

Paper for U.S.-Japan Foundation Project on “Energy, Environment and Security in Northeast Asia”

**Global Dimensions of Energy Growth Projections
in Northeast Asia**

**ANNEX A: COMPARISON OF SELECTED
PROJECTIONS OF ENERGY SUPPLY AND DEMAND AND
CARBON EMISSIONS IN NORTHEAST ASIA**

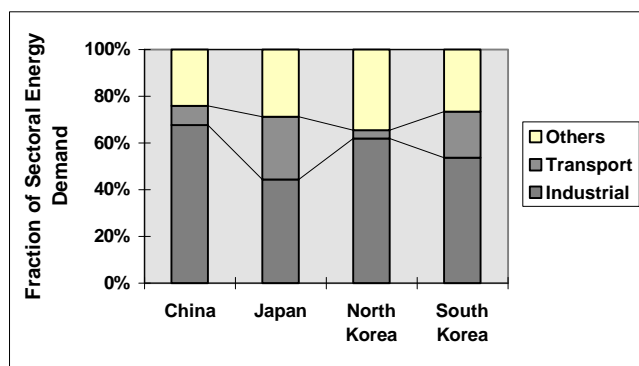
Summary of Current Patterns of Energy Use in Northeast Asia

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Date Last Modified: 31 October, 1996

Energy Use in Northeast Asia and the World, 1995*								
Unit: Million tonnes of Oil Equivalent								
Country	Oil	Natural Gas	Coal	Nuclear Energy	Hydro-electric	Total	Fraction of NE Asia	Fraction of World
China	157.5	15.8	640.3	3.3	16.2	833.1	52.4%	10.2%
Chinese Taipei	35.4	3.9	17.0	9.1	0.8	66.1	4.2%	0.8%
Hong Kong	4.2	-	5.5	-	-	9.7	0.6%	0.1%
Japan	267.3	55.0	85.9	74.3	7.7	490.2	30.9%	6.0%
Mongolia	0.6	-	1.9	-	-	2.5	0.2%	0.0%
North Korea	3.5	-	32.4	-	5.7	38.1	2.4%	0.5%
South Korea	94.8	9.2	27.3	17.3	0.5	149.0	9.4%	1.8%
Total Northeast Asia	563.3	83.9	810.3	104.0	30.9	1,588.8	100.0%	19.5%
NE Asia Fraction of World	17.5%	4.5%	36.7%	17.4%	14.2%	19.5%		
Total Rest of World	2,663.6	1,799.7	1,400.4	492.4	187.6	6,547.0		80.5%
TOTAL WORLD	3,226.9	1,883.6	2,210.7	596.4	218.5	8,135.8		100.0%

*1995 figures from BP World Energy Statistics except for Hong Kong and Mongolia (1992 figures from UN) and North Korea (1990 figures from Von Hippel and Hayes, 1995). See endnotes for full references.

ENERGY CONSUMPTION BY SECTOR, 1992									
Country	Units: Million Tonnes Oil Equivalent				Population (million)	Cons. per capita	Agricultural	Residential	Commercial
	Industrial	Transport	Others	Total					
China	948.3	113.1	340.1	1,401.6	1188	1.18	63.86	209.57	66.71
Japan	141.8	85.9	91.7	319.4	124.32	2.57			
North Korea	16.8	1.0	9.4	27.2	22.62	1.20	0.44	6.06	2.93
South Korea	50.8	18.5	25.3	94.6	43.66	2.17			



Summary of Future Scenarios of Energy Use in Northeast Asia

"Base Case", "Reference" or "Business as Usual" Scenarios for Countries and Regions

By a Number of Different Research Groups

Primary Commercial Energy Demand in Original Units

Source of Scenario	Country or Region	Fuel	Unit	Base Year	Base Year Value	Scenario Years					Growth Rate Base to 2010	Source
						2000	2010	2015	2020	2030		
CCICED	China	All Energy	PJ	1990	27415	41618	58726		82410		3.88%	7
East-West Center	China	All Energy	kboe/day	1993	15500.9	20765.63	28407.9				3.63%	5
Institute of Energy Economics, Japan	China	All Energy	MTOE	1992	709.5	1038.9	1604.7				4.64%	4
RAINS-Asia	China	All Energy	PJ	1990	30236.55	50527.49	73518.19		101015.2		4.54%	6
US DOE EIA International Energy Outlook	China	All Energy	quad. Btu	1993	31.6	43.9	66.7	81.4			4.49%	1
World Bank	China	All Energy	Mtce	1990	987	1560	2380		3300		4.50%	8
CCICED	China	Coal	PJ	1990	21957	33184	45447		61624		3.70%	7
East-West Center	China	Coal	kboe/day	1993	11880	15286	18272				2.56%	5
Institute of Energy Economics, Japan	China	Coal	MTOE	1992	551.7	788.6	1156.7				4.20%	4
RAINS-Asia	China	Coal	PJ	1990	23341.55	37072.55	51079.96		64541.39		3.99%	6
US DOE EIA International Energy Outlook	China	Coal	mil. sh. tons	1993	1273	1685	2465	2998			3.96%	1
World Bank	China	Coal	mil. tonnes	1990	1053		2417.667		3100		4.24%	8
East-West Center	China	Elect. Gen.	TWh	1993	816	1461.2	2599.8				7.05%	5
CCICED	China	Gas	PJ	1990	554	1028	1824		3455		6.14%	7
World Bank	China	Gas	Bil. cu. m.	1990	15		81.66667		115		8.84%	8
CCICED	China	Hyd/Nuc/oth	PJ	1990	456	951	1688		2339		6.76%	7
World Bank	China	Hyd/Nuc/oth	TWh	1990	126		622		870		8.31%	8
East-West Center	China	Hydro/oth	kboe/day	1993	252.7	383.6	873.9				7.57%	5
Institute of Energy Economics, Japan	China	Hydro/oth	MTOE	1992	11.5	19.7	34				6.21%	4
RAINS-Asia	China	Hydro/oth	PJ	1990	1224.65	2654.59	3783.21		5473.18		5.80%	6
US DOE EIA International Energy Outlook	China	Hydro/oth	quad. Btu	1993	1.5	2.6	5.2	7			7.59%	1
East-West Center	China	LNG	mil. tonnes	1993	0	0	4				N/A	5
East-West Center	China	Nat. Gas	kboe/day	1993	286	508	1760				11.28%	5
Institute of Energy Economics, Japan	China	Nat. Gas	MTOE	1992	13.6	23	50.8				7.60%	4
RAINS-Asia	China	Nat. Gas	PJ	1990	948.82	1881.71	3589.83		6383.62		6.88%	6
US DOE EIA International Energy Outlook	China	Nat. Gas	Tcf	1993	0.6	1.3	2.5	3			8.76%	1
US DOE EIA International Energy Outlook	China	Net Elect	TWh	1994	698	1026	1848	2457			6.27%	1
East-West Center	China	Nuc. Elec	kboe/day	1993	4.2	77.7	639.2				34.39%	5
Institute of Energy Economics, Japan	China	Nuc. Elec	MTOE	1992	0	3.6	37.4				N/A	4
RAINS-Asia	China	Nuc. Elec	PJ	1990	0	244.4	870.57		2340		N/A	6
US DOE EIA International Energy Outlook	China	Nuc. Elec	TWh	1993	2	13	31	32			17.50%	1
CCICED	China	Oil	PJ	1990	4447	6456	9766		14993		4.01%	7
East-West Center	China	Oil	kboe/day	1993	3078	4510	6862.8				4.83%	5
Institute of Energy Economics, Japan	China	Oil	MTOE	1992	132.7	204	325.8				5.12%	4
RAINS-Asia	China	Oil	PJ	1990	4721.53	8674.24	14194.62		22276.99		5.66%	6
US DOE EIA International Energy Outlook	China	Oil	mil. bbl/day	1993	3.1	4.4	6.7	8.2			4.64%	1
World Bank	China	Oil	mil. tonnes	1990	112		330.6667		440		5.56%	8

Source

Source of Scenario	Country or Region			Base Year	Base Value	Scenario Years					Growth Rate Base to 2010		
	Fuel	Unit	2000			2010	2015	2020	2030				
East-West Center	CT	LNG	mil. tonnes	1993	1.8	7	14					12.82%	5
East-West Center	CT	Oil	kbqe/day	1993	647	887	1203					3.72%	5
Institute of Energy Economics, Japan	CT/HK	All Energy	MTOE	1992	66.3	92.1	133.3					3.96%	4
RAINS-Asia	CT/HK	All Energy	PJ	1990	2517.65	3995.23	5707.16		8054.18			4.18%	6
East-West Center	CT/HK	Coal	mil. tonnes	1993	37	48	68					3.64%	5
Institute of Energy Economics, Japan	CT/HK	Coal	MTOE	1992	20.6	22.8	27.2					1.56%	4
RAINS-Asia	CT/HK	Coal	PJ	1990	768.84	1276.89	1804.99		2608.41			4.36%	6
Institute of Energy Economics, Japan	CT/HK	Hydro/oth	MTOE	1992	0.3	2	4.5					16.24%	4
RAINS-Asia	CT/HK	Hydro/oth	PJ	1990	76.9	111.18	150.8		150.8			3.42%	6
Institute of Energy Economics, Japan	CT/HK	Nat. Gas	MTOE	1992	3	11.4	24					12.25%	4
RAINS-Asia	CT/HK	Nat. Gas	PJ	1990	56.52	220.3	443.04		881.05			10.84%	6
Institute of Energy Economics, Japan	CT/HK	Nuc. Elec	MTOE	1992	8.8	10.3	16.4					3.52%	4
RAINS-Asia	CT/HK	Nuc. Elec	PJ	1990	308.66	351	468		601.25			2.10%	6
Institute of Energy Economics, Japan	CT/HK	Oil	MTOE	1992	33.6	45.6	61.2					3.39%	4
RAINS-Asia	CT/HK	Oil	PJ	1990	1306.73	2035.86	2840.33		3812.67			3.96%	6
RAINS-Asia	DPRK	All Energy	PJ	1990	1764.07	3186.18	4979.54		7909.88			5.33%	6
East-West Center	DPRK	Coal	mil. tonnes	1993	35	48	58					3.02%	5
RAINS-Asia	DPRK	Coal	PJ	1990	1322.03	2266.35	3466.84		5417.06			4.94%	6
RAINS-Asia	DPRK	Hydro/oth	PJ	1990	271	557.23	988		1778.4			6.68%	6
RAINS-Asia	DPRK	Nat. Gas	PJ	1990	0	0	0		0			N/A	6
RAINS-Asia	DPRK	Nuc. Elec	PJ	1990	0	78	156		234			N/A	6
RAINS-Asia	DPRK	Oil	PJ	1990	171.04	284.6	368.7		480.42			3.92%	6
Institute of Energy Economics, Japan	Japan	All Energy	MTOE	1992	452.6	494.2	562.6					1.22%	4
RAINS-Asia	Japan	All Energy	PJ	1990	17865.51	22605.05	25678.15		28807.75			1.83%	6
US DOE EIA International Energy Outlook	Japan	All Energy	quad. Btu	1993	19	23	26.2	27.6				1.91%	1
East-West Center	Japan	Coal	mil. tonnes	1993	118	138	150					1.42%	5
Institute of Energy Economics, Japan	Japan	Coal	MTOE	1992	75.5	82.2	84.1					0.60%	4
RAINS-Asia	Japan	Coal	PJ	1990	2389.04	3383.71	4623.37		5875			3.36%	6
US DOE EIA International Energy Outlook	Japan	Coal	mil. sh. tons	1993	128	142	157	160				1.21%	1
Institute of Energy Economics, Japan	Japan	Hydro/oth	MTOE	1992	11.2	22.7	45.5					8.10%	4
RAINS-Asia	Japan	Hydro/oth	PJ	1990	338.28	1073.9	1199.61		1352.12			6.53%	6
US DOE EIA International Energy Outlook	Japan	Hydro/oth	quad. Btu	1993	1	1.6	2	2.3				4.16%	1
East-West Center	Japan	LNG	mil. tonnes	1993	39.3	54	70					3.45%	5
Institute of Energy Economics, Japan	Japan	Nat. Gas	MTOE	1992	47.6	62.4	67.9					1.99%	4
RAINS-Asia	Japan	Nat. Gas	PJ	1990	2381.84	3028.51	3254.22		3620.51			1.57%	6
US DOE EIA International Energy Outlook	Japan	Nat. Gas	Tcf	1993	2	2.6	3.5	3.9				3.35%	1
US DOE EIA International Energy Outlook	Japan	Net Elect	TWh	1993	781	1010	1212	1297				2.62%	1
Institute of Energy Economics, Japan	Japan	Nuc. Elec	MTOE	1992	58.4	77.3	115.9					3.88%	4
RAINS-Asia	Japan	Nuc. Elec	PJ	1990	2235.96	2737.8	3434.6		4310.8			2.17%	6
US DOE EIA International Energy Outlook	Japan	Nuc. Elec	TWh	1993	234	281	329	345				2.02%	1
East-West Center	Japan	Oil	kbqe/day	1993	4659	5093	5139					0.58%	5
Institute of Energy Economics, Japan	Japan	Oil	MTOE	1992	260	249.6	249.2					-0.24%	4
RAINS-Asia	Japan	Oil	PJ	1990	10520.39	12381.13	13166.35		13649.32			1.13%	6
US DOE EIA International Energy Outlook	Japan	Oil	mil. bbl/day	1993	5.4	6.4	6.9	7.1				1.45%	1
US DOE EIA International Energy Outlook	Other Asia	All Energy	quad. Btu	1993	19.6	28.6	40.4	46.6				4.35%	1,2
US DOE EIA International Energy Outlook	Other Asia	Coal	mil. sh. tons	1993	206	228	263	315				1.45%	1
US DOE EIA International Energy Outlook	Other Asia	Hydro/oth	quad. Btu	1993	1.2	1.6	1.8	2.1				2.41%	1
US DOE EIA International Energy Outlook	Other Asia	Nat. Gas	Tcf	1993	2.6	4.1	7	8.5				6.00%	1
US DOE EIA International Energy Outlook	Other Asia	Net Elect	TWh	1995	540	830	1181	1363				5.36%	1
US DOE EIA International Energy Outlook	Other Asia	Nuc. Elec	TWh	1993	87	119	164	165				3.80%	1
US DOE EIA International Energy Outlook	Other Asia	Oil	mil. bbl/day	1993	5.1	8.1	11.7	13.2				5.01%	1

Source

Source of Scenario	Country or Region			Base Year	Base Value	Scenario Years					Growth Rate Base to 2010	Source
	Fuel	Unit	2000			2010	2015	2020	2030			
East-West Center	RFE	Coal	mil. tonnes	1993	40.3	67	70				3.30%	5
East-West Center	RFE	Crude Oil	kbb/day	1993	157.4	209	270				3.23%	5
East-West Center	RFE	Nat. Gas	Mcf/day	1993	305	660	1470				9.69%	5
East-West Center	RFE	Oil Prod.	kbb/day	1993	357.4	391	410				0.81%	5
Institute of Energy Economics, Japan	ROK	All Energy	MTOE	1992	113.8	170.1	259.3				4.68%	4
Korea Energy Economics Institute	ROK	All Energy	MTOE	1992	116	217	326		438	555	5.91%	3
RAINS-Asia	ROK	All Energy	PJ	1990	3593.95	6264.05	9497.28		13447.84		4.98%	6
East-West Center	ROK	Coal	mil. tonnes	1993	40	54	77				3.93%	5
Institute of Energy Economics, Japan	ROK	Coal	MTOE	1992	23.8	38.6	59.8				5.25%	4
Korea Energy Economics Institute	ROK	Coal	mil. tonnes	1992	26	62	91		123	157	7.21%	3
RAINS-Asia	ROK	Coal	PJ	1990	974.26	1587.26	2434.92		3901.23		4.69%	6
Korea Energy Economics Institute	ROK	Electricity	TWh	1992	115	258	448		689	961	7.85%	3
Institute of Energy Economics, Japan	ROK	Hydro/oth	MTOE	1992	0.5	0.5	0.6				1.02%	4
RAINS-Asia	ROK	Hydro/oth	PJ	1990	66.08	117.02	132.57		132.57		3.54%	6
East-West Center	ROK	LNG	mil. tonnes	1993	4.5	10	16				7.75%	5
Institute of Energy Economics, Japan	ROK	Nat. Gas	MTOE	1992	4.4	13.4	28.3				10.89%	4
Korea Energy Economics Institute	ROK	Nat. Gas	mil. tonnes	1992	4	13	26		40	56	10.96%	3
RAINS-Asia	ROK	Nat. Gas	PJ	1990	164.27	483.27	1043.68		1772.61		9.69%	6
Institute of Energy Economics, Japan	ROK	Nuc. Elec	MTOE	1992	14.7	22.8	46.1				6.56%	4
RAINS-Asia	ROK	Nuc. Elec	PJ	1990	553.58	728	1250.6		2002		4.16%	6
East-West Center	ROK	Oil	kboe/day	1993	1646	2382	2886				3.36%	5
Institute of Energy Economics, Japan	ROK	Oil	MTOE	1992	70.4	94.8	124.5				3.22%	4
Korea Energy Economics Institute	ROK	Oil	mil. bbl/day	1992	1,409	2.4	3,218		3,913	4,507	4.70%	3
RAINS-Asia	ROK	Oil	PJ	1990	1835.76	3348.5	4635.51		5639.43		4.74%	6

Sources and Notes

Abbreviations of country Names: CT= Chinese Taipei, HK = Hong Kong, ROK = Republic of Korea (South Korea)
DPRK = Democratic People's Republic of Korea (North Korea), RFE = Russian Far East

- 1 US Department of Energy, Energy Information Administration (US DOE EIA), International Energy Outlook, 1996. US DOE, Washington, D.C., USA. 1996.
- 2 "Other Asia" refers to Non-OECD Asia exclusive of China and India
- 3 Korea Energy Economics Institute (KEEI), [Energy Scenarios to 2030--Document in Korean]. KEEI, Seoul, Korea. November, 1994.
- 4 Fujime, K., "Long-Term Energy Supply/Demand Outlook for Asia APEC Nations". Energy in Japan, January 1996. The Institute of Energy Economics, Japan (IEEJ), Bimonthly Report No. 137. 1996.
- 5 Fesharaki, F., A.L. Clark, and D. Intarapavich, editors, Pacific Energy Outlook: Strategies and Policy Imperatives to 2010. East-West Center Program on Resources: Energy and Minerals. East-West Center, Honolulu, HI, USA. March, 1995.
- 6 RAINS-Asia Software
- 7 Working Group on Energy Strategies and Technologies of The China Council for International Cooperation on Environment and Development (CCICED), Alternative Energy Strategy Scenarios for China. Prepared by the Institute for Techno-Economics and Energy Systems Analysis (ITEESA), Tsinghua University, Beijing, and China Integrated Resource Planning Promotion Network (IRPPN) International Energy Initiative (IEI). Beijing, China. April, 1996.
- 8 The World Bank, China: Issues and Options in Greenhouse Gas Control, Summary Report
The World Bank, Industry and Energy Division, Washington, D.C., USA. December, 1994. Page 39.

Summary of Future Scenarios of Energy Use in Northeast Asia

"Base Case", "Reference" or "Business as Usual" Scenarios for Countries and Regions
 By a Number of Different Research Groups
 Growth Rates, early-1990s base year to 2010

Source of Projection	Country				
	China	Ch. Taipei/ Hong Kong	DPRK	Japan	ROK
CCICED	3.88%				
East-West Center	3.63%				
Institute of Energy Economics, Japan	4.64%	3.96%		1.22%	4.68%
Korea Energy Economics Institute					5.91%
RAINS-Asia	4.54%	4.18%	5.33%	1.83%	4.98%
US DOE EIA International Energy Outlook	4.49%			1.91%	
World Bank	4.50%				

Summary of Recent and Future CO2 Emissions from Fuels Use in Northeast Asia

Carbon Dioxide Emissions in MT Carbon

Sources: 1 and 2

Year	Country					TOTAL NE Asia	TOTAL Rest of World	TOTAL WORLD
	China	Ch. Taipei/ Hong Kong	DPRK	Japan	ROK			
1980	403	27	22	272	37	761	4,491	5,252
1992	697	51	36	326	87	1,197	4,896	6,093
2000	1,011	79	52	334	128	1,604	5,465	7,069
2010	1,515	94	114	339	184	2,246	7,502	9,748
Growth, 1980 - 2010	1,112	67	92	67	147	1,485	3,011	4,496

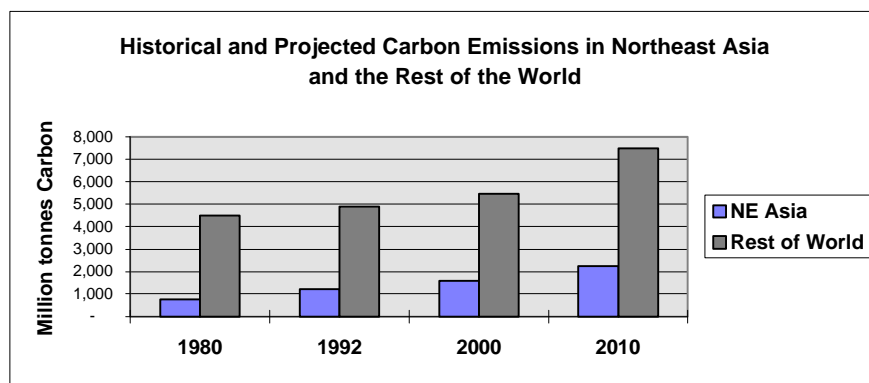
Fraction of Global Emissions

Year	Country					TOTAL NE Asia	TOTAL Rest of World	TOTAL WORLD
	China	Ch. Taipei/ Hong Kong	DPRK	Japan	ROK			
1980	7.67%	0.51%	0.42%	5.18%	0.70%	14.49%	85.51%	100.00%
1992	11.44%	0.84%	0.60%	5.35%	1.43%	19.65%	80.35%	100.00%
2000	14.30%	1.12%	0.73%	4.72%	1.81%	22.69%	77.31%	100.00%
2010	15.54%	0.96%	1.17%	3.48%	1.89%	23.04%	76.96%	100.00%
Fract. of Growth, 1980 - 2010	24.73%	1.49%	2.06%	1.49%	3.27%	33.04%	66.96%	100.00%

Sources and Notes

Abbreviations of country Names: CT= Chinese Taipei, HK = Hong Kong, ROK = Republic of Korea (South Korea)
DPRK = Democratic People's Republic of Korea (North Korea), RFE = Russian Far East

- 1 Fujime, K., "Long-Term Energy Supply/Demand Outlook for Asia APEC Nations". *Energy in Japan*, January 1996. The Institute of Energy Economics, Japan (IEEJ), Bimonthly Report No. 137. 1996.
- 2 1992 value for DPRK is value calculated for 1990 in Von Hippel, D., and P. Hayes, *The Prospects for Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options*. Nautilus Institute Report, Nautilus Institute for Security and Sustainable Development, Berkeley, CA, USA. 1995. The 1980 value for DPRK emissions was taken to be 60 percent of the 1990 value (based roughly on the difference in coal consumption between the early 1980's and 1990 as reported by the UN). Projections for DPRK carbon emissions were based on increasing the 1990/92 value at 4.5 percent per year, which is somewhat less than the growth rate in energy use implied by the RAINS-Asia base case scenario, but accounts for the fact that the DPRK would probably shift toward less carbon-intensive fuels (if indeed its energy use could grow as projected).



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**Global Dimensions of Energy Growth Projections
in Northeast Asia**

**ANNEX B: WORKPAPERS DETAILING COST-EFFECTIVENESS
CALCULATIONS AND ASSUMPTIONS FOR CO₂ EMISSIONS
REDUCTION**

ESTIMATES OF THE COST-EFFECTIVENESS OF MEASURES FOR REDUCING GHG AND/OR ACID GAS EMISSIONS IN NORTHEAST ASIA

NOTE: All Costs Shown are in 1990 US Dollars

Sources

General Assumptions

Fuel	Carbon Emissions Coefficients	
	kg C/GJ	kg CO2/GJ
Crude Oil	20	73.3
Gasoline	18.9	69.3
Diesel	20.2	74.1
Kerosene	19.5	71.5
Fuel Oil	21.1	77.4
LPG	17.2	63.1
Coal	25.8	94.6
Natural Gas	15.3	56.1

Tonnes CO2 emitted per tonne of SOx removed by scrubbers	0.69
Tonnes CO2 emitted per tonne of NOx removed by scrubbers	1.00

1

END-OF-PIPE SOx AND/OR NOx REDUCTION TECHNOLOGIES

2

Technology	Application	Additional Fuel Cons. (GJ/unit)	Implied Additional CO2 (te/unit)	Additional Cost	Units	Cost per te CO2 Reduced
Pre-ESP Sorbent Injection	Existing	430	54	\$ 16,067	per MW-yr capacity	\$ (298)
Post-ESP Sorbent Injection	Existing	430	63	\$ 26,462	per MW-yr capacity	\$ (419)
Wet Scrubbers	Existing	859	104	\$ 81,310	per MW-yr capacity	\$ (784)
Dry Scrubbers	Existing	859	102	\$ 66,416	per MW-yr capacity	\$ (649)
Selective non-catalytic red.	Existing	363	59	\$ 11,335	per MW-yr capacity	\$ (191)
Selective catalytic reduction	Existing	726	110	\$ 48,778	per MW-yr capacity	\$ (442)
Combined NOx/SOx Control	Existing	726	135	\$ 125,376	per MW-yr capacity	\$ (927)
Pre-ESP Sorbent Injection	New	324	42	\$ 16,870	per MW-yr capacity	\$ (400)
Post-ESP Sorbent Injection	New	324	50	\$ 25,881	per MW-yr capacity	\$ (516)
Wet Scrubbers	New	649	81	\$ 81,590	per MW-yr capacity	\$ (1,009)
Dry Scrubbers	New	649	80	\$ 72,263	per MW-yr capacity	\$ (906)
Selective non-catalytic red.	New	315	51	\$ 10,445	per MW-yr capacity	\$ (203)
Selective catalytic reduction	New	631	96	\$ 48,651	per MW-yr capacity	\$ (507)
Combined NOx/SOx Control	New	631	118	\$ 125,249	per MW-yr capacity	\$ (1,066)
Catalytic Converter	Existing/New	0.0	0.00	\$ 35.40	per vehicle-year	N/A

BURNER MODIFICATIONS FOR SOx/NOx REDUCTION

2

Technology	Additional Fuel Cons. (GJ/unit)	Implied Additional CO2 (te/unit)	Additional Cost	Units	Cost per te CO2 Reduced
Atmospheric Fluidized Bed Burner	-	-	\$ 22,657	per MW-yr capacity	N/A
IGCC	(14,016)	(1,326)	\$ 36,999	per MW-yr capacity	\$ 28
low-NOx burners--retrofit	158	15	\$ 2,965	per MW-yr capacity	\$ (198)
low-NOx burners--new	158	15	\$ 1,037	per MW-yr capacity	\$ (69)
Sorbent injection	374	46	\$ 41,626	per MW-yr capacity	\$ (910)

ESTIMATES OF THE COST-EFFECTIVENESS OF MEASURES FOR REDUCING GHG AND/OR ACID GAS EMISSIONS IN NORTHEAST ASIA

NOTE: All Costs Shown are in 1990 US Dollars

Sources

General Assumptions

Fuel	Carbon Emissions Coefficients	
	kg C/GJ	kg CO2/GJ
Crude Oil	20	73.3
Gasoline	18.9	69.3
Diesel	20.2	74.1
Kerosene	19.5	71.5
Fuel Oil	21.1	77.4
LPG	17.2	63.1
Coal	25.8	94.6
Natural Gas	15.3	56.1

Tonnes CO2 emitted per tonne of SOx removed by scrubbers	0.69
Tonnes CO2 emitted per tonne of NOx removed by scrubbers	1.00

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END-OF-PIPE SOx AND/OR NOx REDUCTION TECHNOLOGIES

Technology	Application	Additional Fuel Cons. (GJ/unit)	Implied Additional CO2 (te/unit)	Additional Cost	Units	Cost per te CO2 Reduced
Pre-ESP Sorbent Injection	Existing	430	54	\$ 16,067	per MW-yr capacity	\$ (298)
Post-ESP Sorbent Injection	Existing	430	63	\$ 26,462	per MW-yr capacity	\$ (419)
Wet Scrubbers	Existing	859	104	\$ 81,310	per MW-yr capacity	\$ (784)
Dry Scrubbers	Existing	859	102	\$ 66,416	per MW-yr capacity	\$ (649)
Selective non-catalytic red.	Existing	363	59	\$ 11,335	per MW-yr capacity	\$ (191)
Selective catalytic reduction	Existing	726	110	\$ 48,778	per MW-yr capacity	\$ (442)
Combined NOx/SOx Control	Existing	726	135	\$ 125,376	per MW-yr capacity	\$ (927)
Pre-ESP Sorbent Injection	New	324	42	\$ 16,870	per MW-yr capacity	\$ (400)
Post-ESP Sorbent Injection	New	324	50	\$ 25,881	per MW-yr capacity	\$ (516)
Wet Scrubbers	New	649	81	\$ 81,590	per MW-yr capacity	\$ (1,009)
Dry Scrubbers	New	649	80	\$ 72,263	per MW-yr capacity	\$ (906)
Selective non-catalytic red.	New	315	51	\$ 10,445	per MW-yr capacity	\$ (203)
Selective catalytic reduction	New	631	96	\$ 48,651	per MW-yr capacity	\$ (507)
Combined NOx/SOx Control	New	631	118	\$ 125,249	per MW-yr capacity	\$ (1,066)
Catalytic Converter	Existing/New	0.0	0.00	\$ 35.40	per vehicle-year	N/A

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BURNER MODIFICATIONS FOR SOx/NOx REDUCTION

Technology	Additional Fuel Cons. (GJ/unit)	Implied Additional CO2 (te/unit)	Additional Cost	Units	Cost per te CO2 Reduced
Atmospheric Fluidized Bed Burner	-	-	\$ 22,657	per MW-yr capacity	N/A
IGCC	(14,016)	(1,326)	\$ 36,999	per MW-yr capacity	\$ 28
low-NOx burners--retrofit	158	15	\$ 2,965	per MW-yr capacity	\$ (198)
low-NOx burners--new	158	15	\$ 1,037	per MW-yr capacity	\$ (69)
Sorbent injection	374	46	\$ 41,626	per MW-yr capacity	\$ (910)

2

FUEL-SWITCHING Sources 2

Technology	Fossil Fuel Cons. (GJ/unit)	Implied Additional CO2 (te/unit)	Additional Cost	Units	Cost per te CO2 Reduced
Conventional Coal	10.29	N/A	N/A	per MWh generated	N/A
Conventional Combined Cycle	8.37	(0.50)	\$ 7.95	per MWh generated	\$ 16
Nuclear	0	(0.97)	\$ 13.82	per MWh generated	\$ 14
Hydro	0	(0.97)	\$ 17.15	per MWh generated	\$ 18
Wind	0	(0.97)	\$ 7.74	per MWh generated	\$ 8
Solar Photovoltaic	0	(0.97)	\$ 54.87	per MWh generated	\$ 56
Coal Briquette Stove Replaced	38.15	N/A	N/A	per Household/yr	N/A
By Gas Stove	10.26	(0.83)	\$ 11.48	per Household/yr	\$ 14

ENERGY EFFICIENCY MEASURES 2

Technology	Fossil Fuel Cons. (GJ/yr)	Implied Additional CO2 (te/yr)	Additional Cost	Units	Cost per te CO2 Reduced
Utility--Boiler Improvements	29.30	(2.77)	(\$24.06)	per tce saved	\$ (9)
Utility--Trans. and Distr. Improvements	10.29	(0.97)	\$ 2.23	per MWh saved	\$ 2
-----with Avoided Capacity Credit	10.29	(0.97)	\$ (24.14)	per MWh saved	\$ (25)
Industrial--Continuous Steel Casting	1	(0.09)	\$ 0.45	per GJ saved	\$ 5
-----with Lower Capital Cost Estimate	1	(0.09)	(\$0.02)	per GJ saved	\$ (0)
Industrial--Electric Motor Improvements	10.29	(0.97)	\$ 7.55	per MWh saved	\$ 8
-----with Avoided Capacity Credit	10.29	(0.97)	\$ (18.83)	per MWh saved	\$ (19)
Building Envelope Improvements	29.30	(2.77)	(\$32.90)	per tce saved	\$ (12)
Domestic--Efficient Lighting	10.29	(0.97)	\$ 7.55	per MWh saved	\$ 8
-----with Avoided Capacity Credit	10.29	(0.97)	\$ (18.83)	per MWh saved	\$ (19)
Transportation--High Efficiency Auto	26.33	(1.82)	\$ (6.11)	per Vehicle-yr	\$ (3)

CARBON DIOXIDE CAPTURE METHODS 3

Technology	Cost per te C Reduced	Cost per te CO2 Reduced
Solvent Flue Gas CO2 removal--coal plant	\$ 150	\$ 41
Solvent Flue Gas CO2 removal--gas plant	\$ 210	\$ 57
Oxygen+Flue Gas Recycle--gas plant	\$ 80	\$ 22
Gasification/steam reforming--coal plant	\$ 80	\$ 22

Sources

- Hao Jiming, et al , China: Issues and Options in Greenhouse Gas Control. Estimation of Greenhouse Gas Emissions in China, Subreport Number 1. The World Bank, Industry and Energy Division, Washington, D.C., USA. December, 1994. Page 32.
- For details of cost and fuel consumption assumptions, see Annex 2 of paper 3 of this series: Technological Alternatives to Reduce Acid Gas and Related Emissions from Energy-Sector Activities in Northeast Asia
- Ishitani, H., and T.B. Johansson, Editors, "Energy Supply Mitigation Options". Chapter 19 in Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Published for the Intergovernmental Panel on Climate Change (IPCC) by Cambridge University Press, New York, NY, USA. 1996.