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Life Cycle Analysis

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U.S. Coal Exports – Life Cycle GHG comparison of PRB coal to foreign export competitors in the Asian market

Greg Cooney, Associate

Booz Allen Hamilton

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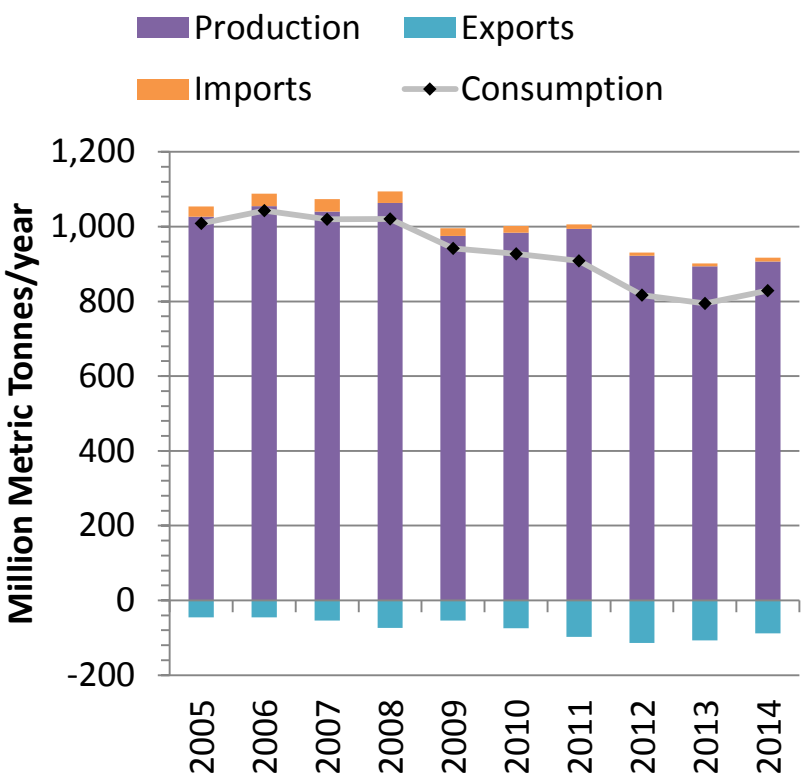
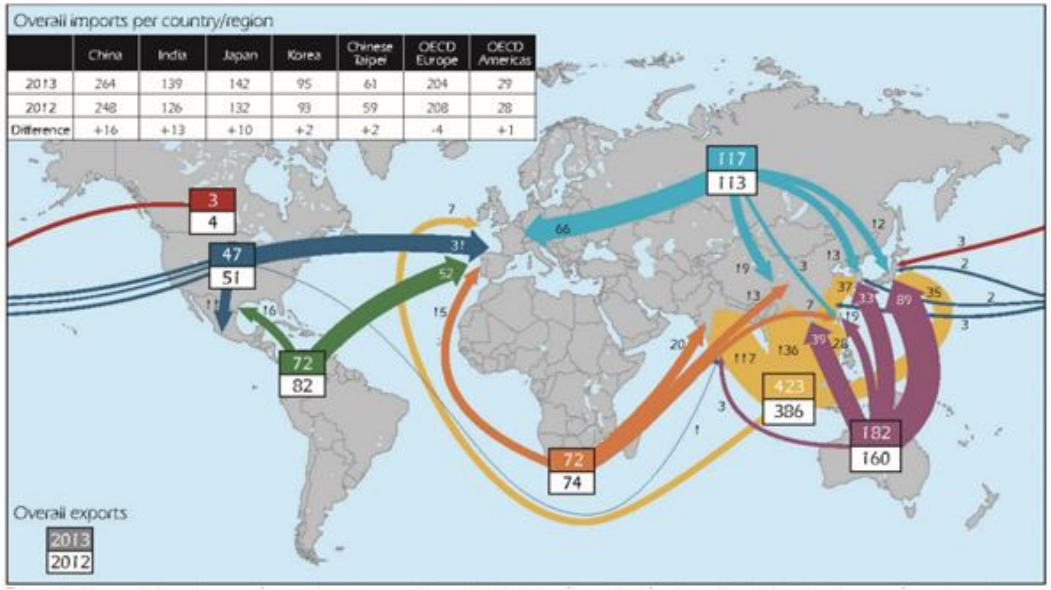
Decrease in U.S. coal consumption and increase in Asian demand has made coal exports to Asia attractive

U.S. Coal Balances, 2005-2014



Major Trade Flows in the Thermal Coal Market, 2013[1]

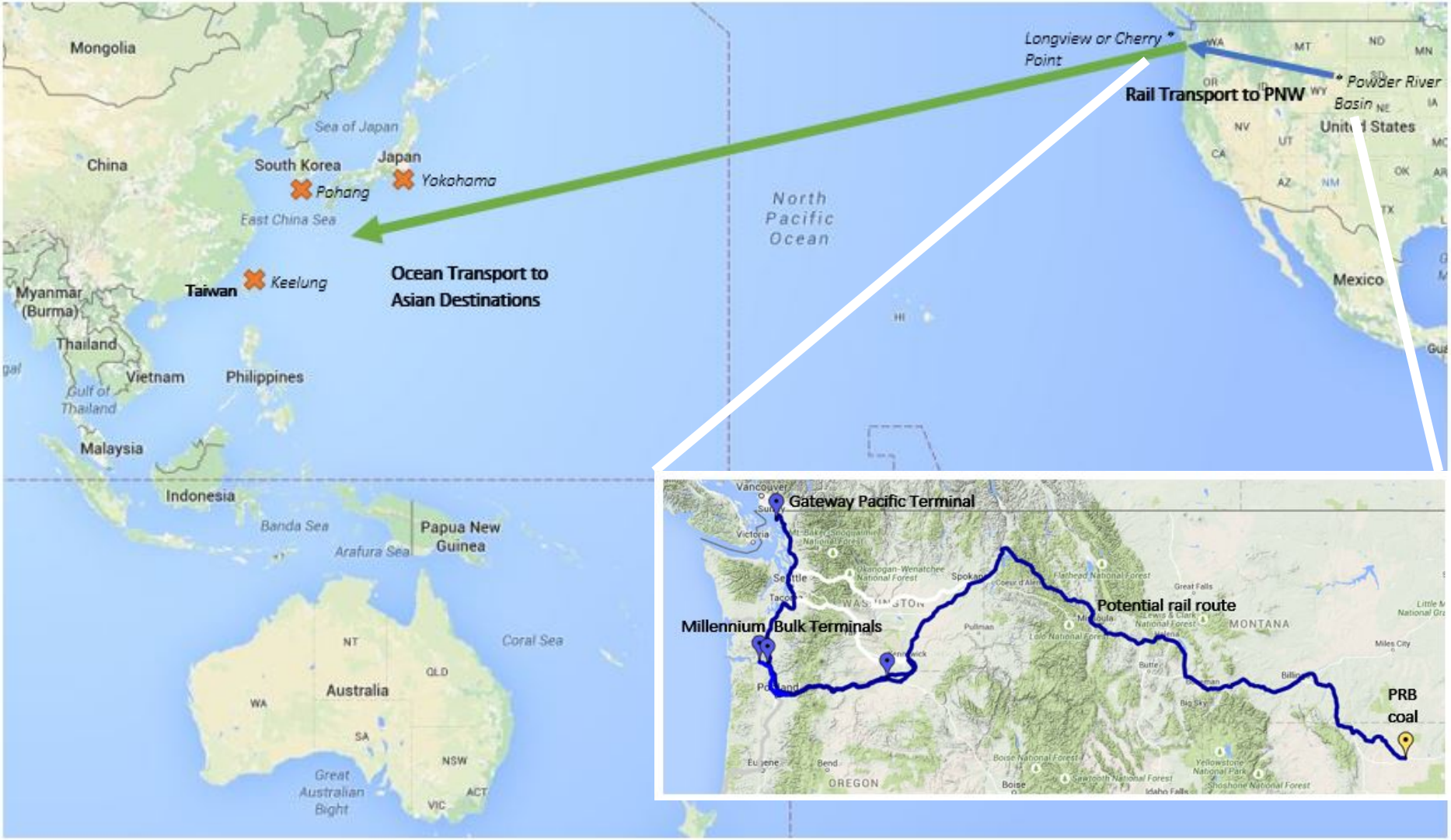


	China	India	Japan	Korea	Chinese Taipei	OECD Europe	OECD Americas
2013	264	139	142	95	61	204	29
2012	248	126	132	93	59	208	28
Difference	+16	+13	+10	+2	+2	-4	+1

Research Question: How does the mining, exporting, and power plant combustion of U.S. Powder River Basin (PRB) coal through the Pacific Northwest (PNW) to Asian destinations compare to the mining, exporting, and combustion of coals from Australia and Indonesia to Asian destinations?

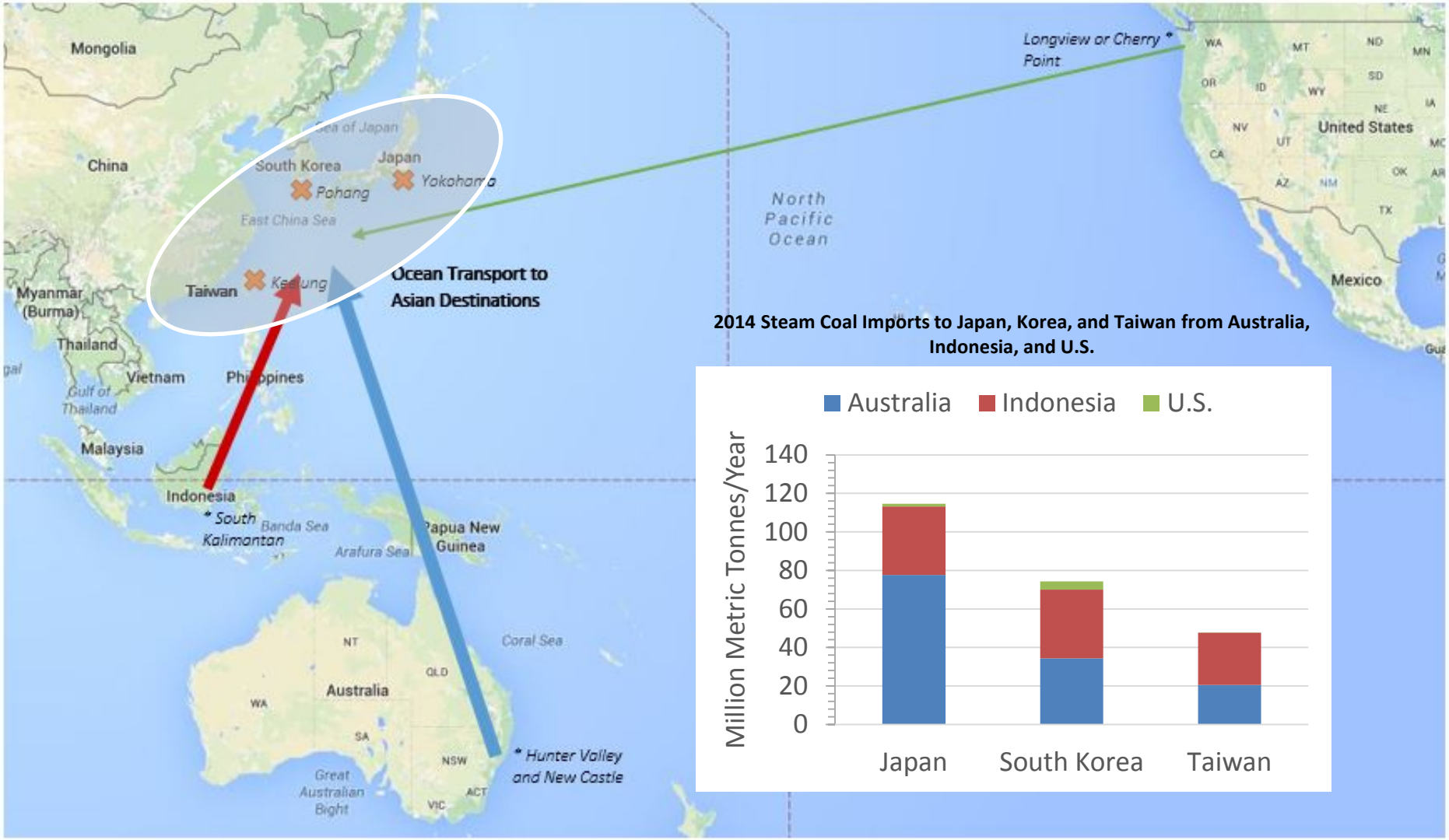
[1] © OECD/IEA 2014 Medium-Term Coal Market Report 2014, IEA Publishing. License: [http://www.iea.org/t&c/termsandconditions/]

Exports from PRB are shipped via rail to proposed terminals in PNW and then across Pacific to Asian markets



Pacific Northwest map was adapted from an interactive map from Oregon Public Broadcasting (http://www.opb.org/news/article/coal-score-card/)

Australia and Indonesia are the largest exporters of coal and are the primary competitors for the U.S. PRB in Asia

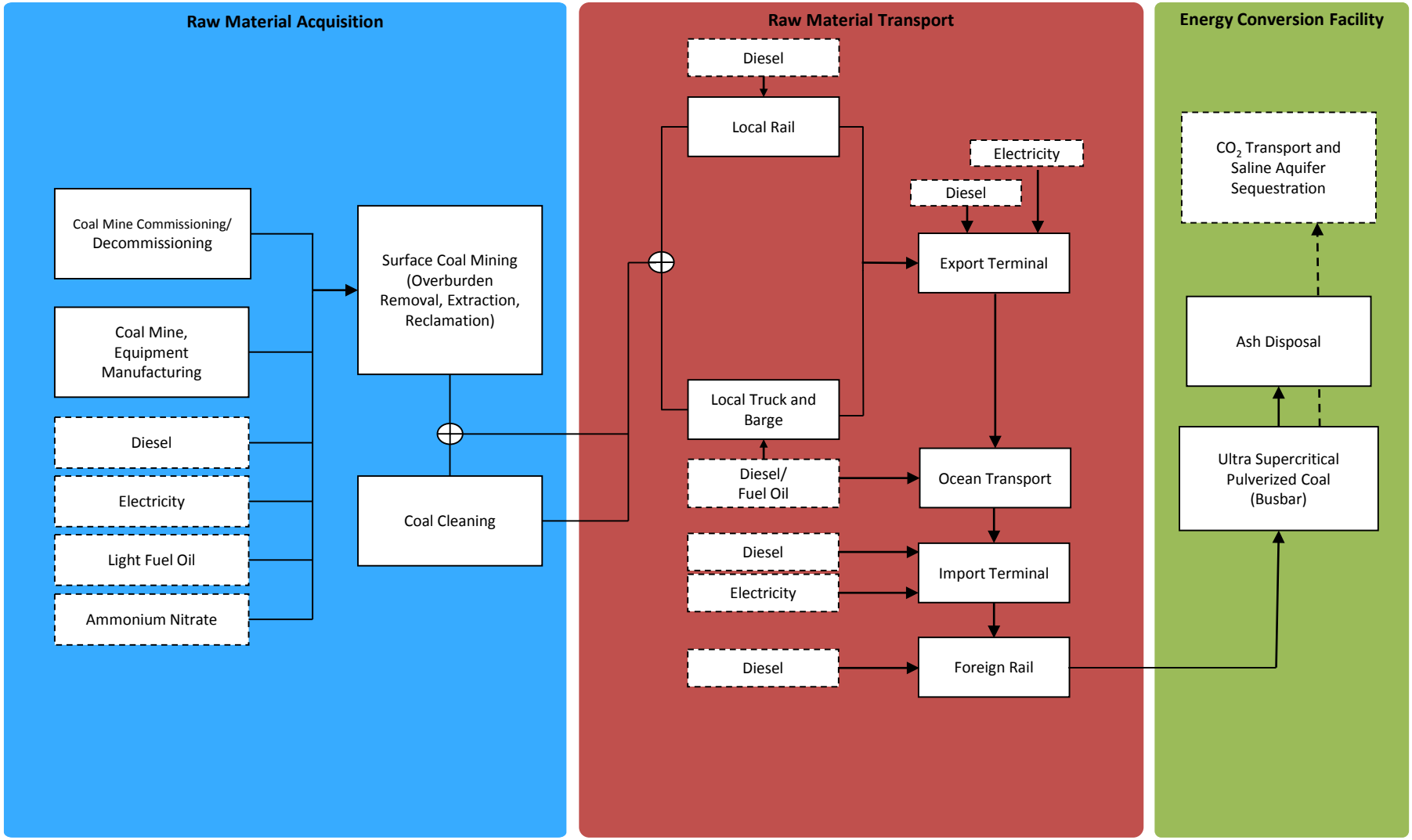


Pacific Northwest map was adapted from an interactive map from Oregon Public Broadcasting (http://www.opb.org/news/article/coal-score-card/)

Existing NETL processes for coal extraction and power generation are used to compare exports

- **System Boundaries and Functional Unit**
  - Cradle-to-busbar; functional unit of 1 MWh (busbar)
- **Representativeness**
  - Temporal
    - Sources utilized to represent upstream coal mining are representative of recent operations in the U.S. and abroad (2000-2015)
    - Detailed coal specifications are a mix of data from 2013 and 2015
    - Power plant data are mostly representative of 2011
  - Technological
    - All of the coal is extracted via surface mining methods
    - Advanced power plant (ultra-supercritical pulverized coal [USCPC]
    - Coal considered is utilized to generate the next marginal MWh
    - No consequential effects, such as the displacement of other power, because coal power production has already been selected and the choice is where to source the coal
- **Modeling approach**
  - NETL coal models tuned to represent specific production
  - NETL transport models (truck, rail, barge, ship)
  - NETL Power Plant Flexible Model (PPFM) for power plant operations
  - NETL Models and Unit Processes available at www.netl.doe.gov/lca

NETL model consists of a flexible network of parameterized processes



Mining processes are tuned with key parameters (strip ratio, CMM, etc.) to represent source differences

Source	PRB			Australia (AU)			Indonesia (ID)		
Destination	Japan	Korea	Taiwan	Japan	Korea	Taiwan	Japan	Korea	Taiwan
CMM – Coal Mine Methane (scf/ton)	0.8 - 8 - 38.7			34.3 – 42.9 – 54.4			27.9		
Diesel Scalar	1			1			2 – 3 – 4		
Mine Electricity Switch	1			1			0		
Strip Ratio	2 – 3 – 4			8 – 9 – 10			3 – 5.5 – 8		
Coal Cleaning (% waste)	N/A			20 – 25 – 30			N/A		
Truck Distance (km)	0			0			10 – 45 – 80		
Rail Distance (km)	1,900 – 2,000 – 2,100			50 – 100 – 150			0		
Barge Distance (km)	0			0			100 - 150 – 200		
Ocean Distance (+/- 10%) (km)	7,892	8,451	9,904	8,075	8,558	7,888	4,683	4,380	2,997
Coal Type	Spring Creek – Decker – North Antelope			Hunter Valley – Ensham[1]			Adaro – Mulia		

[1] Hunter Valley and Ensham coal have nearly identical specifications; thus only Hunter Valley was modeled for this analysis

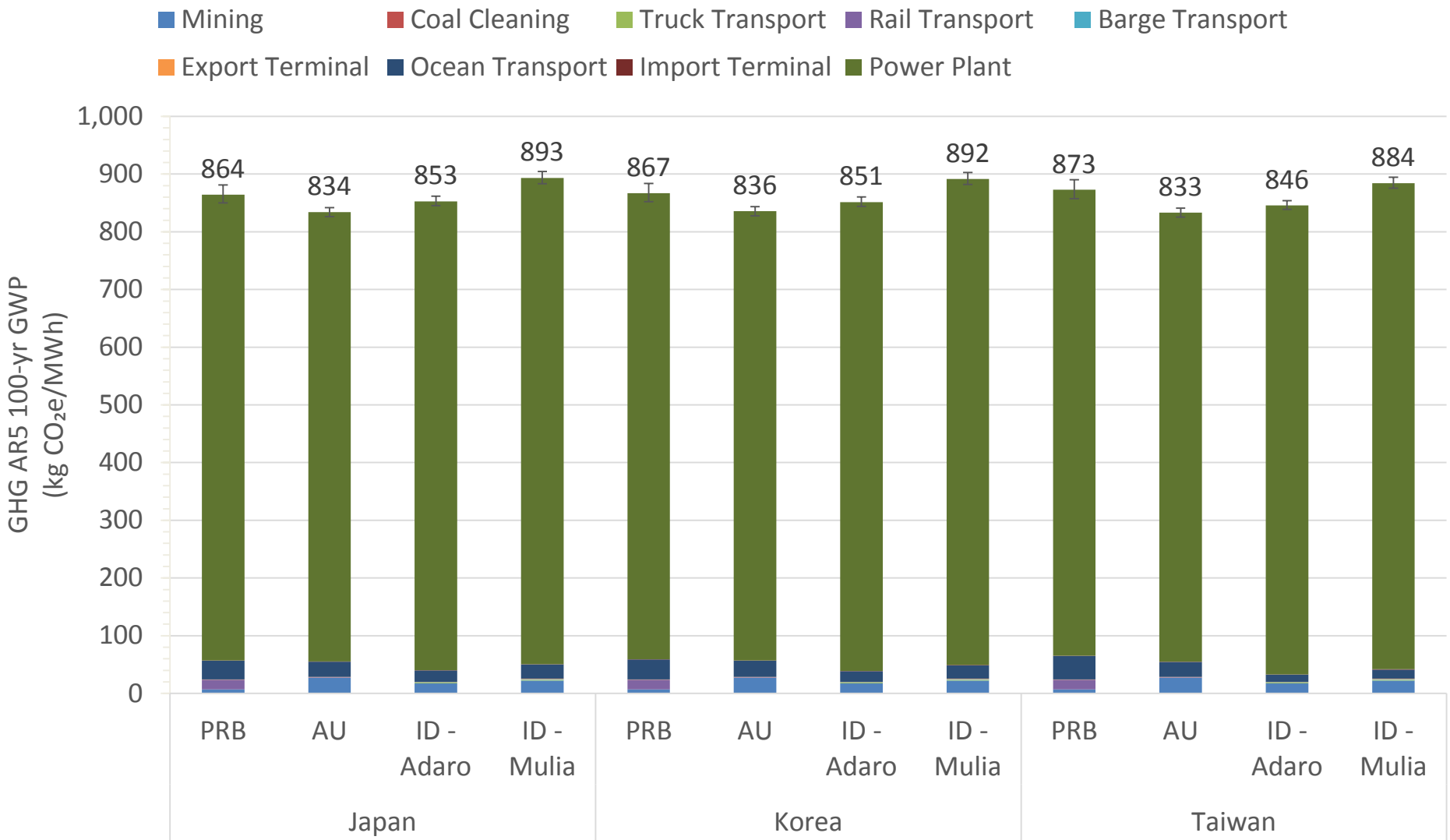
AU coal has highest heating value (less mined/transport per MWh); PRB and ID (Adaro) are comparable

	U.S. PRB						Australia[1]		Indonesia	
Model Variable	Decker	Spring Creek	Black Thunder South	Black Thunder	Antelope	North Antelope / Rochelle Complex	Hunter Valley	Ensham	Adaro	Mulia
Coal Specifications										
Moisture (%)	24.5	26.8	26.0	27.0	26.5	27.6	9.0	11.5	25.0	35.0
Carbon (%)	52.7	55.1	52.4	52.3	52.1	52.1	63.9	63.1	52.2	42.7
HHV (MJ/kg)	21.8	22.8	21.7	21.6	21.6	21.6	26.5	26.2	21.6	17.6
HHV (BTU/lb)	9,373	9,820	9,320	9,300	9,270	9,270	11,406	11,271	9,283	7,575
Power Plant Operations										
Coal Input (kg/MWh)	414	393	416	417	418	419	329	333	421	532
CO_2 Emissions (kg/MWh)	800	796	799	800	800	801	772	772	806	835
Gross power (MW)	578	580	578	578	578	577	596	597	573	557
Net power (MW)	550	553	551	550	551	550	569	569	547	529
Net plant efficiency (%)	39.9	40.1	40.0	39.9	39.9	39.9	41.2	41.3	39.6	38.4

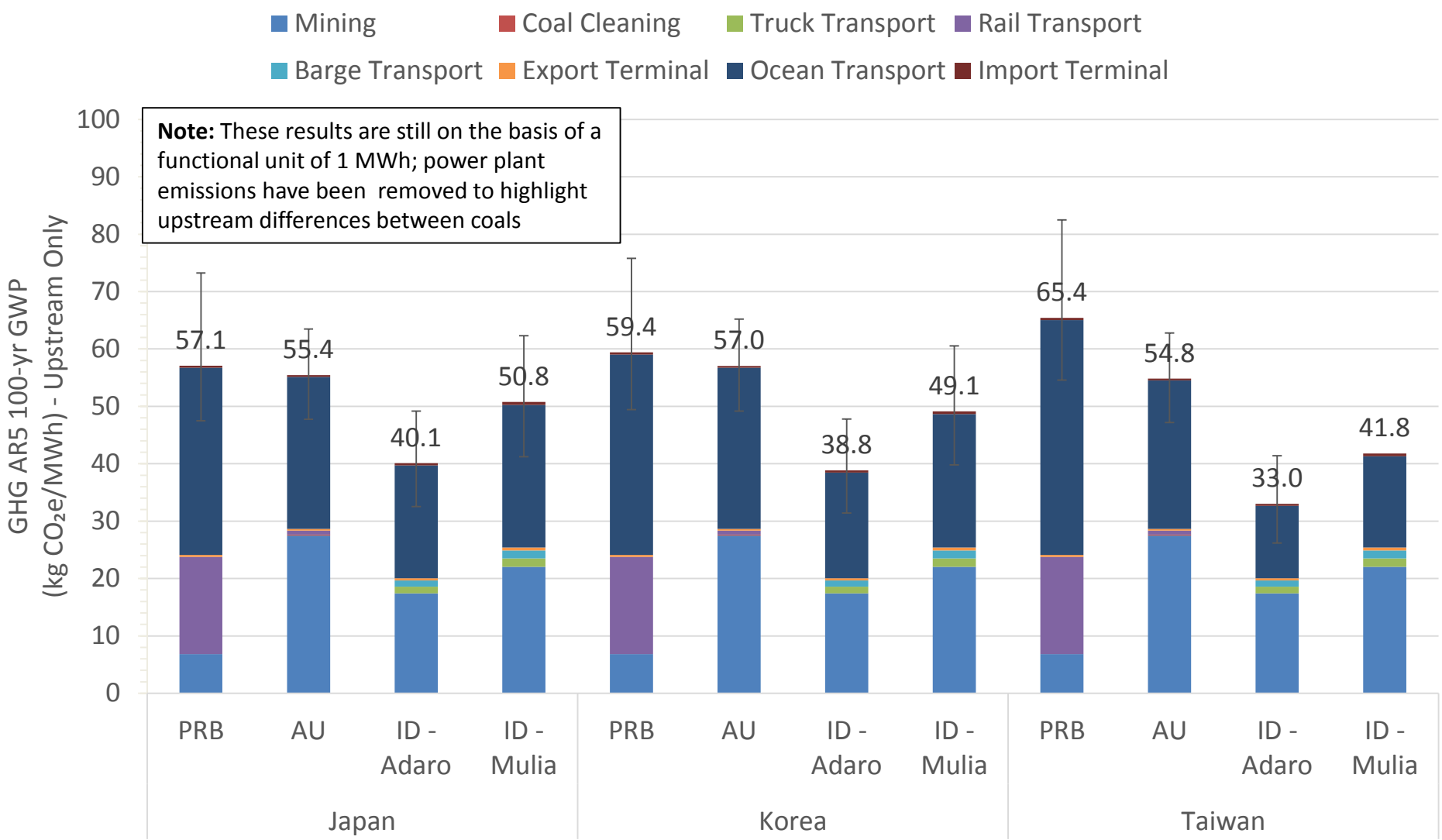
[1] Hunter Valley and Ensham coal have nearly identical specifications; thus only Hunter Valley was modeled for this analysis

Data source: Lighthouse Resources (Michael Mewing) BNSF and UP Railways

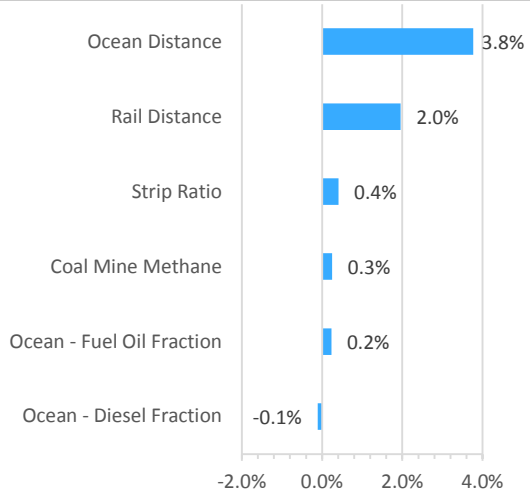
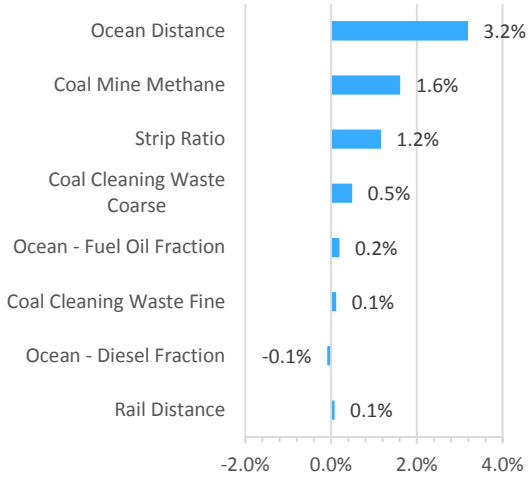
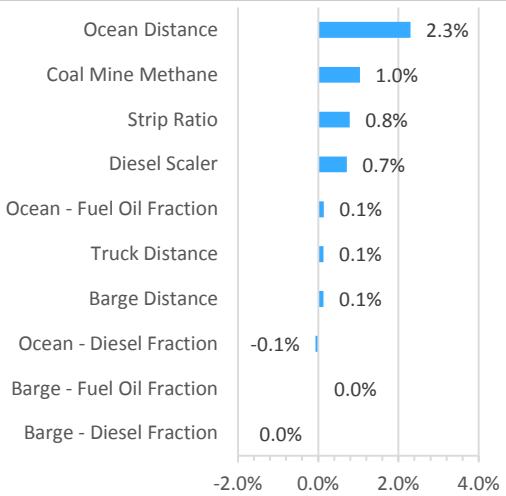
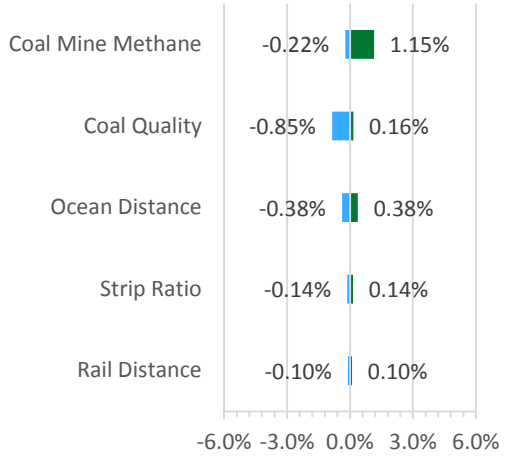
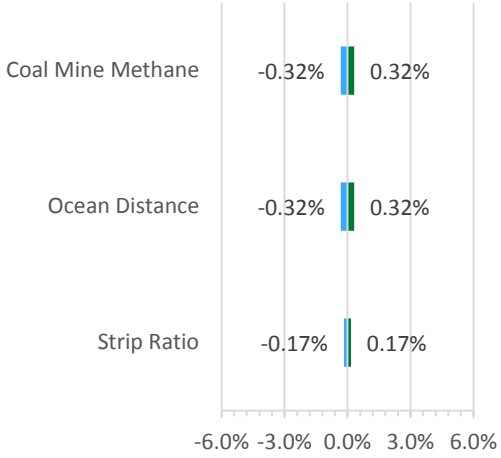
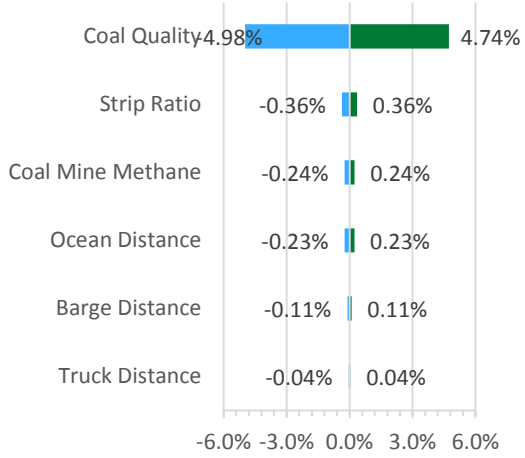
Coal combustion dominates GHG emissions (92 to 96%); transport (2-6%) and mining (1-3%) are less significant



Upstream-only results provide insight to some key differences (mining practices, cleaning, transport modes)



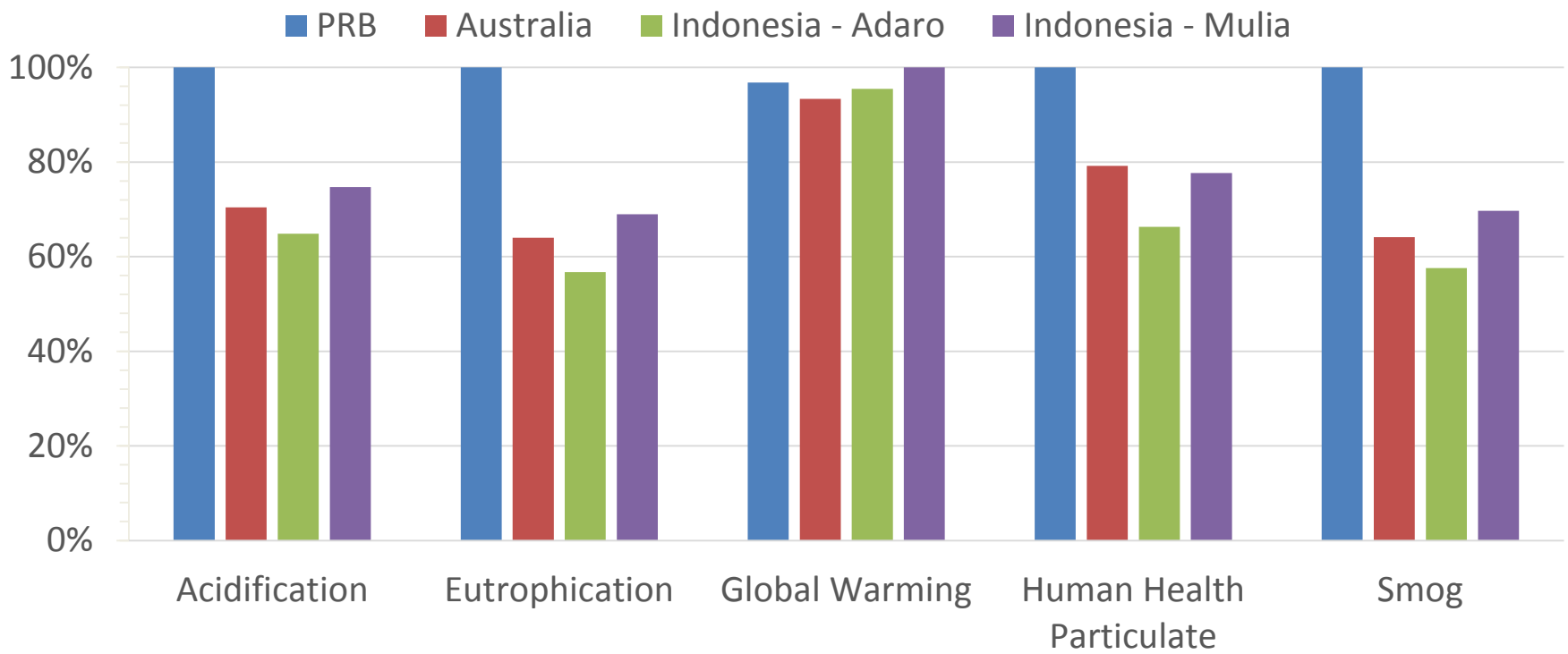
Transport distance, CMM, strip ratio, and coal quality are the most sensitive parameters

	PRB to JP	AU to JP	ID to JP
Sensitivity			
Uncertainty			

Several categories from the TRACI 2.1 LCIA method were used to characterize midpoint impacts

- **TRACI is an impact assessment method developed by EPA's National Risk Management Research Laboratory. TRACI impact categories include the following:**
  - Environmental: ozone depletion, global warming, acidification, eutrophication, photochemical oxidation (smog), and ecotoxicity
  - Human health: criteria air pollutants, carcinogenics, and non-carcinogenics
  - Other: fossil fuel depletion, land use, and water use
- **Midpoint impacts in the following categories were modeled in this analysis:**
  - Acidification
  - Eutrophication
  - Global Warming
  - Human Health Particulate
  - Photochemical Oxidation (smog)
- **The remaining categories were not included in this analysis due to data limitations that did not allow for the proper characterization and interpretation of the comparative impacts across the life cycle of the modelled scenarios**

PRB has highest normalized TRACI impacts (except GWP) due to low heating value and long transport distances



Key Emission(s)	NO_x and SO_2	NO_x	CO_2	$PM_{2.5}$	NO_x
Key Activities	Ocean Transport; Rail (U.S)	Ocean Transport; Rail (U.S)	Power Plant	Power Plant	Ocean Transport; Rail Transport (U.S)

Key Takeaways

GHG Analysis:

- Rank order of expected values for the coal sources do not change, given the destination
- Emissions associated with coal mining activities are much more significant in Australia and Indonesia than PRB
- Coal from Australia has lowest emissions; Indonesia and PRB comparable
- PRB disadvantages: longer transport distance (mine to terminal, terminal to plant) and lower heating value

TRACI 2.1 Impact Assessment:

- Global Warming Potential (GWP) is the only impact category where the coal sources are essentially even
- Non-GWP impact categories are driven by emissions from diesel combustion (transport and mining)
- As a result of the longer transport distances required to ship PRB coal to the destination in Asia, it tends to have higher impacts in the associated categories
- EPA Tier 4 Diesel Requirements implemented between 2020 and 2030 will lower the non-GHG impacts significantly from transporting PRB coal in the U.S.

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Contact Information

Timothy J. Skone, P.E.

Senior Environmental Engineer • Strategic Energy Analysis and Planning Division • (412) 386-4495 • *timothy.skone@netl.doe.gov*

Joe Marriott, Ph.D.

Lead Associate • Booz Allen Hamilton • (412) 386-7557 • *marriott_joe@bah.com*

Greg Cooney

Associate • Booz Allen Hamilton • (412) 386-7555 • cooney_gregory@*bah.com*

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Backup Slides

Coal Export Subject Matter Experts

- **Lighthouse Resources (Ambre Energy)**
  - Michael Mewing (International Coal Marketing)
  - Dustin Sersland (Decker Mine Engineering Manager)
- **Cloud Peak Energy**
  - Darryl Maunder (Spring Creek Mine)
- **Millennium Bulk Terminals**
  - Dan Speck (Lighthouse Resources part owner of MBT)
- **SSA Marine (Gateway Pacific Terminals)**
- **WIA/WRI**
  - Don Collins
  - Al Bland
  - Loyd Drain
  - Ken Miller
  - Jason Begger

Coal Specifications (PPFM Inputs)

	Australia		Indonesia		U.S. PRB					
Coal Property	Hunter Valley	Ensham	Adaro	Mulia	Decker	Spring Creek	Black Thunder South	Black Thunder	Antelope	North Antelope/ Rochelle Complex
Moisture	9.0%	11.5%	25.0%	35.0%	24.5%	26.8%	26.0%	27.0%	26.5%	27.6%
Carbon	63.9%	63.1%	52.2%	42.7%	52.7%	55.1%	52.4%	52.3%	52.1%	52.1%
Hydrogen[1]	4.3%	4.0%	4.8%	4.0%	4.2%	4.0%	4.0%	3.9%	4.0%	4.0%
Nitrogen[2]	1.3%	1.3%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
Chlorine[3]	0.3%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Sulfur	0.6%	0.7%	0.2%	0.2%	0.5%	0.3%	0.2%	0.3%	0.2%	0.2%
Ash	13.5%	12.0%	2.0%	3.9%	5.1%	4.3%	4.6%	5.2%	5.3%	4.5%
Oxygen[4]	7.2%	7.2%	15.2%	13.5%	12.3%	8.8%	12.1%	10.6%	11.2%	10.9%
HHV (MJ/kg)	26.5	26.2	21.6	17.6	21.8	22.8	21.7	21.6	21.6	21.6
HHV (BTU/lb)[5]	11,406	11,271	9,283	7,575	9,373	9,820	9,320	9,300	9,270	9,270
LHV (MJ/kg)	25.4	25.1	20.5	16.5	20.7	21.7	20.6	20.5	20.5	20.5
LHV (BTU/lb)	10,936	10,801	8,813	7,105	8,903	9,350	8,850	8,830	8,800	8,800

[1]Calculated with a correlation based on fixed ash, fixed carbon, moisture, and volatiles
[2]Used NETL QGEES ultimate analysis to estimate
[3]Used NETL QGEES ultimate analysis to estimate
[4]Calculated as the balance component
[5]Calculated from LHV with a correlation from the World Coal Institute (recommended by Michael Mewing)

Data source: Lighthouse Resources (Michael Mewing) BNSF and UP Railways

PPFM Outputs – USCPC no CCS

	Reference	Australia		Indonesia		U.S. PRB					
Coal Property	Montana Rosebud	Hunter Valley	Ensham	Adaro	Mulia	Decker	Spring Creek	Black Thunder South	Black Thunder	Antelope	North Antelope/ Rochelle Complex
Inputs (kg/MWh busbar)											
Coal	454	329	333	421	532	414	393	416	417	418	419
Ground Water In	534	527	526	532	538	532	531	531	531	531	531
Municipal Water In	534	527	526	532	538	532	531	531	531	531	531
Limestone	6.86	3.81	4.82	1.30	1.65	4.11	2.44	1.72	2.97	1.99	1.82
Ammonia	0.97	0.93	0.93	0.98	1.01	0.97	0.96	0.97	0.97	0.97	0.97
Activated Carbon	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Natural Gas	0.14	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Outputs (kg/MWh busbar)											
CO_2	835	772	772	806	835	800	796	799	800	800	801
NO_x	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
SO_2	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
PM	0.05	0.05	0.05	0.01	0.02	0.03	0.02	0.02	0.03	0.02	0.02
Mercury	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wastewater	223	222	222	223	224	223	222	222	223	222	222
Ash	51	52	49	11	24	29	22	22	27	26	22
Plant Specs											
Gross power	578	596	597	573	557	578	580	578	578	578	577
Net power	548	569	569	547	529	550	553	551	550	551	550
Net plant efficiency	39.8%	41.2%	41.3%	39.6%	38.4%	39.9%	40.1%	40.0%	39.9%	39.9%	39.9%

Data source: Lighthouse Resources (Michael Mewing)

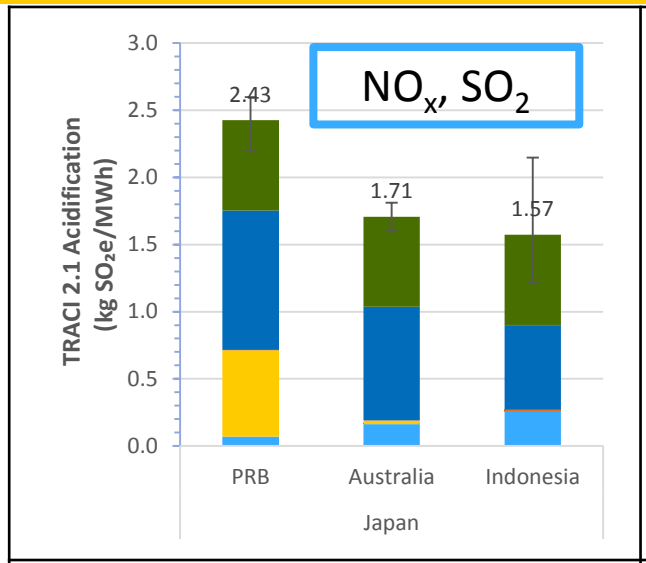
PPFM Outputs – USCPC w/ CCS

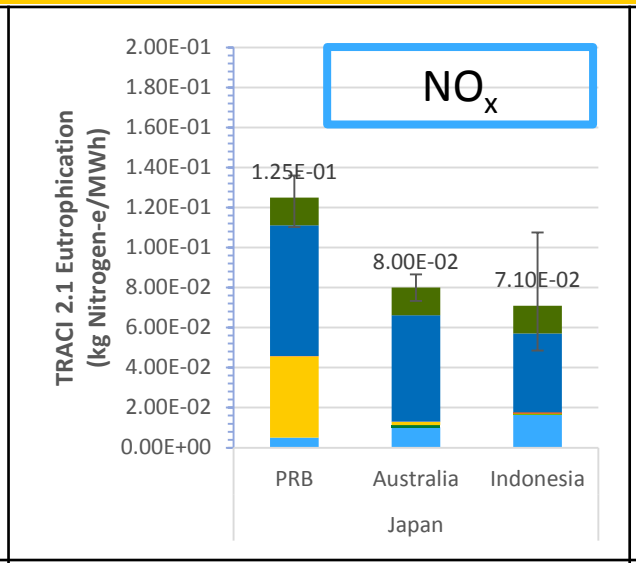
	Reference	Australia		Indonesia		U.S. PRB					
Coal Property	Montana Rosebud	Hunter Valley	Ensham	Adaro	Mulia	Decker	Spring Creek	Black Thunder South	Black Thunder	Antelope	North Antelope/ Rochelle Complex
Inputs (kg/MWh busbar)											
Coal	646	449	453	586	755	577	547	579	581	582	584
Ground Water In	1,595	1,522	1,521	1,507	1,507	1,517	1,515	1,512	1,515	1,514	1,513
Municipal Water In	1,595	1,522	1,521	1,507	1,507	1,517	1,515	1,512	1,515	1,514	1,513
Limestone	9.74	5.20	6.56	1.82	2.34	5.72	3.39	2.39	4.14	2.77	2.53
Ammonia	1.38	1.26	1.26	1.36	1.44	1.35	1.34	1.34	1.35	1.34	1.35
Activated Carbon	0.09	0.08	0.08	0.09	0.10	0.09	0.09	0.09	0.09	0.09	0.09
Natural Gas	0.14	0.13	0.13	0.14	0.15	0.14	0.14	0.14	0.14	0.14	0.14
Outputs (kg/MWh busbar)											
CO_2	119	105	105	112	118	112	111	111	111	111	112
NO_x	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
SO_2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PM	0.06	0.06	0.06	0.01	0.03	0.03	0.02	0.03	0.03	0.03	0.03
Mercury	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Captured CO_2	1,068	954	954	1013	1066	1004	996	1001	1003	1003	1005
Ash	72.4	72	68	15	34	41	30	31	38	36	31
Plant Specs											
Gross power	651	684	684	651	628	658	660	658	657	657	656
Net power	537	580	581	546	519	549	553	551	549	550	549
Net plant efficiency	28.0%	30.2%	30.3%	28.4%	27.1%	28.6%	28.8%	28.7%	28.6%	28.7%	28.6%

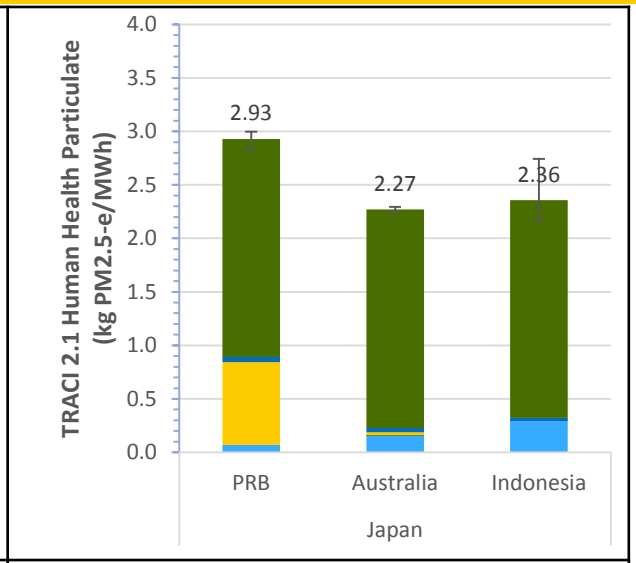
Data source: Lighthouse Resources (Michael Mewing)

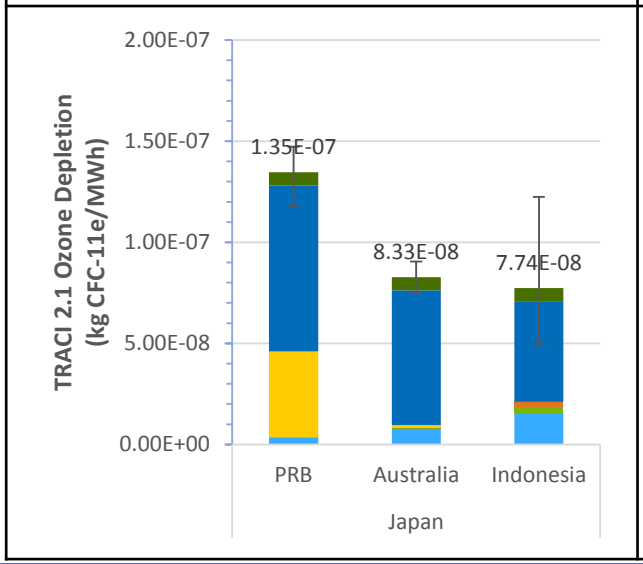
TRACI Results by Impact Category

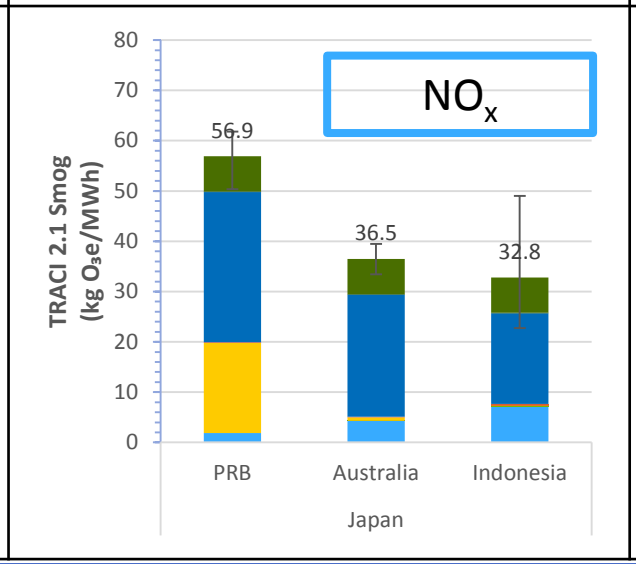
Japan Cases Only

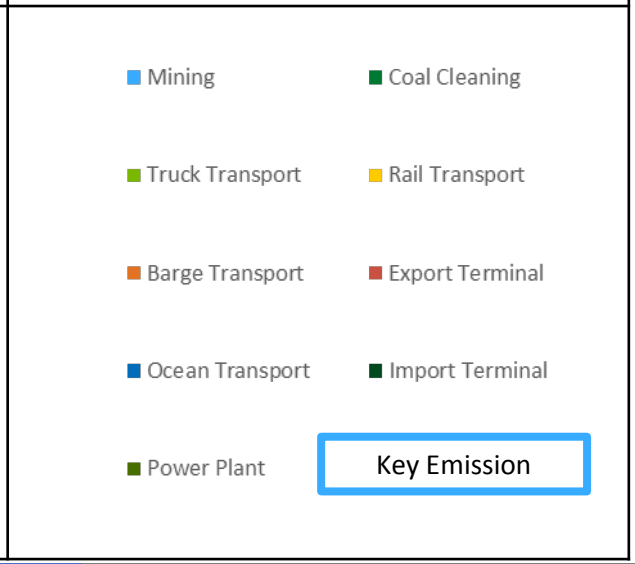






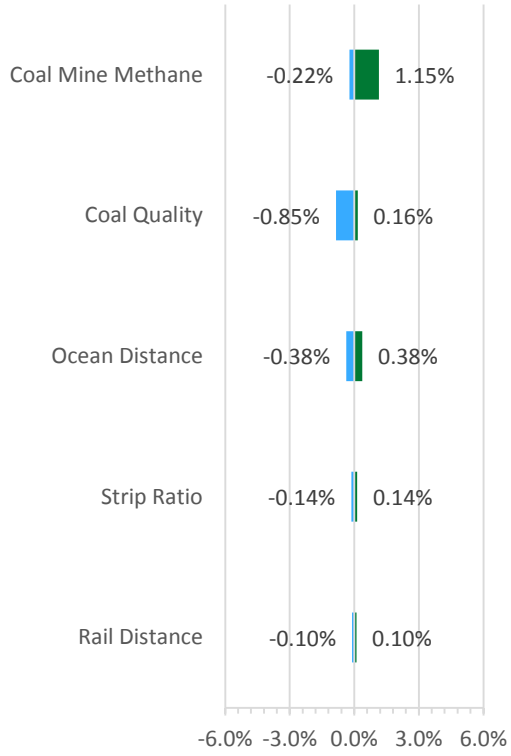
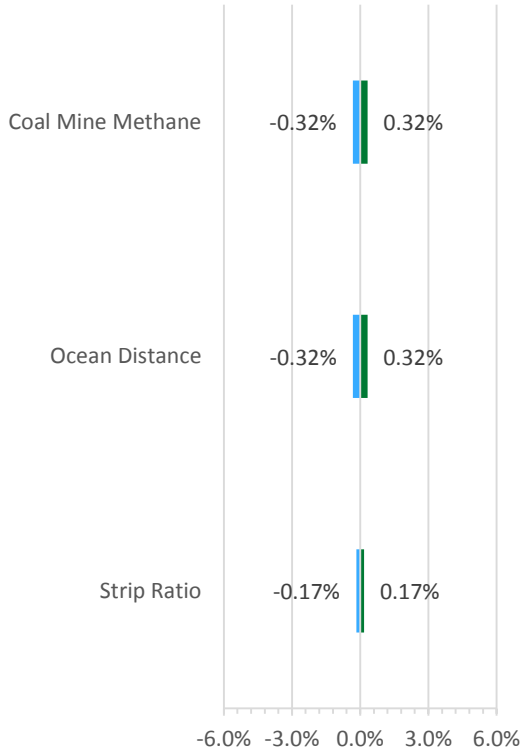
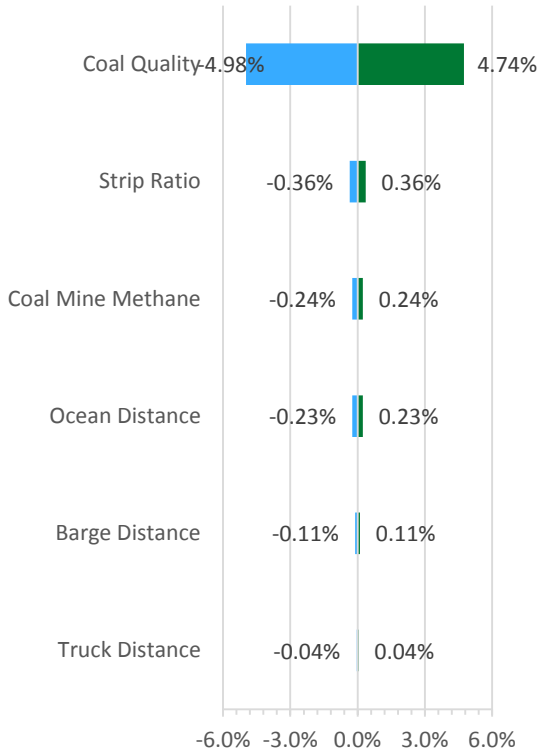






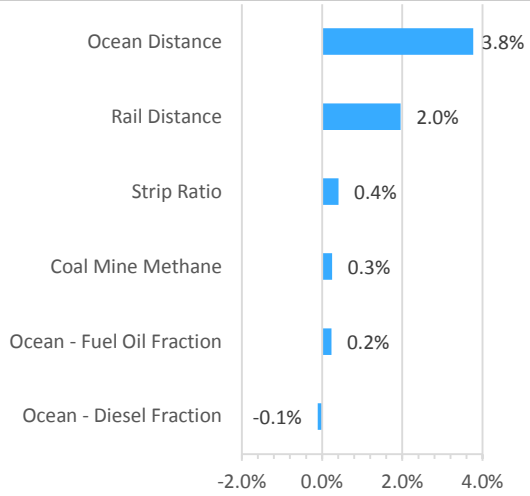
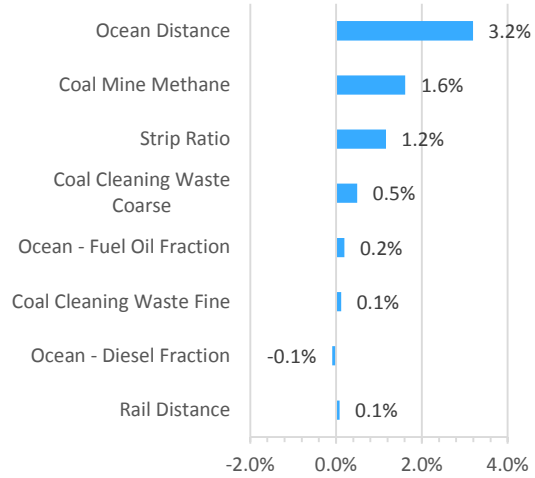
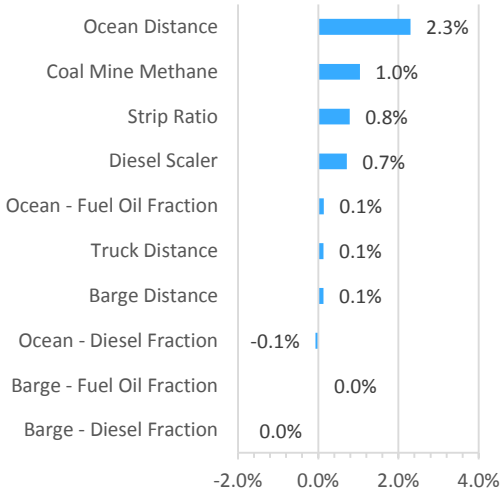
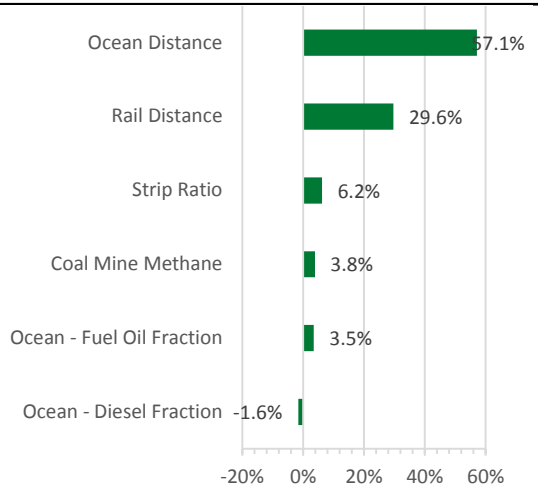
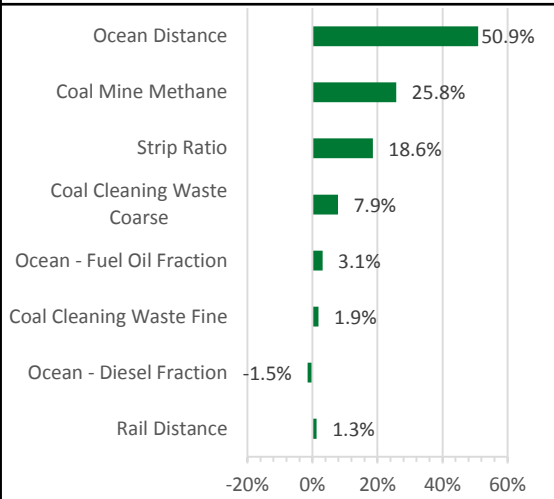
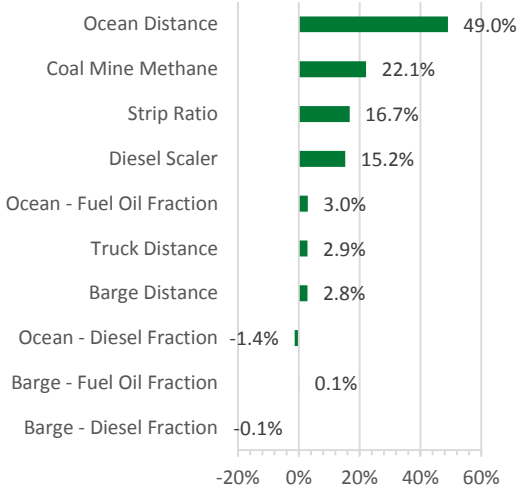
GHG Results – Uncertainty

Results encompass parameter range

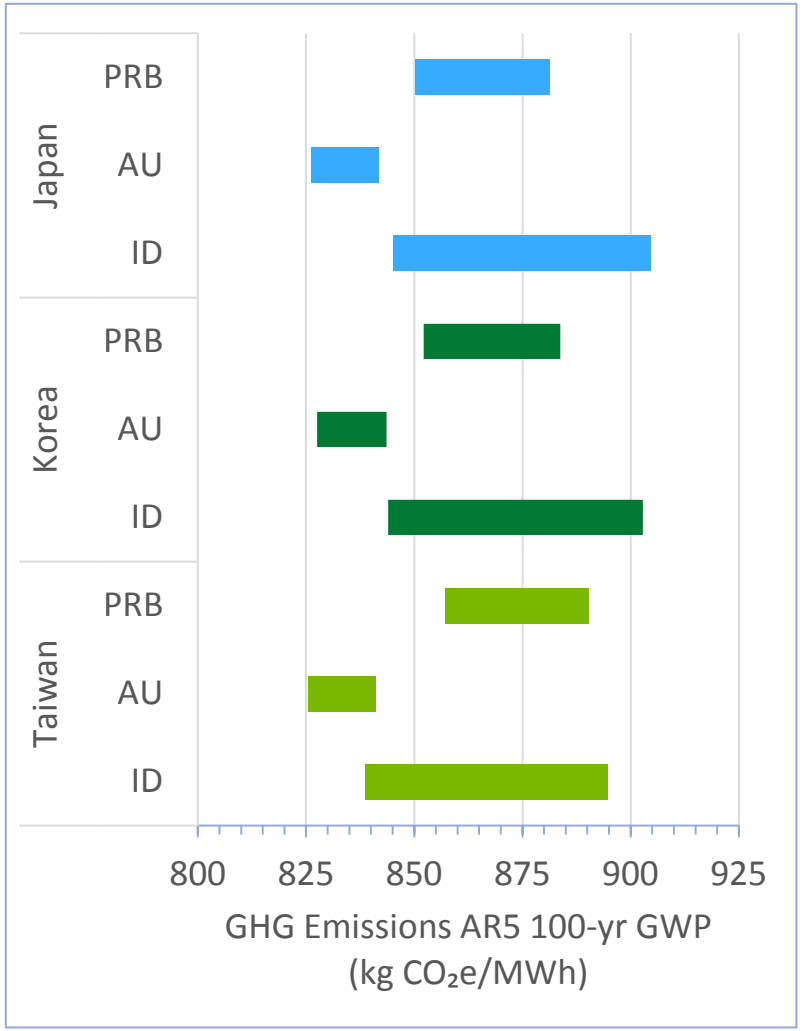
	PRB to JP	AU to JP	ID to JP
Cradle-to-Grave			

GHG Results – Sensitivity

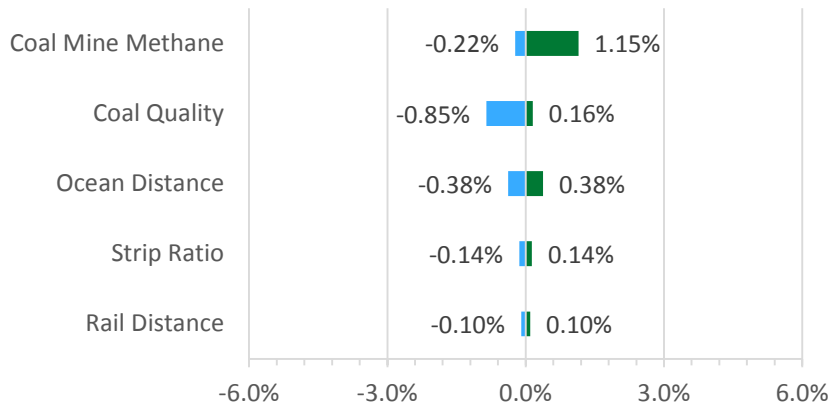
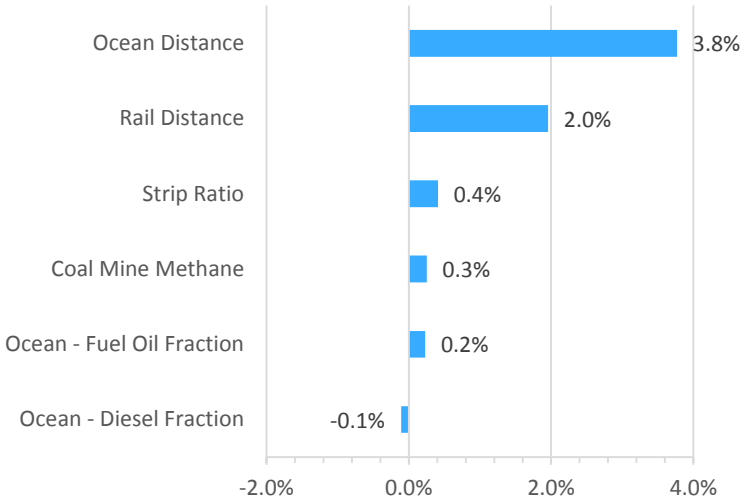
Results based on a unit change

	PRB to JP	AU to JP	ID to JP
Cradle-to-Grave			
Upstream Fraction Only			

Indonesia has the highest level of uncertainty, mainly due to coal quality data. Uncertainty from PRB is mostly from CMM. Ocean transportation distance is the most sensitive parameter to changes for all scenarios. Rail distance and CMM are other sensitive parameters.



GHG Results – Uncertainty – PRB to Japan Drilldown



GHG Results – Sensitivity – PRB to Japan