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Energy Conservation of Hydrogen Manufacturing Plant By Effectively Utilizing Components of Nearby Business Establishments

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◎ **Keywords: Rationalization of heating, cooling, and heat transfer (heating facilities etc.)**
Others (effective utilization of by-product gases)

◎ Outline of Theme

Recently, sulfur-free fuel oil for automotives and domestic use is promoted from the viewpoint of protection of the global environment. Therefore, use of hydrogen that is required for desulphurization of fuel oils is increasing and operation of hydrogen manufacturing plant is also increasing. Energy consumed by hydrogen manufacturing plant accounts for large percentage in the entire oil refineries, and various energy-saving measures have been done to decrease energy specific unit (energy unit consumption). However, due to restrictions of operation and facilities, energy saving is close to the limit. Therefore, we have expanded the horizons and reviewed measures to aim the overall optimization of the entire area including nearby facilities. As a result, we have realized “energy saving by utilizing by-product gases produced from petrochemical facilities” to achieve major results.

◎ Implementation Period of the said Example

October, 1999 – March, 2003 (total 42 months)

- Project Planning Period October, 1999 – March, 2001 (total 18 months)
- Measures Implementation Period December, 2000 – November, 2001 (total 12 months)
- Measures Effect Confirmation Period November, 2001 – March, 2003 (total 17 months)

◎ Outline of Oil Refinery

- Produced items:LPG, naphtha, gasoline, kerosene, diesel oil, heavy oil, lubricant oil
- Number of employees: 510
- Annual energy consumption (Actual record in 2003)

Fuel etc. (crude oil equivalent) :	751,000 kL / year
Electric power:	488,000,000 kWh /year

◎ Outline of Target Facilities

In this refinery, we have given and received utilities and half-finished products with nearby petrochemical facilities. We have focused on the energy saving activities beyond the framework of business establishments regarding the hydrogen manufacturing plant in the oil refinery and the ethylene manufacturing plant in the petrochemical area.(Fig.1)

The hydrogen manufacturing plant uses hydrocarbon such as naphtha as a raw material to produces hydrogen gas of 97% purity or higher by a steam reforming reaction (Fig. 2). Maximum hydrogen yield per day is 1,400,000 Nm^3. Ethylene manufacturing plant uses naphtha as a raw material to produce mainly ethylene and its capacity of production is 370,000 ton per year (Fig. 3).

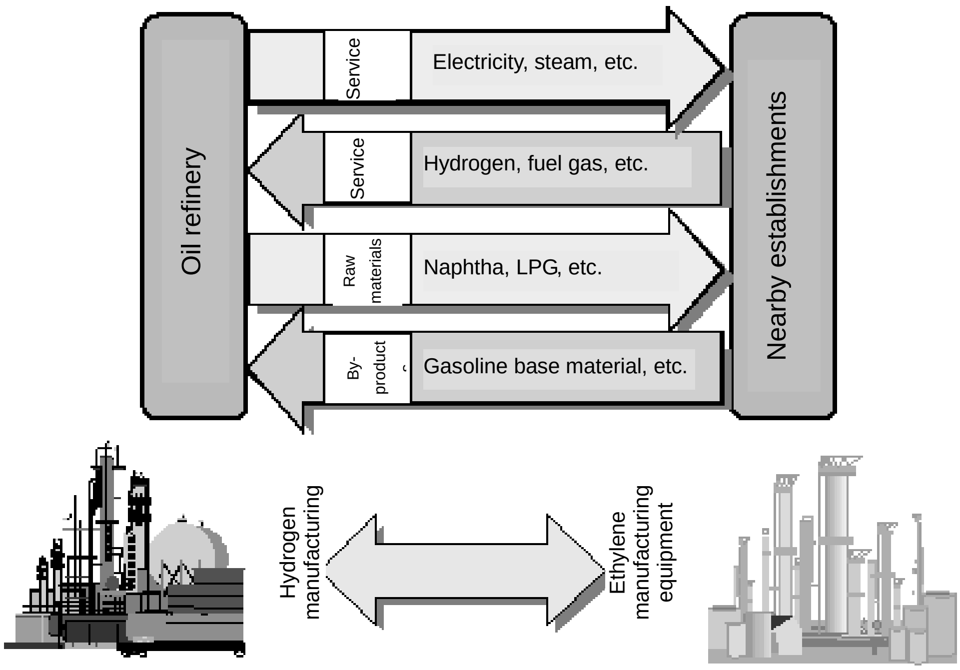


Fig. 1 Giving and receiving fractions and services between the oil refinery and nearby petrochemical facilities

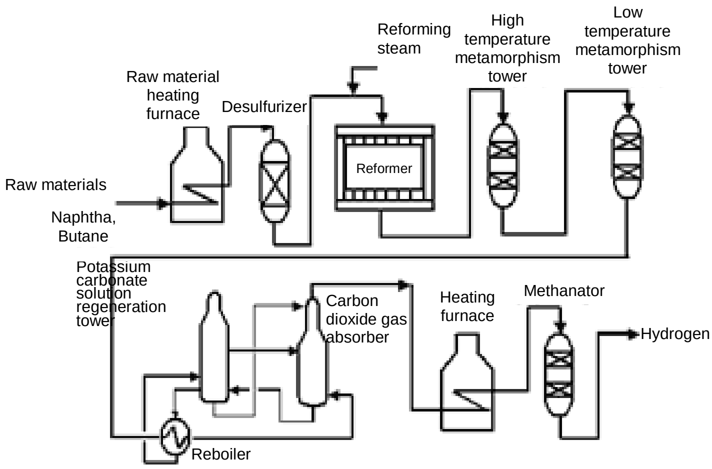


Fig. 2 Overview of flow sheet of the hydrogen manufacturing plant

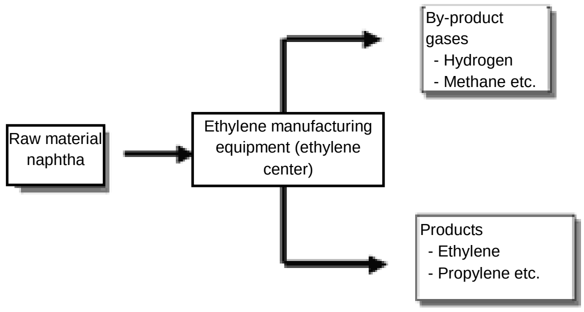


Fig. 3 By-product gases produced in the ethylene manufacturing plant

1. Reasons for theme selection

Fuel consumption of the hydrogen manufacturing plant accounts for 10% of the entire oil refinery (Fig. 4). On the other hand, sulfur-free fuel oil for automotives and domestic use is highly promoted from the viewpoint of protection of the global environment, so operation of hydrogen desulphurization plant, which reacts sulfur compounds contained in petroleum with hydrogen by using catalyst and removes hydrogen sulfide produced by the reaction, is increasing more than ever. At the same time, operation of hydrogen manufacturing plant that produces required hydrogen is increasing. Therefore, we have decided to reduce the fuel consumption of the hydrogen manufacturing plant, which has large energy-saving effect.

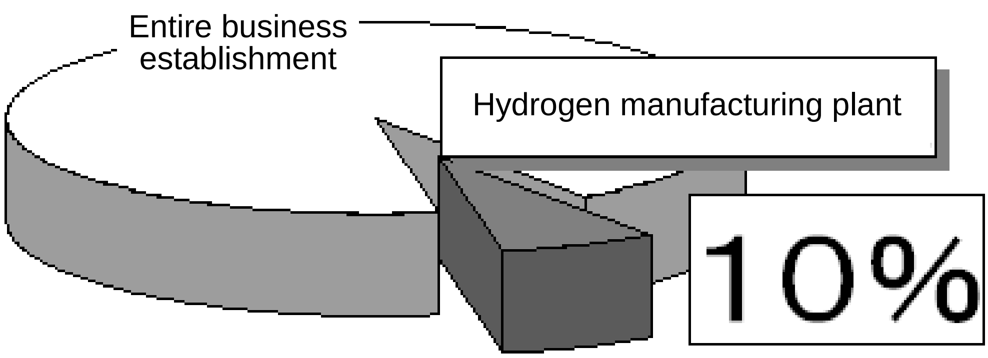


Fig. 4 Ratio of the hydrogen manufacturing plant to the fuel use of the entire business establishment

2. Understanding and Analysis of the Current Situation

(1) Understanding the Current Situation

The part that consumes most energy in the hydrogen manufacturing plant is the reformer that heats raw materials to 800 ℃to react them with steam, which consumes 78% of fuel of the manufacturing plant (Fig. 5). For this reason, we have worked on various improvement in operation and facilities in the past by focusing on the reformer to achieve large energy saving effect (Fig. 6). However, we have run out of improvement issues not only on the reformer but also on the entire plant, and so no more energy saving was expected with the traditional viewpoints in the current situation.

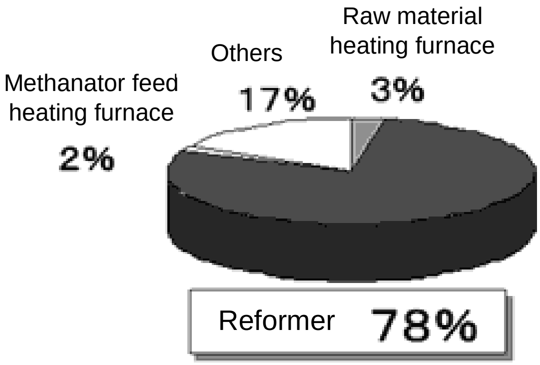


Fig. 5 Breakdown of fuel use within the hydrogen manufacturing plant

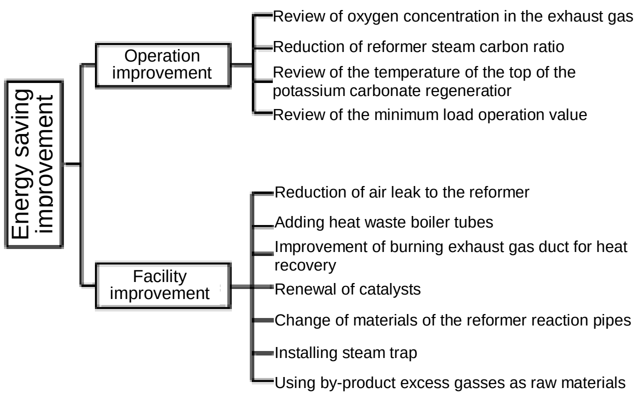


Fig. 6 Major improvements of hydrogen manufacturing plant in the past

(2) Analysis of the Current Situation

We have tried to identify issues by focusing on the reaction of the reformer that consumes most of the energy. The hydrogen manufacturing plant uses light naphtha (mainly carbon number 5) and butane (carbon number 4) as raw materials and manufactures hydrogen by reform reaction with steam. This reaction is a endothermal reaction, so it consumes a lot of energy as described above. The reform reaction performed here is as follows (Fig. 7).

In the process of reaction, higher hydrocarbons are reformed to lower hydrocarbons and eventually reformed from methane (carbon number 1) to carbon dioxide and hydrogen. When lighter carbon hydrides that has higher hydrogen/carbon ratio than naphtha or butane are used as raw materials, manufacturing energy per 1 mol of hydrogen can be reduced, so fuel gas consumption can be reduced (Fig. 8).

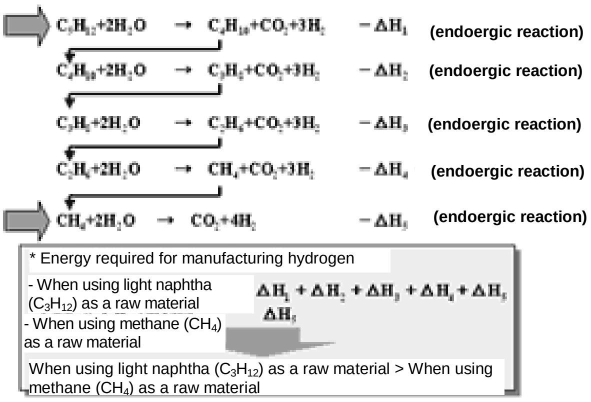


Fig. 7 Reactions and heat quantities of the hydrogen manufacturing plant

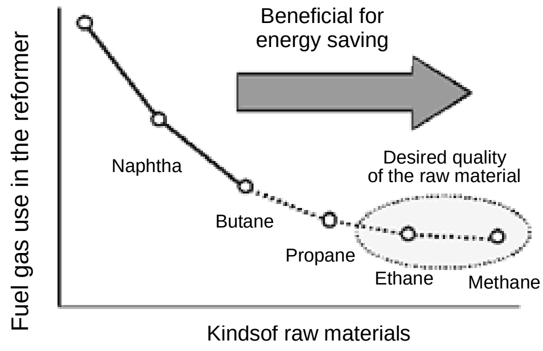


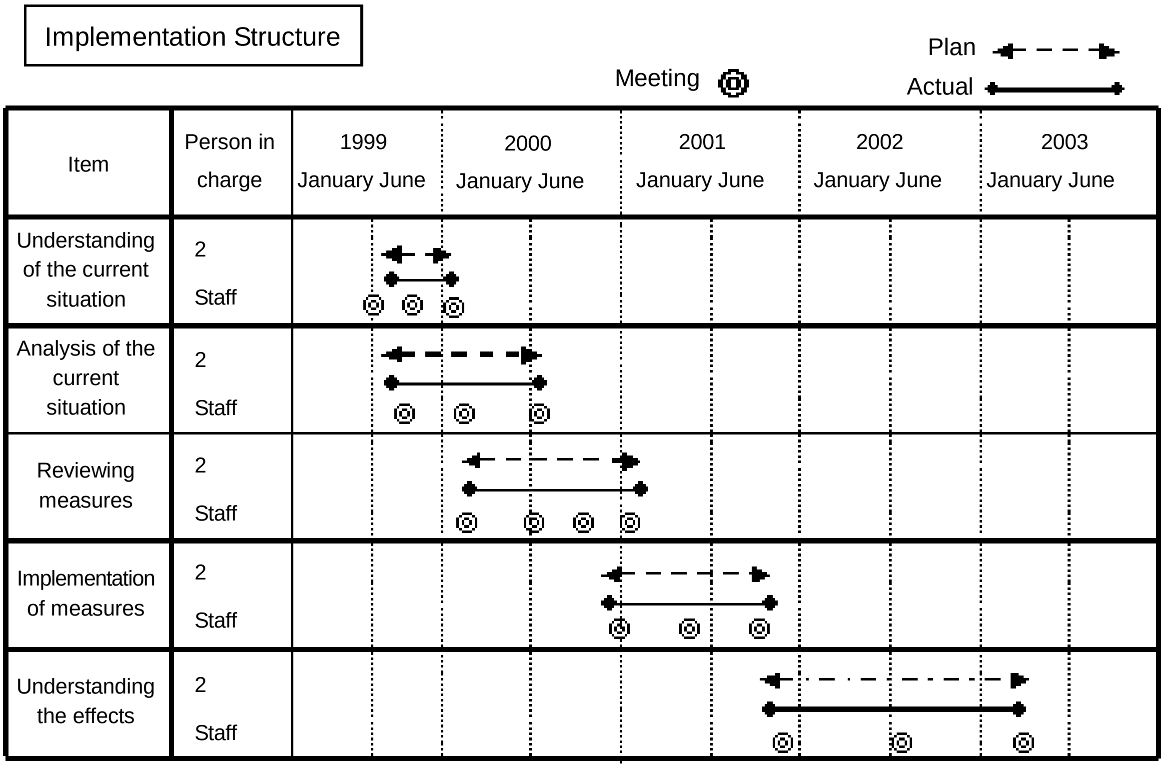
Fig. 8 Relation between the kindsof raw materials and fuel use

3. Progress of Activity

(1) Implementation Structure

Because this improvement activity expands beyond the framework of business establishment to nearby business establishments, and because a larger theme of diversification of raw materials and pursuit of new raw materials is included, it cannot be implemented by Operation Department only. Therefore, we have created a structure to promote overall optimization by including the staff department. The roles are clearly divided as follows as we review (Table 1).

Table 1 Schedule table



(2) Target Setting

The fuel consumption of the hydrogen manufacturing plant is 53,000 kL/year (crude oil equivalent) at maximum level operation. We have set the target at 5% reduction (2,500 kL/year) of fuel consumption (crude oil equivalent).

(3) Problems and Review

Based on the result of analysis of the current situation, we have set a proposition to seek for the source of light hydrocarbon and to ensure stable amount of them. In the oil refinery, there is a by-production gas from naphtha catalytic reformer, which is already used as a raw material. This time, we have expanded the searching range to nearby business establishments and thoroughly surveyed usage of all excess by-product gases (Fig. 9). As a result we have found that methane-rich gas (MRG) produced from the ethylene manufacturing plant located in the nearby petrochemical area has high methane purity and enough amount can be reserved.

Therefore, we have clarified problems when using this MRG as a raw material with staff from the nearby petrochemical plant (Fig.10).

We have identified problems from the viewpoints of gas components and effect to operation and facilities. As a result, we have

found that: the supply pressure from the ethylene manufacturing plant is low and gas can not be supplied with its pressure, and although the methane purity of the gas is as high as 91%, it contains a small amount of ethylene and acetylene (Fig. 11). Furthermore, effect of feed rate fluctuation is extremely large because the raw material is received directly from the plant.

Therefore, the following three major problems were reviewed:

[1] Problems on feeding MRG

[2] Effect of acetylene and ethylene on the hydrogen manufacturing plant

[3] Countermeasures against rapid decrease of feed rate on fluctuation of the ethylene manufacturing plant

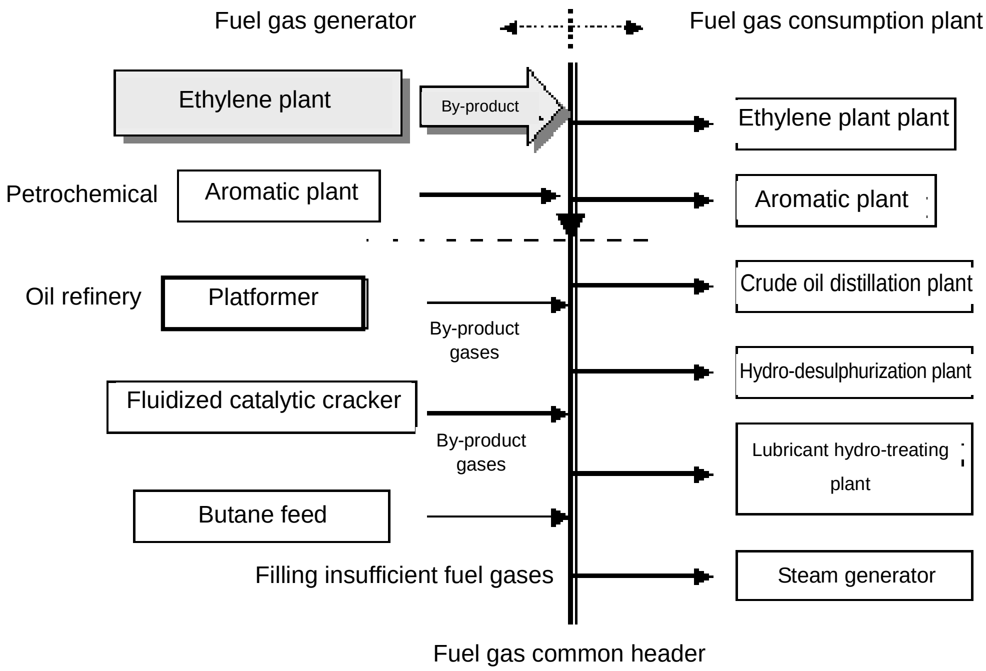


Fig. 9 Simple flow diagram for Domestic fuel gas generation and consumption

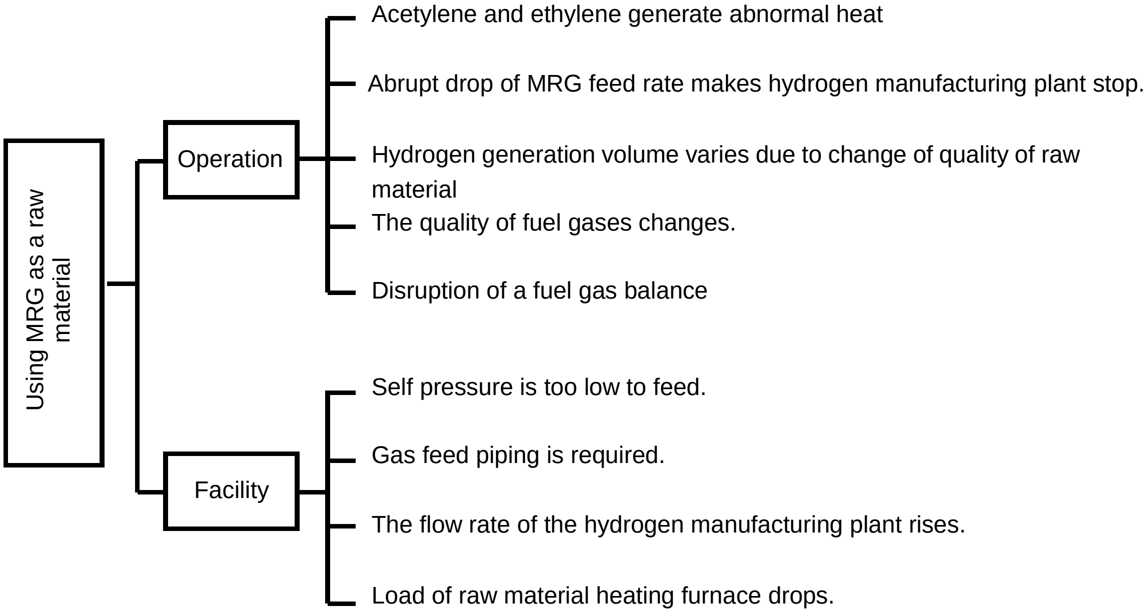


Fig. 10 Issues in using MRG as a raw material

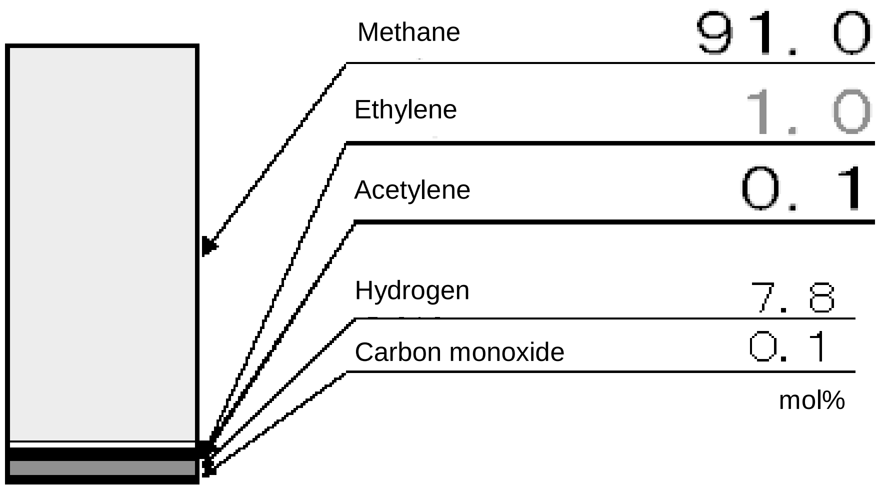


Fig. 11 Composition of MRG (Methane Rich Gas)

1) Problems on feeding MRG

To feed MRG from the ethylene manufacturing plant to the hydrogen manufacturing plant, the pressure must be raised from 0.3 to 3.0 Mpa (Fig. 12).

For that, a compressor for feeding gas is required. However, because MRG contains acetylene, it is found from the result of review that it could separate out filament coke (powder form carbon scale) at relatively low temperature (150 ℃) with the heat compression.(Fig. 13).

When filament coke is deposited, the piston ring in the reciprocating compressor could be warn away abnormally to result in failure (Fig. 14).

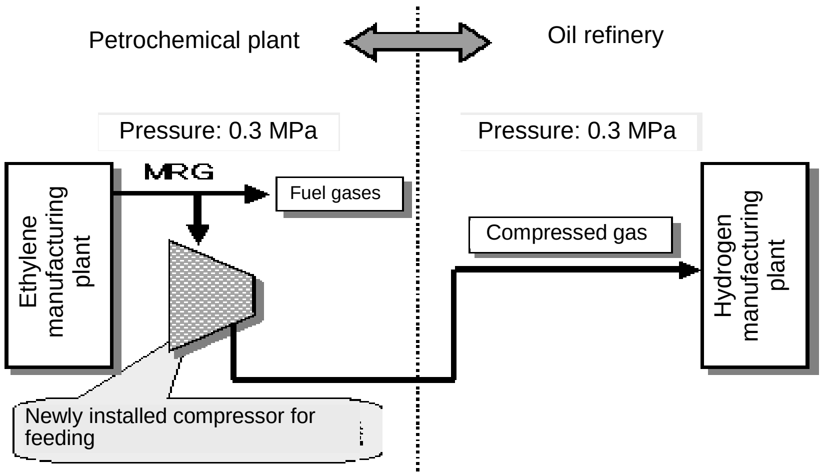


Fig. 12 Need of compressor for feeding MRG

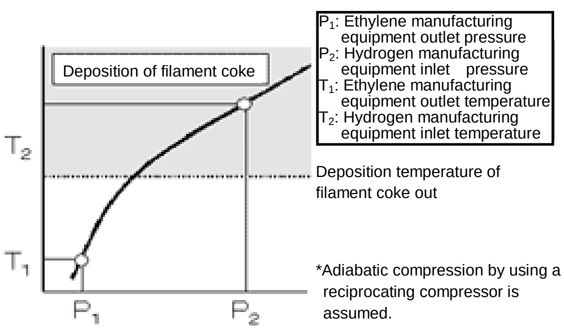


Fig. 13 Deposition Temperature of filament coke

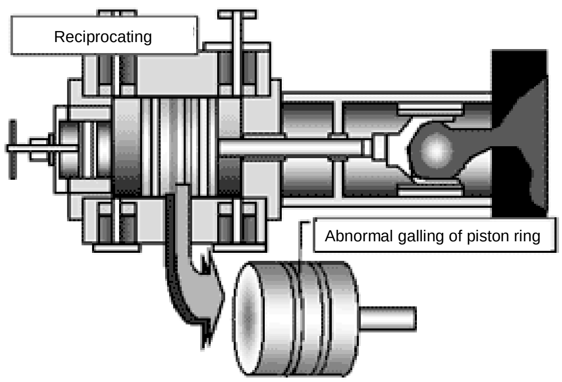


Fig. 14 Abnormal galling of piston ring of the reciprocating compressor

2) Effect of acetylene and ethylene on the hydrogen manufacturing plant

When MRG is used as a raw material for the hydrogen manufacturing plant, acetylene and ethylene contained in the MRG react with hydrogen and generate abnormal heat.
Therefore, there is concern of temperature rise due to heat generation and increase of pressure difference on the catalyst due to coke generation. on the desulphurization catalyst of the hydrogen manufacturing plant We have found that if acetylene and ethylene concentration becomes extremely high, desulphurization tower outlet temperature may exceed the designed temperatue (Fig. 15).

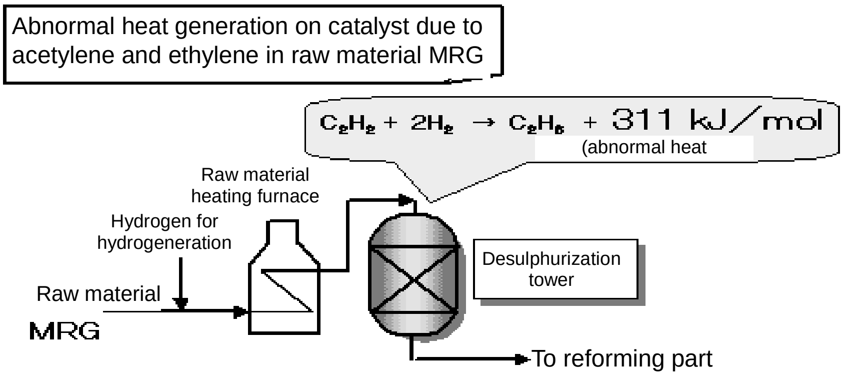


Fig. 15 Hydrogen manufacturing plantequipment: Issues in desulphurization of the raw material oil

3) Countermeasures against rapid decrease of feed rate on fluctuation of the ethylene manufacturing plant

When MRG is used as a raw material, if the feed rate is decreased for some reason, hydrogen manufacturing plant may stop depending on the amount of feed rate change. If the hydrogen manufacturing plant stops, about 60% of major plant using hydrogen (desulphurization plant) will stop, which results in impair of the function of the oil refinery and significant loss on the production plan (Fig. 16).
There are 2 cases are expected in which MRG feed rate drops rapidly: [1] stop of the ethylene manufacturing plant, and [2] stop of MRG feed compressor (Fig. 17).

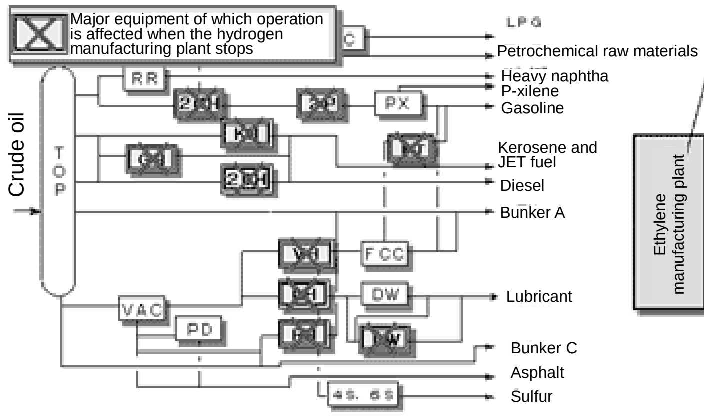


Fig. 16 Impact of stop of hydrogen manufacturing plant

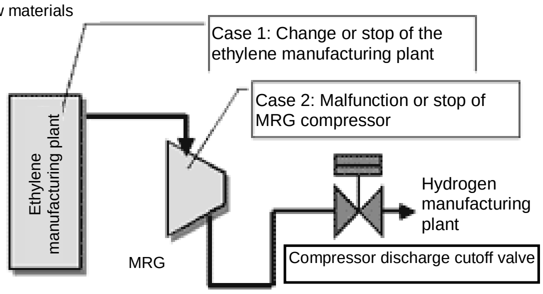


Fig. 17 Cause of rapid drop of MRG feed rate

When MRG feed is abruptly stopped, the hydrogen manufacturing plant must switch the raw material from MRG of a gas to Naphtha of a liquid in a short time. Usually, the switching speed of MRG feed rate can be 1 kNm^3 per hour, but switching must be done at the speed of 20 times faster or more when abnormality occurs. However, switching in a short time could cause rapid decrease of volumetric flow, and may cause pressure change in the plant and load change in the reformer, so stable switching of raw material is impossible with the current plant and technology.

4. Details of Countermeasures

(1) Prevention of Generation of Filament Coke by MRG Feed（Installing Screw Compressor）

To adopt the best compressor for feeding MRG, a reciprocating compressor, a centrifugal compressor, and a screw compressor are tested.
Because prevention of generation of filament coke at gas compression is most valued, we have decided to adopt a screw compressor, which has enough past record of handling similar gases based on the research of other business establishments and high reliability (Table-2).

Table 2 Selection of newly installed compressor type

	similar gases	F Coke generation	Cost	Reliability	Overall judgment
Reciprocating compressor	×	△	○	×	△
Centrifugal compressor	△	○	×	△	○
Oil cooling screw	○	○	△	○	◎

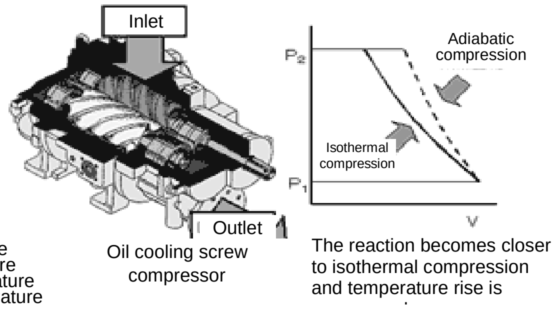


Fig. 18 Oil cooling screw compressor

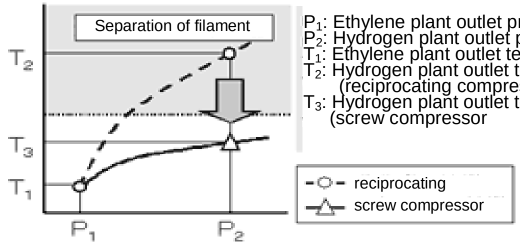


Fig. 19 Comparison of reciprocating compressor and screw compressor

A screw compressor can compress gasses at the isothermal compression while keeping the temperature of the discharge gas low by using lubricant (Fig. 18). In case of a screw compressor compared with a reciprocating compressor, the temperature of gas does not reach 150℃, at which filament coke is deposited, when the gas is compressed at the desired pressure. So the problem of generation of filament coke can be solved (Fig. 19). However, a small amount of lubricant for coolling the screw compressor gets mixed to MRG. As a result of technical review, we have found that the concentration of the lubricant mixed into MRG must be 5.0 wt-ppm or less considering the effect to the hydrogen manufacturing plant.

To prevent that lubricant to cool the screw compressor is mixed into MRG, we installed an oil collector and two mist separators at the downstream of the compressor gas outlet, as a result we could keep the concentration of the lubricant in the gas at 2.0wt-ppm or less (Fig. 20).

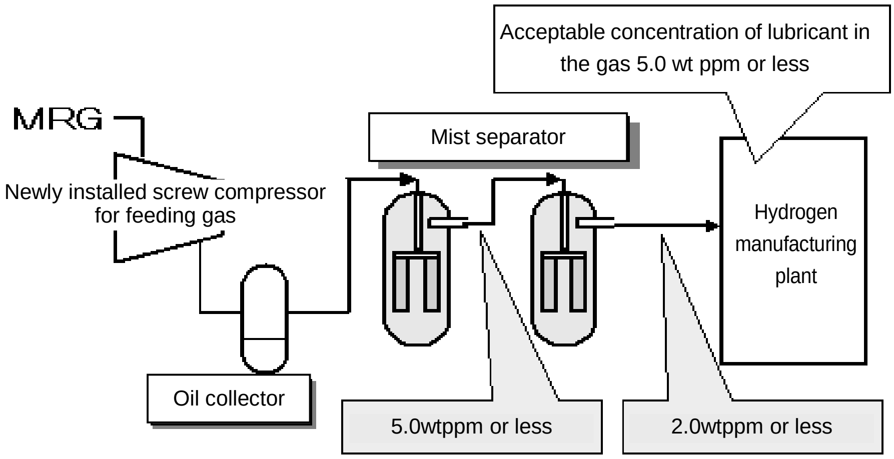


Fig. 20 Removing equipment of lubricant in the outlet gas of the compressor

(2) Effect of Acetylene and Ethylene on the Hydrogen Manufacturing Plant (Installation of Auxiliary Processing Equipment)

To prevent abnormal temperature rise and coke generation in the desulphurization unit, we have adopted a two-step method in which acetylene is hydrogenerated to ethylene before introducing to the desulfurizer and then ethylene is hydrogenerated to ethane again (Fig. 21).

An auxiliary processing equipment is installed to upstream of the desulfurizer to prevent abnormal temperature rise and coke generation. The hydrogen in MRG is used for hydrogenations.

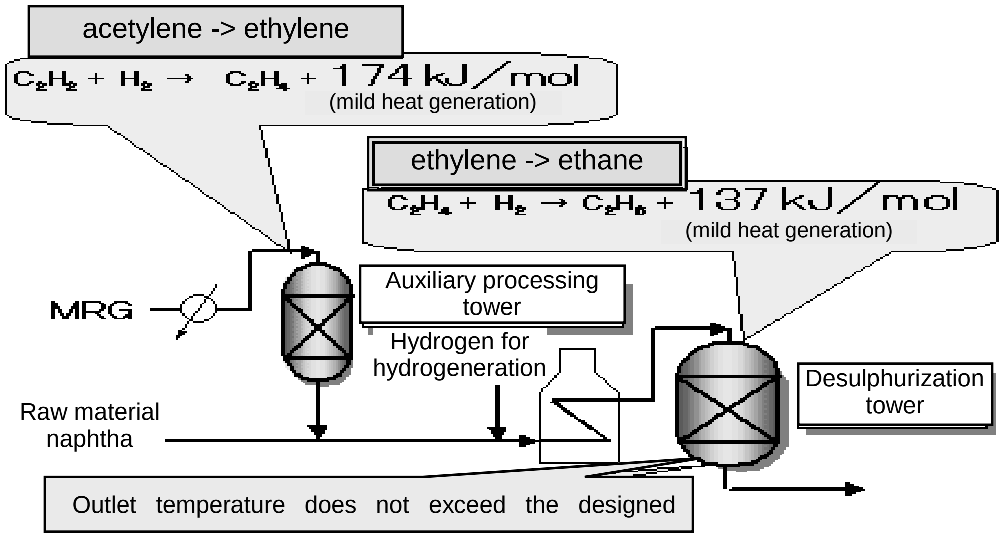


Fig. 21 Prevention of temperature rise at the desulphurization unit

(3) Countermeasures Against Rapid Decrease of Feed Rate on Fluctuation of the Ethylene Manufacturing Plant (Installation of Automatic Backup System for Raw Material Feed)

To prevent stop of the plant due to rapid pressure drop in the system, we have installed a holder (buffer tank) of MRG to prevent rapid drop of MRG feed and built an automatic backup system to quickly switch raw material from MRG to naphtha.

To build this automatic backup system, behavior of the system when MRG feed rate changes was simulated for review.

As a result, we have found that the generated hydrogen amount and the tube surface temperature of the reformer can be kept within the acceptable values if the buffer tank capacity is set so that supply of MRG can be kept for ten minutes (Fig. 22).

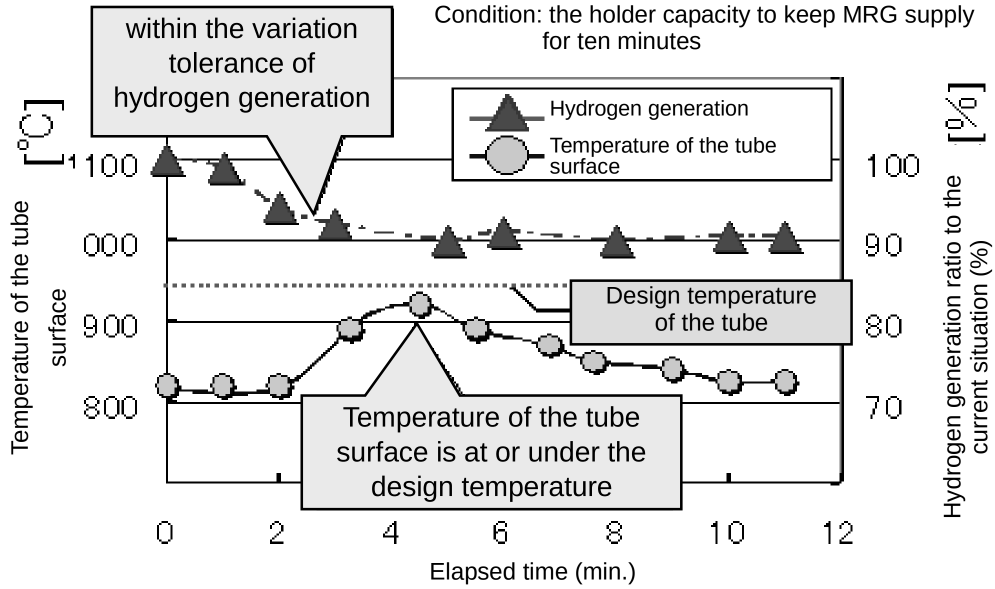


Fig. 22 Simulation after installing an automatic backup system

From this result, the system automatically switches raw materials with distributed control system (DCS).

For the switching procedure, the shutting valve (Fig. 23) to the ethylene manufacturing plant automatically closes when MRG feed rate drop is detected. At the same time, the raw material switching program starts, which rapidly increase raw material naphtha and gradually decrease MRG so that the feed rate at the inlet of the reformer becomes constant (Fig. 24).

As a result, the switching can be completed within 10 minutes.

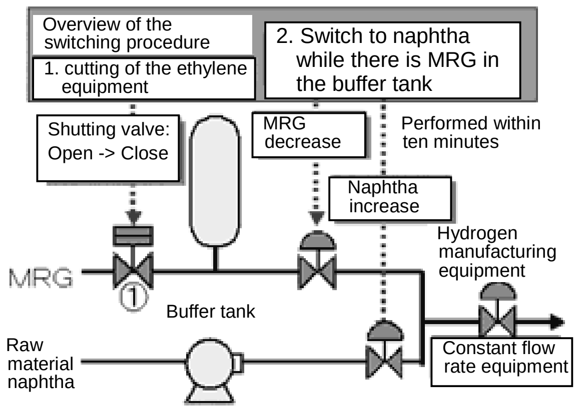


Fig. 23 Flow sheet of the raw material switching system

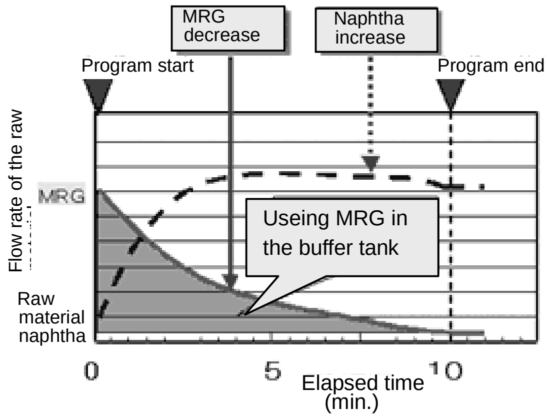


Fig. 24 Overview of the raw material switching system

(4) Summary of the countermeasures (Fig. 25)

[1] Installation of a screw compressor

[2] Installation of an auxiliary processing equipment

[3] Installation of an automatic backup system for raw material feed

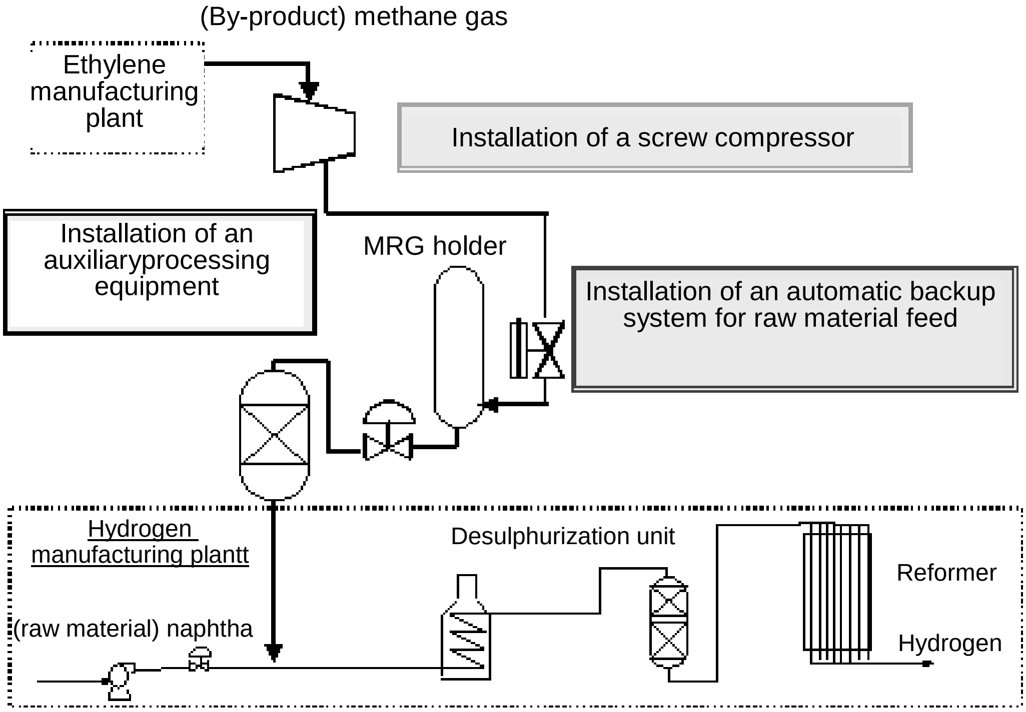


Fig. 25 Overview of the entire system

5. Effects of the Countermeasures

(1) Energy Saving Effect

- The hydrogen manufacturing plant
- Reduction of the specific energy consumption (Reduction of fuel use in the reformer) 25COE-L/kNm^3 (Fig. 26)

  Crude oil equivalent 5,727kL / year .... [1]

  Increase in electric power (increase in compressor load)

  Crude oil equivalent 1,314kL / year .... [2]
- Energy saving [1] - [2]＝4,413kL / year
- Benefit of reduced environmental load ... reduction of 13,660 ton/year (CO^2 equivalent)

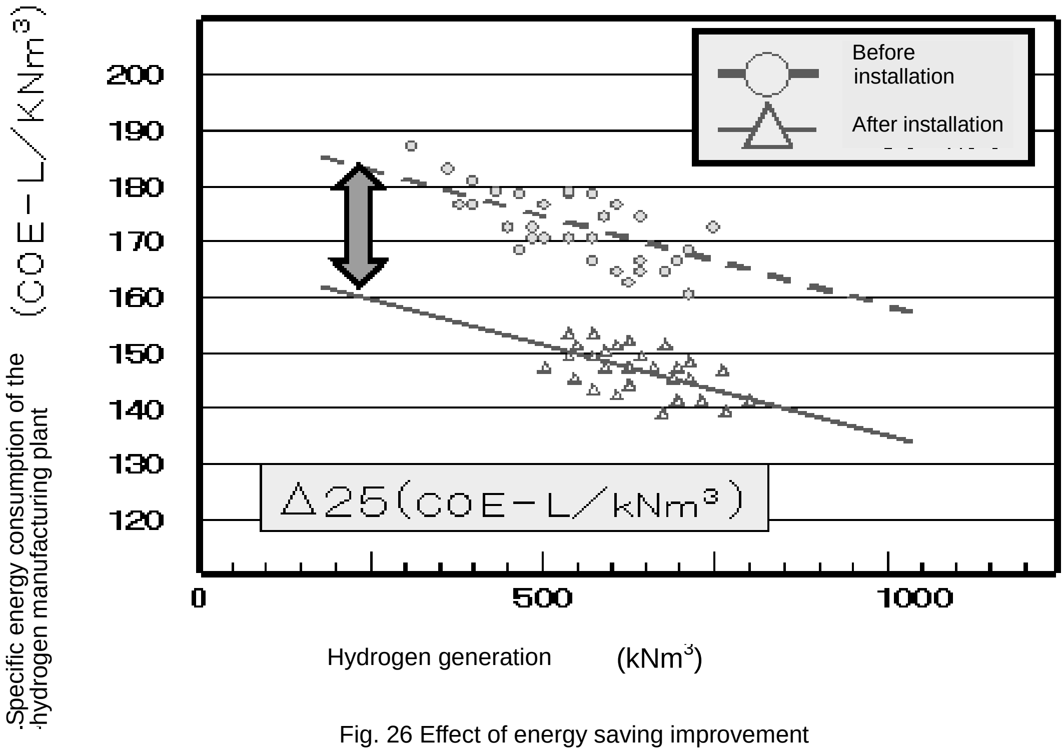


Fig. 26 Effect of energy saving improvement

(2) Result of Improvement

The result during the check period is shown in the following table (Table 3).

Table 3 Verification of the result of improvement

	Problem	Improvement method	Result of improvement
1	Problem in feeding MRG (deposition of filament coke)	Installation of a screw compressor	No filament coke is separated out and the compressor is in stable operation.
2	Impact of acetylene and ethylene on the hydrogen manufacturing equipment	Installation of an auxiliary processing equipment (first in Japan)	There is no abnormal heat generation in the desulphurization unitand coke is not deposited.
3	Countermeasures against rapid drop of flow rate when ethylene manufacturing plant fluctuates	Installation of an automatic backup system for raw material feed	There is no rapid drop of MRG flow rate (confirmed that there is no problem by simulation)

6. Summary

It is expected that hydrogen manufacturing plant will become more important from the view point of protecting global environment. MRG has been used only as fuel for heating furnaces and boilers. Through various discussion and measures beyond the framework of companies, we have succeeded to use MRG as a raw material for hydrogen manufacturing plant and realized significant energy saving in the entire business establishment.

It was verified that the technology established with support from NEDO (New Energy and Industrial Technology Development Organization) has no problems in about two and half years. The technology is contributing to safe operation of the hydrogen manufacturing plant and entire business establishment.

In addition, the approach shift from “energy saving in each business establishment” to “energy saving among nearby business establishments beyond the framework of companies” would be a point for the future energy saving.

7. Future Plan

We would like to pursue overall efficiency more than ever and promote improvement activities not only with nearby business establishments but also expanding to the entire industrial complex to contribute energy saving and environment improvement.