

Global Focus on Knowledge
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

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The Perspectives of Energy Systems

- System Effects and System Engineering
- Formation of the Concept of Energy
- How to Read Energy Statistics
- Demand and Supply of Energy: World and Japan
- 3E Issues: Energy, Economy & Environment

What is Energy System Engineering?

- "System": An aggregate of elements that fulfills coordinated functions as a whole, with plural elements inter-relating organically with each other. Organization. Scheme. [Kojien 4th ed.]
- "Engi(緣起)": A group of various causes and conditions, i.e., an aggregation of relationship.
- "Kuu(空)": Absence of any fixed substance consisting of Engi, i.e., a whole system.
- "Shiki(色)": Physical existence with substance, i.e., elements.
- "Shiki-soku-Zekuu, Kuu-soku-Zeshiki(色即是空、空即是色)": The whole system is prescribed by elements, while elements are prescribed by the whole system. (Yamaji's own interpretation)
- "Hannya-chi(般若知)": Ability to grasp the whole; wisdom to appreciate "Kuu." In contrast, "Funbetsu-chi(分別知)": Ability to comprehend analytically.
- "System Engineering": The way to give mathematical expressions to Hannya-chi.
- "Energy System Engineering": Overall understanding of energy; Energetics.

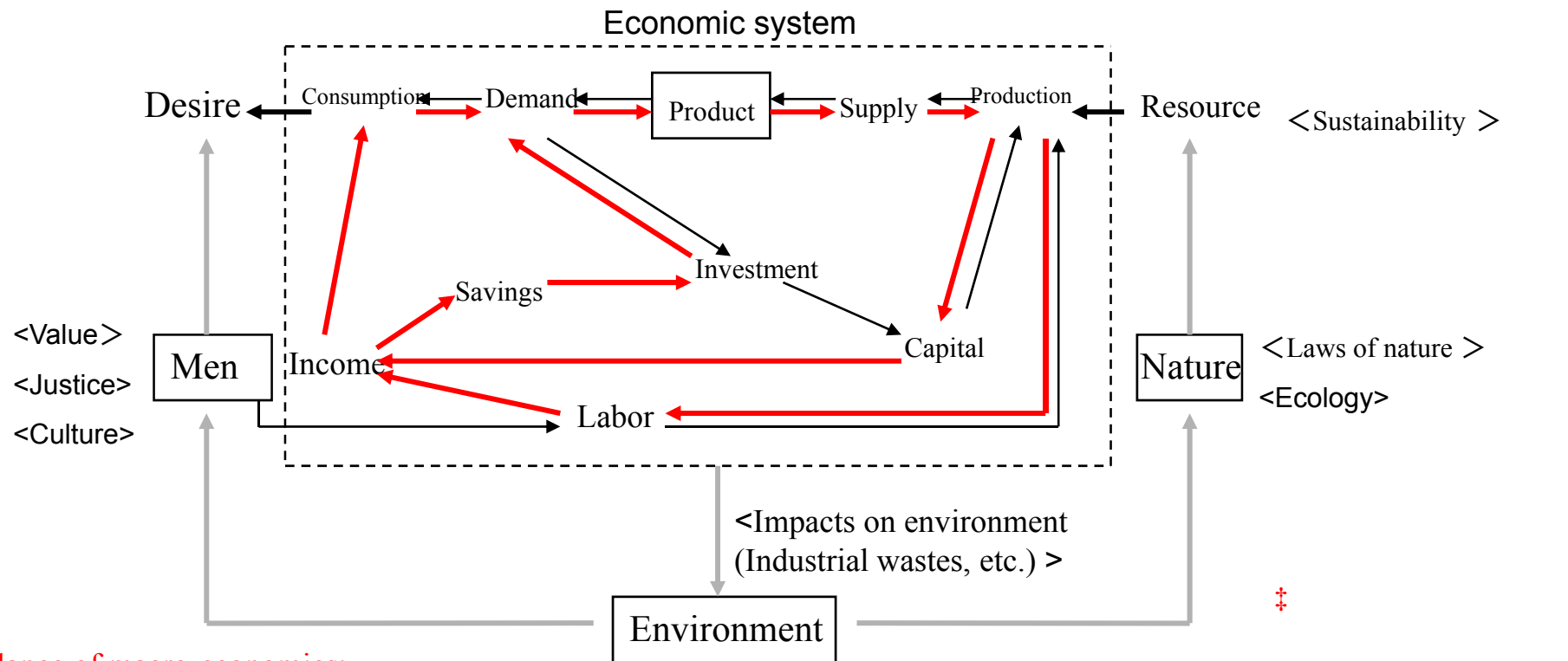
Vertical Knowledge & Horizontal Knowledge

- Science Council of Japan: “A New Knowledge System”
- “Recognition science”: the research into the things which exist.
- “Design science”: the research into the things which should exist.
- “‘Across’ type basic science technology”:

While vertical knowledge covers “being (entity),” horizontal knowledge covers “doing (functions),” exploring universality independent from “being.”

- Engineering in “vertical knowledge”: civil engineering, architecture, mechanical engineering, electrical engineering...
 - to apply universality of the laws of nature specifically to individual objects; making things.
- Engineering in “horizontal knowledge”: system engineering, design engineering, control engineering, etc.
 - Focused on functions, it covers the field across vertical knowledge. There is no universal single correct answer but there is universality in the logical process to seek after solution.
 - Horizontal knowledge brings “doing,” i.e., process and plan, or policy and system, for men or society, rather than “being.”
 - Verification of horizontal knowledge: to solve actual problems in human society.
 - The field to verify energy system engineering: the field of energy policy.
- To seek after “Hannya-chi” which permits understanding the whole system integrating men and nature.

Concept of Global System



Balance of macro-economics:

$$\text{Production} = \text{income} = \text{supply} = \text{demand} = Y$$

$$\text{Income}(Y) = \text{consumption}(C) + \text{savings}(S)$$

$$\text{Demand}(Y) = \text{consumption}(C) + \text{Investment}(I)$$

$$\text{Therefore, Investment}(I) = \text{savings}(S)$$

—→ Flow of goods/services

—→ Flow of money

—→ Relations outside of economic system
(Externality)

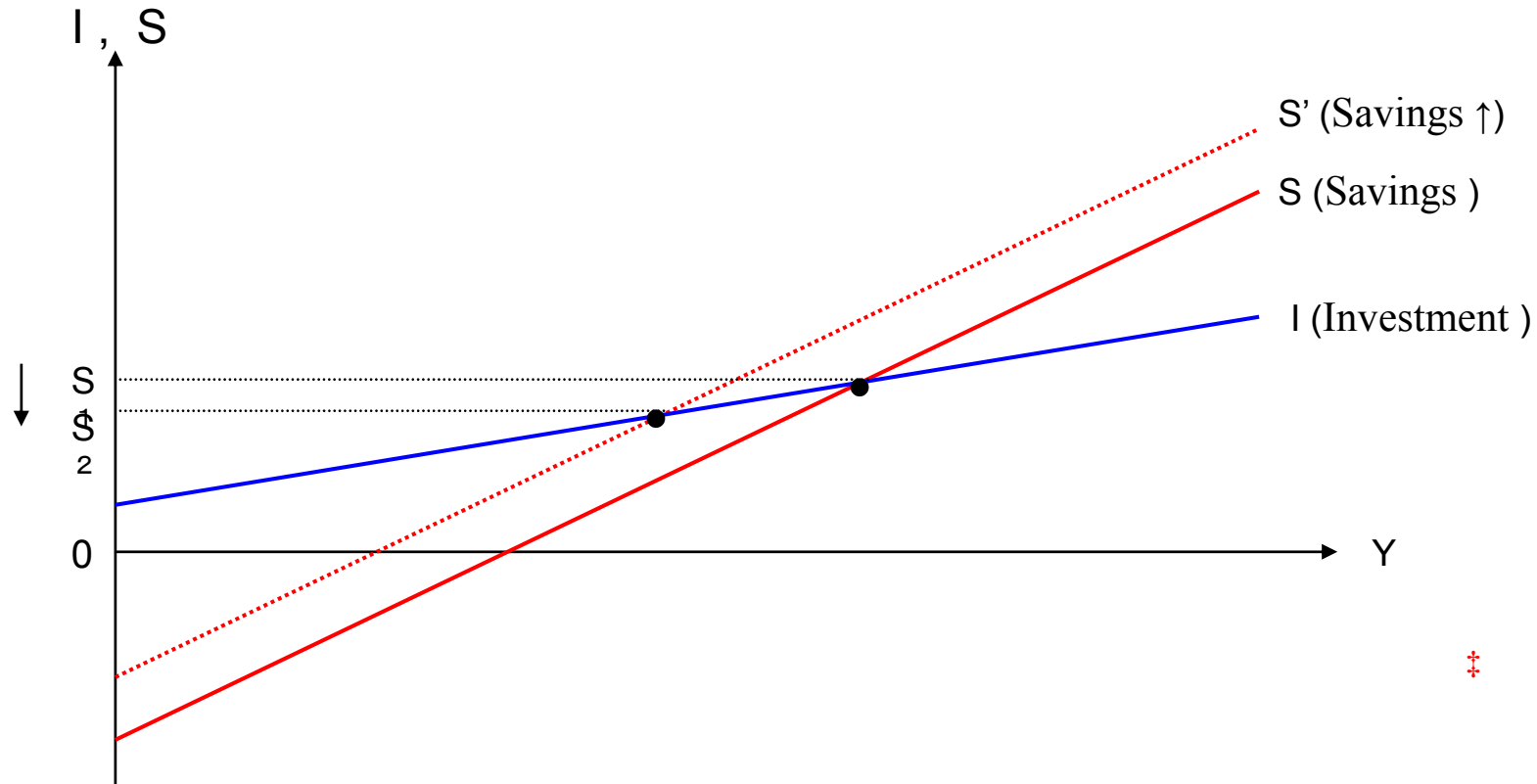
Source: Kenji Yamaji, Energy, Environment and Economic Systems,
Iwanami Shoten, 2006. Chart 1.1 (p.2).

$$Y=C+I=C+S$$

Y: Production=Income=GNP

C: Consumption/ I: Investment/ S: Savings

$$I=S$$



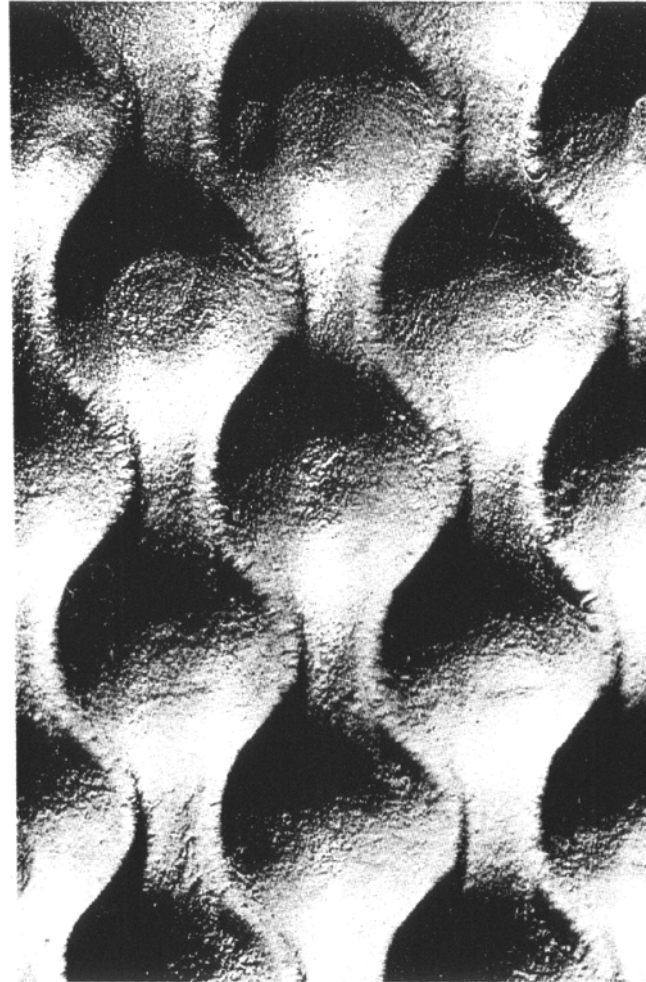
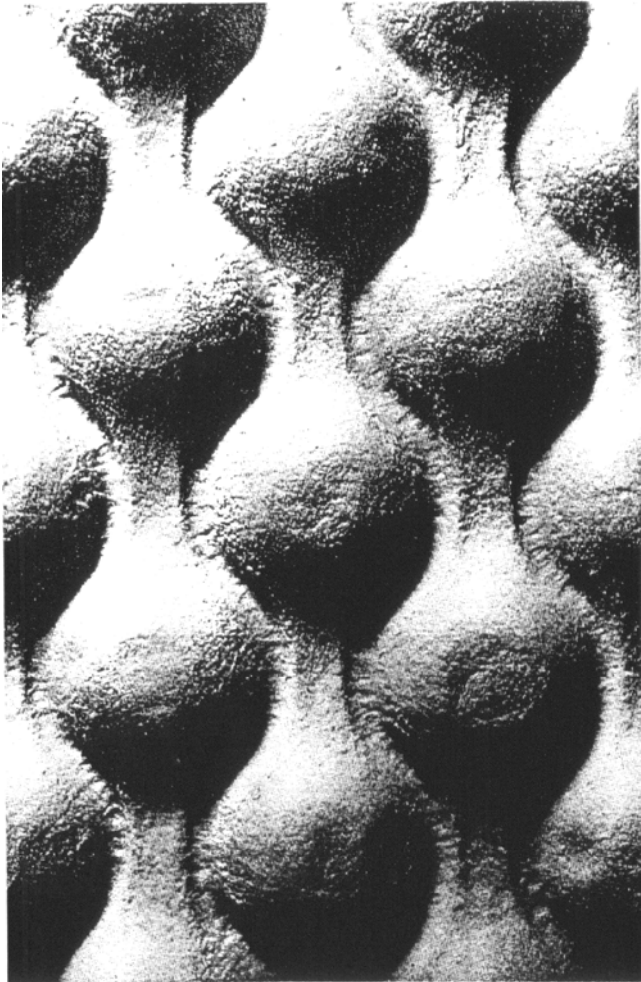
Paradox of Savings

Source: Kenji Yamaji, "Energy, Environment and Economic Systems," Iwanami Shoten, 2006. Chart 1.4 (p.12).



Jung oder alt: In welcher Weise Sie dieses berühmte Bild des amerikanischen Psychologen E. G. Boring sehen, ist ein Hinweis darauf, wie alt Sie sind. Sehen Sie eine junge Frau, die das Gesicht abwendet, sind Sie wahrscheinlich selbst jung. Sehen Sie eine ältere Frau, sind Sie vermutlich nicht ganz jung. Beim ersten Mal braucht man eine Weile, bis man beide Bilder sehen kann, kennen Sie beide Bilder aber, können Sie leicht entscheiden, welches Sie sehen wollen. Die Zeichnung hängt im Wissenschaftsmuseum "Exploratorium" in London.

Young or old: The way you see this famous picture of the American psychologist E.G. Boring, indicates how old you are. If you see a young woman who is turning away her face, then you are probably young. If you see an old woman, you are presumably not so young. First it takes some time to see both pictures; those, however, who then know these pictures can easily decide which one they want to see. The drawing can be seen in the scientific museum "Exploratorium" in London.

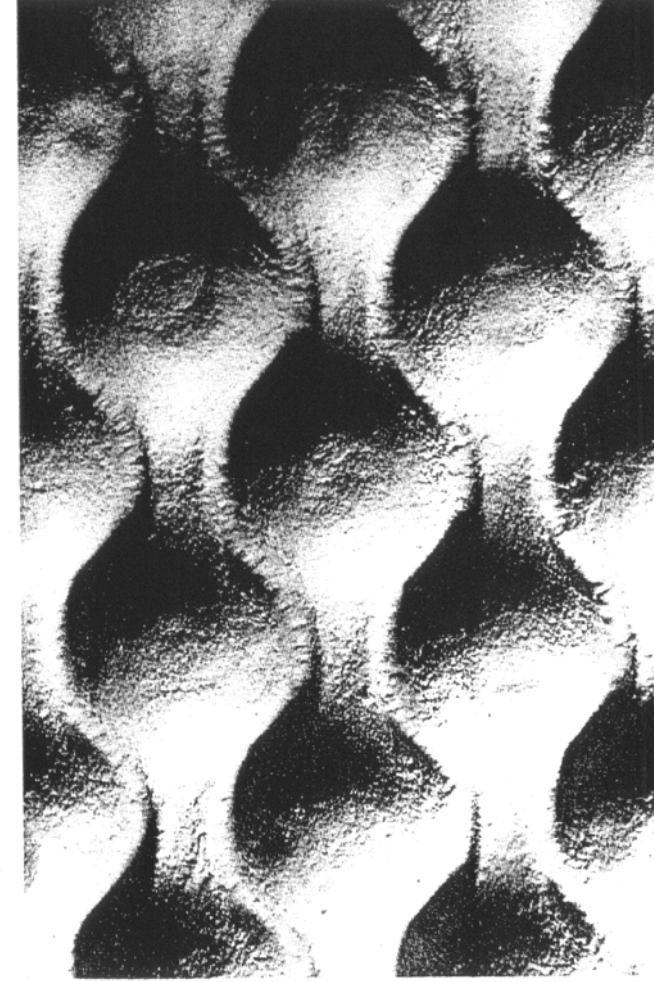
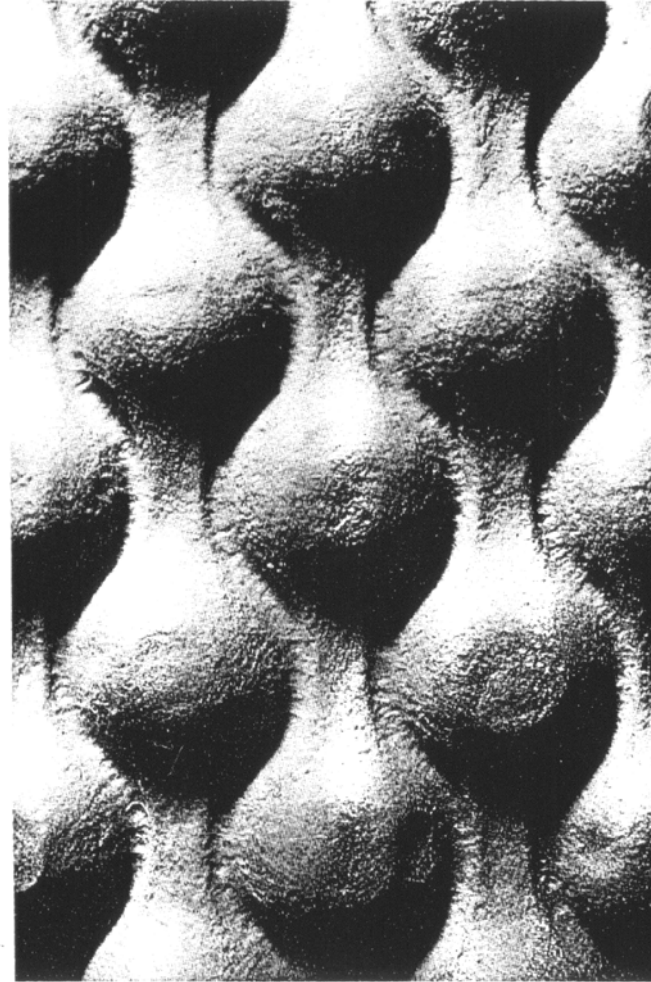


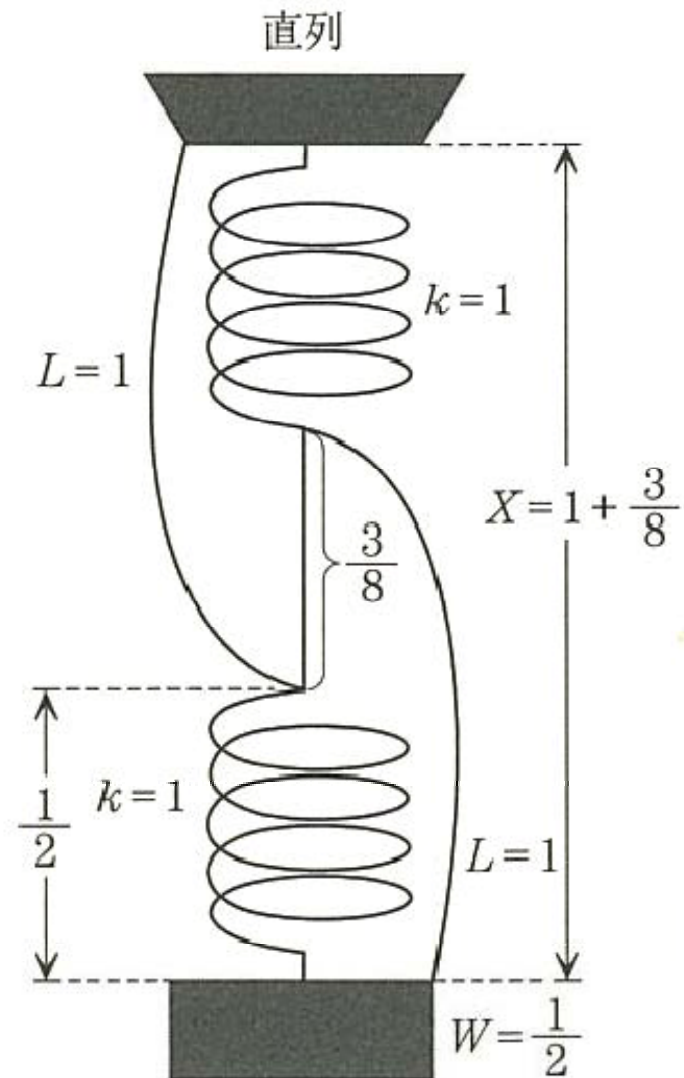
Der Eierbehälter. Ist dieser Eierbehälter nach unten oder nach oben gewölbt? Wenn Sie die Antwort haben, drehen Sie das Heft auf den Kopf. Aus den Erhebungen werden plötzlich Vertiefungen. Ist der Schatten oben, sehen wir eine Vertiefung, ist er unten, sehen wir eine Erhöhung. Ein Hinweis darauf, daß wir auf einem Planeten leben, der sein Licht erfahrungsgemäß von oben und nicht vom Erdboden erhält. Dieser Effekt wurde erstmals im 19. Jahrhundert beschrieben.

The egg-cup: Is this egg-cup arched upwards or downwards? When you have the answer turn the magazine upside down. The elevations suddenly become depressions. Is the shadow at the top, we see a depression, is it below we see an elevation. This is a hint that we live on a planet where the light, as experience shows, comes from above and not from the ground. This effect was described for the first time in the 19th century.

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‡ Source: Kenji Yamaji, Energy, Environment and Economic Systems, Iwanami Shoten, 2006. p13 Chart 1.5

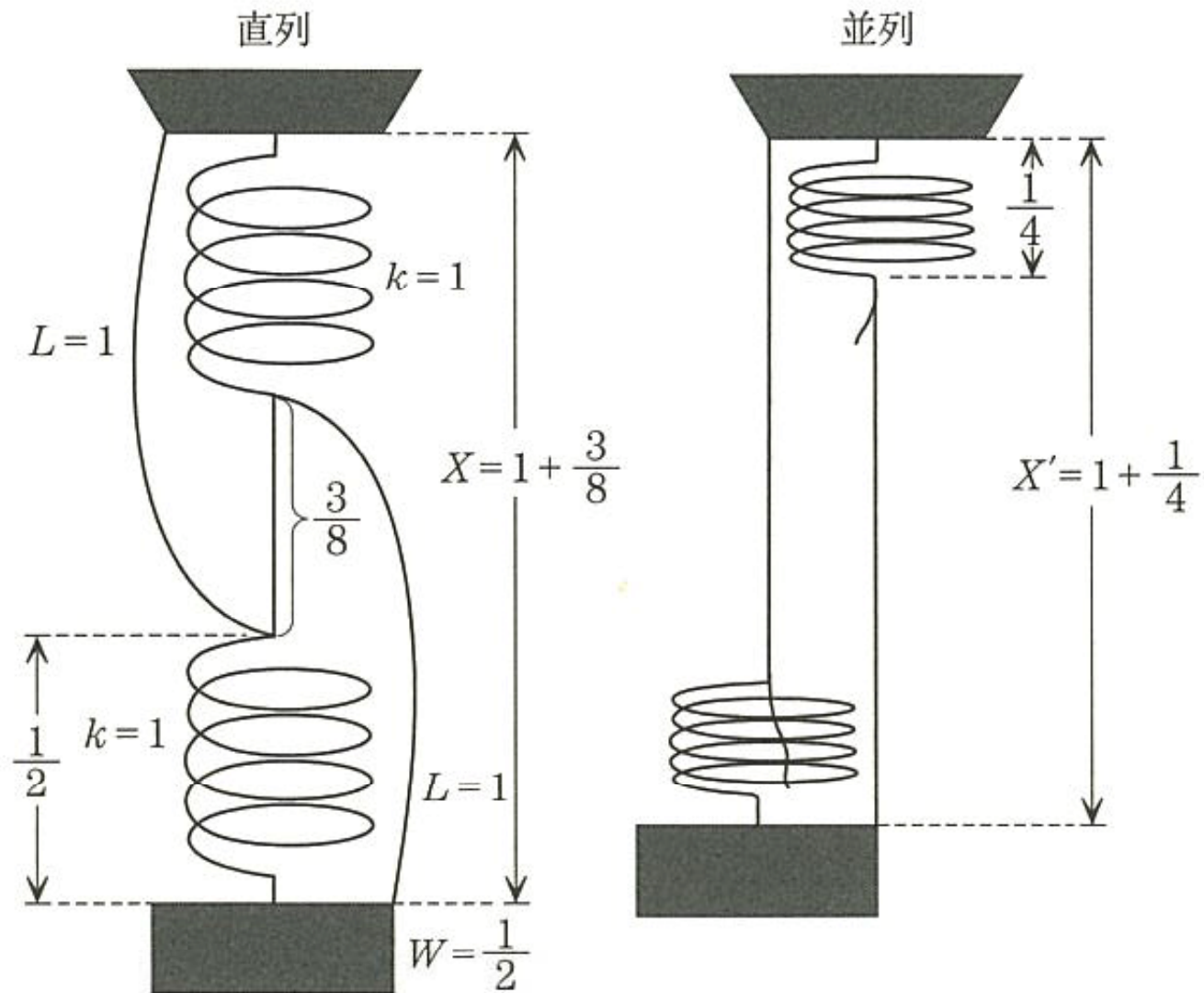


図 1.5 バネと錘から構成される力学システム。

‡ Source: Kenji Yamaji, Energy, Environment and Economic Systems, Iwanami Shoten, 2006. p13 Chart 1.5

Perspectives and Knowledge

Knowledge makes perspectives.

Perspectives make the structure of knowledge

Can structural (paradigm) shift be detected?

Types and Objects of Knowledge

Natural science —————> Program science Arts

(Logical verification type)

(Logical integration type)

←-----Objects----->

Nature, life, artifact, (human beings), system, value, desire...emotion

Linear model —————>

Feedback model

(Discovery of rules →application)

(Hypothesis →verification →hypothesis...)

Formation of the Concept of Energy (1)

- Formative process of the concept of dynamic energy:
 - The Principle of Lever (Greek civilization)→ Da Vinci: “**The Principle of Work.**”
 - Thinking in the 17th century: Descartes’ law of **momentum** (mv) conservation; Leibniz’s law of “**dynamism**” (mv^2) conservation→ Time integration of force is momentum, while space integration is energy ($mv^2 / 2$).
 - Watt** (18th century): calculated workload, defining it as “force added to an object x migratory distance.”
- Discovery of the law of conservation of energy:
 - Young (1807): used the term energy as the concept to express dynamism or ability to carry out a work.
 - Meyer, Joule and Helmholtz (first half of 19C): discovered the law of conservation of energy independently of each other.
 - **Meyer**, having started with research into the color change in sailors’ blood in tropical areas (more vivid than in Europe) as a ship’s doctor, reached the idea of the law of conservation of energy.
 - **Joule** discovered more directly the **mechanical equivalent of heat** through various experiments.
 - Helmholtz** developed his examination based on the fact that the total amount of potential energy and kinetic energy in dynamic systems is invariable.

Formation of the Concept of Energy (2)

- Discovery of the second law of thermodynamics (the law of entropy increase):
 - History of science on heat and combustion: phlogiston→ caloric (Lavoisier) → thermodynamics.
 - Carnot**, Thomson (Lord Kelvin) and Clausius: Based on the discussion of Carnot cycle (maximum value of thermal efficiency) in 1824, **Thomson** (it's not possible to convert a single heat source into all works) and **Clausius** (heat never flows from low temperature to high temperature by itself) formulated independently.
- Philosophical background of energy:

“Ενέργεια (energeia)” in Greek, the origin of the term “energy,” represents “the state in work” with a prefix “en” added to “ergon” meaning work. According to **Aristotle**'s philosophical interpretation, the state where potential essence is realized (=reality of the situation) is “energeia.” The concept of energy established in the 19th century is supported by the inspiration that invisible “dynamism” like heat will convert to specific works.

Is mechanical equivalent of heat ($1\text{ cal}=4.2\text{ J}$) correct?

- Joule calculated mechanical equivalent of heat by converting work into heat (the first law of thermodynamics [energy conservation law] is applied).
- When converting heat to work, the heat temperature must be taken into account (the second law of thermodynamics is involved). Here, exergy plays an important role, which is defined by the maximum workload that can be taken out by the time it has come to equilibrium with the environment. **Exergy** is the concept that takes account of the quality of energy.

Examples: How much is **the mechanical equivalent of 1kg water 1°C higher** than the surroundings (estimated 15°C)?

- Based on the first law, it will release the energy of $1\text{ kcal}=4.2\text{ kJ}$ by the time the water reaches the same temperature as the surroundings. To show this energy by the potential energy of the same 1kg water, it will be **$h=430\text{ m}$** . (formula: $mgh=1\times 9.8\times h=4.2\text{ kJ}$.) Does it seem unrealistic?
- When discussing it by exergy based on the second law (the surrounding temperature is $15^\circ\text{C}=288\text{ K}$), it will be **$h=74\text{ cm}$** . (formula: $1\times 9.8\times h=(289-288)-288\times \log(289/288)\text{ kcal}=0.00173\text{ kcal}=0.00724\text{ kJ}$.)
- As this example shows, you cannot simply add energies of different quality such as heat and work.

The calorific value (Q) and exergy (E) of a resource m(kg) at the temperature T(K) under the pressure Po (the pressure is the same as the outward, while the temperature alone is different from the surroundings) are calculated as follows:

▸ The calorific value released by this resource by the time its temperature becomes equal to that of the environment system (To) (provided that the specific heat under constant pressure Cp is fixed): $Q = mC_p(T - T_0)$

▸ The maximum workload to be taken out of this resource (exergy E; the change in temperature from T to To to be taken into account.):

The maximum work to be taken out of T's temperature $\delta Q = mC_p dT'$ (Carnot cycle): $mC_p dT'(1 - T_0/T')$.

$$E = \int_{T_0}^T mC_p \left(1 - \frac{T_0}{T'}\right) dT' = mC_p \left\{ (T - T_0) - T_0 \ln \frac{T}{T_0} \right\} \cong \frac{mC_p (T - T_0)^2}{2T_0} ; \quad \left| \frac{T - T_0}{T_0} \right| \ll 1$$

•▸ Therefore, the approximation of exergy E of a heat resource can be calculated from normal calorific value Q by $E/Q = (T - T_0)/2 T_0$, if the temperature difference from the outward is small.

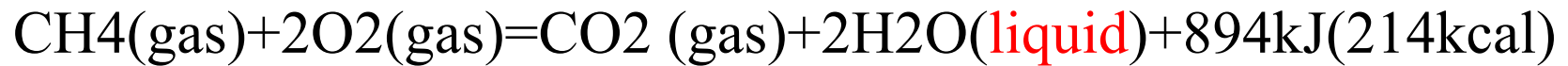
How to Read Energy Data

- **Read the definitions rather than the numerical value...**
Energy unit, **heat value (higher or lower)**, primary energy equivalent of electric power...
- **Learn the sense of proportion from various energy sources around you:**
1kWh, 1 liter gasoline, 1m³ city gas, 1kg wood, 1kg garbage...
- **Confirm the data sources:**
Official statistics (incl. Comprehensive Energy Statistics), individual statistics, estimates...
- **Compare with the energy system structures:**
List of energy balance, total supply of primary energy, final energy consumption...
- **Learn the common sense of figures:**
Oil prices, electric utility rates, energy consumption in Japan...
- **In case of economic statistics, pay attention to money value:**
Adjustment for inflation (price level), currency exchange adjustment...

Higher Heat Value (HHV) and Lower Heat Value (LHV)

In case of methane (CH₄):

Higher Heat Value (HHV):



Lower Heat Value (LHV):

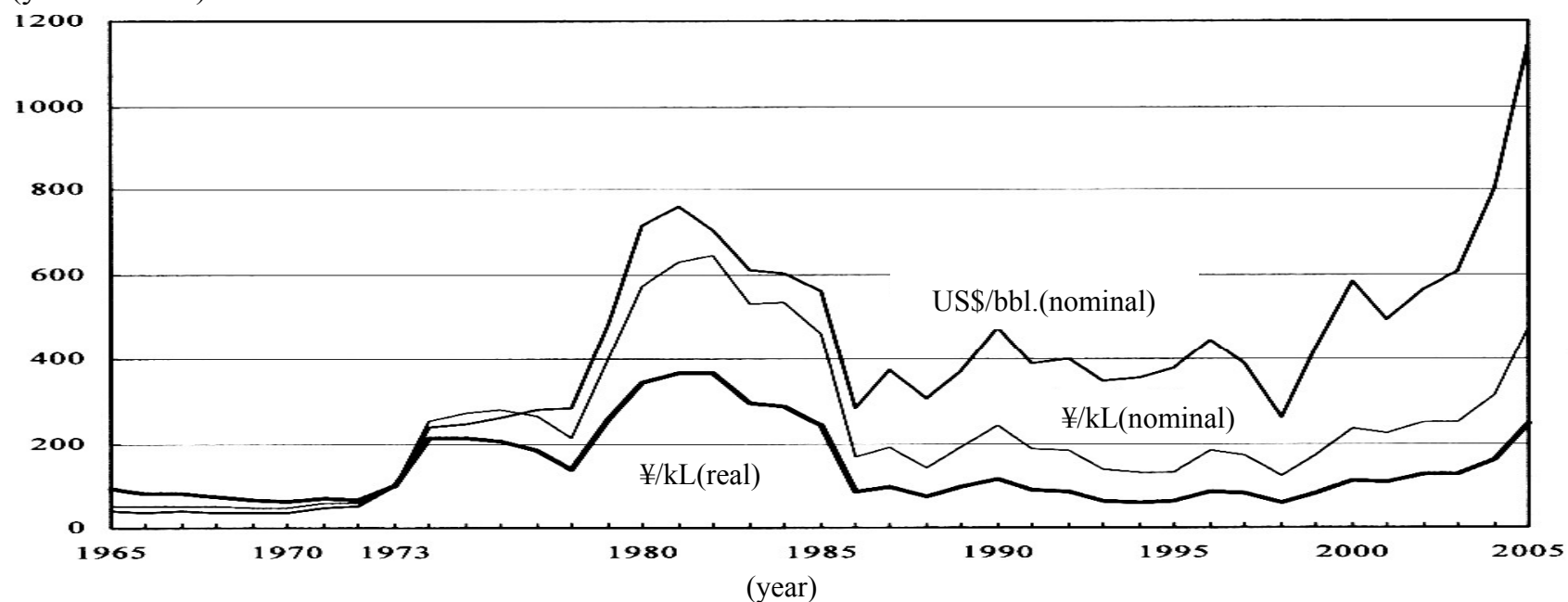


1 mole methane: approx. 16g, 22.4L

→ 1kg methane ~13,000kcal; 1m³ ~10,000kcal

(1) Change in CIF Prices for Imported Crude Oil

(year 73=100)



Year	1965	1973	1979	1985	1990	1995	2000	2005
CIF prices in nominal dollars (\$/bbl.)	1.97	4.85	23.37	27.21	22.97	18.28	28.33	55.68
CIF prices in nominal yen (¥/kL)	4,461	8,343	33,522	38,340	20,138	11,000	19,560	39,580
CIF prices in real yen (¥/kL, price in 2000)	16,040	17,300	44,683	41,935	20,330	10,696	19,618	42,496
GDP deflator (year 2000=100)	27.8	48.2	75.0	91.4	99.1	102.8	99.7	93.1

Reference: *Japan Exports & Imports* (monthly bulletin) by Ministry of Finance, *System of National Accounts* (annual report) by Cabinet Office, etc.

Note: (1) Conversion to CIF prices in real Yen was calculated using the GDP deflator in 2000 as base year.

Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.1 (p.19).

Energy Units

- Energy and power:

Joule (J) and Watt (W): $1\text{W}=1\text{J}/\text{sec}$.

- Energy units:

Common units: J, cal, ton in oil equivalent conversion (TOE)...

Specific units:

Electric power: kWh(kW hour), primary energy conversion of electricity

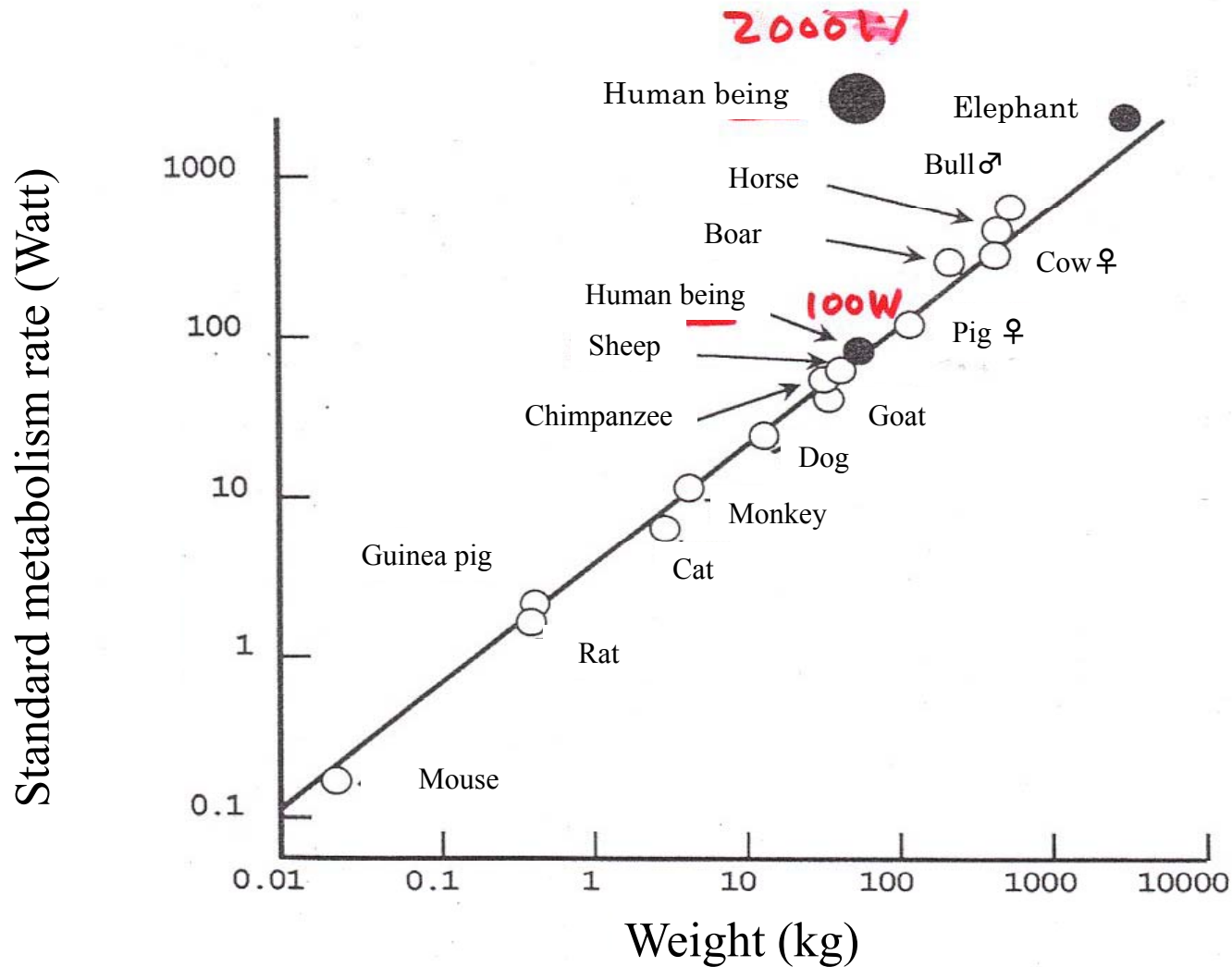
Oil: barrel (bbl), kL

Natural gas: cubic meter (m^3), tcf (trillion cubic feet), ton (in case of LNG)

Coal: ton (t)

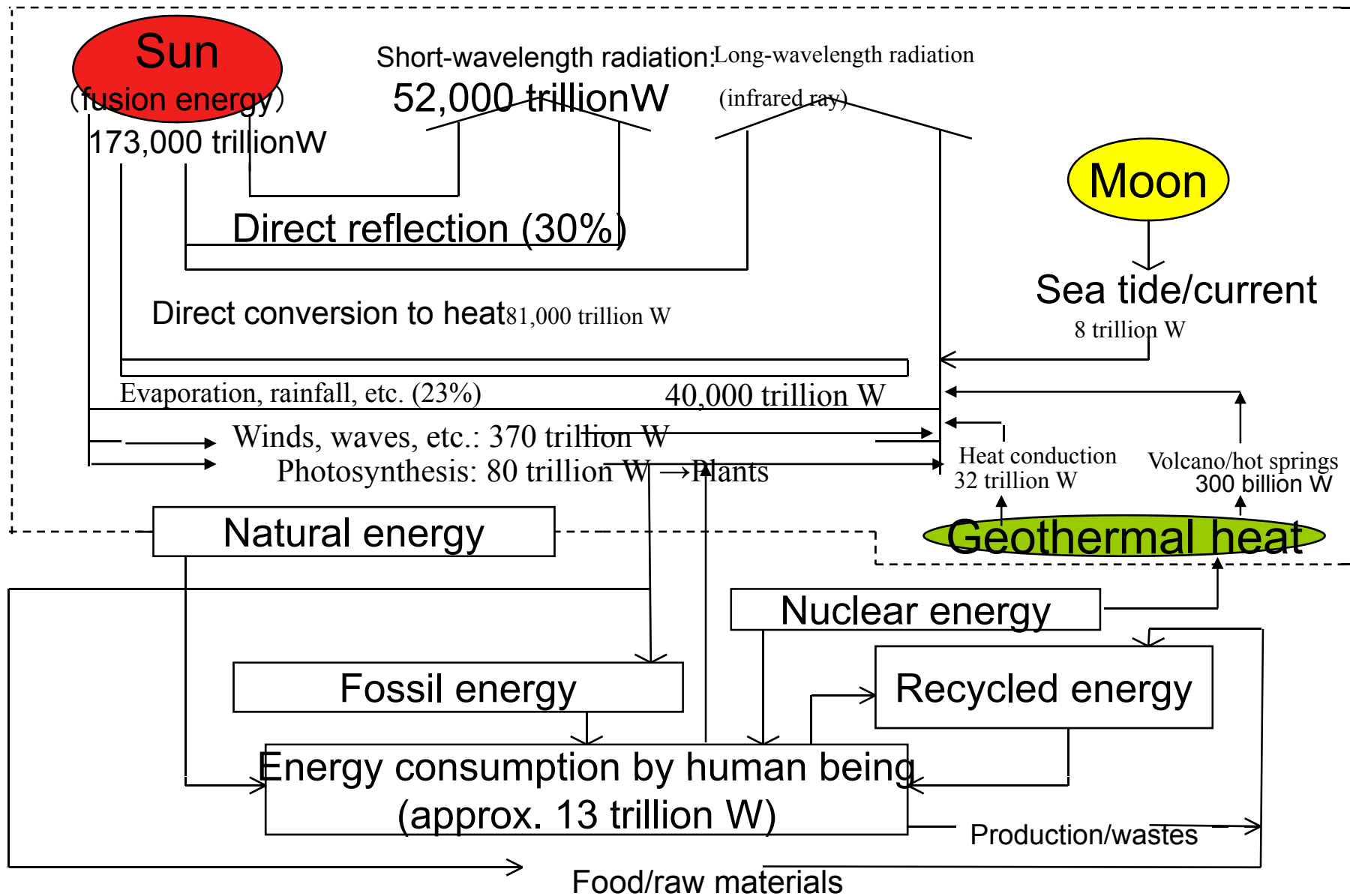
Heat quantity: cal, BTU (British thermal unit), therm

Vital Life Energy



Energy required for animals to live †

Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.2 (p.25).



Energy Balance of the Earth and Various Energy Sources

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

Additional 1 Billion TOE/year Burnt by Non- Commercial Energy
(Mainly, traditional biomass including fuel wood)

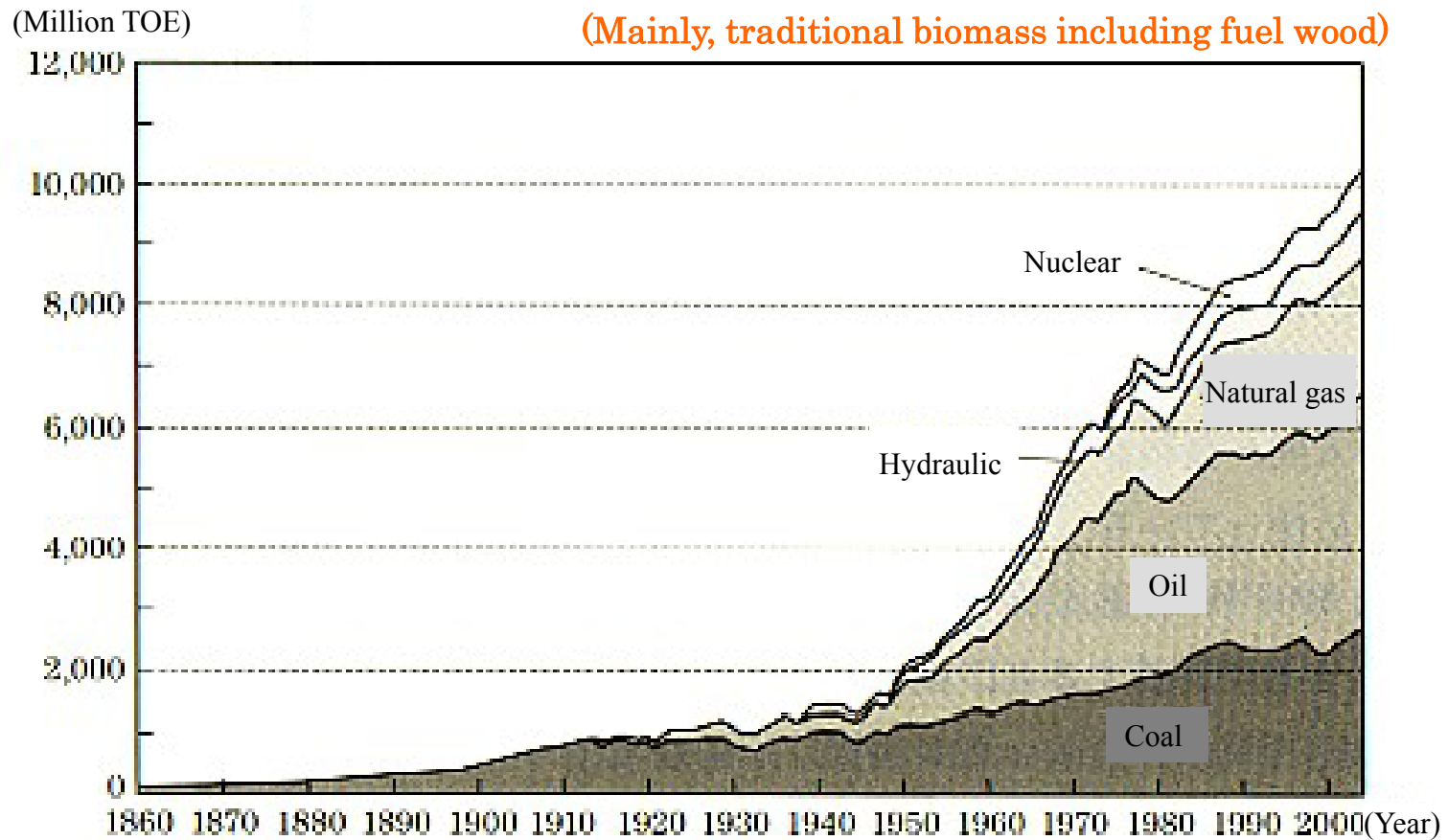
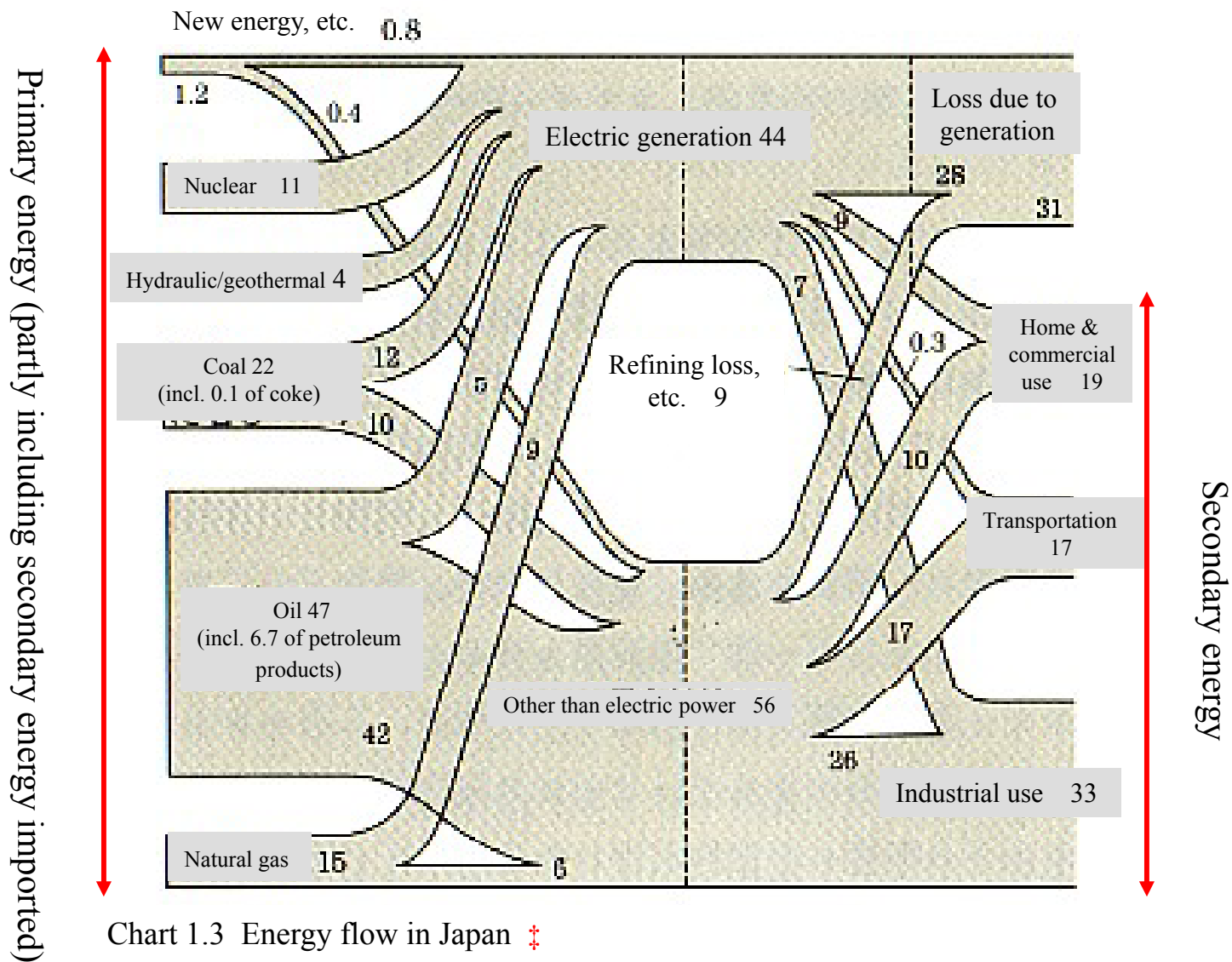


Chart 2 & 3. Change in primary energy consumption in the world.

Reference: Prepared based on: Takao Tomidate, Hisao Kibune, *The Newest: Introduction to Energy Economics*, Toyokeizai Shinpo-sha, 1994 and BP statistics.



The figures show the proportions (%) to the internal primary energy supply (approx. 540 million TOE). Calculation based on 2004 Energy Balance List.

Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 1.3 (p.8).

(4) Condensed List of 2004 Energy Balance

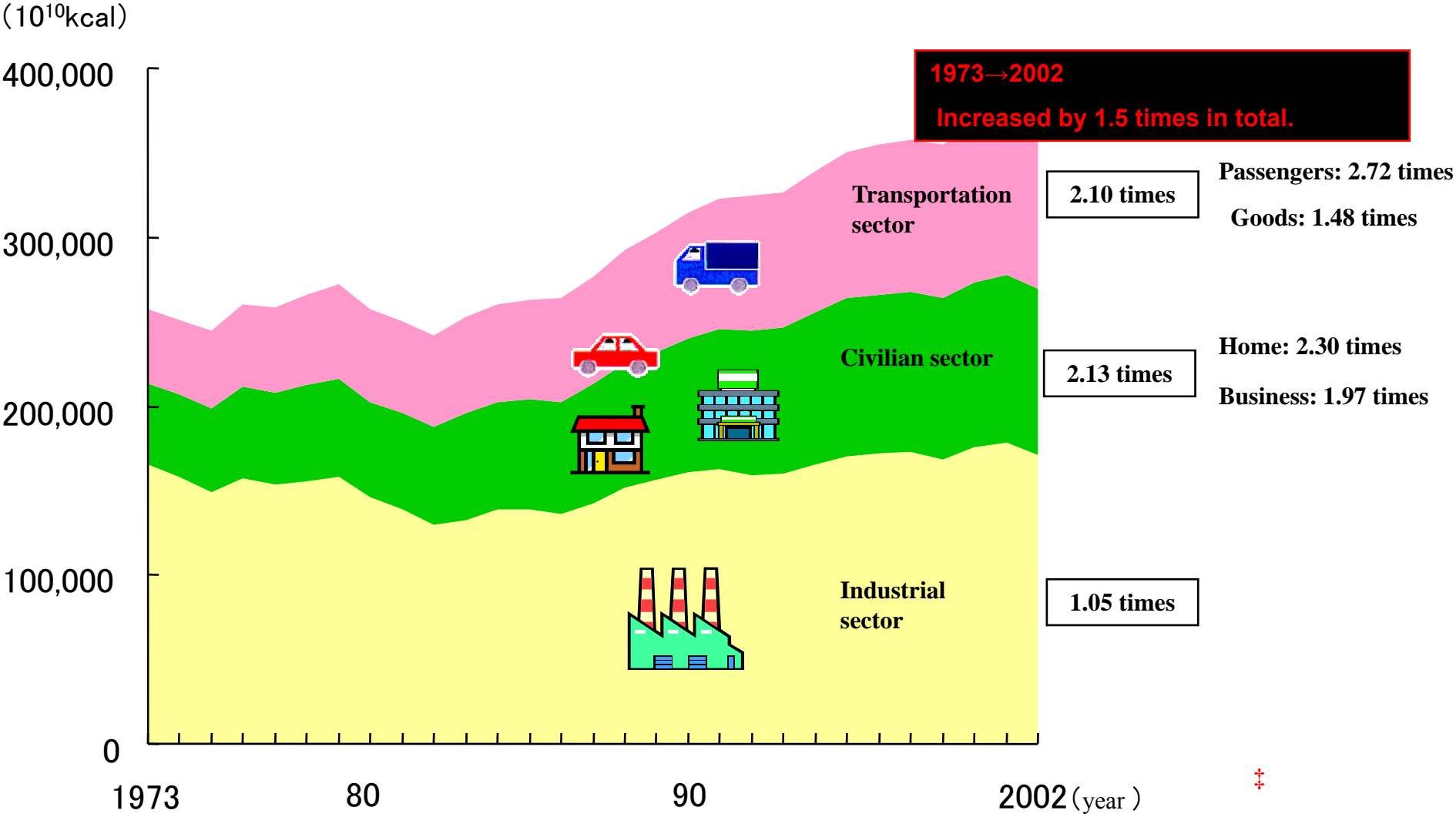
												(10 ¹⁰ kcal)	
	NO.	1	2	3	4	5	6	7	8	9	10	11	12
		Coal	Coke	Crude oil	Petroleum products	Natural gas	City gas	Hydraulic power generation	Nuclear power generation	Geothermal heat	New energy, etc.	Total electric power	Total
Primary energy supply:													
Domestic production	1	684		786		2,890		20,964	60,725	970	6,306		93,325
Import	2	117,818	2,121	220,146	53,830	75,537							469,452
Total supply of primary energy	3	118,502	2,121	220,932	53,830	78,427		20,964	60,725	970	6,306		562,777
Export	4		-1,463		-18,404								-19,867
Inventory change	5	-1,238		-683	658	-2							-1,265
Domestic supply of primary energy	6	117,264	658	220,249	36,084	78,425		20,964	60,725	970	6,306		541,645
Energy conversion and captive consumption													
Electricity companies	7	-49,363	-4,318	-5,708	-10,578	-48,906	-1,412	-19,322	-60,725	-695	-586	80,404	-121,209
Private power generation	8	-10,122	-3,002		-13,221		-2,386	-1,642		-54	-5,892	16,390	-19,929
Heat supply companies	9	-12			-33		-423				659	-99	92
City gas	10		-69		-1,738	-27,547	30,787						1,433
Coke	11	-42,195	36,740		-583								-6,038
Petroleum refinery	12			-213,432	212,234								-1,198
Petrochemical industries	13			-1,133	1,134								1
Others	14												
Captive consumption & loss	15	-110	-3,091	-1	-13,673	-1,052	-714					-10,132	-28,773
Statistical errors	16	236	-3,408	25	6,047	-273	-10			1	2,806	361	5,785
Total consumption of final energy	17	15,698	23,510		215,673	647	25,842			222	3,293	86,924	371,809
Total industrial sector	18	15,698	22,484		85,098	630	9,412			95	2,135	36,459	172,011
Agriculture, forestry & fishery	19				8,850					95		319	9,264
Mining	20				581							195	776
Construction	21				2,908							87	2,995
Total manufacturers	22	15,698	22,484		72,759	630	9,412				2,135	35,858	158,976
Food	23				1,518		1,535					2,434	5,487
Textile	24	28			1,665		184				45	552	2,474
Paper & pulp	25	1,478			2,298		419				2,090	2,988	9,273
Chemicals	26	908	106		44,360	447	1,693					5,592	53,106
Ceramics & building materials	27	4,233	352		2,975		485					1,773	9,818
Steel & iron	28	8,746	21,255		2,407		1,525					7,130	41,063
Nonferrous metals	29	84	199		869		424					1,646	3,222
Metal machinery	30	112	106		456		1,395					7,705	9,774
Others	31	109	466		16,211	183	1,752					6,038	24,759
Total civilian sector	32		1,026		34,854	17	16,430			127	1,158	48,580	102,192
Home	33		20		19,690		9,463				580	24,211	53,964
Business	34		1,006		15,164	17	6,967			127	578	24,369	48,228
Total transportation sector	35				89,893							1,885	91,778
Non-energy	36				5,828								5,828

Reference: EDMC estimate.

Note: From 2000 on, heat values by energy source were reviewed.

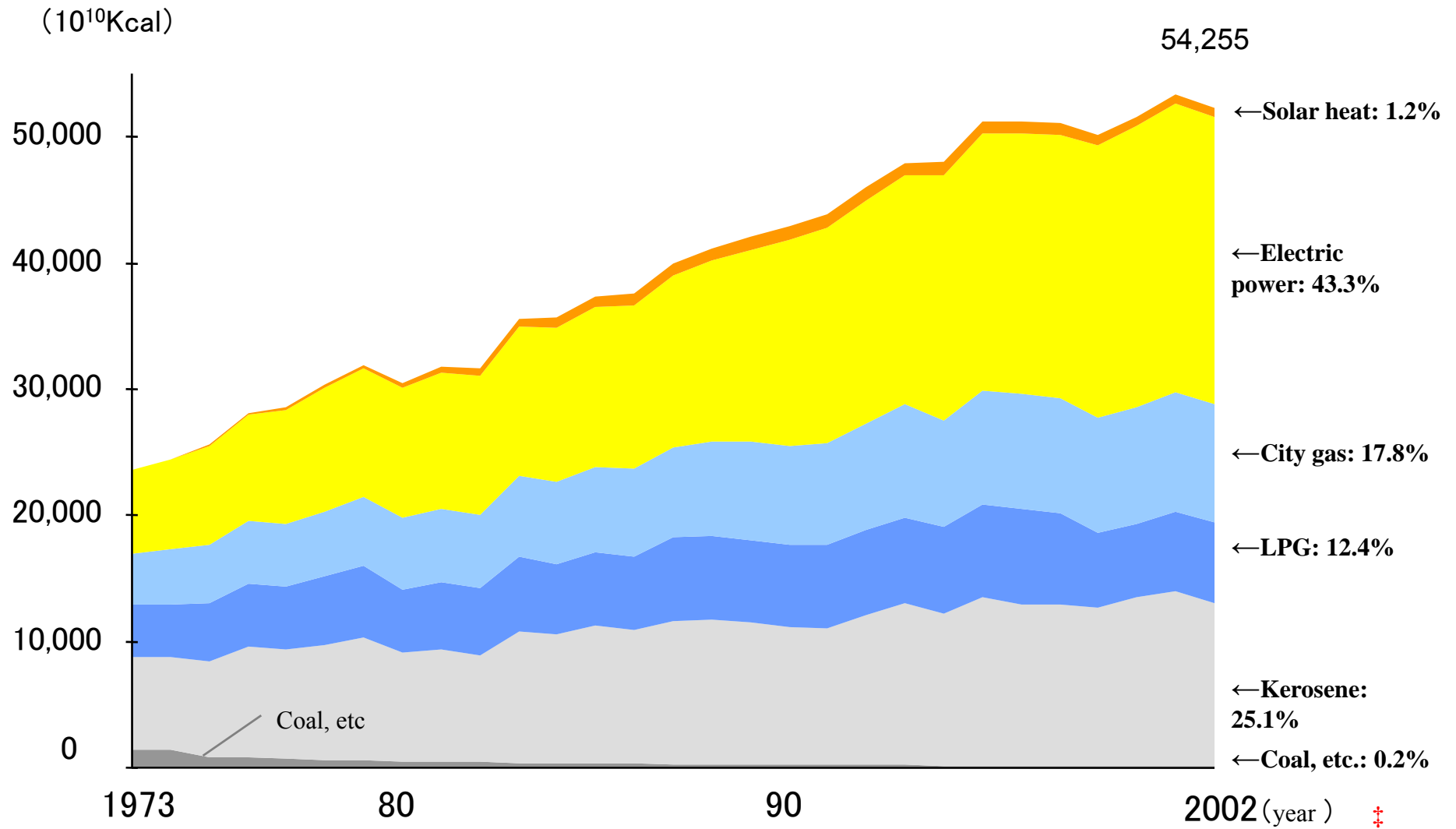
Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Table 2.1 (pp.30-31).

Change in Final Energy Consumption by Sector



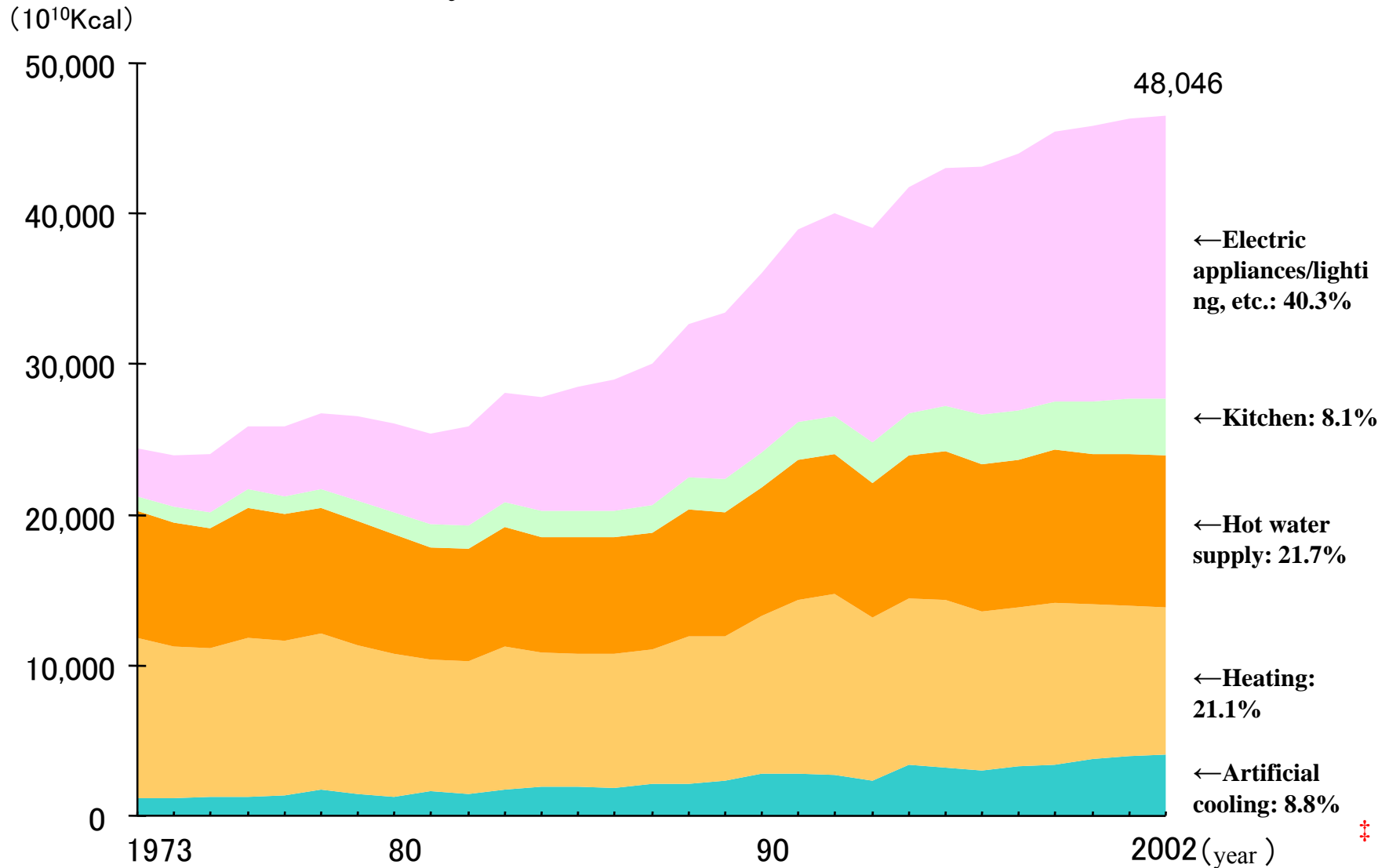
Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.6 (p.34).

Change in Energy Consumption by Energy Source in Home Sector



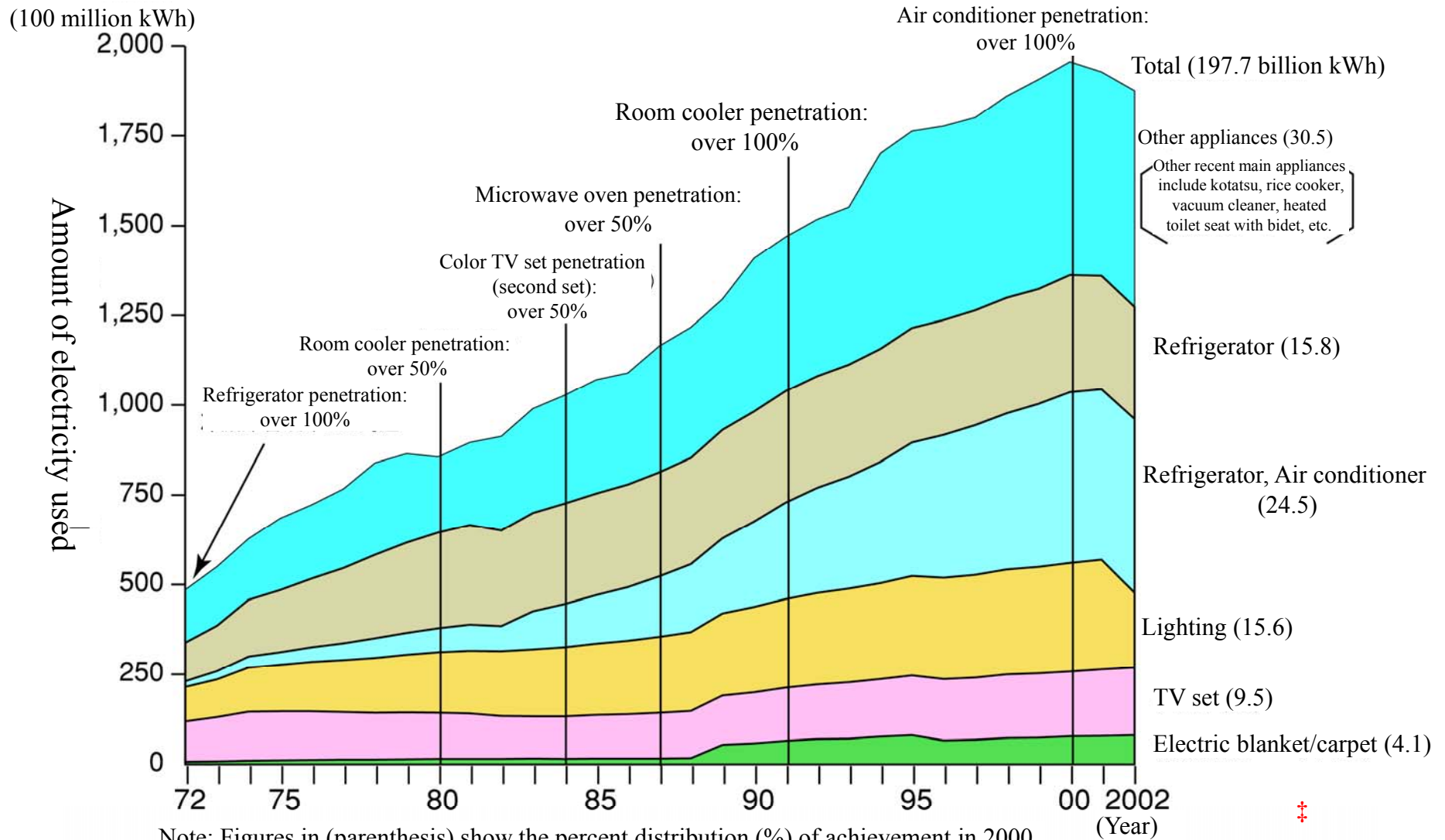
Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.7 (p.35).

Change in Energy Consumption by Use in Business Sector



Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.8 (p.35).

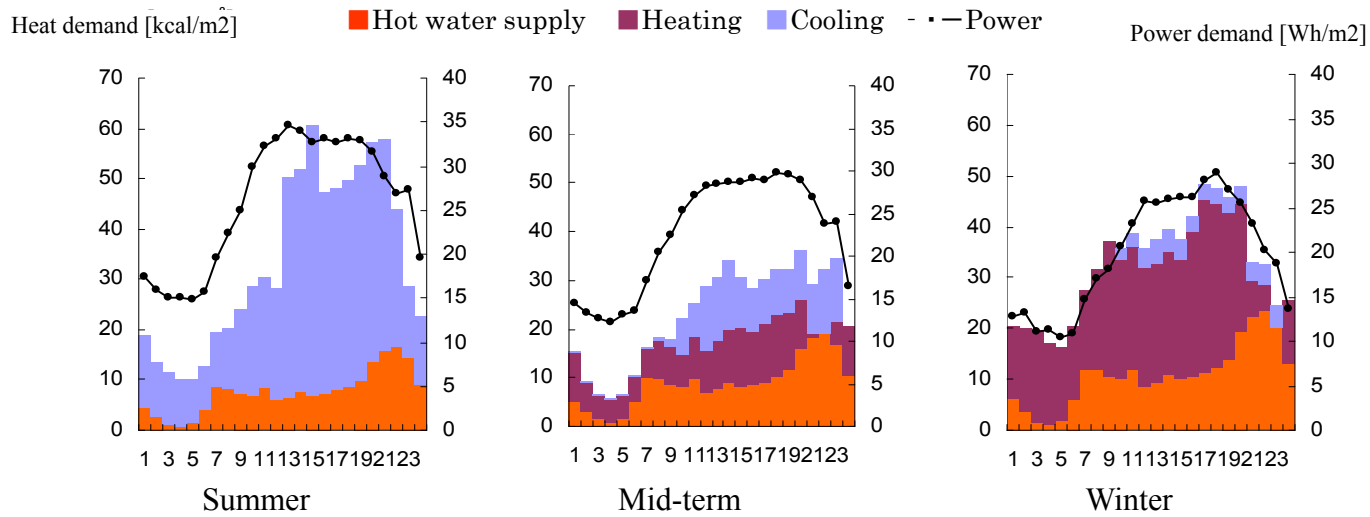
Growth in Home Use of Electricity



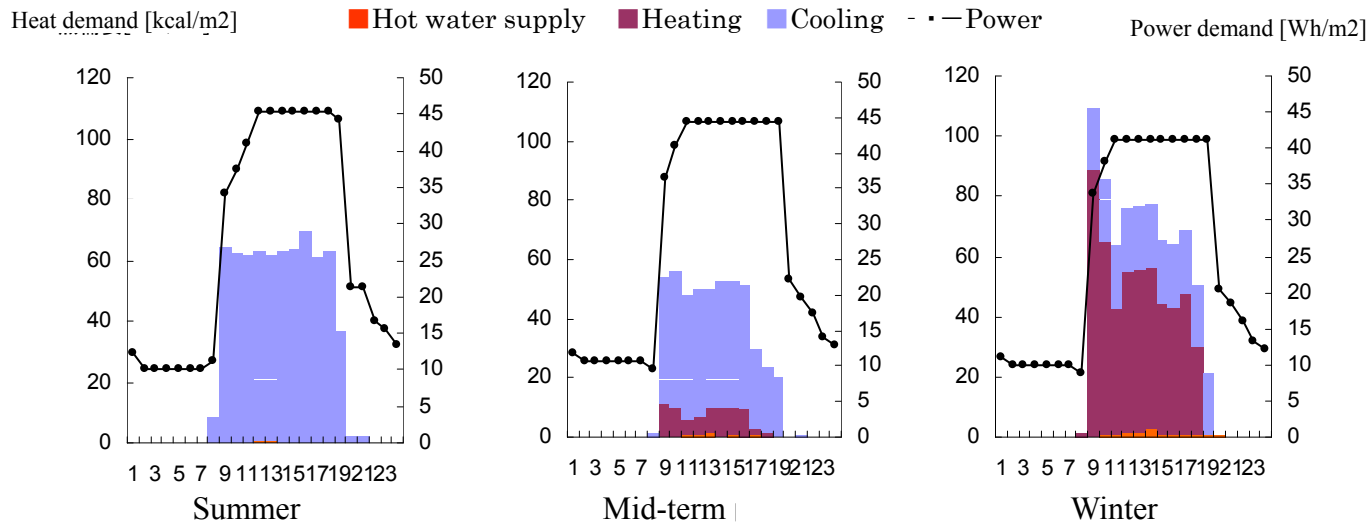
Note: Figures in (parenthesis) show the percent distribution (%) of achievement in 2000.

Due to rounding error, the total may vary.

Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.9 (p.36).

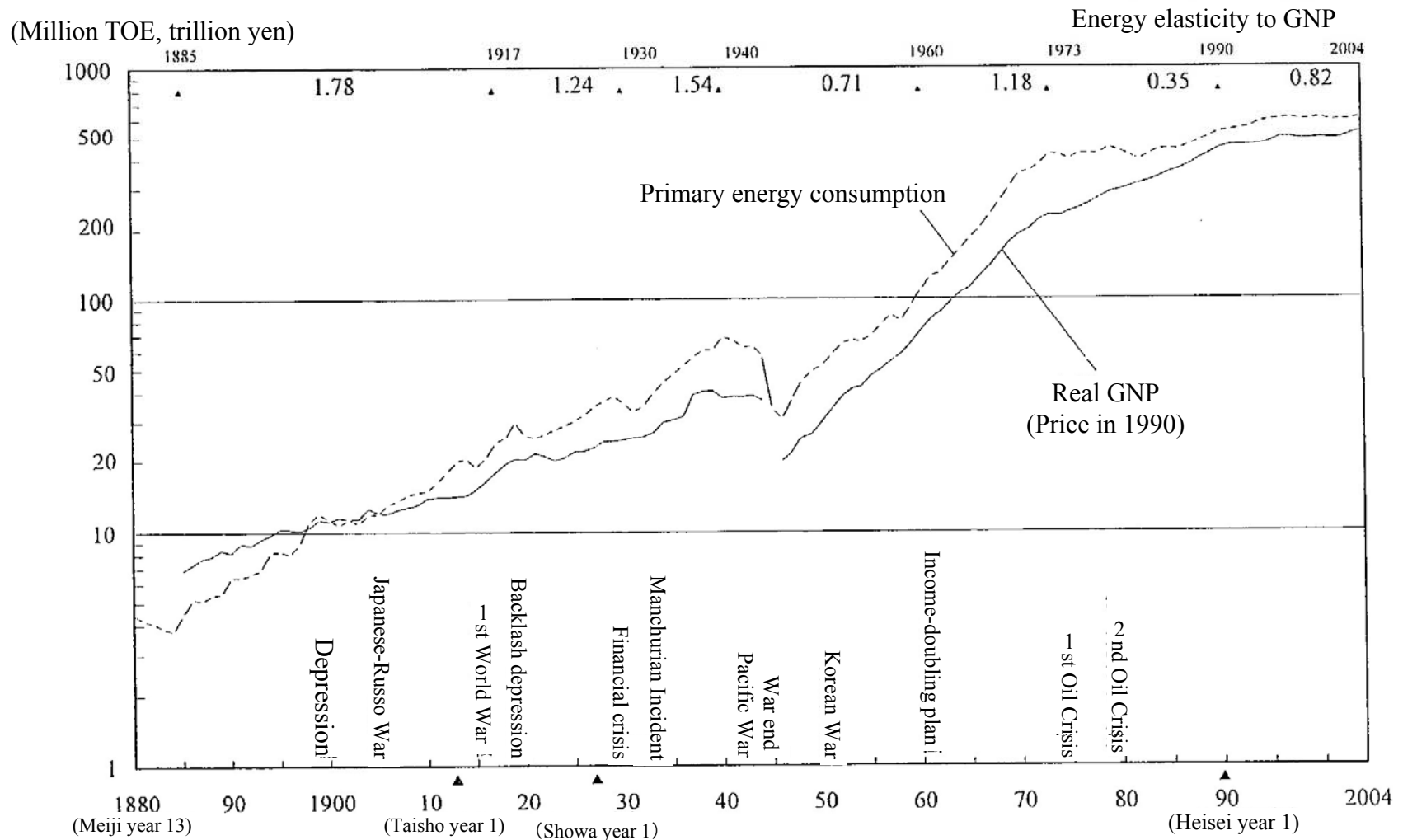


Power and Heat Load in Hotels



Power and Heat Load in Offices

Energy Demand and Economic Activities in Japan (1)

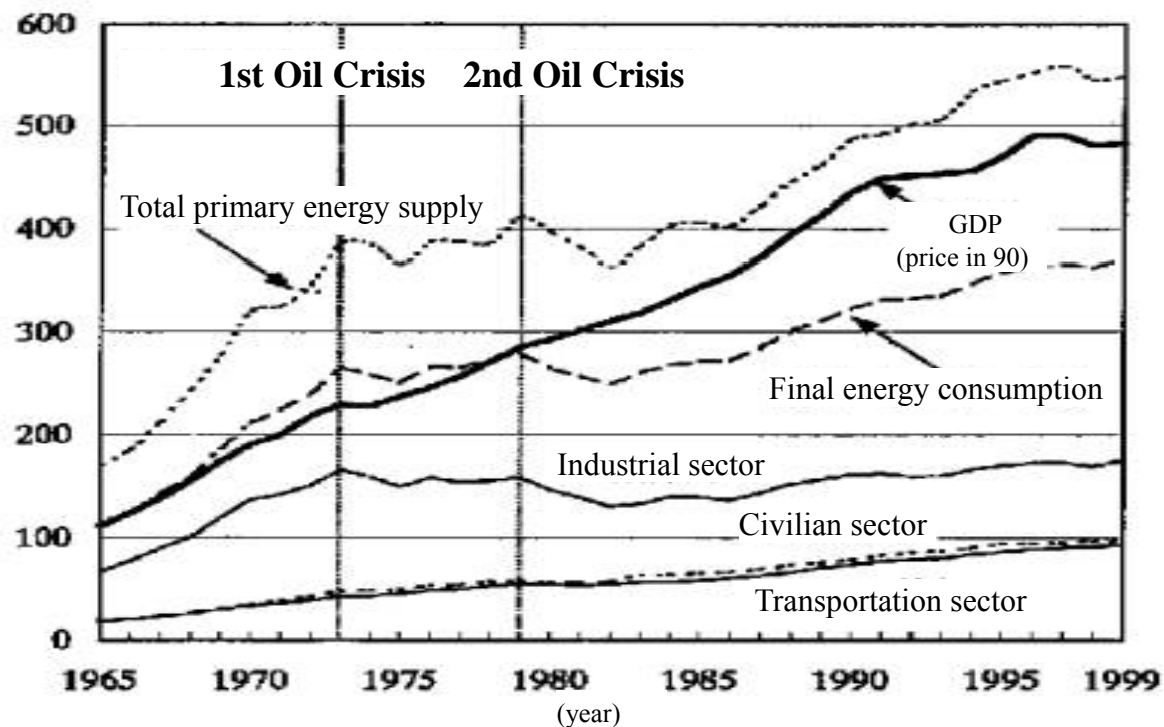


Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.11 (p.38).

Energy Demand and Economic Activities in Japan (2)

(1) Changes in energy demand and GDP

(Trillion yen, Million TOE,)



(2) GDP elasticity of energy demand

	1965-73	73-79	79-86	86-91	91-99
GDP	9.4%	3.7%	3.2%	4.7%	0.9%
Total primary energy supply	10.9%	1.1%	-0.3%	4.1%	1.4%
Final energy consumption	11.8%	0.9%	-0.4%	4.1%	1.5%
Primary energy elasticity	1.15	0.29	-0.10	0.86	1.55
Final energy elasticity	1.25	0.24	-0.13	0.86	1.61

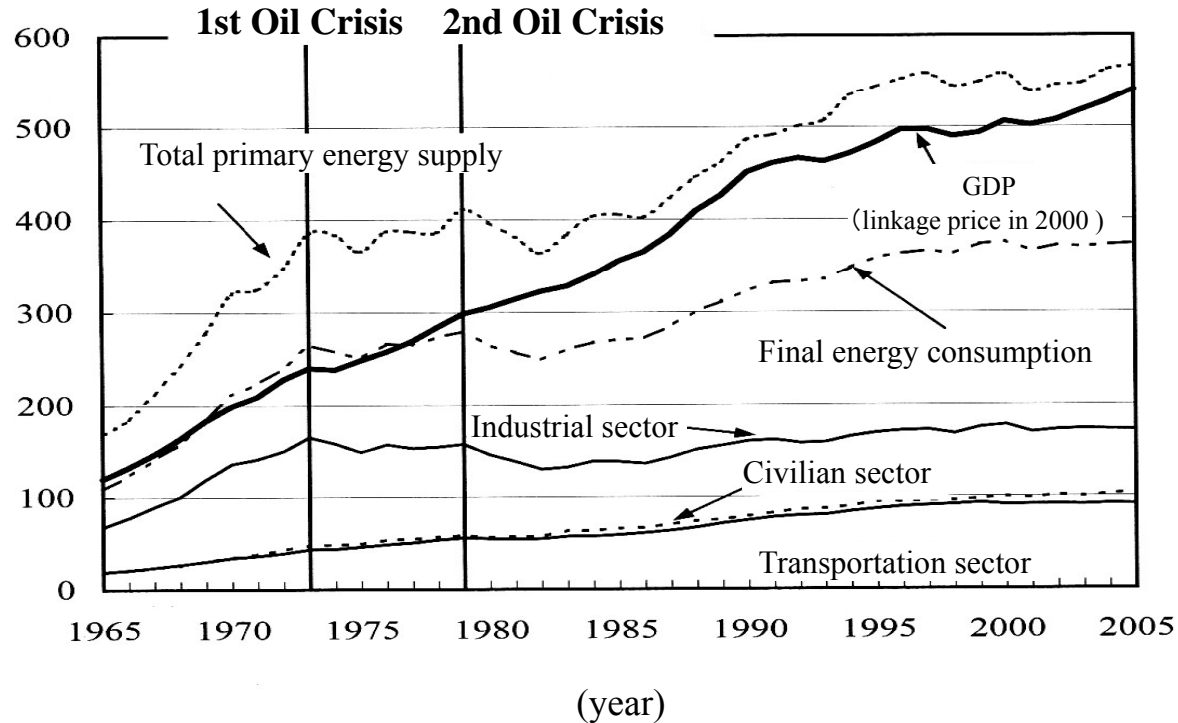
†

Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.12 (p.39) amended.

Energy Demand and Economic Activities in Japan (3)

(1) Changes in energy demand and GDP

(Trillion yen, Million TOE,)

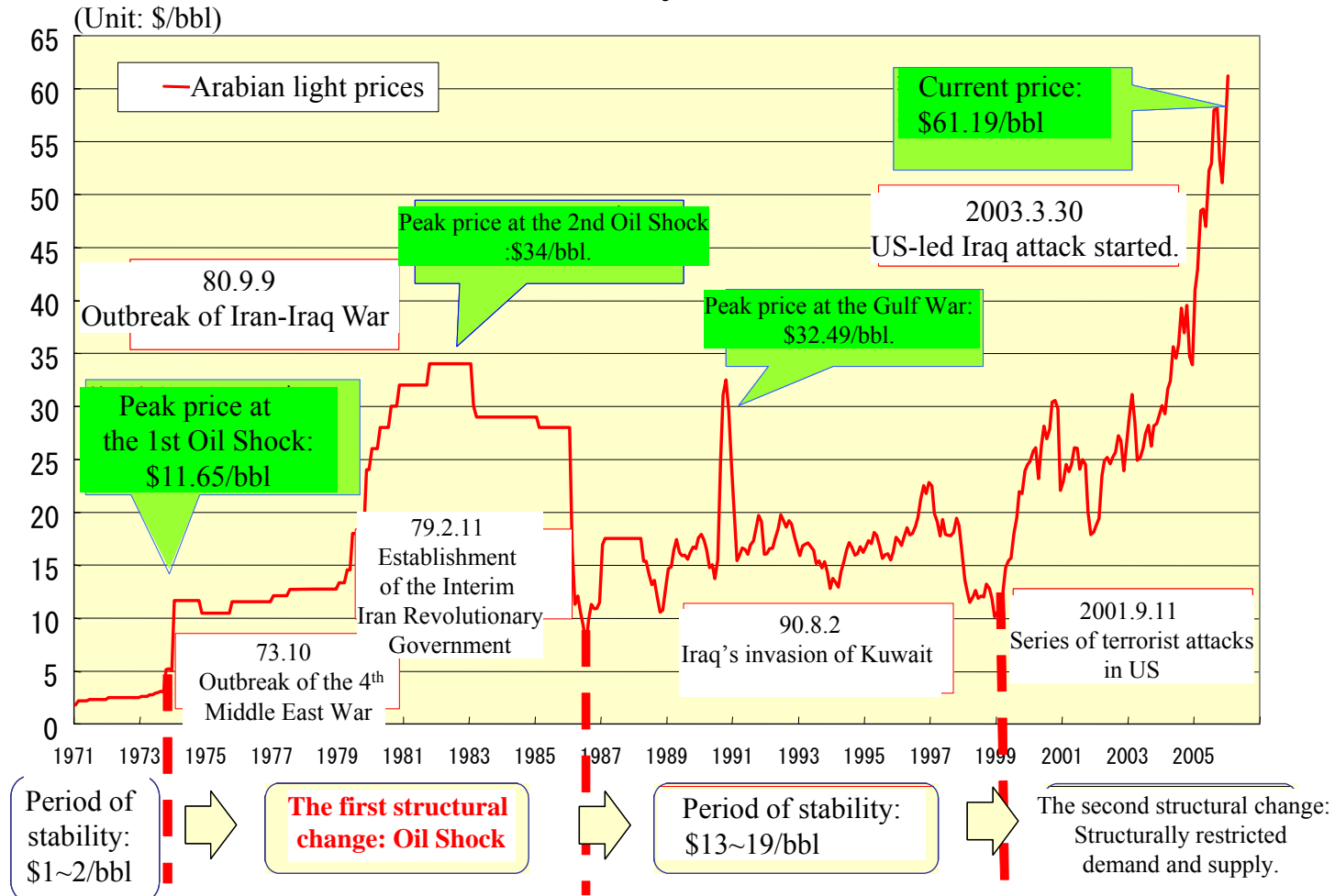


(2) GDP elasticity of energy demand

	1965-73	73-79	79-90	90-00	00-05
GDP	9.1%	3.7%	3.8%	1.2%	1.3%
Total primary energy supply	10.9%	1.1%	1.5%	1.4%	0.3%
Final energy consumption	11.8%	0.9%	1.3%	1.5%	-0.1%
Primary energy elasticity	1.20	0.29	0.40	1.21	0.21
Final energy elasticity	1.30	0.24	0.35	1.32	-0.09

Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.12 (p.39) amended.

Change in Oil Prices by Nominal Price in US\$



Reference: The material prepared by the Ministry of Economics, Trade and Industry.

Change in the price of "Arabian Light" from Saudi Arabia which accounts for substantial business in Japan.

However, the pricing system varies depending on period. The term "current price" represents the most recent month's average (this January).

Source: *New National Energy Strategy*: Ministry of Economics, Trade and Industry, 2006, Chart 1.

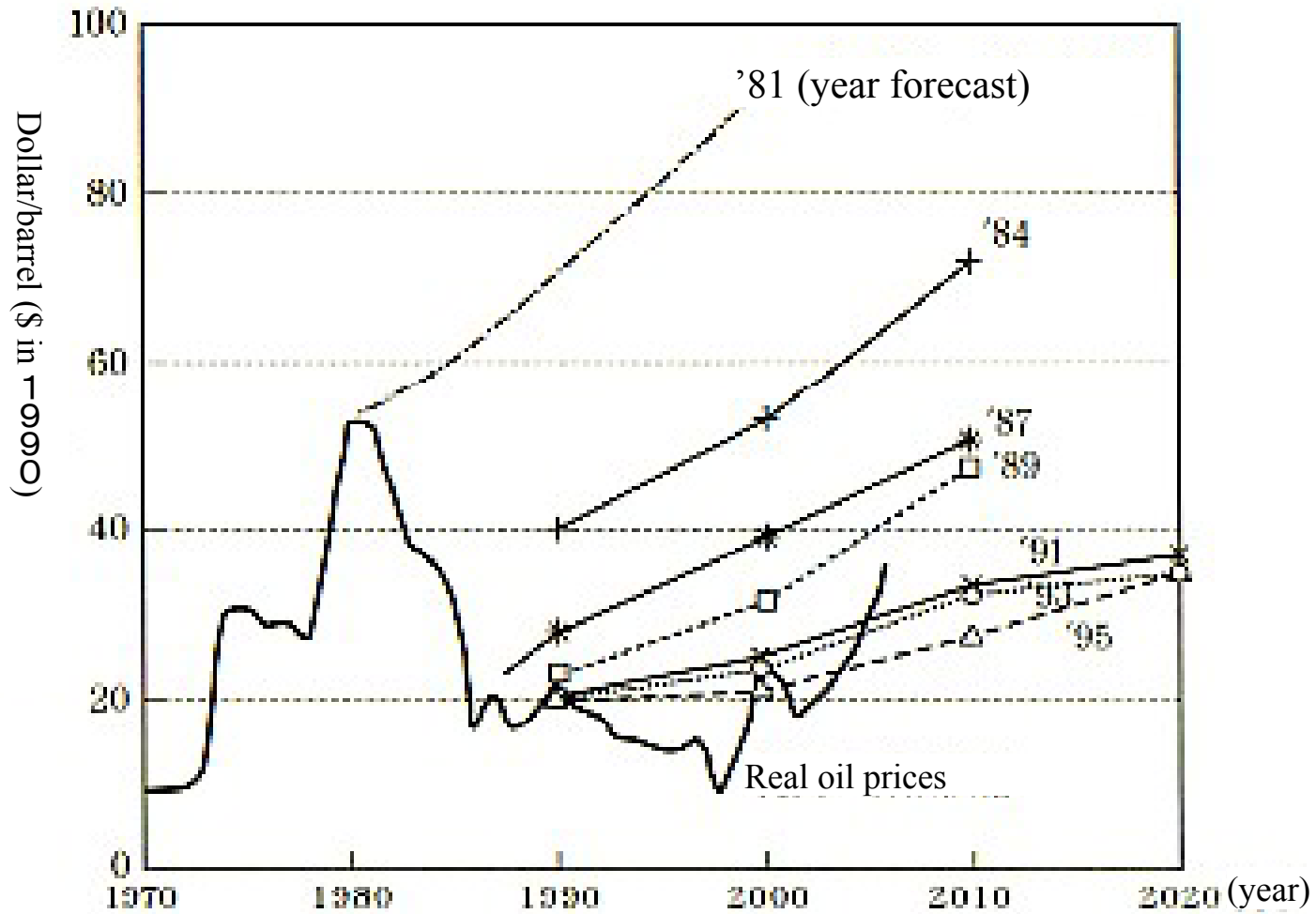
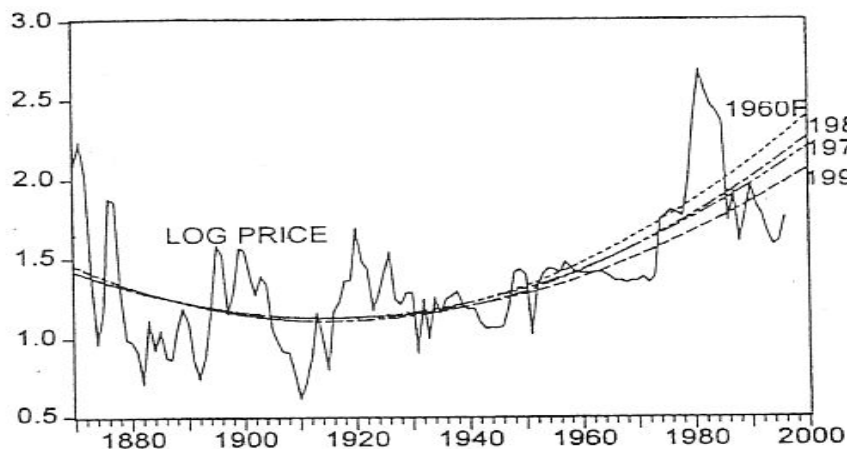


Chart 2.20: Change in oil prices and forecasts

Reference: **L. Schrattenholzer: Selected Results of the 1996 IEW Polls of Energy Projections, IEW/JSER '96, Osaka, June 1996** with recent real prices added.

‡

Figure 1. Log Price of Crude Oil and Quadratic Trend Lines



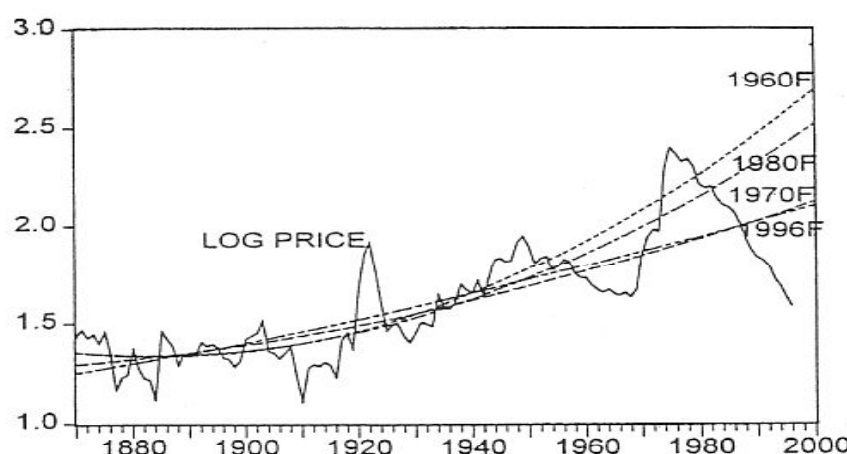
R.S. Pindyck
The Energy Journal
20, No. 2 pp. 1-27
(1989)

1980F (1980-1996) (1980-1996) (1980-1996)

ave: 3.5 \$/barrel

1967 US\$ (WPI)
natural log

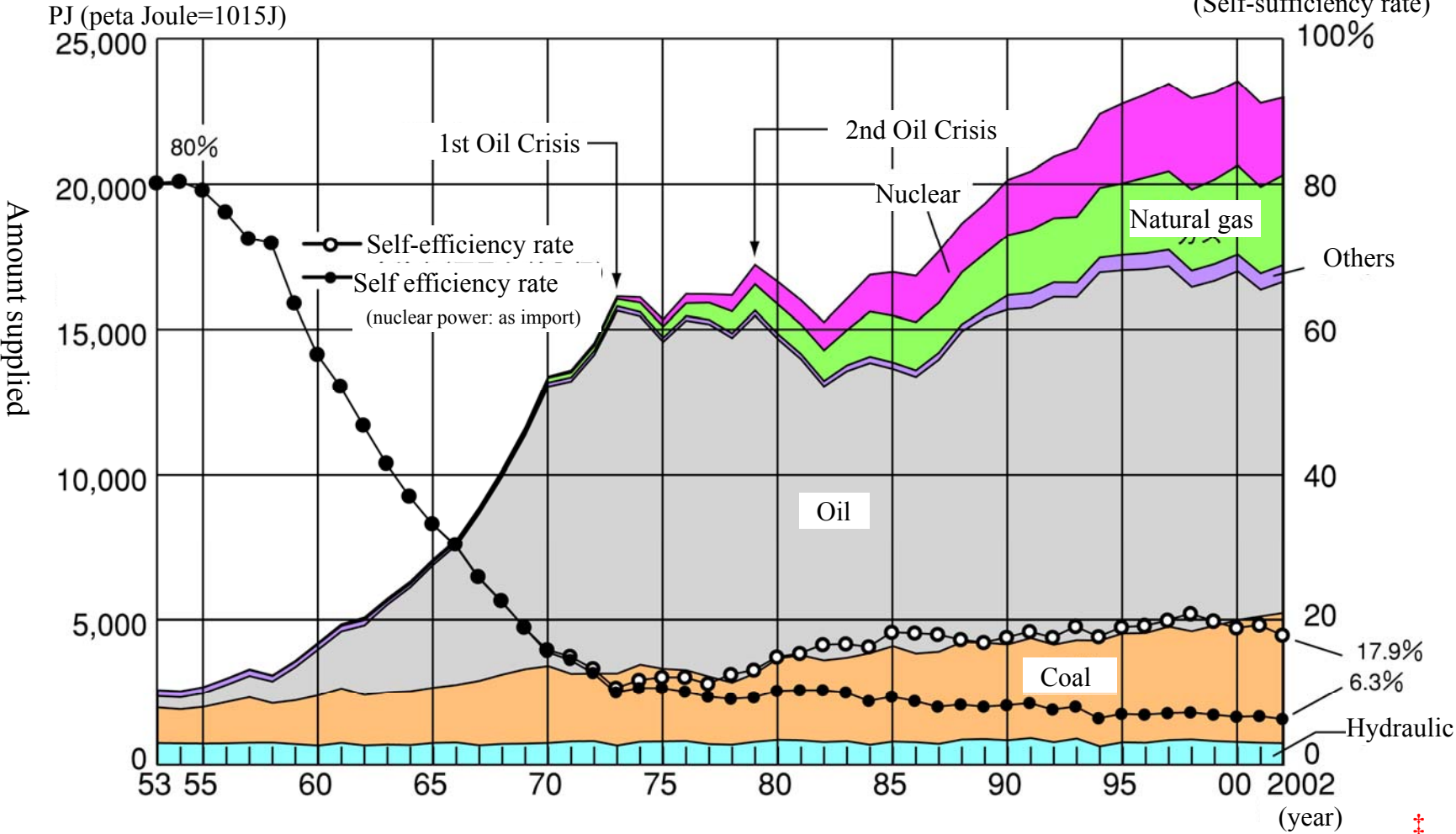
Figure 2. Log Price of Bituminous Coal and Quadratic Trend Lines



ave: 4 1/2 \$/c



Primary Energy Supply History in Japan



Note: 1PJ is equivalent to the calorie of approx. 25,800kl crude oil.

Reference: Comprehensive Energy Statistics (2003 ed.)

Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.13 (p.40)

Change in Dependence on Middle East for Crude Oil Import

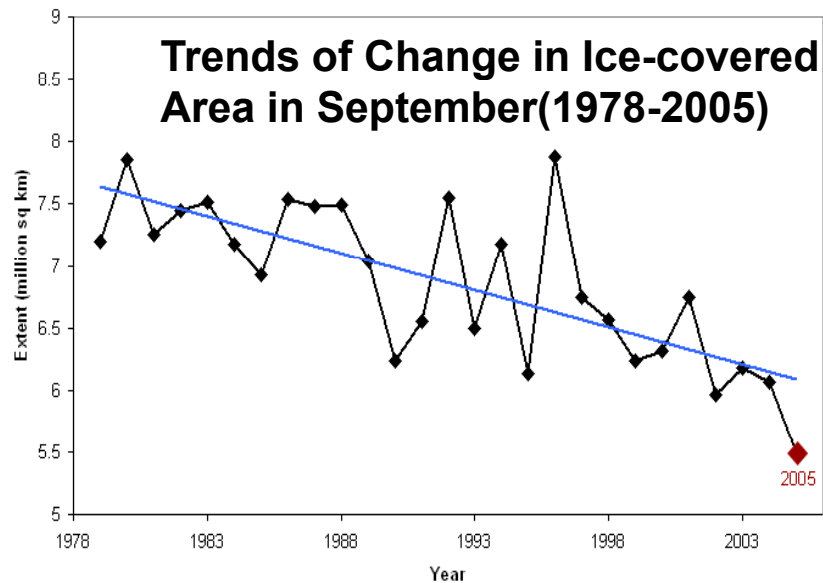


Source: Kenji Yamaji, *Energy, Environment and Economic Systems*, Iwanami Shoten, 2006. Chart 2.14 (p.40)

North Pole Ice Is Melting→

- Average earth temperature:
0.74°C rise in these 100 years.
- Average temperature in Japan:
1.0°C rise in these 100 years.
(3°C in Tokyo)
- **Alaska and western Canada:
3-4°C rise in these 50 years.**
- Glaciers and sea ice melting.
- Snow season shortening.
- Permafrost melting.

Reference: NASA †



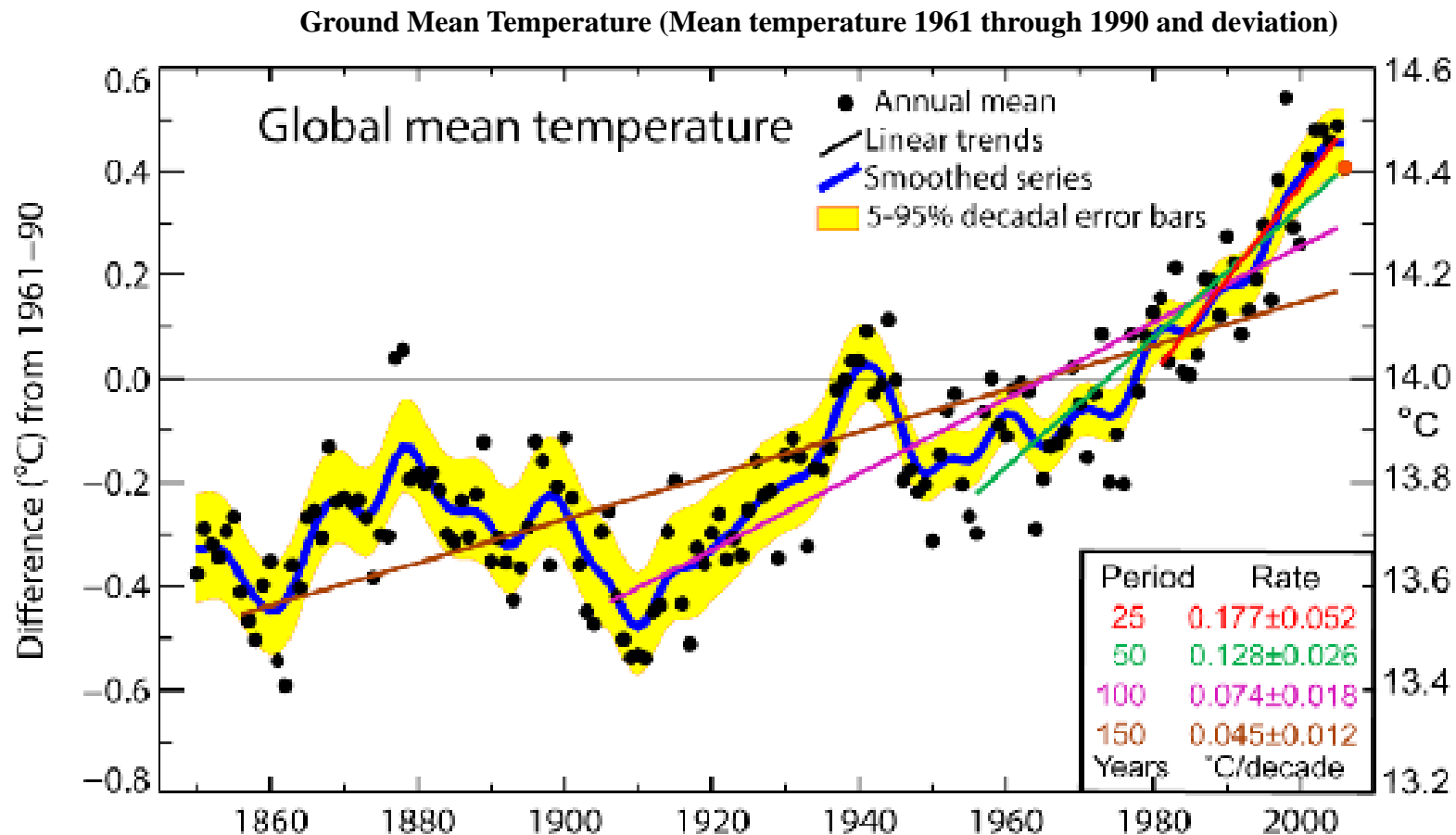
2003 Change in the North Pole Ice (September)



Data: National Institute of Environmental Studies †

Observation of Global Mean Temperature

- In the past 100 years, global mean temperature has risen 0.74°C (0.6°C , according to the report in 2001).
- The trends of rising temperature during these 50 years is almost double that of the past 100 years



Data: National Institute of Environmental Studies.

學而不思則罔

思而不學則殆

He that learns but doesn't think is nothing but ignorant.

He that thinks but doesn't learn is nothing but dubious.