ESTIMATED COSTS AND BENEFITS OF POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA

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Northeast Asia Grid Interconnection Workshop

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COSTS AND BENEFITS OF GRID INTERCONNECTIONS: OUTLINE

- Introduction: Topic, Background and Methods
- Future Electricity Demand in NE Asia
- Current Power Supply and Demand Situation in Neighboring NE Asia Countries
- Estimated Costs and Benefits of Interconnections
- Conclusions and Comparisons
- Recommendations for Follow-up Research

GRID INTERCONNECTION COSTS AND BENEFITS: INTRODUCTION

- **OBJECTIVE: Prepare a rough estimate of the costs and benefits of connecting the ROK, DPRK, RFE and China Power Grids in order to establish:**
  - What the order-of-magnitude capital costs of interconnections will be
  - Whether the potential benefits--including economic, environmental, and other benefits--are sufficiently high to justify investment costs, particularly when compared with other energy sector investments designed to reduce environmental impacts

GRID INTERCONNECTION COSTS AND BENEFITS: INTRODUCTION

- **BACKGROUND: Study of Costs and Benefits of Grid Interconnection draws on several ongoing Nautilus programs:**
  - **East Asia Energy Futures (EAEF) Phase I**: Formulate and evaluate costs of different "paths" representing distinct approaches to energy development.
  - <u>Country Coverage</u>: Japan, China, South and North Korea, plus Chinese Taipei/Hong Kong
  - **"Clean Coal"** electricity supply scenarios for China a part of EAEF work

GRID INTERCONNECTION COSTS AND BENEFITS: INTRODUCTION

- **BACKGROUND: Additional related Nautilus programs:**
  - **Pacific Asia Regional Energy Security (PARES)**: Evaluation Framework for internal, external, security, costs of alternative paths, Japan Case Study
  - **DPRK Energy Sector Analyses and Collaborative Projects**: Compilation of energy balances for the DPRK, future energy sector scenarios, humanitarian village energy project
  - **EAEF Phase II**: Collaborative energy paths research with counterparts from NEA nations using common analysis framework--includes RF researchers

GRID INTERCONNECTION COSTS AND BENEFITS: INTRODUCTION

APPROACH:

- Use existing Nautilus energy paths work for DPRK, ROK, China to identify major areas in the region with significant electricity demand growth
- Review electricity supply situation in neighboring countries (current and projected)
- Estimate Costs of Interconnection:
  - **Obtain capital and operating cost estimates for key transmission line components and options**
  - **Estimate costs of transmission links in different configurations**

GRID INTERCONNECTION COSTS AND BENEFITS: INTRODUCTION

APPROACH (continued):

- Estimate Benefits of Interconnection:
  - **Estimate the economic benefits of transmission links (avoided fuel, capacity costs)**
  - **Estimate environmental benefits in terms of avoided emissions and related impacts**
  - **Estimate technological diversity benefits**
  - **Evaluate qualitative benefits for regional security**
- **Compute cost-effectiveness indices**
  - **Compare cost-effectiveness with other options for reducing pollutant emissions**

GRID INTERCONNECTION COSTS AND BENEFITS: FUTURE POWER DEMAND

❒ Future Electric Energy Demand

Electricity Demand Projections by Country (TWh)

Country	1990	1995	1999*	2000	2010	2015	2020
China**	480	768	1,084	1,050	1,807	2,313	2,838
Chinese Taipei	72	89	130	104	129	144	162
DPRK	41	30	27	39	55	67	82
Hong Kong	24	30	32	42	68	83	102
Japan	747	834	947	931	1,107	1,178	1,260
ROK	99	163	233	265	458	540	626
TOTAL	**1,463**	**1,915**	**2,453**	**2,430**	**3,624**	**4,326**	**5,071**

*1999 Values from USDOE EIA data for provided illustrative purposes.
2000 to 2020 values from Nautilus "Base Case" energy paths for each country.
**Values for China from Nautilus "Clean Coal" paper

GRID INTERCONNECTION COSTS AND BENEFITS: FUTURE POWER DEMAND

- **Future Electric Energy Demand Growth in the Countries of Northeast Asia**

Estimated Rates of Growth of Electricity Demand

(Percent per year, average over period)

Country	2000 to 2010	2010 to 2020	2000 to 2020
China	5.6%	4.6%	5.1%
DPRK	3.5%	4.2%	3.8%
Japan	1.7%	1.3%	1.5%
ROK	5.6%	3.2%	4.4%

GRID INTERCONNECTION COSTS AND BENEFITS: FUTURE POWER DEMAND

- **Future Generating Capacity in NE Asia (GW)**

China-Base Case	1990	1995	2000	2010	2020
Thermal	100	161	229	384	567
Hydro/Other	36	51	57	95	151
PWRs	0	2	3	12	23
DPRK-Base Case	1990	1995	2000	2010	2020
Thermal	4.5	4.7	4.7	5.0	10.8
Hydro/Other	5.0	5.0	5.1	5.3	5.7
PWRs	0	0	0	2.0	2.0
Japan-Base Case	1990	1995	2000	2010	2020
Thermal	131	135	143	169	204
Hydro/Other	37	39	39	43	45
PWRs	12	12	13	13	7
BWRs	19	24	27	32	28
ROK-Base Case	1990	1995	2000	2010	2020
Thermal	11	20	39	75	100
Hydro/Other	2	3	4	5	6
PWRs	7	8	11	15	17
PHWRs	1	1	3	3	3

GRID INTERCONNECTION COSTS AND BENEFITS: FUTURE POWER DEMAND

- **Implications of Nautilus Estimates of Future Electric Energy and "Base Case" Capacity Additions in Northeast Asia:**
  - Significant growth in electricity requirements is likely to continue in ROK, China, and would also occur in DPRK under an economic recovery scenario
  - Most of the added generation capacity is likely to be in fossil-fueled thermal power plants:
    - Largely coal-fired in DPRK, China
    - Coal and gas-fired in ROK (roughly equal proportions)

GRID INTERCONNECTION COSTS AND BENEFITS: CURRENT NEA SITUATION

Current Electricity Supply and Demand Situation by Country: Overview and Trends

- ROK
  - Economy and electricity use rebounding after decline in 1998; electricity demand growth increasing ~10%/yr in 1999 and 2000
  - Installed capacity ~44 GW as of end of 1998
  - Summer peaking system overall
  - KEEI forecast suggests increase in share of electricity from nuclear power, but significant siting problems for new plants

GRID INTERCONNECTION COSTS AND BENEFITS: CURRENT NEA SITUATION

❐ DPRK

- Nominal capacity approximately 10 GW, but currently operable capacity probably closer to 5-6 GW; T&D system working mainly as regional grids
- Electricity currently in short supply in many areas
- Construction of small, local power plants, particularly small hydro, is encouraged
- Investment capital in short supply; foreign exchange income a priority
- Nuclear power plant at Simpo (~2.3 GW) under construction, completion ~2007-2010

GRID INTERCONNECTION COSTS AND BENEFITS: CURRENT NEA SITUATION

- China
  - Currently sufficient supplies of electricity in most areas, with thermal (coal-fired) plants the main source of electricity. Substantial growth in both demand and capacity continuing
  - Plans underway to develop the western portion of China, and to send power from the west to southeastern cities
  - Power grids mostly regional at present, but national interconnections underway

GRID INTERCONNECTION COSTS AND BENEFITS: CURRENT SITUATION

- **Northeast area of China**
  - NE China (Heilongijang, Jilin, Liaoning Provinces, part of Inner Mongolia Region)
  - 92% of power from thermal plants (coal) as of 1996
  - Region is a net importer of coal
  - Relatively few additional hydro resources in area
  - 1997 population roughly 120 million (about 10% of National total)
  - Power supplies sufficient at present. Industrial restructuring underway in some cities of NE China
  - Area faces significant environmental problems, mostly related to coal use in industry

GRID INTERCONNECTION COSTS AND BENEFITS: CURRENT NEA SITUATION

- **Russian Far East and Siberia**
  - Economic decline and contraction of energy usage 1992 to 1998, recovery beginning 1999-2000
  - Forecast electricity consumption in RFE about 25% above 1990 levels by 2010
  - Winter-peaking electricity needs (summer peak <60% of winter)
  - Vast resources, including hydro resources estimated at 1000 TWh/yr, but many resources located at some distance from existing major infrastructure
  - Development of energy resources seen as a key to economic development of the region

GRID INTERCONNECTION COSTS AND BENEFITS: CURRENT NEA SITUATION

- **Russian Far East and Siberia**
  - New hydro plant (Bureiskaya) under construction, with capacity of 2.4 GW
  - Many thermal power plants being/will be rebuilt
  - RFE brown coal relatively low in sulfur
  - A number of different electricity export options under consideration, including from Sakhalin--Japan, East Siberia/South Yakutiya to China, and, near-term, RFE to NE China
  - Resources considered for exported electricity: hydro, coal, nuclear, with variants depending on scenario

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

- **Scenario 1: Line from Northeast ROK Along the East Coast of DPRK and Into China**
  - Allows power from Simpo plants to flow to the ROK or China, and allows any extra baseload nuclear power from ROK to be routed to China as available
- **Line Cost/Capacity Assumptions, Scenario 1**
  - 500 kV line, 1080 km, US Cost $340,000/kM
  - Approximate power capacity: 1800 MW (2 lines)
  - Average Capacity Factor: 65%
  - Solid state AC/DC/AC converter station used at border with China at $125 million/GW capacity

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

Power Cost Assumptions for Scenario 1

- Average capacity costs ($95/kW) for typical Korean nuclear reactor: $2,500
- Fraction of capacity costs and fixed O&M costs for Korean reactors included in analysis: 100%
- Average capacity costs ($95/kW) for typical new Chinese coal-fired plant w/ scrubber: $780
- Cost of coal for Chinese plants $30 per tonne (1999 cost)
- Fraction of import capacity provided that can be considered avoided capacity in China: 100%

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

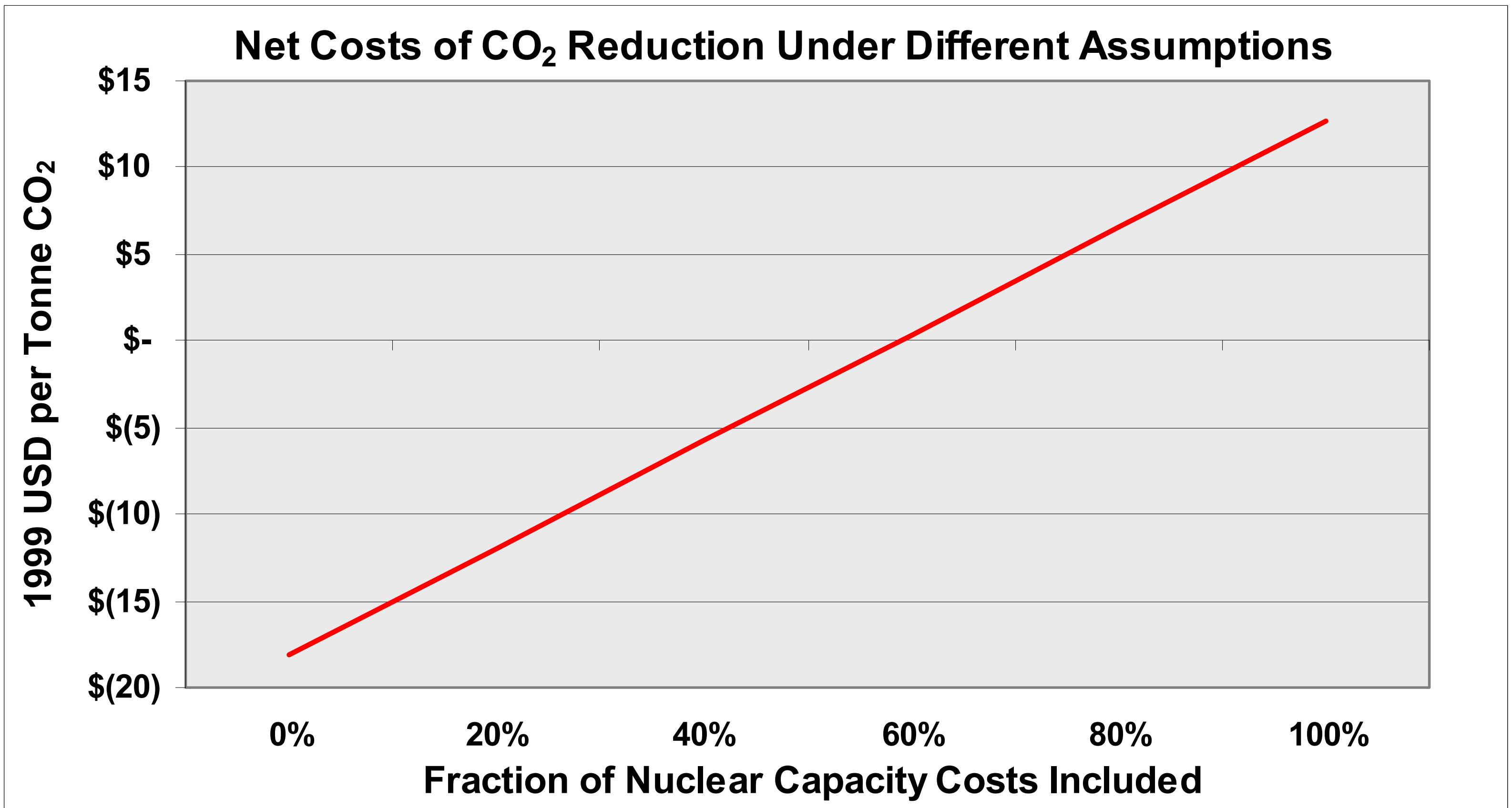
- **Efficiency and Fuel Quality Assumptions**
  - Net efficiency of power generation displaced: 27%
  - Coal at 18.7 GJ/te, 56% carbon, 1.1% sulfur
  - Displaced generation is from plants without scrubbers
- **Emissions Reduction Estimates**
  - **CO_2 reduction: 15 million tonnes/yr (as CO_2)**
  - **SO_2 reduction: 295 thousand tonnes/yr (as SO_2)**

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

Summary of Costs and Benefits of Replacing Coal-fired Power in NE China With Power from a Transmission Line Running from the ROK, Through the DPRK, to NE China, and Supplied by Nuclear Power Plants in the ROK and/or DPRK			
	Annualized Costs/Avoided Costs		
	$/kWh	M$/yr	$/te CO_2
Costs of Providing Power Via Transmission Line			
Line and Converter Station Capital Costs	$ 0.0083	$ 85	$ 5.65
Line O&M Costs	$ 0.0030	$ 31	$ 2.05
Generation Variable O&M and Fuel Costs	$ 0.0090	$ 92	$ 6.12
Generation Capital and Fixed O&M Costs	$ 0.0452	$ 463	$ 30.85
TOTAL	$ 0.0654	$ 670	$ 44.67
Avoided Costs of Power Generation in China			
Generation Variable O&M and Fuel Costs	$ (0.0225)	$ (230)	$ (15.36)
Generation Capital and Fixed O&M Costs	$ (0.0243)	$ (250)	$ (16.63)
TOTAL	$ (0.0468)	$ (480)	$ (31.99)
NET COST OF POWER PROVISION	**$ 0.0186**	**$ 190**	**$ 12.68**

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

- Sensitivity analysis: net cost of abatement versus fraction nuclear capital costs included



GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

- **Scenario 2: Line Connecting Russian Far East, the ROK, the DPRK (including Simpo) and Northeast China**
  - Power from RFE hydro flows to the ROK in summer, to China in spring/fall, ROK/Simpo power to China in spring/fall, ROK/Simpo power to RFE in winter
  - Avoided Generation and Capacity: Coal-fired energy is assumed to be reduced by power transfers for all trading partners, but gas-fired (peaking) capacity is reduced in ROK, coal-fired capacity reduced in other countries

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

- **Line Cost/Capacity Assumptions, Scenario 2**
  - 500 kV line, 2040 km, US Cost $340,000/kM
  - Approximate power capacity: 1800 MW/3600 MW (2 lines, except 4 lines for 200 km into China)
  - Average Capacity Factor: 65%
  - Solid state AC/DC/AC converter station used at border with China at $125 million/GW capacity (2 GW capacity)

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

- **Power Cost Assumptions for Scenario 2**
  - Average capacity costs ($95/kW) for typical Korean nuclear reactor, $2,500; cost for ROK gas-fired plants $580/kW, costs for RFE Hydro $1200/kW
  - Fraction of capacity, fixed O&M costs for Korean reactors/RFE Hydro included in analysis: 100%
  - Capacity costs ($95/kW) for typical new Chinese or Russian coal-fired plant w/ scrubber: $780
  - Cost of coal for Chinese/Russian plants $30/te
  - Cost of coal for ROK plants: $42.5/tonne (1998 cost)
  - Fraction of import capacity provided that can be considered avoided capacity in each country: 50%

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

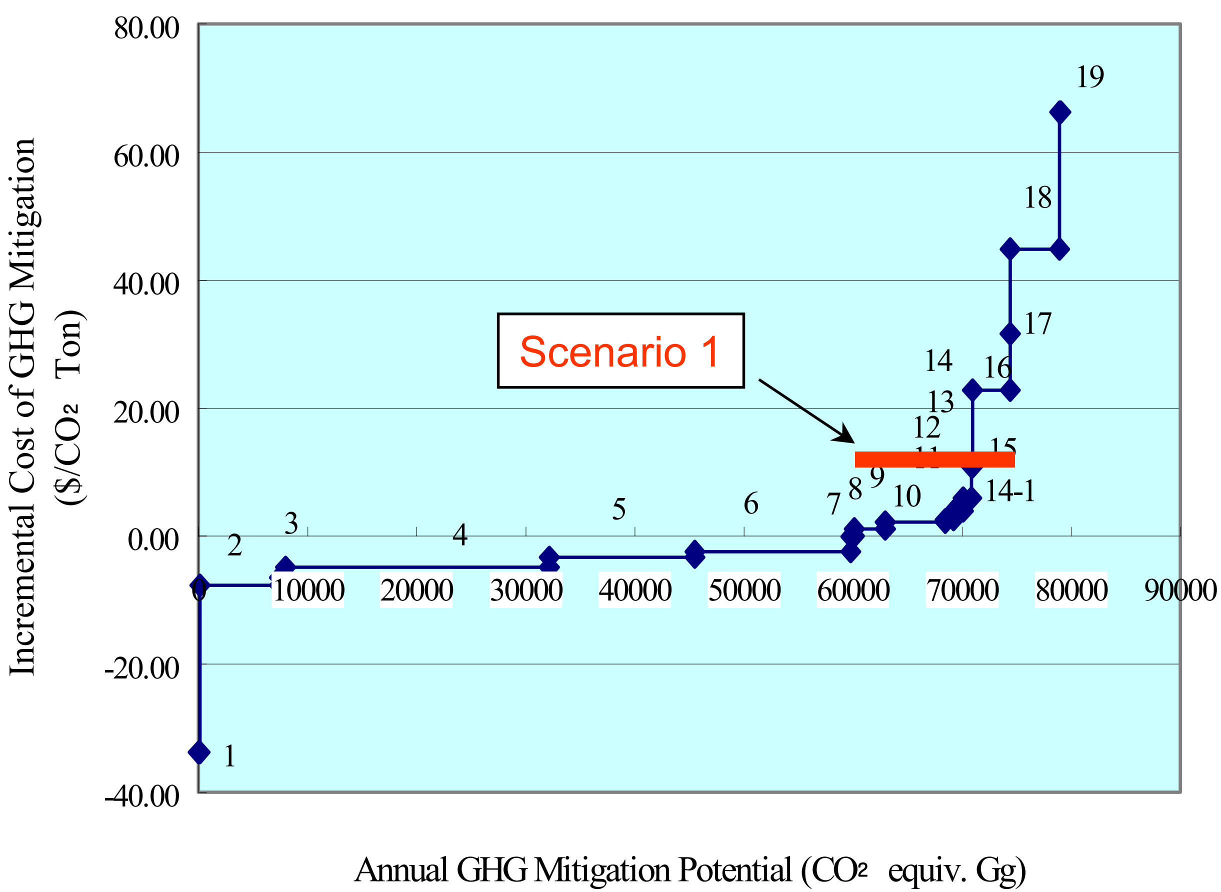
- **Scenario 2: Efficiency and Fuel Quality Assumptions**
  - Net efficiency of power generation displaced: 27% China, 31% ROK, RFE
  - Coal at 18.7 GJ/te, 56% carbon, 1.1% sulfur in China, 1% S in ROK, 0.5% S in RFE
  - Displaced generation is from plants without scrubbers in RFE, China; 50% with FGD in ROK
- **Emissions Reduction Estimates**
  - **CO_2 reduction: 20 million tonnes/yr (as CO_2)**
  - **SO_2 reduction: 360 thousand tonnes/yr (as SO_2)**

GRID INTERCONNECTION COSTS AND BENEFITS: ANALYSIS AND RESULTS

Summary of "Scenario 2": Power Trade to China (spring/fall) from RFE and ROK/DPRK, to ROK from RFE (summer) and From ROK to RFE (winter), with supplies from RFE Hydro Plants, Nuclear Power Plants in the ROK and/or DPRK			
	Annualized Costs/Avoided Costs		
	$/kWh*	M$/yr	$/te CO_2
Costs of Providing Power Via Transmission Line			
Line and Converter Station Capital Costs	$ 0.0089	$ 137	$ 6.76
Line O&M Costs	$ 0.0030	$ 46	$ 2.27
Generation Variable O&M and Fuel Costs, ROK/DPRK	$ 0.0045	$ 69	$ 3.39
Generation Capital and Fixed O&M Costs, ROK/DPRK	$ 0.0226	$ 347	$ 17.08
Generation Variable O&M Costs, RFE (Hydro)	$ 0.0005	$ 8	$ 0.38
Generation Capital and Fixed O&M Costs, RFE (Hydro)	$ 0.0126	$ 194	$ 9.53
TOTAL	$ 0.0521	$ 801	$ 39.40
Avoided Costs of Power Generation in China			
Generation Variable O&M and Fuel Costs	$ (0.0150)	$ (230)	$ (11.33)
Generation Capital and Fixed O&M Costs	$ (0.0081)	$ (125)	$ (6.14)
Avoided Costs of Power Generation in ROK			
Generation Variable O&M and Fuel Costs	$ (0.0037)	$ (57)	$ (2.83)
Generation Capital and Fixed O&M Costs	$ (0.0062)	$ (96)	$ (4.72)
Avoided Costs of Power Generation in RFE			
Generation Variable O&M and Fuel Costs	$ (0.0044)	$ (67)	$ (3.31)
Generation Capital and Fixed O&M Costs	$ (0.0113)	$ (174)	$ (8.55)
TOTAL	$ (0.0488)	$ (750)	$ (36.88)
NET COST OF POWER PROVISION	**$ 0.0033**	**$ 51**	**$ 2.52**

* Expressed per kWh of total annual power carried by interconnection (all countries)

GRID INTERCONNECTION COSTS AND BENEFITS: ROK ALGAS COMPARISON

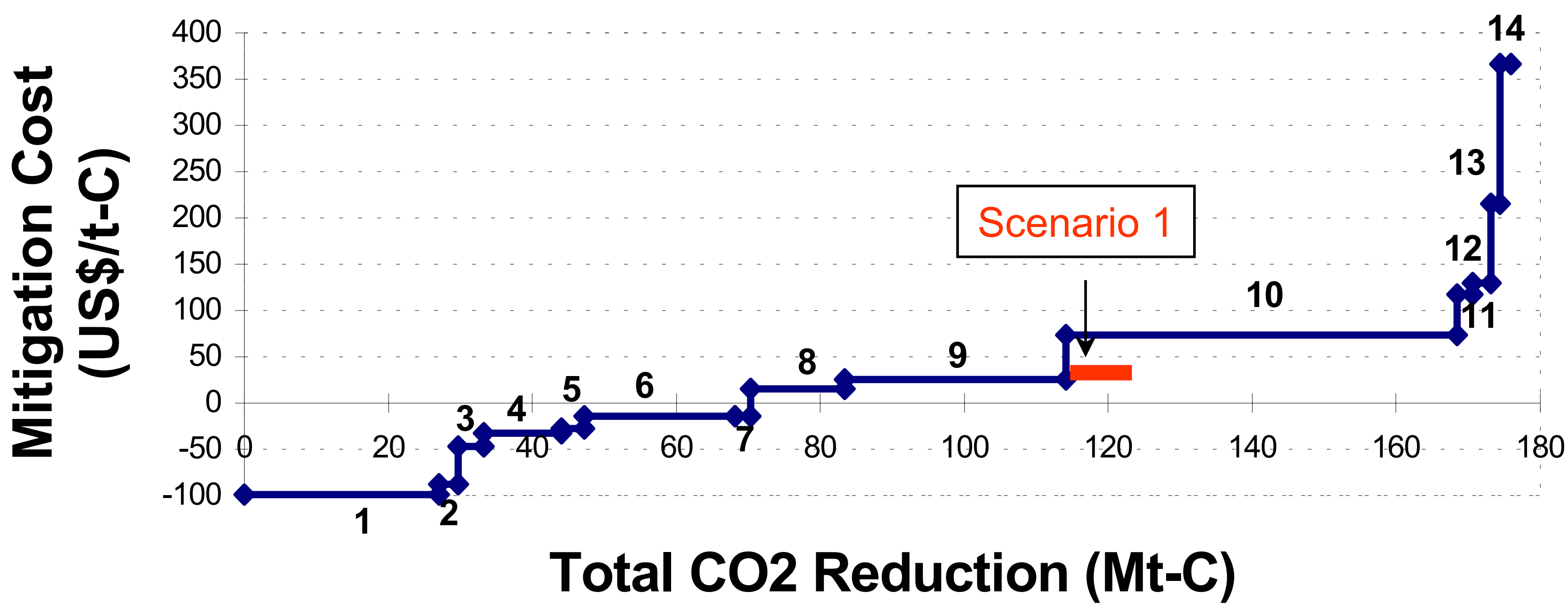


1. Commercial Condensing Boiler
2. Residential Heating
3. Efficient Air Conditioner
4. Motor
5. Waste Management
6. Efficient Lighting
7. Wet Seeding-IF
8. Dry Seeding-IF
9. Wet Seeding-CF
10. New Generation Technologies
11. Forestry Management
12. Urban Forestry
13. Manure Management
14. 14-1 Enhanced Regeneration
15. Feed Supplements
16. Transport
17. Industrial Condensing Boiler
18. LNG C/C
19 Genetic Improvement of Performance

GRID INTERCONNECTION COSTS AND BENEFITS: ROK ALGAS COMPARISON

- Total positive-cost CO_2-reduction measures in ROK avoids 17 M tonnes/yr at cost of 307 M$/yr, similar in performance to Scenario 1 (15 M te), but Scenario 1 costs ~$100 million/yr less
- Scenario 2 saves 2.6 M te CO_2 in ROK, +18 M te in China/RFE, at net cost of $ 50 million/yr
- Question is how CDM mechanisms would assignment GHG costs and savings in a shared project like this one

GRID INTERCONNECTION COSTS AND BENEFITS: CHINA ALGAS COMPARISON



GRID INTERCONNECTION COSTS AND BENEFITS: CHINA ALGAS COMPARISON

Mitigation technology options marked with numbers are as below

1. Technical renovation of motor for general use
2. Reducing ratio of iron/steel in steel & iron industry
3. Renovation of kilns for wet cement production
4. Energy-saving lighting
5. Comprehensive process renovation of synthetic ammonia
6. Renovation of industrial boilers
7. Continues casting of steel making
8. Renovation and reconstruction of conventional thermal power plant
9. Nuclear power
10. Hydro power
11. IGCC and other advanced thermal power generation technologies
12. Biogas and other biomass energy
13. Wind power
14. Solar thermal

GRID INTERCONNECTION COSTS AND BENEFITS: CHINA CDM

- If CO_2 reduction opportunities in China scale with population, 15 Mt CO_2 saved is a significant contribution for NE China
- Degree to which transmission line option is cost-competitive with other GHG reduction options depends principally on whether capital costs for generation supplying the line are paid for or not:
  - If capacity used is arguably “surplus”, costs of GHG reduction are negative, and transmission line option is an even more competitive alternative

GRID INTERCONNECTION COSTS AND BENEFITS: OTHER BENEFITS

- Generation of Foreign Exchange: Interconnection provides opportunity for DPRK, RFE to establish income stream
- Confidence building: Transparency and coordination needed to accomplish technical and economic power exchanges help build confidence between partners
- Regional grid inter-connection could support NEA trade/investment zone (Tumen River)
- Enhances diversity of supply throughout region

GRID INTERCONNECTION COSTS AND BENEFITS: Areas for Further Analysis

- Forecasts of rate of growth in power demand and power capacity deficit under different supply scenarios in NE China
- Determine timing and type of capacity surplus (if any) in ROK, RFE
- More detailed analyses of feasible options for operation of Simpo reactors, disposition of power from reactors
- More detailed comparison with other options for GHG emissions reduction in NE Asia

GRID INTERCONNECTION COSTS AND BENEFITS: Areas for Further Analysis

- Incorporation of consideration of other pollution reduction benefits (including reduction of SO_2 emissions and impacts on acid rain in China and elsewhere in the region)
- Updated review of need for power in DPRK, options for power distribution, T&D upgrades
- Pre-feasibility consideration of potential international transmission routes
- Detailed consideration of transmission line engineering options and constraints

GRID INTERCONNECTION COSTS AND BENEFITS: Areas for Further Analysis

- More detailed consideration of political feasibility of transmission interconnections
- More detailed and accurate consideration of costs of power generation, transmission in ROK, DPRK, Russian Far East, China
- Detailed feasibility study of one or more interconnection options