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# FUEL SWITCHING

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## Background

In the World Energy Outlook 2013, IEA mentioned that major changes have begun to occur in the energy sector, using the phrase "Many of the long-held tenets of the energy sector are being rewritten."

Next points are considered as the major trigger of the changes.

- The importance of CO2 reduction to prevent global warming
- The Reduction of the dependence or the abolition of nuclear power plants, after the disaster of Fukushima nuclear power plants
- The shale gas revolution in the USA

Global warming problem has prompted a shift in the use of natural gas with low CO2 emissions and in the use renewable energy in the countries such as EU nations and Japan.

However, countries such as China, India which have not imposed strong obligations to reduce CO2, resulted to heavily depend on coal fired power plant.

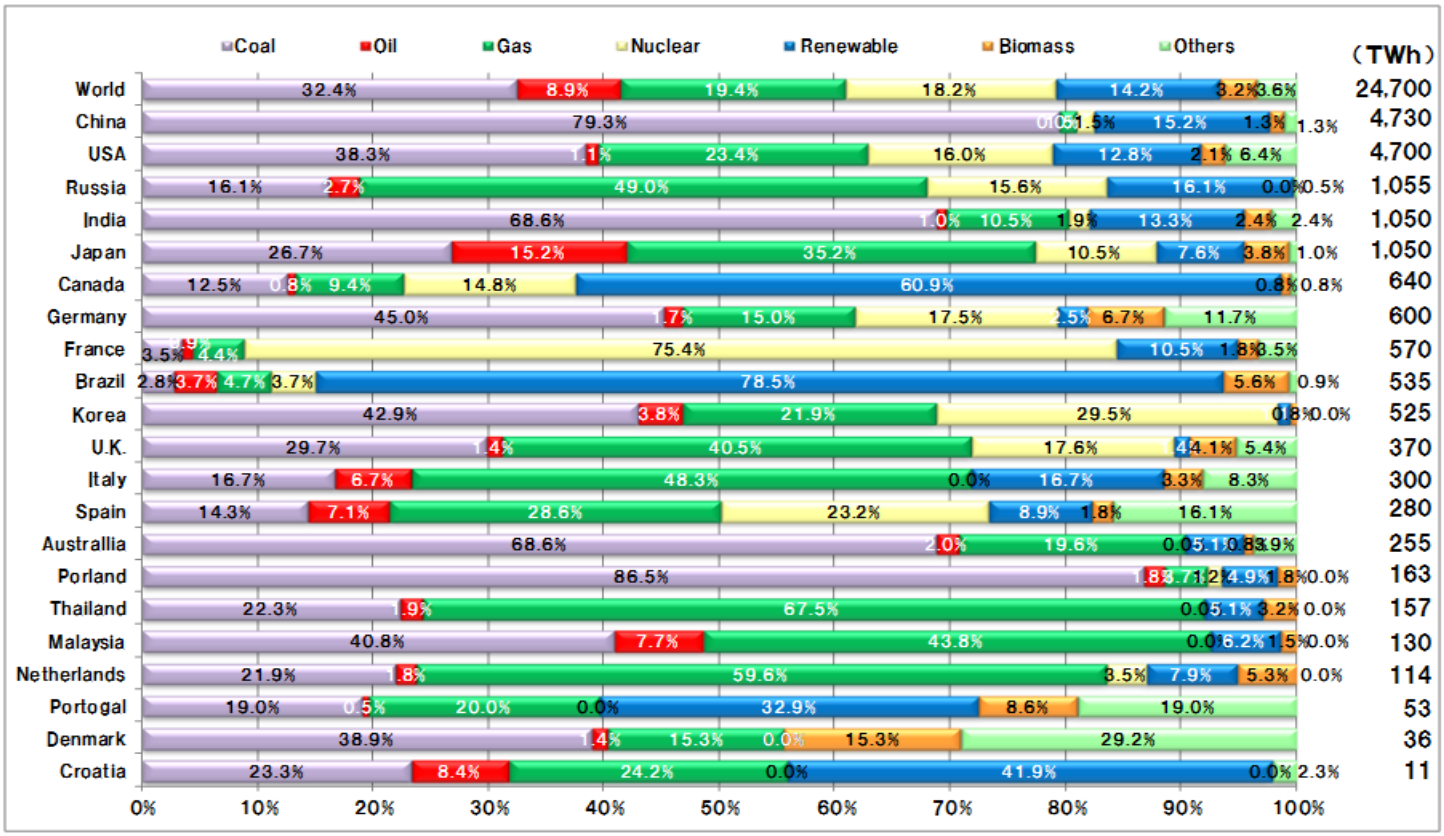


Fig.1 Energy Share in Power Sector

Also in the USA, Germany, South Korea, coal-fired power accounts for maximum share in the power sector.

Fukushima nuclear accident has increased the awareness of promoting more renewable energy, and further increased awareness of energy conservation in some OECD countries such as Japan, Germany where the share of the nuclear power is relatively high.

The shale gas revolution has had a significant impact on the power sector and industrial sector in the USA. Thanks to the shale gas revolution and the tight oil revolution, fuel prices of all fossil fuels including coal have dropped, especially the natural gas price becomes half or 1/4 compared to 5 years ago and becomes even or lower compared to the coal. Several industries of the USA once have shifted their factories to South East Asia and China and are now returning to the United States again because of the lower fuel prices. Unlike the USA, not many countries can enjoy the benefit of the shale gas revolution. Even some countries suffered negative impact on the natural gas consumption. Especially in the power sector in the EU, due to the over flow of the coal from the USA, the natural gas-fired power plant has lost its competitiveness to the coal-fired power. For example, in Germany, power generation cost of natural gas is higher than the wholesale electricity price.

In Asia, especially in the LNG importing countries, situation is more severe. In Japan, for example, due to the increase of the high price LNG import to replace the nuclear power plants by natural gas-fired power plants, national trade deficits and soaring electricity prices have become a political issue, the government and major power companies have started considering the introduction of coal-fired power plants again. Because the electricity price produced by the coal fired is less than 1/3 of the natural gas fired, even if including CO2 credits cost. In addition, efficiency of the state of the art coal fired power plant called IGCC(Integrated Gas fired Clean Coal) is greater than 48%. Japanese government and Tokyo Electric Power Company are making plan to construct new coal-fired ultra-high efficiency power plant as the symbol of Fukushima revival and reconstruction.

In a lot of countries outside USA, high natural gas price becomes big problem and natural gas has lost competitiveness to coal in the power sector. In the industrial sector, traditional oil linked high price LNG and soaring electricity price causes another problem now in Japan. Industrial customers are accelerating to transfer their production sites to the USA and developing countries where energy cost is low and environmental regulation is not severe.

In order to maintain the industrial gas demand in Japan, it is vital to secure low price LNG for the power plants and the industrial use. The shale gas and CBM are new attractive source of LNG, since they are not linked to oil price and produced in politically stable countries outside of Middle East.

Once the benefit of the shale gas revolution widely spread over the world, it is expected that the price competitiveness of natural gas would not be the issue anymore. However, it may take some time to come true. Since the nuclear power plant has lost its credit as the main power generator and renewable energies are still not sufficient to replace the nuclear power, in order to establish low-carbon society, it is necessary to introduce more natural gas in the power generation sector as well as industrial sector.

For this purpose, fuel switching to natural gas from other fossil fuel is important, however, it is not so simple. It is of course required that natural gas price should maintain reasonable price competitiveness and furthermore, the introduction of state-of-the-art technology and the most efficient technology which can achieve significant energy savings are indispensable.

## Aim

## Why do we carry out the "Fuel Switching" from other fuels to Natural Gas?

Natural gas is the most effective fuel to reduce CO2 emission and prevent global warming. Particularly it is very effective to carry out the fuel switching from oil and coal in the industrial sector where fuel consumption is large.

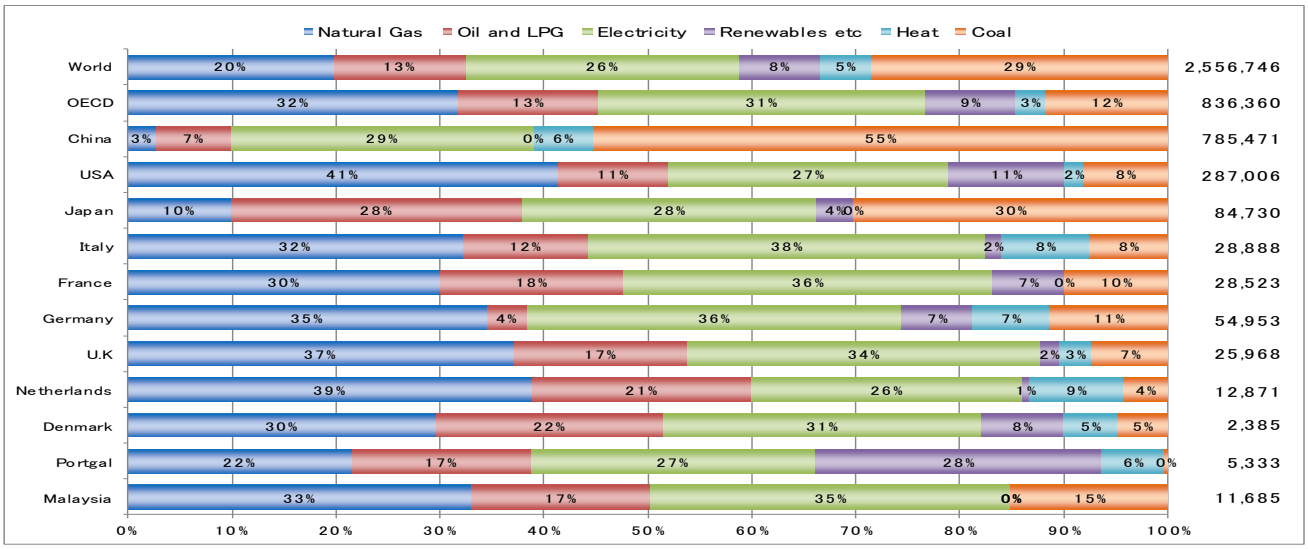


Fig.2 Energy share of the world and major countries in the industrial sector

The energy share of the world and of the major countries in the industrial sector is shown in Figure2. Natural gas share is about 32% in the total OECD countries, but coal and oil also have also secured a certain share.

Looking at individual OECD countries, France, the United Kingdom, and the Netherlands, the ratio of oil accounts for 17-21%, the ratio of coal also accounts for over10% in Germany and France and even in the USA, the ratio of oil is still over 10% and the ratio of coal is 8 %..

Especially, in the USA and Canada, thanks to the "Shale Gas Revolution", the price of natural gas is as low as 1/4 to 1/5 of oil in the industrial sector and in many EU nations, natural gas price is 1/2 to 2/3 compared with oil price. In these countries, it is easy to carry out fuel switching from oil to natural gas because investment recovery period is very short.

On the other hand, LNG importing countries such as Japan, the ratio of oil and coal is around 30% whereas the ratio of natural gas is 10%. In LNG importing countries, natural gas price has been much higher than oil price. Recently, the cost difference is shrinking, but natural gas is still about 10% higher than oil.

Therefore, when performing the fuel switching from oil to natural gas, substantial energy saving is required to reduce energy consumption and total energy cost.

Carrying out fuel switching from coal is very difficult. Usage of coal for industrial sector is limited to some big industrial customers who use a large amount of steam such as paper industries or chemical

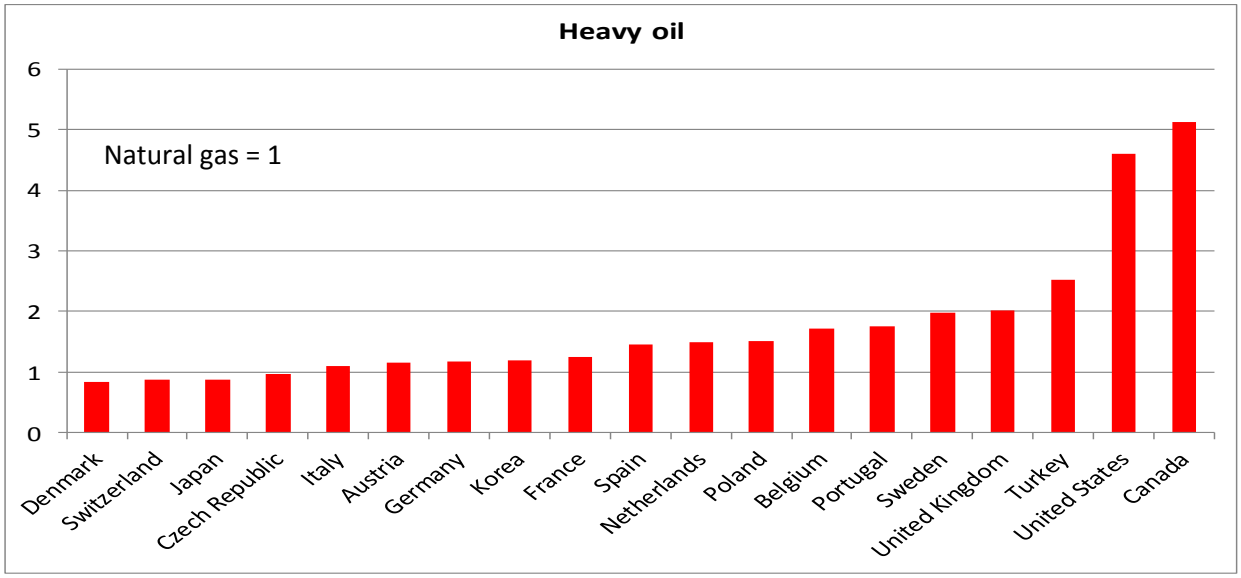


Fig.3 Comparison of the natural gas price and the heavy oil price

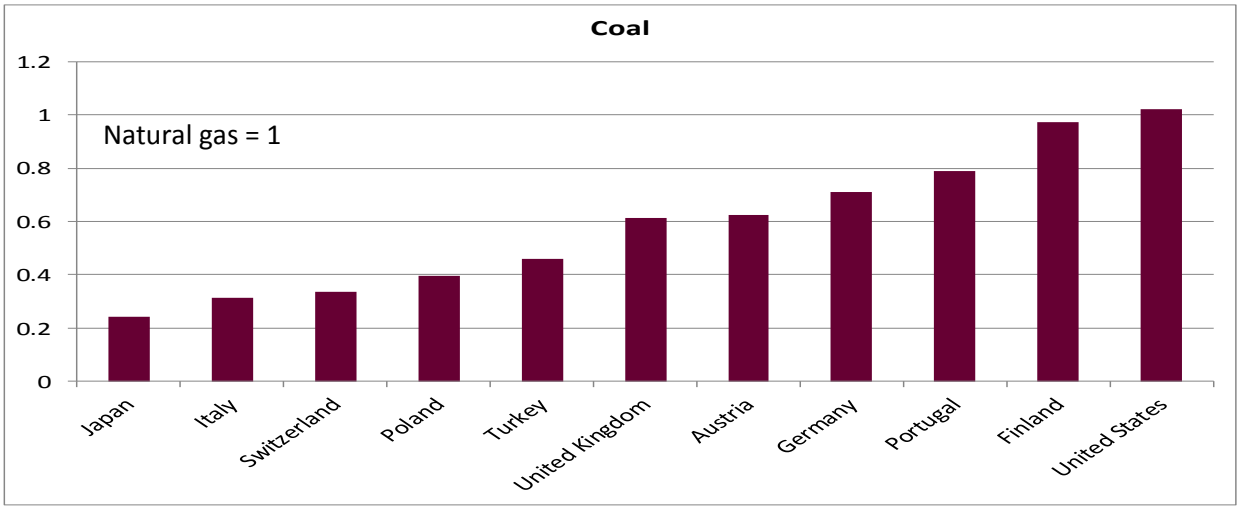


Fig.4 Comparison of the natural gas price and the coal price

industries. They have large scale coal fired boilers and it is very difficult to carry out to switch these boilers to natural gas because of the large difference of the fuel cost. However, it is not impossible to carry out fuel switching to natural gas from coal. For example, if a customer has a number of equipment which use steam, central installation type large scale coal-fired boiler system has many heat loss points such as steam leakage and heat loss from long steam transportation piping and heat loss due to partial load operation or stand-by state. It is very rare that all equipment are working at the same time, so central installation type boiler sometimes becomes partial load operation or stand-by state. In this situation, boiler efficiency is low and heat loss is large. On the other hand, gas fired system, it is possible to install high efficiency small gas boilers beside the equipment, and it can be operated respectively under the more efficient state without any heat loss from the pipe. Decentralized installation of gas fired boiler system can achieve massive energy saving.

Advantages and disadvantages of natural gas in the industrial sector and power sector are described as follows.

- Advantages of Natural Gas

1. Easy to reduce CO2 emission

Natural gas is the least CO2 emitting fuel among all fossil fuels. Only shifting to natural gas, CO2 emission can be reduced by20%.from heavy oil and 40% from coal.

2. Easy to achieve massive energy saving

For oil-fired furnace or boiler user, fuel switching is easy, because thanks to the cleanliness and good combustibility, it is possible to adopt the advanced waste heat recovery technologies and to use high-performance burner. Combined these techniques, natural gas can reduce 50% CO2 emission, in case of fuel switching from oil at the industrial customers.

3. Easy to improve customers product quality and yield of product

Natural gas emits no Sox and fewer Nox, so customer can easy improve their product quality.

For example, in the heat treatment process in metal industry, the product surface scale becomes thinner and yield of the product is improved. For the same reason, the texture of the product is improved even in the textile drying and the yield of the product is improved. In almost all industries, by fuel switching from oil to natural gas, their product quality and yield of product is improved.

4. Good affinity with renewable energy

Food industry disposes a lot of food residue and organic waste water. On the other hand, it is recommended to reuse those as a source of energy. In many cases, food processing factories introduce biogas fermenter to recover energy from the waste. Since main component of Biogas is CH4, biogas is very familiar with natural gas and most effective way to use biogas is mixing it with natural gas.

- Disadvantages of Natural Gas

1. High energy cost

Outside of the USA, as the fuel for thermal power or the fuel for the steam boiler of big industrial customer, the price of natural gas is very higher than the coal. The price of natural gas is twice or 3 times higher than that of coal all over the world outside of the USA.

For the industrial user, compared with the heavy oil, should natural gas 10-30% higher.

2. Huge infrastructure cost
   - Gas supply side

     LNG terminal construction cost, pipe line installation cost is huge and construction work also needs long period.
   - Gas user side

     Gas pipeline and auxiliary equipment (regulator, shutdown valve, and gas-meter) installation cost is needed. Oil is needed oil tank, but generally gas auxiliary equipment is higher than oil equipment.

3. Severe ISO standard for gas furnace compared to the oil furnace

   Gas furnaces are needed more safety devices than oil furnaces and the ISO standard for gas is more severe than for oil.

4. Inferior heat transfer characteristics for high temperature furnace

   For the high temperature furnace, such as glass melting furnace, the heat transfer is mainly depending on the radiation. In this case, the flame of natural gas has lower heat transfer than that of oil because of the lower brightness flame of natural gas compare to the oil.

   As listed above, natural gas has advantages and disadvantages, but in the industrial sector, most Items of disadvantages are related economic issues such as running costs and equipment costs which can be overcome with massive energy saving .

   The greatest advantage of natural gas is to help preventing the global warming.

   For this reason, the fuel switching to natural gas from other fossil fuel is significantly important and we must actively promote this fuel switching for ourselves and our future generations.

## Potential of fuel switching

As shown Figure 2, in the industrial sector, there are much potential for natural gas to fuel switch. The main target is the fuel of oil, coal and electricity used for furnaces.

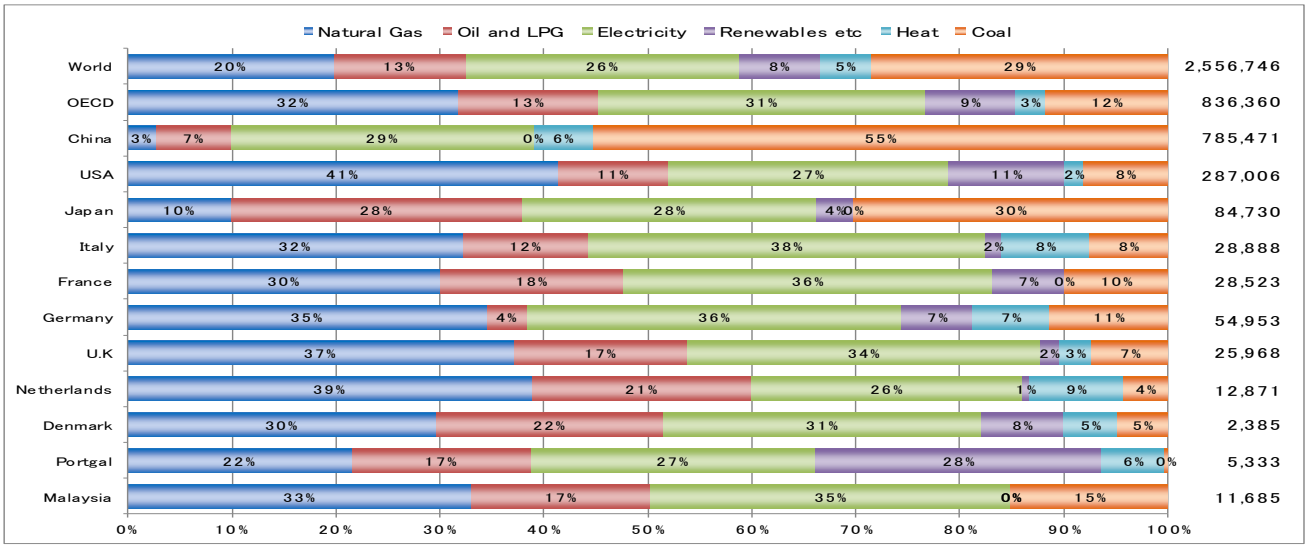


Fig.2 Energy share of the world and major countries in the industrial sector

The aim of fuel switching by natural gas from other fuels is obviously to expand the usage of natural gas, however, by taking advantage of the environmental friendliness of natural gas, there is a great expectation of the outcome of the fuel switching by natural gas, which is to reduce the impact on the global warming.

It is needless to say that replacing oil or coal by natural gas surely reduces the amount of the emission of CO2, NOx and SOx. Replacement of electricity by natural gas seems to increase the emissions at a factory, however, in the most of the countries, electricity is mainly generated by oil or coal at between 30 to 40% of the efficiency, then unless the efficiency of electricity appliances is more than 3 or 4 times of the natural gas appliances, fuel switching by natural gas from electricity is also contribute to reduce the impact on the global warming.

Furthermore, with its cutting edge technologies, natural gas can achieve higher efficiency and reduce the energy consumptions. If the amount of energy to be used is reduced, it results of reduction of the emission of CO2, NOx and SOx.

Thus, development of the fuel switching by natural gas contributes not only for natural gas market enhancement but also for the global environment.

## Methods

### Technologies of "Fuel Switching"

Natural gas is the least CO2 emitting fuel for the same amount of heat among all fossil fuels.

If the heat requirement in the industrial furnace is the same after conversion from the other fuel, only by shifting to natural gas, CO2 emission can be reduced by 25% from heavy oil and 40% from coal.

In 2008 at the G8 summit, the developed countries have pledged to aim to reduce CO2 by 80% in 2050. This goal is too high to be achieved only by simple fuel conversion, but by introducing highly efficient gas system with cutting edge technologies. Especially, for high-temperature furnace, the flame intensity of natural gas is lower than that of heavy oil then the simple fuel switching to natural gas will increase the energy consumption by 3-10%.

Furthermore, the equipment change cost on the fuel switching to natural gas is also large, in order to create enough benefit to the customer, the fuel switching is required to achieve significant energy saving.

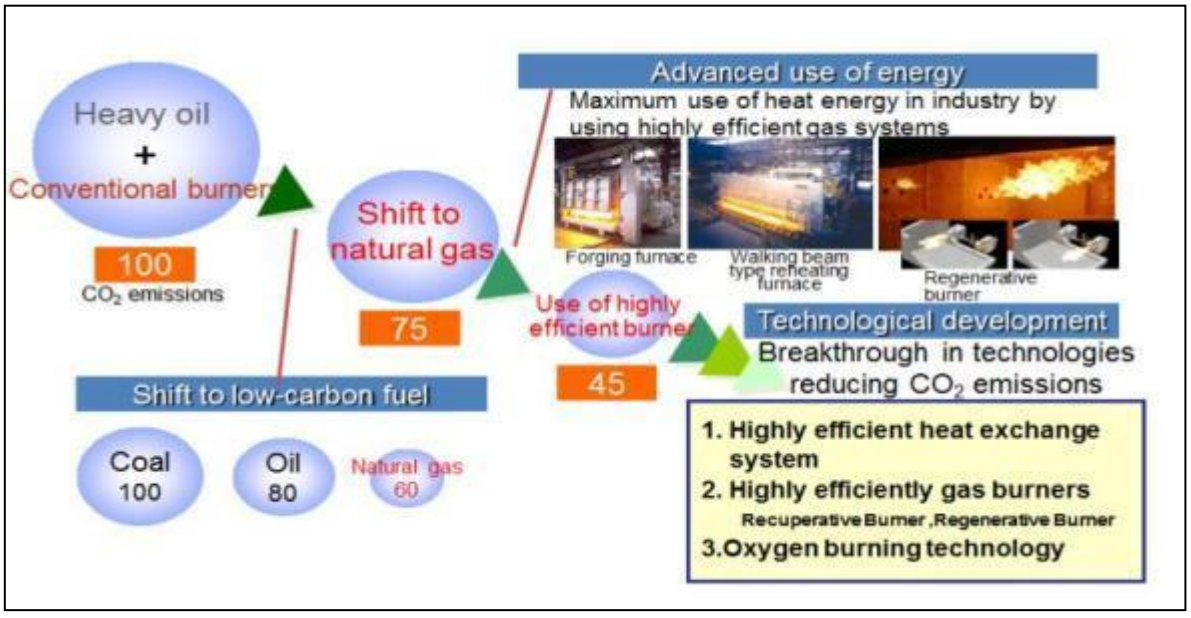


Fig.5. Massive CO2 reduction by natural gas

The procedure of energy saving

Heat loss is the biggest factor which reduces the efficiency of the industrial furnaces, so reducing the heat loss is the best way to save energy.

Since there are various heat losses when manufacturing an industrial product, there is a big difference between the quantity of heat required for a product and the quantity of heat to supply.

To reduce heat losses, there are 3 steps as shown in the Figure 6. The total amount of expenses and the effect of energy saving differs from every step.

1) Simple energy saving without expenditure except natural gas burner installation and re-adjustment of combustion condition.
2) Introduction of cutting edge technology
3) Change process or system etc.

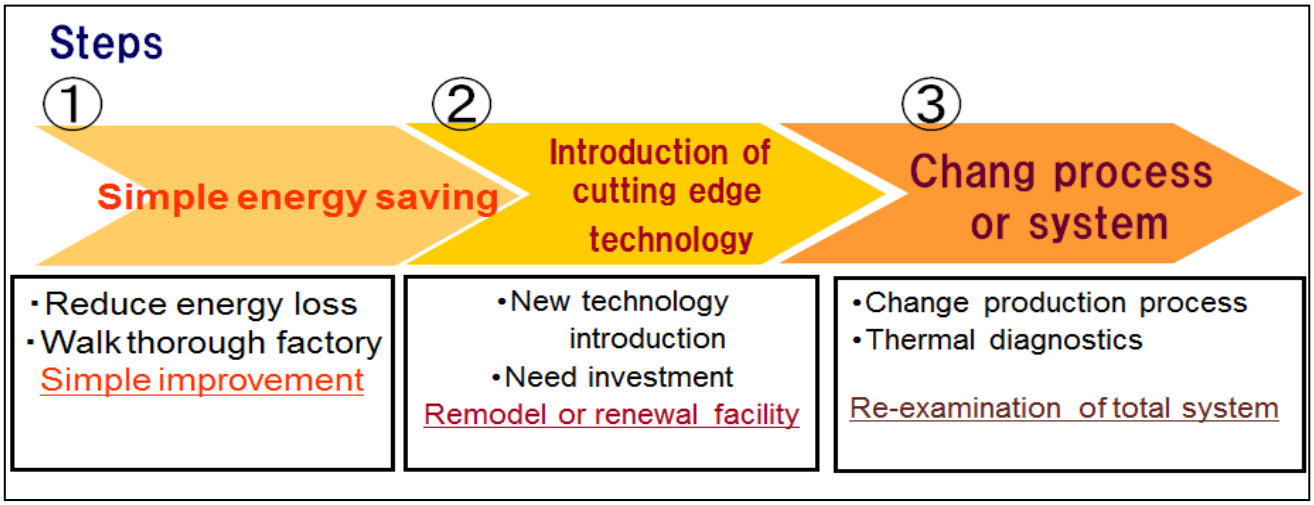


Fig.6 Steps for energy saving

Key point of energy saving to reduce heat losses are shown in Figure 7

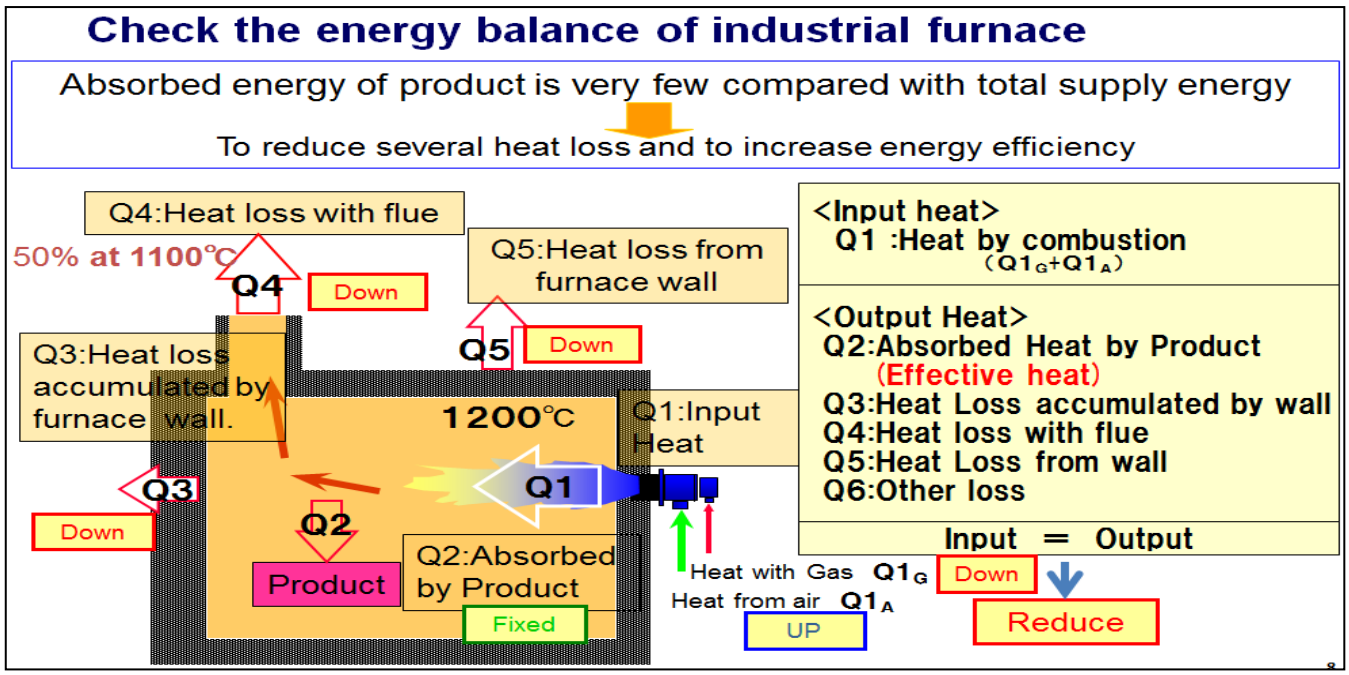


Fig. 7 Key points of energy saving

## Results

## Three Steps of Fuel Switching

1. Simple energy saving

First step is to reduce these heat losses.

Only by reducing these heat losses, significant amount of energy can be saved without large expenditure. For example, the heat loss of flue gas, Q4 in Fig.7, can be reduced massively only by changing from the oil burner to the gas burner. Because as for the oil combustion, in order to obtain good combustion, it is necessary to supply more excess air to the theoretical combustion air compared with natural gas combustion In the case of gas combustion, 1.05-1.2 times as much excess air as theoretical combustion air is need whereas in oil combustion, the 1.3-1.5 times as much excess air is needed as theoretical combustion air.

Especially when the furnace temperature reaches a regular operating condition, the required quantity of heat becomes the minimum and supplied fuel flow rate becomes minimum, in the case of gas combustion, about 1.2 times may be sufficient as an excess air ratio but in oil combustion, it becomes 1.5 or more times. As a result, the exhaust gas loss in oil combustion increases more than that of gas combustion considerably.

Moreover, in case of oil combustion, oil atomization is needed for getting good combustion, so it is not possible to reduce significantly fuel flow rate. If flow rate is reduced less than 1/3, the pressure of oil and air spraying becomes less than 1/9 and atomization condition becomes worse to keep good combustion. For this reason, oil burner's turndown ratio is limited to about one-third, whereas gas burner's turn down ratio is 1/10.

When furnace temperature reaches a regular operation state, in case of gas combustion, the continuous combustion at minimum fuel flow rate is constantly possible, but at low combustion condition, minimum flow rate of oil combustion is higher than that of gas, the on-off combustion is repeated in case of oil combustion.

Air purge is always performed at the time of burner ignition in case of the on-off combustion, an exhaust loss increases remarkably.

The supply amount of air required for combustion of the normal gas burner is said to require 1.1-1.2 times for the stoichiometric quantity of combustion air, whereas in case of oil, it is necessary 1.3-2.0 times for the stoichiometric quantity of combustion air.

As for the batch type of high-temperature furnace, such as the metal heat treatment, the furnace temperature at 1000 degree C or more, only simple fuel switching to natural gas from oil can attain massive energy saving.

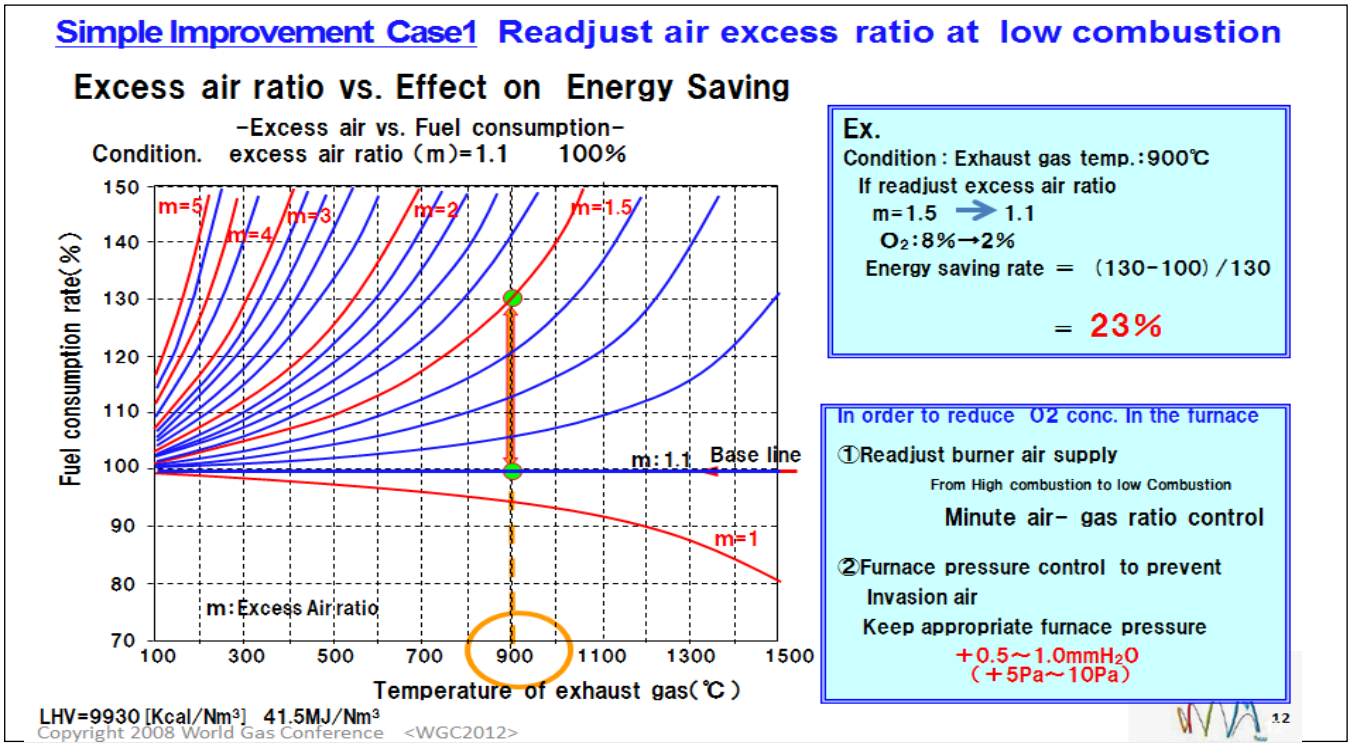


Fig.8 Energy saving by Improvement of Excess Air ratio

2. Introduction of the cutting edge technology

When converted from heavy oil to natural gas, adopting the state of the art technologies such as re-generative burner system can play an important role to recover investment cost. Not only for the economic benefit, but also industrial customers can save energy by more than 60% and reduce CO2 emission by 75% by adopting the gas fired re-generative burner system as shown in Fig. 9.

Simple fuel conversion is easy only in a country where natural gas price is very cheap, but also it is possible for every country to carry out natural gas conversion by adopting the advanced technology , which can achieve energy saving and significant CO2 reduction .

At the same time, adopting advanced technology brings significant economic benefits to industrial customers.

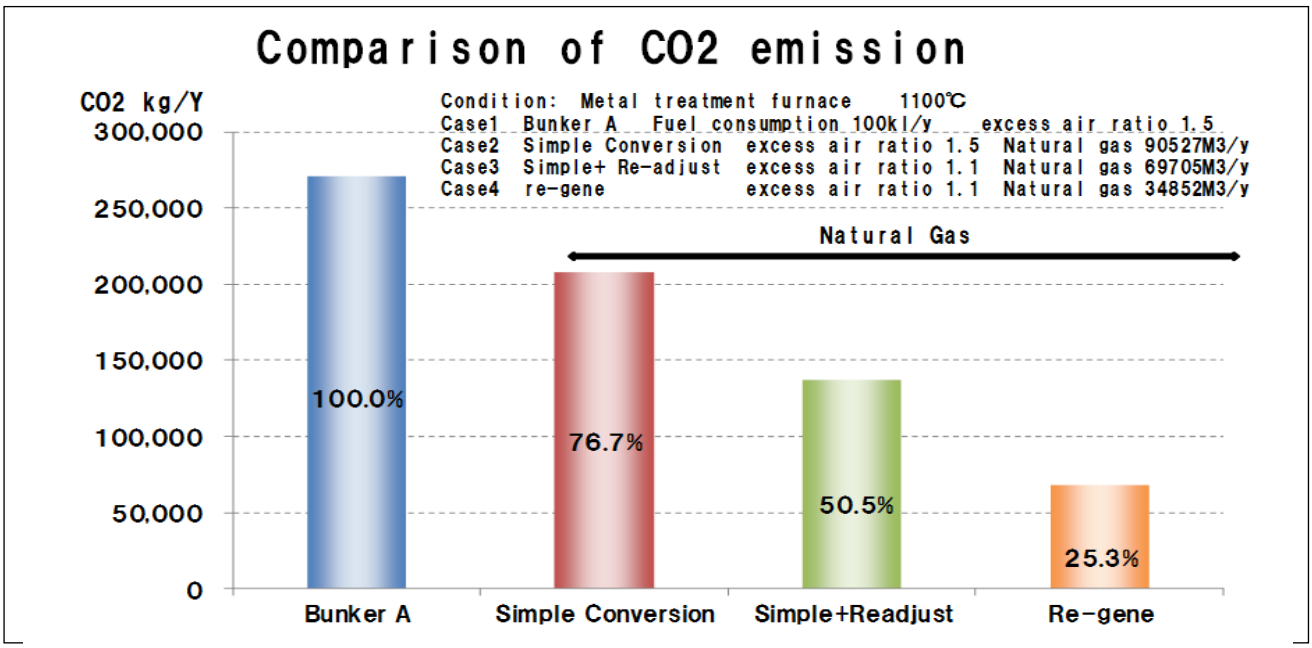


Fig.9 Comparison of CO2 emission by each type of conversions

The calculated results of the payback time of fuel conversion from heavy oil to natural gas in OECD countries are shown in Figure 10. The data for this calculation of the payback period is based on the industrial users' fuel unit price listed in the "Key World energy Statistic 2013" issued by IEA

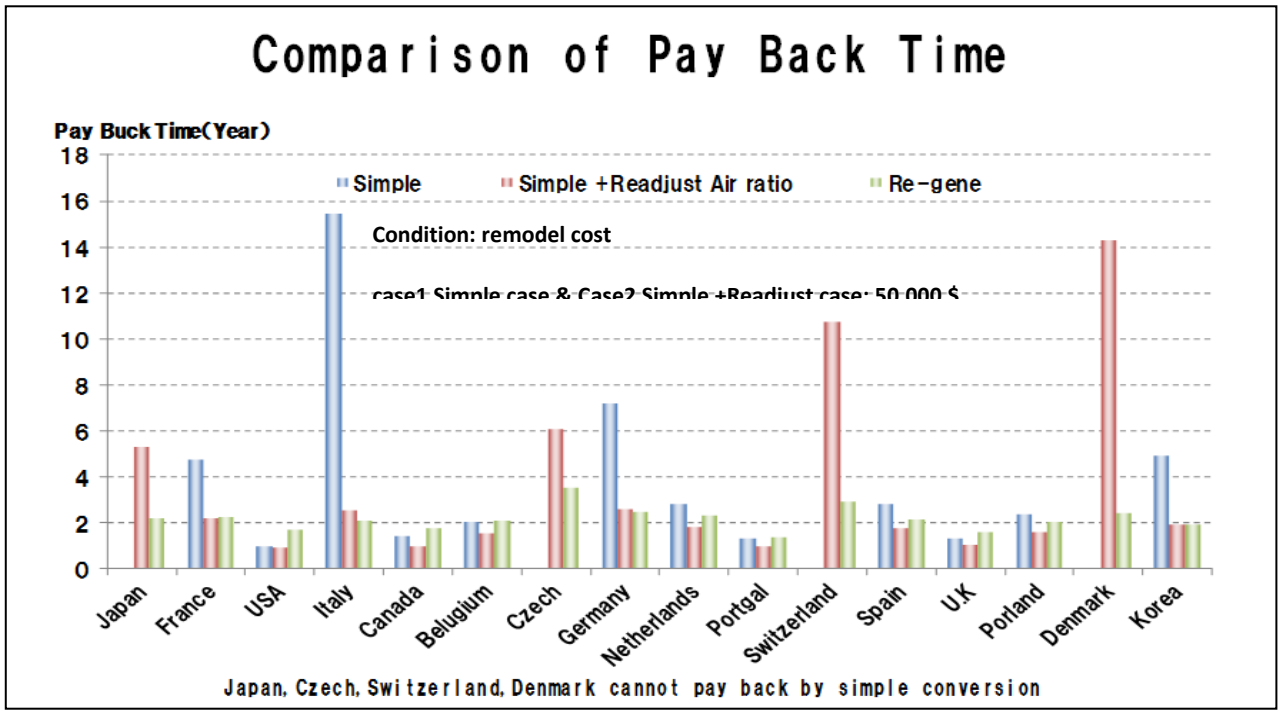


Fig.10 Payback time of fuel conversion in each country

It is obvious that it is very easy to pay back by only simple fuel conversion in the countries such as USA, Canada, Portugal, U.K, where heavy oil is expensive and natural gas is very cheap.

But, in the countries such as Japan, Czech, Switzerland and Denmark where heavy oil is cheap and natural gas is expensive, it is not possible to carry out fuel conversion only by simple fuel switching and improving excess air ratio.

When promoting fuel switching from oil to natural gas in these fields, one of the most important technologies is the re-generative burner system.

1) Types of re-generative burners

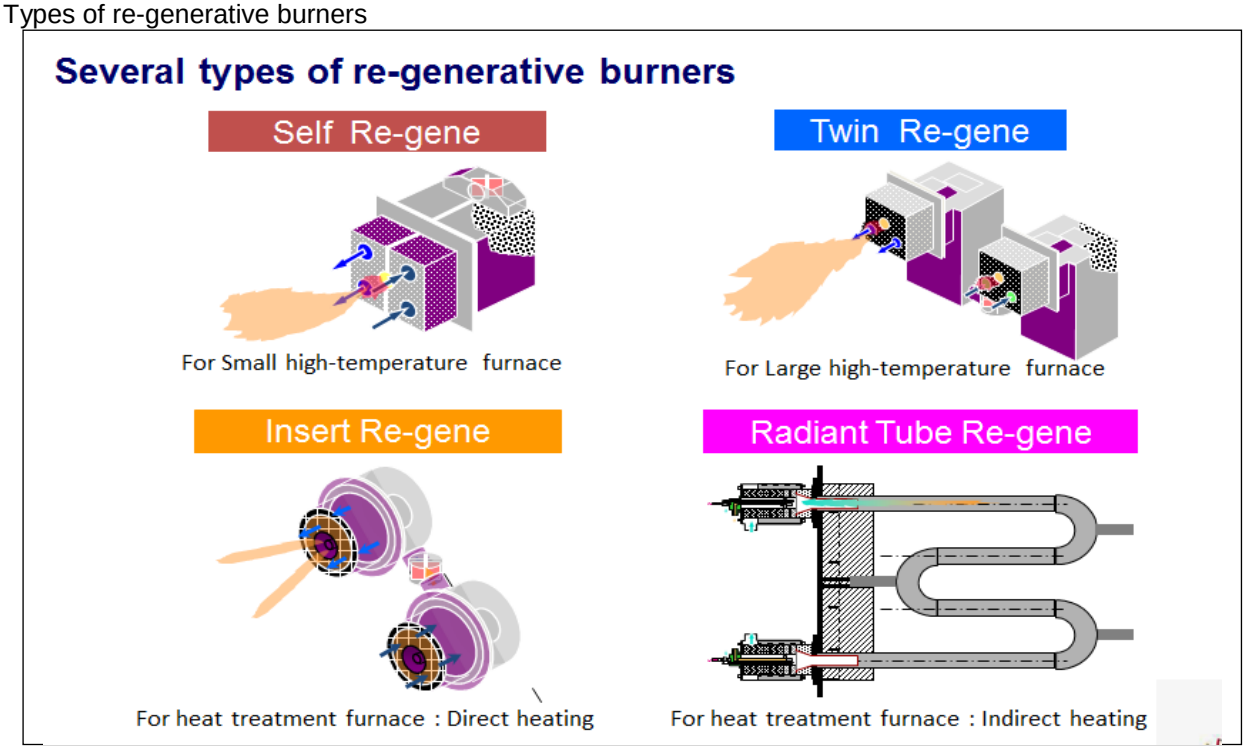


Fig.11 Types of regenerative burner

2) The energy-saving effect by the regenerative burner system

For energy saving of high temperature field, the heat recovery of exhausted gas is indispensable.

The heat exchanger made of stainless steel, of which installation cost is low, is used in the temperature range from 800 degree C to 900 degree C, and in the temperature range over 1000 degree C, regenerative burner system is to be used.

In the temperature range of more than 1000 degree C, energy saving of 30-50% can be achieved by adopting regenerative burner system shown as Fig.11.

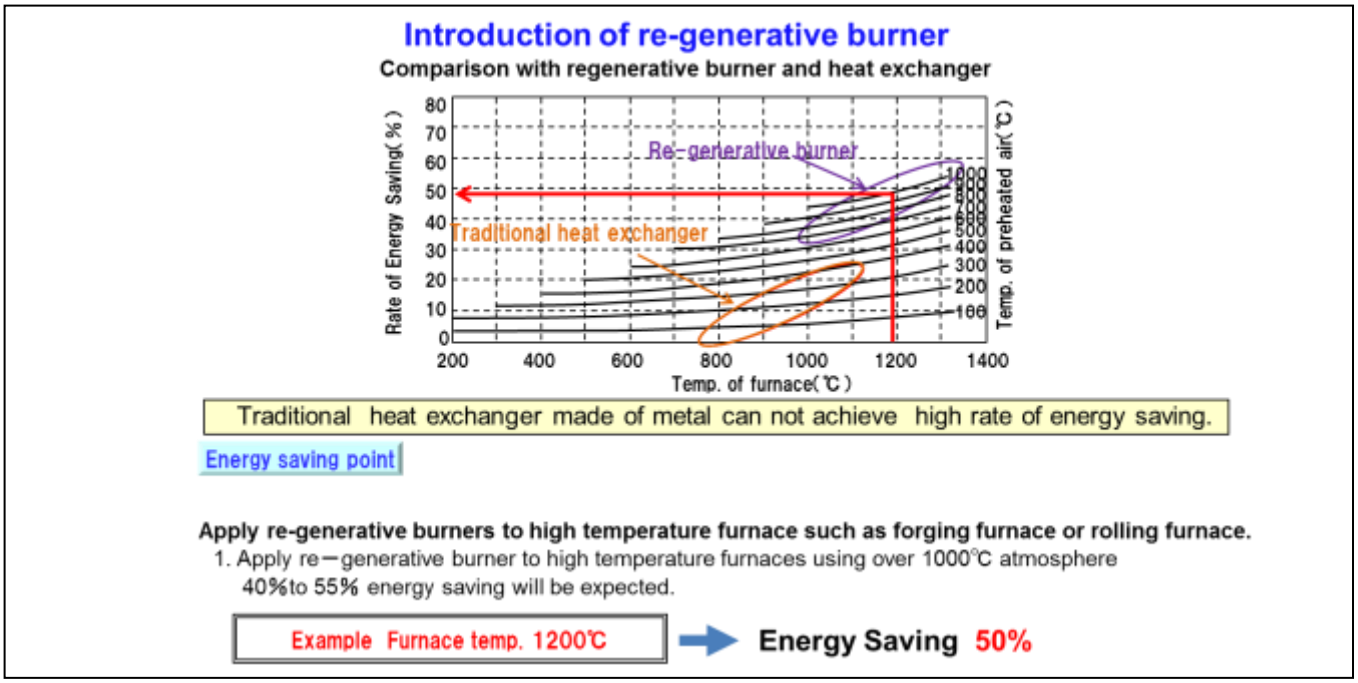


Fig.12 Energy saving effect of introduction of regenerative burner system

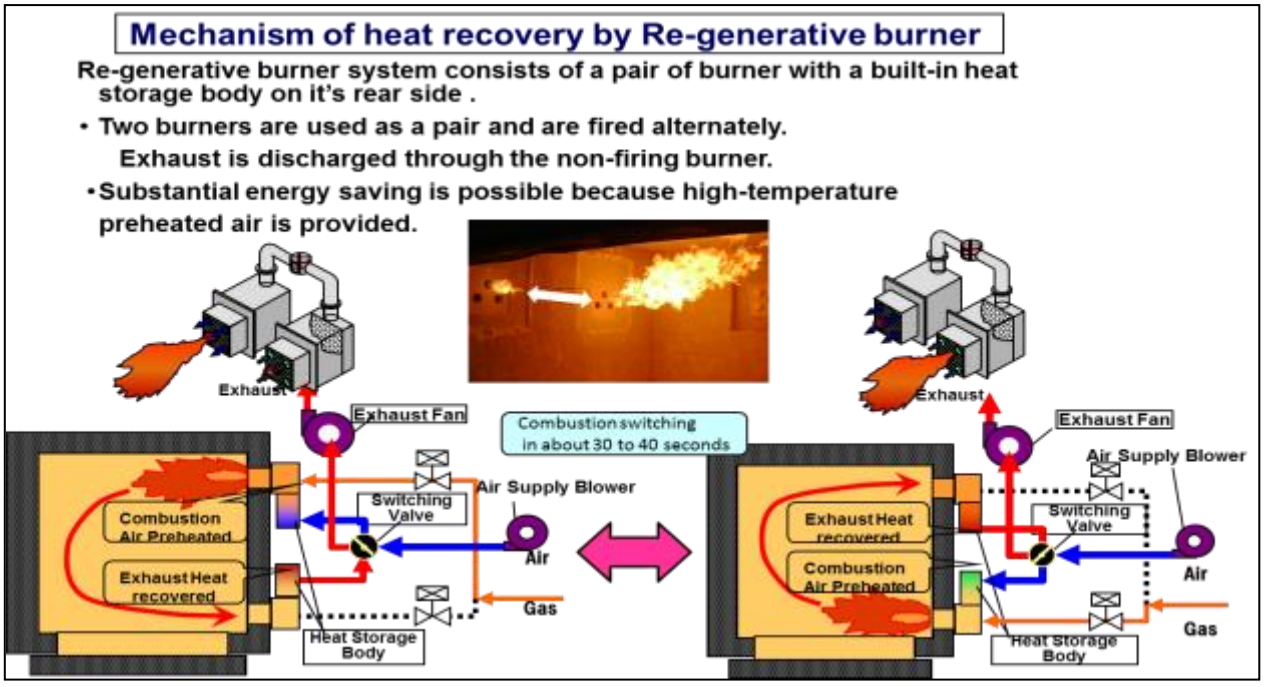


Fig.13 Mechanism of regenerative burner system

As shown in Figure 13, the heating system is basically composed by a pair of burners, and each burner has a box which contains the heat storage material made of ceramic.

While one of the two is burning, another burner plays the role of waste heat recovery.

The heat storage material recovers waste heat from the exhaust gas. As the result, the temperature of the exhausted gas at the inlet of the heat storage material is about the same temperature of the inside of the furnace temperature, but the temperature of the exhausted gas at the outlet of the heat storage material is around 200 degree C to 300 degree C.

After about 30 seconds, the direction of the combustion air supply valve is changed, then outside fresh air is introduced to the heat storage body which recovered waste heat, heated more than 1000 degree C, and supplied to the burner nozzle.

3. Changing process or system associated with the natural gas conversion

If an industrial customer has a high efficient oil- fired boiler, simple fuel switching is very difficult, especially in the county where natural gas is imported as LNG and gas price is very high. In this case the changing process is the effective solution to carry out fuel switching from oil to natural gas.

For example, in a textile drying industry, the customers use oil-fired steam boilers and generated steam and using this steam to generate hot air by heat exchanger for drying textile.

In this case, simple fuel switching such as only replacing oil-fired boiler to gas fired boiler is very difficult due to the efficiency of the oil fired boiler and gas fired boiler are not so different. In this case, changing indirect heating to direct heating is very effective to take the advantage of natural gas. Because exhaust gas of oil fired burner is dirty and contains high level of NOx or SOx and a little particulate material such as soot, on the other hand, exhaust gas of natural gas is very clean, so it is possible to generate hot air using this exhaust gas directly. In case of indirect heating system which uses oil boiler to produce steam and hot air produce by such steam, there are many points to create losses during the system flow; such as drain loss, heat exchanger loss and so on. On the other hand, direct heating system is quite simple and there is no chance to create heat loss. This changing process from an indirect hot air generation system to direct hot air drying, it is possible to reduce the energy consumption by around 30-50%. Changing the process can create more benefit to customers such as reducing labor costs due to free from boiler management or maintenance work and improving productivity because of increased hot air temperature.

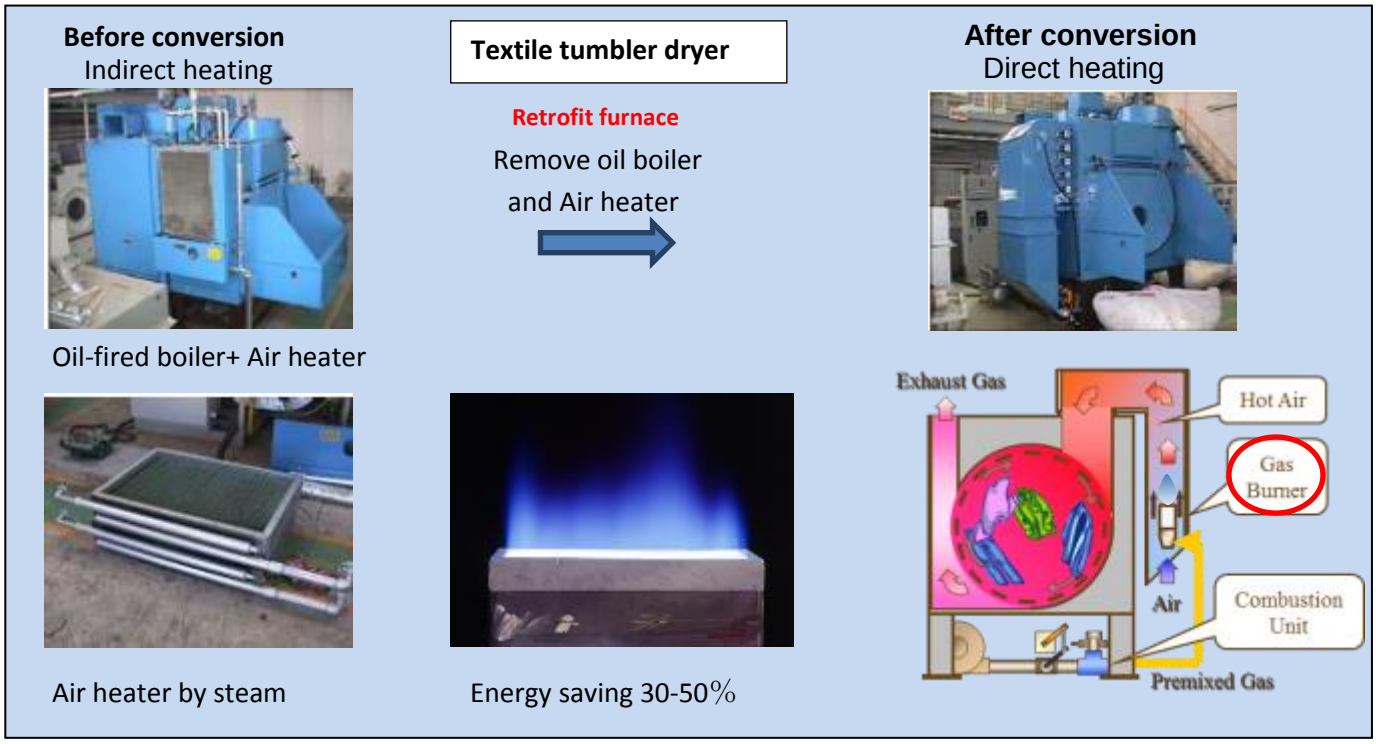


Fig. 14 changing process

## Conclusions

Natural gas is the cleanest fuel among all fossil fuels and relatively cheaper than oil, however the share of natural gas in the industrial sector is about 20% in the world (See in Fig.2) and 32% in the OECD countries. Promotion of natural gas in the industrial sector is the most effective measure for the prevention of global warming, but the share of natural gas is not quite increased because there are several obstacles to its widespread use.

Probably the most significant obstacle for promoting natural gas in the industrial sector is the lack of infrastructure of gas supply. Even in the OECD countries, the power plant or the factories that use gas in the industrial sector, are concentrated in the area near a gas supply trunk pipeline network, introduction of natural gas to the factories in the area without a gas pipeline network has been delayed. Industrial customers in the area without a gas pipe line network still use oil, electricity or coal. Since the construction cost of gas supply pipeline is huge, industrial customers can bear the cost of the modification of furnaces and changing burners, they cannot bear the cost for gas supply to their factories normally. Although a lot of governments offer great support to renewable energy introduction in many cases, but there is few support by governments for the construction of natural gas pipeline network for the industrial customers and power plant. It seems that natural gas conversion will be further accelerated if the government support for the construction of pipeline network to the factories in the industrial sector or power plant and CO2 emission will be most effectively decreased.

The second obstacle is the high auxiliary equipment cost compared to oil and electricity. Since energy density of gas is low as compared with oil, fuel supply pipe to the burner and fuel shut valve, etc. become larger. Moreover, safety standards for gas furnace are stricter than that of oil, they require measures at the time of ignition, fuel leakage measures from pipes, safety valves and so on, and then total equipment cost for the gas furnace is higher than that of oil. For the same reason, total equipment cost for the gas furnace is very higher than that of electric furnace. The electric furnace basically emits no exhaust gas, so there is a merit that the duct and chimney for an exhaust gas is unnecessarily or very small for the electric furnace. For the electric furnace, it is not necessary to equip the safety devices such as flame detector and ignition device.

The third obstacle is severe gas emission regulations. First one is the regulation for CO2 emission. In some countries, the national government or the local government has made a request for the big factories to reduce CO2 emission, and in accordance with this request, some companies change the fuel from gas to electricity. Second one is the regulation for Nox. In some countries, especially in the developed countries, the national government or local government enacts the law about total amount of NOx emission from all furnaces of the big factories in a big city or its neighborhood. For this reason, in some cases, this regulation is the major obstacles to carry out fuel switching from

electricity to natural gas. Furthermore, the regulation for NOx value itself has been an obstacle at the time of carrying out. When carrying out fuel switching from oil to natural gas, there is also a case which cannot adopt a re-generative burner or heat exchanger, for the reason of this severe regulation of NOx value itself. It is known well that a NOx emission value will go up if combustion temperature goes up from the combustion theory. Then, with its high combustion temperature, NOx emission value of the re-generative low NOx burner is higher than that of traditional low NOx burner. But actually, total amount of NOx emission is reduced, thanks to the massive energy saving and reducing total exhausted gas by adopting re-generative burner system.

- **Government Support**

Toward 2030 or 2050, in the power sector, in order to reduce CO2 emission drastically, it is necessary to increase the natural gas-fired power plant by CCGT. For this reason, national government support for the gas pipe line laying is essential, such as strong support to the acquisitions of land for gas pipeline laying and the establishment of subsidy. For the industrial sector, due to the globalization, there is a competition between countries to invite factories and strong environmental regulations could be the disadvantage. It is necessary to reduce the gas emissions, however, for natural gas, the most environmental friendly fossil fuel, it is also unavoidable for natural gas to emit gas from its combustion. So it is necessary for governments not only to restrict the emission by the regulation but also to encourage reducing the emission by subsidies of tax incentives.

## For our future

There is no doubt that natural gas has the lowest impact on the global environment among the fossil fuels, however, it is not the perfect reason for natural gas to take the major share of the energy used in the industrial sector. There are some obstacles for natural gas to enhance its share; such as necessity of huge infrastructure, high equipment costs, or restriction for gas emissions. However, looking at from the different angle, it is also true that there are room for natural gas to increase its share and potential to contribute to prevent the global warming.

In order to do so, natural gas needs to replace oil, electricity or coal in the industrial sector; the "Fuel Switching".

In this paper, it is shown that the reason why the fuel switching is necessary, how the fuel switching can be realized and technologies for the fuel switching with case studies. Even there are obstacles, there are ways to overcome them and it is our duty to continue to enhance the usage of natural gas in the industrial sector for our industry, our society and our planet.

We hope this paper can be a help to accelerate the fuel switching, then improve our environment.

## References

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