ADB

Completion Report

Project Number: 42117-013
Loan Number: 2616
Grant Number: 0196
September 2017

People's Republic of China: Tianjin Integrated Gasification Combined Cycle Power Plant Project

Asian Development Bank

CURRENCY EQUIVALENTS

Currency Unit – yuan (CNY)

		At Appraisal (1 December 2009)	At Project Completion (30 June 2016)
CNY1.00	=	$0.1465	$0.1507
$1.00	=	CNY6.8247	CNY6.6353

ABBREVIATIONS

ADB	–	Asian Development Bank
BOD	–	biochemical oxygen demand
CCF	–	Climate Change Fund
CCS	–	carbon capture and storage
CCUS	–	carbon capture, utilization and storage
CER	–	certified emission reduction
CHNG	–	China Huaneng Group
CO_2	–	carbon dioxide
COD	–	chemical oxygen demand
EIA	–	environmental impact assessment
EIRR	–	economic internal rate of return
EMoP	–	environmental monitoring plan
EMP	–	environmental management plan
EMS	–	environmental monitoring station
EMU	–	environmental management unit
ENPV	–	economic net present value
EPB	–	environmental protection bureau
EXIM Bank	–	Export–Import Bank of China
FIRR	–	financial internal rate of return
FNPV	–	financial net present value
GHG	–	greenhouse gas
Greengen	–	Greengen Company Ltd.
H_2S	–	hydrogen sulfide
HPI	–	Huaneng Power International, Inc.
HTICL	–	Huaneng Tianjin Integrated Gasification Combined Cycle Company Limited.
ICB	–	international competitive bidding
IGCC	–	integrated gasification combined cycle
LIBOR	–	London interbank offered rate
MOF	–	Ministry of Finance
NDRC	–	National Development and Reform Commission
NH_3-N	–	ammonia nitrogen
NO_2	–	nitrogen dioxide
NO_x	–	nitrogen oxide
O&M	–	operation and maintenance
PM	–	particulate matter
PM_{10}	–	particulate matter below 10 microns
PPTA	–	project preparatory technical assistance

PRC	–	People's Republic of China
SO_2	–	sulfur dioxide
SOE	–	state-owned enterprise
syngas	–	synthesis gas
TA	–	technical assistance
TSP	–	total suspended particulates
USC	–	ultra-supercritical
WACC	–	weighted average cost of capital

WEIGHTS AND MEASURES

dB	–	decibel
g	–	gram
gce	–	gram of coal equivalent
GW (gigawatt)	–	1,000 megawatts
GWh	–	gigawatt-hour
h	–	hour
kg/h	–	kilogram per hour
km	–	kilometer
kV (kilovolt)	–	1,000 volts
kWh (kilowatt-hour)	–	1,000 watt-hours
m	–	meter
m^3	–	cubic meter
m^3/h	–	cubic meter per hour
mg	–	milligram
mg/l	–	milligram per liter
mg/m^3	–	milligram per cubic meter
MW (megawatt)	–	1,000,000 watts
t (ton)	–	1,000 kilograms
t/h	–	ton per hour
t/km^2	–	ton per square kilometer

NOTE

In this report, "$" refers to US dollars and "ton" refers to metric ton.

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BASIC DATA

A.	**Loan and Grant Identification**		
	1.	Country	People's Republic of China
	2.	Loan Number	2616
		Grant Number	0196
	3.	Project Title	Tianjin Integrated Gasification Combined Cycle Power Plant Project
	4.	Borrower/Recipient	People's Republic of China
	5.	Executing Agency	China Huaneng Group
	6.	Amount of Loan	$135 million
	7.	Amount of Grant	$5 million
	8.	Project Completion Report Number	1661
B.	**Loan/Grant Data**		
	1.	Appraisal	
		– Date Started	6 May 2009
		– Date Completed	15 May 2009
	2.	Loan/Grant Negotiations	
		– Date Started	24 November 2009
		– Date Completed	24 November 2009
	3.	Date of Board Approval	8 February 2010
	4.	Date of Loan Agreement	28 May 2010
	5.	Date of Loan Effectiveness	
		– In Loan Agreement	26 August 2010
		– Actual	25 August 2010
		– Number of Extensions	0
	6.	Closing Date	
		– In Loan Agreement	31 December 2012
		– Actual	27 February 2015
		– Number of Extensions	2
	7.	Terms of Loan	
		– Interest Rate	London interbank offered rate (LIBOR) + 0.6%
		– Maturity (number of years)	26
		– Grace Period (number of years)	6
	8.	Climate Change Fund Cofinancing (G0196)	
		– Approval	8 February 2010
		– Date of Financing Agreement	28 May 2010
		– Date of Effectiveness	16 August 2010
		– Closing Date in Financing Agreement	31 December 2015
		– Actual Closing Date	19 July 2017
		– Number of Extensions	1
	9.	Terms of Relending (if any)	
		– Interest Rate	LIBOR + 0.6%
		– Maturity (number of years)	26
		– Grace Period (number of years)	6
		– Second-Step Borrower	Export–Import Bank of China

10. Disbursements

a. Dates – Loan

Initial Disbursement	Final Disbursement	Time Interval
9 February 2011	14 November 2014	45 months
Effective Date	**Original Closing Date**	**Time Interval**
25 August 2010	31 December 2012	28 months

b. Dates – Grant

Initial Disbursement	Final Disbursement	Time Interval
10 August 2011	7 November 2014	39 months
Effective Date	**Original Closing Date**	**Time Interval**
16 August 2010	31 December 2015	65 months

c. Amount in $(million)

Category[a]	Original Allocation	Reallocation/ Partial Cancellation	Last Revised Allocation	Amount Disbursed	Undisbursed Balance[b]
ADB Loan					
01A	18.000	(0.102)	19.372	18.973	0.400
01B	44.120	(0.158)	5.378	4.885	0.493
02	50.780	23.217	83.793	80.325	3.468
03	22.100	0.203	3.297	1.550	1.747
Subtotal	**135.000**	**23.160**	**111.840**	**105.732**	**6.108**
CCF Grant					
01A	1.800	0.000	0.000	0.000	0.000
01B	3.000	0.000	4.500	4.467	0.033
02	0.200	0.000	0.500	0.401	0.099
Subtotal	**5.000**	**0.000**	**5.000**	**4.868**	**0.132**

ADB = Asian Development Bank, CCF = Climate Change Fund.

[a] ADB Loan: 01A = works–chemical island, 01B = works–power island, 02 = goods (power plant), 03 = interest and commitment charge. Grant: 01A = works–air separation unit, 01B = works–long-term maintenance contracts, 02 = consulting services.

[b] An undisbursed loan amount of $6,107,779 and an undisbursed grant amount of $132,053 were cancelled when the loan and grant were closed.

Note: Numbers may not sum precisely because of rounding.

C. Project Data

1. Financing Plan ($ million)

Cost	Appraisal Estimate	Actual
Asian Development Bank		
Ordinary Capital Resources	135.00	105.73
Grant from Climate Change Fund	5.00	4.87
Counterpart Financing		
Equity	84.00	134.02
Domestic Loan	195.59	283.79
Total	**419.59**	**528.41**

2. Cost Breakdown by Project Component ($ million)

Component	Appraisal Estimate	Actual
A. Base Costs		
1. Civil Works	65.85	77.86
2. Power Plant Equipment	213.66	229.19
3. Plant Erection and Equipment Installation	57.52	71.48
4. Technical Services including Commissioning	21.29	66.24
5. Project Management	9.81	17.63
6. Land Acquisition and Other Charges	6.86	20.52
Subtotal (A)	**374.99**	**482.92**
B. Contingencies		
1. Physical Contingencies	14.54	1.50
2. Price Contingencies	7.96	0.00
Subtotal (B)	**22.50**	**1.50**
C. Financial Charges During Development	**22.10**	**44.00**
Total	**419.59**	**528.42**

3. Project Schedule

Item	Appraisal Estimate	Actual
Date of Contract with Consultants		June 2013
Completion of Engineering Designs	June 2008	June 2008
Civil Works Contract		
Date of Award	September 2009	September 2009
Completion of Work	December 2011	April 2012
Equipment and Supplies		
First Procurement	September 2008	January 2010
Last Procurement	December 2009	July 2012
Completion of Equipment Installation	June 210	17 April 2012
Start of Operations		
Completion of Tests and Commissioning	December 2012	December 2012
Beginning of Start-Up	December 2012	December 2012

4. Project Performance Report Ratings

	Ratings	
Implementation Period	**Development Objectives**	**Implementation Progress**
From 28 February 2010 to 31 December 2010	Satisfactory	Satisfactory
From Q1 2011 to Q2 2013	On Track	
From Q3 2013 to Q3 2013	Potential Problem	
From Q4 2013 to Q3 2017	On Track	

D. Data on Asian Development Bank Missions

Name of Mission	Date	No. of Persons	No. of Person-Days	Specialization of Members[b]
Consultation	11 Dec 2007	3	3	a, b, c
Fact-finding	6–15 May 2009	8	88	b. d, e, f,g, h
Loan negotiation	24 November 2009	3	3	b, f, i
Inception	26–28 May 2010	2	6	a, d
Review 1	22–25 March 2011	4	15	a, d, h, j
Review 2	22–26 September 2011	1	5	d
Review 3	31 October–2 November 2011	1	3	a
Review 4	19–23 December 2011	1	5	d
Special loan administration	10–12 January 2012	3	9	j, d, a
Review 5	16–17 August 2012	4	8	e, j, d, h
Review 6	28–29 January 2013	3	6	e, d, k
Review 7	17–21 June 2013	3	12	e, d, a
Reconnaissance	1–3 August 2013	2	4	e, a
Review 8	18–21 October 2013	1	4	e
Review 9	18 January 2014	1	1	e
Grants project administration	15 May 2014	1	1	e
Review 10	10–11 July 2014	2	4	e, d
Review 11	19–26 November 2014	1	5	e
Country consultation	26–27 May 2016	2	4	a, b
Project completion	15–18 November 2016	5	17	e, d, l, m

a = director, b = energy specialist, c = advisor, d = project officer, e = finance specialist, f = counsel, g = economics officer, h = administrative assistant, i = project analyst, j = environment specialist, k = external relations officer, l = consultant (environment), m = consultant (financial analysis).

I. PROJECT DESCRIPTION

1. The economy of the People's Republic of China (PRC) grew rapidly in the years leading up to the project appraisal in 2009. This growth greatly increased electricity demand, which had risen at an annual average rate of more than 13% since 2001.[1] Supply could not keep up with demand, resulting in power shortages in some areas of the PRC. This led to an accelerated program of new power generation capacity addition in 2006, most of which was coal-based. The PRC's renewable energy law, enacted in 2005, paved the way for wind- and solar-power deployment, but the costs of this nascent industry were very high, and it was not expected to meet the rising demand. With the projected economic growth trajectory and relatively low per capita electricity consumption, the PRC's demand for electricity was expected to continue to increase rapidly.

2. Coal has been the dominant source of primary energy in the PRC. In 2008, coal accounted for more than 70% of the PRC's energy mix. The electricity sector was the largest consumer of coal, with coal-fired power plants producing 81% of the country's electricity. The sustained increase in coal consumption triggered a surge in the emissions of carbon dioxide (CO_2)—a major greenhouse gas (GHG) and cause of global climate change—sulfur dioxide (SO_2), nitrogen oxide (NO_X) and particulate matter (PM), which cause air pollution. Acid rain, caused primarily by SO_2 and $NO_{x,}$ fell on a third of the country and almost half of its farmland. As part of its climate change mitigation efforts, in 2008, the PRC announced its commitment to reduce its energy intensity by 40%–45% by 2020 compared to the 2005 level.

3. At the time of project appraisal, the PRC had already embarked on wider deployment of high-efficiency low-emission coal power technologies such as supercritical and ultra-supercritical (USC) technologies. But internationally available and more advanced clean coal technologies, such as integrated gasification combined cycle (IGCC), were not installed in the PRC.[2] Key barriers identified at appraisal were (i) higher capital costs, (ii) higher operation and maintenance (O&M) costs having an adverse impact on electricity tariffs, and (iii) technology risks. Notwithstanding the significant risks involved, it was recognized that adoption of IGCC technology would, however, provide the foundation and the opportunity for combining coal-based power generation with carbon dioxide capture and storage (CCS) technology, which has the potential to cut emissions drastically and significantly reduce local air pollution.[3]

4. The Tianjin IGCC Power Plant Project involved constructing and operating a coal-fired power plant with 250-megawatt (MW) capacity[4] in Tianjin Harbor Industrial Park in the Binhai New Area of Tianjin City. The project aimed to introduce IGCC technology, one of the most efficient and least polluting advanced clean coal technologies available, for the first time in the PRC. It was also to be the first IGCC power plant in the Asia and Pacific region.[5]

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[1] ADB. 2009. *Report and Recommendation of the President to the Board of Directors: Proposed Loan and Grant to the People's Republic of China for the Tianjin Integrated Gasification Combined Cycle Power Plant Project.* Manila (Loan 2616-PRC; Grant 0196-PRC). Reference to data prior to 2009 was taken from this report.

[2] Clean coal is an umbrella term widely used in the industry to describe technologies that reduce the environmental impacts of coal-fired power plants. The aim was to reduce SO_2 and particulates, but, considering the impacts on global climate change from CO_2 emissions, the term also refers to technologies that reduce CO_2 emissions.

[3] CCS is included in all climate change mitigation strategies proposed by the United Nations' Intergovernmental Panel on Climate Change and the International Energy Agency. Various international studies have found IGCC power plants with CCS to be the least-cost option to cut CO_2 emissions from coal-fired power plants by up to 90%.

[4] The capacity was since revised to 265 MW based on the rated capacity of the equipment and plants' final design.

[5] Prior to the construction of the Tianjin IGCC plant, one large industrial pilot and six commercial-scale demonstration coal-based IGCC plants were established in the Netherlands, Spain, the Czech Republic, Japan, and the US, over the period 1994–2007.

5. Technologically, the project represents a significant change from conventional coal-fired power plants as it involves gasification of the coal before combustion. In coal gasification, synthesis gas (syngas) is produced and cleaned of impurities such as sulfur, oxides, mercury, and particulates, before its combustion. Syngas is then combusted in the gas turbine to generate the first source of electricity. Heat is recovered from both the gasification process and the gas turbine exhaust to produce steam, which is then used to drive the steam turbine to generate the second source of electricity. These processes constitute a combined-cycle power plant mode. IGCC plants can reach 99.9% desulfurization efficiency with NO_x discharge only 15%–20% of conventional pulverized-coal power plants. By successfully demonstrating the advantages of IGCC technology, the project was expected to reinforce confidence in the viability of this technology and kick-start the government's flagship clean coal program—GreenGen—which was announced in 2005. The program comprised three phases. The Tianjin IGCC project was a cornerstone of the critical first phase. In the second phase, a scaled-up IGCC plant fitted with pilot-scale CCS was expected by 2013, and the third phase was expected to provide a scaled-up IGCC plant, including large-scale CCS, with near-zero emissions by 2015.

6. The Asian Development Bank (ADB) approved a project loan of $135 million from its ordinary capital resources on 8 February 2010 to finance the purchase of goods, works, and consulting services, including taxes and duties on the ADB-financed portion of the project cost. ADB's Climate Change Fund (CCF) provided grant cofinancing equivalent to $5 million to significantly reduce risks and strengthen project management capacity and reporting on compliance with key safeguards.[6] The Export–Import Bank of China (EXIM Bank) acted as the principal onlending agency.[7]

7. The China Huaneng Group (CHNG),[8] a wholly state-owned enterprise (SOE) and the PRC's largest electric company, was the executing agency. Greengen Company Ltd. (Greengen)[9] provided management oversight to the implementing agency during the construction phase. Huaneng Tianjin IGCC Company Ltd. (HTICL)[10] was established to be the implementing agency for the construction, operation, and maintenance of the power plant. At the start of the power plant's operation, CHNG handed over the management of HTICL to the Huabei Branch of Huaneng Power International, Inc. (HPI).[11]

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[6] The CCF was established in May 2008 to facilitate greater investment in developing member countries to effectively address the causes and consequences of climate change. The CCF is a key mechanism for pooling resources within ADB to address climate change through technical assistance and grant components of investment projects. The grant component for the Tianjin IGCC was intended to be utilized for the (i) long-term maintenance contracts with the respective suppliers of the coal gasifier and gas turbines, (ii) civil work contract associated with the air separation unit, and (iii) recruitment of international and national consultants to supervise the project's implementation. $500,000 was allocated to finance the preparation of the roadmap and the study tours to facilitate dialogues with the operators of other IGCC plants.

[7] As outlined in the loan agreement, the loan proceeds were re-lent to the EXIM Bank through the Ministry of Finance on the same terms and conditions as the loan. The EXIM Bank in turn onlent these loan proceeds to CHNG, adding a standard administration fee of 0.15% for providing the on-lending services. All the subsequent on-lending agreements carried the same terms and conditions as the original loan.

[8] CHNG is an SOE. It was established in 1985 when the PRC's power sector was reorganized. At the end of 2016, its installed capacity is 165.5 GW.

[9] Greengen Company Ltd. was established as a limited liability company in December 2005. Its business involves researching, developing, and providing consulting services on clean coal technology for power plants. The project is the initial undertaking in its development program. CHNG holds 51% of Greengen's shares, while the other seven shareholders are the PRC's major power-related SOEs, each holding 7% of the shares.

[10] HTICL was registered as a limited liability company under PRC law in November 2008.

[11] HPI was established in June 1994 with a mandate to develop, construct, operate and manage large power plants in the PRC. It is a publicly listed company in the New York Stock Exchange, Shanghai Stock Exchange and in the Hong Kong Stock Exchange. CHNG exercises control over the company. HPI owns power plants in 24 provinces in the PRC.

8. The design and monitoring framework is in Appendix 1.

II. EVALUATION OF DESIGN AND IMPLEMENTATION

A. Relevance of Design and Formulation

9. At appraisal, energy sector strategies outlined in ADB's country partnership strategy for the PRC focused on supporting measures that promote environmentally sustainable development and inclusive growth.[12] These are consistent with the government's Eleventh Five-Year Plan, 2005–2010 strategies and plans.[13] The strategy supported the PRC's programs in preventing urban pollution, and encouraging investments in industries and areas that promote energy conservation and environmental protection.

10. The project was fully aligned with the government priority to shift to highly efficient energy sources that will improve the country's environment and help mitigate global climate change. The PRC relied heavily on coal for power generation, and with coal expected to remain dominant in electricity production, the project was an important part of reducing environmental and climate change impacts from such plants. Moreover, the Beijing–Tianjin–Hebei region was experiencing urbanization and had a high concentration of energy intensive industries contributing to air pollution. Thus, a highly efficient and low-impact plant—in terms of air pollution—such as IGCC was needed to meet the anticipated more stringent requirements for pollution emissions from coal-based power plants.

11. The government has set out measures to improve the efficiency of its coal-based power plants by constructing new supercritical and USC power plants with advanced technology, and has been closing small, inefficient power plants. It was gradually seeking greater efficiency from newly built plants as well as enhanced environmental performance. Against this backdrop, IGCC plants, which use the most efficient and least polluting advanced clean coal technology, offered a potential solution. Moreover, IGCC plants offer a low-cost platform for CCS to minimize carbon emissions. The demonstration of IGCC technology at Tianjin provided both valuable experience and a design template for similar plants to be established in an urban setting.

12. Working closely with CHNG and Greengen, ADB provided small-scale technical assistance (TA) in 2008 to support project development.[14] The consultant's project preparatory technical assistance (PPTA) report confirmed the feasibility and the environmental benefits of the IGCC project, and recommended its implementation. The project facilities were designed adequately. Previously, in 1997, ADB provided a grant-financed TA project[15] to assess the appropriateness of IGCC technologies and prepare the conceptual design of an IGCC demonstration plan.[16]

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[12] ADB. 2008. *People's Republic of China: Country Partnership Strategy 2008–2010.* Manila. February 2008.

[13] The PRC's Eleventh Five-Year Plan, 2005–2010 for the energy sector focused on energy efficiency and resource conservation. Its target was to reduce energy intensity by 20% in 2010. The plan aimed to cut dependence on coal to 66%, and reduce SO_2 emission by 10%.

[14] ADB. 2008. *Technical Assistance to the People's Republic of China for Capacity Strengthening in Planning and Implementation of Integrated Gasification Combined Cycle Plant.* Manila (TA 7146-PRC, $200,000, approved on 8 October).

[15] ADB. 1997. *Technical Assistance to the People's Republic of China for the Study on Clean Coal Integrated Gasification Combined Cycle Technology*. Manila (TA 2792-PRC, $500,000, approved on 19 May).

[16] The TA produced a conceptual design for the Yantai IGCC plant in Shandong Province that was proposed for implementation by another agency. The TA project was implemented in close cooperation with the Thermal Power Research Institute in Xian, the leading research organization in thermal power engineering in the PRC. The institute is jointly owned by the five main power-generating companies, with CHNG having a majority shareholding of 51%.

B. Project Outputs

13. As designed, the project outputs include (i) constructing and operating an IGCC power plant of 250 MW capacity in the Binhai New Area, Tianjin city; (ii) adequate capacity in project management, safeguard compliance, and plant O&M; and (iii) capacity developed for obtaining carbon offset revenues from IGCC plants. The key components include (i) a 2,000 tons per day coal gasifier; (ii) a 172.8 MW gas turbine generator; (iii) a 94.5 MW steam turbine generator; (iii) a 160,739 cubic meter per hour syngas purification system; (iv) a sulfur recovery and removal system; (v) an air separation unit; (vi) a coal handling system, water and wastewater plants, and standard electrical and mechanical auxiliaries, and (vii) a power plant switch yard and grid connection. On completion, the Tianjin IGCC plant was to generate 1,470 gigawatt-hours (GWh) of electricity annually, which will be evacuated through a 220-kilovolt (kV) transmission line to an existing substation for connection with the Tianjin power grid. The Tianjin power grid is connected to the North China power grid through 500 kV transmission lines.

14. Despite its complex design, the Tianjin IGCC plant was completed successfully and on schedule, commencing operations in December 2012. The event was celebrated in a grand ceremony, with extensive media coverage, and was attended by many dignitaries from the PRC's energy sector. At the ceremony, the Vice-Minister of the Ministry of Science and Technology declared the Tianjin IGCC plant as a "National IGCC Green Coal Research, Development and Demonstration Base".

15. However, plant operators encountered difficulties in synchronizing the highly complex system of components during trial operation. The power plant faced operational performance and reliability challenges including ash- and slag-related blockages in the outlets from the gasifier—primarily attributed to the plant operators' lack of experience—which resulted in temperature spikes. As the operators gained experience, the problem was avoided. Following commissioning, there was also an overheating problem with some nozzles in the combustion chamber. The equipment vendor dealt with this successfully, ensuring operational stability.[17]

16. In July 2013, the Tianjin IGCC plant passed the final 500-hour (h) long-term operation test. In 2014, the plant utilization was 4,084 h, generating 1,082 GWh of electricity. In 2015, the plant utilization was 4,536 h with 1,202 GWh of electricity generation. In 2016, its utilization was 5,003 h generating 1,325 GWh of electricity, including 2 periods of 30 days continuous operation. This shows that the plant is easily able to operate at the designed level of 5,500 h. However, it has not been able to do so owing to limitations on operating hours imposed by the North China power grid due to the prevailing excess power generation capacity. The oversupply situation stemmed mainly from the slowdown in the PRC's economic growth, which softened the demand for electricity, especially in industry-intensive areas such as Tianjin. In addition, to address the worsening air pollution in the Beijing–Tianjin–Hebei region, the government announced its Clean Air Action Plan in 2013. The plan enforced stricter air pollution prevention and control measures, and prompted policy makers to control local coal-fired power generation and to shift coal-fired power generation sources to the PRC's northern and central regions. Despite these stringent measures, the load dispatch allocated to the Tianjin IGCC plant is much higher compared to all other coal-fired plants in the grid due to its higher efficiency and extremely low emission of air pollutants.

17. Since the successful completion of Phase I of the GreenGen plan, CHNG has been actively pursuing Phase 2 of the program, which includes the construction of a pilot-scale carbon capture plant at the Tianjin IGCC complex. The plant was designed to capture about 60,000 - 100,000 tons of CO_2 from the Tianjin IGCC plant by drawing about 7% of the syngas from the power plant and separate CO_2 from it to test the performance indicators for pre-combustion

[17] Consultant's Report under ADB Contract 114918 financed under Grant 0196-PRC.

capture. The pilot capture plant was commissioned in August 2016. Phase 3 has been pushed back to 2018–2025 due to the economic slowdown and new developments in the reduction of dispatchable operating hours allowed for coal-based power plants. CHNG is planning to build a 400–600 MW demonstration plant that will integrate key technologies such as IGCC, carbon capture, utilization and storage (CCUS), and fuel cell power generation. This demonstration plant will achieve efficient coal-fired power generation with near-zero emissions of all major pollutants and CO_2. Meanwhile, efforts are being made to further improve the cost-competitiveness and reliability of the IGCC units for wider deployment.

18. Adequate capacity in project management, safeguard compliance, and plant O&M has been achieved. About 280 plant management and staff received appropriate training and developed adequate capacity in critical areas of operations. In total, safety training equivalent to 1,000 person-days was organized and 3,340 checks were made to consolidate the safety regulations. As a first in the PRC, this innovative project lacked necessary IGCC power plant standards. HTICL therefore developed an engineering quality administration system that complied with both the power industry and chemical industry standards. This system established a quality assurance model for IGCC power plants in the PRC and can serve as model for future power plants. The model passed all the quality inspections conducted by CHNG's quality monitoring center prior to the commencement of operations, a feat in which the implementing agency's technical and support staff takes particular pride. Continuing process of improvement in plant O&M is being achieved.

19. With regard to output (iii)—capacity developed for obtaining carbon offset revenues from IGCC plants—the training program was no longer relevant due to the collapse of the carbon trading market in the European Union owing to the extremely low price of carbon credits.[18] The PRC has recently announced that it is rolling out its own emission trading scheme in 2017, which will have its own set of criteria and guidelines.

C. Project Costs

20. At appraisal, the total project cost, including contingencies and interest and other loan charges during construction, was estimated at $419.6 million equivalent—$140.0 million in foreign exchange cost (33.3% of the total) and $279.6 million in local currency cost (66.6%). At the loan and grant closing, the actual project costs amounted to $528.4 million equivalent—$110.6 million in foreign exchange cost (21.0% of total) and $417.8 million in local currency cost (79.0%), exceeding the appraisal estimates by 25.9%. The actual foreign exchange cost was lower than the appraisal estimate by 21.0%, but the actual local currency cost was 49.0% higher. Cost overruns were experienced in almost all cost components and most significantly, in commissioning cost due to increased oil and gas consumption as a result of the prolonged trial operations.[19] The lower estimates resulted mainly from the lack of experience by the project proponent in constructing an IGCC power plant. The estimated interest during construction and commitment charges was $22.1 million and the actual was $44.0 million.

[18] At the time of project appraisal, the project was anticipated to be eligible for certified emission reductions (CERs) under the Clean Development Mechanism, which was established under the Kyoto Protocol and the United Nations Framework Convention on Climate Change. Each ton of avoided CO_2 was equivalent to 1 CER. However, due to various economic factors, the trading price of CERs collapsed from a high of $20 in August 2008 to $0.31 in December 2012.

[19] Compared to earlier demonstration plants, the Tianjin IGCC plant reached a high availability factor in a relatively shorter time. It took the Buggenum IGCC in the Netherlands 4 years to reach an availability factor of more than 50%, and nearly 10 years to reach 70%. The Wabash IGCC in the United States took 3 years to reach an availability factor above 50% and 5 years to reach 70%. It took the Polk IGCC in the United States 2 years to reach an availability factor above 50% and 4 years to reach 70%. Only the Nakosa IGCC in Japan reached a high availability factor during its scheduled testing period and maintained this at above 80%. The Nakosa IGCC used air blown gasification technology compared to the oxygen blown gasification technology used in the Tianjin IGCC plant.

21. The financing plan at appraisal involved an ADB loan of $135.0 million (32.2%), domestic loans of $195.6 million (46.6%) from domestic banks, a CCF grant of $5.0 million (1.2%), and equity contributions of $84.0 million (20.0%) from the project proponents. The actual funding was as follows: ADB, $105.7 million (20.0%); domestic loans, $283.8 million, (53.7%); CCF grant $4.9 million (0.9%); and equity, $134.0 million (25.4%). A major civil works package that was originally to be financed under the loan was financed using counterpart funds, which resulted in loan savings of $37.7 million. The loan and grant proceeds were reallocated in December 2012 to utilize savings to procure oil and coal for the testing and commissioning phase, but this did not materialize. In November 2013, $23.2 million was canceled as the remaining loan amount was sufficient to cover approved contracts and interest during construction. The undisbursed loan balance of $6.1 million was canceled at financial closing. Shortfalls in funding resulting from cost overruns and other operational requirements were met through additional equity contributions and domestic borrowings. The project costs and financing plans are presented in Appendix 2. A detailed cost breakdown, by project component, is in Appendix 3.

D. Disbursements

22. As of the loan closing date, total disbursements amounted to $105.7 million, 78.3% of the loan amount of $135.0 million. Disbursements included $23.9 million (22.6% of total) for civil works, $80.3 million (76.0%) for goods, and $1.6 million (1.4%) for interest and commitment charges. The loan account was financially closed on 27 February 2015, with a cancellation of $6.1 million. Disbursements under the grant amounted to $4.9 million, including $4.5 million (91.8%) for the long-term maintenance contract, and $0.4 million (8.2%) for consultants. The details are in Appendix 4.

23. The imprest account, reimbursement, and direct payment procedures were used to pay for project expenditures. The statement of expenditure procedure was used to facilitate the reimbursement and liquidation of the imprest accounts. This procedure reduced the workload for disbursements and was implemented very efficiently. The project experienced a delay in the payment of grant proceeds through direct payment due to a technical issue with the beneficiary bank. It took EXIM Bank an excessively long period of time to process the withdrawal applications. This was resolved using the reimbursement procedure. ADB provided support in monitoring and accelerating the processing of withdrawal applications by EXIM Bank.

24. It took time for CHNG to submit withdrawal applications for expenditures incurred on or before the loan and grant closing dates. Final disbursement of the loan proceeds was made in November 2014. However, final liquidation of the outstanding imprest advance was finalized in February 2015, 4 months after the closing date of 31 October 2014. Final disbursement of the grant proceeds was processed in January 2017, 7 months after the grant closing date of 30 June 2016. The refund of the balance of the imprest account for the grant was made in July 2017, 13 months after the grant closing date.

E. Project Schedule

25. On-site pre-construction activities commenced in July 2009. The main civil works started in February 2010. The 72 + 24 hour trial operation was completed on 6 November 2012, as per the original schedule and the power plant was inaugurated on 12 December 2012. After 1 year of trial operations, the power plant achieved a high degree of reliability. The project implementation schedule is presented in Appendix 5. A chronology of major events is in Appendix 6.

26. Due to the significantly more complex operational process of an IGCC plant compared to a conventional coal-fired power plant, the testing and commissioning took longer than anticipated—almost 6–8 months—and required considerable consumption of oil and coal (footnote 19). During the trial operations, some non-critical but essential goods, as well as some ancillary services, were procured up to June 2013. The loan closing date was extended by 12 months, from the original closing date of 31 December 2012 to 4 January 2014, to accommodate utilization of loan savings to procure additional goods for testing and commissioning. Subsequently, the loan closing date was further extended by 10 months, to 31 October 2014.

F. Implementation Arrangements

27. The implementation arrangements envisioned at appraisal were carried out successfully. The project management structure established for the project ensured its timely completion. One key success factor was the establishment of a separate project entity that provided expeditious responses to problems and issues. HTICL formulated regulations for equipment operation, maintenance and overhaul, and trained production and maintenance workers, enhancing their capacity to operate and maintain the power plant. Greengen provided management support and oversight to HTICL, particularly in the areas of procurement, financial management, financial control and accounting, ensuring good governance of the project. CHNG provided overall guidance to the project and demonstrated strong support from its top management. Recognizing the unique challenges of the new technology, CHNG brought in relevant expertise. The eventual transfer of plant operations management to HPI Huabei Branch allowed the staff to benefit from the advice and support of more experienced power plant operators, which facilitated resolution of operational issues relatively quickly.

28. The onlending arrangement for a sovereign-guaranteed project loan to an SOE had a complex institutional setup involving multiple layers of organization. The multiple shareholding arrangements of Greengen and HTICL presented challenges during loan negotiations, signing of loan documents and fulfillment of conditions for loan effectiveness. CHNG's strong leadership and support helped overcome these challenges.

29. Through the joint initiative of ADB and the Ministry of Finance (MOF), the project was awarded the Best Performing Project in 2012 during the 2013 Country Portfolio Review Mission. The award recognized the executing agency's efforts in project implementation through effective institutional setup, timely start-up, smooth disbursement and procurement, strict compliance with loan covenants, and effective delivery of scheduled project outputs. It was also selected as the most successful project for ADB's East Asia Regional Department Award in 2013.

G. Conditions and Covenants

30. The loan covenants were adequate and relevant, and generally complied with. Environmental and social covenants were mostly complied with. Audited project accounts and audited financial statements were submitted regularly and mostly on time. However, the financial losses sustained by HTICL since the start of the plant's operations had an adverse impact on the financial covenants. The losses were primarily a result of underutilized capacity, high O&M costs, and inadequately regulated electricity tariff during the first 3 years of operation (2013–2015). The government approved three successive tariff adjustments during this time, bringing it to the current level of CNY0.75 per kilowatt-hour (kWh), which is at par with the tariff for a natural gas power plant (CNY0.72 per kWh), with comparable environmental benefits.[20] The government also

[20] The National Development and Reform Commission approved successive tariff adjustments for the Tianjin IGCC plant, from CNY0.57 per kWh plus a capacity price to CNY0.65 per kWh in 2014, and further to CNY0.75 per kWh in 2015.

granted a capacity subsidy of CNY60.0 million per year from 2014 to 2016 to cover the plant's underutilization. Other financial support extended by the government includes (i) CNY1.5 million from the special fund for energy efficiency and emissions reduction established by the Tianjin Binhai New Area, (ii) CNY1.45 million of interest subsidy on imported goods granted by the MOF, and (iii) CNY500 million from the State-owned Assets Supervision and Administration given to CHNG as the state's financial support in HTICL. Compliance with the financial covenants will improve once full capacity utilization and full cost recovery is achieved. Appendix 7 shows the status of compliance with the covenants in the loan and project agreements.

H. Related Technical Assistance

31. In June 2013, the government requested a grant from ADB to support the implementation of a CCUS pilot project at the Tianjin IGCC complex. In October 2013, ADB approved a regional PPTA grant for $800,000 from the Carbon Capture and Storage Fund under the Clean Energy Financing Partnership Facility.[21] The PPTA was implemented in two parts: Part A to conduct essential due diligence for the ensuing grant in support of the CCUS plant design, and Part B to capitalize on the unique lessons learned from the due diligence and facilitate best-practice knowledge sharing and dialogue with policy makers and stakeholders. The PPTA commenced on 31 October 2013 and was financially closed on 31 October 2016. The due diligence and the lessons learned from the project were subsequently shared with international stakeholders. The capture plant was constructed, but due to difficulties in identifying an adequate injection site, the enhanced oil recovery and storage test could not be implemented. Outstanding issues are still being addressed.

I. Consultant Recruitment and Procurement

32. Under the loan, contracts were awarded for civil works and goods. Under the grant, contracts were awarded for long-term maintenance of the coal gasifier and gas turbines, and for consulting services. A total of 39 contract packages were awarded—26 for the loan and 13 for the grant—with a combined value of $110.6 million. All packages financed by ADB and the CCF were procured in accordance with ADB's Procurement Guidelines (2007, as amended from time to time), and the Guidelines on the Use of Consultants (2007, as amended from time to time). Since the coal gasifier was a proprietary procurement, ADB did not finance it. The gas turbines were procured through international competitive bidding. Other key components that were internationally procured included the syngas purification system and the air separation unit.

33. No complaints about the procurement process were received. The components were completed generally as designed. The quality of the construction completed by the civil works contractors was also rated *satisfactory*. Appendix 8 lists the ADB-financed contract packages.

34. Two international and nine national consultants were hired under the grant for the preparation of a number of studies to capture key lessons learned from the implementation of the Tianjin IGCC project. The recruitment of consultants and implementation of the studies experienced delays as this was the first time the implementing agency had engaged consultants using ADB procedures. Nonetheless, ADB provided full support to ensure quality recruitment.

J. Performance of Consultants, Contractors, and Suppliers

35. The performance of the international and national consultants was generally rated *satisfactory*. The consulting services conformed to the terms of reference and produced the

[21] ADB, 2013. *Technical Assistance to the People's Republic of China for Tianjin Integrated Gasification Combined Cycle Power Plant (additional financing).* Manila.

deliverables and knowledge products. These contributed to the successful implementation of the project, documented the lessons learned, and helped build the institutional capacity of the staff in the project implementation and operations. The international consultants funded by the grant produced high-quality knowledge products, and these were widely disseminated to industry stakeholders.

K. Performance of the Borrower and the Executing Agency

36. The performance of the MOF as borrower was rated *satisfactory*. It provided timely guidance and approvals for implementation issues. The performance of CHNG as the executing agency was also rated *satisfactory,* acknowledging its expertise in professional management, operational efficiency and global competitiveness. Greengen, during construction, and HPI, during operations, were both effective in providing management oversight to HTICL. The performance of HTICL as the implementing agency was also rated *satisfactory*, and the project was implemented as planned. The project implementation benefitted significantly from the continuity of project coordinators (from CHNG, Greengen, and HTICL) throughout the process. This ensured a clear understanding of the needs of the project and mitigated the coordination risks involved in a multi-party institutional setup. Subsequent changes in the organizational setup and responsibilities of HTICL and Greengen that took effect after the plant commenced operation (para. 7), did not have an adverse impact on the efficient functioning of the organizations.

L. Performance of the Asian Development Bank

37. ADB's performance in monitoring the project was rated *satisfactory*. Project review missions that included the participation of environmental specialists/consultants were conducted regularly. Frequent consultations and briefings with the MOF contributed to the timely resolution of all project implementation issues and facilitated project implementation. ADB approved all relevant procurement packages and processed withdrawal applications promptly for the timely disbursement of funds, and the reallocation of loan proceeds. The continuity of the ADB project officer was recognized by the executing agency as a positive factor in ensuring timely decisions on requested actions and changes in implementation.

III. EVALUATION OF PERFORMANCE

A. Relevance

38. The project is consistent with the priorities of ADB and the government at the time of appraisal, and remains consistent with those priorities. The project design was rated *highly relevant* as it demonstrated a key enabling technology with potential for large GHG emission reductions from coal usage in the largest coal-consuming country in the world. Consultants hired under the grant provided additional technical due diligence, and helped mitigate associated risks, strengthen compliance with safeguard policies, and thereby establish appropriate benchmarks and standards for future IGCC projects. The successful implementation of the project provided the valuable experience, developed the institutional capacity, clarified the difficulties and problems, and determined the workable solutions and further improvements needed to develop a scaled-up IGCC power plant. The knowledge products funded with the grant, i.e., the IGCC and CCS roadmaps, underscored the relevance of the technology for the PRC in the context of the government's efforts to remediate air pollution and mitigate climate change.[22]

[22] ADB. 2015. *Roadmap for Carbon Capture and Storage Demonstration and Deployment*. Manila.

B. Effectiveness in Achieving Outcome

39. The project was rated *effective* in achieving its expected outcome of demonstrating an advanced clean coal technology that met growing electricity demand in an environmentally sustainable manner by improving the thermal efficiency of the power sector and reducing the rate of growth in coal consumption. While CO_2 capture was also successfully pilot tested at the plant, CO_2 utilization and storage could not be achieved at the moment, due to difficulties in getting a CO_2 offtake agreement with an oil field operator.[23] The project achieved its immediate objective of providing additional electricity generation capacity by utilizing less coal, thereby avoiding harmful emissions. As of end 2016, the project had achieved CO_2 reductions equivalent to 0.45 million t since 2013 and is expected to provide an additional 3.5 million t of CO_2 reduction during its economic life (or about 0.16 million t per year). Significant reductions in SO_2, NO_X, and PM have also been achieved. The Tianjin IGCC plant has been operating reliably and can generate its designed output, restricted only by the limitations set by the power grid. IGCC and CCS technologies (paras. 5 and 17) are among the government's key innovative energy technologies to be deployed by 2030.[24] There are currently two commercial-scale IGCC plants in various stages of planning—one in Jiangsu Province and one in Shanxi Province.

C. Efficiency in Achieving Outcome and Outputs

40. The project was rated *less than efficient* in achieving its outcomes and outputs. Major project components were constructed, installed, and commissioned successfully and as planned. However, being a highly complex prototype in the PRC, the project experienced challenges during commissioning and trial operations. These challenges, however, were overcome significantly faster than in previous demonstration projects in other parts of the world (footnote 19). The project design included measures to mitigate some anticipated risks during the early stages of operation, ensuring that high-level expertise was available to the project during its teething phase.

41. The organizational setup, management, and approval processes of CHNG, Greengen and subsequently HPI and HTICL met the project's requirements. International competitive bidding allowed the selection of the most technically suitable and commercially advantageous bids and resulted in savings. Counterpart funds were adequate and provided in a timely manner.

1. Economic Evaluation

42. The economic evaluation of the project followed the methodology used at appraisal following ADB's *Guidelines for the Economic Analysis of Projects*.[25] The recalculated economic internal rate of return (EIRR) was 8.2% (compared with 16.5% at appraisal). This discrepancy was due to a combination of factors: higher than projected project cost; lower revenues from lower electricity generation and sales; and higher O&M costs. The EIRR is below the 12.0% hurdle rate for the economic opportunity cost of capital used at appraisal. The environmental benefits improved the economic viability of the project, from 8.0% to 8.2%. Complete quantification and estimation of all benefits from the project were not calculated at appraisal and at completion due to a lack of time and resources. Thus, the total benefits estimated in this analysis can be interpreted as conservative. A summary of the EIRR calculation is in Appendix 9.

[23] The oil-field operator was reluctant to sign up a CO_2 off-take arrangement due to the prevailing low price of oil, which diminished economic return from injecting CO_2 and produce incremental oil.

[24] National Development and Reform Commission and National Energy Administration. 2016. Notice No. 513 on *The Action Plan for Energy Technology Revolutionary Innovation*, *2016–2030.* Beijing.

[25] ADB. 2017. *Guidelines for the Economic Analysis of Projects.* Manila.

2. Financial Evaluation

43. The financial internal rate of return (FIRR) was determined for the project using actual investment costs, and a combination of historical and projected data for revenues and costs. Operating results for 2016 were used for projections up to 2019. These results were adjusted from 2020 to reflect expected improvements in the plant load factor as measures implemented by the government to optimize capacity utilization of existing fixed-asset investments take shape (para. 45). The recalculated FIRR for the project was 4.4%, compared with 6.4% at appraisal. This is higher than the weighted average cost of capital (WACC) of 2.0%, although lower compared to the estimate at appraisal. The lower recalculated FIRR resulted from (i) higher capital costs; (ii) lower actual energy output and sales until 2019; (iii) higher O&M; and (iv) the plant's high auxiliary consumption, mitigated by the actual higher electricity tariff.[26] A summary of the FIRR calculation is in Appendix 10.

D. Preliminary Assessment of Sustainability

44. The project is rated *likely sustainable*. The operating facilities were designed and installed properly, and are functioning well. The plant, which is staffed by a highly professional and skilled team of engineers, is operating reliably and has attained its performance parameters. HTICL has proven its ability to manage the plant's complex operating system. CHNG continues to provide (i) high standards of professionalism; (ii) organizational direction to achieve goals and targets for global competitiveness; and (iii) strong financial backing.

45. The financial viability of the project was a major concern during the initial years of its commercial operations, and remains so for a variety of reasons (para. 30), foremost of which is the underutilization of available capacity. This constitutes less efficient use of resources, resulting in operational losses. This situation was nevertheless mitigated with government support in the form of direct financial subsidies and adjustments in electricity tariff (para. 30). The three successive tariff adjustments approved for the Tianjin IGCC plant (footnote 20), bringing it to the current level of CNY0.75 per kWh, clearly manifest the government's commitment to support the development of this emerging technology and alleviate the proponent's financial burden. These adjustments aligned the pricing of the IGCC generated power to that of a natural-gas-based power plant, which produces the same environmental performance. The government has likewise adopted measures to promote optimal utilization of resources and ensure viability of clean energy projects by mandating closure of inefficient power plants and restricting addition of new thermal capacities in the power sector. As the PRC economy and the demand for electricity recover, the project is expected to generate modest profits that will allow it to meet ADB's financial covenants. Despite the operating losses sustained in the early years of operations, projected net revenue flows for the project are positive, although modest, and the recalculated FIRR remains above the WACC. Appropriate tariff reforms that allow full cost recovery, with an adequate profit margin, remains crucial to ensure sustainable operations. Higher capacity utilization will improve the sustainability of the Tianjin IGCC project. Further, additional revenues can be generated by the project as it qualifies under PRC's emission trading scheme programmed to be implemented in 2017. The plant's improved environmental performance compared to the coal-fired plant and the government's strong commitment to its clean energy program will keep the project afloat.

[26] The auxiliary consumption of the plant is high as the air compressor and supercharger units of the power plant are currently driven by electricity. If steam drives are adopted, the plant's auxiliary power consumption rate is expected to fall from 21% to just 5%, making the plant even more efficient.

E. Impact

1. Environmental Impact

46. The Tianjin IGCC plant was classified as environmental safeguards category A in accordance with ADB's Environment Policy (2002) criteria. To comply with the environment safeguard requirements, institutional arrangements were established and environmental mitigation measures were performed adequately. HTICL established an environmental management unit (EMU) to coordinate implementation of the environmental management plan (EMP) with the Tianjin Environmental Protection Bureau. Environmental monitoring consultants and contractors supported the EMU and coordinated the EMP monitoring activities with the Tanggu Environmental Monitoring Station (EMS). The Tanggu EMS conducted regular monitoring of air, water quality, noise, ecological impacts, and solid waste treatment in the project area, and together with China National Environmental Monitoring Centre, conducted environmental monitoring for project completion acceptance in March 2014.

47. The EMP has been properly implemented. All the environmental protection facilities were constructed and are operating efficiently. The monitoring results show that the project did not have adverse impact on air and water quality in and around the project areas and that all the environmental pollution emissions comply with relevant standards, with the exception of the noise level at the project's boundary during the early stage of project operation but further mitigation measures have already been implemented to alleviate the concern.[27] No environmental infringements were recorded during the project construction. No environmental complaints from local residents and others were received. Environmental monitoring reports were received for May 2012, March–October 2012, November 2012–October 2013, and November 2012–October 2014.

48. Compared with conventional coal-fired power plants, the Tianjin IGCC plant substantially reduced emissions of major air pollutants including SO_2, NO_x, total suspended particulates, and CO_2. It also consumes only 1/3 cooling water compared to a conventional coal-fired plant. The plant achieved a significant reduction in air pollutant emissions during project operation. By end 2016, the average power generation efficiency of the plant reached 48.7% (or 261 grams of coal equivalent (gce)/kWh). Based on operation data in 2016, the power generation emission coefficients of the Tianjin IGCC plant were SO_2 0.039g/kWh, NO_X 0.159g/kWh and dust 0.002g/kWh, compared with emission limits for coal-fired power plants. In the first half of 2017, dust emission further reduced to 0.01-0.02 g/kWh.[28] Appendix 11 contains a summary assessment of the impact of the project on the environment, and environmental indices.

2. Social Impact

49. The project is classified as category C in terms of involuntary resettlement and indigenous people impacts. Prior to loan approval, the project had acquired 21 hectares of newly reclaimed land in an existing industrial park and therefore did not entail any resettlement. There were no ethnic minority groups in the area affected by the project. The project provided direct social benefits in terms of creating employment and livelihood opportunities and indirect benefits through improved air quality. Equal opportunities were extended to the poor and to women. Women have equal access to services, resources, assets, opportunities and participation in decision-making. During project construction, worker numbers peaked at more than 1,000; about 280 staff are employed for the plant's O&M, 1/3 of which are women. Safety management was emphasized. Numerous safety regulations were developed and safety training was conducted. There were no

[27] In any case, the project is in an industrial zone and the nearest residential area is 5 kilometers away.

[28] The PRC's Emission Standards for Thermal Coal Plants (GB13223-2011). The information and data on the plant's performance were provided by the project company.

reported accidents or injuries. This has exceeded all expectations and has set a benchmark for safety in the construction of IGCC plants.

3. Institutional Development and Capacity Building

50. The staff of Greengen and HTICL received foreign and local training in technical and management aspects. They also attended ADB-sponsored training programs in procurement and project management. Sharing knowledge and experiences with the international and national consultants enhanced the staff's know-how and competence. Training in safeguards monitoring was also provided for the EMU staff and plant personnel. The training programs enhanced the staff's technical, operating, and managerial capabilities, and environmental consciousness. These formal training programs no doubt helped improve the institutional capability and proficiency of the implementing agency's staff, but their experience in going through an entire project development process involving a new and complex technology provided the greatest motivation and reward.

4. Development Impact/ Special Development Impact (Innovation)

51. The Tianjin IGCC plant is the first of its kind not only in the PRC, but also in the Asia and Pacific region, and its development impact in terms of promoting environmentally sustainable growth through reduction of GHG emissions from coal-fired power plants can be considered *satisfactory*. It also successfully demonstrated that undertaking a highly innovative and pioneering project can be commercially feasible. IGCC was one of the PRC's key projects in the 863 Program, or the State High-Tech Development Plan, for the power generation sector. The 863 Program is intended to stimulate the development of advanced technologies. The successful implementation of the Tianjin IGCC project has reaped important lessons for further development of the gasification and pre-combustion carbon capture technology, which are included in the government's Energy Technology Revolution Action Plan, 2016–2030.

IV. OVERALL ASSESSMENT AND RECOMMENDATIONS

A. Overall Assessment

52. Overall, the project is rated *successful*. It was highly relevant to the government's development strategy and ADB's country operational strategy for the PRC, and was effective in demonstrating climate change mitigation through the use of new IGCC technology in a power plant. The project was implemented as designed, without major changes in scope. Project implementation proceeded smoothly and project completion was timely and on schedule. The actual project cost was higher than estimated at appraisal, primarily as a result of lower cost estimates and the longer commissioning, which resulted in substantial oil and coal consumption. The project had environmental and developmental impacts that were significant and largely positive. It achieved an EIRR of 8.2%, and an FIRR of 4.4%, which was higher than the WACC.

53. The project achieved its objective of sustainable energy development in the PRC by demonstrating a more environment-friendly clean coal technology that has substantially reduced emissions. Since the project was completed, air pollution has been reduced (para. 48). Importantly, the lessons learned in the project implementation and operations have been documented through knowledge products funded by the grant and shared through various domestic and international fora. The project had an important role in providing a pathway for the eventual CCS rollout thereby contributing to the PRC's clean energy development goals.

B. Lessons

54. The strong commitment and ownership of the project proponents is critical to the success of a demonstration project that uses the latest technologies for the first time in a country. Establishing a dedicated entity responsible for the review of the technical design, construction and operation of the project facilities is a key success factor. Similarly, strong institutional support is crucial to ensure the viability of a project with complex challenges.

55. Adoption of a relatively young technology that has yet to establish a robust performance track record and achieve lower capital and operating costs, but offers significant improvement potential in terms of lower CO_2 capture costs, can be realized. Meticulous attention to technical design, operating standards and associated costs can deliver commercial attractiveness and competitiveness with other power generation technologies. As highlighted in the knowledge products, the PRC is well positioned to benefit from economies of scale through limiting production costs, and standardization. However, reaching the necessary performance requirements for the plant is critical. Continuing research and improvements to enhance efficiency and bring down O&M costs will be indispensable.

56. There are inherent risks for early-mover projects in new technology areas when the complementary policies and regulations have not yet been well formed. This project is a case in point, as IGCC technology did not have a specific tariff in the PRC. Nonetheless, the project team worked diligently to seek a higher tariff, up to the value of the natural-gas-plant-based tariff, which augurs well for future IGCC plants. Similarly, cost estimation for a new technology being used for the first time in a new setting is always challenging. The dilemma is that if the cost estimates are too conservative, the plant costs may increase so much that the plant construction will be at risk. The overall financial strength of the project sponsors for projects that may require a significant, unanticipated amount of counterpart financing is important. This was demonstrated in the ability to mobilize additional equity and domestic loans needed to finance unanticipated cost overruns.

57. Obtaining assistance from international and national experts in the field is helpful. The grant-funded consultants conducted technical studies that identified areas of improvement in the design and operating procedures, and the monitoring and control of plant performance parameters. These supplemented the knowledge and observations of the plant operators and maintenance personnel.

58. The project demonstrated the ability of the project proponents, supported by ADB, to design and construct a highly innovative high-technology coal-based power plant with natural-gas-like environmental emissions. The project laid the groundwork for achieving substantial environmental benefits, including significant GHG mitigation, and a shift to a cleaner, sustainable energy path.

C. Recommendations

1. Project Related

59. **Further monitoring.** ADB will continue to monitor the operations results of the Tianjin IGCC plant and the measures undertaken by the implementing agency to improve operating performance and profitability as well as compliance to environmental standards. Information on the performance of the pilot CCUS plant and construction of the scaled-up IGCC plant will also be obtained to determine areas of assistance in the development of CCS technology, in which ADB is taking a lead role.

60. **Timing of the project performance evaluation report**. It is recommended that a project performance evaluation review be fielded in 2019–2020. By that time, additional data on the operation of the Tianjin IGCC demonstration project would be available.

2. General

61. The Tianjin IGCC demonstration project is the first of its kind not only in the PRC, but in any developing member country. Valuable lessons can be shared with other developing member countries that are contemplating such projects. Comparison of international experiences with that of the PRC as well as valuable lessons learned in the development of IGCC technology are well documented in the knowledge products funded by the grant. Importantly, a roadmap for CCS technology was also prepared in parallel with the project's implementation, which lends this project and the IGCC technology in an advantageous position for future application of the CCS at this plant to reduce its carbon foot prints.[29] Continuing collaboration with industry leaders, policy makers and experts through exchange of information can pave the way for larger replication of the IGCC power plants throughout the PRC.

[29] The roadmap for CCS demonstration and deployment in the PRC (ADB. 2015. *Roadmap for Carbon Capture and Storage Demonstration and Deployment*. Manila.) was jointly prepared by ADB and NDRC's Department of Climate Change, which is spearheading CCS commercial development in the PRC. It was jointly launched in a high-level side event at the Community of Practice (COP) 21 meetings in Paris. CCS is included as an important technology in PRC's nationally determined contributions under the Paris Agreement.

DESIGN AND MONITORING FRAMEWORK

Design Summary	Performance Indicators/Targets	
	Appraisal	**Actual**
Impact Reduced GHG emissions from coal-fired power plants	Capacity of IGCC plant increases to 3 GW by 2020 from 1 GW by 2015 Multiple IGCC–CCS demonstration plants implemented, storing at least 1 million CO_2 per annum by 2020 Ambient air quality in all cities improved and maintained to at least grade II of national standards by 2015	Further deployment of the IGCC technology is being assessed taking into account the experience and lessons learned in the Tianjin IGCC. Plans are underway to construct commercial scale IGCC plants in the Jiangsu Province and Shanxi Province. A pilot CCUS plant that can capture up to 100,000 tons of CO_2 has been built and completed since August 2016. For the project city, ambient air quality met Class II air quality standards except for PM_{10}. Reduction in CO_2 emissions, compared to a conventional coal-fired plant will be about 3.5 million tons during the project's economic life (0.16 million ton per year).[1]
Outcome IGCC plants demonstrating climate change mitigation effect of new technology deployed	IGCC plant achieves reliability compared to that of conventional coal-fired base-load power plants by 2015	Achieved Tianjin IGCC achieved reliability targets comparable to the conventional coal-fired plants. Actual operational results showed that designed operating level can be achieved but actual dispatch level is controlled by the power grid.
Outputs 1. A 250 MW IGCC demonstration plant constructed at Tianjin	The plant starts generating electricity in 2012, achieves full capacity, and produces 1,470 GWh additional clean coal energy per annum from 2013	The power plant was commissioned in 2012 as scheduled. Full capacity has been achieved and can produce 1,470 GWh as designed but actual production in 2016 has been limited to 1,325 GWh, or 90% of capacity, due to power grid constraints.
2. Adequate plant O&M capacity created	On-the-job training provided as part of suppliers' long-term maintenance contracts New learning successfully applied during project implementation Additional training provided in project management, safeguard compliance, and project reporting	Achieved. On-the-job training for 60 O&M personnel was provided by the equipment suppliers. Achieved. IGCC is a new and complex technology and the first of its kind in the PRC and the region. Extensive training needed to be undertaken and applied successfully to construct, operate and maintain the project. This was effectively demonstrated by both the executing and implementing agencies with the successful continuous operation of the power plant.

Design Summary	Performance Indicators/Targets	
	Appraisal	**Actual**
		Achieved. Training was provided for all the 280 regular staff of the implementing agency in various aspects of operations including project management and project reporting. Supervisory staff and those performing environmental monitoring functions were provided training on safeguard compliance.
3. Capacity developed for obtaining carbon offset revenues from IGCC plants	Adequate training provided for staff of HTICL and Greengen to successfully obtain carbon revenues from IGCC projects Relevant documents prepared Follow-through, which ensures compliance with national and international requirements Organizational setup conducive to achieving intended results	Training program was not organized as subsequent developments in the carbon trading market resulting in the collapse of carbon price rendered it unnecessary. The PRC is setting up its own carbon trading market and developing its own set of criteria and guidelines.
Activities	Construct 250 MW Tianjin IGCC plant with a starting date of 2009 and a completion date of 2012. Plant to generate 1,470 GWh of power from 2012	Achieved. Generation level of 1,470 GWh can be achieved based on results of operations but the actual generation level has been limited to 1,325 GWh in 2016 due to power grid constraints.

CCS = carbon capture and storage, CCUS = carbon capture, utilization and storage, CO_2 = carbon dioxide, GHG = greenhouse gas, Greengen = Greengen Company Ltd., GW = gigawatt, GWh = gigawatt hour, HTICL = Huaneng Tianjin Integrated Gasification Combined Cycle Co. Ltd., IGCC = integrated gasification combined cycle, MW = megawatt, O&M = operation and maintenance, PRC = People's Republic of China.

[1] ADB. 2017. Results Framework Indicator Definitions. Manila.

PROJECT COST AND FINANCING PLAN

Table A2.1: Project Cost
($ million)

Cost	Appraisal	Actual	% Increase (Decrease)
Foreign Exchange Cost	140.00	110.60	(21)
Local Currency Cost	279.59	417.82	49
Total	**419.59**	**528.42**	**26**

Source: Asian Development Bank.

Table A2.2: Financing Plan
($ million)

Cost	Appraisal	%	Actual	%	% Increase (Decrease)
A. Asian Development Bank					
Ordinary Capital Resources	135.00	32.17	105.73	20.00	(22)
Grant from Climate Change Fund	5.00	1.19	4.87	0.92	(3)
Subtotal (A)	**140.00**	**33.37**	**110.60**	**20.93**	**(21)**
B. Counterpart Financing					
Equity	84.00	20.02	134.03	25.36	60
Domestic Loan	195.59	46.61	283.79	53.71	45
Subtotal (B)	**279.59**	**66.63**	**417.82**	**79.07**	**49**
Total	**419.59**	**100.00**	**528.42**	**100.00**	**26**

Source: Asian Development Bank.

COST BREAKDOWN BY PROJECT COMPONENT
($ million)

Item	Appraisal			Actual			% Increase (Decrease)
	FX	LC	Total Cost	FX	LC	Total Cost	
A. Base Cost							
1. Civil Works	1.80	64.05	65.85	23.84	54.02	77.86	18
2. Power Plant Equipment	115.00	98.66	213.66	66.85	162.34	229.19	7
3. Plant Erection and Equipment Installation	0.00	57.52	57.52	0.00	71.48	71.48	24
4. Technical Services, Including Commissioning	5.00	16.29	21.29	4.87	61.37	66.24	211
5. Project Management	0.00	9.81	9.81	0.00	17.63	17.63	80
6. Land Acquisition and Related Charges	0.00	6.86	6.86	0.00	20.52	20.52	199
Subtotal (A)	**121.80**	**253.19**	**374.99**	**95.55**	**387.36**	**482.91**	**29**
B. Contingencies							
1. Physical Contingency	0.00	14.54	14.54	0.00	1.50	1.50	(90)
2. Price Contingency	0.00	7.96	7.96	0.00	0.00	0.00	(100)
Subtotal (B)	**0.00**	**22.50**	**22.50**	**0.00**	**1.50**	**1.50**	**(93)**
C. Financial Charges During Development	**18.20**	**3.90**	**22.10**	**15.05**	**28.96**	**44.01**	**99**
Total (A+B+C)	**140.00**	**279.59**	**419.59**	**110.60**	**417.82**	**528.42**	**26**

FX = foreign exchange, LC = local currency.
Note: Figures may not add up due to rounding.
Source: Asian Development Bank and project implementation units.

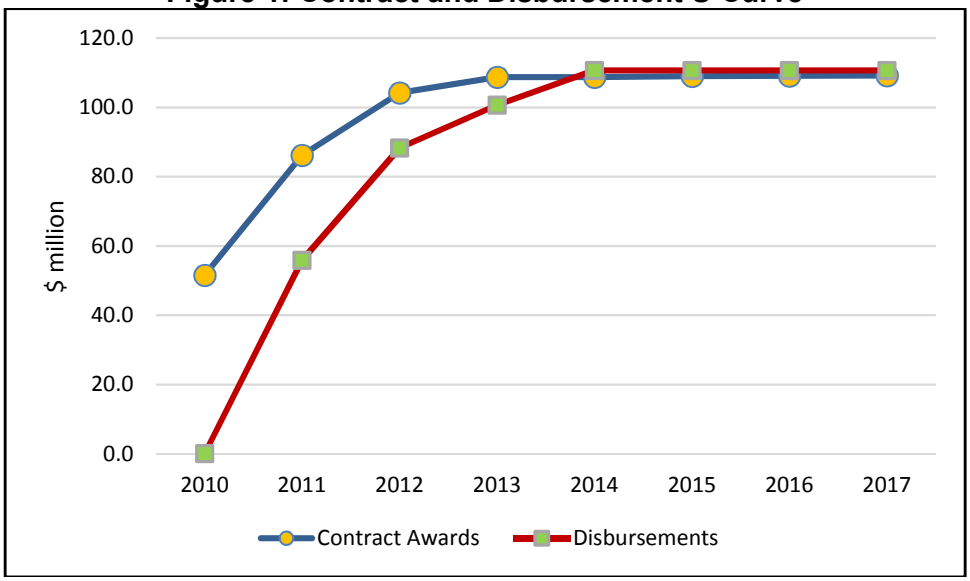
PROJECTED AND ACTUAL DISBURSEMENT

Table A.4: Projected and Actual Contract Awards and Disbursements
($ million)

Year	Contract Awards						Disbursements					
	Proj	Q1	Q2	Q3	Q4	Total	Proj	Q1	Q2	Q3	Q4	Total
2010	51.6	0.0	0.0	48.1	1.9	50.0	0.1	0.0	0.0	0.0	0.1	0.1
2011	34.6	5.1	7.1	10.9	10.5	33.6	55.8	16.8	11.3	13.8	13.5	55.3
2012	18.0	7.9	0.1	10.4	1.6	20.1	32.4	0.5	0.2	17.2	14.5	32.4
2013	4.5	0.9	0.3	4.5	0.4	6.1	12.4	0.0	0.3	0.0	12.2	12.4
2014	0.0	0.0	0.2	0.0	0.2	0.4	10.0	0.0	1.5	0.0	8.5	10.0
2015	0.3	0.2	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0
2016	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4
Total	**109.2**	**14.2**	**7.8**	**74.0**	**14.7**	**110.6**	**110.7**	**17.7**	**13.3**	**31.0**	**48.7**	**110.6**

Proj = projection, Q = quarter.
Source: Asian Development Bank.

Figure 1: Contract and Disbursement S-Curve



PROJECT IMPLEMENTATION SCHEDULE

Item	2008				2009				2010				2011				2012				2013			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Tianjin IGCC Project																								
Project Preparation																								
Pre-Construction																								
ADB Procurement (including consultancy services under the Grant)																								
Sep 2009–Apr 2013																								
Delivery of Plant and Equipment																								
Aug–Oct 2010																								
Civil Works and Construction																								
Sep 2009–Apr 2012																								
Installation of Plant and Equipment																								
Sep 2009–Apr 2012																								
Testing and Commissioning																								
Aug 2012–Nov 2012																								

ADB = Asian Development Bank, IGCC = integrated gasification combined cycle.

Legend: Projected
Actual

CHRONOLOGY OF MAJOR EVENTS

Date	Event
May 2009	Loan fact-finding
July 2009	Date of commencement/groundbreaking
September 2009	Management review meeting Commencement of installation of gasifier
February 2010	Asian Development Bank loan approval
May 2010	Signing of loan and project agreements
August 2010	Loan effectiveness Gas turbine of Tianjin Integrated Gasification Combined Cycle (IGCC) hoisted in position
September 2010	Civil works and installation engineering for gasification island and air separation island were awarded through international competitive bidding
October 2010	Tianjin IGCC gasifier completed
April 2011	Steam turbine installation completed
August 2011	Air separation unit installation completed
April 2012	Completion of equipment installation Gasification unit was ignited successfully for the first time
September 2012	Technological process of Tianjin IGCC power generation system was completed, and first electricity supply to grid test went smoothly
November 2012	Completion of 72+24-hour (h) operation tests
December 2012	Commissioning Tianjin IGCC achieved 1,500 h continuous operation
July 2013	The contract for the long-term maintenance to reduce the operational risks of the complex technology during the plant's first year of operation is now ongoing.
November 2014	Tianjin IGCC achieved 1,500 consecutive hours of running, with the annual power generation exceeding 3,000 gigawatt-hours
March 2015	Tianjin IGCC completed 72 h of full-load test
December 2015	The continuous running of Tianjin IGCC exceeded 80 days
November 2016	Project completion review mission

STATUS OF COMPLIANCE WITH LOAN AND GRANT COVENANTS

Covenant	Reference in Legal Agreement	Status of Compliance
1. CHNG shall cause Greengen and HTICL to carry out, and Greengen and HTICL, shall carry out the Project with due diligence and efficiency, and in conformity with sound administrative, financial, engineering, environmental, construction, operation, maintenance, and energy practices. 2. In the carrying out of the Project and operation of the Project facilities, EXIM, CHNG, Greengen, and HTICL shall perform all obligations set forth in the Loan Agreement to the extent that they are applicable to EXIM, CHNG, Greengen, and HTICL, respectively, and all obligations set forth in the Schedule to this Project Agreement.	Project Agreement (PA), Article (Art) II, Section (Sec) 2.01; Loan Agreement (LA), Art. IV, Sec. 4.01; Grant Agreement (GA), Art. IV, Sec. 4.01; Project Agreement for the Grant Agreement (PGA), Art. II, Sec. 2.01	Complied with. CHNG, Greengen, HTICL and EXIM fulfilled their respective obligations under the Loan and Grant, and Project Agreements.
3. EXIM, CHNG, Greengen, and HTICL shall make available, promptly as needed, the funds, facilities, services, equipment, land and other resources which are required, in addition to the proceeds of the Loan, for the carrying out of the Project.	PA, Art. II, Sec. 2.02; LA, Art. IV, Sec. 4.02; PGA, Art. II, Sec. 2.02	Complied with. CHNG, Greengen, HTICL and EXIM fulfilled their respective obligations under the Loan and Grant, and Project Agreements.
4. In the carrying out of the Project, HTICL shall employ competent and qualified consultants and contractors, acceptable to ADB, to an extent and upon terms and conditions satisfactory to ADB. 5. Except as ADB may otherwise agree, all Goods and Works to be financed out of the proceeds of the Loan shall be procured in accordance with the provisions of Schedule 4 to the Loan Agreement. ADB may refuse to finance a contract where Goods or Works have not been procured under procedures substantially in accordance with those agreed between the Borrower and ADB, or where the terms and conditions of the contract are not in accordance with ADB's Procurement Guidelines.	PA, Art. II, Sec. 2.03; PGA, Art II, Sec. 2.03	Complied with. All packages financed by ADB were procured in accordance with ADB's Procurement Guidelines and the Guidelines on the Use of Consultants, and with the provisions of Schedule 4 of the loan agreement. Consultants hired under the grant provided additional technical due diligence and helped mitigate associated risks, strengthen compliance with safeguard policies, and thereby establish appropriate benchmarks and standards for future IGCC projects.
6. CHNG and Greengen shall cause HTICL to, and HTICL shall, carry out the Project in accordance	PA, Art. II, Sec. 2.04;	Complied with.

Covenant	Reference in Legal Agreement	Status of Compliance
with plans, design standards, specifications, work schedules and construction methods acceptable to ADB. CHNG, Greengen, and HTICL shall furnish, or cause to be furnished, to ADB, promptly after their preparation, such plans, design standards, specifications and work schedules, and any material modifications subsequently made therein, in such detail as ADB shall reasonably request.	PGA, Art. II, Sec. 2.04	CHNG, Greengen and HTICL fulfilled all their respective responsibilities.
7. Greengen shall cause HTICL to, and HTICL shall take out and maintain with responsible insurers, or make other arrangements satisfactory to ADB for, insurance of the Project facilities to such extent and against such risks and in such amounts as shall be consistent with sound practice. 8. Without limiting the generality of the foregoing, Greengen, and HTICL undertake to insure, or cause to be insured, the Goods to be imported for the Project and to be financed out of the proceeds of the Loan against hazards incident to the acquisition, transportation and delivery thereof to the place of use or installation, and for such insurance any indemnity shall be payable in a currency freely usable to replace or repair such Goods.	PA, Art. II, Sec. 2.05; PGA, Art II, Sec. 2.05	Complied with. Complied with.
9. CHNG and Greengen shall cause HTICL to, and HTICL shall, maintain records and accounts adequate to identify the Goods and Works and other items of expenditure financed out of the proceeds of the Loan, to disclose the use thereof in the Project, to record the progress of the Project (including the cost thereof) and to reflect, in accordance with consistently maintained sound accounting principles, their operations and financial conditions.	PA, Art. II, Sec. 2.06; PGA, Art. II, Sec. 2.06	Complied with.
10. ADB, EXIM, CHNG, Greengen and HTICL shall cooperate fully to ensure that the purposes of the Loan will be accomplished. 11. EXIM, CHNG, Greengen, and HTICL shall promptly inform ADB of any condition that interferes with, or threatens to interfere with, the progress of the Project, the performance of their obligations under this Project Agreement, the Subsidiary Loan Agreement, the CHNG Onlending Agreement, the Greengen Onlending Agreement, or the HTICL Onlending Agreement, or the accomplishment of the purposes of the Loan. 12. ADB, EXIM, CHNG, Greengen, and HTICL shall from time to time, at the request of either party, exchange views through their representatives with	PA, Art. II, Sec. 2.07; PGA, Art. II, Sec. 2.07	Complied with. Complied with. Complied with.

Covenant	Reference in Legal Agreement	Status of Compliance
regard to any matters relating to the Project, EXIM, CHNG, Greengen, HTICL and the Loan.		
13. EXIM, CHNG, Greengen and HTICL shall furnish to ADB all such reports and information as ADB shall reasonably request concerning: (i) the Loan and the expenditure of the proceeds thereof; (ii) the Goods and Works and other items of expenditure financed out of such proceeds; (iii) the Project; (iv) the administration, operations and financial conditions of Greengen and HTICL; and (v) any other matters relating to the purposes of the Loan. 14. Without limiting the generality of the foregoing, Greengen and HTICL shall furnish to ADB quarterly reports on the execution of the Project and on the operation and management of the Project facilities. Such reports shall be submitted in such form and in such detail and within such a period as ADB shall reasonably request, and shall indicate, among other things, progress made and problems encountered during the quarter under review, steps taken or proposed to be taken to remedy these problems, and proposed program of activities and expected progress during the following quarter. 15. Promptly after physical completion of the Project, but in any event not later than 6 months thereafter or such later date as ADB may agree for this purpose, Greengen and HTICL shall, prepare and furnish to ADB a report, in such form and in such detail as ADB shall reasonably request, on the execution and initial operation of the Project, including its cost, the performance by CHNG, Greengen, and HTICL of their obligations under this Project Agreement and the accomplishment of the purposes of the Loan.	PA, Art. II, Sec. 2.08; PGA, Art. II, Sec. 2.08	Complied with. The Project provided timely progress reports on an annual basis. HTICL provided timely inputs on the preparation of the project completion report. Generally complied with. Generally complied with.
16. HTICL shall: (i) maintain separate accounts for the Project and for its overall operations; (ii) have such accounts and related financial statements (balance sheet, statement of income and expenses, and related statements) audited annually, in accordance with appropriate auditing standards consistently applied, by independent auditors whose qualifications, experience and terms of reference are acceptable to ADB; and (iii) furnish to ADB, promptly after their preparation but in any event not later than 6 months after the close of the fiscal year to which they relate, certified copies of such audited accounts and financial statements and the report of the auditors relating thereto (including the auditors' opinion on the use of the Loan proceeds and compliance with the	PA, Art. II, Sec. 2.09; Grant Agreement (GA), Art. IV, Sec. 4.02; PGA, Art. II, Sec. 2.09	Complied with. The required financial statements were prepared in accordance with the requirements of *Accounting Methods for the World Bank Financed Projects* and audited in accordance with the Government Auditing Standards of the People's Republic of China and International Standards on Auditing. The project accounts and financial statements were submitted regularly and mostly

Covenant	Reference in Legal Agreement	Status of Compliance
covenants of the Loan Agreement as well as a separate opinion on the use of the procedures for SGIA and statement of expenditures), all in the English language. HTICL shall furnish to ADB such further information concerning such accounts and financial statements and the audit thereof as ADB shall from time to time reasonably request. 17. EXIM, Greengen, and HTICL shall enable ADB, upon ADB's request, to discuss HTICL's financial statements and their financial affairs in relation to the Project from time to time with the auditors engaged by HTICL pursuant to Section 2.09(a) hereabove, and shall authorize and require any representative of such auditors to participate in any such discussions requested by ADB, provided that any such discussion shall be conducted only in the presence of an authorized officer of EXIM, Greengen, and HTICL unless HTICL shall otherwise agree.		on time. The auditor rendered unqualified opinions on the financial statements. Not invoked by ADB.
18. CHNG, Greengen and HTICL shall enable ADB's representatives to inspect the Project, the Goods and Works financed out of the proceeds of the Loan, all other plants, sites, properties and equipment of HTICL relevant to the Project, and any records and documents relevant to the Project.	PA, Art. II, Sec. 2.10; GA, Art. IV, Sec. 4.03; PGA, Art. II, Sec. 2.10	Complied with. Project site visits, especially during construction, were conducted during review missions.
19. EXIM, CHNG, Greengen and HTICL shall, promptly as required, take all action within their powers to maintain their corporate existence, to carry on their operations, and to acquire, maintain and renew all rights, properties, powers, privileges and franchises which are necessary in the carrying out of the Project or in the conduct of their businesses. 20. EXIM, CHNG, Greengen and HTICL shall at all times conduct their businesses in accordance with sound administrative, financial, construction, operation, maintenance, environmental and energy practices, and under the supervision of competent and experienced management and personnel. 21. Greengen and HTICL shall at all times operate and maintain their plants, equipment and other property, and from time to time, promptly as needed, make all necessary repairs and renewals thereof, all in accordance with sound administrative, financial, engineering, environmental, energy, construction, and maintenance and operational practices.	PA, Art. II, Sec. 2.11; PGA, Art. II, Sec. 2.11	Complied with. Complied with. Complied with.
22. Except as ADB may otherwise agree, CHNG, Greengen and HTICL shall not sell, lease or otherwise dispose of any of their assets which shall be required	PA, Art. II, Sec. 2.12;	Complied with.

Covenant	Reference in Legal Agreement	Status of Compliance
for the efficient carrying on of their operations or the disposal of which may prejudice their ability to perform satisfactorily any of their obligations under this Project Agreement.	PGA, Art. II, Sec. 2.12	
23. Except as ADB may otherwise agree, EXIM, CHNG, Greengen, and HTICL shall apply the proceeds of the Loan to the financing of expenditures on the Project in accordance with the provisions of the Loan Agreement and this Project Agreement, and shall ensure that all Goods and Works financed out of such proceeds are used exclusively in the carrying out of the Project.	PA, Art. II, Sec. 2.13; PGA, Art. II, Sec. 2.13	Complied with.
24. Except as ADB may otherwise agree, EXIM, CHNG, Greengen, and HTICL shall duly perform all their respective obligations under the Subsidiary Loan Agreement, CHNG Onlending Agreement, Greengen Onlending Agreement, and HTICL Onlending Agreement, to the extent such Agreements are applicable to EXIM, CHNG, Greengen, and HTICL, and shall not until the Project completion date, take, or concur in, any action which would have the effect of assigning, amending, abrogating or waiving any rights or obligations of the parties under the Subsidiary Loan Agreement, CHNG Onlending Agreement, Greengen Onlending Agreement, and HTICL Onlending Agreement in a manner that would negatively affect the Project.	PA, Art. II, Sec. 2.14; PGA, Art. II, Sec. 2.14	Complied with.
25. Greengen and HTICL shall promptly notify ADB of any proposal to significantly amend, suspend, or repeal any provision of their Charters and shall afford ADB an adequate opportunity to comment on such proposal prior to taking any action thereon.	PA, Art. II, Sec. 2.15; PGA, Art. II, Sec. 2015	No proposal for Charter amendment received.
Principal Onlending Agency 26. EXIM shall be the principal onlending agency and shall be responsible for: (a) onlending the proceeds of the Loan from the Borrower to CHNG in accordance with the terms and conditions set out in Section 3.01(a) of the Loan Agreement; and (b) related disbursement repayment and administration matters.	PA, Schedule (Sch), para. 1; LA, Sch. 5, para. 1	Complied with. EXIM Bank provided full cooperation on the onlending of proceeds of the loan to CHNG.
Project Executing Agency 27. CHNG shall be the Project Executing Agency and shall be responsible for the overall coordination and supervision of the Project. CHNG shall follow the implementation arrangements set forth in this Schedule and Schedule 5 to the Loan Agreement.	PA, Sch. para. 2; LA, Sch. 5, para. 2	Complied with. CHNG's performance as the executing agency is satisfactory.

Covenant	Reference in Legal Agreement	Status of Compliance
Project Implementing Agency 28. HTICL shall be the Project Implementing Agency and shall be responsible for the implementation of the Project. 29. Greengen shall be responsible for: (a) onlending the proceeds of the Loan from Greengen to HTICL; and (b) providing management and implementation support to and oversight of HTICL, supporting Project implementation, particularly in relation to financial management, financial control, and accounting, and ensuring good governance of the Project. Greengen shall also be responsible for liaising with CHNG. 30. HTICL and Greengen shall follow the implementation arrangements set forth in this Schedule and Schedule 5 to the Loan Agreement.	PA, Sch. paras. 3-5; LA, Sch. 5, paras. 3-5	Complied with. HTICL's performance as implementing agency was satisfactory and the project implementation schedule was implemented as planned. Complied with some changes in Greengen's reporting responsibility as discussed in para 7.
Project Management Unit 31. CHNG and Greengen shall cause HTICL to, and HTICL shall establish the PMU which shall be responsible for implementation of the Project, and such PMU shall oversee Project operations, including in particular disbursement, accounting, logistics management, reporting, monitoring, supervision, organization of research activities, and coordinating with relevant government departments, and development partners. 32. CHNG and Greengen shall cause HTICL to, and HTICL shall, ensure that: (a) the PMU is managed and operated by a full-time Project director, acceptable to ADB; (b) the Project director is supported by competent full-time senior officers of HTICL and other personnel acceptable to ADB; and (c) all day-to-day operations for the Project, including procurement and accounting, are conducted by persons with the relevant technical skills and experience.	PA, Sch. paras. 6-7; LA, Sch. 5, paras. 6-7	Complied with. Complied with.
Counterpart Funding 33. CHNG and Greengen shall ensure that: (a) all local and foreign currency counterpart financing necessary for the Project shall be provided, as to when due, to enable completion of the Project activities within the scheduled implementation period; and (b) additional counterpart financing shall be provided, if necessary, for any shortfall of funds or cost overruns, in each case to complete the Project activities on schedule.	PA, Sch. para. 8; LA, Sch. 5, para. 8	Complied with. Counterpart funds of $417 million were provided for the project.

Covenant	Reference in Legal Agreement	Status of Compliance
Operation and Maintenance 34. CHNG shall cause Greengen and HTICL to, and Greengen and HTICL shall be responsible for the operation and maintenance of the Project and shall provide sufficient counterpart funding for such operation and maintenance.	PA, Sch. para. 9; LA, Sch. 5, para. 9	Complied with.
Tariff 35. HTICL shall make a tariff petition to the Borrower's National Development and Reforms Commission (NDRC) for a reasonable tariff for electricity generated by the Project facilities to ensure that it shall cover operating costs, maintenance and depreciation, debt service, and a reasonable return on HTICL's net fixed assets. CHNG shall support HTICL's tariff petition to the NDRC	PA, Sch, para. 10; LA, Sch. 5, para. 10	Complied with. Since the plant operations, 3 tariff adjustments have been granted by the NDRC Price Bureau bringing the tariff to the current level of CNY0.75, which is at par with the tariff for natural gas plant.
Policy Change 36. Within 10 working days of becoming aware of any changes to any policies, procedures, regulations, or guidelines that may adversely affect the financial viability of the Project, including power pricing and load dispatch policies, CHNG, Greengen, and/or HTICL shall advise ADB of such changes.	PA, Sch, para. 11; LA, Sch. 5, para. 11	Complied with. Developments and issues in the electricity dispatch policies are appropriately discussed during project review missions.
Separate Legal Identity 37. CHNG and Greengen shall ensure that HTICL remains a separate legal entity with full financial and managerial autonomy as provided for under the relevant laws of the Borrower.	PA, Sch. para. 12; LA, Sch. 5, para. 12	Complied with.
Financial Performance 38. From the start of commercial operation of the Project, CHNG and Greengen shall ensure that HTICL: (a) maintains (i) a debt service coverage ratio of 1.2, (ii) a debt-equity ratio of 80:20, (iii) a reasonable return on fixed assets; and (iv) its accounts receivable at a level that does not exceed two (2) months of sales revenues; and (b) within five (5) years of the start of commercial operations, improves its debt service coverage ratio to 1.3 and its debt-equity ratio of 75:25.	PA, Sch, para. 13; LA, Sch. 5, para. 13	Not complied with until 2016. Projections from 2017 indicate gradual improvement with the combined effect of increased generation level and full year impact of tariff adjustment enhanced by cost reduction measures being adopted by HTICL. After 2020, when the designed generation level is expected to be attained, financial covenants will be met, except for the debt-equity ratio.
Auditing and Accounting 39. Greengen shall cause HTICL to ensure and HTICL shall ensure that: (a) proper accounts and records are maintained and audited in time to adequately identify the use of Loan proceeds in accordance with the Loan Agreement and the Project Agreement; and (b) a separate audit opinion is	PA, Sch. paras. 14-15; LA, Sch. 5, paras. 14-16	Complied with. The project maintained such records and accounts, and had them audited annually by the China National Audit Office.

Covenant	Reference in Legal Agreement	Status of Compliance
prepared on the Statement of Expenditure procedures and the Second Generation Imprest Account. 40. Within 3 months of effectiveness, CHNG and Greengen will cause HTICL to, and HTICL will: (a) establish internal accounting and financial control systems in accordance with national accounting standards to ensure the (i) regular monitoring of expenditures and all financial transactions, and (ii) the safe custody of all assets financed under the Project, including all Project facilities; (b) establish an independent and autonomous internal audit department; and (c) adopt computerized financial and management information systems to ensure efficient, effective and accountable financial and information management: in each case in a form and manner acceptable to ADB. 41. CHNG and HTICL shall ensure that qualified and independent auditors conduct performance audits or ''value for money'' reviews during Project implementation. Such performance audits may be conducted together with the financial audit as part of the overall annual project audit, in accordance with the Borrower's applicable audit law, regulations and policy. Performance audits or value for money reviews shall be conducted to determine the degree to which Project funds have been effectively and efficiently utilized to implement the Project, and achieve its objectives, outcomes and its performance indicators.		
Anticorruption 42. EXIM, CHNG, Greengen, and HTICL shall, comply with ADB's *Anticorruption Policy* (1998), as amended from time to time. EXIM, CHNG, Greengen, and HTICL agree: (a) that ADB reserves the right to investigate any alleged corrupt, fraudulent, collusive or coercive practices relating to the Project; and (b) to cooperate fully with any such investigation and to extend all necessary assistance, including providing access to all relevant books and records, as may be necessary for the satisfactory completion of any such investigation. In particular, Greengen, and HTICL shall: (i) conduct periodic inspections on the contractors' activities related to fund withdrawals and settlements; and (ii) ensure that all contracts financed by ADB in connection with the Project include relevant provisions of ADB's *Anticorruption Policy* in all bidding documents for the Project specifying the right of ADB to audit and examine the records and accounts of Greengen and HTICL and all contractors, suppliers, consultants and other service providers as they relate to the Project.	PA, Sch. para. 17; LA, Sch. 5, para. 17	No corruption case elevated to ADB during project implementation.

Covenant	Reference in Legal Agreement	Status of Compliance
Transparency and Accountability 43. Within 6 months of the Effective Date, CHNG, Greengen, and HTICL shall establish an internal dispute review mechanism, acceptable to ADB, to receive and resolve any concerns relating to all matters relating to the Project. 44. Within 6 months of the Effective Date, CHNG, Greengen and HTICL shall enhance and further develop the internet Project web-site that describes the Project in order to provide the public with information on the Project, including setting out: (a) a summary of the audited financial statements of the Project; (b) tracking of procurement contract awards; (c) any proposed tariff increases and associated scheduled public hearings; and (d) relevant laws and regulations. 45. HTICL shall periodically ensure such general information regarding the Project is publicly available (such as on radio and in newspapers) in the area within which the Project operates.	PA, Sch. paras. 18-20; LA, Sch. 5, paras. 18-20	Complied with.
Environment 46. HTICL shall ensure that construction, operation, maintenance, and monitoring of the Project facilities is in strict conformity with: (a) all applicable national and provincial environmental laws and regulations, ADB's *Environment Policy* (2002), and other national, provincial, and local laws and regulations and standards on environmental protection, health, labor, and occupational safety; and (b) all environmental mitigation and monitoring measures detailed in the design and construction contracts, the operational guidelines, and the approved Environmental Impact Assessment and Environmental Management Plan for the Project. 47. HTICL shall also ensure that: (a) an adequate number of full-time personnel and sufficient resources are provided to monitor the implementation of the environmental monitoring program, under the guidance of the Tanggu Environmental Protection Bureau (TEPB); and (b) TEPB shall review any changes to the Project design that may have a potential for causing negative environmental impacts, so that environmental monitoring and mitigation measures are adjusted accordingly in consultation with ADB. HTICL shall submit regular monitoring reports and semi-annual environmental reports to ADB, in a format acceptable to ADB, until the Loan Closing Date.	PA, Sch. paras. 21-22; LA, Sch. 5, para2. 21-22	Complied with except for the (i) noise level at project boundary, which has limited impact considering that the project is in an industrial zone and is 5 kilometers away from the nearest residential area, and that the (ii) semi annual submission of monitoring reports were only submitted in the first few years of the project with only annual reports submitted 2013 and 2014.

Covenant	Reference in Legal Agreement	Status of Compliance
Gender 48. CHNG, Greengen and HTICL shall follow the principles of ADB's Policy on Gender and Development during Project implementation, including taking all necessary actions to encourage women living in the Project area to participate in planning and implementing and working on, project activities. CHNG shall cause Greengen and HTICL to, and Greengen and HTICL shall, monitor the project effects on women during the implementation, through, where relevant, gender-disaggregated data collected pursuant to the monitoring and evaluation system referred to in the PPMS.	PA, Sch. para. 23; LA, Sch. 5, para. 23	Complied with. The impact on gender is limited as the project is in an industrial zone with no permanent residents. During construction, women were spared of activities involving hard physical labor.
Sexually Transmitted Diseases 49. With the assistance of the relevant local authorities, CHNG, through Greengen and HTICL, cause civil works contractors to distribute freely available information on the risks of socially and sexually transmitted diseases, including HIV/AIDS and malaria, to those employed during the Project construction and to the local communities living in the vicinity of the Project.	PA, Sch. para. 24; LA, Sch. 5, para. 24	Complied with. Impact is limited as the project is in an industrial zone with no permanent residents and the nearest residential area is at least 5 kilometers away.
Women and Child Labor 50. Greengen and HTICL shall ensure that: (a) there is no differential payment between men and women for work of equal value; and (b) civil works contractors do not employ child labor in the construction and maintenance activities in accordance with the relevant laws and regulations of the Borrower.	PA, Sch. para. 25; LA, Sch. 5, para. 25	Complied with.
PPMS 51. During Project implementation, CHNG, Greengen, and HTICL shall develop the PPMS including baseline performance monitoring, systematic Project performance monitoring, and benefits monitoring and evaluation developed in consultation with ADB, and including monitoring and evaluation on each Component. CHNG and HTICL shall carry out surveys: (a) at the start of Project implementation to establish baseline data; (b) at Project mid-term; (c) at the time of Project completion; and (d) not later than 6 months after Project completion, to evaluate the Project benefits. 52. In consultation with ADB, CHNG and HTICL shall: (i) propose and develop key indicators for the PPMS system; and (ii) compile and analyze data for the purpose of performance monitoring and evaluation in a format developed in consultation with ADB.	PA, Sch. paras. 26-27; LA, Sch. 5, paras. 26-27	Complied with.

Covenant	Reference in Legal Agreement	Status of Compliance
53. CHNG, through Greengen, and HTICL shall monitor, evaluate, and report to ADB, upon Project impacts through a project performance monitoring system, to ensure that the Project facilities are managed effectively. CHNG, through Greengen, and HTICL shall collect data agreed with ADB prior to Project implementation and Project completion, and annually for 3 years after Project completion.		
Monitoring and Monitoring Reports 54. Greengen shall cause HTICL to, and HTICL shall: (a) supply the PMU with monitoring reports of the implementation of Project activities, and a semi-annual report of the implementation of Project activities; and (b) conduct periodic and random monitoring of the Project to determine the degree to which Project funds have been effectively and efficiently used to implement the Project, achieve its objectives, outcomes, and its performance indicators.	PA, Sch. para. 28; LA, Sch. 5, para. 28	Complied with. The project submitted regular progress reports on the implementation of project activities and other information requested by ADB.
Project Review 55. EXIM, CHNG, Greengen, HTICL and ADB, shall together carry out reviews of the Project during the Project implementation period. The reviews shall include an examination of budgetary allocations for the Project, operation and maintenance costs, staffing, implementation arrangements, any environmental, resettlement, gender impacts and other achievements under the Project. The review shall include assessing progress for the Project, identifying difficulties and constraints, and determining ways to overcome them.	PA, Sch. para. 29; LA, Sch. 5, para. 29	Complied with. Regular review missions were carried out by ADB, EXIM, CHNG, Greengen, and HTICL to review project implementation.
Mid-Term Review 56. The Borrower, EXIM, CHNG, Greengen, HTICL, and ADB shall undertake a comprehensive midterm review in 2011, which shall include a detailed evaluation of: (a) scope of the Project; (b) implementation arrangements; (c) resettlement; (d) achievements of the scheduled targets; and (e) reallocation of the Loan proceeds and change(s) to the disbursement percentages. The results of the midterm review shall be discussed by the Borrower, EXIM, CHNG, Greengen, HTICL, and ADB and if required, appropriate corrective measures shall be formulated to ensure successful Project implementation and achievement of the Project objectives by the Loan Closing Date.	PA, Sch. para. 30; LA, Sch. 5, para. 30	Complied with. Special loan administration mission was conducted in January 2012.
57. The Borrower shall ensure that the activities of its departments and agencies with respect to the carrying out of the Project and operation of the Project facilities are conducted and coordinated in accordance with sound administrative policies and procedures.	LA, Art. IV, Section 4.03	Complied with.

Covenant	Reference in Legal Agreement	Status of Compliance
58. The Borrower shall take all action which shall be necessary on its part to enable CHNG, Greengen, and HTICL to perform its obligations under the Project Agreement, including the establishment and maintenance of tariffs as stipulated in paragraph 10 of Schedule 5 to this Loan Agreement, and shall not take or permit any action which would interfere with the performance of such obligations.	LA, Art. IV, Section 4.04	Complied with. The government approved 3 successive tariff adjustments.
59. The Borrower shall exercise its rights under the Subsidiary Loan Agreement and shall cause: (i) EXIM to exercise its rights under the CHNG Onlending Agreement; (ii) CHNG to exercise its rights under the Greengen Onlending Agreement; and (iii) Greengen to exercise its rights under the HTICL Onlending Agreement, in such a manner as to protect the interests of the Borrower and ADB and to accomplish the purposes of the Loan. 60. No rights or obligations under the Subsidiary Loan Agreement, the CHNG Onlending Agreement, the Greengen Onlending Agreement, or the HTICL Onlending Agreement shall be assigned, amended, abrogated or waived without the prior concurrence of ADB.	LA, Art. IV, Section 4.05 (a) and (b)	Complied with.

ADB = Asian Development Bank, AIDS = acquired immune deficiency syndrome, CHNG = China Huaneng Group, EXIM = Export-Import Bank, Greengen = Greengen Company Limited, HIV = human immunodeficiency virus, HTICL = Huaneng Tianjin IGCC Co. Ltd., NDRC = National Development and Reforms Commission, PA = project agreement, TEPB = Tanggu Environmental Protection Bureau.

ADB-FINANCED CONTRACT PACKAGES

PCSS No.	Item	Mode of Procurement	Date of Contract	Contract Amount ($)
	A. Civil Works			
189–191	1. Power island civil works and installation engineering	NCB	Sep/Oct 2010	4,885,200
45, 46	2. Chemical island civil works and installation of engineering associated with (i) gasifier and (ii) air separation unit	ICB	Sep 2010	18,972,559
	B. Power Plant Equipment			
1	1. Absorber	NCB	Jan 2010	297,481
2	2. Dregs lock hopper on-off valve	NCB	Mar 2010	967,012
3	3. High voltage switch cabinet	ICB	Jan 2010	1,260,426
4–188, 8801	4. 4th to 23rd batch of coal chemical accessory equipment [a]	NCB	Feb 2010–Jun 2012	75,517,053
192–199	5. Other equipment and materials	NCB	Dec 2010–Jul 2012	2,282,937
	C. Consulting Services			
G09791	1. Long-term operation and maintenance	SSS	Jul 2013	4,467,371
Various	2. Project implementation supervision consultants	Individual	Apr 2015–Aug 2016	409,553

ADB = Asian Development Bank, ICB = international competitive bidding, NCB = national competitive bidding, PCSS = procurement contract summary sheet, SSS = single source selection.

[a] Each batch consists of several small contract packages with a value of not more than $1 million per package.

Source: Asian Development Bank.

ECONOMIC REEVALUATION

1. This appendix describes the economic analysis of the Tianjin Integrated Gasification Combined Cycle (IGCC) Power Plant Project. The project outputs include (i) constructing and operating an IGCC power plant of 250-megawatt (MW) capacity in the Binhai New Area, Tianjin city, for generating 1,470 gigawatt-hours (GWh) of electricity annually, which will be sold to the North China Grid Company Limited through a 220-kilovolt interconnecting transmission line; (ii) adequate capacity in project management, safeguard compliance, and plant operation and maintenance (O&M); and (iii) capacity developed for obtaining carbon offset revenues from IGCC plants. The analysis was done in line with a standard cost–benefit analysis framework and in accordance with the *Guidelines for the Economic Analysis of Projects* (2017) of the Asian Development Bank (ADB).[1]

A. General Assumptions for Economic Analysis

2. The economic feasibility was evaluated by comparing the without- and with-project scenarios as follows:

(i) Under the without-project scenario, the growth in demand in Tianjin and the North China power grid will be supplied by a newly constructed conventional coal-fired plant;
(ii) Under the with-project scenario, the incremental demand will be served by the proposed project.

3. Incremental costs and benefits were estimated by comparing with- and without-project scenarios. Economic analysis was conducted for the project life span of 25 years plus an implementation period of 5 years. The residual value of physical assets was assumed to equal their depreciated book value at the end of the valuation period. All prices and costs were expressed in 2016 prices and in the domestic currency.

B. Economic Costs

4. The capital costs were adjusted to eliminate price contingencies, subsidies, interest during construction, and taxes. The analysis was carried out using a standard conversion factor of 1.0 for tradables and 0.99 for non-tradables.[2] Tradable commodities were valued at border prices, at the prevailing exchange rate. Non-tradable commodities were valued through shadow prices. Economic costs of land and labor were valued using the standard conversion factor for non-tradables. The O&M costs, assumed to remain constant in real terms, include costs for fuel, water and other raw materials, energy input, salaries and welfare, maintenance and repairs, insurance, and other administration expenses. The O&M costs will be incurred throughout the life of the project.

C. Economic Benefits

5. The main economic benefit of the project is from power generation to meet electricity demand from new users. The power plant is connected to the North China power gGrid and will supply expected demand growth for electricity in Tianjin. Therefore, the project will supply new demand rather than substitute for power from any existing generation capacity. Actual generation and sales levels since the start of operation in 2013 were considered. The actual generation level

[1] ADB. 2017. *Guidelines for the Economic Analysis of Project*s. Manila.
[2] These conversion factors were used consistently for recently approved energy projects in the PRC.

of 1,325 GWh attained in 2016 was used in the projections for the next 3 years, up to 2019. The generation level of 1,470 GWh, assumed at appraisal, is expected to be attained in 2020 with the increasing demand growth and the curtailment of new capacity addition in the system. This represents a 56.0% load factor, or an average load of 142.1 MW, which is considered conservative. The actual in-plant use and transmission and distribution loss of 24.5% of generated electricity was used, decreasing to 22.0% by 2020. Net energy supply to end users is assumed to be 1,000 GWh per year until 2019, increasing to 1,147 GWh per year from 2020. Revenues from by-products (gas and water) were also considered.

6. Incremental economic benefits were valued using the end users' willingness to pay tariff, which was estimated at CNY0.75 per kilowatt per hour (kWh).[3]

7. The benefits from improved air quality include (i) improved human health due to avoided illness and mortality from fine particulates, (ii) improved human welfare due to improved visibility and reduced damage to materials from avoided air pollution, and (iii) positive impacts on environmental resources due to avoided emission of carbon dioxide. For the evaluation of the environmental benefit to human health and welfare, the "benefit transfer method" suggested in ADB's *Evaluation of Environmental Impacts: A Workbook* was used.[4] Complete quantification and estimation of all benefits from the project were not carried out due to a lack of time and resources. The total benefits in this analysis can thus be interpreted as conservative estimates.

D. Economic Internal Rate of Return

8. The results of the economic analysis are presented in the key economic indicators, including the economic internal rate of return (EIRR) and economic net present value (ENPV). Table A9.1 compares the recalculated EIRR and the ENPV with the appraisal estimates.

Table A9.1: Comparison of Economic Internal Rate of Return and Economic Net Present Value

	At Appraisal	At Completion
EIRR		
Without environmental benefits	16.3%	8.0%
With environmental benefits	16.5%	8.2%
ENPV		
Without environmental benefits (CNY million)	CNY764.3	(CNY771.5)
With environmental benefits (CNY million)	CNY795.9	(CNY740.5)

EIRR = economic internal rate of return, ENPV = economic net present value.
Source: Asian Development Bank estimates.

9. The recalculated EIRR with environmental benefits is 8.2% compared with 16.5% at appraisal. Without the environmental benefits it is 8.0% at completion and 16.5% at appraisal. The recalculated EIRR is less than the appraisal estimate because of the following factors: (i) higher capital costs, (ii) higher actual electricity generation, (iii) higher actual station use, and (iv) higher O&M costs. The EIRR is less than the hurdle rate of 12.0% used at appraisal. The recalculated ENPV of the project is (CNY740.5) million. The discount rate of 12.0% was used in calculating the ENPV. The economic benefits and costs are shown in Table A9.2.

[3] ADB. 2002. *Measuring Willingness-to-Pay for Electricity (ERD Technical Note 3)*. Manila.
[4] ADB. 1996. *Economic Evaluation of Environmental Impacts: A Workbook*. Manila.

Table A9.2: Economic Internal Rate of Return for the Project
(CNY Million)

Year	Economic Capital Cost	Economic Operating Cost	Economic Benefit	Environmental Benefit		Net Benefit
2008	36.1	0.0	0.0			(36.1)
2009	126.4	0.0	0.0			(126.4)
2010	1,193.9	0.0	0.0			(1,193.9)
2011	1,251.6	0.0	0.0			(1,251.6)
2012	618.0	0.0	0.0			(618.0)
2013		254.9	114.9	1.2		(138.8)
2014		462.3	588.4	5.9		132.0
2015		469.6	785.6	6.6		322.6
2016		431.3	753.3	7.3		329.3
2017		411.3	758.5	7.4		354.5
2018		411.3	758.5	7.4		354.6
2019		411.3	758.5	7.5		354.6
2020		426.9	868.7	8.2		450.1
2021		426.9	868.7	8.3		450.1
2022		426.9	868.7	8.4		450.2
2023		426.9	868.7	8.4		450.3
2024		426.9	868.7	8.5		450.3
2025		426.9	868.7	8.6		450.4
2026		426.9	868.7	8.6		450.5
2027		426.9	868.7	8.7		450.5
2028		426.9	868.7	8.8		450.6
2029		426.9	868.7	8.8		450.7
2030		426.9	868.7	8.9		450.8
2031		426.9	868.7	9.0		450.8
2032		426.9	868.7	9.1		450.9
2033		426.9	868.7	9.1		451.0
2034		426.9	868.7	9.2		451.0
2035		426.9	868.7	9.3		451.1
2036		426.9	868.7	9.3		451.2
2037		426.9	868.7	9.4		589.5
					EIRR	**8.2%**
					ENPV	**(740.5)**

( ) = negative, CNY = yuan, EIRR = economic internal rate of return, ENPV = economic net present value.
Source: Asian Development Bank estimates.

E. Sensitivity Analysis

10. Sensitivity analysis was performed to test the EIRR's sensitivity to certain changes in parameters. The sensitivity analysis showed that the recalculated EIRR with environmental benefits could decrease to (i) 6.7% if the economic benefits were reduced by 10.0%, (ii) 7.3% if the O&M costs were increased by 10.0%, and (iii) 5.8% if both eventualities were to happen (Table A9.3). Under these sensitivity scenarios, the recalculated EIRR would be below the economic discount rate of 12.0%.

Table A9.3: Results of Sensitivity Analysis of the EIRR and ENPV

Variable	Change	EIRR	ENPV	SI[a]	SV[b](%)
Base case		8.2%	(740.5)		
Benefits decline	10.0%	6.7%	(952.1)	2.9	35.0
O&M costs increase	10.0%	7.3%	(860.2)	1.6	61.9
Combination		5.8%	(1,067.1)		

EIRR = economic internal rate of return, ENPV = economic net present value, O&M = operation and maintenance.
[a] SI = sensitivity indicator. The ratio of the % change in the ENPV to the % change in a variable.
[b] SV = switching value. Shows the % change required in a variable for the ENPV to become zero.
Source: Asian Development Bank estimates.

FINANCIAL REEVALUATION

1. This appendix describes the financial analysis of the Tianjin Integrated Gasification Combined Cycle (IGCC) Power Plant Project. The project outputs include (i) constructing and operating an IGCC power plant of 250-megawatt (MW) capacity in the Binhai New Area, Tianjin city, for generating 1,470 gigawatt-hours (GWh) of electricity annually, which will be sold to the North China Grid Company Limited through a 220-kilovolt interconnecting transmission line; (ii) adequate capacity in project management, safeguard compliance, and plant operation and maintenance (O&M); and (iii) capacity developed for obtaining carbon offset revenues from IGCC plants. It assesses the project's ability to generate sufficient revenues from operations to recover project costs, including O&M costs, and provide adequate cash flows for debt service and a reasonable return on investment. The analysis was performed in accordance with the *Guidelines on Financial Management and Analysis of Projects* (2005) of the Asian Development Bank (ADB).[1]

A. Key Assumptions

2. All actual costs and prices are in constant 2016 currency values. In deriving the financial internal rate of return (FIRR), incremental annual cash flows throughout the 25-year life span and the 5-year implementation period of the project were used. The capital costs were based on actual investments made for the project. These include land-use rights, civil works, equipment and installation costs, materials, consulting and technical services, commissioning, and other pre-operating costs. The residual value of physical assets was assumed to equal their depreciated book value at the end of the valuation period. The financial analysis model compared the project's FIRR with the weighted average cost of capital (WACC). Sensitivity analyses were conducted to assess the impact of various adverse conditions.

3. Revenues were calculated on the basis of the actual and projected sale of electricity from the power plant and by-products of gas and water. The electricity tariff of CNY0.75 per kilowatt-hour (kWh) approved by the National Development and Reform Commission in 2015 was used. Actual electricity generated and sold from the start of operations in 2013 until 2016 were considered. Due to the slowdown of economic growth in the People's Republic of China, demand for electricity decreased, resulting in the prevailing restriction in load dispatch from the grid. The actual generation level of 1,325 GWh attained in 2016 was used in the projections for the next 3 years, up to 2019. The generation level of 1,470 GWh assumed at appraisal is expected to be attained in 2020 with the increasing demand growth and the curtailment of new capacity addition in the system. This represents a 56.0% load factor, or an average load of 142.1 MW, which is considered conservative. The actual in-plant use and transmission and distribution loss of 24.5% of generated electricity was applied until 2019, reducing to 22.0% from 2020 as efficiency improvements are implemented. Net energy supply to end users is assumed to be 1,000 GWh per year until 2019, increasing to 1,147 GWh per year from 2020.

4. O&M costs mainly included fuel, water and other raw materials, energy input, salaries and welfare, maintenance and repairs, insurance, and other administration expenses. Net cash flows from the project were determined after allowing for corporate income taxes at 25% of pre-tax profit, which is the same as the income tax rate assumed at appraisal.

5. The WACC was calculated after tax in real terms using actual capital mix and costs of funds. The real interest costs of loan funds, based on the actual cost of loan funds from ADB and

[1] ABD. 2005. *Guidelines on Financial Management and Analysis of Projects*. Manila.

other funding sources, were considered. The cost of equity is assumed to be 10.0% per annum. The local income tax (25.0% of pre-tax profit) and the average domestic inflation rate (3.0% per year for domestic and 1.8% per year for international) were also netted out as appropriate. As a result, the recalculated WACC for the project is 2.0%. Table A10.1 presents the WACC calculation.

Table A10.1: Calculation of the Weighted Average Cost of Capital (WACC)

Item	ADB Loan	Domestic Loan	ADB Grant	Equity	Budget	Total
A. Amount (CNY million)	686.0	1,938.3	32.1	734.0	181.4	3,571.8
B. Weighting	19.2%	54.3%	0.9%	20.5%	5.1%	100.0%
C. Nominal cost	2.6%	4.4%	10.0%	10.0%	10.0%	
D. Income tax rate	25.0%	25.0%				
E. Tax-adjusted nominal cost [C x (1 - D)]	2.0%	3.3%	10.0%	10.0%	10.0%	
F. Inflation rate	1.8%	3.0%	1.8%	3.0%	3.0%	
G. Real cost [(1+E) / (1+F) - 1]	0.2%	0.3%	8.1%	6.8%	6.8%	
H. Weighted component of WACC	0.0%	0.2%	0.1%	1.4%	0.3%	
Weighted average cost of capital	**2.0%**					

ADB = Asian Development Bank, WACC = weighted average cost of capital, [C x (1 - D)] = [nominal cost times (1 minus income tax rate)], [(1+E) / (1+F) - 1] = [(1 plus tax-adjusted nominal cost) divided by (1 plus inflation rate) minus 1]
Source: Asian Development Bank estimates.

B. Financial Indicators

6. The results of the financial analysis for the project are presented in Table A10.2. The projected cash flows for the FIRR are shown in Table A10.3.

Table A10.2: Projected Financial Indicators

	At Appraisal	At Completion
FIRR	6.4%	4.4%
FNPV (in million)	CNY820.9	CNY1,256.0
WACC	3.7%	2.0%

CNY = yuan, FIRR = financial internal rate of return, FNPV = financial net present value, WACC = weighted average cost of capital.
Source: Asian Development Bank estimates.

7. The recalculated FIRR of 4.4% is less than the appraisal estimate of 6.4% because of the following factors: (i) higher capital costs, (ii) lower actual electricity generation, (iii) higher actual station use, and (iv) higher O&M costs. The negative impact of higher costs was mitigated by the higher actual electricity tariff of CNY0.75 per kWh, compared to CNY0.56 per kWh assumed at appraisal. The FIRR is nonetheless greater than the WACC of 2.0%. The project will generate positive financial net present value of CNY1,256.0 million using the WACC as the discount rate.

Table A10.3: Financial Internal Rate of Return of the Project
(CNY million)

Year	Capital Cost	Revenues	Operating Cost	Income Tax	Net Cash Flow After Tax
2008	37.1	0.0	0.0		(37.1)
2009	129.7	0.0	0.0		(129.7)
2010	1,224.5	0.0	0.0		(1,224.5)
2011	1,283.6	0.0	0.0		(1,283.6)
2012	633.8	0.0	0.0		(633.8)
2013		126.5	257.3	0.0	(130.8)
2014		441.0	465.5	0.0	(24.5)
2015		684.0	473.2	0.0	210.8
2016		651.8	434.2	0.0	217.5
2017		647.7	414.0	0.0	233.7
2018		647.7	414.0	0.0	233.7
2019		647.7	414.0	0.0	233.7
2020		741.7	429.7	5.6	306.4
2021		741.7	429.7	7.3	304.8
2022		741.7	429.7	8.9	303.1
2023		741.7	429.7	10.6	301.5
2024		741.7	429.7	12.3	299.8
2025		741.7	429.7	13.9	298.1
2026		741.7	429.7	15.6	296.4
2027		741.7	429.7	17.4	294.7
2028		741.7	429.7	19.1	292.9
2029		741.7	429.7	20.9	291.2
2030		741.7	429.7	22.7	289.4
2031		741.7	429.7	24.5	287.6
2032		741.7	429.7	26.3	285.7
2033		741.7	429.7	26.7	285.4
2034		741.7	429.7	27.0	285.0
2035		741.7	429.7	27.5	284.6
2036		741.7	429.7	27.9	284.1
2037		741.7	429.7	28.0	422.2
	WACC	**2.0%**		**FIRR**	**4.4%**
				FNPV	**1,256.0**

( ) = negative, CNY = yuan, FIRR = financial internal rate of return, FNPV = financial net present value, WACC = weighted average cost of capital.
Source: Asian Development Bank estimates.

C. Sensitivity Analysis

8. Sensitivity analysis was performed to test the FIRR's sensitivity to certain changes in parameters. The sensitivity analysis focused on three variables: (i) electricity sales decrease by 10%, (ii) O&M costs increase by 10%, and (iii) a combination of both. The analysis shows that the project will remain financially viable for scenarios (i) and (ii) as the FIRR is greater than the WACC, but not under scenario (iii). The sensitivity analysis is shown in Table A10.4.

Table A10.4: Sensitivity Analysis of the Financial Internal Rate of Return

Variable	Change	FIRR	FNPV	SI[a]	SV[b](%)
Base case		4.4%	1,256.0		
Sales decline	10.0%	2.3%	144.8	(8.8)	(11.3)
O&M costs increase	10.0%	3.0%	568.4	(5.5)	(18.3)
Combination		1.1%	(427.5)		

FIRR = financial internal rate of return, FNPV = financial net present value, O&M = operation and maintenance.
[a] SI = sensitivity indicator. The ratio of the % change in the FNPV to the % change in a variable.
[b] SV = switching value. It shows the % change required in a variable for the FNPV to become zero.
Source: Asian Development Bank estimates.

D. Summary of Financial Statements of the Implementing Agency

9. Table A10.5 shows the summary of the financial sustainability of the implementing agency, Huaneng Tianjin IGCC Company Ltd. (HTICL), using key financial indicators, both historical and projected. Profitability was a challenge during the initial years of operation and will continue to be until the Tianjin IGCC plant reaches its designed capacity. As operation improves, HTICL is expected to (i) improve its debt service coverage ratio to 1.3, (ii) achieve a reasonable return on fixed assets, and (iii) maintain its accounts receivable at a level that does not exceed 2 months of sales revenues. The company is highly leveraged as its equity position has been eroded with the heavy losses sustained during the early years. This being the case, the debt-equity ratio of 75:25 will not be attained.

Table A10.5: Financial Indicators

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Financial Ratios												
Return on Net Fixed Assets[a] (%)	(10.8)	(0.14)	(1.50)	1.93	2.08	2.27	7.89	8.61	9.50	10.65	12.16	14.24
Accounts Receivables [b](months)	2.09	0.69	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16
Debt/(Debt & Equity) Ratio[c] (%)	84.40	88.01	90.65	92.56	94.57	96.69	95.73	94.43	92.70	90.47	87.63	84.05
Debt Service Ratio[d] (times)	(0.34)	1.26	1.56	0.80	0.91	0.93	1.25	1.27	1.28	1.30	1.32	1.34

[a] Net operating income after taxes plus loan interest as a percentage of rate base.
[b] Number of month's sales in accounts receivables.
[c] Ratio of long-term debt to long-term debt plus equity.
[d] Ratio of internal cash generation to debt service requirement.
Source: Implementing agency and Asian Development Bank estimates.

ENVIRONMENTAL IMPACT ASSESSMENT

A. Introduction

1. The Tianjin Integrated Gasification Combined Cycle Power Plant Project was approved on 22 May 2009 by the National Development and Reform Commission and on 8 February 2010 by the Asian Development Bank (ADB). The ADB loan was financially closed on 27 February 2015. The project is located in the Harbor Economic Zone, Binhai New Area, Tianjin, in the People's Republic of China (PRC). It involves construction of (i) a coal gasifier with a processing capacity of 2,000 tons per day; (ii) a 171-megawatt (MW) gas turbine and a 110 MW steam turbine in a combined cycle, and a waste-heat boiler to achieve a total installed capacity of 265 MW; (iii) a synthetic gas (syngas) purification system with a processing capacity of 160,739 normal cubic meters per hour; (iv) a sulfur recovery system, and other necessary facilities.

2. The project was classified as environmental category A. Construction started on 6 July 2009 and finished in October 2012. A 72+24 hours continuous trial operation was conducted in November 2012. The domestic environmental impact assessment (EIA) was conducted in 2006–2007, and approved by the State Environmental Protection Administration in July 2007. The EIA was updated in early 2010 following modification of the project design by the project implementation agency, and approved by the Ministry of Environmental Protection. The summary environmental impact assessment (SEIA) was prepared and circulated to the ADB Board of Directors in 2009. It was updated in 2011 to reflect the modification. The SEIA included a plan to mitigate the project's adverse environmental impacts.[1]

3. ADB's project completion review (PCR) mission was conducted from 15 to 17 November 2016. Consultations were held with the executing agency, China Huaneng Group, the implementing agency, Huaneng Tianjin IGCC Company Ltd. (HTICL), and the State Energy Administration. The mission team conducted project document review, site visits and interviews with relevant organizations and institutes to review the effectiveness of environmental management and protection measures. This document presents the key findings.

B. Environment Protection and Management

4. During 2009–2013, Greengen Company, Ltd. (Greengen) was responsible for ensuring that all environmental standards and procedures were followed. From 2014, China Huaneng Group transferred the operation right of the project from Greengen to Huaneng Power International (HPI), Huabei Branch. Prior to project construction, Greengen set up an environmental management unit (EMU), which provided environmental supervision to contractors. The EMU ensures implementation of the environmental management plan (EMP) and the environmental monitoring plan (EMoP) during the construction and operation of the project. The EMU was staffed by a project manager and at least two technical personnel during the construction period. The construction contractor designated an environmental representative, who was responsible for environmental management. A project construction supervision company was engaged during project construction. During project operation, the project operator established an environmental monitoring station, which undertakes environmental monitoring in accordance with the EMP and the EMoP.

5. A third-party consortium consisting of project supervision companies and environmental

[1] For most data monitored, quarterly, monthly or even daily data are available. This report uses annual data to reflect the general trends in emission data. The annual data is the average.

monitoring institutions supported the work of the EMU. Beijing Zhongdalian Consulting Co. and China Chengda Engineering Co. were selected through competitive bidding as project construction supervision companies. They provided close supervision of all contractors to ensure they followed the EMP, set up environmental protection measures, and observed the construction process of environmental facilities. The Tanggu (now Binhai) Environmental Monitoring Station (EMS) conducted regular monitoring of air, water quality, noise, ecological impacts, and solid waste treatment in the project area. The China Hydropower Research Institute monitored water and soil loss in the project area in 2012. The Tanggu (now Binhai) Environmental Protection Bureau (EPB) and the Harbor Industrial Park Management Committee conducted random site inspection during project construction and operation. The China National Environmental Monitoring Centre and the Tianjin EMS conducted environmental monitoring for project completion acceptance in March 2014.

6. Institutional arrangements were established and environmental mitigation measures were adequately performed. Semiannual environmental monitoring reports were prepared from 2010 to 2012. Annual environmental monitoring reports were prepared from 2013 to 2014. The environmental performance evaluation report of the project was completed in 2015. All the reports were submitted to ADB in accordance with the agreed environmental monitoring and reporting requirements. All the environmental monitoring reports were disclosed in the ADB website. During the PCR mission, environmental monitoring data from January 2015 to June 2016 were collected. Details of compliance with the EMP are shown in Table A11.1. In the evaluation, PRC standards were adopted, but these nevertheless conform with international best practice for pollution prevention and control technologies, and practices reflected in the *World Bank Group's Pollution Prevention and Abatement Handbook*.[2] For example, the PRC's air pollution standard for the Tianjin IGCC project has stricter requirements than that of the World Bank standard.

7. At project appraisal, the SEIA estimated the cost of implementing the EMP during the project construction phase to be CNY88.25 million, accounting for 8% of the total project investment. The environmental investment includes waste gas treatment and emission control, wastewater treatment, soil treatment, slag storage, an environmental monitoring station, accident precautions, and emergency measures. At project completion, HTICL reported that the total actual environmental investment for the project was CNY209.88 million, accounting for 7% of the total project investment cost. By the end of 2012, all environmental investment costs had been incurred. The breakdown is shown in Table A11.2. The carbon dioxide (CO_2) capture demonstration project with CO_2 capture capacity of 60,000–10,000 tons per year was constructed in 2015 and completed in August 2016. The estimated project cost is CNY48.53 million.

[2] World Bank Group. 1999. *Pollution Prevention and Abatement Hanbook 1998. Toward Cleaner Production*. Washington, D.C.

Table A11.1 Environmental Impacts, Mitigation Measures and Implementation Status of Mitigation Measures

Phase	Benefits	Negative impacts	Proposed Mitigation Measures	Implementation of Mitigation Measures
Site Selection and Design	In comparison to a conventional coal-fired power plant of 300 MW capacity, the avoided annual emissions from the IGCC plant are estimated at 43 t of total suspended particulate, 1,237 t of SO_2, and 3,325 t of NO_x.	The project will emit waste gas from coal fine preparation, coal fine transport, sulfur recovery system and gas turbine.	Bag dedusting devices will be installed at main dust emitting sources. For H_2S emission control, combustion stove is installed at sulfur recovery system. For emergency coal gas emission, flaring system is constructed.	Bag dedusting devices, combustion stove and flaring system are installed.
	The IGCC plant uses 35% less cooling water than an alternative conventional plant and generates significantly less slag.	Wastewater will be generated from coal gasification system, boiler water treatment system and residential area.	Wastewater from coal gasification is pretreated and sent to local wastewater treatment plant for further disposal. Residential wastewater and other industrial wastewater is treated on site and reused as cooling water.	Treated coal gasification wastewater is sent to harbor industrial park wastewater plant, and other treated wastewater is reused as cooling water for the project.
	The project will provide indirect social benefits through improved air quality in the project area.	Ordinary solid waste (slag and waste coal) and dangerous solid waste (waste molecule sieve absolvent and waste activated carbon) will be generated during project operation.	Dangerous solid waste will be replaced once every 8 years, and sent to qualified environmental companies for treatment. Ordinary solid waste is comprehensively used.	Up to 2016, no dangerous solid waste has been generated; the slag and waste coal is used for the production of building materials.
	The project will save 134,000 t of coal per year of operation compared with similar-scale coal-fired power plants.	There is a lot of equipment generating a high level of noise, such as pumps, air separators and gas turbines.	Low noise equipment, rational layout and noise reduction measures are considered.	Low noise equipment is selected, high noise equipment is distributed away. The project is in an industrial zone with no permanent residents and the nearest residential area is 5 km away.
Construction		Soil erosion will be caused mainly by wind and water; the soil loss modulus is estimated at 150–200 t/km^2, falling in low soil erosion type.	Seven soil-erosion control areas are identified, and comprehensive measures including engineering measures, temporary protection measures and biological measures will be taken.	Compacted topsoil was laid at the appropriate time. Revegetation of exposed surface was implemented as planned. Sedimentation ponds were completed. Traffic was confined to

Phase	Benefits	Negative impacts	Proposed Mitigation Measures	Implementation of Mitigation Measures
				predetermined roads. Spoil generated from construction activities was reused or properly disposed of.
		Generation of septic wastewater from construction workers, equipment wash-down water, and impacts on water reserves from overextraction.	Septic wastewater will be collected, treated in on-site facilities, or recycled on-site. All equipment wash-down areas will include oil separators. Industrial and potable water for the project will be supplied by the industrial park desalinization plant and the municipal water system. The project will not use ground water from the site.	All the septic wastewater during project construction was collected and disposed of on-site. Oil separators were installed at all equipment wash-down areas. The treated wastewater was reused on-site. Industrial park desalinization plant and the municipal water system provided water supply.
		Air pollution during construction will be from vehicle exhaust, construction machinery, pipeline ditch excavation, foundation excavation, cement mixing, building construction, soil backfilling and minor access road construction.	Mitigation measures include (i) paving all major access roads and using water trucks to suppress dust on unpaved roads; (ii) covering temporary soil stockpiles and establishing fenced-off areas for the piling of sand and stone, etc.; (iii) limiting excavation during windy days; (iv) using ready concrete and finished lime at construction site; (v) forbidding construction workers to burn coal or firewood on-site.	All major access roads were paved and water trucks were used to suppress dust. Temporary soil stockpiles were covered properly. Coal and firewood was not burnt on-site.
		Noise impact on construction workers.	Equipment and machinery used at construction site shall strictly conform to the PRC and local noise standards. All equipment will be properly maintained to minimize noise emissions. Noise emissions from the site will meet relevant national standards. Ongoing	These mitigation measures were taken properly.

Phase	Benefits	Negative impacts	Proposed Mitigation Measures	Implementation of Mitigation Measures
			noise monitoring will be undertaken to ensure compliance. Mitigation measures during operation for noise impacts on workers will include occupational health and safety practices relevant to PRC standards.	
		Residential rubbish and waste building materials will be generated. Spillage along access roads or off-site leading to vehicle hazards, increased dust or increased mud.	All residential rubbish and waste building materials will be collected, stored on-site in appropriate storage facilities and transported off-site to approved disposal facilities. No on-site landfills will be developed. Trucks used for transportation of spoil will be covered and any spillage will be cleaned up immediately. Hazardous waste generated during the construction period will be collected and stored separately on-site in approved facilities and will be removed from site to approved hazardous-waste disposal facilities by a licensed waste transportation company.	All residential rubbish and waste building materials were collected, stored on-site in appropriate storage facilities, and transported off-site to approved disposal facilities. Covered transportation of wastes was adopted at trucks. Hazardous waste was collected and stored separately on-site in approved facilities and removed from site at an appropriate time.
		Impact to livelihoods of residents.	Where possible, local labor will be used during construction activities. Locally based suppliers will be used where possible. Mitigation measures will include provision of health education to workers and provision of hygienic worker accommodation.	These measures were implemented.
Operation	Efficient use of coal.	Soil erosion from exposed areas and soil contamination.	Soil erosion from exposed areas will be mitigated by ensuring that exposed areas are compacted and revegetated where possible. Soil contamination will be prevented by installing oil separators at wash-down and refueling areas, and	All the proposed soil erosion measures were adopted throughout the project area, and the implemented measures covered slope protection engineering, site and road hardening, land

Phase	Benefits	Negative impacts	Proposed Mitigation Measures	Implementation of Mitigation Measures
			installing secondary containment at fuel storage sites. All hazardous wastes and hazardous materials will be stored in properly designed storage facilities.	reclamation engineering, flooding control engineering, revegetation engineering, and temporary soil-control engineering.
	Reducing air emissions from coal use.	Generation of industrial wastewater, coal gasification wastewater and residential wastewater.	Recycling system and cooling tower wastewater will be disposed of at the site wastewater treatment plant and then at the Harbor Industrial Park wastewater treatment plant. Chemical water treatment and boiler operation wastewater, coal-gasification wastewater, and sulfur-recovery system wastewater will be treated on site and disposed of at Harbor Industrial Park wastewater treatment plant. Air-separation system wastewater will be recycled as make-up water for the cooling tower. Other industrial wastewater will be collected and treated on site (air flotation) and then reused as make-up water for cooling recycling water. Residential wastewater will be treated on site by two-stage biological contact oxidation method and reused on site.	Wastewater from air-cooling tower and air-separation system is treated and reused as makeup water for the cooling tower. Wastewater from boiler water is partly treated at on-site industrial wastewater treatment facility, and sent to recycling cooling water system of the chemical island, the rest of the wastewater is reused as cooling water together with sea water. Wastewater from coal gasification wet scrubbing system is pretreated on-site, and then sent to harbor Industrial Park wastewater treatment facility for further treatment. Residential wastewater is collected and treated at on-site residential wastewater treatment facility with a capacity of 20 m^3/h, the treated wastewater is sent to recycling cooling water system for chemical island.
	Promoting the development of distributed energy supply system.	Air pollution by dust from the coal storage area, emissions from the pulverized coal system, dust from the coal transport system, emissions from coal gasification system, and power plant emissions.	Cyclone emission control and wet scrubbing will be used for raw syngas purification. Shell—Paques biological desulfurization process is used for sulfur recovery from raw coal gas. Bag dust collector will be installed at coal processing system.	Dust collectors and ventilation devices are installed at each transfer station of coal transport, coal milling and drying systems. A filtering system is installed at raw coal bin, fly ash recycling bin, and coal milling system.

Phase	Benefits	Negative impacts	Proposed Mitigation Measures	Implementation of Mitigation Measures
			Water spraying will be used for dust control at the power plant, and raw coal stored in totally closed bunkers and transported under closed conditions. Closed transport and vehicle cleaning will be used to control flying dust. The coal processing system. NO_x emissions will be controlled by using a low-NO_x burner and steam injection (100 t/h) before the syngas enters the gas turbine. Mercury emissions will be controlled by selecting low-mercury Shenhua coal and high dust removal techniques that will achieve 90% mercury removal efficiency.	The coal milling and drying system is equipped with three raw coal filters, three pulverized coal filters, three fly ash filters, which collect coal dust and fly ash generated from the recycling process of broken coal and milled coal. The pulverized coal feed system has two primary coal dust filters and one secondary dust filter. Water spraying devices are installed at coal transport trestle, coal storage bin, coal transfer station, and conveyor belt for broken coal. Dust collecting bag is installed at fly ash storage site. Wet scrubbing is used to remove dust entrained in coal gas. Lo-Cat II chemical desulfurization process is used for sulfur recovery from raw coal gas, and sulfur removal efficiency is greater than 99.5%. Online continuous air emission monitoring system is installed to monitor SO_2, NO_x, and smoke of the waste gas from waste heat boiler. High quality coal is used with sulfur content less than 0.3% and ash content less than 10%.
	Promoting technical progress with regard to coal use.	Noise impacts.	Enclosure of relevant equipment, noise suppression controls on relevant machinery, and siting of particular facilities away from project boundaries.	Mufflers were installed in some of the machinery to mitigate noise pollution. Extremely noisy equipment is installed in a closed area.

Phase	Benefits	Negative impacts	Proposed Mitigation Measures	Implementation of Mitigation Measures
			Ongoing noise monitoring will assess compliance with the requirements of noise standards at industrial facility boundaries (GB12348-1990). Mitigation measures during operation for noise impacts on workers will include standard occupational health and safety practices to relevant PRC standards.	Low noise equipment is selected as far as possible. Arbors are built all around the project boundary to reduce noise pollution.
	Reducing greenhouse gas emission.	Generation of solid waste.	An emergency ash and slag piling site is established in the project area, with storage capacity of 41,000 tons per year Gasifier slag and syngas ash will be collected and used for the production of building materials. Hazardous waste will be collected and stored separately on-site in approved facilities. Hazardous waste will be removed from site to approved hazardous waste disposal facilities by a licensed waste transportation company. Storage, collection, transportation, and disposal of hazardous wastes will be conducted in conformance with relevant PRC regulations.	Waste coal from coal milling, and slag and fly ash from coal gasification system are collected in bins, temporarily stored at solid waste collection site, and reused at nearby construction site of natural gas-fired power plant, and later sent to local building material companies. Residential solid waste is collected, temporarily stored at solid waste collection site, and then, transported to a municipal landfill site by a local hygiene authority. As at the end of November 2016, there is no hazardous waste generation due to limited operating hours of the project.

H_2S = hydrogen sulfide, IGCC = integrated gasification combined cycle, km = kilometer, m^3h = cubic meter per hour, MW = megawatt, NO_X = nitrogen oxide, PRC = People's Republic of China, SO_2 = sulfur dioxide, t = ton, t/h = tons per hour, t/km^2 = tons per square kilometer.
Source: Huaneng Tianjin Integrated Gasification Combined Cycle Company Ltd. and consultant's analysis.

Table A11.2: Breakdown of environmental investment of the Tianjin IGCC Project

Item	Contents	Amount (CNY million)
Actual project investment		3,178.39
Waste gas treatment	Dust removal system and other slag, ash and dust removal equipment Sulfur recovery system Syngas purification system Flaring system On-line monitoring system, stack and duct	185.59
Wastewater treatment	Wastewater treatment system	12.50
Noise treatment	Noise treatment facilities	1.50
Soil erosion control	Soil erosion control, monitoring, etc.	6.72
Solid waste treatment	Slag site	0.80
Revegetation	Trees and grass planting and conservation	0.97
Others		1.80
Subtotal of environmental cost		209.88
Investment cost/total project cost		7%

Source: China EMS and Tianjin EMS. *Tianjin IGCC Project Completion Environmental Acceptance Monitoring Report*. June 2014.

C. Environmental Impacts and Mitigation Undertaken

8. The SEIA identified the potential environmental impacts of individual project components and proposed mitigation measures for the impacts during project preparation, construction, and operation. Table A11.1 lists the agreed EMP at project appraisal, including possible negative impacts, measures to mitigate these impacts, and the implementation status of mitigation measures during project implementation.

9. The HTICL established an environmental emergency response plan in May 2012. The plan outlines (i) the general principle; (ii) the definition and classification of environmental accidents; (iii) the institutional arrangements; (iv) an early warning and response system; (v) emergency precautions and reporting procedures; (vi) emergency disposal; (vii) site restoration; and (viii) technical training, etc. According to the plan, environmental emergencies are defined as abrupt environmental events that cause serious environmental pollution, harm people's health, and cause major economic and property loss. Examples include (i) wastewater leakage, (ii) fuel oil and toxic chemicals leakage, (iii) an abrupt environmental geologic disaster during project construction, (iv) abrupt waste gas pollution, (v) coal dust flying, and (vi) noncompliance wastewater discharge. Up to the time of the PCR mission, there had been no emergency events.

D. Public Participation to Enhance Environmental Management Plan

10. The project environmental department and the environmental monitoring and advisory agency implemented a public participation program from 2007 to 2012. The purpose of the program was to solicit the views of the affected people to gain a better understanding of the project impacts and any improvements needed, and to provide feedback to the HTICL for implementation of mitigation and corrective actions. Questionnaire surveys, interviews with people in the affected communities, interviews with construction workers, website information disclosure and public participation methods were adopted. Table A11.3 details how public participation was conducted.

11. During project implementation, the HTICL operated a proper channel to address all potential complaints related to the project. A designated staff member was assigned to set up a complaint registry, promptly investigate any complaint associated with the project, and record the details and nature of the complaint, including the name of the complainant, the date and actions taken as a result of the investigation. The designated staff member coordinated with both Tianjin and Binhai New Area environmental protection bureaus (EPBs) to deal with any complaints raised by local organizations and residents. Based on discussions with local government environmental management departments and the HTICL, it is confirmed that up to October 2016, no environmental infringements were recorded during project implementation. Furthermore, no environmental complaints from local residents or others were received.

Table A11.3: Public Concerns and Corrective Actions Taken During Project Construction

Year	Details of public participation	Concerns received and corrective actions taken
2007	On 1 February 2007, the Tianjin Environmental Protection Science Research Institute uploaded the environmental information of the IGCC Project on the institute website (http://www.taes.org) for public review and comments. During the 20 days after uploading, the website was accessed 128 times, but no public response, e-mail, or phone calls were received regarding the project.) for public review and comments. During the 20 days after uploading, the website was accessed 128 times, but no public response, e-mail, or phone calls were received regarding the project. Stakeholder consultation took place between 5 and 7 February 2007, prior to finalizing the EIA, consisting of random distribution of 130 public consultation questionnaires to affected residents and organizations.	The survey is considered to have covered a sufficient number of respondents in the project area and an acceptable demographic cross section. The major environmental concerns were potential impacts to air pollution and water pollution from the project. These concerns were reviewed by management and considered during project design.
2009	As there are five changes with the IGCC project, including designed coal type, water supply, improved air separator, sulfur recovery device and construction of flaring system, the public consultation was conducted again. The project information was announced on the website of the Tianjin Environmental Protection Science Research Institute (http://www.taes.org) on 1 September 2009; the second announcement was on 20 November 2009. Each announcement stayed up for 20 days for stakeholders' comments. A new stakeholder consultation took place between 10 and 18 October 2009, prior to finalizing the revised EIA, consisting of random distribution of 100 public consultation questionnaires to affected residents and organizations.	No comments were received during the period. The major environmental concerns were potential impacts to air pollution, sound environment, and water pollution from the project. These concerns were reviewed by management and considered during project design.
2014	In March 2014, Tianjin Environmental Monitoring Station conducted a public consultation activity for project completion acceptance. Questionnaires were distributed to local stakeholders, including local residents, workers and governmental officials and businesspersons. A total of 100 replies were received.	Regarding environmental impacts during the project trial operation, 81% of people surveyed thought there was no impact on their life and work while 19% thought there was a small impact; 86% of people thought there was no wastewater impact on their life and work, and 9% thought there was small impact; 86% of people thought there was noise impact on their life and work, while 14%

Year	Details of public participation	Concerns received and corrective actions taken
		thought there was small impact; 100% of people thought that no environmental pollution accidents occurred during the trial operation period.

EIA = environmental impact assessment, IGCC = integrated gasification combined cycle.
Source: Summary Environmental Impact Assessment for the Tianjin Integrated Gasification Combined Cycle Power Plant Project. 2011, and annual environmental monitoring reports, 2012–2014 by Huaneng Tianjin Integrated Gasification Combined Cycle Company Limited.

E. Environmental Monitoring

12. The SEIA described the environmental monitoring program for the Tianjin IGCC project. The program was developed to focus on the project from 2007 to 2016. Field sampling and laboratory tests were conducted by subcontractors including China National Environmental Monitoring Centre, Tianjin EMS, Tanggu (later renamed as Binhai) EMS, and the China Hydropower Research Institute, and the advisory agency confirmed that (i) the monitoring exercises covering surrounding environmental quality parameters were relevant to the environmental performance of the IGCC project, (ii) sampling and analytical methods were credible, and (iii) monitoring results were all valid. Table A11.4 presents details of the environmental monitoring program, including the implementation activities.

Table A11.4: Environmental Impacts, Mitigation Measures, and Implementation Status

Issue	Major impacts	Mitigation Measures	Monitoring Frequency	Responsible Party and Compliance Status
Construction Period (2009–2012)				
Air	Dust and waste gas emission from construction equipment and transportation vehicles	All major access roads were paved and water trucks were used to suppress dust; Temporary soil stockpiles were covered properly; Coal and firewood was not burnt on-site	Continue operation at an automatic air quality monitoring station 200 m away from the project site Daily site inspection for air pollution control	Local EMS and construction supervision companies.
	Air quality was monitored 200 m northeast of the project site by an automatic air quality monitoring station: PM_{10}, SO_2 and NO_2 were monitored.			The air quality reached the Class III air quality standard (GB3095-1996). Fully complied with.
Solid waste from construction activities and residential area	All residential rubbish and waste building materials were collected, stored on-site in appropriate storage facilities, and transported off-site to approved disposal facilities. No on-site landfills were established. Trucks used for transporting spoil were covered. Hazardous waste generated during construction was collected and stored separately on-site in approved facilities, and removed from site to approved hazardous waste-disposal facilities by a licensed waste transportation company.			Local EPB, EMU, supervision companies. Fully complied with.
Soil loss and contamination	Compacted topsoil was laid at an appropriate time, and revegetation of exposed surfaces was implemented as planned.			Local EPB, EMU, supervision company, China Hydropower Research Institute.

Issue	Major impacts	Mitigation Measures	Monitoring Frequency	Responsible Party and Compliance Status
	Sedimentation ponds were established to receive rain and on-site wastewater. Traffic was confined to predetermined roads. Spoil generated from construction activities was stockpiled and disposed of properly. Oil separators at wash-down and refueling areas were installed. Hazardous waste and hydrocarbon storage facilities were installed on-site. All septic waste was collected and removed from the site. All hazardous and non-hazardous waste was removed from the site and taken to approved wastewater disposal sites. Soil loss and contamination was monitored by supervision companies on a daily base, and comprehensively monitored by the China Hydropower Research Institute by the end of construction period.			Fully complied with.
Water	Water pollution by residential and construction wastewater	Construction wastewater is treated by settling pond; the treated wastewater is reused on-site. The septic wastewater is treated by septic tank, and treated wastewater is discharged to the Harbor Industrial Park Wastewater Treatment Plant. Monitored by EMU and supervision companies on a daily base, and by local EPB as needed.		Local EPB, EMU, supervision company. Fully complied with.
Noise	Noise pollution from transport vehicles, construction machinery	Equipment and machinery used during project construction conformed to PRC and local noise standards. All equipment was maintained to minimize noise. Personal protection measures were taken to reduce noise impact on workers. Monitored by EMU and supervision companies on a daily base, and by local EPB as needed.		Local EPB, EMU, supervision company. Fully complied.
Human health	Possible epidemic disease from construction workers	Epidemic disease control and keeping hygienic environment	Daily/ongoing as needed	Local public health department and EMU. Fully complied with.
Operation Period (2013–2016)				
Water	Production and residential wastewater discharge	Wastewater from air-cooling tower and air-separation system is reused as makeup water for the cooling tower Wastewater from boiler-water treatment system is partly treated at on-site		Tianjin EMS and EMU. Fully complied with.

Issue	Major impacts	Mitigation Measures	Monitoring Frequency	Responsible Party and Compliance Status
		industrial wastewater treatment facility; the rest is sent to cooling water system Wastewater from coal gasification web scrubbing system is pretreated on-site and then sent to the Harbor Economic Zone wastewater treatment facility for further treatment Other wastewater from coal gasification is collected and treated on-site and recycled as make-up water for the cooling tower Residential wastewater is collected and treated at on-site residential wastewater treatment facility; the treated wastewater is sent to recycling cooling water system Daily, online COD and NH_3-N monitoring for treated wastewater		
Water	The treated residential wastewater and industrial wastewater is reused for recycling cooling water at Chemical Island. The water quality meets the Water Quality Standards for Reused Water for Recycling Cooling Water System (HG/T 2923-2007) The treated wastewater from coal gasification system meets the Class II standard of the Comprehensive Discharge Standard for Wastewater (DB12/356-2008)			Fully complied with.
Air	Dust and waste-gas emissions from project operation	Dust collectors and ventilation devices are installed at each transfer station; a filtering system is installed at raw coal bin, fly ash recycling bin, and coal milling system Water spraying devices are installed at main dusting points Dust collecting bag is installed at fly ash storage site Wet scrubbing is used to remove dust entrained in coal gas Lo-Cat II chemical desulfurization process is used for sulfur recovery from raw coal gas Online continuous air emission monitoring system is installed to monitor SO_2, NO_x, and smoke of the waste gas from waste heat boiler Continuous air quality monitoring by a monitoring station close to the project site TSP monitoring monthly at project site		Local EMS and EMU. Fully complied with.
	Monitoring results show how air quality, based on daily average, meets the Class III air quality standard (GB3095-1996)			PM_{10} exceeded the Class III standard within a few months; the NO_x emissions sometimes exceeded the emission limit at

Issue	Major impacts	Mitigation Measures	Monitoring Frequency	Responsible Party and Compliance Status
	The SO_2, smoke and NO_x emission concentration of the flue gas meets the standard emission limit requirement for gas turbine (fueled by non-natural gas) (GB13223-2011) The TSP emission concentration is within the allowable limit required by the Comprehensive Emission Standard for Air Pollutants (GB16297-1996)			the start of project operation, and later met the standard after technical retrofit.
Soil	Soil loss and contamination	Soil erosion from exposed areas are compacted and revegetated where possible. Soil contamination is prevented by installing oil separators at wash-down and refueling areas, and installing secondary containment at fuel storage sites. All hazardous wastes and hazardous materials will be stored in properly designed storage facilities.		EMU and local water resource bureau. Fully complied with.
Solid waste	Hazardous solid waste including waste solvents, waste activated carbon and waste COS hydrolysis will be collected, transported and disposed of by Tianjin Hejia Veolia Environmental Service Company Ltd. Waste coal from coal milling, and slag and flay ash from coal gasification system are collected in bins, temporarily stored at solid waste collection site, and reused at nearby construction site of natural gas-fired power plant Residential solid waste is collected, temporarily stored at solid waste collection site, and then transported to a municipal landfill site by a local hygiene authority Monitored by local EPB as needed			EMU and local EPB. Fully complied with.
Noise	Noise impact on workers and local residents	Mufflers are installed in some noisy machinery to mitigate noise pollution Extremely noisy equipment is installed in a closed area Low noise equipment is selected Arbors are built all around the project boundary to reduce noise pollution Earmuffs are provided to workers in noisy environments to protect their hearing Monitoring is conducted quarterly by the EMU at three noisy points; project completion monitoring is conducted by local EMS		EMU and local EMS. Project boundary noise was monitored only once in 2014, and the monitoring results show that most of the project boundary noise level exceeded the Emission Standard of Environmental Noise for Boundary of Construction Site (GB12523-2011)

COD = chemical oxygen demand, COS = carbonyl sulfide, EMS = environmental monitoring station, EMU = environmental management unit, EPB = environmental protection bureau, H2S = hydrogen sulfide, km = kilometer, m = meter, MW = megawatt, m^3/h = cubic meter per hour, NH_3-N = ammonia nitrogen, NO_2 = nitrogen dioxide, NO_x = nitrogen oxide, PM_{10} = particulate matter below 10 microns, PRC = People's Republic of China, SO_2 = sulfur dioxide, t = ton, t/km^2 = tons per square kilometer., TSP = total suspended particulates.
Source: Huaneng Tianjin Integrated Gasification Combined Cycle Company Limited and consultant's analysis.

13. Table A11.5 presents the monitoring results of effluent discharged at various wastewater treatment facilities at the project site. The results show that wastewater quality met the Class III Comprehensive Discharge Standard for Wastewater (DB12/356-2008) and the Water Quality Standards for Reused Water for Recycling Cooling Water System (HG/T 2923-2007). The monitoring of treated residential and industrial wastewater ceased in 2015 as the project owner believed there was insufficient treated wastewater, and attention shifted to monitoring the quality of cooling water, which uses treated residential and industrial wastewater.

Table A11.5: Wastewater Quality Data

At residential wastewater treatment plant					
HG/T 2923–2007 Water Quality Standards for Reused Water for Recycling Cooling Water System					
Standard	**Year**	**2013**	**2014**	**2015**	**2016**
6–9	PH	8	8.2		
15	NH_3-N (mg/l)	40	4		
80	COD (mg/l)	17	14		
5	BOD (mg/l)	6.6	3.2		
At industrial wastewater treatment plant					
HG/T 2923-2007 Water Quality Standards for Reused Water for Recycling Cooling Water System					
Standard	**Year**	**2013**	**2014**	**2015**	**2016**
6–9	PH	8.3	7.9		
15	NH_3-N (mg/l)	0.3	0.6		
80	COD (mg/l)	43	11.8		
5	BOD (mg/l)	2.6	3.2		
At coal gasification wastewater treatment plant					
DB 12/356-2008 Comprehensive Discharge Standard for Wastewater					
Class III	**Year**	**2013**	**2014**	**2015**	**2016**
6–9	PH	8.1	8.3	8.6	8.7
35	NH_3-N (mg/l)	19	18.6	20	18
500	COD (mg/l)	62	22	25	25
300	BOD (mg/l)	125	169	189	240

BOD = biochemical oxygen demand, COD = chemical oxygen demand, mg/l = milligram per liter, NH_3-N = ammonia nitrogen, pH = potential of hydrogen

Note: Water quality monitoring of treated industrial and residential wastewater has not been conducted since 2015 due to a reduction in the amount of wastewater produced (about 5 tons per day for treated residential wastewater and about 10 tons per day for treated industrial wastewater) and its consistent quality.

Source: Huaneng Tianjin Integrated Gasification Combined Cycle Company Limited.

14. There have been no impacts on marine flora and fauna within the project's area of influence. The concentrated seawater discharged from the cooling tower is piped to the Tianjin Harbor Concentrated Seawater Comprehensive Utilization and Zero Emission Project constructed by Tianjin Binhai Seawater Desalting Company. This project was completed at the end of 2016. Before the project was put into operation, the concentrated seawater was piped to the Dagu wastewater discharge point. The concentrated seawater discharge will result in a temperature rise of 0.221°C, which is lower than the required 4°C. The impact of salt concentration levels in the discharged seawater is limited to the Dagu wastewater discharge canal. It does not affect the marine flora and fauna around the seawater discharge point. Monitoring of cyanide and temperature is not required as part of the EMoP; cyanide is found mainly in the coal gasification wastewater, which is pre-treated at the project site and sent to the harbor wastewater treatment plant for further disposal. This means there is no direct discharge of wastewater containing cyanide from the project.

15. Table A11.6 presents ambient air quality, which was measured 200 meters from the project site. The monitoring results show that ambient air quality met Class II air quality standards

(GB3095-1996) except for particulate matter below 10 microns (PM_{10}). The ambient air quality can meet Class III standards. The continuous air quality monitoring station is operated by the local environmental management department, which was also responsible for its construction.

Table A11.6: Ambient Air Quality Data During Construction and Operation

Air quality standards (GB3095-1996) (daily, mg/m³) Class III			Ambient air quality (daily average, mg/m³)					
Class III	Class II	Year	2011	2012	2013	2014	2015	2016
0.15	0.10	PM_{10}	0.14	0.11	0.11	0.13	0.12	0.11
0.10	0.06	SO_2	0.02	0.05	0.06	0.05	0.03	0.03
0.12	0.12	NO_2	0.01	0.04	0.05	0.08	0.04	0.05

m^3 = cubic meter, mg = milligram, NO_2 = nitrogen dioxide, PM_{10} = particulate matter below 10 microns, SO_2= sulfur dioxide.
Source: Harbor Economic Area Environmental Monitoring Station, 2011–2016.

16. Table A11.7 presents the air pollution emissions of flue gas from the gas turbine during project operation. The results show that the sulfur dioxide (SO_2), smoke (including all sizes of particulates in the flue gas) and nitrogen oxide (NO_x) emission concentrations are within the emission limit for a gas turbine (fueled by syngas). The NO_x emission concentration was near the emission limit before 2015, and further reduced after technical retrofit for de-NO_x in 2015.

Table A11.7: Monitoring Results of Air Emissions from Gas Turbine

		Air emissions from gas turbine (daily average, mg/m³)			
Emission limit	Year	2013	2014	2015	2016
35	SO_2	0.57	6.62	9.26	7.48
50	NO_x	45.72	41.87	34.47	21.64
10	PM	0.23	0.55	0.87	0.33

mg/m^3 = milligrams per cubic meter, NO_x = nitrogen oxide, PM = particulate matter, SO_2 = sulfur dioxide.
Note: The emission limit requirement is applicable for a gas turbine (fueled by non-natural gas) (GB13223-2011)
Source: Annual environmental monitoring reports (2013–2016) by HTICL.

17. Table A11.8 shows the data on total suspension particulates (TSP) at the combined cycle tower, integrated gasification tower and air separation workshop during project construction and operation. The results show that all the TSP concentrations monitored are far below the emission limit required by GB13223-2011.

Table A11.8: TSP Monitoring Data During Construction and Operation

Integrated emission standard of air pollutants (GB16297-1996) (new pollution sources)		TSP (daily average, mg/m³)				
Standard	Year	2012	2013	2014	2015	2016
18	CC tower	0.16	0.59	0.26	0.37	0.26
18	IG tower	0.16	0.58	0.28	0.39	0.29
18	Air separation workshop	0.13	0.52	0.27	0.35	0.24

CC = combined cycle, IG = integrated gasification, TSP = total suspended particulates.
Source: Annual environmental monitoring reports (2013–2016) by HTICL.

18. Tianjin EMS monitored dust emission concentrations at the fly ash bin filter, the pressurized transport system, the pulverized coal bin, and the coal grinding and drying system in March 2014. The monitoring results show that all the dust emission concentrations are within the allowable limits required by the Comprehensive Emission Standard for Air Pollutants (GB16297-1996) (Table A11.9).

Table A11.9: Monitoring Results of TSP and Main Pollution Sources

Pollution source	Monitoring site		Monitoring times	Waste gas flow (m (Nm^3/h)	Emission concentration (mg/m^3)	Emission rate (kg/h)
Fly ash bin filter	Outlet A		6	409-410	0.94-1.16	$3.7\text{-}4.7*10^{-4}$
	Outlet B		6	408-411	0.86-1.06	$3.7\text{-}4.3*10^{-4}$
	Accumulative emission		6			$8.3\text{-}8.8*10^{-4}$
	GB16297-1996			120	39	
Pressurized transport system	Outlet A	6	2895-2907	39.4-50.4	0.11-0.15	
	Outlet B	6	2891-2908	3.68-5.11	$(1.1\text{-}1.5)*10^{-2}$	
	Outlet C	6	2888-2902	34.9-43.7	0.10-0.13	
	Accumulative emission				0.244-0.271	
	GB16297-1996			120	99.8	
Pulverized coal bin	Deduster A	6	2387-2549	22.2-31.9	$(5.4\text{-}8.1)* 10^{-2}$	
	Deduster B	6	2350-2512	19.2-28.8	$(4.2\text{-}5.2) *10^{-2}$	
	Deduster C	6	2559-2712	15.6-22.0	$(4.2\text{-}5.8)* 10^{-2}$	
	Accumulative emission				0.16-0.18	
	GB16297-1996			120	49.5	
Coal grinding and drying system	Outlet A	6	12801-13282	19.5-21.8	0.25-0.28	
	Outlet B	6	11037-11357	48.5-51.8	0.53-0.58	
	Outlet C	6	11340-11657	36.3-42.5	0.41-0.48	
	Accumulative emission				1.22-1.29	
	GB16297-1996			120	116	

kg/h = kilograms per hour, m^3/h = cubic meter per hour; mg/m^3 = milligrams per cubic meter; Nm^3/h = normal cubic meters per hour, TSP = total suspended particulates.
Source: China Environmental Monitoring Station. 2014. *Environmental Monitoring Report of IGCC project for Project Completion Acceptance*.

19. Hydrogen sulfide (H_2S) emission was monitored in March 2014. Monitoring was conducted at two discharge points in the sulfur recovery system. The results show that the H_2S emission rate exceeded the Emission Standard for Effluvium Pollutants (DB12/-059-95). The implementing agency took corrective measures immediately. The measures mainly included the expansion of the absorption chamber's volume and an increase in absorption time. After the upgrade, H_2S was monitored again in August 2014, and the monitoring results show that H_2S emission from the sulfur recovery system can now meet the standard (Table A11.10).

Table A11.10: H_2S Emission from Sulfur Recovery System Before and After Upgrade

	Monitoring site	Monitoring times	Waste gas flow (m^3/h)	Emission concentration (mg/m^3)	Emission rate (kg/h)
Before upgrade	Outlet A	6	6069-6208	31.2-248	0.19-1.5
	Outlet B	6	6338-6522	25.3-202	0.16-1.3
After upgrade	Outlet A	6	6095-6286	0.031-0.149	$(1.9\text{-}9.4)*10^{-4}$
	Outlet B	6	5763-6008	0.694-5.0	0.0042-0.02
Standard (DB12/-059-95)					0.91

H_2S = Hydrogen sulfide, kg/h = kilogram per hour, m^3/h = cubic meter per hour; mg/m^3 = milligrams per cubic meter.
Source: China National Environmental Monitoring Centre. 2014. *Environmental Monitoring Report of IGCC project for Project Completion Acceptance*.

20. Tables A11.11, A11.12 and A11.13 show noise monitoring data during construction and operation. The results show that noise levels at the project boundary met the Emission Standard of Environment Noise for Boundary of Construction Site (GB 12523－2011), but failed to meet the Emission Standard for Industrial Enterprises at Boundary (GB12348-2008) during project

operation. The monitoring results show that the noise levels at project boundary are 2–17 decibels (dB) (A) higher than the limit during daytime, and 5–26 dB (A) higher than the limit. The noise at four main noise sources was monitored weekly. Some mitigation measures such as the use of noise control devices and the installation of extremely noisy equipment in isolated and closed environments helped to reduce noise by 15–30 dB (A). However, the monitoring results of major noise sources showed that the noise levels ranged from 60.2 dB (A) to 90.3 dB(A). High noise was detected at the air separation workshop particularly. The implementing agency provides workers with earmuffs to protect their hearing when working in noisy environments within the Tianjin IGCC plant.

Table A11.11: Noise Monitoring Results During Project Construction. Unit: dB (A)

Monitoring location	Monitoring date		
	13 Feb 2012	14 Feb 2012	15 Feb 2012
CC tower	40.9	42.9	41
IG tower	41	39.8	40
Air separation workshop	45	43	44
Noise emission standard - day	70		
Noise emission standard - night	50		

CC tower = combined cycle power generation cooling tower, dB = decibel, IG tower = coal gasification island cooling tower.
Source: Greengen Company, Ltd.

Table A11.12: Noise Monitoring Results at Main Noise Sources. Unit: dB (A)

Monitoring date	CC Tower	IG Tower	In the front of the Air Separation Workshop	At bottom of Coal Gasifier
2014.2.28	60.5	76.3	65.4	72.7
2014.3.20	61.2	75.6	63.2	70.2
2014.3.28	79.5	77.9	87.6	77.3
2014.4.4	76.1	78.8	90.3	72.7
2014.4.11	78.2	78.3	88.9	75.4
2014.4.18	61.7	68.4	63.2	74.5
2014.4.25	79.4	78.3	88.7	76.2
2014.7.21	79.2	78.4	87.9	77.1
2014.7.28	79.5	78.8	88.2	76.9
2014.8.20	79.1	78.2	87.8	76.5
2014.8.27	79.2	78.1	87.9	76.4
2014.9.5	79.9	78.3	88.2	76.6
2014.9.10	79.8	78.2	88.1	76.3
2014.9.15	79.2	78.1	88.1	76.2
2014.9.25	79.2	78.2	88.3	76
2014.10.17	79.1	78	88.2	76.2
2014.10.24	79.9	77.2	86.9	74.5

CC tower = combined cycle power generation cooling tower, dB = decibel, IG tower = coal gasification island cooling tower.
Source: Quarterly environmental monitoring report by Huaneng Tianjin Gasification Integrated Combined Cycle Company Limited. Monitoring was done at daytime.

Table A11.13: Results of Noise Monitoring at Project Boundary. Unit: dB (A)

No.	Monitoring location	Daytime	Standard	Night	Standard
1	1m outside north boundary	62	65	60	55
2	1m outside north boundary	62		60	
3	1m outside east boundary	79		79	
4	1m outside east boundary	82		82	
5	1m outside east boundary	80		76	
6	1m outside east boundary	69		68	
7	1m outside east boundary	67		68	
8	1m outside south boundary	56		66	
9	1m outside south boundary	61		65	
10	1m outside west boundary	62		60	
11	1m outside west boundary	76		78	
12	1m outside west boundary	73		68	
13	1m outside west boundary	66		69	

dB = decibel, m = meter.

Source: China National Environmental Monitoring Centre. 2014. *Environmental Monitoring Report of Integrated Gasification Combined Cycle Company Limited project for Project Completion Acceptance*.

21. Environmental monitoring was properly carried out throughout the project except for project boundary noise monitoring, which was conducted by the local environmental monitoring station for limited times only. The monitoring results show that the project did not have a significantly adverse impact on air and water quality in and around the project areas. However, the noise level at the project boundary exceeds the standard due to a combination of noise from the project itself, the Tianjin Alkali Plant and nearby traffic. Currently, monitoring of the noise at project boundary is conducted monthly. Additional mitigation measures, including a noise reduction upgrade at the air separation workshop and the construction of a noise isolation wall at the cooling water towers, are being implemented.

F. Environmental Benefit

22. IGCC power generation can reduce coal consumption for each kilowatt-hour (kWh) of on-grid electricity. In 2014, the average on-grid electricity coal consumption was 318 grams of coal equivalent (gce) per kWh while Tianjin IGCC power generation efficiency reached 41% (or 299 gce/kWh), about 6% lower than that of coal-fired power generation. If air-blown coal gasification is adopted, the net power generation efficiency could reach 48%. The IGCC power plant can also be combined with fuel-cell humid-air-turbine (HAT) cycle advanced power generation technology, forming more efficient integrated-gasification-fuel-cell-cycle and integrated-gasification-HAT (IG-HAT) power generation patterns. This could increase development potential for coal-fired power generation. In addition, water consumption for IGCC is only two-thirds that of a conventional coal-fired power plant with the same installed capacity. The coal gasification option offers higher value for coal use.

23. The Tianjin IGCC plant has achieved significant air emission reduction during project operation. Based on operation data in 2015, the power generation emission coefficients of the Tianjin IGCC plant are SO_2 0.043 g/kWh, NO_x 0.284 g/kWh and dust 0.004 g/kWh, compared with emission limits for coal-fired power plants set by the Emission Standard for Thermal Coal Plants (GB13223-2011). The project has the potential to achieve remarkable emission reduction (Table A11.14).

Table A11.14: Calculated Emission Reduction During Project Operation

Type of Pollution	2013	2014	2015	2016
SO_2 (t)	134.31	654.61	727.21	801.63
NO_x (t)	37.52	182.86	203.14	142.78
Smoke (t)	14.65	71.41	79.33	87.45
CO_2 (t)	29,171.69	133,544.77	138,763.69	152,963.30

CO_2 = carbon dioxide; NO_x = nitrogen oxide, PM = particulate matter, SO_2 = sulfur dioxide, t = ton.
Source: Huaneng Tianjin Integrated Gasification Combined Cycle Company Limited and consultant's analysis.

24. Development of a distributed energy system is important in promoting a revolution in energy supply. Natural gas is the ideal fuel for a distributed energy system, but its high price makes it suitable only for small- and medium-size energy supply systems. When comparing natural gas projects with IGCC technology, coal-based distributed energy systems have significant competitive advantages. IGCC power plants can produce multiple energy products including electricity, heat, steam, cooling water, and hydrogen, thereby meeting the energy demands of different users, particularly industrial parks. IGCC-based distributed energy systems therefore have good potential for popularization.

25. The PRC government aims to decrease CO_2 emission intensity per unit of GDP by 60–65% by 2030 compared with that in 2005. Otherwise, CO_2 emissions will reach their peak before 2030. Fossil energy consumption is the largest greenhouse emission source in the PRC, and greenhouse gas emissions from coal combustion accounts for about 80% of total CO_2 emission from energy consumption. Increasing coal-fired power generation efficiency and CO_2 capture and storage are important ways to reduce CO_2 emissions. IGCC can greatly increase coal-fired power generation efficiency. It can reduce the CO_2 emission factor of on-grid electricity by about 6%. IGCC also offers a feasible way to reduce CO_2 emissions from coal-fired power generation by adopting the mature hydrogen production from coal gas technology, which can separate over 90% of total CO_2. Technically, it can achieve near-zero emissions of major air pollutants. Compared with post-combustion CO_2 capture at conventional coal-fired power plants, the CO_2 pre-combustion capture cost can be reduced by more than 50%. Flue Gas Desulphurization (FGD) has been installed at two 300 MW plants in the Yangliuqing thermal power plant. The FGD upgrade at the Yangliuqing plant shows that TSP emissions were reduced from 326 t/a to 24.35 t/a in 2016, which sufficiently offsets TSP emissions from the IGCC project.

G. Conclusions and Recommendations

26. The Tianjin IGCC project's EMP has been properly executed by the implementation agency and relevant companies and organizations. All the environmental protection facilities were constructed and are operating stably and effectively. The monitoring results show that all the environmental pollution emissions comply with the relevant standards, except for noise emission at project boundary during project operation.

27. The Tianjin IGCC plant substantially reduced emissions of major air pollutants including SO_2, NO_x, total suspended particulates, and CO_2 when compared with conventional power plants. In comparison to the emission limits of the PRC's coal-fired power plants, the Tianjin IGCC plant reduced its emissions of SO_2 by 90%, NO_x by 51% and smoke by 98%. The project also consumes 35% less cooling water than a conventional coal-fired power plant.

28. Most of the monitoring activities are being conducted as required, however monitoring of treated residential water and industrial wastewater, and noise level at project boundary are not fully implemented in accordance with the EMoP. It is recommended that quarterly monitoring of noise at the project boundary and continuous monitoring of treated residential and industrial wastewater should be conducted to ensure that water quality meets the required standards.

29. Further noise pollution mitigation measures are needed. The executing agency should monitor the noise on a regular basis while the local EMS should monitor the noise as needed. There are no sensitivity receptors outside the project boundary (only some factories and storage sites). The noise mainly impacts worker health and safety as the nearest residential area is 5 km away. Proposed measures include, but are not limited to, the following: (i) establishing noise barriers around major noise sources, including equipment and facilities; (ii) installing noise absorption material at major noise workshops; (iii) planting arbors along project boundaries to reduce the noise level. Following the PCR mission, noise monitoring at the project boundary is conducted monthly, as per the EMP requirement. Some monitoring points still exceed the standard because the noise level at the project boundary is affected not only by the project itself, but also by Tianjin Alkali Plant and nearby traffic. Additional mitigation measures, including a noise reduction upgrade at the air separation workshop and the construction of a noise isolation wall at the cooling water towers, are being implemented.

30. The daily monitoring of treated wastewater from the residential and industrial wastewater plants was restored in 2017, following the PCR mission. In addition, the residential and industrial wastewater treatment systems are now in normal operation, and monitoring of the treated wastewater is conducted daily.