CTCN Technical Assistance:
Benchmarking energy consumption and GHG emissions of iron & steel industries of Thailand

Comprehensive Report of Outcomes

Summary of the CTCN Technical Assistance

The iron & steel industry in Thailand is an important part of the Thai economy. The iron & steel industry is an energy intensive sector, and energy generally forms a major cost component in the overall cost of steel production. The domestic industry is facing competition from imports and is therefore interested in reducing its energy consumption to reduce its costs and remain competitive. The iron & steel industry structure in Thailand can be clearly divided into units involved in (i) steel making (ii) finishing & coating and (iii) forming. In each of these industry sub-sectors, there are a large number of units that are in operation. The technologies and processes used in units in each of these sub-sectors are different hence requiring separate in-depth studies. Organizations like the Iron & Steel Institute of Thailand (ISIT) have undertaken preliminary studies in a few sub-sectors within iron & steel industry in the past and have identified a large potential for energy efficiency improvements in the iron & steel industry in Thailand. The Energy Conservation Promotion (ENCON) Act, 1992 of Thailand mandates large companies to implement energy conservation measures and reporting. The Board of Investments (BOI) and Thailand Energy Efficiency Revolving Fund (TEERF) have been created to support large investments on energy efficiency projects.

In order to have a systematic and detailed study of iron & steel companies, a 'benchmarking' of key sub-sectors was conducted. The study undertook comprehensive analysis of individual sub-sectors (scrap recycling of long & flat products, hot rolling of long & flat products) in terms of 'Specific Energy Consumption' (SEC) levels and CO2 emissions. A detailed field survey of units was conducted to collect data for the benchmarking of iron & steel companies in Thailand. The project established a practical benchmarking tool for evaluating SEC and GHG emissions.

The CTCN assistance also conducted detailed performance assessment of representative units within selected iron & steel sub-sectors to identify potential technological options for energy efficiency improvements. Those units included a few EAF based scrap melting units, hot-rolling mills and cold rolling mills. One of the main outputs of the study is an "Energy Efficiency Manual" for Thailand iron & steel companies highlighting relevant technological options and standard operating practices. The manual allows managers at Thai steel companies to learn about the benefits of various potential technological upgrades in their respective units. Financing options for companies interested in technological upgrades were also explored as a part of the CTCN assistance. A national workshop on benchmarking study was organised on completion of project activities for dissemination of findings amongst all key stakeholders.

1. Overview of the CTCN technical assistance

1.1 Technology aspects

The CTCN technical assistance project provided technical support for benchmarking of 'specific energy consumption' (SEC) and GHG emissions of iron and steel companies in Thailand. The benchmarking tool is expected to support iron & steel companies in Thailand to evaluate their existing performance with respect to other companies operating in their country as well as in other countries around the world. An Energy Efficiency Manual was also prepared with a specific reference to Thailand iron & steel companies. The manual will help the companies identify relevant energy efficient (EE) technologies for adoption and improve their energy performance.

1.2 Objectives (outcomes)

The main objective of the Response Plan has been to benchmark SEC and GHG emissions of energy intensive sub-sectors of iron & steel companies of Thailand. The benchmarking would serve as an indicator of present level of performance and available energy saving potential for improvements.

1.3 Results (outputs from CTCN assistance)

The outputs from the CTCN assistance for iron & steel companies of Thailand include the following:

(i) Benchmarking of SEC and GHG emissions in key energy intensive sub-sectors of iron & steel companies

(ii) Energy Reporting Guide (ERG) for reporting of data on energy consumption by iron & steel companies

(iii) Energy Efficiency Manual providing details on Energy Efficient Technologies (EETs) and 'Standard Operating Practices' (SOPs) to help as a guide for Thailand iron & steel companies in identification of technologies

(iv) Potential financing options that would help iron & steel companies to invest in high cost technologies.

1.4 Expected use of outputs

The benchmarking will help various individual iron & steel units in Thailand to understand their existing status in terms of energy as well as environment performance. The exercise would help evaluate potential scope for individual units in key iron & steel sub-sectors for energy and environmental improvements. The manual on EETs and SOPs will act as a guide for individual companies to identify relevant energy efficient technological options for adoption. The Energy Reporting Guide would help policy makers to access regular data and information pertaining to iron & steel companies. The benchmarking exercise in the longer term will serve as an important tool for policy makers to set guidelines on technology interventions in iron & steel industry. The financial options and the modelling tool will help steel plant managers make decisions about investing in EETs and finding sources of third party financing to finance the improvements.

2. Outcomes of Assistance Activities

The Response Plan for iron & steel companies of Thailand has specified four distinct activities that would complement each other and help in achieving project objectives, as shown in the box below.

Activity-1: Designing specific questionnaires for different sub-sectors of Thailand iron & steel industry
Activity-2: Undertaking field survey on energy consumption data
Activity-3: Benchmarking of energy consumption pattern and developing energy reporting guidelines
Activity-4: Preparation of energy efficiency manual and assessing financing options

The outcomes of the activities and sub-activities associated with each identified activities are reported below.

Activity-1: Designing specific questionnaires for different sub-sectors of the Thailand iron & steel industry

The first activity under the Response Plan was to design and develop suitable questionnaires required for field survey of iron &

steel companies. Since iron & steel companies in Thailand comprise a wide range of sub-sectors, including scrap recycling, finishing (hot rolling and cold rolling/drawing) &coating and forming, it was important to identify and focus on key sub-sectors within these companies, which are energy intensive and account for a major share of energy consumption within the industry. Activity-1 focused on identifying such key sub-sectors and designing specific questionnaires for each of them as the main tool for collection of data and information pertaining to iron & steel industry of Thailand.

Sub-activity 1.1: Kick-off meeting of the project

The project was initiated with a face-to-face kick-off meeting on August 1, 2017 in Bangkok with all key stakeholders to share views and reach consensus on essential points. Following the kick-off meeting, practitioner-level meeting was held among Japanese experts (NSRI and JFE-TEC) and Thailand Experts (ISIT) to discuss in detail the contents of the activities as well as the timeline. Summary of the meetings are provided below.

Summary of CTCN kick-off meeting

1) Date & Time ： 11:30~13:00 Tuesday, 1 August, 2017

2) Participants ：

- ✧ **National Science Technology and Innovation Policy Office (STI)**
  Dr. Surachai SATHITKUNARAT, Senior Director of STI Information and Foresight Centre
  Ms. Supak VIRUNHAKARUM, Policy Specialist
  Ms. Oranuch RATANA, Policy Developer
- ✧ **Iron and Steel Institute of Thailand （ISIT）**
  Mr. Wirote ROTEWATANACHAI、 President
  Mr. Nattapon RATANAMALEE、 Researcher (Metallurgical Engineer)
- ✧ **NEDO**
  Mr. Masanori Kobayashi, Director for Global Environment Technology Promotion
  Ms. Haruka SAITO, Representative, Asian Representative Office
  Ms. Prae WONGPRECHA, Coordinator, Representative Office in Bangkok
- ✧ **NSRI**
  Dr. Okazaki Teruo, Director, Environment & Energy Research Department
- ✧ **JFE-TEC**
  Mr. Michio Nakayama, Researcher

Participants of CTCN Project Kick-Off Meeting

3) Location: Office of STI in Bangkok

4) Agenda:

1. Introduction of Participants
2. Overview of the Project (structure, activities, schedule, etc.)

3. Major concerns and discussion points
4. Others (procedure for information sharing and reporting, etc.)

5) Major conclusions of the meeting:

- General agreement on how to advance this CTCN project in cooperation between Thailand and Japan has been reached (see Figure 1)
- From STI, a sense of security and understanding was expressed for the fact that this project will be carried out with the aid of the experiences of Japanese experts.
- From NSRI, relevant experiences of the Japanese experts on the following topics were described:
    1. a series of activities such as energy and CO2 intensity calculation, data collection, improvement potential evaluation, target setting and energy conservation measures implementation in the framework of the step-by-step approach in APP Steel Task Force for improving energy efficiency of the steel industry (see Figure 2), and
    2. data collection and reporting based on the low carbon society implementation plan and the energy conservation law in Japan (see Figure 3).
- From STI, a concern has been expressed that, while there are various types in the steel industry of Thailand and many steel mills, only four sites will be visited physically. STI also thinks that it is better to increase the number of studied sites from 27. An explanation was provided from the Japan side that it is effective for the implementation of the project to focus on the four of steel industry sub-sectors with large CO2 emission/ energy consumption and potential for improvements.
- From STI, its responsibility to exchange information with CTCN was expressed. It was agreed that Japanese side will report on the progress of the project 3 times: August kick-off meeting, second visit in October, Workshop in January 2018 (See Figure 4).

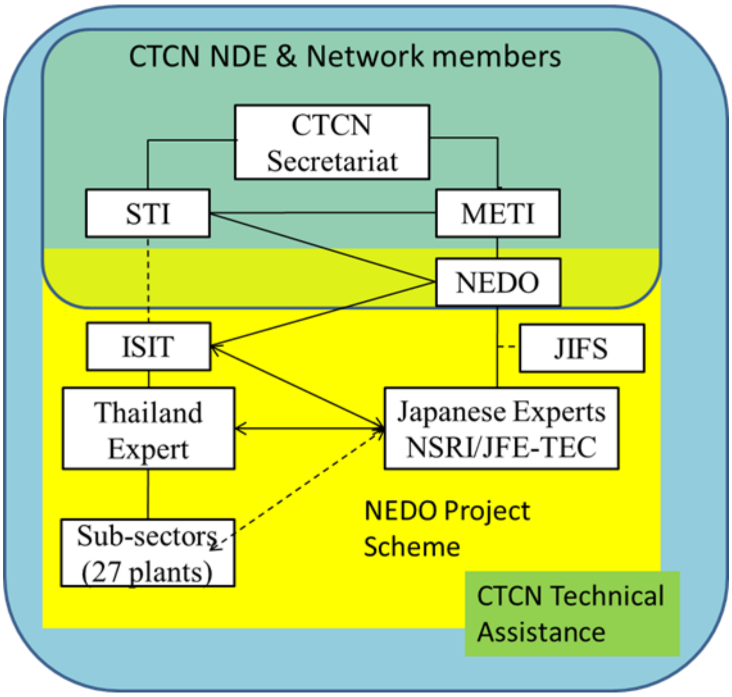

Figure 1: Kick-off meeting material: CTCN Project Formation

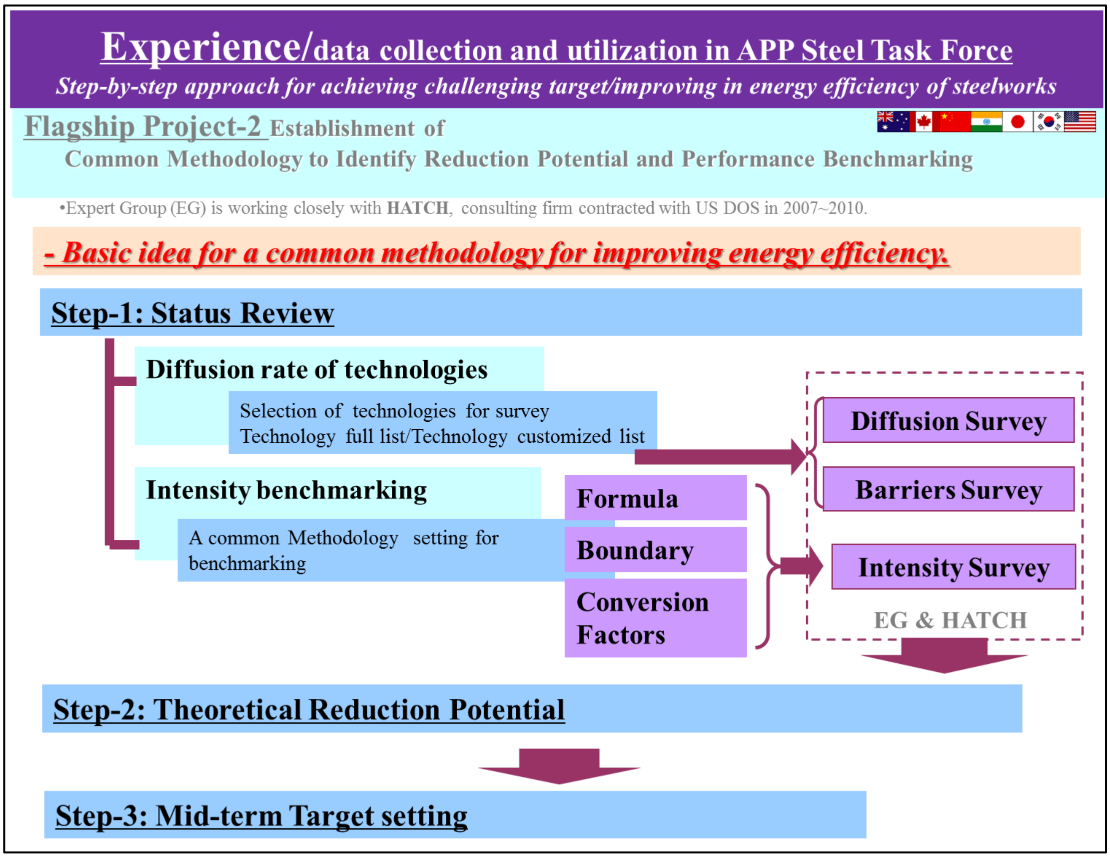

Figure 2: Kick-off meeting material: relevant experience of Japanese Experts (1)

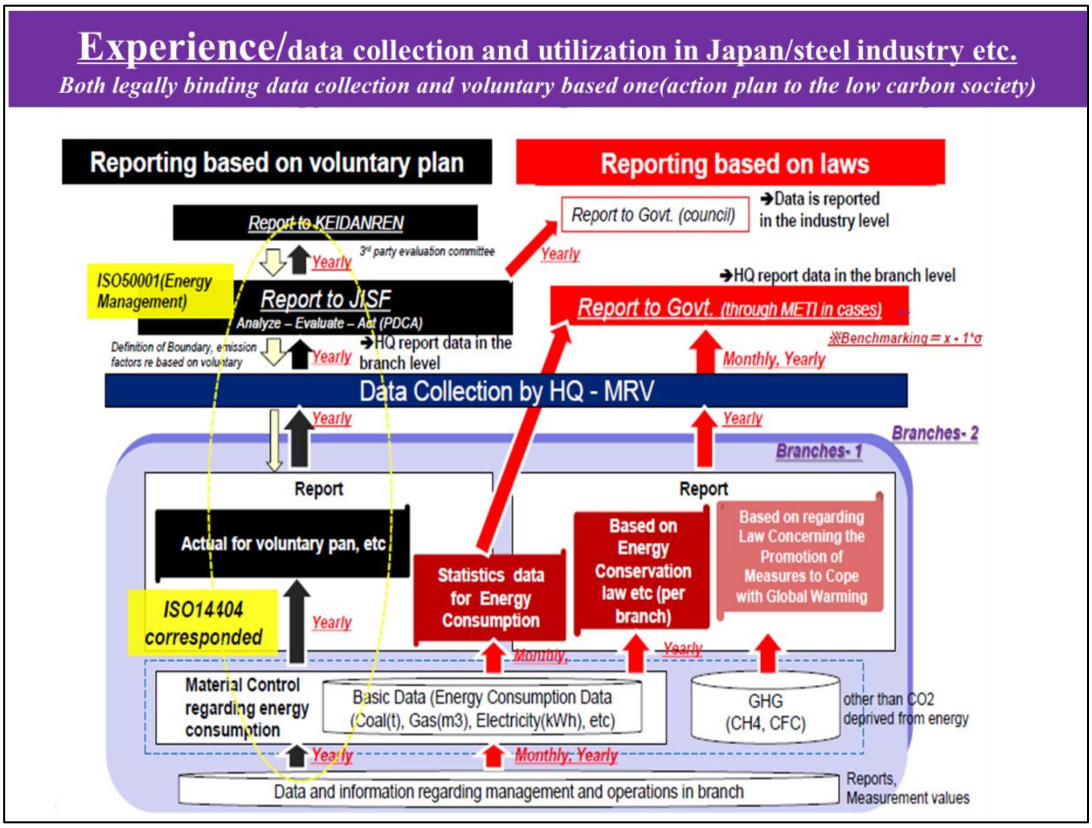

Figure 3: Kick-off meeting material: relevant experience of Japanese Experts (2)

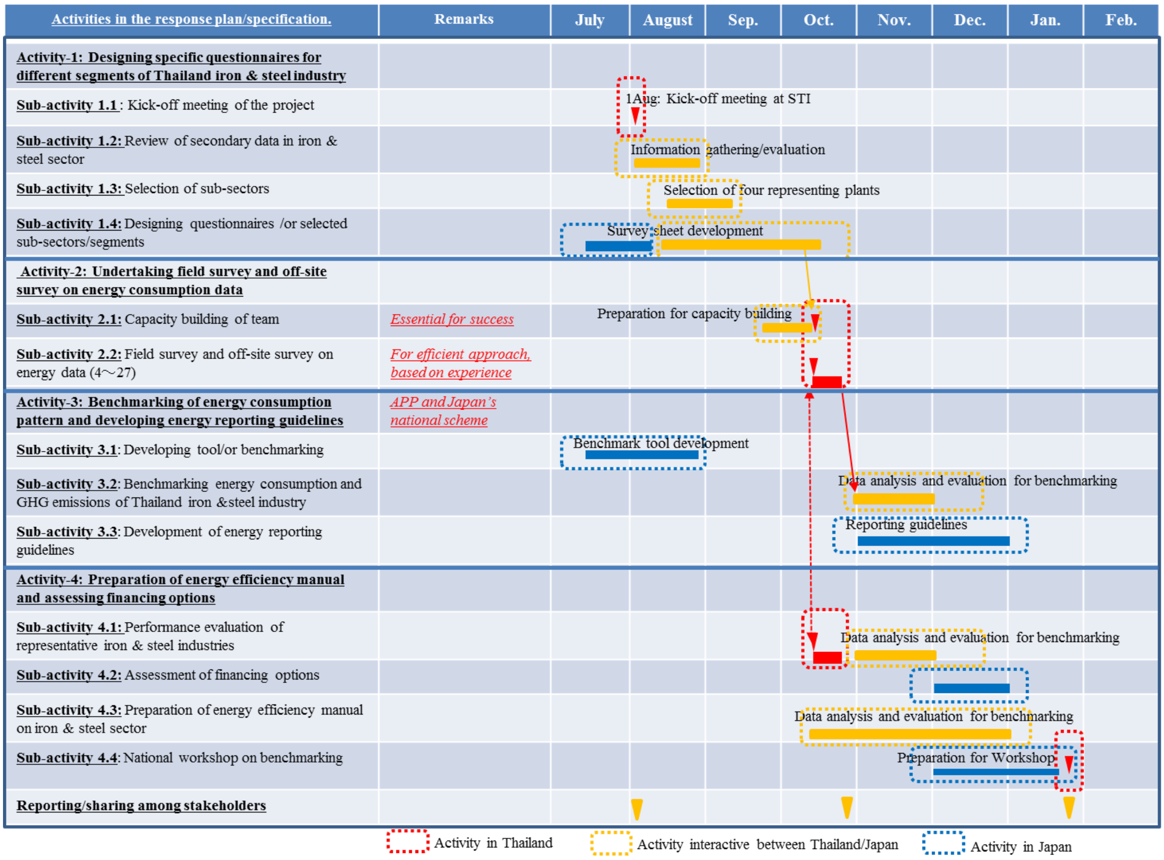

Figure 4: Kick-off meeting material: timeline for CTCN activities and reporting

Summary of Expert Meeting between ISIT, NSRI and JFE-TEC

1) Date & Time : 9:30~13:00 Wednesday, 2 August, 2017

2) Participants :

- ✧ **Iron and Steel Institute of Thailand (ISIT)**
  Mr. Nattapon RATANAMALEE, Researcher (Metallurgical Engineer)
  Mr. Nattapon ONGPISUT, Researcher (Metallurgy)
  Mr. Atinat BUDDHIVANICH
  Mr. K. SOMPRUKIT
  Ms. Thittiya JANLEE
- ✧ **NSRI**
  Dr. Okazaki Teruo, Director, Environment & Energy Research Department
- ✧ **JFE-TEC**
  Mr. Michio Nakayama, Researcher

3) Location: Conference room of ISIT, BANGKOK

4) Agenda :

1. Introduction of participants
2. Action to the concerns raised by STI in the kick-off meeting held on Tuesday 1 August 2017, especially the number of steelworks visited(four) and surveyed(twenty seven).
3. Roles of ISIT-NSRI/JFE-TEC in this CTCN Project and Action Plan for time being.
4. Brief description of a contract between ISIT-NSRI and its procedures.
5. Other issues, if any.

5) Major conclusions shared between ISIT-NSRI/JFE-TEC.

- ISIT-NSRI/JFE-TEC shared a consensus that it is crucial to work together for a success of the present CTCN Project with efficient collaboration.
- ISIT suggested that benefits of participation of survey for the experts in steelworks in Thailand should be effectively explained in the beginning part of the survey sheets to be distributed. Experts in Thailand are interested in the information which is based on the experience of Japanese experts.
- Next visit of NSRI/JFE-TEC will be coming October. At that time, capacity building session will be prepared for the engineers in ISIT who attend the meeting on Wednesday 2 August between ISIT-NSRI/JFE-TEC. It is basically allowed to participate for engineers in steel industry in Thailand.
- A set of survey sheets will be distributed to steelworks by ISIT in end of August. In the original plan, in the first step a set of survey sheets is distributed to the four steelworks and in the second step it will be distributed to other steelworks after some revision of a set of survey sheets, if necessary.

- The first three months action is crucial for success. Action Plan is shared and agreed. All year around, frequent and continuous communication between ISIT and NSRI is very important.

Sub-activity 1.2: Review of secondary data in iron & steel industry

The project collated information and data from past studies that were undertaken in the Thailand iron & steel industry by ISIT. The review of secondary data helped in understanding existing the status of iron & steel industry of Thailand in terms of supply and demand, industry structure, number of units in each sub-sector, energy consumption, share of energy consumed by different sub-sectors, and more.

Overview of supply and demand

*Figure **5*** shows the current supply and demand of Thailand's iron & steel industry. Although the apparent steel consumption (finished steel products) dropped in 2009 because of the global financial crisis, it has been substantially increasing and went up by 50% in the last decade. Though consumption declined for these 2 years, in 2016 it increased 15% from the previous year to 19.21 million tons. The rate of crude steel self-sufficiency was low at 42% in 2016[1] and imports of long products and flat products were the highest ever recorded.

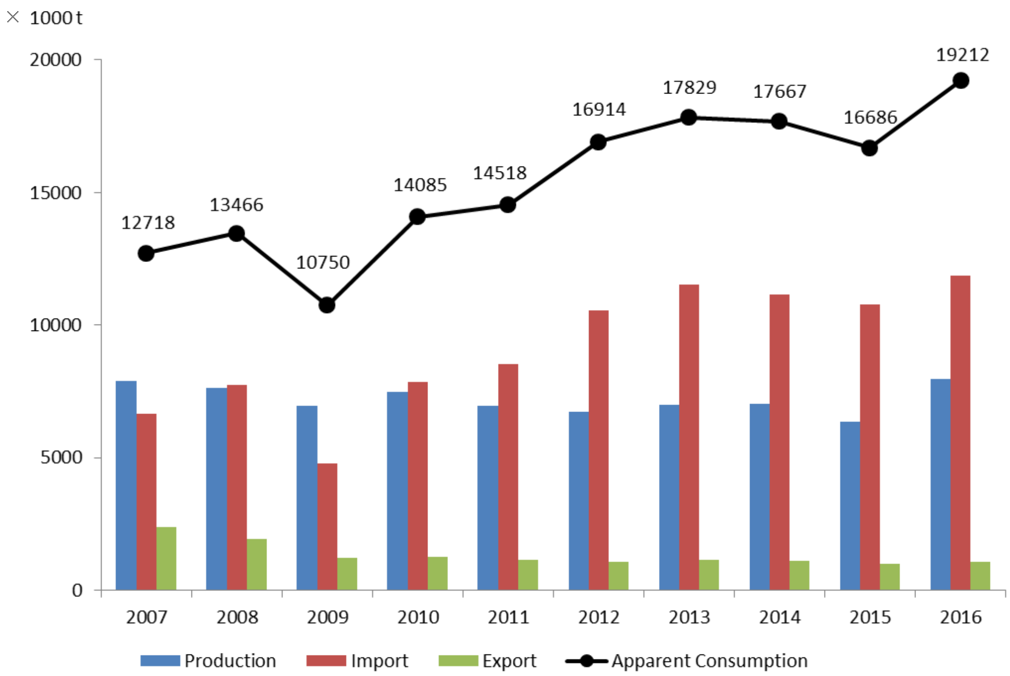

Figure 5: Supply and demand of Thailand iron & steel industry[2]

As *Figure **6*** shows, the main source of demand is the construction industry. The market size of the Thai construction industry has been growing and went up by 50% in the last decade (see *Figure **7***). Steel consumption is expected to increase in the future because Thailand's government is planning to appropriate $54 billion for infrastructure development by 2022, which includes improvement and expansion of the long-distance railroad network.

[1] SEAISI Statistical Handbook 2017

[2] NSRI made based on "SEAISI Statistical Handbook 2017 (WSA)"

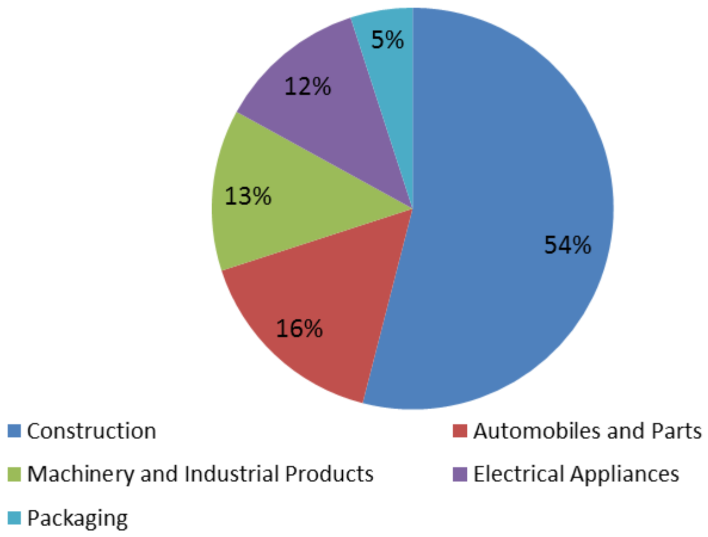

Figure 6: Rate of demanders (2013)[3]

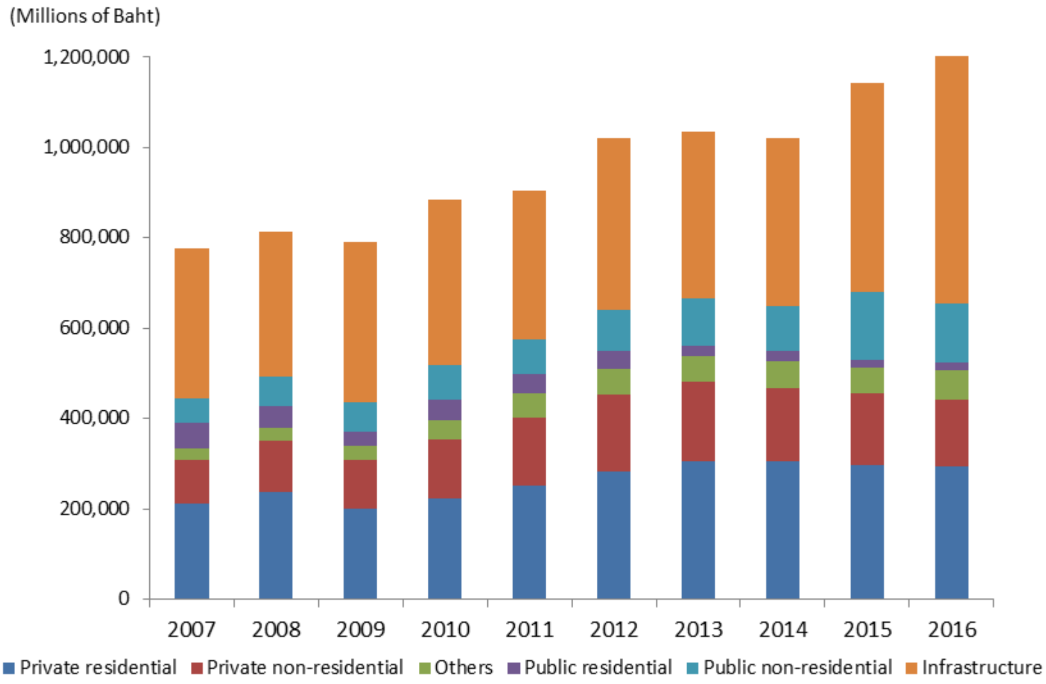

Figure 7: Market size of Thai construction industry[4]

<u>Industry structure</u>

The main steel production routes in Thailand are scrap recycling (melting in Electric Arc Furnaces) and hot rolling of imported long and flat steel products (see *Figure **8***). The production volumes of long steel and flat steel in 2016 were 5.3 million tons and 2.68 million tons respectively, so the ratio of long and flat steel products was 1 to 2 in that year.[5]

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[3] NSRI, based on "Energy Efficiency in the Thai Steel Sector : ISIT's Efficiency Action Plan (ISIT)"

[4] NSRI, based on the data of Office of the National Economic and Social Development Board (NESDB) (Note: the data of 2016 is estimated by Q1/2016 growth (compare with Q1/2015) of each sector)

[5] SEAISI Statistical Handbook 2017

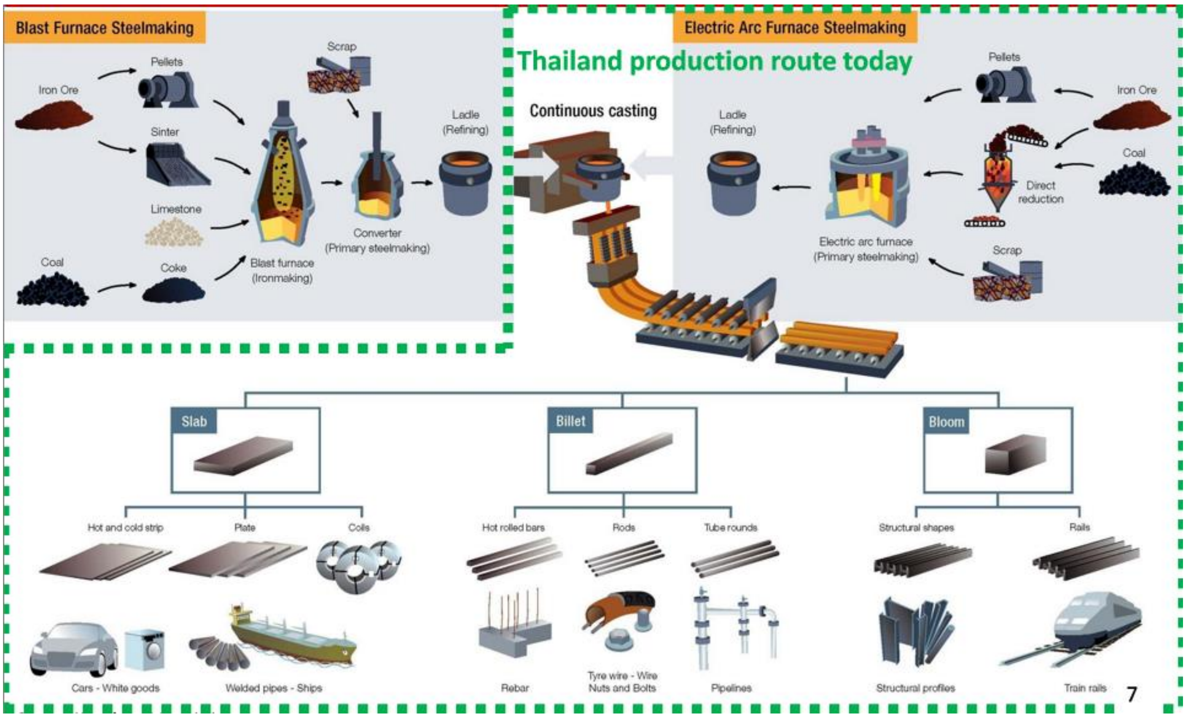

Figure 8: Thailand steel production route[6]

Figure ***9*** shows the current industry structure of Thailand's iron & steel industry. Operation rates were low at 30-40% in 2016.[7] This is mainly because the facilities have become too old and the production cost is higher than the import cost. Consequently, domestic production has not increased though steel consumption has been growing, as shown in *Figure* ***5***.

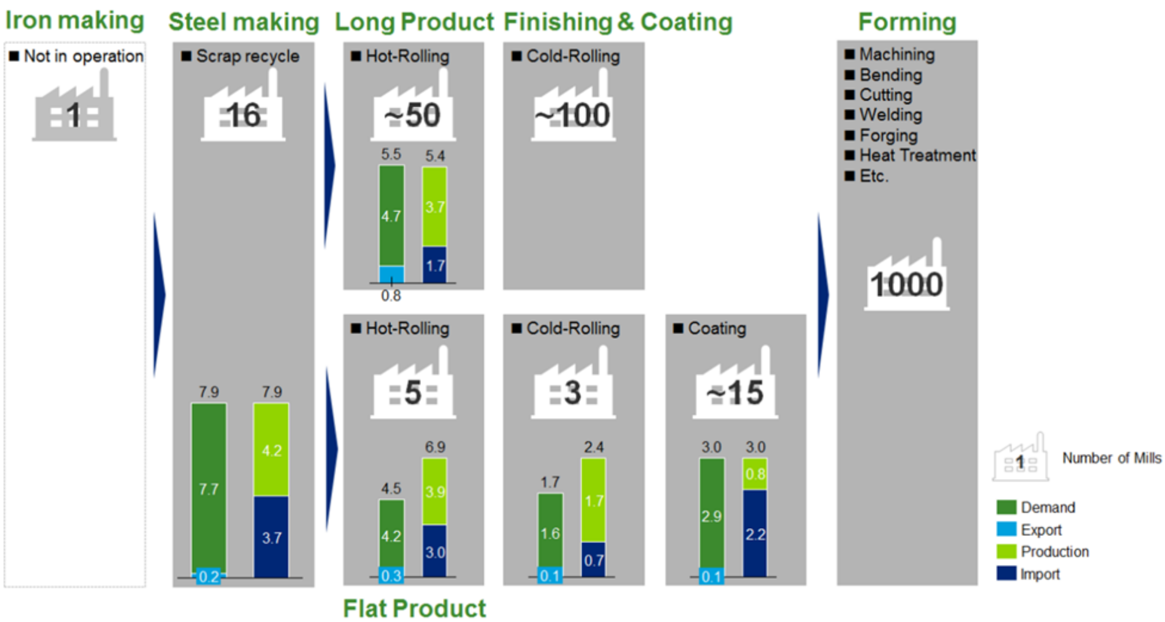

Figure 9: Industry structure of Thailand iron & steel industry (2013)[8]

Energy consumption and energy share

[6] "Energy Efficiency in the Thai Steel Sector : ISIT's Efficiency Action Plan (ISIT)"

[7] "UPDATE THAILAND STEEL REPORT (ISIT)"; NSRI, based on the data of Office of the National Economic and Social Development Board (NESDB) (Note: the data of 2016 is estimated by Q1/2016 growth (compare with Q1/2015) of each sector)

[8] "Feasibility study of JCM project for energy saving technologies for iron and steel industry in Thailand (METI)"; "Energy Efficiency in the Thai Steel Sector : ISIT's Efficiency Action Plan (ISIT)"

The energy consumption of Thailand's iron & steel industry was 922 ktoe in 2012.[9] *Figure **10*** shows energy intensity by product and *Figure **11*** shows production volume by product.

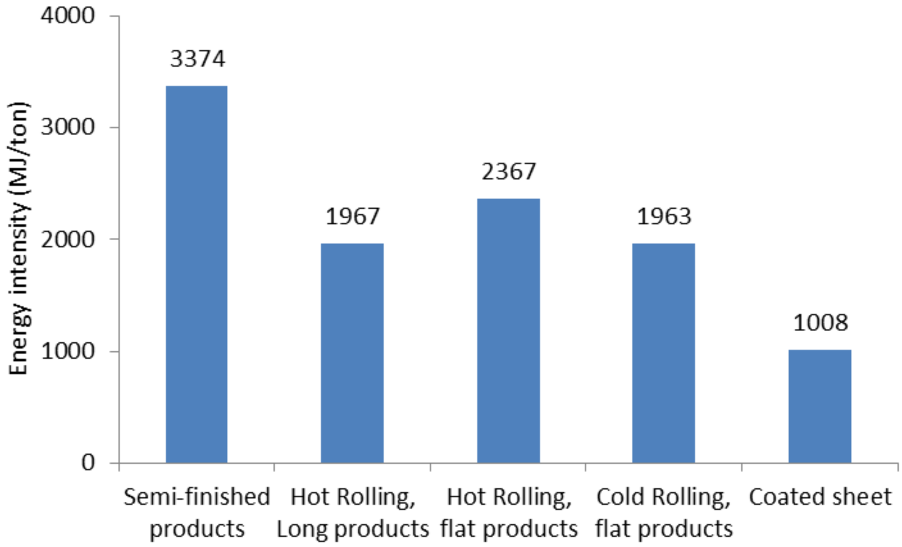

Figure 10: Energy intensity by product of Thailand iron & steel industry (2012)[10]

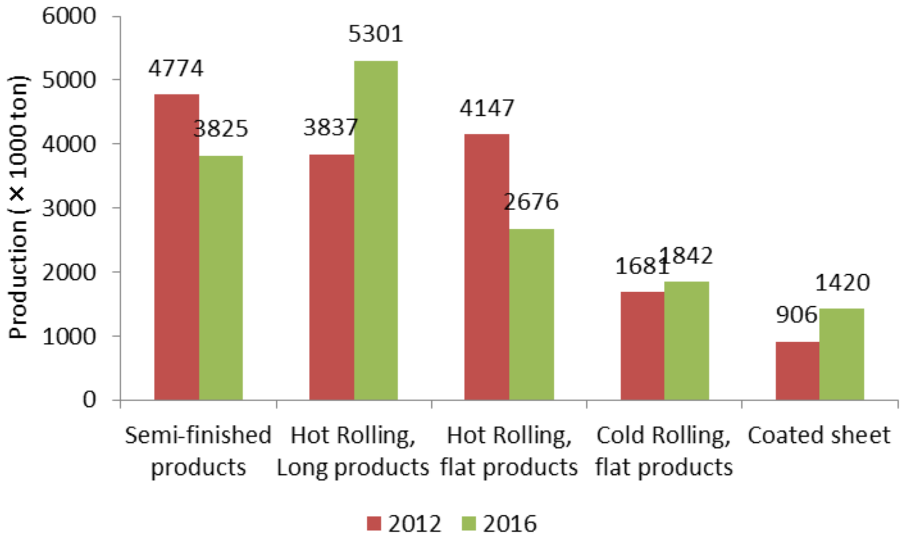

Figure 11: Production volume by product of Thailand iron & steel industry (2012)[11]

*Figure **12*** shows the energy consumption share by sub-sector. Hot rolling mills consume 44% of total energy consumption and EAF mills consume 35% of total energy consumption (2012). On the other hand, Figure 13 shows the average of energy consumption share by process of an EAF mill making long products in Japan (2008). The EAF process consumes 69% of total energy consumption and rolling process consumes 26% of total energy consumption in a mill. Thai scrap recycling plants are considered to have similar trends and figures. This data suggests that EAF mills can conserve energy with effect by tackling energy saving of EAF process as priority.

[9] "Energy Efficiency in the Thai Steel Sector : ISIT's Efficiency Action Plan (ISIT)"

[10] NSRI, based on "Energy Efficiency in the Thai Steel Sector : ISIT's Efficiency Action Plan (ISIT)"

[11] NSRI, based on "Energy Efficiency in the Thai Steel Sector : ISIT's Efficiency Action Plan (ISIT)" and "UPDATE THAILAND STEEL REPORT (ISIT)"

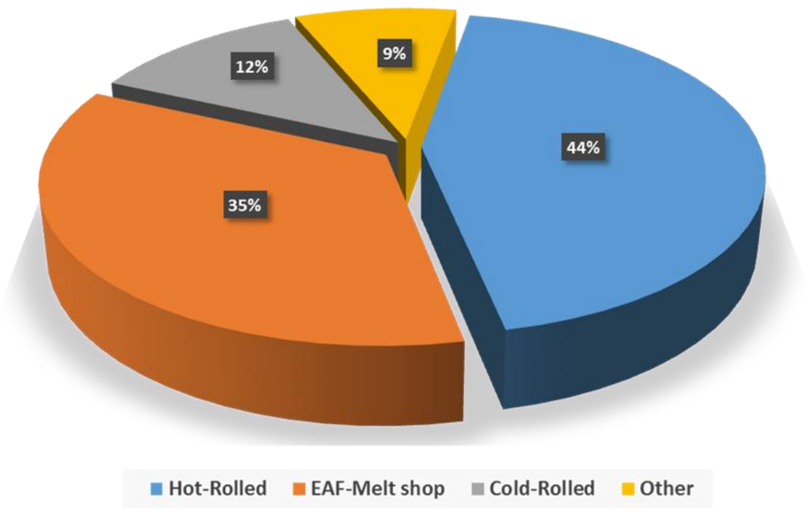

Figure 12: Energy consumption share by sub-sector in Thailand (2012)[12]

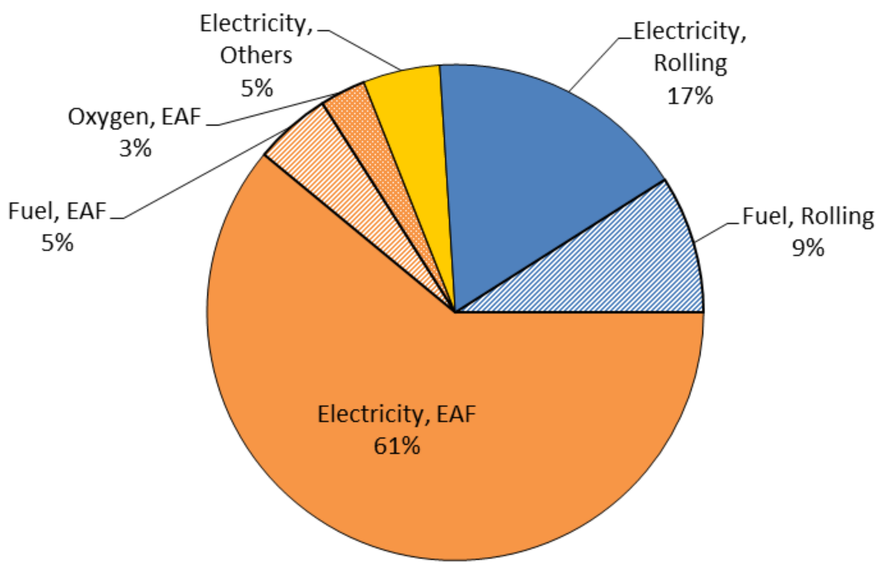

Figure 13: Average of energy consumption share by process of a Japanese EAF mill (2008)[13]

Sub-activity 1.3: Selection of sub-sectors

The iron & steel industry in Thailand comprises steel making, finishing & coating, and forming operations, which are diverse in nature and exhibit variable levels of energy consumption. Of these sub-sectors, some are quite energy intensive and account for higher energy consumption levels. In order to maximize impacts on energy efficiency improvements and GHG reductions, it is worthwhile to focus on sub-sectors that account for a major share of energy consumption overall in the iron & steel industry. For example, the benchmarking study by ISIT indicates that processes like scrap recycling (melting in Electric Arc Furnaces) and hot rolling of long and flat steel products are quite energy intensive, and exhibit higher SECs as well as high energy consumption levels. A set of selection criteria including production capacity, energy consumption, and fuel type was prepared and used for the selection of sub-sectors. It was decided that the focus should be on the sub-sectors of EAF and hot rolling. Each of these sub-sectors has different configurations for the production processes for flat products and long products.

Furthermore, the ASEAN-Japan Steel Initiative (AJSI), Ministry of Economy, Trade and Industry (METI) and the Japan Iron and

[12] "Thailand's Steel Industry Energy Consumption by Process, 2012 : Vision of ISIT (ISIT)"

[13] NSRI, based on the private memo from JISF to ISIT regarding energy consumption

Steel Federation (JISF) have conducted plant studies in order to deploy energy saving and low carbon technologies widely used in Japanese steel industry in other ASEAN countries in the past few years, focusing on EAF and hot-rolling. A major finding from this work is that there is a significant potential to improve in energy efficiency in these sub-sectors. This provides an additional reason to focus on these sub-sectors in this CTCN project.

The selection of the 4 sub-sectors was discussed with ISIT using the existing data and information from ISIT and the Japan experts. A field survey was conducted in one plant in each category below. Sites were selected according to the provided data and their intention to study energy saving.

(1) Scrap recycling of long products
(2) Scrap recycling of flat products
(3) Hot rolling of long products
(4) Hot rolling of flat product

Sub-activity 1.4: Designing questionnaires for selected sub-sectors

(1) Designing Questionnaire

The questionnaires were focused on the electric arc furnace (EAF) and reheating furnace (RHF) and their relevant utilities and auxiliary equipment that consume a large amount of energy in the sub-sectors selected in Sub-activity 1.3. The questionnaires were also designed to ensure the collection of all the relevant data and information necessary to perform an energy benchmarking analysis.

Moreover, in order to evaluate the logistics of high temperature objects such as ladles and billet/slab from the viewpoint of energy efficiency, the questionnaires were also designed to collect the logistics information of the equipment in the steel plant.

With these questionnaires, it is possible to calculate the energy intensity and the CO2 intensity of each facility that is described in Activity 3.2. Regarding questions about consumed energy and emitted CO2 in the whole steel plant, ISO 14404-2 has an international standard calculation sheet specialized for steel plants with EAF which was used for the calculations for plants with EAF and re-rollers without EAF.

The outline of the question items concerning with EAF and RHF is below. As there are no particular differences in the equipment and operation methods of EAF and RHF when producing flat or long products, the same questionnaires were used regardless of the difference in the product shape.

For EAF:
-Product mix and product size
-Annual steel production and energy consumption
-Specifications and operating practices for main equipment (EAF, ladle furnace, and continuous casting machine (CCM)
-Specifications and operating practices of utilities and auxiliary equipment
-Logistics of ladles inside of melt shop
-Others (recent improvements in facility and operations)

For hot rolling (RHF):
-Product mix
-Annual steel production and energy consumption
-Specifications and operating practices of RHF

-Logistics between continuous casting machine and hot rolling mill, hot charge ratio
-Others (recent improvements in facility and operations)

After sending the questionnaires (in English) to the Thai expert team on August 16th, the Thai expert team confirmed the contents of the questionnaires, and sent them out to the companies. To compensate for a potentially low response rate, the number of questionnaires distributed to the companies increased to 63. Every questionnaire that was sent out also included a Thai letter was attached to clearly explain the purpose and significance of the survey. The letter also stated that the report will be fed back to the cooperated companies and individual company names will not be stated when the report is published.

(2) Questionnaire response rate
The questionnaire was distributed to 63 companies through ISIT. Figure 14 shows questionnaire response rate. The response rate was 27%. From the responses, the data useful for analysis included 9 furnaces for EAF, 20 furnaces for RHF, a total of 29 furnaces. The coverage ratio representing the amount of steel production of respondent companies to the total amount of steel production in Thailand was over 70%. Therefore, the survey data was considered representative of Thai steel plants, and useful for the benchmarking study.

Category	Number of steel mills		Furnaces in plants that responded**		Production of final products in 2016	
	Total number	Number of Responses	EAF (Number of plant)	RHF	Total Mt-steel/y	Responded Mt-steel/y
FLAT with EAF	2	2 [100%]	2 (2 *)	1 ┐ (5*)	1.3	1.3 [100%]
FLAT without EAF	2	2 [100%]	-	4 ┘	1.3	1.5 [>100%]
LONG with EAF	14	8 [57%]	7 (10*)	10 ┐ (10*)	3.4	2.5 [74%]
LONG without EAF	45	5 [11%]	-	5 ┘	1.9	0.6 [32%]
Grand total	***63***	***17*** ***[27%]***	***9*** *(12*)*	***20*** *(15*)*	***7.9***	***5.8*** ***[73%]***
			total ***29*** *(27*)* *[107%]*			

* target number of furnaces, ** data used for analysis

Figure 14: Questionnaire response rate

Activity-2: Undertaking field survey and off-site survey on energy consumption data
Activity 2 is composed of two sub-activities: Sub-activity 2.1: Capacity building of team, and sub-activity 2.2: Field survey and off-site survey of energy data". "Sub activity 2.1" involves sharing of knowledge with Thai experts concerning the data collection and performance evaluation of Thailand steel mills. "Sub activity 2.2" includes (1) Data collection and analysis based on questionnaire and (2) Field survey by Thai and Japanese experts of 4 plants.

The aim of Activity 2 was to collect reliable energy consumption data from as many steel plants in the selected sub-sectors of Thailand as possible for the benchmarking analysis in Activity-3. In addition to off-site survey using the questionnaire designed in Activity 1, total of 4 plants (1 plant from each of the 4 selected sub-sectors) were selected for field survey.

At the beginning phase of the project, it became evident that winning participation of Thai steel companies was a major challenge. In anticipation of this challenge, the questionnaire was disseminated to all 63 steel companies existing in Thailand. As a result, energy consumption could be collected from total of 29 plants, overcoming the target of 27 plants as specified in the response plan.

The field surveys and off-site surveys facilitated the collection of data and information from companies in the selected sub-sectors using questionnaires designed for the purpose. The surveys captured all relevant data and information required for further analysis.

The expert team of Thailand joined the Japanese experts in conducting the field survey to take advantage of these occasions also as opportunities for hands-on capacity building of the Thailand expert team.

Sub-activity 2.1: Capacity building of team

The field survey on energy data was conducted by a dedicated team composed of Japanese and Thai experts. The Iron and Steel Institute of Thailand has been identified as the local organisation having requisite capacities to entrust the responsibility for carrying out the survey in selected key sub-sectors of iron & steel companies, under the assistance of the Japanese Expert Team.

Data collection on energy related subjects in steel plants require highly specialized knowledge and experiences, as there are many nuances at the plant-level and process-level that need to be understood and taken into consideration in order to ensure the data collected is relevant for benchmarking analysis. Hence, it was considered essential that all members of field survey team were provided adequate orientation and training before participating in the field survey.

For this purpose, a capacity building workshop covering the necessary information was organised on November 9, 2017 and November 10, 2017. The outline of the capacity building workshop is described below.

Date: November 9, 2017 and November 10, 2017
Location: Office of Iron and Steel Institute of Thailand in Bangkok
Participants:
<Thai Expert Team>
Mr. Atinat Buddhivanich
Ms. Thittiya Janlee
Mr. Nattapon Ongpisut
Mr. Nattapon Ratanamalee
<Japanese Expert Team>
Mr. Naoto Koda (JISF)
Dr. Teruo Okazaki (NSRI)
Ms. Mio Kitayama (NSRI)
Dr. Seiji Itoyama (JFE-Tech)
Mr. Michio Nakayama (JFE-Tech)

Contents:
Sharing of information and discussion among the experts took place according to the following agenda.

【November 9, 2017】

Time	Topic	Presenter
9:30-9:45 (15 min)	**Opening Remarks**	ISIT
9:45-10:00 in)	**CTCN Project Overview and Purpose of the Workshop**	NSRI

10:00-10:30 (30 min)	**Introduction to steel production processes and energy consumption** part-1: steel industry in general basic information on steel production processes overview of energy usage in steel production processes part-2: EAF based steel industry Outline of EAF steel making process Features of EAF process Q&A	NSRI (Dr. Okazaki) JFE-TEC (Mr. Nakayama)
11:00-11:30 (30 min)	**Overview of Japanese steel industry and its energy saving activities** Overview of Japanese steel industry Introduction of Japanese energy saving activities Q&A	JISF (Mr. Koda)
11:30-13:00	*Lunch Break (1.5hr)*	
13:00-13:45 (45 min)	**Development of questionnaire for benchmarking 【Activity-1】** Total energy consumption, EAF and RHF questionnaire review How to choose the factors to include in each questionnaire Feedback from ISIT/steel companies: difficulties, suggestions for improvements, etc. Q&A	JFE-TEC (Dr. Itoyama) ISIT (TBD)
13:45-14:15 (30 min)	**Planning and conducting field survey of steel mills【Activity-2】** Steps for planning and conducting field survey Overview of 4 sites to be visited for CTCN project Confirming work assignments of ISIT staff Q&A	JFE-TEC (Mr. Nakayama)
14:15-14:30	*Break (15 min)*	
14:30-15:15 (45 min)	**How to Make and Use Thermal Balance 【Activity-2】** Purpose of Thermal Balance Thermal Balance for EAF Thermal Balance for RHF Candidate Furnaces Q&A	JFE-TEC (Mr. Nakayama)
15:15-15:45 (30 min)	**Development of Benchmarking Tool 【Activity-3】** What is benchmarking? Choosing set of emission/energy factors suitable for Thailand Development of benchmarking tool in Microsoft Excel Examples of benchmarking application (Japan and Europe cases) Q&A	NSRI (Ms. Kitayama)
15:45-16:00	*Break (15 min)*	
16:00-16:30 (30 min)	**Application of ISO14404 Series in benchmarking Thailand steel industry [Activity-3】** Introduction to ISO14404 series How to apply ISO14404 series to Thailand steel industry Q&A	NSRI (Ms. Kitayama)
16:30-17:00 (30 min)	**Development of Reporting Guideline 【Activity-3】** Explaining reporting guideline in Japan Feedback from ISIT/steel companies…what should be done differently for Thailand Q&A	NSRI (Dr. Okazaki)
17:00-17:30 (30 min)	**Improvement of energy efficiency using ISO50001【Activity-3】** Introduction of ISO50001 Activity of Japanese steel industry using ISO50001 Q&A	NSRI (Dr. Okazaki)
17:30-17:45	*Closing of 1st day (wrap-up discussion)*	

【November 10, 2017】

Time	Topic	Presenter
9:30-10:15	**Development of energy efficiency manual (technology customized list) for Thailand 【Activity-4】** Experiences of developing India and ASEAN customized list Steps for identifying relevant SOPs and technologies (full list to customized list) Q&A	JFE-TEC (Dr. Itoyama)
10:15-11:00	**Introduction of energy saving technology for EAF and RHF【Activity-4】** Energy saving technology for EAF Energy saving technology for RHF Q&A	JFE-TEC (Mr. Nakayama)
11:00-11:45	**Conducting cost-benefit analysis of energy efficiency projects 【Activity-4】** Factors to consider (investment cost, running cost, energy saving benefit, interest rate, CO2 policy) Case studies Various initiatives to support implementation of energy efficiency projects Q&A	NSRI (Ms. Kitayama)
11:45-13:00	*Lunch Break (1.5hr)*	
13:00-14:00	**Overview of Thailand steel industry** Basic information on Thailand steel industry Q&A	ISIT (Mr. Nattapon Ongpisut)
14:00-17:00	**Discussions on related topics** Past energy studies conducted by ISIT Contents of mandatory energy reporting to Ministry of Energy Review of current status of data collection through questionnaire and discussion of actions required Confirmation of field survey sites and schedule	ALL

Feedback from Thailand Expert Team:

Thailand Expert Team members who participated in the workshop commented that the workshop was quite informative and very useful. Especially, they mentioned in the feedback survey the following topics as particularly interesting points:

- Global comparison of Steel's Energy Efficiency and crude steel production
- Electricity consumption of EAF
- Energy saving activities in Japan especially "Three ecos".
- How to choose the factors to include in each questionnaire
- Steps for conducting field survey
- Thermal efficiency calculation
- Development of benchmarking tool in Microsoft Excel
- Calculation method of ISO14404
- Calculation methodology
- ISO50001 Certificate
- Information considered for Preparing Energy Efficiency Manual for Thailand
- Scrap pretreatment to reduce charging frequency

- Payback Period Analysis

Sub-activity 2.2: Field survey and off-site survey on energy data

The field survey and off-site survey of iron & steel industries companies of in Thailand by identified organisation is are essential components of the benchmarking study. The survey focused on the collection of relevant data from the EAF and hot-rolling sub-sectors identified in Sub-activity 1.3 (below). Plant visits were conducted by Thai experts and Japanese experts. A field survey was conducted at one plant from each sub-sector listed below. During the each site visit, answers to the questionnaire were reviewed and additional information was collected if any gaps in the data were identified. Actual steel plant operations were observed to see real operational phenomena and confirm data.

(1) Scrap recycling of long products
(2) Scrap recycling of flat products
(3) Hot rolling of long products
(4) Hot rolling of flat product

Sub-activity 2.2 is divided into two activities: "Sub-activity 2.2.1 Field survey conducted by Thai and Japanese experts", and "Sub-activity 2.2.2 Off-site survey conducted by Thai and Japanese experts". Detailed energy data, discussed upgrades, and potential energy savings are explained in the Chapter "Sub-activity 4.1 Performance evaluation of representative iron & steel companies", and Outcomes of Sub-activity 2.2.2 is explained in the Chapter "Sub-activity 3.2 Benchmarking energy consumption and CO2 emissions of Thailand iron & steel industry". This Chapter discusses the outline of visited plants, visiting schedule, and visitors. For confidentiality purposes, company names are anonymous and product details are not shown.

Table 1: Outline of visited site

Site	Sub-sector	Steel Production (2016)	Main facilities
A	Scrap recycling of long products	> 480,000 ton/y	One 100 ton EAF One 125 ton/h RHF, one mill line
B	Scrap recycling of flat products	> 600,000 ton/y	Two over 130 ton large EAFs One hot strip mill
C	Hot rolling of long products	180,000 ton/y	Two 25 ton EAFs 50, 70 ton/y RHF each Two bar mill lines
D	Hot rolling of flat product	1,280,000 ton/y	Three 250-275 ton/h large RHFs One hot strip mill

Participants of field survey

<ISIT member>

A : Mr. Atinat Buddhivanich
B : Ms. Thittiya Janlee
C : Mr. Nattapon Ongpisut

<Japanese visitor>

D : Mr. Osamu Katayama (NEDO)
E : Mr. Naoto Koda (JISF)
F : Dr. Teruo Okazaki (NSRI)
G : Ms. Mio Kitayama (NSRI)
H : Ms. Mai Yonezawa (NSRI)
I : Ms. Masako Nakajima (NSRI)
J : Dr. Seiji Itoyama (JFE-Tech)
K : Mr. Michio Nakayama (JFE-Tech)

Table 2: Visiting Schedule

Site	Date	Visitor
A	November 14, 2017	A, B, C, D, E, F, G, J, K
B	November 13-14, 2017	A, B, C, D, E, F, G, J, K, L, M
C	November 16, 2017	A, B, C, G, H, J, K
D	November 20-21, 2017	A, B, G, H, J, K

Activity-3: Benchmarking of energy consumption pattern and developing energy reporting guidelines

Companies in the iron & steel industry in Thailand exhibit a wide range of variations in their energy and environmental performance, because of factors such as differences in the choice of production processes and sources of energy. Age, production capacities and capacity utilization of the facilities are also contributing factors. Benchmarking would help companies understand their positions in terms of energy efficiency and GHG emissions as well as the possibilities and directions for future improvements. Using such information, companies would be able to set appropriate targets and take actions for improving energy efficiency.

Activity-3 consisted of three sub-activities, including development of Benchmarking Tool (sub-activity 3.1), benchmarking of energy consumption and CO2 emissions of Thailand iron & steel industry (sub-activity 3.2), and development of Energy Reporting Guidelines (sub-activity 3.3). *Table **3*** provides the summary of major outcomes of the three sub-activities. Further details are provided in the following sections.

Table 3: Major outcomes of Activiyt-3

Sub-activities	Major Outcomes
Sub-activity 3.1: development of Benchmarking Tool	Benchmarking Tool was developed as a tool to be used by Thailand iron & steel industry to track the progress of energy performance.
Sub-activity 3.2: benchmarking of energy consumption and CO2 emissions of Thailand iron & steel industry	An in-depth analysis was conducted using the data collected in Activity-2 to benchmark energy consumption and CO2 emissions of Thailand iron & steel industry
Sub-activity 3.3: development of Energy Reporting Guidelines	Energy Reporting Guidelines were developed to guide Thailand iron & steel companies to effectively use the Benchmarking Tool developed in Sub-activity 3.1 for various types of energy reporting.

It is recommended that the iron & steel industry in Thailand implement the industry-wide reporting scheme, and repeat the reporting cycle every year by using the Benchmarking Tool and Energy Reporting Guidelines. Further details of recommended actions are provided in the "Conclusions and Recommendations" Chapter.

Sub-activity 3.1: Developing benchmarking tool

The Benchmarking Tool will help iron & steel companies track and improve their energy consumption and energy costs. The purpose of the Benchmarking Tool is to use the data that is entered into it to generate a visual comparison of one company's energy intensity and carbon emission intensity to the industry averages (which are generated from industry data collected from previous years) and generate an annual energy report for a given steel plant. The Benchmarking Tool provides a useful means of understanding a company's energy performance relative to its peers in the industry.

The Benchmarking Tool was developed using Microsoft Excel, and was designed to be user-friendly. The tool has an instructions sheet, input sheets, and output sheets, and supplementary instructions on the input sheets that clearly describe the proper way to feed data into the tool.

The first step of developing Benchmarking Tool was to select the most important indicators for tracking the energy performance of Thailand iron and steel industry. While the questionnaire developed in sub-activity 1.4 was very comprehensive, it was considered too ambitious to record and analyse such detailed information every year. In order to make sure that the Benchmarking Tool is realistically useful for the iron and steel companies, three most important energy performance indicators were chosen to be calculated in the Benchmarking Tool: (1) energy consumption and CO2 emission intensity of the entire steel plant, (2) electricity intensity of EAF and (3) fuel intensity of RHF.

The Benchmarking Tool's input sheets that facilitate the collection of various data and information pertaining to selected sub-sectors of the iron & steel industry. Plant managers may choose to enter monthly data or annual data into the Benchmarking Tool. The Benchmarking Tool automatically generates outputs in terms of energy intensity and CO2 intensity.

The tool's outputs appear on two sheets: one sheet provides a visual benchmarking analysis that allows steel plant managers to gauge their energy performance against the industry average, while the other output sheet generates a report sheet for the plant manager to send to ISIT as part of the industry-wide reporting scheme. Thus, in addition to providing insights on actual performance of individual iron & steel companies, the Benchmarking Tool also facilitates the collection of important data for the iron & steel industry of Thailand and relevant stakeholders.

It is important to note that there are two versions of the Benchmarking Tool: one version for facilities with EAF and one version for facilities without EAF. Both versions of the Benchmarking Tool calculate energy intensity and CO2 intensity for the for steelmaking plant as a whole. Energy intensity and CO2 intensity are appropriate performance indicators which can help steel plant managers make decisions for taking action for improving plant energy performance.

Sub-activity 3.2: Benchmarking energy consumption and CO2 emissions of Thailand iron & steel industry

In sub-activity 3.2, the benchmarking of energy consumption and CO2 emissions of Thailand was conducted using data collected through Activity-2. The details of analysis results have been compiled into an independent report titled "Results of Benchmarking Study", which is attached to this report as Appendix-1. While the Benchmarking Tool selected three indicators of energy performance, (1) energy consumption and CO2 emission intensity of the entire steel plant (2) electricity intensity of EAF and (3) fuel intensity of RHF, the benchmarking analysis took advantage of the detailed questionnaire responses to conduct more in-depth analysis of energy performance and contributing factors. The main results of the benchmarking study are introduced below.

(1) Energy consumption of steel plant as a whole

Figure ***15*** shows the average of energy consumption for steel plants in the 3 years from 2014 to 2016. The average energy intensity of 9 EAF based steel plants was 9.1 GJ/t-steel. Other data are shown in green for reference. The average energy consumption among the steel plants studied is 38% higher than the average energy consumption in Japanese EAF based steel plants. The average of energy intensity of the 6 re-roller plants surveyed was 2.5 GJ/t-steel.

In the analysis, the difference in energy consumption due to the difference in the shape of the product to be manufactured was examined, but there was no clear influence on energy consumption based on the difference in product shape. Since there are few surveyed companies that manufacture flat products (2 companies with EAF, and 2 without EAF), there was concern that individual company names might be discerned if product shape information was described in the figures, so product shape information was not included in the figures.

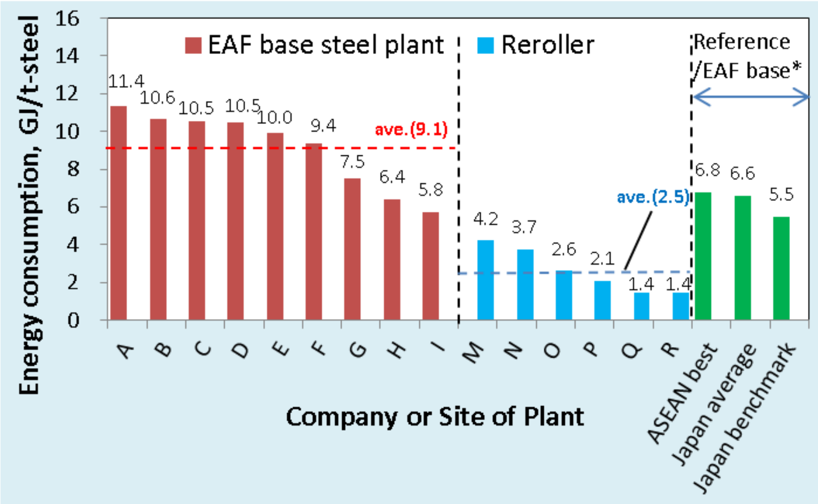

Figure 15: Energy consumption in steelmaking plant[14]

(2) CO2 emissions of steel plant as a whole

Figure ***16*** shows the average of CO2 emission for steel plant as a whole in the 3 years from 2014 to 2016. The CO2 emissions for steel plants with and without EAF was 0.56 and 0.19 t-CO2/t-steel, respectively.

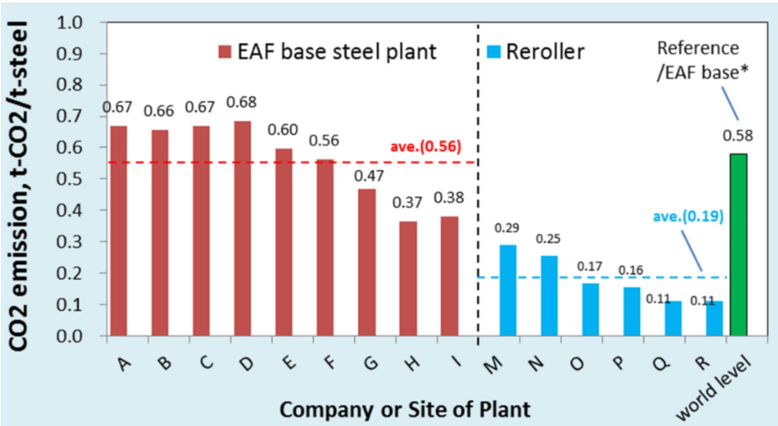

Figure 16: CO2 emission in steelmaking plant[15]

(3) Electricity consumption of EAF

Electricity consumption ranged from 360 to 550 kWh/t, and the average 412 kWh/t (*Figure* ***17***). Reference data are also shown. The average value in the present study is 8% higher than the average electricity consumption in Japan.

[14] Japan data in 2016 is from http://www.enecho.meti.go.jp/category/saving_and_new/benchmark/2016/benchmark28.pdf and ASEAN data in 2014 was researched by JFETEC.

[15] Reference data: JSCE-G, Vol.70, No.6, II_239-II_247, 2014.

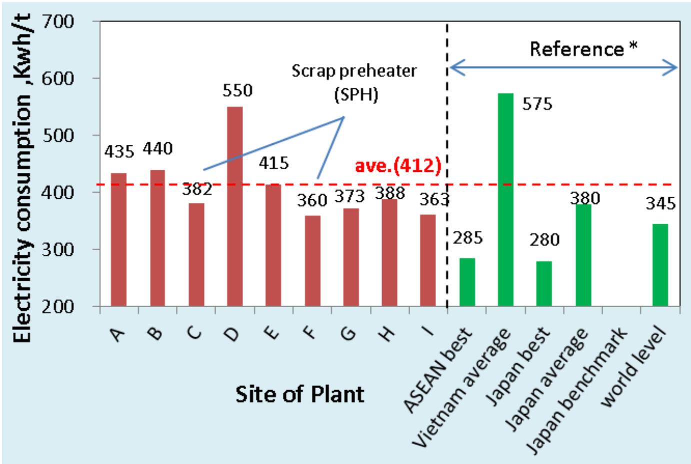

Figure 17: Electricity consumption of EAF[16]

(4) Fuel consumption of RHF

Fuel consumption levels were shown with hot charge, cold charge, and monthly average, respectively in *Figure **18***. Comments in the figure provide information affecting fuel consumption. Fuel consumption in hot charge indicates the lowest value 0.95 GJ/t of the three conditions. This value is 29% lower than that in cold charge. The monthly average 1.44 GJ/t is 34% higher than Japan average.

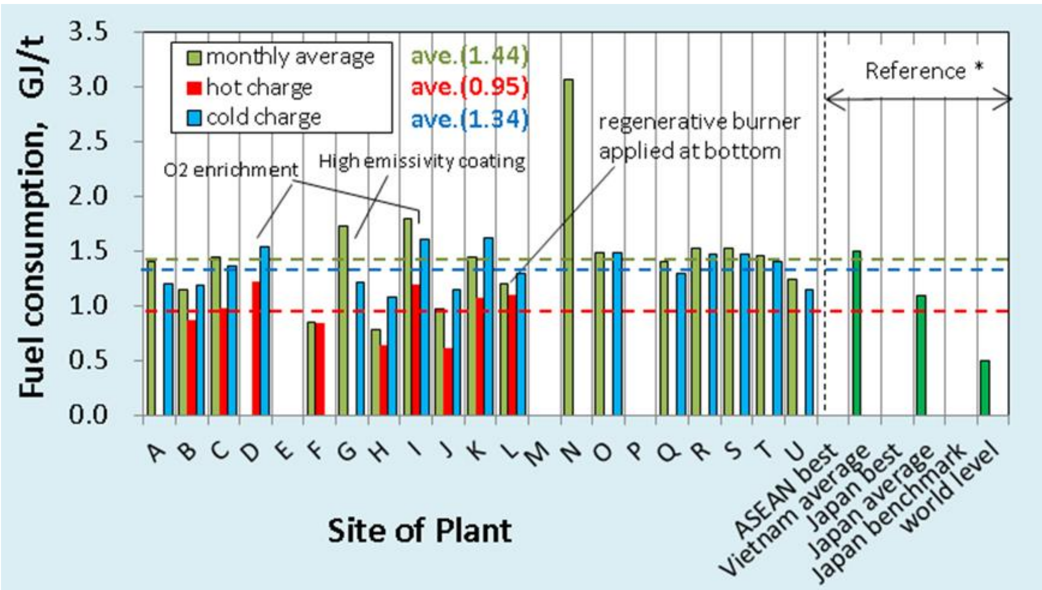

Figure 18: Fuel consumption in reheating furnace[17]

Fuel consumption is strongly affected by the hot charging ratio and temperature of charging material. *Figure **19*** shows effect of hot charge ratio (Rhot) on fuel consumption. Fuel consumption decreases as the ratio increases.

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[16] Japan data in 2016 is from http://www.enecho.meti.go.jp/category/saving_and_new/benchmark/2016/benchmark28.pdf and ASEAN data in 2014 was researched by JFETEC; Vietnam data was estimated by JFETEC on based with Nguyen Thi Ngoc Tho (Energy Efficiency and Conservation Center of Ho Chi Minh City), "Overview of Steel and Paper Industry – Energy Saving Potential" 2012; The “world level” was referred from P. Dahlmann, R. Fandrich and H. B. Lüngen: Stahl Eisen, 132(2012), Nr.10, 29

[17] Estimated from Japan data from http://www.enecho.meti.go.jp/category/saving_and_new/benchmark/2016/benchmark28.pdf on the assumption of Rhot=50% and charging temperature=500 °C by JFETEC

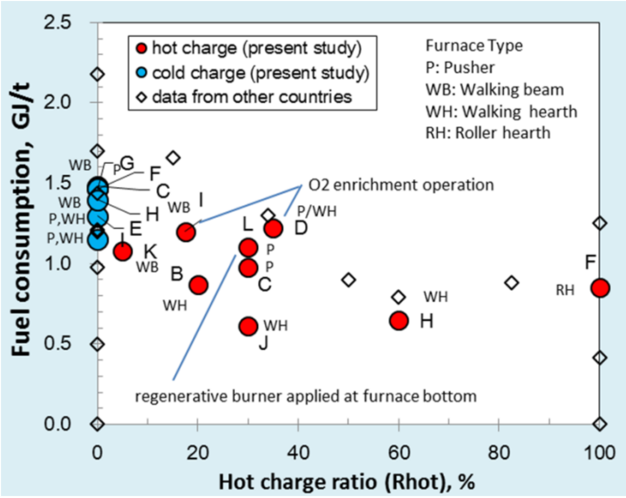


Figure 19: Effect of hot charge ratio on fuel consumption

Summary

(1) Comparison with Japan data

*Table **4**: Summary of questionnaire analysis on the basis of comparison with Japan data*is a summary of the comparison with Japan data. It was found that there is the potential to improve energy consumption in EAF and RHF. As for EAF plants, plant energy consumption was indicated to be 38% higher than Japan data. In the table, reference values for benchmark (which are calculated as the mean minus the standard deviation in cases of energy and fuel[18] and are calculated as mean plus standard deviation in the case of efficiency[19]) of various evaluation indexes concerning energy consumption are also shown. For European benchmark values, specific energy consumption is calculated as the average from the top 10%.[20] When applying this idea to the EAF based steel industry in Thailand, the best data becomes to be the benchmark because the number of data collected this time (N = 9) was less than 10.

As a result, to improve EAF electricity consumption, LF energy efficiency, ladle preheater fuel consumption, and dedusting fan may be good candidates for energy improvements. As for RHF plants, energy consumption was roughly 34% higher than Japan data. To improve RHF energy consumption, energy efficiency and recuperator temperature efficiency may be good candidates for energy improvements.

[18] Based on Agency of Natural Resources and Energy, Japanese government: for example, http://www.meti.go.jp/committee/sougouenergy/shoene_shinene/sho_ene/koujo_wg/2016/pdf/001_03_00.pdf

[19] Calculated just for reference

[20] Official Journal of the European Union (2011/278/EU), Commission Decision of 27 April 2011.

Table 4: Summary of questionnaire analysis on the basis of comparison with Japan data

Factor	unit	Thailand average	Thailand reference for benchmark *1	Japan	Comparison with Japan data
Plant with EAF Electric Arc Furnace (EAF)					
Plant Energy consumption (with EAF)	GJ/t	9.1	7.1	6.6	38% higher
Plant CO2 emission (with EAF)	t-CO2/t	0.56	0.44		
Electric Arc Furnace					
EAF Electricity consumption	kWh/t	412	352	380	8% higher
EAF Electrode consumption	kg/t	1.5	0.9	0.8-2.0	same performance
Fe yield	%	89	90.9	92-93	3% lower, but no significant difference in consideration of O2 consumption
Oxygen consumption	Nm3/t	30-50	-	10-20	
EAF Energy efficiency	%	62	72	50-67	no significant difference
Ladle furnace					
LF Energy efficiency	%	17	30	35	20% lower
Ladle preheater					
Ladle preheater fuel consumption	GJ/t	0.57	0.29	0.2-0.3	2 times higher
Oxygen burner	GJ/t	0.3	-	-	
Regenarative burner	GJ/t	0.9	-	0.17	5 times higher
Ladle logistices					
(EAF+LF) Electricity consumption vs time(t) from tapping start to CC end	GJ/t				50kWh/t larger (at t=100min.)
Auxiliary equipment					
Dedusting fan electric consumption	kWh/t	36	28	ca. 30	20% higher, influenced by operatio ratio
Reheating Furnace (RHF)					
Plant Energy consumption (without EAF)	GJ/t	2.6	1.4	-	
Plant CO2 emission (without EAF)	t-CO2/t	0.18	0.11	-	
Reheating Furnace					
RHF Fuel consumption (monthly)	GJ/t	1.44	0.94	1.1	34% higher (Thai: billet, bloom & slab, Japan ave.: 50% hot charge at 500degC of slab)
RHF Fuel consumption (cold charge)	GJ/t	1.34	1.17		
RHF Fuel consumption (hot charge)	GJ/t	0.95	0.73		
RHF Fuel Energy efficiency	%	47		57	10% lower (at 500 degC of charging temp.)
Recuperator Temperature efficiency	%	51	58	80	30% lower

*1: average-standard deviation (energy and fuel), or average+standard deviation (efficiency)

(2) Comparison among Thai companies

*Table **5*** is a summary on the comparison of operating performance among steel plants in Thailand. Four technologies in particular were found to be effective for improving energy consumption. Those are 1) Scrap preheating, 2) Ladle preheating by oxygen burner, 3) Dedusting fan control by VVVF (Variable Voltage Variable Frequency), and 4) Hot charging operation.

Table 5: Summary of questionnaire analysis of comparison of operating performance among steel plants in Thailand

Factor	unit	with	without	Performance evaluation of "with"	
Scrap preheater					
EAF Electricity consumption	kWh/t	371	423	12% lower	○
	N	(2)	(7)		
EAF Electrode consumption	kg/t	1.2	1.6	27% lower	○
	N	(2)	(7)		
Tap-tap time	min.	61	58	3 minites shorter	△
	N	(2)	(6)		
EAF Energy efficiency	%	72	59	13 points higher	○
	N	(2)	(6)		
Fe yield	%	87.0	90.0	3 points lower	△
	N	(2)	(7)		
Ladle preheater by Oxygen burner					
Fuel consumption	GJ/t	0.30	0.72	2.5 times lower	○
	N	(3)	(3)		
Ladle preheater by Regenarative burner					
Fuel consumption	GJ/t	0.90	0.72	25% higher	×?
	N	(1)	(3)		
Dedusting fan control by VVVF					
Electricity consumption	kWh/t	34	37	10% lower	○
	N	(2)	(6)		
Hot charging into RHF					
Fuel consumption	GJ/t	0.95	1.34	29% lower	○
	N	(9)	(16)		
Remarks ○: better performance, △: relatively poor performance, ×?: need more survay					
N: number of data					

Sub-activity 3.3: Development of energy reporting guidelines

The Energy Reporting Guidelines (ERG) were developed to regularly aggregate energy consumption data of the iron & steel industry in Thailand. The ERG accounts for the diversified nature of iron & steel companies and sub-sectors in Thailand, and focuses on collecting data to produce energy intensity and CO2 intensity metrics for each company.

The ERG includes the following content:

- discussion of the importance and applications of energy data collection and reporting
- directions on how to input data in the Benchmarking Tool for energy reporting
- description of a proposed industry-wide energy reporting scheme for the Thai iron & steel industry

The ERG describes an industry-wide reporting scheme for energy consumption in which steel companies use the Benchmarking Tool to create annual reports on energy consumption which are then used to create an industry-wide report on energy consumption. The annual energy reporting scheme will be immensely helpful for both individual steel companies that want to improve their energy performance and for steel industry stakeholders and government bodies making policy and business decisions.

Activity-4: Preparation of energy efficiency manual and assessing financing options

Benchmarking indicates the degree to which there is a potential for energy performance improvements for individual companies. However, benchmarking does not provide directions for achieving increased energy efficiency and reduced CO2 emissions. In order to realize potential energy savings revealed in the benchmarking analysis, a company may need additional resources to understand the specific operational changes and equipment upgrades that can increase energy efficiency, and the options for financing such equipment upgrades.

Several activities and deliverables were prepared to address this need:

- A performance evaluation of representative iron & steel companies was undertaken to reveal important issues and lessons for energy efficiency.
- An Energy Efficiency Manual was created to identify and share specific technologies and practices relevant for Thailand for further adoption along with financing needs.
- A Financing Options document was prepared to outline potential techniques and sources of financing for equipment upgrades that improve energy efficiency.

Each of these activities is described in greater detail in the following sections, along with a description of the national energy benchmarking workshop.

Sub-activity 4.1: Performance evaluation of representative iron & steel companies

During the site survey at the steel plants selected in "Sub-activity 2.2: Field survey and off-site survey on energy data", Japanese experts proposed efficient energy saving technologies and discussed with the staff. The proposal and discussion were conducted based on the data collected from the questionnaires and on-site observation.

The performance evaluation focused on EAF (Electric Arc Furnace for scrap melting) and RHF (Reheating Furnace for rolling), because these facilities consume much energy; EAF consumes about 50% of total plant energy and RHF consumes about 25%. The processes of both EAF and RHF are complicated and have much room for improvement. Energy saving technologies for such auxiliary equipment as ladle heater, dedusting line, and water treatment line were discussed. Japanese experts proposed thermal balance measurement and analysis for EAF and RHF for further quantitative study. Some companies showed interest in the EAF thermal balance analysis, but because of the lack of time for sensor preparation and disagreement of management, EAF thermal balance was not conducted. A detailed manual on conducting thermal balance analyses was transferred to the ISIT experts, who can distribute it to any companies interested in conducting it by themselves. Thermal balance analyses for RHF were conducted for two sites.

Energy data from the main facilities and discussion with the site staff are explained below:

<Site A : Scrap recycling of long products (EAF)>

Energy data

EAF electricity consumption	: 360 - 365 kWh/ton
Number of scrap charges	: 4 - 5 times
Fuel consumption	: 4.5 - 5.0 m3N/ton
Oxygen	: 35 - 37 m3N/ton
Coke injection	: 18 - 20 kg/ton
Fe yield	: 90.7 – 90.8%

The following was concluded after discussion

Electricity consumption of 360-365 kWh/ton is a top level performance in ASEAN, close to Japanese high performance furnace. Observing operations lead to the following assumptions about reasons for good performance:

(1) Closing slag door during melting by using coherent burner contributes minimizes cold air invasion
(2) Good slag foaming by coherent burner
(3) Shorter refining time to judge proper temperature and C content

Further improvement to 340-350 kWh/ton may be possible by reducing the scrap charging time by scrap pretreatment. 4 - 5 charges seems high, and reducing the number of charges to 3 by compacting the scrap, a reduction in energy intensity of 20 kWh/ton is expected. In other words, decreasing the number of charges by one can result in 20 kWh/ton savings.

*Figure **20*** shows a comparison with similar sized Japanese EAFs relating oxygen and electricity consumption. Each additional 1 m3N/ton of oxygen is said to contribute to 4 kWh/ton of electricity saving. *Figure **20*** clearly shows this tendency, and EAF in Site A has about the same level of performance as quality Japanese furnaces.

*Figure **21*** is the sketch and photo of the coherent burner. The oxygen jet from the centre hole is restricted to expand the combustion around the jet. The combustion is generated by the fuel and oxygen from the peripheral nozzles. When lances from slag door cannot reach the back side of a large furnace, this burner installed on the backside works efficiently.

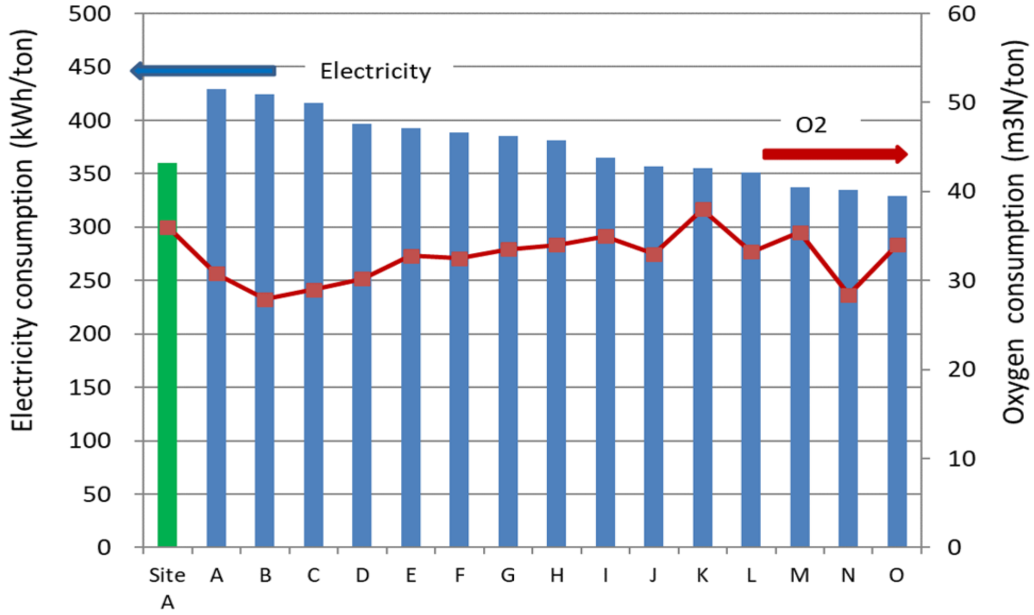


Figure 20: Comparison with similar size Japanese EAFs

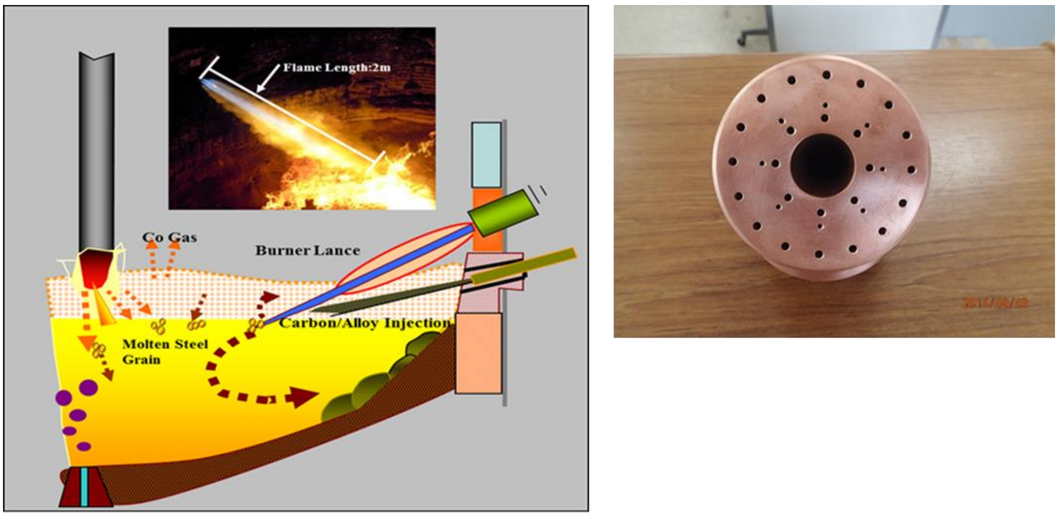


Figure 21: Coherent burner

*Figure **22*** shows a comparison of the relationship of oxygen consumption and Fe yield at Site A and Japanese EAFs. The coherent burner contributes to increase productivity and reduce electricity, but consumes more oxygen, natural gas, and tends to decrease Fe yield. How to use a coherent burner depends on the productivity and yield, and the consumption of natural gas and oxygen. It is essential to compare the cost reduction resulting from productivity increase and electricity saving and the cost increase resulting from oxygen/fuel increase and scrap oxidation.

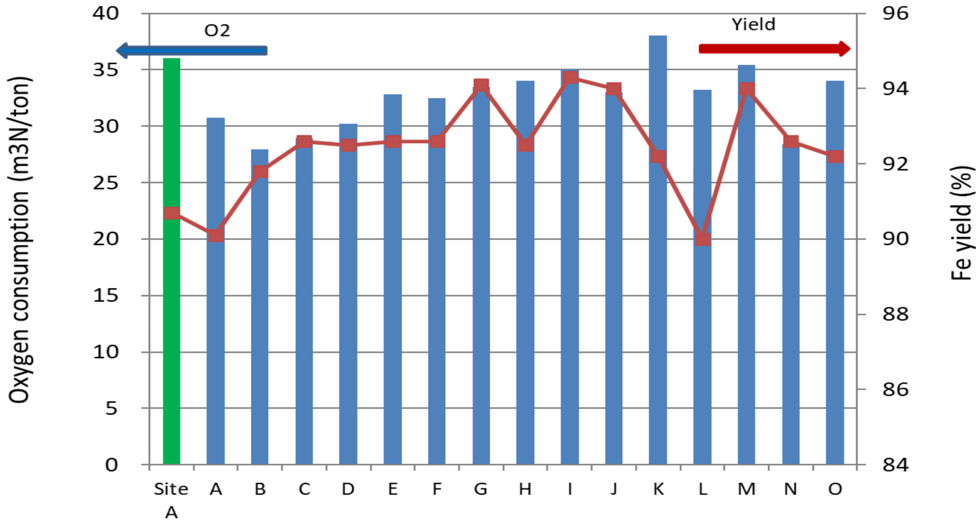


Figure 22: Oxygen consumption and Fe yield

<Site B : Scrap recycling of flat products (EAF)>

Energy data

EAF capacity	: > 130 ton x two units
EAF electricity consumption	: 415 kWh/ton (350 kWh/ton possible)
TTT (Tap-Tap Time)	: 85 minutes
Number of scrap charges	: 3 times
Fuel consumption	: 5.0 m3N/ton
Oxygen	: 50 m3N/ton
Coke injection	: 8 kg/ton Billet
Fe yield	: 89% (91% possible)

The following was concluded after discussion

*Figure **23*** is a comparison with similar sized Japanese EAFs (100-150 ton) on electricity consumption and Fe yield. Electricity consumption of 415 kWh/ton is higher and Fe yield is lower than those of Japanese EAFs. Improvement to 350 kWh/ton and 91% Fe yield can be expected without large scale investment.

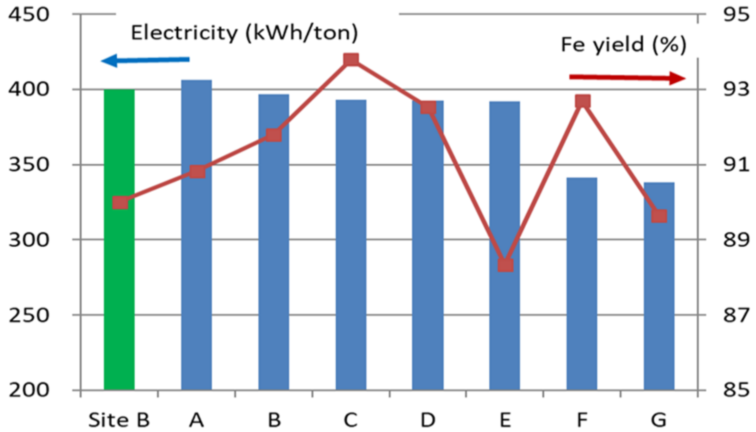


Figure 23: Comparison with similar size Japanese EAFs

The reasons for lower efficiency may include:

(1) Longer TTT (85 minutes) compared to average TTT (55-60 minutes) due to capacity shortage of continuous casting machine (scrap charging is delayed for several minutes after tapping)

(2) Inferior slag foaming by JetBox burner unit (insufficient oxygen use causes low Fe yield)

(3) Water-cooled oxygen lance requires slag door to be fully open, which causes cold air invasion

Japanese experts proposed charging cold scrap just after the tapping of previous heat and waiting for several minutes before power on (*Figure* ***24***). Radiative heat loss from hot brick and hot heel may be decreased and absorbed by cold scrap. Combustibles in the scrap will burn during this waiting period and work as scrap preheating. For better slag foaming in a large furnace, a coherent burner is recommended.

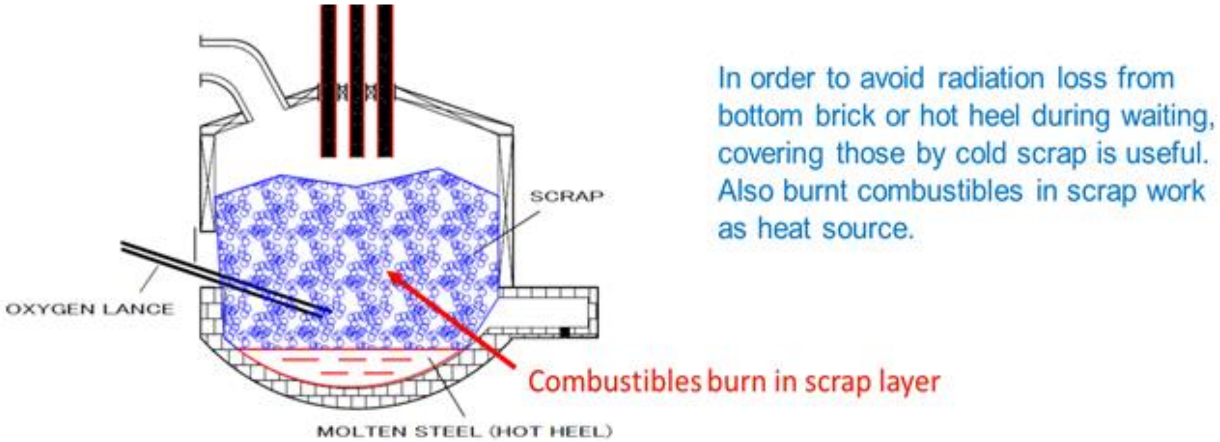


Figure 24: Earlier scrap charge before power-on to absorb radiation heat loss

When large scale investment is possible, "High temperature continuous scrap preheating EAF" shown in *Figure* ***25*** is the best way to improve efficiency. In addition to the high electricity saving to 280 kWh/ton, one EAF can be stopped because of high productivity of ECOARC.

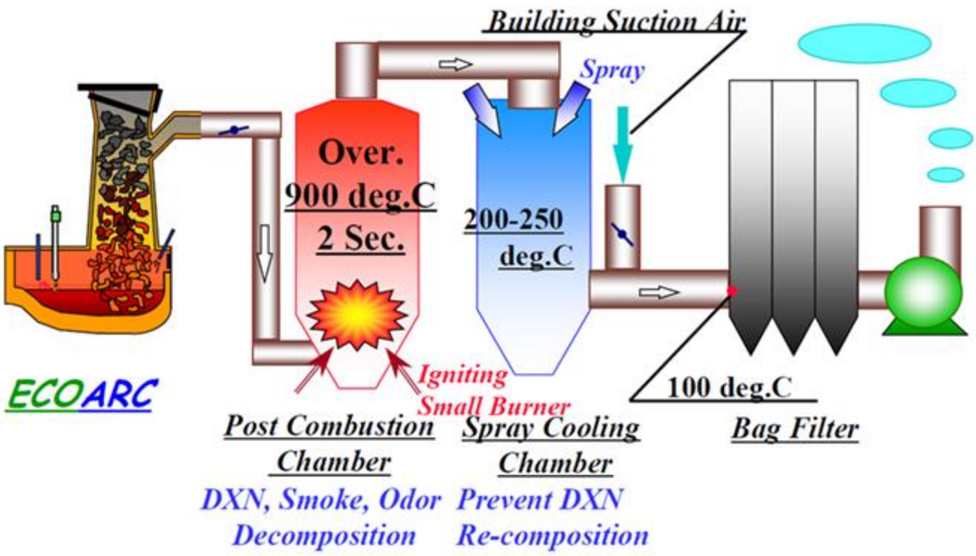


Figure 25: High temperature continuous scrap preheating EAF (ECOARC)

<Site C : Hot rolling of long products (RHF)>

Energy data

RHF heat consumption	: 36.4 kg-oil/ton (1,525 MJ/ton) (cold charge at stable condition)
Exhaust gas temperature at recuperator inlet	: 650 - 750 °C
Preheated combustion air temperature	: 365 - 400 °C
Oxygen content in exhaust gas	: 5 - 7%
Oxygen enrichment	: to 22 - 24%

Effect of oxygen enrichment (trial calculation by RHF simulator)

Heat consumption	1,525 MJ/ton at 21% O2 (100%)
	1,487 MJ/ton at 22% O2 (97.5%)
	1,450 MJ/ton at 24% O2 (95.1%)

The following was concluded after discussion

Heat consumption of 1,525 MJ/ton for cold charging is within an acceptable range comparing to standard ASEAN RHDs, but considering that the off-gas and preheated air temperatures are lower than the design values, some improvement can be expected. Lower temperature may be caused by cold air invasion in the furnace charge end. Oxygen content of 5-7% is explained by this phenomenon.

This furnace uses oxygen enrichment in the combustion air, as there is some extra oxygen supply. The effect of enrichment is calculated by RHF simulator. Enrichment to 22% causes 2.5% energy saving and to 24% causes to 5% saving.

Visitors and Site C engineers discussed air ratio control and combustion air temperature, as proper control of these factors is the first step of efficiency improvement (refer to Chapter 3 of the Energy Efficiency Manual). Proper air ratio is important for stable combustion and fuel efficiency. As the composition of fuel is not constant, an easy way of setting air ratio is to measure the oxygen content of the furnace atmosphere gas. *Figure **26*** is the oxygen content and air ratio. From this graph, the actual air ratio may be around 1.3, which is too high.

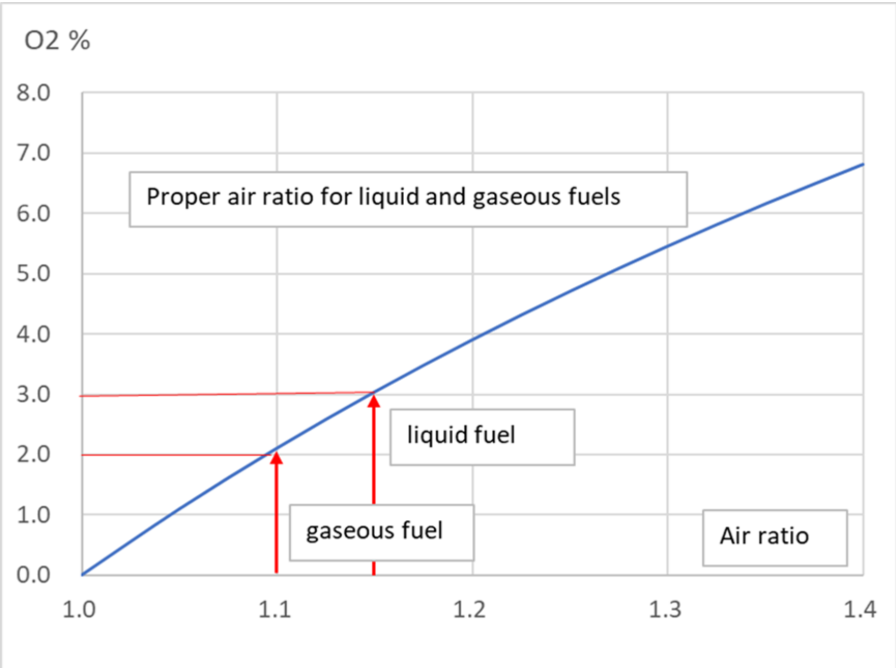


Figure 26: Oxygen content and air ratio

The O2 content in the furnace is sometimes disturbed by air invasion. As heat loss from hot gas leakage is smaller than that of the cold air invasion, furnace pressure should be slightly positive, but the pressure gauge may show a positive value due to the flow pattern even though the actual pressure is negative. Pressure setting should be decided by observing air invasion at the charge end.

Another discussion was held on the subject of how to raise combustion air temperature. After improving operations to reduce air invasion, next step is replacing the recuperator tube with high-grade material.

<Site D : Hot rolling of flat products (RHF)>

Energy data (on Nov. 20 during site survey)

Fuel	: Heavy fuel oil (high Sulphur), 9,803 kcal/kg
Production	: 197.8 ton/h (Heating to 1,250 °C, higher than billet furnace 1,100 °C)
Heat consumption	: fuel 6,324 kg/h = 1,312 MJ/ton
Exhaust gas temp. at recuperator inlet	: 760 °C (set 830)
Exhaust gas temp. at recuperator outlet	: 378 °C (set 250)
Preheated combustion air temp.	: 433 °C (set 560)
Oxygen content in exhaust gas	: 5.7%
Set air ratio	: 1.1 for PH & HT zones, 1.0 for SK zone
Actual air ratio (calculated by fuel and air flow rates)	
Top zones	: PH 1.23 HT 1.06 SK 1.20
Bottom zones	: PH 1.11 HT 1.04 SK 0.99

The following was concluded after discussion

From the experience of Japanese experts, heat consumption of 1,312 MJ/ton is very good value considering the slab heating temperature 1,250 °C, which is higher than standard billet heating of 1,100 °C. A feature of this furnace is a very high design temperature of combustion air: 560 °C. Actual air temperature was 433 °C, which is still higher than other furnaces. Set air ratio was 1.1 for preheating zone and 1.0 for soaking zone, but actual values calculated from air and fuel flow rates as above were different from the set ratio.

Furnace pressure control and combustion air temperature were discussed with Site D engineers, as they were with the engineers at Site C.

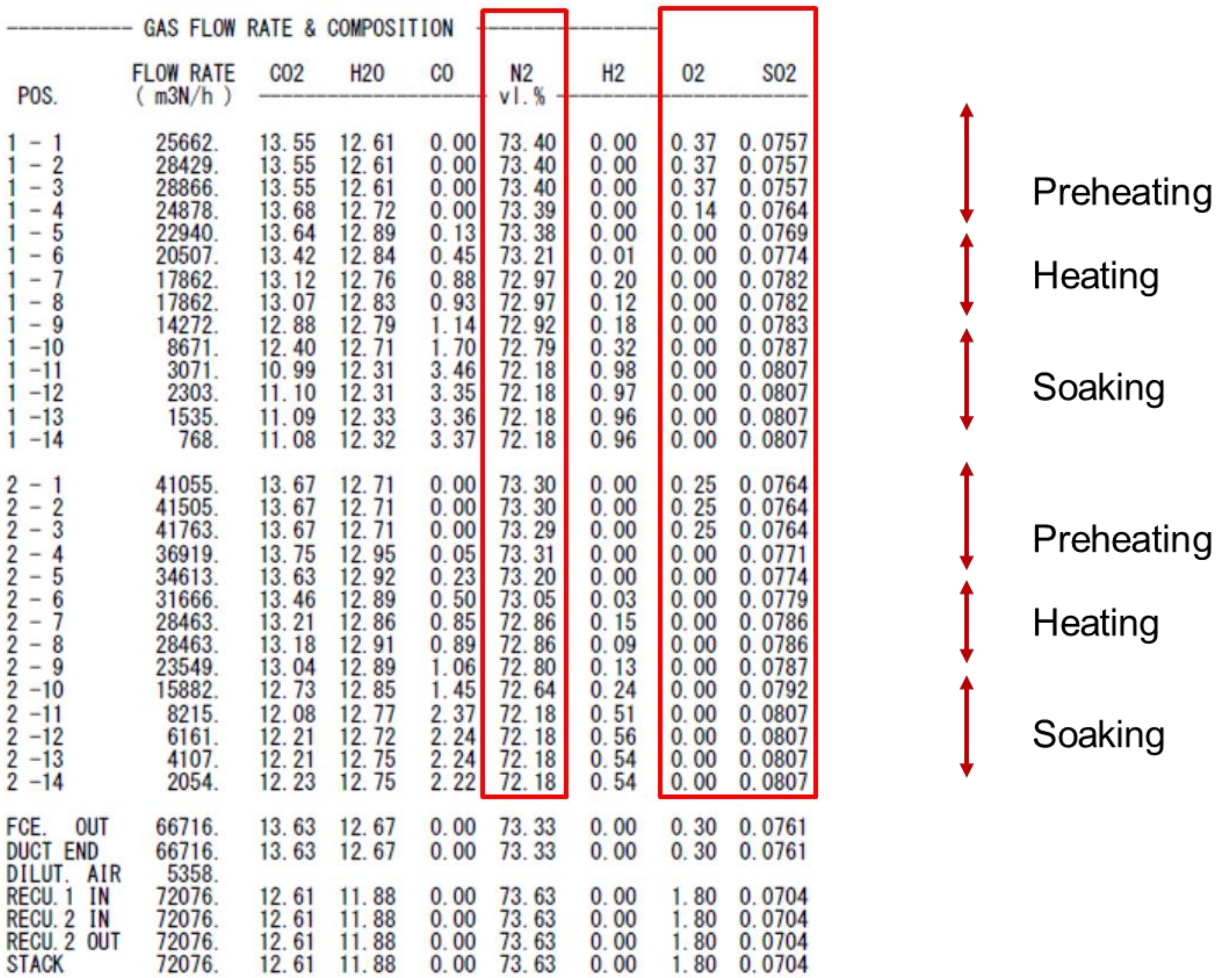
Site D is planning to change the fuel from the heavy fuel oil with high sulphur to natural gas. This fuel change can facilitate CO2 reduction, regenerative burner use, and further waste heat recovery from off-gas (for conventional burner).

A trial calculation using ideal values of air ratio and air temperature was conducted using the RHF Simulator. The results are shown in *Table **6*** and *Figure **27***. The effect of air temperature raising is 5.6% and air ratio setting 2.1%.

For a high temperature furnace like slab heating, the air ratio in soaking zone is sometimes set to lower than 1.0 to leave the combustibles in the atmosphere gas and no oxygen to reduce scale loss. These combustibles will be burnt in the heating and preheating zones with the excess air. *Figure **27*** is the distribution of flow rate and composition of atmosphere gas. Scale loss decreasing rate is calculated as 13% ((0.31 – 0.27)/0.31 = 0.129).

Table 6: Effects of air ratio and air temperature change

CASE	Condition	Set air temp.	Air ratio	Scale loss	Heat cons.	Rate
1	Base	432 degC	observed on Nov.20	0.31 %	1,312 MJ/ton	100 %
2	Raise air temp.	565 degC (design value)	observed on Nov.20	0.31 %	1,239 MJ/ton	94.4 %
3	Air ratio change	432 degC	PH zone : 1.10 HT Zone : 1.00 SK zone : 0.95	0.27 %	1,285 MJ/ton	97.9 %
4	Combination B & C	565 degC (design value)	PH zone : 1.10 HT Zone : 1.00 SK zone : 0.95	0.27 %	1,227 MJ/ton	93.5 %



GAS FLOW RATE & COMPOSITION

POS.	FLOW RATE (m3N/h)	CO2	H2O	CO	N2 vl.%	H2	O2	SO2
1 - 1	25662.	13.55	12.61	0.00	73.40	0.00	0.37	0.0757
1 - 2	28429.	13.55	12.61	0.00	73.40	0.00	0.37	0.0757
1 - 3	28866.	13.55	12.61	0.00	73.40	0.00	0.37	0.0757
1 - 4	24878.	13.68	12.72	0.00	73.39	0.00	0.14	0.0764
1 - 5	22940.	13.64	12.89	0.13	73.38	0.00	0.00	0.0769
1 - 6	20507.	13.42	12.84	0.45	73.21	0.01	0.00	0.0774
1 - 7	17862.	13.12	12.76	0.88	72.97	0.20	0.00	0.0782
1 - 8	17862.	13.07	12.83	0.93	72.97	0.12	0.00	0.0782
1 - 9	14272.	12.88	12.79	1.14	72.92	0.18	0.00	0.0783
1 -10	8671.	12.40	12.71	1.70	72.79	0.32	0.00	0.0787
1 -11	3071.	10.99	12.31	3.46	72.18	0.98	0.00	0.0807
1 -12	2303.	11.10	12.31	3.35	72.18	0.97	0.00	0.0807
1 -13	1535.	11.09	12.33	3.36	72.18	0.96	0.00	0.0807
1 -14	768.	11.08	12.32	3.37	72.18	0.96	0.00	0.0807
2 - 1	41055.	13.67	12.71	0.00	73.30	0.00	0.25	0.0764
2 - 2	41505.	13.67	12.71	0.00	73.30	0.00	0.25	0.0764
2 - 3	41763.	13.67	12.71	0.00	73.29	0.00	0.25	0.0764
2 - 4	36919.	13.75	12.95	0.05	73.31	0.00	0.00	0.0771
2 - 5	34613.	13.63	12.92	0.23	73.20	0.00	0.00	0.0774
2 - 6	31666.	13.46	12.89	0.50	73.05	0.03	0.00	0.0779
2 - 7	28463.	13.21	12.86	0.85	72.86	0.15	0.00	0.0786
2 - 8	28463.	13.18	12.91	0.89	72.86	0.09	0.00	0.0786
2 - 9	23549.	13.04	12.89	1.06	72.80	0.13	0.00	0.0787
2 -10	15882.	12.73	12.85	1.45	72.64	0.24	0.00	0.0792
2 -11	8215.	12.08	12.77	2.37	72.18	0.51	0.00	0.0807
2 -12	6161.	12.21	12.72	2.24	72.18	0.56	0.00	0.0807
2 -13	4107.	12.21	12.75	2.24	72.18	0.54	0.00	0.0807
2 -14	2054.	12.23	12.75	2.22	72.18	0.54	0.00	0.0807
FCE. OUT	66716.	13.63	12.67	0.00	73.33	0.00	0.30	0.0761
DUCT END	66716.	13.63	12.67	0.00	73.33	0.00	0.30	0.0761
DILUT. AIR	5358.							
RECU. 1 IN	72076.	12.61	11.88	0.00	73.63	0.00	1.80	0.0704
RECU. 2 IN	72076.	12.61	11.88	0.00	73.63	0.00	1.80	0.0704
RECU. 2 OUT	72076.	12.61	11.88	0.00	73.63	0.00	1.80	0.0704
STACK	72076.	12.61	11.88	0.00	73.63	0.00	1.80	0.0704

Figure 27: Flow rate and composition of furnace atmosphere gas

<Summary of field survey>

Part of the purpose of the CTCN project is to fix benchmarking values for energy efficiency. Based on the field surveys and discussions at 4 sites, benchmarking values (target values) to be achieved by conventional types of EAF and RHF are proposed (refer to *Table **4***). Electricity consumption of EAF can be reduced to 352 kWh/ton with the simple operational improvements, such as good slag foaming, closing slag door, scrap pretreatment, and operation pattern review. And reheating furnaces can achieve the heat consumption of 1,170 MJ/ton by furnace pressure control to avoid air invasion, air ratio adjustment, and recuperator maintenance to realize design value of combustion air temperature. Heating condition is assumed as cold charge, 1100 °C heat at stable condition. These changes do not require much investment.

Possible to achieve EAF electricity consumption of 352 kWh/ton by

* good slag foaming
* closing slag door
* scrap pretreatment
* operation pattern review

Possible to achieve RHF thermal energy consumption of 1,170 MJ/ton by

* furnace pressure control
* air ratio adjustment
* recuperator maintenance

(for cold charge, 1100 degC heat, stable condition)

These are the first steps for improving energy efficiency without large scale investment. Technology upgrades that further improve energy efficiency and may require more investment are explained in detail in the document "Energy Efficiency Manual for Thailand Iron & Steel Companies".

Financial Modelling

Four energy efficient technology upgrades were selected from the Energy Efficiency Manual for an analysis of annual energy savings, CO2 emissions reduction, payback period, and loan financing. Two of the selected technologies are for steel plants with EAF, and two are for RHF in hot-rolling steel plants.

1. Regenerative Burner for Ladle Heating (EAF)
2. Scrap Pretreatment (EAF)
3. Air Conditioning with Absorption Type Refrigeration (RHF)
4. Fiber Block Insulation (RHF)

The model was built using an Excel Workbook. For each of the four technologies, a model was built on one sheet in the workbook. Each model contemplates a self-financed scenario and a loan-financed scenario.

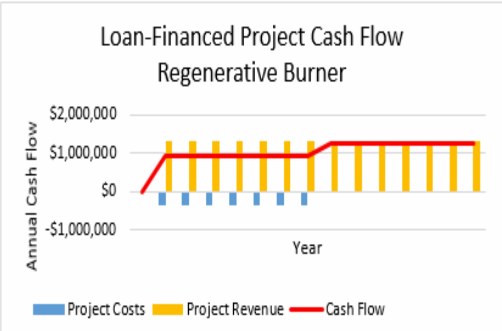
Various assumptions were made about energy savings, emissions reductions and cash flows of each technology for the purposes of this analysis. It was assumed that the upgrades would be made in a steel plant with an output of 500,000 tons a year, that the useful life of the upgrades would be 14 years, that energy savings would be delivered at varying rates on the basis of energy saved per ton of steel produced, and that the costs of energy were $14.40 per GJ and $0.097 per kWh and were constant throughout the life of the project. It was further assumed that average annual operations and maintenance expenditures were 3% of the upfront investment cost, that the project owner has a discount rate of 5%, and that the carbon content of the fuels is based on the averages cited in Part 2 of the ISO 14404 document. Though they were not used in this analysis, the model also has the capability to account for changes in energy prices, subsidies or grants that impact project economics, and value generated from reducing CO2 emissions. Each of the four technologies has unique investment cost estimates and energy savings estimates pulled from the Energy Efficiency Manual.

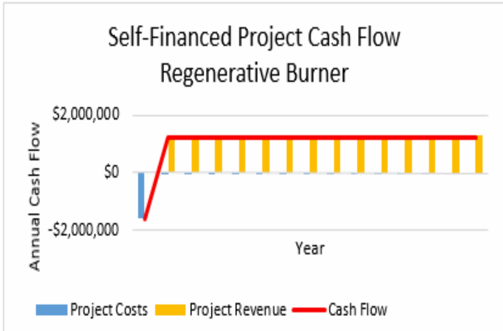
For the loan financing scenario, it was assumed that the steel plants would be able to acquire a loan for 7 years at 10%. This is a very conservative assumption, as Thailand has a programme called the Energy Efficiency Revolving Fund through which banks provide loans for 7 years at 3.5%. The terms of the currently available financing through the EERF are much more attractive than those that are modelled. (To account for potential variation in lending terms, a sensitivity analysis was performed for the rates and terms of the loan for each of the four technologies that were modelled.) In each model of the four technologies, all assumptions about cost, savings, output, and conversion factors were clearly outlined in each sheet. Values were then calculated and arranged on an annual basis for energy savings, CO_2 emission reductions, cost savings, potential revenue from emissions reductions, project-related expenditures, and project cash flows for both scenarios. Payback periods (for the self-financed scenario) and debt service coverage ratios (for the loan-financed scenario) were also calculated. Each model also produces graphs for the annual project revenues, project costs, and net cash flow for both scenarios, and a sensitivity analysis on the impact to net present value of the project by varying the terms of financing. A fifth model was also created for the future use of steel plant managers. In this model, all the input cells were left blank, so managers can model the savings and cash flows of a potential investment in high-efficiency equipment using their own data and inputs.

Table 7: Results of Modelling Savings from Energy Efficient Technologies

1)

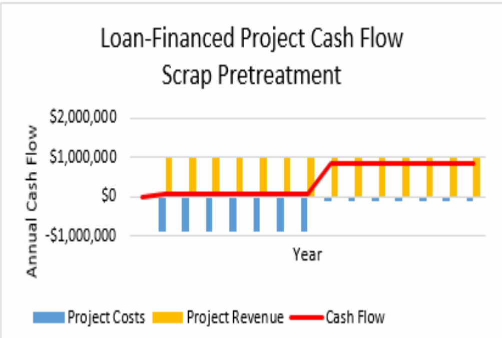
Regenerative Burner for Ladle Heating (EAF)	
Investment Cost	$1,600,000
Annual Savings	$1,296,000
Payback Period	1.23
NPV of Self-Financed Project	$10,241,432
NPV of Loan-Financed Project	$9,954,114
Term	7
Interest Rate	10%

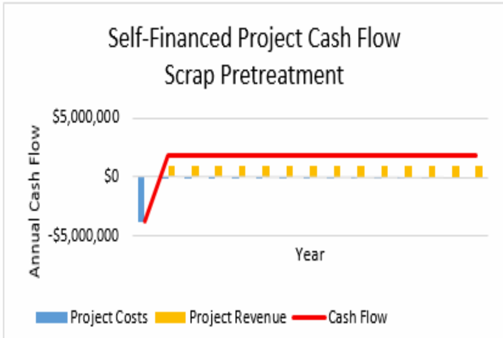




2)

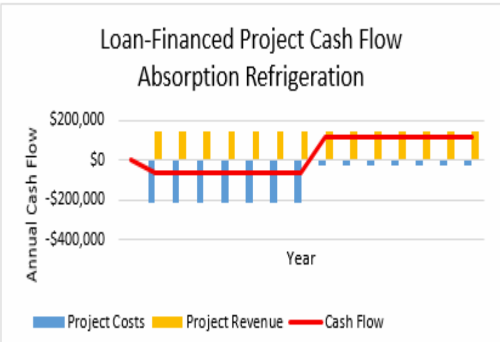
Scrap Pretreatment (EAF)	
Investment Cost	$3,800,000
Annual Savings	$970,000
Payback Period	3.92
NPV of Self-Financed Project	$13,642,674
NPV of Loan-Financed Project	$3,768,320
Term	7
Interest Rate	10%

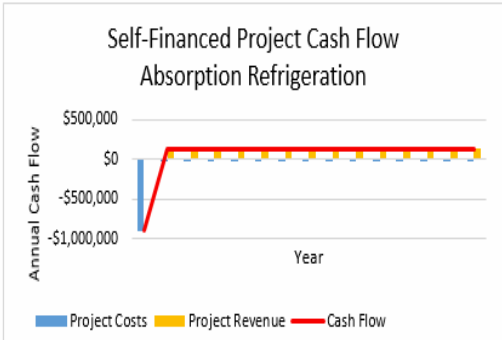




3)

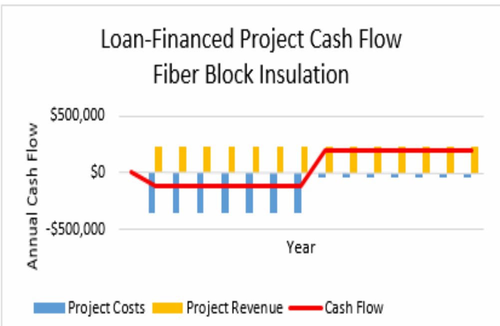
AC with Absorption Type Refrigeration (RHF)	
Investment Cost	$900,000
Annual Savings	$145,500
Payback Period	6.19
NPV of Self-Financed Project	$259,989
NPV of Loan-Financed Project	$98,373
Term	7
Interest Rate	10%

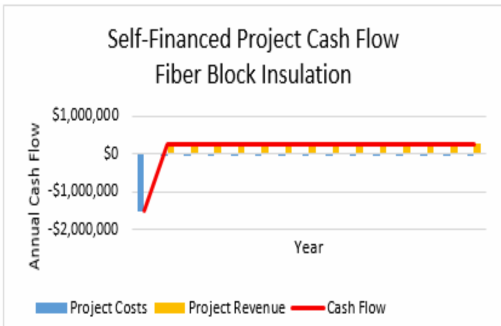




4)

Fiber Block Insulation (RHF)	
Investment Cost	$1,500,000
Annual Savings	$281,880
Payback Period	5.32
NPV of Self-Financed Project	$804,562
NPV of Loan-Financed Project	$110,973
Term	7
Interest Rate	10%





As demonstrated by the outcome of the modelling, each of these four energy efficient technologies can provide value in the form of energy savings. All four technologies had a positive net present value (NPV) under the self-financed and loan-financed scenarios.

Self-financing the technologies generally results in a large negative cash flow impact in the first period (the upfront cost of the project), followed by many years of positive cash flow (the savings from the project). Payback periods for the four technologies ranged from a little more than one year to a little more than six years. Financing the technologies with a loan results in a negative cash flow impact for first seven years of the project life (the loan payments), which are offset by the positive cash flow from the savings. Two of the four technologies had net positive cash flows in the first year of the project, meaning the annual project revenue (savings) is greater than the annual project expenses (loan payments) throughout the life of the project. The other two projects had negative annual net cash flows for the first seven years of the project life (while the loan is being repaid), followed by positive annual net cash flows for the remaining seven years of the project life. The four technologies produce CO2 savings ranging from approximately 10,000 tons to 70,000 tons over the life of the projects.

Sub-activity 4.2: Assessment of financing options

The options identified for improving energy performance and reducing CO2 emissions for iron & steel companies in Thailand range from improving Standard Operating Practices (SOP) that involve no or marginal investments to retrofits involving medium level investments and large technological changes requiring significant investment.

Large technological interventions may require higher levels of capital investments. A steel company may not be able to pay for larger investments solely relying on its own cash reserves, and may need to seek financing from government programmes, banks, or other financial institutions. A Financing Options Report was developed to identify and describe various financing options that exist for Thai steel companies seeking to improve their energy performance with larger investments in energy efficient equipment. The Financing Options Report covers financing options from Thai and Japanese government programmes, Thai commercial banks, development finance institutions, and other international organisations. There are several real-world and hypothetical examples of financing structures that could be emulated for the purposes of the Thai iron & steel industry.

For a steel company evaluating its need for financing, the first step is to determine whether there are economically attractive energy efficient projects or upgrades it can implement on-site. The Financial Model created as a part of this project has a sheet designed to serve as a tool to help plant managers estimate the changes in cash flows from self-financing or loan-financing an energy efficiency improvement. Once plant managers have determined a given energy efficiency upgrade is economically attractive, and they may then decide to seek third party financing for the upgrade.

Financing can come in various forms: equity (shares of ownership), debt (loans), leases, de-risking mechanisms, subsidies, and others. It is a common practice to combine different forms of financing to finance a single project. For energy efficiency projects in steel plants, financing is likely to come in the form of a loan to the company, an equipment lease, and/or subsidies for the installation of the energy efficiency equipment.

The sources of financing for an energy efficiency project in a Thai steel plant can be divided into four categories: government programmes, Thai commercial banks, development finance institutions, and international organisations. The financial option report lists several potential sources of financing in each category, and examples of relevant financings from each category.

One attractive source of financing for energy efficiency improvements in Thai steel plants are the Thai commercial banks that are participating in Thailand's Department of Alternative Energy Development and Efficiency (DEDE) Energy Efficiency Revolving

Loan Fund (EERF). In the EERF programme, DEDE uses money from Thailand's ENCON Fund to supply commercial banks with zero cost capital to on-lend at low rates to businesses for the purpose of financing energy efficiency improvements. DEDE also offers subsidies for energy efficiency projects that can be combined with financing from commercial banks in the EERF programme. DEDE provides a subsidy for 20% of the upfront cost of an efficiency upgrade, so a steel plant would only need to borrow 80% of the total cost of from a commercial bank to eliminate the upfront cost entirely. DEDE's other subsidy programme pays a company up to 10 million THB based on the savings achieved after the project is implemented, and this payment can be used to repay the financing used to pay for the implementation of the project.

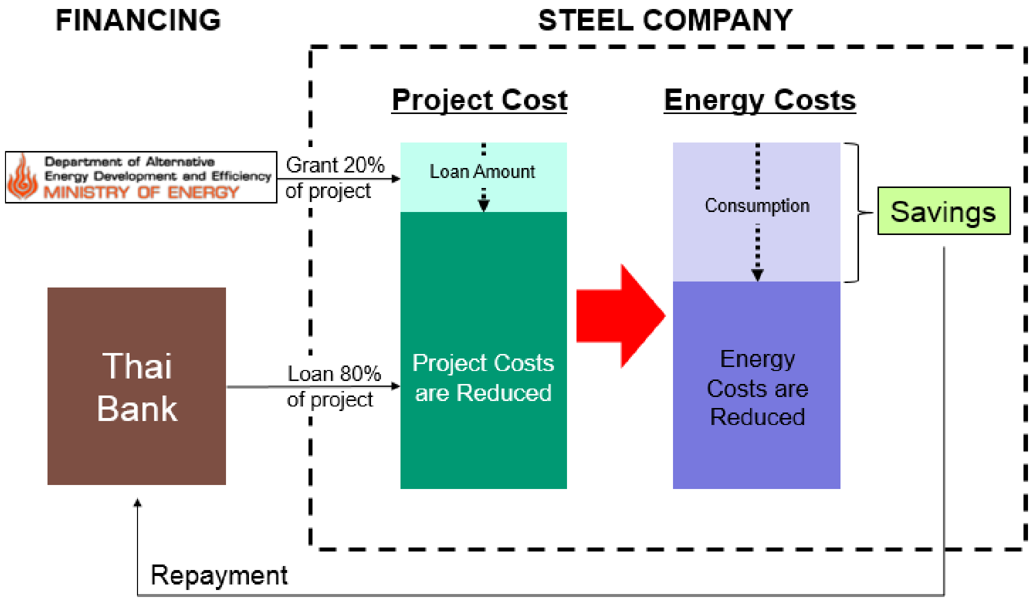


Figure 28: Financing Project with Subsidy & Loan

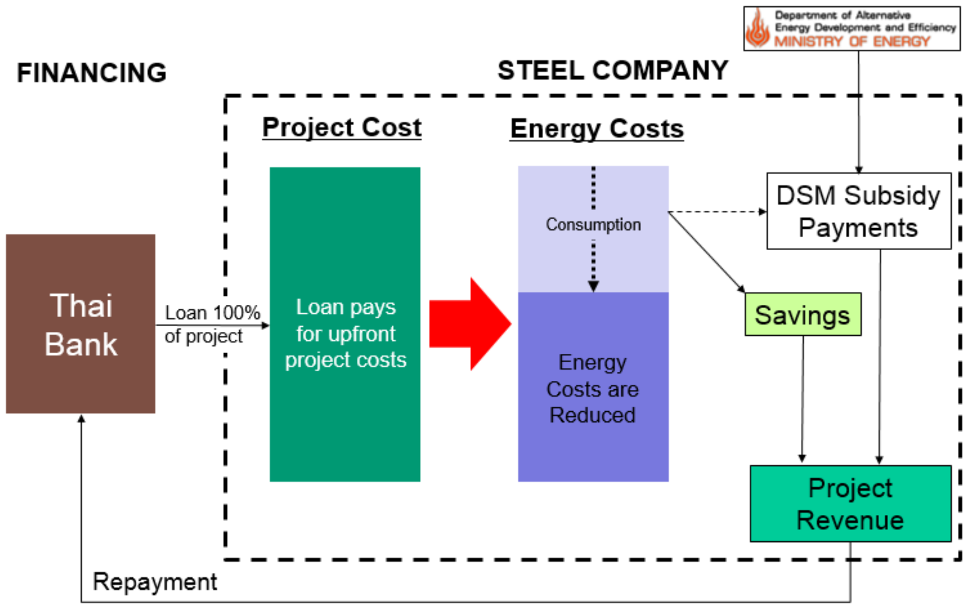


Figure 29: Financing Project with Loan & DSM Subsidy

To access international sources of financing, a more ambitious proposal must be developed to achieve the desired scale and impact of international financial institutions. One attractive international source of financing for GHG-reducing projects (including energy efficiency projects) is the Green Climate Fund (GCF).

To access GCF financing, a project must be proposed by an appropriate Accredited Entity (AE), and supported by a country's Nationally Designated Authority (NDA) or Focal Point. Thailand's Focal Point is ONEP, and while there are no in-country AEs in Thailand, there are many international AEs that have previously financed projects in Thailand, such as the Asian Development Bank. By partnering with an international AE and devoting their own resources to a given project, government bodies and/or financial institutions in Thailand can apply for GCF financing.

One hypothetical financing structure to propose to the GCF could involve using funds from the GCF and Thailand's ENCON Fund to capitalise a $60 million fund that would co-finance and de-risk energy efficiency investments in the industrial sector with Thai commercial banks. Such a proposal would require the partnership of an international AE, such as the Asian Development Bank, which could provide either financial support, technical assistance, or both.

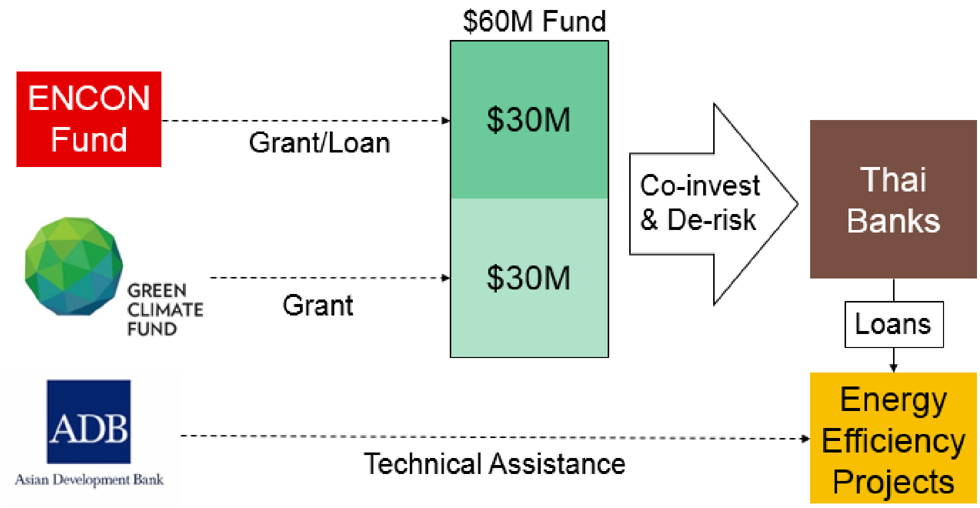


Figure 30: Proposal for GCF Financing

To achieve a level of scale that would be attractive to the GCF and the ADB, it may be necessary to create a fund that would invest in and de-risk energy efficiency improvements across the entire industrial sector of Thailand, rather than just the steel industry.

To access any form and source of third party financing, it is critical that Thai steel companies collect and record energy consumption data. Energy consumption data, as well as plant output and energy intensity data is an important component of many financing arrangements. Any steel plant manager in Thailand that may be interested in seeking financing for energy improvements in the future should prepare immediately by beginning to collect and record data on energy consumption. Energy data at the plant-level, and ideally at the process-level as well, is necessary to establish a "baseline" or "reference level" of energy consumption against which future energy improvements and the resulting energy savings can be measured. Similarly, energy data is necessary to calculate a baseline of greenhouse gas emissions against which the emissions reductions resulting from future energy improvements can be measured. Many government programmes and other mission-oriented financial institutions will not provide financing for projects if they cannot measure the energy savings and/or emissions reductions that result from the project. For this reason, collecting energy data can be an important requirement for securing some types of financing.

Sub-activity 4.3: Preparation of energy efficiency manual for iron & steel industry

Based on inputs from the performance evaluation of the representative companies in the iron & steel industry (as mentioned under Activity 4.1 above), an "Energy Efficiency Manual for Thailand Iron & Steel Companies" was prepared. The manual highlights details of technologies and standard operating practices along with cost and savings information.

The technologies explained in this manual were discussed and generated interest during the field survey of Thailand steel plants by Thai and Japanese experts in 2017. For more detailed and general information, Technologies Customized List (TCL) for ASEAN made by Japan Iron and Steel Federation (JISF) in 2016 should be referred to.

The study of energy saving opportunities was concentrated on EAF (Electric Arc Furnace) and RHF (Reheating Furnace for Rolling), as EAF consumes approximately 50% of total energy consumption of the steel plant and RHF consumes approximately 25% of total energy consumption in steel plant. These two sub-sectors have much room for efficiency improvement and deserve to study. Explained technologies are categorized as below;

(1) Technologies for operational improvement & small investment for EAF
(2) Technologies for large scale investment for EAF
(3) Technologies for operational improvement & small investment for RHF
(4) Technologies for large scale investment for RHF

Sub-activity 4.4: National workshop on benchmarking
Two national level workshops were organised focusing on the dissemination of outcomes of the benchmarking study. Through these workshops, the companies and other key stakeholders were able to understand (1) the existing status of their iron & steel industry, (2) the potential opportunities for energy saving, and (3) the energy efficient technology options available for adoption in Thailand's iron & steel industry.

The first workshop was held on November 9, 2017 and November 10, 2017 as a capacity building workshop for Thai experts. Japanese experts explained about energy saving technologies and activities of Japanese iron & steel industry, the questionnaire and field survey of this project, the development of the benchmarking tool, and more. For details, see chapter Sub-activity 2.1.

The second workshop was held on January 24, 2018 as a final reporting workshop. Japanese experts and Thai experts reported on the result of this project to the companies and other key stakeholders. The following are the details.

Final Workshop on CTCN Technical Assistance:
Benchmarking energy consumption and GHG emissions of iron & steel industries of Thailand
Date and Time： January 24, 2018 1:20pm to 5:00pm
Venue： The Four Wings Hotel Bangkok, Thailand
Participants： 46 people (22 people from ASEAN, 17 people from Japan, and 7 people from the Secretariat)

Participants of Final Workshop on CTCN Technical Assistance

Agenda：

Time	Agenda	Speaker
13:00-13:05	**Opening Remarks**	**Dr. Surachai Sathitkunarat** Assistant Secretary General National Science Technology and Innovation Policy Office (STI) CTCN Thailand NDE, Focal Point
13:05-13:20	**CTCN Project Results Overview**	**Dr. Teruo Okazaki** General Manager, Environment & Energy Research Department Nippon Steel and Sumikin Research Institute Corporation
Session 1: Current status of energy consumption and GHG emissions of Thailand iron & steel industries		
13:25 - 14:10	**Outcomes of the Benchmarking Study, focusing on questionnaire analysis** ✓ Presentation and Q&A	**Dr. Seiji Itoyama** Researcher, Business Consulting Division JFE Techno-Research Corporation
14:10 - 14:40	**Outcomes of the Benchmarking Study, focusing on field survey and overall summary** ✓ Presentation and Q&A	**Mr. Michio Nakayama** Researcher, Business Consulting Division JFE Techno-Research Corporation
14:40 - 14:50	Coffee Break	
Session 2: Tools for improving the energy efficiency in Thailand iron & steel industries		
14:50 -15:35	**Presentation of the Energy Efficiency Manual** ✓ Presentation and Q&A	**Mr. Michio Nakayama** Researcher, Business Consulting Division JFE Techno-Research Corporation
15:35 - 16:00	**Presentation of the Financial Options** ✓ Presentation and Q&A	**Ms. Mio Kitayama** Researcher, Environment & Energy Research Department Nippon Steel and Sumikin Research Institute Corporation
Session 3: Tools for tracking improvement of the energy efficiency in Thailand iron & steel industries		
16:00 - 16:15	**Presentations of the Energy Reporting Guideline** ✓ Presentation and Q&A	**Ms. Masako Nakajima** Researcher, Environment & Energy Research Department Nippon Steel and Sumikin Research Institute Corporation
16:15 - 16:30	**Presentation of the Benchmarking Tool** ✓ Presentation and Q&A	**Ms. Mai Yonezawa** Researcher, Environment & Energy Research Department Nippon Steel and Sumikin Research Institute Corporation
Session 4: Discussion of future steps		
16:30 - 16:40	**Recommendations from Japan Side**	**Dr. Teruo Okazaki** General Manager, Environment & Energy Research Department Nippon Steel and Sumikin Research Institute Corporation
16:40 - 16:50	**Vision of ISIT for future steps based on CTCN outcome**	**Ms. Thittiya Janlee and Mr. Atinat Buddhivanich** Researcher, Energy Research Department Iron and Steel Institute of Thailand
16:50 - 17:00	**Q&A and Discussion**	
17:00 - 17:05	**Closing Remarks**	**Mr. Masanori Kobayashi** Director for Global Environment Technology Promotion, International Affairs Department, New Energy and Industrial Technology Organization (NEDO) CTCN Network Member of Japan
17:05 - 17:10	**Photo Session**	

Overview of Final Workshop：

- Japanese experts explained Activities 1 through 4 of the Response Plan in accordance with the PDCA cycle. The Japanese experts also:
  - Reported the results of the field survey of 4 mills and questionnaire survey of 29 furnaces, including the results of companies, Thai averages, Japanese data, and ASEAN data.
  - Provided advice for improvement of energy efficiency, such as energy saving technologies and financial options (the contents of "Energy Efficiency Manual" and "Financing Options Report").
  - Proposed a reporting scheme in Thailand iron & steel industry like Japan (the contents of "Energy Reporting Guidelines"). Introduce the benchmarking tool for calculating energy consumption and CO2 emission.

- Thai experts (ISIT) gave an overview of Thailand iron & steel industry, explained the current activities of ISIT and the future vision of ISIT.

Overview of presentations and Q&A：

Opening Remarks (Dr. Surachai)

- Dr. Surachai for STI, which is the National Designated Entity of this project, made the following opening remarks.
  - This project has been realized by support from NEDO. This activity is a new model of CTCN called a Pro bono[21] model. I hope this model will be a good base practice model for international organisations supporting developing countries. And I also hope this project become a stepping stone for not only benchmarking of GHG in Thailand but also investment in technologies.

CTCN Project Results Overview (Dr. Okazaki)

- Reported the overview of this project.
- Explained the results of each activity as each step of a PDCA cycle for improving energy efficiency of steel plants.

Outcomes of the Benchmarking Study, focusing on questionnaire analysis (Dr. Itoyama)

- Reported the result of questionnaire survey of 29 furnaces.
- Showed the results of companies, Thai averages, Japanese data, and ASEAN data.

  （For details, see chapter Sub-activity 3.2.）

Outcomes of Benchmarking Study, focusing on field survey and overall summary (Mr. Nakayama)

- Reported the result of field survey of 4 mills.
- Showed the recommended target value of energy consumption for EAF and RHF.

  （For details, see chapter Sub-activity 2.2 and 4.1.）

Q&A

[Thailand participant]

Could you tell us benchmarking values of other country?

[Mr. Nakayama]

It is difficult to decide a Japanese benchmarking value of RHF since specifications of furnace vary from factory to factory. I think specification values set by a plant engineering company should be the first target for mills in developing country. Mills should give priority to operational improvements and maintenance of recuperator over investment in facilities in order to archive this target.

Presentation of the Energy Efficiency Manual (Mr. Nakayama)

- Introduced 13 energy saving technologies for EAF and RHF.
- Introduced the thermal balance measurement, which helps the understanding of energy saving opportunities.

[21] A Latin phrase for professional work undertaken voluntarily and without payment

（For details, see “Energy Efficiency Manual.”）

Presentation of the Financial Options (Ms. Kitayama)

- Introduced financial options, which are able to use when companies want to conduct energy saving projects in Thailand.
- Introduced simulation examples of payback periods regarding 4 energy saving technologies.
  （For details, see “Financing Options Report.”）

Presentation of the Energy Reporting Guideline (Ms. Nakajima)

- Explained the importance of knowing the current status of energy consumption for improving energy efficiency of a steel plant.
- Proposed each company record their energy consumption per year / month / facility.
- Proposed each company report their energy consumption to ISIT and ISIT compiles and provides feedback to each company.
  （For details, see “Energy Reporting Guidelines.”）

Presentation of the Benchmarking Tool (Ms. Yonezawa)

- Introduced the Benchmarking Tool as a resource for companies to use to understand their energy consumption.
- Demonstrated the results of benchmarking by inputting data into the tool.
  （For details, see “Benchmarking Tool.”）

Recommendations from Japan Side (Dr. Okazaki)

- Introduced Japanese energy saving activities that the Japan Iron and Steel Federation got certified under ISO50001 and explained the PDCA cycle for improving energy efficiency of steel plants.
- Proposed a reporting scheme for Thailand iron & steel industry based on Japan model.

Vision of ISIT for future steps based on CTCN outcome (Ms. Thittiya, Mr. Atinat)

- ISIT made the following presentation about the current and future activities of ISIT.

✧ ISIT wants to reduce the cost by improving energy efficiency in the Thailand iron & steel industry.
✧ This project reveals there is still room for energy efficiency improvement. Some companies have shown interests in some technologies which Japanese experts introduced.
✧ ISIT has already been tackling the energy saving projects in the hot-rolling process.
✧ ISIT also thinks it is important to work the PDCA cycle for improving energy efficiency of steel plants. So they want to introduce the reporting scheme recommended from Japan and make an annual industry report.

Q&A

[Japanese participant]
I hope that Japanese proposal and ISIT’s vision are able to be put into practice. Do you have any cooperation plans between Japan and Thailand in order to promote these activities?
[Dr. Okazaki]
The Japan team and ISIT have agreed to continue our cooperation next fiscal year and beyond, though this CTCN project will end by this fiscal year. We have already proposed some support ideas to ISIT, but it has not decided formally yet. However, we have positive thoughts about our cooperation and the contents of the future activity will be decided from now on.
[ISIT]
ISIT has also agreed to cooperate in the future. We are in the stage of working out details now.

[Japanese participant]
Do you have any plans to cooperate with the Thailand government in order to conduct any activities which help industry?

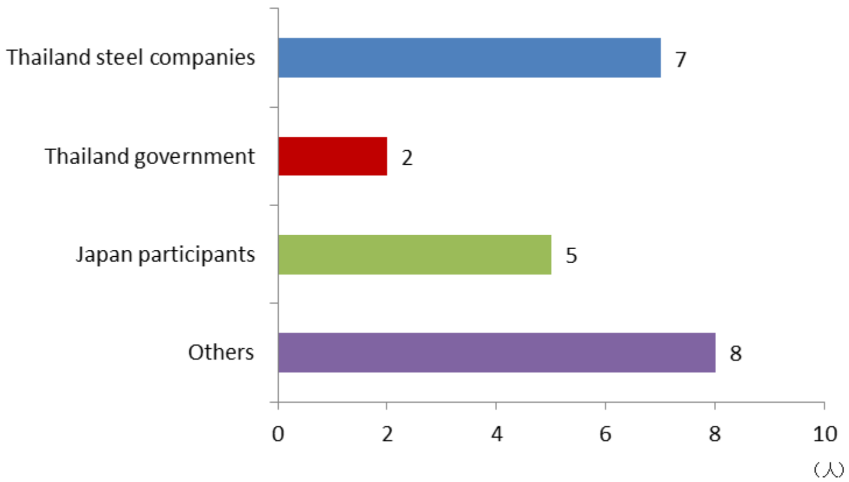
[Dr. Okazaki]
On that point, we have shared one tool. That is the analysis tool for deciding investment and we introduced it in this workshop. Such tool will be important in deciding future action plans.
[ISIT]
We are aware of the current problem of energy cost and energy consumption. We also want to associate with the Thailand government in order to acquire technical and financial support. In regard to technology, we think that we have to learn from many countries including Japan and support companies for technology which can be adopted in Thailand.

Closing Remarks (Mr. Kobayashi)

- Mr. Kobayashi for NEDO made the following closing remarks.
- ✧ I would like to appreciate all the stakeholders of this project, because the outcomes of this project could not be achieved without the Thailand side's kind cooperation. This time, I understand the Thailand iron & steel industry has a good awareness and ambition to undertake energy saving measures and new government policies. The Japanese iron & steel industry experts are tackling energy management and issues proactively and voluntarily. I heard Dr. Surachai also respected the Japanese activity, which is not a top-down approach but a bottom-up approach. The Japanese iron & steel industry has plenty of experience in these activities, and NEDO and Japanese government also have good experience and practice in the past. I hope this activity not only completes successfully but also continues more and more.

Feedback survey：
A feedback survey was conducted for this workshop and got 21 answers. The results is as follows.

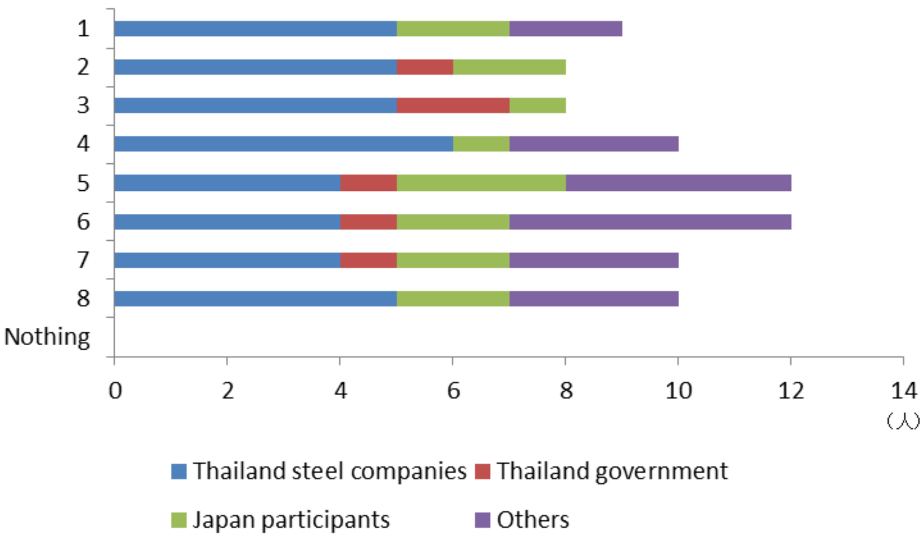
Q1. What is your affiliation?



Q2. Please tell us which presentations were particularly interesting to you (please check multiple answers).

1. CTCN Project Results Overview
2. Outcomes of the Benchmarking Study, focusing on questionnaire analysis
3. Outcomes of the Benchmarking Study, focusing on field survey and overall summary
4. Presentation of the Energy Efficiency Manual
5. Presentation of the Financial Options
6. Presentations of the Energy Reporting Guideline
7. Presentation of the Benchmarking Tool
8. Session 4: Discussion of future steps

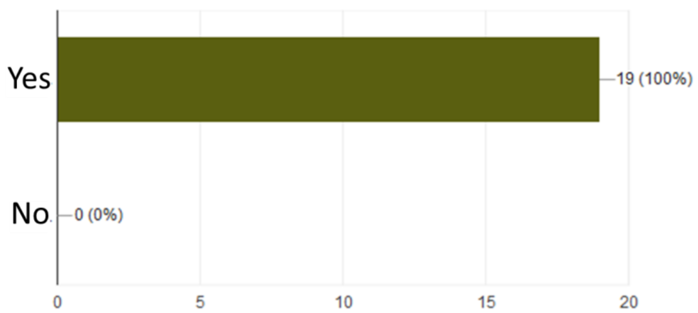
Nothing



Q3. Could you get any useful information for you in this workshop?

☐ Yes（If "YES" go to Q4. ）

☐ No（If "NO" go to Q5.）



Q4. （For who said "YES" in Q3）Which information was useful or interesting to you?

- 1) Financing support from International organisation 2) Technology support from Japanese expert. - The energy efficiency manual - The energy reporting guideline - GCF, JCM - The Benchmarking Tool - Company attitude toward business activities - energy benchmarking and energy efficiency guideline - Outcomes of the Benchmarking Study - Benchmark energy consumption of EAF & RHF, project economics for each technology - Financial Options and future of cooperation between Thai and Japan - Financial Options and future steps for business opportunity - Financial options - Benchmarking Report on field survey: energy saving technologies for EAF & RHF, thermal balance - Benchmarking tool and PDCA cycle

- Outcomes of the Benchmarking Study, focusing on questionnaire analysis

Q5. （For who said “NO” in Q3） What kind of information did you want?

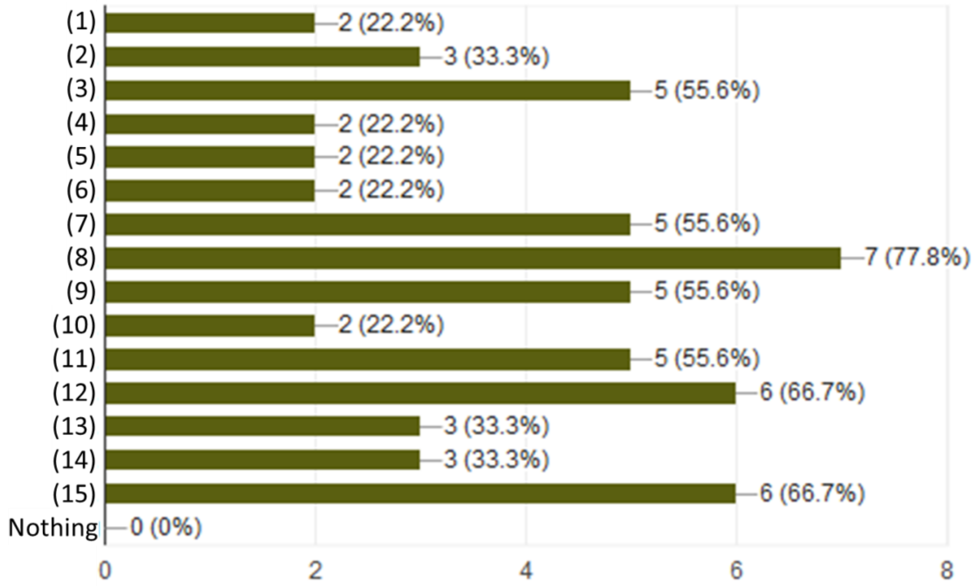
- Result of benchmarking and suggesting

Q6. Did you have any questions or anything you want to know more about?

- I would like to benchmark our energy performance with other steel works. How could JISF set up platform to do such kind of thing?
- How local banks can contribute
- As for the benchmarking tool, I want to see the demo
- Suggestion of future plan such as 5 years and 10 years for iron & steel industry of Thailand
- Japan support programme and foundation

Q7. （For steel companies） Did you find any energy saving technologies interesting in the Energy Efficiency Manual? (presentation④) (please check multiple answers)

(1) Good slag foaming with coherent burner
(2) Effective use of combustibles in scrap
(3) Correlation of record and results of operating pattern
(4) High temperature continuous scrap preheating EAF
(5) Regenerative burner or oxygen burner for ladle heater
(6) Scrap pretreatment to reduce charging frequency
(7) Sufficient combustion air temperature
(8) Proper air ratio & furnace pressure control
(9) Oxygen enrichment for combustion air
(10) Direct rolling and hot charge
(11) Fiber block for insulation
(12) Low NOx regenerative burner
(13) Air conditioning by absorption type refrigerating
(14) EAF thermal balance measurement
(15) RHF thermal balance measurement
(16) Nothing

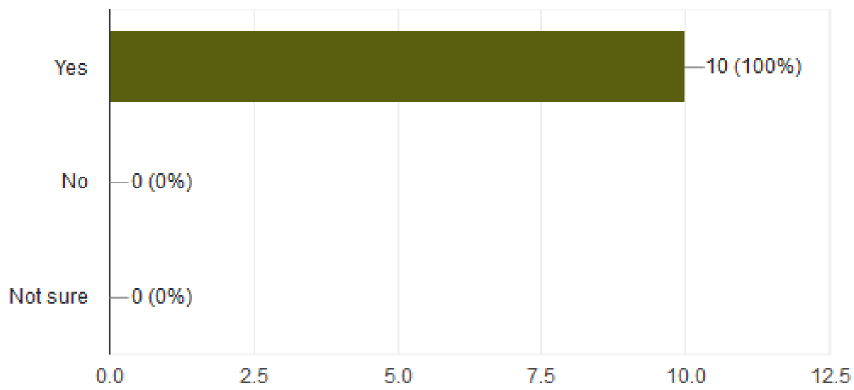


Q8. （For steel companies） Are you interested in using Benchmarking Tool introduced in this workshop? (presentation⑥⑦)

☐ Yes（reason：　　）

☐ No（reason：　　）

☐ Not sure：（reason：　　）



<Comments of respondents>

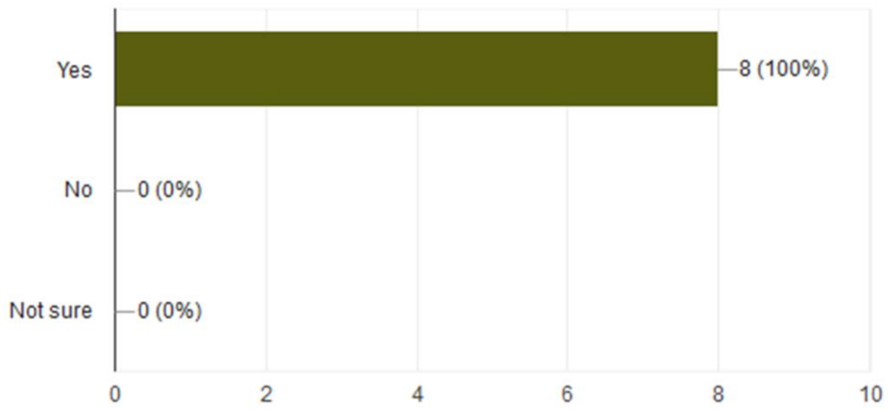
- It would be helpful for Thailand & steel industry for energy efficiency improvement.
- It can use for developing energy efficiency in steel plant.
- That is the standard to figure the situations
- To improve the skill of using the comparison tool correctly

Q9. (For steel companies) Are you interested in taking part in the industry-wide PDCA cycle for improving energy efficiency in Thailand Iron & Steel industry? (presentation⑥⑦⑧)

☐ Yes（reason：　　）

☐ No（reason：　　）

☐ Not sure：（reason：　　）

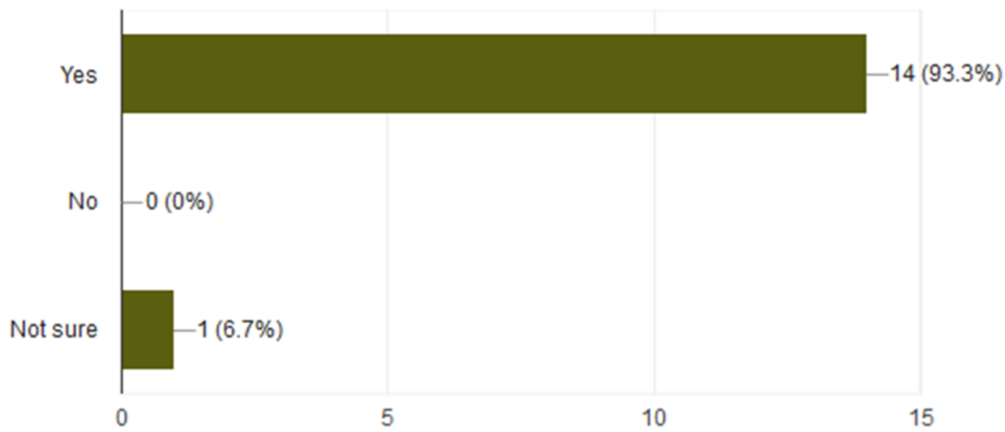


＜Comments of respondents＞

- Very effective
- Follow "Energy Development Plan"
- 1) It's a good cycle for complete the project and improving energy efficiency in Thailand steel. 2) To know "What should we do on the next step".

Q10. Do you think that the use of the Benchmarking Tool is helpful for your company or the Thailand Iron & Steel industry? (presentation⑥⑦⑧)

☐ Yes（reason：　　）
☐ No（reason：　　）
☐ Not sure：（reason：　　）



＜Comments of respondents＞

- Can be improving energy efficiency in Thailand steel
- We can use the benchmarking result for setting out target to reduce energy usage.
- Help flexible and fast to know status of energy efficiency of steel industry
- It's important tool to compare energy efficiency in the plant.

Q11. What do you think about the energy management activities of Japanese Iron & Steel industry? (presentation⑧)

- It's quite good cooperation between Steel works and JISF. If it is possible, I would like learn more details from Japanese side.
- It is very helpful policy
- Japanese iron & steel industry have the high performance technology, resulting the high-level of energy saving
- Good cooperate for energy sectors (Gov., steel companies, technology provider)

- It's quite an interesting but not sure for implementation with Thai steel company - Japanese Iron & Steel industry are good energy management activities

Q12. Please provide any other comments you may have.

- My idea is how to make cooperation between Government to Government and Private to Private companies. In term of practice sharing and learning from each other. - Thank you very much. It is very useful. - more measure in-depth for steel mill and suggestion - Thank you for all of your information from your study. If you study and give us more information of world data to compare the benchmark, it will be great.

Conclusions and Recommendations

This technical assistance serves as the first step for the iron & steel industry in Thailand toward identifying opportunities for energy savings and GHG emissions reductions in iron & steel industry that would help them lower energy costs to become a more globally competitive sector and contribute to the mitigation of global climate change. The benchmarking study was conducted through Activity 1, 2 and 3 to provide essential information of past and current energy use patterns in the iron & steel industry in Thailand, which is essential for setting the targets and action plan for future energy efficiency improvement. The Benchmarking Tool and Energy Reporting Guidelines were established in Activity 3 to serve as the tools for tracking the progress of energy performance improvements of a company and the Thai iron & steel industry as a whole. Moreover, the Energy Efficiency Manual and Report on Financing Options were developed in Activity 4 to assist iron & steel companies in Thailand in actually implementing the energy saving technologies.

In combination, the outputs from this technical assistance would enable iron & steel industry and companies in Thailand to implement the PDCA (Plan-Do-Check-Act) cycle for continually improving their energy performance. *Figure **31*** demonstrates the contents of PDCA cycle, and in which step each of the technical assistance outputs can be used.

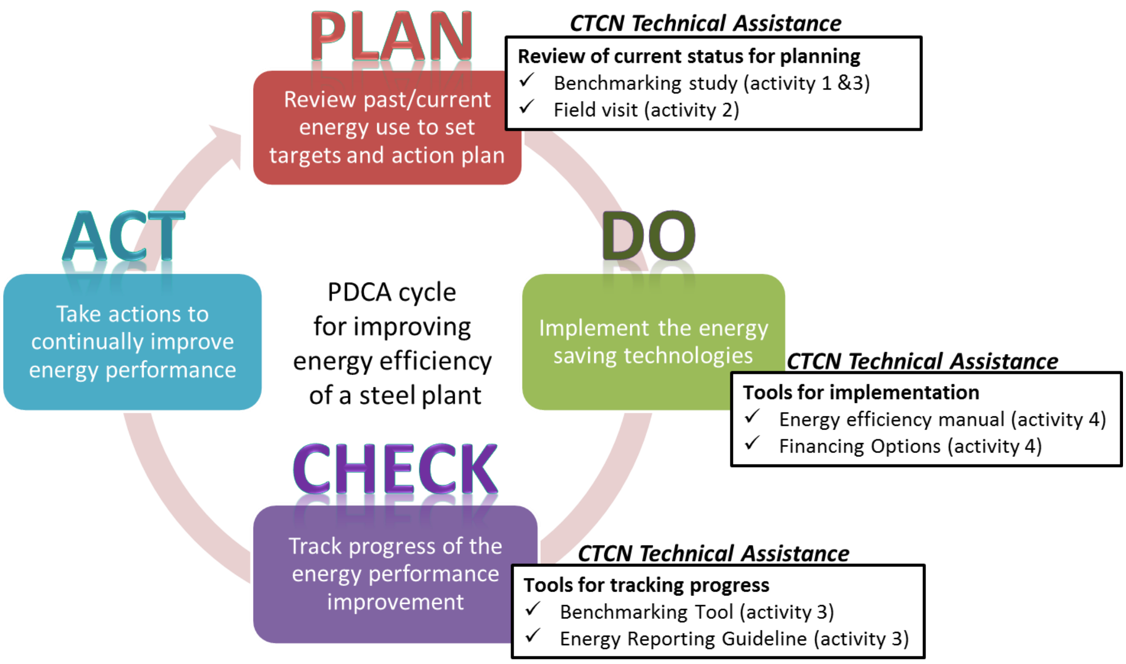


Figure 31: PDCA Cycle for Energy Efficiency Improvement

These outcomes can be utilized in many ways to complement existing industry efforts, policies and framework, which are already in place to support the energy efficiency improvements in Thailand. For example, the tools such as Energy Efficiency Manual, Report on Financing Options, and Benchmarking Tool can be used in line with the ongoing action plan for energy conservation in Thailand's iron & steel industry developed by ISIT (2014-2019) and the master plan on energy management on iron & steel industry in 2012-2032. Additionally, the results of the benchmarking study can be used to inform the next phases of the action plan as well as the master plan for energy conservation in Thailand steel industry. It is hoped that the CTCN technical assistance outcomes will be utilized by the stakeholders most effectively to achieve synergy effects with existing frameworks for energy efficiency improvements in the Thailand iron & steel industry. The following are some recommendations to the iron & steel companies in Thailand, ISIT, the Thai government, and CTCN for making effective use of the outcomes of this CTCN Technical Assistance.

Recommendations for iron & steel companies in Thailand

- Take advantage of all tools developed in this project to implement or strengthen PDCA cycle of continuous energy efficiency improvement. Implementation of this PDCA cycle can improve the competitiveness of iron & steel companies through reduction of energy costs and introduction of other co-benefits, such as productivity improvement associated with energy efficiency improvement projects.
- Participate in the industry-wide reporting scheme
- Collect data on energy consumption and energy costs consistently, preferably on monthly basis
- Identify opportunities to reduce energy costs with energy efficiency improvements using the Energy Efficiency Manual, Report on Financing Options and Financial Modeling Tool

Recommendations for ISIT:

- Implement the industry-wide reporting scheme, repeat the reporting cycle every year, taking advantage of support from international community (e.g. Japan)
- Collect and maintain anonymous data on the energy intensity and CO2 intensity of the Thai iron & steel industry
- Serve as an information resource for member companies and government agencies in Thailand
- Once the reporting scheme is well established, get industry-wide certification of ISO 50001 to solidify the energy management system

Recommendations for Thai Government

- Promote the benefits of voluntary reporting and benchmarking scheme of energy data, which is an effective way to accumulate energy consumption/CO2 emission data and encourage energy efficiency improvements, and encourage Thai iron & steel companies to participate in the industry-wide reporting scheme. A company's participation in the reporting scheme ensures that it has a reliable baseline data for observing improvement after project implementation. Also, the industry-wide energy performance trend will serve as the baseline data to observe industry-wide impact of any government programs for energy efficiency improvement. Such information can be useful for verifying impacts of any government programs to improve energy efficiency.
- Work together with ISIT to develop support program for energy efficiency improvement projects, taking advantage of the Energy Efficiency Manual for priority technologies and operational improvements. One possibility for such a support program is a transparent pilot project to prove the energy savings and profit potential of introducing a set of technologies from Energy Efficiency Manual.
- In line with the Thailand energy efficiency revolving fund (TEERF), which has been established by the Government of Thailand in 2012 and managed by DEDE through the ENCON Fund, provide more capacity building opportunities for financial institutions (including non-bank financial institutions such as insurance, leasing and pension funds) and non-financial institutions in Thailand to support financing for climate change mitigation and/or energy saving projects in Thailand. Possible paths include:

    - Encourage more local financial institutions doing co-financings with DFIs and international organizations, which have more experiences with financing energy saving projects.

- Develop de-risking mechanisms, such as providing subordinate debt and loan loss reserves that encourage more private investors (including banks) to finance energy efficiency projects
- Develop and submit a proposal for GCF and/or ADB financing to provide low cost, long term capital at scale for energy efficiency and on-site renewable projects in the industrial and commercial sectors

Recommendations for CTCN

- Encourage steel industries in other countries to implement the PDCA cycle for energy efficiency improvement using the tools such as benchmarking tool and annual reporting scheme, adjusting for unique conditions in each country. While a worldwide data collection and benchmarking scheme for CO2 emissions exist for the iron & steel industry, it is difficult to set a target and action plan and implement the PDCA cycle of energy efficiency improvement and GHG reduction at a global scale, because targets and action plans depend highly on the national policies on energy efficiency and GHG reduction, which vary widely from country to country. Therefore, it is realistic to promote the implementation of the PDCA cycle at a national scale, as it has been proposed in this CTCN Technical Assistance for Thailand.
- Encourage similar Technical Assistance projects for other energy intensive industries, such as cement, textiles, manufacturing, mining, and energy.