Transportation of Barley in the Base Case and No Barge Case

Emissions Component (lbs)	Base Case	No Barge Case	Percent Change
NOx	128,946	152,928	18.60
HC	8,593	12,630	46.98
CO	30,698	48,100	56.69
PM	4,707	8,155	73.25
SOx	16,319	13,755	-15.71
Total Emissions	189,263	235,568	24.47

Table 20--Emissions Attributed to Truck Transportation of Barley for the Base Case and No Barge Case

Measure	Base Case	No Barge	Percent Change
NOx (lbs)	43,475	90,197	107.47
HC (lbs)	4,717	9,786	107.46
CO (lbs)	19,071	39,568	107.48
PM (lbs)	2,871	6,807	137.10
SOx (lbs)	1,025	2,552	148.98
Total Emissions	71,159	148,910	109.26

Table 21--Emissions Attributed to Rail Transportation of Barley for the Base Case and No Barge Case

Measure	Base Case	No Barge	Percent Change
NOx (lbs)	49	244	397.96
HC (lbs)	2	10	400.00
CO (lbs)	6	31	416.67
PM (lbs)	1	6	500.00
SOx (lbs)	4	18	350.00
Total Emissions	62	309	398.39

Table 22--Emissions Attributed to Barge Transportation of Barley for the Base Case and No Barge Case

Measure	Base Case	No Barge	Percent Change
NOx (lbs)	85,422	62,487	-26.85
HC (lbs)	3,874	2,834	-26.85
CO (lbs)	11,621	8,501	-26.85
PM (lbs)	1,835	1,342	-26.87
SOx (lbs)	15,290	11,185	-26.85
Total Emissions	118,042	86,349	-26.84

General conclusions for barley are that rail takes on most of the barley, which would have been transported by barge. Rail ton-miles increase by 150% and truck ton-miles increase by 107%. Barge Btu's decrease by 27%. Subsequently, total Btu usage increases by 41%. Emissions increase by 24% in total with increases in the NOx, HC, CO, and PM components and a decrease in SOx. Note that the percent changes in energy consumption and particularly emissions output associated with the transportation of barley without barge on the Snake River are large. Changes in Btu's and the various emission components must be examined to identify actual changes in amounts of fuel consumed and emissions created.

Summary and Conclusions

One of the intentions of this report was to establish baseline measures of energy use and emissions for current wheat and barley transportation. This provides policy makers with an opportunity to understand the current energy and emission impact of transporting wheat and barley in eastern Washington. The model used in this study addresses one of the prevalent policy questions in eastern Washington today: What impact will a Snake River drawdown have?

A drawdown would affect the movement of wheat and barley by barge. Without barge, most of the transportation of wheat will be take up by rail because rail is more cost (rate) effective than truck. One possible problem associated with the increased workload of rail in the case of a drawdown is the historical evidence of shortages in rail cars for the shipment of grain in the Pacific Northwest. Transportation planners and producers will certainly have to address this possible shortage in the event of a drawdown.

A drawdown does cause slight increases in energy consumption and has a mixed affect on emission output, because some components of emission increase while others decrease. The energy consumption for the movement of wheat increases by 1.5% in terms of Btu's when barging is not available above Tri-Cities. Total emissions output for wheat movement increases by 4%, with a significant decrease in sulfur oxide components. As for the movement of barley, overall Btu usage increases by 41% and overall emissions levels increase by 24%.

As other potential reactions to drawdown occur, such as rail car capacity shortages, increased rail rates, etc., it can be expected that energy consumption and emissions output will be increased even more than in this pilot study. Further research is underway evaluating these more complex and realistic situations.

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