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ZEBRA Battery - Material Cost Availability and Recycling

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Abstract

The material for the cells of ZEBRA batteries (standard 21 kWh) is nickel, salt and boehmite. This material represents 28$/kWh of the final cell price, which is an indication of the low cost potential of 100$/kWh for the battery incl. Controller for large volume production.

Worldwide nickel production is 1 million tonnes p.a. from resources of 200 million tonnes. The resources are based on nickel sulphides and nickel laterites and are spread over the globe in different political areas. A shortfall of nickel is unlikely and the battery related share of the demand in only 5% of the total annual production.

The US company INMETCO (PA) has successfully recycled ZEBRA cells in 20 tonne loads to produce nickel containing remelt alloy which is used in the stainless steel industry. The slag resulting from this process is sold as a replacement for limestone and is used for road construction. The material value covers the battery recycling process cost and the transportation from a collection point to the recycling plant.

Keywords: “ZEBRA”, “Battery”, “Recycling”, “Battery Cost”, “Raw Material Availability”

1. Introduction

The ZEBRA high energy battery, based on the electrochemical couple Sodium/nickel chloride, is produced on a commercial scale in Switzerland by MES-DEA (ref1). The high specific energy of this battery (~120 Wh/kg) makes it particularly suitable for EV traction and it is now in use in Europe, US, Canada, South Africa and Australia (Fig.1).

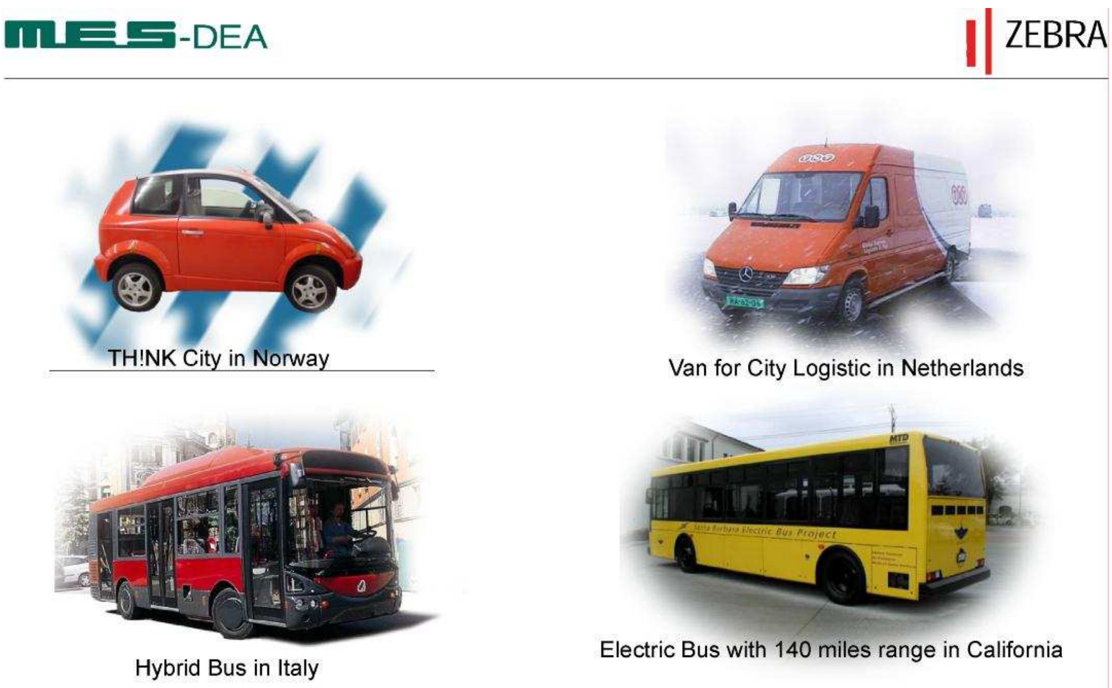

Fig. 1 Some ZEBRA Applications

2. Material Cost

2.1 Cells

The principle components of a ZEBRA cell (Fig. 2) are indicated below along with actual material cost per cell and per kg. With 38Ah/2,58 V one 100% charged cell delivers 98 Wh resulting in the breakdown for material cost tab.1.

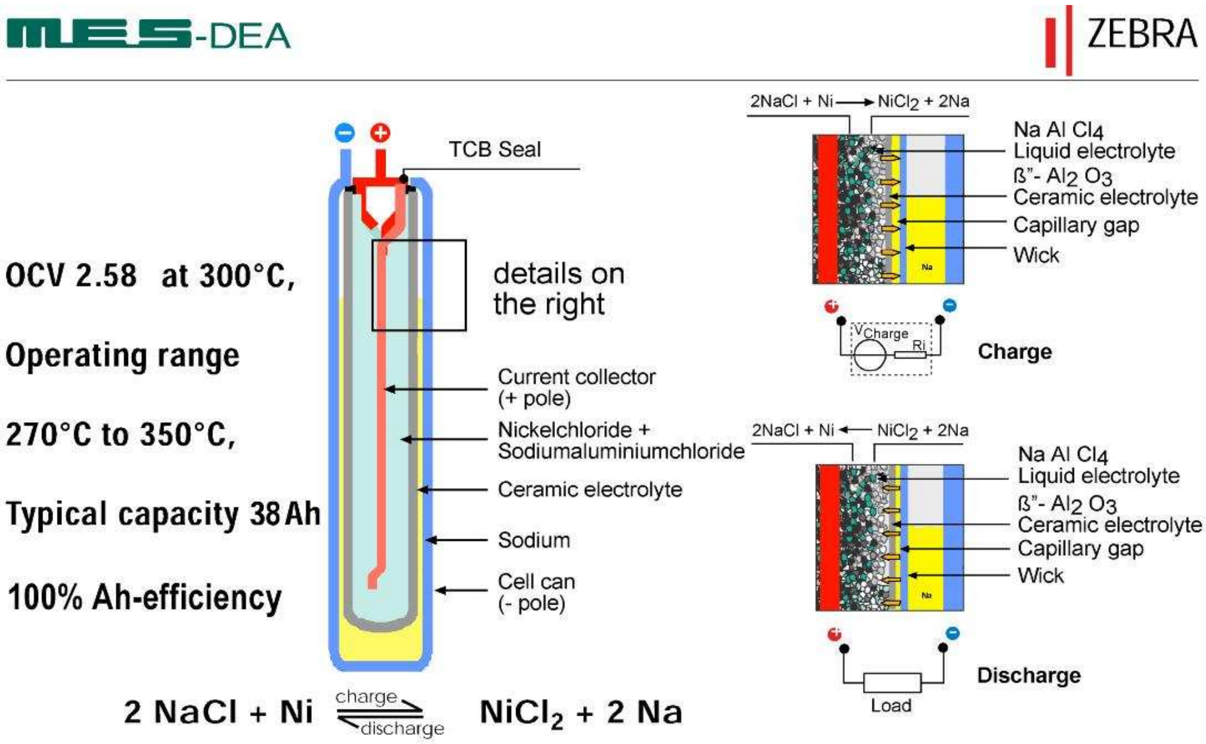

Fig.2 ZEBRA Cell Design (ML3P)

Material	kg/cell	kg/kwh	$/kg	$/cell	$/kWh
Ni (powder + sheet)	0.15	1.53	11.6	1.74	17.75
Iron (powder + sheet)	0.14	1.43	3.36	0.47	4.80
Copper	0.03	0.31	2	0.06	0.61
Halide salts	0.22	2.24	0.77	0.17	1.73
beta-alumina (boehmite)	0.14	1.43	2.38	0.33	3.40
Total	**0.68**	**6.94**	**4.08**	**2.77**	**28.28**

Tab. 1 ZEBRA Cell ML3P Material Cost

The major cost is the nickel. Battery grade nickel powder is used in the electrode and nickel sheet for the cell current collector and hermetically sealing the cell.

However while nickel is predominant in the cell it has been noted (ref 2) that the ZEBRA battery delivers more energy per kg of nickel than other nickel systems available. With the latest battery design 1.53 kg of nickel per kWh of rated energy is used whereas the figures given for Ni/Cd and NiM Hydride suggest between 3.5 and 6.8 kg/kWh. Apart from the high utilization of nickel, the principle advantage is the high e.m.f. of the ZEBRA cell which at 2.58V is twice that of the other nickel battery systems.

While the negative electrode for the ZEBRA cell is sodium, the metal is not used in the fabrication of the cells. They are assembled in the discharged state using sodium chloride (common salt) and the sodium electrode is generated by electrolysis during the charge cycle. Sodium chloride is of course readily available at very low cost. The grade used in the ZEBRA cell is less than 0.30$/kg.

2.2 Battery Case

The battery case is composed of a double wall stainless steel box, the cooling system and the microporous foamed silica plates that fill the gap between the inner and outer wall and provides the extremely low heat conductivity of 0,006 W/mK.

Material	kg/bat	kg/kWh	$/kg	$/bat	$/kWh
Stainlees Steel	18	0.85	3.2	57.6	2.72
Steel (cooling system)	7.5	0.35	1.5	11.25	0.53
Thermal isolation	7.5	0.35	12.5	93.75	4.42
Miscellenious	4	0.19	9	36	1.70
Total	**37**	**1.75**	**5.4**	**198.6**	**9.37**

Tab. 2 ZEBRA Battery Z5 (21 kWh) Case Material Cost

The material (Tab. 2) is given for a 21 kWh standard battery type Z5. It is proportional to the battery surface (fig. 3) and not to the energy content.

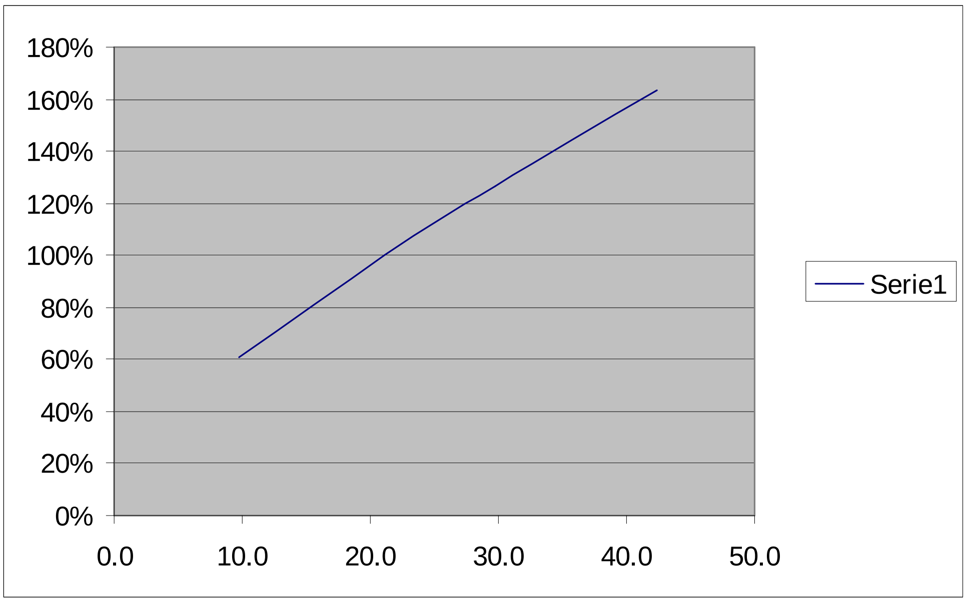

Fig. 3 Battery Case Material Cost vs Battery Size

2.3 Battery System Cost

The ready to mount ZEBRA battery system is composed of the cells, the battery case with thermal management and the battery controller.

For the projection of the low cost potential of mass produced ZEBRA batteries in Tab. 3 the following considerations are applied:

- the cell assembly line may be comparable to the highly automatic assembly lines for electro-mechanical components for which the raw material is 70% of the total cost.
- for the ceramic production cost the energy is important. For the large volume production this is 1,7 $/kWh using a tunnel kiln for sintering.
- The battery assembly line has a lower degree of automation and is assumed to operate with a material cost share of 50%.
- The battery controller cost is independent of the battery size and is estimated to cost 200-300 $ dependent on it's functionalities as part of the vehicle system. For this estimate a mean value of 250 $ is used.
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Part		**$/kWh**	**Battery in $**
Cells	Material tab 1	28.28	599.6
	Assembly	12.12	257.0
	Energy	1.7	36.0
Case	Material tab 2	9.37	198.6
	Assembly	9.37	198.6
Controller			250
Total		**72.63**	**1539.9**

Tab. 3 Cost Projection of a 21 kWh Mass produced ZEBRA Car Battery

2.3 EV Operating Cost

ZEBRA Battery technology has proven calendar life of more that 10 years and cycle life of 1000 to 2500 nameplate cycles dependent on operating parameters (ref. 3, 4). The real world life is also influenced by production quality and ambient conditions. For this reason MES-DEA has started to systematically collect real world battery life statistics. This database covers more that

200 batteries at present. The extrapolation of these results is not in contradiction to the laboratory results. Assuming that the battery production cost (Tab. 3) are 2/3 of the selling price we end up with 2310 $ for a 21,2 kWh battery (109 $/ kWh).

The realistic cycle life of 1500 nameplate cycles result in 0,073 $/ kWh battery cost per energy throughput. A car needs ca. 32 kWh /100m so that energy (0,05 $/ kWh off peak power) and battery cost total 3,93 $/100m, compared to 4,5 $/100m (33 mpgal, 1,5 $/gal) for a conventional car. Battery powered EVs offers economic oil independent mobility.

3. Raw Material Availability

While the dominant material in the cell is nickel this is readily available worldwide. Recent figures indicate global nickel production exceeded 1 million tonnes in 2002 from proven reserves of more than 200 million tonnes (Inco Private Communication). Nickel is distributed as nickel sulphides and nickel laterites and these resources are spread globally so that production is not sensitive to geo-political tensions (Fig.4). Thus continuity of supply should be preserved in the years ahead and since battery use for nickel is less than 5% of annual nickel production a shortfall in nickel for battery production is unlikely.

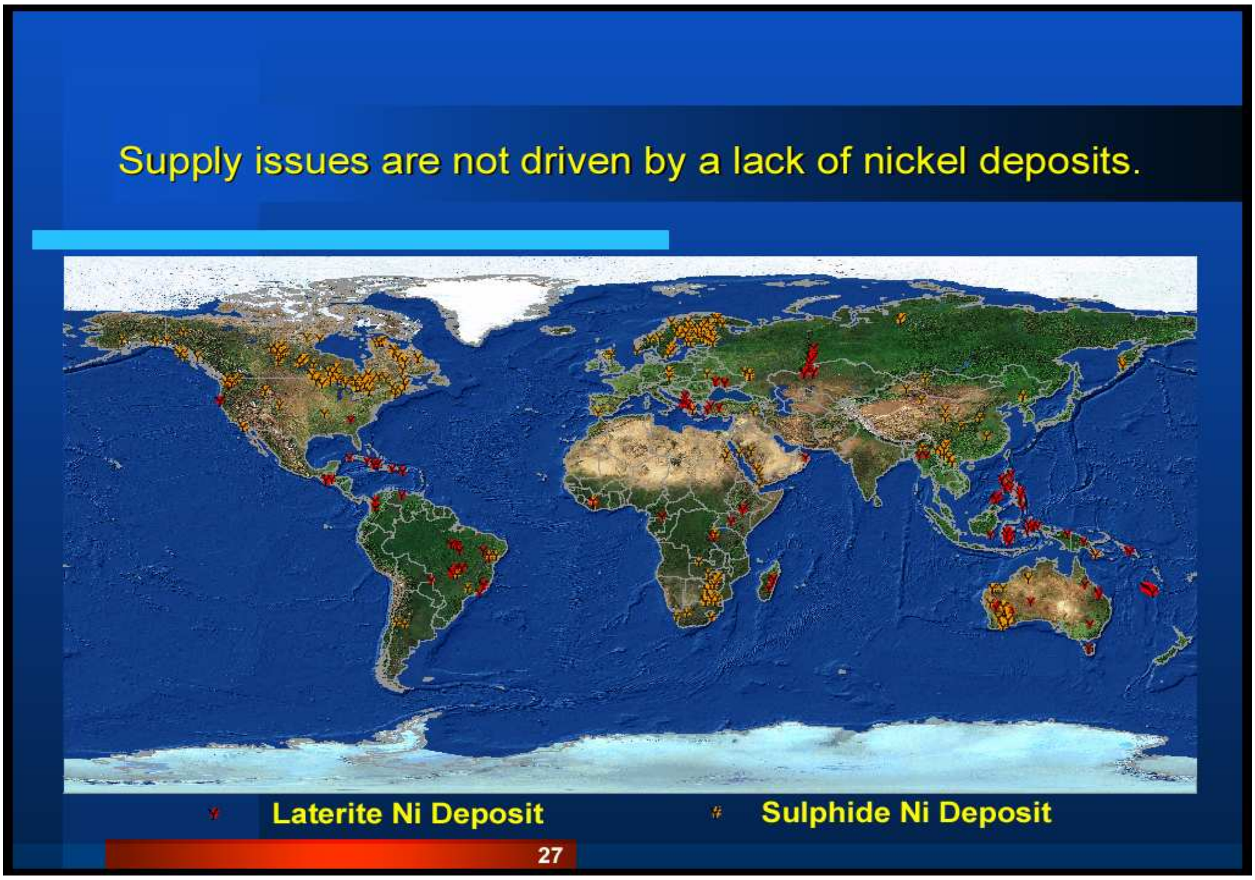

Figure 4

With regard to raw material availability sodium/nickel chloride batteries are better placed than lithium batteries. Lithium is a moderately rare element in the earth's crust compared to sodium:

Element	ppm	
Lithium	65	
Sodium	28300	(Source Ref.5)

A paper published in 1996 (Ref. 6) indicated a world annual lithium production of only 10,000 tonnes. This would have to be increased substantially as a significant EV market developed.

4. Recycling

As the EV population increases, battery recycling infrastructure will need to be in place to process spent batteries without adverse impact on the environment. The US company, Inmetco has successfully recycled 20 tonne loads of ZEBRA cells by adding them to their standard submerged arc smelting furnace to produce nickel containing remelt alloy used in the stainless steel industry. The ceramic and salt contained in the cells collects in and the slag and is compatible with their process. This is sold as a replacement for limestone used in road construction - nothing goes to landfill. Inmetco has a wealth of experience in battery recycling and typically process about 5000 tonnes of nickel based batteries per year. There is scope for increase as total nickel containing raw material throughput is in excess of 60,000 tonnes per annum. Thus there is ample recycling capacity as the ZEBRA battery production is ramped up.

The present MES-DEA production facility has been planned with a maximum production capacity of 30,000 batteries per year. Even at full capacity amounting to 5400 tonnes per year the quantity of spent batteries accumulating annually should be measured in hundreds of tonnes which is well within the recycling capability.

High value nickel powder from a primary source is used to manufacture the ZEBRA battery. At the end of its life the nickel is converted into a constituent of remelt alloy used in the manufacture of stainless steel around the world. One of the weak links in any recycle process is the collection at the end of life. In the case of the ZEBRA battery, customers (in Europe) are required to return old ZEBRA batteries to MES-DEA. After removal of the management electronics the cells are packaged in their case ready for shipping to Inmetco. ZEBRA vehicle batteries are large - a 20kWh, Z5 battery weighs 180 kg and is packaged as one unit so it is envisaged that in future complete battery packs will be shipped for recycling. Another weakness in recycling schemes is the cost of collection, transport and processing. Fortunately for the ZEBRA battery there is sufficient value to cover the transport costs to Inmetco and the cost of their processing. The net worth of the nickel ensures that the entire recycle process is cost neutral. So with the ZEBRA battery there is no additional recycling cost in addition to the purchase price. This is not the case with all battery systems.

5. Conclusions

The low material cost/kWh for the ZEBRA battery indicates 100 $/kWh scope for price with high volume production. This coupled with long life in service gives competitive non oil dependent mobility cost of 3,76 $/100m.

The world resources of nickel are plentiful and will be able to support the growth in nickel battery production anticipated.

A proven recycling process for ZEBRA batteries is in operation, which is cost neutral.

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6. References

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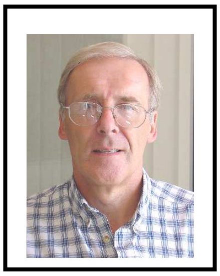

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Roy Galloway obtained a Ph. D. from the University of Edinburgh. He has worked on the ZEBRA Battery for 25 years, first in South Africa at the CSIR in Pretoria, then at Beta Research and Development Ltd. in Derby, England and latterly at MES-DEA. Present Duties include responsibility for production of the positive electrode as well as research to improve the cell.

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