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Cost savings for manufacturing lithium batteries in a flexible plant

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HIGHLIGHTS

- Flexible plants save costs if the electrodes for all batteries have the same size.
- The power-to-energy for the battery can be set by the electrode thickness.
- The factors setting cost are the cell area for the battery and production level.
- For the four batteries studied, the price range was \$20–24 m^{-2} of cell area.

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ABSTRACT

The flexible plant postulated in this study would produce four types of batteries for electric-drive vehicles – a hybrid (HEV), 10-mile range and 40-mile range plug-in hybrids (PHEV), and a 150-mile range battery-electric (EV). The annual production rate of the plant is 235,000 battery packs (HEV: 100,000; PHEV10: 60,000; PHEV40: 45,000; EV: 30,000). The cost savings per battery pack calculated with the Argonne BatPaC model for this flex plant *vs.* dedicated plants range from 9% for the EV battery packs to 21% for the HEV packs including the battery management systems (BMS). The investment cost savings are even larger, ranging from 21% for EVs to 43% for HEVs. The costs of the 1.0-kWh HEV batteries are projected to approach \$714 per unit and that of the EV batteries to approach \$188 per kWh with the most favorable cell chemistries. The best single indicator of the cost of producing lithium-manganate spinel/graphite batteries in a flex plant is the total cell area of the battery. For the four batteries studied, the price range is \$20–24 per m^2 of cell area, averaging \$21 per m^2 for the entire flex plant.

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1. Introduction

The demand for batteries for electric-drive vehicles may be too low for some years to come to economically produce them in plants dedicated to one type of vehicle battery. Also, upgrades to the products and orders from new customers must be easily undertaken with existing processing equipment. In this report, we term the type of plant that can produce batteries for different types of vehicles a *flexible plant* and abbreviated it as *flex plant*. Manufacturers of automobile batteries are already taking this approach. Batteries for vehicles can be produced at moderate cost if the batteries for several types of vehicles are produced in a single plant with only moderate changes to the production lines to accommodate the various products. With the emergence of grid electrical energy storage, lithium-ion batteries for grid storage can be co-produced in a flex plant with transportation batteries, which may serve to bring down the unit cost of the batteries. For over a decade Argonne has designed batteries for electric vehicles based on modeling with Microsoft Office Excel spreadsheets [1–4]. This effort was extended to calculating the cost of manufacturing lithium ion batteries [5–12]. The modeling program, BatPaC [5–7], which resulted from these previous studies, was used in this study to evaluate the feasibility of manufacturing several different types of batteries on the same manufacturing line to achieve economies of scale. Cost projections for Li-ion battery manufacturing have also been reported by others. Patry et al. [13] reported that thicker electrodes are attractive for reducing cost and mass, but detrimental for power and aging characteristics. Sakti et al. [14] concluded from their analysis that economies of scale are reached at 300 MWh of battery capacity in a plant. Cost modeling and projections have also been reported by TIAX [15] and Mock [16]; battery manufacturing has been addressed by Shawn et al. [17], and Mareike et al. [18] asserts the importance of the manufacturing

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process optimization on battery performance and production costs; Benjaafar et al. [19] and Balakrishnan et al. [20] discuss flexible manufacturing processes.

Studies with BatPaC have shown that the major costs for manufacturing lithium-ion vehicle batteries are 1) materials, 2) plant facilities, and 3) labor and energy. The materials costs per unit of production are not greatly affected by the production rate of a single battery manufacturing plant because the materials are similar for batteries for all applications. The electrode materials are made by chemical manufacturers, the current collector foils by metal suppliers and the separators by specialty manufactures of battery supplies. These materials are thus priced like commodities and BatPaC treats their prices as inelastic on the scale of a single plant producing 100,000 battery packs per year or less. On the other hand, the capital cost of the plant and the cost of labor are greatly affected by the scale of operations at every stage of the processing. Only very large plants with the highest speed electrode coating equipment and the most automated cell and module handling and testing equipment can approach minimum costs. This would require production of 200,000 to 500,000 large all-electric vehicle (EV) batteries per year, greater than at any lithium-ion factory now in production. The smaller hybrid-electric (HEV) and plug-in hybrid vehicle (PHEV) batteries would require even higher production levels measured in units per year in dedicated plants to approach minimum costs.

The overall thesis of this study is that the scale of production can be increased and, thus unit cost decreased, by producing several types of batteries in the same plant. As stated above, this requires that the batteries can be produced on the same plant production lines with easily made adjustments to accommodate the different battery designs. That the unit cost will decrease with increasing throughputs at each processing step is not at issue here because it is a well-established industrial fact [21] and is built into the BatPaC model [6,7]. What is at issue is if batteries of very different capacities and power-to-energy ratios can be designed to be produced on the same line of plant equipment with only slight, rapid adjustments to the equipment settings.

The most common lithium-ion cell designs are cylindrical wound cells, flat wound cells, and prismatic cells with flat plates. We believe that the flex plant approach would be applicable for each of these types of cells. Cylindrical cells have been employed in Tesla batteries with the selection of the standard dimensions of 18,650 cells (18-mm diameter × 65-mm length). The electrode strips to be wound would have the same widths for all applications and would vary only in the thickness of the coatings, the composition of the electrode materials, and the lengths of the strips. These differences could be easily accommodated by the coating and electrode slitting equipment. After winding and testing the cells, the assembly of the modules and battery packs would be similar for all battery applications.

Flat wound cells could be handled in a flex plant in a similar way to that for the cylindrical cells. It would require that the length of the cell, which determines the width of the electrode strips, be the same for all of the battery applications. Also, if the width and thickness of the cells are to be the same for all applications, the application that requires the smallest cell to meet the voltage requirement with a single string of cells would determine the size of the cell for all applications. That size, however, would have a larger capacity than for the cylindrical design because of the superior heat dissipation characteristic for thin flat cells.

The cell design chosen for the BatPaC model is the prismatic design with flat plates because that design easily accommodates a wide range of capacities and power-to-energy ratios. And, therefore we have selected that design to facilitate the study.

A major processing step in battery manufacturing today is the coating of the electrode materials onto both sides of current collector foils, which are of aluminum for the positive electrode and usually of copper for the negative electrode. The coating process handles wide sheets of foil materials that are coated with electrode-material layers that are typically 25 to 100-microns thick when finished. For a prismatic multi-plate cell, these coated sheets are calendered and slit into individual plates. These plates are dried under vacuum, stacked into multi-plate cells with separator sheets between the positive and negative electrodes and then the electrodes are ultrasonically welded to the feedthroughs. To accommodate several types of vehicle batteries in a single plant, the width and length of the plates should be standardized for that plant because changes in the lengths or widths of the electrodes require complex adjustments in some of the steps making automation more difficult and expensive. However, the thickness of the coating can be allowed to vary because the coating process and the steps that follow can easily accommodate changes in the electrode thicknesses. That allowance and variation in the electrode compositions permits the wide range in the power-to-energy (P/E) ratio needed for the various types of vehicle batteries.

Standardizing the electrode widths and lengths will also result in approximately standard cell widths and lengths. The cell thickness, which determines the number of electrodes per cell, has default values in the BatPaC model [6 mm for hybrid electric vehicles (HEV), 8 mm for plug-in hybrid electric vehicles (PHEV) and 12 mm for electric vehicles (EV)]. For the flex plant, the cell thickness can be varied to adjust the cell capacity and battery voltage.

In the BatPaC design, the above standards would result in the modules for all vehicle types having approximately the same length and height and varying only moderately in width (the dimension determined by the thickness of the cells and their number per module). The similarities in the cells and modules favor increased use of automation in the handling of the great numbers of these parts in a flex plant and, thus lead to economies of scale. Because of the standard electrode sizes, the height of all battery packs produced in a flex plant would vary by only a few millimeters and could be set to allow fitting the packs under the back seat of sedans.

To demonstrate the efficacy of the proposed flex plant, it is necessary to show that batteries of a wide range of capabilities from a HEV battery with a high power-to-energy ratio (P/E) to an EV battery with a low P/E can be designed with electrodes of the same width and length. It is also necessary to demonstrate that the flex plant can produce the batteries at substantially less cost than dedicated plants for each battery type producing at the levels needed for each battery type. To illustrate the feasibility of accomplishing these goals, this study designed batteries that meet a set of representative performance goals, shown in Table 1, and calculated their prices when produced both in a flex plant and in dedicated plants at the production rates shown.

Table 1
Example of battery pack parameters and production volumes for manufacturing in a flexible plant.

Battery type	HEV	PHEV10	PHEV40	EV
Vehicle range (miles)[a]	1.25	10	40	150
Target total energy (kWh)[a]	1.0	2.86	11.4	35.3
Available battery energy (% of total)	25	70	70	85
Target power for 10 s (kW)	35	65	130	150
Annual production volume (235,000 total)	100,000	60,000	45,000	30,000

[a] Assumes efficient, light-weight vehicles with energy requirements on the UDDS cycle of 200 Wh-mile^{-1}.

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