Energy Balance of Global CO_2 Recycling and Amounts of Reduction of CO_2 Emission

Sci. Rep. RITU A43 (1997) pp. 153-160
No. 2, March 1997

Energy Balance of Global CO_2 Recycling and Amounts of Reduction of CO_2 Emission*

K. Hashimoto[a], E. Akiyama[a], H. Habazaki[a], A. Kawashima[a], M. Komori[b], K. Shimamura[b] and N. Kumagai[c]

a *Institute for Materials Research, Tohoku University, Sendai, 980-77 Japan*
b *Mitsui Engineering & Shipbuilding Co., Ltd., 1 Yawatakaigan-Dori, Ichihara, Chiba, 290 Japan*
c *Daiki Engineering Co., Ltd., 11 Shintoyofuta, Kashiwa, Chiba, 277 Japan*

(Reseived January 22, 1997)

On the basis of tailoring of amorphous alloy electrodes for seawater electrolysis to form H_2 and amorphous alloy catalysts for conversion of CO_2 to CH_4, we are proposing global CO_2 recycling: At deserts; power generation by solar energy, at coasts close to the deserts; production of H_2 by electrolysis of seawater, production of CH_4 by the reaction of H_2 and CO_2 transported, and at energy consuming districts; combustion of CH_4, recovery of CO_2 and transportation of liquefied CO_2 to the coast close to the deserts. Since Egyptian scientists agree with us to do collaboration, the energy balance and the amount of reduction of CO_2 emission in the global CO_2 recycling between Middle East and Japan are estimated for the operation of a 1 GW CH_4-combustion power plant. The energy consumed in a year up to liquefaction of CH_4 including that corresponding to the repayment of solar power plant is almost the same as that spent up to obtaining LNG. The energy necessary for the global CO_2 recycling is only 8.7% higher than the energy necessary for LNG combustion for power generation without control of CO_2 emission. The extra energy is for recovery, liquefaction and transportation of CO_2. The reduction of CO_2 emission by the global CO_2 recycling is 79% of CO_2 emission from an LNG combustion power plant, that is, 2.62 Mtons/year.

KEYWORDS Global CO_2 recycling, CO_2, CH_4, electrode, catalyst, global warming, energy supply

1. Introduction

CO_2 emission increases with development of economy. In order to avoid global warming recovery of CO_2 at fixed CO_2 emission sources will be requested particularly in developed countries. In addition, we will have to face to energy shortage in the 21st Century.

In order to avoid global warming and to supply abundant energy the authors have tailored amorphous alloy electrodes for seawater electrolysis[1-4] and catalysts[5,6] for methanation of CO_2, and are proposing global CO_2 recycling[7,8]. The global CO_2 recycling is schematically shown in Fig. 1. Electricity is generated at deserts from solar energy, sent to the coasts close to the deserts and used for production of H_2 by electrolysis of seawater. H_2 thus produced is used for conversion of recovered CO_2 into CH_4. CH_4 is liquefied and sent to energy consumers. After combustion of CH_4, the energy consumers recover CO_2 and send liquefied CO_2 to the coasts close to the deserts. Consequently, energy consumers use solar energy on deserts in the form of CH_4 and do not emit CO_2 into atmosphere. For substantiation of this idea the global CO_2 recycling plant was constructed on the roof of the Institute for Materials Research, Tohoku University in 1996 using amorphous alloy electrodes and catalysts.

For realization of the global CO_2 recycling, the energy balance has been studied in the present paper. The global CO_2 recycling is supposed to be carried out between Middle East and Japan, because collaboration is being discussed with Egyptian scientists and politicians.

2. CH_4-Combustion Power Plant in Japan

Assumptions made are that a CH_4-combustion power plant of 1 GW is operated with 39% efficiency and that the rate of operation in a year is 75%.

The generating power is 6.57×10^9 kWh/year (1)

The energy of CH_4 = 13,183 kcal/kg. (2)

The necessary amount of CH_4 for the operation of the power plant for 1 year and the total energy input for the power plant are:

the weight of CH_4 for 1 year = 1,099,521 tons (3)

the total energy input for the power plant = 14,494 Tcal/year. (4)

3. Solar Cell Power Plant

*IMR, Report No.2073

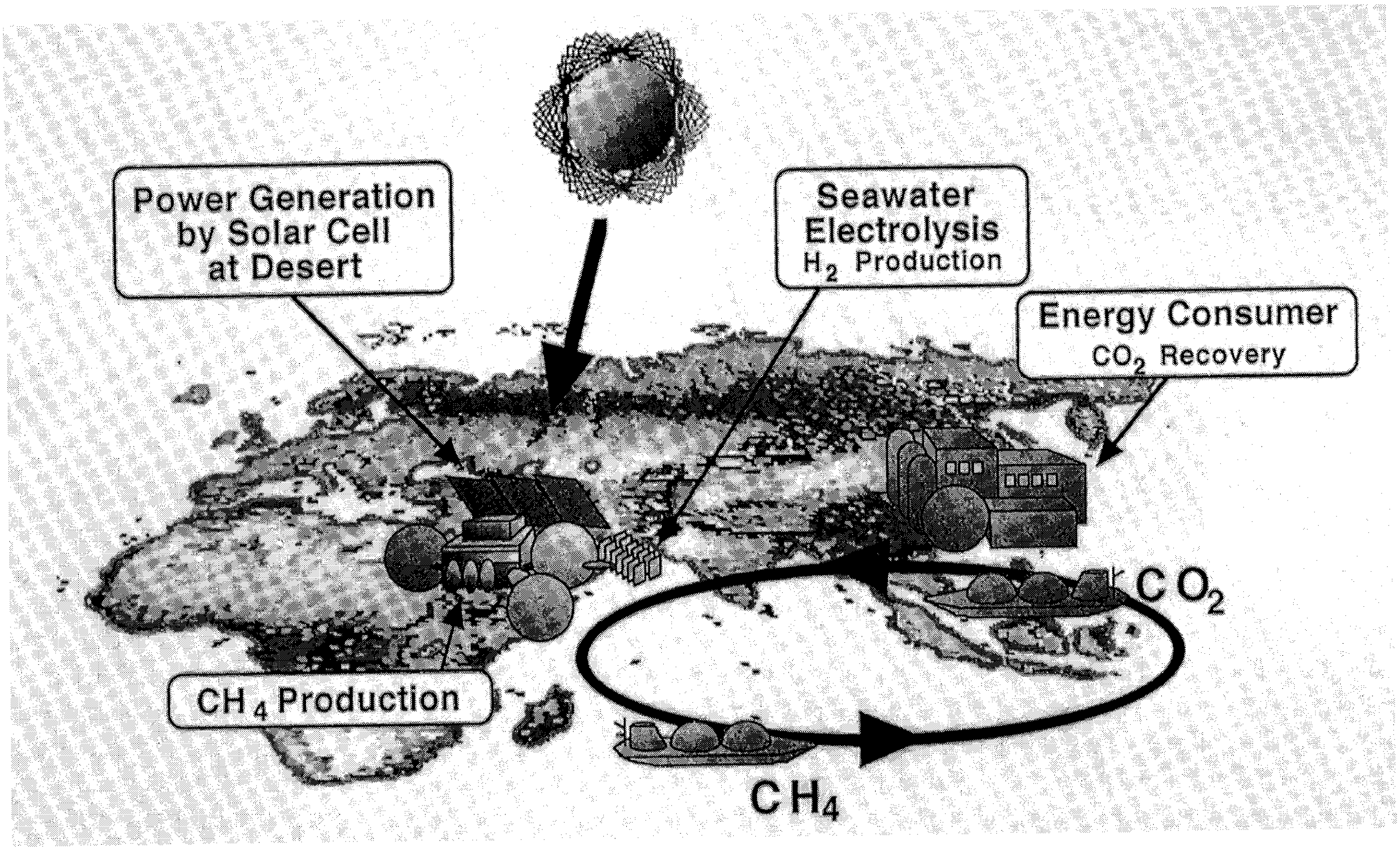

Fig. 1 Global CO_2 recycling

When solar cells are operated for 3,000 h/year at a desert and if 100% of power generated is converted to CH_4, the necessary size of the solar power plant is

$$(1{,}099{,}521 \text{ ton}/3000/3600) \times 13{,}183 \times 4.184 = 5.61538 \text{ GW} \quad (5)$$

When the conversion of the electricity to CH_4 is 50, 70 and 90%, the necessary sizes of the solar cell power plant are:

$$5.61538 \text{ GW}/0.5 = 11.23 \text{ GW} \quad (6)$$
$$5.61538 \text{ GW}/0.7 = 8.022 \text{ GW} \quad (7)$$
$$5.61538 \text{ GW}/0.9 = 6.239 \text{ GW} \quad (8)$$

The energy balance for 0.01, 1 and 100 GW solar cell power plants made of amorphous and polycrystalline silicon has been reported by the Society of Chemical Engineers, Japan[9]. For the global CO_2 recycling the DC/AC inverter is not necessary. Using the published data[9], after subtraction of the energy for the DC/AC inverter, the total energy inputs for construction of solar cell power plants are obtained and are shown in Table 1. The total energy inputs for construction of a solar power plant with sizes shown in eqs. (6)-(8) were estimated by interpolation of values shown in Table 1. When the repayment periods of the power plant are assumed as 20 and 30 years, the average energy input in a year and its fraction to the generating power of the 1 GW CH_4-combustion power plant in a year are shown in Table 2.

4. Energy Input for Building of Various Plants

The calculation of the energy input for building of various plants is carried out following the procedures described in literatures[9-11]. Heat rates of energy sources and energy consumption rates of production of raw materials are given in the literatures[10,11], and are summarized in Tables 3 and 4. Following the report[10], the total energy consumption for building of a plant is estimated from the energy consumption for production of raw materials on the basis of assumption that the energy consumption for the production, construction and transportation of a plant is an increase of 20% over the energy consumption for production of raw materials, and that further 30 % increase is required for necessary equipments for operation of the plant, Accordingly, the total energy consumption is generally (the energy consumption for production of raw materials)/0.8/0.7.

4-1 Electrolysis Plant

On the basis of the data of the plant which we built for substantiation of our idea of the global CO_2 recycling, raw

Table 1 Total energy input for construction of solar cell power plants (kWh)

Size of plant	0.01GW	1GW	100GW
Polycrystalline silicon plant	4.84×10^7	3.44×10^9	2.75×10^{11}
Amorphous silicon plant	5.43×10^7	3.03×10^9	2.53×10^{11}

Table 2 The average energy input in a year for construction of an amorphous silicon solar cell plant and its fraction to the generating power of the 1 GW CH_4-combustion power plant in a year

Size of plant	11.23GW	8.022Gw	6.239GW
Total energy input (kWh)	3.183×10^{10}	2.338×10^{10}	1.857×10^{10}
Total energy input/20 years (kWh/year)	1.591×10^{9}	1.169×10^{9}	9.283×10^{8}
Fraction	0.2422	0.1779	0.1412
Total energy input/30 years (kWh/year)	1.061×10^{9}	7.793×10^{8}	6.189×10^{8}
Fraction	0.1615	0.1186	0.0942

Table 3 Heat rares of energy sources

	Energy	Literature
Electricity	2,250 kcal/kWh	10
CH_4	13,183 kcal/kg	eq. (2)
Petroleum	10,000 kcal/kg	10

Table 4 Energy consumption rates of raw matereials

	Energy(Mcal/ton)	Literature
Iron	6,125	10
Aluminum	50,375	10
Stainless steel	12,250	10
Concrete	209	10
Poly ethylene	10,900	11

materials for building of the electrolytic cells to produce H_2 necessary for production of CH_4, the amount of which is shown in eq. (3), are 9.155×10^4 tons of polyethylene and 3.660×10^4 tons of stainless steel, and hence the energy consumption including that of necessary equipments is 2,066 Tcal. If the repayment period is 20 years, the average energy input in a year and its fraction to the total energy input for the 1 GW CH_4-combustion power plant in a year shown in eq. (4) are :

2,066 Tcal / 20 = 103.30Tcal/year (9)

103.30 / 14,500 = 7.13×10^{-3} = 0.713% (10)

4-2 CH_4 Production Plant

For conversion of H_2 produced in the electrolysis plant into CH_4, the construction of the reactor requires 152 tons of Type 316 stainless steel, and the total energy consumption is 3.325 Tcal. If the repayment period is 20 years, the average energy input in a year and its fraction to the total energy input for the 1 GW CH_4-combustion power plant in a year are :

3.325 Tcal / 20 = 0.16625 Tcal/year (11)

0.16625 / 14,500 = 1.147×10^{-5} = 0.001147% (12)

4-3 1 GW CH_4-Combustion Power Plant

The energy input for the construction of an LNG-combustion power plant is reported in the literature[10]. The construction of the power plant requires 41,130 tons of steel, 230 tons of aluminum and 71,270 tons of concrete, and hence the total energy consumption is 606.53 Tcal. If the repayment period is 30 years, the average energy input in a year and its fraction to the total energy input for the 1 GW CH_4-combustion power plant in a year are :

606.53 Tcal / 30 = 20.218 Tcal/year (13)

20.218 / 14,500 = 1.395×10^{-3} = 0.1395% (14)

5. Energy Balance for Liquefaction of CH_4

The energy required for liquefaction of CH_4 is equal to the sum of the energy necessary for cooling of CH_4 from ambient temperature (25°C) to the boiling point (-161°C), that is, 0.72 kcal/mole and the heat of evaporation of liquid CH_4 at -161°C, that is 2.0 kcal/mole[12]. Consequently,

the energy required for liquefaction of CH_4
= 2.72 kcal/mole (15)

The heat of sublimation of solid CO_2 at -78°C and 1 atm is 6.03 kcal/mole, and the heat of melting of solid CO_2 at -56°C and 5 atm is 1.99 kcal/mole[12]. From the difference the heat of evaporation of liquid CO_2 at -56°C and 5 atm is 4.04 kcal/mole. The sum of this value and the energy necessary for cooling of CO_2 gas from ambient temperature (25°C) to -56°C, that is, 0.55 kcal/mole yields the energy required for liquefaction of CO_2.

The energy required for liquefaction of CO_2
= 4.59 kcal/mole (16)

In our global CO_2 recycling, the heat of evaporation of liquid CO_2 sent by energy consumers after recovery and liquefaction can be used for liquefaction of CH_4. Consequently, the energy required for liquefaction of CH_4 using the heat of evaporation of liquid CO_2 is

$$2.27 - 4.59 = -1.87 \text{ kcal/mole} \quad (17)$$

Accordingly, if the heat of evaporation of liquid CO_2 is used for liquefaction of CH_4, liquefaction of CH_4 requires no extra energy, and the excess energy can be utilized for another purpose.

The excess energy in a year = -127.38 Tcal/year (18)
The fraction = - 8.788×10^{-3} = -0.8788% (19)

6. Energy Required up to Liquefaction of CH_4 in the Global CO_2 Recycling and Natural Gas

Liquefied natural gas (LNG) consists mostly of CH_4 and liquefied CH_4 (LCH_4) can be used in the same manner as LNG. Accordingly, a comparison of energy inputs for production of LCH_4 and LNG is performed. An estimation was made for all the energy inputs from the construction of the solar cell power plant to liquefaction of the necessary amount of CH_4 for operation of the 1 GW CH_4-combustion power plant with the 39% efficiency and with the rate of operation of 75% in a year. The energy efficiency for electrolysis of pure water by using the solid polymer electrolyte is assumed as 80-90%[13,14]. About 22% of the energy of H_2 is consumed for production of CH_4 from H_2. The high efficiency in the electrolysis of pure water cannot be attained in seawater electrolysis in our global CO_2 recycling. Assuming 70% efficiency for conversion of electricity to CH_4, the energy inputs are calculated at the repayment periods of the amorphous silicon power plant of 20 and 30 years. The results are summarized in Tables 5 and 6.

When the repayment periods of the amorphous silicon power plant are 20 and 30 years, the energy input for production of LCH_4 are 17.8 and 11.7% of the energy input for operation of the 1 GW CH_4-combustion power plant in Japan. On the other hand, the energy input of production of LNG is known as 10-15%[10].

Consequently, if liquefied CO_2 is transported to the coast close to the desert from energy consuming districts, the price of LCH_4 is almost the same as that of LNG.

7. LCH_4 Tanker

7-1 Building of LCH_4 Tanker

A liquefied CH_4 (LCH_4) tanker is the same as an LNG tanker. The energy input for the LNG tanker is reported in the literature[10], and hence after a small modification the estimation of the energy input can be done. The capacity of an LCH_4 tanker is 125,000 m^3 and 53,125 tons. Building of an LCH_4 tanker requires 21,400 tons of steel, 600 tons of stainless steel and 3,000 tons of aluminum, and hence the energy consumption for the building of a tanker including that of necessary equipments is 361.9375 Tcal. The speed of the LCH_4 tanker is 20 knots, and the distance between Middle East and Japan is about 10,300 km. It takes less than 24 days for a round trip, and 15 round trips can be done in a year. Necessary are 1.3798 LCH_4 tankers. If the repayment period is 20 years, the average energy input in a year and its fraction to the total energy input for the 1 GW CH_4-combustion power plant are :

$$361.94 \text{ Tcal} \times 1.3798 / 20 = 24.970 \text{ Tcal/year} \quad (20)$$
$$24.970 / 14{,}500 = 1.722 \times 10^{-3} = 0.1722\% \quad (21)$$

7-2 Fuel Consumption by LCH_4 Tanker

According to the literature[10], an LNG tanker for transportation of 1 ton of LNG for 1,000 nautical mile consumes 1.5 kg of petroleum and 7.6 kg of LNG boiled off. The total energy consumption for transportation of LCH_4 in a year and its fraction to the total energy input for the 1 GW CH_4-combustion power plant in a year are :
the total energy consumption for transportation
= 1,409.3 Tcal/year (22)

Table 5 The energy input for production of LCH_4 using electricity generated by an amorphous silicon solar cell plant at a desert and its percent to the total energy input for the 1 GW CH_4-combustion power plant. The repayment period of the amorphous silicon power plant is assumed as 20 years.

	Energy input	Energy%
Amorphous silicon solar cell plant	1.169×10^9 kWh/year (2,578 Tcal/year)	17.79
Electrolysis	103.3 Tcal/year	0.713
Production of CH_4	0.166 Tcal/year	0.011
Liquefaction of CH_4	-127.4 Tcal/year	-0.879
Total	2,554 Tcal/year	17.64

Table 6 The energy input for production of LCH_4 using electricity generated by an amorphous silicon solar cell plant at a desert and its percent to the total energy input for the 1 GW CH_4-combustion power plant. The repayment period of the amorphous silicon power plant is assumed as 30 years.

	Energy input	Energy%
Amorphous silicon solar cell plant	7.793×10^8 kWh/year (1,719 Tcal/year)	11.86
Electrolysis	103.3 Tcal/year	0.713
Production of CH_4	0.166 Tcal/year	0.011
Liquefaction of CH_4	-127.4 Tcal/year	-0.879
Total	1,695 Tcal/year	11.71

$$1{,}409.3 / 14{,}500 = 9.730 \times 10^{-2} = 9.730\% \quad (23)$$

8. Energy for Liquefaction and Transportation of Recovered CO_2

8-1 Energy for Liquefaction of Recovered CO_2

Liquefaction of CO_2 recovered at fixed CH_4 combustion plants is necessary. In CH_4-combustion plants the heat of evaporation of LCH_4 can be used for liquefaction of CO_2. As shown in eqs. (15) and (16) the energies required for liquefaction of CH_4 and CO_2 are 2.72 and 4.59 kcal/mole, respectively. Thus, the energy necessary for liquefaction of CO_2 using the heat of evaporation of LCH_4 is :

$$4.59 - 2.72 = 1.87 \text{ kcal/mole} \quad (24)$$

Since the total molar amount of CO_2 formed in a year is the same as that of CH_4 consumed, the total amount of CO_2 formed in a year at the 1 GW CH_4-combustion power plant is 6.8155 x 10^{10} mole. The total energy input in a year for liquefaction of CO_2 and its fraction to the total energy input for the 1 GW CH_4-combustion power plant in a year are :

$$1.87 \text{ kcal/mole} \times 6.8155 \times 10^{10} \text{ mole/year} = 127.38 \text{ Tcal/year} \quad (25)$$

$$127.38 / 14{,}500 = 8.79 \times 10^{-3} = 0.879\% \quad (26)$$

If the heat of evaporation of LCH_4 is not utilized, the energy required is 2.45 times larger than that given in eq. (25).

8-2 Building of LCO_2 Tanker

A liquefied CO_2 (LCO_2) tanker transports LCO_2 at -56°C and 5 atm. This condition is similar to that of an LPG tanker, and hence the energy consumption is estimated similarly to the LPG tanker. The capacity of an LCO_2 tanker is 22,000 m^3 and 25,500 tons. Building of an LCO_2 tanker uses 9,000 tons of steel. The energy consumption including that of necessary equipments is 68.906 Tcal.

The total amount of CO_2 formed

$$= 3{,}003{,}826 \text{ tons/year} \quad (27)$$

The speed of the LCO_2 tanker is 15 knots. It takes 31 days for a round trip between Middle East and Japan, and 11 round trips can be done for 341 days in a year. Necessary are 10.710 LCO_2 tankers. If the repayment period is 20 years, the average energy input in a year and its fraction to the total energy input for the 1 GW CH_4-combustion power plant in a year are :

$$68.906 \text{ Tcal} \times 10.710 / 20 = 36.898 \text{ Tcal/year} \quad (28)$$

$$36.898 / 14{,}500 = 2.546 \times 10^{-3} = 0.255\% \quad (29)$$

8-3 Fuel Consumption by LCO_2 Tanker

Petroleum consumption by an LCO_2 tanker is assumed as 45 kg/km. The total petroleum consumption in a year is :

$$10.710 \times 11 \times 20{,}600 \times 45 = 1.0925 \times 10^5 \text{ tons/year} \quad (30)$$

The total energy consumption for transportation of LCO_2 in a year and its fraction to the total energy input for the 1 GW CH_4-combustion power plant in a year are :

$$1.0925 \times 10^5 \text{ tons/year} \times 10{,}000 \text{ kcal/kg} = 1092.5 \text{ Tcal/year} \quad (31)$$

$$1092.5 / 14{,}500 = 7.537 \times 10^{-2} = 7.537\% \quad (32)$$

8-4 Energy for Liquefaction and Transportation of Recovered CO_2

In order to avoid CO_2 emission into atmosphere, recovery, liquefaction and transportation should be done. When the global CO_2 recycling is performed between Middle East and Japan, the total energy for liquefaction and transportation of recovered CO_2 is summarized in Table 7.

9. A Comparison of Energies between Global CO_2 Recycling and LNG Combustion

From above data total energy inputs can be estimated. Fig. 2 shows the comparison of the energy inputs between global CO_2 recycling and LNG combustion in a 1 GW power plant in a year. The energy inputs for production of LNG are taken as 12.5 and 15% of the energy input for the operation of the 1 GW CH_4-combustion power plant in Japan. For the global CO_2 recycling the repayment periods of the solar power plant are assumed as 20 and 30 years.

The energy input in the global CO_2 recycling between Middle East and Japan up to power generation by combustion of CH_4 is almost the same as that in the LNG plant. The extra costs are CO_2-recovery, liquefaction and transportation to the coast close to the desert. The cost for CO_2-transportation to the coast close to the desert comprises 87% of the extra cost. In both the global CO_2 recycling and LNG fuel, energies required up to liquefaction of CH_4, for building of LCH_4 tankers, for transportation of LCH_4 by tankers, and for building of a 1 GW CH_4-combustion power plant are necessary in addition to the energy of CH_4 for power generation, that is, 14,494 Tcal/year.

$$1{,}695 + 24.970 + 1{,}409.3 + 20.218 + 14{,}494 = 17{,}643 \text{ Tcal/year} \quad (33)$$

The rate of extra cost is:

$$1{,}256.70 / 17{,}643 = 0.0712 = 7.12\% \quad (34)$$

Consequently, the extra cost required for the global CO_2 recycling in comparison with LNG combustion without recovery of CO_2 is about 7%. This amount of cost may be covered by the government subsidy from the carbon tax.

10. CO_2 Emission

Combustion of 1 litter of petroleum emits 1400 liters of CO_2 and the density of petroleum is assumed as 0.925.

10-1 CO_2 Emission in 1 GW CH_4-Combustion Power Plant

The total CO_2 emission in 1 GW plant is already given in eq. (27) as 3,003,826 tons/year.

10-2 CO_2 Emission in Transportation of LCH_4 by LCH_4 Tanker

Petroleum and CH_4 consumption for transportation of CH_4 by tankers are described in 7-2. The CO_2 emissions by combustion of petroleum and CH_4 are= 5.4684×10^4 and 2.54029×10^5 tons/year, respectively. Accordingly,

the total CO_2 emission by LCH_4 tankers

$$= 308{,}712 \text{ tons/year} \qquad (35)$$

Table 7 The total energies required for liquiefaction and transportation of CO_2 recovered in a year from the 1 GW CH_4-combustion power plant operated with 39% efficiency and 75% operation rate and its percent to the total energy input for the power plant in a year

	Energy input	Energy%
Liquefaction of CO_2	127.38 Tcal/year	0.879
Building of LCO_2 tankers	36.90 Tcal/year	0.255
Fuel consumption by LCO_2 tankers	1092.43 Tcal/year	7.537
Total	1256.70 Tcal/year	8.670

10-3 CO_2 Emission in Transportation of LCO_2 by LCO_2 Tanker

As shown in eq. (30), petroleum consumption by LCO_2 tankers is 1.0925×10^5 tons/year. Hence,

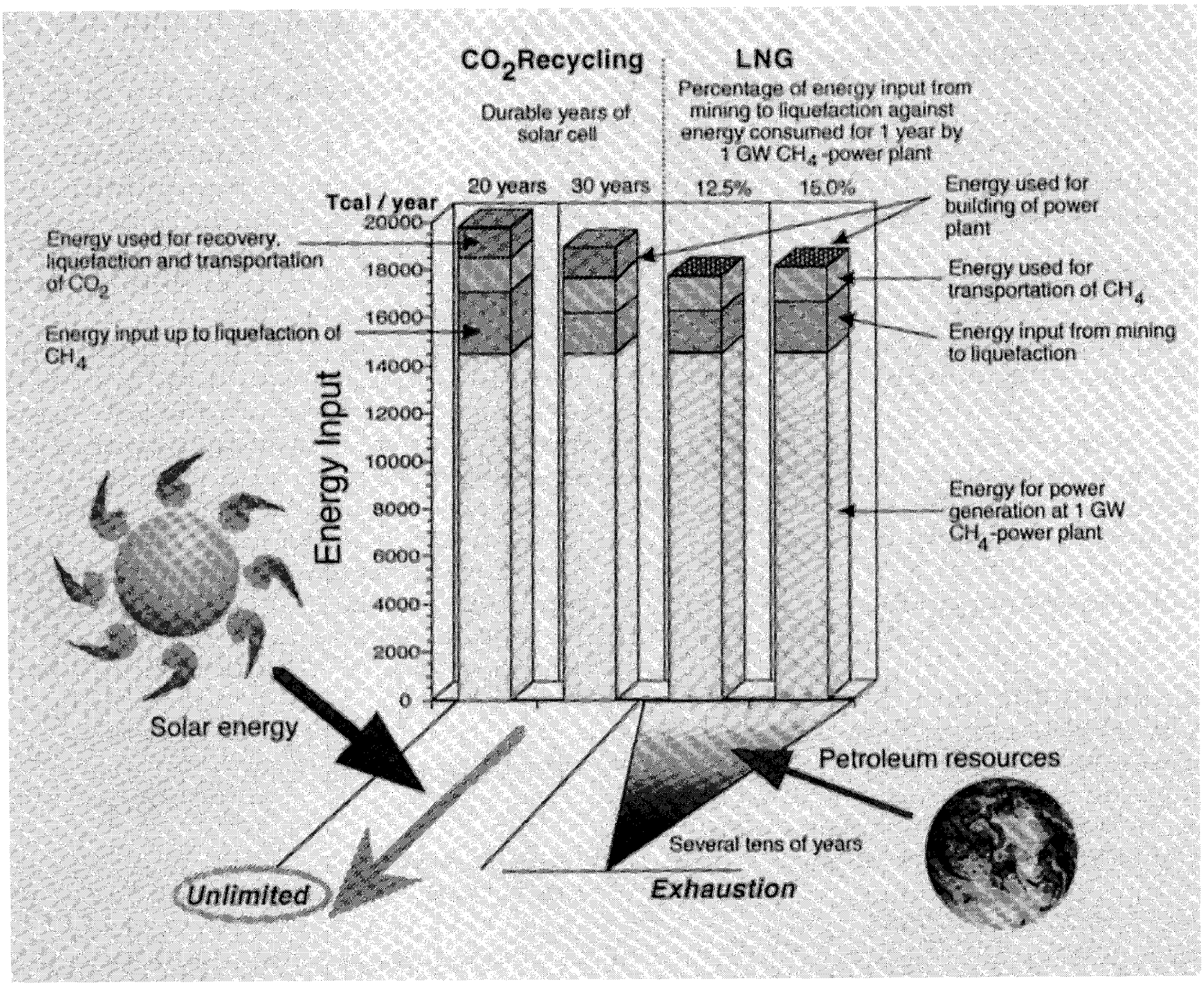

Fig. 2 A comparison of the energy inputs between global CO_2 recycling and LNG combustion in a 1 GW power plant.

Table 8 CO_2 emission for 1 year in the global CO_2 recycling between Middle East and Japan for a 1 GW CH_4-combustion power plant in Japan

	CO_2 emission tons/year	%
Emission estimated from energy for building LCH_4 tankers	7,440	1.06
Emission during transportation of CH_4 by LCH_4 tankers	308,712	43.98
Emission estimated from energy for building of a 1 GW power plant	6,024	0.86
Emission estimated from energy for liquefaction of CO_2	37,954	5.41
Emission estimated from energy for building LCO_2 tankers	10,994	1.57
Emission during transportation of CO_2 by LCO_2 tankers	330,891	47.12
Total	702,016	100.00

Table 9 CO_2 emission for 1 year without emission control for a 1 GW LNG-combustion power plant in Japan

	CO_2 emission tons/year	%
Emission estimated from energy for building LNG tankers	7,440	0.22
Emission during transportation of CH_4 by LNG tankers	308,712	9.28
Emission estimated from energy for building of a 1 GW power plant	6,024	0.18
Emission at the power plant	3,003,826	90.32
Total	3,326,003	100.00

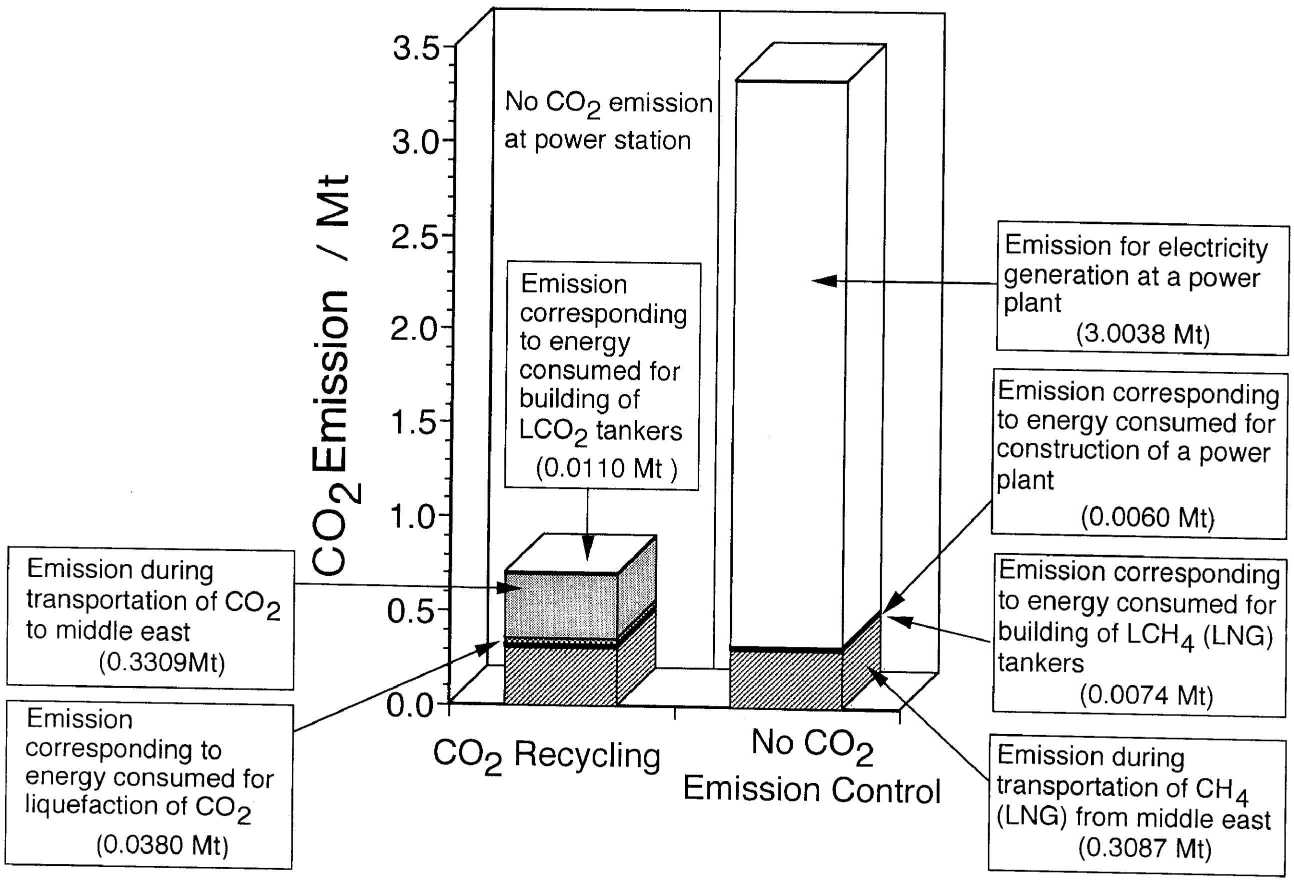

Fig. 3 A comparison of CO_2 emissions between global CO_2 recycling and LNG combustion in a 1 GW power plant.

the total CO_2 emission by LCO_2 tankers

$$= 330{,}891 \text{ tons/year} \quad (36)$$

11. The Effect of the Global CO_2 Recycling on Reduction of CO_2 Emission

The amount of reduction of CO_2 emission by the global CO_2 recycling between Middle East and Japan is calculated for 1 year operation of the 1 GW CH_4-combustion power plant. Extraction of natural gas at wells induces a large amount of CO_2 emission, but the data are not available. LNG and LCH_4 are essentially the same as each other. In this work a comparison is done for CO_2 emission after liquefaction of natural gas and CH_4. In this calculation an assumption was made that energies for building of plants and tankers are obtained by combustion of petroleum. Results are summarized in Tables 8 and 9.

When the global CO_2 recycling is performed, the reduction of CO_2 emission in a year and the percent reduction in comparison with the LNG combustion power plant are :

$$3{,}326{,}003 - 702{,}016 = 2{,}623{,}987 \text{ tons/year} \quad (37)$$

$$2{,}623{,}987 / 3{,}326{,}003 = 0.7889 = 78.89\% \quad (38)$$

Fig. 3 compares CO_2 emissions in 1 year operation of 1 GW CH_4-combustion power plant between the global CO_2 recycling and LNG combustion without CO_2 emission control.

In conclusion, the global CO_2 recycling for 1 year operation of 1 GW power plant results in reduction of 79 % of CO_2 emissions, that is, 2.62 Mtons in comparison with the LNG combustion power plant without CO_2 emission control.

12. Summary and Conclusion

The present authors are proposing the global CO_2 recycling shown in Fig. 1. Energy consumers can use solar energy on deserts in the form of CH_4 without emitting CO_2 into atmosphere. It is well known that the oil resources are limited. The life of the sun is estimated as five billion years. In order to solve energy problems in the world, the use of solar energy is strongly recommended. In order to avoid global warming, recovery and treatment of CO_2 will be required in the quite near future. The global CO_2 recycling can solve both problems of energy shortage and global warming.

In the present work the energy balance and amount of reduction of CO_2 in the global CO_2 recycling between Middle East and Japan are studied. The total energy for the operation of a 1 GW CH_4 combustion power plant for 1 year in the global CO_2 recycling is only 8.7% higher than that of the use of LNG for power generation without control of CO_2 emission.

In the practical global CO_2 recycling the recovery of CO_2 will be done near the plant for seawater electrolysis, since CO_2 transportation results in energy consumption and CO_2 emission. On the other hand, Solar Terminal Plant of 194 MW has been operating since 1984 at a desert in south California, in which solar light is focused by concave mirrors for heating an oil turbine to generate the electricity with the efficiency of indeed 22%[15]. As shown in equation (14) the average energy input in a year for 30 repayment years for construction of the 1 GW CH_4 combustion power plant is only 0.14% of the total energy input for the operation of the 1 GW CH_4 combustion power plant in a year. Even if the construction of a solar heat power plant in a desert consumes 10 times larger energy than that of the CH_4 combustion power plant, the energy cost will be significantly lower than that of the construction of a solar cell power plant. In conclusion, in the real global CO_2 recycling if a solar heat power plant is used at a desert and if CO_2 is recovered near the plant of seawater electrolysis, the energy consumption to obtain LCH_4 will be smaller than that to obtain LNG, and in the operation of a 1 GW CH_4 combustion power plant in a year we can reduce about 90% of CO_2 emission on the whole, that is, about 3 Mtons in comparison with a currently used LNG combustion power plant.

1) M. Hara, K. Hashimoto and T. Masumoto: Electrochim. Acta 25 (1980) 1215.
2) N. Kumagai, A. Kawashima, K. Asami and K. Hashimoto: J. Appl. Electrochem. 16 (1986) 565.
3) A. Kawashima, E. Akiyama, H. Habazaki and K. Hashimoto: Mater. Sci. Eng. (1997) in press.
4) K. Izumiya, E. Akiyama, A. Kawashima, K. Asami and K. Hashimoto: J. Appl. Electrochem. (1997) in press.
5) K. Wakuda, H. Habazaki, A. Kawashima, K. Asami and K. Hashimoto: Sci. Rep. RITU A38 (1993) 76.
6) K. Shimamura, M. Komori, H. Habazaki, T. Yoshida, M. Yamasaki, E. Akiyama, A. Kawashima, K. Asami and K. Hashimoto: Mater. Sci. Eng. (1997) in press.
7) K. Hashimoto: Kinzoku 63 [7] (1993) 5. (in Japanese)
8) K. Hashimoto: Mater. Sci. Eng. A179/A180 (1994) 2.
9) "Evaluation of Power Generation Technology by Solar Light" (Society of Chemical Engineers, Japan, 1993). (in Japanese)
10) Y. Uchiyama and H. Yamamoto: Economic Research Center Report No. Y90015, (Central Research Institute of Power Generation, Japan, 1991). (in Japanese)
11) Report of Investigation Committee of Natural Resources, the Science and Technology Agency, No.88 (1982). (in Japanese)
12) KAGAKUBINRAN, ed. Chemical Society of Japan (Maruzen, 1993). (in Japanese).
13) M. Yamaguchi, K. Yagiuchi and K. Okisawa: Proc. 11th World Hydrogen Energy Conf. 1996, Stuttgart, Germany, p.781.
14) M. Nagai, H. Tazima, A. Sakanishi, N. Hisatome and S. Ohkura: Proc. 11th World Hydrogen Energy Conf. 1996, Stuttgart, Germany, p.825.
15) L. R. Brown: "STATE OF THE WORLD 1990" (W.W. Norton & Company, Inc., New York), (Japanese Edition, Diamond Big Co., Ltd., 1990) p.40, p.286.