# Sustainable energy systems taking global warming and resource consumption into consideration

**1. A long-term vision on energy and global environment of Ministry of Economy, Trade and Industry, Japan**
**2. A concept of sustainability on resource consumption and environmental emissions**
**3. Technology evaluation based on the sustainability and the role of nuclear fuel**

2005.10.12

Ryuji Matsuhashi

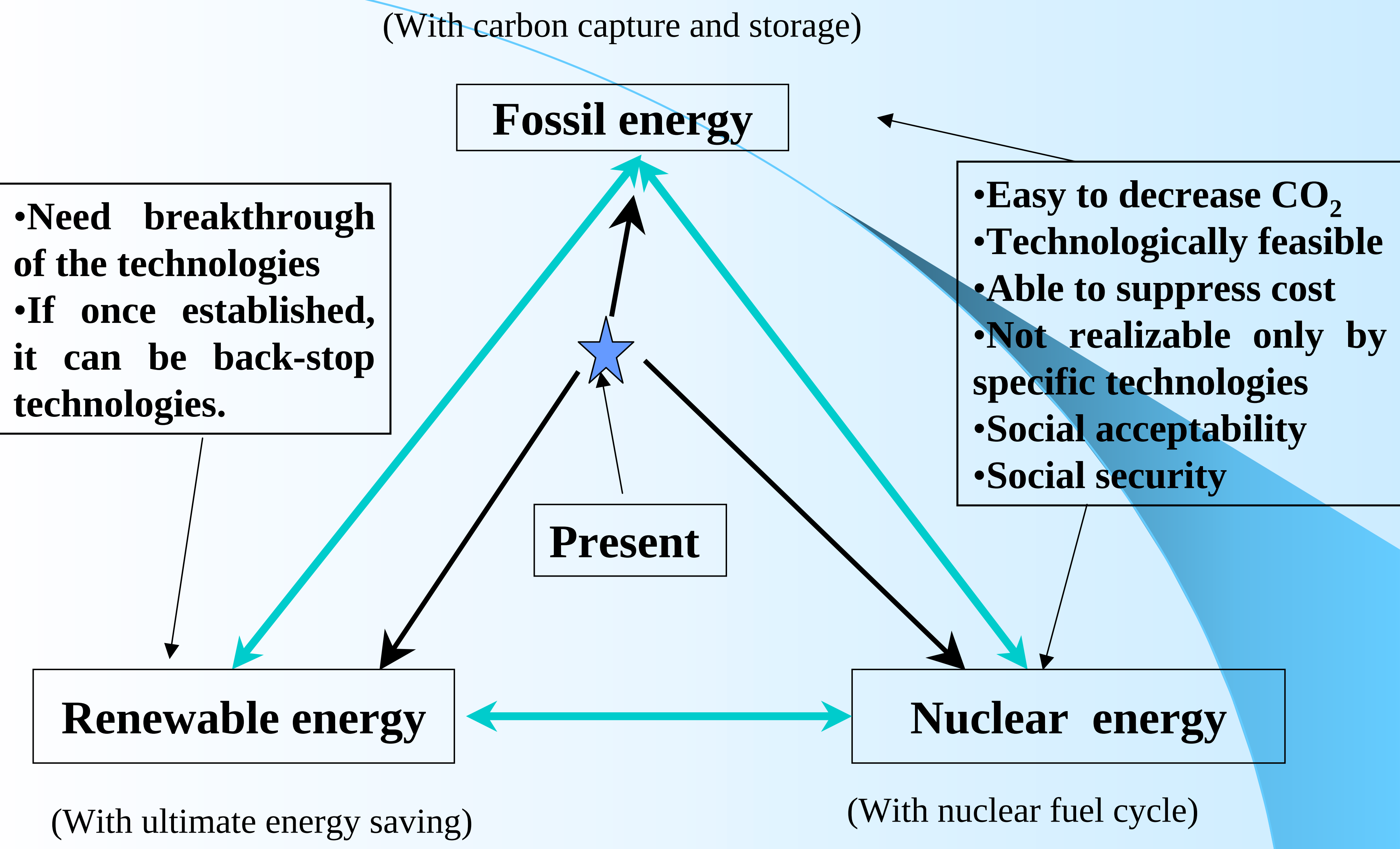
# 1. A long-term vision on energy and global environment of Ministry of Economy, Trade and Industry, Japan

# Long-term energy scenarios of METI, Japan

1. Aim to stabilize GHG density at 550ppm.
2. Hence world needs to suppress $CO_2$ emissions in 2050 and 2100 at present level.
3. As they assume that world GDP grows three times in 2050 and ten times in 2100, $CO_2$/GDP should be 1/3 in 2050, and 1/10 in 2100.
4. Japan also aims to improve $CO_2$/GDP to be 1/3 in 2050, and 1/10 in 2100.

# METI's projection on Technological progress in 2050

1. (Conversion) $CO_2$ intensity of electricity should be decreased from present 370 g/kWh to 120 g/kWh.
2. (Industry) $CO_2$ intensity of industrial production should be decreased 30% in 2050.
3. (Residential) $CO_2$ emissions per household should be decreased to 1/3 in 2050.
4. (Transport) $CO_2$ emissions per t·km should be decreased to 1/3 in 2050.


(With carbon capture and storage)
Fossil energy
•Need breakthrough of the technologies
•If once established, it can be back-stop technologies.
•Easy to decrease $CO_2$
•Technologically feasible
•Able to suppress cost
•Not realizable only by specific technologies
•Social acceptability
•Social security
Present
Renewable energy
Nuclear energy
(With ultimate energy saving)
(With nuclear fuel cycle)

# 2. A concept of sustainability on resource consumption and environmental emissions

# Sustainability limitations of resources and emissions

We should ultimately stop using non-renewable resources and rely only on renewable resources. However, complete reliance on renewable resources is impossible in actual world. We need a more practical and acceptable idea than the excessive concept for sustainability. In this presentation, we propose a concept of sustainable resource use based on "changing rate" of consumption rather than "absolute value" of consumption. If efficiency of life cycle utilization of a non-renewable resource is steadily increased at a certain speed, decrease of R/P of the resource can be avoided even with utilizing the resource. We call this concept "sustainable limit", as is mathematically derived in the next.

# Sustainability limitations of resources and emissions

$R_0$ : Reserves of the resources at initial time period.
r : Rate of increase of $R_0$ by improvement of geophysical prospecting and mining.
$\mu_0$ : Life cycle IEB of the resources at initial time period.
a : Rate of increase of $\mu_0$.
$C_0$ : Rate of recyle of the resources at initial time period. Although recycle is physically impossible
in energy resources, it corresponds to the rate of cascading.
c : Rate of increase of $C_0$.
$P_0$ : Production of the resources at initial time period.
$D_0$ : Demand of the resources at initial time period.
b : Rate of increase of $D_0$.

As far as non-renewable resources are concerned, the sustainability condition is derived as follows. Suppose that grade of a resource is expressed in the function of $f(R,P)$=R/P, then the following equation is obtained by differentiating the function $f(R,P)$.

# Sustainability of resources and emissions

$$\frac{\partial f}{\partial t}=\lim_{\Delta t\to 0}\left[\frac{1}{\Delta t}\left[\frac{R_0\exp(r\Delta t)-\dfrac{D_0\left\{1-C_0\exp(c\Delta t)\right\}\exp\{(b-s)\Delta t\}}{\mu_0\exp(a\Delta t)}\cdot\Delta t}{\dfrac{D_0\left\{1-C_0\exp(c\Delta t)\right\}\exp\{(b-s)\Delta t\}}{\mu_0\exp(a\Delta t)}}-\frac{R_0}{D_0(1-C_0)\big/\mu_0}\right]\right] \tag{1}$$

$$=\lim_{\Delta t\to 0}\left[\frac{1}{\Delta t}\left[\frac{\mu_0 R_0}{D_0}\times\frac{\exp\{(a+s-b+r)\Delta t\}}{\{1-C_0\exp(c\Delta t)\}}-\Delta t-\frac{\mu_0 R_0}{D_0(1-C_0)}\right]\right]$$

$$=\frac{\mu_0 R_0}{D_0}\left\{\frac{a+s-b+r}{1-C_0}+\frac{C_0 c}{(1-C_0)^2}\right\}-1$$

$$a+r+s-b+\frac{C_0 c}{(1-C_0)}\geq\frac{D_0}{\mu_0 R_0}\;(1-C_0)=\frac{P_0}{R_0} \tag{2}$$

Condition (2) indicates that depletion of a non-renewable resource can be avoided if the left hand side including the factors of technological improvement is larger than the reciprocal number of $R_0/P_0$. Therefore we define this as a sustainability condition of a non-renewable resource.

(1) R／P of each resource is estimated based on proven reserves and production.

(2) Sustainability limitation of each resource is evaluated by Eq.(1) based on the above estimated R/P.

(3) The values in Eq.(1) are calculated as the average values during certain periods for mineral resources and for energy resources.

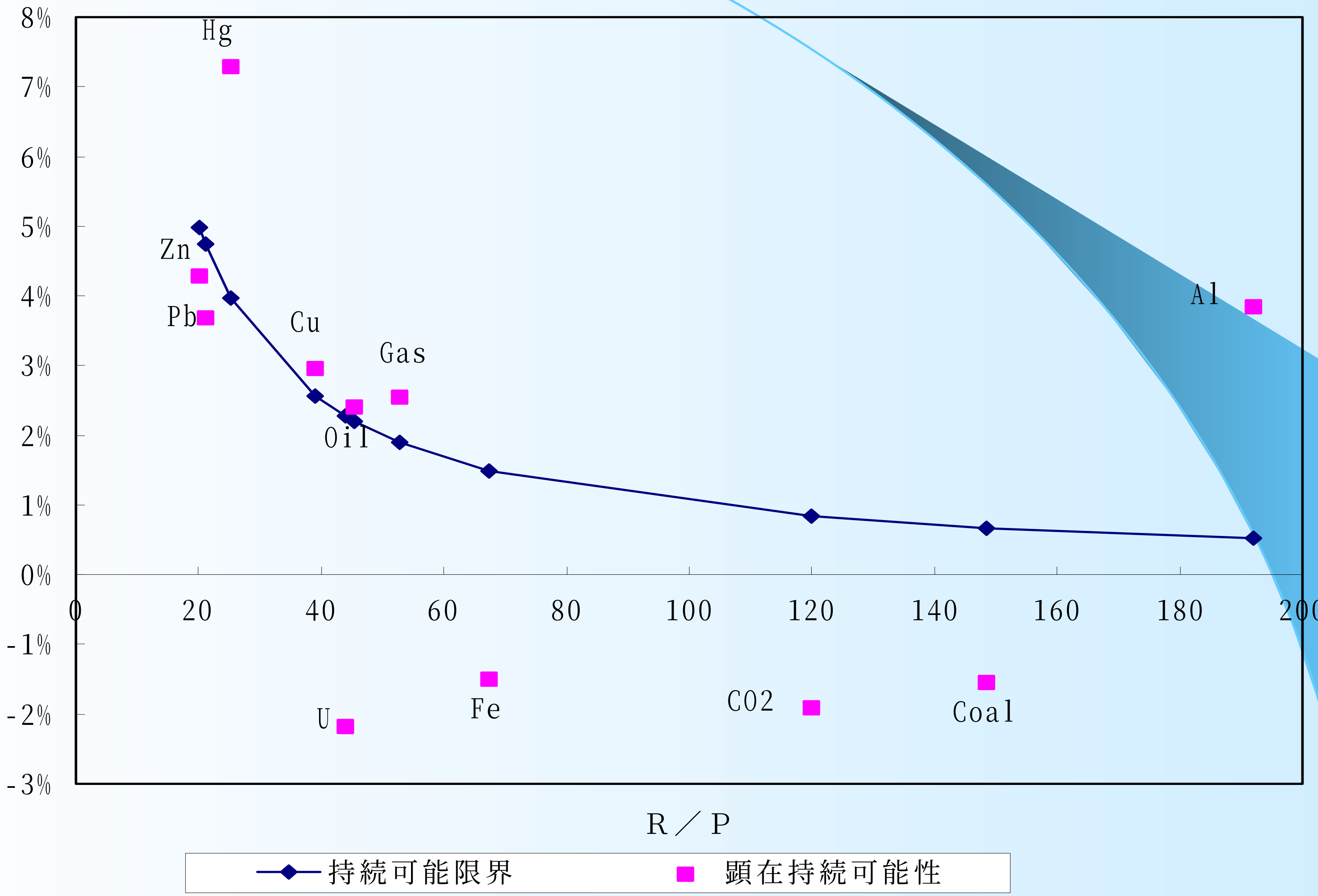
(4) We can evaluate the distance between sustainable condition and actual situation of each resource.　This distance is defined as actual unsustainability.

(5) Reserves of those resources are supposed to increase as exploring and mining technologies are improved. Therefore we evaluated the value of r in Eq.(1) assuming that the proven reserve of each resource will approach the ultimate reserve in fifty years.

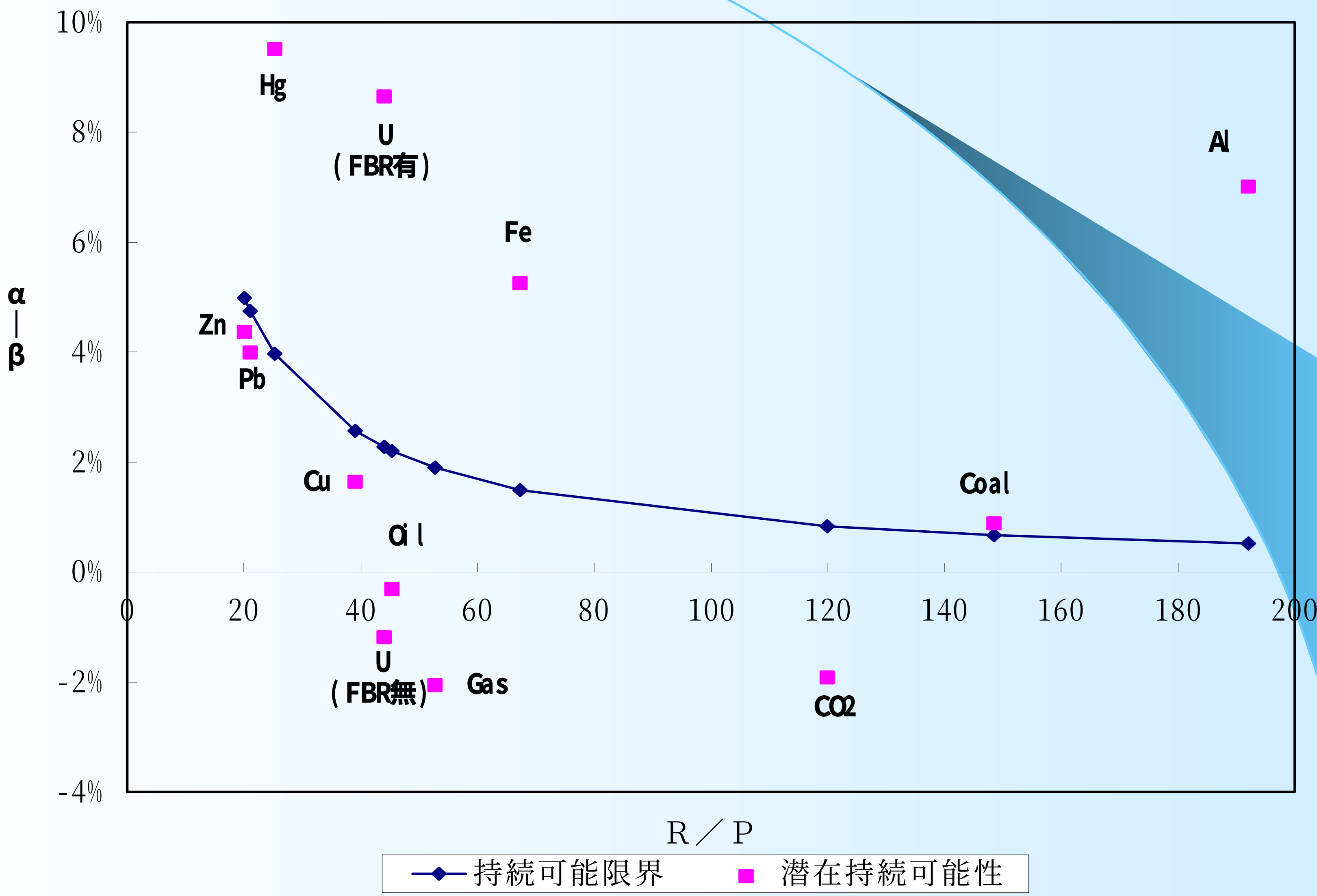
(6) Thus we can investigate the potential risk of depletion of each resource, which is defined as potential unsustainability.

(7) As far as $CO_2$ is concerned, sustainability limitations and present situation is assessed based on airborne fraction and maximum permissible accumulation in the atmosphere.　Maximum permissible accumulation is assumed to be 560 ppm, twice of that in pre-industrial era.

# Actual sustainability of resources and emissions



# Potential sustainaility of resources and emissions



# 3. Technology evaluation based on the sustainability and the role of nuclear fuel

# Economic comparison of mitigation options based on the sustainability

1. **We evaluate fossil-fired power plants with or without systems removing $CO_2$. We also evaluate solar power generating systems as representative renewable options.**
2. **We compare coal-fired power plants with and without systems to remove $CO_2$.**
3. **In the power plants with $CO_2$ removal systems, fuel input has to increase due to efficiency reduction caused by the energy requirement of removing the $CO_2$. This efficiency reduction is defined as the energy penalty.**

# Coal fired power plants with and without $CO_2$ removal systems

**Rprice : price of resource**
**Cprice : price of $CO_2$**
**EP : energy penalty ( 0.1〜0.3 )**
**REC : Rate of removing $CO_2$ ( approximately 0.9 in chemical absorption )**
**Cv : Variable cost of CFPS without $CO_2$ removal systems**
**ΔCf : Increase of fixed cost by adding $CO_2$ removal systems**

$$\Delta(CO_2) = \frac{REC - EP}{1 - EP} (t - C / year) \tag{12}$$

$$\Delta(Cost) = \frac{EP}{1 - EP} C_v + \Delta C_f \quad (yen / year) \tag{13}$$

$$\frac{EP}{1 - EP} \cdot C_v + \Delta C_f \leq \frac{REC - EP}{1 - EP} \cdot Cprice - \frac{EP}{1 - EP} \cdot Rprice \tag{14}$$

# Economic comparison between solar power generation systems and coal fired power stations

**EB** : **Integrated energy balance of photovoltaics**

**CP** : **Ratio of fixed cost of solar power generation systems to that of coal fired power stations**

$$\Delta(CO_2) = 1 - \frac{1}{EB} = \frac{EB-1}{EB} \quad (t-C/year) \tag{15}$$

$$\Delta(Cost) = (CP-1)C_f - \frac{\mathrm{EB\text{-}1}}{\mathrm{EB}} C_v \quad (yen/year) \tag{16}$$

$$(CP-1)C_f - \frac{\mathrm{EB\text{-}1}}{\mathrm{EB}} C_v \leq \frac{EB-1}{EB} Cprice + \frac{EB-1}{EB} Rprice \tag{17}$$

# Economic comparison of mitigation options based on the sustainability

1. These evaluations have identified the region, in which each energy technology is the most economical. The figure shows the economical regions of the evaluated measures.
2. The area A expresses the economic region of conventional coal-fired power plant.
3. The area B expresses its economic region with $CO_2$ sequestration system.
4. As far as PV systems are concerned, the area C expresses its economic region.

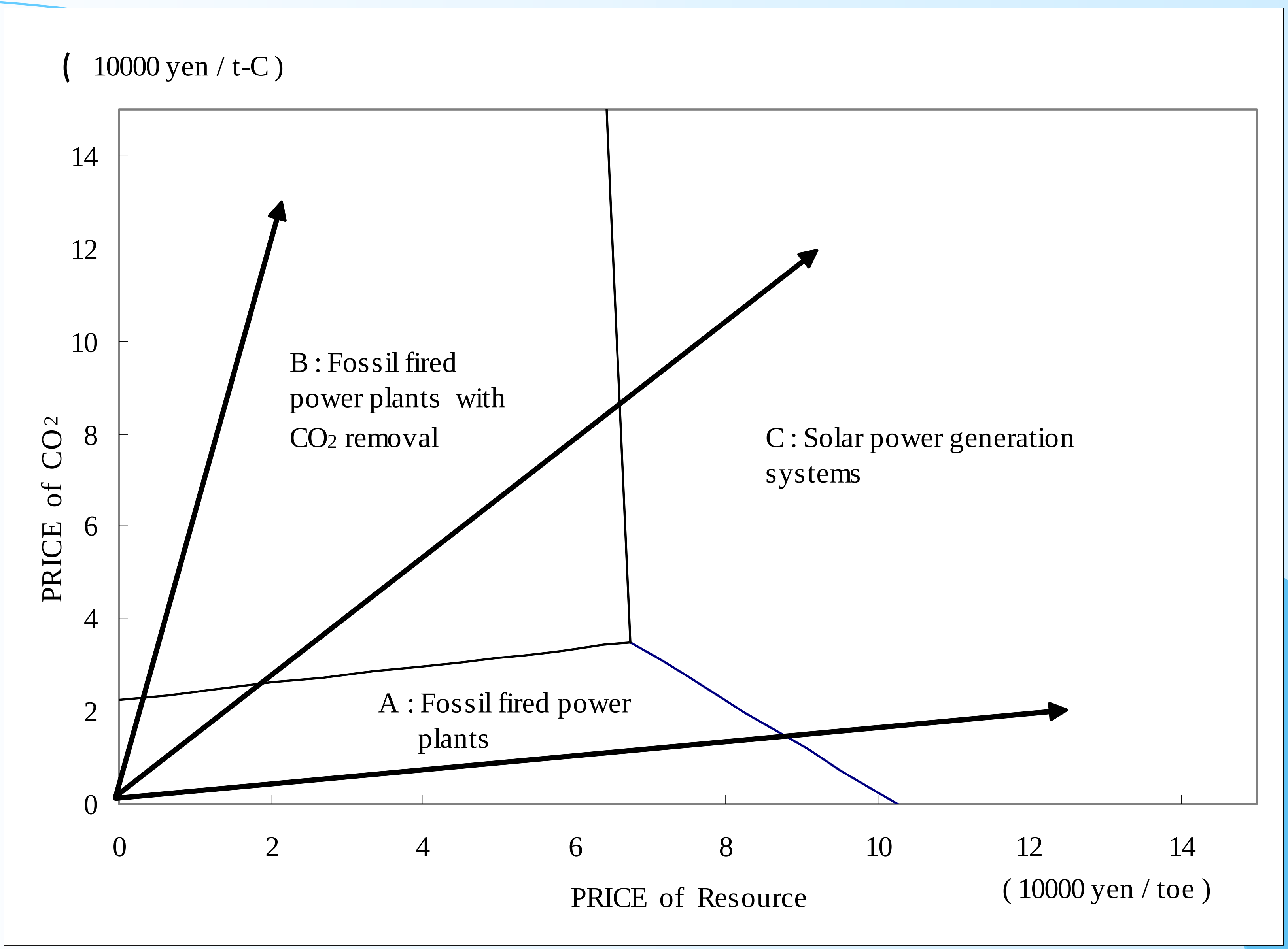



**Figure. Economical regions of the evaluated technologies**

## Long-term energy scenarios and Nuclear options

1. **Nuclear technologies could be a strong relievers in the 21st century.**

2. **As back stop technologies, nuclear fuel would compete with some other technologies, such as renewable technologies.**

3. **So as to be the strongest relievers, nuclear society has to solve the issues on nuclear proliferation and public acceptance.**

# Conclusions

1. A long-term energy vision of METI, Japan was explained.

2. We proposed a concept of sustainability and then applied the concept to technology evaluation.

3. Role of nuclear fuel in the sustainable energy scenarios was explored.