"Energy Chain", A New Concept in Evaluating Future Energy Conservation and Greenhouse Abatement Alternatives and Effectiveness

Background

The energy demand and supply system consists of many kinds of energy subsystems, for example, grid network, fuel (city gas, LPG, kerosene and so on) networks, prospective fuel (hydrogen) networks and demand-side equipments such as heat pump and cogeneration. In recent years, many evaluation methods and factors have been proposed and discussions of energy policy about innovative technology are becoming more multifaceted. In addition, as a result of specialization and segmentation of engineering science, too much discussion has been centered on particular details of efficiency, rather than on the overall needs of the energy supply and demand system. Integration of these evaluations and discussions is necessary for criteria for judgment. Critical review is always necessary to ensure that prospective technologies are really energy saving and contribute to greenhouse abatement over the whole spectrum from producing energy to end-use.

Objectives

To introduce a new concept of "Energy Chain" from producing energy through transmission, utilization and end-use, and to propose engineering methodology and evaluation method with examples.

Principal Results

1.Proposing a New Concept of Energy Chain and Evaluation Method

What the energy end-user needs is "energy benefit". This include all kinds of benefit [*1] that end-users enjoy. The energy chain (EC) concept is defined as energy paths from source [*2] to energy consumption to final end-use energy benefit (Fig.1 (a)). As shown in the figure, there are a lot of paths in an EC to meet an energy benefit. Two indices based on time-depending demand are proposed to measure the effectiveness of the process (Fig.1 (b))[*3]. Energy Chain Joule Index (ECJI) expresses the level of energy conservation and Energy Chain Carbon Index (ECCI) expresses the level of greenhouse abatement (CO_2 emissions). A larger value indicates an effective energy chain with respect to energy conservation or greenhouse abatement. EC diagram can represent visually the flow of energy. This diagram also can represent quantities and places of exhaust heat generation and consumption. This is useful to grasp features of ECs.

2.Examples of Evaluation with Energy Chain Method

(1) Analysis results that use time-depending demand are presented in Fig. 2. Two ECs are compared; "Grid + Heat Pump" and "PEFC Cogeneration + Grid". As shown in these figures, both ECs have same effectiveness of energy conservation but Grid + Heat Pump excels in terms of greenhouse abatement.

(2) Equivalent energy conservation conditions with respect to rated demand [*4] can be obtained by making ECJI of both ECs equal (Fig.3), and this is represented in the figure as an energy conservative competitive border (ECCB). In AREA 1 which is shut in thick-dashed curve and ECCB, the cogeneration system is more energy conservation than Grid + Heat Pump. When value of demand rate of heating to electricity (ϕ) increases, AREA 1 becomes small and finally disappears at a certain value. When η_g and ζ_{HP} increase, AREA 1 becomes small, too. The cogeneration system presented in (1) exists in AREA 1 as a result of analysis based on rated demand. The system, however, exists on the ECCB as a result of analysis based on time-depending demand, because the system does not make full use of recovery heat. This result shows it is necessary to use time-depending demand for EC evaluation.

Future Developments

The concept and evaluation method of EC will be made known at home and abroad. Authors will develop software which involves this method as soon as possible, and will accumulate more examples.

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Reference

T.Hamamatsu, M.Saikawa and K.Hashimoto, 2004, "Energy Chain", A New Concept in Evaluating Future Energy Conservation and Greenhouse Abatement Alternatives and Effectiveness", Proceedings 19th World Energy Congress, Sydney

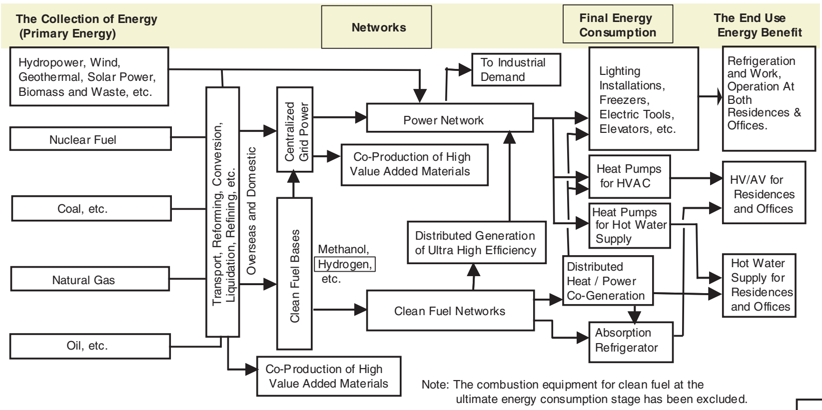
K.Hashimoto, M.Saikawa and T.Hamamatsu, 2004, "A Comparative Study of the Distributed Cogeneration System and the Centralized Grid with Heat Pump System Using "Energy Chain" Concept", Proceedings 14th ICPWS, Kyoto

*1 : What the energy end-user needs is "energy benefit" in terms of heating, cooling, lighting and so on, but neither city gas/oil nor electricity.

*2 : The primary energy supply into Japan.

*3 : Energy Chain Workshop (Aug. 2001 - Mar. 2003, host: CRIEPI, project manager: Prof. Kasagi (Univ. of Tokyo)) consisted of intellectual mechanical, electrical, energy and civil engineers and government officers. They discussed and agreed that EC indices are important and have international availability and objectivity.

*4 : "Rated demand" (a) is classified into electricity and heat, (b) does not depend on time. And (c) demand ratio of heat to electricity is fixed and equal to ratio of heat recovery to generation efficiency of cogeneration



The energy chain concept is defined as energy paths from source to energy consumption to final end-use energy benefit in terms of heating, cooling, lighting and other benefits of energy

Energy Conservation:

ECJI: Energy Chain Joule Index

$$= \frac{\text{End-Use Energy Benefit (MJ)}}{\text{Primary Energy Consumption (MJ)}}$$

Greenhouse Abatement:

(ECCI: Energy Chain Carbon Index)

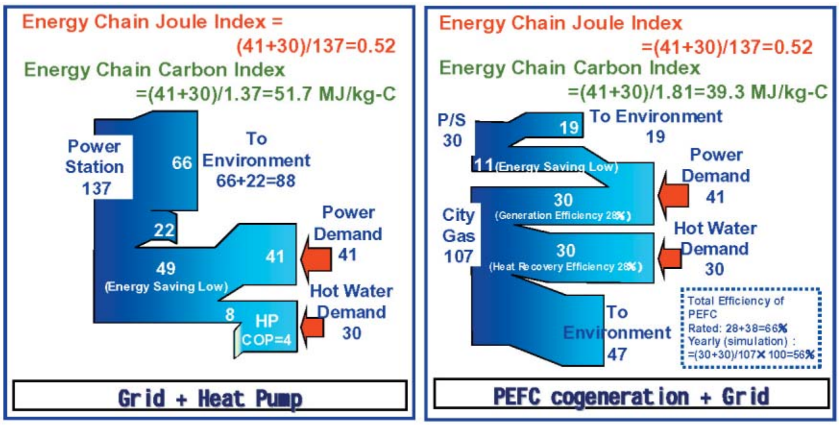
$$= \frac{\text{End-Use Energy Benefit (MJ)}}{\text{CO}_2\text{ Produced from Primary Energy (kg-C)}}$$

※Should be based on "high heat value (HHV)"

Two indices are proposed to measure the effectiveness of the process. Energy Chain Joule Index (ECJI) expresses the level of energy conservation. Energy Chain Carbon Index (ECCI) expresses the level of greenhouse abatement.

(a) Concept of Entire Energy Chain (b) Indices Definition

Fig.1 Concept of Energy Chain and Indices Definition.

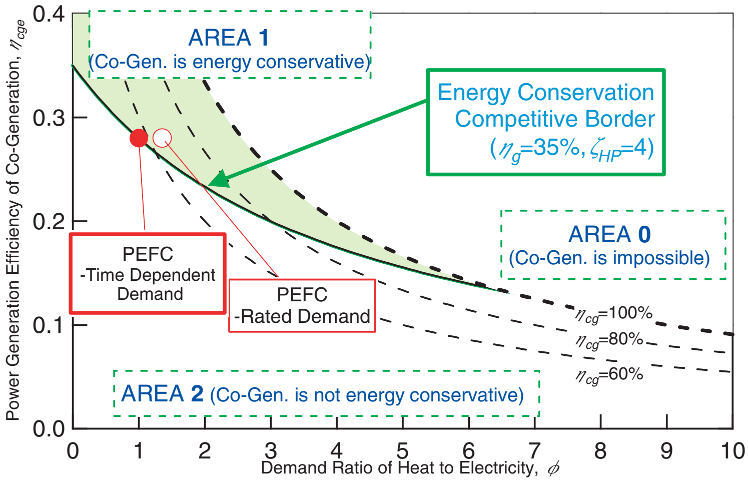


Energy demand and supply analysis for Japanese residence using yearly time-depending demands is done. There are two kinds of energy supply system. One is Grid + Heat Pump, other is PEFC + Grid. ECJI of both systems is equal, but ECCI of Grid + Heat Pump is larger than that of PEFC + Grid.

※Grid power efficiency at demand end is about 0.36 (by the energy saving law in Japan). COP (=heat output / input electricity) of heat pump water heater is about 4 (achieved value).

※In evaluation of ECCI, unit of demand is "MJ", CO_2 emission factor of electricity equal to 0.101kg-C/kWh and that of city gas equal to 0.0140kg-C/MJ.

Fig.2 Examples of Energy Chain Evaluation
(Comparison between grid-power & heat pump and on-site cogeneration)



The thick-dashed curve representstheoretical maximum of cogeneration efficiency, which means total efficiency of cogeneration (η_{cg}) equals 100%. Therefore, in the top-right area of the map (AREA 0), cogeneration is impossible because the total efficiency of cogeneration systems exceed 100%. Below the EECC curve (AREA 2), cogeneration is disadvantageous to energy conservation. Two fine-dashed curves represent total efficiency of cogeneration is 80% and 60%, respectively. This figure is named "energy conservation map", x-axis is demand ratio of heat to electricity (ϕ) and y-axis is power generation efficiency of cogeneration (η_{cge}).

η_g: Grid power efficiency at demand end, ζ_{HP}: Coefficient of performance (heat pump), η_{cge}: Generation efficiency of cogeneration, η_{cg}: Total efficiency of cogeneration, ϕ: Demand ratio of heat to electricity.

Fig.3 Energy Conservation Map based on Energy Chain Joule Index