The Way to a Zero Emission Society

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Basic target in addressing climate change

Stabilization of global surface temperature

We should achieve this target regardless of what temperature we set as the limit of temperature rise in future

⇒ How do we achieve this target ?

Greenhouse effect of GHGs

1. Main 3 GHGs (CO2, CH4, N2O)

   See next page

2. Montreal gases

   Developed countries: scheduled not to use these by 2020

   Developing countries: scheduled not to use these by 2030

Greenhouse effect of the constant emission of GHGs

The amount remaining in the air

$$\sum A \exp(-\gamma t) = \frac{A}{\gamma}(1 - \exp(-\gamma T))$$

$$\rightarrow \frac{A}{\gamma} \text{ (constant value)}$$

The above result indicates that GHGs of shorter life time will saturate at constant level

earlier and

increase in GHG effect → increase in temperature

will become to zero.

About 3 main GHGs

1. Life time in the air

   CO_2 20~30% several thousand years

   CH_4 12 years

   N_2O 114 years

2. Their impacts on the global temperature

   CH_4, N_2O: become zero unless large increase in their emissions

   <u>CO_2: keeps the impact of temperature increase in the long run</u>

→ CO2 zero emission is indispensable for stabilization of the global temperature in the long run

Fig. Relation between cumulative CO2 emission and the rise in global surface temperature

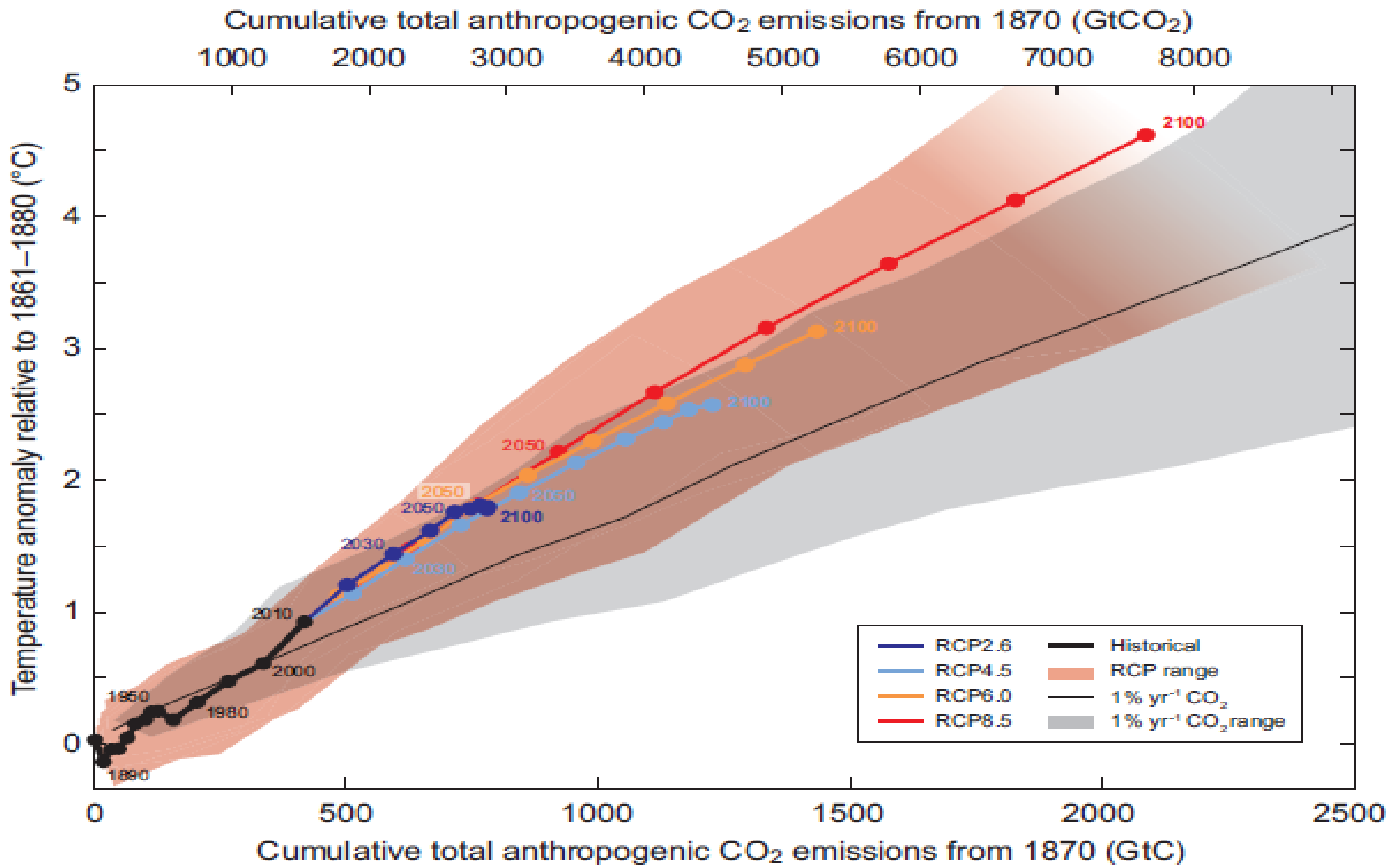


Figure SPM.10 | Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence. Multi-model results from a hierarchy of climate-carbon cycle models for each RCP until 2100 are shown with coloured lines and decadal means (dots). Some decadal means are labeled for clarity (e.g., 2050 indicating the decade 2040–2049). Model results over the historical period (1860 to 2010) are indicated in black. The coloured plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. The multi-model mean and range simulated by CMIP5 models, forced by a CO_2 increase of 1% per year (1% yr^{-1} CO_2 simulations), is given by the thin black line and grey area. For a specific amount of cumulative CO_2 emissions, the 1% per year CO_2 simulations exhibit lower warming than those driven by RCPs, which include additional non-CO_2 forcings. Temperature values are given relative to the 1861–1880 base period, emissions relative to 1870. Decadal averages are connected by straight lines. For further technical details see the Technical Summary Supplementary Material. {Figure 12.45; TS TFE.8, Figure 1}

Source: IPCC AR5 WG1, SPM, 2013

Stabilization of the global surface temperature and zero emission - suggestion by IPCC --

Cumulative total emission of CO_2 and global mean surface temperature response are approximately linearly related

(IPCC AR5 WG1 SPM p.27)

⇒ To Stabilize the temperature requires to make CO_2 emission approximately zero.

Note: In the past anthropogenic absorption of CO_2 was almost zero, so only CO_2 emission was mentioned here. If CO_2 absorption is taken into account the target is to make net anthropogenic emission of CO_2 to be zero.

CO2 anthropogenic absorption(1) -past example-

The amount of CO2 absorption by forest（Kyoto protocol）

country	Amount of CO2 recognized	ratio to the total emission
Russia	33Mton CO2 /y	4．0%
Japan	32	3．9
Canada	12	7．3

Note: only countries of which the recognized amount of CO2 by forest absorption are larger than 1Mton/y

CO2 anthropogenic absorption (2) - actual measures being planned -

In IPCC scenarios satisfying 2 degree target
BECCS (Biomass CCS) or AR (Afforestation) will be introduced by 2100.
amount: 3.3 Gton C.
→ land area required: 380 ~ 700 Mha*
(*source: Smith, P. et al: Nature C.C. vol.6,2016)
This is 30~50% of the entire arable land area in the world.
・・・low realizability due to competition with food production

Desirable direction of the world

1. Except CCS for fossil fuel use it is hard to realize large anthropogenic absorption of GHGs in future.

↓

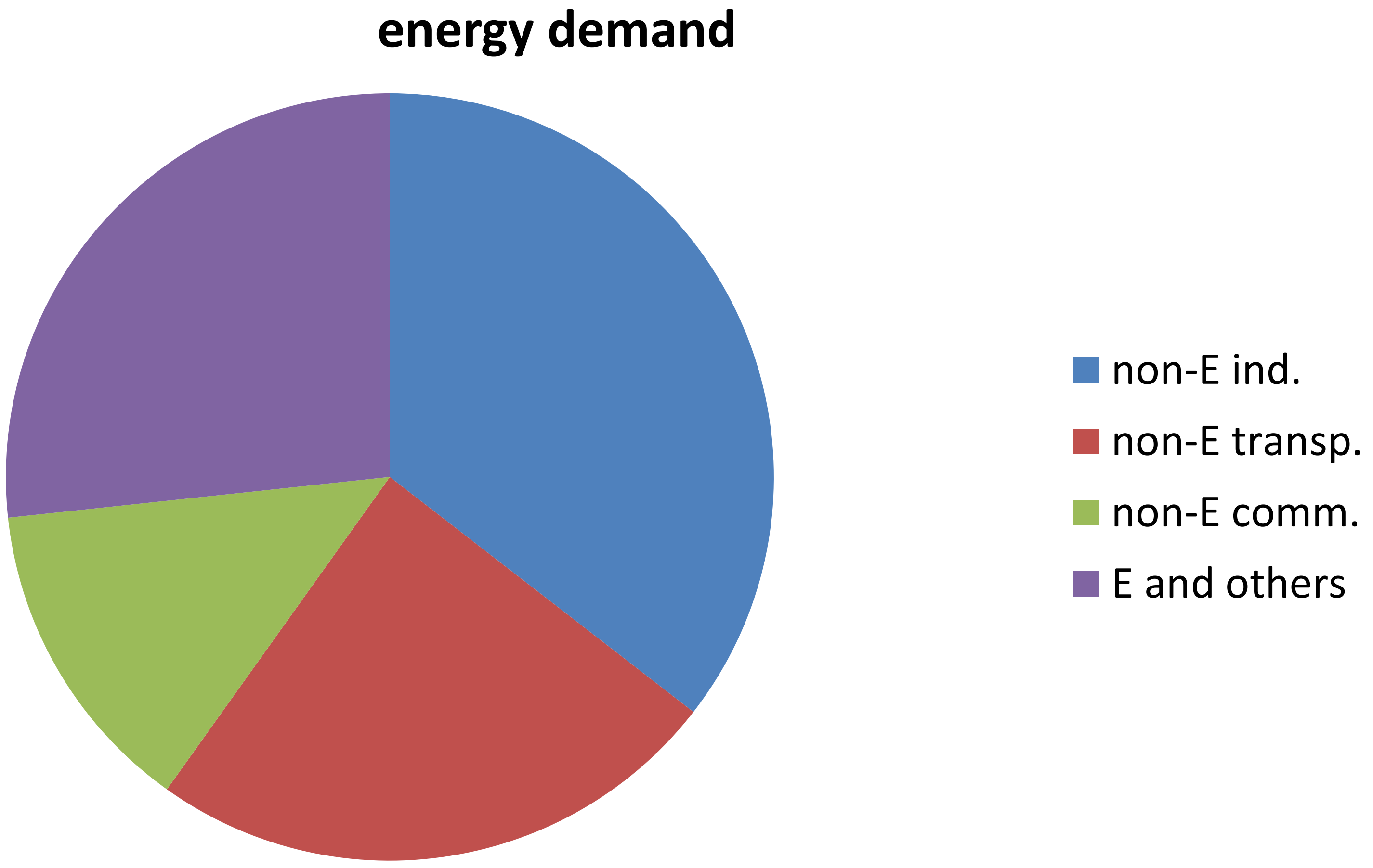
2. Make efforts for realizing zero anthropogenic emission of CO_2

↓

3. Make efforts for realizing zero emission of CO_2 from fossil fuels
(Regardless of how much the temperature target is)

Note: CCS of CO_2 from fossil fuels is to be included in the efforts for reduction in CO_2 emission.

Structure of energy demand, Japan (2013)



Details of non-electric energy demands of Japan (2013)

	ratio to the total demand
１. Industrial demand	35 ％
２. Transportation demand	24
automobiles	
airplanes	
Ships	
３. Residential and commercial demand	13

Note: demands for airplanes and ships are only those for domestic transportation. International transportation demand, particularly of Ships are relatively large.

Characteristics of energy demand

１．Demand can be divided into electric and non-electric demands.
２．More than 99% of non-electric demand are covered by fossil fuels.
３．CO2 in energy sector is emitted from fossil fuels.
４．Therefore CO2 zero emission should be covered by either of the following three measures.
  １）Coverage of non-electric demand by non-fossil fuels
  ２）Substitution of fossil fuels for power generation by non-fossil fuels
  ３）introduction of CCS into fossil fuel fired power plants
５．Fossil fuels occupy more than 80% of the world primary energy.

Since realization of CO2 zero emission is a drastic revolution of energy systems, we have to expect that it takes a long time.

⇒ necessity of step by step approach (to be described later)

Non-fossil fuels substituting fossil fuels

Candidates are:

１）bio-fuels

First generation ━food based

Second generation━non-food based
（cellulose)

２）hydrogen

３）electric power

2) 3) are secondary energies, therefore what are their primary energies is the key concern.

Investigation of non-electric industrial demand

1. Non-electric industrial demands are mainly
   direct heating,
   steam and/or hot water generation and etc.
   Temperature ranges between several tens and several thousands degrees in Celsius.
2. These demands may be covered by electric power, hydrogen or bio-fuels. Which is appropriate depends upon demands (and processes) and further investigation is indispensable.

Future non-electric transportation fuels

1. Automobiles

   Electric power（EV), hydrogen（FCV) are applicable to automobiles.

   First generation biofuels are already utilized . (Their neat use is still a matter of investigation)

   About second generation biofuels are to be investigated including the transformation into hydrogen.

2. Airplanes

   1) Application of second generation biofuels are now at the stage of R&D.

   2) Electric power: may be limited due to available batteries.

   3) Hydrogen: may be applicable but to be investigated.

3. Ships

   1) Biofuels: may be utilized but to be investigated.

   2) Electric power: limited due to available batteries.

   3) Hydrogen: probably not applicable due to the size of turbines.

Future treatment of non-electric residential and commercial demands

1.Non-electric demands are the following types.

1)air conditioning 2)water heating 3) cooking

２．The temperature range of air conditioning and water heating is lower than 100℃, and they can be supported by heat pumps operated by electric power.

３．Theoretically cooking can be managed by electric power including IH(Inductive Heater). However how to deal with traditional cooking such as those using blaze are to be investigated.

On primary energy for hydrogen

１. There are 3 choices.

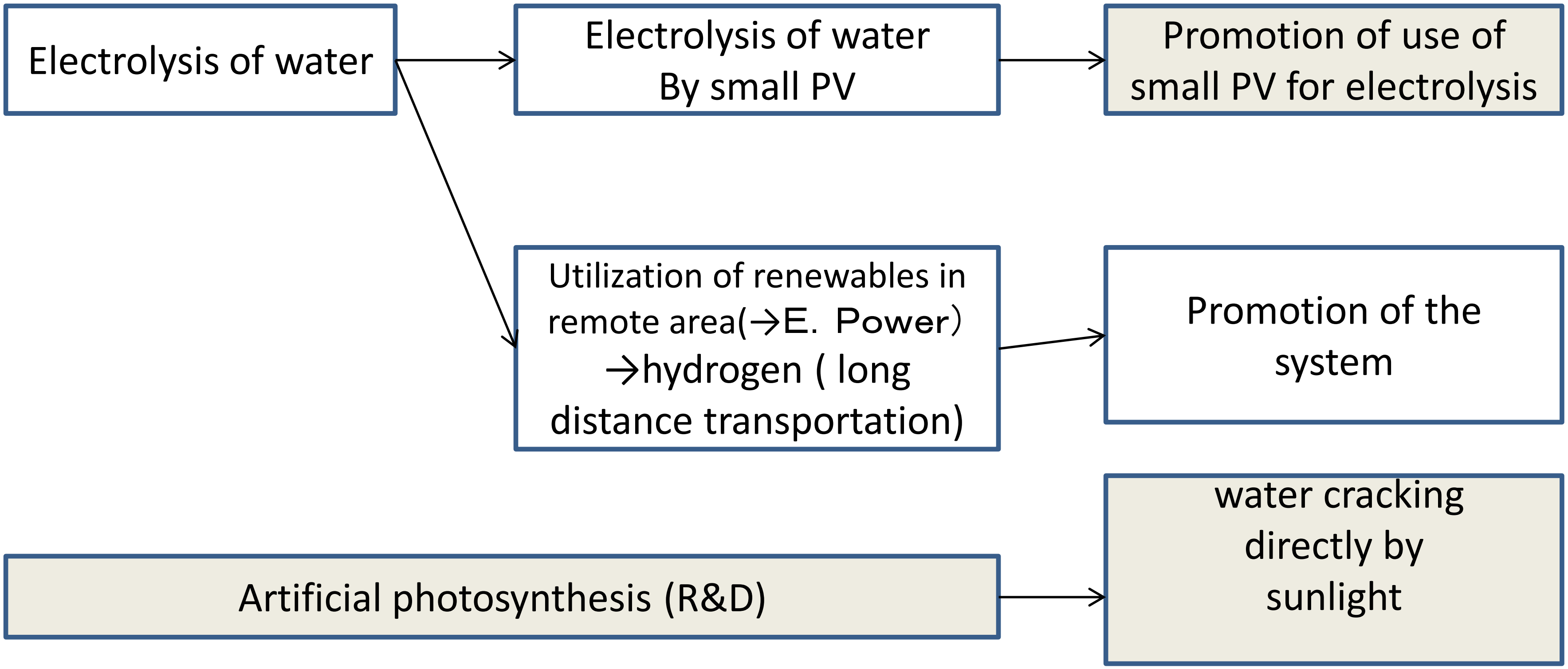
１）Electrolysis of water

２）Thermo-chemical cracking of water via nuclear heat (high temperature gas reactor)

３） Use of fossil fuels for cracking of water with CCS

２. There are various constraints in choices 2) and 3). Rather we should choose 1) with the condition of utilizing low carbon electric power.

＜Future of hydrogen production＞



Non fossil fuels for power generation(1)
- basic understanding -

1. About 70% of fuels for power generation are fossil fuels.
2. For decarbonization of fossil fuel plants introduction of CCS is indispensable.
3. At present the following non carbon energies are used:
   1) nuclear power
   2) renewables

4. Expansion of nuclear power more than several tens % of the total power is not easy in most countries, and the choice is then <u>mostly expansion of renewables</u>.

Non fossil fuels for power generation(2) - expansion of renewables -

1.Irregular fluctuation of outputs taken into account either of the following choices are indispensable.

choice 1: introduction of fossil fuel power plants with CCS

choice 2: introduction of large scale storages

2. Taking the limitation of introducing CCS into account we should make more efforts for R&D of choice 2 .

_1) large scale batteries (NaS batteries etc.)

2) development of chemical storage systems

Ex. Dimethyl ether (DME) : total efficiency 50~60%

energy density: almost 10 times larger than those of batteries

source: Gencer,E. et al, Energy Policy, 88, Jan 2016

Fossil fuel fired plants and CCS

1. Introduction of huge amount of renewables into the power grid requires the facilities to adjust demand-supply balance of electric power.

   Fossil fuel fired plants and power storages have the ability for this adjustment.
2. In the future zero emission society fossil fuel fired plants can be utilized only with CCS.

CCS（CO2 capture and storage)

1. History of CCS

１）It has been utilized in the form of EOR (Enhanced Oil Recovery)mainly in USA.

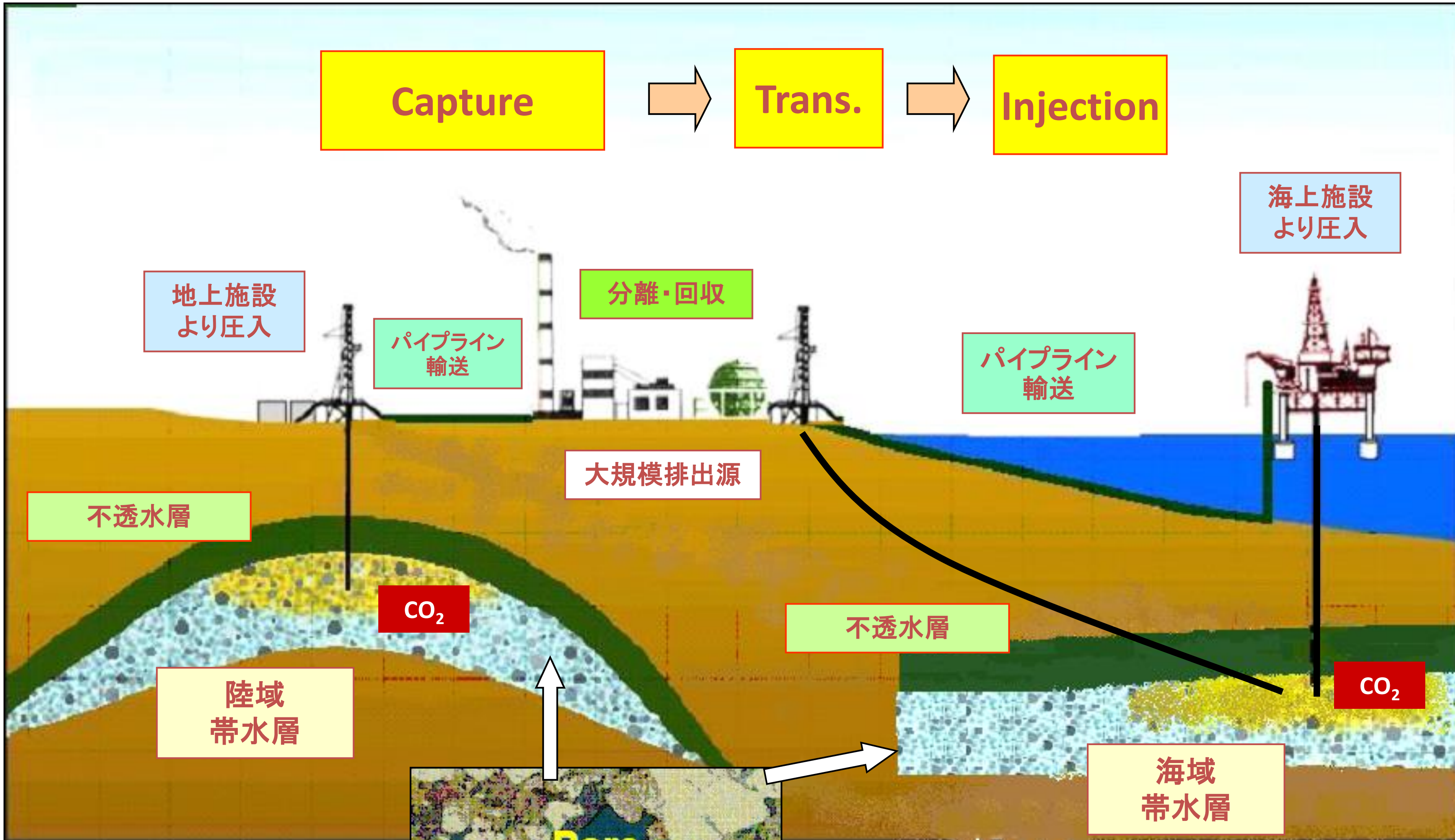
２）In 1996 CO2 accompanied by natural gas from Sleipner gas field in North sea was stored in the underground of sea bottom. (1Mton CO2/year)

2. Future direction

CO2 captured at fossil fuel fired power plants→ stored in the underground.

This will make the plants to be zero emission plants.

The structure of CCS system



Detailed picture of aquifer

CO2 is stored in the pore.

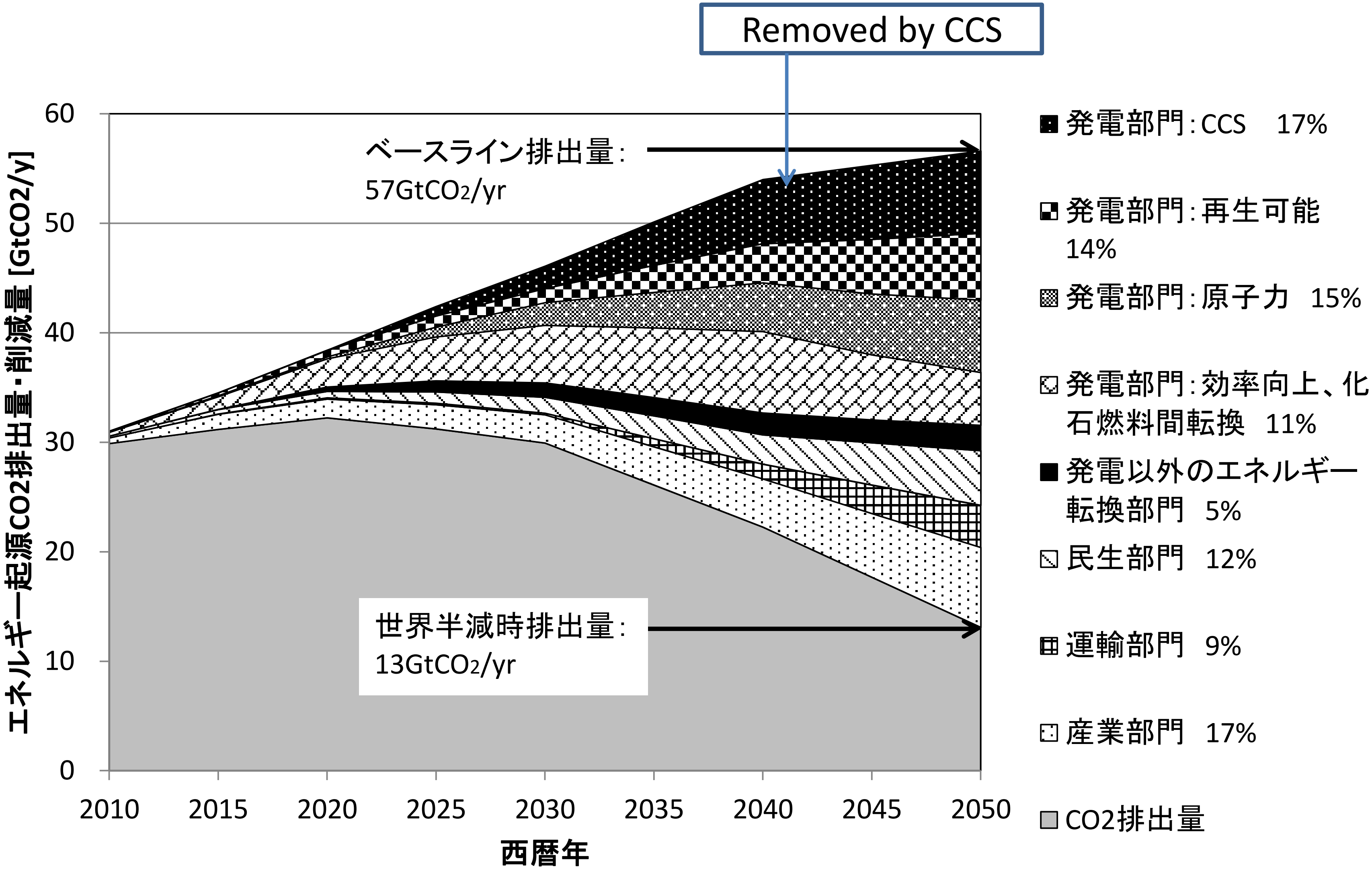


Fig. The scenario for halving CO2 emission by 2050
(via RITE DNE21+ model)

CCS: merits and problems

１. merit

CO2 zero emission plant can be realizable by employing CCS.

２. problems

１）At present CCS is relatively expensive：

several tens dollars/ton CO2 or more

→ power price will be elevated at least by several cents / kWh.

２）Public acceptance around storage sites.

Possibility of drastic increase in future electric power demand

As mentioned before non-electric power demands will be in future covered by electric power, hydrogen, and/or biofuels.

It is highly probable that hydrogen will in future be produced by electric power (electrolysis of water).

→ electric power demand +
electric power replacing non electric demand +
electric power producing hydrogen

⟶ **Drastic increase in electric power demand in future**

Response to drastic increase in future power demand

1. Mid term future
   1) renewables + large-scale power storage
   2) large-scale concentrated solar power (CSP)
2. Long term future
   1) Space solar power systems (SPS)
   2) Nuclear fusion systems

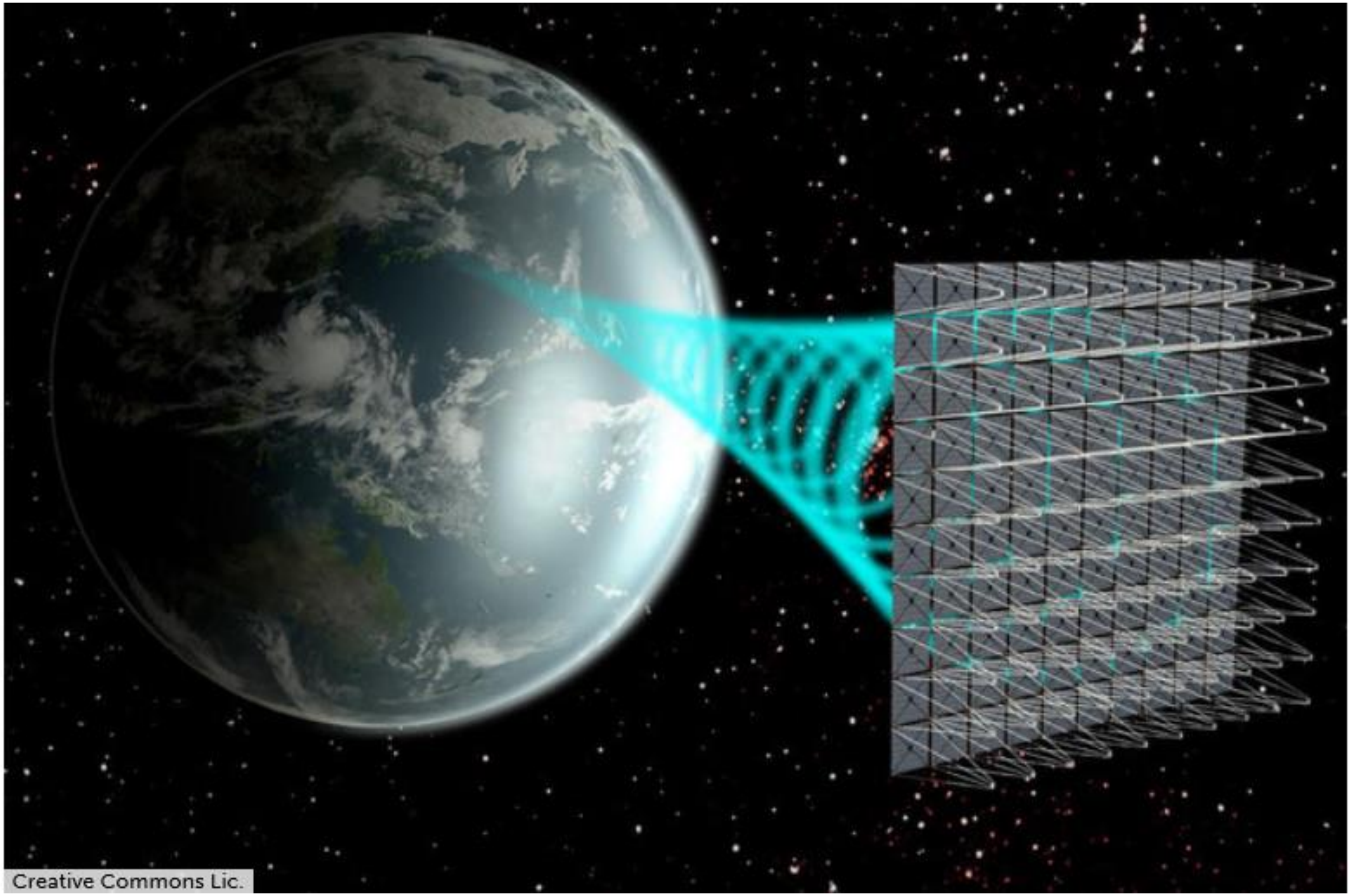


Fig. Image of space solar system (SPS)

Main features of space solar system(SPS)

１. Due to its location on stationary orbit of 38,000km far from the earth the relative location of SPS and the rectenna on the earth is fixed.

２. Since the power from SPS will be transported by microwave to the earth the power will be received with little turbulence by clouds. (lower than 20GHz)

３. The key is how to reduce high costs of facilities, transportation by rockets and of construction of the system in the space.

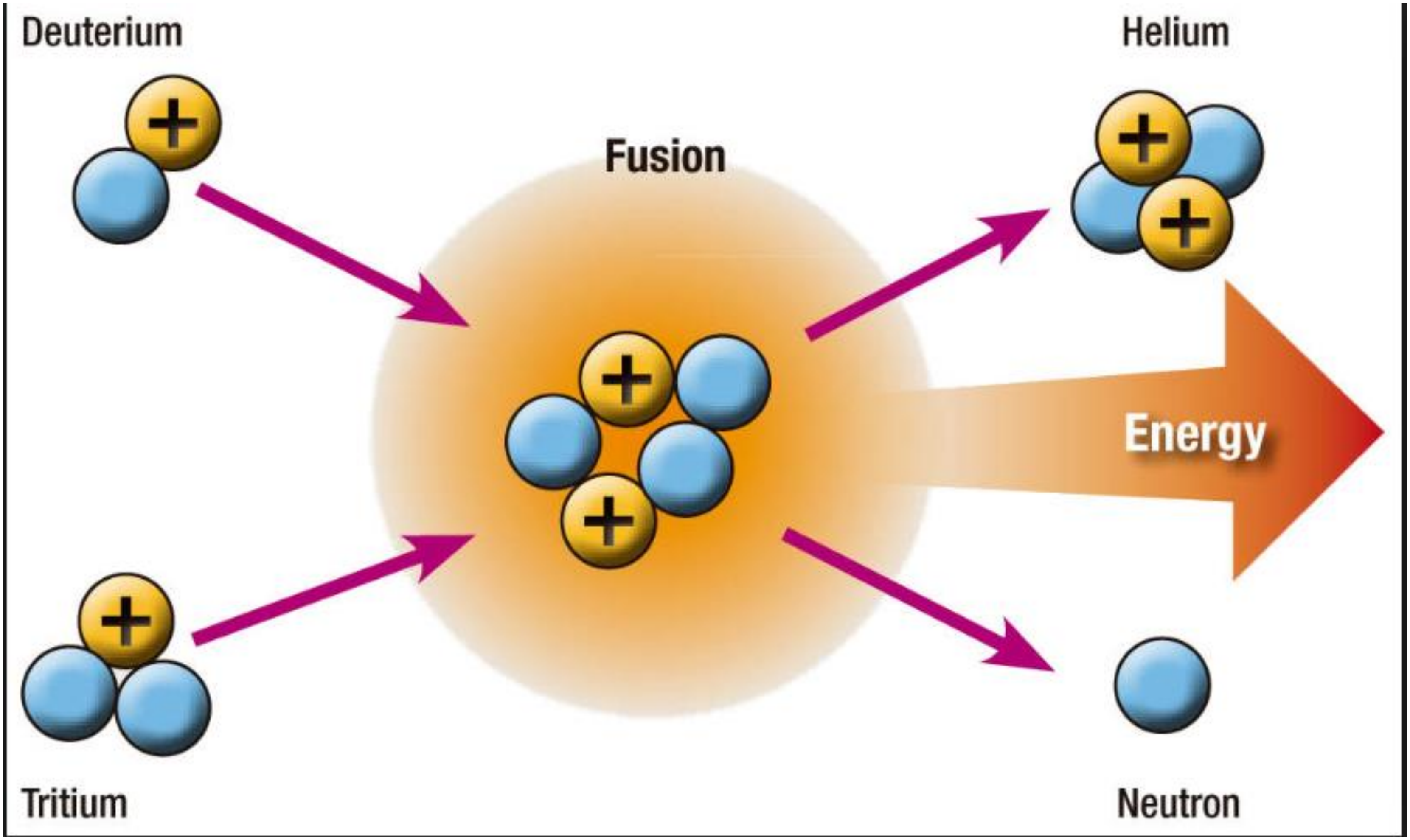


Fig. Principle of nuclear fusion

The PS10 solar power plant in Andalucía, Spain, concentrates sunlight from a field of heliostats onto a central solar power tower.

Features of concentrated solar power(CSP)

１. Power output can be stabilized due to heat storage.
２. Basic technologies are already developed. More than 3 GW plants are in operation around the world.
３. Power produced in deserts ー dry area → long distance transmission → demand area
Large scale power generation /transmission can be realized in the above scheme.

Example：Dessertec plan imagined in the early stage of 21 century
Sahara desert CSP → DC transmission → Europe
In the plan about 1/15 of the total European demand will be covered. It was however suspended due to political instability around Sahara area.

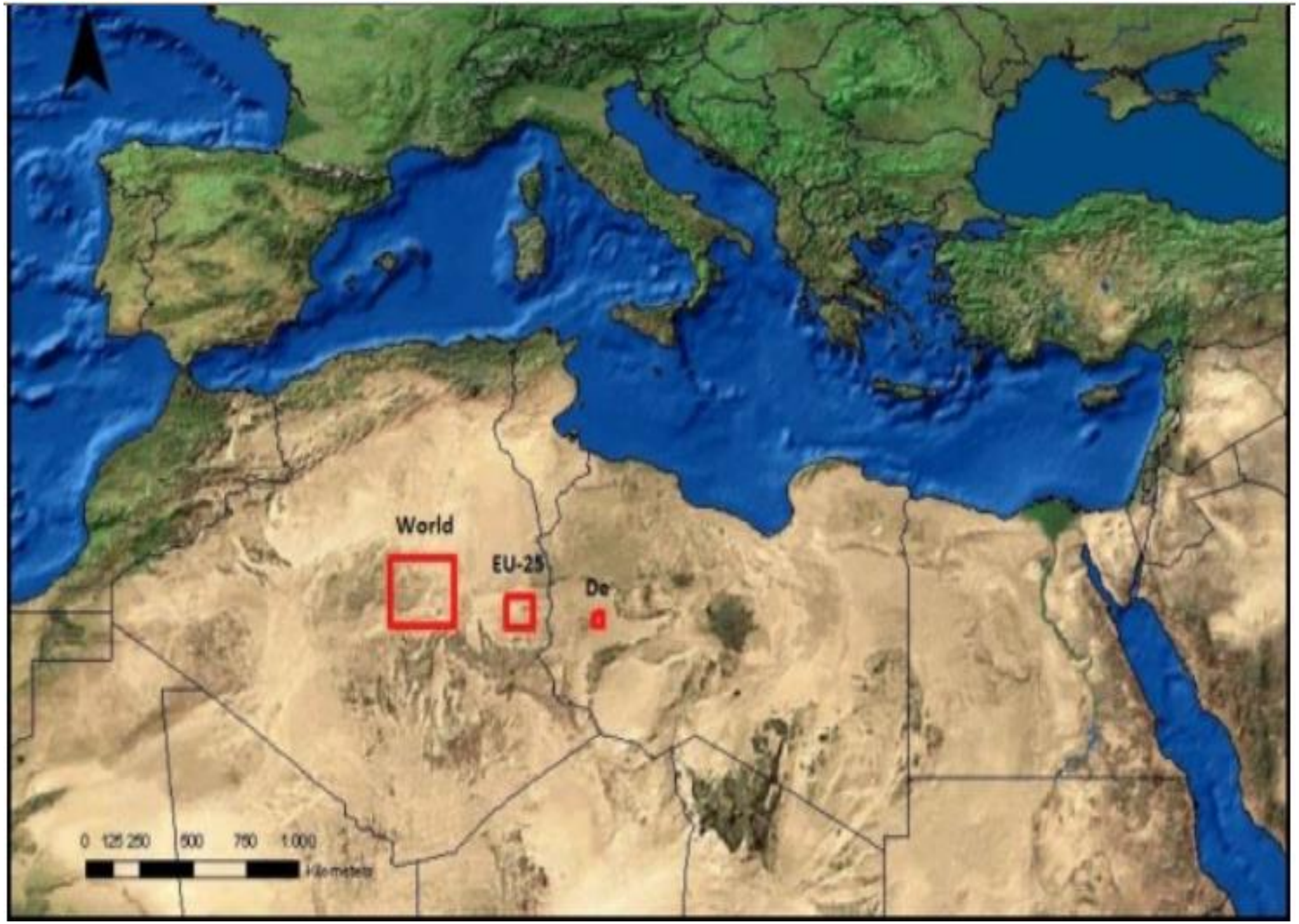
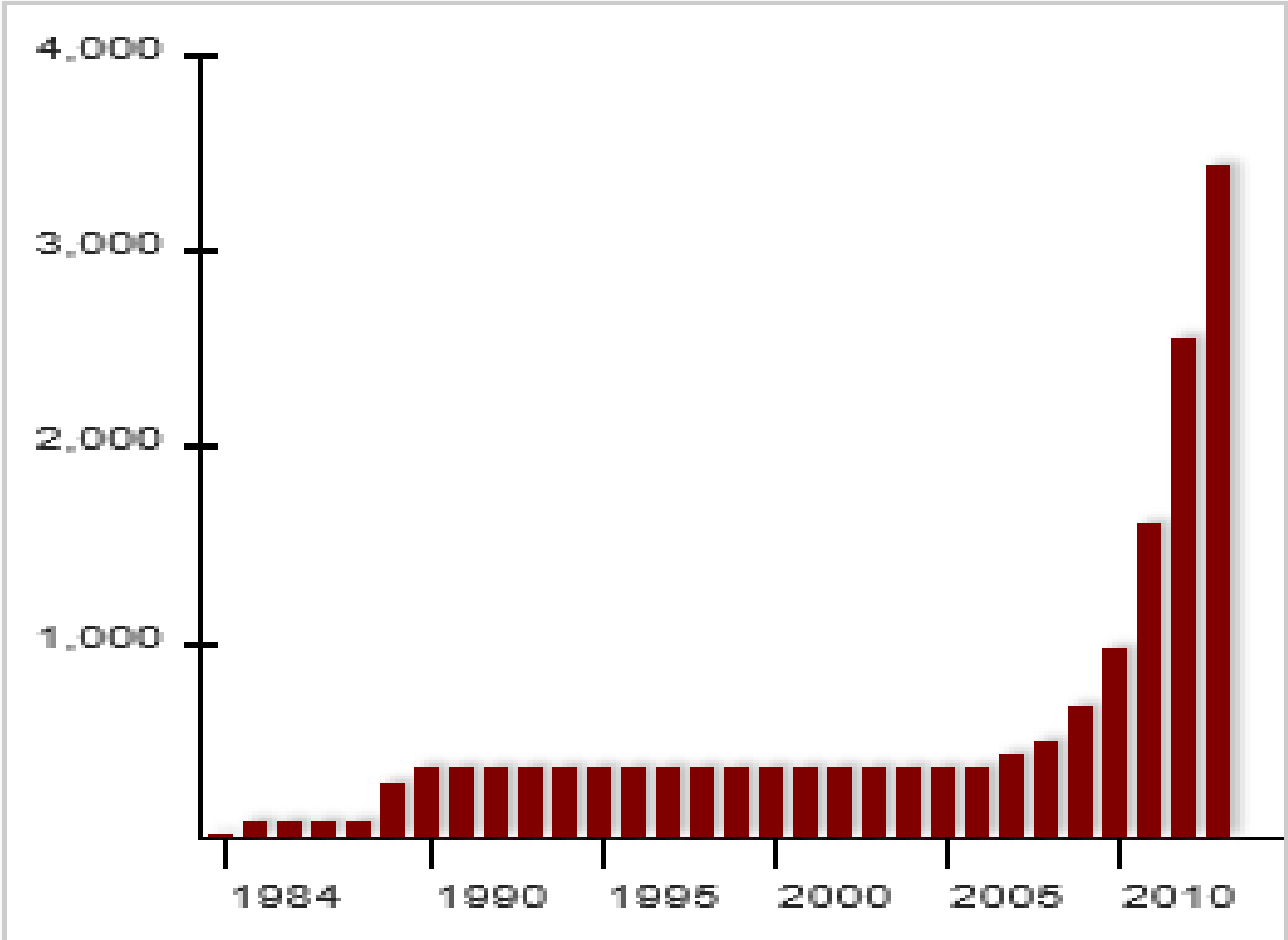


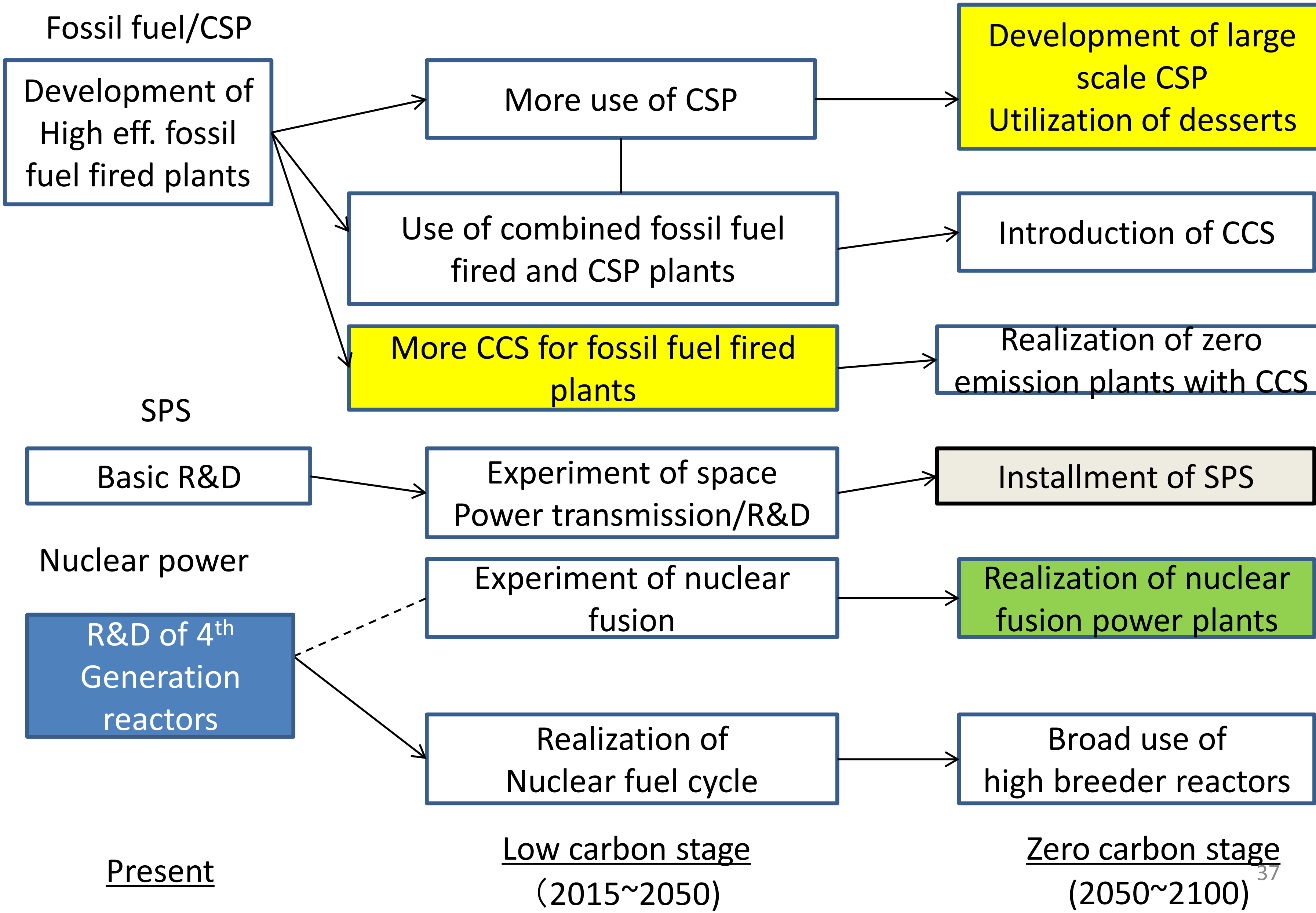
Fig. The area to be covered by CSP：In case of Sahara desert
（from Dessertec plan）

MW



Worldwide CSP capacity since 1984 in MW_p

< power generation technologies>



Final remarks

１. Ultimate goal in addressing climate change：
Achievement of net zero anthropogenic emission of CO_2

２. We should make efforts for 1) decarbonization of non-electric industrial demand, 2) decarbonization of transportation demand , and 3) decarbonization of power generation.

３. The road map from present to net zero emission stage via low emission stage should be established.

４. Key middle term technologies include large scale renewables with large scale storage systems, the second generation biofuels and large scale concentrated power systems (CSP).

５. Key long term, large scale technologies include space power systems (SPS) and nuclear fusion which should be developed via international collaboration.