

INTRODUCTION OF TECHNOLOGIES USED FOR SELECTED REPRESENTATIVE SUBPROJECTS

A. Subproject 1: Advanced Biogas and Organic Fertilizer Project

1. Various types of mixed organic waste will be anaerobically digested to generate biogas, which in turn will be used to produce bio-natural gas as a replacement for conventional natural gas in transport, and organic fertilizer as a replacement for chemical fertilizer. This would have multiple economic, ecological, and environmental benefits as described below.

1. Introduction of Subborrower

2. China Energy Conservation and Environmental Protection Group (CECEP) is the only state-owned enterprise (SOE) with a mandate for energy conservation and environmental protection in the People's Republic of China (PRC). At present, CECEP owns 543 subsidiaries, among which 27 companies are wholly-owned or holding subsidiaries at secondary level and 7 are stock listed companies. Over the years, CECEP has successfully transferred from a national policy-based investment company to a professional industrial group, devoted to energy conservation, environmental protection, and resource recycling, providing design and consulting services and has become the most competitive and the largest service-oriented industrial group in the energy conservation and environmental protection field in the PRC.

3. CECEP Green Carbon Environmental Protection Company (the company) is a wholly-owned subsidiary of CECEP, with a registered capital of CNY700 million and focuses on utilization of organic waste resources. The company builds overall industrial chain integrating consultancy, planning and design, technology research and development, construction investment, product marketing, operation management, equipment manufacturing, financial services, and provides comprehensive solutions for regions at county-level in organic waste treatment, distributed energy and agriculture waste utilization, to promote environmental protection, resource utilization, eco-organic agriculture, and clean energy.

4. The company aims to become (i) the largest organic fertilizer supplier, (ii) the largest biogas supplier, (iii) the largest integrator, and (iv) the largest operational service provider in biomass utilization in the PRC. As the main operating body for this subproject, CECEP Fengqiu Biomass Environmental Protection Co., Ltd. is responsible for the daily operation and equipment maintenance of the project. The company was founded in December 2014 with a registered capital of CNY34.52 million.

2. Technology Adopted

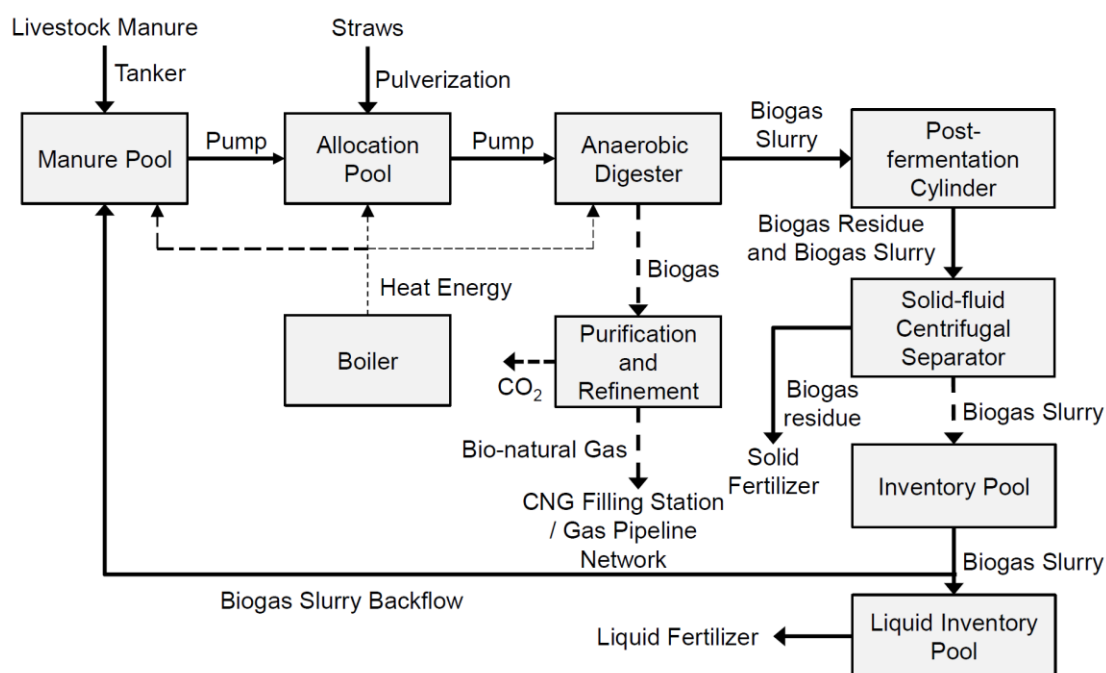
5. The Fengqiu project uses anaerobic fermentation technology for biogas production. The produced biogas is then purified and compressed. The compressed bio-natural gas is sold to consumers to replace gasoline and diesel for transport in the filling station. The biogas residue and slurry is used to produce organic fertilizer in replacement of chemical fertilizer (see Figure 1).

6. In the PRC, the organic waste production from straws, livestock manure, and agricultural waste amounts to over 3.5 billion tons per year. Based on statistics from the Ministry of Agriculture, the annual applicable waste resource for biogas production amounts to 1.4 billion tons (among which straw resource amounts to 180 million tons, livestock manure 1.06 billion

tons, other organic waste 164 million tons). The potential for raw biogas production is up to 122.7 billion cubic meters (m³) and compressed bio-natural gas production is 84.4 billion m³.

7. The air pollution caused by the open burning of straw is a key problem the government has been striving to resolve. Despite more rigorous enforcement of a “no burning” policy, some of the farmers still secretly burn the straw. This is because they are concerned that the straws returned to field will bring germs and insects from crops to underground and contaminate the crops to be planted next; if there are too much straw to be buried back to the field, the slow corrosion will lead to decreased crop yield.

Figure 1: Flow chart diagram of the advanced biogas and organic fertilizer project



CNG = compressed natural gas, CO₂ = carbon dioxide.

8. Direct use of livestock manure brings serious adverse impact to the environment. Untreated livestock sewage that goes directly into lakes and rivers contributes to eutrophication. When done continuously, the waterbody will become black and stinky, causing permanent organic contamination that can be hardly treated or recovered. With the chemical reaction of microbes, livestock manure will emit a lot of harmful and smelly gas such as ammonia and sulfur dioxide, affect the air quality around livestock farm, and endanger the health of livestock keepers and residents nearby. A great deal of pathogenic microbes, parasite ovum, and fly's eggs from livestock waste will cause the spreading of zoonosis. In the worst-case scenario, zoonosis can lead to human and livestock epidemics. If highly concentrated livestock sewage is directly used for irrigation, it will block soil pores, decrease soil's penetrability of air and water, harden the soil, and negatively impact soil quality.

9. Attempting to raise crop yields further has resulted in over-application of chemical fertilizers in the PRC. Such over-fertilization not only harms the crops and wastes resources, but also seriously contaminates the soil and underground water, endangering biological balance and human health. For instance, if ammonia fertilizer is applied to the soil, part of it may react through denitrification and produce nitrogen and nitrous oxide that diffuse from the soil and

spread to the air. When the nitrous oxide reaches the ozone layer, it reacts to produce nitric oxide and reduces the ozone amount. The application of ammonia fertilizer and phosphate fertilizer generates nutrients containing a great amount of nitrogen and phosphorus that enter the waterbody. Thus, eutrophication of the waterbody takes place, leading to excessive algae reproduction (and cyclical demise), and the dissolved oxygen is greatly consumed. The lack of oxygen in the water causes the death of fish and shrimps. Long-term application of ammonia fertilizer, especially ammonium fertilizer in large amounts, will also gradually acidize, harden the soil, and will make the soil no longer suitable for planting.

10. The replacement of chemical fertilizer with organic fertilizer could improve soil quality, increase crop yields and quality, and avoid negative impacts caused by the chemical fertilizer. There is a great potential in the replacement of chemical fertilizer with organic fertilizer in the PRC. According to a recent study, the organic fertilizer generated from livestock manure could replace 11.87 million tons of ammonia fertilizer, 8.06 million tons of phosphate fertilizer, and 11.69 million tons of potash fertilizer, taking up 38%, 52%, and 87% of actual chemical fertilizer consumption in 2014 respectively.¹ In livestock solid-fluid manure in Beijing suburbs, nutrients of nitrogen, phosphate and potash take up 58,700, 21,300, and 29,800 tons respectively, which equals to 99.3%, 185.2%, and 62.7% of crops field nutrient demand.²

11. The Fengqiu Biogas Project has the potential to resolve the environmental problems described above and is strongly supported by the government. In the past 2 to 3 decades, central financial institutions have invested nearly CNY40 billion to support biogas development in rural areas, but the actual operation has not been as expected. The biogas industry needs a new business model with an industrialized, scaled-up, and a market and growth-oriented approach.

12. The lack of sustainable supply of fermentation materials, the limited market penetration of organic fertilizer, the large amounts of biogas slurry production, the limited grid connection of biogas-generated electricity, and poor economic returns of biogas projects are issues that will affect the development of the biogas industry. Based on the existing issues in organic waste treatment and the barriers to biogas industry development, this project adopts a new business model, and incorporates an innovative technology and technique, aiming to provide a replicable example for the development of organic waste treatment and resource utilization in the future. Special features of the project included:

- (i) **Suitable technology.** The project adopts Continuous Stirred-Tank Reactor (CSTR) technology for biomass generation which is a proven and best available technology for treating mixed feedstock (manure and biomass). The CSTR is a vertical cylinder shaped digester with a massive roof and height/diameter ratio of close to 1:1. Its contents are perfectly mixed by a vertical, ultra-low speed turbine mixer with extremely high pumping capacity, being placed in the central axis of the tank. The low rotational speed results in a gentle treatment of the anaerobic biomass. At the same time, the permanent mixing produces optimum mass transfer rates for the bacterial conversion of the organic material into biogas. CSTR is particularly suitable for the treatment of organic waste and slurries with

¹ Lu, G.B. and Wang X.Z. (2016) *Potential Estimation of Organic Fertilizer Replacing Chemical Fertilizer Based on Nutrient Balance*. China Swine Industry, 11(11), pp. 15–18.

² Jia W., Li Y.H., Chen Q. and Chadwick D. (2014) Analysis on Livestock Manure Resource Status Quo and Its Replacement Potential of Chemical Fertilizer in Beijing Suburb. *Transactions of the Chinese Society of Agricultural Engineering*, 30(8), pp. 156–167.

- high solids concentrations and for materials with a high propensity for scum production. Sediments can easily be removed during operation.
- (ii) **Mixed fermentation.** The project uses straw and livestock manure for mixed fermentation. In the fermentation cylinder, the percentage of dry material could amount to 11%. Based on the sales performance of liquid fertilizer, the output quantity of biogas slurry could be controlled by increasing straw input quantity or increasing the capacity of returns of biogas slurry and digestive fluid.
 - (iii) **Higher production efficiency.** Carbon excipients such as corncob are added into raw material. By keeping balance of nutrient elements, carbon nitrogen ratio (C/N ratio) and potential of hydrogen (pH) value in the fermentation substrate, the fermentation technology could enhance the buffering ability of fermentation broth, improve the synergistic effect of microbes, increase the hydrolysis efficiency of straw and reduce the constraints to fermentation process caused by harmful substances, therefore increase biogas production efficiency. The project uses straw and livestock manure as mixed raw material, among those corncob is the main carbon source while livestock manure is the main nitrogen source. The mixed feeding of these two kinds of raw materials is favourable for the adjustment of C/N ratio in the fermentation system, so that the C/N ratio is within the best range of 15–20:1. The mixed feeding of raw materials helps solve the issue of low production efficiency of methane bacteria and the system's acidification incurred by imbalanced C/N ratio of single raw material.
 - (iv) **Sufficient resources.** Per the statistics provided by the Agricultural Bureau of Fengqiu County, the cultivated area of main crops in Fengqiu County such as wheat, corns, and rice took up 1,795,000 mu and the straw production yield was 858,500 tons in 2013.³ The project's annual corn straw consumption was 43,000 tons, taking up 17.2% of available corn straw resource in Fengqiu. Per the statistics provided by the Animal Husbandry Bureau of Fengqiu County in 2012, the number of animals were 532,000 pigs, 75,000 cows, 405,000 sheep and 6 million poultries respectively, which can produce 1.571 million tons of livestock manure. The project can treat pig manure of 30,000 tons per annum, taking up 9.4% of annual pig manure production in Fengqiu. Yingju Town, where the project is located, is on the boundaries of Yuanyang County, Yanjin County, and Fengqiu County that are all major agricultural counties in the PRC.
 - (v) **Well-designed collection system.** To ensure abundant supply of raw materials, the project adopts an "active collection mode" on raw material collection. The collection is done by signing an acquisition contract with specialised straw purchasers, in-house listing acquisition or by cooperative acquisition with harvester manufacturers. The straw collection radius is defined within 12 kilometer (km) from Fengqiu County, and it is applicable to include Yuanyang County and Yanjin County into the straw collection zone. In the collection of livestock manure, the project uses self-collection mode and outsourcing mode where the company will outsource the acquisition and transportation of livestock manure to several professional acquisition companies. The project company is only responsible for quality examination in the factory. At the same time, the project company will also purchase manure collection freight vehicles, and will rent out some of the vehicles to collection staff hired externally as a backup source. To ensure the raw material collection, the project company has signed an exclusive agreement with the local government, which guarantees that no

³ mu is a Chinese unit for area, 1 mu = 666.67 m².

more organic agricultural waste treatment projects or alike will be approved in Fengqiu County, therefor to secure the raw material supply.

- (vi) **Energy efficient devices.** Sufficient energy conservation measures were used in the project including: (i) overflow device is installed between the first plate and second plate of anaerobic fermentation cylinder, so that the energy consumption of material delivery pump is reduced; (ii) all energy-consuming equipment including mixer, fan, water pump and lighting devices are replaced with energy-saving products; (iii) the captive well is equipped with deep-well submersible pump with variable frequency drive to control the operation of the water pump based on the water demand; (iv) in adoption of dry-type transformer that is self-equipped with a forced air cooling device: when one transformer is in default or under maintenance, the forced air cooling device will start to raise the transformer's rated capacity by around 50%; (v) reactive power self-compensation device is used on the transformer in the load centre; and (vi) optimise the logistics route of production and operation based on the principle of reasonable technical process, clear functioning division, concise pipeline and compact layout, therefore shorten the route and save energy.
- (vii) **Better purification.** Biogas purification and refinement unit utilizes pressure swing adsorption equipment (PSA) that could refine the methane with a concentration of more than 99%, thereby enhancing the calorific value of bio-nature gas and increasing the market competitiveness of bio-nature gas. Per the gas quality test report of similar reports, the methane concentration is as high as 99.99% and the high calorific value reaches 37.11 megajoule per cubic meter (MJ/m³) (10.31 kilowatt hour per cubic meter [kWh/m³]) which is up to the first-class standard of natural gas (GB 17820-2012).
- (viii) **Various organic fertilizers.** The production process of solid organic fertilizer could produce not only primary powdery organic fertilizer of low cost, but also particle bio-organic fertilizer of high value to respond various market demands; and two kinds of fluid organic fertilizer could also be produced. By mixing and allocating the fluid organic fertilizer with solid organic fertilizer, complete product structure will be formed and market competitiveness of the organic fertilizer product can be enhanced.
- (ix) **Flexible selling methods.** The project allows various selling modes and sales channels for organic fertilizer: (i) to clients with large demand, the project plans to use "company + farmer" direct selling mode; (ii) to clients near the project site (within 100 kilometres) with small demand, the projects plan to establish a CECEP brand stores to see to the clients directly; (iii) to clients with a distance between 100 to 500 kilometres from the project site, the project plans to adopt traditional agricultural supply agency system, i.e., to sell the products via wholesalers; and (iv) to clients with a distance of more than 500 km., the company is to establish sales offices, build warehouses, and stock inventories for sales activity.
- (x) **Use of biogas.** Unlike the traditional biogas utilization in electricity generation, the project produces natural gas and uses it in transport to replace gasoline and diesel, which can not only reduce the air pollutant in low altitude but also improve the financial viability of the project. Meanwhile, to ensure the sales of natural gas, the Company has obtained the approval of natural gas filling station from the local government and will construct a filling station as one component of the project. The station will be located on the southwest of the project site. Connected by high-pressure pipeline, the station is adjacent to the main site of

the project, thus saving the cost of tanker transportation and achieving higher return.

3. Estimated Energy Savings and Emission Mitigation

13. The project consumes 43,000 tons of corn stock and 30,000 tons of pig manure to produce 4,200,000 m³ of biological natural gas, 32,400 tons of solid organic fertilizer, and 15,000 tons of liquid organic fertilizer annually. The biological natural gas is compressed and transported to the filling stations. The total output of biological natural gas is 155,862 GJ⁴ or 43.3 GWh or 5,318 tons of coal equivalent (tce) and could replace 4.90 million liters of gasoline⁵ or 4.25 million liters of diesel⁶ based on the heating value calculation. The biological natural gas will improve the availability of local natural gas supply and to encourage more vehicle owners to switch from gasoline or diesel to natural gas. Meanwhile, the project owner will purchase 6,810,000 m³ liquefied natural gas (LNG) to fully utilize the capacity of the filling station. There are no direct emissions from the project.⁷

14. Gasoline usage for taxi,⁸ corn stock open burning and nitrogenous fertilizer utilization⁹ are selected to be the reference cases. As the gasoline consumed should meet the standard of GB 17930 Gasoline for motor vehicles, the emissions from gasoline-powered taxi which meet Stage IV emission standard is considered as the baseline for pollutant mitigation calculation. The emissions of reference case are listed in Table 1. A research conducted by China Automobile Research Center indicated that the compressed natural gas (CNG) emissions will reduce 34% of total hydrocarbon (THC), 70% of carbon monoxide (CO), 80% of nitrogen oxide (NO_x), and 83% of particulate matter (PM)¹⁰ compared to Stage IV fuel. The energy savings and emission mitigation from the project implementation is listed in Table 2. Figure 2 illustrates how the emissions reductions are created.

4. Conclusion

15. Emissions from vehicles contribute in part to the haze of the Beijing–Tianjin–Hebei (BTH) region. Using natural gas as a substitution fuel for gasoline and diesel is one of the options to reduce emissions from automobiles. In 2015, the share of natural gas in primary energy consumption was only 5.9% in the PRC, much less than the world average of 23.7%. More than 30% of the natural gas consumed is imported in the PRC. Increasing availability of domestic natural gas supply could benefit not only pollutant mitigation, but also energy security.

16. This project adopts a proven and best available technology for agricultural waste treatment and produces 4,200,000 m³ natural gas from agricultural waste. It will save 5,318 tce of energy per annum and reduce CO₂, SO₂, NO_x, PM, CO, and hydrocarbon/VOCs emission at 15,499, 19.3, 192.7, 514.1, 2,393.2, and 453.3 tons respectively.

⁴ According to the sample testing report, the heat value of biogas is 37.11MJ/m³ and H₂S content is 0 mg per cubic meter (limit of detection is 0.03 mg/m³) which meets the natural gas standard of GB 17820-2012.

⁵ The density of gasoline is 1,353 liter per ton and heat value 43,070 kJ/kg.

⁶ The density of diesel is 1,164 liter per ton and heat value 42,652 kJ/kg.

⁷ The CO₂ emissions from purifying biogas process come from renewable sources which does not take account.

⁸ Due to the drastic cost reduction by switching fuel from oil to natural gas, the CNG vehicles are mainly used for business purposes, like taxi and freight trucks. Currently, most of CNG is used by taxi.

⁹ Nitrogenous fertilize is the main chemical fertilizer used in the PRC.

¹⁰ Source: <http://news.cnpc.com.cn/system/2016/05/31/001594788.shtml>.

17. The business model designed for this project can solve the problems faced during the biogas industry development such as low economic performance, unsustainable feedstock supply, and others. It could be replicated to other projects, to form a biogas production industry using agricultural waste. The organic fertilizer produced by this project could improve the soil quality in the long run and improve the air quality as well.

Table 1: Emissions of Reference Cases

	Category	CO	THC	NO _x	PM	SO ₂ ^a	CO ₂ ^b
Taxi	Baseline emission factor ^c (g/km)	2.45	0.277	0.135	0.003	50 ppm	--
	Correct factor ^d	1.47	1.43	1.58	1.12	--	--
	Emission factor ^e (g/liter)	33.32	3.66	1.98	0.031	0.074	2,361
	Emissions from gasoline ^f (ton)	163.2	17.9	9.7	0.15	0.36	11,569
Total reference case emissions		163.2	17.9	9.7	0.15	0.36	11,569

CO = carbon monoxide, CO₂ = carbon dioxide, g/km = grams per kilometer, g/liter = grams per liter, kg/ton = kilograms per ton, NO_x = nitrogen oxide, PM = particulate matter, SO₂ = sulfur dioxide, THC = total hydrocarbon.

^a GB 17930-2016 Gasoline for motor vehicles Stage IV.

^b China carbon trade network: CO₂ emission factor of gasoline 2.361 kg/liter (www.tanpalfang.com).

^c Emission under the scenario of speed 30 km/h, temperature 15°C, moisture 50% and 50 ppm sulfur content.

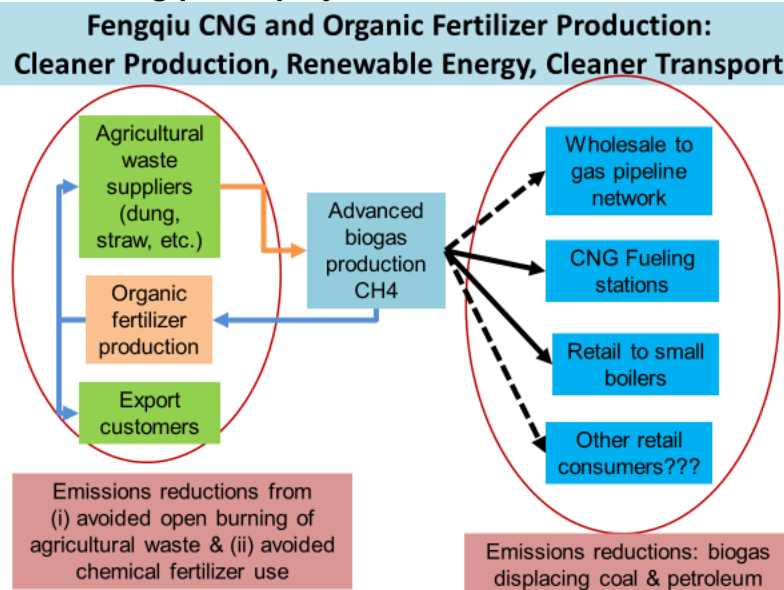
^d Consider the impacts from temperature, moisture, sulfur content of gasoline, average speed of taxi (assuming 30–40 km/h) and the deterioration of catalytic converter.

^e Fuel consumption is 10.8 liter/100 km which meets the GB 20997-2007 Limits of fuel consumption for light duty commercial vehicles.

^f Gasoline consumption of 3,618,807 liters.

Source: Ministry of Environmental Protection: Technical Guidelines of Air Pollutant Inventory for Automobiles.

Figure 2: Fengqiu Subproject Emissions Reductions Pathways



CH₄ = methane, CNG = compressed natural gas.

Table 2: Energy Savings and Pollutant Mitigation

Energy Savings (tce)	5,318 ^a					
	CO ₂	SO ₂	NO _x	PM	CO	THC/VOCs
Total reference case emissions (ton)	11,569	17.9	9.7	0.15	163.2	17.9
Project emissions (ton)	0	0	1.9	0.03	49.0	11.8
Emission reduction(ton)	11,569	17.9	7.8	0.12	114.2	6.1

CO = carbon monoxide, CO₂ = carbon dioxide, NO_x = nitrogen oxide, PM = particulate matter, SO₂ = sulfur dioxide, tce = ton of coal equivalent, THC = total hydrocarbon, VOC = volatile organic compounds.

^a Excluding energy consumption of the project.

B. Subproject 2: Industrial By-product Gas Utilization

18. This subproject will use coke oven gas, an industrial by-product, to produce LNG for use in the transportation sector, as a preferred option in terms of greater market and environmental benefits, to the current practice of using such coke oven gas to generate onsite electricity and steam, or to produce urea or methanol.

1. Introduction of Subborrower

19. Shanxi Liheng Iron & Steel Co., Ltd. (Liheng) was set up in 2002 with a registered capital of CNY400 million and has about 4,000 employees. Liheng has facilities of coke-making, iron-making, steel-making, steel-rolling, combined heat and power (CHP) plants using by-product gas, grinding mill of blast furnace slag, and water treatment and recycling. It is in the 10-million-ton Steel Recycling Industrial Park of Quwo County, Linfen City, occupying 1,500 acres' land with convenient transport network.

20. Liheng is among the top 100 best private enterprises of Shanxi and top 500 private enterprises of the PRC. It is awarded with ISO9001:2000 certification and has been consecutively recognized as "top taxpayer," "model company of energy-saving & emission-reduction," and "enterprise of safety production" in the past years.

21. Liheng has adopted many energy-efficient and environmentally-sound technologies such as coke dry quenching (CDQ) technology, waste heat recovery from sintering mills, exhaust gas recovery from blast furnaces and coke ovens and conversion for power generation. All these efforts enabled the company to realize zero discharge of waste water, 100% recycling of the slag, and 100% self-sufficient for power supply to the steel production.

2. Technology Adopted

22. The proposed project uses industrial by-product coke oven gas to produce LNG for use in the transportation sector. The annual LNG output is 180,000 metric tons. The project includes compressor station, gas purification, gas liquefaction, LNG storage tank and associated facilities such as controlling system and LNG filling station. All these facilities are owned and operated by Liheng.

23. Coke oven gas, the by-product of coke-making, is produced during the manufacture of metallurgical coke by heating bituminous coal to temperatures of 900°C to 1,000°C in a chamber from which air is excluded. Coke oven gas can be used as a fuel gas since it has a medium calorific value. Its main compositions are hydrogen (55%–60%), methane (23%–27%), and carbon monoxide (5%–8%). Other components include nitrogen, CO₂, and hydrocarbons. Raw

coke oven gas also contains various contaminants such as hydrogen sulfide, hydrogen cyanide, and benzene. The heating value of coke oven gas ranges from 17 to 19 MJ (4063 to 4541 kilocalories [kcal]) per cubic meter. Currently, most of the coke oven gas is used for electricity and steam generation. Coke oven gas is also used for making hydrogen, ammonia, methanol, and other chemicals. Making natural gas is a more recent technological option for coke oven gas utilization in the PRC.

24. Taking up the highest concentration in coke oven gas, hydrogen is the main component among the resources produced. Since steel companies need a certain amount of hydrogen as the protective gas for steel mills, direct hydrogen production is the first choice of steel companies in the utilization of coke oven gas. Since the 1980s, steel companies such as Baosteel, Ansteel, Wuhan Iron and Steel, Benxi Steel, and Baotou Steel have built up several sets of PSA equipment on hydrogen-making from coke oven gas that range from 100 cubic meter per hour (m^3/h) to 5,000 m^3/h with a purity rate of 99.999%. Hydrogen-making process from coke oven gas mainly utilizes PSA technology to separate hydrogen from cold coke oven gas. A stable demand for hydrogen is the key for a PSA. With the development of fuel cell and hydrogen vehicles, there is a broad prospect for hydrogen-making from coke oven gas. Nevertheless, the economic impact at this moment is not high yet due to the limited market for hydrogen.

25. Alternatively, ammonia synthesis loop (Haber-Bosch process) can use the hydrogen synthesized from coke oven gas and nitrogen from air to produce urea. This technology is rather mature, so many factories have been set up since the 1960s. However, as the domestic fertilizer industry develops continuously, the synthesis loop ammonia production from coke oven gas has become less competitive in production cost and sales market compared to that from coal, casting a shadow on the prospect of ammonia synthesis from coke oven gas.

26. Alternatively, methanol is the fundamental raw material of many chemical products as well as a new alternate energy resource. The production of methyl ether from methanol to replace liquid petroleum gas (LPG) for residents and gasoline and diesel with methanol fuel has become the trend of development. During 2006–2009, a series of policies issued by the PRC Government attracted vast amounts of investment for the manufacturing of methanol production equipment, including methanol-making from coke oven gas, resulting in the excessive production of methanol. In 2010, the methanol production capacity was nearly 38 million tons and the methanol consumption capacity was 20.92 million tons, leading to methanol capacity utilization rate of only 46%. Many of methanol production equipment was commissioned into operation after 2010. The excessive production of methanol will exist for the foreseeable future.

27. Thus, judging from the current market, the use of coke oven gas to produce LNG is the best available choice and enjoys broader development prospects. LNG production with coke oven gas has lower cost and higher energy efficiency comparing to LNG from the gas fields due to the following reasons: (i) the transportation cost of LNG from coke oven gas is lower due to closer distance from the coking plant to the market; (ii) the price of coke oven gas is lower than that of natural gas, so LNG is more competitive in price; (iii) although there is a large amount of hydrogen and nitrogen in the feeding gas, most of the hydrogen is extracted before liquefaction without going through methanol low temperature gas separation, so the energy efficiency is relatively low. If mixed refrigerant cycle (MRC) is applied, the energy efficiency will be further reduced; and (iv) in addition, the hydrogen in this process is recycled and reused, so that the comprehensive energy efficiency is reduced. In recent years, the PRC started to strongly promote energy conservation and emission reduction and greatly encourages comprehensive application of coke oven gas. On July 30, 2007, National Development and Reform Commission (NDRC) officially issued Policies on the Utilization of Natural Gas, clearly stating that “it is

prohibited to construct LNG project with natural gas produced from large or medium gas field,” which restricts the construction of LNG stations and lessens market competitiveness.

28. LNG is natural gas in liquid form that has been pre-processed by the removal of impurities such as heavy hydrocarbon, sulphide, CO₂ and water, etc., and converted to liquid at close to atmospheric pressure by cooling it to approximately -162°C. It only takes up to 1/625 of the volume of natural gas in the gaseous form. The liquefaction of natural gas can greatly save storage space and cost, enable more flexible transportation and improve the combustion performance. LNG has higher energy density than CNG. For the same volume of cylinder, the storage capacity of LNG is more than 2.8 times higher than that of CNG, making the LNG vehicles travel longer distance. The production of 1 m³ of natural gas will consume about 2.35 m³ of coke oven gas; the production of 1 ton of LNG (calorific value of 35.16 MJ/Nm³) and by-production of 1,600 m³ purge gas (calorific value of 10.32 MJ/Nm³) will consume about 3,200 m³ coke oven gas.

29. There are three processing options for making LNG from coke oven gas:
- Option 1: only to separate methane from coke oven gas. This option is simple with a small amount of investment but low LNG yield;
 - Option 2: to separate methane and hydrogen from coke oven gas. This option has a better economic performance if hydrogen market is good;
 - Option 3: to add a methanation process to convert carbon monoxide and carbon dioxide into methane. This option needs a large amount of capital expenditure but with high LNG yield.

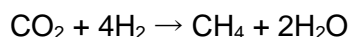
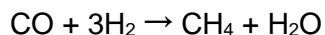
30. Liheng proposes to adopt option 3, the methanation process, to produce more LNG as shown in the figure below, and detailed in the following paras (paras. 31–24). Methanation is a mature technology that is a common section of ammonia production process.

Figure 3: LNG Production Flow from Coke Oven Gas



31. **Purification.** The coke oven gas from coking plant contains several kinds of impurities, among which the contents of benzene and naphthalene are especially higher, about 3,000 mg/Nm³ and 300 mg/Nm³ respectively. These two need to be removed to avoid harm to the separation process in downstream. Adsorption method will be used to remove benzene, naphthalene, and tar in the following processes: (i) first, it will use adsorbent to adsorb heavy contents such as benzene, naphthalene, and tar in low pressure and temperature, and (ii) then the adsorbent will be stripped and recycled in high temperature and low pressure. In this way, the adsorbent is recycled and hazardous gas is separated. Therefore, catalyst for later process is protected from contamination, and equipment like pipeline and chiller are protected from being blocked by the crystallization of naphthalene after the pressure rises. Meanwhile, there are various sulphides in coke oven gas that are strongly toxic to the methanation catalyst. So sulphides shall be removed from the coke oven gas before the coke oven gas enters methanation reactor. Generally, wet desulfurization–fine dry desulfurization process will be utilized for gases containing organic sulfur and complex non-organic sulfur. The application of wet desulfurization is mainly to reduce the cost (operation cost and desulfurizer cost) of fine dry desulfurization. With proper desulphurization, the total sulfur in coke oven gas after purification can be as low as 0.1 parts per million (ppm) and can meet methanation treatment standards.

32. **Methanation.** The core reaction in the natural gas production from coke oven gas is CO and CO₂ hydrogenated methanation. The CO and CO₂ contents in the purified coke oven gas are normally 7%~11%. By using the methanation reaction, the CO and CO₂ contents can be decreased to an appropriate level. The chemical reactions of methanation are:



33. **Separation.** The unwanted hydrogen is separated after methanation. Currently, the prevailing hydrogen separation technologies are mainly PSA and membrane separation. The adsorption of hydrogen is far lower than other components, so PSA is widely applied in hydrogen purification and recycling field. PSA has the advantages of low capex, low operation cost, easy operation, high flexibility and free of environmental pollution. The separated hydrogen is partly used for methanation reaction; the rest could be directly used in hydrogen boiler or sold as products.

34. **Cryogenic liquefaction.** The gas converts to liquid below the temperature of -162°C and normal pressure to form LNG.

35. The application of LNG has not received much attention until recent years. *China National 12th Five-Year Plan for Natural Gas Development* clearly encourages high-efficiency natural gas application projects in LNG vehicles and shipping fuels.¹¹ The new edition of Policies on the Utilization of Natural Gas issued in December 2012 also lists natural gas vehicles as “preferential development category.” LNG’s application on transportation is becoming the highlight of natural gas sector. As the policy enabling environment was created with the issuance of “The replacement of oil with gas,” many companies were pushing the construction of LNG filling stations. The number of LNG filling stations has been rapidly growing: in 2011, there were 241 stations; in 2012, there were 811 stations, while in 2013 there were 1,844 stations. The equipment manufacturing industry associated with LNG vehicle production has also been developed, including the manufacturing of the LNG vehicle itself and components such as vehicle engines, vehicle-mounted gas cylinder and gas supply system, to LNG filling equipment covering the whole industrial chain. This lays the foundation for the widespread application of LNG and opens the broad market to produce LNG from coke oven gas.

36. LNG is a better fuel for heavy-duty and long-distance transportation than diesel in terms of cost competitiveness and pollutant emission reduction. The project will improve the availability of LNG supply and encourage more truck drivers to purchase LNG trucks or retrofit their diesel trucks to LNG trucks. Through information technologies, Shanxi Liheng Iron & Steel Co. Ltd. has built e-commerce based sales and logistic systems. 140,000 heavy-duty trucks have been registered on its logistic cloud platform. They are the target customers for the LNG produced by the project.

3. Estimated Energy Savings and Emission Mitigation

37. The project will use 576 million m³ coke oven gas to produce 180,000 metric tons of LNG which could replace 239.4 million liters of diesel. Comparing to power generation, this project has a higher energy efficiency. Considering the coke oven gas consumption, power consumption and steam recovery, the energy efficiency of coke oven gas to LNG project is 69%,

¹¹ Government of the PRC. 2012. *Twelfth Five-Year Plan for Natural Gas Development*. Beijing.

much higher than the 40% of energy efficiency from coke oven to electricity.^{12,13} 1,156 GWh electricity will generated from the coke oven gas if no it's no used for LNG production.

38. The emissions from diesel-powered heavy-duty trucks which meet Stage IV emission standard, and natural gas produced from flare are reference cases for the pollutant mitigation calculation is in Table 3. The diesel consumed should meet the standard of GB 19147-2016 Automobile Diesel Fuels Stage IV as well. The emission data of the reference case is listed in Table 1. A study indicates that, in comparison with Stage IV fuel,¹⁴ LNG emission will reduce 72% of HC, 97% of CO, 20% of CO₂, and 100% of SO₂ and PM. The data of energy savings and emission mitigation from the project implementation is listed in Table 4. Figure 4 illustrates the emission reductions pathways.

Table 3: Emissions of Reference Cases

	Category	CO	THC	NO _x	PM	SO ₂ ^a	CO ₂ ^b
Truck	Baseline emission factor^c (g/km)	2.2	0.129	5.554	0.15 3	350 ppm	--
	Correction factor^d	0.867	0.521	0.792	0.57 0	50 ppm	
	Emission factor^e (g/liter)	4.144	0.237	10.850	0.20 3	0.0859	2,630
	Diesel emission (ton)	992.1	56.7	2,597.4	48.6	20.6	629,622
Power generation	Emission factor (kg/m³)	--	--	0.000215	0	0.0012	0.79
	Coke oven gas emission (ton)^f	--	--	123.8	0	691.2	455,040
Total reference case emissions		992.1	56.7	2,721.2	48.6	711.8	1,084,662

CO = carbon monoxide, CO₂ = carbon dioxide, g/km = grams per kilometer, g/liter = grams per liter, kg/m = kilograms per cubic meter, NO_x = nitrogen oxide, PM = particulate matter, ppm = parts per million, SO₂ = sulfur dioxide, THC = total hydrocarbon.

^a GB 17930-2016 Gasoline for motor vehicles Stage IV.

^b China carbon trade network: CO₂ emission factor of diesel 2.630kg/liter (www.tanpalfang.com).

^c Emission under the scenario of speed 30 km/h, temperature 15°C, moisture 50%, load 50% and 350 ppm sulfur content.

^d Consider the impacts from temperature, moisture, sulfur content of diesel, average speed of trucks (assuming 40–80 km/h) and the load factor (100%).

^e Fuel consumption is 43 liter/100 km which meets the GB 30510-2014 Fuel Consumption Limits for heavy-duty commercial vehicles Stage II.

^f Annual coke oven gas consumption is 576 million cubic meters.

Source: Ministry of Environmental Protection: Technical Guidelines of Air Pollutant Inventory for Automobiles

Table 4: Energy Savings and Pollutant Mitigation

Energy Savings (tce)	100,224					
	CO ₂	SO ₂	NO _x	PM	CO	THC
Reference case total emissions (ton)	1,084,662	711.80	2,721.24	48.6	992.1	56.7
Project emissions (ton)	503,697.6	20.6	779.2	0	962.4	40.9
Emission reduction(ton)	580,964.4	691.20	1,942.04	48.6	29.7	15.8

CO = carbon monoxide, CO₂ = carbon dioxide, NO_x = nitrogen oxide, PM = particulate matter, SO₂ = sulfur dioxide, tce = ton of coal equivalent, THC = total hydrocarbon.

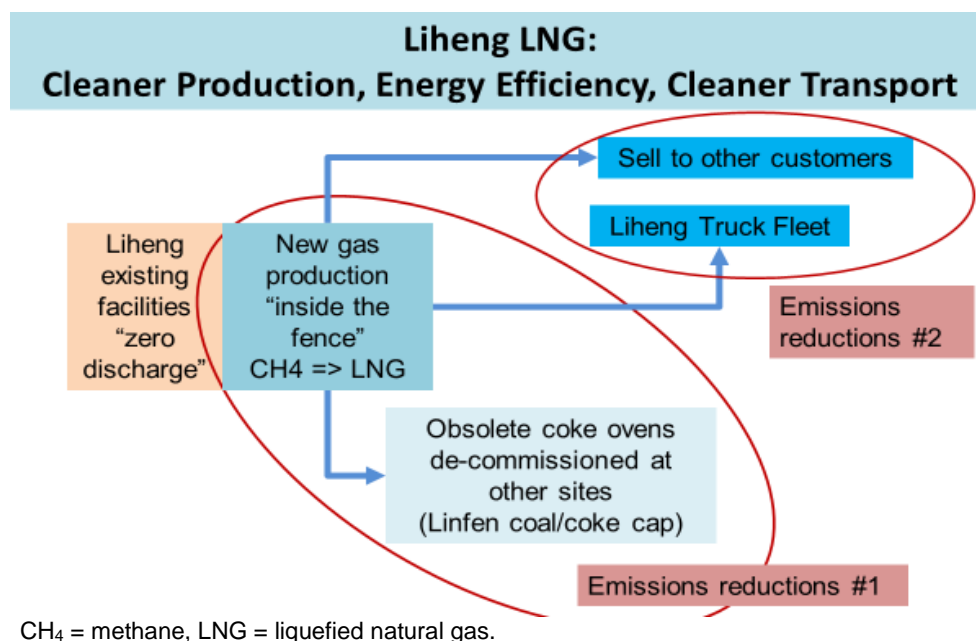
¹² Wang Xiulin and etc. Technology and economic analysis for coke oven gas to LNG, China Petroleum and Chemical Industry Standard and Quality, No. 2, Page 37

¹³ TAO Peng-wan, Technology and economic analysis for coke oven gas to produce compressed natural gas, Coal chemical industry, 2001, 3, 11-1

¹⁴ <http://www.lngche.com/article-1594-1.html>.

39. Emissions from vehicles contribute in part to the haze in the BTH region, especially from heavy-duty vehicles. Data from the Ministry of Environmental Protection states that heavy-duty vehicles accounts for 4% of total vehicles, but their emissions of NO_x and PM makes up 78% and 82% of the total vehicle emissions. There are 5.7 million vehicles in total in the Beijing region. Among them, only 0.2 million are diesel-powered heavy-duty vehicles, but they contribute to 90% of PM and 60% of NO_x emissions in total vehicle emissions, respectively. The use of natural gas as a substitute fuel for diesel is one of the options to reduce emissions from such automobiles. In 2015, the share of natural gas in primary energy consumption was only 5.9%, much less than the world average of 23.7%. More than 30% of the natural gas consumed is imported, therefore increasing availability of natural gas supply would improve air pollution as well as energy security.

Figure 4: Liheng Emission Reduction Pathways



4. Conclusion

40. This project adopts a proven and best available technology for coke oven gas utilization and produces 180,000 tons of LNG every year. It will save 100,224 tce of energy and reduce CO₂, SO₂, NO_x, PM, CO, and hydrocarbon/VOCs emission at 580,964.4 tons, 6,912.0 tons, 1,942.04 tons, 48.6 tons, 29.7 tons, and 15.8 tons per annum respectively.

41. The market is ready to use natural gas as transport fuels. By the end of 2015, there were 230,000 LNG vehicles and 2,650 LNG filling stations operating for business. According to the *China National 13th Five-Year Plan for Natural Gas Development*, by the year of 2020, there will be 400,000 to 500,000 LNG vehicles on the road. The LNG demand will create a LNG-supply based sector other than the traditional natural gas industry. This project is replicable for other projects to meet the market demand.

C. Subproject 3: Smart Industrial Zone Development

42. This project creates a micro-energy grid network consisting of six sub-micro energy grids, including incorporation of renewable energy technology and energy storage technology. In doing so, it addresses energy production and supply issues under various resource circumstances, while meeting a range of customers' demands. It further optimizes energy utilization by allowing for energy trading between the sub-grids, and an islanded interconnection with the regional grid for bidirectional trade of power.

1. Introduction of Subborrower

43. Integrated Electronic Systems Lab Co., Ltd. (iESLab) is a key and new high technology enterprise of the PRC. The main business of iESLab include Smart Grid, Smart Gas, Smart Water, and Smart Energy and Information Security. It is also a leading automation and information solution provider. The company was listed on the Shenzhen Stock Board for small and medium-sized enterprises in 2010. In 2015, the sales revenue of the company reached nearly CNY1.5 billion.

44. iESLab Energy Co., Ltd. (iESLab Energy), a wholly-owned subsidiary of iESLab, focuses on consulting, planning, designing, operation, maintenance, and investment in fields such as energy internet, micro-energy grid, new energy, energy conservation management, etc., and on research and development, production and sales of related software and hardware. In April 2015, based on the technology and strategic study on energy internet and micro-energy grid, iESLab Energy built the first micro-energy grid demonstration project nationwide in Suncun Industrial Park, Jinan Hi-tech Development Zone, Shandong Province. The demonstration project consists of a 400-kW roof-top photovoltaic (PV) power generation system (including monocrystalline silicon and polycrystalline silicon units); 2x1, 200 kW gas-based combined cooling heat and power system (tri-generation); 4,000 refrigeration ton measured in hours (RTH)¹⁵ chilled water storage system; and 5 kW wind power generator. A built-in energy management system for smart micro grids will coordinate the multi-energy technologies to form a flexible and resilient micro-energy grid. Under the smart-grid management system, the PV power generation system can operate up to 1,174 hours per year in full load, which is 10% higher than the average availability hour of 1,080 hours for PV power generation in Shandong Province,¹⁶ providing a solution to address the current solar curtailment issue. In contrast, due to the direct control of regional power grid, the roof-top PV power generation system built in China CNR Corporation Limited, which is adjacent to iESLab Energy, operates at only 839 hours per year in full load under the same solar resource. The smart-grid energy management system explores the micro-energy grid's operation and management mechanism under multi-energy technologies in various modes. It helps gain construction and management experience of micro-energy grid projects, as well as technical accumulation and practical management experience for scaled-up micro-energy grid construction. With the increasing need for development of smart city infrastructure concurrent with emissions reduction, the construction of micro-energy grids will grow rapidly in future. A micro-energy grid construction and operation industry, and related equipment manufacturing industry are already emerging.

2. Technology Adopted

¹⁵ 1 RTH = 351,685 kWh.

¹⁶ *Statistics Evaluation Report on China PV Power Generation Construction in 2014* by China National Administration.

45. This project is based on an existing micro-energy grid demonstration project and expands it to include various renewable energy technologies and energy storage technology. It essentially broadens the application of the micro-energy grid, addresses energy production and supply issue under various resource circumstances, and at the same time meets a range of customers' demands. The proposed micro-energy grid project consists of six enterprise-level sub micro-grids, which manage and control the energy production and consumption of each enterprise. The six subgrids then form a micro-energy grid that could trade energy among the enterprises based on the energy production and consumption features of each enterprise, and could connect to the regional grid to conduct bidirectional power trade.

46. **PV power generation.** It mainly utilizes monocrystalline and polycrystalline silicon modules. The nominal outputs of both modules are qualified with national mainstream products. The PV power generation system consists of solar panel (module), controller, and inverter. The inverter is capable to collect information automatically.

47. **Gas-based tri-generation.** The project utilizes direct-fired internal combustion engine plus lithium bromide hot-chilled water unit using exhaust waste gas and hot water. Waste heat recovery from gas and cylinder sleeve water provides heat to the internal combustion engine. It recovers waste heat from gas to produce chilled/hot water for cooling/heating supply by sending high-temperature gas produced from power generator to lithium bromide hot-chilled water absorption unit. Based on the economic effectiveness and energy use, the project deploys a direct-fired engine for operation.

48. **Energy storage system with lithium iron phosphate (LFP) cell.** The energy storage system is using lithium ion phosphate cell as the cathode material, which is more secure and coherent with long recycling period and higher charging (discharging) efficiency of more than 98.5%.

49. **Compressed-air energy storage system.** The system makes use of a generator at off-peak time to compress the air into a sealed container using air compressor. The compressed air will be discharged to drive the turbine to produce electricity.

50. **AC chilled water storage system.** The system uses refrigerant at off-peak time during the night and stores the cooling energy in the form of low-temperature chilled water. During peak hours in daytime, the chilled water is pumped out to supply cooling to shift the load, increase the efficiency of primary energy utilization, reduce AC operation cost and improve the AC quality. The area covered by this system takes up 26,000 m². In 2016, the annual electricity consumption for the cooling period (4 months from June to September) was 145,396 kWh in total.

51. **Linear Fresnel solar thermal heating system.** The system uses arrays of mirrors as reflectors to reflect sunlight onto compound parabolic collectors (CPC), and then the CPC collect thermal energy to solar vacuum tubular collectors to produce medium-high temperature steam that could be used for power generation and heating supply.

52. **Air source heat pump.** The technology utilizes air to obtain low-temperature heat source. Through the condenser or evaporator from traditional air conditioning equipment, the heat is extracted or released by/from the air by heat exchange. The energy is therefore transferred into the building by recycling system to meet residents' demands for hot water, radiant floor heating and air conditioning operation.

53. The core technology of the project is the energy management center of micro-energy grid (regional energy internet center). It is the central pivot of the micro-energy grid and is based on a comprehensive energy data management platform. The energy management center builds up a distributed control model through distributed smart PCs, and designs a hierarchical control mode based on different operation targets at various levels, such as micro-grid, court, feeder line and distribution network, etc., to realize a multi-level control mode of “local control–level control–overall control.”

54. With the optimal design of a micro-energy grid framework and coordination among distributed energies, the energy management center of the micro-energy grid could make the micro-energy grid system flat, with the equipment digitalized, the energies complementary, the supply and demand decentralized, the data transparent, the information parallel, and the trade liberal. This in turn enables personalized energy customization, improve customer’s energy consumption locally, reduces the volatility of renewable energy power generation, and achieves the utmost local consumption of renewable energy. By efficient coordination and smart control of various types of energies (wind, solar, gas, cooling, heating, electricity, etc.) within the micro-grid, the energy management center could coordinate system performance among the micro-grids and between the micro-grids and main grid, therefore increase the efficiency of energy utilization, meet the demand of energy users, improve energy supply quality and enhance the reliability of energy supply. By reasonably planning and optimal integration of storage and energy-saving technologies, the energy management center could greatly reduce users’ energy consumption, energy cost and energy loss during energy conversion. By reducing the difference between peak and valley consumptions of the energy in demand side, the energy management center could reduce the designed capacity of the energy in supply side, thereby optimizing supply side investments and greatly increasing the annual energy supply hours and the equipment utilization ratio.

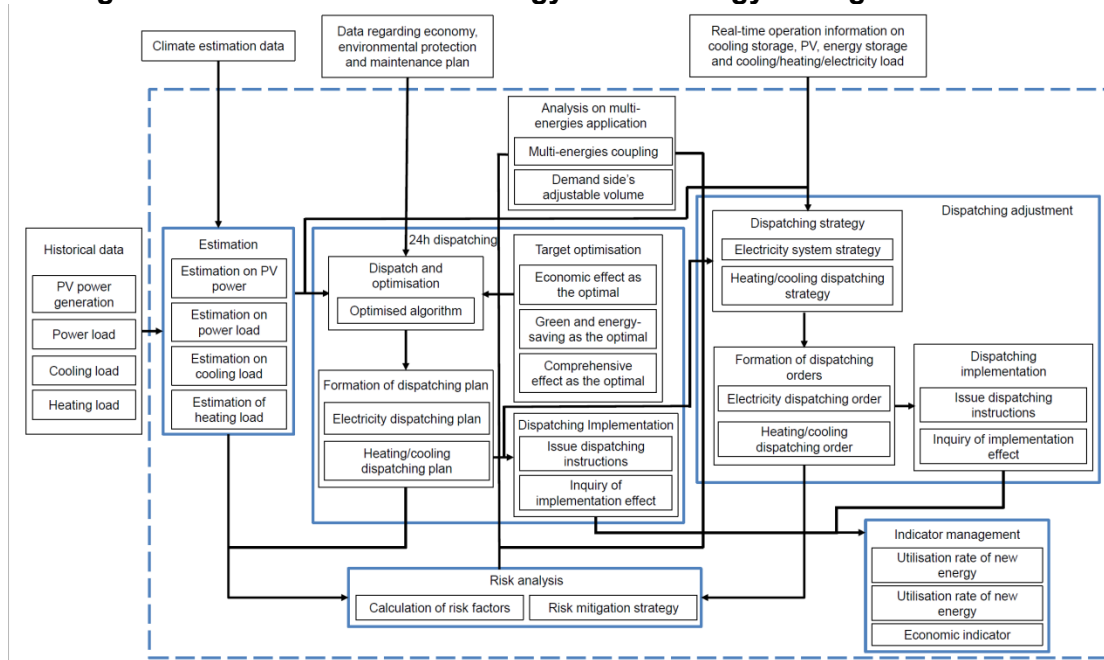
55. The Energy Management Center of the micro-energy grid is responsible for energy coordination and dispatching within and among the sub micro-energy grids. In the micro-energy grid system, all the elements under the system are assigned with different tasks and the whole system depends on the cooperative operation of each sub micro-energy grid. For instance, the energy storage unit within the sub-grid needs to not only maintain its individual state-of-charge and output range, but also obey the overall coordination of the sub-grid, and participate in the sub-grid’s voltage and frequency regulation; meanwhile, the sub-grid shall maintain internal power balance and participate in energy dispatching in the middle-voltage network. In this way, energies among several industrial zones are interconnected. It not only increases the energy efficiency among sub micro-energy grids and reduces energy cost, but also raises clean energy consumption ratio and reduce the curtailment greatly.

Table 5: Content of Construction

Name of subproject	Content of construction
Sub micro-energy grid of iESLab industrial park	3 MW PV power generation system (400 kW completed); 2x1,200 kW gas-based tri-generation system (completed); 1MWh energy storage system with Lithium Iron Phosphate (LFP) cell; 0.5 MWh compressed-air energy storage system; 4,000 RTH AC chilled water storage system (completed); 3,000 m ² Linear Fresnel solar thermal heating system; 6.9 MW air source heat pump; Energy management system of sub micro-energy grid (completed).
Sub micro-energy grid of Shandong Fin CNC Machine	1 MW PV power generation system; 0.5 MW air source heat pump; Energy management system of sub micro-energy grid.
Sub micro-energy grid of China CNR in Jinan Hi-tech industrial zone	5.9 MW PV power generation system (completed); 1 MWh energy storage system with LFP cell; Energy management system of sub micro-energy grid.
Sub micro-energy grid of Inspur industrial parks	1.8 MW PV power generation system; 2 MWh energy storage system with LFP cell; 2.4MW gas-based tri-generation system; 8,000 RTH AC chilled water storage system; 3 MW air source heat pump; Energy management system of sub micro-energy grid.
Sub micro-energy grid of Qingqi Suzuki Motorcycle industrial park	5.9 MW PV power generation system; 1 MWh energy storage system with LFP cell; Energy management system of sub micro-energy grid.
Sub micro-energy grid of Shandong Xinhua bookstore Group logistic center	3.7 MW PV power generation system; 1 MWh energy storage system with LFP cell; Energy management system of sub micro-energy grid.
Energy management center of micro-energy grid	Management system of energy management center; Energy trading platform; Data center room of micro-energy grid's energy management center.

AC = air conditioning, kW = kilowatt, LFP = lithium iron phosphate, m² = square meter, MW = megawatt, MWh = megawatt per hour, PV = photovoltaic, RTH = refrigeration ton measured in hours, Tri-generation = combined cooling, heating, and power system.

Figure 5: Structure of Micro-Energy Grid's Energy Management Center



56. Micro-energy grid has the distinct features as shown below:

- Complementary application of multi-energies.** By the comprehensive cascade usage of renewable energies and fossil energies, to achieve the coordinative development among energy efficiency, energy environment, energy structure and energy security; and, to promote a sustainable energy system, thereby realize the integrated innovation and demonstration of energy conservation, environmental protection and renewable energy technologies. To address the technical barriers in applying and dispatching various renewable energies together and improve the performance of the system, the project focuses on key technologies, such as distributed power generation and heating supply technology by complimentary application of multi-renewable energies, performance control and smart distributed energy supply technology. The project also provides a platform for verification and promotion of advanced technologies by developing complementary distributed energy and micro-energy demonstration projects.
- Integrated optimization.** This project has many demonstration effects including (i) building up a distributed combined cooling, heating and power pilot project with complementary application of clean fuels and renewable energies such as solar and wind energy; (ii) creating an innovative technology by integrating distributed energy system with complementary energy application, energy cascade use and active control; (iii) exploring a way in energy complimentary applications combining clean fuels and renewable energies to promote smart micro-energy grid; and (iv) build up a distributed energy system demonstration project with dual objectives of energy conservation and environmental protection. By implementing this project, key technologies such as (i) complementary energy application, power supply and distribution of alternating current (AC) and direct current (DC), and energy optimal dispatching and management will be mastered; (ii) demonstration system on micro-energy grid with complementary application of multi-energies will be established; and (iii) grid's friendly-access and highly

efficient operation will be achieved under the scaled-up development of micro-energy grid and distributed renewable energy will be realized.

- **Grid-friendliness with high penetration rate.** This project will allow more fluctuating renewable energy to the power distribution network, and the establishment of regional power grid that integrates renewable energy power's generation, transmission, storage and consumption with high penetration rate. Meanwhile, the regional power grid is designed with strong regulation ability: (i) enabling friendly interaction with public grid, (ii) stabilizing fluctuation caused by the renewable energy, and (iii) mitigating peak-valley difference of power grid and replace or partly replace peak-shaving power. When the regional power grid is operating together with the public grid, the power trade and trading period can be controlled, and it is favorable to regulate the voltage and frequency within the micro-energy grid.

3. Estimated Energy Savings and Mitigation

57. The project integrates various technologies to form a micro-grid and supply electricity, heat and cooling to the region. The conventional boiler, electric air conditioning and thermal power plant are reference cases for energy savings and pollutant mitigation calculation:

- **PV power generation.** This project will operate 21.3 MW PV power to generate 25.01 GWh per year.¹⁷ Considering the transmission loss of the power grid and the loss of the low voltage distribution network, PV power generation can replace 28.76 GWh thermal power generation. It will save 10,209.9 tce¹⁸ and reduce CO₂, SO₂, NO_x, and PM at 21,853.0,¹⁹ 13.6, 12.4, and 2.6 ton respectively.²⁰
- **Gas-based tri-generation system.** The tri-generation system consumes 1 m³ natural gas to generate 3.8 kWh electricity and 4 kWh heating/cooling with the power generating efficiency of 35%.²¹ If the electricity and heat is supplied by a reference system which includes a gas-fired power plant with the same of generating efficiency of 35% and a coal-fired boiler, the reference system will consume additional 0.6555 kgce of bituminous coal with the boiler efficiency of 75%. Assuming the tri-generation system consume 5.7 million m³ natural gas²² to generate 22.8 GWh heating/cooling, the reference system would consume 3,736.3 tce coal more. This component can save 3,736.3 tce of energy and reduce emissions of CO₂, SO₂, NO_x, and PM at 9,792.6, 43.2, 26.4, and 79.5 ton respectively.
- **Air source heat pump.** The 14.3 MW air source heat pump could supply space heating, hot water and cooling if it operates year around. The total heating supply is 107.3 GWh which consumes 13,181 tce of coal if coal-fired boiler was used.²³ Assuming the energy efficiency of the heat pump is 500%, it consumes 21.45 GWh electricity (or 6,756.8 tce) from the grid annually. The project saves 6,424.3

¹⁷ Capacity factor is 0.134 or 1,174 operating hours per year in full load.

¹⁸ According to the China Power Sector Annual Development Report 2016 issued by CEC (China Electricity Council), the average coal consumption of thermal power plant per kWh supplied to the grid is 315 gce/kWh. This number will be used for calculating energy savings when electricity saved.

¹⁹ NDRC issues CO₂ emission per kWh every year for CDM project development. The carbon emission factor of North China Grid is 0.7598 t-CO₂/MWh in 2015.

²⁰ According to the China Power Sector Annual Development Report 2016 issued by CEC (China Electricity Council), the PM, SO₂, and NO_x emission factor of thermal power generation was 0.09, 0.47, and 0.43 g/kWh respectively in 2015.

²¹ The research is conducted by Sino-French Energy Services. <http://www.cqgas.cn:9888/zfny/energy/151>.

²² The system will operate 4500 hour at full load and power generation efficiency is 38% in average.

²³ Assuming efficiency of coal-fired boiler 75%.

tce energy. This component indirect emissions of CO₂, SO₂, NO_x, and PM is 1,130.5, 7.5, 3.0, and 9.2 tons respectively while the reference case emissions are 34,543.3, 228.2, 93.2, and 280.3 tons respectively.²⁴ This component will reduce emissions of CO₂, SO₂, NO_x, and PM at 18,245.5, 218.1, 83.9, and 278.4 tons respectively.

- **Linear Fresnel system.** The solar resource in Jinan area is about 4,647.57 MJ/m² per year. Assuming the heat collecting efficiency is 68% for this liner Fresnel system, the 3,000 m² heat collector will supply 9,482 GJ heat to the heat pipelines. 646 tons of bituminous coal could be consumed if the heat was supplied by a coal-fired boiler. There are no emissions from the project. This component will save 431.3 tce of energy and reduce emissions of CO₂, SO₂, NO_x, and PM at 1,130.5, 7.5, 3.0, and 9.2 tons respectively.
- **Energy storage system.** The energy storage system will help the peak shaving and therefore improve the curtailment of the renewable energy and optimize the power grid in Jinan. This component will save 9,858.0 tce of energy and reduce emissions of CO₂, SO₂, NO_x, and PM at 25,824.8, 83.8, 73.0, and 9.2 tons respectively.²⁵

Table 6: Projected Emission Reduction Table

Energy category	Standard coal replaced (t)	Emission reduced			
		CO ₂ (t)	SO ₂ (t)	NO _x (t)	PM (t)
PV	10,209.9	21,853.0	13.6	12.4	2.6
Gas-based tri-generation	3,736.3	9,792.6	43.2	26.4	79.5
Linear Fresnel system	431.3	1,130.5	7.5	3	9.2
Air source heat pump	6,424.3	18,245.5	218.1	83.9	278.4
Energy storage system	9,858.0	25,824.8	83.8	73.0	15.8
Total	30,659.8	76,846.4	366.2	198.7	385.5

CO₂ = carbon dioxide, NO_x = nitrogen oxide, PM = particulate matter, PV = photovoltaic, SO₂ = sodium dioxide, t = ton, tri-generation = combined cooling, heating, and power system.

4. Conclusion

58. The energy management center is the core operational control mechanism of a micro energy grid, which enables it to function under varying dynamic load scenarios. With good environmental benefits, the project could replace 30,659.8 tce, which is equivalent to 76,846.4 tons of CO₂, 366.2 tons of SO₂, 198.7 tons of NO_x, and 385.5 ton of PM. The project also includes various energy systems such as water energy storage, small wind turbine and middle-temperature solar thermal system, which could provide knowledge on how to integrate different energy resources into the micro-energy grid.

²⁴ Coal-fired boiler with wet scrubber, bituminous coal with S content of 0.8% and ash content of 20%. The emission factor of CO₂, SO₂, NO_x, and PM is 1.75 ton, 11.56 kg, 4.72 kg, and 14.2 kg per ton of coal.

²⁵ Coal saved from this component is estimated at 318 gce/kWh based on the "Thirteenth Five Year Plan". Emission factors used are as following: CO₂ is 2.62t/t SCE, SO₂ is 8.5 kg / tce, and NO_x is 7.4 kg/t SCE based on the "Comprehensive Energy Consumption Calculation General Rules" GB2589-81 ", " China Resources Bureau, and "New Energy Demonstration City Evaluation Index System and Description'.

59. The development of energy internet is a key strategy during the PRC's 13th Five-Year Plan period. The project is to accelerate smart development in all fields and segments of the energy industry, including (i) the development of energy production and application equipment; (ii) enhancing energy monitoring, energy measuring, dispatching and intelligent management system; and (iii) construction of an energy internet that integrates and coordinates among energy production, energy transmission, energy consumption and energy storage using various energies. As a key area for the development of the PRC's energy industry, in conjunction with power sector reform, smart microgrid can be rapidly developed. The energy management center of micro-energy grids could be deployed extensively in areas facing serious wind and solar curtailment to enhance renewable energy consumption. It could also be applied to build energy internet with cities, parks (schools), and new towns in eastern China where the demand centers are located, to greatly improve energy efficiency and broadly deploy clean and low-carbon energy supply.

D. Subproject 4: Deep-well Geothermal District Heating

60. The project will create a geothermal district heating infrastructure using deep-well geothermal energy technology, as an economically and environmentally advantageous alternative to the current practice of using coal-based space heating systems in Dezhou City, Shandong Province.

1. Introduction of Subborrower

61. Shandong Luhai Petroleum Technology Co. Ltd. (Luhai) is a listed company, whose predecessor was Shandong Luhai Petroleum Equipment Co., Ltd. that was founded in 2008 with registered capital of CNY10 million. On July 16, 2015, Luhai was successfully listed in National Equities Exchange Quotations and converted into a Public Limited Corporation. The main business lines of Luhai include production and sale of drilling equipment and tools, research and development of measurement while drilling (MWD), exploration and development of geothermal energy, and technical services for horizontal (directional) wells. Luhai also provides services in geothermal heating system construction, engineering design of special process wells such as, geothermal wells, directional wells, horizontal wells, drilling operations and related technology services. Their products are widely used in oil and drilling companies, and are supplied to countries such as Korea, Russia, and Iran. Luhai has acquired certifications from ISO9001, Health Safety and Environmental Management Systems and the American Petroleum Institute. Luhai has also obtained API7K, API5CT, API7-1, and API6A certifications.

62. In recent years, by virtue of its technical capabilities in oil drilling and equipment manufacturing, Luhai successfully entered the geothermal development market with deep-well water source heating as the main business, and, based in Shandong Province and other areas nearby, began to provide heating service for rural areas that are unable to be covered by thermal power plants and district heating network. Up to now, 76 geothermal wells of various types have already been constructed in provinces like Hebei, Henan, Shanxi, etc. The operation of the wells is in good condition and gained market recognition. As the construction of new rural area expands, more and more new rural communities need central heating service. Under this circumstance, geothermal heating will enjoy a broad market prospect and a new industry with geothermal resource development and geothermal heating as the core will therefore take shape.

2. Technology Adopted

63. The project is to develop a geothermal district heating system for newly-built, reconstructed and expanded residential areas in Mi County, Lingcheng District, Dezhou City, Shandong Province. It will be constructed in phases: eight geothermal wells will be drilled (four producing wells and four disposal wells) and four heat exchange stations will be built in each phase, covering 160,000 m².

64. There are two technical options for geothermal heating. One is with heating from shallow ground source and heat pump; the other is direct heating with deep-well geothermal hot water:

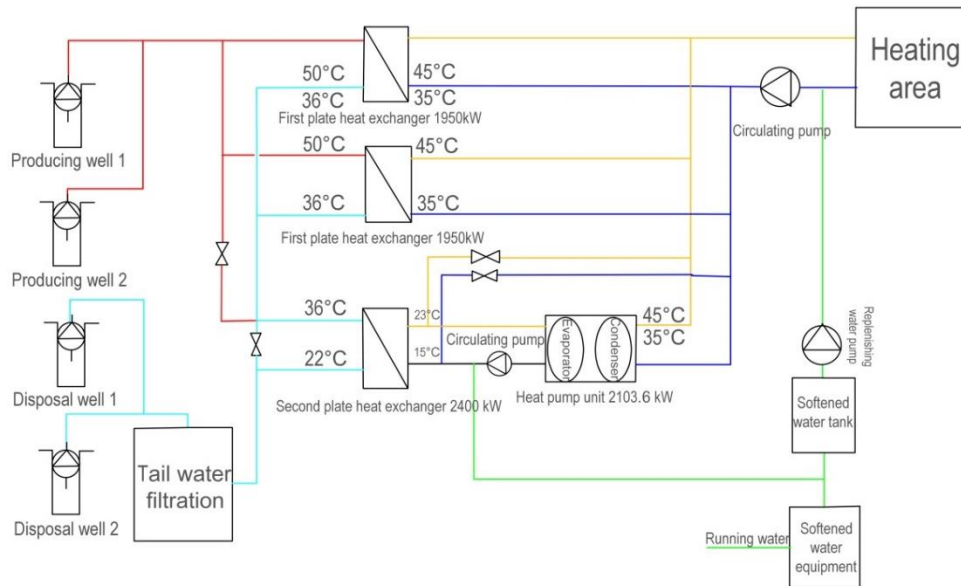
- Shallow ground source heating involves extracting geothermal energy from ground water at around 16°C, via heat exchange tubes buried at a depth of 80–120 meters, then using a heat pump to increase the temperature to around 50°C. The advantages of this technology are: (i) deep drilling technology is not needed, and there is minimal impact on groundwater resources; (ii) the coefficient of performance (COP) of shallow ground source heat pump is above 4, which is higher than those of air source heat pump or electric boiler, etc. However, this technology also has disadvantages, mainly is that multiple shallow wells may be needed to draw enough heat energy. Generally, the proportion of areas for buried tube against heating area is 1:3. Hence, for this project's 800,000 m² heating area, 270,000 m² of buried tube area is needed, equaling to 17,800 buried tubes. The length of horizontal buried tube is more than 1.2 million meters while that of vertical buried tube is more than 900,000 meters. Secondly, a large amount of electricity will still be consumed by the heat pump during the heating period. The power consumption is 39 kWh for heating per square meter per heating period (counts as 15 hours per day, 120 days per year). Thirdly, heating and cooling imbalance will lead to the decay of geothermal energy after long years' operation.
- The other option, deep-well geothermal energy involves extracting underground water at 50°C–60°C from the depth of 1,000-2,000 meters' underground, and exchanging heat via indirect countercurrent heat exchangers for heat supply. The water extracted from underground will then be filtered and recharged back underground. The whole system consists of geothermal well, pump room and pipe networks, among those the water pump is the only energy-consuming equipment. Compared to shallow ground source heat pump, deep-well geothermal energy has the tri-fold advantages of occupying less land, providing stable heating and low maintenance cost. For this project of 800,000 m² heating area, only 20 producing wells and 20 disposal wells are needed for construction, and a heat pump is not necessary to boost the heat to higher temperature. However, the environmental risk of deep-well geothermal energy is the potential impact to underground water quality, so it is a must to ensure that the extracted water is filtered and recharged back underground.
- Weighing between the two technologies explained above, the project is to adopt deep-well geothermal energy technology for heating.

65. Dezhou City is one of the cities with severe air pollution in the BTH region and its neighboring regions. In 2016, Dezhou ranked the last in Shandong Province for the comprehensive air quality index, it is urgent that Dezhou needs to develop clean heating such as geothermal for heating to mitigate the severe air pollution issue. Dezhou is endowed with rich geothermal resource which is generally located in reservoirs at the depth of 1,100–1,450

meters with water temperature of 50°C–58°C. The heating yield of a single well is about 90–120 m³/h. Its abundant geothermal energy can satisfy the heating demand for the entire Dezhou.

66. Technical features of the projects include: (i) in the aspect of geothermal well drilling, Luhai, along with its extensive experience working in oil fields, cooperates with universities such as China University of Petroleum and Yangtze University, developed a range of drilling technologies for geothermal well. The set of technologies is suitable for geothermal reservoirs of various geological conditions, and adopts different aquifer protection measures; (ii) in the aspect of well path control, the project employs qualified personnel and deploys orientators to ensure no deviation in well path control; (iii) in the aspect of well completion technologies, the project chooses suitable well drilling technology and well flushing methods based on geological features of various regions to ensure geothermal well's normal operation after well completion; (iv) in the aspect of underground water utilization, the project adopts water reinjection technology to recharge the geothermal well in the reservoir on a continual basis, thereby ensuring simultaneous extraction and reinjection (the technical process is shown in Figure 6 below). After the geothermal water exchanges heat via the heat exchanger, the geothermal tail water will be purified through purifying equipment to remove impurities, to ensure the water is qualified for recharge; (v) to ensure the stability of heat source well and avoid water (heat) interflow, the project adjusts the distance between the disposal well and water intake well to the best position; (vi) the exchange stations are located near the heat load center. To resolve the corrosion and scaling issue, water softening equipment will be installed in the replenishing water pump of the secondary heating network. The project will use oil casing as the heating network, with rigid polyurethane foam as the thermal insulation material for prefabricated insulation, and external high density polyethylene pipe covering as the protective layer; and (vii) running water is processed to softened water via automatic water softening equipment and enters a softened water tank. The softened water diverges respectively into high-zone, mid-zone and low-zone circulating water system via three variable-frequency replenishing water pumps; the pressure for the variable-frequency replenishing water pump is identified in accordance to the backwater pressure signal of the heating system, so that electricity use is minimized.

Figure 6: Water Recharge Flow Chart



67. Various energy saving measures are taken by this project: (i) in respect of water pump type, a German-made Ritz submersible pump will be used. The pump is equipped with an alternating current variable frequency drive to enable stepless variable speed regulation of the asynchronous motor. Compared to a conventional submersible pump with the same lift and water volume, the selected pump could save 20% of electricity; (ii) in respect of insulation measures of the heating network, the project uses a polyurethane insulation layer, on buried vertical-run high density polyethylene insulated tubes. This allows heating network transmission efficiency of up to 98%; (iii) the project uses smart equipment such as integrated temperature transmitters and electromagnetic flowmeters to control parameters such as water temperature and operation frequency, for better energy efficiency; and (iv) in respect of water saving, geothermal water will be recharged back underground, after circulation in the heat exchanger. Rain water is also collected via a rainwater network into fire water pool, for road watering and greening purposes.

3. Estimated Energy Savings and Mitigation

68. Dezhou City is located in the northwest of Shandong Province. The winter heating period lasts for 24 hours a day, 122 days per year, from November 15 every year to March 15 the following year. Per the national standard for heating load calculation,²⁶ the 800,000 m² of heating area will need 379,469 GJ or 12947.3 tce per heating period. Compared to heating from coal-fired boiler, deep-well geothermal heating could save 13,119.9 tons of standard coal²⁷ (i.e. 76% of the 17,263.1 tce energy consumed by conventional large coal fired boiler). As a renewable energy technology, deep well geothermal energy consumes little electricity and there is no direct emission of greenhouse gas or other pollutants. The project will consume 13.15 GWh electricity per heating season (around 14.4kWh per square meter per heating period).

69. The project consists mainly of a plate heat exchanger, heat pump unit, and high-, mid- and low-zone circulating water pumps, replenishing water pump and softened water device. The

²⁶ 45 W/m².

²⁷ Supposed boiler efficiency is 75%.

devices with electricity consumption all use variable frequency drives, saving electricity consumption up to 24%.

Table 7: Projected Emission Reduction Table

Energy Savings (tce)	13,119.9			
	CO₂	SO₂	NO_x	PM
Reference case emissions (ton)	45,229.3	146.7	127.7	4.9
Project emissions (ton)	9,991.4	6.2	5.7	0
Emission reduction(ton)	35,237.9	140.5	122.0	4.9

CO₂ = carbon dioxide, NO_x = nitrogen oxide, PM= particulate matter, SO₂ = sulfur dioxide, tce = ton of coal equivalent.

^a The emission factor is CO₂ 2.62 t/tce; SO₂ 8.5 kg/tce; NO_x 7.4 kg/tce and PM 0.283 kg/tce according to General Principles for Calculation of the Comprehensive Energy Consumption GB2589-81, Interim Measures on Promotion of Energy-saving and Low-carbon Technologies (File No. [2014]19), and Evaluation Indicator System and Illustration of New Energy Demonstration Cities in China by China National Energy Administration).

^b The emission factor is CO₂ 759.8 t/GWh; SO₂ 0.47 t/GWh; NO_x 0.43 t/GWh and PM 0.09 kg/GWh.

4. Conclusion

70. The project has a stable heating source. It adopts mature drilling technology for geothermal wells, utilizes tail water recharging technology for the sustainable heat extraction without any water depletion (as it recharges water back to the underground reservoir after purification, to avoid reservoir water depletion and environmental pollution). The project has significant effect on energy saving and emission reduction in that 13,119.9 tce could be replaced, equivalent to 35,237.9 tons of CO₂, 140.5 tons of SO₂, 122.0 tons of NO_x, and 3.7 tons of PM emissions reduced.

71. Deep-well geothermal energy is pollution-free and a renewable clean energy. The PRC is endowed with geothermal energy.²⁸ Many of the core technologies and the equipment involved in geothermal heating have already been developed and deployed, and were widely used in the new economic and technology development zones, green industrial parks, high-efficiency ecological agricultural demonstration projects in rural areas, in household heating (national hydrothermal geothermal heating area reaches to 102 billion m² by the end of 2015), power generation, refrigeration, drying, and industries such as chemical, planting and breeding, real estate development, tourism, medical bathing treatment, healthy entertainment, etc. However, heating from deep-well geothermal is not widely deployed since it requires the good understanding of drilling, geological condition, and special equipment is needed. This project can be replicated for continuous heating and cooling using 100% renewable energy with zero direct emissions.

E. Subproject 5: Hydrogen-based Low-emissions Transport

72. The subproject will utilize hydrogen gas (H₂) produced from surplus wind energy in sustainable transport applications via investments in hydrogen fuel cell buses and fueling infrastructure.

²⁸ Per the research result published by Ministry of Land and Resources, hydrothermal geothermal resource amounts to 1.25 trillion tce and the annual exploitation quantity equals to 1.9 billion tce.

1. Introduction of Subborrower

73. Shandong Yixing Electric Auto Company Ltd. (Yixing) was established in 2003, wholly acquired by East-Lake Industrial Investment Fund in 22 June 2013, with a registered capital of CNY300 million focusing on the planning, design, assembly, and operation of advanced new energy vehicles including zero-emissions vehicles. As of end of 2016, Yixing has invested more than CNY500 million to deploy more than 400 vehicles. Yixing is the Eastern Manufacturing Base of East-Lake New Energy Auto Group (East-Lake) whose headquarters is in Hubei Province, in which East-Lake provides financial support to Yixing's operations.

74. Yixing has partnered with Blue-G New Energy Science and Technology Corporation (Blue-G) of Beijing for multiple development efforts in the greater BTH region, including fuel cell bus deployment in the Beijing-Tianjin corridor and in the city of Zhangjiakou (a key venue of the 2022 Winter Olympics). Blue-G serves as an integrator of hydrogen technology provided by Hydrogenics Ltd., whose headquarters is in Canada and has global operations including East Asia. Yixing uses the hydrogen fuel cell power train systems provided by Blue-G and Hydrogenics and is responsible for final assembly of fuel cell vehicles.

75. Yixing and Blue-G expect to deploy at least 50 hydrogen fuel cell buses in 2017 and at least 100 per year from 2018 onward. The market for hydrogen fuel cell vehicles is expected to expand rapidly based on government policy for new energy vehicles and specific incentives for buses. Hydrogen gas supply is also expected to grow rapidly to reduce curtailment of solar and wind power (see additional discussion below).

76. The proposed project in Zhangjiakou will utilize hydrogen from surplus wind energy to be used by fuel cell buses. The hydrogen production system is being developed by Hebei Construction & Investment Group Co., Ltd. and the fueling stations are being developed by SinoHetec. Yixing will deliver and operate a minimum of 100 fuel cell buses. The subborrower will be a financial leasing company established by Yixing and East-Lake. The subproject structure is presented in Figure 7.²⁹

2. Technology Adopted

77. Hydrogen gas is produced using surplus electricity to drive a hydrolyzer, which splits water (H₂O) into hydrogen (H₂) gas and oxygen (O₂) gas.³⁰ This power to gas (P2G) process has very high scale-up potential in the PRC, as renewable electricity output is currently underutilized.³¹ Hydrolysis technology is well-proven and has been in use for decades. However, it has not been deployed at scale for P2G, mainly due to high upfront capital costs. P2G is technically one of the best options for energy storage, as H₂ can be stored indefinitely.

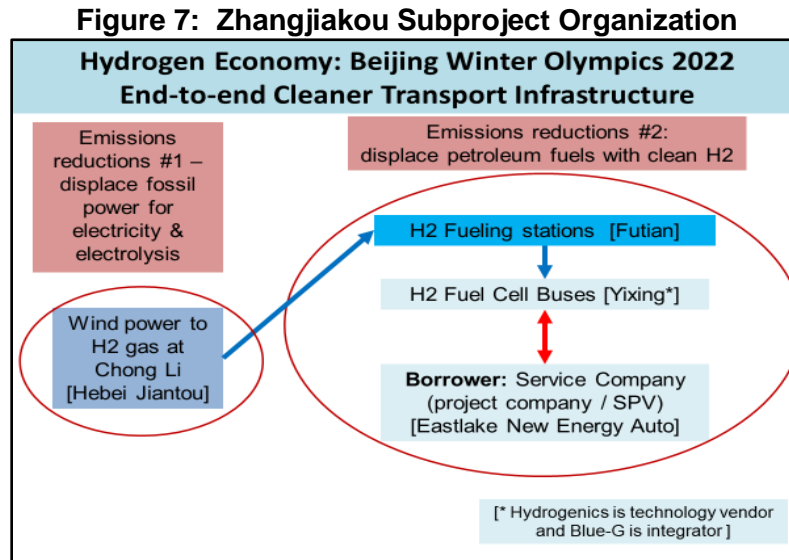
78. P2G is also one of the best options in the PRC for using renewable energy for transport applications, while also addressing electricity grid stability and energy storage issues. Reducing street-level emissions requires reducing vehicle tailpipe emissions, which for practical purposes requires use of electricity as a transport fuel in battery or fuel cell vehicles. Reducing lifecycle and regional emissions means that renewable electricity must be used as a transport fuel. Fuel

²⁹ The proposed arrangement with a leasing company can be utilized for other subprojects using hydrogen technology.

³⁰ The stoichiometric balance is: $2\text{H}_2\text{O} \Rightarrow 2\text{H}_2 + \text{O}_2$.

³¹ Various estimates indicate that 30-40% of solar and wind output is being curtailed.

cell vehicles have a decided advantage in terms of range, refueling time, and compatibility with long-term storage of surplus renewable electricity.



H2 = hydrogen, SPV = special purpose vehicle.
Source: Asian Development Bank

79. There are multiple pathways for production and end-use of hydrogen.³² One of the simplest options is to blend hydrogen with natural gas: modern gas pipeline systems can accept up to 10% hydrogen. Fuel cells can be used for stationary electricity production or for motive power in vehicles. O₂ can be sold to the commercial markets for industrial applications and other uses (e.g., in hospitals and other health care facilities). Hydrogen can be used instead of petroleum fuels in internal combustion engines (ICE) or to power fuel cells which generate electricity by recombining H₂ and O₂ back into H₂O, meaning fuel cell vehicles don't create tailpipe pollution when they're driven.

80. P2G can be used to reduce curtailment of renewable energy, mainly from wind farms. Using hydrogen as a transport fuel to displace diesel is one of the best applications in terms of reducing the public health hazards posed by PM_{2.5} emissions from diesel combustion in the greater BTH region. Refueling a fuel cell vehicle is comparable to refueling a conventional car or truck; pressurized hydrogen is sold at hydrogen refueling stations, taking less than 10 minutes to fill. Once filled, the driving ranges of a fuel cell vehicle vary, but are similar to the ranges of gasoline or diesel-only vehicles (200–300 miles). Compared with battery-electric vehicles—which recharge their batteries by plugging in—the combination of fast, centralized refueling and longer driving ranges make fuel cells particularly appropriate for larger vehicles with long-distance requirements, or for drivers who lack plug-in access at home.

81. Table 8 shows the projected growth in fuel cell vehicles in the PRC from 2016–2020.

Table 8: Projected Growth in Fuel Cell Vehicle Fleet

Year	2016	2017	2018	2019	2020
Number of Vehicles	500	3,000	5,000	10,000	20,000

³² Hydrogen is also a by-product of some industrial processes, e.g., fertilizer production. There are other potential subprojects using by-product hydrogen for coke production in Pingdingshan, Henan Province and liquefied natural gas generation in Bazhou, Hebei Province, which may be developed separately from the Zhangjiakou subproject.

Source: Tsinghua University

3. Estimated Energy Savings and Emission Mitigation

82. The project will not directly result in energy savings; but rather, surplus electricity which would otherwise be wasted (i.e., not generated) will be used to produce hydrogen fuel. Emissions reductions result from using hydrogen instead of electricity (which is dominated by coal-fired power) or diesel fuel. Figure 8 shows CO₂ emissions from various combinations of fuel and propulsion technologies,³³ illustrating that fuel cell vehicles using low-carbon energy source have the lowest emissions; among these, hydrogen from wind has the lowest emissions.

83. Figure 9 presents estimated CO₂ emissions from battery electric vehicles based on national-level grid emissions factors. The PRC grid is still dominated by coal-fired electricity, therefore a battery electric vehicle charged by the typical grid mix will have CO₂ emissions comparable to that of a gasoline fired internal combustion engine vehicle, i.e., about 250 grams CO₂-equivalent per kilometer.³⁴

84. According to the national standard of GB30510-2014 Fuel consumption limits for heavy-duty commercial vehicles, the diesel consumption for city bus should not more than 40 liters per 100 kilometers (between 14 to 49 liter/100 km based on weight of vehicles). 100 diesel-powered buses will operate 40,000 kilometer per day and consume 6,336,000 liters of diesel per year (operate 330 days per year). So the hydrogen will reduce 6,336,000 liters of diesel consumption, equal to save energy of 7,847.4 tce. Table 11 presents the emission of reference cases. There are no direct emissions from the project. The emissions reductions therefore are the same as the reference case emissions.

4. Conclusion

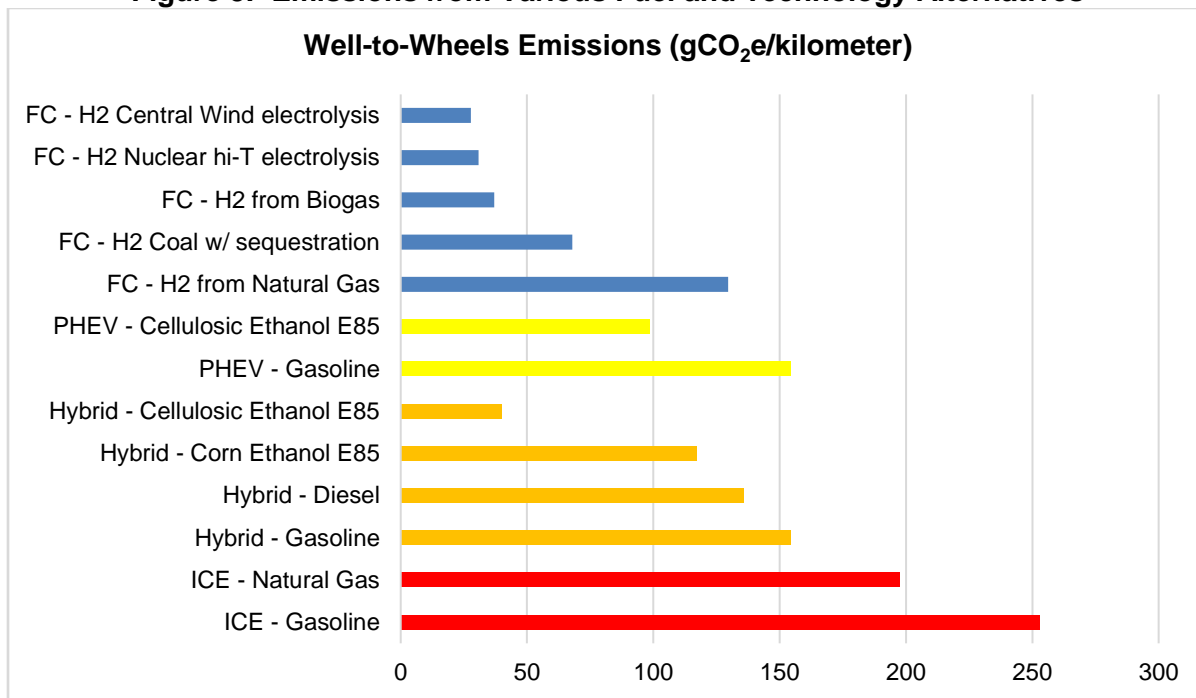
85. The subproject adopts a proven and best available technology for transport applications. It will supply 100 hydrogen fuel cell buses in the Zhangjiakou urban area, providing the final link in the end-to-end hydrogen low-emissions transport infrastructure. The subproject will reduce 6.336 million liters of diesel usage per annum and reduce CO, HC, NO_x, PM, and CO₂ emissions at 59.4, 3.17, 197.8, 7.66, 0.51, and 16,663.7 tons per year, respectively.

86. P2G is also one of the best options in the PRC for using renewable energy for transport applications, while also addressing electricity grid stability and energy storage issues. Reducing street-level emissions requires reducing vehicle tailpipe emissions, which for practical purposes requires use of electricity as a transport fuel in battery or fuel cell vehicles. Reducing lifecycle and regional emissions means that renewable electricity must be used as a transport fuel. Fuel cell vehicles have a decided advantage in terms of range, refueling time, and compatibility with long-term storage of surplus renewable electricity.

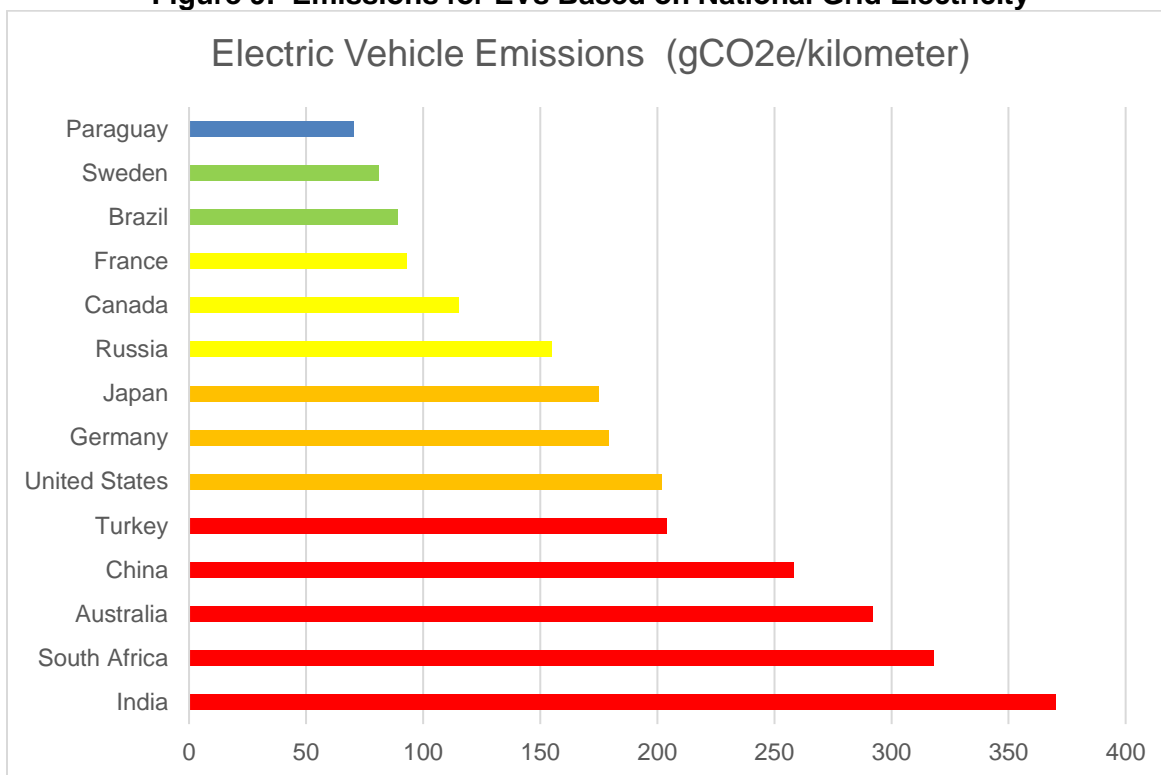
³³ CO₂ emissions are taken as a proxy for conventional pollutants PM_{2.5}, NO_x, and SO₂.

³⁴ Battery electric vehicles charged directly by renewable electricity will have lower emissions than if charged by the typical grid mix. However, battery vehicles are less attractive than hydrogen fuel cell vehicles based on range and refueling times.

Figure 8: Emissions from Various Fuel and Technology Alternatives



E85 = blend of 85% ethanol and 15% gasoline, FC = fuel cell, gCO₂e = grams carbon dioxide equivalent, H₂ = hydrogen, ICE = internal combustion engine, PHEV = plug-in hybrid electric vehicle.

Figure 9: Emissions for EVs Based on National Grid Electricity

gCO₂e = grams carbon dioxide equivalent.

Table 9: Typical Vehicle Emissions Under Different Conditions

Vehicle	Condition (km/h)	CO (%)	HC (ppm)	NOx (ppm)	Particulate (g/m ³)
Gasoline	Idle 0	4.0–10.0	300–2000	50–100	0.005
	Acceleration 0–40	0.7–5.0	300–600	1,000–4,000	
	Constant speed 40	0.5–1.0	200–400	1,000–3,000	
	Deceleration 40–0	1.5–4.5	1,000–3,000	5–50	
Diesel	Idle 0	0	300–500	50–70	0.1–0.3
	Acceleration 0–40	0–0.5	200	800–1,000	
	Constant speed 40	0–0.1	90–150	200–1,000	
	Deceleration 40–0	0–0.05	300–400	30–35	
H ₂ Fuel cell	Idle 0	0	0	0	0
	Acceleration 0–40	0	0	0	
	Constant speed 40	0	0	0	
	Deceleration 40–0	0	0	0	

CO = carbon monoxide, H₂ = hydrogen, HC = hydrocarbon, g/m³ = grams per cubic meter, km/h = kilometer per hour, NOx = nitrogen oxide, ppm = parts per million.

Table 10: PRC Vehicle Emissions Load

Vehicle Fuel	Gasoline	Diesel	Natural Gas
Inventory (number of vehicles)	75,428,000	15,733,000	1,483,000
Carbon monoxide (CO, tons)	23,043,000	4,183,000	734,000
Hydrocarbons (HC, tons)	2,360,000	937,000	95,000
Nitrogen oxides (NOx, tons)	1,698,000	3,887,000	179,000
Particulate Matter (PM, tons)	n/a	590,000	n/a

CO = carbon monoxide, HC = hydrocarbon, NOx = nitrogen oxide, PM = particulate matter.

Source: [PRC] Motor vehicle pollution prevention and control of annual report in 2012.

Table 11: Energy Saving and Emission Reduction from the Subproject

	Category	CO	THC	NO _x	PM	SO ₂ ^a	CO ₂ ^b
Bus	Baseline emission factor ^c (g/km)	3.25	0.107	9.892	0.280	350ppm	--
	Correction factor ^d	0.867	0.521	0.792	0.570	50ppm	
	Emission factor ^e (g/liter)	9.371	0.513	31.224	1.228	0.0799	2,630
	Diesel emission (ton)	59.4	3.17	197.8	7.66	0.51	16,663.7
Emissions Reduction (ton)		59.4	3.17	197.8	7.66	0.51	16,663.7

CO = carbon monoxide, CO₂ = carbon dioxide, g/km = grams per kilometer, g/liter = grams per liter, kg/m = kilograms per cubic meter, NO_x = nitrogen oxide, PM = particulate matter, ppm = parts per million, SO₂ = sulfur dioxide, THC = total hydrocarbon.

^a GB 19147-2016 Automobile diesel fuels Stage IV.

^b China carbon trade network: CO₂ emission factor of diesel 2.630kg/liter (www.tanpalfang.com).

^c Emission under the scenario of speed 30 km/h, temperature 15°C, moisture 50%, load 50% and 350 ppm sulfur content.

^d Consider the impacts from temperature, moisture, sulfur content of diesel, average speed of trucks (assuming 40–80 km/h) and the load factor (100%).

^e Fuel consumption is 40 liter/100 km which meets the GB 30510-2014 Fuel Consumption Limits for heavy-duty commercial vehicles Stage II.

Source: Ministry of Environmental Protection: Technical Guidelines of Air Pollutant Inventory for Automobiles

F. Subproject 6: Super-ESCO Project

1. Introduction of Subborrower

87. Ansteel Energy Service Co., Ltd. (Ansteel ESCO) was founded in December 2010, with a registered capital of CNY20 million which was increased to CNY100 million later. Based on the technical advantage of Ansteel Engineering Technology Co., Ltd (Ansteel Engineering Technology), Ansteel ESCO actively promotes energy saving projects and their implementation based on energy performance contracts. In March 2011, it obtained the approval from NDRC and Ministry of Finance (MOF) and became one of the only two ESCO companies recognized by MOF and NDRC in iron and steel industry in the PRC. In recent years, by conducting energy efficiency diagnosis, promoting energy management contracting (EMC) and sharing energy savings mode, Ansteel ESCO not only helps reduce production cost and gain profit for clients, but also strengthens its own capacity.

88. With the vision of “energy efficient market led by financing, industrial development led by market” and the integration of Ansteel Engineering Technology’s technical expertise and

energy saving projects' short payback period, Ansteel ESCO has obtained a loan of CNY451.6 million for its EMC projects. By far, its client market has extended outside of Ansteel Group Corporation (Ansteel Group), covering several other steel enterprises in the PRC. In recent years, Ansteel ESCO mainly conducts energy-saving service projects in the following fields, such as waste heat and energy recovery, renovation of industrial boiler systems, and system improvement of industrial furnace, electric motor driving, dedusting equipment and water system. By the end of 2015, 44 EMC projects have been completed by Ansteel ESCO, among which 38 have been put into operation with an investment of CNY633 million, generating CNY309 million of energy-saving revenue for the Group.

89. The iron and steel industry is the fundamental industry that supports society development. The PRC will continue to maintain the top ranking as the world's largest iron and steel industry for a long time to come. Long production process, large consumption of various raw materials (including energy) during the process and high pollutant emission are the features of iron and steel industries in the PRC. By years of endeavor, energy consumption per unit of GDP and emission intensity of PRC's iron and steel industry have dropped drastically, but there is still a big gap between the PRC and international advanced level (Table 12) and the PRC has great potential in emission reduction. According to *Annual Statistic Report on Environment in China 2015*, pollutant emissions, namely SO₂, NO_x, and PM, of iron and steel industry are 1.368 million tons, 551,000 tons, and 724,000 tons, respectively taking up 7.4%, 3.0%, and 4.7% of national emission amount. Iron and steel industry becomes the third most polluting industry after electricity industry and cement industry. Among the top four provinces with the highest emission of the three pollutants, three are from the greater BTH Region. Among the provinces with the pollutant emissions exceeding 1 million tons, almost all are located in greater BTH Region. Therefore, to lower the energy consumption and pollutant emission of iron and steel companies will be of great contribution to the air quality improvement of greater BTH Region.

90. A series of emission standards and national standards of energy consumption released by Ministry of Environmental Protection in 2012 regulate strictly on pollutant emission and energy intensity of iron and steel companies. Hence, Super ESCOs, like Ansteel ESCO, are needed for iron and steel companies to provide comprehensive one-stop service in energy saving and emission reduction.

91. As a subsidiary of Ansteel Group, Ansteel ESCO is very familiar with the production process and technology used in iron and steel industry. In addition, with its years of EMC experience in several other steel companies, Ansteel ESCO is capable of being the super ESCO of iron and steel industry.

92. Ansteel Group, headquartered in Anshan City, Liaoning Province, was reorganized from Anshan Steel and Iron Group Corporation and Panzhihua Iron & Steel Group Corporation in May 2010, being an SOE under State-owned Assets Supervision and Administration Commission of the State Council of the PRC. After the reorganization, Ansteel Group has formed cross-regional, multi-bases and international operation layout and become a steel enterprise with the greatest resource advantages in the PRC.

Table 12: Comparison in per ton emission of key iron and steel companies

kgce/ton kg/ton	2001	2012	2015	International and domestic advanced level
Energy	906(2000)	601	572	470 (Ping'an Steel Company, China, 2016)
SO ₂	4.64	1.53	0.85	0.44 (Nippon Steel & Sumitomo Metal, Japan 2009)
PM	4.59	0.99	0.81	0.42 (thyssenkrupp AG, Germany, 2009) 0.14 (POSCO, South Korea, 2009)

kg/ton = kilogram per ton, kgce/ton = kilogram per coal equivalent per ton, PM = particulate matter, SO₂ = sulfur dioxide.

Source: Li (2015),³⁵ Page 68, 261. China Environment Newspaper, July 21, 2016

2. Technology Adopted

93. Ansteel ESCO mainly deploys shared energy-savings model for its EMC projects, under which Ansteel ESCO covers all the project investment and is responsible for project construction work. After completion of the project, Ansteel ESCO oversees the project operation with a shared energy-saving benefit between the ESCO and client company before the EMC period ends. When the agreed EMC period expires, the ESCO transfers assets under the EMC projects free of charge to the client company; the latter takes charge of the project operation and solely enjoys the energy-saving benefit.

94. Table 13 lists 7 selected energy-saving projects that Ansteel ESCO intends to apply for financing from the proposed ADB loan. These projects are allocated in different locations with various technologies adopted. The application for loan with projects bundling could not only help energy efficient projects with small amount of investment to obtain financing, but also negotiate energy-saving benefit sharing method with clients to ensure the investment to be paid back within a short and reasonable period, to ensure the sustainable development of Ansteel ESCO.

Table 13: Energy Saving Projects of Ansteel Group
(EMC shared saving period being 6 years)

	Project Name	Technology Adopted	Location	Sharing Ratio of ESCO and Client Company	Payback Period (Year)
1	Waste Heat Recovery from Flue Gas of Heating Furnace at Chaoyang Steel Plant	To recover waste heat from flue gas with heat exchanger	Chaoyang City, Liaoning Province	7:3	2.2
2	Industrial Waste Heat Recovery for Residential District Heating in Anshan	low-temperature waste heat in replacing high-temperature steam for heating with water source heat pump	Anshan City, Liaoning Province	9:1	3.9
3	Reconstruction of 100-ton Mechanical Vacuum Degassing in Anshan	Mechanical vacuum degassing in replacing steam vacuum degassing	Anshan City, Liaoning Province	7:3	2.2
4	Energy-Saving Reconstruction on High-Pressure Quenching Water Pump at Bayuquan Heavy Plate Mill	Water Pump reconstruction with permanent magnet speed-adjustment device	Bayuquan District, Yingkou City, Liaoning Province	8:2	3.1
5	Draft Fan Frequency Adjustment at Bayuquan Pelletizing Plant	Draft fan frequency adjustment	Bayuquan District, Yingkou City, Liaoning Province	8:2	3.1
6	Water Pump Energy-saving Reconstruction at Anshan Steel Plant	Replacement of water pump of higher efficiency	Anshan City, Liaoning Province	7:3	3.3

³⁵ Li Xinchuang (2015), *How to Transform and Upgrade China's Steel Industry*, ISBN 978-7-5024-6795.1 (in Chinese)

7	Energy-saving reconstruction on Circulating Water Pump and Engine of Blasting Furnace at Anshan Steel Plant	High-efficient water pump or engine in replace of general water pump	Anshan City, Liaoning Province	7:3	3
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EMC = energy management contracting.

95. Waste Heat Recovery from Flue Gas of Heating Furnace at Chaoyang Steel Plant.

In Chaoyang Steel Co., Ltd. (Chaoyang Steel), there are two heating furnaces for steel rolling process that both use mixed gas as the fuel. Based on the measurement at ambient temperature of 1°C, the average exhaust gas temperature is 450°C and the maximum is 500°C. Since there is no waste heat recovery equipment, the heating energy is seriously wasted. The project will recover waste heat from flue gas emitted at the end of the two heating furnaces and to lower the exhaust gas temperature. The recovered heat generates medium-pressure saturated steam that is connected to the heat grid. The reconstruction work is to keep the original flue pipe system and add a twinning high-temperature flue pipe with waste heat recovery equipment installed on it. The flue gas of around 450°C from the heating furnace flows via the twinning flue pipe (the motorized damper of the main flue pipe closes) and then enters waste heat recovery equipment for heat exchange. After being cooled down to the temperature of around 145°C, the flue gas flows back to the main flue pipe by the induced draft fan and then exhausts via the original chimney. The steam generated through waste heat recovery from flue gas amounts to 23 (11.5x2) ton per hour (t/h), with annual operation time of 7,200 hours, pressure of 1.3 MPa and temperature of 194°C. The waste heat recovery equipment uses waste heat boiler with heat pipe for heat exchanging. The generated steam is then sent to the existed superheated steam pipe network of the steel rolling plant. The energy output of the project equals to 15,707.8 tce and the energy consumption is 1,874.8 tce, resulting to the net amount of energy saving of 13,833.0 tce.

96. Industrial Waste Heat Recovery for Residential District Heating in Anshan. Current space heating for Lingshan District is supplied by Ansteel through a long-distance steam pipeline (called #41 pipeline). The steam is generated by blast furnace gas. The steam flow at Ansteel is about 65 t/h and decreased to 39 t/h when it arrives at Lingshan District due to the pressure and heat losses along the pipeline. The proposed project will use the waste heat of cooling water from the Heavy Plate Mill and Wire Rod Plant located in Lingshan District to replace the steam from Ansteel for space heating. Water-source heat pumps will be used to increase the 23–35°C cooling water to 63–65°C hot water. Two heat exchange facilities will supply 53–55°C hot water for space heating during winter season. A heat pump is designed to transfer thermal energy from one place to another place by absorbing heat from a warmer place and releasing it to the cold one using a small amount of electricity. The #41 pipeline will be removed after the project. A total of 523,497.6 GJ of steam will be saved during the 4-month space-heating season. The saved blast furnace gas generated steam will be sent to Combined Cycle Power Plant to generate more electricity. A total of 61.2 GWh electricity will be generated by the saved gas. The heat pump system will consume 20.2 GWh electricity per year.

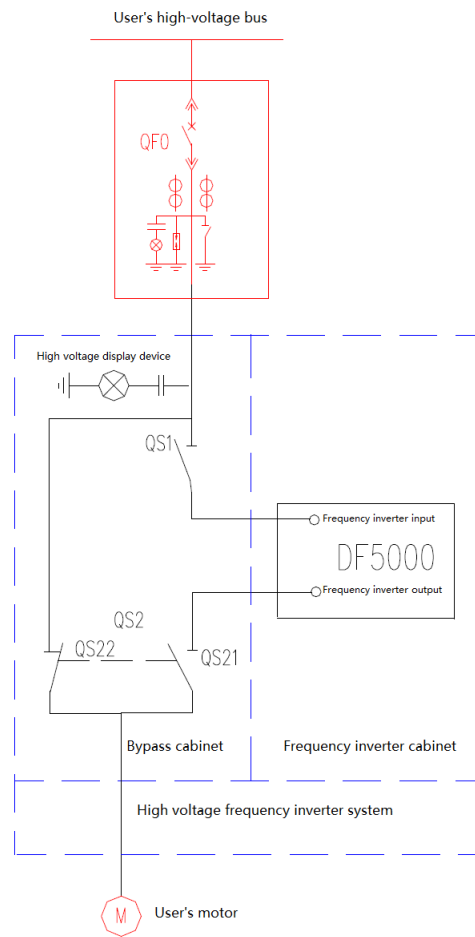
97. Reconstruction of 100-ton Mechanical Vacuum Degassing in Anshan: Due to the aging of current steam vacuum degassing system, the cost of the annual steel production of 900,000 tons is relatively high, with the annual steam and electricity consumption being 69,840 tons and 6.255 million kWh. In contrast, mechanical vacuum degassing is competent with low operation cost and higher energy efficiency. The project is to combine pumps at different levels by mainly applying roots pumps and screw pumps: five primary-level roots pumps + five secondary-level roots pumps + three third-level screw pumps + three fourth-level screw pumps.

With the exhaust capacity of 160,000 m³/h, the pump unit adopts variable frequency controller that fits with the technical processes and operation methods under various conditions. High-efficiency, low-energy consumption, low-thermal load and long-life cycle are the features of the pump units. The connection of four-level pump units could efficiently avoid pump's compression ratio being too high. Pumps at each level could operate isolated. The malfunction of one pump will affect neither the operation of other pumps nor regular production process. The entire project adopts dry vacuum degassing system instead of steam vacuum degassing, greatly lowering the production cost per ton of steel. As the steam saved could generate electricity of 6.285 million kWh, while the dry vacuum degassing system consumes 0.9 million kWh of electricity, the net-saved electricity amounts to 5.385 million kWh.

98. Energy-Saving Reconstruction on High-Pressure Quenching Water Pump at Bayuquan Heavy Plate Mill. Bayuquan Heavy Plate Mill is equipped with four high pressure quenching water pumps that could be launched directly, among which three are in operation and one for back-up. No matter whether the quenching process is undergoing, the water pumps are in operation all the time, resulting in energy waste. To reduce cost, enhance energy efficiency and save energy, the project is to improve water pumps' operation efficiency during non-quenching period. The plan is to install a set of permanent magnet speed-adjustment device between each of the engines and water pumps to build up contactless torque transfer between engines and load. The operation speed of the engine remains the same; water flux and water pressure are under continuous control as the operation speed of the water pump being regulated by the adjustment of the air gap. The annual electricity consumptions before and after reconstruction are 5.161 million kWh and 2.464 million kWh.

99. Draft Fan Frequency Adjustment at Bayuquan Pelletizing Plant. The project is to conduct frequency adjustment to draft fans at the Pelletizing Plant, nine engines, including annular cooler, heat recovery ventilator, dedusting fan and main exhauster are under reconstruction. It is a common phenomenon in the design and operation of draft fans chosen by steel companies that most of the selections on engines are made upon the largest load capacity, making the engine's rate of power larger than the load's shaft power. In real operations, on the contrary, the engines rarely work in full speed. A variable speed drive (VSD) is used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage. The fixed-speed motor load applications (operating under non-full speed condition) that are supplied directly from AC line power can save energy when they are operated at variable speed by means of variable frequency drive (VFD). For example, at the speed of 63% a motor load consumes only 25% of its full-speed power. When the VSD defaults or is out of operation, the system manually switches to power frequency operation, under which the engine is either launched directly, or by existing liquid resistance starter. The typical primary circuit after reconstruction is illustrated in Figure 10. The electricity consumptions before and after reconstruction are 34.805 million kWh and 28.976 million kWh.

Figure 10: Typical primary circuit after reconstruction



100. **Water Pump Energy-saving Reconstruction at Anshan Steel Plant.** 19 sets and 39 units of water pumps (including pumps in operation and for back-up) in Anshan steel plant need to be reconstructed. Most of the pump stations and water treatment equipment were built during 1998-2003 with high energy consumption and low energy efficiency. During long-time operation, along with the abrasion of the equipment sealing and machine vibration, part of the components, such as bearings and sealing components, in the pumps and machines are wearing out, causing inner leaking in some parts of the system and leading to large energy loss. The project is to replace some of the pump units with water pumps of higher energy efficiency. The electricity consumptions before and after reconstruction are 51.383 million kWh and 43.916 million kWh.

101. **Energy-saving reconstruction on Circulating Water Pump and Engine of Blasting Furnace at Anshan Steel Plant.** The project is to conduct the reconstruction by replacing existing ordinary water pumps with water pumps or engines of higher energy efficiency. In addition, metering devices will be installed to monitor the operation data and electricity consumption. For better maintenance and compatibility, the devices are suggested to be of the same type. Meanwhile, some of the valves will be changed as needed. The electricity consumptions before and after reconstruction are 55.606 million kWh and 48.412 million kWh.

3. Estimated Energy Savings and Emission Mitigation

102. **Waste heat recovery from flue gas of heating oven at Chaoyang Steel Plant.** This project consumes 183,600 ton softened water, 100.8-ton cooling water, 7,200-ton fresh water and 7.26 GWh electricity to recover 165,600-ton steam with the temperature at 194°C and pressure at 1.3 MPa (or 460,368 GJ) per year from flue gas. The project will save 13,849.5 tce energy annually. The coal-fired boiler and coal-fired power plant are reference cases for emission reduction calculation. The coal-fired boiler will consume 19,634.7 tce of coal to generate 460,368 GJ of steam and emit CO₂, SO₂, NO_x, and PM of 51,364.4, 8,639.3, 245.4, and 1,458.9 tons respectively. The electricity consumed by the project will emit CO₂, SO₂, NO_x, and PM 5,516.1, 3.41, 3.12 and 0.65 tons respectively. The project will reduce emission of CO₂, SO₂, NO_x, and PM by 45,848.3, 8635.9, 242.3, and 1458.3 ton respectively.

103. **Waste heat recovery for resident space heating at Ansteel:** This project will save 551,050 GJ blast furnace gas to generate 61.2 GWh electricity. Deducting the 20.2 GWh electricity consumed by the heat pump system, the project will generate 41.0 GWh more electricity that equal to 13,038 tce saved. It will reduce CO₂, SO₂, NO_x, and PM by 31,15.8, 19.27, 17.63, and 3.69 tons respectively.

104. **Other 5 projects:** These projects will all save electricity. The thermal power plant is reference case for energy savings and pollutant mitigation calculation. The total energy savings and emission reduction is summarized in Table 14.

Table 14: Energy Savings and Pollutant Mitigation

Project name	Energy Savings (tce)	CO ₂ (t)	SO ₂ (t)	NO _x (t)	PM (t)
Waste Heat Recovery from Flue Gas of Heating Furnace at Chaoyang Steel Plant	13,849.5	45,848.3	8635.9	242.3	1458.3
Industrial Waste Heat Recovery for Residential District Heating in Anshan	13,038 (41 GWh)	31,992.3	19.27	17.63	3.69
Reconstruction of 100-ton Mechanical Vacuum Degassing in Anshan	1,696.3 (5.385 GWh)	4,201.9	2.53	2.32	0.48
Energy-Saving Reconstruction on High-Pressure Quenching Water Pump at Bayuquan Heavy Plate Mill	849.6 (2.697 GWh)	2,104.5	1.27	1.16	0.24
Draft Fan Frequency Adjustment at Bayuquan Pelletizing Plant	1836.0 (5.8287 GWh)	4,548.1	2.74	2.51	0.52
Water Pump Energy-saving Reconstruction at Anshan Steel Plant	2,352.1 (7.467 GWh)	5,826.5	3.51	3.21	0.67
Energy-saving reconstruction on Circulating Water Pump and Engine of Blasting Furnace at Anshan Steel Plant	2,266.1 (7.194 GWh)	5,613.5	3.38	3.09	0.65
Total	35,887.6	100,135.1	8,668.6	272.2	1,464.6

CO₂ = carbon dioxide, GWh = gigawatt per hour, NO_x = nitrogen oxide, PM = particulate matter, SO₂ = sulfur dioxide, t = ton, tce = ton of coal equivalent.

4. Conclusion

105. An ESCO is a company that operates based on EMC, whose primary purpose is gaining profit. The main businesses of ESCOs include providing client with project fund, technology and operation and maintenance service, sharing energy-saving benefit in agreed proportion with clients within the contract period, and transferring energy-saving benefit and proprietary right to clients as the contract period ends. ESCO gains profit by sharing the energy-saving benefit made from the project implementation with the clients, while it undertakes most of the project risk, addressing the main barriers of energy-saving project. However, since the borrowing amount of an individual energy-saving project is relatively small, while the cost is high and processes are complicated, it is difficult for a single project to gain financing, which negatively impact the energy-saving market and related companies. For this reason, Super ESCO, which tends to facilitate large-scale implementation of energy-efficiency projects, comes into play. Super ESCO will package small projects and apply for a loan. Super ESCOs operate in industrial companies or a certain sector with extensive industrial knowledge, profound technical expertise and the capability for sustainable development in businesses.

106. PRC will continue to maintain its top ranking as the world's leading iron and steel exporter for a long time to come. Being an energy intensive and heavy-polluting industry, the PRC's iron and steel industry has great potential in energy saving and emission reduction. In comparison to the energy consumption limit in national standards and international advanced values, the energy saving potential of iron and steel production process ranges between 20% and 300% (see Table 14). As iron and steel companies need a Super ESCO that could provide comprehensive one-stop service, Ansteel ESCO arises to meet this need.

107. The seven selected projects will in total replace 35,887.6 tce, equaling to 100,135.1 tons of CO₂, 8,668.6 tons of SO₂, 272.2 tons of NO_x, and 1,464.6 tons of PM. The establishment of a Super ESCO like Ansteel ESCO will enable companies in iron and steel industry to be renovated and improved using various technologies that are accumulated by Ansteel ESCO. Supporting such kind of Super ESCO will make significant contributions to the energy conservation and emission reduction of iron and steel sector. It will also help transformation and upgrade of steel industry in the PRC. The model of Ansteel ESCO is exemplary to other steel companies or companies of high energy consumption.