ON THE INTERNAL LOGIC OF ENERGY ISLANDS

C. Marchetti
Energy Systems Program, International Institute for Applied Systems Analysis, Laxenburg (Austria)

ABSTRACT

The structure of an energy system, from production through to consumption, is fundamentally influenced by the physical properties of the energy medium, and in particular its transportability. For oil, which is highly transportable, the system optimizes on a world scale. Electrical systems, in contrast, optimize over areas hundreds of kilometers in diameter. In future systems nuclear reactors may be interfaced with hydrogen as the energy medium. If the hydrogen is in gaseous form, the optimal system configuration will be at the level of a continent; if the hydrogen is liquid, then, as in the case of oil, the system optimizes at the world level. Generating centers will then be optimally very large: the paper gives a rapid overview of the main problems associated with such "energy islands" together with some possible solutions.

1 INTRODUCTION

The production, transportation, and distribution of something faces boundary conditions and optimization constraints which are formally independent of the nature of the thing produced, be it ammonia or electricity. Consequently it is possible to analyze the process in a general form and to check the quality of the formulation using examples taken from very diverse areas.

In order to minimize the cost of the unit of final product delivered one has to compromise between the economies of scale that come from concentrating production at a few points and the diseconomies of transportation that come from the consequent lengthening of the feed lines. Because economies of scale usually fall in a relatively restricted range, what really determines the spatial structure of a production system is the transportability of the product, which can in fact vary by orders of magnitude.

These concepts have for a long time been organized by geographical economists under the name of "central-place theory". I will use them to describe the energy system and to predict some of its long-term features if certain switches are turned on. I will make more than a prediction in the strict sense; I will in fact describe an attractor configuration. (Here I use "attractor configuration" to represent a finally-evolved configuration toward which all intermediate configurations tend.)

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In order to simplify the argument I have taken an actual system, the electrical system, as a reference case and have described the other systems in relative terms. Such a parametric analysis avoids actual optimizations, which are nonessential at this level of analysis.

A fundamental characteristic of nuclear (or fusion) energy sources is that they provide energy in the form of (low entropy) heat, unlike the fossil sources that preceded them, where high-free-energy chemicals were at play. Heat is not very convenient from the point of view of transportation, storage, and distribution; consequently the problem of an optimal energy system based on nuclear energy sources needs to be thought over.

In Table 1 the basic characteristics of energy systems have been tabulated in a semiquantitative form, basically to establish some rank between them and to give an aid to intuition. The table provides an extremely simplified picture; for example, the spatial density of energy consumption is assumed to be the same for all cases and equal to that of electricity. Transportability is measured in terms of the distance where transportation costs equal 20% of production costs but does not take account of economies of scale in transportation. However, the scattering of the data does not permit a better numerical approximation. In spite of these drawbacks I think that the fundamental information about rank is preserved.

TABLE 1 Energy transportability and generation-plant size[a].

Energy type	Transportability (km)	Technical maximum (km)	Size of generation plant (GW)
Hot water	≈ 2	50	0.2
Electricity	100	1000	1
H_2	1000	3000	100
Compressed air	2–3	10	10^{-3}
Adam and Eva[b]	20	200	0.04
Natural gas	1000	3000	100
Oil	10^4	10^4	2000[c]

[a] The table is an attempt to rank energy vectors by their ability to spread. The transportability indicator is estimated as the distance at which transportation costs are about 20% of value. The size of plant is estimated with reference to an electric plant, taken as unity, and assuming the same spatial density of consumption as for electricity.

[b] Adam and Eva is based on the process

$$CH_4 + H_2O \underset{}{\overset{40\ \text{kcal}}{\rightleftarrows}} CO + 3H_2$$

with the reaction running (endothermally) to the right at reactor level and (exothermally) to the left at consumer level.

[c] Possible production from a field.

As can be seen from the table, the poor transportability of hot water calls for small central generators, contrary to the tendency of reactors to be big due to the very high technical and systemic economies of scale. It is in fact only the existence of an electric network of sufficient density and transportability to accommodate 1-GW generators that has made nuclear energy a practical proposition.