INNOVATIVE ENERGY EFFICIENCY AND EMISSION REDUCTION TECHNOLOGIES

1. **Introduction.** Among the possible subprojects of the implementing agency, the China Haohua Chemical Group (CHC),[1] two subprojects with significant energy efficiency and emission reduction outcomes have been selected and evaluated for the first batch to be financed through the revolving escrow fund. The two strategic subprojects involve innovative and high-impact energy efficiency and emission reduction technologies with large demonstration and replication potential. The technologies applied in the subprojects are discussed below.

Process Transformation Subproject at Dezhou Shihua Chemical

2. **Subproject components.** The first selected subproject will demonstrate the transformation of coal-derived calcium carbide–based polyvinyl chloride (PVC) production technology with a new, energy efficient process technology and a mercury-free catalyst. This process transformation was domestically developed and is the first of its kind. The subproject developer will be Dezhou Shihua Chemical (DSC).

3. **Dezhou Shihua Chemical.** DSC, a wholly owned subsidiary of CHC and its leading PVC producer in terms of profitability, technical capability, and product quality, was established on 30 August 2007. In 2011, the company moved to its present industrial site, with an area of about 88 hectares, in the Tianqu Industrial Zone, Dezhou City, Shandong Province. DSC's industrial complex consists of (i) an ionic-membrane caustic soda[2] plant with an annual production capacity of 400,000 metric tons per annum (tpa) of caustic soda, 120,000 tpa of liquid chlorine, and 100,000 tpa of hydrochloric acid, and an attached facility with a production capacity of 40,000 tpa of trichloroethylene and 100,000 tpa of hydrogen peroxide; (ii) a PVC plant with 360,000 tpa of production capacity; and (iii) an industrial combined heat and power plant with an installed power generation capacity of 50 megawatts.

4. **Polyvinyl chloride.** PVC is a synthetic thermoplastic resin with a wide variety of uses including consumer products, water pipelines, construction materials, and many more. PVC is widely used in construction, automobile manufacturing, packaging, and the production of household appliances. Spurred by rapid economic growth and fast urbanization in the People's Republic of China (PRC), demand for PVC more than doubled between 2001 and 2007 and grew by 54.4% more between 2007 and 2013 to reach a total of 15.5 million metric tons in 2013. Capacity growth outpaced demand growth from 2001 to 2013. The PRC's PVC production now accounts for more than one-third of global production.

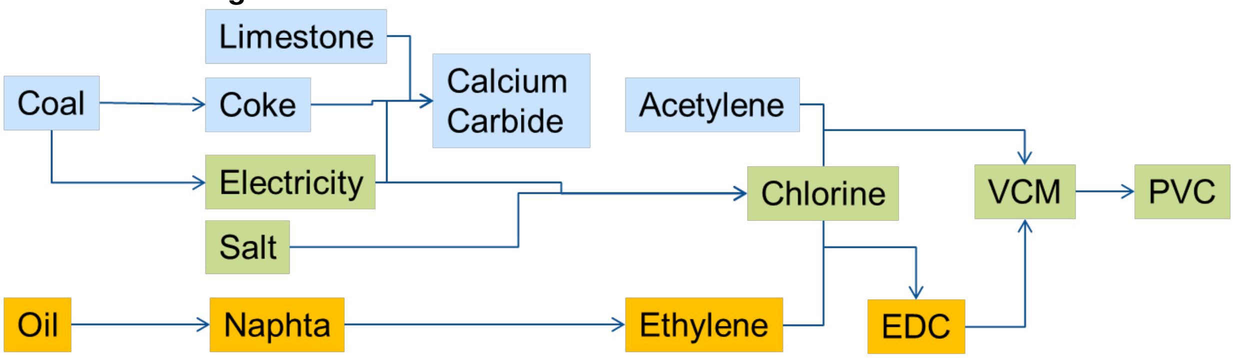
5. **Different routes of vinyl chloride monomer synthesis.** PVC is produced through the liquid-phase polymerization of the intermediate product vinyl chloride monomer (VCM). VCM, in

[1] CHC is a subgroup of the China National Chemical Group (ChemChina).

[2] Electric current is passed through a solution of brine (common salt or, in chemical terms, sodium chloride and water) to produce chlorine, caustic soda (also called sodium hydroxide), and hydrogen. This process is called electrolysis. Chlorine is used in a vast range of processes to create thousands of products, including pharmaceuticals, medical devices, windows, flooring and insulation material and pipes, and pure silicon for the production of photovoltaic cells. At DSC, it is used in VCM synthesis. Caustic soda is an alkali used widely in many industries, including the paper and pulp, food, textile, and soap and detergent industries, as well as for water treatment and effluent control and many other uses. The hydrogen produced at DSC is used in making hydrogen peroxide.

turn, can be synthesized in several different ways, essentially with either coal-derived calcium carbide[3] or petroleum- or natural gas–derived ethylene as initial feedstock (Figure 1).

Figure 1: Coal-Based versus Petroleum-Based PVC Process



EDC = dichloroethane, PVC = polyvinyl chloride, VCM = vinyl chloride monomer.
Source: ADB project preparatory technical assistance team.

6. The calcium carbide–based VCM synthesis technology uses relatively simple, low-cost equipment compared with other methods, such as ethylene cracking, and produces high yields. The fixed-bed reactor-type equipment used in VCM synthesis has been used for over 50 years in the chemical process industry. It requires little automation. Personnel with a relatively low level of skill can operate and maintain the process. Modern ethylene crackers, in contrast, require modern controls and continuous process control and analysis for good results. Generally, therefore, the ethylene process requires a higher level of skill in handling process operations and maintenance servicing.

7. **Economic advantages of calcium carbide–based PVC production process.** In the PRC, the calcium carbide–based PVC production process has a distinct market advantage over the petroleum-based ethylene process because it is adapted to the specific resource endowment of the country. Given the PRC's insufficient petroleum resources, the older calcium carbide–based process is being promoted. Feedstock independence is an important goal of the PRC's chemical industry so as not to weaken further the country's already fragile energy security. Also, even if calcium carbide–based PVC production is more than twice as energy intensive as the ethylene route, its total life cycle costs are significantly lower than those of the latter in the PRC. Franke, et. al., found in a their study comparing the calcium carbide–based process with an ethylene-based process that due to the low coal price in the PRC, that at a market price of €800 per ton PVC the carbide–based process yields high profits of about €250 per ton. [4] Therefore, the calcium carbide–based method, with its energy security and cost efficiency advantages, dominates the PRC's PVC production.

8. **Energy efficiency penalty and environmental burden of calcium carbide–based PVC production.** Although the calcium carbide–based technology is technically simple, and can rely on local resources, it holds serious disadvantages in terms of both environmental hazards and energy inefficiency. It is more than twice as energy intensive as the ethylene route.[5] Moreover, it uses mercuric chloride–impregnated activated carbon as catalyst. This

---

[3] Calcium carbide is produced from the reaction of limestone and coke under high pressure and heat. Limestone is converted to lime in a limekiln, while moisture is removed from coke in a coke dryer. The two charged materials are then conveyed to an electric arc furnace, the primary piece of equipment used in producing calcium carbide.

[4] Franke, B., Li, N., Ahati, J., Detzel, A., Zhao, C., Busch, M., and Derreza-Greeven, C. 2014. *Technological and Economic Challenges in Making Urumqi's PVC Industry More Energy Efficient.* Berlin.

[5] Footnote 4.

technology results in the generation of large amounts of waste mercury catalysts, mercury-containing activated coal, mercury-containing hydrochloric acid, and mercury-containing alkaline agents in production. These mercury-containing products are rarely recycled, for technical and economic reasons, except for the used catalyst. Each type of material poses serious environmental risks, as mercury is toxic. The handling of the used catalyst also causes additional problems, as workers are exposed to high levels of extremely reactive chemicals, including mercury.[6]

9. The use of mercury in PVC production in the PRC alone represents one of the biggest global uses of mercury. Relatively advanced calcium carbide–based PVC plants in the PRC use between 1.1 and 2 kilograms (kg) of mercury catalyst per ton of PVC produced. Accordingly, the PRC's PVC industry is believed to have used at least 1,300 tons of mercury in 2013. This accounts for more than 70% of intentional mercury use in the PRC, and about 50% of use worldwide. To provide the needed mercury, the PRC continues to engage in mercury mining. It is one of the few countries that still do so.

10. **PVC production in the PRC.** The PVC sector has grown more than fivefold since 2001, from about 3 million tons in 2000 to 15.5 million tons in 2013. The share of calcium carbide–based PVC production in the PRC's total PVC production increased during the capacity expansion boom with the addition of a number of large-scale PVC facilities in central and western PRC, near raw material resources. In 2009, calcium carbide–based plants produced around 63% of the PRC's PVC output; in 2013, these plants' production of 12.5 million tons of PVC represented 82% of the country's PVC output that year.[7] Ethylene-based VCM synthesis, on the other hand, accounted for only 18% of PVC production in the PRC in 2013.

11. **The slump in oil prices are not expected to invoke feedstock switching.** The slump in oil prices since July 2014 has also not changed the relative competitiveness of the calcium carbide–based process to the ethylene-based process in the PRC, because in tandem with the decline in oil prices, coal prices have dropped equally drastically in the PRC to reach their lowest level since 2004.[8] Also in such large industrial processes, investments are path dependent, and the oil price shock would need to persist for a long time before investor abandon existing assets switch their process. A short to medium term price decline in oil prices will not incentivize owners with coal based existing PVC processes to switch to an ethylene based process as it would require construction of a completely new industrial plant and leave existing assets.

12. **Regulatory initiatives to decrease mercury use in the PRC's PVC industry.** In view of the increasingly serious mercury pollution caused by the PVC industry, the Government of the PRC has issued a series of notices and guidelines to address the issue:

- (i) On 28 December 2009, the Ministry of Environmental Protection (MEP), the National Development and Reform Commission (NDRC), the Ministry of Industry and Information Technology (MIIT), and five other ministries issued the Guidelines for Strengthening the Prevention and Control of Heavy Metal Pollution (GBF [2009] No. 61).

---

6 China Council for International Cooperation on Environment and Development. 2011. *Special Policy Study on Mercury Management in China.* Beijing.

7 China National Chemical Information Center. 2014. *Status and Outlook for China PVC Industry.* Presentation at the Asia Petrochemical Industry Conference (APIC). Pattaya, Thailand. 15–16 May.

8 China 5e. 2015. Coal and Power News Review. *5e Energy Weekly* No. 405. 2 June 2015. pp. 3-4.

(ii) In February 2010, MIIT launched its Implementation Program for Cleaner Production Technology of the Polyvinyl Chloride Industry, clarifying the working concept of mercury minimization and elimination. [9] In 2010, MIIT, the China Petroleum and Chemical Industry Federation, the China Chlor-Alkali Industry Association, and the China Chemical Industry Environmental Protection Association also jointly drafted the Guidelines for Strengthening the Prevention and Control of Mercury Pollution in the Polyvinyl Chloride Industry, which recommended that all PVC industries (a) use low-mercury catalyst in production by 2015, and (b) recover 100% of the waste mercury catalyst.

(iii) In 2011, the MEP issued the Notice on Strengthening the Mercury Pollution Prevention and Control in the Calcium Carbide Process-based Polyvinyl Chloride and Related Industries (HF [2011] No.4). By the end of 2015, according to the notice, (a) the high-mercury catalyst should have been completely eliminated from PVC production, (b) capacity for low-mercury catalyst production should have been reasonably and moderately expanded, (c) the production of the low-mercury catalyst should have been improved and increased to meet the needs of other applications, and (d) research and development work on the mercury-free catalyst should have progressed, with encouragement from the government (footnote 7).

(iv) Research on alternative catalyst technologies was included in the PRC's National Basic Research Program 973. Intensive research has been done, with the objective of developing a mercury-free catalyst for the calcium carbide route of VCM synthesis. Except for the pilot plant at DSC and one other pilot plant (para. 24 in the present document), none of these research initiatives have led to the scale-up of a pilot plant. To solve the problem of mercury pollution sustainably and over the long term, the development of non-mercury catalysts must be accelerated and scaled up for commercial application.

13. **Minamata Convention on Mercury.** The PRC is a party[10] to the Minamata Convention on Mercury, an international treaty regulating mercury supply, use, and anthropogenic emissions that had 123 signatory countries by the end of 2014.[11] One stipulation of the treaty relevant to the use of mercury in PVC production is for the parties to cut in half their per unit mercury use in the production of VCM, the intermediate product for PVC production, by 2020 compared with their 2010 use. The parties also agreed to (i) support research and development with respect to mercury-fee catalysts and processes, and (ii) phase out mercury-containing catalysts in the industry within 5 years after alternative catalyst technologies have been proven to be technically and commercially viable.

14. **Objective of the subproject.** DSC proposes to demonstrate a process transformation of the calcium carbide–based PVC production process with a scale-up of a pilot-tested new technology improve energy efficiency and eliminate mercury use in the production process. With this demonstration project, ChemChina and the government intend to pave the way for a complete elimination of mercury in the PRC's PVC industry.

---

[9] Ministry of Environmental Protection. 2011. *R&D Progress of and Feasibility Study Report on Mercury-free Catalyst in China.* Beijing.

[10] The PRC signed the convention, but has not yet ratified it.

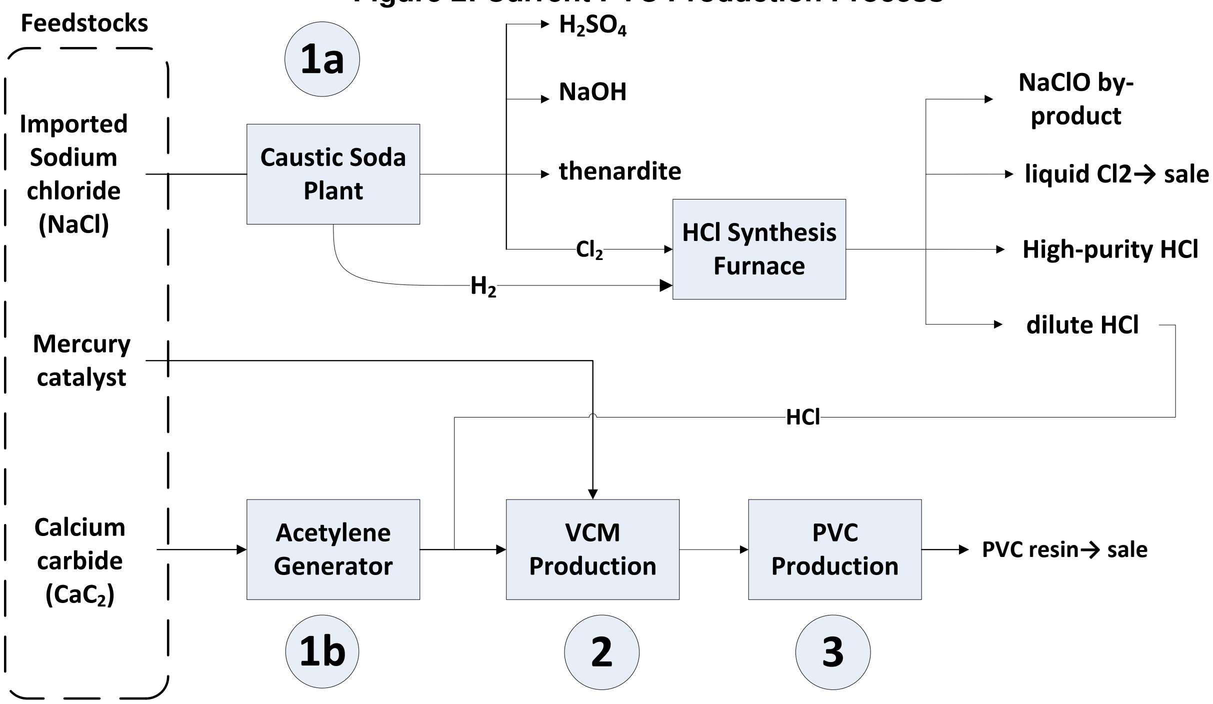
[11] www.mercuryconvention.org.

15. DSC developed its mercury-free VCM synthesis technology in partnership with the National Basic Research Program (973 Program) of the Ministry of Science and Technology.[12] DSC has pilot-tested the new technology for 2 years at a scale of 500 tpa, and for 1.5 years at a production scale of 2,000tpa. In August 2014, a panel of independent experts from NDRC, MEP, MIIT, the China Petroleum and Chemical Industry Federation, and the China Chlor-Alkali Association reviewed the results of the tests and gave the technology the highest possible rating. They also declared it a technology of national importance.

16. **Current PVC production process in the PRC.** DSC, like most other PVC manufacturers in the PRC, uses two main feedstocks, calcium carbide and hydrogen chloride (HCl).[13] Purchased calcium carbide is crushed and mixed with water to generate acetylene gas. The generated acetylene is dried, purified, and then sent to the VCM synthesis process.

17. The HCl used in the process comes from the reaction of hydrogen with chlorine in DSC's caustic soda production chain (Figure 2). Purchased solid sodium chloride[14] is mixed with water to form brine. Electrolysis of the brine produces caustic soda, which is sold, and chlorine and hydrogen gases as by-products. These gases are sent to the HCl synthesis furnace. The chlorine thus produced is sold and the weak HCl by-product is used in PVC production.

Figure 2: Current PVC Production Process

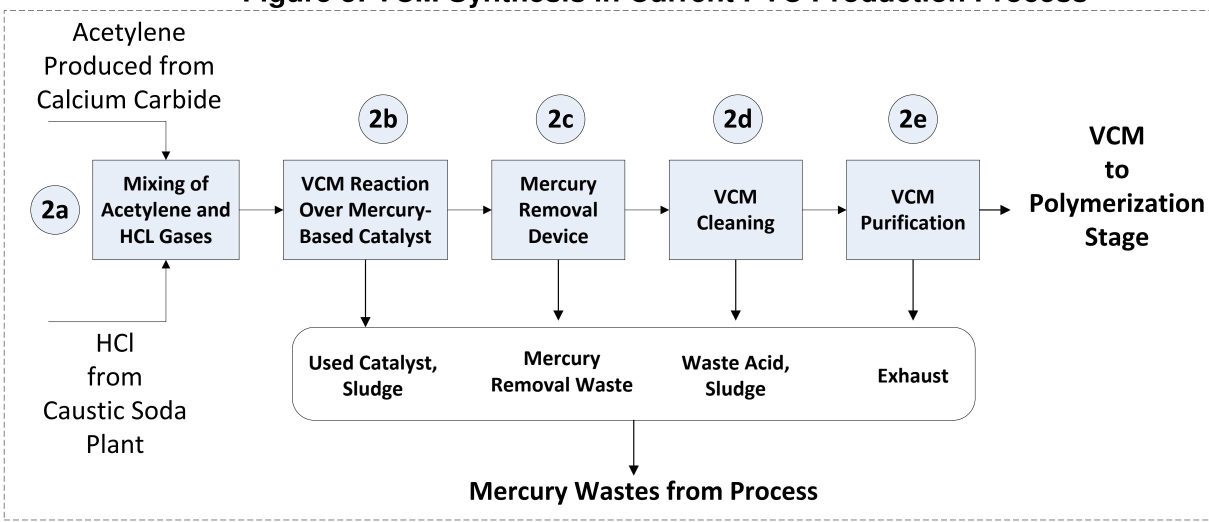


CaC_2 = calcium carbide, Cl_2 = chlorine, H_2 = hydrogen, HCl = hydrogen chloride, H_2SO_4 = sulfuric acid, NaCl = sodium chloride, NaClO = sodium hypochlorite, NaOH = sodium hydroxide, PVC = polyvinyl chloride, VCM = vinyl chloride monomer.
Source: Asian Development Bank.

[12] Project number 2011CBA00500, subject number 2011CBA00507.
[13] At room temperature, HCl is a colorless gas, which forms white fumes of hydrochloric acid on contact with atmospheric humidity.
[14] Sodium chloride, also known as salt, common salt, or table salt, is the main feedstock for electrolysis.

18. VCM synthesis, the key feature of the mercury-free PVC transformation project, takes place acetylene reacts with HCl over mercuric chloride deposited on activated carbon as catalyst. Figure 3 shows the various steps in the process. First, acetylene and HCl are mixed (2a). Then the acetylene–HCl mixture is fed into a fixed-bed catalytic reactor and VCM is synthesized over mercuric chloride on activated carbon as catalyst (2b). After that, mercury is removed from the synthesized VCM (2c), and the VCM is purified and dried (2d) and sent to the polymerization stage (2e). During VCM synthesis, mercury emissions may occur at various points, as shown in Figure 3.

Figure 3: VCM Synthesis in Current PVC Production Process



HCl = hydrogen chloride, VCM = vinyl chloride monomer.
Source: Asian Development Bank.

19. In the polymerization unit, VCM is mixed with a polymerization initiator and polymerized into PVC in a liquid-phase batch reactor. The aqueous suspension of raw PVC produced is purified, cooled, dried, and then packaged for sale.

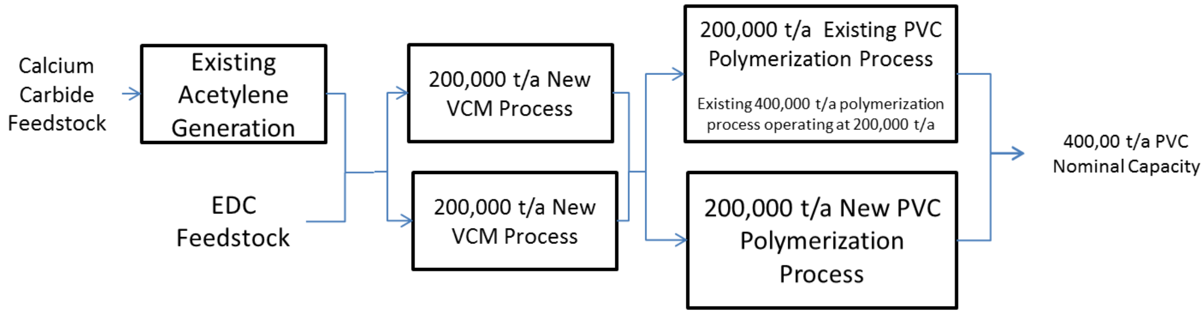
20. **New process.** The main feature of the new "dual technology" for VCM synthesis (Figure 4) is its replacement of (i) the mercury-based catalyst with a barium chloride–based catalyst,[15] and (ii) about 46% of the calcium carbide feedstock with dichloroethane (commonly known as ethylene dichloride, or EDC).[16] There will be a retrofitting of various processes: acetylene compression and drying, and EDC purification, gasification, reaction, separation, condensation, and distillation. Acetylene gas will react directly with EDC in a heat-insulating fixed-bed reactor, and 0.1 kg of barium chloride on activated carbon as a carrier will be added for each ton of VCM and will act as catalyst. The new technology can couple endothermic cracking and exothermic addition reactions to conserve internal chemical energy, significantly reducing the amount of energy used in the process. Figure 4 compares the current and proposed processes.

---

[15] Barium chloride is also a toxic chemical compound. But it must be taken into the body in significant quantities to be of any danger to human health. Barium chloride waste will be sent back to a barium chloride supplier for chemical treatment and recycling. It will be mixed with sodium sulfate to produce barium sulfate (nontoxic) and sodium chloride.

[16] EDC is a chlorinated hydrocarbon sourced from both the PRC domestic market and overseas suppliers.

Figure 4: New PVC Process after Proposed Process Transformation



EDC = dichloroethane, PVC = polyvinyl chloride, t/a = tons per annum, VCM = vinyl chloride monomer.
Source: Asian Development Bank.

21. **Important features of DSC's dual technology for mercury-free VCM synthesis.** Several important features make its replication and adoption attractive:

(i) Energy intensity is reduced through the substitution of 46% of the calcium carbide feedstock with EDC.
(ii) Energy consumption is reduced by 34%, or by 1.079 tons of coal equivalent (tce) per ton of PVC, resulting in total energy savings of 388,521 tce per year.
(iii) Mercury consumption is eliminated equivalent to 35 tpa
(iv) Emissions of the following harmful substances are avoided (a) carbon dioxide by 1.359 million tons per year; (b) sulfur dioxide by 1,350 tons per year; and (c) mercury by about 600 kg per year (Table 1);
(v) The equipment used in the proposed subproject is (a) simpler and easier to maintain than that used in the old mercury catalyst–based process; and (b) far simpler to operate compared with that used in ethylene-based processes.
(vi) A better-quality product and a more efficient feedstock conversion rate are projected. Conversion rates are expected to reach 99%, compared with 92% for ethylene VCM synthesis technology.
(vii) The barium chloride–based catalyst has a favorable life cycle cost, as its use in the pilot plant indicates, and can also be manufactured and recycled reliably.
(viii) Barium chloride as catalyst, while a potential safety risk to humans, can be safely treated and would need to be ingested in great quantities in repeated exposure cycles to be a threat to human health. Barium chloride is not a persistent organic pollutant and will not build up in human body tissues or in the environment (footnote 13).
(ix) This 100% domestic process accords with the overall goal of the PVC industry and the government of supporting the commercialization of innovative domestic research initiatives.

Table 1: Energy Efficiency and Emission Reduction Estimates for Process Transformation Subproject Components

			Emission Reduction		
Item	**Total Investment Cost** (CNY million)	**Net Energy Savings** (tce/yr)	**Carbon Dioxide** (t/yr)	**Sulfur Dioxide** (t/yr)	**Mercury** (t/yr)
Process transformation		388,521	1,359,480	1,350	0.63

CNY = yuan, t/yr = tons per year, tce/yr = tons of coal equivalent per year.
Sources: Feasibility study report and Asian Development Bank estimates.

22. **Alternative gold-based mercury-free catalyst for calcium carbide-based PVC production process.**[17] Jacobs Matthey is a private chemical process company that has been working on mercury-free catalyst development in the PRC since 2006. In 2011, the company announced that it had developed a viable mercury-free catalyst based on gold and that the technology had great commercial potential. A pilot plant built in 2012 achieved high performance and stable production for 3 months. Plans were announced for a commercial-scale plant. The Jacobs Matthey alternative has several interesting features: (i) a professed conversion rate of 99%; (ii) a catalyst life cycle cost of under 2%; (iii) 100% calcium carbide feedstock; and (iv) a "drop-in" retrofit solution for existing mercury catalyst–based plants requiring minimal expenditure for conversion. But it also has several drawbacks, which explain why this technology was not considered as a feasible solution during the preparation of the ADB project. The main drawback is the use of gold in the catalyst, resulting in the need for a huge security apparatus along the production chain, from catalyst production to the process facility and the recycling operation, to prevent the theft of gold, greatly increasing the life cycle cost of the gold catalyst far beyond the 1.5%–2% range estimated by Jacobs Matthey. Additionally, since a commercial-scale plant retrofit has not yet been demonstrated, the "drop-in" claims have not been wholly proven. The Chlor-Alkali Industry Association and the China Petroleum and Chemical Industry Federation maintain that the gold required to retrofit a significant portion of the VCM manufacturing facilities in the PRC is quite large and is likely to outstrip available local gold supplies and lead to significant import dependence for this precious metal.

23. **Risk assessment.** The overall risk rating of the subproject is moderate to high. This rating is based on the technical risks inherent in chemical process scale-up. Related to the technical risk is an implementation delay risk of the project.

24. **Technical performance risk.** The proposed VCM process transformation project involves scaling up an experimental process from pilot scale to commercial scale. A review of the development trajectory showed the technology to be credible, feasible, and ready for commercial scale-up. The proposed level of scale-up is reasonable, considering the expected development trajectory for a chemical process of this nature.

25. The most critical technical risks connected with the performance of the scaled-up mercury-free VCM process have to do with unforeseen physical and chemical dynamics of the larger process. Fundamental chemical reactions and mechanical phenomena associated with heat transfer devices, fluid delivery networks, and material properties of machinery and vessels often change in a nonlinear fashion. Feedback loops in mechanical systems and critical chemical phenomena, which have been stabilized within a certain operational regime, can become more pronounced and cause unforeseen instability when significantly increased in scale. These dynamic effects could reduce the conversion rates within fixed-bed reactors or lower the performance of mechanical systems, such as those associated with heat exchange and fluid transfer. The resultant risk is a reduction in product quality or production rates. Correcting these unforeseen operating dynamics on a larger scale could delay subproject completion or fundamentally reduce the final production capacity of the PVC process.

26. **Implementation delay risk.** The due diligence identified further risks of subproject time overruns beyond the expected delivery period of 2.5 years. But during project preparation,

[17] This alternative technology is assessed against several performance criteria. A key criterion, besides production volume and stability, is the life cycle cost of the catalyst. Life cycle cost is determined not only by the cost of manufacture, but also by the length of use of the catalyst, its productivity over production batches, and its ability to undergo recycling.

experts declared the proposed project delivery organization, including project management and technical design support, capable of successful project delivery.

27. **Operational risks.** Operational risks are moderate to low, because the operation of the mercury-free VCM technology is similar to that of the technology used in the existing plant. Currently employed operational personnel have adequate skills to operate capably all equipment in the transformed process.

28. The two new hazards in the VCM manufacturing process are associated with the change in the feedstock mix and the use of a mercury-free catalyst. With the introduction of EDC as feedstock, new storage facilities and guidelines for hazardous operations are expected to be required. The new mercury-free catalyst, on the other hand, is composed of barium chloride, which can be toxic if ingested in sufficient quantities (footnote 13).

Energy Efficiency Optimization and Emission Reduction Subproject at the Zhonghao Chenguang Research Institute of Chemical Industry

29. **Subproject components.** The second subproject will be implemented at the plant of the Zhonghao Chenguang Research Institute of Chemical Industry (CGY) in Zigong City, Sichuan Province. It involves the implementation of comprehensive energy efficiency optimization measures and the installation of a real-time energy management system that will reduce CGY's energy consumption by 10,145 tce per year. During project preparation, ADB proposed that this subproject be packaged together with the plasma gasification of fluoroform (HFC-23) to scale up CGY's existing pilot project.[18]

30. **Fluoropolymers.** Fluoropolymers possess excellent properties, such as outstanding chemical resistance, weather stability, low surface energy, low coefficient of friction, and low dielectric constant. These properties arise from the special electronic structure of the fluorine atom, the stable carbon–fluorine covalent bonding, and the unique intramolecular and intermolecular interactions between the fluorinated polymer segments and the main chains. Because of their special chemical and physical properties, fluoropolymers are widely used in the chemical, electrical and electronic, construction, architectural, and automotive industries, and in households. The global consumption of fluoropolymers has seen tremendous growth. Worldwide sales of fluoropolymers in 2000 exceeded $2.0 billion, compared with $1.5 billion in 1994. Although the economic downturn that began in 2008 also affected the fluoropolymer industry, a turnaround, along with the recovery of the world economy for fluoropolymer markets, especially for motor vehicles, wire and cable, advanced batteries, fuel cells, and photovoltaic modules, is expected.

31. **The PRC's fluoropolymer industry.** The development of the fluoropolymer industry in the PRC began in the 1950s. In the 60 years since then, the country's fluoropolymer production technology has become increasingly mature, with gross production capacity exceeding 150,000 tpa. Constantly increasing demand for these products has increased the urgency of environmental protection, emission reduction, and energy saving issues.

32. A key challenge to the future development of the industry is its high energy intensity and environmental footprint. The fluoropolymer production chain is among the most energy-intensive and polluting industrial sectors. The building blocks of many fluorinated polymers are derived

---

[18] CGY's pilot project has an incineration capacity of 200 tons of HFC-23 per year. It was set up in 2007 and has since performed reliably meeting all performance requirements.

from fluorine gases. Considering the global-warming and ozone-depleting potential of many fluorinated gases used in fluoropolymer manufacturing, this sector is considered critical to environmental sustainability initiatives for the chemical industry and global climate change mitigation.

33. **Zhonghao Chenguang Research Institute of Chemical Industry.** CGY, established in 1965, is one of the founders of the organic fluorine and organic silicone materials industry in the PRC. The company has its headquarters in Fushun County, Zigong City, Sichuan Province. Its manufacturing facility covers 200 hectares and is located in Zigong's Industrial Park, just west of Fushun County, at a site on the northern bank of the Tuo River.

34. For more than 50 years, CGY has been an industry leader in the technological development of organic fluoride monomers and high-performance fluorine polymers. CGY has a long history of innovative research, and works hard to maintain its competitive edge, both domestically and internationally. As of 2014, CGY had been awarded 116 patents in the PRC. CGY has also received various awards and recognitions, including the following:

(i) Executive Vice President Plant of the China Association of Fluorine and Silicone Industry,
(ii) National High-Tech Enterprise,
(iii) National Enterprise and Institutional IPR [Intellectual Property Rights] Demonstration Unit,
(iv) National Innovative Enterprise, and
(v) One of the Top 10 in the First Batch of National Industries with Independent Innovative Capability.

35. Plant modernization has been focused on improving the technologies in the component unit operations (reactors, furnaces, utility services, ancillary equipment, etc.), dealing responsibly with waste streams using incineration technologies, and implementing an intelligent process automation system.

36. **Overview of CGY's production process and key products.** The company produces over 200 branded products, including organofluorine materials and engineered plastics. The fluorine polymer manufacturing process produces a number of intermediate products as described briefly in Table 2.

Table 2: Intermediate and End Products of CGY's Fluoropolymer Production

Product	Description	CGY Production Capacity (tpa)
Intermediate products		
Anhydrous hydrogen fluoride (AHF)	AHF is a dry compound and the primary source of fluorine for the manufacture of fluorinated compounds. It results from the reaction of mineral fluorite with sulfuric acid. When mixed with water, it produces hydrofluoric acid.	10,000
Chloroform	Chloroform, sourced from outside the CGY enterprise, is a common solvent used industrially to produce fluorinated gases. It reacts with AHF in HCFC-22 manufacture.	-

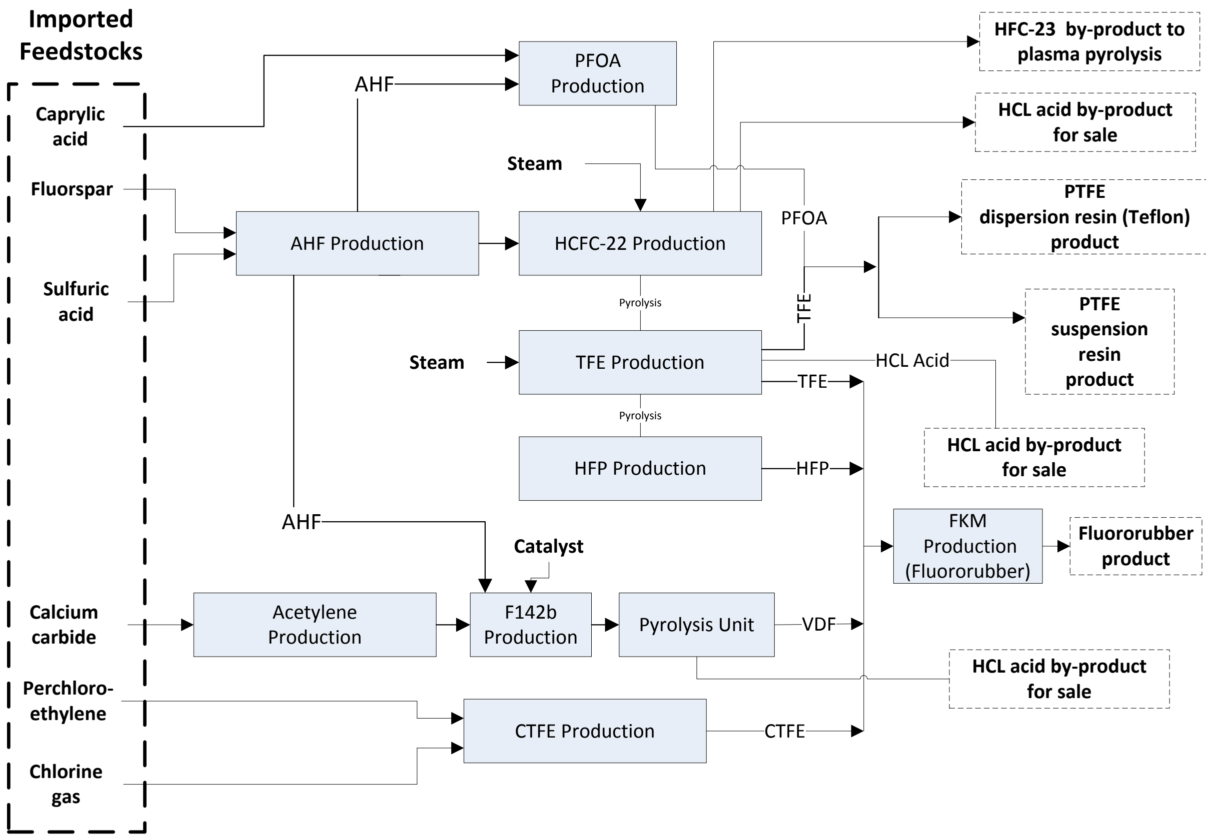
Product	Description	CGY Production Capacity (tpa)
Difluoromono-chloromethane (HCFC-22)[19]	HCFC-22 is a key intermediate product used in the manufacture of downstream fluoropolymer products at CGY, such as PTFE, FKM, and perfluoropropylene. CGY is equipped with three trains for the manufacture of HCFC-22. Over the 2011–2013 period, HCFC-22 production averaged 92% of full capacity. The manufacture of HCFC-22 and downstream end products process is highly energy intensive. Unit operations require high-energy utility services such as steam, chilled brine, natural gas, electricity, and compressed air. Between 2011 and 2013, energy consumption for each ton of HCFC-22 produced averaged 0.20 tons of coal equivalent.	38,000
Tetrafluoro-ethylene (TFE)	TFE is an organic halogen compound and the starting material in the manufacture of polytetrafluoroethylene.	30,000
End Products		
Polytetrafluoro-ethylene (PTFE)	PTFE is commonly marketed under the commercial name Teflon and is a widely used fluoropolymer typically manufactured into a resin for sale and distribution. PTFE has high heat resistance and is inert to most chemicals. For those reasons, it is the coating of choice for industrial, medical, and consumer products.	23,000
Polyvinylidene fluoride or polyvinylidene difluoride (PVDF)	PVDF is a highly nonreactive and pure thermoplastic fluoropolymer produced through the polymerization of vinylidene difluoride. Like many other fluorinated polymers, PVDF has properties that make it important to many high-tech industries. PVDF resins can be combined with many other polymers and compounds to make products such as plastic piping for the chemical industry, wire insulation coating, and special fabrics. PVDF products can have high tensile strength and can be processed in factories. PVDF also exhibits piezoelectric properties, i.e., it will produce an electrical charge under mechanical stress.	2,500
Fluoroelastomer (FKM)	FKM is the generic term for fluoroeleastomers of fluororubber end products, used in a vast number of commercial and consumer end-use applications. The excellent chemical resistance of FKM makes it a popular material in the manufacture of parts for engines and machinery. FKM is used in the manufacture of many gaskets, seals, and coatings in the automotive industry.	7,000

CGY = Zhonghao Chenguang Research Institute of Chemical Industry , tpa= tons per annum.
Source: ADB project preparatory technical assistance team.

37. The following diagram gives an overview of the CGY enterprise production chain.

[19] HCFC-22, the feedstock for the fluoropolymer production of CGY, is an Annex C (Group 1) ozone-depleting substance under the Montreal Protocol, and is included in ADB's prohibited investment activities list. The PRC is among the developing countries allowed to exceed the prescribed levels for the domestic consumption and production of HCFC, but it must still gradually reduce HCFC-22 use as prescribed under the protocol. Its use as an intermediate feedstock in the fluoropolymer industry does not require phaseout, neither in the PRC nor in other countries like the United States. All the HCFC-22 produced at CGY is used as an intermediate product and is not sold as a refrigerant.

Figure 5: Overview of Zhonghao Chenguang Research Institute of Chemical Industry's Production Chain



AHF = anhydrous hydrogen fluoride, caprylic acid = octonoic acid, CTFE = chlorotrifluoroethylene, F142b = 1-chloro-1, 1-difluoroethane, FKM = fluoroelastomer, HCFC-22 = difluoromonochloromethane, HCl = hydrochloric acid, HFC-23 = fluoroform or methyl trifluoride, HFP = hexafluoropropylene, PFOA = perfluorooctanoic acid, PTFE = polytetrafluoroethylene or Teflon, TFE = tetrafluoroethylene monomer, VDF = vinylidene fluoride or fluororubber.

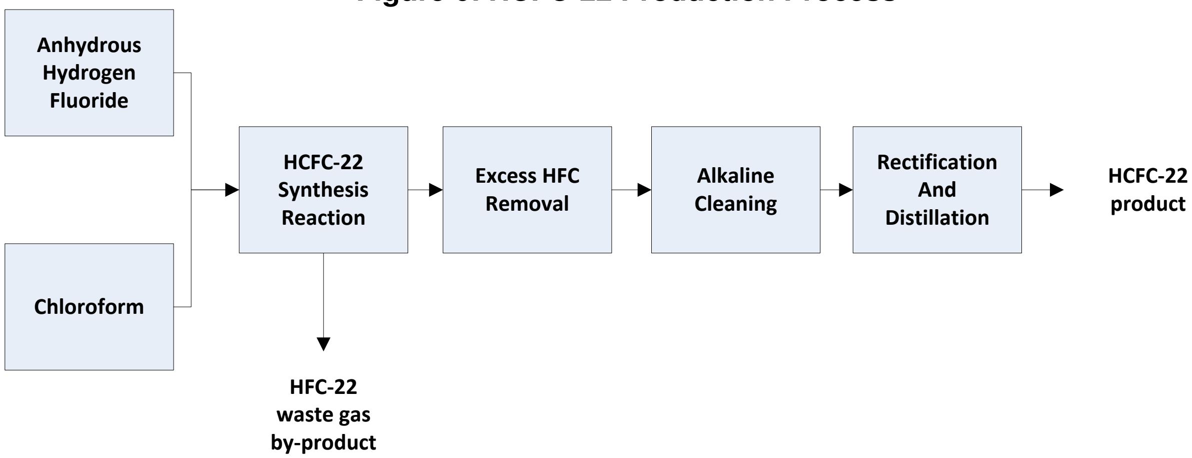
38. At its average production level of 35,000 tpa over the past 3 years, 2012-2014, CGY has been producing about 1,000 tpa of HFC-23. So far, only the smallest of the three HCFC-22 production chains, with a capacity of 6,000 tpa, is able to capture and treat HFC-23 by-product through plasma cracking. The HFC-23 emissions from the other two units—about 15 million tons of carbon dioxide equivalent—are vented into the atmosphere.

39. **Subproject delivery mechanism.** The delivery strategy for this subproject is also unique. The environmentally significant but commercially low-value plasma pyrolysis subproject will be bundled with energy efficiency subprojects that have a financially attractive, process optimization outcome. The holistic package will integrate the relative costs and benefits of all subprojects to deliver financial and technological outcomes that are positive overall.

40. **GHG emission abatement component.** The GHG emission abatement component of the subproject consists of strengthening CGY's capacity to reduce HFC-23 emissions through plasma gasification. When AHF reacts with chloroform to produce HCFC-22 for the downstream manufacture of fluoropolymer, the unwanted by-product HFC-23 is produced (Figure 6). HFC-23 is a highly potent GHG. According to the Fourth Assessment Report of the International Panel on Climate Change, HFC-23 has a global-warming potential of over 14,800 times that of carbon

dioxide over a 100-year time horizon, and an atmospheric life of 270 years. HFC-23 is effective in trapping heat in the atmosphere because of its strong infrared absorption band, high density, and long atmospheric life span.[20]

Figure 6: HCFC-22 Production Process



HCFC-22 = difluoromonochloromethane, HFC = hydrofluorocarbon, HFC-23 = fluoroform.
Source: Asian Development Bank.

41. **Plasma pyrolysis technology** is an innovative waste treatment technology. It uses alternating-current, direct-current, power-frequency, high-frequency, and other approaches to instantly generate a high-temperature plasma torch or plasma beam between electrodes and quickly break down hazardous waste into individual carbon, hydrogen, chlorine, silicon, and other individual elements in the energy-intensive plasma furnace, thus achieving harmless disposal. With the temperature of the arc or beam core reaching more than 7,000°C, general hazardous wastes decompose within a few milliseconds.

42. Plasma pyrolysis technology is used mainly to treat all kinds of high-risk pollutants, including: (i) by-products and exhaust gas from the organic fluorine production process; (ii) HFC-23, to reduce emissions; (iii) chemical industry waste products, such as emulsions, waste organic solvents, catalysts, waste organic acids, waste dye and paint, waste mineral oil, highly toxic pesticides that have become ineffective, and photosensitive material waste; and (iv) hazardous waste. This is a sophisticated, reliable, high-efficiency, pollution-free secondary environmental industrial process technology for dealing with the growing problem of hazardous waste, which presents special disposal challenges because of the environmental and public health concerns around typical incineration and other management approaches.

43. **CGY's plasma pyrolysis system for HFC-23 destruction.** CGY's proposed plasma pyrolysis system will consist of two completely new 500 t/a processing units and an existing unit whose 200 t/a treatment capacity has been expanded to 500 t/a. Combined, the three units will have a theoretical peak capacity of 1,500 t/a for HFC-23 destruction, for a net increase in capacity of 1,300 t/a.

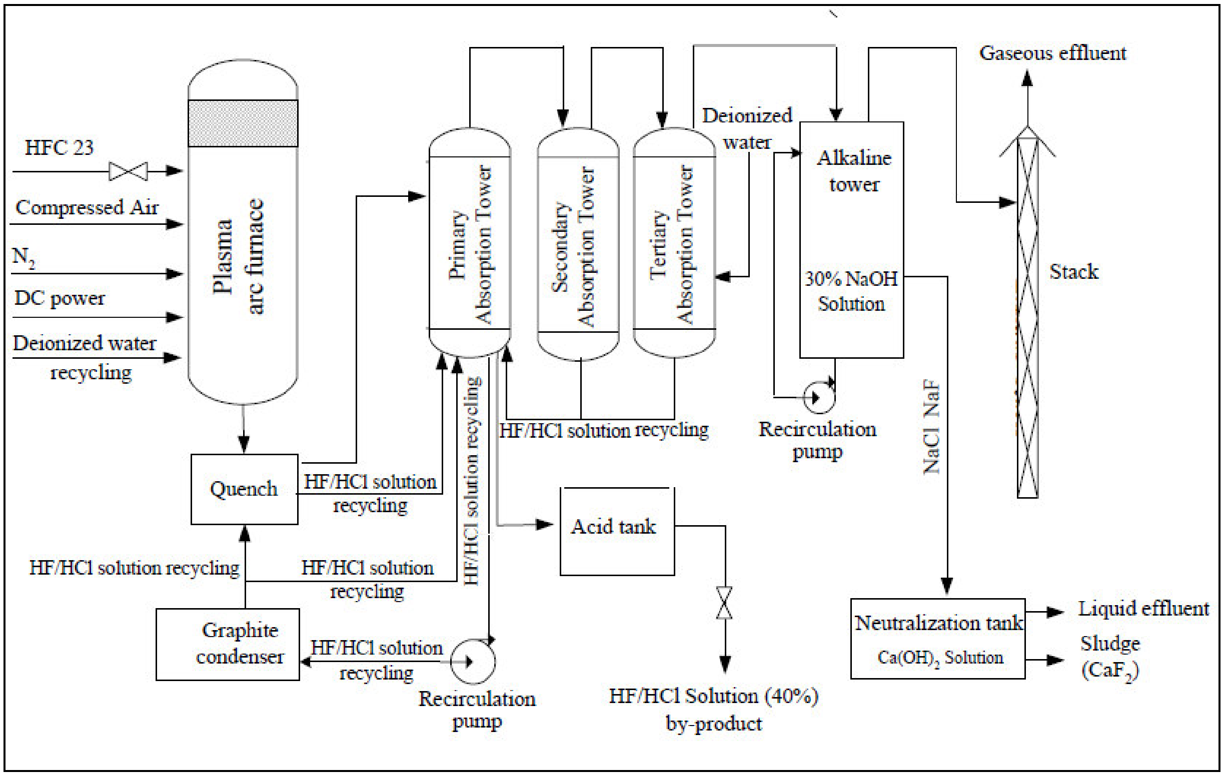
44. CGY's plasma pyrolysis system uses a high-energy, direct-current electric arc generator and nitrogen gas as the plasma carrier. Unwanted wastes are injected with water into the generated plasma, where it is instantaneously ripped apart and transformed at the molecular

[20] US Environmental Protection Agency (EPA). Integrated Risk Information System: Tetrafluoroethane Summary. http://www.epa.gov/iris/subst/0656.htm.

level. The resulting instantaneous chemical reaction neutralizes the negative properties of the wastes through an oxidation reaction, which results in the production of relatively environmentally benign compounds that can be captured and safely recycled or disposed of.

45. The proposed plasma pyrolysis system will incorporate technology enhancements resulting largely from CGY's research and development experience in plasma pyrolysis waste destruction technology. The proposed system will represent a shift from foreign-supported waste destruction technology to the fruits of domestic innovation.

Figure 7: Schematic Diagram of the Proposed HFC-23 Destruction System



Ca(OH)= calcium hydroxide; DC= direct current; HF= hydrogen fluoride; HFC= hydrofluor carbon; N_2= nitrogen gas; NaCl= sodium chloride; NaF= sodium fluoride.
Source: From the project design document of the UNFCCC CDM project HFC23 Decomposition Project at Zhonghao Chenguang Research Institute of Chemical Industry, Zigong, Sichuan Province, China[21]

46. Overall, the design of the proposed 1,500 t/a HFC-23 plasma pyrolysis system is based on a set of basic operating principles that are almost identical to those of the existing 200 t/a system put into service in 2007. However, the proposed system will include the following key design modifications to improve its reliability, increase the HFC-23 destruction rate, and reduce the system's energy consumption:

(i) improved materials and system serviceability;
(ii) reduced production of dioxins through a higher post-incineration quench rate (more rapid cooling) for hot gases;
(iii) 3.6% more efficient use of electricity by the system overall, through improved real-time monitoring and automation of the plasma torch and the operation of the associated plasma pyrolysis post-incineration treatment unit;

[21] Accessed at: https://cdm.unfccc.int/UserManagement/FileStorage/486EI0927S94QCCVOCCZ877VOPE7ZG.

(iv) better flow of waste materials and plasma carrier gas, through improved fluid dynamics of the plasma torch device and the waste injection zone;
(v) improved safety systems of the plasma pyrolysis system, integrating alarms into the centralized distributed control system to reduce safety hazards in operations; and
(vi) more stable HFC-23 destruction rate, increasing the system's destruction rating to 99.99% availability.

47. These design improvements can potentially reduce CGY's carbon emissions by more than 13 million tons of CO_2 equivalent. This subproject is also important from the standpoint of serving as a model for modernizing chemical process facilities by partnering with a third-party energy service company. The plasma pyrolysis destruction technology and energy efficiency measures support CGY's continued efforts to green its processes through technology initiatives developed within the enterprise and through partnerships with PRC technology companies.

48. No regulation in the PRC prevents the venting of HFC-23. In 2013, the PRC produced nearly 550,000 metric tpa of HCFC-22, and 216,700,000 million tons of CO_2 equivalent of HFC-23, of which 77,400,000 million tons of CO_2 equivalent was treated, while the rest—about 140 million tons of CO_2 equivalent —was vented. Other HCFC-22 producers in the PRC that destroy their HFC-23 by-product use imported conventional incineration technology. The plasma incineration method used by CGY was designed by CGY and is the best available technology for treating HFC-23 effectively, with a destruction efficiency of up to 99.99%. The technology has five key advantages over conventional incineration methods: (i) relatively lower investment cost; (ii) low operating expenses, due to the thermal efficiency of the plasma torch and low maintenance requirements; (iii) no dioxin formation during the incineration process; (iv) use of high-purity nitrogen instead of argon gas, thus significantly reducing operating expenses; and (v) high reliability and flexibility in operation. This clean, low-cost option has significant demonstration potential and can be adopted by other organofluorine industries even without government regulations.

49. **Energy efficiency measures.** This subproject includes the implementation of a range of equipment retrofits and intelligent process management systems that will help CGY achieve its facility modernization objectives. The energy efficiency measures that CGY proposes to implement in this subproject consist of process optimization, automation, and supervisory control; equipment modernization (retrofits); and waste heat recovery measures.

(i) The **process optimization, automation, and supervisory control strategy** involves (a) replacing vapor heat-circulation dryers with state-of-the-art far-infrared tunnel and twin-screw extruder dryers for CGY's PTFE and fluororubber production, respectively; (b) establishing a digital energy management and control center to improve overall process monitoring and real-time optimization; and (c) installing 150 real-time electricity meters for major equipment, and ultrasonic flow meters for chilled brine and steam, industrial and fresh water supply, and natural gas supply, for real-time leak detection.
(ii) The **equipment modernization strategy** comprises (a) retrofitting the brine distribution system pump and electromechanical equipment; and (b) upgrading the industrial water system and the natural gas boiler.
(iii) As part of the **waste heat recovery strategy**, CGY proposes to recover and reuse (a) low-pressure steam from the fluorine and PTFE production chains; and (b) heat from the boiler stack.

50. **Real-time energy management.** The process automation measure is key not only to improving the energy and resource efficiency of current plant operations, but also to identifying, developing, and planning future projects. Rather than relying on the hundreds of distributed automation and control systems in the existing plant, the proposed process automation technology will use a centralized system for the recording and visualization of operational data in real time. Data for interdependent plant subprocesses can be centrally collated and analyzed for improved production flow, resulting in reduced material and energy consumption. Information from the centralized plant automation systems can be leveraged to improve planning not only for technical modifications but also for wider enterprise resource planning by streamlining maintenance, financial control, human resource management, and supply logistics.

51. **Introduction of innovative fluoropolymer drying technologies.** Improving final product drying and post treatment according to best available technology standards is a major feature of the subproject. The 53 sets of vapor-heat circulation ovens for the post-treatment of CGY's 7,500 tpa PTFE production will be replaced with two sets of continuous-feed far-infrared tunnel drying ovens. Infrared heat is efficient in heating applications, because the heat is transmitted directly to the object; the PTFE, in this case, absorbs far infrared, which increases the products' temperature and induces dehydration. Tunnel dryers have been shown to improve system energy efficiency, because the resulting hot air is driven through the tunnel before extraction and thus does not mix with the cooler ambient air outside the tunnel. This process optimization measure has the advantages of (i) reducing net energy consumption; (ii) significantly accelerating the drying process (the tunnel dryers reduce drying time per tonne from 24 hours to 30 minutes); (iii) improving product quality by automating the drying process; (iv) reducing the potential exposure of plant staff to toxic materials and gases; and (v) decreasing the land footprint of the product line. The estimated annual energy savings from this measure are estimated at 4,691 tce for the PTFE production chain.

52. In addition, CGY proposes to replace 12 sets of vacuum ovens using steam as heat source to dry the 1,500 tpa of fluororubber with one state-of-the-art twin-screw extrusion drying oven. Instead of being placed in the vacuum dryer, the fluororubber will be fed continuously into the extruder. Squeezing the fluororubber through the twin-screw extruder snail will reduce 95% of humidity; the remaining 5% will evaporate as the product is heated during the extrusion process. The thermal energy generated in the process will be recovered and used for preheating the fluororubber to further enhance the efficiency of the drying process and allow for near-zero energy loss. This process optimization measure offers several advantages. It will (i) reduce net energy consumption; (ii) significantly accelerate the drying process (the extruder can dry the same quantity in one-fourth of the time required by the existing technology); (iii) improve product quality by automating the drying process; and (iv) decrease the land footprint of the product line. The estimated annual energy savings from this measure are estimated at 1,040 tce for the fluororubber production chain.

53. **Compliance of measures with the priority measures of the Government.** Comprehensive energy system optimization through automation and control, retrofitting, and waste heat recovery measures is among the 10 key energy efficiency projects in the government's program for the 12th Five-Year Plan period. The measures to be undertaken by the CGY management to reduce the plant's energy consumption will realize savings as follows:

(i) The installation of the energy management system combined with the intelligent metering and control system is an essential part for the modernization of the industry. The system will be integrated into CGY's enterprise resources and planning system and is expected to generate overall optimized energy resources and utilities savings equivalent to 3,046 tce/year.

(ii) The retrofitting of inefficient equipment together with waste heat recovery will result in energy conservation equivalent to 694 tce.

54. **Expected energy savings from the subproject.** According to CGY statistics, CGY's total energy and utility consumption averaged 73,864 tce per year from 2012 to 2014 (Table 3). Annual energy savings equivalent to 15% of this average are foreseen to result from the energy efficiency measures under this subproject. The annual net energy savings from this subproject are estimated at 8,905 tce; 10,888 tce per year will be saved as a result of the energy efficiency measures; and the plasma incineration of HFC-23 is expected to consume an additional 1,983 tce (Table 4).

Table 3: Energy Consumption Baseline of Zhonghao Chenguang Research Institute of Chemical Industry

Item	Quantity	Unit	Conversion (tce per unit of utility)	Energy (tce)
Industrial water	15,000,000	tons	0.0003	3,855
Natural gas	33,170,000	Nm^3	0.0012	40,278
Power	231,650,000	kWh	0.0001	28,470
Diesel	157	tons	1.4044	221
Coal	1,040	tons	1	1,040
Total				**73,864**

kWh = kilowatt hour, Nm^3 = normal cubic meters, tce = tons of coal equivalent.
Source: Zhonghao Chenguang Research Institute of Chemical Industry. 2015. *Feasibility Study Report.* Zigong.

Table 4: Energy Efficiency and Emission Reduction Estimates for the Energy Efficiency Optimization and Emission Reduction Subproject

Subproject Component	Total Investment Cost ($ million)	Net Energy Savings (tce/yr)	Emission Reduction	
			Carbon Dioxide (t/yr)	Organic Fluorine (t/yr)
Plasma gasification of HFC-23 gas	5.72	(1,983)	13,173,066	1,205
Process optimization through installation of BAT for final product drying	16.81	5,731	288,850	
Automation, installation of digital energy management control system and meters	10.94	3,046		
Retrofitting and waste heat recovery measures	6.02	2111		
Total	**39.35**	**8,905**		

() = negative, BAT = best available technology, HFC-23 = fluoroform, t/yr = tons per year, tce/yr = tons of coal equivalent per year.
Sources: Feasibility study report and Asian Development Bank estimates.

Table 4: Summary of Energy Savings in Subproject 2

Project Category	Power (tce)	Natural Gas (tce)	Brine (tce)	Steam (tce)	Nitrogen (tce)	Industrial Water (tce)	Deionized Water (tce)	Fresh Water (tce)	Compressed Air (tce)	Energy (tce)
Plasma pyrolysis	(504)		(290)		(953)		(18)	(1)	(216)	(1,983)
FKM drying	(35)			1,077		(2)				1,040
PTFE resin drying	289			4,371		32				4,691
Waste heat utilization				1,418						1,418
VFD cracking furnace		7								7
PTFE cracking furnace		158								158
Automation		1,198	1,438		196	115	2	39	12	3,046
Electrical equipment upgrades	528									528
Total Energy Efficiency	**781**	**1,363**	**1,438**	**6,865**	**196**	**145**	**2**	**39**	**12**	**10,888**
Overall Totals	**277**	**1,363**	**1,148**	**6,865**	**(757)**	**145**	**(17)**	**38**	**(204)**	**8,905**

() = negative, FKM = fluoroelastomer, PTFE = polytetrafluoroethylene, VFD = vinylidene fluoride or fluororubber.
Sources: Project preparatory technical assistance feasibility study report and Asian Development Bank estimates.

55. **Risk assessment.** The overall risk of the proposed subproject, considering its technical, implementation, and operational dimensions is low. Huatai is expected to manage successfully the design and implementation of the proposed components, and available contractors within the region should complete construction competently and without difficulty.

56. The proposed plasma pyrolysis system is an evolution and improvement of technology that is now in use at the CGY facility. The new system is not expected to introduce hazards that are significantly different from those associated with current operations. Current plant operators should be sufficiently skilled and should need only minimum additional training.

57. The remaining energy efficiency upgrades are also considered low risk because of their conventional nature. The proposed equipment retrofits, heat recovery measures, and central automation upgrades will not introduce extraordinary technical risks and should be implemented without difficulty by available contractors. From an operational perspective, additional training will be required to familiarize operational personnel with the oven technologies and centralized plant automation to be introduced. The PRC process industry is already familiar with these technologies. Existing plant operational personnel should be able to acquire the skills needed to operate the new equipment with ease.