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HOW TO PROGRAM SUCCESS IN POWER SOURCES DEVELOPMENT

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1. Introduction

Much effort has been devoted within the last three decades to develop new power sources and energy storage devices. Have we made any progress within this period of time? Could success have been greater than it really was? How should success be defined and progress measured? What are the reasons for success or failure to meet the goals? Can we learn from the past to improve future activities?

Many questions arise. These questions may not be typical for power sources. However, the answers could also be an example for other areas.

Mr Rommel, the Mayor of Stuttgart, mentioned recently that he believes that technicians succeed more frequently than politicians, since they are generally starting with an analysis based on premises and calculations, which are normally correct and which will be experimentally controlled. He expressed the desire that politicians should proceed in the same way [1]. Is his belief really correct? Are scientists and engineers really behaving as Mr Rommel believes they do?

Enquiring into the seriousness and determination of our work, we first have to define the goals at which we are aiming. Three targets can be envisaged:

(a) The goal may be purely scientific. A deeper insight into the object of research can be considered to be a success.

(b) If screening for the suitability of an effect or a material for a certain application is envisaged, the goal is achieved when a candidate for this application is determined.

(c) The goal may be to develop a product for an application. It is achieved when market penetration takes place.

The most serious questions arise when a goal of the third type is aimed at. In this case, a profound analysis should show that the technical and economical potential of the product to be developed is high enough to meet the goals prior to starting a development program.

This procedure has not always been followed and according to the type of procedure, negative or positive results have been obtained in power sources development. In order to indicate in more detail what is felt to be negative or positive, some examples will be discussed and conclusions drawn from them as to how we should proceed in the future.

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2. Some negative examples

One negative example concerns fuel cell development for propulsion of electric vehicles, especially passenger cars. The feasibility of fuel cells has been proved. Does this, however, mean that the development was a success in the sense defined above?

Apparently it was not a success, because fuel cells are not used to propel EVs in spite of the fact that some types were developed to a point where, in principle, they could be used for the purpose. The reason is not only that costs are still too high, but also that the power density of full fuel cell systems is still too low. In addition, the probability may be slight that the power density will ever be high enough for this application. It should be higher than 100 W/kg in order to achieve an acceleration comparable with today's cars, and a maximum velocity which is adequate for driving on a highway from one city to another. These properties are absolutely essential since, during market introduction and, perhaps, for a very long time afterwards both EVs and conventional cars will be operating in the same areas and it would be intolerable that one vehicle should hinder the other [2]. The conclusion, that the power density of fuel cells is too low to achieve these aims can, for instance, be drawn from Fig. 1, which is a superimposition of the properties of electrochemical power sources, published in 1981 [3], and from a very precise presentation of the requirements, with respect to range and maximum velocity, of a 1 tonne vehicle, published in 1968 [4]. The same conclusion has been drawn in ref. 5.

It could have been achieved at a much earlier date, since all the facts concerning the application were already known when fuel cell development was started. The correct way to proceed should not have been first to

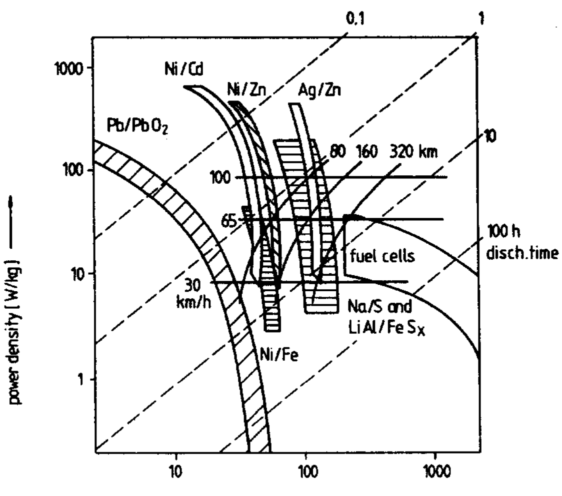

Fig. 1. Specific power and specific energy requirements of electrochemical power sources for steady driving with a 1 tonne vehicle superimposed on battery characteristics [3, 4].

develop fuel cells and then to look for possible applications, but to limit the experiments to the aim of achieving higher power density. We would have avoided giving sponsors the impression that we were willing to develop full systems regardless of their usefulness. This does not mean that fuel cell systems will be useful for other applications.

Another negative example is the development of MHD generators for fossil fueled power plants, consisting of a high temperature MHD part and a low-temperature, conventional, steam power part. Much experimental effort has been devoted to developing the MHD part. The major goals are to achieve a higher fuel efficiency in order to save primary fuel and to produce electricity economically, both by comparison with conventional power plants. While the first goal can be largely achieved, the second one will presumably never be attained. The reason is that the investment costs of the conventional components of the power plant, which can be estimated very accurately, are already so high that the overall costs are unacceptable, even if the most optimistic costs for the nonconventional components are assumed [6]. This conclusion has been arrived at after many years of MHD experiments in several countries. If the study had been performed earlier, experimental work could have been directed towards more realistic aims.

3. Some positive examples

The development and market penetration of primary cells using lithium as the negative reaction material is certainly one of the positive examples of how to bring a product from a first concept, to production. The idea was originally, and finally, to create power sources with a much higher volumetric and gravimetric energy density than conventional primary cells. On the other hand, market studies showed that a need existed for those elements, especially because of the miniaturization of electronic equipment. For this reason, it was expected that the more expensive raw materials, leading to a higher price, would be tolerated. The consequence of this analysis was a screening program for potential electrolytes [7], positive reaction materials [8] and, finally, the development of several types of primary cells.

Another positive example, according to the definitions above, is a screening program for sodium conducting solid electrolytes. The objective of this program, which is not a national approach but more a common understanding, is to find a substitute for β-alumina in Na/S cells. This means that the electrolyte should have a higher conductivity and/or a longer life and/or it should be easier to fabricate. NASICON is one of the results of this screening program. Since the lifetime of this material in contact with sodium is too low, the screening experiments are still going on. An incorrect decision would have been to start the real development of one of the potential solid electrolyte materials at this state of knowledge.

A third example is the idea of using hydrogen storage fuel cell facilities for load levelling purposes in electric networks. Several studies show that the

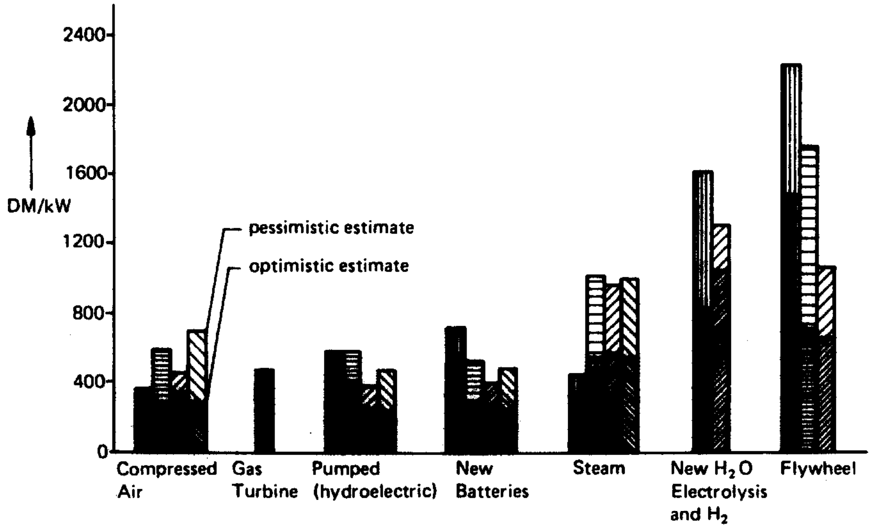

Fig. 2. Investment costs of energy storage devices according to 4 studies [9]. Energy production costs are high if investments costs are high [9].

cost of peak power electricity using these devices will be much higher than the utilization of competing conventional or other future peak power devices [9], see also Fig. 2. For this reason a technical development of H_2-storage fuel cell devices has not yet been started.

4. What can we learn from the examples?

The examples, especially the negative examples, show that the sequence of definitions, decisions and activities was not optimal in some cases. Development could had been more effective if the following rules had been observed:

(a) The goals of a program should be clearly defined. Neglecting the fact that we are normally members of institutions oriented either to the scientific or to the production aspects of the discipline, and that it is natural to have a leaning to one's own interests, we should, nevertheless, decide which aspect would be appropriate for a program. Definition of the goals is strongly dependent on whether it is a scientific, screening, or technical program.

(b) It is necessary, especially for product development, to initiate an analysis or a feasibility study prior to the start of a program. The analysis must show that the goals can be achieved. A positive result is no guarantee of success. A negative result, however, means at least that the probability for success is very low.

(c) It has been mentioned already that we have the freedom to make our choice, whether a program shall be scientific, a screening, or a product oriented approach. We should make use of this freedom. It may be better for credibility to perform some scientific experiments with a small amount of money and a high probability of success rather than to manage a large development program with little chance of success.

(d) It would be helpful if the constraints on flexibility with regard to an individual transfer from industry to university or *vice versa* could be reduced.

5. Prospects for new power sources

The future of advanced power sources will, at least, depend on:

(a) the conditions and restrictions arising from problems such as primary energy and raw material availability, pollution, etc;

(b) whether we will be able to observe the above mentioned rules in order to be effective.

Bearing these aspects in mind, it seems, that the prospects for power sources are better than they have been in the past for the following reasons:

— Our resources of mineral oil will further decrease within the next decades and the price of gasoline will further increase in consequence. In addition, pollution problems will play an increasingly important role. The need to develop substitutes for our ICE-operated vehicles, especially within highly populated areas, will increase. Battery operated EVs could well be a solution to the continuing need to drive individually within, and close to, our cities. On the other hand, the development of new, complex systems such as advanced secondary batteries also requires a very long time. Figure 3 shows that increasing the energy, power density, and life of Na/S cells to an appropriate value for applications required approximately 10 years. Increasing the corresponding properties of batteries to a desired level and introducing EVs into the market will follow similar paths. Finally, the substitution of an appreciable number of cars within our cities will need several decades. Similar considerations can be made for load levelling devices with batteries. That the time necessary for these substitution processes has not been overestimated can also be concluded from the fact that more than ten years was needed for the much simpler development and market introduction of advanced primary cells. In conclusion it may be said that the development of new power sources should be accelerated, since the time for development and market penetration seems to be longer than the time during which other solutions must be substituted.

— Pressure to concentrate development on the most promising systems will result from economic restrictions. This fact will force the developers, and sponsors, to analyze the potential systems with regard to applicability. The probability of success according to the definition above will increase.

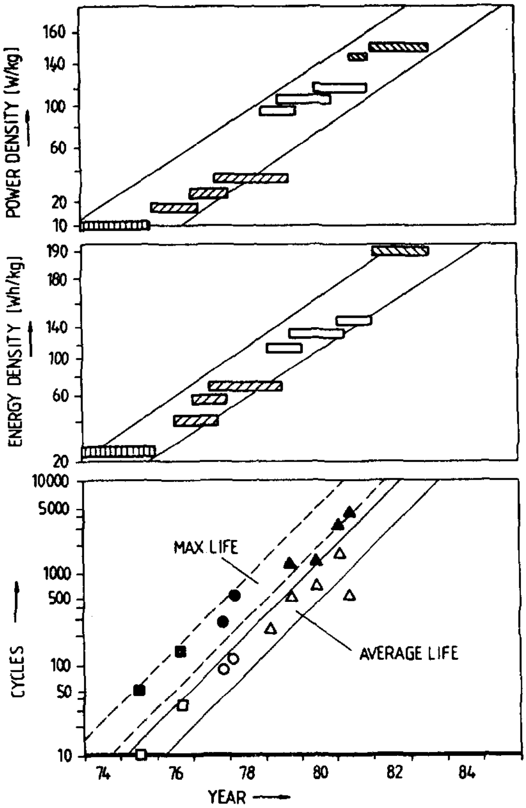

Fig. 3. Power density at 2/3 OCV, energy density at 2 h discharge rate, and cycle life of Na/S cells *vs.* development time.

— Finally it may be expected that individuals and institutions responsible for the development of power sources will have learned from mistakes of the past. It is well known that price decreases with the accumulated quantity of a product. It will be expected, even more, that well-educated scientists and engineers will increase the probability of success in consequence of cumulative experience.

6. Conclusions

The environmental conditions for the application of advanced power sources within the next decades are excellent. However, success in the sense that they will penetrate the market will also depend on our ability to restrict our efforts to systems with a high probability of meeting the goals necessary for their application.

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