USE OF HYDROGEN AND HYDROGEN-RICH COMPONENTS AS A MEANS OF STORING AND TRANSPORTING ENERGY

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TEMPO has been interested in advanced energy utility systems, which we call Eco-Energy Systems (fig. 1) where the ecology and economics are kept in balance. Our conclusion has been that using hydrogen for transport and storage can lead to very clean, flexible systems that with improving technology and depletion of natural fuel resources can become competitive. While the primary source of energy is shown here as nuclear, the basic concept can apply for any thermal source, or for wind energy, etc. (fig. 2).

With a nuclear reactor an important reason for using hydrogen storage is to keep efficient full-load operation of the reactor while the customer demands fluctuate. With wind, Sun, and tidal energy, both the supply and the demand fluctuate so some form of storage is even more important. Hydrogen, or hydrogen plus oxygen, is an important candidate, because of its easy transport by pipeline and the flexibility it has for serving all of the energy sectors.

There are many ways of storing energy (fig. 3). The merits for a particular application depend on such things as the energy density, the ease and flexibility of reconversion to a form of energy useful to customers, and the cost per unit of delivered energy. Energy density (fig. 4) and flexibility of conversion are, of course, important ultimately for cost determinations. Hydrogen as a cryogenic liquid and as metal hydrides is more attractive than hydrogen as a gas. Of course, the hydrides of nitrogen (NH_3) and carbon (gasoline) are even more compact.

There is a rough road ahead to get the costs down. The costs of storage vessels can be reasonably determined (fig. 5, curve from the source material of the Synthetic Fuels Panel). But to really determine the cost of storage we have to examine all the energy conversions required, their efficiency, and their capital cost.

To illustrate (fig. 6), I've assumed a 1-megawatt wind energy source that operates half the time. Half of its output is used to serve customers directly as electricity; the other half is to be stored. For a system of this size, a cost of electricity at the generator of 10 mills (one cent per kilowatt-hour) may be low, but it is a convenient unit. As conversions of the storage portion are made to hydrogen, to liquid hydrogen, to stored LH_2, and back to electricity, the energy costs and capital costs of the conversions escalate the unit cost per kilowatt-hour remaining until electricity at 12.9 cents per kilowatt-hour results. Figure 6(a) shows the next level of detail of the assumptions.

Many of the high costs result from scale size and would be less for a 100- or 1000-megawatt system. With adequate research, technology will improve all of these. Such alternative means of storage as Mg_2NiH_4 and $FeTiH_2$ are being actively explored at Brookhaven National Laboratory both for mobile and utility applications. And for all but the biggest systems they may be less costly than LH_2.

Another possibility, which in the largest systems may be the best, is storing in the form of ammonia (fig. 7). While this concept shows both electricity and fossil fuel used to make the NH_3, either could be used alone.

In conclusion, system configurations that consider the storage alternatives are an important part of the research needed to achieve economic viability.

DISCUSSION

Q: One of your figures appeared to show a block with heat energy going into something and hydrogen and oxygen coming out. Are you really showing thermal dissociation as a way of making hydrogen and oxygen?

A: I made that block diagram very general so it could cover everything. But thermal dissociation of hydrogen, particularly things like the Marketti process, Mark 1 process, is one of the things that on a very large scale look best. But this, of course, requires a thermal source and this is a wind energy conference; thus, electrolysis is the means of preference.

Q: Most people dealing with hydride storage tend to talk about the volume of hydrogen that can be stored in a given volume of storage material, but since the installed cost of that system depends on how much you have to buy, would you care to comment on how many pounds of hydride or whatever is required to store it?

A: Well, let's deal in terms of per cubic foot, and I said that with liquid hydrogen you get about 4.4 pounds per cubic foot, whereas with ease you can get 6 pounds of hydrogen per cubic foot. Now the density of magnesium - and magnesium nickel is principally magnesium (only about 6 percent nickel) - is, I think, about 2 or 2½, so you've got about 150 pounds of magnesium for your 6 pounds of hydrogen. Iron titanium is, of course, a higher density, about 5 or 6, so you've got more pounds, but it's a cheaper material. For portable use like in a car, you probably want magnesium. For utility use, I think the iron titanium with its lower cost per pound is probably superior.

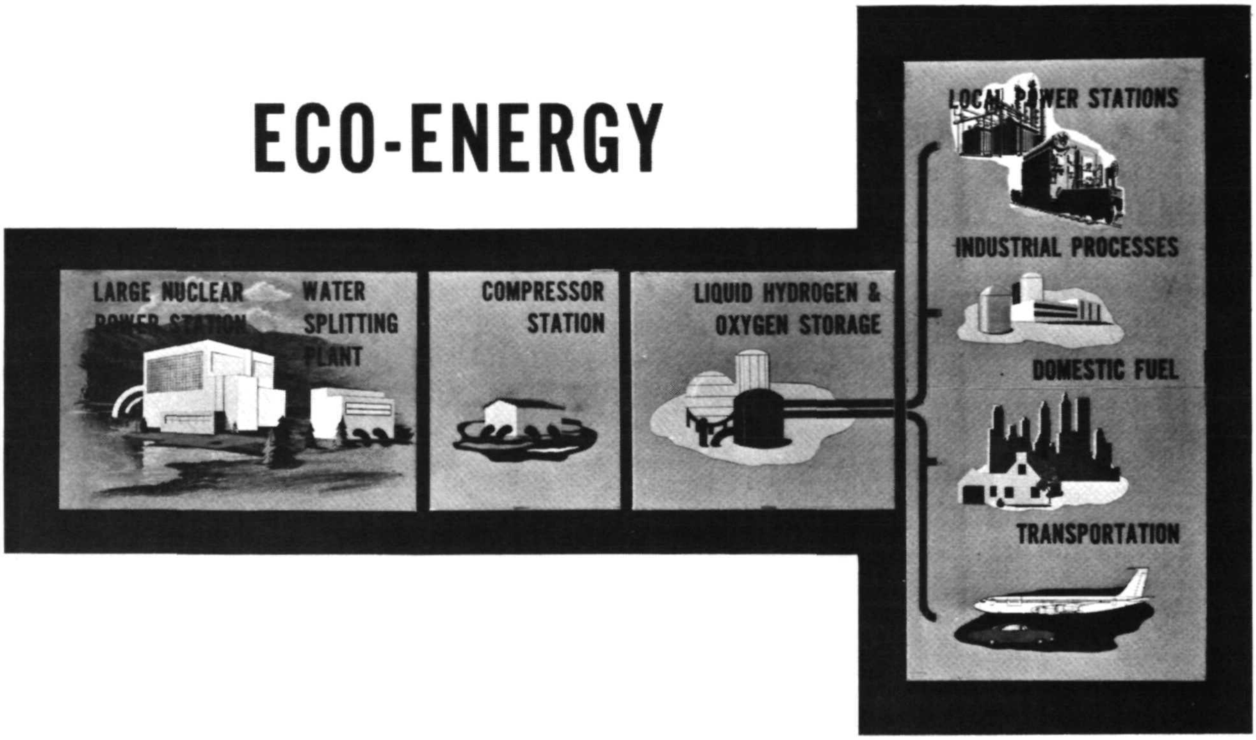

Figure 1

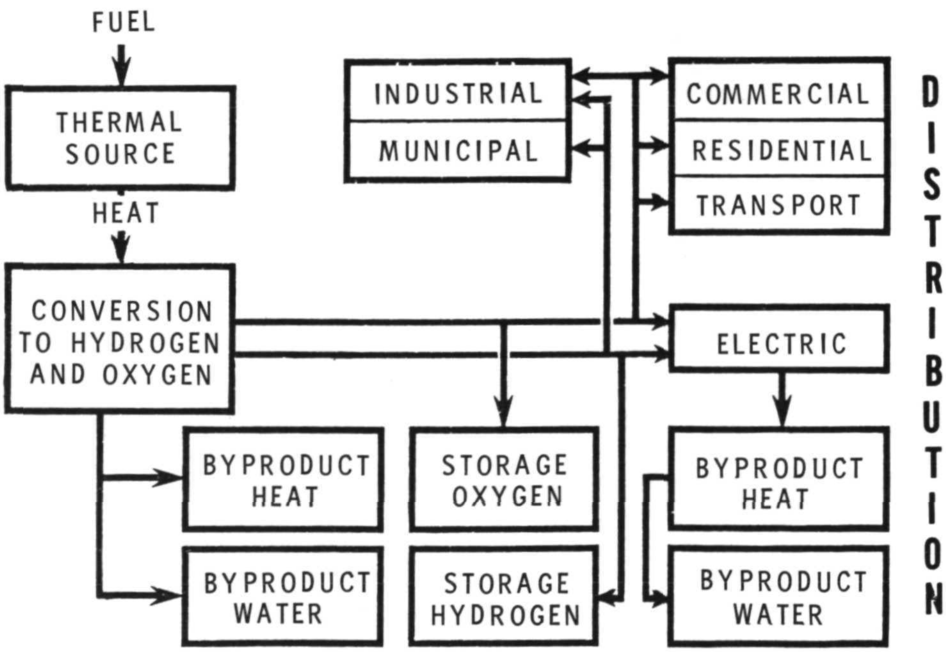

Figure 2

MEANS OF STORAGE

MECHANICAL
HOT ROCKS/METAL
HOT WATER/STEAM
MOLTEN SALTS

HYDROGEN
- GAS
- LIQUID
- HYDRIDES

AMMONIA
METHANOL
GASOLINE

BATTERIES

Figure 3

ENERGY DENSITY

			BTU/FT^3
PUMPED STORAGE (100 ft head)			14
HOT ROCKS/METAL	60-500°F		8,000-12,000
MOLTEN SALTS	60-500°F		10,000-20,000
STEAM	15 psi	212°F	40
	130	347	340
	500	467	1,270
WATER	15	212	9,000
	130	347	16,000
	500	467	21,000
HYDROGEN			
• GAS	15	60	280
	1,000	60	18,500
• LIQUID	15	-425	200,000
• HYDRIDE (Mg_2N_i or F_eT_i)			250,000
AMMONIA			340,000
METHANOL			430,000
GASOLINE			830,000
BATTERIES			10,000-80,000

Figure 4

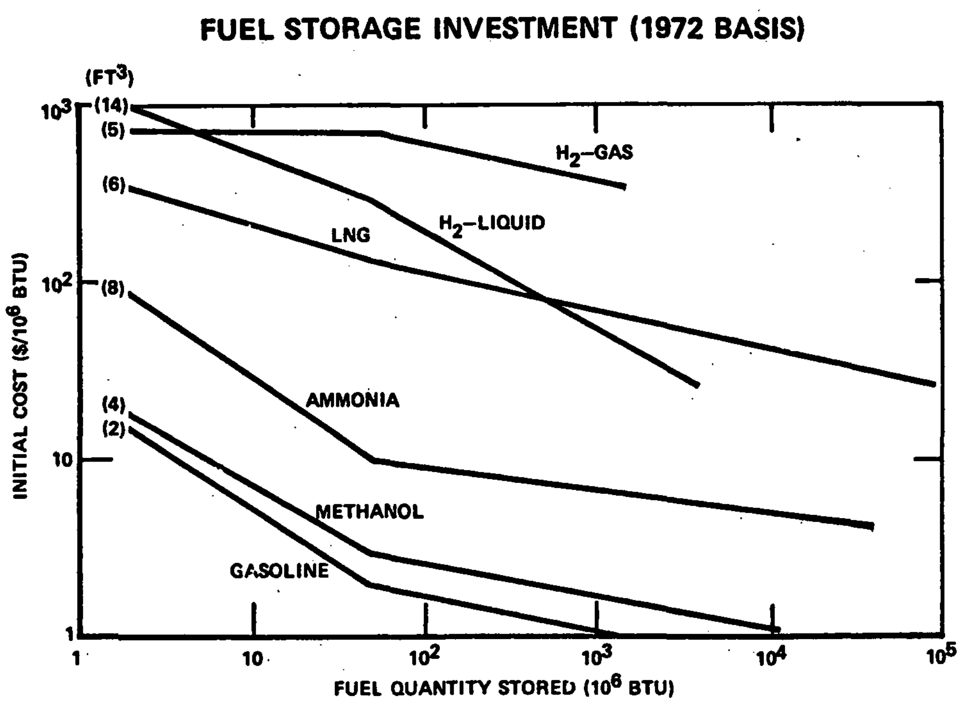

Figure 5

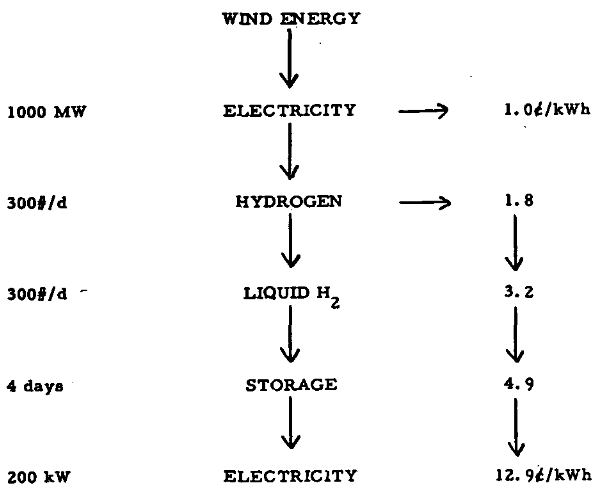

Figure 6

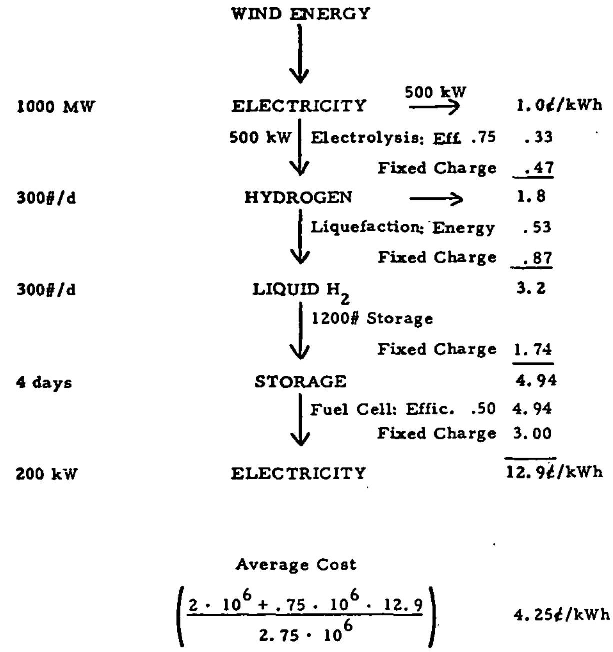

Figure 6A

FLOWSHEET OF AMMONIA SYNTHESIS

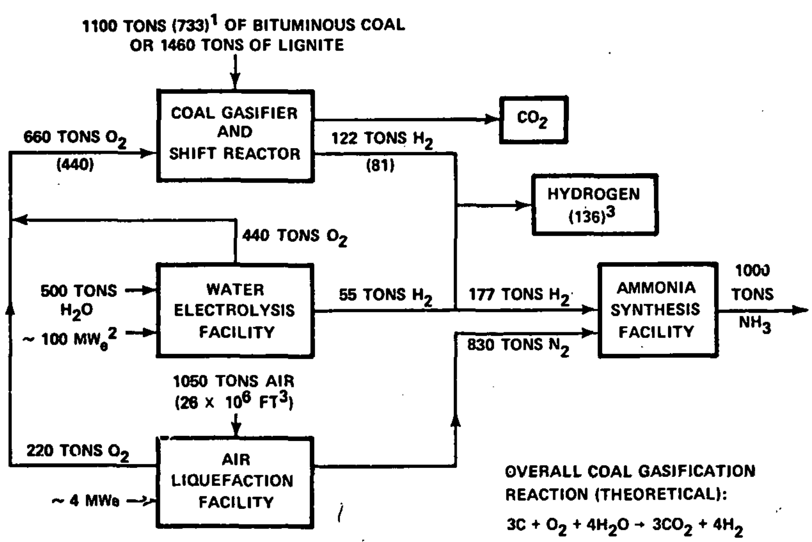

Figure 7