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Mitigating global warming by substituting technology for energy

MITI's efforts and new approach

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In the last two decades, Japan has successfully overcome energy and environmental constraints despite a fragile energy and environmental structure, while maintaining a high rate of economic growth. Much of this success can be attributed to the substitution of an unconstrained production factor (technology) for a constrained production factor (energy) stimulated by MITI's industrial technology policy. With the recent fall of international oil prices and the succeeding 'bubble economy', Japan again faces the prospect of energy and environmental constraints. This paper reviews Japan's path and MITI's efforts to overcome energy and environmental constraints by substituting technology for energy. It also analyzes the sources of the current fear concerning energy and environmental constraints.

Keywords: Environmental constraints; Technology development; Industrial technology policy

The global environmental consequences of CO_2 discharge resulting from energy use are causing mounting concern regarding the sustainability of our future development. The Japanese economy, despite many handicaps, has historically maintained a high rate of economic growth by focusing efforts on improving the productivity of relatively scarce resources (Economic Planning Agency, 1965–92). In the 1960s the primary scarce resource was capital stock, followed by the supply of labor, environmental capacity constraints and then the supply of energy after the first energy crisis in 1973 (EPA). The driving force behind this achievement was the development of manufacturing industry (Watanabe and Honda, 1991) and the rapid enhancement of productivity levels was most typically observed in overcoming energy supply constraints by means of technological development (MITI, 1988). In the light of its success, substituting an unlimited resource (technology) for a limited resource (energy) (Watanabe, 1992a) may be a solution to overcoming energy and environmental constraints while maintaining sustainable development (Watanabe, 1992b)

The paper first describes Japan's path in dealing with energy and environmental constraints – a path aiming to overcome the energy crises through technological substitution for energy. The next section reviews MITI's efforts to induce such substitution, followed by an analysis of the sources of the current fears about energy and environmental constraints. The final section assesses MITI's new comprehensive approach for the mitigation of global warming by integrating energy and environmental technologies.

Japan's route to overcoming energy and environmental constraints

Comprehensive approach

Figure 1 illustrates trends in Japan's efforts to reduce SO_x emissions over the last quarter century, demonstrating the significance of a comprehensive system approach that encompasses incentives, regulations, and a web of industrial policies, as illustrated in Figure 2. Figure 3 and Table 1 which analyzes the contributing factors to such a dramatic reduction of SO_x emissions

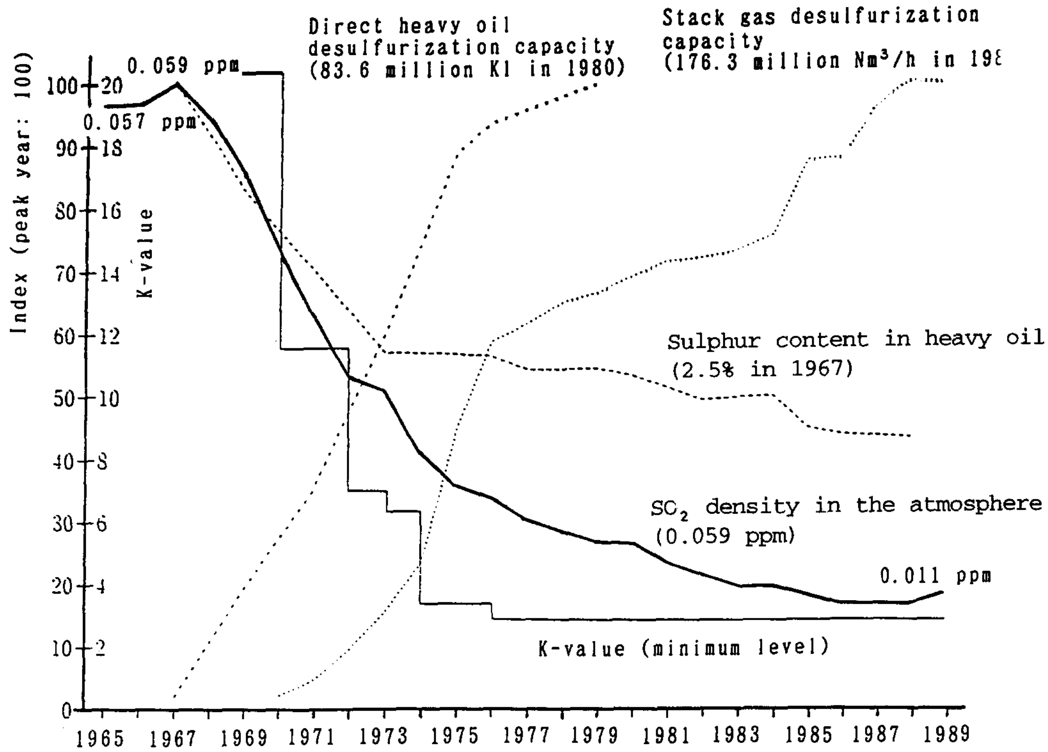

Figure 1 Trends in Japan's efforts to reduce SO_x emissions (1965–89)[a]

[a]Figures in parentheses indicate peak levels.

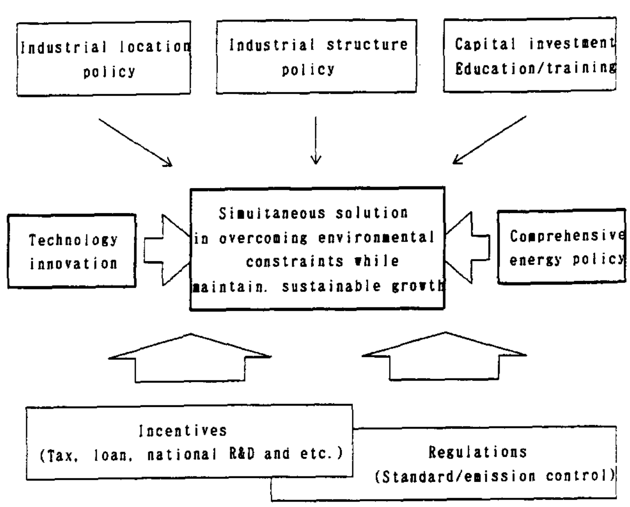

Figure 2 Japan's systems approach to overcoming environmental constraints

over the period 1966–90, indicates that in the period before the 1973 energy crisis, 65% of the reduction of SO_x discharge resulted from a change in fuels; 30% from an increase in desulfurization capacity; 4% from energy conservation; and 1% from a change in industrial structure (change in quality of products). During the period after the energy crisis, 40% came from energy conservation; 38% from a change in fuels; 18% from an increase in desulfurization capacity; and 4% was due to a change in industrial structure. After the second energy crisis in 1979, the significance of energy conservation became apparent as it contributed to 56% of SO_x reduction during the period 1979–90. Thus, the dramatic reduction of SO_x in Japan after the energy crisis was largely based on efforts to reduce energy dependence, which have resulted in increasing energy productivity. This demonstrates Japan's success in overcoming both energy and environmental constraints while maintaining sustainable development despite the damaging impact of the energy crises on the energy supply.

Improvement in energy productivity

Figure 4 illustrates trends in production, energy consumption and CO_2 discharge in Japan's manufacturing industry during the period 1970–90.[1] Despite the damaging impact of the energy crises, industry was

[1]Share of Japan's CO_2 discharge in 1990 is as follows (including CO_2 in the power generation process): industry 47.6% (manufacturing industry 43.1%); residential and commercial 22.6%; transport 18.5%; and others 11.3%.

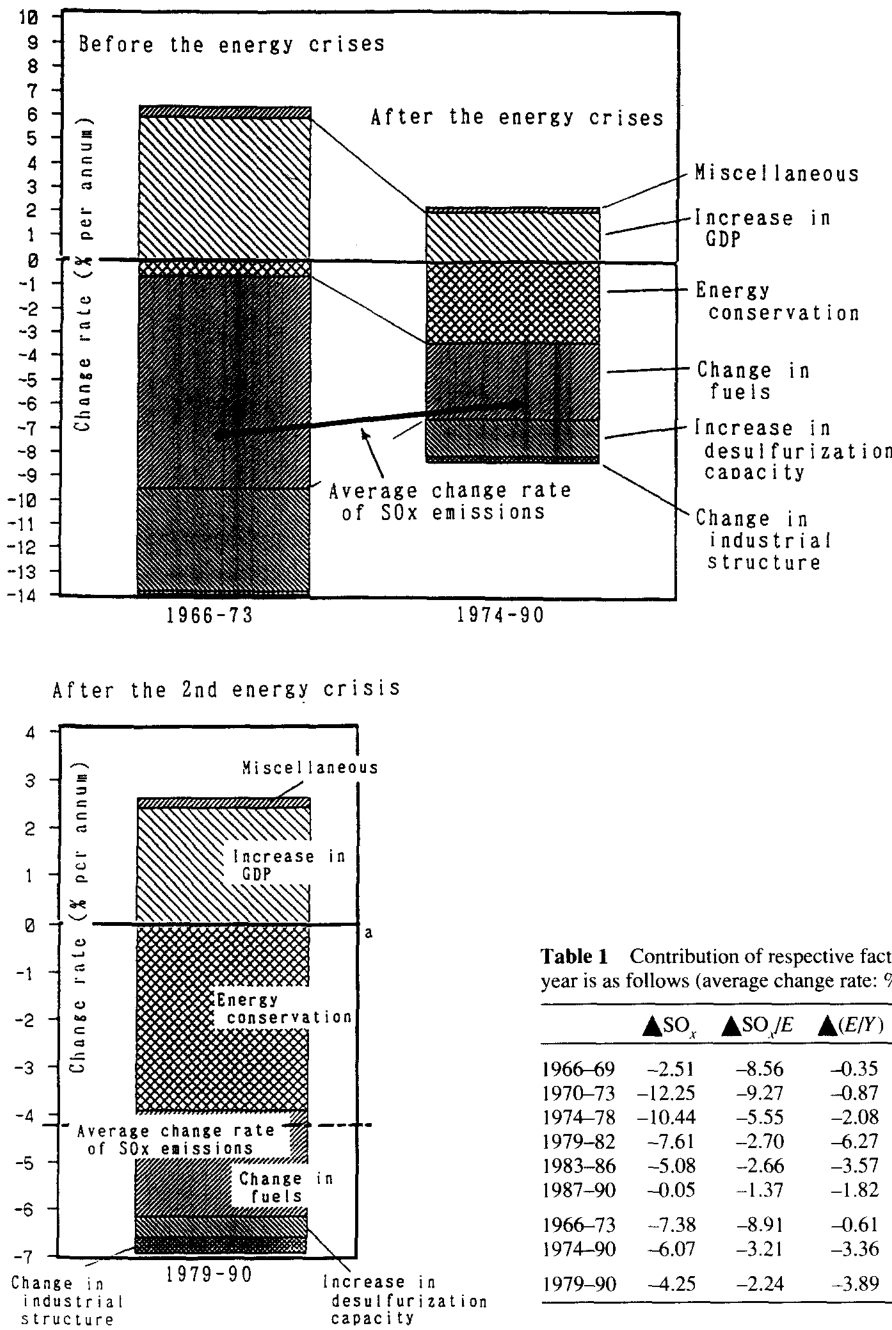

Figure 3 Factors contributing to change in SO_x emissions in Japan, 1966–90

Table 1 Contribution of respective factors to reducing SO_x emissions in each year is as follows (average change rate: %)

	▲SO_x	▲SO_x/E	▲(E/Y)	▲(Y/V)	▲(DSF)	▲(V)	η
1966–69	–2.51	–8.56	–0.35	0.26	0	6.14	0
1970–73	–12.25	–9.27	–0.87	–0.54	–8.25	5.78	0.90
1974–78	–10.44	–5.55	–2.08	–0.15	–4.20	1.37	0.17
1979–82	–7.61	–2.70	–6.27	–0.68	–0.26	2.26	0.04
1983–86	–5.08	–2.66	–3.57	–0.26	–0.68	1.96	0.13
1987–90	–0.05	–1.37	–1.82	–0.04	–0.36	3.06	0.48
1966–73	–7.38	–8.91	–0.61	–0.14	–4.13	5.96	0.45
1974–90	–6.07	–3.21	–3.36	–0.28	–1.54	2.12	0.20
1979–90	–4.25	–2.24	–3.89	–0.33	–0.43	2.43	0.21

able to sustain steady development and increase production, while keeping CO_2 discharge to a minimum. Figure 5 analyzes factors contributing to change in CO_2 discharges by manufacturing industry after the first energy crisis. While the average annual increase in production by value added between 1974 and 1990 was 4.55%, average CO_2 discharges fell by 1.01%. Figure 5 indicates that this reduction in CO_2 discharges was largely the result of efforts to reduce energy dependency (60% of such a reduction can be attributed to efforts to improve energy efficiency). Indeed, Figure 6 demonstrates that Japan's efforts to reduce energy consumption after the 1973 energy crisis were dramatic and conspicuous among the advanced countries. Such a dramatic improvement in energy productivity was a response to counter the sharp increase in energy prices

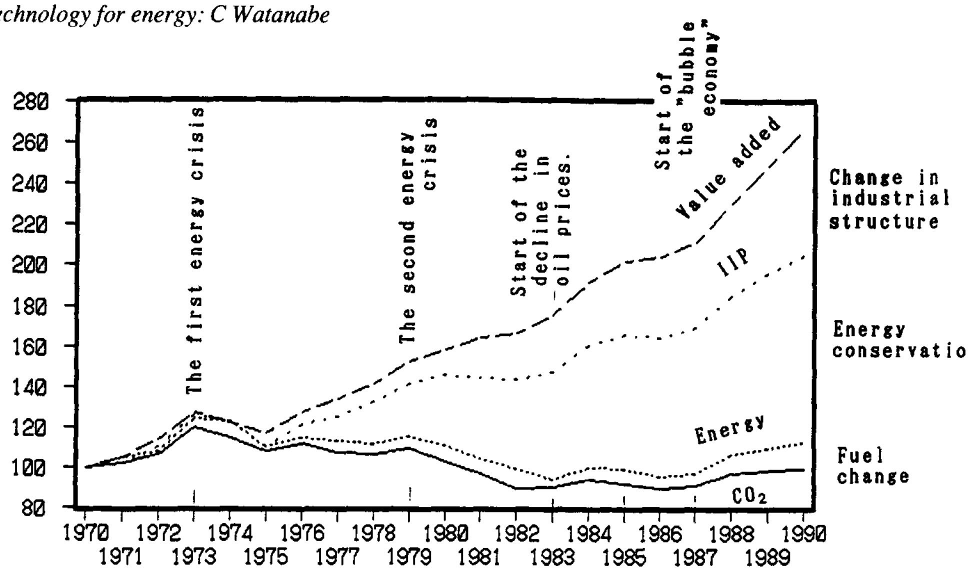

Figure 4 Trends in production, energy consumption and CO_2 discharges by Japanese manufacturing industry, 1970–90 (index: 1970 = 100)

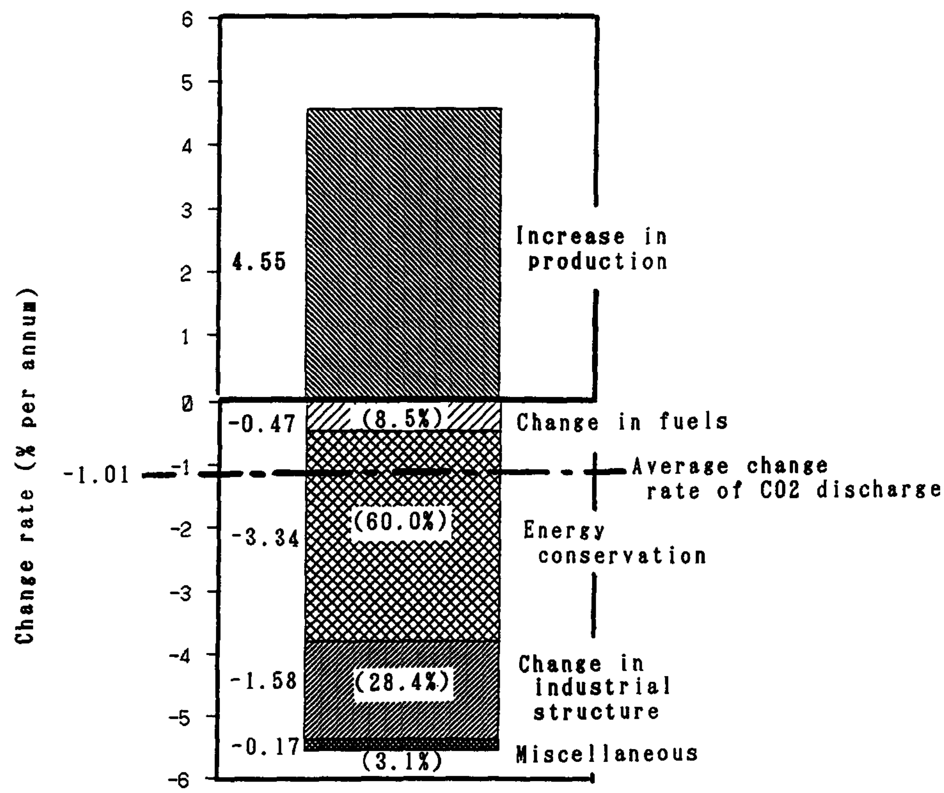

Figure 5 Factors contributing to changes in CO_2 discharges by Japanese manufacturing industry, 1974–90

Figures in parentheses indicate shares of contribution to reducing CO_2 discharge. Magnitude of contribution is measured by the following equation:

$$C = C/E \cdot E/I \cdot (V/I)^{-1} \cdot V$$

where $C = CO_2$, E = Energy, I = IIP (production weight) and V = value added.

$$\underbrace{\blacktriangle C/C}_{} = \underbrace{\blacktriangle (C/E)/(C/E)}_{\text{change in fuels}} + \underbrace{\blacktriangle (E/I)/(E/I)}_{\text{energy conservation}} - \underbrace{\blacktriangle (V/I)/(V/I)}_{\text{change in industrial structure}} + \underbrace{\blacktriangle V/V}_{\text{change in production}} + \eta$$

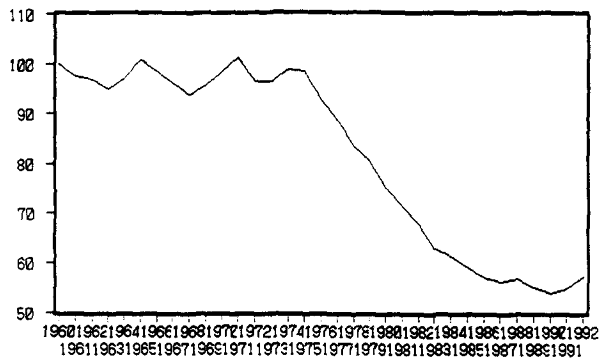

Figure 6 Trends in unit energy consumption in Japanese manufacturing industry, 1960–92 (index: 1960 = 100)[a]

[a]Unit energy consumption: energy consumption per IIP (production weight).

caused by the energy crises (Watanabe and Honda 1991; Watanabe *et al*, 1991).

Substitution of technology for energy

It is generally pointed out that most efforts aimed to overcome a 'constrained economy' focus on the substitution of a constrained (or limited) production factor by unlimited production factors. This is similar to an ecosystem where, in order to maintain homeostasis (checks and balances that dampen oscillations), when one species slows down, another speeds up in a compensatory manner in a closed system (substitution), while dependence on supplies from an external system leads to a reduction in homeostasis (complement) (Odum, 1963).

In the case of Japan, the constrained production factor is energy, while the unlimited production factor is technology. Figure 7 illustrates the extent of energy substitution for other production factors in the Japanese manufacturing industry over the last two decades. In order to overcome sharply increased energy constraints while maintaining sustainable development, intensive efforts (such as energy conservation and oil-replacing energy technologies, and energy-efficiency improvements) were made to substitute technology for energy, followed by efforts to substitute capital for energy (typically energy conservation investments) (Watanabe, 1992a). As a result of such substitution, Japan maintained its economic development and improved its

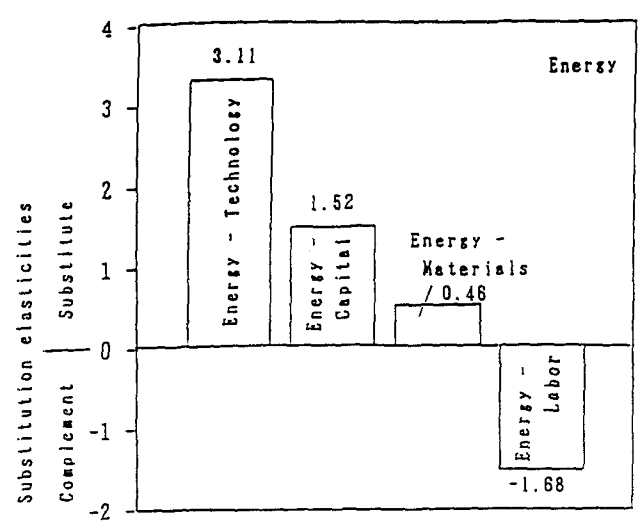

Figure 7 Average substitution elasticities of energy in Japanese manufacturing industry, 1974–87

Substitution elasticities are measured based on the following price function:

$$
\begin{array}{llllll}
Ml = 0.1471 & + 0.0996 \ln Pl & + 0.0091 \ln Pk & - 0.0892 \ln P\mathrm{m} & - 0.0277 \ln Pe & + 0.0082 \ln Pt \\
(98.15) & (12.86) & (1.71) & (-10.30) & (-6.97) & (6.87) \\
Mk = 0.1591 & + 0.0091 \ln Pl & + 0.0723 \ln Pk & - 0.0837 \ln P\mathrm{m} & + 0.0058 \ln Pe & - 0.0035 \ln Pt \\
(34.84) & (1.71) & (7.72) & (-7.93) & (1.16) & (-2.47) \\
Mm = 0.5952 & - 0.0892 \ln Pl & - 0.0837 \ln Pk & + 0.2093 \ln P\mathrm{m} & - 0.0260 \ln Pe & - 0.0104 \ln Pt \\
(234.24) & (-10.30) & (-7.93) & (12.14) & (-5.62) & (-6.73) \\
Me = 0.0831 & - 0.0277 \ln Pl & + 0.0058 \ln Pk & - 0.0260 \ln P\mathrm{m} & + 0.0455 \ln Pe & + 0.0023 \ln Pt \\
(27.97) & (-6.97) & (1.16) & (-5.62) & (12.59) & (2.78) \\
Mt = 0.0156 & + 0.0082 \ln Pl & - 0.0035 \ln Pk & - 0.0104 \ln P\mathrm{m} & + 0.0023 \ln Pe & + 0.0033 \ln Pt \\
(23.96) & (6.87) & (-2.47) & (-6.73) & (2.78) & (5.31)
\end{array}
$$

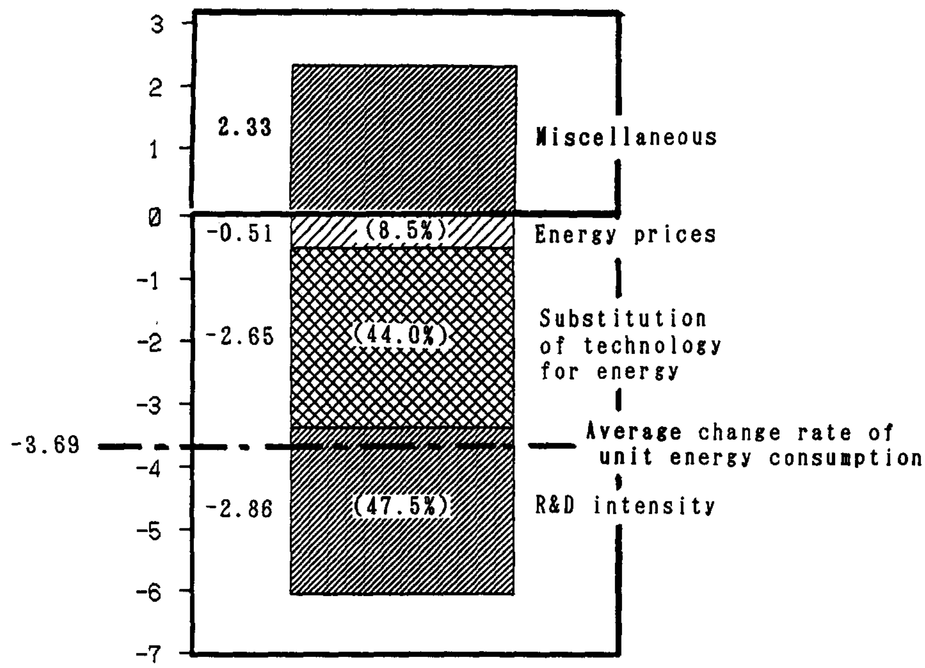

Figure 8 Factors contributing to the change in unit energy consumption in Japanese manufacturing industry, 1976–90

Magnitude of contribution is measured by the following equations:

$\sigma\, te = (Bte + Mt \cdot Me)/(Mt \cdot Me) = 1 + Bte(GC/GTC)\,(GC/GEC)$

$\sigma\, te - 1 = Bte(GC/R)\,(GC/E \cdot Pe) = Bte(S/R\,(GC/S)\,(IIP/E)\,(GC/IIP)\,(1/Pe)$

$E/IIP = Bte \cdot (\sigma te - 1)^{-1}\,(R/S)^{-1}\,(Pe)^{-1}\,(GC/IIP)\,(GC/S)$

$\ln E/IIP = \ln Bte - \ln(\sigma te - 1) - \ln R/S - \ln Pe + \ln(GC/IIP)\,(GC/S)$

$\blacktriangle E/IIP = -\blacktriangle(\sigma te - 1) - \blacktriangle R/S - \blacktriangle Pe + \eta$

where $\sigma\, te$ = substitution of technology for energy; Bte is a coefficient; Mt and Me = cost share of technology and energy respectively; GC = gross cost; GTC = gross technology cost; GEC = gross energy cost; R = R&D expenditure (= gross technology cost); E = energy consumption; Pe = prices of energy; S = sales; IIP = index of industrial production; η = miscellaneous.

Contribution of respective factors to reducing unit energy consumption is as follows (average change rate: %):

$\blacktriangle E/IIP$ (unit energy consumption): –3.69
$\blacktriangle(\sigma te - 1)$ (substitution of technology for energy): –2.65
$\blacktriangle R/S$ (R&D intensity): –2.86
$\blacktriangle Pe$ (energy prices): –0.51
η (miscellaneous): 2.33

(the year 1980 is not included because of inconsistently drastic change due to the second energy crisis in 1979).

overall technological level (MITI, 1988; Watanabe 1992a; Watanabe *et al*, 1991; Watanabe, 1993a).

In order to demonstrate the important role technology substitution played in improving energy productivity in Japan's manufacturing industry, I analyzed factors contributing to change in unit energy consumption over the period 1976–90 (see Figure 8). The analysis indicates that 44% of the reduction in unit energy consumption was attributable to the substitution of technology for energy, and the remaining contribution was made by R&D intensity (47.5%) and energy price increases (8.5%). Clearly technology made a considerable contribution to the dramatic improvement in energy productivity seen in Japan's manufacturing industry.

MITI's efforts to induce technology substitution for energy

Function of MITI's energy R&D policy

Japan has adopted different industrial policies in different stages of its economic development; these have reflected the international, natural, social, cultural and historical environment of the post-war period (Watanabe and Honda, 1992). In the late 1940s and 1950s, Japan made every effort to reconstruct its war-ravaged economy and lay the foundation for viable economic growth. During the decade of the 1960s, Japan actively sought to open its economy to foreign competition by liberalizing trade and the flow of international capital. In the process, it achieved rapid economic growth led by both chemical and heavy industries. Unfortunately, the heavy concentration of such highly material-intensive and energy-intensive industries along with increased population in Japan's Pacific belt area led to serious environmental pollution problems (Ogawa, 1991). This necessitated a reexamination of industrial policy (MITI, 1972a; 1972b).

Recognizing the need for a change in direction, MITI formulated a new plan for Japan's industrial development. This plan, which was published in May 1971 as *MITI's Vision for the 1970s*, proposed a shift to a knowledge-intensive industrial structure which would place less of a burden on the environment by depending less on energy and materials and more on technology.[2]

In order to facilitate the establishment of the industrial structure it was proposing, MITI set up a research group in May 1971 consisting of experts from ecology-related disciplines, in order to define an ecological science for studying the global environment (MITI, 1972c). This research group proposed the concept of industry–ecology as a comprehensive method for analyzing and evaluating the complex mutual relations between human activities, particularly industry, and the environment. In the summer of 1973 MITI outlined both a new policy principle to be applied to its industrial policy and a new policy system based on this principle. Efforts were directed to further developing R&D programs in the hope of rebalancing the ecosystem by creating an environmentally friendly energy system (MITI, 1970–90).

The first energy crisis occurred a few months later; this encouraged the reduction of redundancy by taking ecological considerations into account. The majority of MITI's efforts focused on securing an energy supply in the face of a dramatic increase in oil prices. Given such circumstances, a new policy was initiated based on the 'basic principle of industry-ecology' and aimed at solving basic energy problems by means of R&D on new and clean energy technology. This policy led to the establishment of the Sunshine Project (R&D on New Energy Technology), a new program initiated in July 1974.

The 'basic principle of industry-ecology' suggests that substitution among available production factors in a closed system should be the best way to achieve sustainable development under certain constraints (Odum, 1963). The Sunshine Project initiated this approach by enabling substitution of technology-driven energy, which has unlimited potential for limited energy sources, such as oil. Further substitution efforts should be made not only in the energy supply field but also in the field of energy consumption. Improvement in energy efficiency by means of technological innovation (ie technology substitution for energy) would contribute to reducing dependency on energy. In line with this policy consideration, the Moonlight Project (R&D on Energy Conservation Technology) was initiated in 1978 (Figure 9) (MITI, 1970–90).

The second energy crisis occurred in 1979, and MITI was able to implement policies capable of inducing industrial vitality for sustainable development by substituting an unlimited resource, technology, for a limited resource, energy.[3]

MITI's budget for the Sunshine Project and the Moonlight Project represented 14% of MITI's total R&D budget in 1979, and in 1982 it increased to 29%. It was only 5% in 1974. Table 2 and Figure 15 summarizes Japan's R&D expenditures for energy technologies in 1990. As can been seen, out of the nation's total energy R&D expenditures of 915 billion yen, MITI expended 130 billion yen (14.2% of the total). Of this, 51 billion yen was used for the Sunshine and Moonlight Projects, and 79 billion yen was used for coal, oil and gas, electric power and nuclear R&D.

Stimulation of industry's energy R&D

MITI's efforts to stimulate the substitution of technology and technology-driven energy for energy and also for limited energy sources encouraged industry to invest in energy R&D. A survey of manufacturing firms involved in MITI's energy R&D program projects indicates that in addition to supplementing industry's own R&D activities, a significant number of firms expressed the strong expectation that such projects would stimulate industry's own R&D in relevant fields. An analysis with respect to correlations between MITI's energy R&D expenditures and R&D expenditures for energy R&D initiated by Japan's manufacturing industry demonstrates a strong correlation between industry efforts and MITI's initiative with respect to energy R&D (Watanabe, 1994a). Correlations of R&D on energy conservation, renewable energy and coal technologies led

[2]In order to establish a knowledge-intensive industrial structure, the plan stressed the significant role of innovative R&D which would reduce Japan's dependency on materials and energy in the process of production and consumption. It also stressed that such reduced dependency could be achieved by means of intensive conservation and recycling of resources (materials and energy) in a long-term, global and *ecological* context, and that R&D aiming to develop 'limit-free energy technology' (technology driven clean energy) was required: Industrial Structure Council of MITI (1971).

[3]The mechanism of MITI's policy system for such an inducement can be summarized as follows: (1) penetration and identification of future prospect and strategic areas; (2) formulation and publication of visions; (3) provision of policy measures which stimulate substitution in order to induce industries to increase their R&D intensity; (4) the potential for further technological development increases as the degree of R&D increases; (5) expectations on the outcome of technological development among industries increase; (6) inducing further investment in R&D activities; and (6) building up dynamism conducive to technological development: Watanabe and Honda (1991).

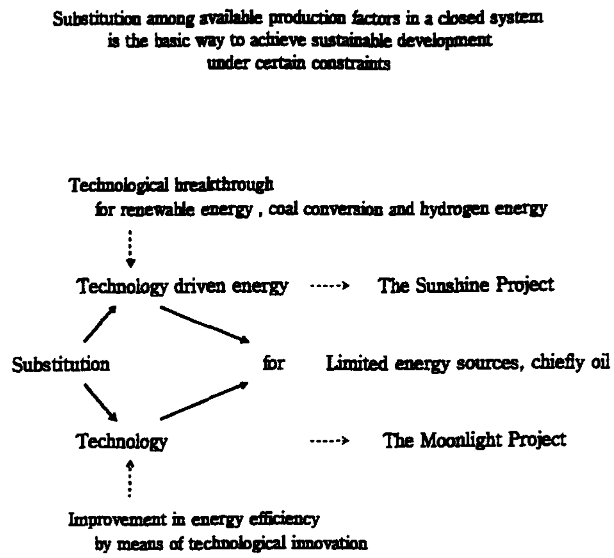

Figure 9 Basic concept of the Sunshine and Moonlight Projects.

Table 2 R&D expenditures on energy and environmental technologies in Japan, 1990 (¥ 100 million)[a]

	Industry (Manufacturing industry)	Research institutions[b]	University	Total
Energy technology	3492 (2819)	5241	417	9150
Nuclear	827 (660)	2922	272	4021
Non-nuclear	2665 (2159)	2319	145	5129
Energy conservation	1882 (1693)	1754	66	3702
Renewable	145 (120)	86	52	283
Coal	172 (117)	185	8	365
Oil and gas	294 (177)	198	10	502
Electric power	172 (52)	96	9	277
Environmental technology	1428 (1360)			

SSML	512	Moonlight	(ML)	116	Energy conservation		(ML)	116	Conservation	(ERS)	1693
					Hydrogen		(SSH)	1			
		Sunshine	(SS)	296	Renewable	Solar	(SSS)	74	Renewable	(ERR)	120
						Geothermal	(SSG)	54			
						Wind/ocean	(SSO)	18			
					Coal conversion		(SSC)	249	Coal	(ERC)	117
nSM	787	Coal/oil/nucl/elc.			Coal		(MC)	66			
					Oil/gas		(MOG)	256	Oil and gas	(EROG)	177
					Electric power		(ME)	119	Electric power	(ERE)	52
					Nuclear		(MN)	346	Nuclear	(ERN)	660
MITI's total energy R&D (SSML + nSM)	1299								Manufacturing industry's energy R&D (ERT)		2819

[a] Total R&D expenditure in 1990 (natural sciences): 11 993.5 billion yen (industry 9267.2; research institutions 1401.2; universities 1325.2).
[b] Research institutions are those organizations established by central or local governments or by private organizations which perform R&D.

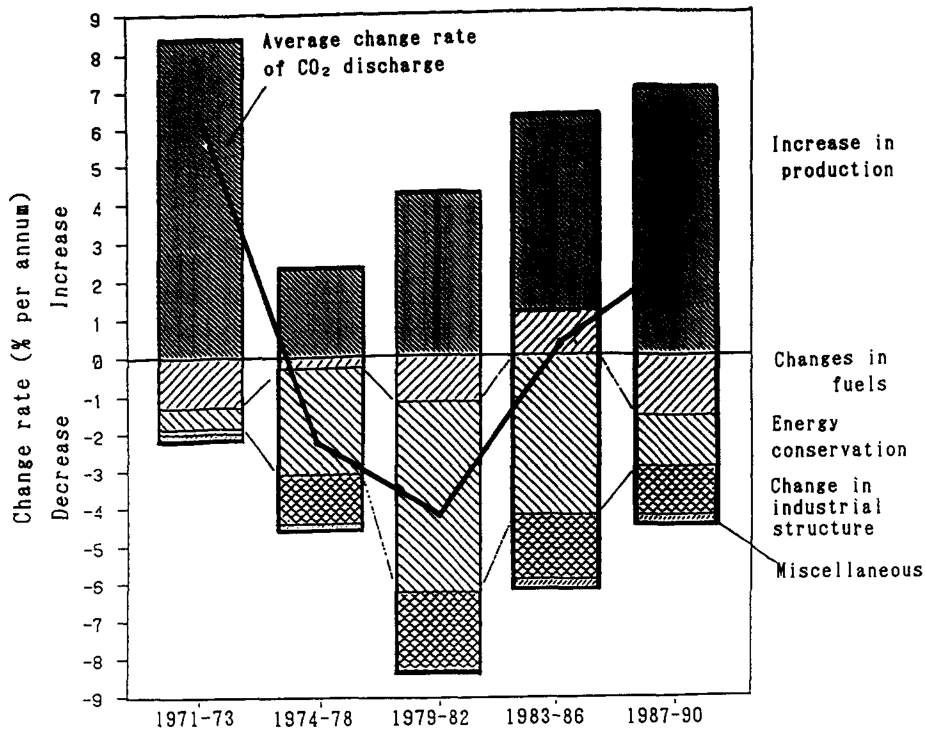

Figure 10 Factors contributing to change in CO_2 discharges by the Japanese manufacturing industry, 1971–90

Shares of contribution to reducing CO_2 discharge in each period are as follows:

	1971–90	1971–73	1974–78	1979–82	1983–86	1987–90
Energy conservation	58	27	61	61	83	30
Change in industrial structure	27	6	29	24	33	30
Change in fuels	12	60	6	14	–21	35
Miscellaneous	3	7	4	1	5	5
Total	100%	100%	100%	100%	100%	100%

by both the Moonlight Project and the Sunshine Project are more distinctive than correlations with other R&D projects. These analyses demonstrate that MITI's energy R&D program projects such as the Sunshine Project and the Moonlight Project have functioned well in stimulating related R&D activities initiated by industry.

Prospect of energy and environmental constraints

Trends in factors contributing to change in energy and environmental constraints

Figure 10 analyzes the factors that contributed to change in production, energy consumption and CO_2 discharge in Japan's manufacturing industry over the period 1970–90. Looking at the trend of CO_2 discharge and the contributing factors in each era, we find that the CO_2 discharge level fell dramatically after the first energy crisis in 1973, as energy conservation efforts increased. Much of this resulted from the substitution of technology (energy conservation technology) and capital (energy conservation facility) for energy (see Figure 7). At the same time the contribution of fuel switching (which represents the outcomes of similar substitutions involving oil-alternative technologies and capital investment) turned out to be less significant. This has been attributed to the increased dependency on coal as a promising alternative to oil. Figure 10 shows that CO_2 discharges began to increase again after 1983 (when international oil prices began to fall) as a result of the increased use of coal and reduced energy conservation efforts. The reduction in energy conservation efforts after 1987, the year of the start of Japan's so-called 'bubble economy', resulted in an increase in CO_2 discharge, and a decrease in marginal energy productivity (Watanabe, 1994a). Figure 8 suggests that this decrease in energy conservation efforts arose primarily from decreases in R&D intensity and the substitution of technology for energy (which can be attributed to the technology stock of energy R&D (Watanabe, 1994a).

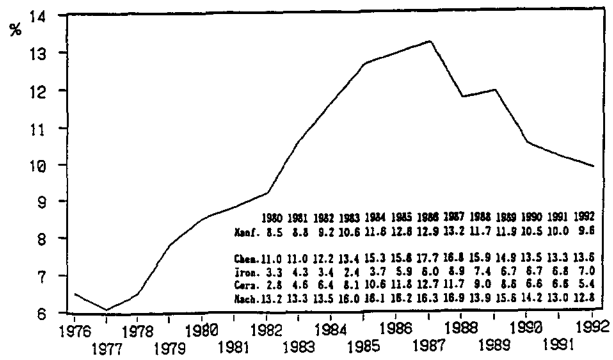

Figure 11 Trends in R&D investment share of total investment in Japanese manufacturing industry, 1976–92[a]

[a]Correlations between R&D investment share out of total investment (IR) and R&D intensity (RS) in the Japanese manufacturing industry are as follows (1978–90):

Manufacturing total

$$\ln RS = 0.81 + \underset{(20.30)}{0.17}\,\mathrm{Lag2}\,(\ln IR) + \underset{(2.86)}{0.22}\,D \qquad 1990=1$$

Adj.R^2: 0.975
DW: 1.41

Chemicals

$$\ln RS = -0.02 + \underset{(12.96)}{0.52}\,\mathrm{Lag2}\,(\ln IR)$$

Adj.R^2: 0.933
DW: 2.53

Iron and steel

$$\ln RS = 0.07 + \underset{(7.36)}{0.30}\,\mathrm{Lag1}\,(\ln IR) + \underset{(4.14)}{0.21}\,D \qquad 1985\text{–}87=1$$

Adj.R^2: 0.907
DW: 1.58

Machinery

$$\ln RS = -0.24 + \underset{(8.74)}{0.58}\,\mathrm{Lag2}\,(\ln IR) + \underset{(2.66)}{0.06}\,D \qquad 1980,\ 90=1$$

Adj.R^2: 0.886
DW: 1.51

The R&D intensity has a strong correlation with the share of R&D investment in total investment with a one- to two-year time lag (Watanabe, 1993b), and looking at the decreasing trend in R&D investment share of total investment in the period of the 'bubble economy' (Watanabe, 1992c; 1993b) as illustrated in Figure 11, it is strongly feared that R&D intensity may further decline as a result of the the bursting of the 'bubble economy' (since 1991) and the consequent economic stagnation. Such a decrease in R&D intensity may have a significant impact on the 'quality' of R&D activities.

Table 3 compares factors that stimulated R&D for energy, environmental protection, and information technology in Japan's manufacturing industry in the period 1976–90. We can note that R&D for environmental protection and energy are sensitive to the level of R&D intensity, in contrast with R&D for information technology. The analyses in Figure 11 and Table 2 suggest that the R&D intensity of Japan's manufacturing industry has stagnated, resulting in a decrease in energy R&D. Thus, as a reuslt of the the fall in international oil prices after 1983 and a decline in R&D intensity, energy R&D efforts have stagnated, producing a stagnation of the technology stock of energy R&D.

Changes in the technology stock of energy R&D have both quantitative and qualitative impacts on the total technology stock. Quantitatively, the technology stock of energy R&D is a part of the total technology stock and its stagnation results in a stagnation of the total technology stock. Qualitatively, it induces the technology stock of non-energy R&D (Watanabe, 1994a). A stagnation of the technology stock of energy R&D therefore results in a slower rate of increase in the total technology stock, which in turn results in not only a decrease in production but also in the marginal productivity of technology stock to production.

These analyses provide a warning that despite its success in overcoming energy and environmental constraints in the 1960s, 1970s and the first half of the 1980s, the Japanese economy once again faces the prospect of energy and environmental constraints and consequent stagnation following the fall of international oil prices and the succeeding 'bubble economy' (Industrial Structure Council, 1992).

Trends in inducing impacts of MITI's energy R&D

MITI's energy R&D budget was influenced by its overall R&D budget and also by trends in energy prices.[4] As international oil prices fell and the global environmental consequences gave rise to mounting concerns regarding the sustainability of our development future, MITI's priority for energy R&D shifted to other policy fields such as the Global Environmental Technology Program, initiated in 1989 (Watanabe and Honda 1992). Together with government financial constraints after the energy crises, MITI's budget for energy R&D has stagnated since 1982, as illustrated in Table 1. Considering the significant impacts of MITI's energy R&D on R&D intensity, the substitution of technology for energy and the technology stock of energy R&D initiated by manufacturing industry, such stagnation has discouraged manufacturing industry's efforts to increase R&D intensity, the technology stock of energy R&D and technology substitution for energy, which were the main sources of the decrease in energy productivity in Japan's

[4]MITI's energy R&D budget (*MER*: majority is dependent on special accounts for energy security sources which are subject to energy prices) is influenced by its R&D budget (*MRD*) and energy prices (*Pe*) as follows:

$$\ln MER = -6.66 + \underset{(8.55)}{1.02}\ln MRD + \underset{(4.59)}{1.02}\ln Pe + \underset{(3.42)}{0.36}\,D \qquad 78 = 1$$

Adj.R^2: 0.975, DW: 1.51

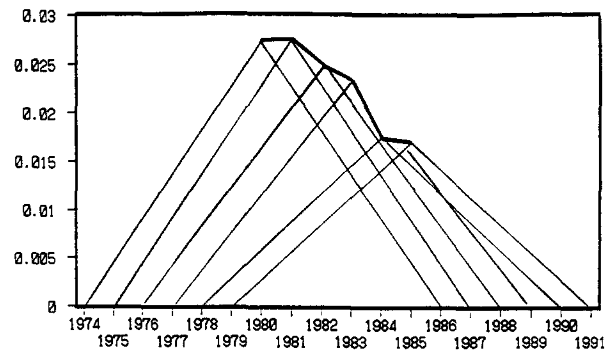

Figure 12 Trends in the marginal productivity of technology stock to production in Japanese manufacturing industry, 1974–91, by moving correlations with 8 degrees of freedom (index: 1974–86 = 0.0275)

Marginal productivity (MP) is measured by the following equation:

$$Y = A\, L\hat{}\alpha * K\hat{}\,\beta * ME\hat{}\,\tau * T\hat{}\,\delta$$

$$\mathrm{Ln}\, Y = -0.45 + 0.22\mathrm{Ln}\, L + 0.19\mathrm{Ln}\, K + 0.60\mathrm{Ln}\, ME + 0.08\mathrm{Ln}\, T \quad (1974\text{–}91)$$
$$\qquad (1.88) \qquad (1.69) \qquad (5.00) \qquad (1.91)$$

Adj. R^2: 0.999 DW: 1.52
where Y = production, L = labor, K = capital stock, ME = materials and energy, T = technology stock, A = scale factor.

$MP = \sigma Y/\sigma T = \delta Y/T$

δ, Y/T and MP in the respective periods are as follows:

	δ	Y/T	MP
1974–86	0.098	0.28	0.0275
1975–87	0.115	0.24	0.0276
1976–88	0.109	0.23	0.0251
1977–89	0.102	0.23	0.0235
1978–90	0.080	0.22	0.0176
1979–91	0.081	0.21	0.0170

Table 3 Inducing factors for R&D on energy, environmental protection, and information technology in Japanese manufacturing industry (1976–90)[a]

Energy R&D

$$\ln ERT = 2.12 + 0.77 \ln ENERS + 1.50 \ln RS + 0.45 \ln Pe + 0.12\, D$$
$$\qquad (2.64) \qquad (3.70) \qquad (1.29) \qquad (1.34)$$

Adj. R^2: 0.918 DW: 1.54 D: 1990=1

R&D for environmental protection

$$\ln ENVRD = 2.86 + 1.07 \ln ENVRS + 2.08 \ln RS + 0.21 \ln Pe - 0.14\, D$$
$$\qquad (7.94) \qquad (8.97) \qquad (1.57) \qquad (-1.77)$$

Adj. R^2: 0.847 DW: 1.85 D: 1986 = 1

R&D for information technology

$$\ln INFRD = 2.75 + 1.53 \ln INFRS + 0.87 \ln RS + 0.27 \ln Pe$$
$$\qquad (23.10) \qquad (6.25) \qquad (4.92)$$

Adj: R^2: 0.999 DW: 2.44

Multipliers of inducing factors

	R&D Share by objectives	**R&D intensity**	**Energy prices**
Energy R&D	0.77	1.50	0.45
R&D for environmental protection	1.07	2.08	0.21
R&D for information technology	1.53	0.87	0.27

[a] Firms with capital of more than 100 million yen.
ERT, *ENVRD* and *INFRD*: R&D expenditures for energy R&D, R&D for environmental protection and R&D for information technology respectively. *ENERS*, *ENVRS* and *INFRS*: the ratio of R&D expenditures for energy, environmental protection and information technology respectively. *RS*: R&D intensity. *Pe*: Prices of energy. All 1985 constant prices.

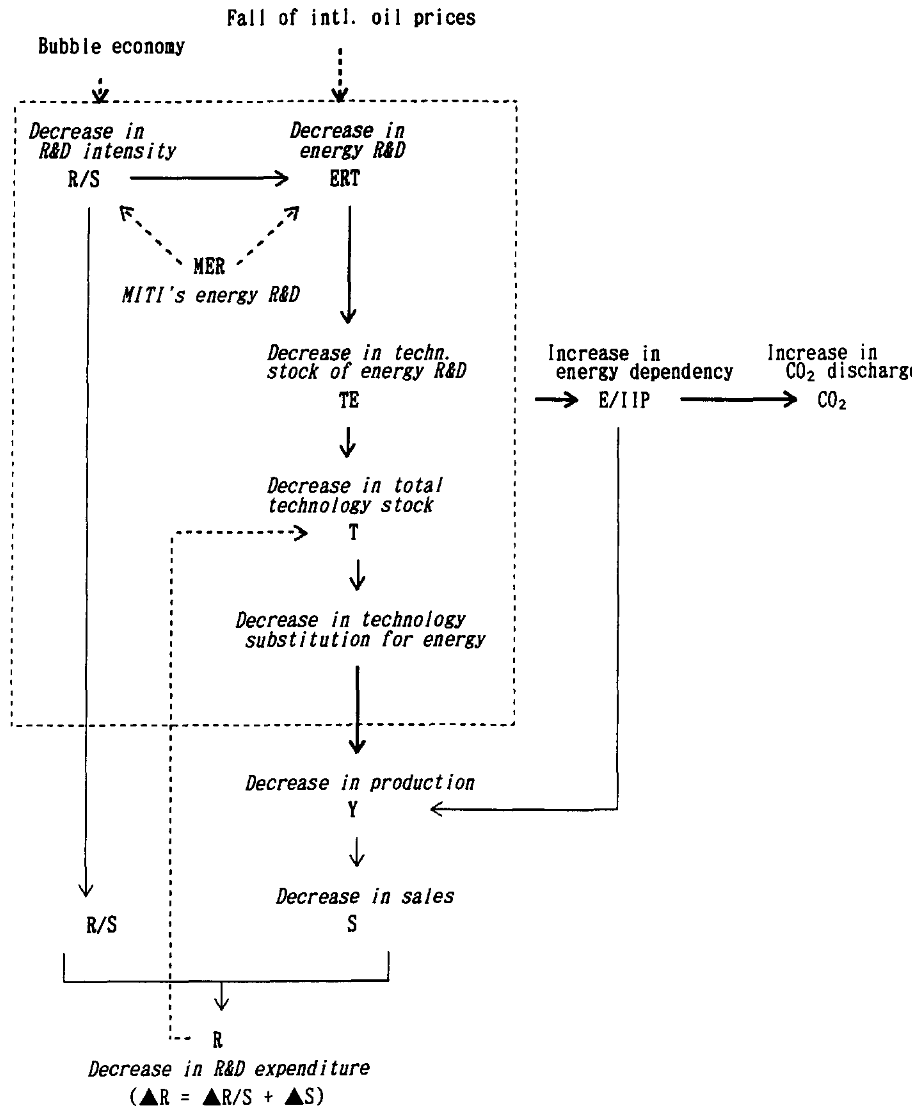

Figure 13 Impacts of the fall in international oil prices and the succeeding bubble economy on energy and environmental constraints and sustainable growth in Japanese manufacturing industry

manufacturing industry, as indicated in Figure 8. As MITI's budget stagnated, its return of investment to R&D intensity and the technology stock of energy R&D decreased, as analyzed in Figure 12. This is a clear warning that the R&D intensity of manufacturing industry and the technology stock of energy R&D will structurally stagnate in the near future.

As a result of these stagnating trends in both industry's R&D activities and in inducing impacts of MITI's energy R&D, Japan's manufacturing industry appears to have fallen into a negative spin cycle as illustrated in Figure 13. MITI's energy R&D contributed to induce industry's R&D efforts. However, this inducement has been declining. Faced with the prospect of energy and environmental constraints, and also a stagnation of sustaining development, MITI needs to initiate intensive energy R&D to stimulate improvements in the quality and quantity of the total technology stock. This will in turn help to overcome the current fear in this time of economic stagnation.

MITI's new comprehensive approach: the New Sunshine Program

Integration of energy and environmental technologies

The situation outlined above demands that MITI undertake effective policy measures to reactivate efforts directed towards substituting technology for constrained

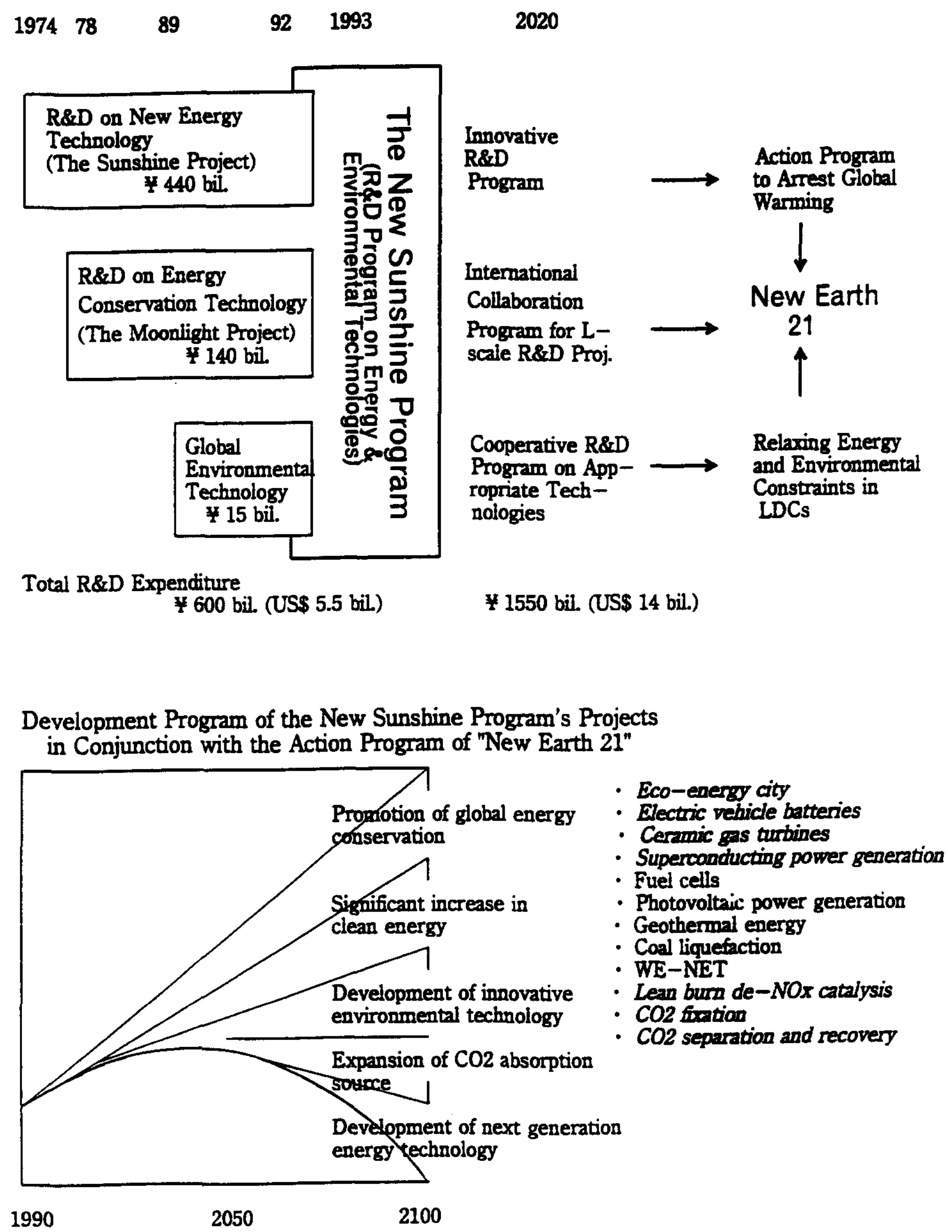

Figure 14 Basic concept of the New Sunshine Program[a]

[a]Total R&D expenditure indicates accumulation of MITI's R&D budget

production factors such as energy and environmental capacity. Given the two-sided nature of the issue of the global environment and energy consumption, MITI should develop a comprehensive approach based on the integration of related programs for strong and effective measures to address the mounting concerns regarding the sustainability of the world's development future in the face of increasing energy and global environment constraints (Industrial Technology Council, 1992; Watanabe, 1994b). To respond to these concerns, a comprehensive approach based on R&D programs on new energy technology, energy conservation technology and global environmental technology could lead to sustainable development by overcoming both energy and environmental constraints simultaneously (Industrial Structure Council, 1992).

In April 1993, MITI therefore decided to establish the New Sunshine Program (R&D Program on Energy and Environmental Technologies) by integrating the Sunshine and Moonlight Project and the Global Environmental Technology Program (Industrial Technology Council, 1992; Watanabe, 1994b). Through

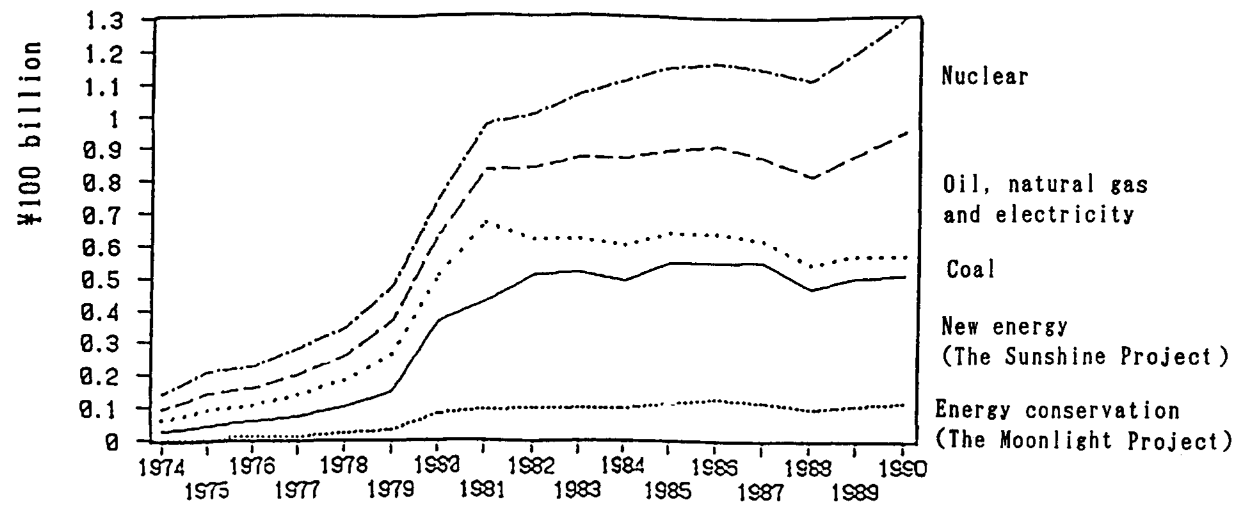

Figure 15 Trends in MITI's energy R&D budget

Source: Annual Report on MITI's Policy

the integration of these R&D activities, effective and accelerated achievement of R&D in the fields of energy and environmental technologies is expected by means of co-utilization and supplementation of such key technologies as catalysts, hydrogen, high-temperature materials and sensors common to new energy, energy conservation and environmental protection. The New Sunshine Program is also expected to provide a new concept for an environmentally friendly technology system and inspire a new principle to be pursued under global environmental constraints.

Structure of the development program

The New Sunshine Program comprises three R&D programs in the field of energy and environmental technologies:

(1) the Innovative R&D Program, which aims to accelerate R&D on innovative technology essential for achieving the goal of the Action Program to Arrest Global Warming to stabilize per capita CO_2 emissions at 1990 levels by the year 2000;
(2) the International Collaboration Program for Large-Scale R&D Projects, to initiate large-scale international R&D projects, is expected to make a significant contribution to the achievement of the goal of 'New Earth 21' to restore the earth over future decades through the reduction of greenhouse gases;
(3) the Cooperative R&D Program on Appropriate Technologies, which aims to develop and assimilate appropriate technologies in developing countries through cooperative R&D on technologies originating from the Sunshine and Moonlight Projects.

Priority projects in the New Sunshine Program can be classified into two basic types. The first are acceleration projects, which are expected to lead to practical use in the near future by means of a virtuous spin cycle (decrease in cost by technological improvement leading to increase in demand leading to further decrease in cost through mass production) triggered by an acceleration of R&D. Examples include photovoltaic power generation and fuel cell power generation. The second are innovative synthetic system projects which are expected to achieve an extremely high-level of breakthrough by means of the synthesis of key technologies. Examples include a broad area energy utilization network system and an international clean energy network using hydrogen conversion (WE-NET project).

The development program of the New Sunshine Program's projects undertaken in conjunction with the Action Program of 'New Earth 21' is illustrated in Figure 14.

Implications for mitigating global warming

Increasing energy and environmental constraints, especially the global environmental consequences of CO_2 discharge resulting from energy use, are causing mounting concern around the world, and it is widely warned that such constraints may be 'limits to sustain our development future'.

In the light of this, Japan's experience could provide useful answers to the question of how technology can be utilized to sustain development. Japan's focus on efforts to break through the limits of the scarcest resources of the 1970s and 1980s may be particularly instructive since it strongly suggests that a comprehensive approach which challenges the limits of sustainable development by substituting new technology for energy and environmental constraints could lead to a new frontier.

Given the above, MITI's industrial technology policy in the 1970s and the first half of the 1980s is instructive because it functioned well in stimulating such substitution, thereby inducing the vitality of industry. However, following the fall of international oil prices and the succeeding 'bubble economy' in the later half of the 1980s, Japan may once again face the prospect of energy and environmental constraints as various indicators provide a warning that Japan's economy has been falling into a negative spin cycle. In order to avoid such an outcome while also facing a stagnation trend with respect to industry's R&D efforts after the bursting of the 'bubble economy', MITI's new comprehensive approach is expected to lead to the reconstruction of a virtuous spin cycle for effective stimulation of sustainable substitution of technology for energy.

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