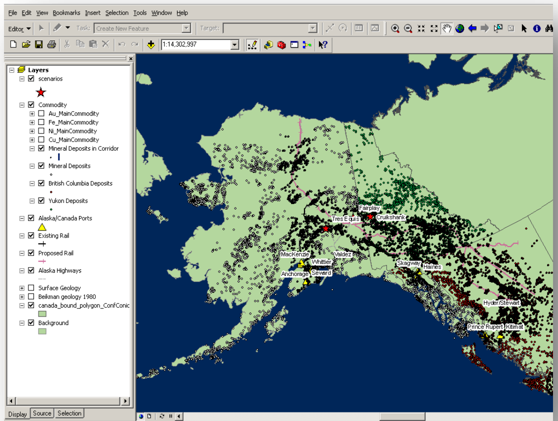
MOREV Tool

Mineral Occurrence Revenue Estimation & Visualization Tool

A System for Evaluating Potential Revenue and Carbon Emissions from Mineral Resources for Existing and Expanded Transportation Networks in the Alaska - Northwest Canada region



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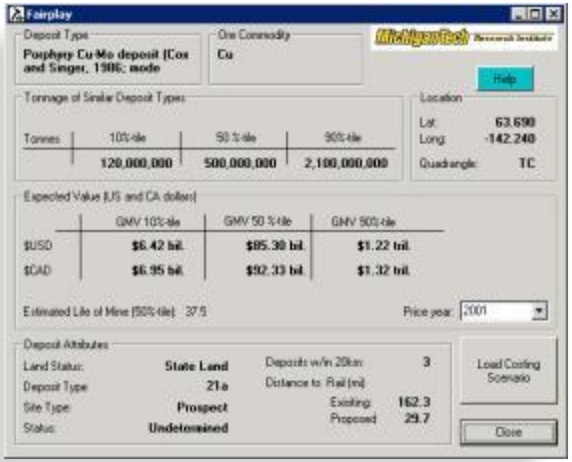
Airships VI Conference, December 4, 2011



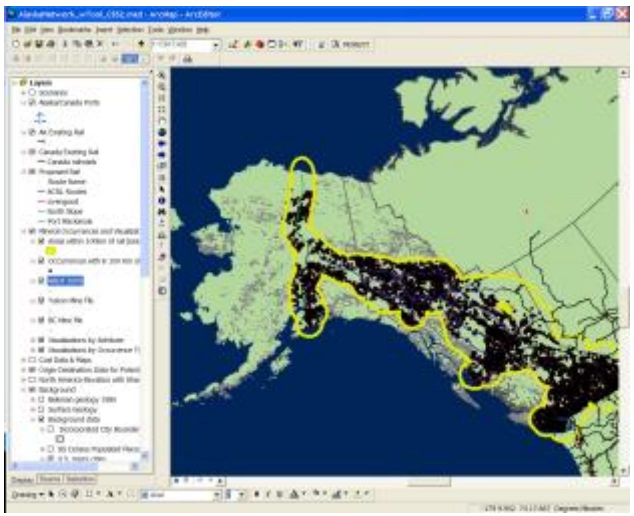
www.mtri.org
www.mtri.org/mineraloccurrence.html

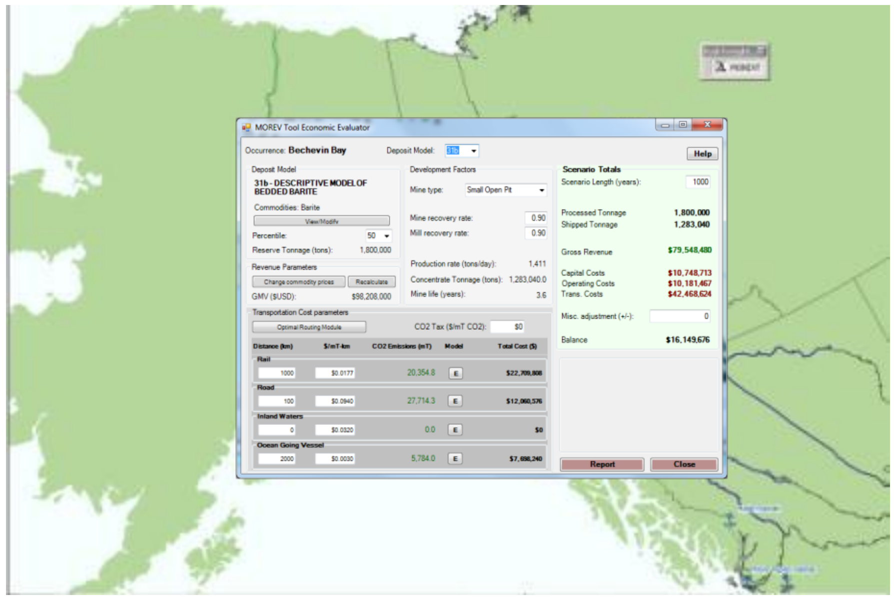
Presentation Outline

- **Background & Motivation**
- **Current Capabilities & Upcoming Developments**
- **Screen Shot Demo**
- **Tool Methodology**
  - **Revenue Estimation Methodology**
    - Calculation of Gross Metal Value
    - Estimation of potential freight volumes
  - **Cost Estimation Methodology**
    - Capacity, Mining cost (Capital Expense, Operating)
    - Transportation cost (multimodal)
  - **Carbon Accounting: Transportation Carbon Accounting Module (TCAM)**
    - Rail, Truck, Waterborne (OGV & barge)
  - **Dynamic Network Routing Module**
- **Adapting MOREV Tool for Airship Transportation**
- **Detailed Screen Shot Walk-through**
  - **Visualization examples**
  - **Step-by-step tool usage**

MOREV: Purpose

- Provide **GIS-based visualization** for decision makers to **evaluate revenue potential** from **mineral exploitation** in **Alaska**, **Yukon**, and **BC**
  - *Especially in light of potential airship links*
  - *Decision support for multi-modal options*

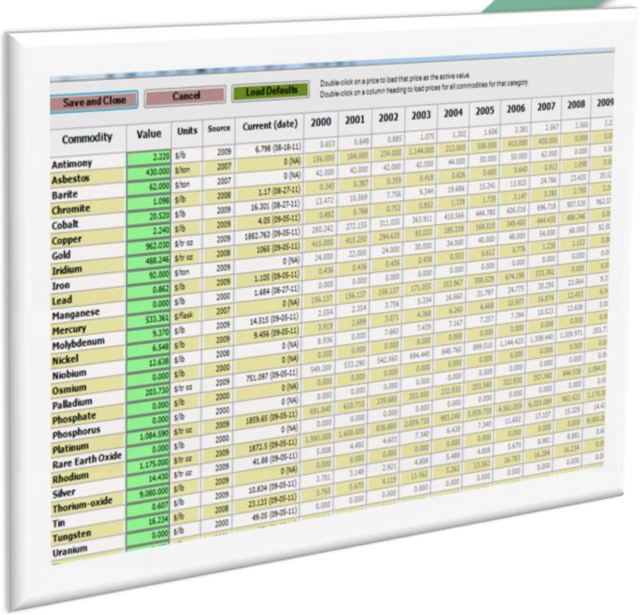


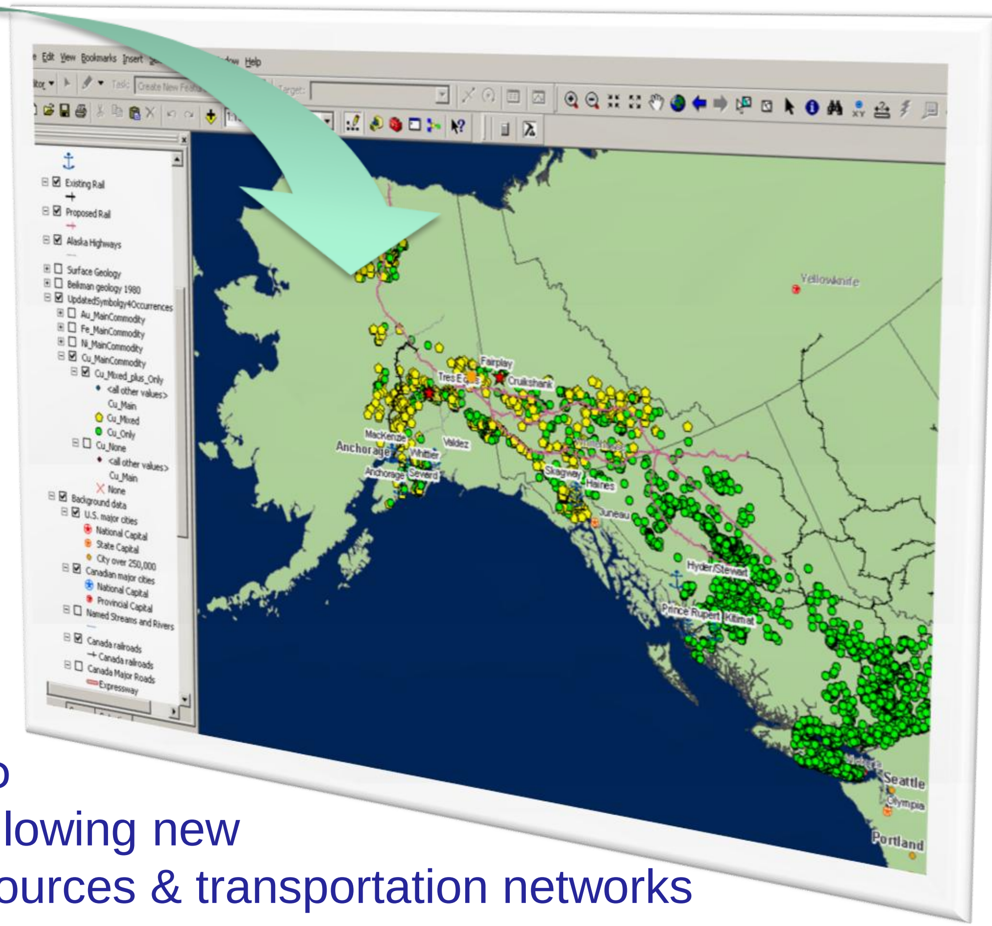


MOREV: Background

Starting point: **Gross Metal Value of Identified Major Mineral Occurrences in ARR Extension Corridor in Alaska** (P. Metz, full ARDF version, revised 2010 from 2007 ACRL Phase I study)

…but, to be useful it is desirable to make resource databases available to more users in **resource development** & **transportation** communities, so…





…we implemented Metz's methodology into ARDF, BC mine file, and Yukon mine file, allowing new ways of exploring scenarios for mineral resources & transportation networks

MOREV: Key Points

- Spatializing the mineral occurrence database allows integration of disparate data important to resource development & transportation decision makers

- Example uses:
  - → Calculate potential revenue & freight volumes from occurrences within 100-km of a proposed transport link
  - → Visualize proximity to existing infrastructure, historic mines, nearby deposits
  - → Visualize land use patterns, watersheds, political boundaries
  - → Track CO_2 in transportation segment for a proposed mine
  - → Calculate and visualize most efficient multi-modal transportation route.

- Sensitivity analyses can be performed, for example:
  - Transportation costs with and without a new transportation link
  - Carbon impact of multimodal routing options: truck/rail/OGV → **airship extensions!**

- Inputs and assumptions are transparent to and modifiable by the user
  - e.g. modal shift costs, carbon cost per ton-mile, port charges, mineral occurrence tonnage, costs per ton-mile, commodity price, mine recovery rate, etc.

- Occurrence data are updateable

MOREV: Potential Users

- Small to midsized exploration interests in pre-feasibility stages of project planning for new mining projects
- Transportation & infrastructure planners
  - State & local government
- Potential for helping in permitting process
  - Example: Preparation of NI 43-101 mineral project disclosures in Canada
- Government agencies & resource database maintainers
- Investment community & lenders
- Researchers (geological, transportation, economic, etc.)

MOREV: Current Capabilities

- Database Linkage
  - **Gross Metal Value** can be automatically calculated for any ***collection of*** mineral deposits with a valid USGS Deposit Model
    - Currently applies to **67%** of ALL metallic mineral occurrences in the combined ARDF, BC, and Yukon mine files (**73%** of ARDF occurrences)
    - We have added functionality so that the **user can select/change a deposit model** for the occurrences with unidentified deposit types

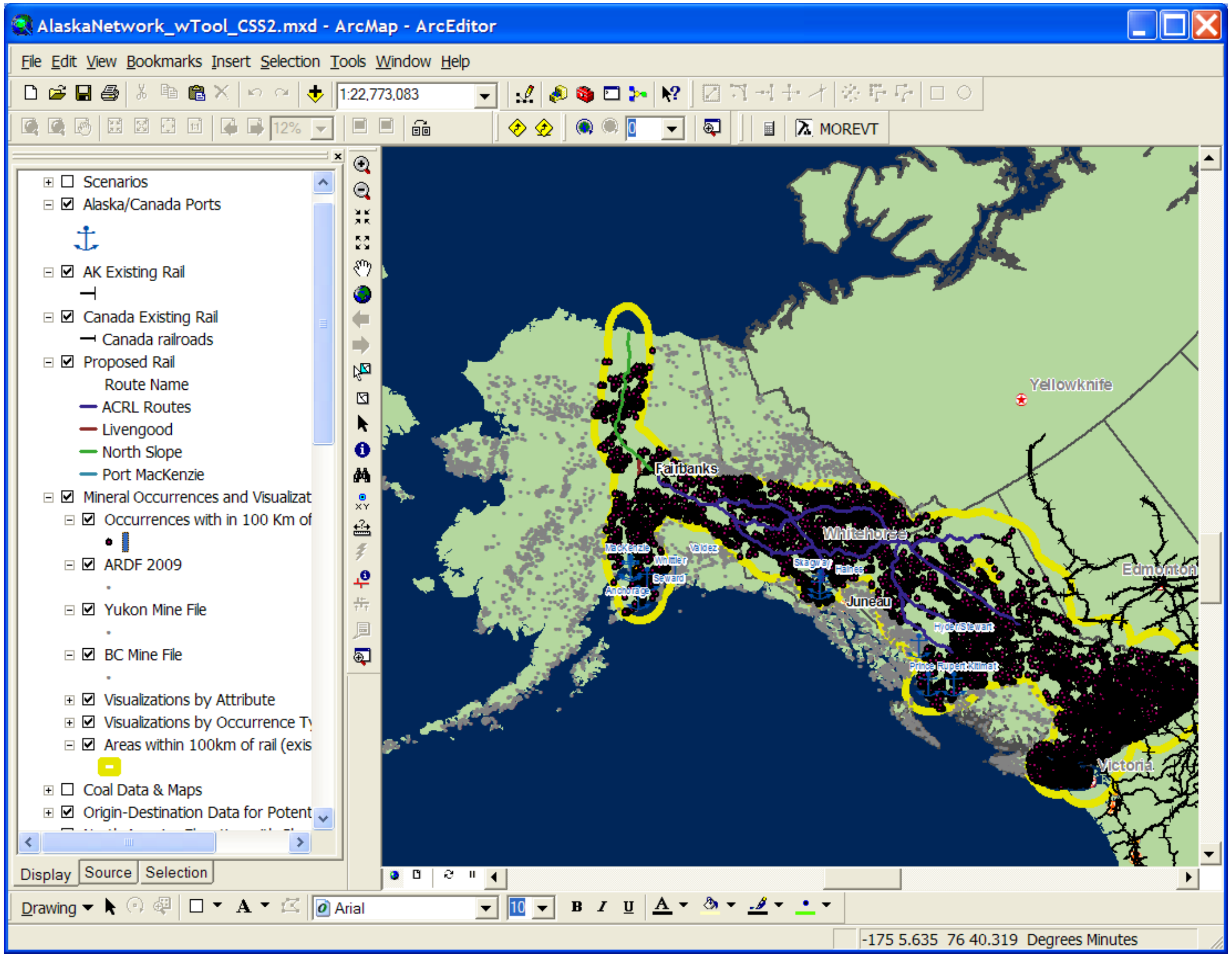
- Scenario Evaluation
  - Calculates and displays **mine capacity** (tons/day) based on Modified Taylor Rule (updated by Long 2009)
    - From this value, calculate Mine Capital Expense and **Mine Operating Cost**
    - User can input known or estimated costs/revenues

  - **Dynamically calculates optimal route** from mineral occurrence to user-chosen destination based on transportation costs
    - Derives total multi-modal **transportation cost** and **carbon emissions** associated with transporting minerals along the calculated route

MOREV Workflow Details: Example Scenario Setup

User visualization of geographic context of candidate mineral occurrences (ACRL corridor as well as all AK, Yukon, BC)

- Proximity to existing + proposed rail/road/grid infrastructure
- Transport distance/route selection to port
- Proximity to candidate mineral occurrences, known deposits, existing/historic mines
- Map display options:
  (examples next page)
  - In-corridor occurrences
  - Gross Metal Values*
  - Deposit Type
  - Commodity groupings



*P. Metz. UAF

Example Single Mineral Occurrence Selection

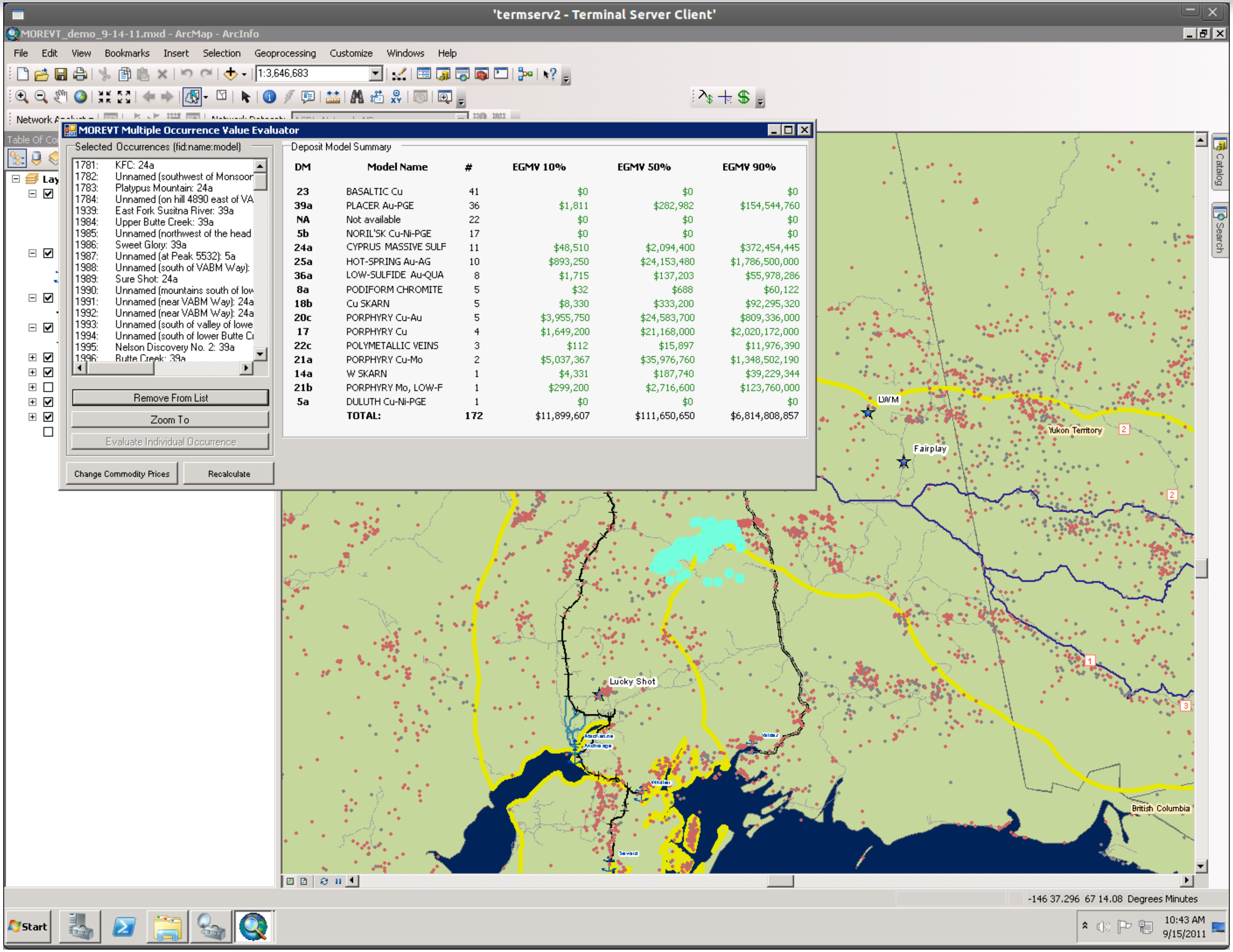
MOREVT Commodity Price Database

Save and Close | Cancel | Load Defaults

Double-click on a price to load that price as the active value.
Double-click on a column heading to load prices for all commodities for that category

Commodity	Value	Units	Source	Current (date)	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
Antimony	4.700	$/lb	2010	6.798 (09-01-11)	4.700	2.220	2.560	2.567	2.381	1.606	1.302	1.075	0.885	0.649	0.653
Asbestos	642.200	$/ton	2010	0 (NA)	642.200	1,060.400	851.000	430.000	410.000	508.000	212.000	1,144.000	234.000	184.000	156.000
Barite	43.200	$/ton	2010	0 (NA)	43.200	43.200	47.080	62.000	50.000	50.000	44.000	42.000	42.000	42.000	42.000
Chromite	2,404.000	$/ton	2010	2185 (09-06-11)	2,404.000	9,200.000	2,196.000	1,824.000	1,280.000	1,370.000	1,252.000	836.000	718.000	774.000	690.000
Cobalt	20.000	$/lb	2010	16.132 (09-08-11)	20.000	20.520	23.435	24.766	13.925	15.241	19.686	9.344	7.756	10.569	13.472
Copper	3.500	$/lb	2010	3.966 (09-15-11)	3.500	2.240	2.780	3.280	3.147	1.735	1.339	0.852	0.752	0.768	0.882
Gold	1,225.029	$/tr oz	2010	1802.5 (09-15-11)	1,225.029	962.030	907.530	696.718	606.518	444.780	410.566	363.911	311.035	272.155	280.242
Iridium	642.034	$/tr oz	2010	1074.947 (09-16-11)	642.034	420.000	488.246	444.430	349.450	169.510	185.330	93.020	294.620	415.250	415.000
Iron	108.570	$/ton	2010	0 (NA)	108.570	92.000	68.000	54.000	48.000	40.000	34.000	30.000	24.000	22.000	24.000
Lead	0.950	$/lb	2010	1.095 (09-15-11)	0.950	0.862	1.153	1.238	0.776	0.612	0.553	0.438	0.436	0.436	0.436
Manganese	1,221.071	$/ton	2010	3205 (09-06-11)	1,221.071	1,140.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mercury	1,082.098	$/flask	2010	0 (NA)	1,082.098	613.992	634.112	533.361	674.198	558.529	353.967	171.055	156.137	156.137	156.137
Molybdenum	17.000	$/lb	2010	14.515 (09-16-11)	17.000	9.370	23.564	30.295	24.775	31.797	16.660	5.334	3.756	2.354	2.554
Nickel	10.000	$/lb	2010	9.828 (09-15-11)	10.000	6.548	12.453	16.874	10.977	6.668	6.260	4.368	3.071	2.699	3.919
Niobium	5.518	$/lb	2009	0 (NA)	0.000	5.518	12.638	10.523	7.394	7.257	7.167	7.439	7.660	0.000	8.936
Osmium	250.491	$/tr oz	2010	0 (NA)	250.491	252.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Palladium	525.566	$/tr oz	2010	730.822 (09-15-11)	525.566	203.730	1,209.971	1,308.440	1,144.420	899.510	848.760	694.440	542.560	533.290	549.300
Phosphate	58.760	$/ton	2010	0 (NA)	58.760	105.914	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Phosphorus	0.000	$/lb	2000	0 (NA)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Platinum	1,608.960	$/tr oz	2010	1812.256 (09-15-11)	1,608.960	1,084.590	846.538	357.340	322.930	203.540	232.930	203.000	339.680	610.710	691.840
Rare Earth Oxide	286.700	$/lb	2009	0 (NA)	0.000	286.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rhodium	2,383.543	$/tr oz	2010	1850.133 (09-16-11)	2,383.543	1,175.000	982.422	6,203.089	4,561.059	2,059.730	983.240	2,059.730	838.880	1,600.000	1,990.000
Silver	20.229	$/tr oz	2010	40.392 (09-15-11)	20.229	14.430	15.329	17.107	11.602	7.340	6.438	7.340	4.603	4.492	5.008
Thorium-oxide	136.000	$/lb	2009	0 (NA)	0.000	136.000	136.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tin	10.250	$/lb	2010	10.653 (09-15-11)	10.250	6.070	8.881	8.981	5.670	4.808	5.488	4.808	2.921	3.148	3.701
Tungsten	12.737	$/lb	2009	20 (09-12-11)	0.000	12.737	16.605	16.284	16.783	13.562	5.262	13.562	4.119	5.670	3.760
Uranium	0.000	$/lb	2000	52.748 (09-16-11)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zinc	0.900	$/lb	2010	.986 (09-15-11)	0.900	0.720	1.345	1.542	1.588	0.671	0.526	0.671	0.386	0.440	0.558

Example Multiple Mineral Occurrence Selection



DM	Model Name	#	EGMV 10%	EGMV 50%	EGMV 90%
23	BASALTIC Cu	41	$0	$0	$0
39a	PLACER Au-PGE	36	$1,811	$282,982	$154,544,760
NA	Not available	22	$0	$0	$0
5b	NORIL'SK Cu-Ni-PGE	17	$0	$0	$0
24a	CYPRUS MASSIVE SULF	11	$48,510	$2,094,400	$372,454,445
25a	HOT-SPRING Au-AG	10	$893,250	$24,153,480	$1,786,500,000
36a	LOW-SULFIDE Au-QUA	8	$1,715	$137,203	$55,978,286
8a	PODIFORM CHROMITE	5	$32	$688	$60,122
18b	Cu SKARN	5	$8,330	$333,200	$92,295,320
20c	PORPHYRY Cu-Au	5	$3,955,750	$24,583,700	$809,336,000
17	PORPHYRY Cu	4	$1,649,200	$21,168,000	$2,020,172,000
22c	POLYMETALLIC VEINS	3	$112	$15,897	$11,976,390
21a	PORPHYRY Cu-Mo	2	$5,037,367	$35,976,760	$1,348,502,190
14a	W SKARN	1	$4,331	$187,740	$39,229,344
21b	PORPHYRY Mo, LOW-F	1	$299,200	$2,716,600	$123,760,000
5a	DULUTH Cu-Ni-PGE	1	$0	$0	$0
	TOTAL:	172	$11,899,607	$111,650,650	$6,814,808,857

New functionality added to MOREV tool in 2011; expanded help as well

Revenue Estimation Methodology

- Calculation of **Gross Metal Value**
  - Tonnage from USGS Mineral Deposit Models for occurrence (after Cox & Singer); *or user can input known or measured tonnages and commodity prices*

- Installation and operating cost estimates from statistical models from historical economic mines (after USGS, Camm)

- Multimodal transportation costs of shippable tonnage derived from US Transportation Statistics database

- *Parameters are user-updateable*

Revenue Estimation Methodology:
Significance of GMV

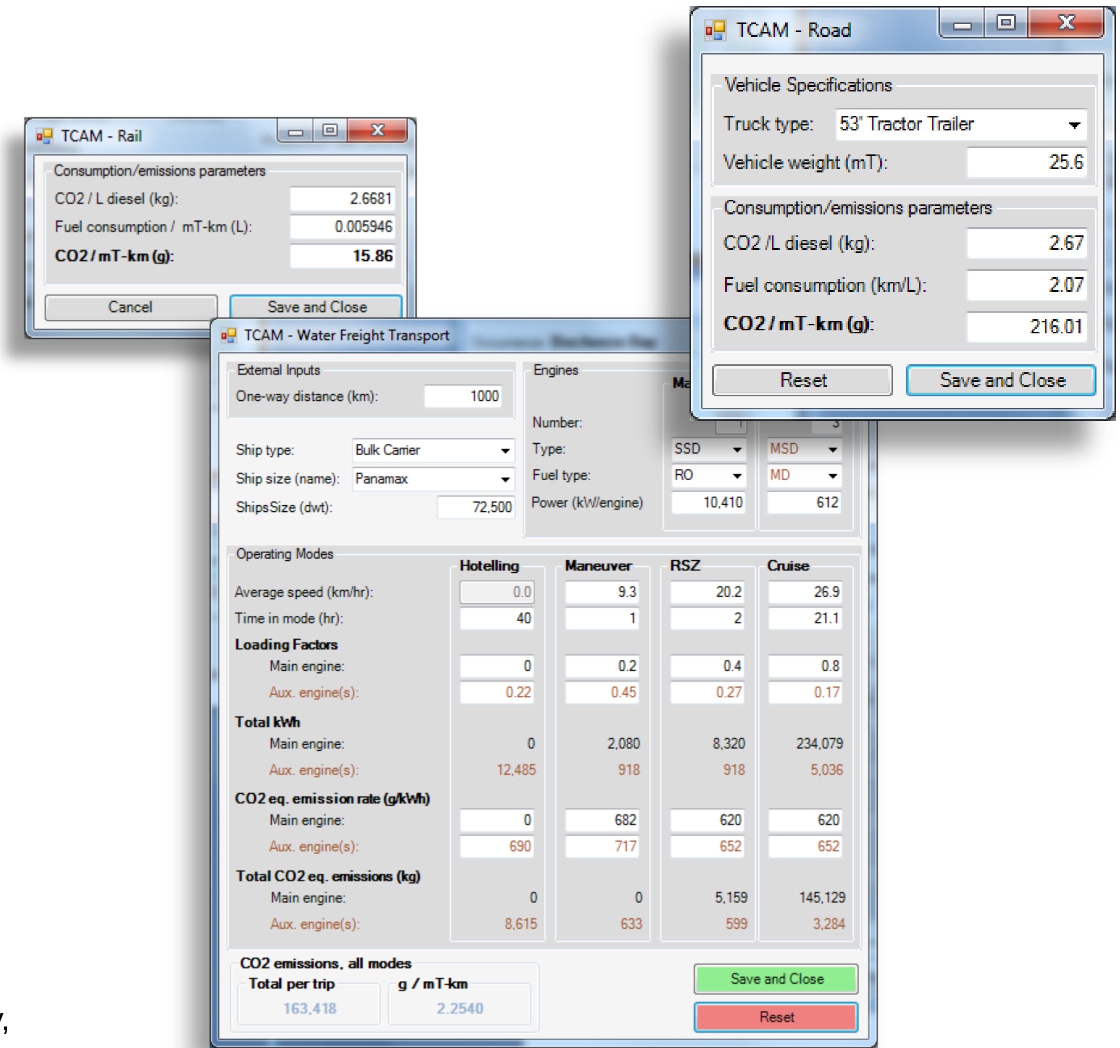
- Multiplier effect in local economy – new wealth generation from development of mineral resources
- Fort Knox Gold Mine - $104 million per year during 12 year estimated life of mine
  - 1999 Information Insights report for the Fairbanks North Star Borough
  - Through multiplier effect - wages, supplies, property taxes, reduced energy costs
- Estimated GMV = $1.2 billion
- The value to communities of mineral resource development can be equal to the GMV

Fort Knox operation
(from www.gov.state.ak.us)

Carbon Accounting

Transportation Carbon Accounting Module (TCAM)

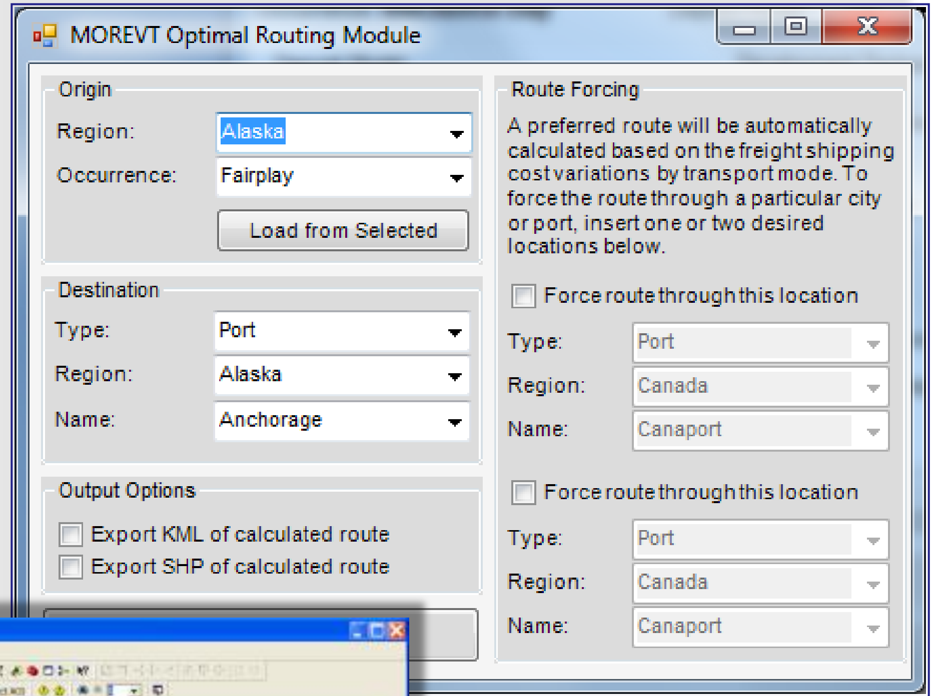
- **Rail**, **truck**, **barge**, and **OGV** (ocean going vessel) emissions models (based on fuel usage estimates) are incorporated
- Mode-specific calculator forms show model assumptions and allow user-modification of default parameters
- Interacts with dynamic routing module to enable user to select most carbon efficient shipping logistics route
- **CO2 equivalent** (which includes:CO2, CH4, and N2O) values are used
- Sources for fuel consumption/emissions model data:
  - **Rail**: Association of American Railroads, US EPA
  - **Truck**: USDOT Federal Highway Administration, Vehicle Inventory and Use Survey (VIUS) 2002, US EPA
  - **Water**: MAN Diesel, European Environment Agency, US EPA, ICF International, Lloyd's Register

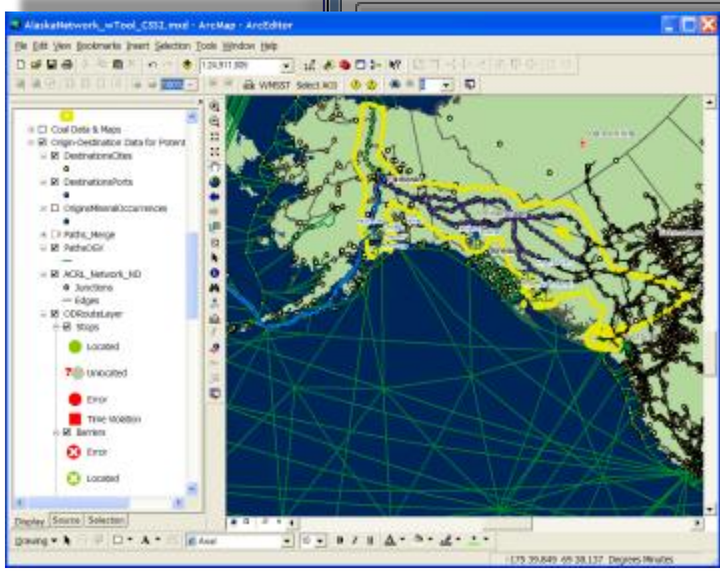


Dynamic Network Routing

Users can choose origins & destinations

- Routing is dynamically calculated from user-defined mineral occurrence origin and specified destination points (port, cities, or facilities; U.S., Canada or overseas for destination)
- Most cost efficient route is automatically chosen, but user will have the ability to force route through certain locations
- Can select most carbon-efficient means of shipping mineral concentrates
- Modal distances and intermodal transition points that were calculated will be loaded directly into the transportation costing calculations w/ option for exported KML visualization of route as well





MOREV: Requirements for incorporating airships

- **Minimum requirements for adding airship modality**
  - Base cost ($) per revenue tonne-kilometer of freight
    - For example:
      - Road: $0.094 / mT-km
      - Rail: $0.0177 / mT-km
      - Barge: $0.032 / mT-km
- **Needs for routing module**
  - "Nodes" : take-off/landing points – can assume existing airfields
  - "Paths" : can use straight-line distance initially

MOREV: Requirements for incorporating airships

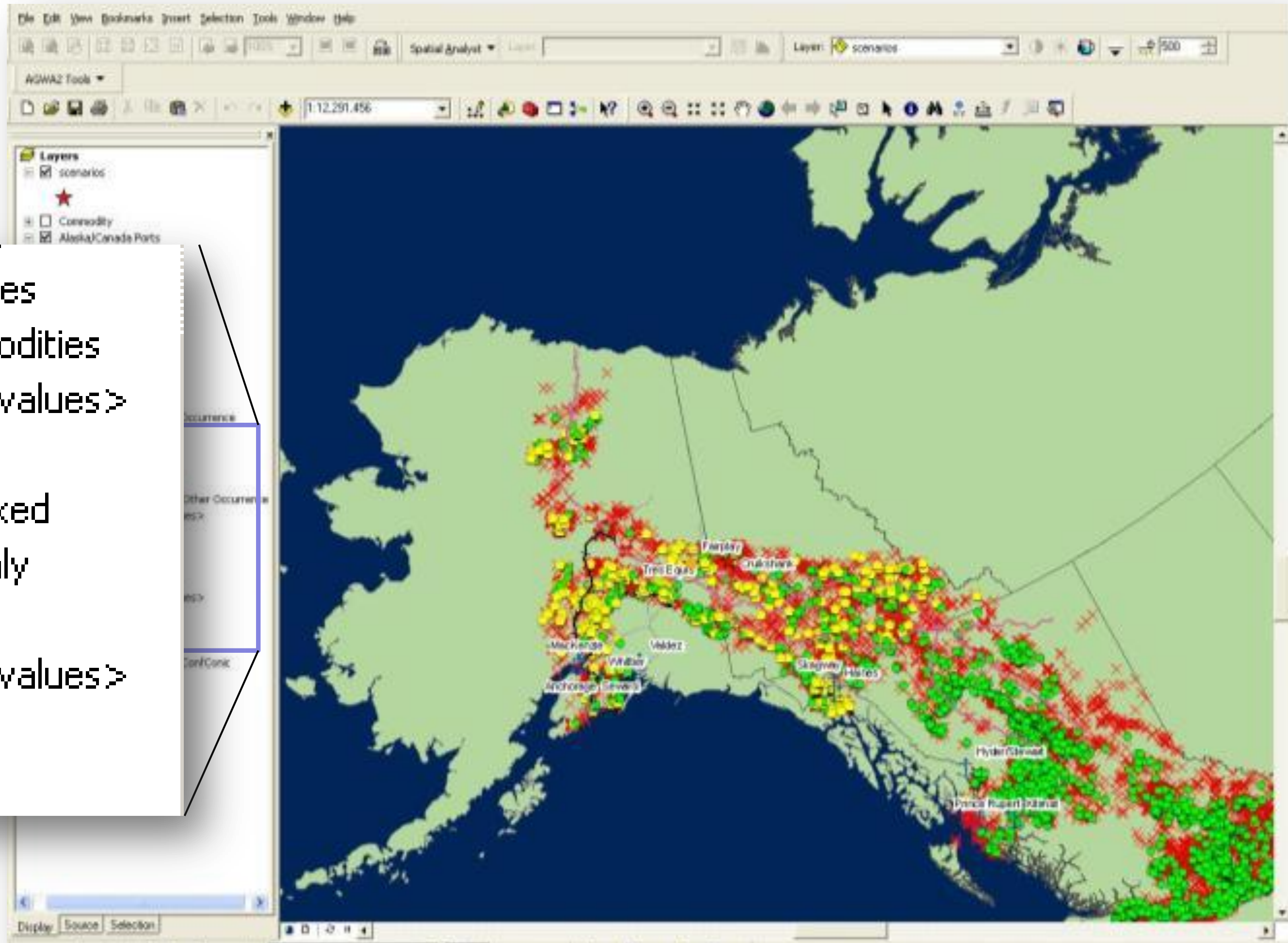
- Needs for carbon accounting module
  - **Basic model**
    - Fuel type (e.g. Jet A, diesel)
    - Fuel efficiency at cruise (starting point: 8 gallons per hour*)
    - Mean cruise speed (starting point: Skyship = 30 knots*)
  - **Possible components of a more nuanced model**
    - Fuel efficiency and cruise speed as a function of specific airship model
    - Fuel efficiency as a function of vehicle/cargo weight
    - Fuel efficiency at take-off/landing vs. cruise
    - Take-off/landing speed/time

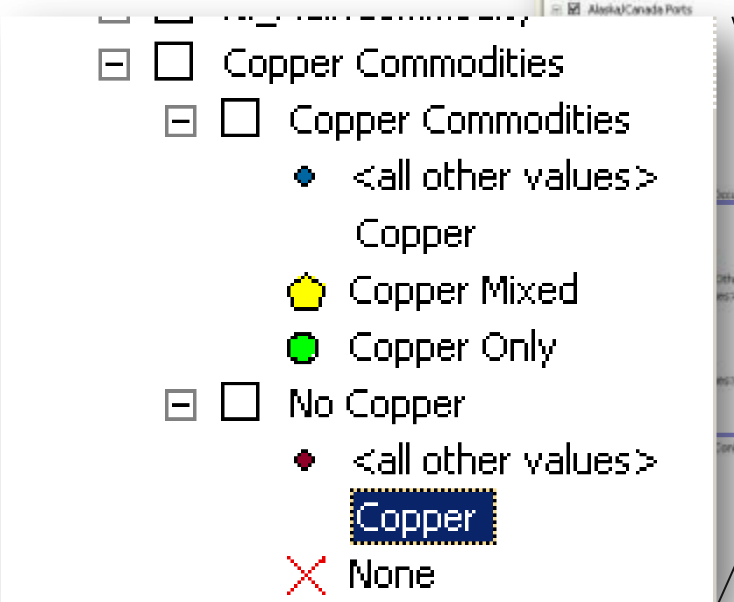
*http://www.airshipman.com/faq.htm

Map Display Examples

- Allow Filtering by Attribute, Commodity Type

E.g., Copper within 100 km of proposed ACRL

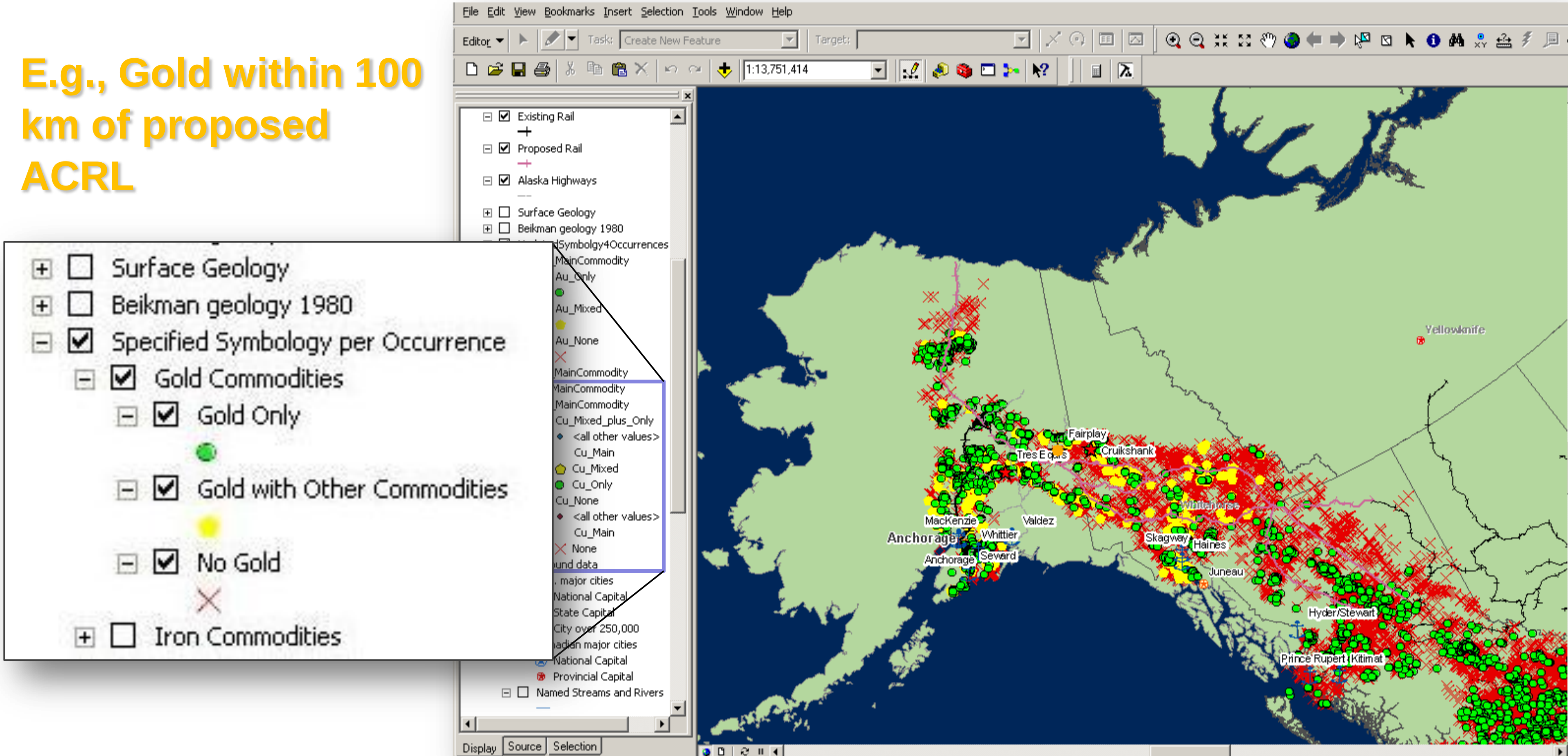




Map Display Examples

- Allow Filtering by Attribute, Commodity Type

E.g., Gold within 100 km of proposed ACRL



Transportation Expenses

- **Transportation expense calculation: Freight volumes**
  - Freight volume is estimated from concentrate tonnage (which is dependent on reserve tonnage, commodity grades, and mine and mill recovery rates; deposit model) and distance traveled for each of four transportation modes: **Rail**, **Road**, **Inland Water**, and **Ocean Going Vessel**
    - ***We calculate daily freight volume of concentrate (& summarize as total shippable tonnage)***

Processed Tonnage	1,800,000
Shipped Tonnage	1,283,040

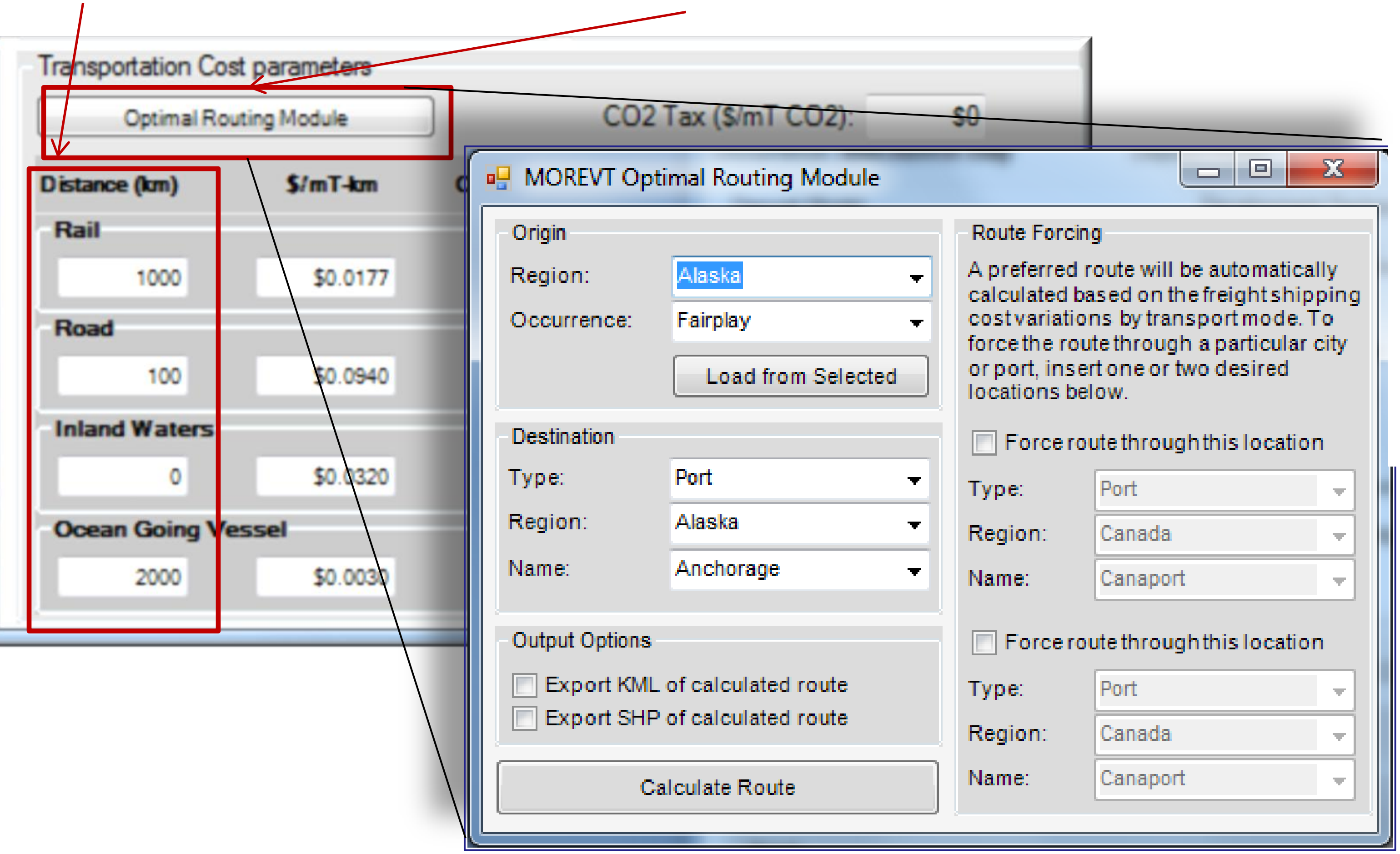
  - Cost per revenue tonne-kilometer for each mode were derived from literature review of Bureau of Transportation Statistics publications

	Distance (km)	$/mT-km	CO2 Emissions (mT)	Model	Total Cost ($)
Rail	1000	$0.0177	20,354.8	E	$22,709,808
Road	100	$0.0940	27,714.3	E	$12,060,576
Inland Waters	0	$0.0320	0.0	E	$0
Ocean Going Vessel	2000	$0.0030	5,784.0	E	$7,698,240

Transportation Expenses & Dynamic Routing Form

Transportation expense calculation: Routing

The user can choose to use a preset ore destination and route ……….**or can set their own**



This routing module will automatically calculate a route the minimizes transportation costs.

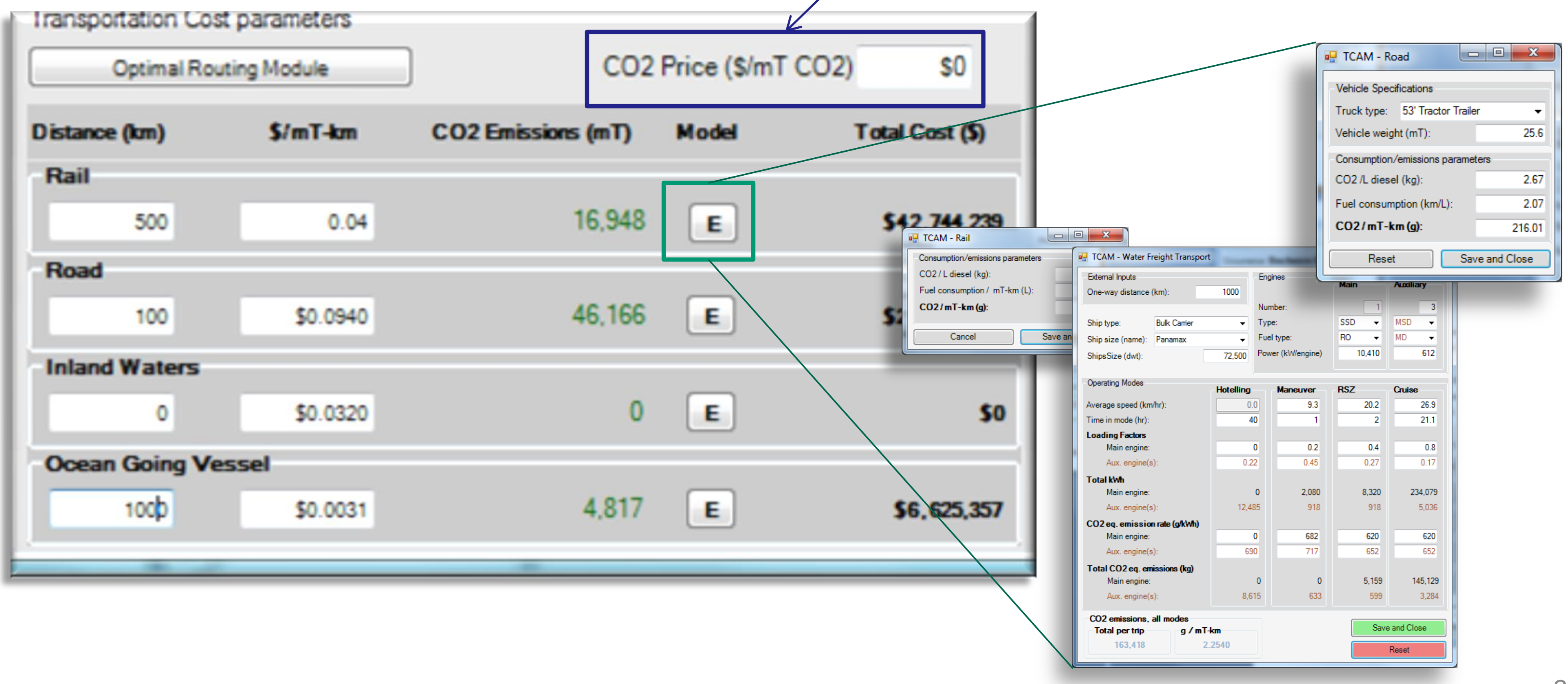
The user can also force the route through a particular port or city if desired.

CO2 emissions: TCAM module

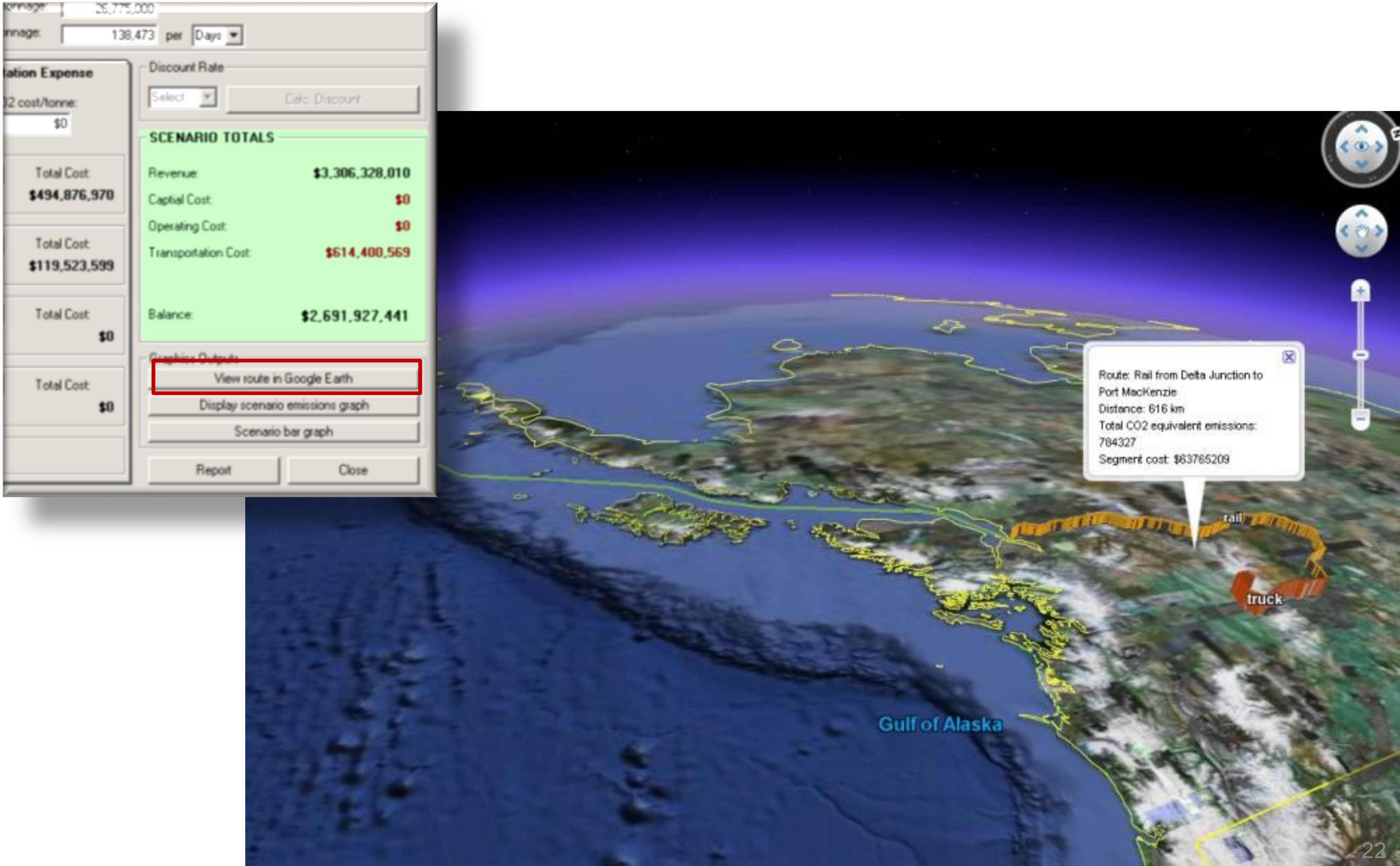
Transportation expense calculation: CO_2 emissions

Total CO_2 equivalent emissions for each transportation mode are calculated from mode-specific emissions models, with the option to set an offset price that will be incorporated into transportation costs

Mode-specific emissions calculators have been incorporated so that users can modify default parameters

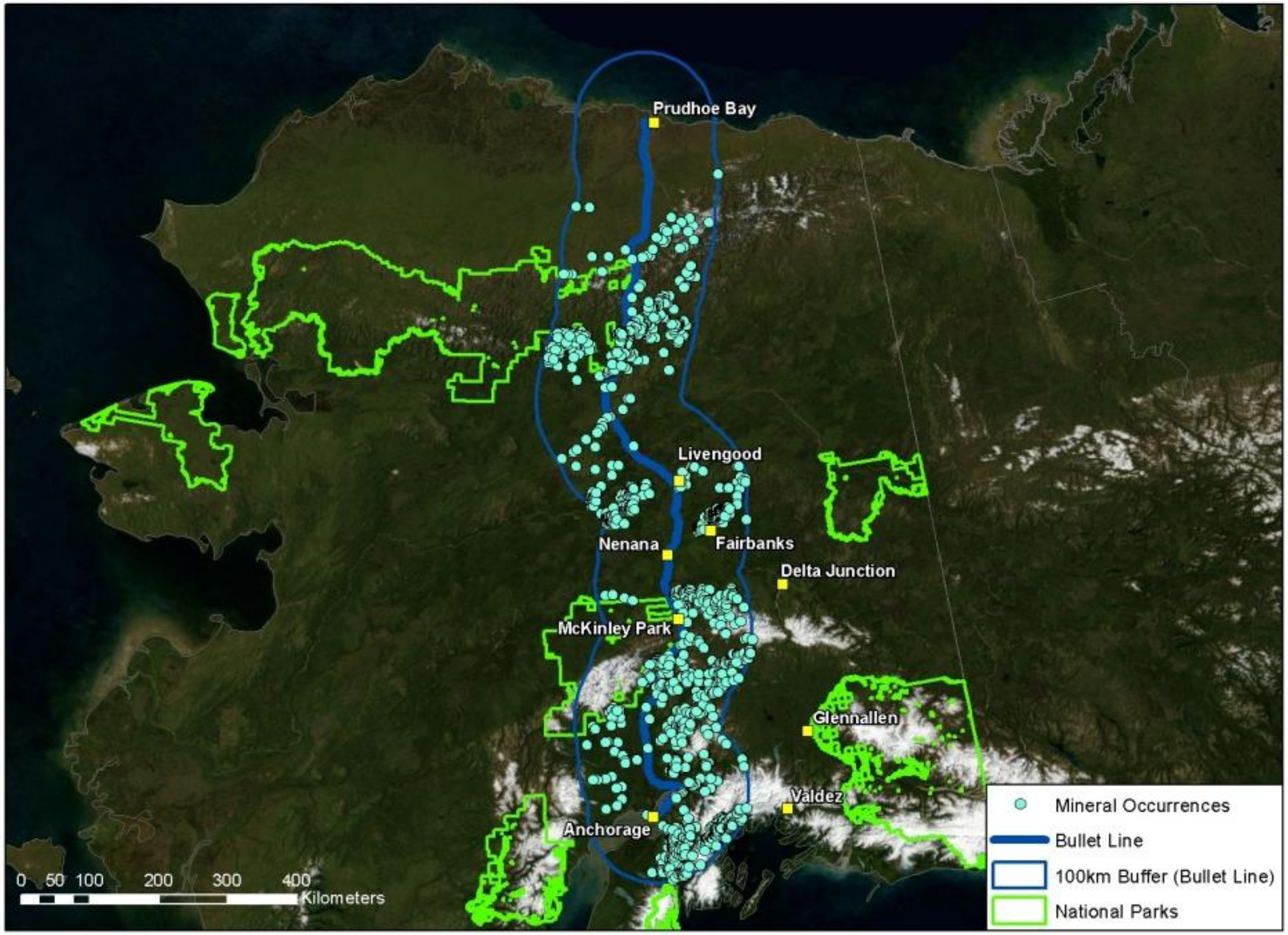


Tool Outputs: Route KML in Google Earth



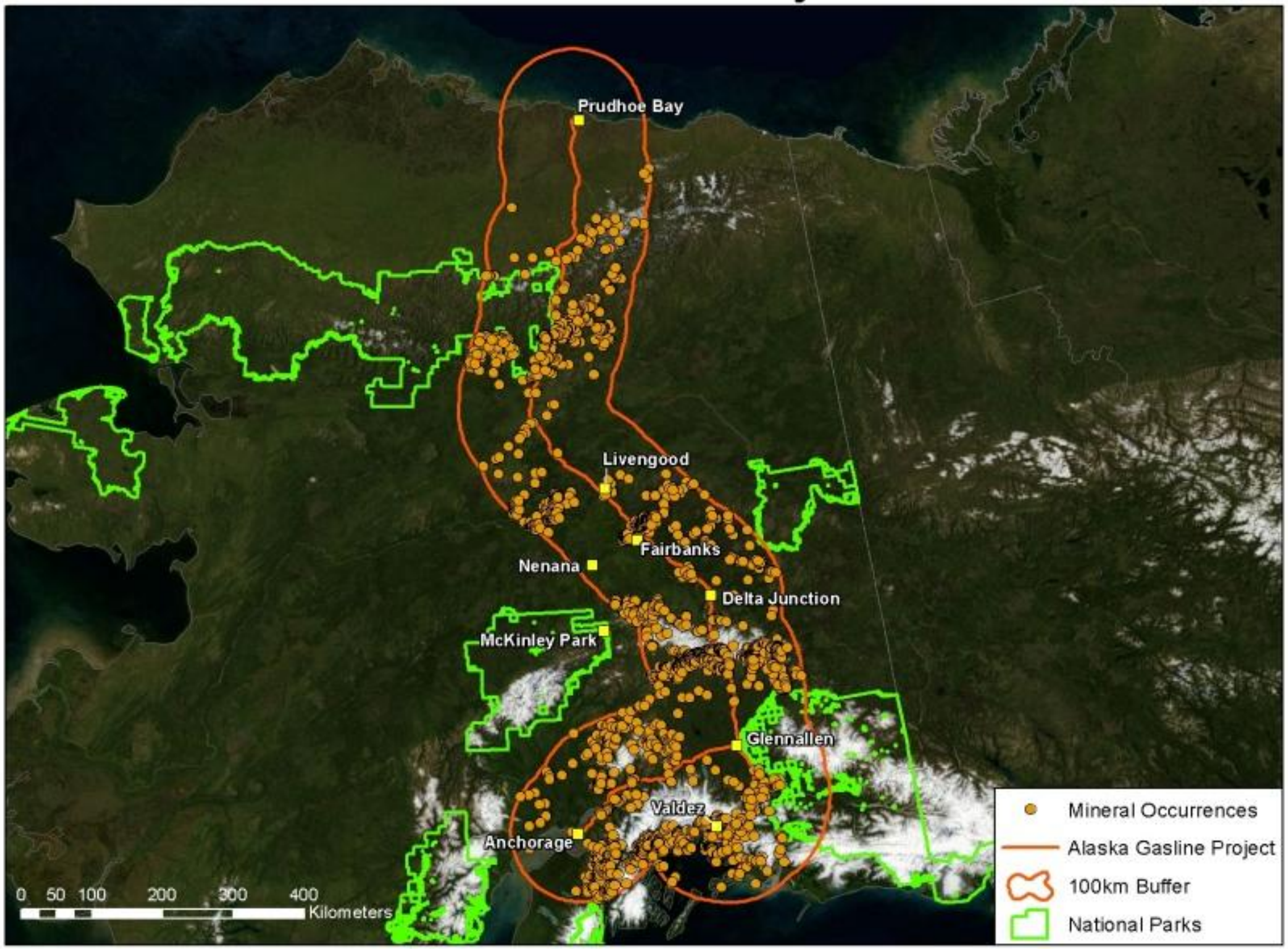
Scenario: Alternative Pipeline Route

ENSTAR Bullet Line



Proposed Bullet Line (from Prudhoe Bay to Anchorage) with mineral occurrences within 100-kilometers of pipeline.

Alaska Gasline Project



Proposed Alaska Pipeline Project (from Prudhoe Bay to Valdez) with mineral occurrences within 100-kilometers of pipeline.

Pipeline Scenario: Potential Revenue Evaluation

Tabulated Estimated Gross Metal Value (EGMV) statistics for mineral resources in100-km pipeline corridor

- EGMV: GMV x Probability of Development (Metz) – 0.001 for 10th & 50th percentile, 0.0005 for 90th

Alaska Pipeline Project - Updated 11/2/2010 with Development Probability

Model Code	Name	Metals	Amt	GMV (10th Perc.)	GMV (50th Perc.)	GMV (90th Perc.)
10	Carbonatite	Niobium - Rare Earth	1	$771,795,431	$9,329,300,739	$38,420,308,164
26a	Carbonate-Hosted Au-Ag	Au-Ag	1	$277	$4,707	$33,641
27b	Almaden Hg	Hg	1	$0	$0	$0
30a	Sandstone-Hosted Pb-Zn	Pb-Zn-Ag	1	$9,896	$304,823	$4,793,022
31b	Bedded Barite	Barite	1	$1,489	$30,713	$260,597
38a	Lateritic Ni	Ni-Co	1	$1,247,069	$9,779,654	$38,216,657
39b	Placer PGE-Au	Pt-Au-Os-Ir-Pl	1	$157	$11,918	$253,611
9	Alaskan PGE and Epiterthermal Veins	Pt	1	$0	$0	$0
14b	Sn Skarn	Sn	2	$45,007	$630,525	$4,768,965
15b	Sn Veins	Sn	2	$1,818	$67,510	$1,119,755
25g	Epithermal Mn	Mn	2	$2,523	$39,424	$275,968
39c	Shoreline Placer Ti	Zr-Ti	2	$149,486	$7,742,151	$152,147,019
6a	Komatitic Ni-Cu	Ni-Au-Cu	2	$31,998	$540,902	$6,552,870
15c	Sn Greisen	Sn	3	$44,141	$654,326	$4,957,754
20b	Sn-polymetallic veins	Au-Ag-Pb-Zn	3	$0	$0	$0
32a	Mississippi Valley Zn-Pb	Pb-Zn	3	$0	$0	$0
24c	Volcanogenic Mn	Mn	4	$7,065	$207,528	$2,343,891
31a	Sedimentary Exhalative Zn-Pb	Zn-Pb	4	$469,315	$9,963,579	$106,186,580
18a	Porphyry Cu Skarn	Cu-Ag-Au-Mo	5	$3,135,635	$23,837,669	$90,867,849
8d	Serpentine-Hosted Asbestos	Asbestos	6	$61,078	$588,154	$2,950,605
18d	Fe Skarn	Fe	7	$654,326	$19,828,066	$277,592,918
19a	Polymetallic Replacement	Pb-Zn-Cu-Ag-Au	7	$57,062	$1,872,126	$30,815,076
18c	Zn-Pb Skarn	Zn-Pb-Cu	8	$72,529	$1,594,558	$17,322,805
21a	Porphyry Cu-Mo	Cu-Mo-Au-Ag	8	$15,788,676	$110,237,308	$397,001,891
21b	Porphyry Mo, Low F	Mo	9	$1,789,382	$16,246,773	$74,015,336
25a	Hot Spring Au-Ag	Au-Ag	12	$0	$0	$0
17	Porphyry Cu	Cu-Ag-Au-Mo	19	$6,709,091	$86,823,819	$632,182,850
34c	Phosphates	P2O5-P	19	$0	$0	$0
20c	Porphyry Cu-Au	Cu-Au-Ag-Mo	23	$11,927,285	$67,332,511	$202,579,108
14a	W Skarn	W	24	$9,738	$422,162	$8,821,286
24b	Besshi Massive Sulphide	Cu-Ag-Au-Pb-Zn	28	$13,550	$574,074	$11,034,567
8a	Podiform Chromite	Cr	33	$82,492,478	$10,453,592,312	$59,085,521,764
18b	Cu Skarn	Cu-Ag-Au	34	$35,981	$1,442,311	$27,864,929
27d	Simple Sb Deposits	Sb-Ag-Au	34	$138	$7,222	$186,206
5b	Noril'sk Cu-Ni-PGE	Au-Pd-Pt	50	$0	$0	$0
24a	Cyprus Massive Sulphide	Cu-Ag-Au-Pb-Zn	52	$206,510	$8,853,963	$115,958,480
28a	Kuroko Massive Sulphide	Cu-Pb-Zn-Au-Ag	79	$344,782	$14,664,440	$285,809,883
23	Basaltic Copper	Au-Ag-Cu-Ni-Zn-Co	88	$0	$0	$0
22c	Polymetallic Veins	Ag-Au-Pb-Zn-Cu	115	$1,596	$152,342	$7,481,083
36a	Low Sulfide Au-Quartz Veins	Au-Ag	367	$591	$47,265	$6,399,194
	No Description		405	$0	$0	$0
39a	Placer Au-PGE	Au-Ag	520	$3,309	$39,426	$2,150,505
	TOTALS		1987	$897,109,410	$20,167,434,999	$100,018,774,830

MOREV tool next steps

- A web-mapping version of the tool to help users understand the tool's functionality is being developed. Will be available through http://www.mtri.org/mineraloccurrence.html

- A site-specific desktop GIS version, for detailed, in-depth analysis, will be available by contacting Dr. Paul Metz, Colin Brooks, & Dr. Robert Shuchman.
  - Include more advanced costing, economic benefits to local communities & governments, user-selectable corridors / regions

- This project is part of a larger cooperative international investigation linking Alaska and Canada rail systems involving the University of Alaska, Michigan Technological University, and the University of Calgary.

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www.mtri.org
www.mtri.org/mineraloccurrence.html

References

- Alaska Canada Rail Link Project. 2007. “Rails to Resources to Ports.” ACRL Phase I Feasibility Study. ALCAN RaiLink Inc., Whitehorse, Yukon.
- “Expanding Alaska–Canada Rail: Jointly Visualizing Revenue Freight, Development Cost, Mineral Commodity Value, and Carbon Dioxide Impacts,” Brooks, Billmire, Dobson, Kourous-Harrigan, Keefauver, Michigan Tech Research Institute, for publication in the Transportation Research Record.
- Ballou, R. 1998. Business Logistics Management, 4th Edition, Upper Saddle River, NJ: Prentice Hall.
- Camm, T. W. 1991. “Simplified cost models for prefeasibility mineral evaluations.” Information Circular 9298, U.S. Department of the Interior Bureau of Mines.
- Cox & Singer Mineral Deposit Models http://pubs.usgs.gov/of/2004/1344/mainfrms.htm
- A Test and Re-Estimation of Taylors Empirical Capacity–Reserve Relationship, Keith R. Long Natural Resources Research, Vol. 18, No. 1, March 2009 (2009)

References, Cont'd

- MAGORMINRailExenCompleteV2.xls (Metz Spreadsheet)
- Gartner Lee report: http://alaskacanadarail.com/documents/WPA2/WPA2a%20traffic_data_development_mineral_resources2006_04_18.pdf
- A simplified economic filter for open-pit gold-silver mining in the United States, Singer, Menzie, David, Long, USGS Opefile report 98207, 1998
- Course materials website, Prof. Bradley Paul
- Singer, Introduction to Quantitative Mineral Resource Assessments and Required Deposit Models http://pubs.usgs.gov/of/2007/1434/1_Introduction_and_models.pdf
- QCI Logistics Mineral Resources Evaluation http://alaskacanadarail.com/documents/WPA2/WPA2d%20MP%20LogisticsEvaluationMineralResources(2)2006_05_17.pdf

APPENDIX -TCAM Equations & Data Sources
Overview

- **Rail**
  - Based on US freight fleet-wide fuel economy as reported by American Association of Railroads
- **Road**
  - Fuel economy regression equation based on total vehicle weight derived from US DOT VIUS and FHA *Highway Statistics*.
- **Water**
  - Methodology adopted from ICF/EPA port emission inventory best practices. Utilizes emission factors based on engine power output (g/kWh) instead of fuel consumption. Data sources include: ICF Consulting, US EPA, Swedish Methodology for Environmental Data, Lloyd's Register, MAN Diesel.

Total Rail CO_2 (kg) = F * R * C

Where:

F = Revenue tonne-kilometers of freight: *distance(km) * tonnes of freight,* both figures being derived from the user-defined scenario

R = Fuel consumption rate (L diesel/tonne-km): default value = **0.005946**, following American Association of Railroads (AAR) *Railroad Facts 2008* (p. 40), which provides the following fleet-wide average: 436 revenue-ton-miles / gallon fuel consumed for 2007. This figure was converted to L/tonne-km using the following equation:

*L/tonne-km = 1 / (436 * 0.264 gallons/liter * 1.609 km/mile * 0.907 tonnes/ton)*

C = CO_2/L of diesel (kg); default value = **2.6681**, according to US EPA

APPENDIX -TCAM Equations & Data Sources
Road

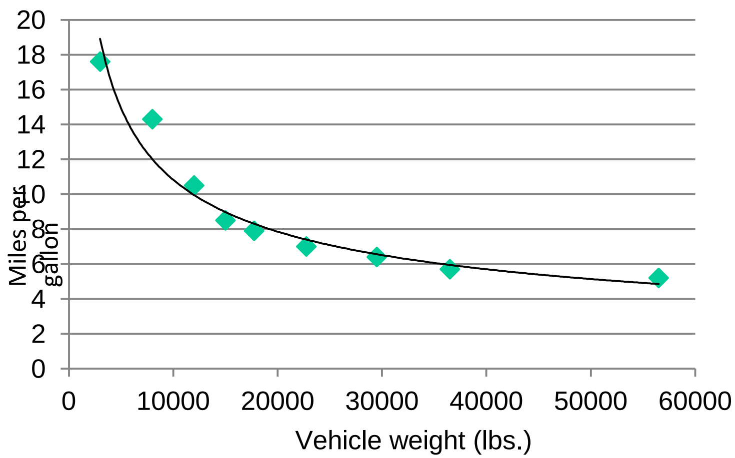
Total Road CO_2 (kg)= F * R * C / W

Where:

F = Revenue tonne-kilometers of freight: *distance(km) * tonnes of freight,* both figures being derived from the user-defined scenario

R = Fuel consumption rate (L diesel/km, or 1/*e* where *e* is *fuel economy*). Fuel economy is based on total vehicle weight. Data on vehicle weight from the **US Department of Commerce Bureau of the Census** *2002 Vehicle Inventory and Use Survey* and the **US DOT Federal Highway Administration** *Highway Statistics 2007 (*for Class 8 combination trucks) was used to derive a regression equation to calculate fuel economy from combined vehicle and cargo weight (converted to metric units afterwards):

miles-per-gallon= ***772.04 * w**$^{-0.463}$* , where ***w*** = *total vehicle weight (lbs.),* $r^2 = 0.9605$



C = CO_2/L of diesel; default value = **2.6681**, according to US EPA

W = Total vehicle weight (tonnes), defined here as equal to *curb weight* (weight of empty vehicle) plus *freight tonnage*. *Curb weight* values for each truck Class are derived from the FHA's Development of Truck Payload Equivalent Factor (TPEF)

APPENDIX -TCAM Equations & Data Sources
Water Freight

$$\textbf{Total Water } CO_2 \text{ (kg)} = \sum_t \left(\sum_m \left(H_{m,v} * L_{m,t,v} * P_{t,v} * N_{t,v} * E_{m,t} \right) \right) \text{ for vessel type } v$$

Where:

t = engine type (2 total) (*propulsion/main*, *auxiliary*)

m = activity mode (4 total) (*cruise*, *reduced-speed-zone* (*RSZ*), *maneuvering*, *hotelling*)

v = vessel type (8 options) (auto carrier, bulk carrier, container ship, cruise ship, general cargo, RORO, reefer, tanker)

H = average or expected amount of time (hrs) a vessel of type *v* spends in activity mode *m*. Default values: *hotelling* = 40, *maneuvering* = 1, *RSZ* = 2. Values for *cruise* activity mode are automatically calculated from scenario-derived *distance* (km), and *average cruise speed* for a vessel of type *v*. Sources: *Thesing and Edwards 2006, Lloyd's Register, ICF/EPA 2006*

L = loading factor (percent). The percentage of the maximum continuous rating (MCR) used by engine type *t* in mode *m* for vessel type *v*. Source: US EPA Analysis of Marine Vessel Emissions and Fuel Consumption Data

P = Maximum Continuous Rating (MCR) for engine type *t* in kW. Auxiliary engine power is based on ICF/EPA fleet averages.

Main engine power is derived from ship domestic weight tonnage (DWT) and vessel type *v* based on the following EPA regression equation and table:

*Main engine power (kW) = (a * DWT) + b*

Vessel Type	a	b	r^2
Auto Carrier	0.4172	7602	0.17
Bulk Carrier	0.0985	6726	0.55
Container Ship	0.8000	-749.4	0.59
Cruise Ship	6.810	-4877	0.72
General Cargo	0.2880	3046	0.56
RORO	0.5264	4358	0.76
Reefer	1.007	1364	0.58
Tanker	0.1083	6579	0.66

N = number of engines of type *t*, which varies by vessel type *v*. Generally, *N* =1 for main engines, and $N < 6$ for auxiliary.

Source: ICF/EPA 2006: Current Methodologies and Best Practices for Preparing Port Emission Inventories

E = CO2 equivalent emissions rate in grams per kilowatt hour (g/kWh), specific to *m* and *t*.

Source: SMED Methodology for Calculating Emissions from Ships

APPENDIX -TCAM Equations & Data Sources
References

American Association of Railroads (AAR). 2008. *Railroad Facts 2008*.

Browning, Louis, and Kathleen Bailey. ICF Consulting and U.S. EPA. 2006. *Current Methodologies and Best Practices for Preparing Port Emission Inventories*. Proc. of 15th International Emission Inventory Conference, New Orleans, LA.

Lloyd's Register of Shipping. 1995. *Marine Exhaust Emissions Research Programme*. London, United Kingdom.

MAN B&W Diesel A/S . 2004*. Propulsion Trends in Bulk Carriers*. Copenhagen, Denmark, September 2004.

MAN B&W Diesel A/S . 2004*. Propulsion Trends in Container Vessels*. Copenhagen, Denmark, December 2004.

MAN B&W Diesel A/S . 2005*. Propulsion Trends in Tankers*. Copenhagen, Denmark, August 2005.

Swedish Environmental Research Institute. 2004. Swedish Methodology for Environmental Data*. Methodology for Calculating Emissions from Ships. 1. Update of Emission Factors*. By David Cooper and Tomas Gustafsson. Norrkoping: Swedish Meteorological and Hydrological Institute (SMHI).

Thesing, Kirstin B. and Alice Edwards. E.H. Pechan & Associates and Alaska Department of Environmental Conservation, Air NonPoint & Mobile Source Program. 2006. *Nine Ports in the 49th State: Commercial Marine Inventory for Alaska*. Proc. of 15th International Emission Inventory Conference, New Orleans, LA.

U.S. Department of Commerce, Bureau of the Census, 2002.*Vehicle Inventory and Use Survey*. Additional information: http://www.census.gov/econ/overview/se0501.html

U.S. Department of Transportation Federal Highway Administration. 2007. Office of Freight Management and Operations. Development of Truck Payload Equivalent Factor (TPEF). By Mohammed Alam and Gayathri Rajamanickam. Washington, D.C.

U.S. Department of Transportation Federal Highway Administration. 2007. Office of Highway Policy Information. *Highway Statistics 2007*. Washington, D.C.

U.S. Environmental Protection Agency. Office of Transportation and Air Quality. 2000. *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data*. Energy and Environmental Analysis Inc. EPA420-R-00-002.

U.S. Environmental Protection Agency. Office of Transportation and Air Quality . 2005. *Emission Facts: Average Carbon Dioxide Emissions*