ON ENERGY SYSTEMS

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1. Our problem is that of structure and behavior of energy systems. I have been educated as a physicist and I try to look at things with a physicist's eye. It now appears that energy systems, in spite of being mostly of sociological character, can be dealt with or analyzed in a way which strongly resembles astronomical systems: very precisely and with very simple mathematics.

The starting point of the analysis, i.e. the clue that gave me the possibility of dealing with such precision with energy systems over very long periods of time, was a very simple hypothesis. The hypothesis is that our system is actually a learning system and that learning follows very simple laws.

Now let us look at Figure 1. If you take a very complex process, like for instance the one of learning a language, you may think that describing that process in detail or with precision over a very long span of time can be a desperate enterprise. In fact, learning a language is such a complex process which taxes the ingenuity and the vitality of the mind of a child and of the young man that you may think this is beyond our possibility. However, if you take an indicator of the evolution, like for instance the vocabulary that a child has at any time, then we find that the learning process from the point of view of the vocabulary as a descriptor can be mapped with good precision by a very simple functional relationship, which is a logistic. You are physicists, and I am not entering into the trivial arithmetics of that curve.

There is one particular feature I want to attract your attention to, and that is, that if you take 1% of the curve as a kind of starting point and the 99% as a kind of ending point -- in
Figure 1. The evolution of the vocabulary of a child is depicted here. F is the fraction of the words the child possesses at about 6 years, when his 'natural' vocabulary will be completed.

Fact, we use truncated logistics — then you will see first that the curve is symmetric and second that there is a half-time, or a characteristic time of the curve which is the time for going from 1% to 50%. This characteristic time will play a very important role in the description of the energy system, as I will show you in a moment.

The second graph is the same as the first one, but is a different form of presentation that has been given basically for visual purposes, because there are many bent curves but only one straight line and so it is much easier to check visually that the experimental points fit the logistics, and it is much easier to make interpolation and extrapolation. So it is just for convenience that in most of my presentations the logistic curve will be presented in this way.

Now, going from the learning of a language as measured by the size of the vocabulary under control, we can go next to another process which has the same kind of complication, but which operates not at the level of the individual but at the level of society or of a subset of society. This is technological development. I analyzed, historically, three different technologies, and I took as an indicator of the development of each one of these technologies the second law efficiency of the best item appearing on the market.

In Figure 2, \( \varepsilon \) is efficiency and \( 1 - \varepsilon \) is the inefficiency, and since they appear as a ratio I called this the Yang-Ying plot. It is clear that over very long periods of time the development of