JEMIMA Whitepaper

The systems approach to improve energy efficiency in manufacturing industries

June 1, 2017

JEMIMA
Energy / Low-carbon Committee

Table of Contents

1. Introduction

For the realization of a low carbon society with high energy efficiency, it has been requested to develop social infrastructure including high energy efficient solutions for industries, buildings, homes and transportation networks.

In the field of industrial automation, energy-saving measures have been mainly for improving productivity of the plant. However, it becomes necessary to promote energy-saving activities from the view point of building a low carbon society as well as improving productivity of the plant. There may be a limit to energy savings by individual optimization such as improving individual equipment and improvement activities by an organization. Systematic approach focusing on the overall optimization of the total energy use will provide further energy-savings in industries.

It has been an urgent task to apply advanced measurement and control technologies for improving overall energy performance.

Based on these facts, International Organization for Standardization, Industry Associations and administrative organizations have been promoting cooperative activities for the realization of a highly energy efficient society. It would be ideal for those organizations to do their best in every performance in an autonomous and distributed manner so that the overall performance can be optimized.

However, practically in some cases, means for enhancing the performance of energy savings are applied temporarily to facility/equipment, manufacturing processes, organization of the enterprise, and so on. These cases will not necessarily bring a good result as a whole.

There may be a limit to energy savings only by the optimization of individual equipment for further improvement. It is necessary to promote a cross organizational activities that are done from various perspectives and achieve the optimum solution as a whole. “Systems approach” provides such various perspectives to promote further energy savings. So, it is helpful to provide “A guide for Systems approach”.

From this standpoint, IEC/TC65 and ISO/TC301 have been developing international standards that show the approach to apply the standard to practical applications with well-organized terminologies.

This whitepaper explains “Systems approach” matching with the direction of international standardization including methodologies and linking to the practical activities for energy savings.

JEMIMA would feel amply rewarded for the whitepaper, if this whitepaper can help persons in charge of promoting energy efficiency improvement, leading energy saving project and executing practical works.

2. International Energy consumption trends and reasons why IEC/TC65/JWG14 was organised

The world's energy consumption has been steadily increasing along with the economic growth. Figure 1 shows the world energy consumption trend. Energy consumption of OECD countries has been flat. On the other hand, the energy consumption in developing countries including China and India has been increasing remarkably in both growth rate and value.

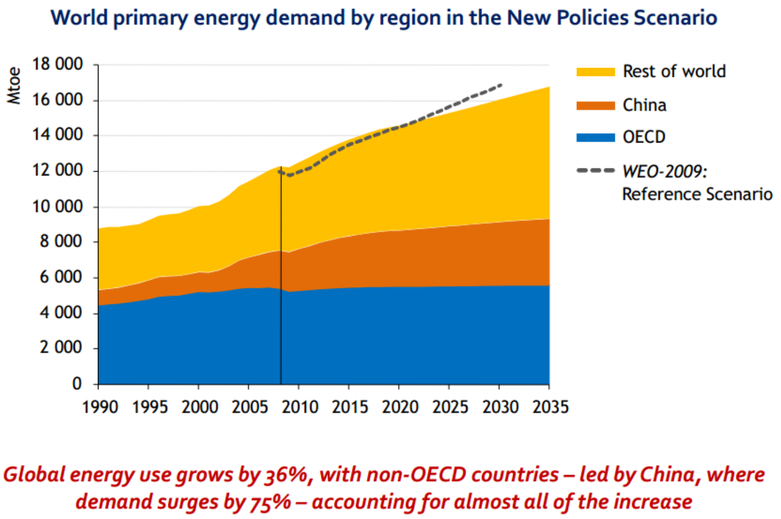


Figure 1 World energy consumption trend

Source : IEA World Energy Outlook 2010

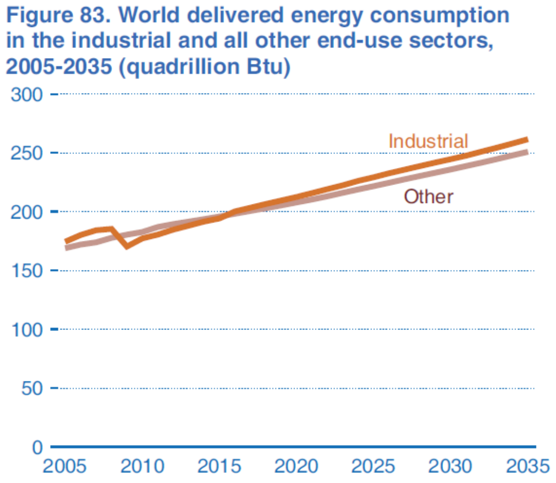


Figure 2 Sector comparison of global energy consumption

Source: International Energy Outlook 2010DOE/EIA-0484(2010)

Figure 2 shows the trend of energy consumption by sector. The energy consumption of industry sector is increasing more than 50% of the total consumption. This causes serious concern with environmental and energy problems. So, it is quite urgent for industry sector to improve the energy efficiency.

Based on these facts, in 2010, IEC published a whitepaper about energy issue titled “Coping with the Energy Challenge: The IEC’s role from 2010 to 2030” (1) showing the IEC’s vision for the future. SMB (Standardization Management Board)/SG1 issued 34 recommendations for IEC to generate standards to improve energy efficiency in industry. In February 2010, Energy Efficiency Joint Workshop was held and IEC/TC65/JWG14 was organized to develop guidelines for the design and operation of energy efficient systems in the field of industrial automation and industrial process control from a system point of view, as requested by the recommendation #7 of IEC SMB SG1.

JEMIMA actively participated in all meetings from the first meeting of JWG14 (2010/7/9 Stuttgart) and made a substantial contribution to issue a technical report IEC/TR62837 Edition 1.0 2013-09 “Energy efficiency through automation systems”(2) . JEMIMA ELCC/WG1 has been playing a central role in JWG14 as the Japanese National Committee for IEC/TC65/JWG14.

This whitepaper summarizes JEMIMA’s proposals that have been reported in IEC/TR62837 through the discussions in ELCC/WG1.

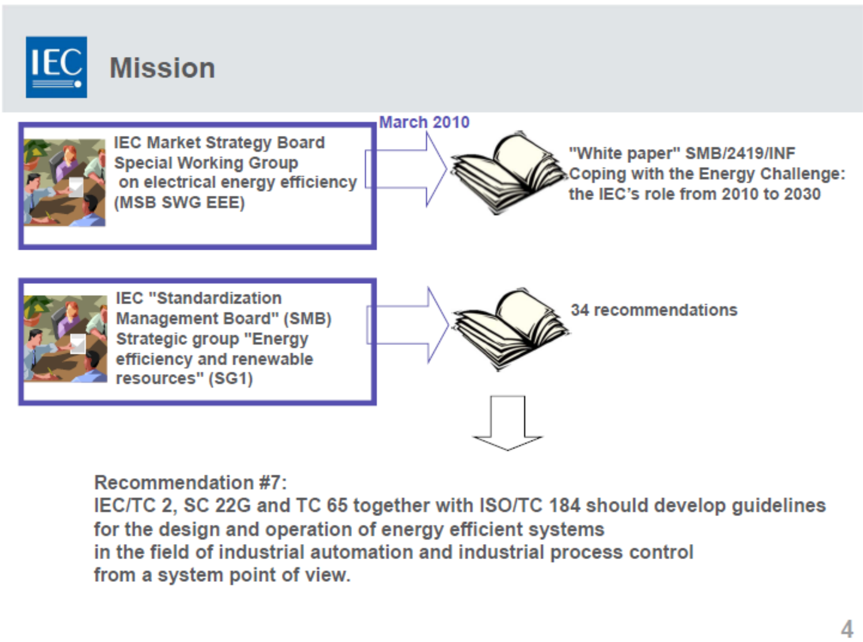


Figure 3 Background of organizing IEC/TC65/JWG14

3. Energy management

Although the cost of energy may have unstable fluctuation in the short term, the global energy demand is expected to continue to increase on a long-term basis because of the increase of energy consumption of developing countries. Energy management will become more important for an enterprise to continue its stable operation.

ISO50001 was published to support the activities of energy management. Many enterprises in Germany, United States, China and other countries have been improving the energy efficiency rapidly by introducing the standard actively.

In Japan, many energy-saving countermeasures have been taken as much as possible for many years. Though it is generally said that there is a limit to improvement, many experts point out that there is still room for further energy savings.

In order to realize the possibility of further energy savings, it is effective to introduce ISO50001 actively, starting with measuring the energy performance indices. The international standards for energy management have been developed based on the best practices of many countries in the world including examples of advanced cases in Japan. It is expected that Japanese manufacturing enterprises will establish a position of leadership of energy savings by early introduction of international energy management method.

3.1. Procedure

Energy management for business activities of enterprises such as operation of factories should be performed from various points of view. It is important to promote the activation of energy management activity defining the target process, indices to be measured and clearly authorizing the roles and responsibilities of respective organization and persons in charge.

Figure 4 shows the Energy management system model for ISO50001. Energy management process is initiated by Energy Review that requires the organization to gather information about present situation of energy performance. Based on the Energy Review, the target of energy management is defined with the EnPI (Energy Performance Indicator), and measures how to improve the energy performance is decided. Energy baseline is set for comparing the effectiveness of improvement. Then, improvement action is started. During the execution process of improvement, ongoing monitoring of EnPIs and continuous improvement action are done. It is not unusual that energy consumption is changed due to the change of the production process and equipment. It is necessary to maintain and improve the EnPIs. Details of energy management process are referenced by the ISO50001[(5)], ISO50006[(6)] .

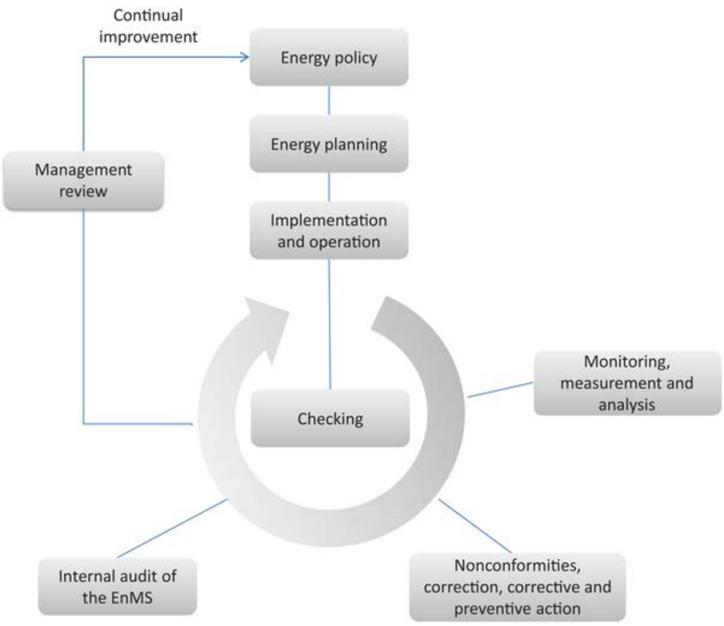


Figure 4 ISO50001 Energy management system model for this International Standard

Source：ISO50001 Energy management systems — Requirements with guidance for use

3.2. Energy performance

Energy performance is defined in ISO50001 as “measurable results related to energy efficiency, use and consumption”. It includes Energy consumption, Energy use, Energy efficiency, etc..

3.3. Energy performance indicator (EnPI)

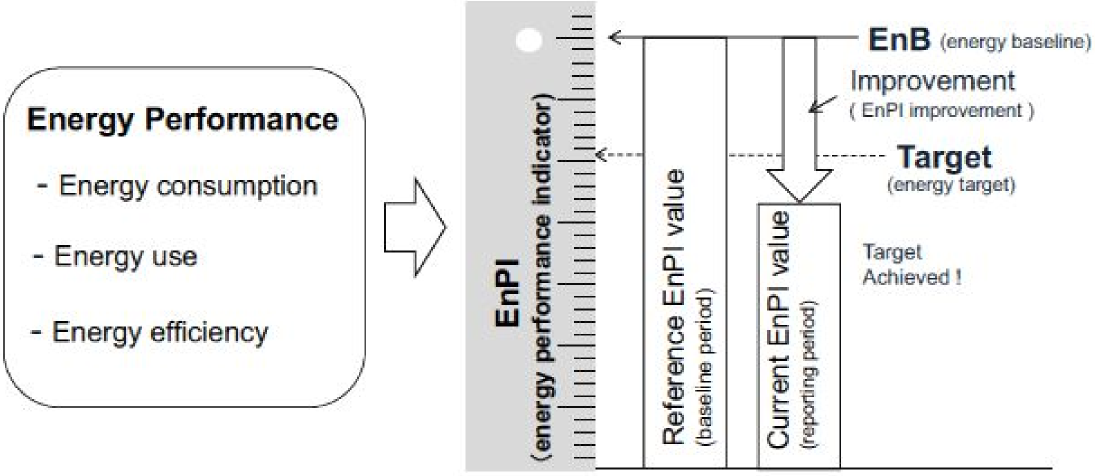


Figure 5 Energy performance indicator (EnPI)

Source：ISO50006 Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance (4)

Boundary (EMU) is defined as the target of energy management. EnPI is set to each boundary. It is desirable that multiple EnPIs are set as shown below so that persons in charge can perform their mission effectively from the view point of their position in the organization.

- EnPI is set to an unit of equipment, an unit of energy system such as air conditioning and steam generation, an unit of production process, and an unit of organization or activity in the organization.
- Especially, it is important that EnPI is set to an unit of EPIA(Energy performance improvement action) for the boundary that includes particular equipment or production process.
- Figure 5 shows the concept of Energy Performance Indicator (EnPI) that is used as a ruler to measure energy performance. A basis for comparison of EnPI is defined as “energy baseline” that is a target value of EPIA. In order to achieve the target EnPI value, EPIA will be implemented while comparing the current EnPI value with the target value.

3.4. Energy baseline (EnB)

ISO50001 defines Energy Baseline as "quantitative reference(s) providing a basis for comparison of energy performance". As shown in Figure 6, Energy Baseline (EnB) is the value of EnPI during the baseline period. EnB is the initial value of EnPI. It is necessary for an organization to measure the change of energy performance by comparing the energy performance during the reporting period with that during the baseline period. EnB is determined based on the same kinds of information that specify EnPI during the baseline period.

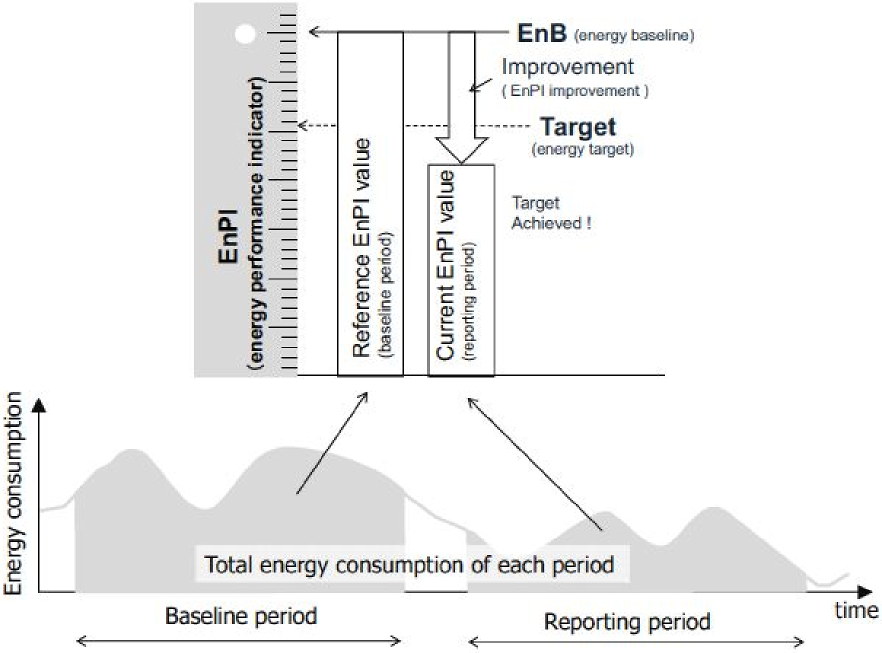


Figure 6 Energy baseline

Source : ISO50006 Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance (4)

3.5. Benchmark

Benchmark is a point of reference for evaluating performance, or level of quality. Benchmark may be set from a company's own experience, from the experience of other companies in the same industry, or from legal requirements such as environmental regulations. Energy utilization index is primarily used to indicate the energy consumption level and energy use intensity of different operating entities.

Energy consumption benchmark is used as a target for improvement among companies in the specified industry sector. Based on the sector benchmark, a company may set its own energy utilization indices that allow the company to evaluate objectively the level of rationalization of energy use.

Japanese Energy Conservation Act classifies energy intensive industries into the following sectors. ANNEX_A1 shows the classified industry sectors and the target value of sector benchmarks of energy consumption. The sector benchmark is used as a medium- to long-term reference for energy savings of industry sectors.

(1A) Iron manufacturing using blast furnaces
(1B) Common steel manufacturing using electrical furnaces
(1C) Special steel manufacturing using electrical furnaces
(2) Electrical supplier
(3) Cement manufacturing
(4A) Paper manufacturing
(4B) Paperboard manufacturing
(5) Oil Refinery
(6A) Petrochemical Industry
(6B) Soda Industry

4. Systems approach for energy efficiency improvement

4.1. What is Systems Approach

Systems approach is a methodology that improves the total energy use by rather overall optimum operation of the system components than individual optimization of individual equipment and improvement activities by an organization. Production line is a system that is composed of several equipment and facilities. Energy management indices are applied to each equipment and facilities. It is important to evaluate the effectiveness of operation of system components to optimize the overall performance for the particular application as well as evaluating the energy performance of individual component. Optimizing the performance of individual components will not necessarily improve the overall energy performance.

It is necessary to promote energy management to each level such as production line, batch and product. Systems Approach has become increasingly important to solve such complex problems as defining an appropriate boundary to match the purpose of the energy management and guiding the process for action.

Based on the understanding that guidance to "Systems Approach" is necessary to be provided, IEC/TC65 and ISO/TC301 have been developing international standards that show the approach to apply the standard to practical applications with well-organized terminologies.

4.2. Energy efficiency

ISO50001 defines energy efficiency as "ratio or other quantitative relationship between an output of performance, service, goods or energy, and an input of energy".

EXAMPLE:

Conversion efficiency %;
Energy required/energy used;
Output/input;
Theoretical energy used to operate/energy used to operate a product /GJ

NOTE: Both input and output need to be clearly specified in quantity and quality, and be measurable.

As energy efficiency is defined by a ratio, caution is necessary to select appropriate measurements for the numerator and denominator of the ratio.

Energy GENTAN-I is specified as an index of energy efficiency in Japanese Energy Conservation Act. It is widely used as an index to evaluate overall performance of energy savings of the factory.

JEMIMA's understanding

Energy efficiency = Energy consumption/ Variable closely related to energy consumption

Note:

Energy GENTAN-I and EI (Energy intensity) are used as the unit of energy efficiency. Energy GENTAN-I is a measure of the energy efficiency of equipment or process to produce product. Ex: MJ/ton
Energy intensity is a measure of the energy efficiency of a nation's economy. It is calculated as units of energy per unit of GDP. (Wikipedia)
Ex: MJ/GDP (US$)

4.3. Boundaries

ISO50001 defines boundaries as "physical or site limits and/or organizational limits as defined by the organization".

EXAMPLE: A process; a group of processes; a plant; an entire organization; multiple sites under the control of an organization.

For energy management, it is important to specify a boundary in order to evaluate the energy efficiency change of the boundary.

4.3.1. EMU (Energy Managed Unit)

In order to evaluate the energy efficiency of a system, its boundary should be clearly defined. The system could be a device, a production line or the entire factory depending on the requirements for energy management. Energy Managed Unit (EMU) is introduced as energy related functional partitioning that allows us to define the system boundary and provides generic methodologies for energy management in production systems.

Figure 7 shows the architecture of EMU defined in IEC/TR 62837[(2)]. For energy management, all input and output across the system boundary of the concerned EMU should be quantified and KPIs (EnPI: ISO50001) are defined as the indices for improving energy efficiency. Practical examples of EnPI are energy consumption, energy efficiency, cost of used energy, and so on. Materials and energy which are necessary to produce a product are counted as the input to the EMU. Products, reusable material, waste, release and energy are counted as the output from the EMU. Services related to energy used in EMU are included in the input and output of EMU.

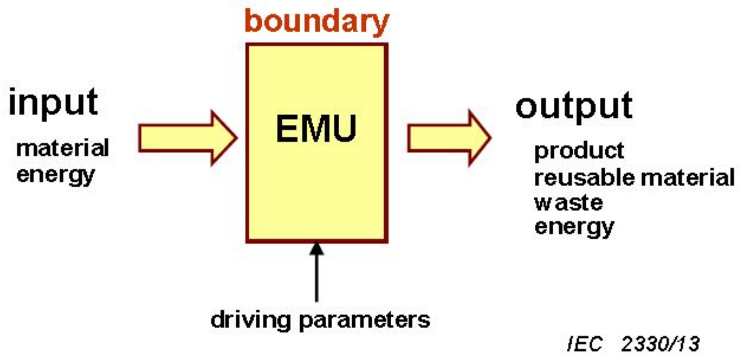


Figure 7 EMU (Energy Managed Unit)

Source：IEC/TR 62837 "Energy efficiency through automation systems" (2)

Driving parameters are factors that affect the energy efficiency of the EMU such as production volume, outside temperature and operating conditions of manufacturing facilities.

ISO50006 defines "relevant variable" and "static factors" as factors that affect energy performance. Relevant variable is defined as quantifiable variable that impacts energy performance. Static factors are defined as conditions or variables that affect energy performance and do not routinely change. Driving parameters include both relevant variable and static factors.

EXAMPLE of relevant variable (ISO50006)

Production parameters (production, volume, production rate), weather conditions (outdoor temperature, degree days), operating hours, operating parameters (operational temperature, light level).

EXAMPLE of static factors (ISO50006)

Facility size, design of installed equipment, the number of weekly production shifts, or the number or type of occupants (e.g. office workers), range of products.

4.3.2. How to define EMU

Energy management in actual operations of a company should be done from multilateral viewpoints. Important issues are to define the target by identifying savings opportunities in plant facilities and process equipment, to define EnPI to the target and to assign energy responsibilities to the organization and persons in charge. EMU can be defined flexibly as a boundary for energy management according to the purpose of management. Figure 8 shows examples of EMU. EMU1 is defined for an entire enterprise. EMU2 is defined for a factory including production lines. EMU3 is defined for a combination of several equipment. EMU4 is defined for a single device.

In the process of energy efficiency improvement, it is important to find the most inefficient part of a production system. The concept of EMU can be used effectively to focus on the part by flexibly adjusting the EMU boundary. From the boundary around the entire factory, the boundary of EMUs should be focused successively around the most energy intensive part of the production system. This allows to direct the energy efficiency improvement efforts where it matters and with the required detail.

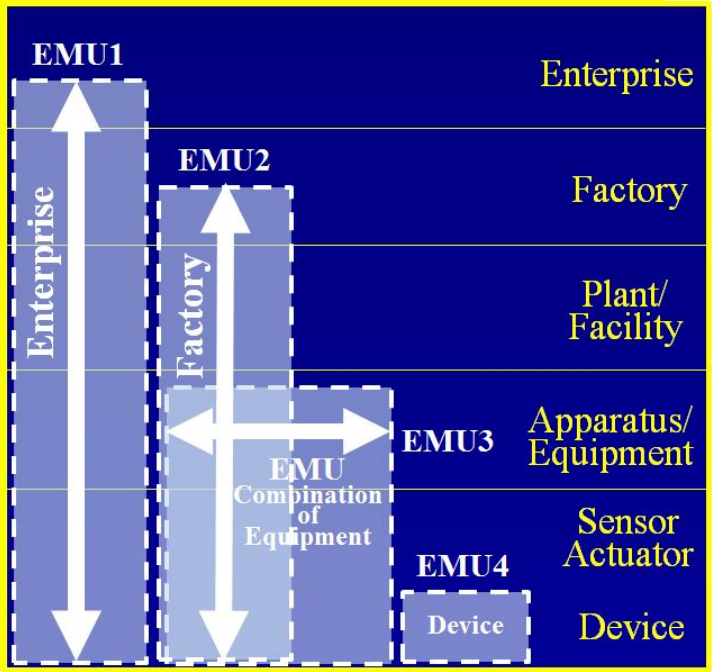


Figure 8 Flexible definition of EMU

Viewpoints for defining EMU as a boundary for energy management according to the purpose of management are explained as follows.

4.3.2.1. Physical EMU

Physical EMU is an EMU that is defined for a physical entity such as physical asset equipment of a factory.

A production line is composed of several physical asset equipment which are linked together to produce a specific number of products or product families. A production line can be defined as a physical EMU. Physical asset equipment of the factory can be also defined as physical EMUs. Figure 9 shows a hierarchy of EMU.

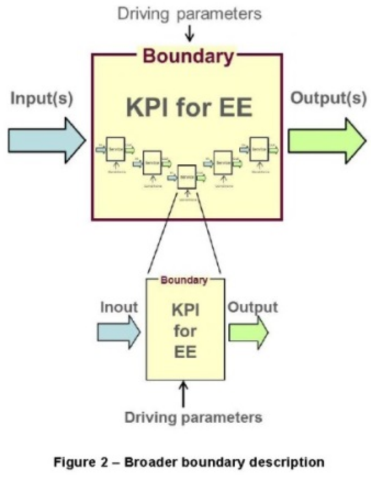


Figure 9 Hierarchy of EMU

4.3.2.2. Organizational EMU

Figure 10 shows a typical example of organization of a manufacturing factory. Each organizational unit established has a specific function and responsibility. EMU can be defined for the organizational unit according to an operation purpose of energy management. An EnPI defined for an EMU is an energy management index for the manager of the organization. In the company shown in Figure 10, production department and energy supply facility are located in a factory building. Sales department and engineering department are located in a sales building. This company has two business units, BU A and BU B. BU A is responsible for Product A. BU B is responsible for Product B. Each BU has a production department, sales department and engineering department. An Energy manager is assigned for the factory. A company has a financial department as a common organizational unit of the company. Table 1 shows examples of EMU and EnPIs related to organizational units.

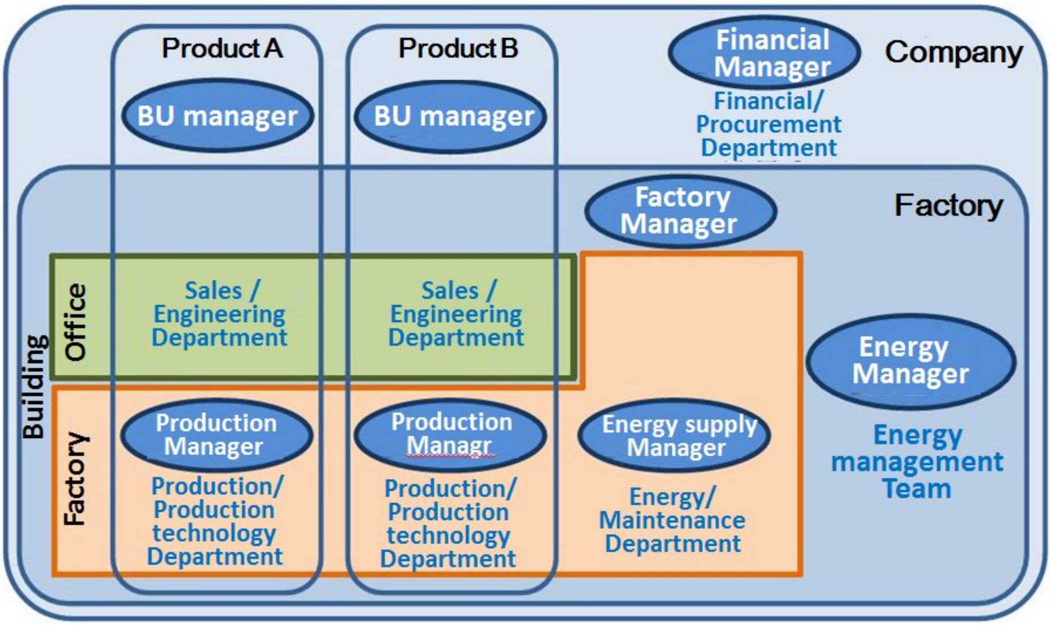


Figure 10 Organization of a manufacturing factory and EMU

Redrawn based on Source：JEITA 国際標準のエネルギー管理手法 ～EnPI 導入ガイド～ 実践編[32]

Table 1 Examples of EMU and EnPI related to organizational units

User	EMU	Example of EnPI	Objective of EnPI
Factory manager	Entire factory	Amount of energy use of the factory	Grasp of energy saving effect
BU managers of Product A and B	Production line and sub-line in charge of the product	Target achievement ratio of an energy consumption rate of each product, energy cost	Grasp and reduction of energy cost for the production
Production department	Production facility, equipment group and individual equipment in the factory	Specific energy consumption, etc.	Planning of energy efficiency improvement measure, execution of the improvement plan and the achievement of the energy target.
Energy supply department	Energy supply facility including thermal energy, and distribution facility, etc.	Amount of energy use, etc.	Planning of efficiency improvement measure for the generation of steam and electric power, execution of the improvement plan and the achievement of the efficiency target.
Energy manager	Indices for energy efficiency improvement measure	Energy efficiency, etc.	Management of efficiency improvement measure, planning, execution and achievement.
Energy saving team (appointed by each department)	Indices for energy efficiency improvement measure	Trend of energy efficiency, etc.	Management of efficiency improvement measure, planning, execution and achievement.

Source：JEITA 国際標準のエネルギー管理手法 ～EnPI 導入ガイド～ 実践編(4)

4.3.2.3. EMU for System

Energy using system such as air conditioning system and steam system has the function of energy conversion and distribution in addition to the use of energy. In order to process the total energy management, entire energy using system including piping and wiring can be defined as an EMU.

4.3.2.4. EMU for EPIA (Energy Performance Improvement Action)

It is effective to promote cross organizational activities for energy performance improvement such as energy cost reduction of an entire company and improvement of specific energy consumption to produce a specific product. In such a case, EMU should be flexibly defined including related organization units and equipment.

As energy consumption of a factory is heavily dependent on the production volume and the product type, energy management in conjunction with the production scheduling becomes necessary. Necessary energy for manufacturing facilities is supplied from the utility plant. Utility plant is usually designed to have the supply capacity to meet the maximum demand of the manufacturing facilities. So, when the production volume is reduced, energy loss will be increased due to the mismatch between energy demand and supply capacity. Figure 11 shows an example of EMU that is defined by an EPIA boundary. When energy demand and supply is managed in an optimized balance in conjunction with the production scheduling, energy efficiency of the factory will be expected to be improved significantly.

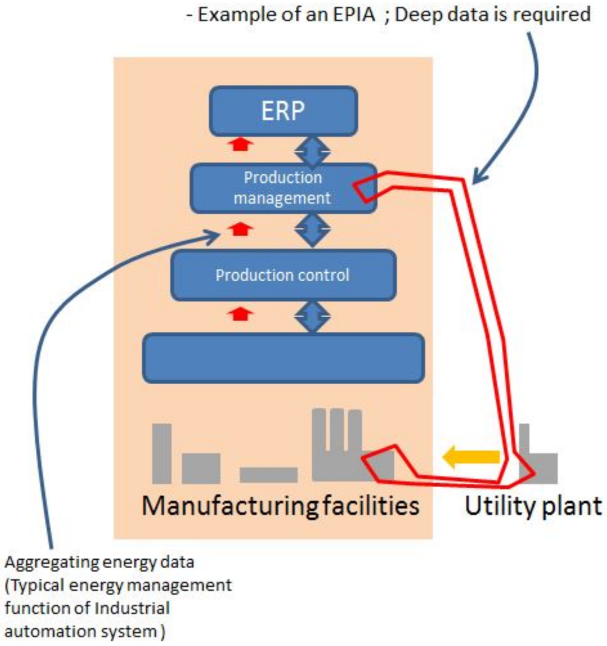


Figure 11 Example of EPIA boundary in a production system

4.3.3. EMU status and boundary in time domain [7]

4.3.3.1. EMU status

Practical production processes and equipment are operated based on the operation status that are defined for the specific operations such as “Stopped”, “Starting”, “Producing” and “Stopping”. This means EMU has a status in the direction of the time axis. Figure 12 shows the relationship between energy consumption and status of EMU. The operation of EMU is done under the operation condition specified by each EMU status from S1 through S5. Ei shows the energy consumption characteristic for Si. (i=1,2…5). As shown in Figure 13, Stopped, Starting, Producing and Stopping are defined as examples of “EMU status” that have different energy consumption characteristics. Practical production processes have their own specific “EMU status” that should be defined for their effective operation and energy management. The total energy consumption of the production process is the integral of Ei over time of the production. However, such status as "Stopped", "Stopping" and "Starting" may consume considerable energy that provides no contribution to the production. In order to improve energy efficiency, it is important to reduce the integral of Ei as well as reducing individual Ei itself. Operation time should be minimized for such status that has no contribution to the production. An actual production process may be stopped accidentally by an unexpected failure of equipment. This causes loss of energy. It is obvious that establishing a reliable and productive production process should reduce the loss of energy. Operating condition is one of the key factors that give significant effects to EMU. In case of paper or car manufacturing factories, there are several abnormal operating statuses such as preparation for production, grade change, equipment failure and so on, during the daily routine production time. The duration of time in a daily production varies for such abnormal status that has different energy consumption characteristics. It is important to define an appropriate EMU status taking the actual operation situation into account.

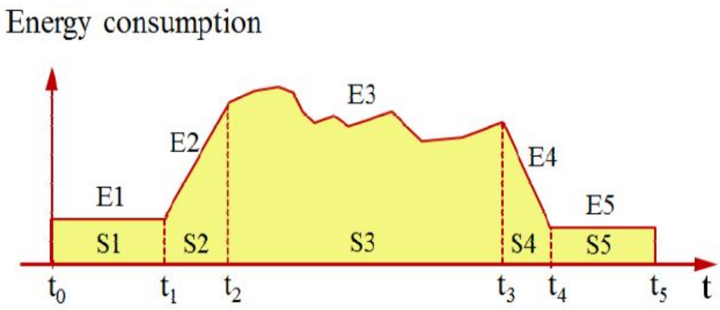


Figure 12 EMU status and Energy consumption

Source：JEITA Space-time boundary for effective energy management (7)

4.3.3.2. Boundary in time domain (7)

Figure 13 shows the energy consumption of EMU during the operation along the time axis. In space axis, EMU_i (i=1,2,..,n) are put in descending order of total energy consumption during the operation. EMUi is defined as a component of the production system for the energy management. In time axis, EMU statuses are put in the order of production process. As explained in 4.3.3.1, EMU status can be interpreted as a "Boundary in Time domain" in terms of a unit of energy management. Boundary in time domain is defined depending on the energy management of application and operation of the production system.

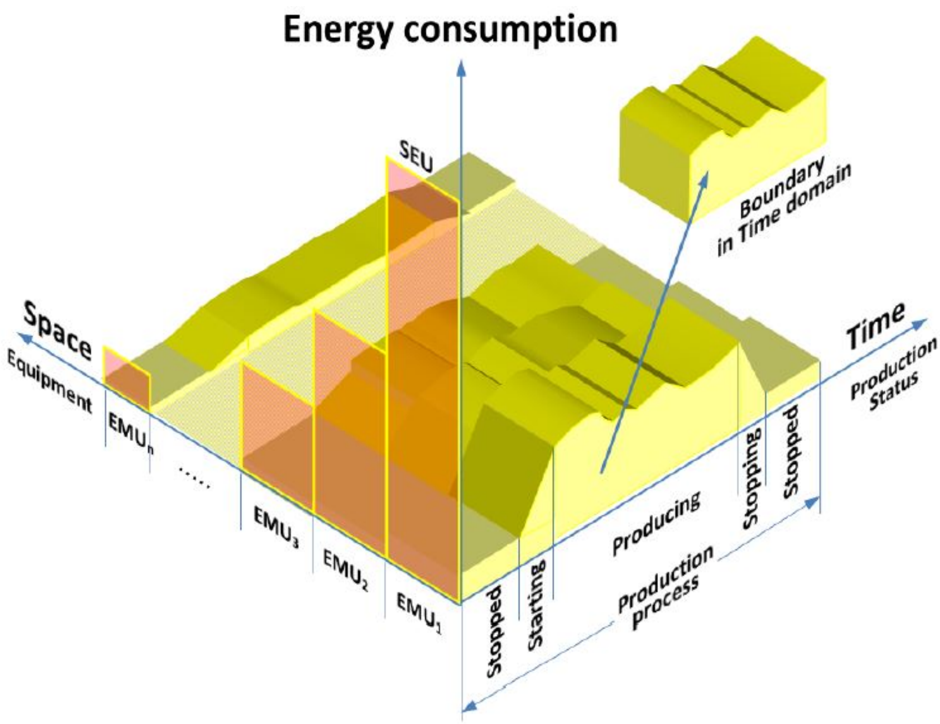


Figure 13 Boundary in time domain

Source：JEITA space-time boundary for effective energy management (7)

4.3.3.3. Boundary in time domain in production processes

Figure 14 shows a comparison of production statuses of batch, continuous and utility processes. As explained above, production status is interpreted as "Boundary in time domain". The green colored plane indicates "Boundaries in space domain" that represent batch, continuous and utility processes. In a batch process, boundaries in time domain are defined for every batch. The brand of product is changed at frequent intervals. While the energy consumption characteristic varies widely by the brand, the production process is designated by the brand. In a continuous process such as oil refinery, same brand is continued in production under the same production conditions for a long term. Even in an oil refinery, the energy consumption characteristic of the process changes in case of the material (crude oil) change. Boundary in time domain for continuous processes can be defined same as for batch processes. As a utility process in a factory should provide energy conversion and supply continuously during the entire operation of the factory, the operation status is represented in a long time "Boundary in time domain". For effective energy management, Concepts of "Boundaries in space domain" and "Boundary in time domain" are introduced. These two concepts are integrated into the concept of "Space-time boundary".

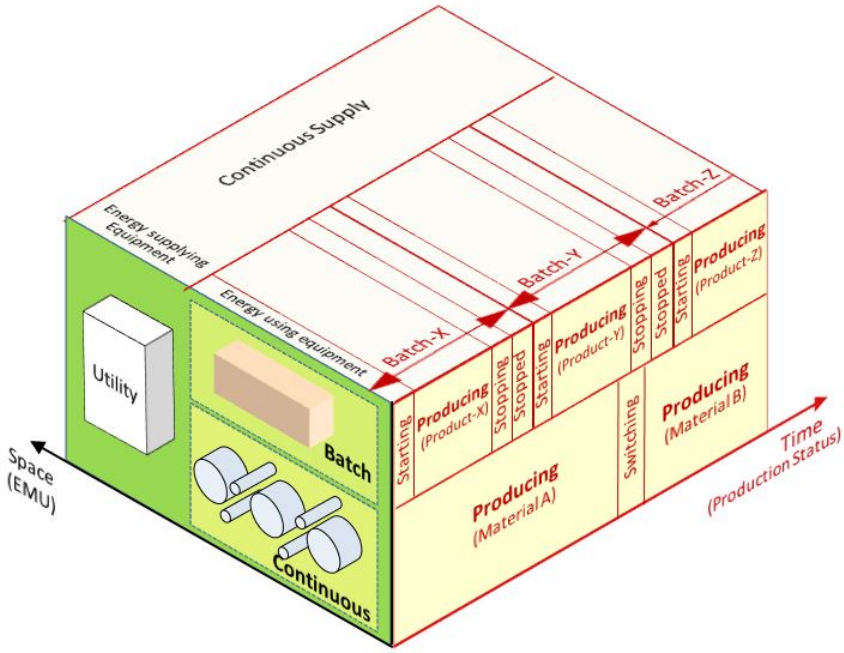


Figure 14 Comparison of production status

Source：JEITA space-time boundary for effective energy management [7]

4.4. Energy flow visualization

For energy management, it is important to visualize the entire energy flow. Figure 15 shows the energy flow of a factory using a fence diagram. Fence diagrams visually show flow of energy within and across the EnPI boundary along the flow of production so that metering points are identified. The factory shown in Figure 15, produces product A, B and C from raw materials using natural gas, electricity and nitrogen. Boilers in building 2 supply steam necessary for the production processes in building 1 and 3. The energy performance of a manufacturing factory is greatly affected by the energy flow. So, it is important to measure the energy consumption for each EnPI boundaries such as entire factory, production line, production process, and product.

Note: EnPI boundary is defined in ISO50006. This concept is similar to EMU.

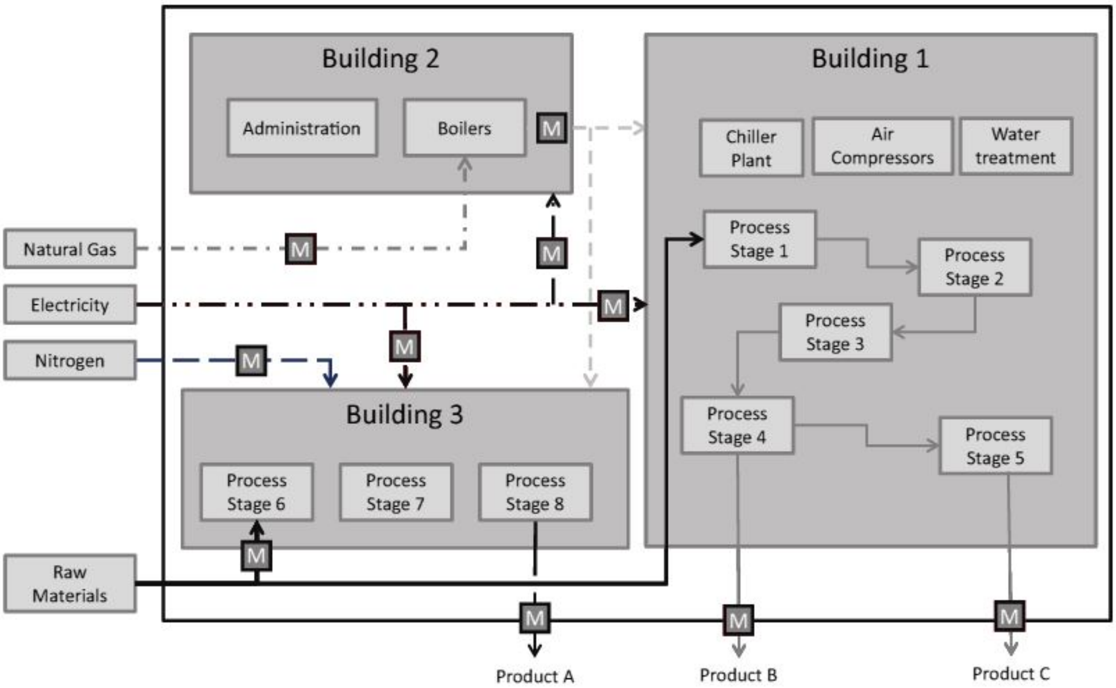


Figure 15 Visualization of energy by Fence diagram

Source : Energy management systems − Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) − General principles and guidance(6)

4.5. Improvement process

4.5.1. Viewpoints

Figure 16 shows six view points for energy saving activities along the energy flow in a factory. Electricity, heat energy and mechanical energy are major energy sources that can transfer from one form to another. Even among them, heat energy can be a key factor of the total energy efficiency of a factory. Followings are the viewpoints to improve the energy efficiency.

① To enhance combustion efficiency of fuel
② To enhance utilization efficiency of heat energy generated by combustion
③ To utilize the energy by waste heat recovery
④ To enhance conversion efficiency for electricity generation
⑤ To enhance thermal insulation performance so as to reduce such losses as radiation loss, conduction loss and resistive loss.
⑥ To enhance conversion efficiency from electricity into heat, mechanical power, etc..

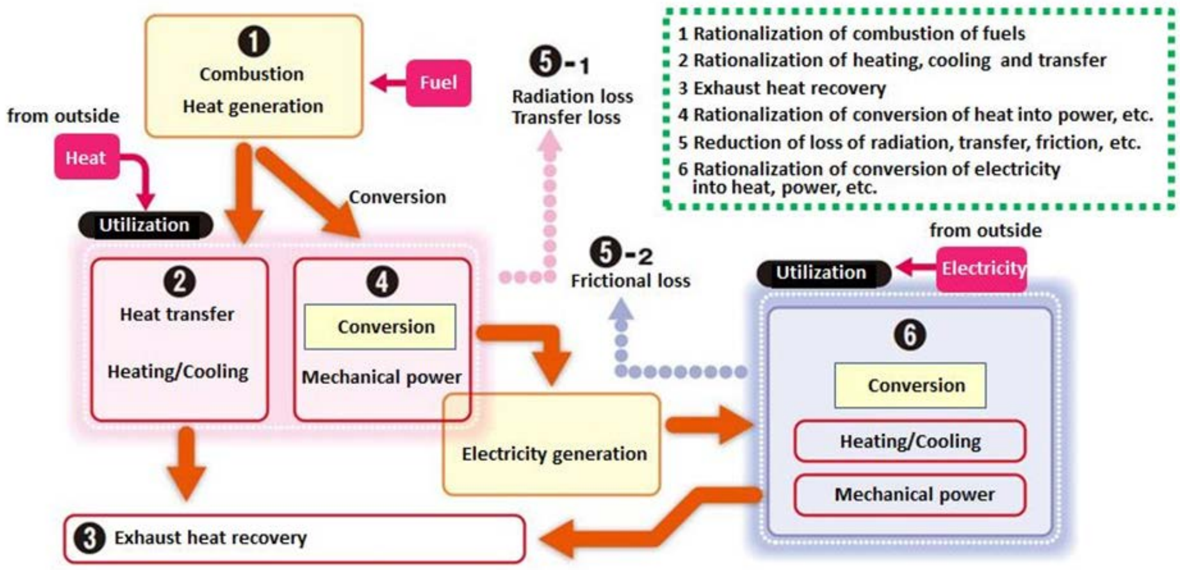


Figure 16 Viewpoints for energy savings (8)
Redrawn based on Source：省エネ診断・節電診断の進め方（省エネルギーセンター）
電気と保安 電気と保安 2013 年 1・2 月号

Examples of viewpoints are shown in Table 2. On the level of equipment and devices, energy efficient equipment and devices may be considered at the time of implementation. On the other hand, energy efficiency can be improved sometimes by finding the optimum operation conditions of existing equipment even as it is. Tuning PID parameters of control system is one practical example. It is also important to define the boundary of energy management from the system's viewpoint. When the boundary is defined over a wider range than individual equipment, it will be easier to find further improvements from a viewpoint of overall optimization that can bring substantial improvement. It is recommended to proceed as possible cooperative approach with related organizations as possible.

Table 2 Viewpoints for energy management

	Equipment and devices	Operation/Control/Tuning	Boundary/ Cooperation
0 Common	Improving efficiency of equipment Top Runner equipment Maintenance Pressure loss in the piping	Check and inspect equipment Overcapacity of facility Consumption during non-operating time Idling stop Control strategy selection Stabilization of operation Averaging loads PID parameters Readjust operation time	Cooperation between organizations Boundary definition Pinch technology RENKEI control
1 Rationalization of fuel combustion		Combustion control Air-fuel ratio control Remaining heat	
2 Rationalization of heating, cooling and transfer	Improving heat insulation of furnace Heat pump		Hot charge
3 Waste heat recovery	Waste heat recovery facility		Utilization of unused energy Waste heat of heated objects
4 Rationalization of converting heat to power	Heat insulation		
5 Reduction of energy loss radiation, transfer, resistive loss, etc.	Heat insulation		
6 Rationalization of converting electricity to power, heat, etc.	High efficiency motor Inverter driven motor Top Runner		

4.5.2. Waste heat recover for efficient use of energy

4.5.2.1. Heat balance

Heat balance is defined as the distribution of heat and the relationship between the heat energy supplied to a system (as a steam power plant) and the various output including both useful output and losses. The definition also includes an evaluation or record of such distribution.

It is important to manage the heat balance of entire system in process plant. Heat energy is one of the important factors of energy management in a process plant.

Heat energy in a process plant is used in various forms such as combustion of fuels, heating and cooling of fluid. Chemical reaction causes heat absorption and heat generation. Figure 17 is an example of “Sankey diagram” that provides a visual representation of heat balance. Horizontal width of the diagram represents amount of heat. Input heat, output heat and heat loss are represented along a vertical direction. Heat recovery is represented by a circle on the right hand side. Sankey diagram represents visually inputs, outputs and losses so that energy managers can focus on finding improvements in a prioritized manner. Heat input comes from potential heat in raw materials, potential heat in pouring water and electricity, heat from combustion, potential heat in fuel and air, and reaction heat. Heat output goes out as potential heat in the product. Heat loss is wasted in exhaust gas, cooling water and heat dissipation. Heat recovered by heat exchanger is reused for production process.

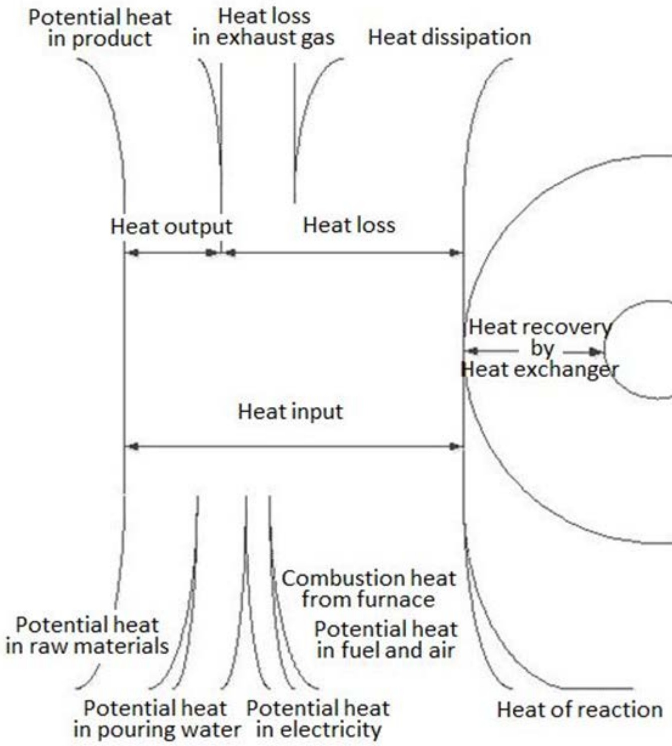


Figure 17 Sankey diagram

4.5.2.2. Utilization of waste heat

Various forms of heat energy are used in process industries. Effective utilization of waste heat energy is decisively important to improve energy efficiency. Figure 18 shows the energy flow in a material manufacturing process. Energy input to the process is converted into (1) Potential heat energy in products, (2) Exergy loss mainly in burning process and (3) Waste heat in processes. In chemical processes, it is said that 60% of input heat energy is conserved in products, 30% is exergy loss and 10% is waste heat. Energy regeneration / recovery and minimizing the amount of waste heat can bring a good result in energy savings in process industries.

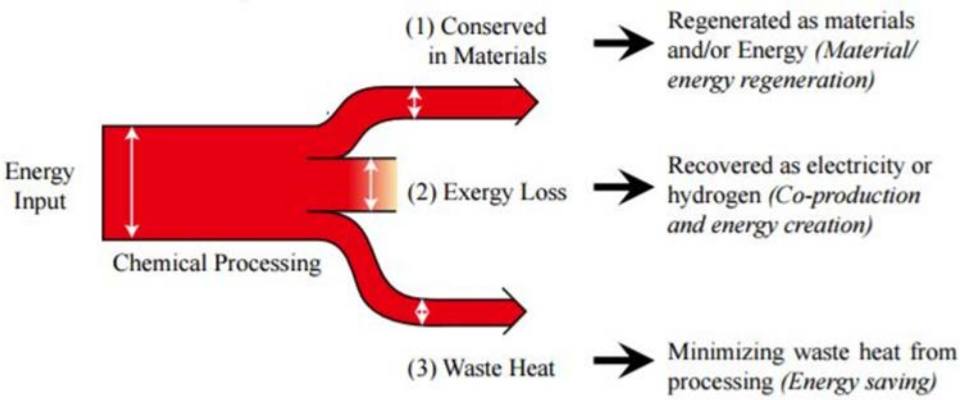


Figure 18 Energy flow in material manufacturing processes

Source: Strategic Technology Roadmap in Energy Field（AIST）(9)

Table 3 shows characteristics of waste heat in manufacturing industries. Figure 19 shows temperature ranges of production and waste heat in industry sectors. The majority of demand of heat source in industry is medium and low temperature heat source for production processes such as concentration, drying, sterilization etc. except petrochemical and iron and steel industries. When chemical energy in fuel is used for such demand of low temperature heat by converting fuel into thermal energy, a large range of "Exergy loss and destruction" is generated. It is necessary to apply thermal technologies that enable efficient utilization of heat energy and minimize exergy loss based on thermodynamics. Exergy implies "the quality of energy" defined as "the potential to convert energy into work". Thermal processes in industry such as combustion, heat transfer, chemical reactions and etc. are irreversible processes that inevitably lose exergy due to the destruction. In an actual plant, thermal energy and exergy are lost during the production process and finally become unavailable energy not to do work（heat energy at environment temperature）. As shown in Table 3, many industries have been wasting low temperature heat that is desirable to be recovered. The efficient use of low temperature waste heat is an important issue for energy management in industries.

Table 3 Characteristics of waste heat in manufacturing industries

Industry	Waste heat in manufacturing
Electricity	About 95% of waste heat is low temperature waste gases below 150℃
Chemical	Temperature of waste heat is distributed in a wide range. About 45% of waste heat is low temperature waste gases in the range of 150～200℃ that is relatively difficult to be recovered. Considerable amount of waste heat is low temperature drain in the range of 40～60℃.
Iron and steel	About 50% of waste heat is low temperature gases below 200℃. High temperature waste heat below 350℃ is easier to be recovered. Considerable portion of the heat loss is from heated solid streams over 500℃.
Cleaning	About 45% of waste heat is low temperature waste in the range of 150～300℃. Waste steam heat is a characteristic feature of cleaning industry.
Ceramics	About 40% of waste heat is low temperature waste gases below 150℃
Pulp and Paper	Mostly low temperature waste gases below 150℃
Oil refinery	Low temperature waste heat in the range of 150～200℃ that is relatively difficult to be recovered.

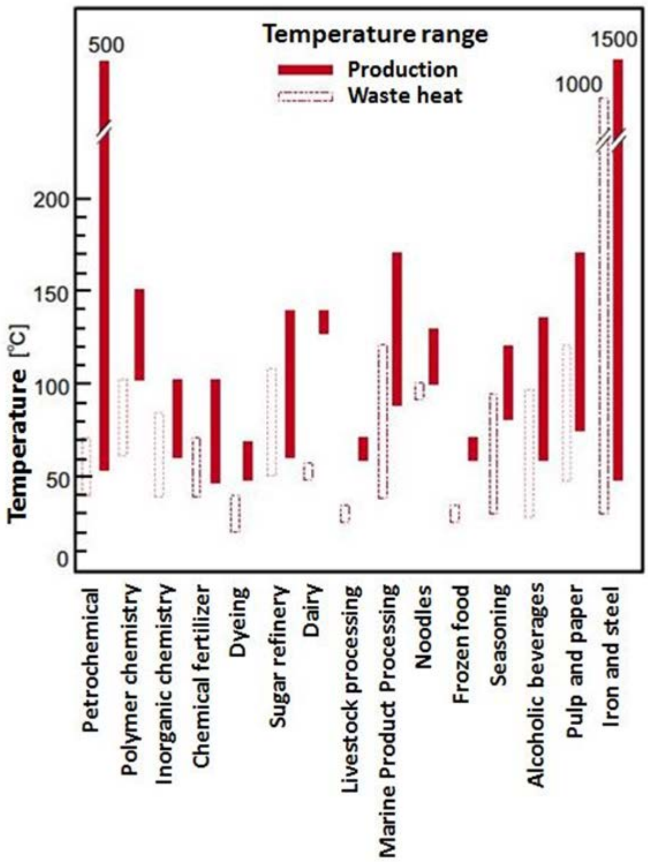


Figure 19 Temperature range of production and waste heat

Redrawn based on Source：Technology Survey on Advanced Utilization of Medium to Low Temperature Heat(10),Japan Science and Technology Agency (JST) Center for Research and Development Strategy

4.5.2.3. Exergy

For the best use of total energy in a plant including low temperature waste heat, the thermodynamic performance of a process should be evaluated by performing an exergy analysis in addition to the conventional energy analysis.

Exergy is defined as the maximum work potential of a system or component at a given state in a specified environment. The environment is usually specified in terms of pressure and temperature as P_0 = 1 atmosphere. T_0 = 25°C (77°F). Exergy is the energy that can be converted into work according to the second law of thermodynamics. Exergy implies the quality of energy for production. The higher is the temperature of the fluid, the higher is the exergy of the fluid.

In an actual plant, exergy is reduced by exergy loss or destruction due to thermodynamic irreversible processes such as combustion, heat transfer, pressure drop in flowing fluid, etc., and finally becomes useless energy as the energy at environment temperature. So, reduction of exergy loss and destruction is the key for the higher utilization of total energy. Energy efficiency can be improved by designing the process introducing such energy conversion methods that the exergy loss is minimized for high exergy heat source and enables the utilization of low exergy heat source as much as possible. Exergy analysis can provide more insights and be a more useful tool in efficiency improvement than energy analysis.

4.5.2.4. Effective utilization of waste heat in petrochemical complex [3]

In the petrochemical complex, the cascade utilization of low temperature waste heat with low level exergy has been studied for further energy savings by cross-organizational activities between equipment, plants, factories and even enterprises. This is known as process integration, heat integration and energy integration. Figure 20 Effective utilization of thermal energy by Pinch Technology shows an example of effective utilization of thermal energy by analyzing the heat flow by Pinch Technology. In the oil company, low temperature(80～150℃) waste heat is recovered into hot water by heat exchanger and transferred to the adjacent chemical company. In the chemical company, the transferred hot water is used to preheat the feed water to the boiler. Preheating the boiler feed water increases the boiler efficiency and reduces the fuel cost. Pinch Technology provides a systematic methodology for energy saving in processes and total sites by optimizing heat recovery systems, energy supply methods and process operating conditions. The methodology is based on thermodynamic principles. Pinch technology is quite effective to recover the low temperature waste heat and results in substantial energy savings for the energy consuming industries such as oil refinery, petrochemical, iron and steel, pulp and paper, cement, etc.

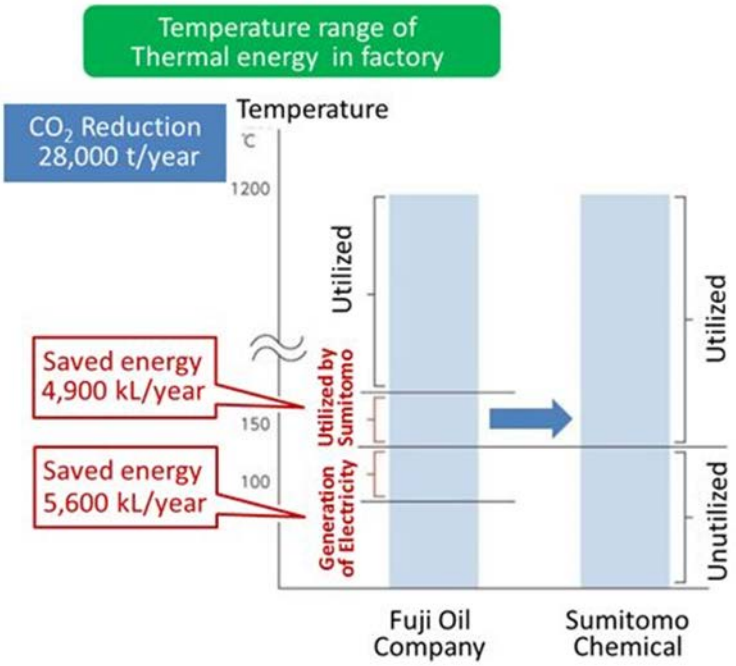


Figure 20 Effective utilization of thermal energy by Pinch Technology

Redrawn based on Source：(NEDO）複数工場間で熱を共有しコンビナート全体での省エネを実現[(11)]

4.5.2.5. Heat recovery and utilization of waste heat in Iron and Steel Plant

Figure 21 shows the heat recovery in iron and steel plant. In the integrated steel mills, steel is made from iron ore using such manufacturing processes as blast furnace, basic oxygen furnace, continuous casting and metal rolling. These processes consume high temperature heat energy and generate by-product gases such as coke oven gas (COG), blast furnace gas (BFG) and basic oxygen furnace gas (BOFG). By-product gases are fully reused for the internal generation of electricity, saving additional fossil fuel resources. The pressure of blast furnace top gas is about 300kPa and used to drive a top-pressure recovery turbine for electric power generation. Technologies for heat recovery have been thoroughly studied and implemented in actual plants to improve total energy efficiency of the integrated steel mills. Heat energy of exhaust gas from high temperature equipment such as hot stove, heating furnace is also recovered. Exhaust heat energy from red-hot coke, sintered ore is recovered for generating steam and electricity.

The steel industry in Japan has already achieved the world's top-level energy efficiency by making persistent efforts for energy savings. However, as shown in Table 3, about 50% of waste heat is low temperature gas heat that is hard to be recovered. It is an important future subject for the industry to utilize the low temperature waste heat.

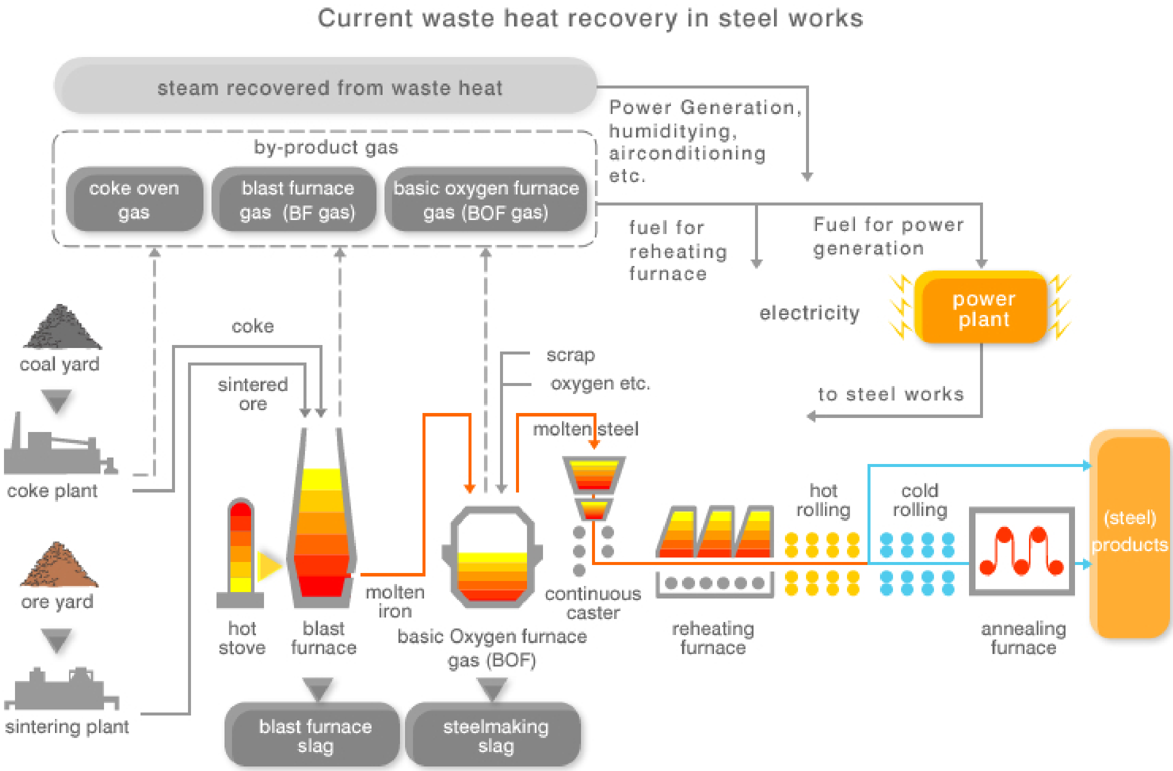


Figure 21 Heat recovery in Iron and Steel plant

Source : Steelmaking process by Innovative technology for COURSE50[(12)]

COURSE50 : **CO_2 U**ltimate **R**eduction in **S**teelmaking process by Innovative technology for cool **E**arth **50**

4.5.3. Top-down approach and Bottom-up approach for energy management

As explained in 4.3, EMU can be defined in a hierarchical fashion. Figure 22 shows a hierarchical structure of EMU in an enterprise. EMU on the top layer (L_{n+2}) is defined for the entire enterprise or factory. The second layer (L_{n+1}) is defined for a production line of the factory. The third layer (L_n) is defined for equipment or facilities of the production line. The higher the layer of EMU is, the wider the boundary is defined for the EMU. The lower the layer of EMU is, the smaller the boundary is defined for the EMU. Defining a wider boundary is necessary for the overall optimization. Smaller boundaries make it easier to find specific and practical solutions for improvement.

When the target EnPIs of a company is established, "Top-down approach" starts from the top layer of EMU hierarchy and proceeds downward to lower layers to identify the significant opportunities for energy performance improvement.

"Bottom-up approach" starts from the lowest layer of EMU hierarchy finding improvement opportunities for individual equipment or facilities on the layer, and proceeds upward to the higher layers. For example, it is easier to define the boundaries and EnPIs clearly for such activity as improving boiler efficiency in expectation of immediate effects. On the other hand, top-down approach from the level of enterprise or factory may make certain that energy consumption for air conditioning is greater than that of manufacturing equipment. In such a case, it is effective to improve the energy consumption for air conditioning rather than the manufacturing equipment.

In order to find a better solution, the target of efficiency improvement should be defined as an EMU. It is necessary to evaluate the contribution of the EMU to the upper level EMU (possibly the highest level of the organization) for improving energy performance. Typical bottom-up approach is an efficiency improvement project for individual equipment or facilities. As people who are involved in such a project are usually familiar with individual equipment or facilities, they are active to propose many feasible ideas for improvement. It is important to proceed with the project by evaluating the contribution of the bottom-up approach to the organization sharing the understanding of importance.

It is effective to process both Top-down approach and Bottom-up approach in a mutually complementary manner rather than an individual approach. For example, after a bottom-up approach has been scheduled, simulating a top-down approach to the same process will show the effectiveness of the bottom-up approach from the standpoint of organization. The reverse is also effective. After a top-down approach has been scheduled with some improvement plans for equipment or facilities, simulating the bottom-up approach will provide a chance to evaluate the effectiveness of the improvement plans.

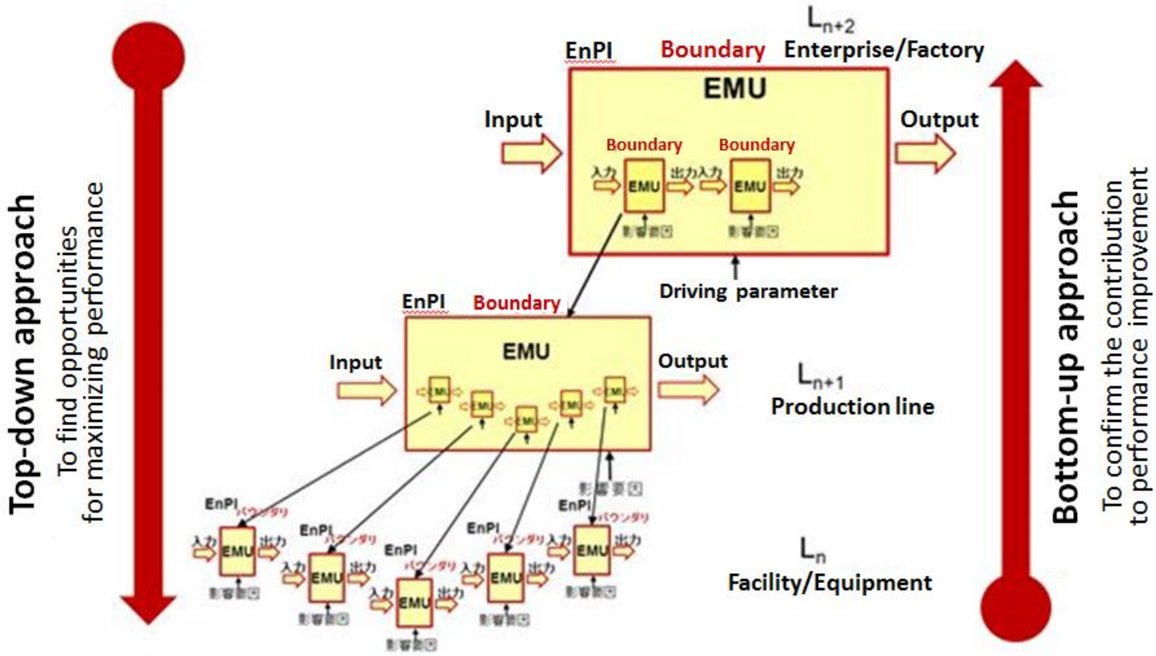


Figure 22 Top-down approach and Bottom-up approach for energy management

Redrawn based on Source：(JEMIMA) 製造業におけるエネルギー効率向上へのシステムアプローチ(13)

4.5.4. SEU (Significant Energy Use)

ISO50001 defines SEU (significant energy use) as “energy use accounting for substantial energy consumption and/or offering considerable potential for energy performance improvement”. Significance criteria are determined by the organization. It is noted that SEU includes not only the energy consumption but also considerable potential for energy performance improvement. Figure 23 shows EnPI boundaries division process to identify SEU. In the process of energy performance improvement, it is important to find the most inefficient portion in the production system. An EnPI boundary can be used effectively to focus on this portion by narrowing the boundary. The target boundary should be divided into several EnPI boundaries. As a next step, the EnPI boundary should be narrowed on the SEU of the production system to find a more detailed point for the energy efficiency improvement. Figure 23 shows the steps to focus on the SEU. As a first step the EnPI boundary of SEU is the entire factory. As the second step the SEU is a facility in the factory. As the third step the SEU is equipment in the facility.

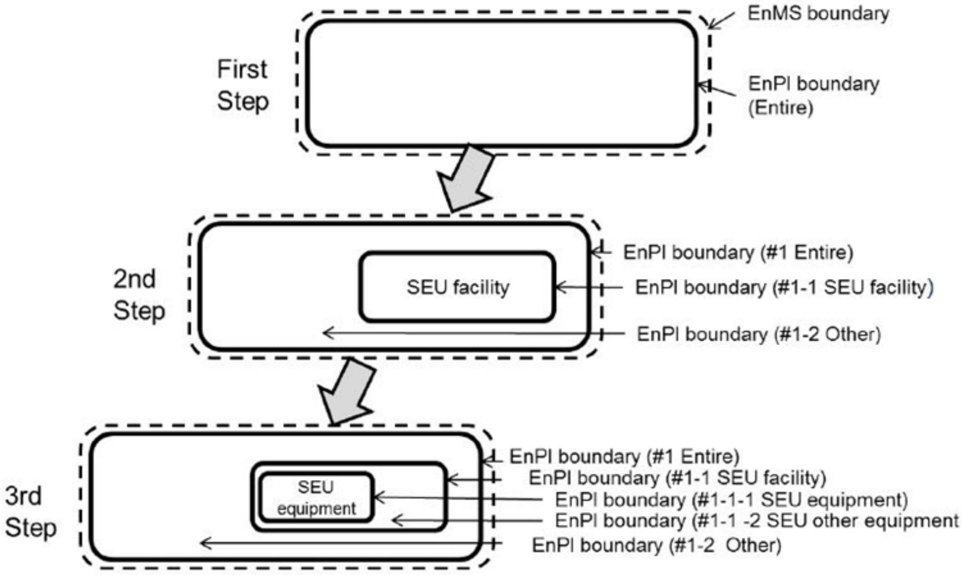


Figure 23 EnPI boundaries division process

Source : ISO50006 Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPIs) — General principles and guidance—(4)

5. Production system and process control technologies for energy efficiency improvement

Plant control systems have been expected to provide better solutions for energy efficiency improvement of the plant operation. It is necessary to keep the high control performance by monitoring and evaluation of control performance setting the set point to the optimum operating point. Topics of control technologies are control method for flow rate distribution of pumps, monitoring and evaluation method for control performance, event driven type of modeling technology, etc..

5.1. International comparison of energy efficiency in industries

Japan has few domestic energy resources, and imports significant quantities of resources such as coal, crude oil, and liquefied natural gas. So, Japanese industries have been promoting substantial energy-saving efforts with advanced results ahead of other countries. Especially, energy intensive sectors such as iron and steel, cement have achieved the world-top level energy efficiency by energy efficient production technologies. Figure 24 shows comparisons of the international energy consumption of major material industries. Energy consumption of foreign countries is shown in normalized data against 100 for Japanese industry. For example, for iron and steel manufacturing to produce 1 ton of steel, Korean industry needs 4% more , Chinese industry needs 17% more energy than Japanese industry. Other industries also produce products with less energy consumption than foreign countries. The energy efficiency is closely related to the productivity of the industry that is supported by process control technologies. Japanese energy saving technologies is expected to make a substantial contribution to improve the energy efficiency of the worldwide industries.

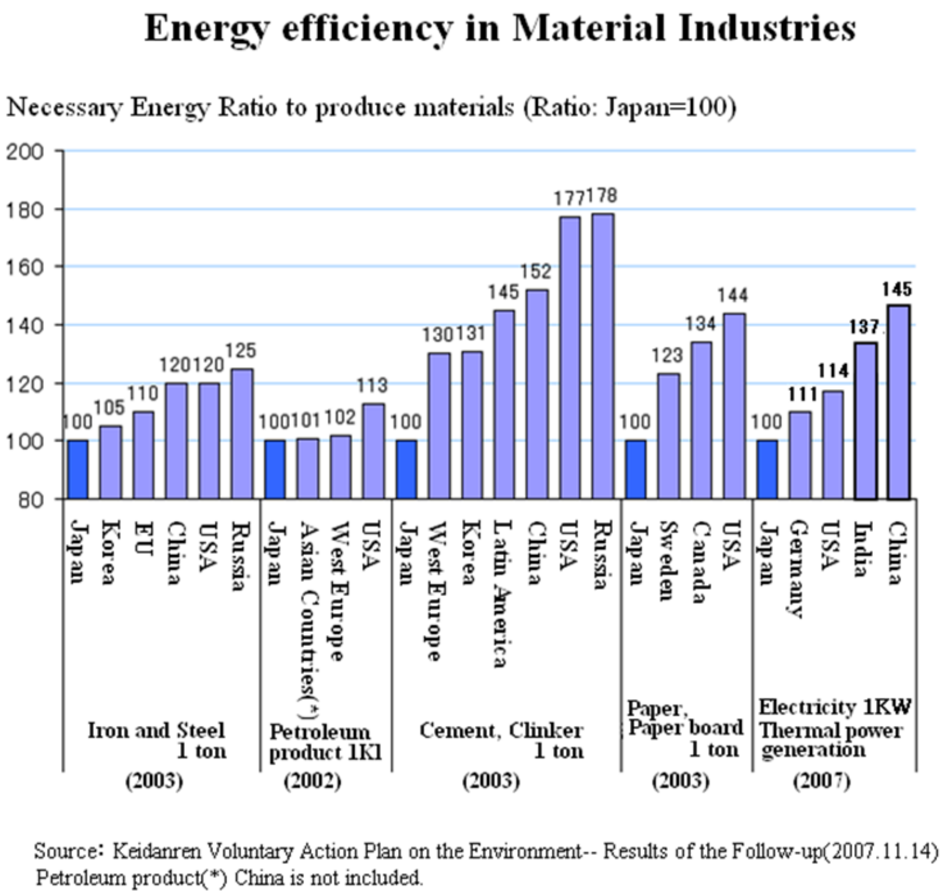


Figure 24 International comparison of energy efficiency in material industries

Redrawn based on Source : Results of the Fiscal 2013 Follow-up to the Voluntary Action Plan on the Environment (Summary) —Section on Global Warming Measures—

< Performance in Fiscal 2012 >, KEIDANREN[(14)]

5.2. Characteristics of production process

Figure 25 shows types of production process and control in process industries. Production process is classified into continuous process, hybrid (batch) process and discrete process by the types of raw materials and products. Raw materials processed in Continuous process are mainly gas and liquid. Processed materials in Batch process are mainly liquid and powder. Discrete process handles mainly solid materials and products. When the kind of crude oil for an oil refinery plant is changed, it becomes necessary for even a continuous process to change operating conditions of the plant like a batch process. The grade change of a product, product change and operational phases such as start-up and shut-down can also be seen in continuous processes as well as batch processes.

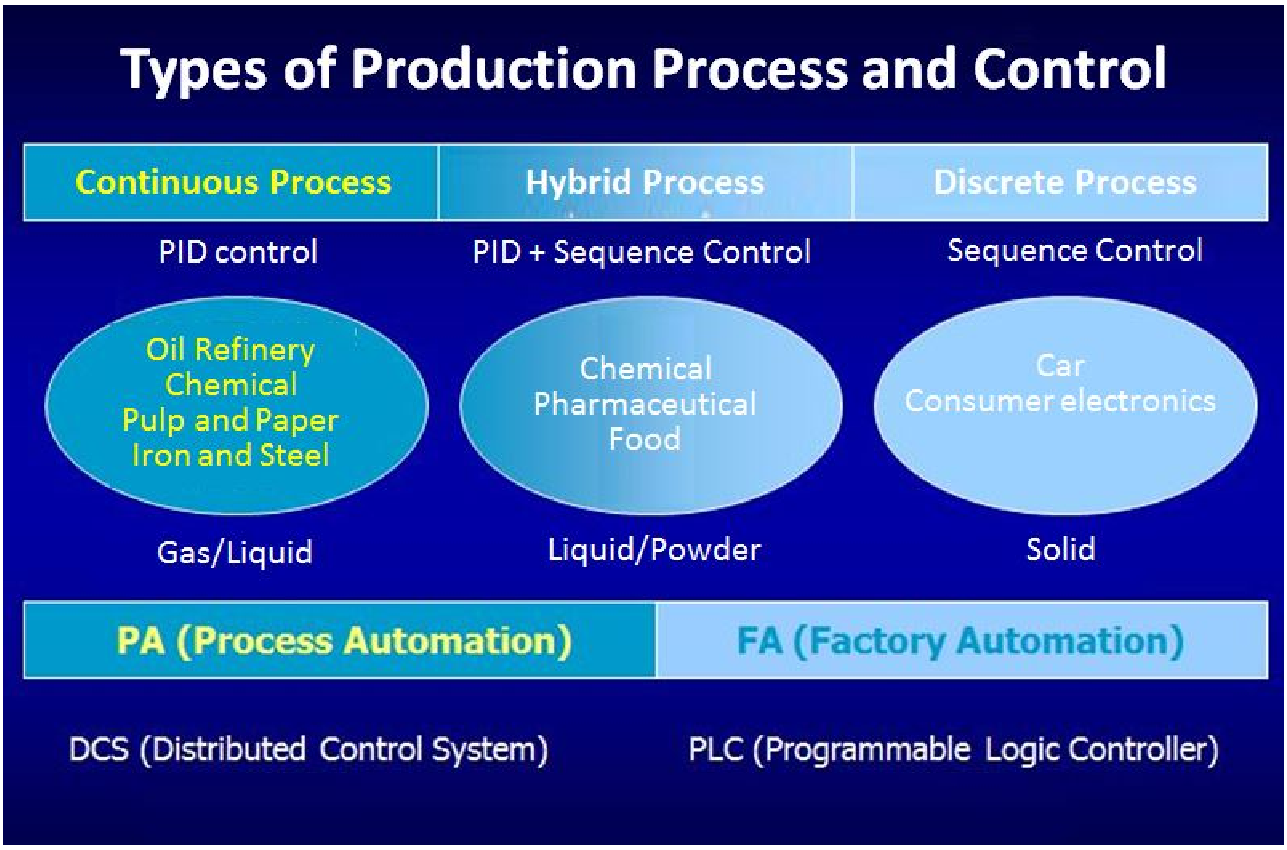


Figure 25 Types of Production Process and Control

5.2.1. Continuous process

Continuous process is a flow production method used to produce, or process materials without interruption. Examples of continuous process are oil refinery plant, polymer producing process in a petrochemical plant, blast furnace in an iron and steel manufacturing, chemical pulp process in a pulp and paper plant, etc.

5.2.1.1. Oil refinery process

Figure 26 shows the oil refinery process. The crude oil is passed into the crude oil atmospheric pressure distillation unit that allows the separation of the crude oil into different fractions like naphtha, kerosene, diesel and gas oil depending on the difference in boiling temperature. The crude oil is transferred into useful products such as liquefied petroleum gas (LPG), gasoline or petrol, kerosene, jet fuel, diesel oil and fuel oils. As shown in Figure 26, oil refinery plant is operated by several processes such as atmospheric distillation, desulfurizer, catalytic cracking etc. These processes are equipped with heating furnaces that are the most energy consuming equipment in the oil refinery plant. Every possible effort to improve the energy efficiency of the entire oil refinery plant have been made by improving the thermal efficiency of heating furnaces and using proper number of heat exchangers for thorough heat recovery.

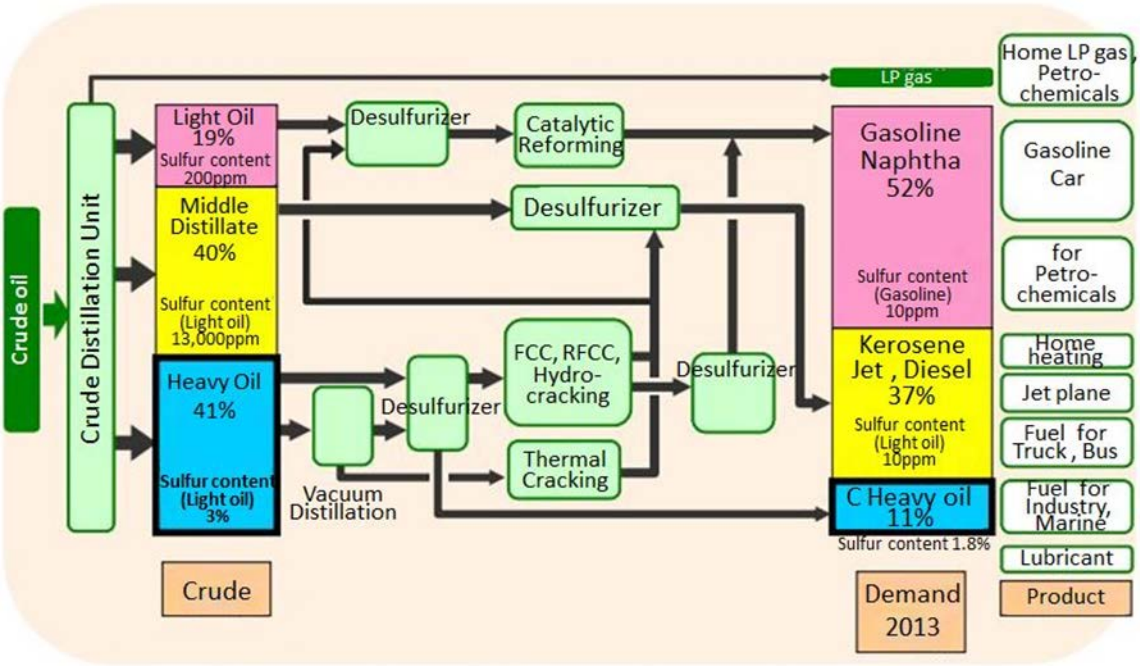


Figure 26 Oil refinery process

Redrawn based on Source：Petroleum Association of Japan (PAJ)

5.2.1.2. EMU and EnPIs for oil refinery process

Figure 27 shows examples of EMU and EnPIs for each equipment hierarchy in an oil refinery plant. The first step is to define EMU to the entire plant. Energy consumption of the entire plant and specific energy consumption are defined as EnPI for the EMU. The second step is to define the facility level EMU to the catalytic reforming unit. In order to evaluate the energy efficiency of the unit, energy consumption of the catalytic reforming unit, specific energy consumption and heat recovery efficiency are defined as EnPI for the facility level EMU. The reforming process is a catalytic process which converts low octane naphtha into higher octane reformate products for gasoline blending. Naphtha is heated up to the reaction temperature by the heating furnace. The third step is to define the equipment level EMU to the heating furnace that consumes significant energy. Amount of fuel consumption, energy efficiency are defined as EnPI for the equipment level EMU. Relevant variables that affect EnPIs are air to fuel ratio, O_2, CO concentration in the exhaust gas, COT：(the outlet temperature of a heating furnace) ,etc. Relevant variables are monitored continuously. Air to fuel ratio is explained in 5.4.4 Combustion control.

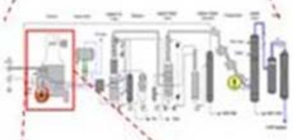
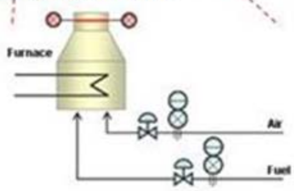
Layer	Boundary	EnPI
Plant	Refinery Plant 	Energy consumption (by energy source) Specific energy consumption
Facility	Reforming Unit 	Energy consumption (by energy source) Specific energy consumption Energy utilization efficiency Heat recovery efficiency
Equipment	Heating furnace 	Energy consumption(Fuel) Energy efficiency

Figure 27 Example of EnPI in an oil refinery plant

5.2.2. Batch process

5.2.2.1. Characteristics of batch process

JIS C 1807 defines batch process as follows. "A batch process is a process that leads to the production of finite quantities of material by subjecting quantities of input materials to an ordered set of processing activities over a finite period of time using one or more pieces of equipment".

Figure 28 shows a typical batch reactor that consists of a tank with an agitator and integral heating/cooling system. Raw materials as reactants are placed in, mixed together, heated for the reaction to take place and are cooled. The products formed inside the reactor are poured out. During the reaction process, operating conditions such as the reaction time and temperature are monitored and controlled.

In a batch plant, products are produced by lots (batch). Production line can be used to produce several products. In order to increase productivity of batch production, several units such as reactors are connected to have the multi-path structures that are series (single-stream), parallel (multi-stream) and a combination of the two as shown in Figure 30. Multiple-path structure enables to produce several batches in parallel.

Batch processes are used in the production plant of fine chemicals, biotechnology, beverage, food, pharmaceutical, etc. These industries produce large number of products and develop new products frequently. In order to follow the increasing demands from market on flexibility and customer-driven production, high productivity batch processes that enable the multiproduct variable quantity production have been established. When new products are put on the market, it may be necessary to design a new production process. However, existing plant also can be utilized for such demands by devising the operation of the plant. Standardized methods based on the functional characteristic of batch process have provided solutions for flexible production.

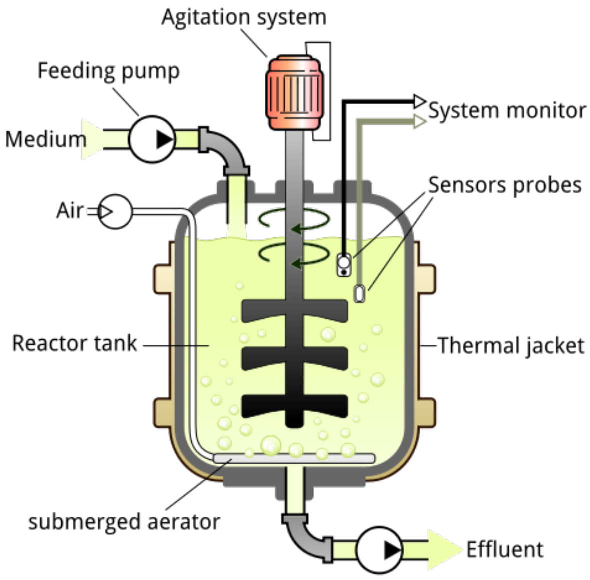


Figure 28 Schematic structure of bioreactor

Source：Wikipedia(15)

5.2.2.2. Models of batch process

In a batch system, product, process and procedure are related to each other. Whenever new products are put on the market, it has become necessary to change hardware, software and operation procedure. The cost for the change has been inevitably increased.

IEC61512 (ISA S88) was developed to provide a standardized systematic method that should enable the cost reduction and shortening the lead time. This standard describes batch control from two different viewpoints: the process view and the equipment view. Following 4 models are defined. (1)Process model, (2) Physical model, (3) Procedural Control Model and (4) Management activity model.

(1) Process model･･･Process view (Process design, Product type)

Process model represents the process view normally of the chemists. This model specifies such information necessary to produce a product as kind of raw materials, mixing ratio, with or without catalysts, reaction temperature, etc., and describes the chemical and physical changes during the production processes. Process model does not consider the actual equipment.

(2) Physical model･･･ Equipment view

The equipment view is represented by the physical model and is normally the view of the product engineer or the process operator. The physical model of S88 defines the hierarchical relationships between the physical assets involved in batch manufacturing. Figure 29 shows hierarchical 7 layers of the physical model defined by IEC61512 (ISA S88). 7 layers are Enterprise, Site, Area, Process cell, Unit, Equipment Module and Control Module.

- A process cell contains one or more units.
- A unit can carry out one or more major processing activities such as react, crystallize or make a solution. Units can operate independently of each other. A unit consists of equipment modules and control modules. Reactor is a typical example of Unit.
- An equipment module can carry out a finite number of minor processing activities like weighting and dosing. It combines all necessary physical processing and control equipment required to perform those activities. An equipment module consists of control modules and may contain subordinate equipment modules.
- A control module is typically a collection of sensors, actuators or controllers. A control module may contain other control modules.

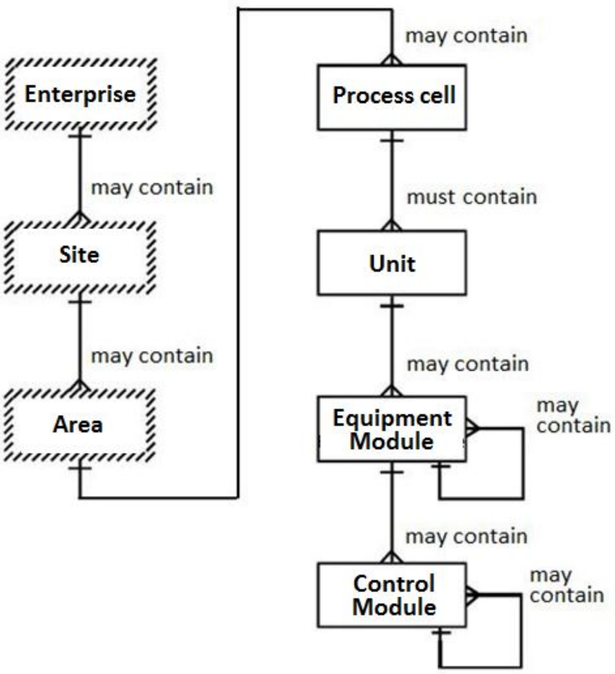


Figure 29 Physical Model IEC61512 (ISA S88)

Source：IEC61512 (Formerly ANSI/ISA–S88.01–1995) (16)

The physical structures of a process cell are classified in the 3 types: single path, multiple path, and network. Figure 30 shows an example of the multiple-path structure of a process cell. Several batches may be in progress at the same time. A train is composed of all units and other equipment that may be utilized by a specific batch.

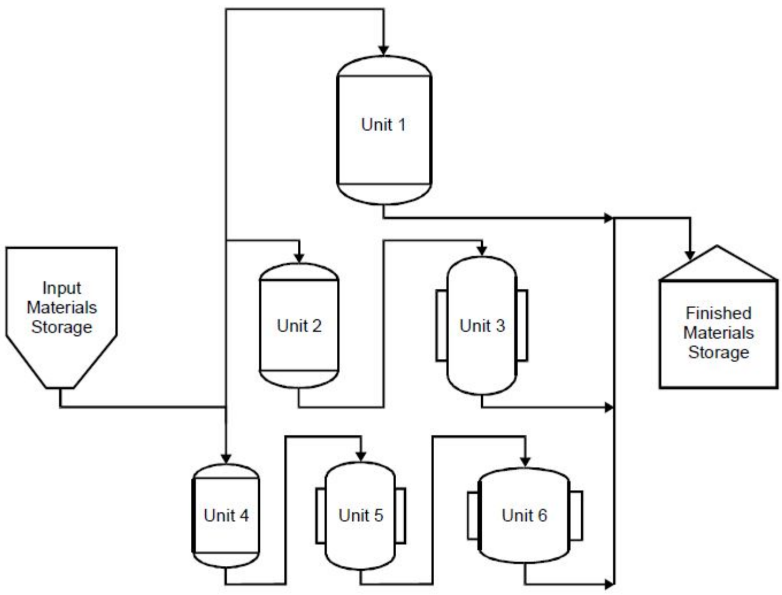


Figure 30 Multiple-path structure of Process cell

Source : IEC61512 (Formerly ANSI/ISA-S88.01-1995) (16)

The physical structures of a process cell are classified in the 3 types: single path, multiple path, and network. Figure 30 shows an example of the multiple-path structure of a process cell. Several batches may be in progress at the same time. A train is composed of all units and other equipment that may be utilized by a specific batch.

(3) Procedural Control Model(33) ・・・ Procedural Control Model consists of Procedures, Unit procedures, Operations, and Phases.

- Procedure --- The procedure is the highest level of the model and defines the strategy for accomplishing a major processing action such as making a batch. An example of a procedure is "Make a batch of product A".
- Unit Procedure --- A unit procedure defines a set of related operations that initiates a production sequence to take place within a unit.

Examples of unit procedures are "Polymerize", "Recover ", "Dry"

・ Operation --- An operation is a sequence of phases that defines a major processing sequence.

Examples of unit procedures are "Preparation "," Charge "," React ".

・ Phase --- Phase is the smallest element of procedural control that can accomplish a process-oriented task. It defines a product independent processing sequence.

Examples of Phase are "Add catalyst "," Heat ".

(4) Management activity model ・・・ Information management

5.2.2.3. Recipe management for batch processes

IEC61512 (ISA S88) defines “Recipe” as “The necessary set of information that uniquely defines the production requirements for a specific product.” Recipe does not consider the actual equipment. There are four types of recipes defined as follows: general, site, master, and control.

(1) General Recipe: A type of recipe that expresses equipment and site independent processing requirements and may include product specific processing information.

(2) Site Recipe: A type of recipe that is site specific.

(3) Master Recipe: A type of recipe that accounts for equipment capabilities and may include process cell-specific information.

(4) Control Recipe: A type of recipe which, through its execution, defines the manufacture of a single batch of a specific product and may include Batch ID, batch size, in-process operator and/or system generated information.

Recipe contents shown in Figure 31 are as follows.

Header: Information about the purpose, source and version of the recipe such as recipe and product identification, creator, and issue date.

Procedure: The recipe procedure defines the strategy for carrying out a process. Unit procedure describes the procedure of unit operation. For example, operation of polymerization tank is divided into 3 operations that are feed material, temperature control and agitation. Operation is divided into detailed phases. For example, the phase of temperature control describes to heat the polymerization tank up to 40℃, then to leave it 10 minutes at the constant temperature.

Formula: A category of recipe information that includes process inputs, process parameters, and process outputs.

Equipment requirements: Equipment requirements constrain the choice of the equipment that will eventually be used to implement a specific part of the procedure.

Other information

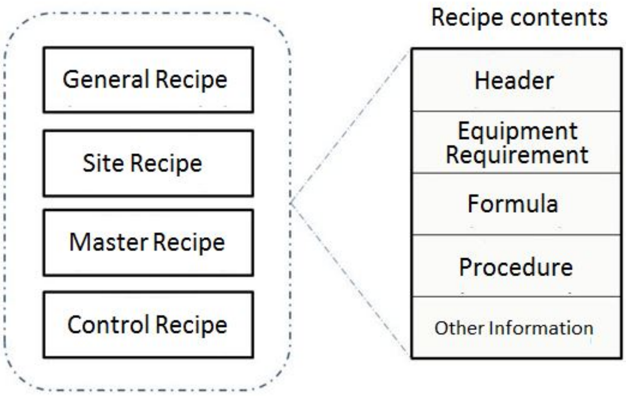


Figure 31 Recipe contents

5.2.2.4. Relationship between recipe and models

A batch process is operated by the "Recipe" that specifies the necessary set of information that uniquely defines the production requirements for a specific product.

That is to say, a batch process produces products (Process model) using specific equipment (Physical model) and following the described procedures (Procedural model) based on the information of "Recipe". Figure 32 shows the relationship between recipe and models. "Equipment requirements" specified in the recipe is related to all layers of the physical model. "Procedure" specified in the recipe is related to all layers of the procedural model that is divided into "Procedure", "Unit procedure", "Unit operation" and "Phase" . "Equipment requirements" of the procedural model describes the processing procedure of equipment of a unit. "Unit operation" defines the order of processing. For example, operation of polymerization tank is divided into 3 operations that are feed material, temperature control and agitation. Operation is divided into detailed phases. For example, the phase of temperature control describes to heat the polymerization tank up to 40℃, then to leave it 10 minutes at the constant temperature.

Devices including instruments of the plant equipment are controlled by the command from the "Phase".

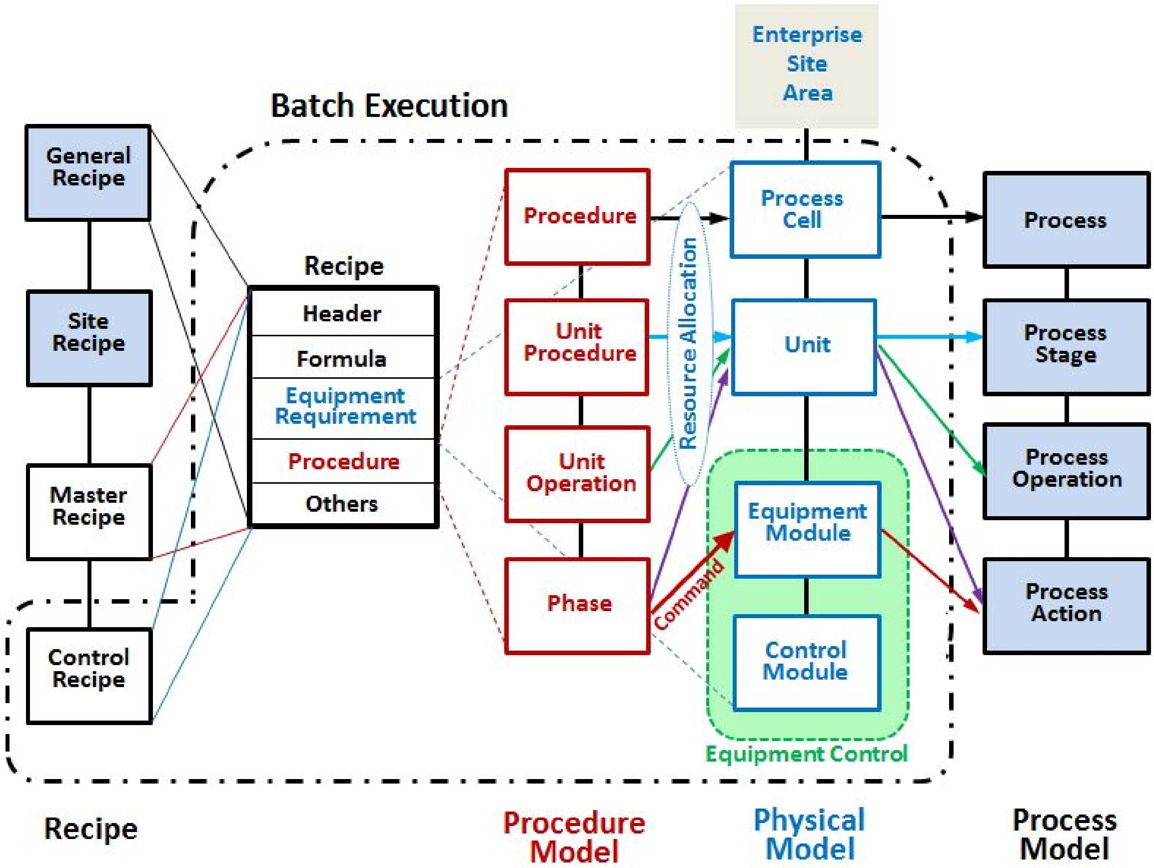


Figure 32 Relationship between recipe and models

Redrawn based on Source : Sugiura, 38th Seminar The Society of Chemical Engineers, Japan, 2004(17)

5.2.2.5. Energy management of batch process

5.2.2.5.1. Energy management per lot (batch)

As a batch process produces various kinds of products, the energy management is done per lot (batch) or a product (unit production). EnPIs are defined according to the purpose of management, for example the amount of energy consumed, specific energy consumption, energy efficiency, amount of saved energy, CO2 emission, energy cost, etc. It is important to find efficient operating conditions for improvement by comparing to the previous result data of the same lot. The best practice in the past is called "the Golden Batch". Figure 33 shows an example of energy consumption calculation per lot. Recipe α (lot number 1234, lot size 100kg) is produced through the process A, B and C. Process A starts at 13:00 and ends at 13:40. Process A consumes energy E(A). The processing time and energy consumption of the process B and C are displayed same as process A. The energy consumption of this lot is given by the sum of E(A), E(B) and E(C), and used for the calculation of specific energy consumption of the lot.

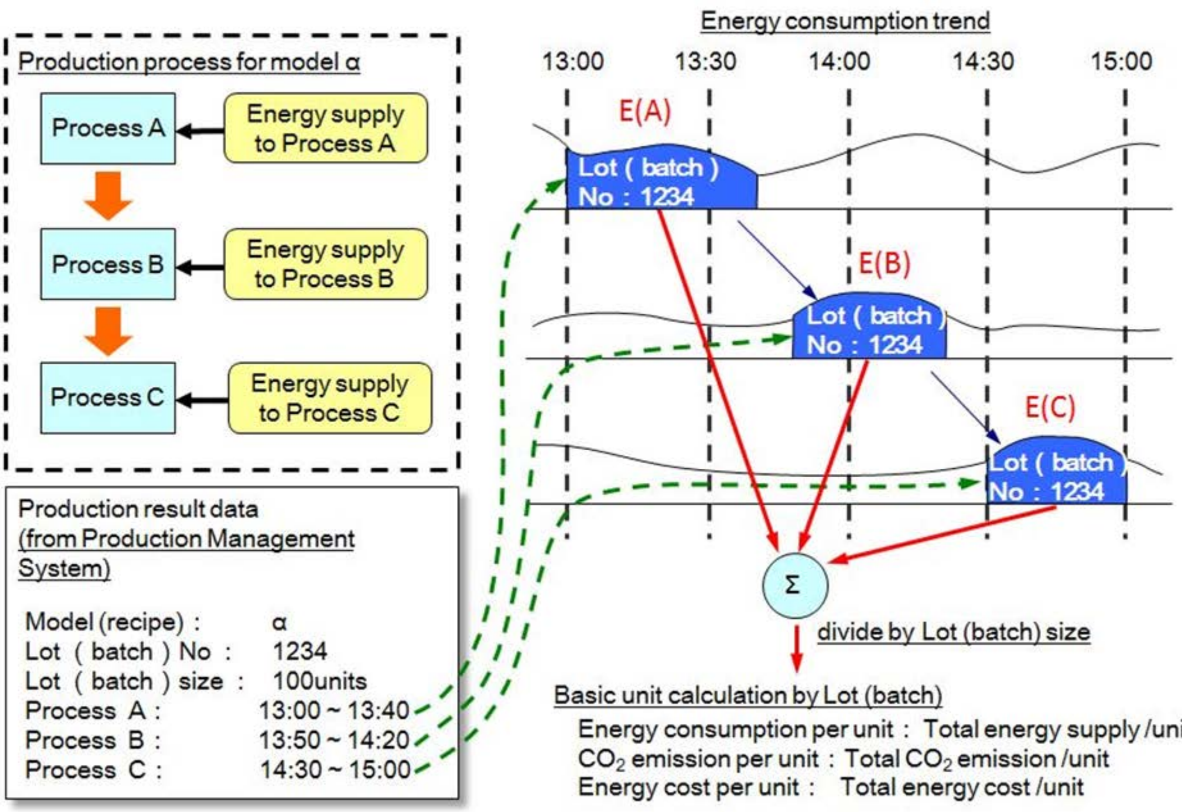


Figure 33 Calculation of energy consumption of production lot

5.2.2.5.2. Case example (1): Power consumption reduction of a spray dryer

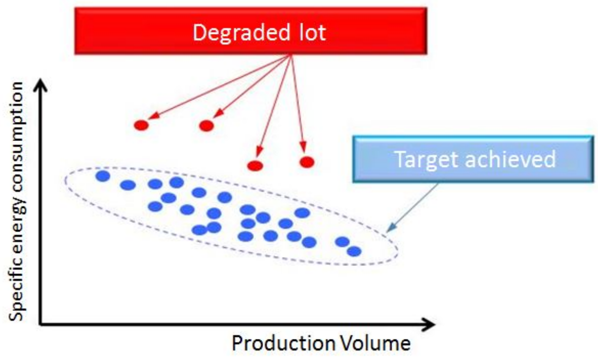


Figure 34 Specific energy consumption per Lot

A spray dryer is equipment used for producing a dry powder from a liquid or slurry by rapidly drying with a hot gas, and usually used for drying of many thermally-sensitive materials such as foods and pharmaceuticals. In this case example, energy consumption of the spray dryer tends to result in a variation per lot depending on the skill level of operator.

Figure 34 shows the results of the specific energy consumption per lot and production volume. Blue dots are grouped in a target of the specific energy consumption. Red dots are out of the target and mean degraded lots. A target zone can be defined by the results. It is important to track down the cause of degraded lot for improving the total energy efficiency of the process. The specific energy consumption divided by production volume gets worse in appearance for smaller volume. This comes from the calculation including the fixed energy of the equipment.

Figure 35 shows a "Drill-down analysis" to find opportunities for improvement. In this case example, energy sources are steam, cooling water, power and air. Measuring the specific energy consumption for each energy source has proved the fact that the power consumption has a large variation by lot. As shown in Figure 35, the profile of startup time has a large variation depending on the skill level of operator. This means the variation in the power consumption is caused by the operation during the start-up of process. This approach has identified opportunities for improvement such as appropriate start-up time, feed timing of a liquid and temperature profile control, etc. Following these opportunities has resulted in a considerable reduction of power consumption.

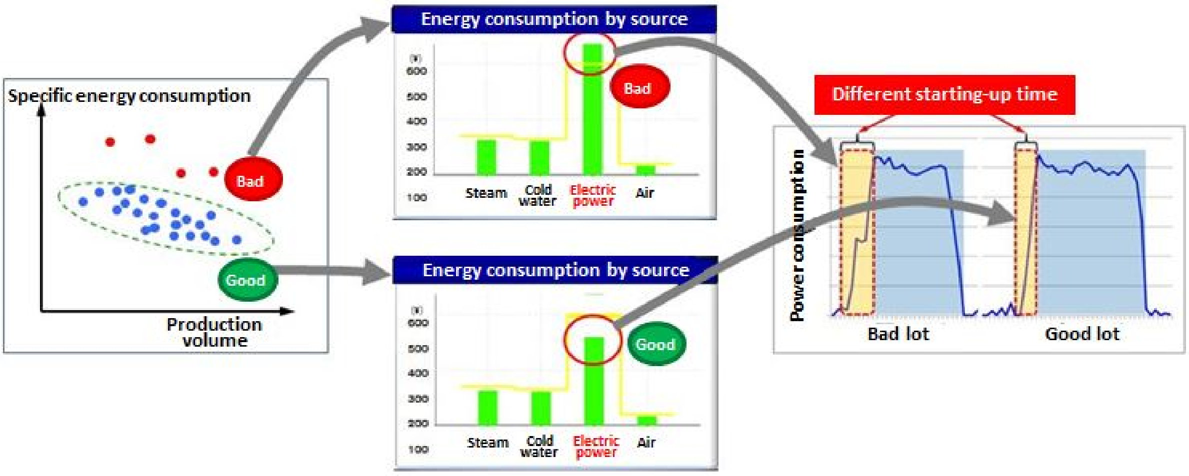


Figure 35 Drill-down analysis

5.2.2.5.3. Case example (2) Energy management in polymerization process

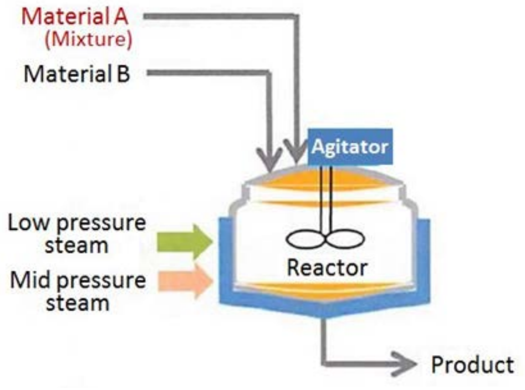


Figure 36 Polymerization process

Figure 36 shows a polymerization process that produces a product out of raw material A and B. Materials fed into the reactor are mixed and heated up to the specified temperature for the polymerization reaction. The reactor is heated by two kinds of steam. While the reactor temperature is low, low-pressure steam (low temperature and low cost) is fed to heat the reactor. When the reactor is heated up to the pre-defined change-over point of temperature, the mid-pressure steam starts heating instead of the low pressure steam, and continues to heat the reactor up to the reaction temperature of polymerization. As the raw material A is a mixture, the input volume of raw material A is decided to cope with an occasional fluctuation of the composition in order to keep the stable production volume and quality.

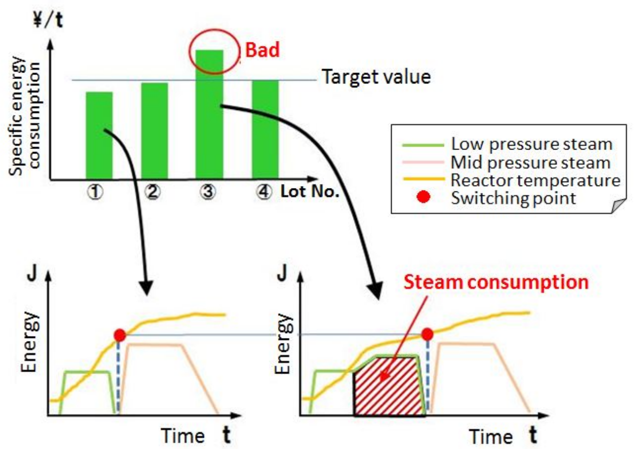


Figure 37 Energy consumption of each Lot

Figure 37 shows the record of specific energy consumption per lot that indicates the lot ③ did not achieve the objective of specific energy consumption. It becomes clear that lot ③ needed longer time to be heated up to the switching temperature than other lots.

Lot ③ consumed more steam than other lots. This caused the degradation of specific energy consumption of lot ③. As the reaction time depends on the material composition of lot, lot ③ must have had such material composition that causes longer reaction time. When the reactor temperature is heated up to the pre-defined switching point, low pressure steam is scheduled to switch to mid-pressure steam.

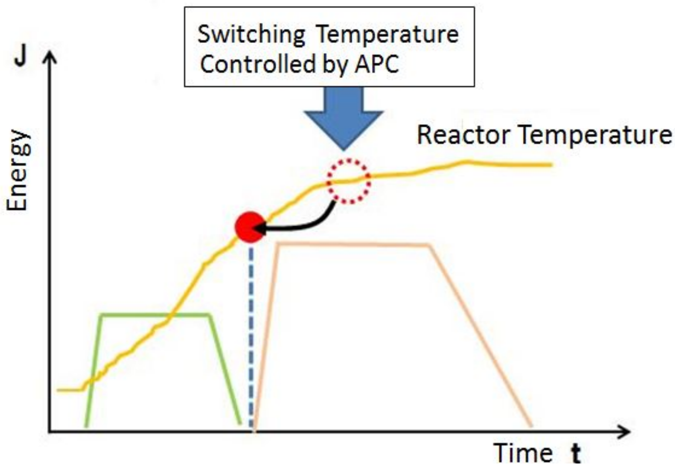


Figure 38 Switching temperature change by APC

After the relationship between the composition of material A and the energy consumption has been verified, the switching temperature has been changed from the pre-defined constant to a variable temperature that is calculated by APC (Advanced Process Control) taking into account several variables such as energy input, property of material A, internal pressure of reactor, etc. Figure 38 shows the method of steam switching controlled by APC. Energy cost reduction and shortening the production time have been achieved. APC is explained in 5.4.5 APC (Advanced Process Control).

5.2.3. Discrete process

Discrete process is a production process that produces distinct items by way of machining and assembling. Automobiles and electric appliances are examples of discrete manufacturing products. Discrete manufacturing line is automated by such equipment as numerical controlled machining equipment, industrial robots, in-house conveyance vehicles etc. As shown in Figure 25, the automation is done by mainly sequence control that is called FA（Factory automation）.

5.2.3.1. Energy consumption of manufacturing machineries

Coolant pumps are used to circulate cutting lubricant and cooling oil in machine tools such as grinding machines and machining centers for metal machining. It is reported that coolant pumps consume 40% of total power of machine tools. Inverter drive of coolant pumps can reduce the power consumption of machining tools significantly. Figure 39 shows the energy consumption and an approach to energy saving in machine tools. (18)

① Stand-by energy is consumed when power is connected therefore it is necessary to save power by turning off the power frequently, etc.

② Steady-state energy is consumed over the entire production time, therefore if the absolute amount can be reduced, the effects increase in proportion with production time.

③ Dynamic energy changes with the machining state, etc., therefore it is both necessary to increase machining efficiency and shorten machining time and reduce the necessary energy.

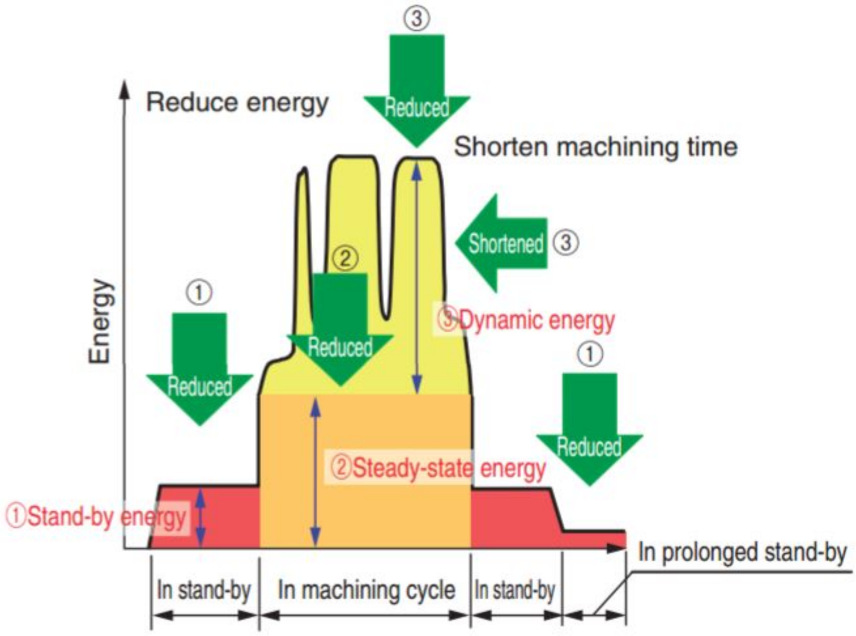


Figure 39 Energy consumption in machine tools

Source: Approach to Energy Saving in Machine Tools(18)
JTEKT Engineering Journal No.1010(2012)

5.2.3.2. Operation status of equipment during production：Time model(7)

As shown in Figure 40, ISO22400 “Manufacturing operations management - Key performance indicators” defines "Time model" for the operating status of production equipment. Planned operation time (POT) is for executing an order. Throughput time (TPT) that is defined as Execution time is broken down into Busy time (BT), Processing time (PCT) and Production time (PDT). These times include Transportation time (TT), Wait time/set aside time (WT), Delay time (DeT) and Effective setup time (ESUT). These times do not contribute to the production.

When production equipment is defined as an EMU, each unit time above can be interpreted as the status in time domain that is a boundary for energy management.

It is important to reduce the energy consumption of each operation time taking into account the energy consumption characteristic of the unit time. It is also important to minimize the times that do not contribute to the production. The energy consumption characteristics of PDT(Production time/ Main usage time), ESUT(Effective setup time), DeT(Delay time), TT(Transportation time), WT(Wait time/set aside time) are shown in Figure 40. The concept of "Boundary in time domain" explained in 4.3.3.2 Boundary in time domain comes from the concept of "Time model".

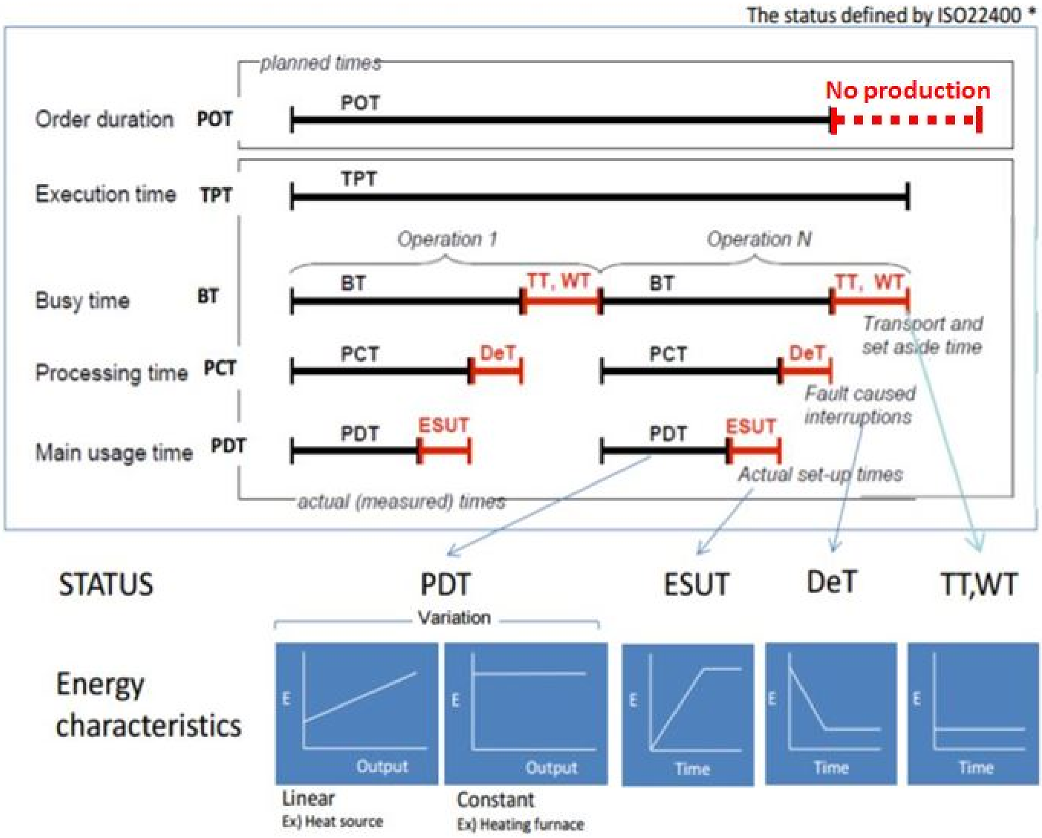


Figure 40 Operation status of equipment during production —Time model

Source：JEITA space-time boundary for effective energy management (7)

Redrawn based on ISO22400-2 Automation systems and integration

- Key performance indicators (KPIs) for manufacturing operations management −Part 2

5.3. Hierarchical structure of production system

5.3.1. Energy functions mapped over the functional hierarchy levels of production system

Figure 41 shows energy management functions that are mapped over the functional hierarchy levels of production system defined in IEC 62264-1(19)

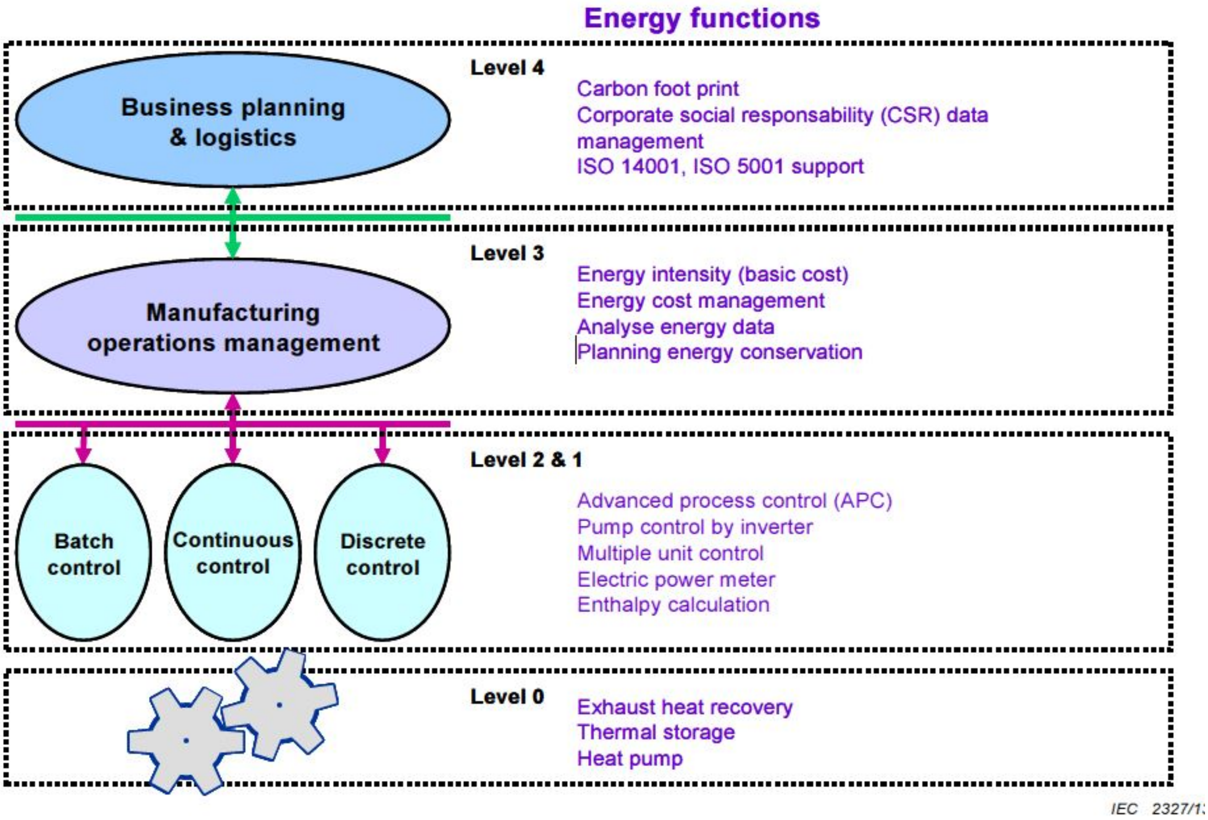


Figure 41 Energy functions mapped over the functional hierarchy levels

Source：IEC/TR62837 Edition 1.0 2013-09

“Energy efficiency through automation systems”(2)

Level 4：Business Planning & Logistics

The level 4 of the functional hierarchy of production systems in IEC 62264 can be split into two parts:

・ Energy efficiency related to demand/response:

The activities of the factory may change taking into account the outside environment conditions. The outside environment communicates the energy availability using pricing and time segments; this is the (supply side) demand.

The system can react with planning and scheduling of activities; this is the (consumer side) response.

NOTE; Supply side demand is not an energy demand in this context.

- Energy efficiency related to internal plant management:

Depending on the internal status of the plant, decisions may be made related to consumption, generation and storage of energy.

EXAMPLE; Events that influence the status of the plant include raw material availability, breakdowns, staff planning, delivery planning.

Time Frame: Months, weeks, days, shifts

Level 3 : Manufacturing Operations Management

In the context of level 3 and lower of the functional hierarchy of production systems in IEC 62264, two basic aspects of energy efficiency are considered:

- intrinsic energy efficiency
- managed energy efficiency

Intrinsic energy efficiency is achieved by the design of components. Managed energy efficiency is achieved by a systematic energy management, supported by automation systems and systems integration.

Time Frame: Shifts, hours, minutes, seconds

Level 2,1 :

2 - Monitoring, supervisory control and automated control of the production process

1 - Sensing the production process, manipulating the production process

Level 0 :

The physical production process

5.3.2. Hierarchical model of control information flow of production system

Figure 42 shows a hierarchy of production systems with reference to IEC 62264-1:2013. A manufacturing enterprise is organized into a multilevel hierarchy by functions. The total system may be divided into subsystems and equipment. Generally, an enterprise operates the total factory to maximize or minimize an objective function. Examples of objective functions are profit, cost, quality, energy efficiency and so on. Usually, the different objectives are not compatible. So, an optimum operation of the total factory is necessary by finding the values of the variables that minimize or maximize the objective function while satisfying the constraints.

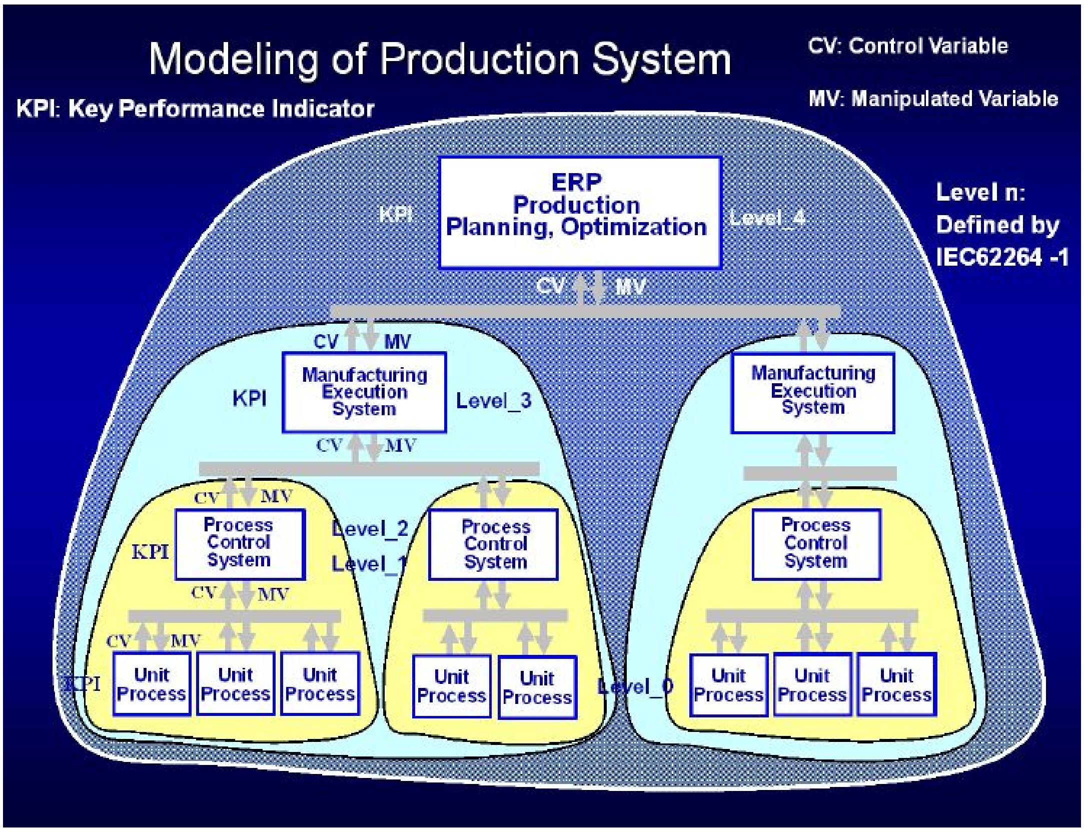


Figure 42 Hierarchical model of production system

Source：IEC/TR62837 Edition 1.0 2013-09

"Energy efficiency through automation systems"(2)

Figure 42 shows the information flow between subsystems using the notation of CV and MV. CV (controlled variable) and MV (manipulated variable) are the terminologies in process control. In Figure 42, CV represents a set of present status including KPIs (EnPIs) in the layer that is reported to the upper layer. The upper layer system calculates MV that is sent back to the lower layer as a target value for control. The level 4 system (ERP) can execute the calculation for plant-wide optimization using the CV from the lower level systems. KPIs (EnPIs) are defined in each level and controlled to their optimum values by the system. However, controlling individual KPIs to their optimum values does not necessarily result in the optimization of a KPI in the higher level system. When the production volume of a corporation is changed, for example, Level_4 (ERP) system calculates an optimum MV to minimize the total energy consumption while energy efficiency is the objective function. This MV is a command for the lower level systems to operate for the plant-wide optimization. As KPIs and the measured values are key information for plant-wide optimization, it will be efficient to use a common structure of information. It is recommended that the structure of KPI description is standardized in ISO 22400-2 [(20)] as shown in Table 4.

A concept that maximizes the total energy efficiency is explained in 5.4.8 RENKEI control.

5.4. Energy efficiency improvement through process control technologies

5.4.1. Energy Consumption Characteristics of production equipment

Figure 43 shows a typical load versus efficiency characteristics of equipment that is used for optimization. The energy consumption characteristics of equipment shown in Figure 43 should be provided as a kind of energy information of equipment. The following should be specified for optimum operation:

- maximum and minimum operation limit,
- energy consumption characteristics for the output range,
- energy consumption for startup,
- energy consumption for shut down.

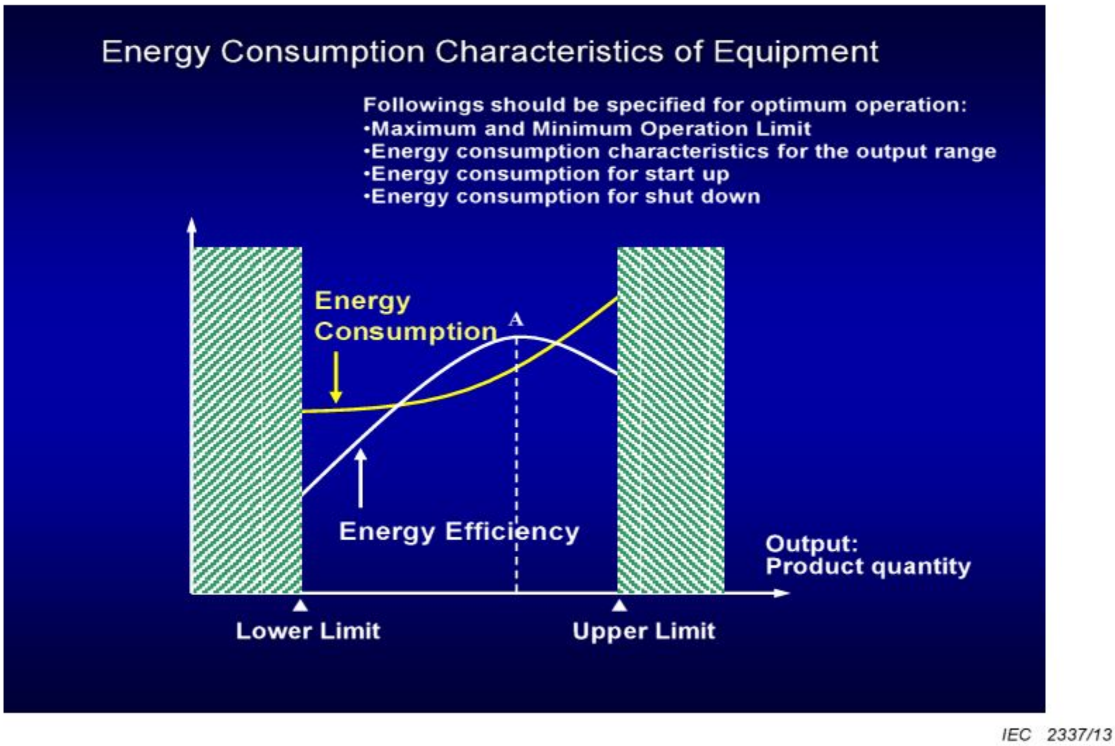


Figure 43 Energy consumption characteristics of equipment

Source : IEC/TR62837 Edition 1.0 2013-09

"Energy efficiency through automation systems"(2)

5.4.2. Variable-frequency drive

Motors are a key device indispensable for social and industrial activities. They consume electric power that accounts for nearly 40% of the global energy consumption. It is reported that about 60% of electric power in Japan is consumed by equipment with motors, and more than 90% are three-phased induction motors.

In the process industries, fans and pumps that are driven by motors are widely used to control air flow and liquid flow. A conventional way of flow control is to drive a pump at a constant rotating speed with its flow being throttled by a control valve or a damper. Variable Frequency Drive (VFD) is to control the rotating speed of a motor by an inverter, keeping the damper or the valve fully open.

Figure 44 shows the energy saving of a motor by variable-frequency drive. When the flow rate is changed to 80% of full span, operating point of the motor is changed from A to C for VFD. Power consumption is reduced 50%. However, in case of throttling by a valve, operating point is changed from A to B with almost no reduction of power consumption.

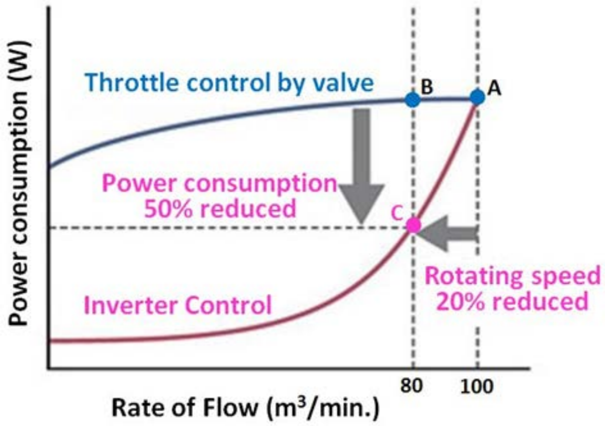


Figure 44 Energy saving of motors by variable-frequency drive

Redrawn based on Source：モータの省エネ化が日本を救う(21) (nikkeiBPnet)

In the case of flow control by a control valve as shown in Figure 46, the pressure loss of the throttling valve: Loss (ΔP) becomes exactly the energy loss of the system. In the case of Figure 45, a motor is driven by Variable Frequency Drive under the condition that the valve is full open. In this case, the pressure loss of the throttling valve: Loss (0) becomes almost zero. So, Loss (ΔP) can be saved as energy by using VFD.

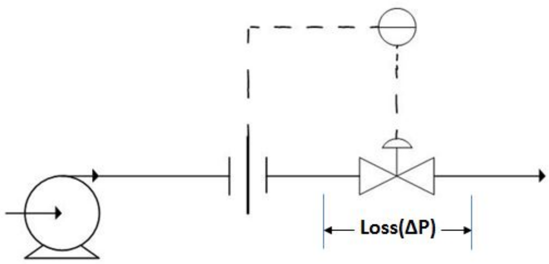


Figure 46 Flow control by a control valve

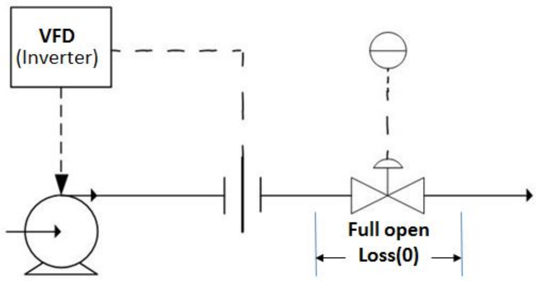


Figure 45 Flow control by Variable Frequency Drive

In Japan, the “Top Runner Program” was introduced in April 2015 to regulate motor efficiency. As shown in Figure 47, it is expected that “Top runner motor” specified in JIS C 4210(2010) that is compatible with IEC efficiency class IE3(Premium Efficiency) can achieve about 35% loss reduction compared to IE1. In the actual field in Japan, 97% of three-phased induction motors are reported to be IE1 class. If all of these IE1 motors are replaced with the top runner motors, it is estimated that about 1.5% of total power consumption in Japan can be reduced. And it is expected that the replacing can be significant energy saving measure.

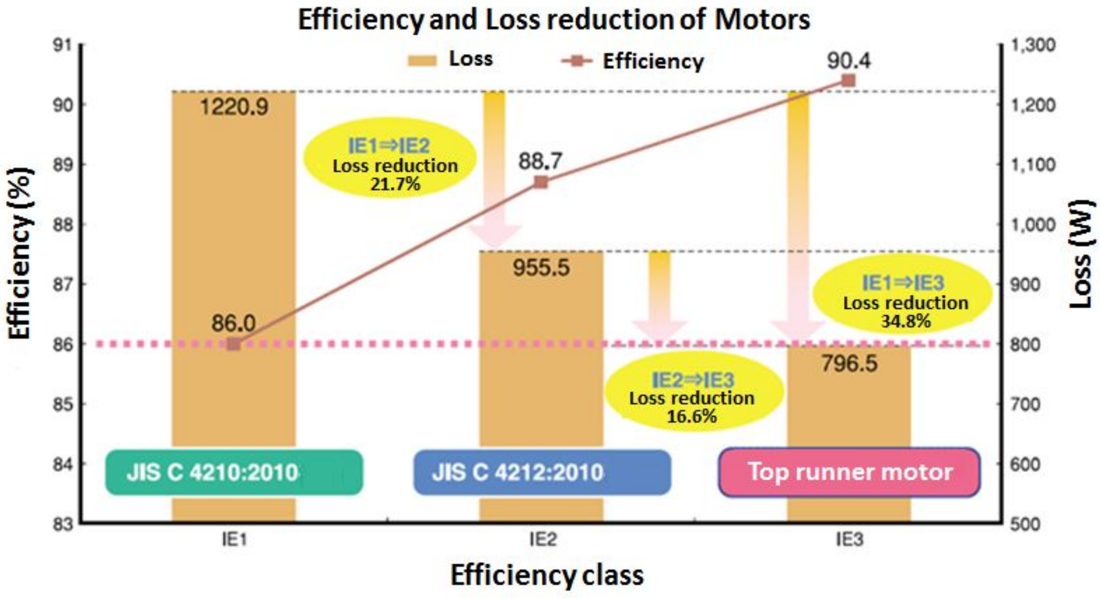


Figure 47 Top runner motor

Redrawn based on Source : Top runner motor (JEMA) (22)

Note:

IE = International Efficiency:

IE1 (Standard Efficiency), IE2 (High Efficiency), IE3 (Premium Efficiency), IE4 (Super Premium Efficiency)

5.4.3. Control loop performance improvements

In process plants, there are many kinds of control variables (CV) such as temperature, pressure, level, and flow rate, which are measured and controlled to the target values. Figure 48 shows a basic control loop that is widely used for many kinds of industrial process applications. Control loops consist of a measurement element (transmitter, sensor), an actuator (most commonly a control valve), and an executed control algorithm (control function FC with set variable SV) such as a PID control. Efficient and effective execution of basic plant control loops is essential to successful operation of a plant and to other functions such as advanced control and real-time optimization. Improvements in each of these elements can lead to reduced energy consumption.

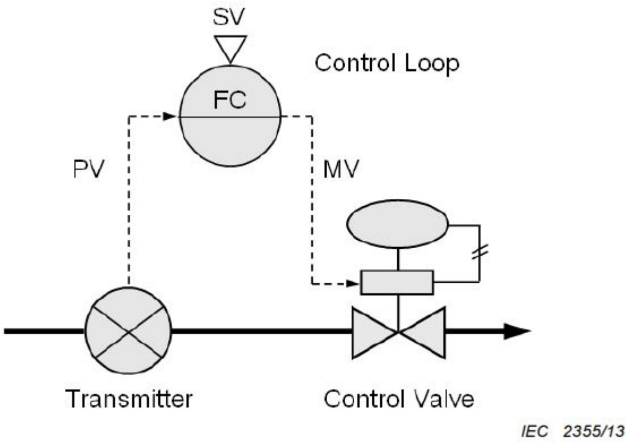


Figure 48 Basic control loop

Source : IEC/TR62837 Edition 1.0 2013-09
"Energy efficiency through automation systems"(2)

Figure 49 shows the actual improvement from control performance analysis and tuning. Line speed changes disturb the control loops. If a control loop is not well-tuned for PID control parameters, the disturbance causes unstable output with some overshoot and oscillation. That consumes more energy than a well-tuned control. PID tuning is a practical opportunity to improve the energy efficiency of a plant.

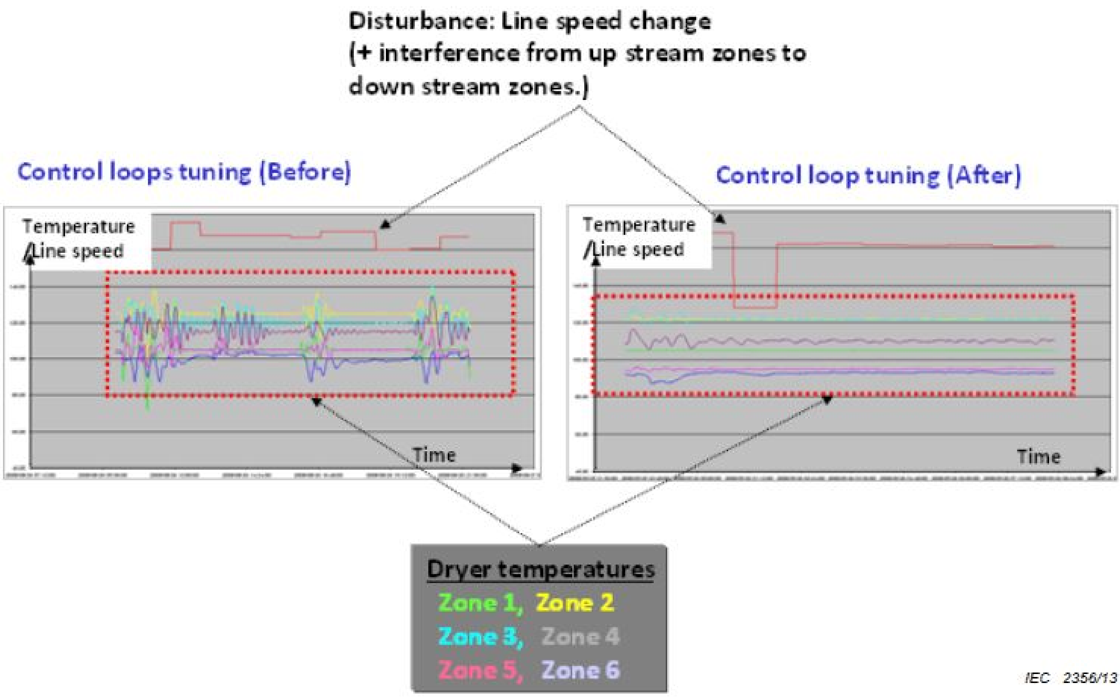


Figure 49 The effects of control performance analysis and tuning

Source : IEC/TR62837 Edition 1.0 2013-09
"Energy efficiency through automation systems"(2)

5.4.4. Combustion control [(23)]

Combustion requires fuel and air (oxygen), and a lean air-fuel mixture causes incomplete combustion with soot and smoke. On the other hand, a rich air-fuel mixture causes problems, such as the emission of excessive amounts of exhaust gas and the heating of the excessive air, resulting in lower fuel efficiency. Figure 50 shows the principle of the air-fuel ratio and the state of combustion. The air-fuel ratio plotted on the horizontal axis shows the ratio of actual supply air to the theoretical amount of air required for fuel combustion (theoretical air amount).

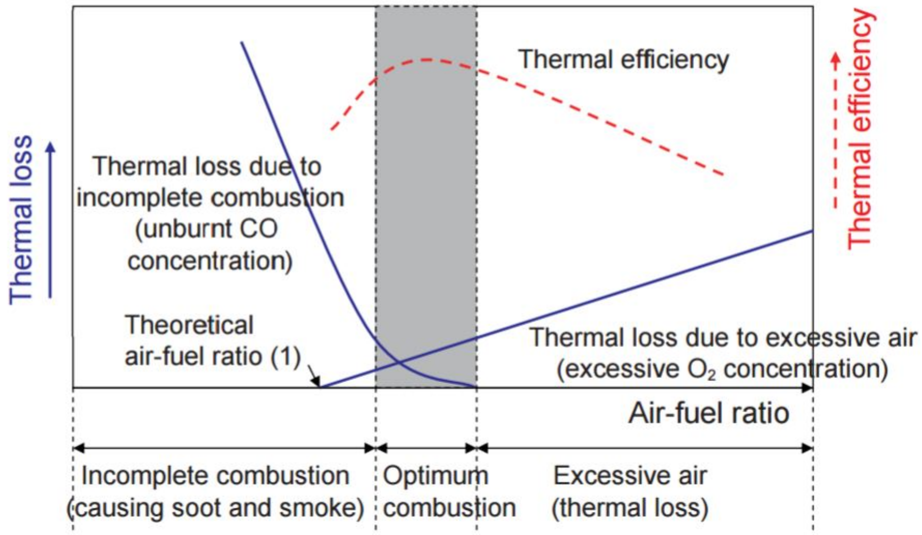


Figure 50 Relationship between air-fuel ratio and heat efficiency (combustion)

Source：Optimum Combustion Control by TDLS200 Tunable Diode Laser Gas Analyzer
Yokogawa Technical Report Vol.53 No.1 (2010) [(23)]

For combustion furnaces such as heating furnaces and boilers in plants and factories, small scale controllers such as single loop controllers are used to optimize the air-fuel control ratio for improving combustion efficiency (see Figure 51). In large combustion furnaces, distributed control systems (DCS) and advanced control (multivariable predictive control, etc.) are used. These mainly control the air-fuel ratio and internal pressure of the furnace to prevent CO, CO2 and NOx (nitrogen oxide) from being emitted and apply a cross limit circuit to prevent incomplete combustion while controlling combustion to maximize efficiency. Figure 51 shows the combustion control system that controls the air-fuel ratio of the combustion by the real time measurement using a laser gas analyzer.

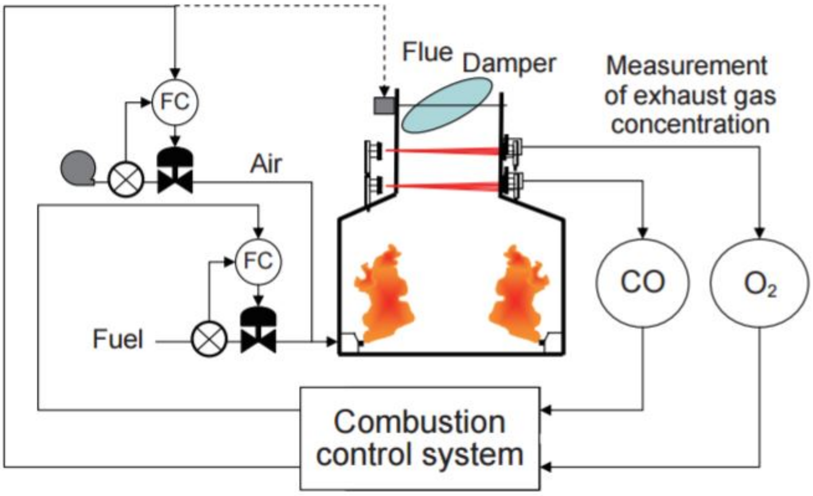


Figure 51 CO and O2 control system for combustion furnace

Source：Optimum Combustion Control by TDLS200 Tunable Diode Laser Gas Analyzer Yokogawa Technical Report Vol.53 No.1 (2010) [(23)]

5.4.5. APC (Advanced Process Control) [(24)]

APC is a control technology based on Multivariable Model Predictive Control. It represents the target process as a model with multiple inputs and multiple outputs, and performs control by predicting the behavior of the process several steps ahead.

Figure 52 shows an example of APC application in which less energy is consumed by reducing the allowance as much as possible within a range not exceeding the operational limit of the target process. The period with large amplitudes on the left of the trend data in Figure 52 is the one during which APC is not activated (before APC is introduced). Basic control loops such as those for flow-rate, temperature, level, and pressure are controlled during this period by systems such as a distributed control system (DCS), and the operator adjusts the set-points manually to achieve energy consumption targets. Accordingly, the data usually varies significantly, so a large allowance is required against the operational limit in case unexpected changes occur during operation. During the period in which APC is activated, the introduction of APC improves the control performance and results in the reduction of data variation. A decrease in data variation results in an increase in the gap between the fluctuating data and the operational limit, so optimization of control makes it possible to bring the set-point even closer to the operational limit as shown during the period in which the optimization of control is activated.

As described above, APC can be defined as a control methodology that not only aims at improving control performance but also maximizes effects such as energy conservation by automatically bringing the operation closer to the optimum level.

Figure 52 shows an example in which APC is applied to a distillation column to reduce energy consumption.

Application examples of oil and chemical processes:

- heating furnace;
- pass balance control;
- exhaust gas oxygen concentration control;
- distillation column;
- reactor;
- application examples in other processes;
- utility facilities (boiler, turbine, and generator), electrolyze.

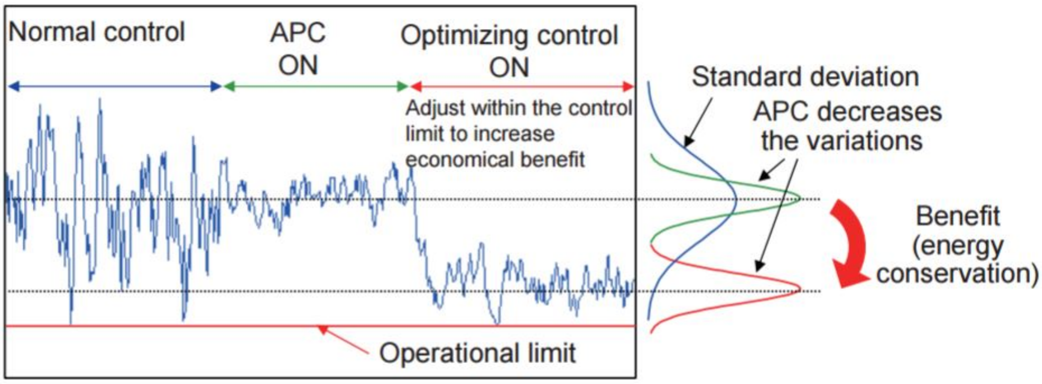


Figure 52 Stabilizing the process control by APC

Source : Yokogawa Technical Report Vol.53 No.1 (2010)(24)

5.4.6. Air supply pressure control

By measuring the required terminal pressure at the production line, it is possible to reduce the load of compressors by lowering the header pressure, as shown in Figure 53. Around 3 % of energy-saving is possible by changing the header pressure value when the load is low.

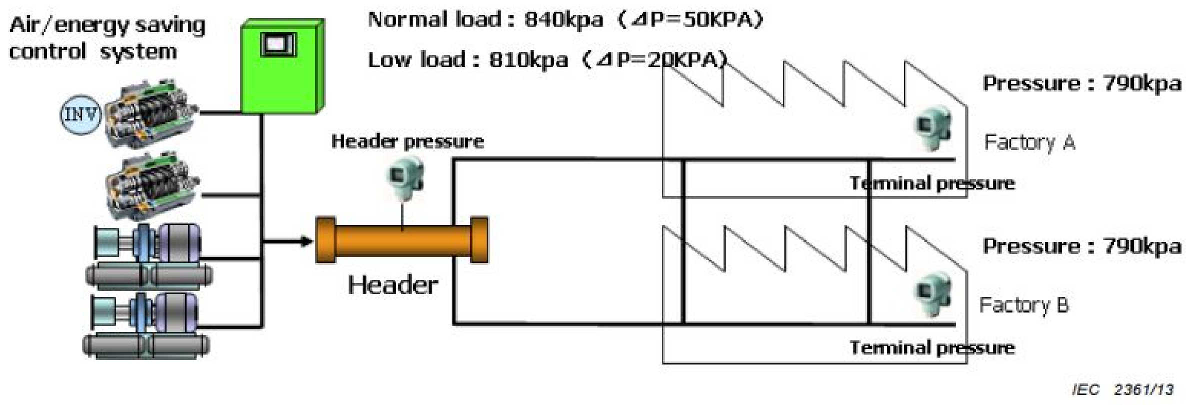


Figure 53 Air supply pressure control

Source：IEC/TR62837 Edition 1.0 2013-09

"Energy efficiency through automation systems"(2)

5.4.7. Steam header pressure control (2)

Figure 54 shows the control of steam header pressure by means of compressor quantity control. Operating the minimum quantity of the compressors is achieved by predicting the compressor load based on header pressure.

Compressor no. 1: 15 kW with inverter.

Compressor no. 2: 11 kW.

Compressor no. 3: 22 kW.

Compressor no. 4: 22 kW.

Compressor no. 5: 37 kW.

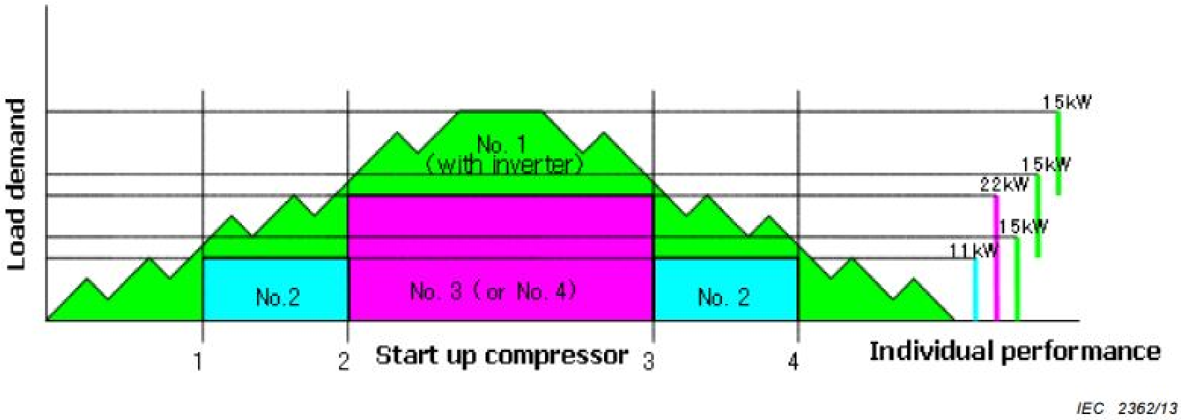


Figure 54 Control of steam header pressure by means of compressor quantity control

Source : IEC/TR62837 Edition 1.0 2013-09
"Energy efficiency through automation systems"(2)

In case of load-up:

1) Compressor no. 1 at 100 % < air consumption:
   Start up compressor no. 2. Compensate for deficiency with compressor no.1.
2) Compressors no. 2 and no. 1 at 100 % < air consumption:
   Start up compressor no. 3, and stop compressor no. 2. Compensate for deficiency with compressor no. 1.

In case of load-down:

3) Compressors no.2 and no.1 at 100 % > air consumption:
   Stop compressor no.3, compressor no.1 at 100 %.
4) Compressor no.1 at 100 % > air consumption:
   Stop compressor no. 2.

5.4.8. RENKEI control [(25)]

"RENKEI" control is a generic concept of optimization control technology that maximizes the total energy efficiency by controlling independent equipment to work in concert with each other for harmonizing the demand and supply of energy.

Figure 55 shows the energy flow in an industrial factory, and the RENKEI Control Conceptual Structure with three categories that are Supply side RENKEI, Demand & Supply RENKEI and Demand side RENKEI.

"Demand and Supply RENKEI" strikes an optimum balance between energy supply equipment and the demand. “Supply side RENKEI” strikes an optimum load balance between equipment of a supply facility to the demand. Additionally, energy supply facility can be controlled and operated based on the demand forecast reflecting the factors such as production schedule and weather forecast. RENKEI Control is an advanced control technology that provides energy savings solutions utilizing existing facilities and equipment in both supply and demand sides. By implementing RENKEI control, an overall integrated optimum control system can be established by having the demand and supply side facilities operate in concert with each other. One thing is to be noted that RENKEI control does not necessarily mean automatic control. It includes the manual control such as guidance systems. Guidance systems are useful approach when the automatic system is too costly or the automated reasoning appears to be more risky

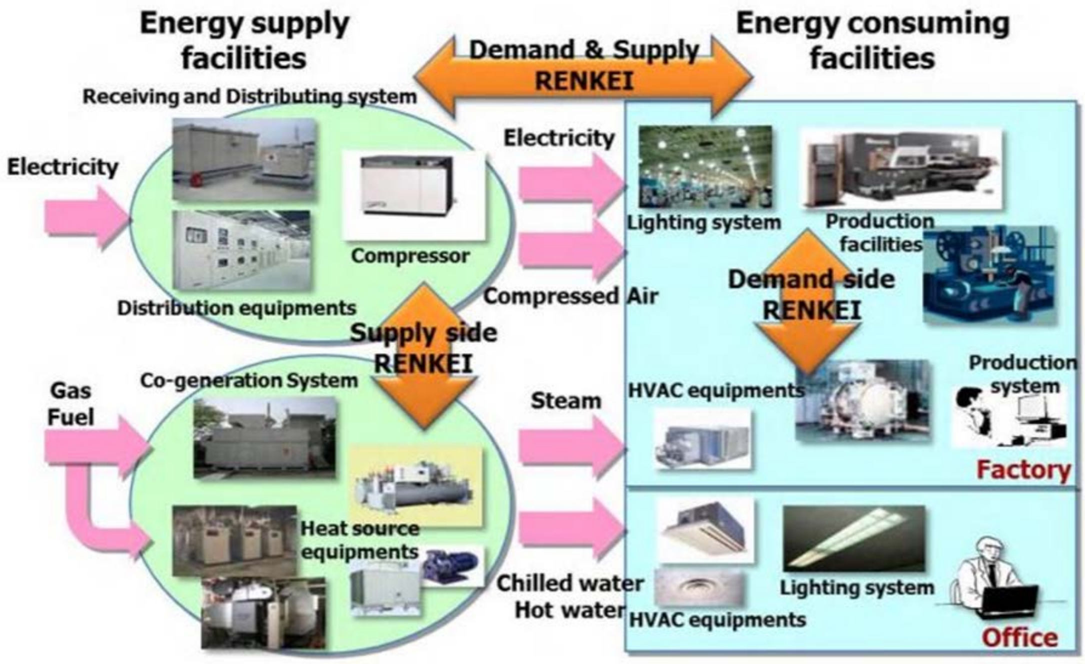


Figure 55 RENKEI Control Conceptual Structure

Source：RENKEI Control Guidebook (JEITA)[(25)]

6. Future perspectives

6.1. Energy management based on Internet of Things

IoT(Internet of things) is the internetworking technology that connects various products（things）and enables M2M（Machine to Machine）communication between these objects to collect and exchange data. It is expected that gathered data is stored in “Big data” to provide an advanced utilization way of the Internet. Various sensors and cameras are connected to collect information that is used for the real time monitoring of operating status of equipment and enables the improvement of productivity that results in improving the specific energy consumption of products. The operating status of equipment includes such various information as operating temperature, power consumption, vibration, noise, leakage from a pipe, smell etc. Real time monitoring of operating status enables to enhance the function of predictive maintenance of the plant and to build an advanced FEMS（Factory Energy Management System）. Patrol monitoring of equipment in a plant has already been implemented using mobile terminals that are connected over the wireless communication. Industrial robots and AI (Artificial Intelligence) are being put into practical application and used to collect operation know-how, knowledge and experience. Such information is expected to improve the operational efficiency of a plant and improve the skill of plant engineers.

“IoT Acceleration Lab” has been organized by METI to support creation of advanced model businesses and improvement of business environment through regulatory reform, etc., and challenges and prospects to change in industrial structure have been investigated as shown in Figure 56.

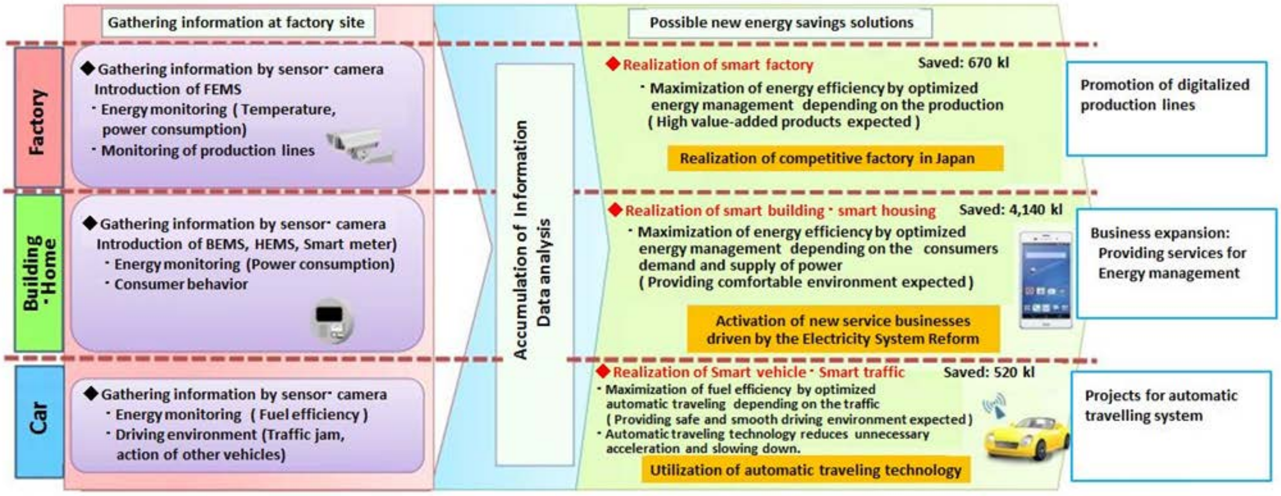


Figure 56 Energy management enhanced by IoT

Redrawn based on Source：省エネルギー対策について（資源エネルギー庁)(26)

6.2. Smart grid： Optimization of energy management between factory and community

Figure 57 shows an overview of the Customer domain and utility to consumer interactions. The Customer domain is usually segmented into sub-domains for home, building/commercial, and industrial. Energy management systems for the subdomains are HEMS(Home Energy Management System), BEMS(Building Energy Management System) and FEMS(Factory Energy Management System) .The EMS is the entry point for such applications as remote load control, monitoring and control of distributed generation, in-home display of customer usage, reading of non-energy meters, and integration with building management systems and the enterprise.

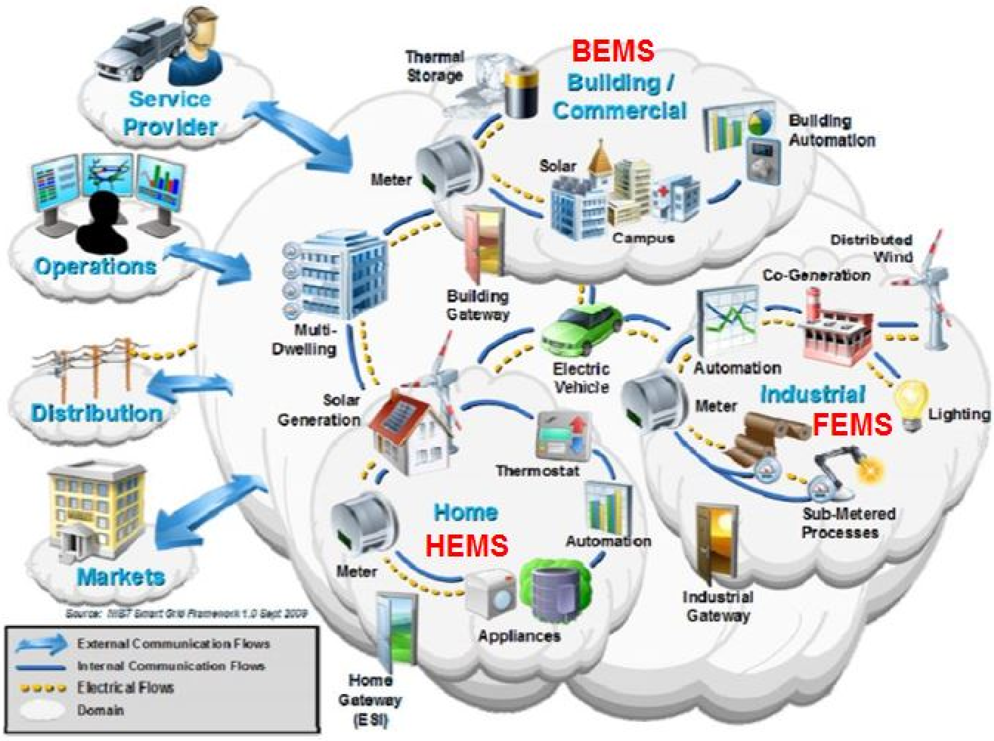


Figure 57 Overview of the Customer Domain

Redrawn based on Source：SMART GRID CONCEPTUAL MODEL[27]

Typical Applications within the Customer Domain are as follows.

Building /Home Automation

A system that is capable of controlling various functions within a building such as lighting and temperature control.

Industrial Automation

A system that controls industrial processes such as manufacturing or warehousing.

6.2.1. FEMS Factory Energy Management System

Figure 58 shows the concept of FEMS (Factory Energy Management System) proposed by JEMA (The Japan Electrical Manufacturers' Association).

FEMS is a system that supports a factory to achieve management indices that are set to improve the energy efficiency during the operation by monitoring and analyzing the production process and the status of energy consumption using sensors, measurement equipment and analyzing software.

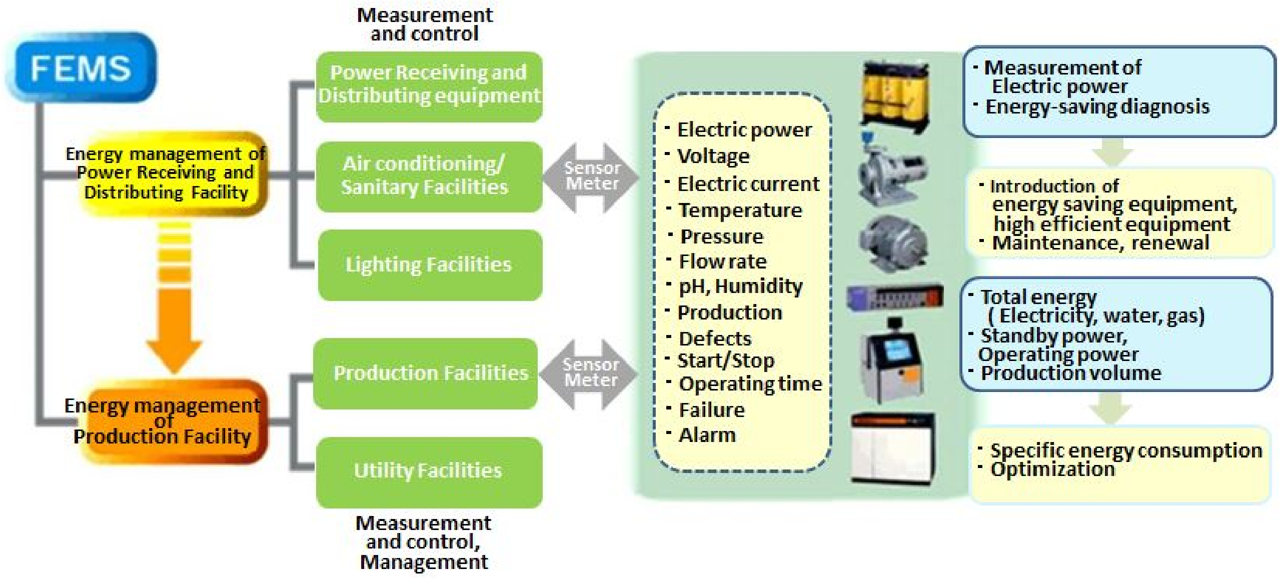


Figure 58 Concept of FEMS

Redrawn based on Source： FEMS proposed by JEMA(28)

6.2.2. FEMS and Smart grid

Factory is not only a consumer of electric power but also a supplier that is equipped with DER (Distributed Energy Resource). DER includes a private electrical power generation facility, "green power" such as wind, photovoltaic, geothermal, biomass, or hydroelectric power and storage. Factory is able to be an energy supplier to the electrical grid, when it has enough operating reserve depending on the demand for the factory operation. The supply of electricity is stabilized by exchanging supply and demand information between factory and electricity distribution system over the smart grid. Such information is effective for averaging operation of peak demand.

IEC/TC65/WG17 has been working to generate an international standard and published IEC/TS62872 (System interface between industrial facilities and the smart grid）. Figure 59 shows the configuration of connecting FEMS to Smart grid. Power (blue line) and information (red line) are exchanged between FEMS and Smart grid. Use cases of the information are classified into 7 categories.

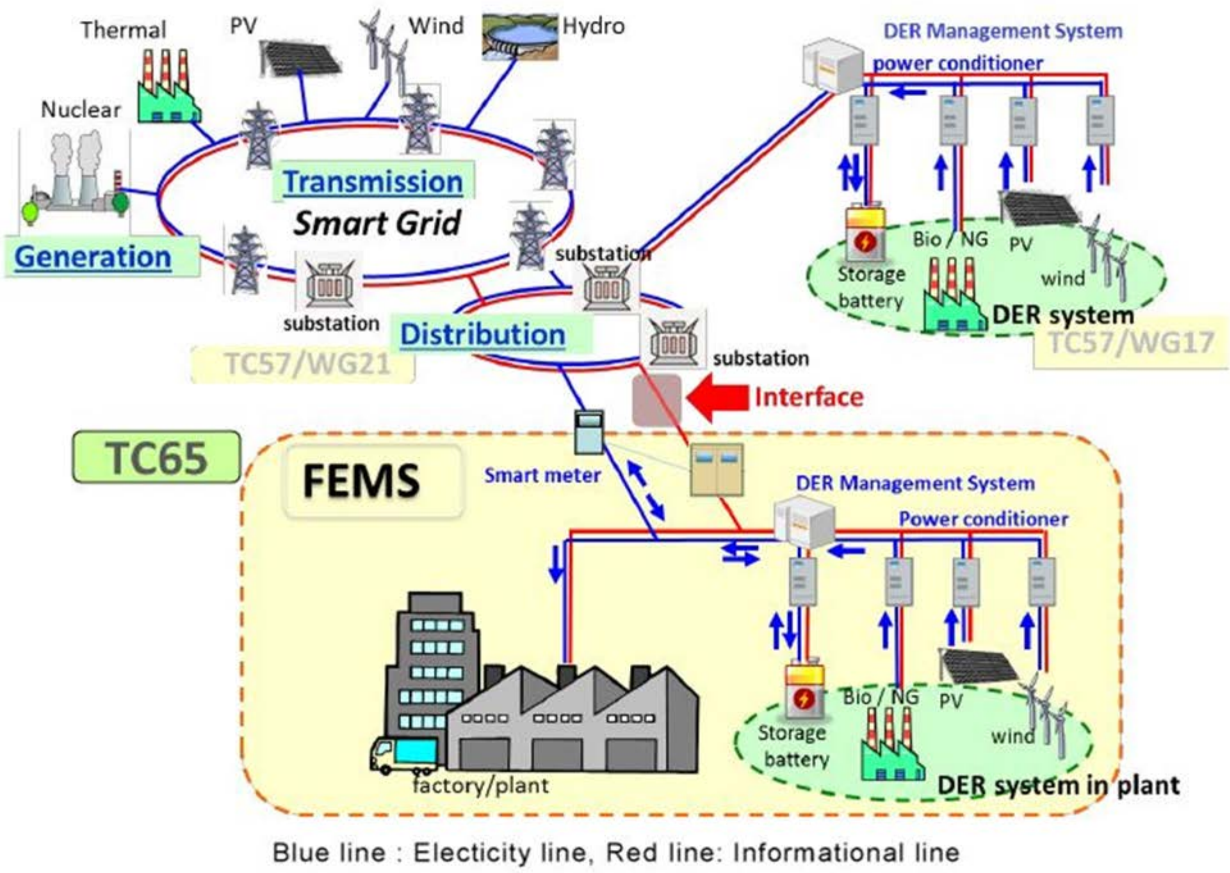


Figure 59 Interconnection of FEMS and Smart grid

Source: IEC/TS 62872: System interface between industrial facilities and the smart grid(3)

6.2.3. FEMS and CEMS for the smart energy supply

CEMS（Community Energy Management System）has been developed for "Smart community" and "Smart city". CEMS (Community Energy Management System) is the platform for providing the community with energy and environmental services connecting various consumers in the community by ICT. CEMS is the system that enables stabilized supply of energy and energy savings adjusting energy demand and supply balance between the community and the utility. Distributed power resources in the region are also utilized.

Energy demand in the community is not only electric power but also such energy as cold/hot water, heat, gas, etc. Exhaust heat from factories can be utilized for the energy demand in the community. The cooperation between CEMS and FEMS must enable more efficient utilization of energy for the overall optimization. Figure 60 shows the concept of a coordination system between CEMS and FEMS.

Reference：Smart Community Demonstrations in Japan by METI

As Japan's representative Smart Community pilot projects, four major "Projects for Demonstrating the Next Generation Energy and Social System" were launched in April 2010, led by METI (Ministry of Economy, Trade and Industry) , and ended in 2014. Yokohama City, Toyota City, Keihanna City and Kitakyushu City were selected for the projects. Objectives of the projects were the promotion of technical development and demonstration test including technologies, business models and economic impacts.

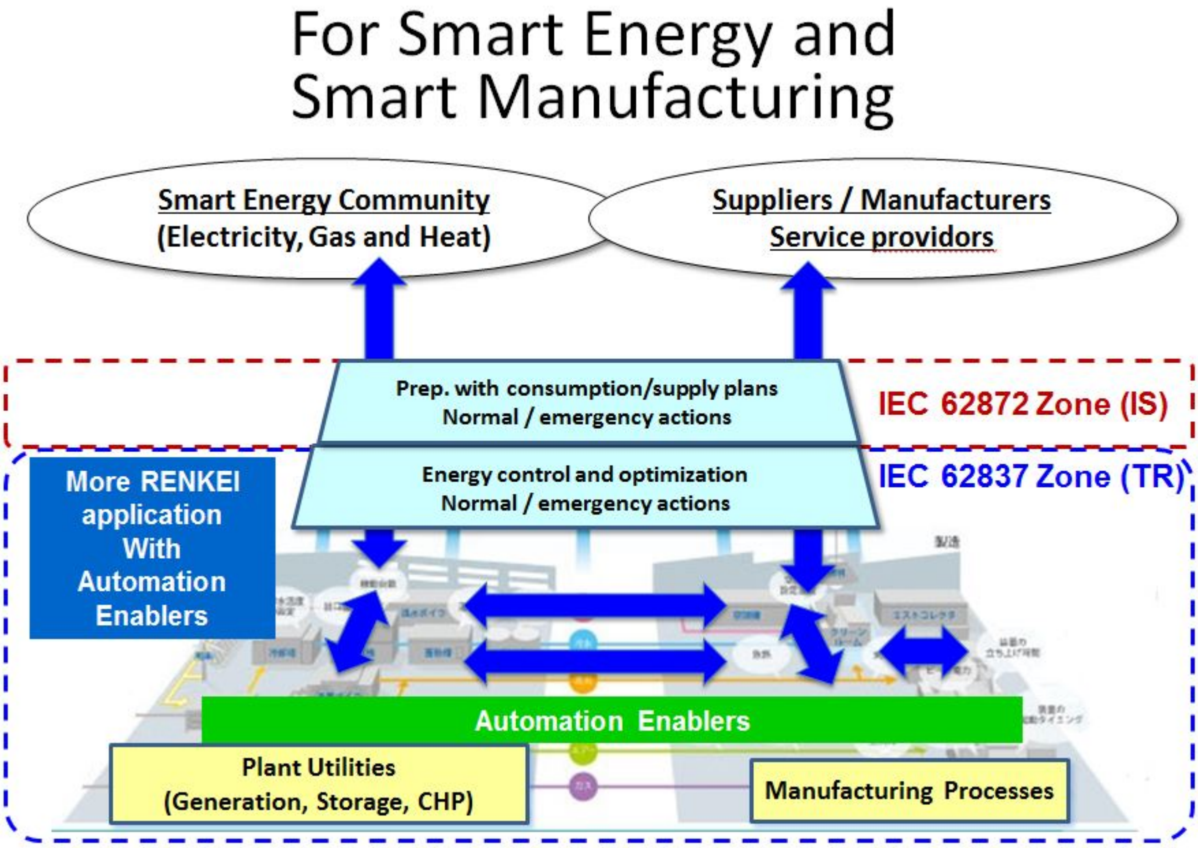


Figure 60 FEMS and CEMS for the smart energy supply

6.3. Next generation production process

6.3.1. Strategic Innovation Program for Energy Conservation Technologies

NEDO (New Energy and Industrial Technology Development Organization) and METI (Minister of Economy, Trade and Industry) have formulated "Energy Efficiency Technology Strategy" that includes "Key technologies" for every energy consuming sectors in Japan. Energy conservation technologies are required in many different fields. Key technologies are selected with specific focus on the requirement.

The fourth "Basic Energy Plan" was approved by the Japanese cabinet in April 2014. Energy policy was formulated taking Japan's mid- and long-term energy portfolio into account. In order to realize the highly energy-efficient society with smart and flexible energy consumption activities, the energy policy requires all concerned in residential/commercial sector, transport sector and industrial sector to find opportunities for energy efficiency improvement.

It is a crucial issue to strike a balance between economic growth and sustainable energy savings. As energy saving is the ongoing challenge that must be tackled in various fields, it is necessary for all sectors to promote the strategic development of energy saving technologies based on the key technologies shown in the "Energy Efficiency Technology Strategy".

●Energy Conservation Technologies for production process
Technologies for energy savings in an integrated production process （chemical, iron and steel, glass, cement, etc.）. Technologies that can bring significant energy savings in production process taking the exergy efficiency into account in addition to the energy efficiency. About exergy, see 4.5.2.3 Exergy.

【Example】

・Innovative Material, Production/Processing Technology
・Innovative Iron and Steel Making Process
・Ultra High-Efficiency Heat Pump
・Cogeneration system, Heat utilization system

●Systems approach to energy conservation system and processing technologies. Technologies that can bring significant energy savings by

・combining conventional technologies

- enabling such systematic use of thermal energy as thermal energy storage, heat transportation.
- improving production processes that use such cross-cutting processes as thermal processing and electric power.

●Technologies that can accelerate to develop energy efficient products during the operation. Such products can bring the significant life cycle energy savings while operating in various production processes.

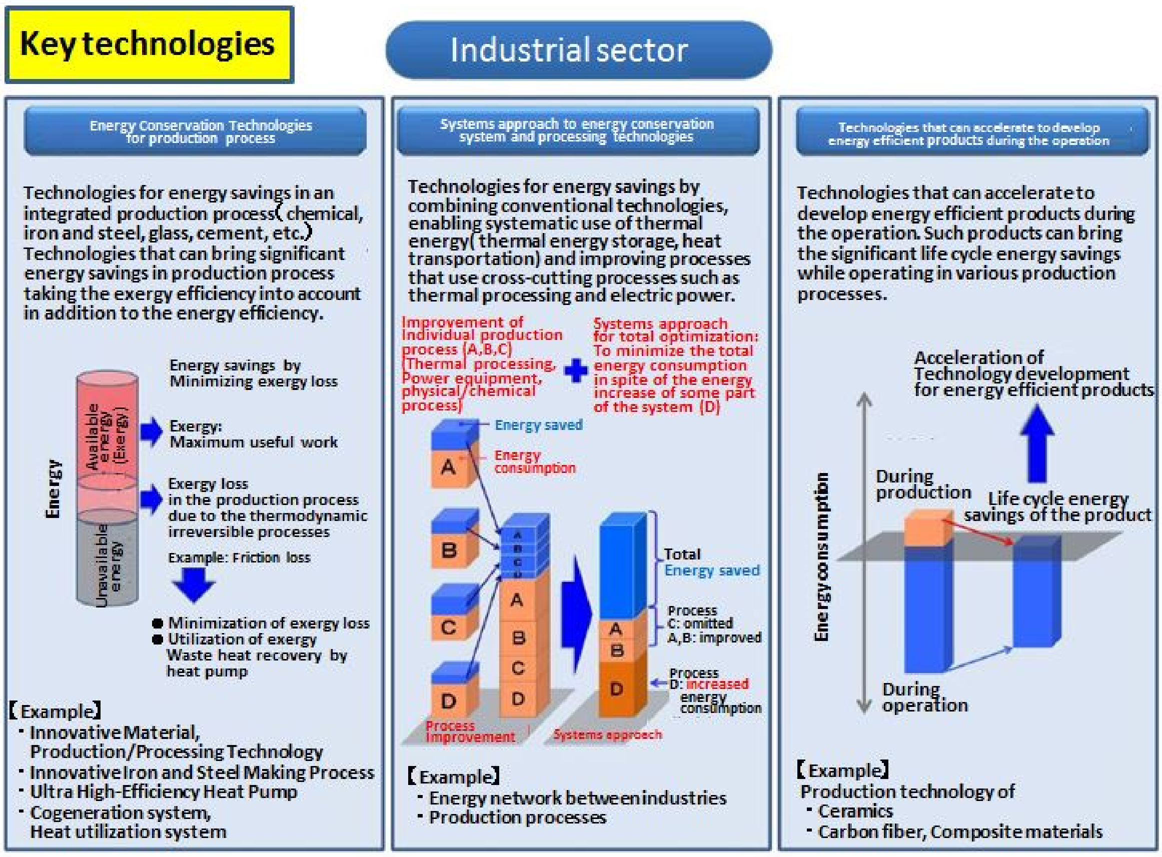


Figure 61 Strategic Innovation Program for Energy Conservation Technologies

Redrawn based on the source： 戦略的省エネルギー技術革新プログラムの概要（NEDO)[29]

6.3.2. Technology Roadmap for the development of energy technology

Innovative energy technology development roadmap was developed based on the fourth Basic Energy Plan that was approved by the Japanese cabinet in April 2014.

The roadmap takes a general view of the innovative technologies that will stabilize the energy supply and demand and improve safety and productivity of industries from a mid- to longer-term perspective. The roadmap focuses on the following energy intensive processes.

High efficient energy utilization for Industrial Application

Environmentally Harmonized Steelmaking Process

Innovative oil refining process

Innovative cement production process

Figure 62 shows the image of "Environmentally Harmonized Steelmaking Process Technology"

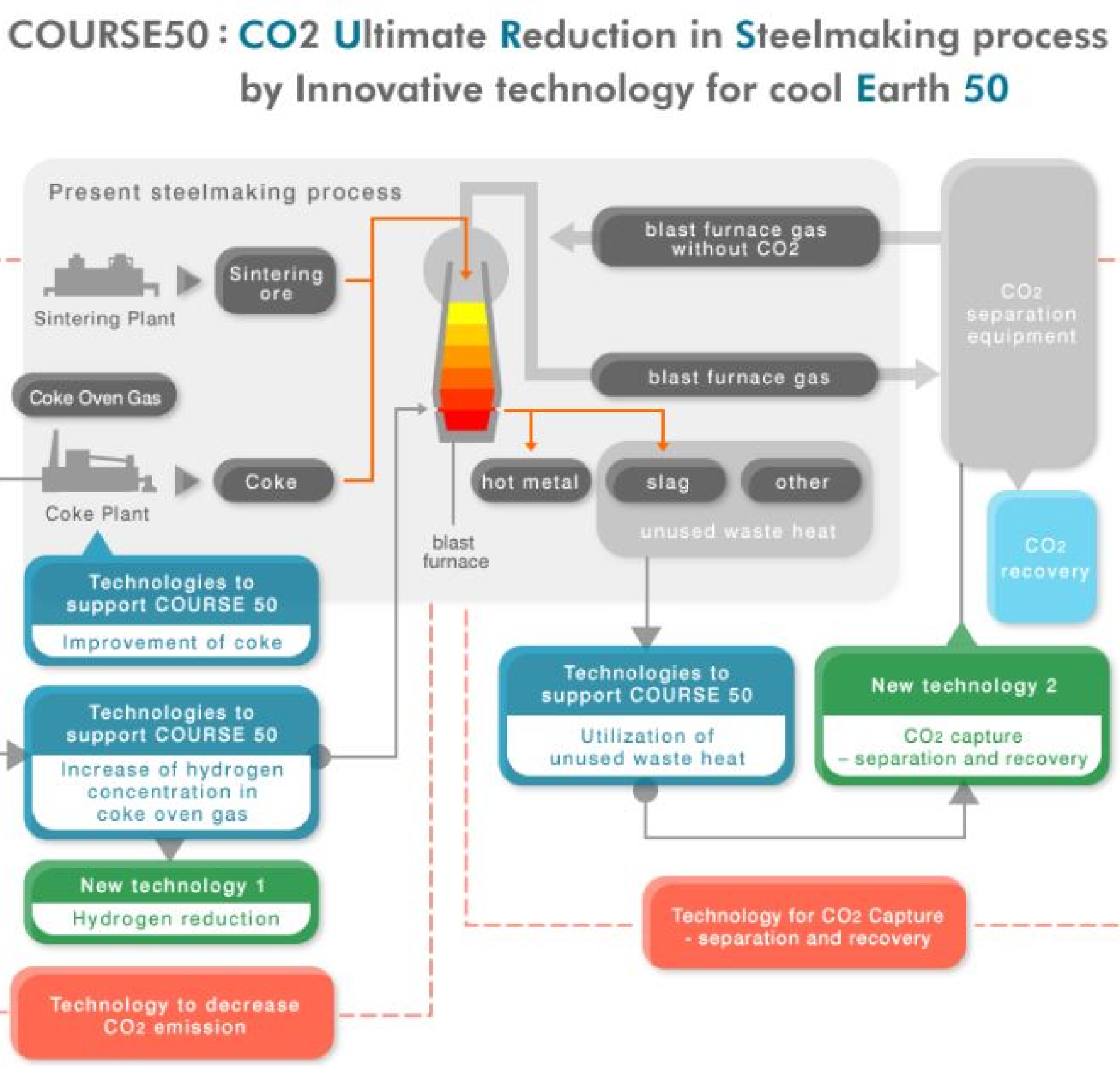


Figure 62 Environmentally Harmonized Steelmaking Process Technology

Source : JIST Outline of COURSE 50[30]

Note: COURSE50 stands for

CO2 Ultimate Reduction in Steelmaking process by innovative technology for Cool Earth 50

COURSE 50 aims at developing technologies to reduce CO_2 emissions by approximately 30% through suppression of CO_2 emissions from blast furnaces as well as capture - separation and recovery - of CO_2 from blast furnace gas (BFG).

6.4. Energy management for global environmental protection

The 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) was held in Paris, France on November 30, 2015. As an international framework for the global warming countermeasures from 2020, "Paris Agreement" was adopted formally with legally binding effect as well as the Kyoto Protocol. Japanese government has already set the target to reduce 26% emission of a greenhouse gas such as CO2 to the 2013 levels by 2030. The target has become an international commitment of Japan by CO21. The amount of reduction is equivalent to 50.30 million kl (in a crude oil equivalent) reduction and equivalent to the annual energy consumption of all households (about 56 million households) in 2013 in Japan.[(31)] These are the goals that shall be worked out by the entire Japan. However, Japanese industries have already reached the world's top level of energy savings. For further improvement, it is necessary to have new viewpoints such as the introduction of innovative production processes, overall optimization with the cooperation between organizations etc., in addition to the conventional approach such as the improvement of energy efficiency of individual equipment.

This whitepaper was written from the viewpoint of energy management to widely spread the system approach based on the international standardized methodologies for energy management. Figure 63 summarizes the issues that should be focused on. Japan has been expected to demonstrate leadership for the global energy savings.

Figure 63 Energy management for global environmental protection

7. References

(1) IEC SMB/2419/INF
Coping with the Energy Challenge: the IEC's role from 2010 to 2030
http://www.iec.ch/smartenergy/pdf/white_paper_lres.pdf

(2) IEC/TR62837 Edition 1.0 2013-09、
"Energy efficiency through automation systems"

(3) IEC TS62872
"System interface between Industrial Facilities and the Smart Grid."

(4) JEITA エネルギー性能指標(EnPI)導入ガイド
国際標準のエネルギー管理手法 ---エネルギー性能指標(EnPI)導入ガイド---

(5) ISO50001
Energy management systems —Requirements with guidance for use

(6) ISO50006
Energy management systems —Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) —General principles and guidance

(7) Space-time boundary for effective energy management
http://home.jeita.or.jp/upload_file/20140210133703_AfXs3jvqzZ.pdf

(8) 省エネ診断・節電診断の進め方（省エネルギーセンター）
電気と保安 電気と保安 2013 年 1・2 月号

(9) Strategic Technology Roadmap in Energy Field
The National Institute of Advanced Industrial Science and Technology (AIST)
http://www.iae.or.jp/wp/wp-content/uploads/2014/09/ene_vision_2100/overview.pdf

(10) RESEARCH REPORT
Technology Survey on Advanced Utilization of Medium to Low Temperature Heat, Japan Science and Technology Agency (JST) Center for Research and Development Strategy
http://www.jst.go.jp/crds/pdf/2013/RR/CRDS-FY2013-RR-02.pdf

(11) Achieving Energy Saving on the Level of Industrial Complexes through the Sharing of Heat between Factories, NEDO
http://www.nedo.go.jp/content/100587252.pdf

(12) Utilization of unused waste heat
http://www.jisf.or.jp/course50/tecnology03/index_en.html

(13) エネルギー効率化のためのシステムアプローチ入門
(A guide to the system approach for energy efficiency)
https://www.jemima.or.jp/publication/report/tr001-2014j.html
(14) Results of the Fiscal 2013 Follow-up to the Voluntary Action Plan on the Environment (Summary) −Section on Global Warming Measures—
< Performance in Fiscal 2012 >, KEIDANREN
http://www.keidanren.or.jp/en/policy/2013/101.pdf
(15) Bioreactor（WIKIPEDIA）
https://upload.wikimedia.org/wikipedia/commons/e/ee/Bioreactor_principle.svg
(16) ANSI/ISA–88.01–1995 (Formerly ANSI/ISA–S88.01–1995)　IEC 61512
(17) Sugiura, 38th Seminar The Society of Chemical Engineers, Japan, 2004
(18) Approach to Energy Saving in Machine Tools
http://eb-cat.ds-navi.co.jp/enu/jtekt/tech/ej/img/no1010e/1010e_03.pdf
(19) IEC 62264-1 Ed 2: Enterprise system integration
- Part 1: Models and terminology
(20) ISO22400-2
Automation systems and integration-Key performance indicators (KPIs) for manufacturing operations management-Part 2:Definitions and descriptions
(21) モータの省エネ化が日本を救う(nikkeiBPnet)
http://www.nikkeibp.co.jp/article/reb/20110622/275169/
(22) Top runner motor
https://www.jema-net.or.jp/Japanese/pis/top_runner/sansou_yudou.html
(23) Optimum Combustion Control by TDLS200 Tunable Diode Laser Gas Analyzer
Yoshitaka Yuki, Akihiro Murata: Yokogawa Technical Report English Edition Vol.53 No.1 (2010)
https://www.yokogawa.com/rd/pdf/TR/rd-te-r05301-004.pdf
(24) Energy-saving Solutions by Advanced Process Control (APC) Technology
Hiroshi Wakasugi, Kazuo Sueyoshi: Yokogawa Technical Report Vol.53 No.1 (2010).
https://www.yokogawa.com/rd/pdf/TR/rd-te-r05301-002.pdf
(25) RENKEI Control Guidebook (JEITA)
https://www.jeita.or.jp/english/public/data/RENKEI_Control.pdf
(26) 省エネルギー対策について_資源エネルギー庁
http://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/007/pdf/007_05.pdf
http://www.kantei.go.jp/jp/singi/keizaisaisei/pdf/kaikaku2020_gaiyouen.pdf

(27) SMART GRID CONCEPTUAL MODEL
http://www.sgip.org/wp-content/uploads/Smart_Grid_Conceptual_Model_20100420.pdf
(28) FEMS proposed by JEMA
http://www.hitachi-ies.co.jp/solution/energy_fems/jema_fems.htm
(29) 戦略的省エネルギー技術革新プログラムの概要
国立研究開発法人新エネルギー・産業技術総合開発機構(NEDO)
Energy Efficiency Technology Strategy
http://www.nedo.go.jp/content/100773783.pdf
(30) Outline of COURSE 50
http://www.jisf.or.jp/course50/outline/index_en.html
(31) 5030 万 kL(原油換算)の削減目標をどう達成するか
月刊「省エネルギー」 Vol.68 No.1 2016
(32) 国際標準のエネルギー管理手法 ～EnPI 導入ガイド～ 実践編
http://home.jeita.or.jp/upload_file/20161004170422_BFV4HTaX8b.pdf
(33) Batch Production Processes - Automatic control (LTH)
http://www.control.lth.se/media/Education/EngineeringProgram/FRTN20/2015/Lecture-03-2015.pdf

Annex

A1. Target values of KPI by industry sectors in Japan

http://www.meti.go.jp/committee/materials2/downloadfiles/g90819a08j.pdf

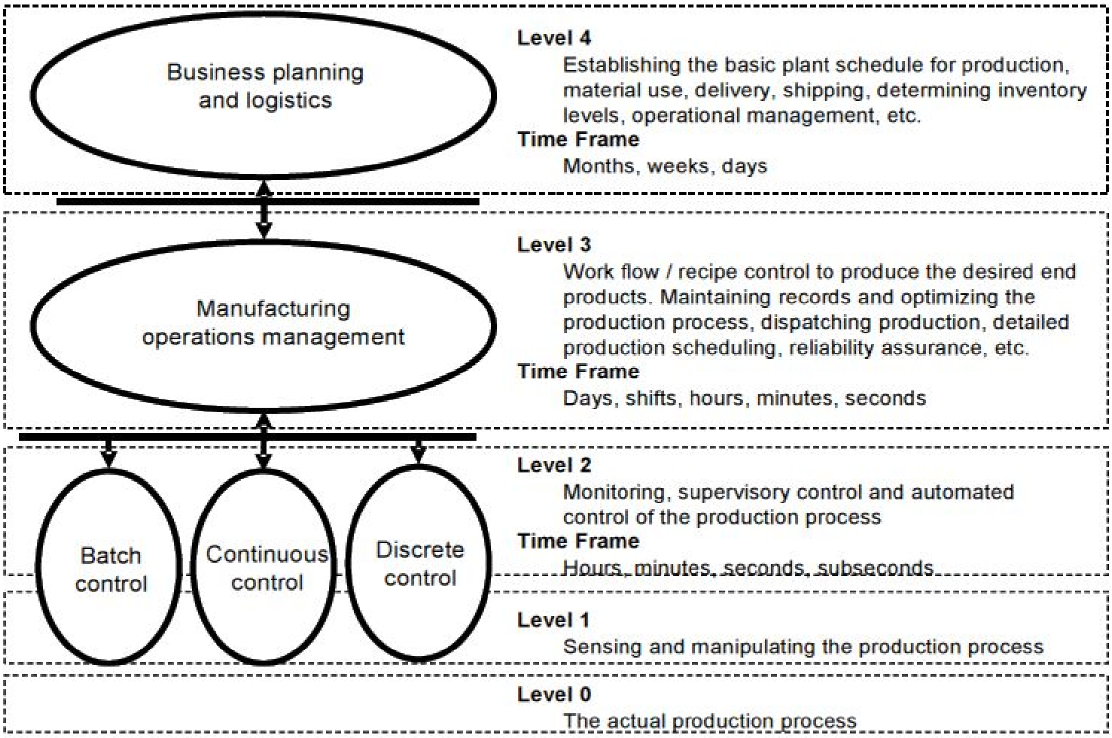
Table 6: A1 Benchmark indices and the target level to be achieved for mid and long term

Classification	Business field	Benchmark index	Target level
1A	Iron manufacturing using blast furnaces (business to manufacture pig iron using blast furnaces to manufacture products)	The value obtained by A/B A: Energy consumption in the blast furnaces for steel business B: Amount of raw steel	0.531 kl/t or less
1B	Common steel manufacturing using electrical furnaces (business to manufacture pig iron using electrical furnaces to manufacture rolled steel products, excluding iron manufacturing using blast furnaces)	Sum of 1) and 2) 1) The value obtained by A/B A: Energy consumption in the process to manufacture raw steel using electrical furnaces B: Amount of raw steel 2) The value obtained by A/B A: Energy consumption in the process to manufacture rolled common steel products from billet B: Amount of rolled steel	0.143 kl/t or less
1C	Special steel manufacturing using electrical furnaces (business to manufacture pig iron using electrical furnaces to manufacture special steel products (rolled special steel products, hot special steel pipes, cold-drawn	Sum of 1) and 2) 1) The value obtained by A/B A: Energy consumption in the process to manufacture raw steel using electrical furnaces B: Amount of raw steel 2) The value obtained by A/B	0.36 kl/t or less

	special steel pipes, cold-finished special steel products, forged special steel products, casted special steel products), excluding iron manufacturing using blast furnaces)	A: Energy consumption in the process to manufacture special steel products (rolled special steel products, hot special steel pipes, cold-drawn special steel pipes, cold finished special steel products, forged special steel products, casted special steel products) from billet B: Amount of shipped (sold) steel	
2	Electrical supplier (industry that supplies electricity determined by 2.1 of Act on the Rational Use of Energy among general electricity industry determined by 2.1.1 of Electricity Utilities Industry Law or wholesale electricity industry determined by 2.1.3 of Electricity Utilities Industry Law)	The value obtained by A/B (thermal efficiency standardized index) A: Thermal efficiency obtained by a performance test of rated output at thermal electric power generation facilities of factories that run this business (excluding low power facilities) B: Designed efficiency of the rated output In the case of plural facilities in the factory, the value is determined by a weighted average method based on the rated output. The value obtained by A/B (thermal electric power generation efficiency) A: Total electrical energy generated by thermal electric power generation facilities of factories that run this business B: Higher calorific value of the fuel that was required to generate the total energy	100,3 % or more of thermal efficiency standardized index
3	Cement manufacturing (business to manufacture portland cement (JIS R 5210), blast furnace cement (JIS R 5211), silica cement (JIS R 5212), fly-ash cement (JIS R 5213))	Total of 1) to 4) 1) The value obtained by A/B A: Energy consumption in the raw material process B: Production volume in the raw	3891 MJ/t or less

		material part 2) The value obtained by A/B A: Energy consumption in the pyroprocess B: Production volume in the pyroprocess part 3) The value obtained by A/B A: Energy consumption in the finishing process B: Production volume in the finishing part 4) The value obtained by A/B A: Energy consumption in the shipping process, etc. B: Shipping volume	

A2. IEC62264 Functional Hierarchy



Level 0 defines the actual physical processes.

Level 1 defines the activities involved in sensing and manipulating the physical processes. Level 1 typically operates on time frames of seconds and faster.

Level 2 defines the activities of monitoring and controlling the physical processes. Level 2 typically operates on time frames of hours, minutes, seconds and sub-seconds.

Level 3 defines the activities of the work flow to produce the desired products. It includes the activities of maintaining records and coordinating the processes. Level 3 typically operates on time frames of days, shifts, hours, minutes and seconds.

Level 4 defines the business-related activities needed to manage a manufacturing organization. Manufacturing-related activities include establishing the basic plant schedule (such as material use, delivery and shipping), determining inventory levels and making sure that materials are delivered on time to the right place for production. Level 3 information is critical to Level 4 activities. Level 4 typically operates on time frames of months, weeks and days.

JEMIMA: Energy / Low-carbon Committee/WG1/ (2016)

Toru Ishikuma（Azbil Corporation）
Chairman: Energy / Low-carbon Committee
Hitoshi Takayama（Azbil Corporation）
Convener: Energy / Low-carbon Committee /WG1
Kuniaki Mizukoshi（Yokogawa Electric Corporation）
Hiroshi Watanabe（Yokogawa Electric Corporation）
Tomoyuki Ikeyama（Yokogawa Electric Corporation）
Tomoji Kanno (Fuji Electric)
Yutaka Wakasa（JEMIMA） Editor
Kazuna Nozato（JEMIMA）
Toshiyuki Matsumoto（JEMIMA）

JEMIMA Japan Electric Measuring Instruments Manufacturers' Association

For inquiry related to the contents of this document,
please contact: http://www.jemima.or.jp/english_top.html