PEER-REVIEWED PAPER

Energy assessments under the Top 10,000 Program – a case study for a steel mill in China

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Abstract

One of the largest energy-savings programs for the Chinese industrial sector was the Top 1,000 Program, which targeted the 1,000 largest industrial enterprises in China. This program was launched in 2006, implemented through 2010, and covered 33 % of national energy usage. Because of the success of the Top-1000 initiative, the program has now been expanded to the Top 10,000 program in the 12th Five-Year Plan period (2011–2015). The Top 10,000 program covers roughly 15,000 industrial enterprises, or about two-thirds of China's total energy consumption. Implementing energy audit systems and conducting industrial energy efficiency assessments are key requirements of the Top-10,000 program. Previous research done by Lawrence Berkeley National Laboratory (LBNL) has shown that there is a significant potential for improvement in energy assessment practices and applications in China. Issues such as lack of long term policy mechanisms, insufficient motivation for industrial enterprises, limited technical scope of energy assessments, and lack of systematic standardization have been identified.

Through the support of the U.S. Department of Energy (DOE) and the U.S. State Department (with additional co-funding from the Energy Foundation China), LBNL, Oak Ridge National Laboratory, the Institute for Sustainable Communities (ISC), and DOE Energy Experts worked collaboratively with Chinese local organizations and conducted a series of industrial energy efficiency assessment demonstrations in selected Chinese industrial plants. The project's goal is to strengthen the practices of energy assessments and build up local capacity in China through structured training programs to introduce standardized methodologies and bring the "systems approach" for energy system analysis to the Top 10,000 enterprises. Five energy system assessment training workshops were conducted under the project, and more than 300 Chinese experts from local energy conservation centers, universities, research organizations, energy service companies, and plant engineers were trained.

This paper begins by introducing China's national energy intensity and carbon intensity reduction targets. Then, the paper explains the development of Top 10,000 program, including program requirements, the method for target allocation, key supporting policies, as well as challenges in implementing the program. By focusing on a process heating energy system assessment conducted in a Chinese steel mill, the paper presents an example of an energy system assessment conducted on steel reheating furnaces, including overall energy efficiency levels, areas of heat loss, and the potential for energy savings. In addition, the paper provides energy-savings recommendations that were identified during the assessment, as well as potential energy and energy costs savings. To conclude, this paper presents key findings that could further improve the Top 10,000 program by implementing a systems approach and providing a well-structured capacity building program for energy assessments.

Introduction

Industrial energy use represents about one third of global energy demand. Energy efficiency is viewed as one of the most cost-effective options to reduce the impact of growing demand and achieve greenhouse gas emission reduction goals (Worrell et al, 2003; IEA, 2012). Although the energy intensity of industrial processes has declined over the past decades, the energy intensity of most industrial processes is at least 50 % above the theoretical minimum as determined by the laws of thermodynamics (IEA, 2006). Studies have shown that the potential for energy efficiency improvements in industry is significant. It is estimated that about 31 exajoules (EJ) of savings or 26 % of final industrial energy demand could be achieved through industrial energy efficiency (IEA, 2009; UNIDO, 2011).

China became the largest energy user in the world in 2009, and the largest energy-related carbon dioxide (CO_2) emitter since 2007. Industry accounts for approximately 70 % of China's total energy use as well as CO_2 emissions. Although renewable energy has been growing fast in China in recent years, coal still represents 69 % of the total primary energy supply in 2011 (NBS, 2012). China's industrial sector consumed 70 % of total energy in 2011 (NBS, 2012). Within the industrial sector, half of the industrial energy use is dominated by energy and emission intensive sectors. China produced 61 % and 48 % of the world's pig iron and raw steel, respectively, in 2012 (USGS, 2013). The iron and steel sector used about 30 % of the total manufacturing energy in China and emitted 32 % of the CO_2 emissions from the manufacturing sector in 2008 (Lu and Price, 2012). The carbon intensity of steel production in China is also higher than other countries, about 3.1 to 3.8 tCO_2 per tonne of steel in China compared to 1.25 tCO_2/t in Brazil and 2.0 tCO_2/t in the U.S. (Kim and Worrell, 2002). The potential for energy-saving and carbon mitigation is substantial in Chinese industrial sectors. Research shows that a maximum total abatement potential of 1.6 Gt of CO_2e emissions could be achieved in China's industrial sector by 2030 through improving energy efficiency and recovery and reuse of by-products and wastes. China's steel sector could improve its physical energy intensity by 24 % by 2030 (from the 2005 level) if it fully adopts commercialized energy-efficiency technologies (McKinsey, 2009).

Facing the challenge of growing energy demand and environmental stresses, the Chinese government committed to reducing energy intensity (defined as energy use per unit of Gross Domestic Product, GDP) by 20 % by 2010 compared to 2005 levels; the actual reduction in energy/GDP during this period was 19.1 %. In China's 12th Five-Year Plan (2011–2015), China established a similar energy intensity reduction target of a 16 % reduction in energy/GDP by 2015 compared to 2011 levels and added a similar carbon intensity reduction target of 17 % reduction in CO_2/GDP during the period. Further, China committed to a carbon intensity reduction target in 2009 through the Copenhagen Accord which sets a goal of reducing the CO_2/GDP by 40–45 % from the 2005 level by 2020. Policies and programs have been developed to support all of these targets. Given the large share of energy and CO_2 emissions from industry in China, the Top 1,000 and the Top 10,000 programs are among the key comprehensive energy-efficiency programs to improve energy efficiency in the industrial sector, China's largest energy-consuming sector.

Top 1,000 and Top 10,000 Programs

PROGRAM TARGETS AND REQUIREMENTS

The Top 1,000 Energy-Consuming Enterprises Program was introduced in 2006 and covered the largest 1,000 energy-intensive companies, each of which consumed more than 180,000 tonne of coal equivalent (tce) annually (5,275 TJ/year). The total energy consumption of the Top 1,000 Enterprises constituted about 33 % of China's national energy use. Industrial companies in this program were required to conduct energy assessments at the beginning of the program. By the end of 2010, the Top 1,000 Program reportedly exceeded its energy-saving target of 100 Million tce (Mtce) (2,931 PJ) and achieved 125 Mtce (3,663 PJ) of savings.

Based on the success of the Top 1,000 program, the initiative has been expanded to the Top 10,000 Program in the 12th Five-Year Plan period (2011–2015). The Top 10,000 Program covers more than 15,000 industrial enterprises and about 2,000 large buildings and transport entities. This includes 15,000 industrial enterprises that use more than 10,000 tonnes of coal equivalent (tce) per year (293 TJ/year), and around 160 large transportation enterprises (such as large shipping companies), and public buildings that use more than 5,000 tce per year (147 TJ/year). Overall, the Top 10,000 program covers about two thirds of China's total energy consumption (ERI 2011), or 85 % of total estimated industrial energy use (He, 2011) (Figure 1). At the national level, the National Development and Reform Commission (NDRC) is the responsible for supervising and evaluating the progress of the program. Local governments, such as local Development Reform Commissions and local Economic Information Commissions are responsible for implementation and evaluation.

The total energy saving target during 2011–2015 for the Top 10,000 program is 250 Mtce (7,327 PJ). The program also aims to improve the energy efficiency of industrial enterprises, improve the energy intensity of key products to the advanced domestic levels, and to establish a long-term energy-efficiency mechanism.

Under the Top 10,000 program, industrial enterprises are required to conduct industrial energy assessments. Energy assessments are only required to be conducted once for each industrial enterprise, unless it fails to pass the government review. A typical energy assessment required in the Top 10,000 program includes key components such as energy analysis of current energy consumption, identification of energy-saving opportunities, and proposal of concrete energy-saving measures. In addition, as illustrated in Figure 1, industrial enterprises in the Top 10,000 program are required to conduct energy efficiency benchmarking, implement energy audit systems and technical retrofits projects, establish energy management systems, implement an energy utilization reporting system, and accelerate energy conservation retrofits and improvement of energy management skills (NDRC, 2011).

Government responsibility for this program includes expansion of the training pilots of energy managers to more provinces and cities, promotion of energy-efficient technologies, financial incentives and financing support for energy-efficient technical retrofits, adjustment of the export taxation policy to limit exports of energy-intensive products, fiscal and financial

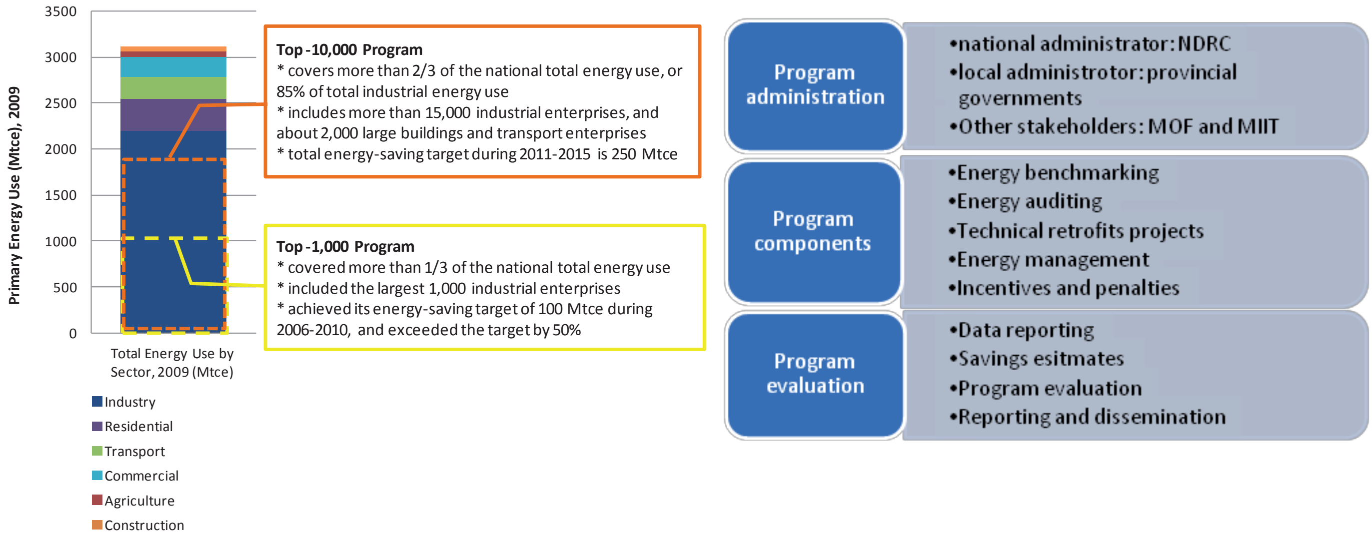

Figure 1. Coverage (left) and Program Structure (right) of Top 10,000 Program. Note: NDRC = National Development and Reform Commission; MOF = Ministry of Finance; MIIT = Ministry of Industry and Information Technology. Source: NBS, 2010.

incentives to encourage and promote energy performance contracting and energy service companies (ESCOs), and promotion of new market mechanisms, such as voluntary emission trading pilots and energy savings trading.

TARGET ALLOCATION

The goal of the Top 10,000 Program is to achieve an absolute energy-savings target of 250 Mtce (7,327 PJ) by 2015 (NDRC, 2011). The target is defined as the total energy savings in 2015 against a growth baseline (ERI, 2011). If China's GDP continues to grow at 7.5 % annually from 2013 to 2015 based on China's 12th Five-Year Plan, achieving the 16 % energy intensity reduction target will save 760 Mtce (22,274 PJ) of energy compared to the energy use if energy intensity (energy/GDP) is frozen at the 2010 level. This means that the Top 10,000 program is expected to contribute 33 % of the national energy-saving target.

Given the scale and large number of industrial enterprises in the program, the 250 Mtce (7,327 PJ) saving target has been disaggregated to local provinces and cities. The target setting process is reported to be (ERI, 2011):

- Local companies report their estimated energy-saving potentials to the local government.
- Local provinces estimate total energy-saving targets for their provinces and submit their proposed targets to the central government.
- The central government reviews the proposed target.
- Provincial and central governments negotiate the targets before final targets are determined.

Local governments evaluate local enterprises' progress toward their energy-saving target and publicize the results. For the enterprises that do not meet their annual energy-saving target, mandatory energy audits will be conducted and adjustment/retrofits will be required. Local governments are authorized to supervise the progress of local enterprises, as well as supervise the centrally owned large State-Owned Enterprises in their region.

FINANCIAL INCENTIVES

Financial rewards are provided by China's Ministry of Finance to industrial enterprises that undertake energy-saving projects or retrofits. During the 11th Five-Year Plan, enterprises were rewarded at a rate of 200 RMB (30 USD[1] or 22 Euro[2]) for every tonne of coal equivalent (tce) saved per year in East China and 250 RMB (37 USD or 28 Euro) for every tce saved per year in Middle or West China. To receive the financial rewards, industrial enterprises had to conduct energy-saving projects in the following areas: 1) coal-fired boiler (furnaces) retrofits; 2) district cogeneration projects; 3) waste heat and waste pressure utilization projects; 4) conservation and substitution of oil; and 5) motor system energy conservation projects. Minimum energy savings for each eligible project had to be over 10,000 tce (293 TJ) in order to receive the rewards. By the end of 2010, the central government had allocated 8.1 billion RMB (1 billion USD or 0.9 billion Euro) in the central government budget and had allocated another 22.4 billion RMB (3.3 billion USD or 2.5 billion Euro) as special funding to support these projects. In total, more than 5,100 energy-saving projects were implemented during the 11th Five-Year Plan.

To support the expanded Top 10,000 program in the 12th Five-Year Plan, China continued and increased the financial reward policy. The rewards were increased to 240 RMB (35 USD or 27 Euro) per tce-saved for East China, and 300 RMB (44 USD or 33 Euro) per tce-saved for Central and West China. The threshold for minimum energy savings to qualify for the financial rewards was reduced from 10,000 tce (293 TJ) to 5,000 tce (147 TJ).

Even so, under the Top 10,000 program, there are no direct incentives for industrial enterprises to conduct energy assessments. Financial incentives are only available for implementing energy-saving projects that meet the requirements, but not to other energy-saving activities that are required under

1. 2010 average rate: 1 RMB = 0.1475 USD (http://www.oanda.com/currency/historical-rates/) is used in this paper.
2. 2010 average rate: 1 RMB = 0.1114 Euro (http://www.oanda.com/currency/historical-rates/) is used in this paper.

the Top 10,000 program, such as energy management, energy reporting, energy-efficiency benchmarking, and conducting energy assessments.

CURRENT RESULTS AND CHALLENGES

It has been reported that China's Top 10,000 program is on track to achieve its 250 Mtce (7,327 PJ) energy-saving target. A government evaluation of 16,078 industrial enterprises showed that a total energy savings of 170 Mtce (4,982 PJ) was reached during the first half of the 12th Five-Year Plan period (2011–2012). This is 68 % of the total target. In 2012, 1,536 industrial enterprises were not included in the evaluation, mostly due to plant closures, mergers, and capacity phase-outs. Among the enterprises that were evaluated, 3,760 enterprises, or 26 % of the total, exceeded their energy saving targets. More than 50 % of the evaluated enterprises have completed their targets. 14 % of enterprises "basically" reached their targets. There were 1,377 enterprises that did not achieve their targets, representing about 10 % of the total enterprises evaluated (NDRC, 2013).

Chinese local energy conservation centers as well as energy service companies (ESCOs) have been undertaking industrial energy assessments since the 1980s and have gained experiences in multiple industrial sectors and systems. As a result, the government included a requirement for energy assessments in multiple comprehensive energy efficiency policies. China's national standard on energy auditing was established in 1996 and energy assessments have been incorporated into comprehensive programs such as the Top 10,000 program. Nevertheless, previous research done by Lawrence Berkeley National Laboratory (LBNL) has shown that there is significant potential for improving energy assessments practices and applications in China (Shen et al., 2010). Issues such as lack of long term policy mechanisms, insufficient motivation for industrial enterprises, limited technical scope of energy assessments, and lack of systematic standardization were identified.

International Collaboration on Energy Assessments

PROJECT STRUCTURE

The China Energy Group of Lawrence Berkeley National Laboratory (LBNL) has been working with Chinese research and governmental organizations for the past 25 years. Based on the local demand for improved energy assessments, capacity building needs to train energy auditors, as well as the urgency to meet national and local energy-saving targets, LBNL collaborated with Oak Ridge National Laboratory, the Institute for Sustainable Communities (ISC), and international energy experts to bring U.S. energy assessments expertise to energy-intensive industrial sectors in China.

U.S. experts that participated in the project, which was called the International Industrial Energy Efficiency Technology & Deployment (IIEETD) project, were funded by the U.S. Department of Energy and the U.S. State Department. The project also received local support from various other organizations, such as Chinese national and local energy conservation centers, universities, and industrial companies. Energy Foundation China also provided co-funding for this project. The structure of institutional design of the project is illustrated in Figure 2.

The goal of this project was to strengthen the practice of energy assessments and build up local capacities in China. By conducting a series of formal training workshops, the program aimed to introduce a framework of a formal training program that can increase both the quantity and quality of energy assessments being conducted. Based on the 30-year experience of the United States in the area of industrial energy assessments, the project introduced energy assessment methods and tools, explained key components of an effective energy assessment, demonstrated the systems approach in energy assessments, and presented information on energy-efficient technologies to industrial companies in China.

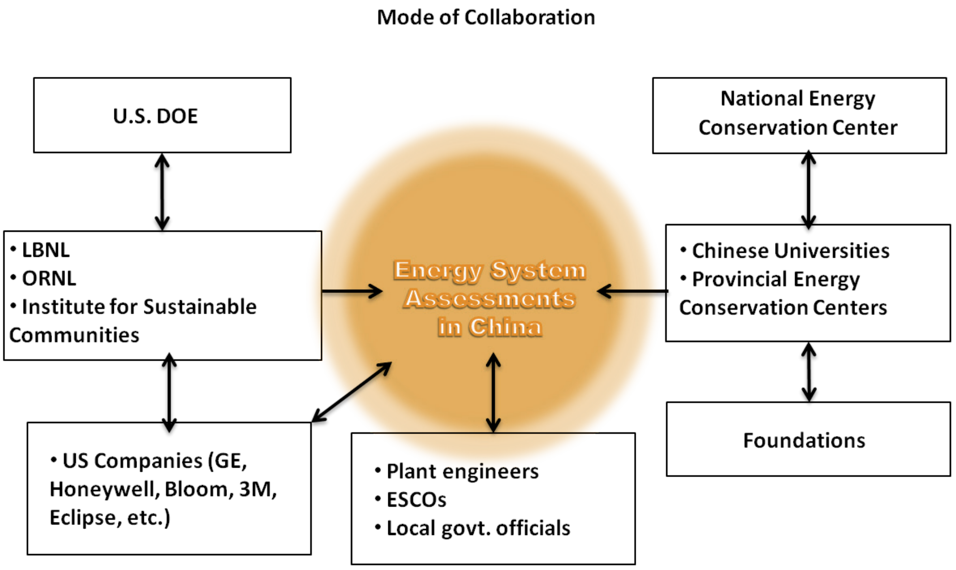

Figure 2. Collaboration Model for Energy Assessments Project.

The IIEETD project conducted five energy system assessments in China. Two of the workshops focused on steam systems in petrochemical and pulp & paper plants. Three of the workshops focused on the process heating system in aluminum, cement, and steel plants. The section below provides information on a process heating assessment conducted in one of the steel mills in China.

TARGETED SECTORS AND SYSTEMS

The iron and steel sector is one of the key industrial sectors for the IIEETD project. It is the largest CO_2 emitting manufacturing sector in the world, accounting for 27 % of the total manufacturing CO_2 emissions (IEA, 2007). It has been estimated that the global energy intensity of the iron and steel sector could be improved by 29 % by 2020 using existing technologies and energy-efficient measures (de Beer et al., 2000). In 2006, the iron and steel industry consumed 13.6 % of the primary energy consumption in China. With an annual production growth rate of 18.5 % since 2000, China's steel production reached 627 million tonnes in 2010, accounting for 46.6 % of global production.

The process heating system is one of the most energy-consuming systems in the industrial sector. In the United States, process heating systems account for 28 % of the total industrial energy use. Although data in China are not available, it is estimated that China's process heating system consumes a similar share of energy. Typically, a process heating system can achieve 10 % to 30 % of energy savings (Thekdi, 2012). In the steel sector, a variety of heating equipment are utilized in various processes or systems, such as boilers, coke ovens, air heaters, basic oxygen furnaces, steel refining systems, tundish and ladle heaters, steel reheating furnaces and annealing furnaces. It is for these reasons that the IIEETD project focused on the process heating system, especially in the iron and steel sector.

METHODOLOGY AND TOOLS

The IIEETD project introduced the energy system assessment standards developed by the American Society of Mechanical Engineers (ASME) as the basis for the demonstrated energy assessments in China. ASME has developed standards not only for process heating systems, but also for compressed air, steam, and pumping systems. These standards set requirements on how to conduct energy assessments for specific industrial systems and also provide a basis for industrial facilities to measure system energy efficiencies, improve energy performance, optimize fuel utilization, and perform energy assessments.

For technical and economical analyses in the energy assessment, the IIEETD project utilized the Process Heating and Survey Assessment Tool (PHAST) that was developed by the Department of Energy and E3M Inc. with technical support and review by the manufacturing industry users. There are other software packages available to allow very detailed analysis for furnace performance, but they require considerable more resources. The PHAST Tool, which is specially designed for improving the thermal efficiency of process-heating equipment, can create heat balance tables for the assessed equipment or systems and is used to identify the most promising areas for improving efficiency. It allows an engineering analysis for a system with fairly accurate results. The results are used as a guide to select areas of energy-saving opportunities where more detailed analysis may be required. The tool also allows users to test various operation conditions and options to achieve optimized results. The PHAST Tool can be applied to any industrial sector that has process-heating equipment or systems. It has been used as a useful screening tool for a large complicated process heating system without spending too much time or other resources. It has been used widely in U.S. industrial energy assessments and it is available online through the DOE website at no cost (U.S. DOE, 2010).

The PHAST Tool is based on the use of a "systems approach" for energy auditing. Traditional energy analysis approaches often target one piece of equipment at a time, such as the boilers and furnaces, but did not emphasize other key elements of the whole systems nor the interactions among key stages of industrial energy systems. A systems approach evaluates the entire system to determine how the system components can be most effectively utilized to serve the system demands. A systems approach is the most effective and comprehensive method to optimize the efficiency, reliability, and performance for the evaluated energy systems.

An excel-based version of the PHAST Tool (PHASTEx) was developed to meet the requirements of multiple component fuel-fired processes, as well as to accommodate the need for a standalone version of the PHAST Tool for use in China. PHASTEx has been translated in to Chinese, localized to accommodate Chinese units (energy, mass, temperature, etc.), and more features were added, such as an option for multiple selection of load materials and a library of commonly used materials.

Case Study: Energy Assessment from a Steel Mill

PLANT INFORMATION

The assessed steel mill is located in central China and is a steel rolling plant of a local Top 10,000 enterprise. It has been operating since 1998. It mainly produces 12–40 mm diameter steel rods and deformed steel bars. The original design capacity was 200,000 tonnes per year. To accommodate increasing demand, the steel mill expanded its capacity and produced 850,000 tonnes of steel rebar in 2010.

The steel mill has one reheating furnace, one steel rolling production line, and a water-cooling system. Coal is the main fuel. The plant reported that the average heating content of the coal is 6,000 kcal/kg (or 25,121 kJ/kg) and the average cost is about 500 RMB (74 USD or 56 Euro) per ton. Coal is converted to coal gas through the coal gasification process. The plant has nine coal-gas generator units and uses stream over heated coal to generate coal gas, which is a combination of hydrogen, carbon monoxide, and small amounts of carbon dioxide, nitrogen, and methane.

The main process-heating equipment is a pusher-type walking beam reheating furnace. The furnace is in continuous operation year-around, and has three operating zones: preheating (700–900 °C), heating (1,220–1,290 °C), and soaking (1,220–1,250 °C). The plant use carbon steel billets as the input materials to produce steel rebar. The steel pellets are transported from the headquarter steel plant in another city, and cold charged

Figure 3. Billet charge inlet and discharge of the reheat furnace.

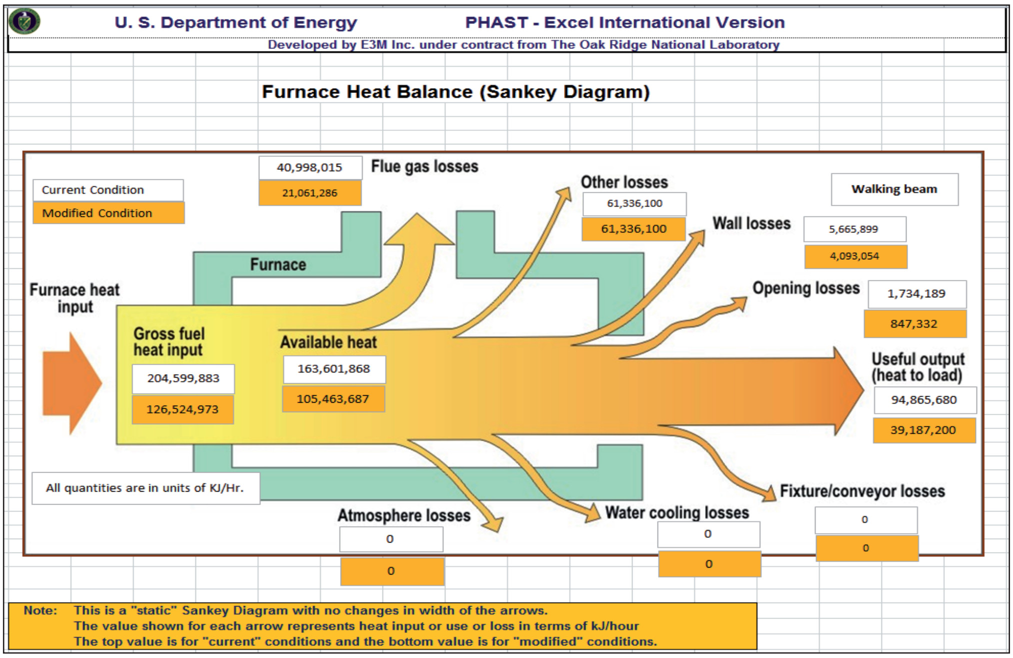

Figure 4. Heat balance of the assessed steel rolling furnace.

(i.e., at ambient temperature) to the furnace, going through the pusher first and then through the walking-beam reheating furnace. The plant reported that it consumed 60 kilograms of coal per ton of steel and used 52 kWh of electricity per ton of steel. Figure 3 shows the billets charge inlet and discharge of the reheating furnace.

DATA COLLECTION

To analyze the energy efficiency and performance of the furnace, the IIEETD project team utilized the PHASTEx tool and collected production data (materials and dimensions of billets, production rates), fuel data (fuel type and heat content), and measured the dimensions and temperatures of the furnace walls and openings. The assessment team also collected and measured flue gas temperature, combustion air temperature, and temperatures of furnace operating zones.

During the data collection and energy assessment process, the IIEETD project team received assistance and cooperation from the plant managers and engineers at the steel mill. The plant personnel expressed interest in the data collection instruments used by the IIEETD project team, the PHASTEx Tool, and the energy assessment findings.

ENERGY EFFICIENCY ANALYSIS

One the required data are collected, the PHASTEx Tool produces a Sankey diagram to show how the furnace heat is used by the different components of the steel mill's process heating system (Figure 4). The Sankey diagram presents areas of heat consumption and documents how much heat is lost to key system components.

The steel mill's energy use and heat losses are shown in the white cells of Figure 4. Of the total fuel heat input of about 205 GJ per hour, only 46 % of the energy input went to heat the final product (i.e., steel billets in this case). The plant's main heat loss was due to hot gases escaping from furnace openings, especially the opening for the billets charge inlet, which was open all the time. This represented about 30 % of the total heat input. Heat contained in the exhaust gas accounted for 20 % of the total heat input. Other losses, such as heat losses through the furnace walls accounted for about 3 % of the total heat input. Heat loss from openings was 1 % of the total heat input.

One of the key energy-efficiency analyses conducted in the assessment was the exhaust gas analysis. The exhaust gas analysis is used to measure the oxygen level in the flue gas and to estimate heat losses from the flue gas. The IIEETD project team used a flue gas analyzer and measured the combustion air temperature, flue gas temperature, and oxygen content in the exhaust gas.

Table 1 shows the measured exhaust gas data in the "current" column. At the time it was measured, the flue gas temperature was 230 °C with 9 % oxygen content. The measured ambient temperature was 30 °C. The high oxygen content indicates that significant amount of excess air is present in the flue gas. The energy input for the steel billets was not optimized and a significant amount was used to heat the excess air and then released to the air. One way of optimizing the combustion is to control the oxygen content in the flue gas. As shown in Table 1 under the "modified" column, by reducing the oxygen content from 9 % to 3 %, the available heat is increased from 79.96 % to 83.35 %. Available heat is the key energy efficiency indicator for process heating equipment. Increasing the available heat means that heat losses to other furnace components are reduced and more heat can be used by the charge materials.

Table 1. Exhaust Gas Analysis.

Exhaust Gases Available Heat or Combustion Efficiency			
		Current	Modified
Furnace Flue Gas Temperature	C	230	230
Select Input (% XS Air or % O2)		% Oxygen	% Oxygen
Oxygen in Flue Gases (%)	%	9.0	3.0
% Excess Air	%		
Combustion Air Temperature	C	30.0	30.0
Calculated % XS Air	%	67.13	14.92
Available Heat (%)	%	79.96	83.35
Available Heat (If User Defined) (%)	%		
Available Heat to Use In Calculation		Calculated	Calculated
Available Heat	**%**	**79.96**	**83.35**

ENERGY-SAVING FINDINGS

For the steel mill, the PHASTEx Tool was used to calculate the energy use of the system under the "modified condition" which could be achieved through implementing energy-saving measures in the areas that have the largest energy-saving opportunities. Results of the modified energy use and heat losses are shown in the yellow cells of Figure 4. The summary of energy consumption of each system component under the "current" and "modified" conditions is presented in Table 2.

The oxygen level at the steel mill was 9 % when it is measured during the energy system assessment. Through optimized combustion control, the oxygen level in the flue gas could be reduced and maintained at 3 %. The PHASTEx Tool estimated that by implementing this measure, the plant could save more than 167,000 GJ per year, or 26 % of the total identified energy-saving potential. Based on the plant's average cost of coal (500 RMB per ton) and heating value of the purchased coal, the plant could reduce coal use by approximately 6,700 tonnes per year and save more than 3.3 million RMB (about 487,000 USD or 367,000 Euro) annually.

The furnace doors at this steel mill were kept open 100 % of the time. There is one inlet door for charging steel billets and two other openings for discharge. Energy savings could be achieved if furnace door opening time is reduced from the current 100 % level. The PHASTEx Tool estimated that by reducing the inlet furnace door opening time to 50 % and the discharge furnace door opening time to 20 % of the current level, the energy saving potentials is 7,450 GJ per year, saving about 150,000 RMB (22,000 USD or 17,000 Euro) per year. Although this measure only represents 1 % of the total identified energy-savings potential, it is relatively easy and less expensive to implement.

Heat losses through the furnace walls can be reduced by using and maintaining proper insulation and refractories. The potential energy savings from reducing heat losses are more than 13,000 GJ per year, saving 263,000 RMB/year (39,000 USD/year or 29,000 Euro/year). However, in practice, this measure may not be feasible and may require high capital investments. Upgrading the wall insulation or refractories may only be possible when the furnace is rebuilt or a new furnace is constructed. It is estimated that implementing this measure would contribute about 2 % of the total identified energy-saving potentials.

The steel mill currently uses cold charging, i.e., steel billets are received from another plant and reheated from the ambient temperature to the desired high temperature (more than 1,200 °C). If the plant can change cold charging to hot charging, or preheat the steel billets, significant energy savings could be achieved cost-effectively. The PHASTEx Tool estimated that if the steel billets are charged at 700 °C instead of the current ambient temperature (38 °C in summer when this was measured), the energy savings could be as high as 468,000 GJ per year, accounting for 71 % of the total technical identified energy-saving potential. At a coal price of 500 RMB per ton, this measure could save close to 10 million RMB (1.5 million USD or 1.1 million Euro) per year.

The IIEETD team also identified but did not quantify other energy-saving measures including using an advanced control and data collection system, using pressure control to reduce hot gas leakage from the furnace, and using adequate insulation for ducts and pipelines.

Overall, the IIEETD team identified a total technical energy-saving potential of 655,800 GJ per year. Although actual cost savings will depend on the degree of implementation, this identified energy saving represents a reduction of 38 % of the current total energy input at the steel mill. The largest energy-saving potentials are in two areas: optimizing combustion control by reducing oxygen content and preheating charge materials. At the reported coal purchase price of the steel mill, the total cost saving potential could be more than 13 million RMB (2 million USD or 1.4 million Euro) per year. Total cost savings will be increased if the coal price increases. For example, at a cost of 900 RMB (133 USD or 100 Euro) per ton of coal (instead of 500 RMB per ton [74 USD or 56 Euro]), total cost savings will be more than 23 million RMB (3.4 million USD or 2.6 million Euro) per year.

Conclusions

Through the IIEETD project, the project team demonstrated the energy systems assessment approach for energy auditing at five industrial facilities throughout China. Through these five assessments, the project team provided training to representatives from local governments, universities, research organizations, energy service companies, and plants in China on energy assessment standards, tools for assessments, and capacity building at the local level in support of the Top 10,000 program.

Table 2. Energy-Savings by Areas.

Energy use or loss category	Energy use – loss (Current)		Energy use – loss (Modified)		Energy Savings [a] (Current – modified)				Coal Reduction	Cost Savings
	kJ/hour	kgCE/hour[b]	kJ/hour	kgCE/hour	kJ/hour	GJ/Year	TCE/Year[c]	% of Savings	Tonnes[e]	RMB[f]
Charge material	94,865,680	3,238	39,187,200	1,337	55,678,480	467,699	15,962	71 %	18,618	9,308,925
Fixtures, trays, conveyor etc.	0	0	0	0	0	0	0	0 %	0	0
Wall surface heat losses	5,665,899	193	4,093,054	140	1,572,845	13,212	451	2 %	526	262,967
Water or air cooling (internal)	0	0	0	0	0	0	0	0 %	0	0
Atmosphere or makeup air	0	0	0	0	0	0	0	0 %	0	0
Radiation losses from openings	1,734,189	59	847,332	29	886,857	7,450	254	1 %	297	148,282
Other heat loss or heat addition	61,336,100	2,093	61,336,100	2,093	0	0	0	0 %	0	0
Flue gas loss	40,998,015	1,399	21,061,286	719	19,936,729	167,469	5,716	26 %	6,666	3,333,247
Exothermic heat from process	0	0	0	0	0	0	0	0 %	0	0
Total gross heat input required	**204,599,883**	**6,983**	**126,524,973**	**4,318**	**78,074,911 (38.2 %)[d]**	**480,461 (38.2 %)[d]**	**22,383 (38.2 %)[d]**	**100 %**	**26,107**	**13,053,421**

[a] *Assuming plant's operating hours per year are equal to 8,400 hours.*

[b] *1 kgCE = 29,300 kJ or 29.3 MJ net heating value.*

[c] *1 Metric ton of "standard" coal equivalent tce = 29.3 GJ.*

[d] *The percent energy savings is the ratio between saved energy and current level of total gross heat input for the process heating system. Actual energy savings are less than the sum of all energy savings from each individual measures. Actual energy savings depend on implementation rates of recommended measures, as well as the changes in gross heat input.*

[e] *Coal reduction is estimated based on the coal heating value of 6,000 kcal/kg, or 25,121 kJ/kg, as reported by the steel mill.*

[f] *Cost saving is estimated based on purchased coal cost of 500 RMB per tonne, as reported by the steel mill.*

This paper provides information on the energy audit results for a process heating system assessment at a steel mill in China that was one of the five project assessments. The case study at the steel mill shows that significant energy-saving opportunities exist at the plant level (38 % of technical energy-saving potential). Identified energy savings measures include optimizing combustion controls, using flue gas to preheat combustion air, preheating charge materials, reducing furnace door opening time, and adopting advanced monitoring and control systems. Plant engineers were especially cooperative and showed keen interest in the team's measuring instrument, energy-assessment tools, energy-efficient technologies, and energy-saving recommendations from the assessment.

The Chinese government is providing financial incentives for energy-saving projects as a supporting measure for realizing the national energy and carbon intensity reduction targets and for the Top 10,000 program. Based on the experiences of the IIEED project, there is notable local demand for qualified energy auditors and technical energy assessments. Capacity building through structured training programs aided with proven energy auditing tools can unlock energy-saving potentials significantly in China. However, currently there is still lack of direct financial incentives for other non-project based energy-saving activities, such as conducting energy assessments, training and capacity building for energy auditors, implementing energy management, and energy data collection and reporting. China's Top 10,000 program and energy assessment activities can be improved if specific financial funds can be channeled to support such energy assessments, capacity building for energy managers and energy auditors, and standardization of tools and standards that can be further adopted in industry.

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