BATTERIES FOR STORAGE OF WIND-GENERATED ENERGY

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Batteries are the one form of energy storage which is familiar to everyone. What is often overlooked is that they are generally used for storing relatively small quantities of energy on a widely distributed basis, perhaps the best example being the automobile starting battery. An estimated 50 000 megawatt-hours are currently stored in automobile batteries alone. Storage of wind-generated energy is similar in concept, involving fewer but much larger storage units. Batteries will be used for this purpose if they are cost competitive with other storage systems. Due to time limitations, I will forego any discussion of how batteries convert chemical energy into electricity; I will concentrate instead on why batteries should be considered, what factors influence their costs, and a brief summary of the state-of-the-art of the most likely candidate systems.

Figure 1 shows the reasons batteries are considered for energy storage. Batteries are attractive because they are simple, easy to use devices which require no complex facilities and little repair or maintenance during their operating life. They can be built in convenient packages and are free of the geographic constraints found in pumped water or gas storage systems. They produce no harmful emissions and are available for use on an almost instantaneous basis.

The factors which affect the costs of battery storage systems are summarized in figure 2. Costs of batteries are largely determined on how they are used. One obvious factor is the size or total quantity of energy which must be stored. This will be fixed by the power to be delivered and the maximum length of windless period during which the battery is expected to operate. The next factor to be determined is life. This will be affected by the total number of operating cycles, the rate at which the battery is charged and discharged, and the depth of discharge, or fraction of the total energy removed in a cycle. Since designs aimed at maximizing lifetime also result in higher initial costs, it will probably be necessary to optimize the battery for minimum cost for a particular installation.

In general, three classes of batteries are considered for bulk energy storage - conventional types, metal-gas batteries, and high energy density alkali metal types. *Figure 3 summarizes the characteristics of the conventional* types most often considered. Three batteries seem suitable.

The lead-acid battery is the standard for comparison. For this service the energy density, which measures the size of battery required to store a given quantity of energy, is 10 watt-hours per pound. The power density, measuring its ability to deliver high current, is 20 to 30 watt-hours per pound. Batteries of this type are good for about 1500 charge-discharge cycles and cost about $80 per kilowatt-hour. It does not appear that this cost will be any lower in the future as this is a mature, cost-conscience manufacturing industry. An updated version of the nickel-iron battery is under development; it is expected to deliver 25 watt-hours per pound and 50 watts per pound. Cycle life is unknown, and a cost close to the lead-acid battery is projected. Since this battery produces substantial amounts of hydrogen on charging, reduced current efficiency and the need for frequent water additions result. The only other current competitor to lead-acid is the nickel-zinc cell. Substantial performance gains at comparable costs are expected, but the cycle life is only 200 to 400 cycles. In summary, at present no conventional battery appears able to compete successfully with the lead-acid battery for bulk storage.

Metal-gas batteries, shown in figure 4, have attracted attention because they promise at least a 4 to 5 improvement in energy density over the lead-acid battery. Zinc-air and iron-air cells offer the possibility of one free reactant which should reduce cost. Nickel-hydrogen is of interest because it makes use of two stable electrodes and should deliver long cycle life. Since air contains carbon dioxide which can reduce the life of air batteries, work on oxygen electrodes coupled with zinc or cadmium has been carried out. Each of these combinations requires air or oxygen electrodes which use precious metal catalysts. These offset the economic advantage of using air. Lifetimes measured from hundreds up to one or two thousand cycles are the best reported, so improvement is needed in that area. An attractive newcomer is an unusual zinc-chlorine battery built by Udylite Corporation to power an electric car. Chlorine is stored as a stable solid compound, chlorine hydrate, at temperatures below 10° C which eliminates the need to handle and store gaseous chlorine. Raw materials costs are low (16¢/lb for zinc and 3½¢/lb for chlorine), and inexpensive carbon can be used for the chlorine electrode. Life is unknown, but this system may have the best near term chance to replace lead-acid.

Exotic alkali metal batteries like those in figure 5 have received much attention in recent years. Energy densities of 100 watt-hours per pound and power densities of 100 watts per pound appear reasonable, and raw materials are plentiful and cheap. The most advanced is the sodium-sulfur battery which runs at 300° C and uses sodium beta-alumina, a ceramic-like sodium ion conductor as the solid electrolyte. Life has so far been limited to 2000 cycles or less. Even with cheap materials, costs of $10 to $30 per kilowatt-hour are expected. A substantially lower cost may be possible if a concept under development by Dow Chemical, which uses fine hollow glass capillaries as the electrolyte, can be brought to fruition. Argonne National Laboratory has pioneered another high temperature battery which uses lithium and sulfur. This system has suffered from severe corrosion problems and apparently will require expensive materials of construction. A lithium-chlorine battery development by Sohio has been unsuccessful. Only one large complete battery of this class has been built, a 30 kilowatt -- 30 kilowatt-hour sodium-sulfur battery to power a van. In general, these advanced systems are expected to require at least 10 years and $30 to $40 million worth of development to reach the point where they are ready for large-scale use.

Batteries work. The role they will play in wind power cannot be determined until a detailed analysis of the storage requirements of wind-generated energy systems is made.

DISCUSSION

Q: You mentioned $80 per kilowatt-hour for the lead-acid battery cost. I wonder if you could tell what's involved in that cost estimate? Also, I wonder if you have any idea what the efficiency of the lead-acid battery is?

A: Well, in answer to your first question, the cost I spoke of is the cost of the battery alone. That's about what it costs to buy commercial, industrial grade, lead-acid batteries, and it's probably as low as that cost figure is going to get. In answer to your second question, the energy in to energy out is a little more difficult, because you have to look at more than the battery. It depends on whether your wind system is driving an ac machine. If so, you're going to have to convert it to dc and use that to charge the battery; then you will have to take the dc out and convert it back to ac. If you can use dc power and produce dc power with your windmill, then your efficiency is going to be better. In that case it's probably going to be of the order of, oh, I'd guess about 60 to 70 percent. It depends on how fast you are doing the charging, and what your inefficiencies are. Without a specific design and a specific rate, it's a difficult question to answer. It will not be 100 percent.

Q: Which batteries are amenable to scaling to very large sizes?

A: That's a good point; I meant to bring it out and I forgot to.

Q: There is an auxiliary question here: where is the crossover point in shifting from very large batteries to the hydrogen-oxygen fuel cell group?

A: Let me first answer the first question. The one characteristic of a battery that you have to remember is that it does not scale well; a 2 kilowatt-hour battery tends to weigh about twice as much and cost almost twice as much as 1 kilowatt-hour battery. There is a scaling factor in practical cell sizes, but it's not like a piece of machinery, for instance, in which you can double the power by increasing the size of the wheel a very small amount.

That is the scaling factor for batteries is nearly linear in terms of the amount of energy stored. This is why you find batteries used and why they will continue to be used in places where at the present cost level relatively small quantities of energy are stored.

Now let me answer your second question. Batteries do not scale in the sense of rotating machinery where the physical size only changes a small amount for a much larger increase in output. In the past I worked on the SNAP-2 project where mercury turboalternators and a SNAP-2 alternator produced a few hundred watts.

If you go up to SNAP-8 and you're talking 30 kilowatts, the system gets a little bigger, but not 15 times as large. Batteries tend to scale more linearly.

Concerning the crossover point, I think that's an economic consideration. Most installed costs I've seen projected for fuel cells tend to be high; for instance, for a 3-megawatt system based on an acid electrolyte fuel cell, the best figure I've seen is $145 per kilowatt installed. Now you're talking power in one case and energy in the other. If you want to compare the fuel cell, then you have to compare the storage tank as well for some given quantity of energy.

Q: I would like to mention two aspects which often get overlooked. First, I don't think you can say the emissions are zero when the efficiency that you point out is 50 or 60 percent. There is one heck of a lot of heat that has to be accommodated, especially in a 1,000,000-pound battery. Actually, I have seen a 7,000-pound battery in a Mercedes bus, and it had a complete air conditioning system that goes along with it. Second, when we think of costs, we must think of costs for the application we are considering. I would be very surprised if we're not talking about 15- to 30-year life systems. If we're talking about a 30-year system, you had better multiply your cost factor of 6, according to your own numbers.
A: That's right.

Q: I would like to mention something about the batteries. We have demonstrated the performance characteristics of at least lead-acid battery powered systems. Some of the things you have in your slides run into a very difficult problem, which is creeping up on us very rapidly. This is the materials availability and cost problem. Of all the material you would want to use in your battery, I would say lead, zinc, and copper are the three most critical raw materials that face us today in terms of price escalation and availability. And of those three, copper and lead have an awful lot of recycle potential and zinc has virtually no recycle. Zinc used in our economy is mostly for corrosion protection. As such, it is sacrificed, and therefore not recoverable. While it would appear that zinc air or zinc chlorine might be a promising candidate for wide-scale use in applications, there could be a real material problem. I think that's another factor that we have to look at very carefully. And for that reason I view with a considerable amount of optimism, if we're going to use batteries, the sodium approach, which is at least one metal that is very energy intensive. I think we have to look at the availability of materials much more with batteries. We ought to also address the question of material costs. It's one place where it is proportional to the energy and power usage: twice as much power, twice as much mass. We also have to worry about the competitive uses of these fairly scarce materials.

A: If I may make a short answer to your question, I try to stay away from the subject of electric vehicles although it's near and dear to my heart. I'm going to give the keynote address at the Electrochemical Society's fall meeting on batteries for electric vehicles. I think it's a tremendous application, but when you begin talking about power in the megawatt hour scale, I'm not sure our experience in electric vehicles is really appropriate here. It's a whole new ballgame. None of us, I really feel, knows a great deal about it. Your comments on materials availability are well-taken. The cost estimates on nickel-zinc batteries, for instance, have been done by battery manufacturers and are based on recycling zinc plates in the manner in which they recycle lead-acid batteries now. But look at the vehicle situation, for instance. It would be impossible in this country to convert all the vehicles we have on the road at the present time to lead acid because we simply haven't got enough lead. That's not an answer for hundreds of millions of vehicles, and I suspect it's also not an answer for power in the scale we're talking about here. It's a good point.

<u>ADVANTAGES OF BATTERY ENERGY STORAGE</u>

- SIMPLE
- EASILY MODULARIZED
- NO SPECIAL SITING REQUIREMENTS
- NO EMISSIONS
- INSTANT STARTUP

Figure 1

<u>COSTS ARE INFLUENCED BY</u>

- TOTAL ENERGY STORED
- OPERATING LIFE
    - NO. CHARGE-DISCHARGE CYCLES
    - RATES OF CHARGE AND DISCHARGE
    - DEPTH OF DISCHARGE

Figure 2

CONVENTIONAL BATTERY PERFORMANCE

SYSTEM	PERFORMANCE		CYCLE LIFE	PROJECTED COST	PROBLEMS
	WH/LB	W/LB			
LEAD-ACID	10	20-30	1500	$80/KWH	
NICKEL-IRON	25	50	?	$100/KWH	GASSING, MAINTENANCE, EFFICIENCY
NICKEL-ZINC	30	150	200-400	SAME AS LEAD-ACID?	LIFE

Figure 3

METAL-GAS BATTERY PERFORMANCE

SYSTEM	PERFORMANCE		PROBLEMS
	WH/LB	W/LB	
IRON-AIR	40-50	10-20	CATHODE CORROSION, LIFE
ZINC-AIR	40-50	10-20	LIFE, COST
NICKEL-HYDROGEN	30-40	?	VOLUME, LIFE
ZINC-OXYGEN	50-60	10-30	LIFE, COST
CADMIUM-OXYGEN	30-40	?	LIFE, COST
ZINC-CHLORINE	50-75	40-60	LIFE

Figure 4

ALKALI METAL-HIGH TEMPERATURE BATTERY PERFORMANCE

SYSTEM	PERFORMANCE		CYCLE LIFE	PROBLEMS
	WH/LB	W/LB		
SODIUM-SULFUR (BETA ALUMINA)	80-100	80-100	200-2000	LIFE, COSTS
SODIUM-SULFUR (GLASS)	80-100	80-400	100+	LIFE, MATERIALS STABILITY
LITHIUM-SULFUR	100	> 100	2000	MATERIALS CORROSION, COSTS
LITHIUM CHLORINE (CARB-TEK®)	50	≫ 100	100	LIFE

Figure 5