DEMONSTRATION PROJECT FOR CONVERSION FROM HCFC-22/HCFC-142b TECHNOLOGY TO CO2 WITH METHYL FORMATE CO-BLOWING TECHNOLOGY IN THE MANUFACTURE OF XPS FOAM AT FEININGER (NANJING) ENERGY SAVING TECHNOLOGY CO. LTD.

FINAL REPORT

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Submitted by:

Foreign Economic Cooperation Office, Ministry of Environmental Protection, China (FECO/MEP)

and

United Nations Development Programme (UNDP)

Executive Summary

Demonstration project for conversion from HCFC-22/HCFC-142b technology to CO2 with methyl formate co-blowing technology in the manufacture of XPS foam at Feininger (Nanjing) Energy Saving Technology Co. Ltd. was approved by the 64th Executive Committee meeting at a funding level of US$ 1,973,300.

This demonstration project was successfully implemented, and established the suitability of methyl formate co-blowing technology as a viable replacement of the currently used HCFC-22 / HCFC-142b in the manufacture of XPS foam at Feininger (Nanjing) Energy Saving Technology Co. Ltd.

The project activities includes product redesign and development, equipment installation and modifications safety, laboratory testing and performance evaluation, product trials, production line conversion, technical assistance and training.

The successful completion of the demonstration project showed that the methyl formate co-blown with CO2 exhibited the industrial feasibility in the production of XPS foam board. XPS foam board produced by this conversion technique can be used for frost insulation of roads, railways, trafficked areas, light weight fill for reduction of horizontal and vertical earth pressure and other civil engineering applications etc.

1. Introduction

The Demonstration Proposal prepared and submitted to the 62nd ExCom meeting. And the Executive Committee approved the XPS Demonstration project in 64th meeting in July 2011 at a funding level of US $ 1,973,300. The project's implementing agency is UNDP. The national agency implementing this project is Foreign Economic Cooperation Office (FECO), Ministry Of Environmental Protection, China.

The objective of this demonstration project is to establish the suitability of CO2 with methyl formate co- blowing technology as a viable replacement of the currently used HCFC-22/HCFC-142b blowing agent in the manufacture of XPS foam at Feininger (Nanjing) Energy Saving Technology Co. Ltd.

The successful implementation of this demonstration project will provide an environment friendly and cost-effective alternative for enabling replication of this technology in similar applications and enterprises in the XPS Foam Sector, and result in reductions in HCFC consumption of 12.3 ODP tones, contributing to compliance with the 2013/2015 control targets in China. It will also lead to net annual emission reductions of 420,250 tonnes CO2-eq.

1.1 Background

The XPS Foam Sector in China has experienced remarkable growth in the past several years. Due to the steep growth in the construction industry, demand for XPS foam boards for building thermal insulation has increased significantly, ascribed also to enhanced energy-efficiency standards for buildings. The 2009 estimated HCFC consumption in the sector was about 41,000 metric tonnes. Based on information from surveys, there are about 20 indigenous manufacturers of XPS extrusion lines and an estimated 500 manufacturers of XPS foam in the sector.

Another defining characteristic of this sector is that most of the polystyrene raw material used in XPS foam manufacturing originates from recycled polystyrene scrap with aim to reduce the production cost. Recent zero-ODP XPS foam technologies introduced by multinational corporations are expensive and have been closely guarded in terms of intellectual property， for example complex cell technology used isobutene as blowing agent by Kaneka Corporation and pure CO2 foaming technology by Dow Corporation. Due to this, these technologies are not cost-effectively accessible for most of XPS foam enterprises of China and may not be compatible to operate with a high proportion of recycled polystyrene scrap. There is, thus, a clear and present need for a cost-effective and environmentally safe technology alternative for the XPS foam sector of China, in order to remain sustainable and maintain product quality.

Feininger (Nanjing) Energy Saving Technology Co. Ltd. was established in 2002 and it is one of the major manufacturers of Extruded Polystyrene (XPS) foam and XPS foam machines in China. The enterprise also manufacturers XPS foam boards with thickness from 20 mm to 100 mm. Other products include Extruded Polyethylene (XPE) foam boards and sheets, XPS foam pipe sections and PVC pipes. Feininger currently employs 143 persons, of which about 50 are technical.

Feininger has been recognized as one of the leading companies in the XPS industry in China with excellent management and high quality products. The enterprise has 26 patents, covering almost all the core technologies in XPS manufacturing. Feininger has been identified as a national high technology enterprise. It has obtained the Class-A Tax Credit Certification Award promulgated by the Internal Revenue Service and the Local Taxation Bureau of Nanjing, Jiangsu. It has also obtained ISO 9000, ISO14001 and CE certifications.

The enterprise currently operates two XPS foam manufacturing lines, both built in-house. The main technical parameters of the baseline equipment in these two manufacturing lines are tabulated below:

Parameter	Unit	Line 1/ SE 150/200*	Line 2/TE 75/200
Type	N/A	Single/Single Tandem	Twin/Single Tandem
Capacity	kg/hr	480-720	480-720
	m3/day	300-450	300-450
Diameter of primary extruder	Mm	SE 150	TE 75
Diameter of secondary extruder	Mm	SE 200	SE 200
Power of primary extruder	kW	110	110
Power of secondary extruder	kW	75	75
Connected load	kVA	250	250
Electrical supply	Volts	380V/3 Ph/50 Hz	
XPS board thickness	Mm	20-100	
XPS board width	Mm	600, 900, 1200	
Blowing agents	N/A	HCFC-142b/22 (50:50)	HCFC-142b/22,142b
HCFC consumption**	Metric tonnes	205	290

*Line 1/ SE 150/200 have been converted to non-HCFC technology in this demonstration project.
** 2010

The manufacturing line 1/SE 150/200 is a primary single-screw extruder/single-screw tandem extrusion system and line 2/TE 75/200 is a twin-screw extruder/single-screw tandem extrusion system. Compared with the primary single-screw (line 1), the primary twin-screw (line 2) has some advantages, such as steadier feeding, better dispersive and distributive mixing and better temperature control capability. These characteristics result in XPS foam with lower density and better insulation value. In the past three years, due to demand for improved product standards, the line 2/TE75/200 twin-screw system has been used for a larger share of the production. The existing extrusion line 1/SE 150/200 comprises of the following main equipment:

- Primary extruder 150 mm (36:1)
- Secondary extruder 200 mm (34:1)
- Pre-blending system for additives
- Two single stage blowing agent pumps delivering to the primary extruder
- Static mixer at the discharge of the secondary extruder
- Extrusion die and shaper
- Interconnecting piping and fitting
- Controls and indications

Feininger has rich experience in manufacturing a wide range of XPS foam-related products including the full range of XPS processing equipment. The enterprise has been engaged in research and development in XPS foams, XPS manufacturing machinery and auxiliary equipment such as XPS recycling machines, for several years. The enterprise also has technically competent staff and good management and is financially sound. It has a good market recognition and reputation. Any technology successfully adopted at Feininger provides a good opportunity for wider and more effective dissemination and adoption by the downstream users of XPS machinery and equipment provided by Feininger.

Based on these considerations, Feininger was considered to be the most suitable and appropriate for carrying out this demonstration project.

1.2 Technical Choice

The main zero-ODP alternatives to HCFCs for the XPS foam sector include HFCs, CO_2 and Hydrocarbons. However, these technologies require a high level of process optimization and changes, significant investments up to several million dollars, and are closely guarded in terms of intellectual property rights by a very few large multinational corporations and can be potentially used by only very large enterprises under license or as subsidiaries of these corporations. The introduction of these alternative technologies is therefore a difficult challenge for the Chinese XPS foam industry. The challenge is to develop an alternative technology that can be environmental-friendly, easy and stably used by the large number of XPS foam enterprises in China, particularly because high levels of polystyrene scrap is used as raw material. This is critical because the sector is experiencing a high growth due to rapidly increasing demand in building and other infrastructural construction uses in China.

The selected technology for demonstration is CO_2 and methyl formate co-blowing technology for the following reasons:

- CO_2 has zero ODP and GWP of 1, with a low cost and wide availability in China. It is also non-flammable and stable. It is thus favorable in terms of environment, health and safety. However CO_2 has a small molecule and tends to diffuse through the polymer structure quite easily. The insulation performance with CO_2 alone is therefore not favorable. CO_2 also requires high-pressure operation. Thus, CO_2 alone is not suitable and requires a co-blowing agent.

- Methyl formate is an industrial chemical which is widely and cost-effectively available. The thermal conductivity of methyl formate is low (10.7 m-W/m-K), which is quite close to that of HCFC-142b and HCFC-22 (10 m-W/(m-K and 11 m-W/m-K) respectively and much better as compared with other co-blowing agents such as ethanol (17.1 m-W/m-K) and HFC-152a (13.6 m-W/m-K). The co- blowing of methyl formate with CO2 is thus expected to lead to a lower thermal conductivity of XPS foam as compared with CO2 alone or co-blown with ethanol or HFC-152a. Additionally, the combination will have very low GWP.

Methyl formate has a boiling point of 32℃ giving rise to some concerns on dimensional stability of XPS foam boards at room temperature. In order to customize and improve the physical, mechanical, thermal and flammable properties of the XPS foams to bring them on par with the current HCFC technology, a third co-blowing agent will need to be introduced，for example HFC-152a. The boiling point of HFC-152a is -24.7℃，which is favorable to the dimensional stability and the thermal resistance of the XPS board.

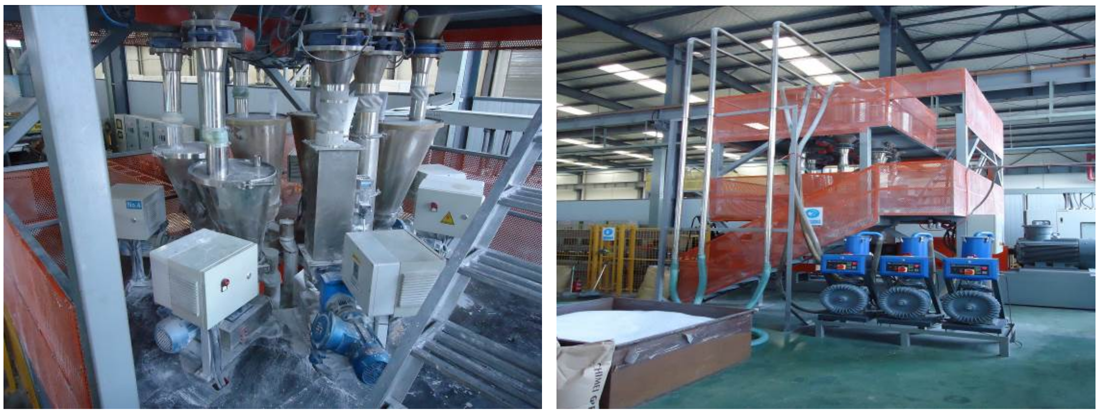
2. Project Implementation

The project was approved by 64th Executive Committee meeting in 2011 at a funding of US$ 1,973,300. The project implementation started at 2012, the conversion project was completed in June 2014.

According to the project implementation plan, the following activities were carried out: the retrofitting plan evaluation, procurement, equipment installation and commissioning, pilot running, properties testing, industrial feasibility assessment etc.

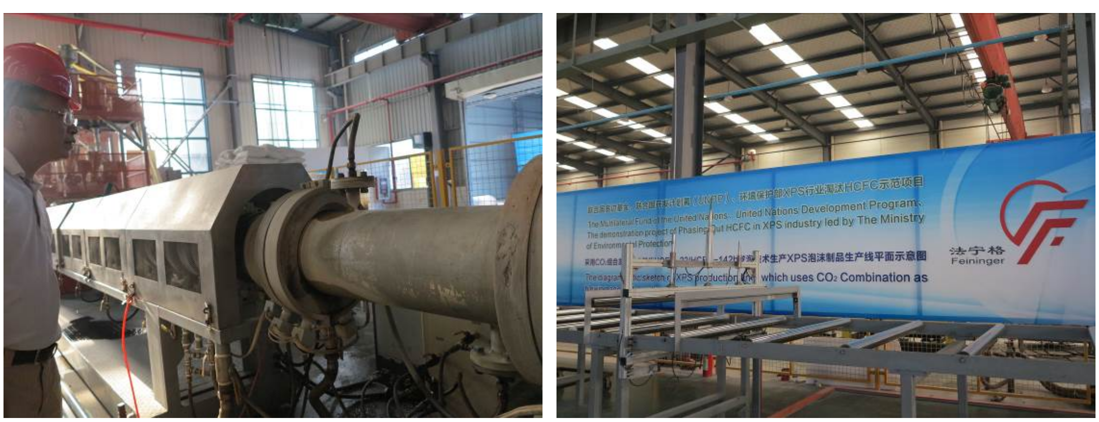
2.1 Extrusion foaming line retrofitting

Based on the implementation plan, Feininger updated its original production line to new twin screw extruder tandem single screw extruder line. The high accurate material gavimetric feeder and blowing agent injection and metering system, the high automated downstream parts were equipped with the new line.



Feeder and gravimetric dosing system for PS resin

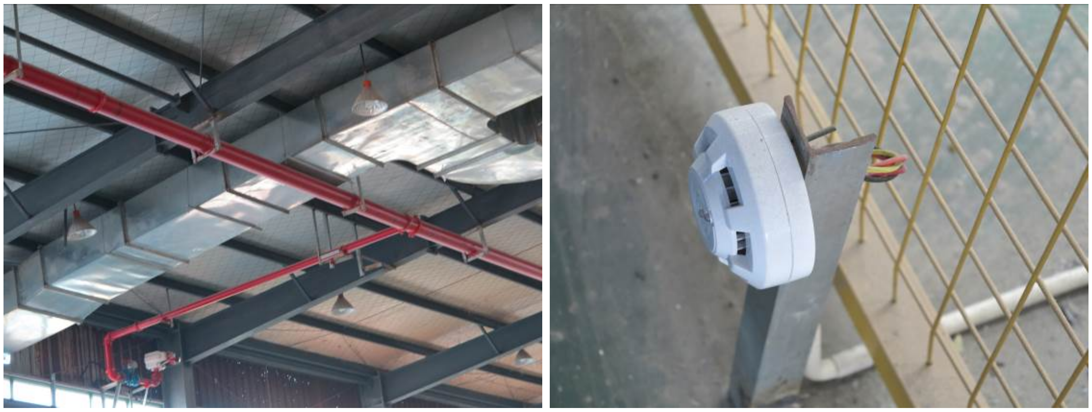
Blowing agent tank and diaphragm pump metering system



Extrusion foaming extruder and the downstream parts

2.2 Ventilation and fire safety systems retrofitting

The ventilation and fire safety systems of the production workshop were retrofitted and also came into use. An external safety audit was carried out to ensure that the safety systems were consistent with local regulations.

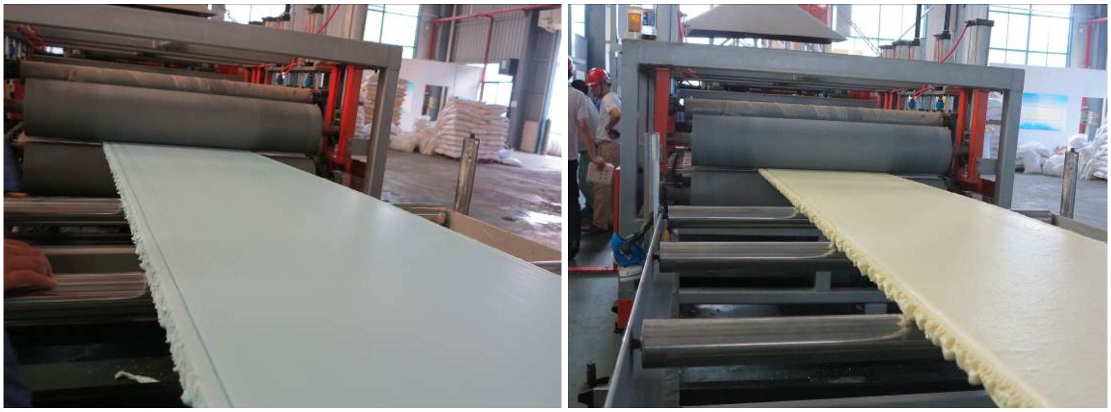


Forced ventilation system and highly sensitive flammable gas sensor

Fire equipment and anti-explosive control cabinet

2.3 Commissioning/Trial-production

Co-blowing system comprising of CO2/Methyl formate, CO2/Methyl formate/Ethanol were choose as the substitutes for the HCFC-22/HCFC-142b. The effect of those new blowing systems on the processing process and the properties of the XPS foam board were evaluated. By use of CO2/Methyl fomate blowing system, the XPS foam board was manufactured in the new line to verify the industrial feasibility. Some special formula was introduced to assess the stability and reliability of the production in the commissioning process.

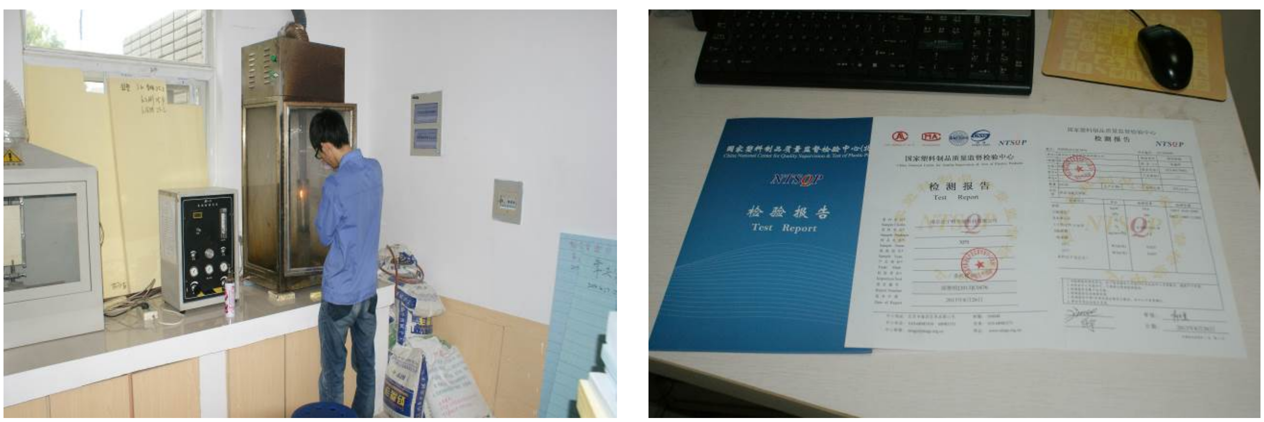


Commissioning/Trial-production by use of the CO_2/Methyl formate co-blowing agent

2.4 XPS board properties testing

The XPS foam board from the new line was delivered to specialized laboratory to test properties. The thermal resistance of the board was compared in the below table.

Testing Item	Standard	Unit	50/50 CO_2/EtOH	50/50 CO_2/Methyl Formate	50/20/30 CO_2/EtOH/Methyl formate
Thermal conductivity	GB/T 10294-2008	W/m.K	0.0345	0.0342	0.0336



XPS board properties testing and the relevant test report

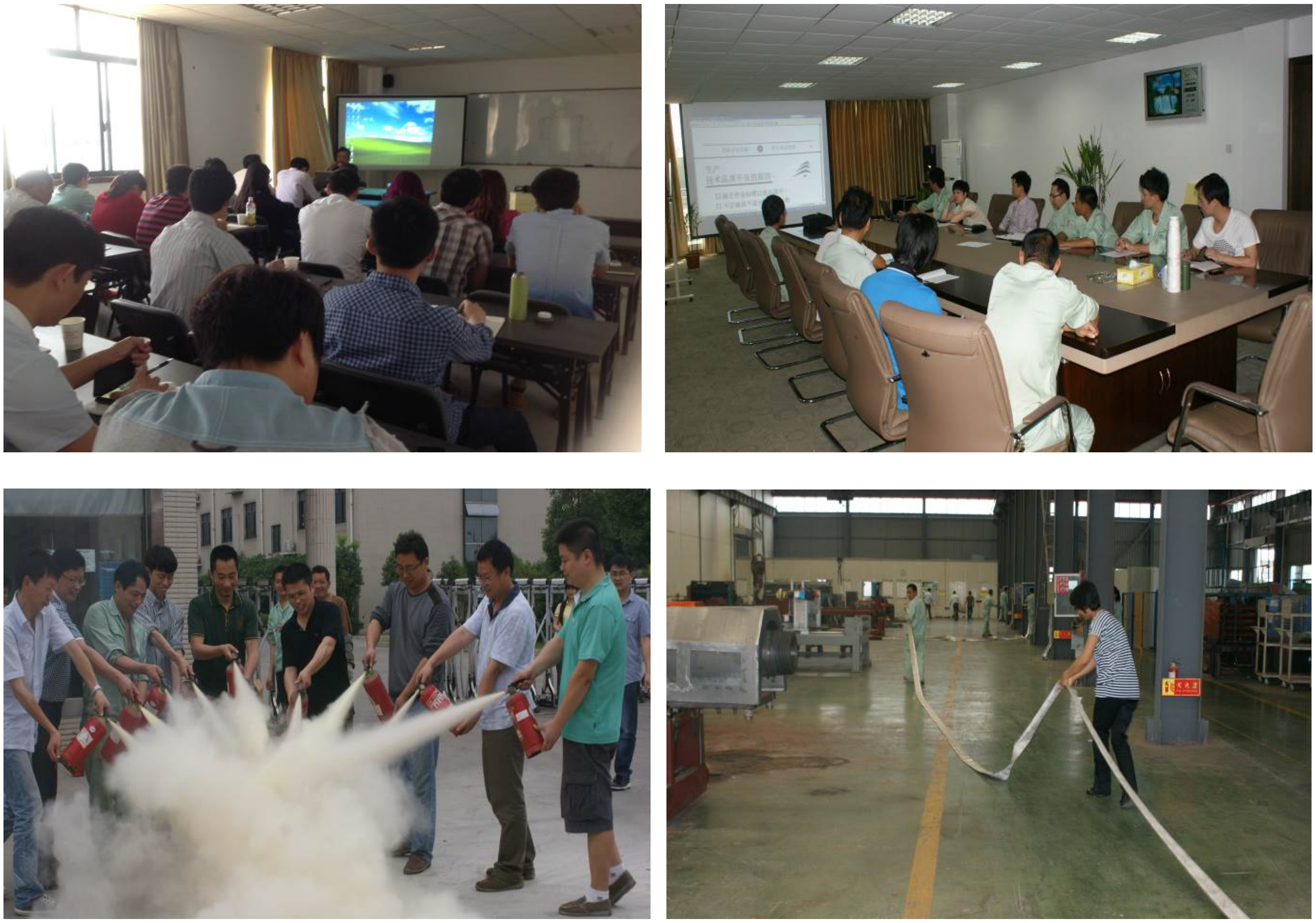
2.5 Process and safety training

Process and safety training were provided to the manufacturing, installation and maintenance personnel from August 2013 to December 2013.

To ensure the production safety, Feininger retrofitted the ventilation and fire safety systems of the workshop, which comprised the forced ventilation system, the static protection system, the highly sensitive detection, alarm and control system for flammable and explosive gas, the emergency power supply system etc.

Feininger invited a lot of polymeric foam processing experts to conduct training. Feininger had carried out almost 60 person/time of technical training on the research staff, the technical and safety training for equipment operators. Feininger compiled a safety production booklet for using methyl formate and ethanol in the production of XPS foam board and would like to share with other enterprises.

Process and safety training were provided to the manufacturing, installation and maintenance personnel. It was verified that the internal technical acceptance were completed and technical commissioning and relevant personnel training were finished.



XPS board Processing training and fire safety training

2.6 Management

The project was under the overall management and coordination of the Foreign Economic Cooperation Office, Ministry of Environmental Protection of China. UNDP was the implementing agency for the project, which provided international coordination and technical assistance.

The project employs the Performance-based Payment (PBP) mechanism in its implementation. Under the PBP mechanism, the enterprise tasked to carry out the conversion would play the role as a key executer, which is responsible for all the activities related to the conversion. The procurement was organized fully in line with the marketing principle to ensure cost-effective and timely installation of equipment for CO_2 based manufacturing operations.

FECO and UNDP were not involved in the procurement activities of the enterprise by any means other than make payment to the enterprise in tranches for the costs of procurement and conversion, at agreed payment dates given in the payment schedule, and when milestones prerequisite for the tranche have all been achieved on time.

Before each payment, FECO invited independent experts to verify whether the performance for each milestone that the payment depends on have been satisfying. The verification reports were submitted and accepted by UNDP as the main supporting documents for requesting the installment of payment.

During project implementation, FECO and UNDP organized 5 verification missions combined with monitoring and evaluation at Feininger (Nanjing) factory - once in 2011, once in 2012, 2 times in 2013and once in 2014. The experts group included technology experts and finance experts, FECO staff and UNDP staff as well. The experts team traced the project implementation situations, evaluated the project technical issues and progress, and verified whether the performance for each milestone that the payment depends on have been satisfied. Each verification activity was carried out in a process of planning, preparation, data confirmation, technical material checking, on-the-spot investigation, result confirmation and conclusion.

3. Outcomes

The project was implementing smoothly according to the program schedule, and was completed in June 2014. The national acceptance will be completed by the end of 2014. The production line is running commercially, and IOC will be disbursed to enterprise in 2015. The industrial application feasibility of methyl formate together with CO2 and ethanol in the production of XPS foam board has been well verified.

The following are the salient outcomes of the project.

- The enterprise completed the redesign of extruder production line, foaming agent injection control system and fire safety system in 2012.
- Equipment for extruder production line was procured in 2012.
- The fire safety system and explosion-proof retrofit were completed in 2013.
- Technical commissioning was completed successfully and relevant personnel were trained in 2013.
- The project Completion verification has been carried out in June 2014.

4. Technical performance

Technical performance of the XPS foam manufactured after implementation of conversion technology is given below.

- CO_2 has zero ODP and GWP of 1, with a low cost and wide availability in China.
- CO_2 is non- flammable and stable. It is thus favorable in terms of environment, health and safety.
- Methyl formate is an industrial chemical which is widely and cost-effectively available.
- The thermal conductivity of methyl formate is low, which is quite close to that of HCFC-142b and HCFC-22 respectively.
- The co-blowing of methyl formate with CO2 was thus expected to lead to a lower thermal conductivity of XPS board as compared with CO2 alone or co-blown with ethanol if the processing process could not be severely influenced.
- Methyl formate could be used as the co-blowing agent of CO2 basically. Using methyl formate as the co-blowing agent of CO2 had no significant influences on the processing process of XPS board.

5. Project management and monitoring

5.1 Project progress

The project was implementing smoothly according to the program schedule, and was completed in June 2014. The national acceptance will be completed by the end of 2014. The capacity of the production line has been converted to use substitute Foaming agent.

Each of milestones was achieved and verified, the details are as follows:

Milestones		Status
1st	Project Contract to be signed with enterprise	FECO and the enterprise signed contract in March 2012
2nd	Feininger (Nanjing) sign the procurement contracts with conversion equipment suppliers	Finished in October 2012
3rd	Conversion equipment was installed in KDL	Finished and verified in January 2013
4th	The trial run of conversion equipment was verified by expert team	Finished and verified in December 2013
5th	The enterprise submitted the completion report	Finished in May 2012
6th	Completion verification was organized by FECO and UNDP	Finished in June 2012

5.2 Conversion cost

Total Project Costs:
The total contract amount with the enterprise is US$1,844,635, including ICC US$1,557,635, and IOC US$287,000.

Incremental Capital Costs:
The actual incremental capital costs for conversion was US$1,743,186, among which US$ 1,557,635 was funded by MLF, and US$185,551 was co-financed by the enterprise. The details of ICC are as follows:

No.	Item/Description	Grant funds (US$)	Counterpart funds(US$)	Actual cost (US$)
1. Extruder Retrofitting				
1.1	Extruder Retrofitting	565,000	99,516	664,516
1.2	Extrusion die (include die heating control system)	15,000	15,484	30,484
1.3	Static mixer	25,000	-2,419	22,581
1.4	Foaming agent injection control system and Explosion-proof retrofit	142,000	-37,161	104,839
Subtotal		**747,000**	**75,420**	**822,420**
2. Blowing agent supply system				
2.1	Storage tank with accessories for CO_2, methyl formate, third blowing agent, CO_2 metering system and Blowing agent piping (high and low pressure)	130,000	-9,516	120,484
2.3	Methyl formate and the third blowing component injection and metering system	160,000	17,186	177,186
Subtotal		**290,000**	**7,670**	**297,670**
3. Ventilation and fire safety system				
3.1	Fire safety system design	10,000	-4,355	5,645
3.2	Transformation of ventilation system and Fire safety system	326,000	55,452	381,452
Subtotal		**336,000**	**51,097**	**387,097**
4. Other				
4.1	Technology transfer from external process expert	25,000	15,323	40,323
4.2	Process trials and safety training	75,000	103,728	178,728
4.3	Product evaluation and certification	10,000	2,271	12,271
4.4	External safety audit	5,000	-323	4,677
Subtotal		**115,000**	**120,999**	**235,999**
5.Contingency		**69,635**	**-69,635**	
Total		**1,557,635**	**185,551**	**1,743,186**

Incremental Operating Costs:
The agreed total incremental operating costs calculated one-year duration amount to US$287,000. The production line is running commercially, and the IOC will be disbursed to enterprise in 2015. The data of IOC is preliminary value.

The cost for the baseline HCFCs based two-stage systems are summarized as below:

- In the HCFCs technology:

1. HCFC-22 /142b price is US$ 1.9 /kg
2. Raw material (reclaimed materials) price is US$ 1.45 /kg

- In the CO_2 technology:

1. CO_2 price is US$ 0.11/kg
2. Methyl formate price is US$ 2.25 /kg
3. Raw material (new PS resin materials) price is US$ 1.8 /kg

Incremental Operating Cost Source	**HCFCs technology**		**CO_2 technology**	
	consumption in one year(kg)	**Cost(US$)**	**consumption in one year(kg)**	**Cost(US$)**
HCFC-22 /142b	200,000	380,000	-	
CO_2	-		120,000	13,200
Methyl formate	-		80,000	180,000
Raw material	2,000,000	2,900,000	2,000,000	3,600,000
Total		**3,280,000**		**3,793,200**

Based on the above table, the actual incremental operating cost on a yearly basis is estimated to US$513,200.

6. Impact

6.1 Environmental Impact

The HCFC consumption in 2010 at Feininger (Nanjing) Energy Saving Technology Co. Ltd. was 495 metric tonnes. The successful implementation of this demonstration project on one manufacturing line has resulted in a reduction of HCFC consumption by 205 metric tonnes.

The ODP, GWP and MW data of HCFC-142b/-22, CO2 and Methyl Formate are tabulated below.

Substance	**ODP**	**GWP**	**Molecular weight**
HCFC-142b/22 (50:50)	0.06	2050	93
CO_2	0	1	44
Methyl formate	0	0	60

The successful implementation of this demonstration project on one manufacturing line has resulted in a reduction of HCFC consumption by 205 metric tonnes. Taking into account both ODP and GWP values of HCFCs, the successful implementation of this project will result in an annual reduction of a minimum of 12.3 ODP tonnes and annual emission reductions of 420,250 tonnes CO2-eq.

6.2 Results

The successful implementation of this project will result in the following:

(a) Sustainable reductions in HCFC consumption in the XPS sector in China of 12.3 ODP tonnes, contributing to China's compliance with the 2013 and 2015 control targets.

(b) Demonstration and availability of an environmentally safe and cost-effective alternative for enabling replication of this technology in similar applications and enterprises in the XPS Foam Sector in China.

(c) XPS foam board produced by this conversion technique can be used for frost insulation of roads, railways, trafficked areas, light weight fill for reduction of horizontal and vertical earth pressure and other civil engineering applications etc.