Motor System Optimization in China: A Capacity-Building Model for Industrial Energy Efficiency

Aimee McKane, Lawrence Berkeley National Laboratory
Robert Williams, United Nations Industrial Development Organization
Vestal Tutterow, Lawrence Berkeley National Laboratory
Steven Nadel, American Council for an Energy-Efficient Economy
Zou Guijin, China Energy Conservation Investment Corporation

ABSTRACT

Industrial electric motor systems consume more than 600 billion kWh annually, accounting for more than 50% of China's electricity use. If optimized, the efficiency of most industrial motors systems in China could be improved by 20% or more. In response to this opportunity, China established the *China Motor Systems Energy Conservation Program* in late 2001 in cooperation with the United Nations Industrial Development Organization, the US Department of Energy, and the Energy Foundation. A previous paper presented the overall structure and objectives of the program. This paper provides a detailed look at program implementation at the mid-point of this 3-year pilot project. The focus is on the results of an intensive effort by an international team of experts to train 22 Chinese engineers in two provinces (Shanghai and Jiangsu) on system optimization techniques through classroom instruction and hands-on training on measurement and assessment techniques in Chinese factories. This in-country training included pump, fan, motor/drive, and compressed air system optimization techniques. As of this writing, two system optimizations projects have already been completed by the Chinese engineers since training commenced in April 2002.The results of an independent interim program evaluation are also presented, along with lessons learned in the process of completing the "train-the-trainer" portion of the pilot program. Details are provided on the strengths and weaknesses of the training model in preparing Chinese engineers for conducting plant assessments, developing projects, and training factory personnel. Plans for the next phase of the project beyond the 3-year pilot are also presented. Finally, practical implications for refining and applying the program model to other countries in Asia, South America, and elsewhere are discussed.

Introduction

The China Motor System Energy Conservation Program is a pilot program whose purpose is to demonstrate motor system optimization opportunities and benefits for Chinese industry. This Program is a direct outgrowth of activities begun in 1995 by the China State Development and Planning Commission (SDPC) and the United States Department of Energy (USDOE) as part of a China-US bilateral cooperation agreement. The Energy Conservation Law, put into place by the Chinese government in 1999, includes optimization of motor systems as a specific policy objective. The Chinese government has demonstrated a strong interest in improving industrial motor systems through its financial and in-kind support of workshops, industrial site visits, and other activities already completed under this agreement. Motor system optimization offers great potential for near term benefits to

Chinese industrial enterprises such as reduced operating costs and increased system reliability. These benefits are extremely important to industries trying to manage a difficult transition to open competition through China's participation in the World Trade Organization.

Industrial electric motor systems consume more than 600 billion kWh annually, accounting for more than 50% of China's electricity use (Hinge, et al 1996) Improved equipment design, more optimized system integration, and improved operations and maintenance practices can reduce motor system energy use by 20% or more, providing substantial energy and emissions savings (e.g., CO_2 and SO_x) while reducing factory operating costs and contributing to the economic viability of the factory. Assuming achievable savings of 5-10% of current motor system energy use would result in an electricity savings in China of 35 to 70 billion kWh by 2010, or 14 to 28 MMT of annual carbon reduction (51-102 MMT of annual CO2 reduction).

Program Overview

The China Motor System Energy Conservation Program seeks to: 1) develop and test the effectiveness of a variety of education materials, analysis tools and standards for promoting motor system optimization in China and 2) develop a local delivery infrastructure in two provinces (Shanghai and Jiangsu) to create awareness, conduct plant assessments, and develop projects that improve the efficiency of industrial motor driven systems. The lessons learned from the pilot program will inform the development of Phase II of this effort, currently under development, and ultimately, a national program. Within approximately ten years, the Chinese government plans to establish and train a network of motor system optimization experts throughout China, and to use these experts to assist individual factories to implement motor system improvement projects.

Primary funding for the pilot program is being provided by the United National Foundation (UNF) with substantial in-kind contributions from USDOE and SDPC. Additional funding is being made available from the Energy Foundation. The United Nations Industrial Development Organization (UNIDO) is administering the program on behalf of UNF. Due to reorganizations within the Chinese government, responsibility for the program will be transferred to the State Development and Resource Commission (SDRC) in mid-2003.

Shanghai and Jiangsu were selected for the pilot program because they expressed strong interest, included a significant industrial base, have organizational support, and have a small cadre of energy professionals who can be trained on the technical specifics of motor system optimization. Two existing organizations, the Shanghai Energy Conservation Service Center and the Jiangsu Energy Conservation Center, have become central to the implementation of this program. Program objectives for the project period of three years, include the following activities:

(i) Develop a series of educational materials and application tools (e.g., software) to assist motor system experts and factory engineers to assess and better optimize motor systems;
(ii) Revise existing Chinese national standards on the economic operation of motors, fans and pumps;

(iii) Train 10-16 motor system optimization experts who will work in Shanghai and Jiangsu;
(iv) Implement and evaluate a series of 8 to 12 motor system improvement demonstration projects in different industrial sectors in Shanghai and Jiangsu and prepare case studies of these projects;
(v) Train ~400 Shanghai and Jiangsu factory managers and engineers and provide technical assessments to at least 32 Shanghai and Jiangsu factories to assist them to identify and undertake their own motor system optimization projects;
(vi) Evaluate the different project components and assess how the project can be improved; and
(vii) Assist the Chinese government to plan for and lay the groundwork for a major national motor system improvement program.

The design of the program is drawn from program design elements of the US (Motor Challenge, BestPractices) and the UK (Best Practice Programme) and the training expertise of the International Team. The overall effort represents the first time that a comprehensive capacity- building approach has been taken in a developing country in the area of industrial system optimization.

Program Design

The China Energy Conservation Investment Corporation (CECIC) was selected by UNIDO in August 2001 through a competitive bidding process as the primary subcontractor for in-country implementation. CECIC is responsible for overall management of program implementation activities, including contracting with local agencies in Jiangsu and Shanghai, which began in October 2001. A substantial evaluation component is also included to determine the effectiveness of the pilot programs. Evaluation is the responsibility of a Project Management Office (PMO) established by the SDPC. Preliminary evaluation results are included in this paper. The pilots will be completed by late 2004.

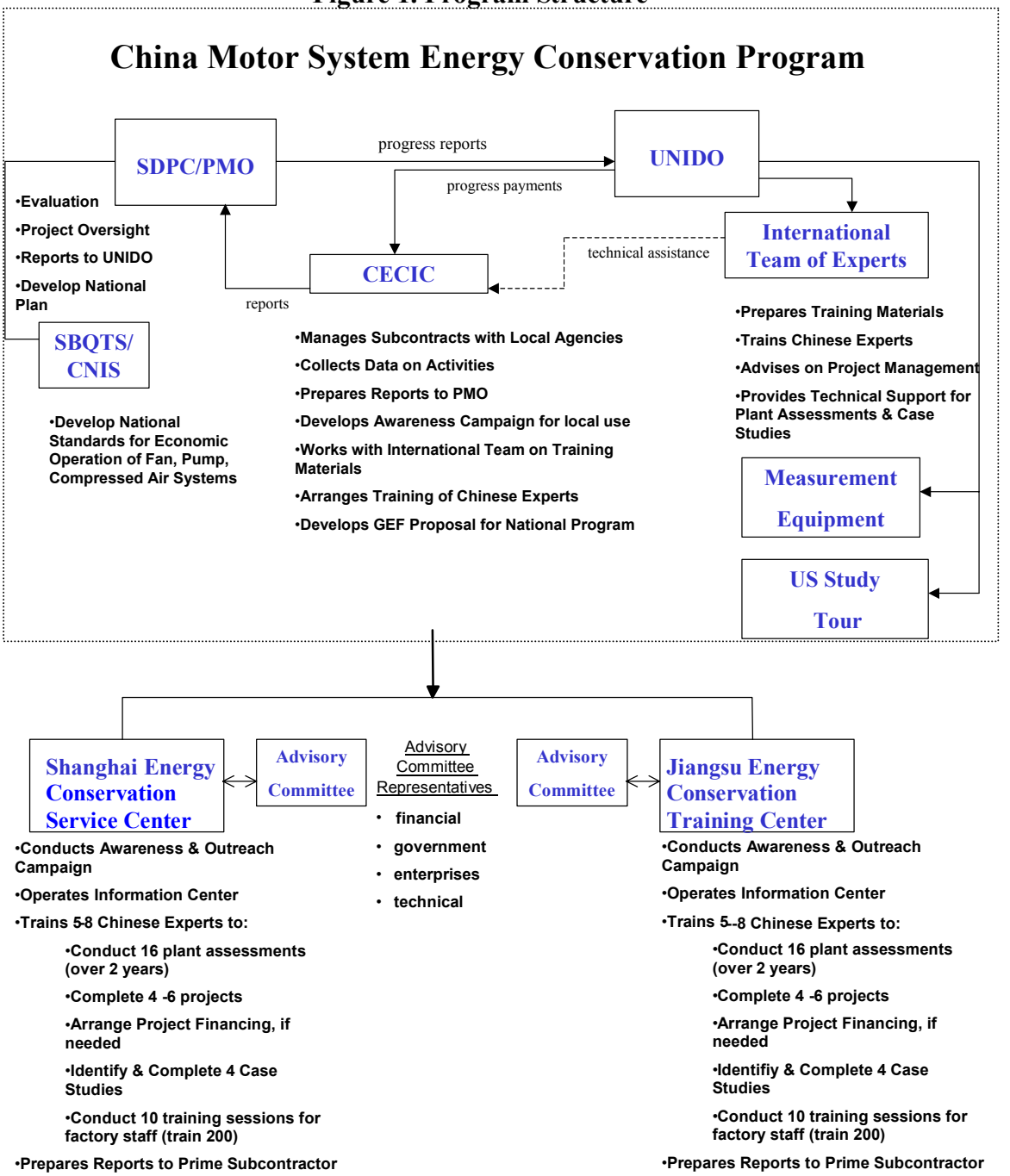
Developing an International Team & Training Program

UNIDO selected a Chief Technical Advisor (CTA) for the project in March 2001 to assist UNIDO in: forming an International Team of Experts, selecting the Chinese experts to be trained, and providing assistance to CECIC in the development of an implementation framework for project management, reporting, and fiscal management. In August 2001, CECIC and the CTA spent several days sketching out the requirements for reporting, financial management, and data collection. A preliminary schedule was developed and plans for an inception meeting were finalized. CECIC and the CTA decided to conduct training for the entire group of Chinese experts in alternating cities. Three two-week training components were identified: 1) pump systems, 2) motors/drives and fan systems, 3) compressed air systems. For each component, CECIC and the CTA agreed that a follow-up visit would be conducted two to four months after the initial training to assess progress and provide additional technical assistance.

At the request of the Jiangsu and Shanghai Energy Center staff, a training component on project development, report preparation, and financing options was added. All training

was conducted by an International Team of Experts, selected by UNIDO with the guidance of the CTA.

Figure 1. Program Structure



The International Team of Experts was assembled by August 2001 to develop educational materials and application tools to assist motor system experts and factory engineers in assessing and optimizing motor systems. The Team developed two sets of curricula -- one to train the Chinese experts and one for the Chinese experts to use when training factory personnel. The educational materials and application tools were drawn from

the International Team's own materials and existing information drawn from motor system programs in the US and the UK. The Experts training was designed to be a mix of classroom instruction and hands-on training in factory settings, including instruction on the use of sophisticated measurement equipment. Each two-week follow-up visit included a week in each province to work in smaller groups (10-12) on issues unique to the province and Energy Center. Specific activities included observation of factory training conducted by Chinese experts, visits to plants where the Chinese experts had taken measurements and made preliminary recommendations to review their work, critiques of assessment reports and case studies. As the project progressed, the International Team found that additional supervised work with the measurement instrumentation was also an important element of the follow-up visits. Continued technical support is being provided for plant assessments, project development, and case study preparation via posting reports, photos, and data analysis for review on a shared website, accompanied by an exchange of e-mail.

International Team of Experts

Program Administrator
Robert Williams, UNIDO
Chief Technical Advisor
Aimee McKane, Lawrence Berkeley National Laboratory
Motors & Drives Experts
Hugh Falkner, AEA Technology
Vestal Tutterow, Lawrence Berkeley National Laboratory
Pumping System Experts
Steven Bolles, Process Energy Solutions
Gunnar Hovstadius, ITT Fluid Technologies
Fan System Expert
Ronald Wroblewski, Productive Energy Solutions
Compressed Air System Experts
Wayne Perry, Kaeser Compressors
Tom Taranto, Pneumatech/ConservAIR
Evaluation
Jane Peters, Research into Action
Steven Nadel, ACEEE

Chinese Project Management and Implementation

Project Management Office
Dai Lin and Xin Dingguo, ERI/BeCon
China Energy Conservation Investment Corporation
Zou Guijin
Shanghai Energy Conservation Service Center
Ye Wen Baio
Jiangsu Energy Conservation Training Center
Li Yuqi

Selecting Chinese Experts

The success of the program depends entirely on the ability of the Chinese experts to understand and apply the systems approach in conducting plant assessments, develop projects, and train factory personnel on the benefits of undertaking additional projects using

the systems approach. In addition, it is anticipated that some of these experts will form a core group that will be prepared to train other experts as part of a future national program. The pilot program included a fixed budget for 12 weeks of intensive training of the Chinese experts over a 12-month period by the International Team. Careful selection of the Chinese experts to receive the training was critically important -- if this training was unsuccessful, the goals of the pilot program would not be met. Criteria were developed for the selection of individuals who had existing technical skills, familiarity with industrial processes, interest in working with others to promote motor system optimization, and institutional support to work with industry. CECIC, the Shanghai and Jiangsu Energy Conservation Centers, and the CTA finalized selection of 22 experts in a series of interviews with the candidates in December 2001, based on a set of criteria approved by the International Team. The selected experts are a mix of Energy Center staff and engineers from key industries in the two provinces. A group of 22 was selected to allow for attrition while still meeting the program target of 10-16 trained Chinese system optimization experts.

Over the 12-month intensive training period there were some changes in the roster of Chinese experts being trained. The two most common reasons for this were: 1) a few individuals in key industries changed jobs and were no longer in a position to participate; 2) individuals with a specific interest and background in one type of motor-driven system participated in training only for that system. A total of 30 Chinese experts participated in at least one component of the training program; a core of 19 Chinese experts completed all three components of the training program. As a capacity-building exercise, the International Team concentrated on making sure that a core group of 8 Energy Center staff (or consultants to the Energy Center), evenly split between Jiangsu and Shanghai, completed all components and had extra time to consult with the International Team on project development, trouble-shooting use of the measurement equipment, and report writing. All Chinese experts participating in the training demonstrated a high level of skill in engineering principles.

Program Implementation

The pilot program officially started with an inception meeting in Nanjing, China in December 2001. At this time, the training schedule through March 2003 was fleshed out in detail and the CTA provided financial management training for the Jiangsu and Shanghai Energy Conservation staff. The period from January – March 2002 was used to develop and translate pump system training materials, select and order measurement equipment kits in consultation with the International Team, and identify factory sites for the first training session. The program focus through March 2003 was on building an infrastructure of trained system optimization experts in Shanghai and Jiangsu provinces. This was accomplished by a series of three training sessions and three follow-up visits conducted by the International Team. The International Team spent a total of 34 person-weeks in China (typically in teams of 3) during the period from April 2002 through March 2003 training Chinese experts and preparing factory sites for onsite training.

The training developed by the International Team for the Chinese experts combined classroom instruction, hands-on practice with measurement equipment, and onsite assessment of motor-driven systems at selected Chinese factories. Despite the considerable challenges resulting from differences in language and industrial practices as well as the physical difficulties inherent in conducting onsite training in noisy factory environments, this

model of instruction is producing results. Experience has shown that there is no reasonable substitute for direct on-site interaction and coaching the Chinese experts through application of system optimization techniques in actual factory settings.

The first train-the-trainer session on pumping systems was held in April 2002 in Shanghai. A meeting of the Pumping Experts from the International Team, CTA, CECIC, and the senior members of each Energy Center was held immediately after completion of the training to review and discuss the students' written evaluations and Pumping Experts' observations. This established a pattern of identifying the "lessons learned" from each training class, incorporating them into a written report prepared after each training session, and using them to inform the development of the next training session.

The motor/drive and fan system training was originally scheduled for July 2002, but was moved up to June due to concerns about the high temperatures frequently found in the factories in Jiangsu province during the summer. This resulted in an accelerated schedule for the preparation of training materials and factory site selection for the motor/drive and fan system training. During May, the International Team also worked with CECIC and the Jiangsu Energy Center to prepare and translate pumping system materials for use by the Chinese experts who would be providing training to technical and managerial staff at factory sites. In June, the second train-the-trainer session on motors/drives and fan systems was held in Jiangsu province (Nanjing). The Pump System Experts returned at the end of the training to observe and assist the Chinese experts with measurement techniques and plant assessment reporting. At the request of the Chinese experts, additional training was also given on project development and financing issues. The Pump Experts observed the Chinese experts conducting their first factory training sessions in Nanjing and Shanghai on pumping systems and the benefits of implementing energy efficiency projects. Again, the experts' training was followed by a discussion of lessons learned and preparation of a written report. Although program goals were met for the June training, allowing additional time for future training preparations is recommended.

During July and August 2002, the Compressed Air Experts developed training materials and CECIC had them translated. Final preparations were made for measurement equipment purchases and factories for onsite training. In addition, the Motor/Drive and Fan System Experts began preparation of the materials for the Chinese experts to use in factory training scheduled for November.

The third train-the-trainer session on compressed air systems was held in Shanghai in October 2002. This was the most complex topic in the series; in response, the Shanghai and Jiangsu ECCs added a total of four new Chinese experts with a particular interest and knowledge of compressed air. The training was scheduled to include four class days instead of the usual three plus two days on-site at plants, for a Sunday through Friday schedule. To assist the students in developing their plant assessment skills, the Compressed Air Experts collected data at the plant training sites for several days prior to the start of the training. During the final briefing after the completion of the compressed air system training, the return visit of the Compressed Air Experts was scheduled for March 2003 to allow the Energy Centers adequate time to practice using the measurement equipment and conducting plant assessments.

The Motor/Drive and Fan System Experts returned to Shanghai and Jiangsu in November 2002 to observe factory training, to conduct additional small-group training in field measurement techniques for fan systems and motors/drives; to discuss and analyze the

data collected, and work on plant assessment report development. Additional discussions were held on use of the measurement equipment.

The Compressed Air Experts developed a factory-training module on compressed air in January 2003 for translation and use by the Chinese experts. In March 2003, the Compressed Air System Experts returned to Nanjing and Shanghai to observe compressed air factory training by Chinese experts and to provide additional small-group technical assistance on measurement and plant assessment techniques. A supplemental training on developing a measurement plan was prepared and delivered by the Compressed Air Experts. The International Team felt that this additional training would be beneficial, because the development of a measurement plan before attempting to make measurements is a critical element of plant assessments that is not well understood. This is the most rigorous part of systems optimization training; technically-trained people, in general, tend to want to focus on use of measurement equipment rather than first conducting a thorough walk-through of the system to identify critical points to measure.

As of October 2002, the Chinese experts had already completed and documented two good-quality pumping system optimization projects, a remarkable track record within six months of receiving pump system training. Several plant assessments have been completed and four additional projects are under already development.

The first project to be fully documented in a case study is at the New Asiatic Pharmaceutical Company. The plant implemented a pump system optimization project that improved the system's effectiveness by applying proper pumps, adding a variable frequency drive (VFD) to the system, and performing maintenance to clean the pipes and improve the effectiveness of chiller heat exchangers. The total cost of the project was RMB 1,200,000 (US$144,000). With annual energy savings of 1.09 million kWh or RMB 660,000 (US$79,000), the project's simple payback was just 1.8 years. The energy usage of the system was reduced by 49%. In addition, the Shanghai Energy Center provided a shared-savings arrangement for project financing (Shanghai Energy Conservation Service Center 2002).

Considerations for Future Program Activities

Several issues surfaced during the intensive 12-month training period, and as the result of the interim evaluation, that warrant further attention. This is particularly important if the pilot program is to serve as a model for a future national program.

First, the technical expertise of the Chinese experts was very high, which allowed the instructors to move quickly through basic instruction and focus training on introduction of the systems approach. Participants without this level of technical expertise might require additional time to develop a technical context for applying the systems approach.

Second, the purchase of sophisticated measurement equipment for use in developing countries is challenging, expensive, and must be done carefully. While it is very important for measurement accuracy and repeatability to purchase top-quality equipment, it must also be operational in hostile environments, adaptable to high voltage conditions, hold up in a multiple user environment, and have in-country service support. In addition, the equipment for the UNIDO project needed to be reasonably easy to train others to operate and meet fairly tight budget constraints. For future efforts, a careful review and budgeting of equipment requirements is recommended. The purchase of an identical kit for use by the instructors is an

essential element. The availability of the kit allowed the instructors to study the equipment manuals and troubleshoot possible issues with connections in advance of their arrival in-country to conduct training.

Third, if the International Team, Project Managers, Energy Centers had the opportunity to do it over again, we would extend the interval between the training modules for the Chinese experts. An interval of three months between each training module should be considered the minimum for any future such effort. This interval would permit the Chinese experts to apply the information from one training module and complete at least one plant assessment before moving on to the next topic of instruction. Similarly, the follow-up visit to monitor progress should occur approximately 5-6 months after the initial training, assuming that regular electronic interaction with the instructors could occur in the interim.

Fourth, a mechanism needs to be established at the outset that encourages the Chinese experts to communicate regularly with the International Team throughout the training process. Experience has shown that relying on e-mail is insufficient, particularly since many e-mail systems in China do not support the transfer of large files, such as plant assessment results with photographs, diagrams, and data tracings. During the March 2003 follow-up visit, we established that a combination of e-mail and a website for posting shared documents would be a more workable mechanism. In addition, the Chinese experts were very receptive to a proposal to post exercises on the website that they could work on and submit to the instructors for review.

Fifth, cultural differences between Western and Chinese students surfaced during both training of the Chinese experts and also in factory training given by the Chinese experts that needed to be addressed. Chinese students are accustomed to lecture-style instruction and require substantial encouragement to interact with instructors and each other. While several hours of instruction might pass without a single question from the students, as soon as a break occurred, the students clustered around the instructors to ask questions individually. Several techniques were tested to modify this approach. The use of exercises in the classroom that require student participation and announcing a specific time set aside for questions and answers seemed to yield good results. Toward the end of each week of training by the International Team, the Chinese experts were asked to make presentations of their analysis based on measurements taken at the plant sites. These presentations generated a lot of discussion -- partly because the instructors and students had established a rapport during the week and partly because use of the presentation format required the Chinese experts to formulate and explain their analyses. Overall, the caliber of the presentations was excellent, especially given that these analyses were typically prepared the evening before based on data collected that day.

Sixth, the next step for the Chinese experts in developing a workable business model for system optimization will be to start thinking about areas of specialization, by system type and also by function. For example, in the US and the UK, some individuals become very skilled in the use of measurement instrumentation, while others become very skilled in determining what to measure and how to interpret the data collected. There are already indications that this is occurring at the Shanghai and Jiangsu Centers and more specialization is expected as individual strengths surface during the plant assessments. Intensive practice is essential to developing facility in the use of complex measurement equipment.

Seventh, another issue that surfaced is the need for standardization and quality control in plant assessments and report development. These could be accomplished by use of:

standard report formats; plant wide general assessment approach (utility and facility information reporting); consistent use of standardized units for pressure and flow; standard spreadsheets for calculations; instrumentation procedures; and review of reports by senior members. The provision of sample reports proved very helpful; earlier introduction of these materials into the training is recommended. With assistance from the International Team, CECIC is positioned to coordinate future efforts in this area.

Finally, although the Chinese experts are making very good progress in developing system assessment skills, there is an ongoing need for technical assistance from the international experts as the Chinese experts begin to apply their system assessment skills in plants. It is likely that another three-four years of support will be required beyond the UNIDO pilot program before a core group of Chinese experts will be ready to train other Chinese engineers on the application of system optimization techniques without any assistance from international experts. Since the international experts typically each have twenty or more years of experience in their area of expertise, the need for six to seven years to effect a transfer of sufficient knowledge for the Chinese experts to function at this high level expertise seems reasonable.

Planning for a National Program

In 2003, the primary program focus will be on pilot program objectives to: conduct 16 plant assessments in each province, complete 4-6 projects, develop case studies on these projects, and conduct training for 200 factory representatives in each province. A study tour of the US by Chinese engineers is also planned for late-2003.

Development of national standards for the efficient operation of motors, fans, and pumps has begun and will be completed with the cooperation of the State Bureau of Quality and Technical Supervision in 2004. These standards, although voluntary, will provide an important tool at the provincial level to encourage industries to use the system optimization services available through the Energy Centers.

An interim evaluation of the program has just been completed (Peters and Xin 2003). Findings from this evaluation are that the program is now well underway and that the level of enthusiasm on the part of all involved is very high and the commitment to fulfill the requirements of the project is equally high. The Chinese experts value the training they have received, have learned a lot, and are starting to apply this training including teaching workshops and conducting assessments. Factory personal interviewed as part of the evaluation also show substantial interest in motor system optimization and found the workshops given by the Chinese experts informative and useful. Many of the factory personnel are beginning to think about specific projects to implement in their plants. In Shanghai, the Energy Conservation Service Center has brought together a skilled team of experts (including both internal staff and outside experts) to conduct assessments and their initial assessments use an array of different system optimization techniques. The Shanghai Center has also raised a pool of capital to finance optimization projects. In Jiangsu, the Energy Conservation Center is mostly using internal experts to conduct assessments. Many of the other experts are factory personnel who are using the training to help identify projects at their plants, with assistance from Jiangsu Center experts. In Jiangsu, several variable speed drive projects are in the planning stages, to be financed by the factories themselves. Both Centers, but particularly Jiangsu, need additional training in finding system solutions to

problems and also in developing a business plan for ongoing optimization work. There is also a need to increased communication between the Chinese and international experts via email and other electronic means including sharing of draft plans, analyses and reports for comments and suggestions. A website mechanism has been established for this purpose. The results from this evaluation will be used as an input to improving the pilot and planning a national program. UNIDO, USDOE, and the Chinese government will work to secure sources of international funds for a national program.

In the final year of the pilot program (2004), a comprehensive program evaluation will be completed. It is anticipated that the pilot program model will be refined and applied in other countries with an emerging industrial sector.

The current proposal for Phase II, will use funding from the Global Environmental Facility (GEF) to continue work in Jiangsu and Shanghai while initiating training and programs in several other provinces and to extend activities to include guidelines for new project design and the economic operation of motor drive systems, including work with "design institutes" (engineering design firms) on use of these guidelines.

It is anticipated that the creation of a national program will occur incrementally as Chinese engineers in additional provinces are trained on the system optimization approach by colleagues from other provinces that were earlier program participants. This national program will evolve from the Phase II effort, with a core group of highly skilled experts from Jiangsu and Shanghai providing a core of highly-trained instructors who can provide a service to other provinces similar to the assistance provided by the International Team during the Phase I pilot program. A proposed framework for a national program will be included in the final evaluation of the UNIDO pilot.

UNIDO has already spearheaded an effort to launch programs in additional countries that will be based on the experience of the Chinese pilot program.

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