Global Focus Lecture: Energy and the Earth Environment

THE ROLE OF TECHNOLOGY IN ENERGY & EARTH ENVIRONMENT ISSUES

By

Kenji Yamaji

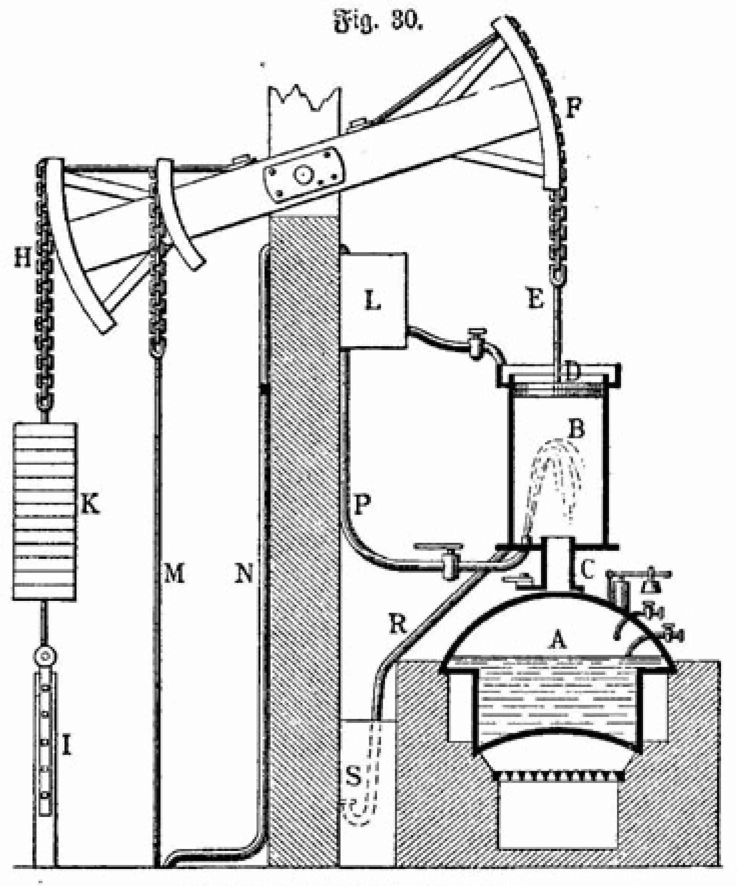
(October 22, 29 and November 5)

- **The Perspectives of Energy Systems**
- **Energy Resources and Technology**
- **Long-term Technological Scenario against Global Warming**

Energy Resources and Technology

- -Development of Energy Technology Started with Power Revolution
- -Availability of Fossil Fuel Resources
- -Atomic Power (Nuclear Fission and Fusion) Technology and Resources
- - Supply Capability of Natural Energy and Technology
- -Energy Technology to Be Watched

Start of Power Revolution

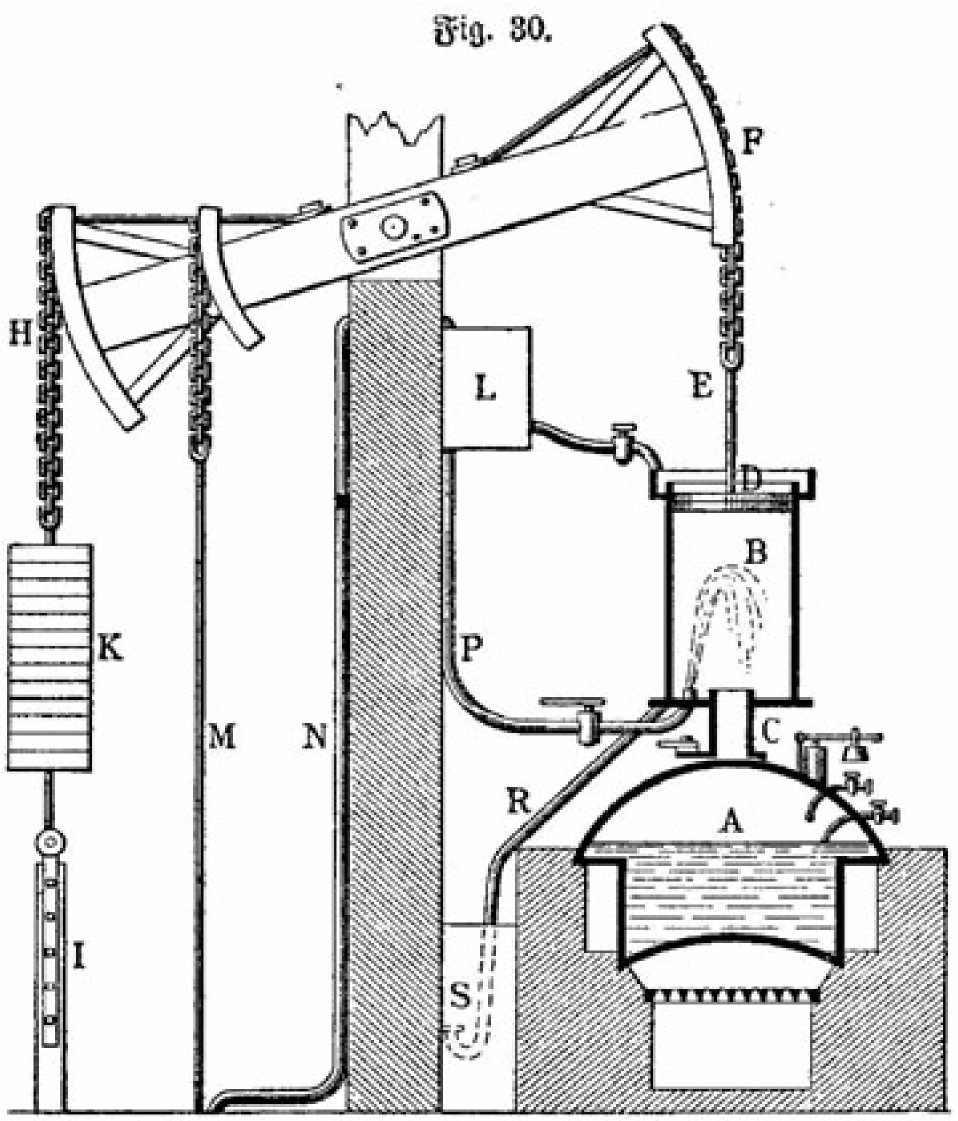


Newcomens Dampfmaschine.

Newcomen’s steam engine (utilizing vacuum power)

Source：http://upload.wikimedia.org/wikipedia/commons/8/8e/Newcomens_Dampfmaschine_aus_Meyers_1890.png

Newcomen's Steam Engine



Newcomens Dampfmaschine.

Source：http://upload.wikimedia.org/wikipedia/commons/8/8e/Newcomens_Dampfmaschine_aus_Meyers_1890.png

From Power Revolution to the Age of Electricity and Cars

1712: Newcomen: steam engine
1769: Watt: separator-condenser (?) patented
1800: Volta: battery
1814: Stephenson: steam locomotive
1831: Faraday: the law of electro-genetic induction
1857: Colonel Drake: oil production
1860: Renoir: practical gas engine
1876: Otto: 4-cycle engine →1885: Daimler: petrol engine
1879: Edison: carbon lamp; Siemens: electric train
1882: Edison: electric business (incorporated in 1881); power system
1884: Parsons: steam turbine
1895: Diesel: compression ignition engine (diesel engine)
1903: Wright brothers: airplane
1938: Hahn: discovery of nuclear fission
1942: Fermi: nuclear reactor
1944: Whittle: jet plane (gas turbine)
1965: Gemini No. 5 equipped with fuel cell

Steam engine
Electricity
Internal-combustion engine

Speed of Technological Progress (1)

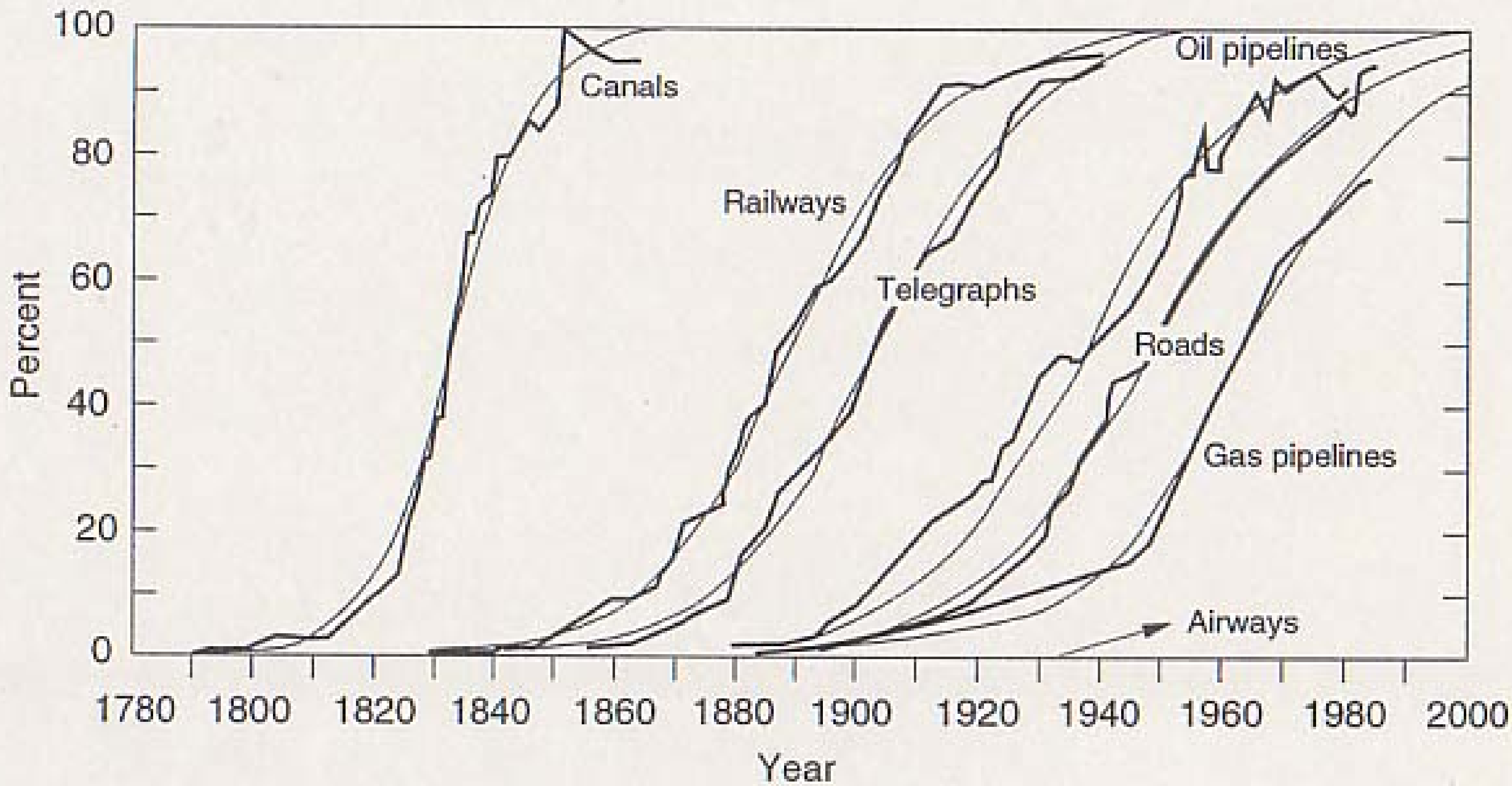


Figure 2.10: Growth of US transport infrastructures as a percentage of their maximum network size, empirical data (bold jagged lines) and model approximation (thin smooth lines). Source: Grübler and Nakićenović (1991). For the data of this graphic see the Appendix.

‡

Expanded transport networks in US ⇒ Slower infrastructure development

Source : A.Grubler: , Cambridge Univ. Press, 1998

Speed of Technological Progress (2)

Transition from Horses to Cars in U.S.

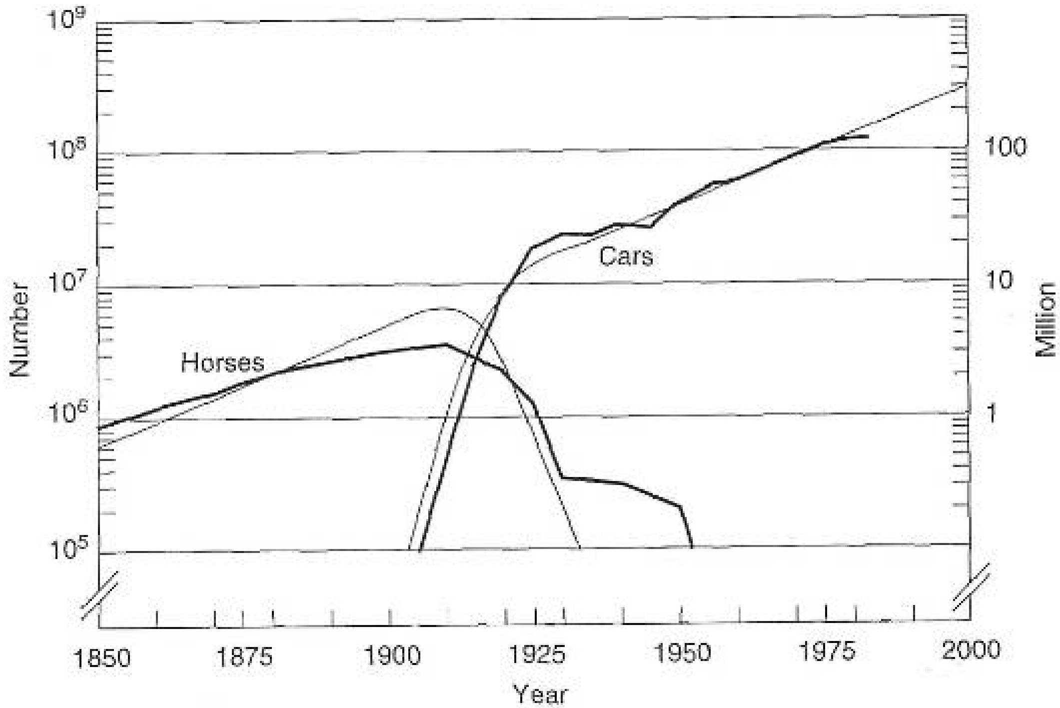


Figure 2.11: Number of (urban) draft animals (horses) and automobiles in the USA, empirical data (bold jagged lines) and estimates (thin smooth lines) from a logistic model of technological substitution. Source: Nakićenović (1986:321).

Model T: 16million cars for 1908—1926: corresponds

160GW introduction in less than 20 years assuming 10kW/car.

‡

Shift in transportation mode from horse-and-buggy to automobile (USA)
⇒Faster change in infrastructure technology

Source：A.Grubler: *Technology and Global Change*, Cambridge Univ. Press, 1998

Examples of Expanded Demand Brought by Technological Progress

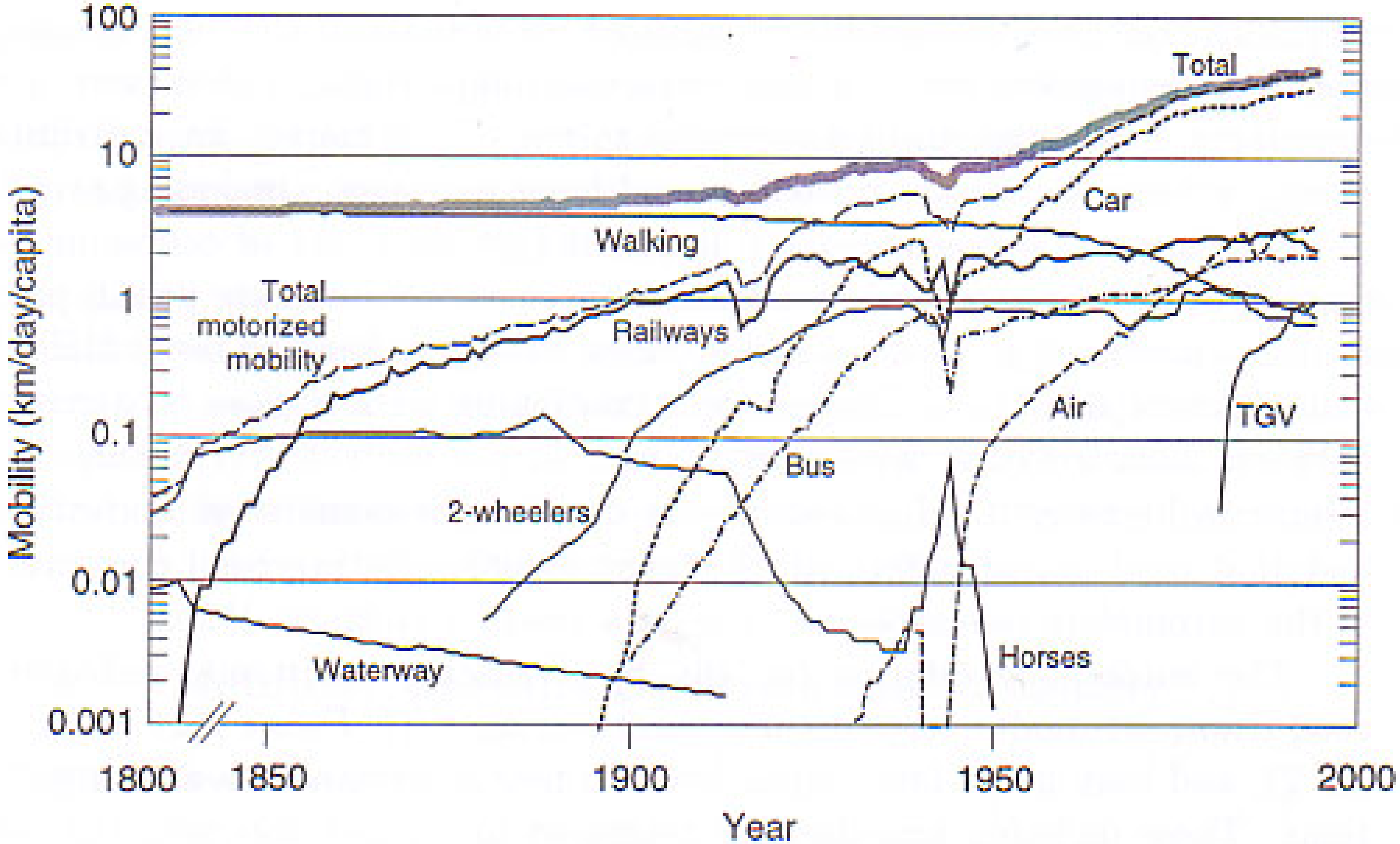


Figure 7.9: Daily mobility (passenger-kilometers traveled per person) in France since 1800, mobility by mode, and total motorized and aggregate mobility. Source: adapted from Grübler (1990a:232). For the data of this graphic see the Appendix.

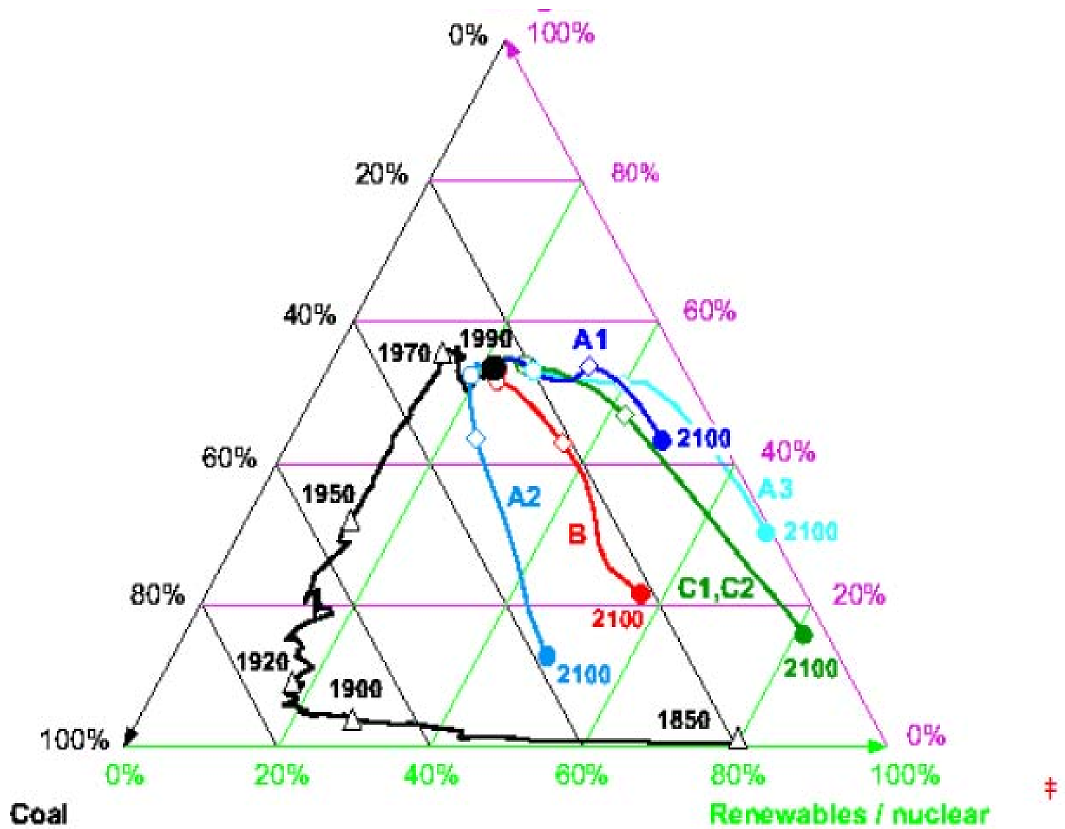
‡

Innovation in Transport Technology and Expanded Mobility Demand (France)

Source：A.Grubler: Technology and Global Change, Cambridge Univ. Press, 1998

Change in Composition of Global Primary Energy Resources, Including Non-commercial Energy: Past and Future Prospect

Figure 2: Evolution of primary energy structure, shares of oil and gas, coal, and non-fossil ources, in percent, historical development from 1850 to 1990 (triangles) and in scenarios to 2020 (open circles), 2050 (diamonds), and 2100 (closed circles). For an explanation of the figure see text.



Source: Kenji Yamaji, 2006, *Energy, Environment and Economic Systems*, Iwanami Shoten. Chart 2.4 (p.27).

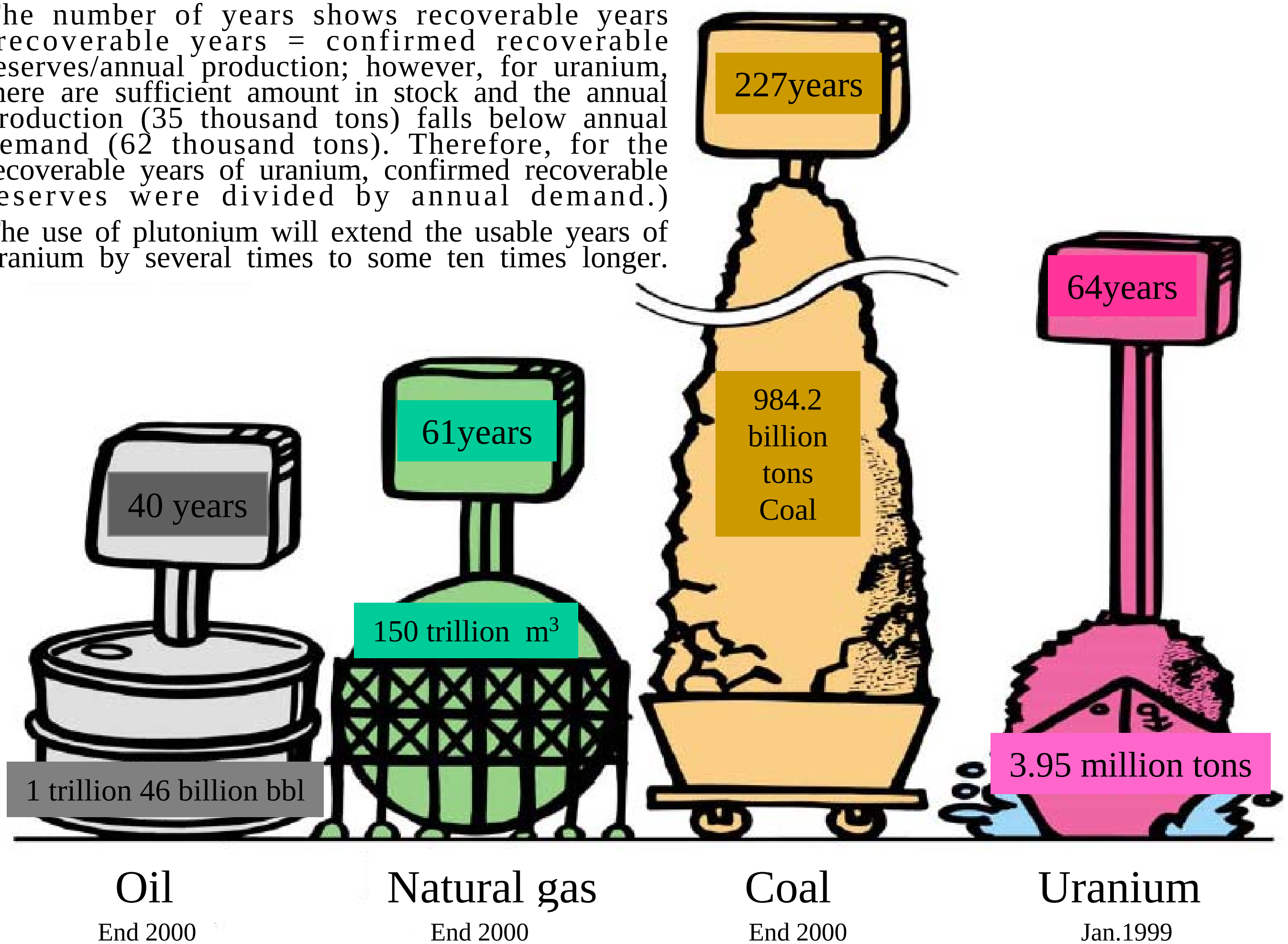
Definitions of Energy Resources

- -- Confirmed reserves
- -- Yet-to-be-discovered resources
- -- Ultimate amount of recoverable resources:
- Cumulative usage + confirmed reserves + resources to be discovered
- -- Collection cost and collection technology
- Primeval reserves, enhanced collection technology (EOR, etc.) …

Confirmed Reserves of Global Energy Resources

(Note 1) The number of years shows recoverable years (recoverable years = confirmed recoverable reserves/annual production; however, for uranium, there are sufficient amount in stock and the annual production (35 thousand tons) falls below annual demand (62 thousand tons). Therefore, for the recoverable years of uranium, confirmed recoverable reserves were divided by annual demand.)

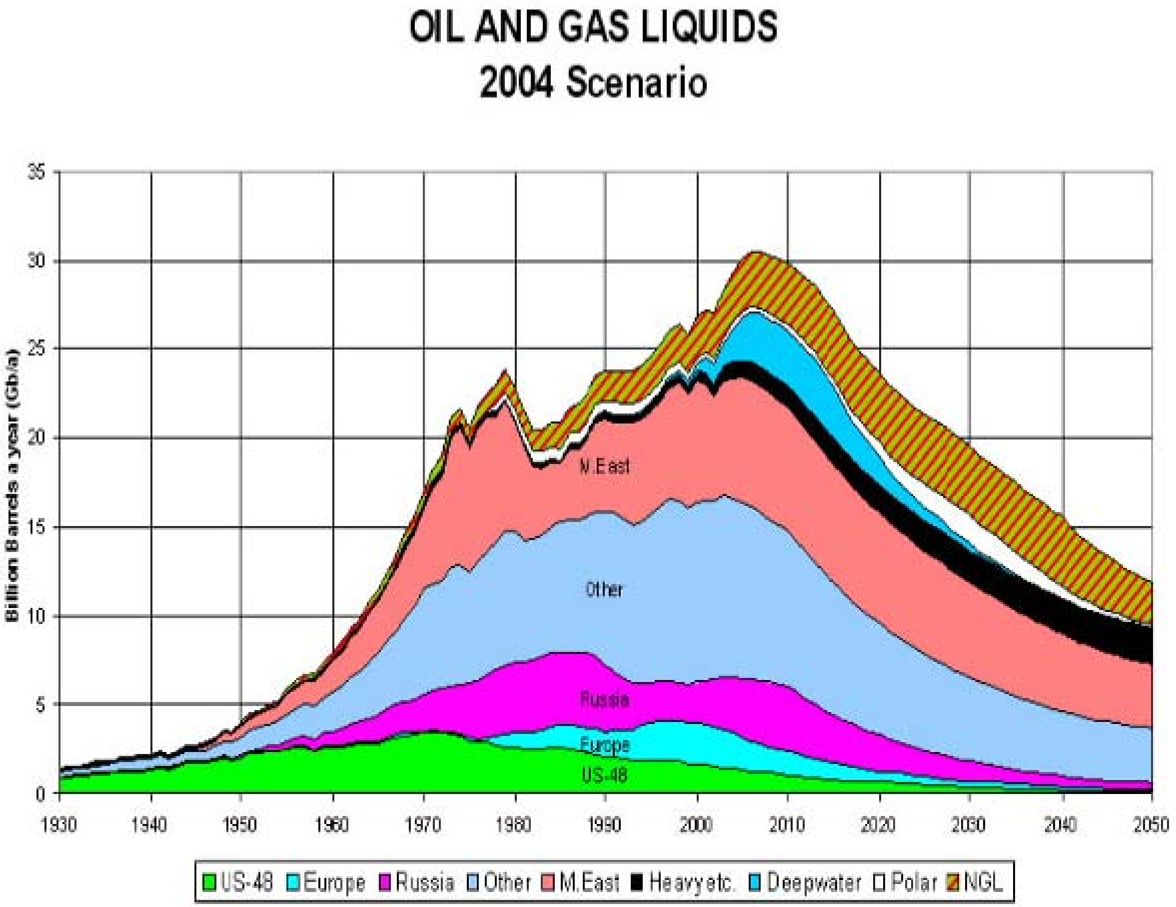
(Note 2) The use of plutonium will extend the usable years of uranium by several times to some ten times longer.



Source: Drawing Book of Nuclear Power and Energy?

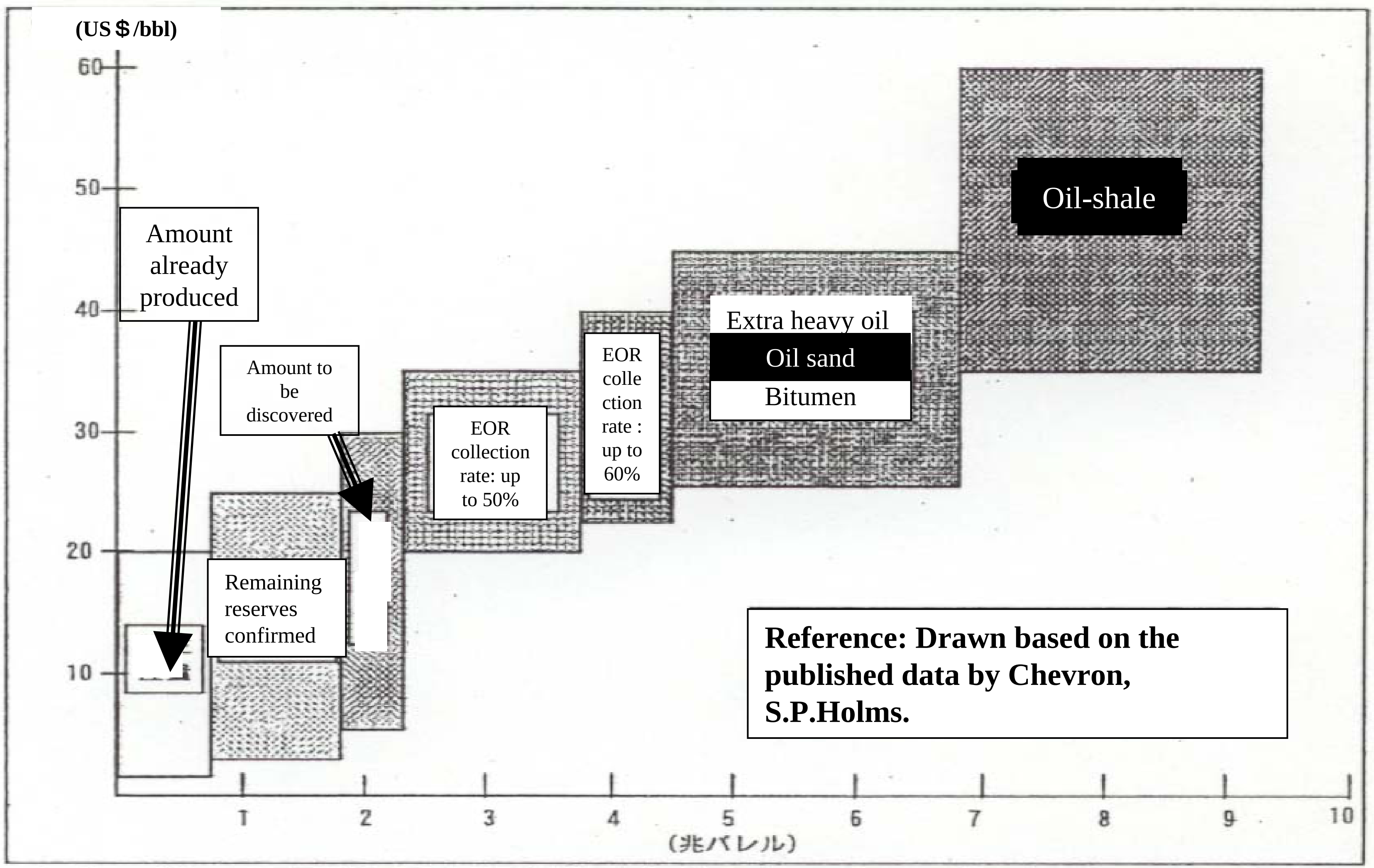
http://www.fepc-atomic.jp/library/zumen/pdf-data/all01.pdf

A View That Petroleum Peak Use Will Come Before 2010

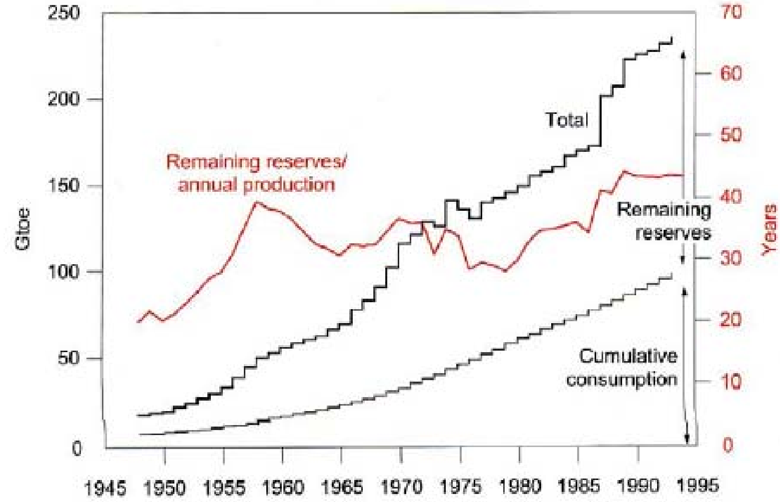


Source: Kenji Yamaji, 2006, *Energy, Environment and Economic Systems*, Iwanami Shoten. Chart 2-16 (p.45).

Relations Between Conventional/Unconventional Resources & Crude Oil Prices



Source :http://www. Meti. Go. jp/report/download files/g41004b02j.pdf,Report of Ministry of Economics, Trade & Industry (METI), p.19.



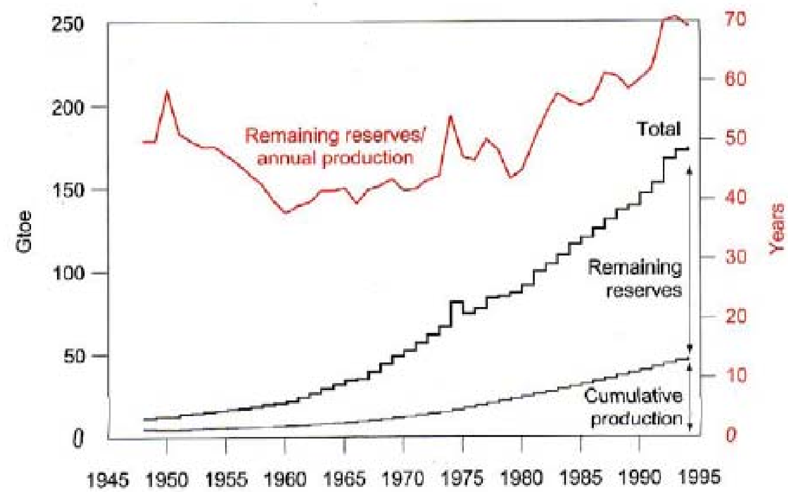


Figure 4.12: Technically and economically recoverable reserves and cumulative production of (*top*) conventional oil and (*bottom*) natural gas, in Gtoe. The increase in the reserve base despite growing production (i.e., the continuous replenishment of reserves from resources) is reflected in the stable or increasing reserve-to-production ratios shown in the figure.

‡ Source :N.Nakicenovic, et al.: Global Energy Perspectives, Cambridge Univ. Press, 1998 Fig.

Table 1: Global fossil and nuclear energy reserves, resources, and occurences, in Gtoe.

	Consumption[a] 1850–1990	Consumption[a] 1990	Reserves[b]	Resources[c]	Resource base[d]	Additional occurrences
Oil						
Conventional	90	3.2	150	145	295	
Unconventional	–	–	193	332	525	1 900
Natural gas						
Conventional[e]	41	1.7	141	279	420	
Unconventional	–	–	192	258	450	400
Hydrates[f]	–	–	–	–	–	18 700
Coal[g]	125	2.2	606	2 794	3 400	3 000
Total[h]	256	7.0	1 282	3 808	5 090	24 000
Uranium[i]	17	0.5	57	203	260	150
in FBRs[j]	–	–	3 390	12 150	15 550	8 900

Sources: Masters *et al.*, 1994; Nakićenović *et al.*, 1993; WEC, 1992; Grübler, 1991; MacDonald, 1990; Rogner, 1990; BP, 1995 and earlier volumes; BGR, 1989; Delahaye and Grenon, 1983.

– negligible amounts; blanks, data not available.

[a] Grübler and Nakićenović, 1992.

[b] Masters *et al.*, 1994; IPCC, 1995b; OECD/NEA and IAEA, 1995; WEC, 1993.

[c] Resources to be discovered or developed to reserves. Masters *et al.*, 1994 (upper range); IPCC, 1995; OECD/NEA and IAEA, 1995.

[d] Resource base is the sum of reserves and resources.

[e] Includes natural gas liquids.

[f] MacDonald, 1990; Kvenvolden, 1988 and 1993.

[g] WEC, 1993.

[h] All totals have been rounded.

[i] OECD/NEA and IAEA, 1995.

[j] Fast breeder reactors.

Source: N.Nakicenovic, et al.: Global Energy Perspectives, Cambridge Univ. Press, 1998, Table1, p52

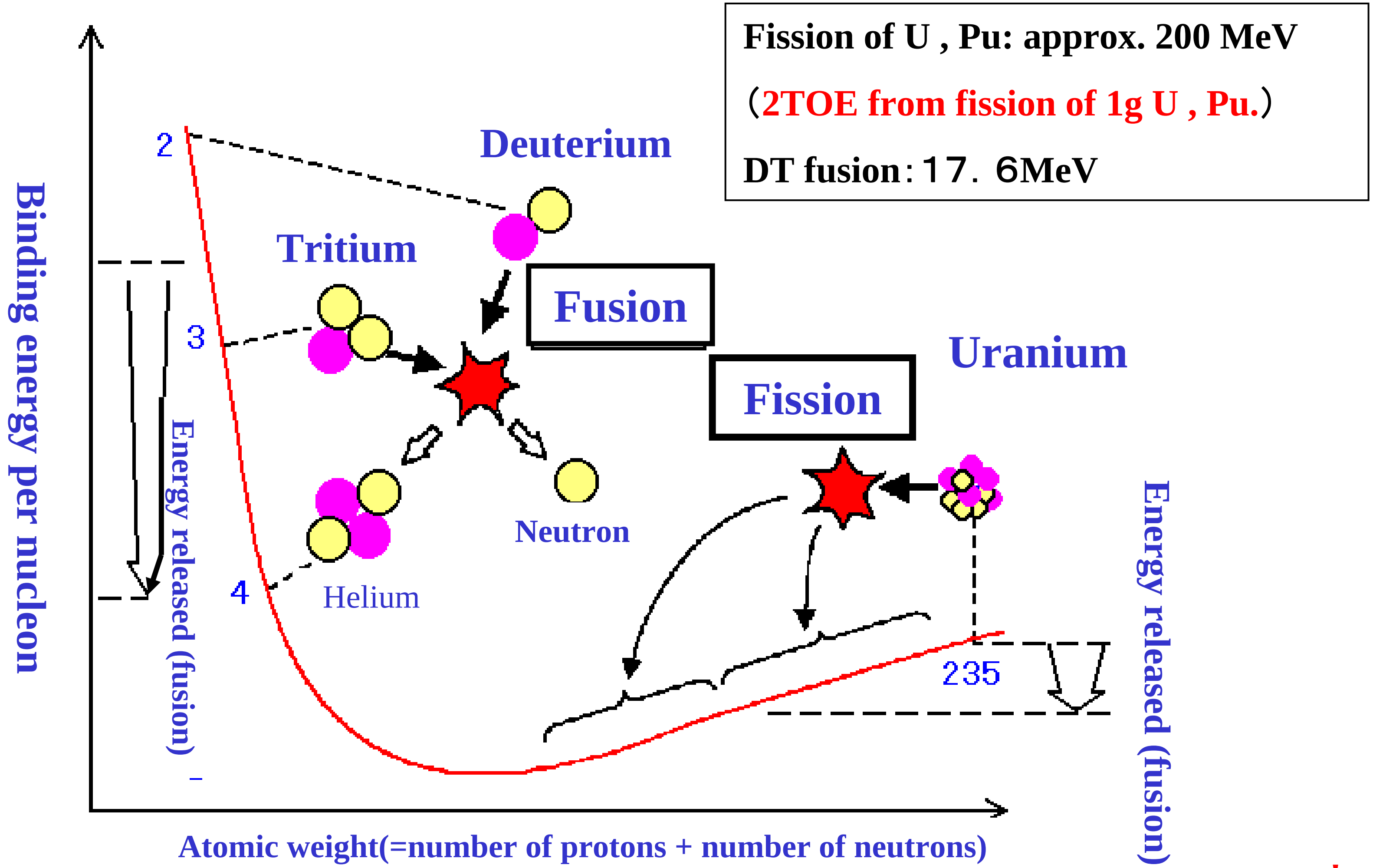


Chart 1. Inter-nucleon Binding Energy & Nuclear Reaction Energy

Source： Masao Kitunezaki: *Exposition: Nuclear Fusion*, JAERI-M 90-150, Japan Atomic Energy Research Institute, (May 1996), p.9, Chart 1.

Types of Fusion Reactions

$$D + D \rightarrow T(1.01\,\mathrm{MeV}) + p(3.03\,\mathrm{MeV})$$

$$D + D \rightarrow He^3(0.82\,\mathrm{MeV}) + n(2.45\,\mathrm{MeV})$$

$$T + D \rightarrow He^4(3.52\,\mathrm{MeV}) + n(14.06\,\mathrm{MeV})$$

: The reaction closest to practical application

$$D + He^3 \rightarrow He^4(3.67\,\mathrm{MeV}) + p(14.67\,\mathrm{MeV})$$

Neutron (n) emission will cause the material to activate.

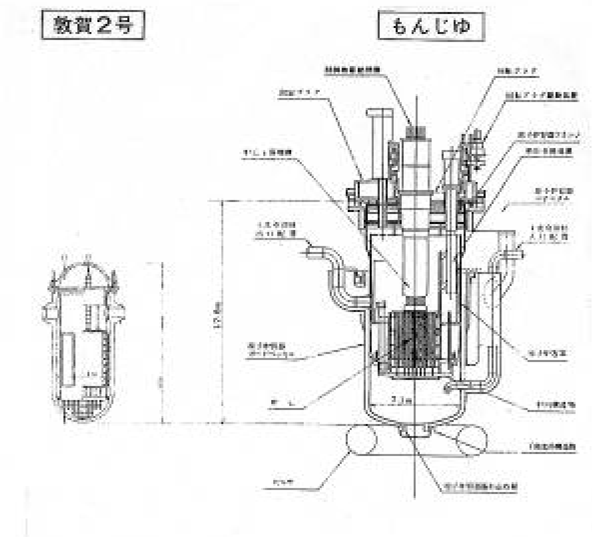
Since tritium (T) is not naturally-occurring, it needs to be produced from lithium.

$$Li^6 + n \rightarrow T + He^4 + 4.8\,\mathrm{MeV}$$

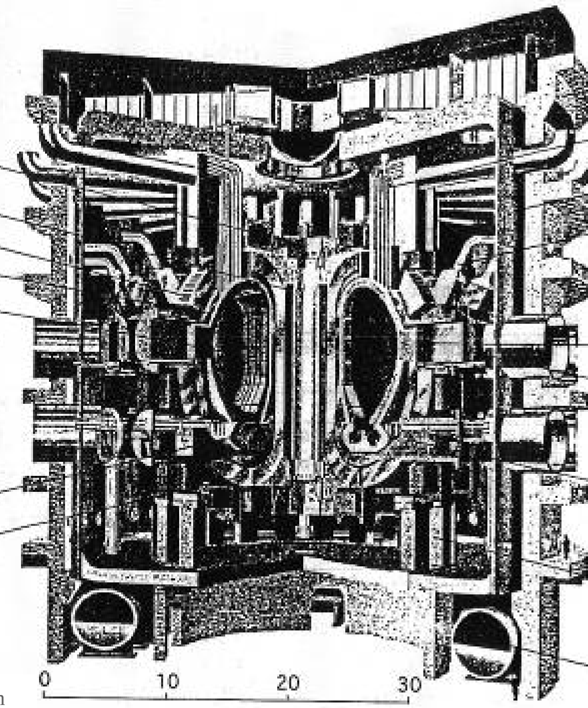
$$Li^7 + n(2.5\,\mathrm{MeV}) \rightarrow T + He^4 + n$$

Natural abundance ratio of lithium isotope
Li6/Li7=7/93

Will the Change Happen?
Light-Water Reactor→Fast-Breeder Reactor→Fusion Reactor
LWR, FBR and Fusion Reactor



Comparison of reactor vessel size of Tsuruga No.2 and Monju



Tsuruga No.2 (PWR): Electrical output of 1.16 million kWe

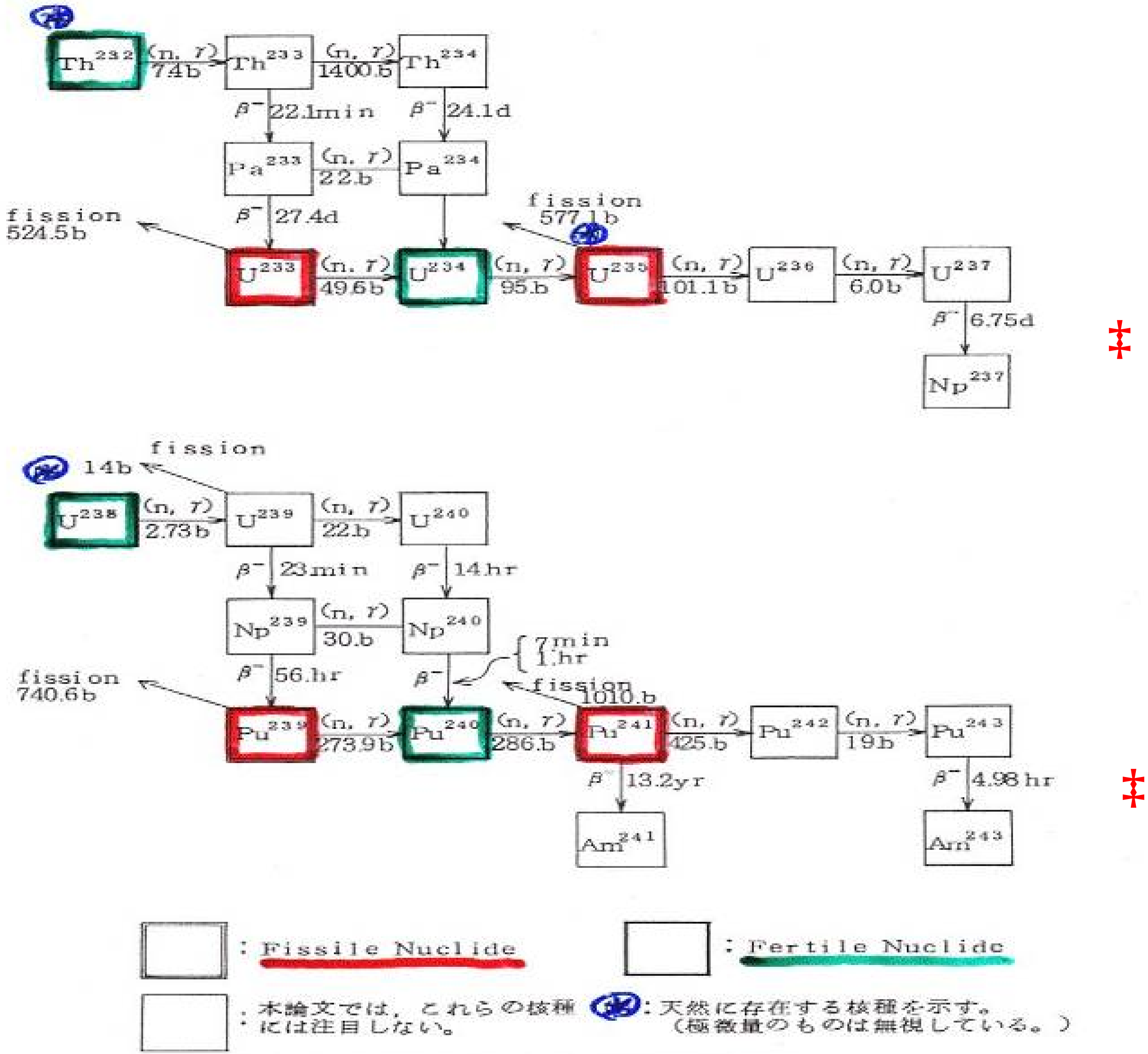
ITER tokamak reactor

Monju (FBR prototype reactor): Electrical output of 280 thousand kWe

ITER (fusion experimental reactor): Heat output of 1.5 million kWt ？

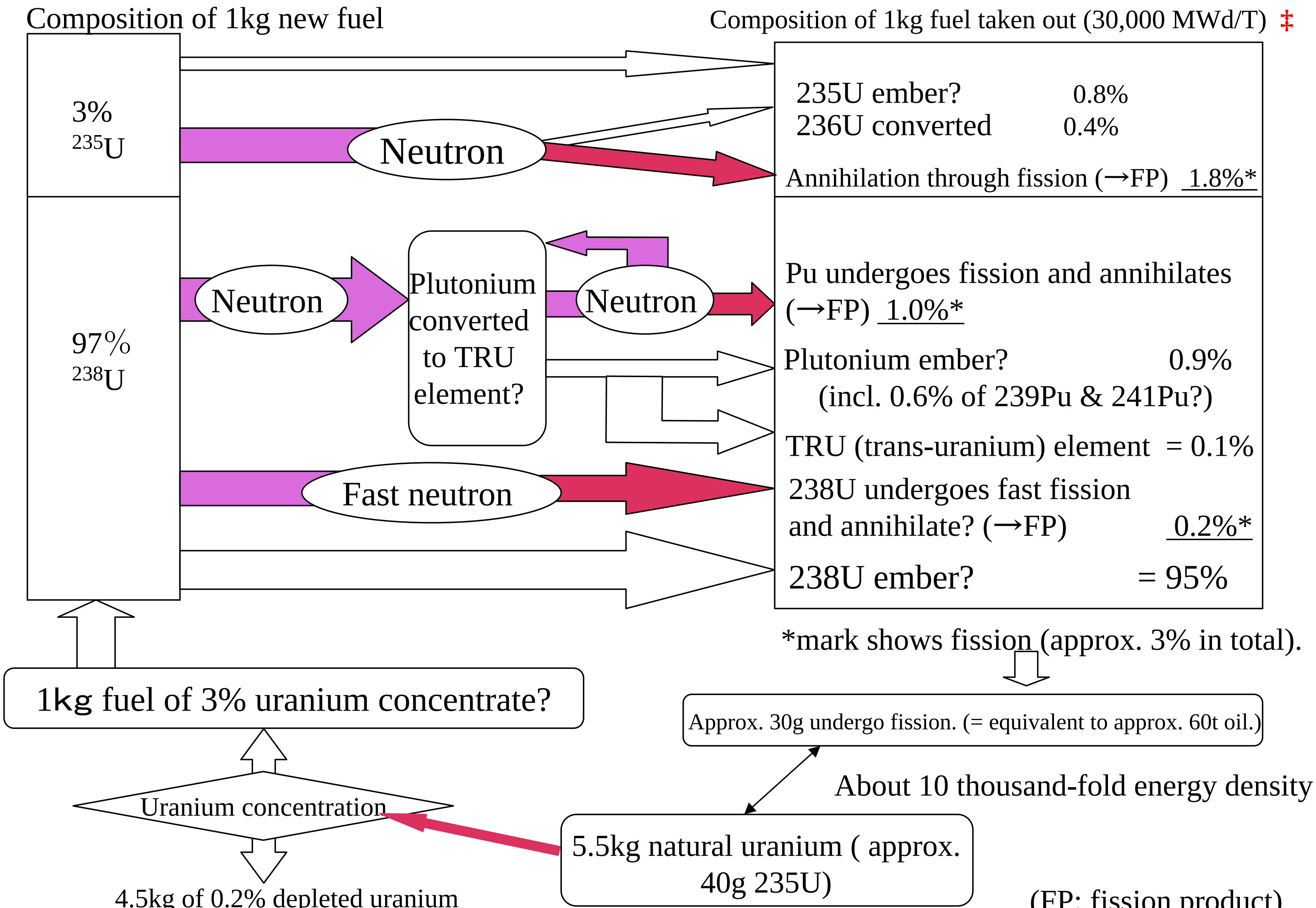
<u>Comparison of reactor vessel size</u>

‡ Kenji Yamaji, 990609



Source : top : A.F. Henry, ”Nuclear Reactor Analysis”MIT Press, Fig.6.2(p263)
below : A.F. Henry, ”Nuclear Reactor Analysis”MIT Press, Fig.6.1(p263)

Fuel burning in LWR



Source: Kenji Yamaji, 2006, *Energy, Environment and Economic Systems*, Iwanami Shoten. 2006, Chart 2-17 (p.47).

Table 8. Global Uranium Reserves by Country

(as of January 1, 2001)

(Unit: thousand tons U)

Country	Reserves confirmed*1
Australia	930
Kazakhstan	854
Canada	437
South Africa	367
USA	348
Namibia	283
Brazil	262
Russia	175
Uzbekistan	172
Ukraine	131
Mongol	83
India	78
China	73
Niger	55
Japan	7
Others	288
Total	4,543
Adjusted total *2	4,084

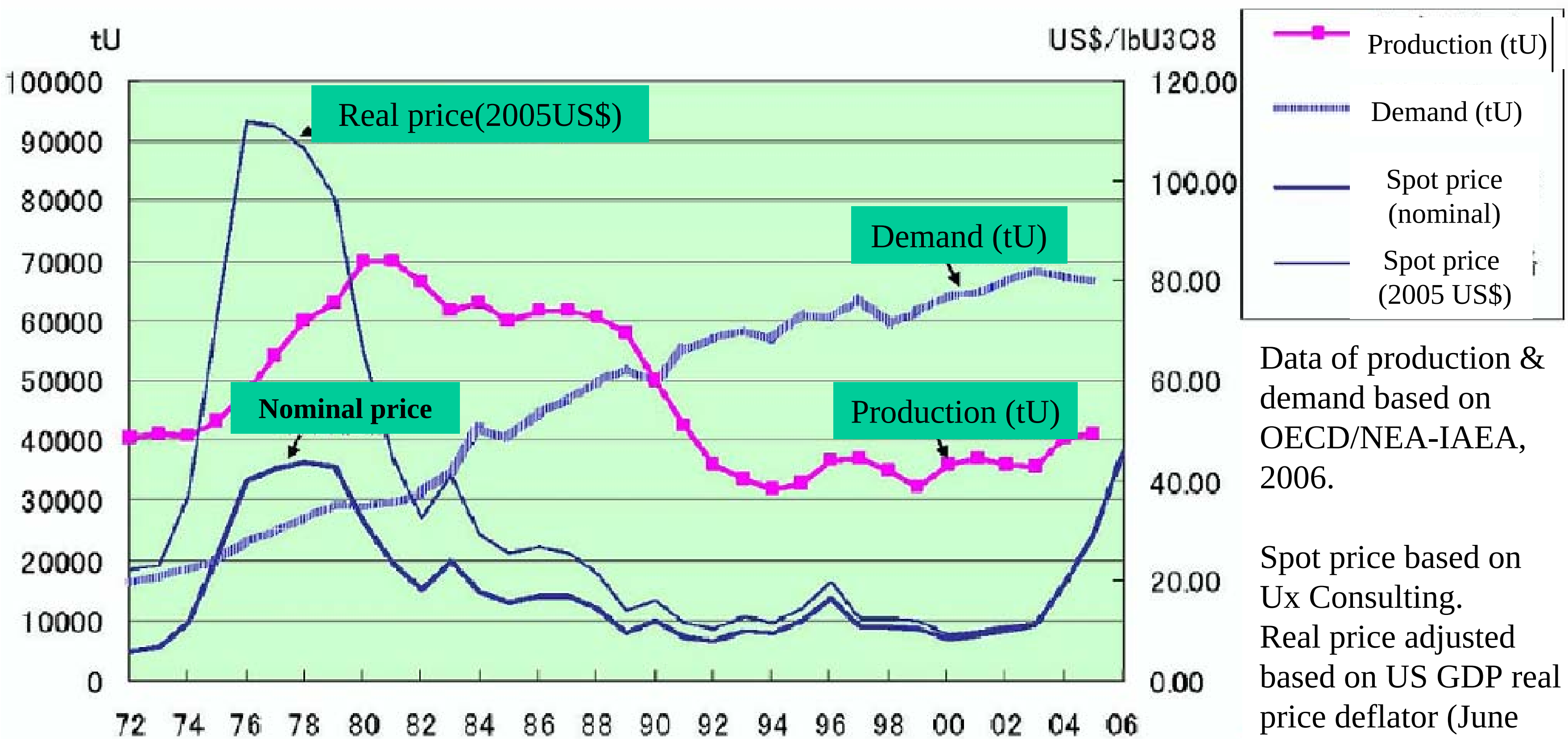
Data: OECD/NEA, IAEA *URANIUM Resources, Production, Demand 2001*. ‡

(Note) *1: The tern "Reserves confirmed" here refers to "known resources" in the reference data.

***2: Adjusted total is the value less mining and refining losses.**

Source: Atomic Energy Commission (ed.): *White Paper on Atomic Energy*, 2003 version (Dec., 2003), p.139.

Change in Uranium Production, Demand and Spot Price



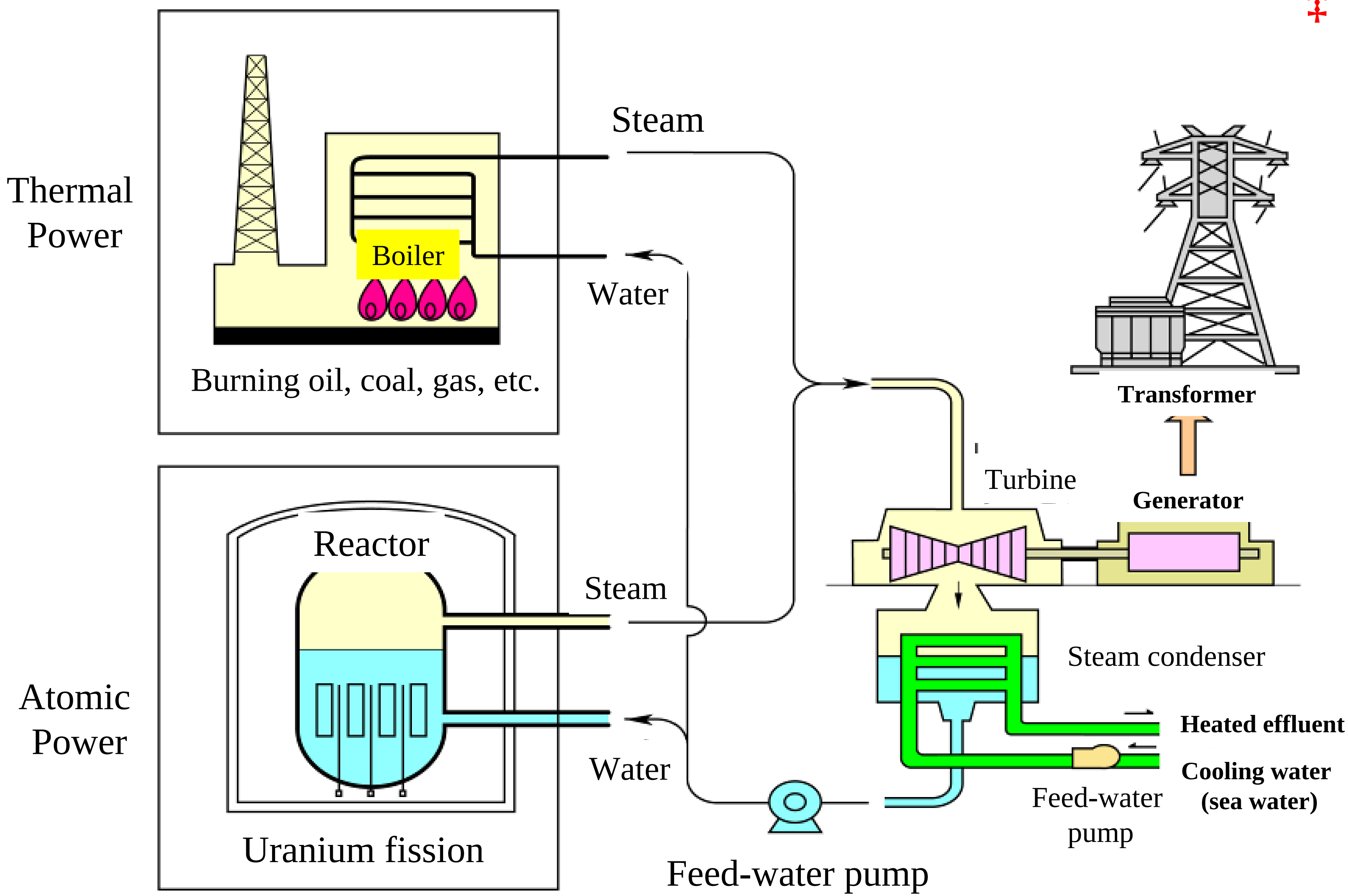
Data of production & demand based on OECD/NEA-IAEA, 2006.

Spot price based on Ux Consulting.
Real price adjusted based on US GDP real price deflator (June 2006).

*Balance between demand and supply is covered by commercial stock, nuclear disarmament HEU, re-concentration of depleted uranium, collected uranium, etc.

Source:http://www.jaea.go.jp/03/senryaku/seminar/06-10.pdf(p21)

Difference Between Thermal Power Generation & Atomic Power Generation



Source:http://www.tepc-atomic.jp/library/zumen/pdf-data/all05.pdf First sheet(p49)

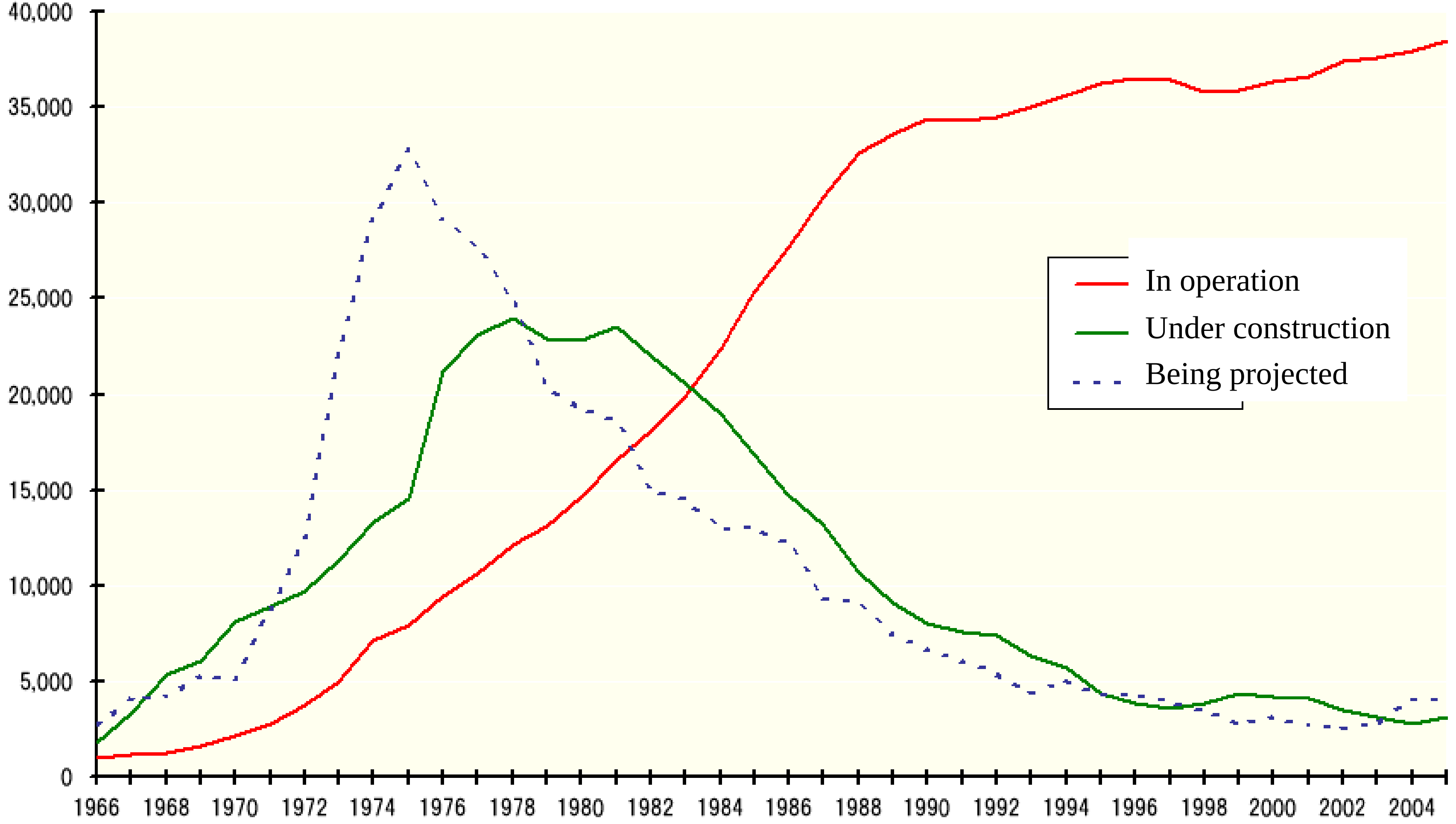
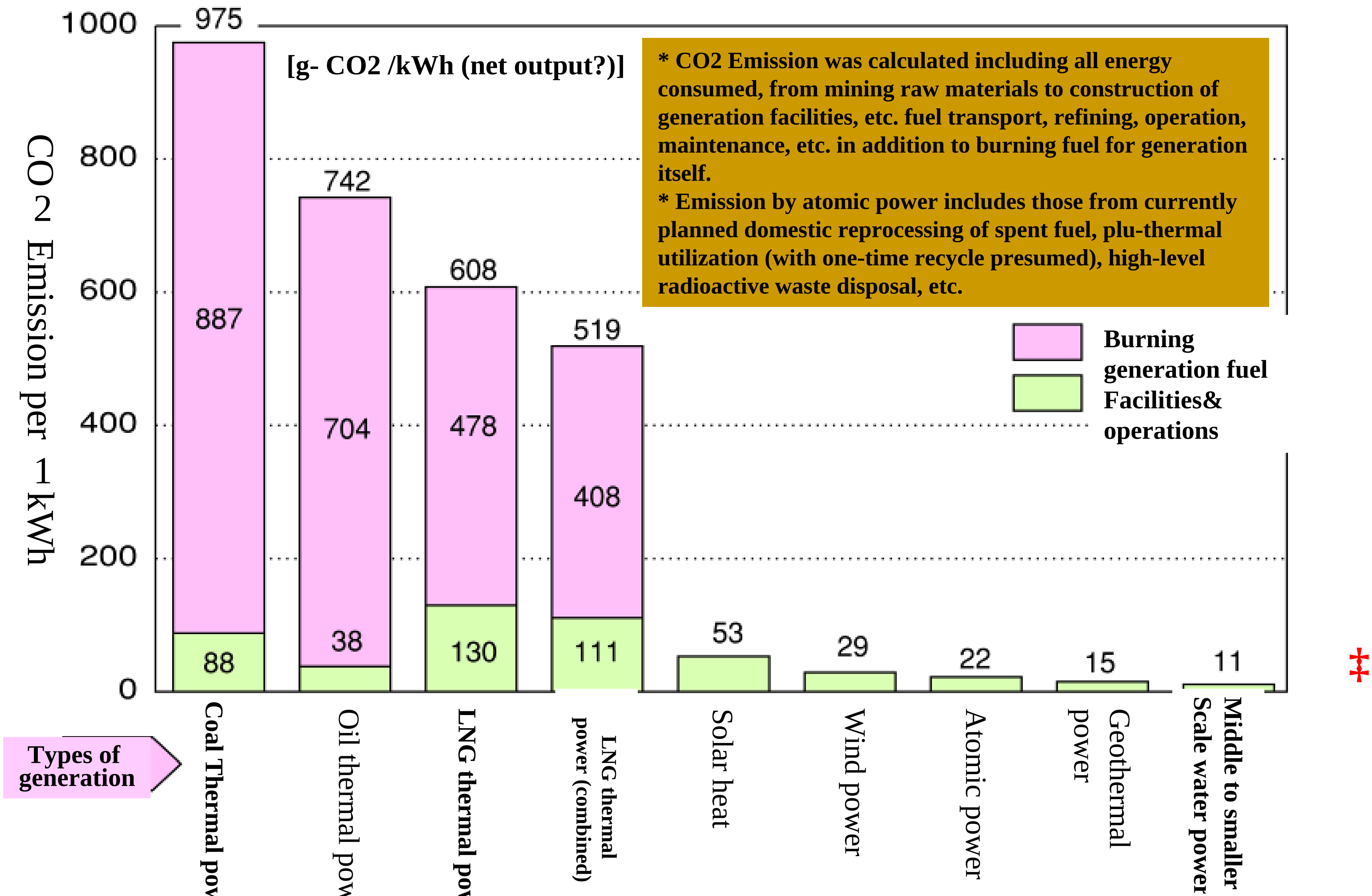


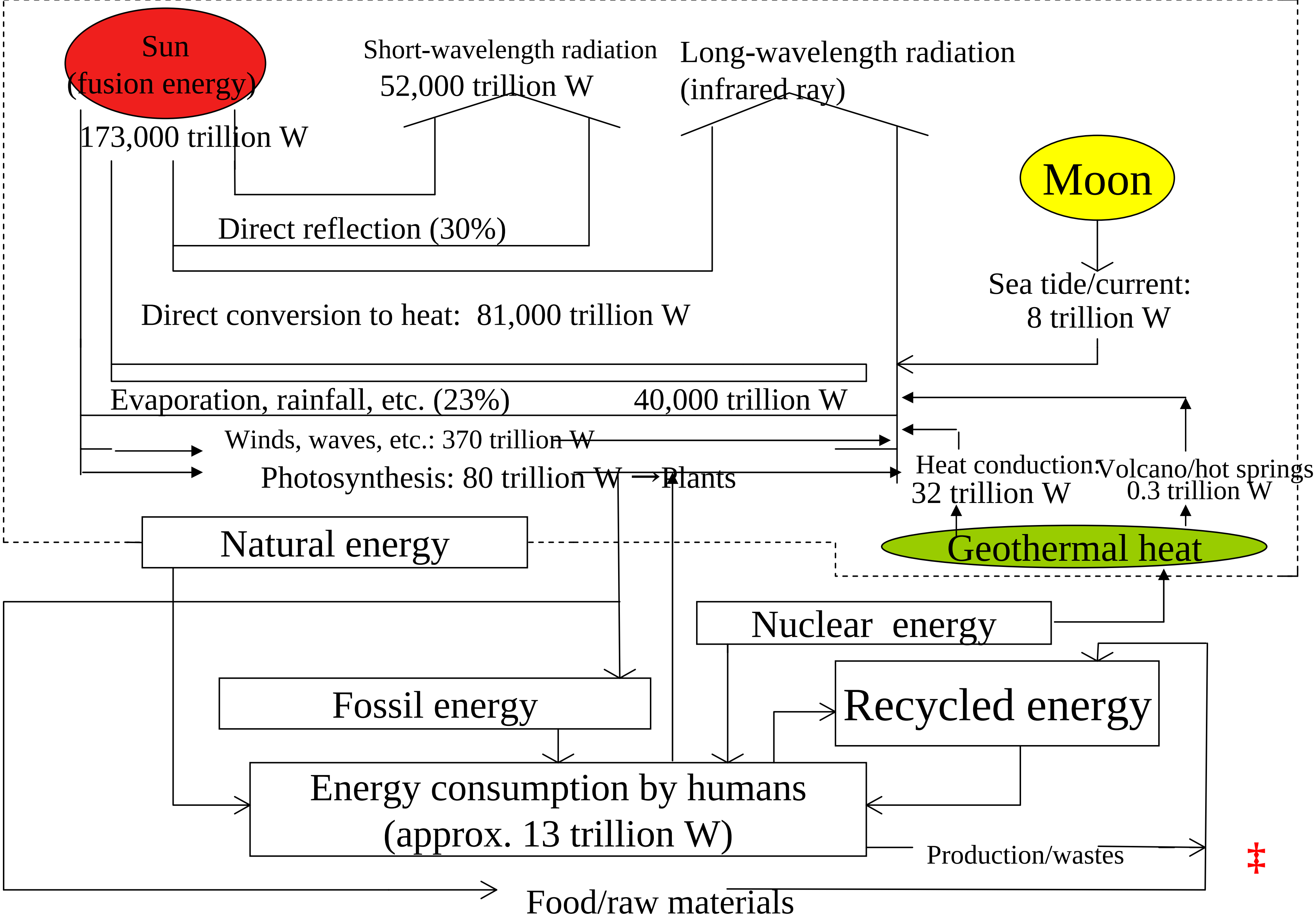
Chart 2 Change in Capacity of Atomic Power Generation Facilities in the World

Source: http://www.nucpal.gr.jp/atomica/chart.html

Amount of CO2 Emission by Power Source



Source: http://www.fepc-atomic.jp/library/zumen/pdf-data/all05.pdf 9th sheet p45



Energy Balance of the Earth and Various Energy Resources ‡

Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 1.2 (p.19).

Natural Energy Poses Economic Efficiency Concerns Rather Than the Concerns about Amount of Resources

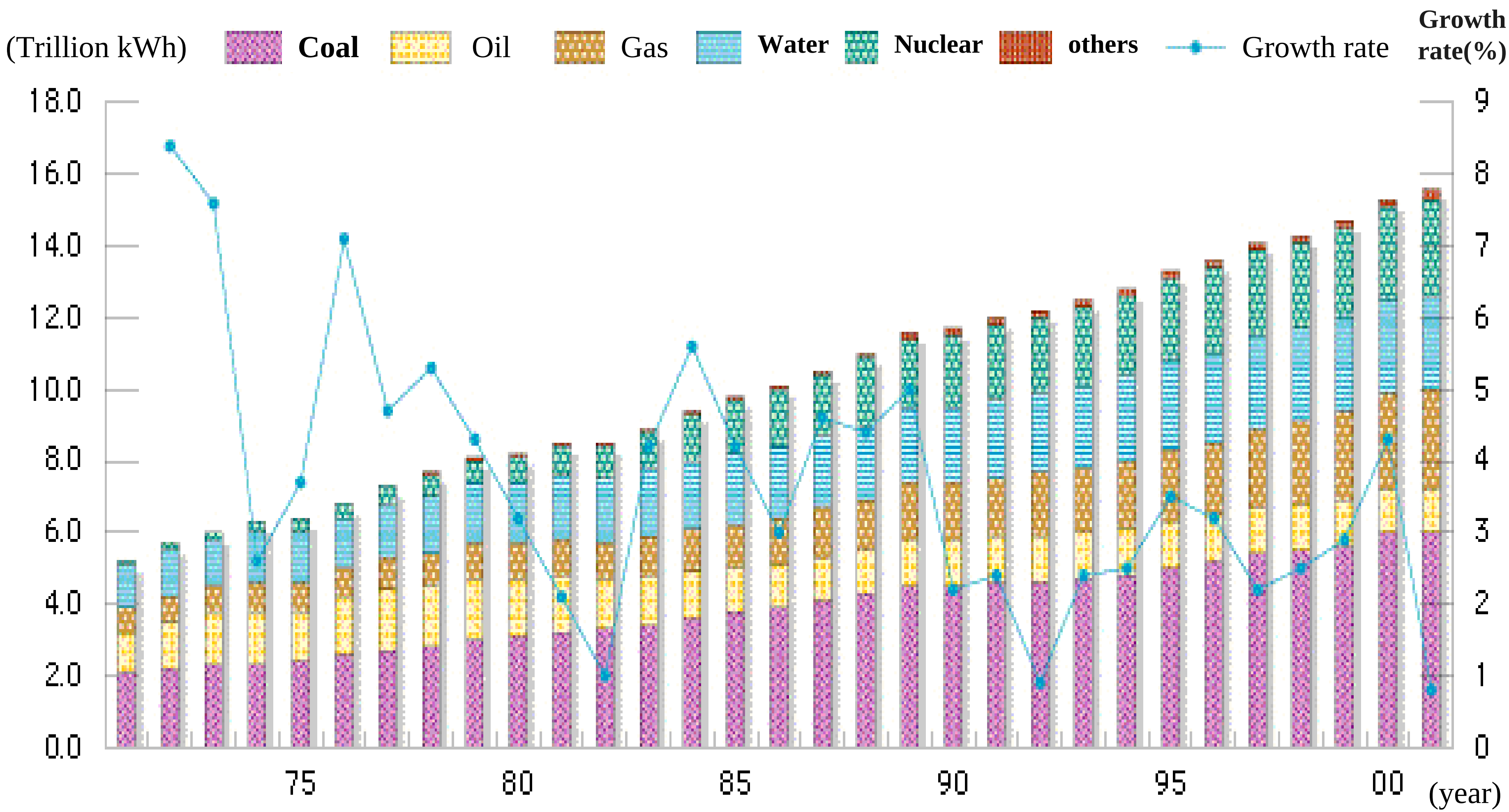
In Case of Solar Battery

- Background information:
- Facility occupancy rate = actual output (kWh)/ (rating capacity of the facility (kWh) x 8,760 (h))
- Provided that the rating capacity of solar battery is 1kWh, then annual output will be about 1,000kWh under the insolation condition in Japan.
- Facility occupancy rate of solar battery is 11~12% (= 1,000/8,760); whereas it is 70~80% in case of thermal or atomic power.

- Economic efficiency of solar battery generation:
- Facility cost: X yen/ kW
- Area required for installation: η as efficiency, $1/\eta$ (m2/kW); if η=10%, 10km2 for 1 million kW.
- Facility life: Y years
- Simple generation cost with discount rate* disregarded: X/1,000Y.
- X = 500 thousand yen, Y = 20 years → generation cost = ¥25/kWh.

- However, the above calculation seems too easy:
- 1) Discount rate (future money value should be discounted): as 3%/year, capital recovery coefficient for 20 years is 0.067 → annual capital cost of 0.067 X yen → generation cost = ¥33.5.
- 2) Electricity from solar battery is not always supplied as needed. → additional cost, including storage devices, required.

World Power Generation



Data: IEA *Energy Balance of OECD Countries& Energy Statistics and Balances of non-OECE Countries.*

Source: Agency for Resources and Energy, .enecho.meti.go.jp/topics/hakusho/2006EnergyPdf/pdf/18ene223.pdf **P272, NO.223-1-5.**

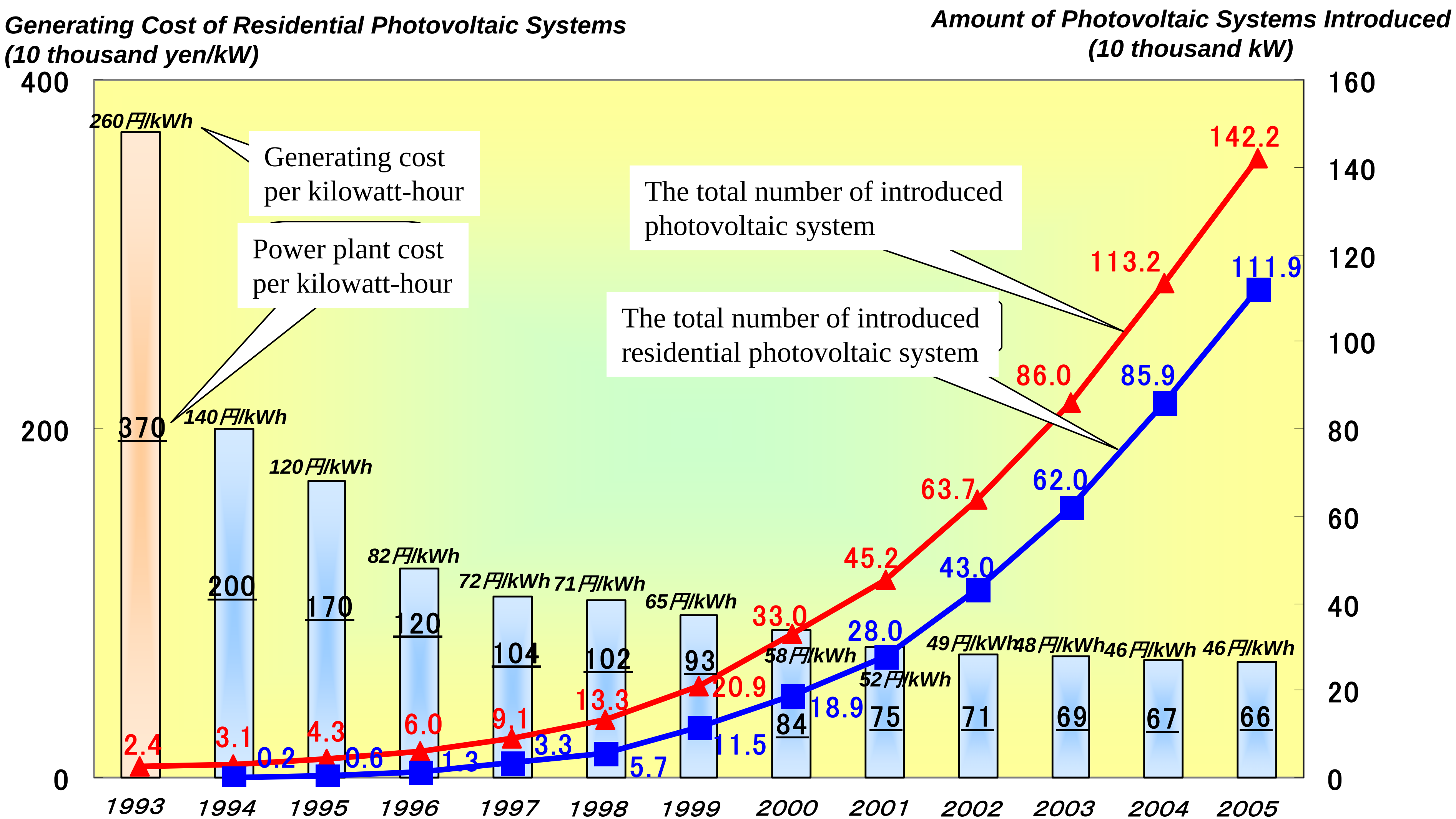
新エネルギー導入実績と導入目標 New Energy in Japan

		2002年度	2010年度目標	
Electric generation	Photovoltaic	15．6万kl （63．7万kW）	118万kl （482万kW）	838万Kl
	Wind power	18．9万kl （46．3万kW）	134万kl （300万kW）	
	Waste power & Biomass power	174．6万kl （161．8万kW）	586万kl （450万kW）	
Heat Utilization	Solar heat	74万kl	90万kl	1072万Kl
	Waste heat	164万kl	186万kl	
	Biomass heat	68万kl	308万kl ※1	
	Unutilized energy ※2	4．6万kl	5．0万kl	
	Black liquor & Waste material	471万kl	483万kl	
Sum (Primary energy supply ratio)		991万kl （1．7%）	1，910万kl （3%程度）	

※発電分野及び熱利用分野の各内訳は、目標達成にあたっての目安
※１輸送用燃料におけるバイオマス由来燃料（５０万ｋｌ）を含む。
※２未利用ｴﾈﾙｷﾞｰには雪氷冷熱を含む。
※３黒液・廃材等はバイオマスの１つであり、発電として利用される分を一部含む。黒液・廃材等の導入量は、エネルギーモデルにおける紙パの生産水準に依存するため、モデルで内生的に試算されたもの。

~Present Status around Photovoltaic Generation in Japan~

- For PV generation, cost reduction to one fifth has been achieved, compared with that of the early 90's.
- As a result, Japan has secured a position as a world leader in technology and introduction.



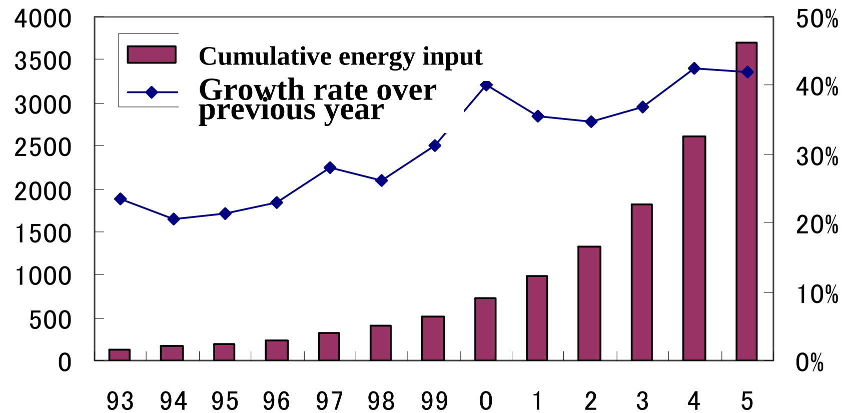
Data: Japan Photovoltaic Energy Association

International Trends on Renewable Energy

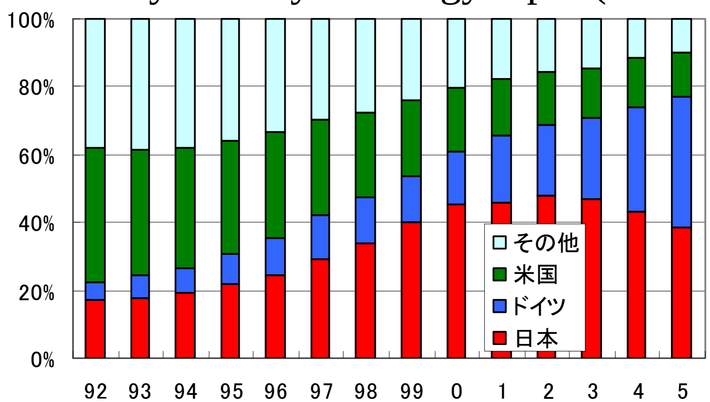
・In recent years, cumulative energy input by solar heat has been increasing at the annual rate of about 40% over previous years throughout the world, while wind power is increasing by 20~25%.
・For solar heat, Germany has reached the same level as Japan in cumulative energy input. For wind power, Japan remains at a low level compared with major countries, although her share is increasing.

Solar Heat PV

MW World energy input (cumulative) and its growth

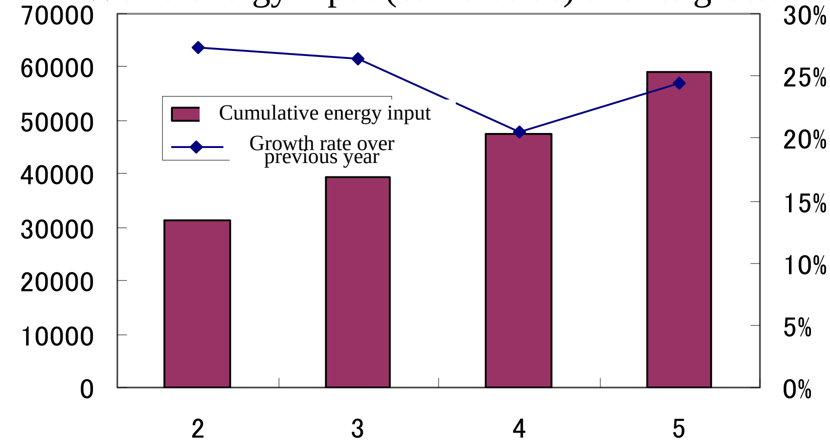


Share by country in energy input (cumulative)



Wind Power

MW World energy input (cumulative) and its growth



Share by country in the energy input (cumulative)

	End 2001	End 2005
Germany	8753(35.6%)	18427(31.1%)
Spain	3335(13.6%)	10028(16.9%)
USA	4245(17.2%)	9142(15.4%)
Japan	300(1.2%)	1150(1.9%)
World total	24574(100%)	59206(100%)

Source: METI, http://www. meti. go. jp/committee/materials/downloadfiles/g61108d07j.pdf p14(15th sheet)

Present Situation of Japan and Her Immediate Goal
~Positioning of Renewable Energy and Current Picture~

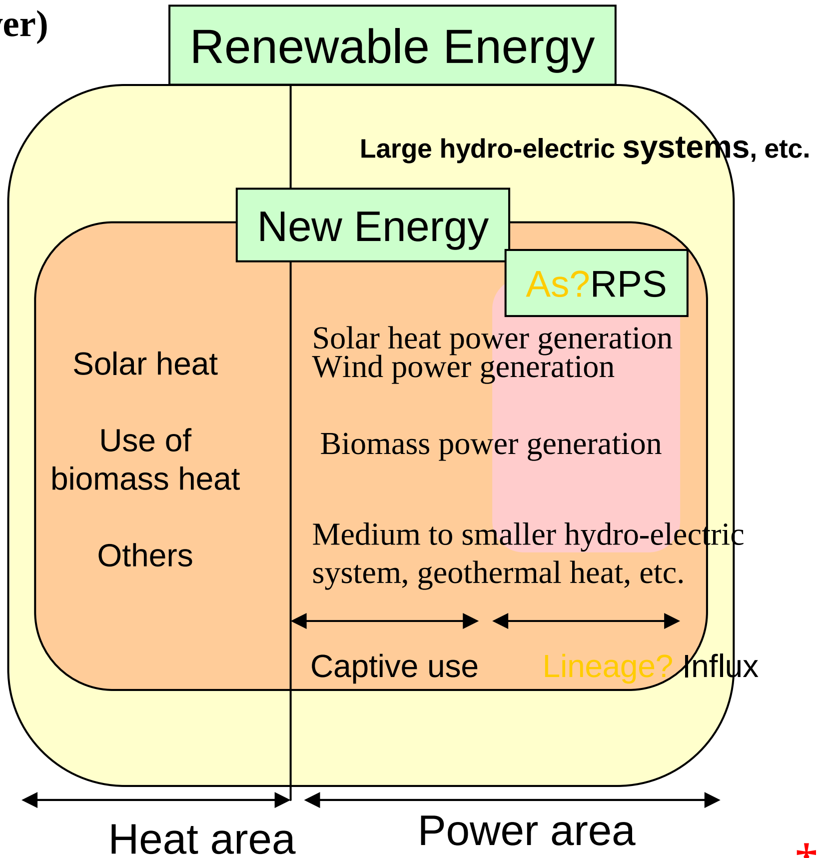
- On the whole, Japan is in no way inferior to Europe and USA now in the input level of renewable energy in the area of electric power.

Input proportion of renewable energy (in the area of electric power)
(Trilateral comparison)

	Japan	Europe(EU15)	USA
Hydraulic power	8. 2%	10. 1%	6. 9%
Geothermal heat	0. 33%	0. 20%	0. 37%
Biomass	1. 21%	1. 38%	1. 34%
Wind power	0. 09%	1. 62%	0. 28%
Solar heat	0. 09%	0. 02%	0. 01%
Total	9. 9%	13. 3%	8. 9%

Reference: Figures for Japan based on the data from Resources and Energy Agency. For other figures, IEA, *Energy Balance of OECD Countries, 2003-2004.*
Note: The power input includes captive use.

‡



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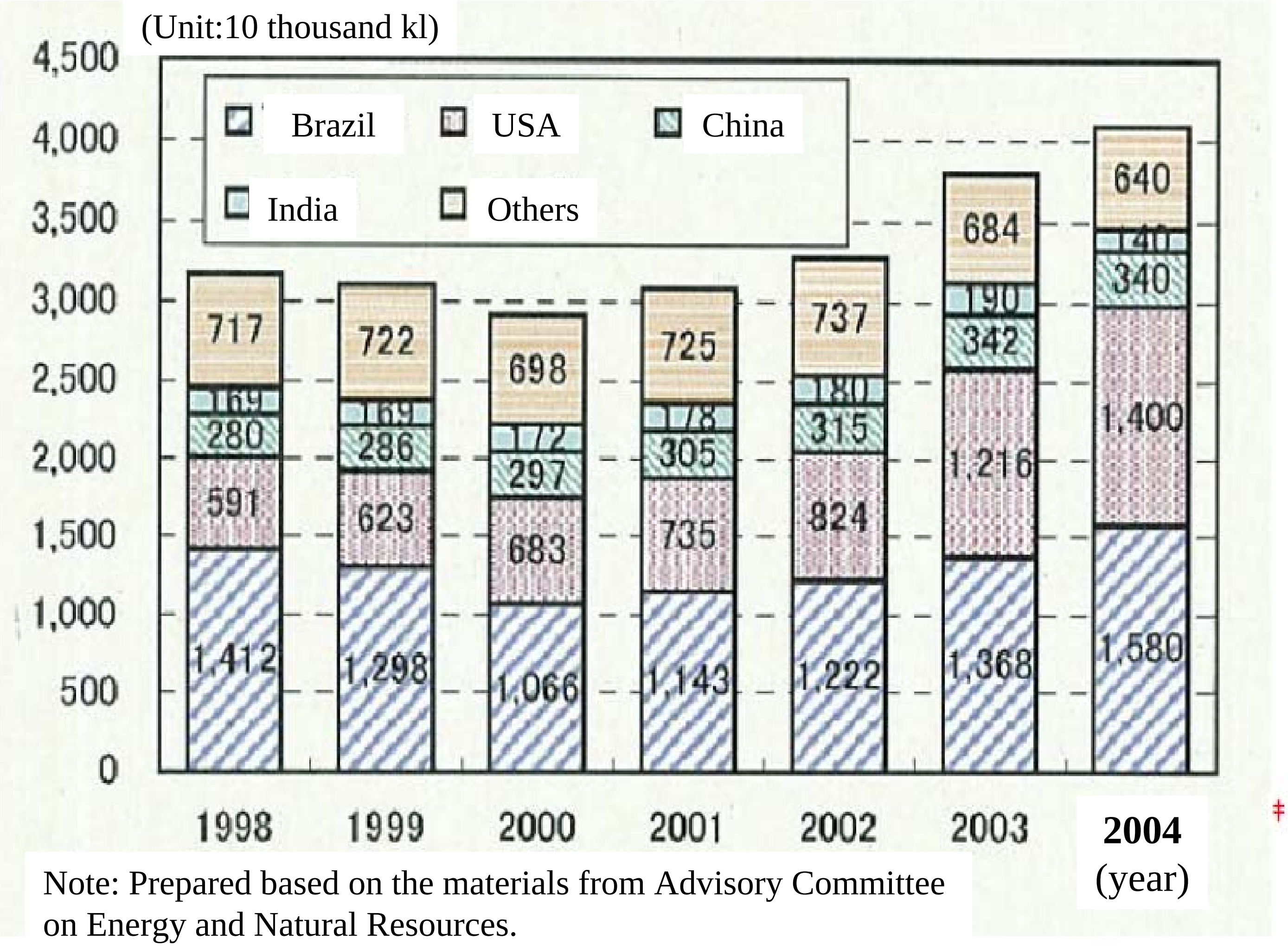
Source: METI, http://www.meti.go.jp/committee/materials/downloadfiles/g61108d07j.pdf p3(4th sheet)

Energy Technology to Be Watched

- — Bio fuels
- — Hydrogen
- — New car technology
- — Enhanced efficiency in energy conversion
- — Lighting technology and heat pump
- — CO_2 collection and storage (CCS)
- — Lifestyle options (though not of technology)

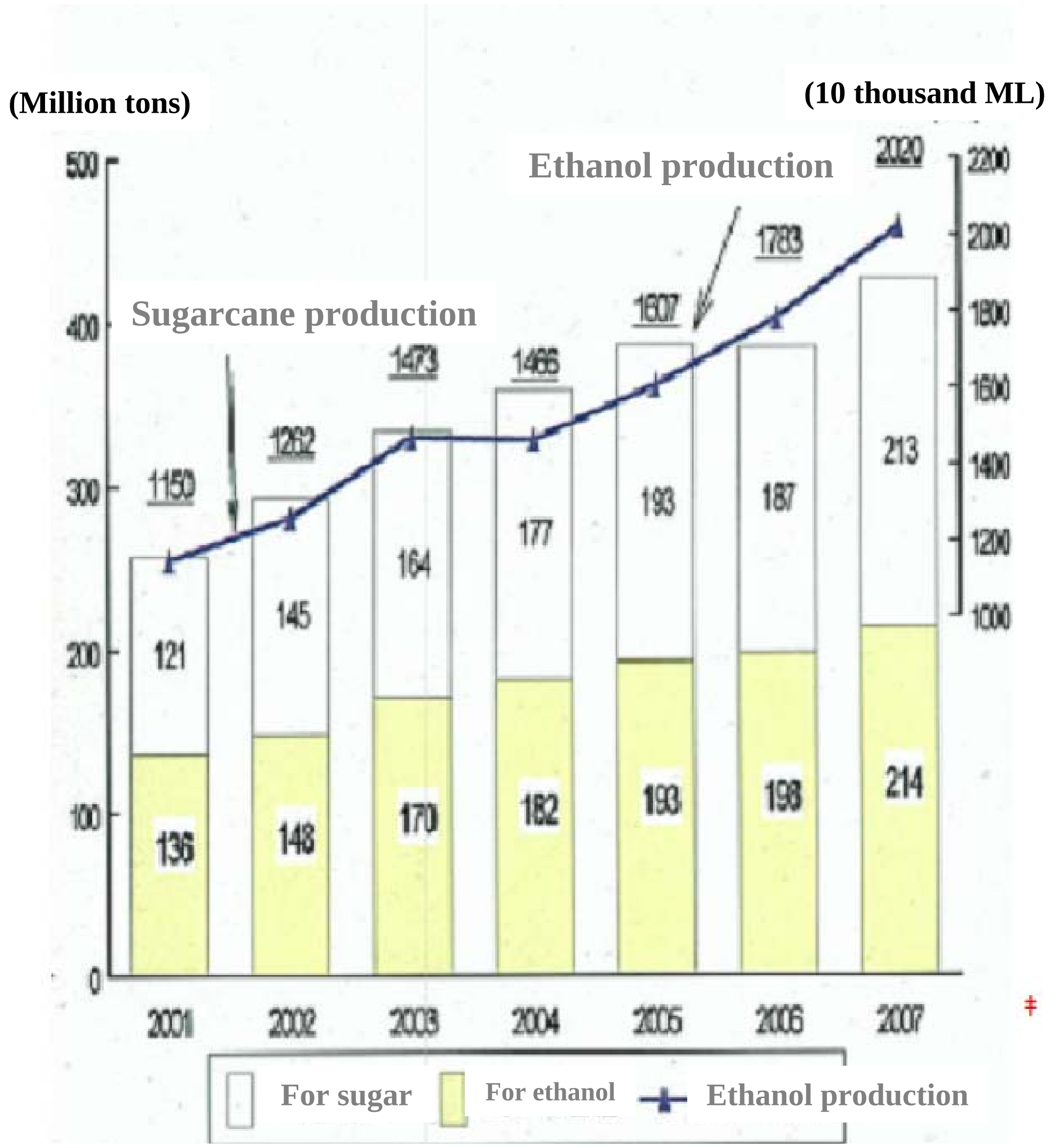
Change in Ethanol Production in Major Countries



Note: Prepared based on the materials from Advisory Committee on Energy and Natural Resources.

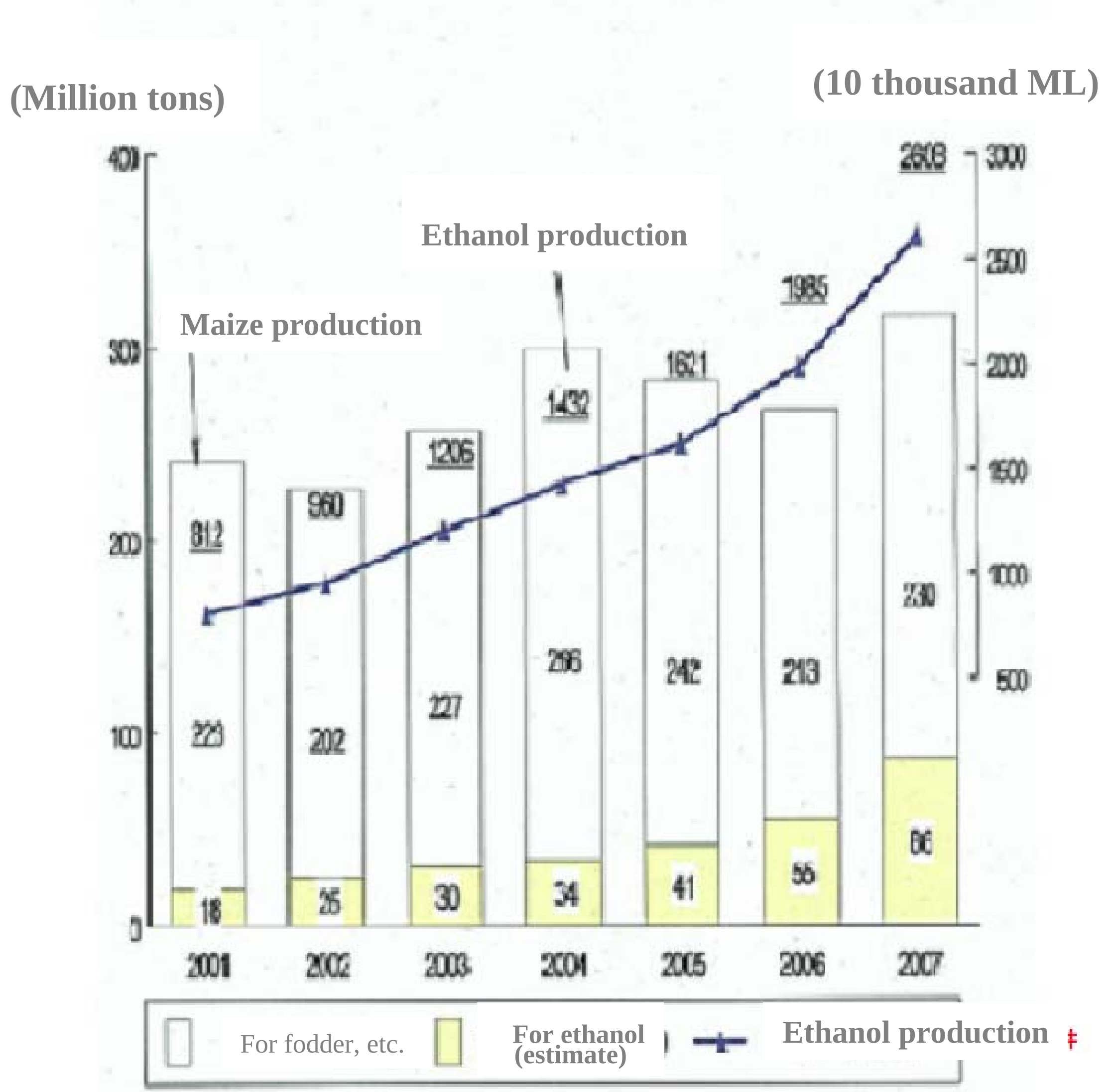
Source: Development Bank of Japan, http://www.dbj.go.jp/japanese/download/pdf/indicate/no105.pdf p4,chart 12

☐ Change in Sugarcane Production in Brazil



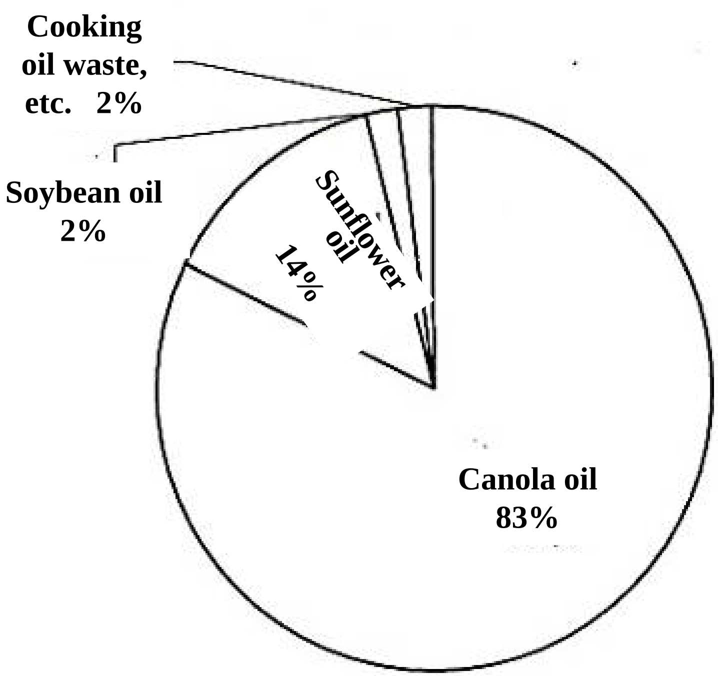
Source: presented by Biomass Policy Office, Environmental Biomass Policy Section, Minister's Office of Ministry of Agriculture, Forestry and Fishery.

☐ Change in Maize Production in the USA

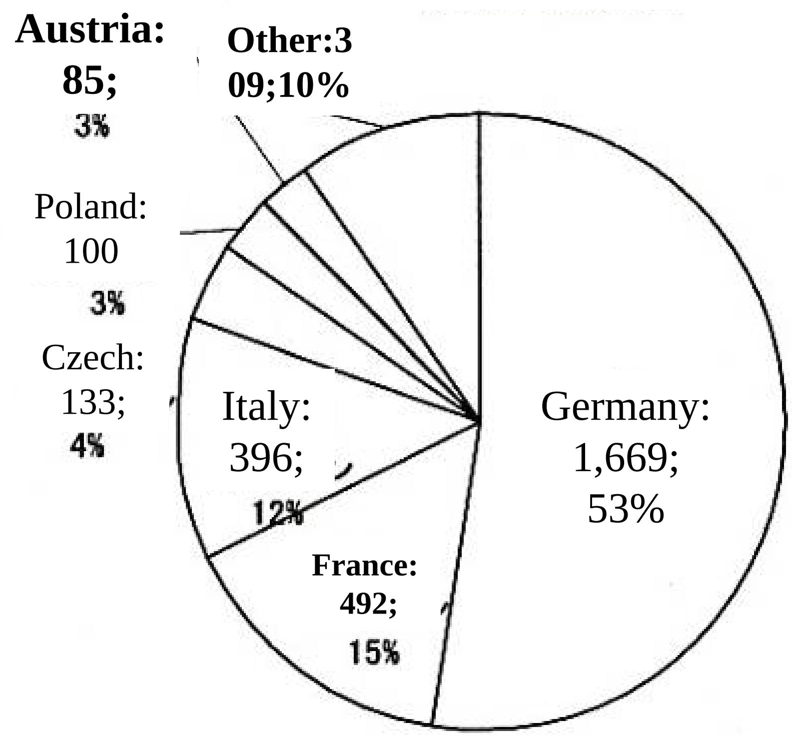


Source: presented by Biomass Policy Office, Environmental Biomass Policy Section, Minister's Office of Ministry of Agriculture, Forestry and Fishery.

Proportion of BDF Materials in EU



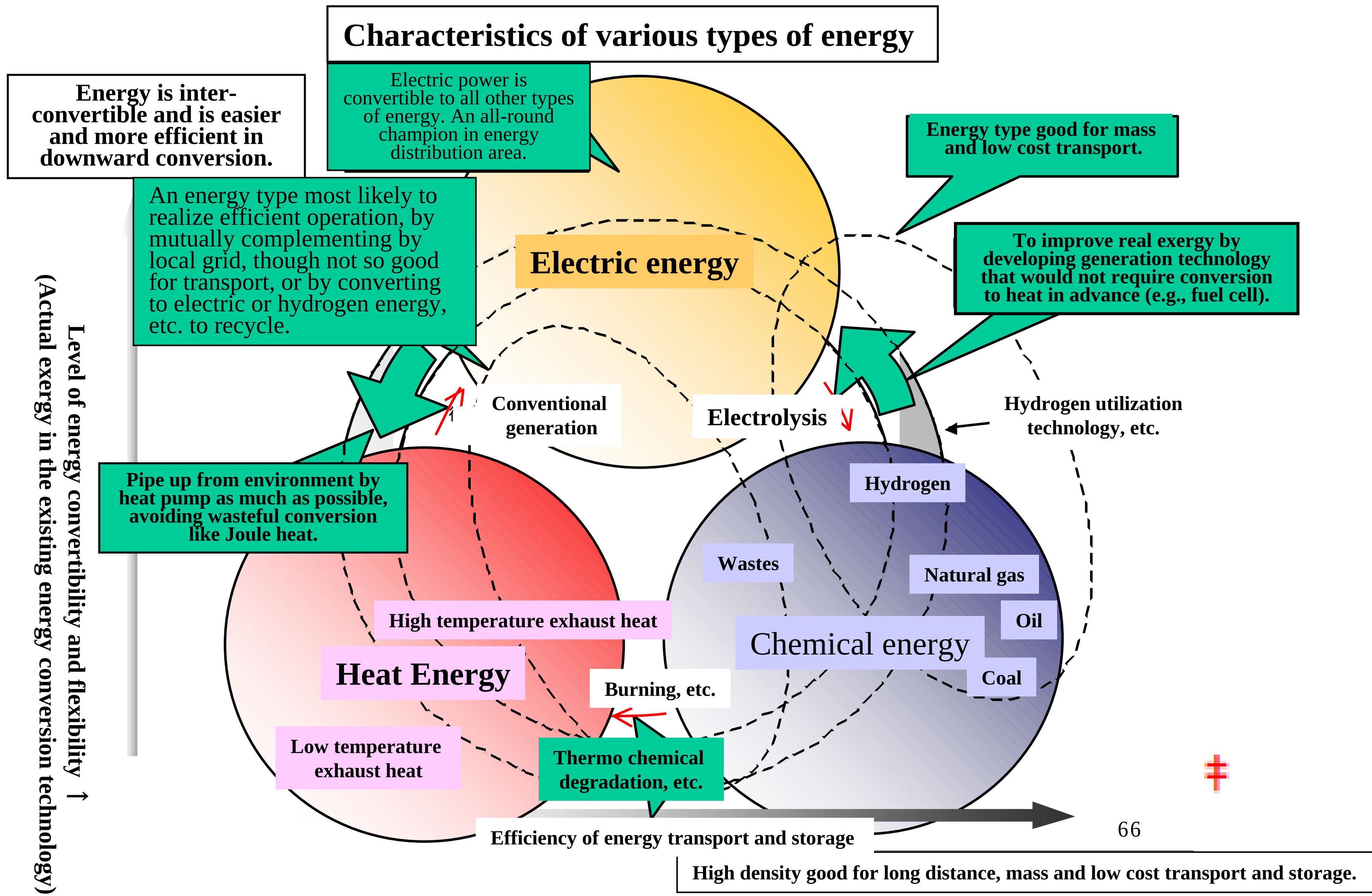
BDF Production in EU (unit: thousand tons)



In the tropics, palm oil is marked as bio-diesel material now.

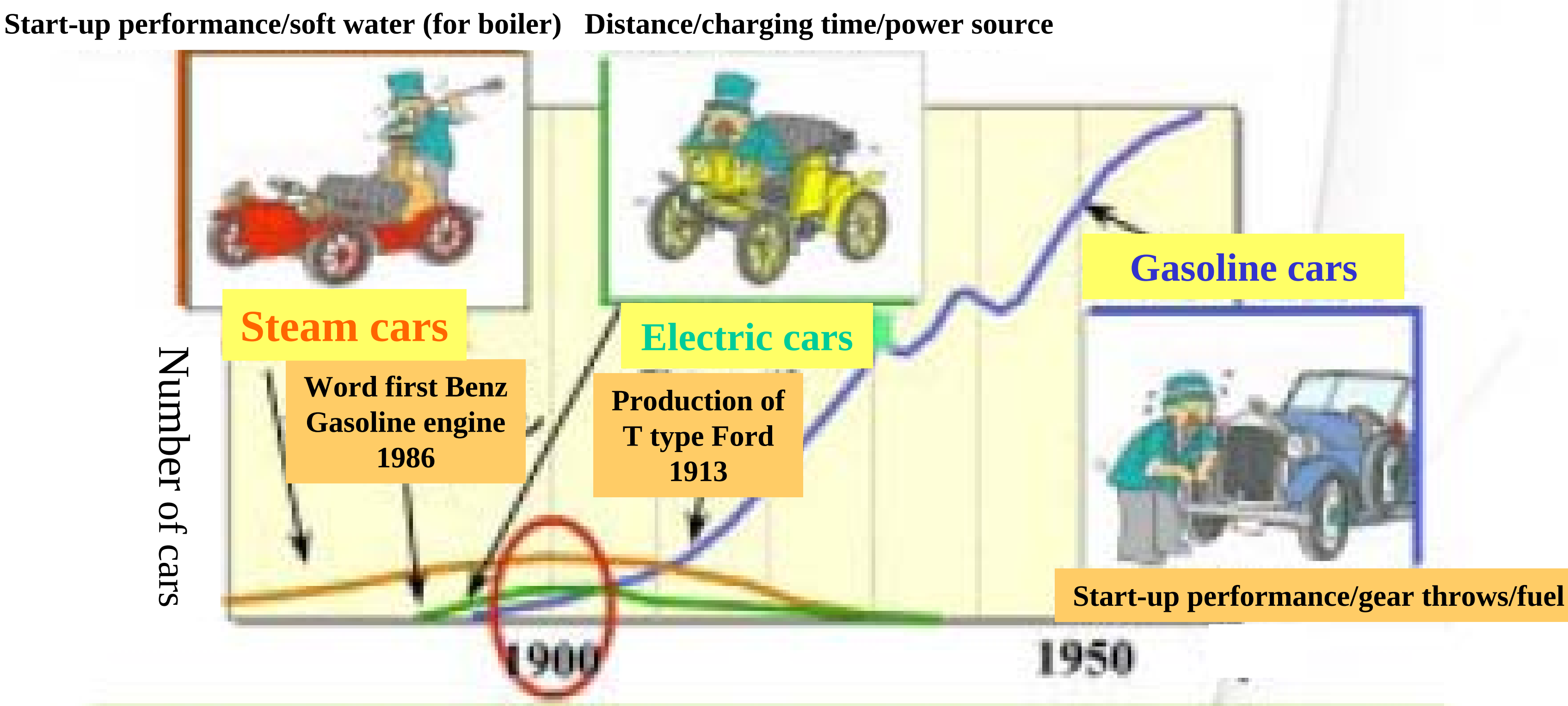
Source: Right: http://www.meti.go.jp/commitee/materials/downloadfiles/g50525a40j.pdf METI, The 20th Fuel Policy Sub-committee, p.26.
Left: House of Representatives Research Division and Ministry of Agriculture, Forestry and Fishery's Research Office/Environment Research Office, *On the Use & Utilization of Biomass—with Emphasis on Bio-derived Fuels—*, February, 2007, p.23.

Characteristics by Energy Type and Role of Hydrogen



Source: METI's Energy Study Group (prepared by Tokyo Gas Co.,Ltd.)

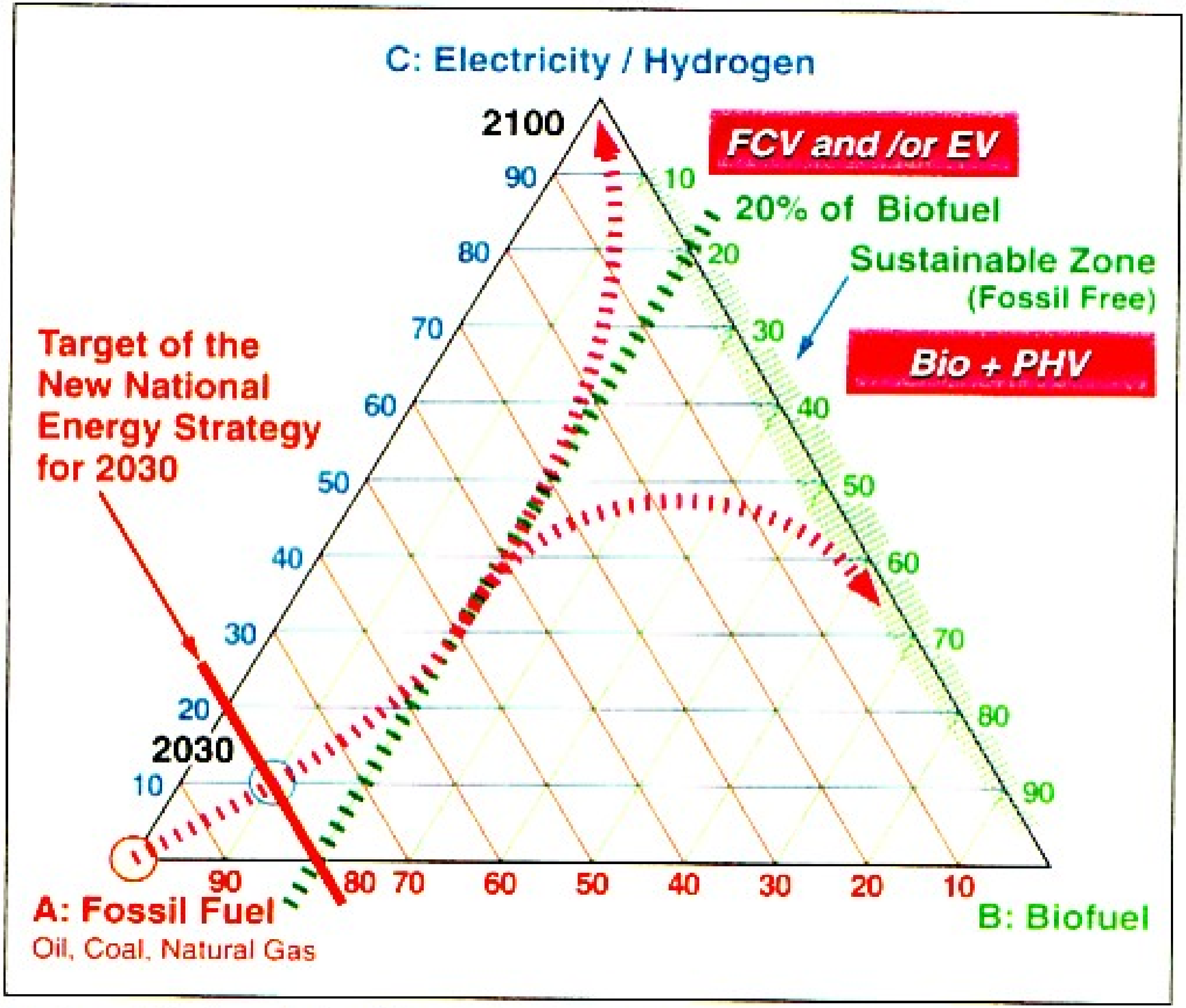
History of Cars



It took 27 years for gasoline cars to dominate the market.
⇒ Fuel battery cars are worked on considering mid- to long-term perspectives as well.

Source: Taiyo Kawai, EIT Journal, 54, April 2007, Chart 11 (p.38)
http://www.eit.or.jp/magazine/pdf/EIT54.pdf

Chart 2 Automobile energy sources



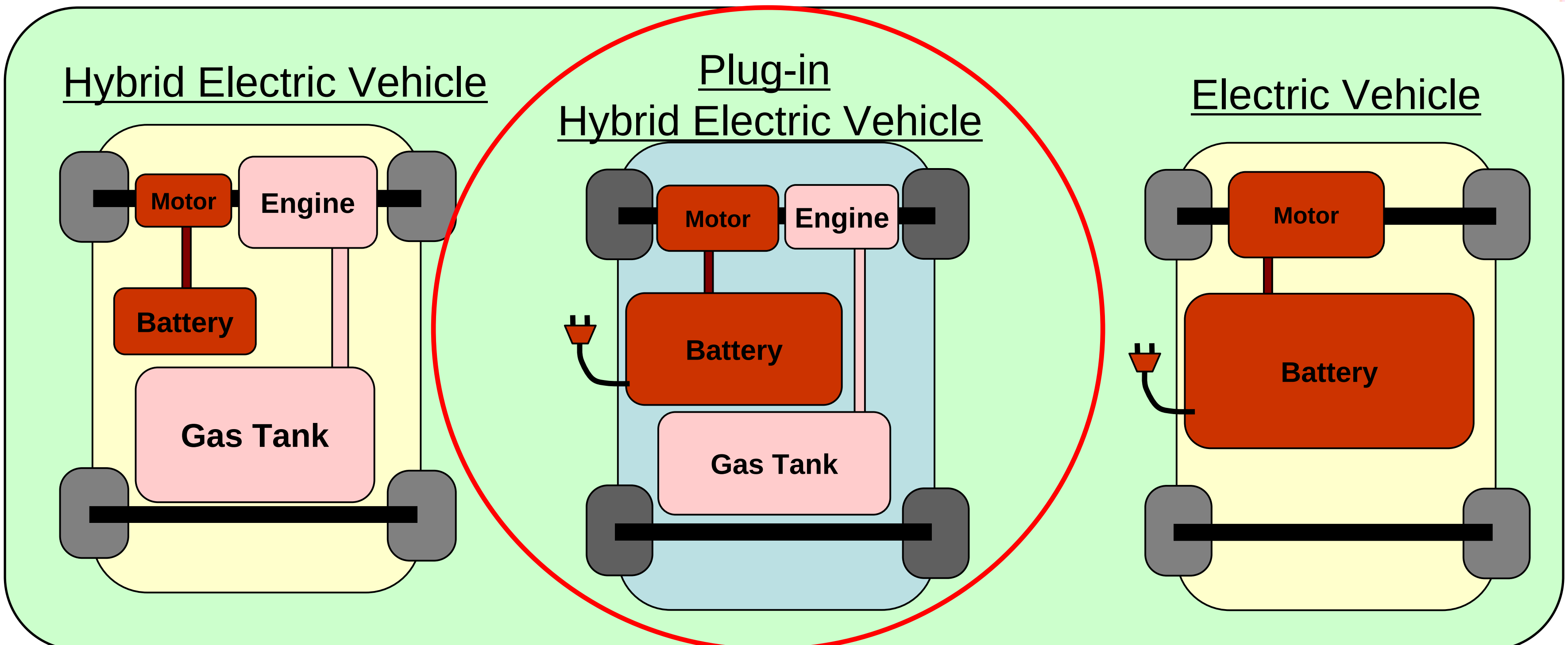
Note : *3D plane defined by A+B+C=1. The chart permits trends to be discussed without any constraint of the temporal axis.*

Source : *Toyota Motor Corp.*

Source: JEF, Japan Spotlight, Sept./Oct.2007 chart2.p19

Plug-in Hybrid Electric Vehicle (PHEV)

- Expanded battery size allows hybrid car to make a trip of several tens of kilometers by electric power alone.
- The car may trip as electric vehicle for short distance, and for long distance as hybrid vehicle.



Source: Hiwatari, Report of Central Research Institute of Electric Power Industry, L05008
http://criepi.denken.or.jp/jp/pub/annual/2006/06kiban11.pdf, Chart 1, p.2.

Realization of Highly-Efficient Thermal Power Generation

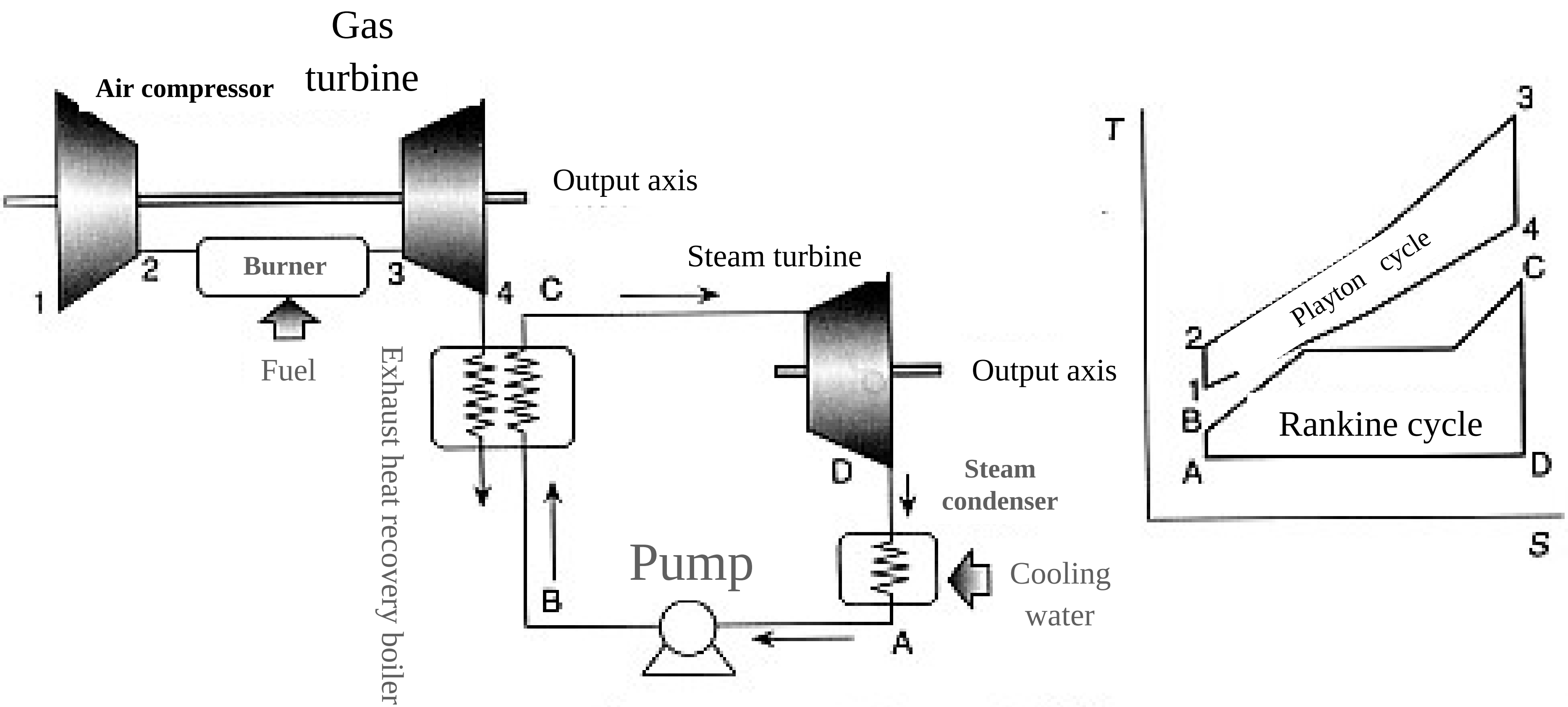
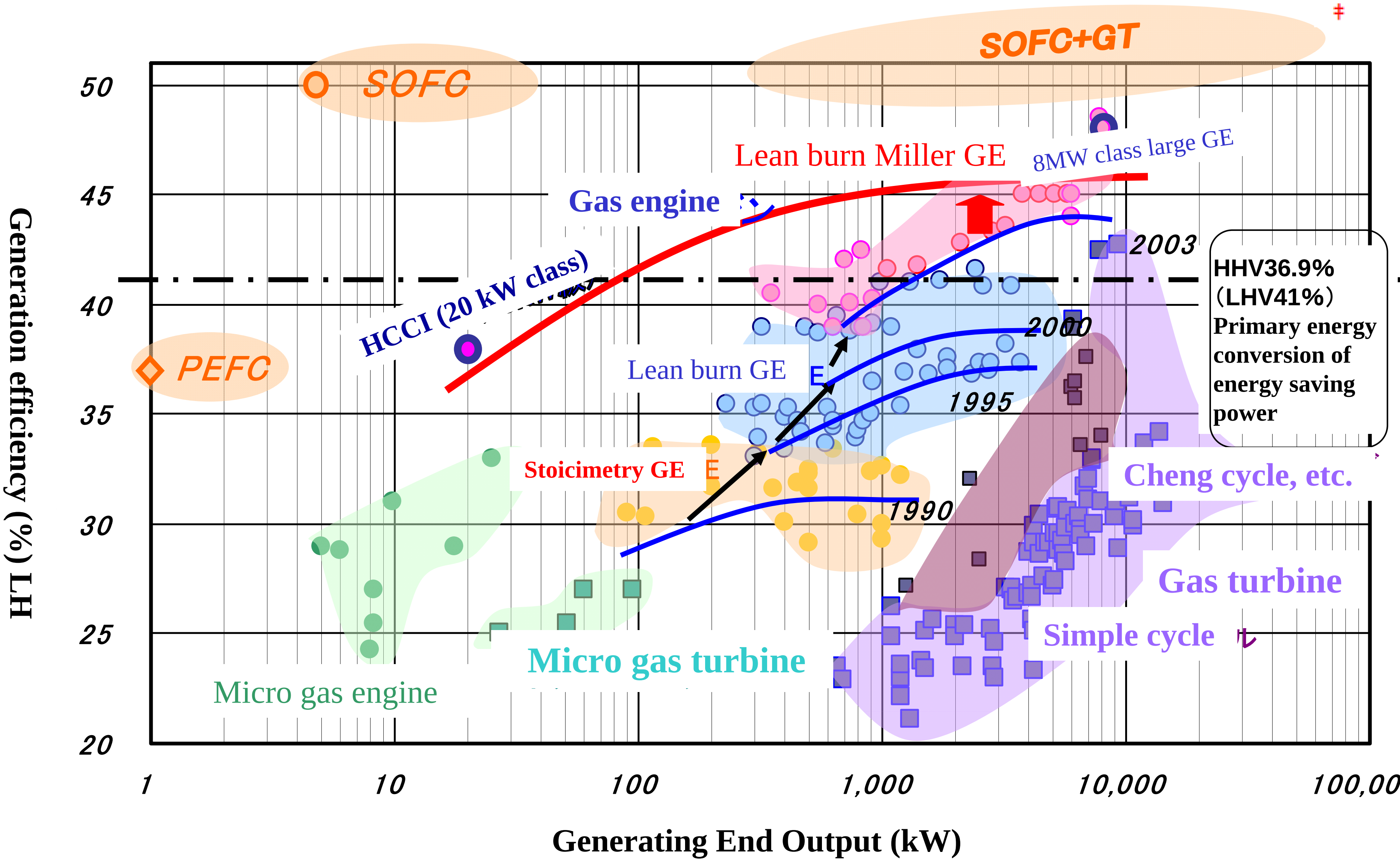


Chart 3.8 Combined Cycle and its T-S Linear Drawing

Source: Yasumasa Fujii, Yoichi Kaya, *Energy Theory*, Iwanami Shoten, Chart 3.8 (p.71) ‡

In the future, there will be a combination of high-temperature-type fuel batteries and gas turbines.

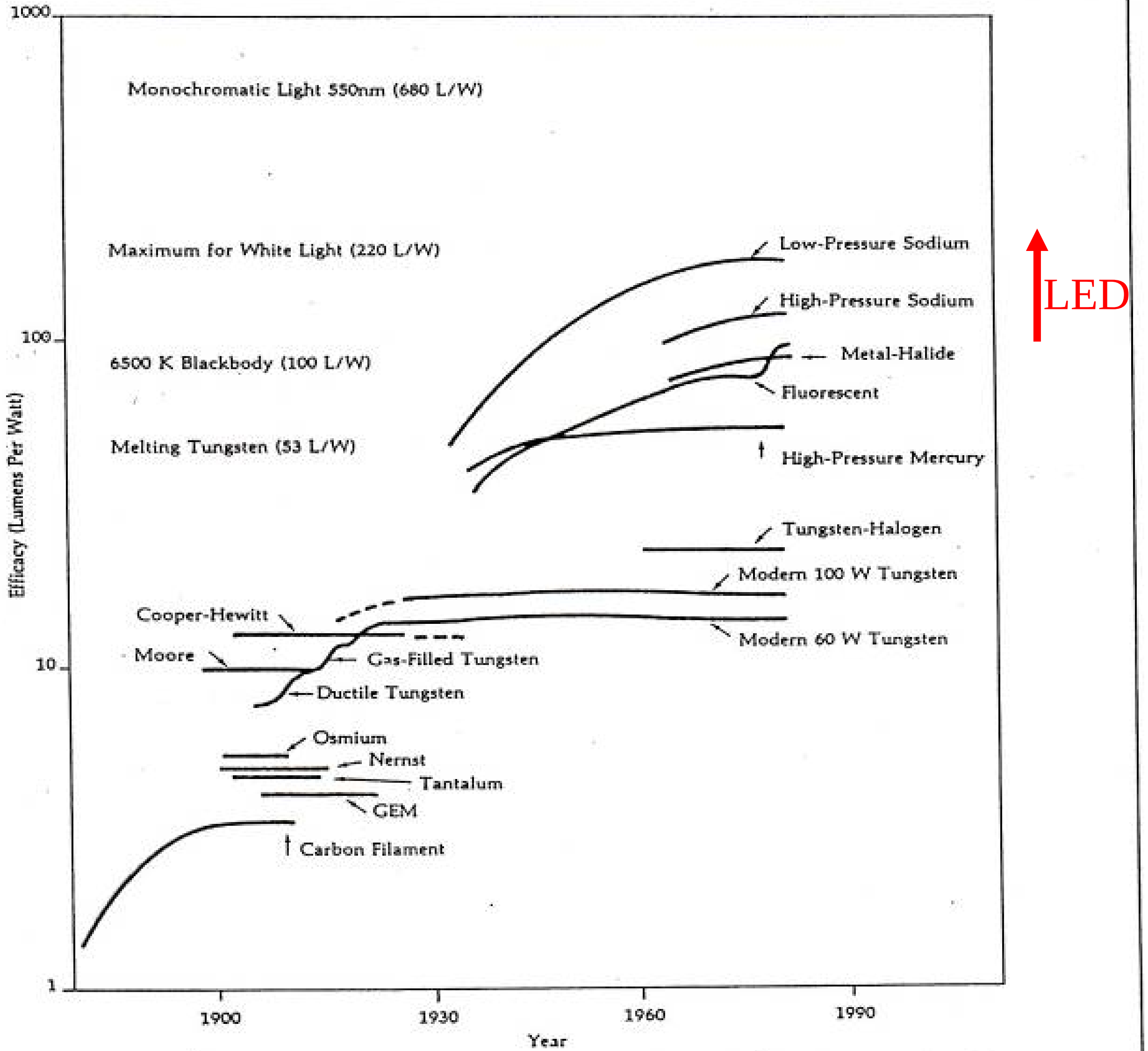
Realization of Highly-Efficient Natural Gas Cogeneration



Dispersed power source can be used for cogeneration (combined heat and power).

Source: Shigeru Muraki, EIT Journal, 54, April 2007, Chart 3 (p.20)
http://www.eit.or.jp/magazine/pdf/EIT54.pdf

Figure 5. Changes in the Efficacies of Various Light Sources Over Time



This plot shows the evolution of lighting performance within each technology as well as the progress from one technology to another. The efficacies for several standard sources are indicated for comparison.

Source: J.M. Anderson and J.S. Saby, "The Electric Lamp: 100 Years of Applied Physics," *Physics Today* (October 1979): 32-40.

Enhanced Efficiency in Lighting Technology & Growth of Lighting Demand (UK)

	Unit (100)	Year 1800	Year 1900	Year 2000
Fuel unit price	(22 pence/ kWh)	100	27	18
Technical efficiency	(35 lumen-hrs/ kWh)	100	1,450	70,000
Lighting unit price	**£5 thousand/million lumen-hrs)**	100	2.4	0.03
Lighting demand	(50 billion lumen-hrs)	100	22,000	3,400,000

(Currency values were calculated by using the year 2000 as a base.)

Extremely big rebound effect: whereas unit price is 1/3000, demand shows 30 thousand-fold growth.

Enhanced technical efficiency had far more influences than lowered fuel unit price had.

Source: P.J.G. Pearson: International Conf. on Science and Technology for Sustainability, Tokyo, Dec. 16-19, 2003

CO2 Collection and Storage: CCS Underground Storage/ Ocean Storage

CO_2 Separation recovery Plant

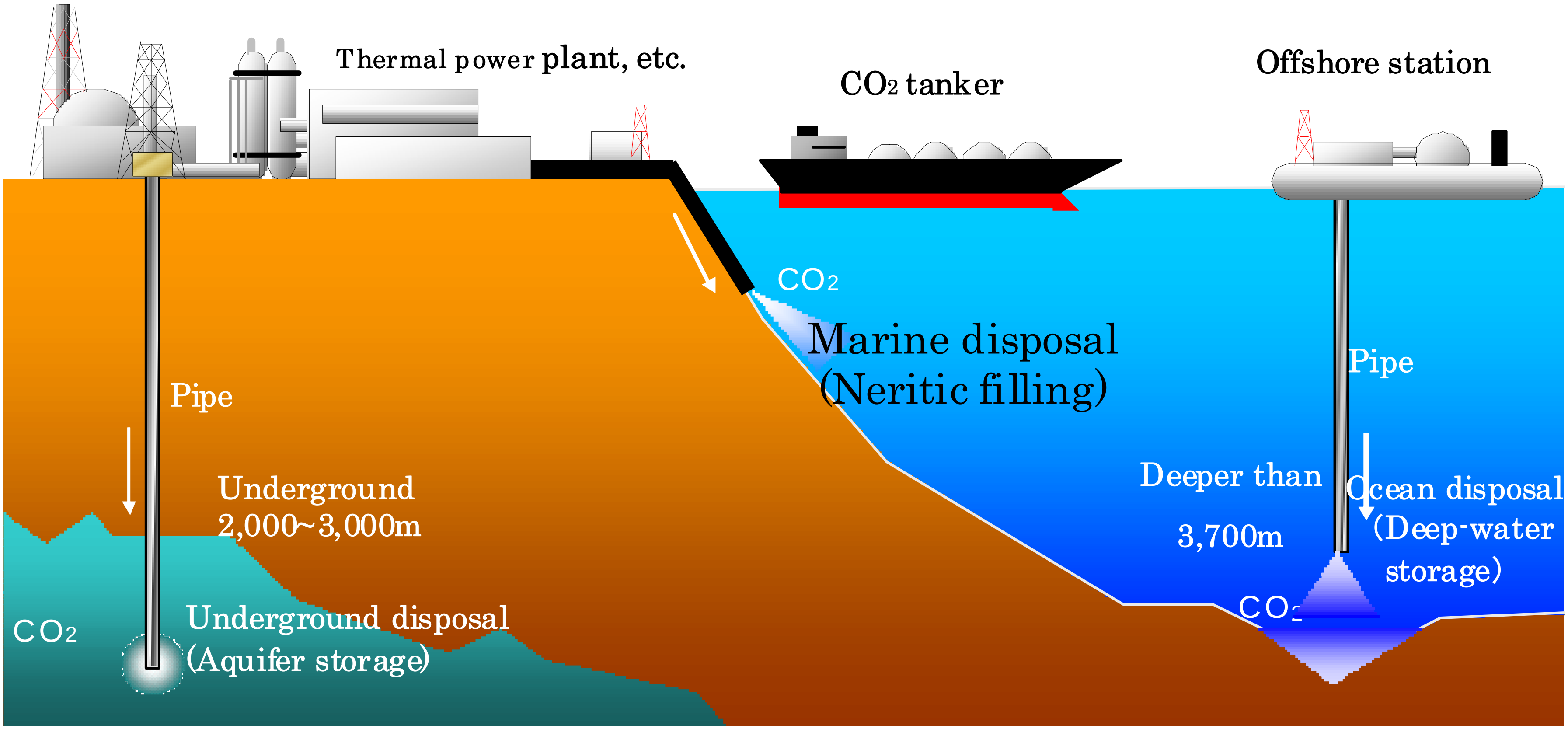
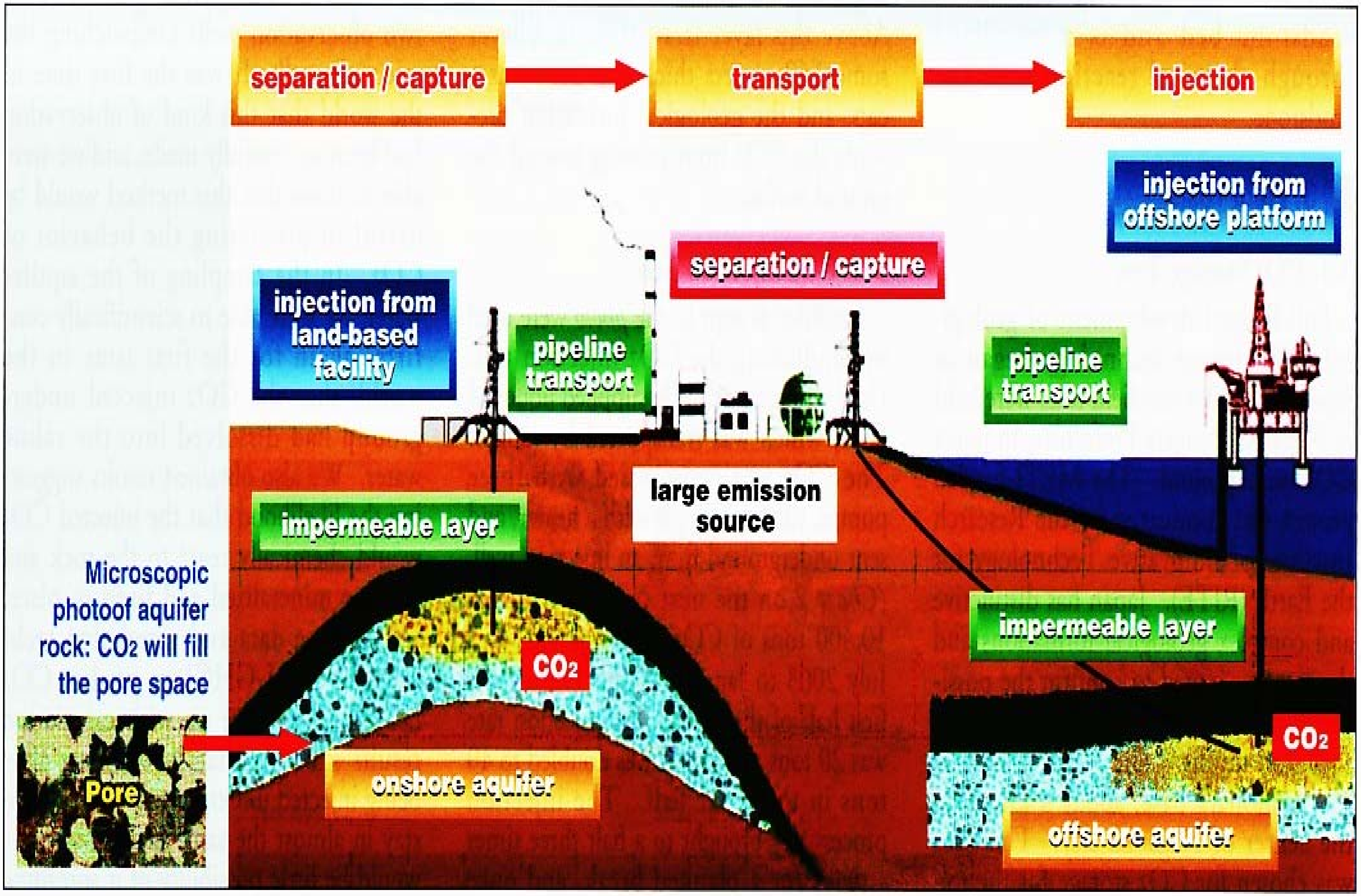


Chart 1 Schemes of CO_2 capture & its geological storage



Source : RITE

Source：JEF, Japan Spotlight, Sept./Oct. 2007