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## COMMERCIALIZATION PLAN

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Aerocapacitor Commercialization Plan

Current Power-One Involvement

Due to conflicting business priorities, Power-One has pulled out of the Aerocap project. The commercialization plan presented below was formulated while Power-One was actively involved in the Aerocap project. Although this commercialization plan reflected Power-One's marketing plan at the time it was written (9/12/95), this plan does not reflect the current intentions of Power-One in regards to marketing of the Aerocap. Please note that items that were marked TBD had strategy definitions contingent to implementation of other strategies described in this plan. Since Power-One is no longer actively involved in the Aerocap project, strategy formulation for these TBD items is no longer being pursued.

Introduction.

The purpose of the Power-One Aerocapacitor Commercialization Plan is to communicate to members of management and to all employees the overall objectives of the corporation.

Power-One, Inc. has participated in a US Federal Government Technology Reinvestment Project (TRP), entitled "Advanced Power Conversion based on the Aerocapacitor": the project is a group effort, with Lawrence Livermore National Labs, GenCorp/Aerojet, PolyStor Corp. (a start-up company), and Power-One forming the consortium. The expected resulting technology is the "Aerocapacitor", which possesses much higher performance levels than the usual capacitors on the market today. Power-One hopes to incorporate the Aerocapacitor into some of its products, hence enhancing their performance, as well as market privately-labeled aerocapacitors through its distribution channels. Following are the details of Power-One's plan to bring to market and commercialize the Aerocapacitor and Aerocapacitor-based products.

Power-One Background

Power-One, Inc. consists of a group of three independent companies: Power-One, Inc., Poder Uno de Mexico, S.A. de C.V., and Power Electronics, Inc. These companies are jointly operated by a central corporate management team in Camarillo, California.

Power-One, Inc. is the largest privately held manufacturer of direct current power supplies in North America. Power-One designs, manufactures and markets under its own brand name a broad line of standard power supplies to a wide range of customers. Our brand name is one of the most recognized and respected in the power supply industry.

The company produces and sells over 500 different power supplies in six main product lines, broadly classified into linear and switching power supplies. Power-One was founded in 1973 as a designer and manufacturer of linear power supplies, and remains the industry leader in the linear power supply market. During the past decade, product lines have been expanded to include switching power supplies (40W-2500W). Many of Power-One's power supplies have been designed so that they can be easily modified into a broad array of different configurations, allowing Power-One to meet its customers' technical specifications quickly and inexpensively while maintaining minimal inventories.

With sales expected to exceed $72M in 1995, Power-One is among the top ten domestic manufacturers of power supplies. In 1995, over 10,000 customers are expected to purchase a Power-One power supply. The majority of these customers are small electronics companies who buy their supplies from industrial distributors. Power-One has the industry's largest network of electronic distribution companies, with sales to distributors in 1995 expected to exceed $40 million (over 50% of total sales). The remaining sales are to over 500 leading original equipment manufacturers.
Power-One's base of OEM customers is in diverse market segments such as telecommunications, computers, medical equipment and industrial instrumentation. Many of our OEM customers are Fortune 500 companies and leaders in their respective industries.

Power-One has demonstrated superior financial performance under its current management team. The Company's sales, EBIT, operating income and pre-tax income have all grown each year since 1990.

Power-One is headquartered in Camarillo, California, 50 miles northwest of Los Angeles. The ISO-9001 certified Camarillo facility houses research and development, marketing, administration and light manufacturing. The Company operates three ISO-9002 certified modern factories in Isabela, Puerto Rico; San Luis, Mexico; and Santo Domingo, Dominican Republic. Each facility is strategically located in areas with a large pool of low-cost labor. The Company has 1500 full-time employees.

Customers think of Power-One's operations, products, and brand as belonging to a single entity. Employees think of each company as being a part of the same company.

Power-One's worldwide customer base exceeds 10,000, with one million units of product shipped to them annually. Power-One is a US leader in its field, and the largest privately-held US power supply manufacturer.

Power-One is active in several electronics/electrical-machinery markets, including, but not limited to, computers and peripherals, communications and telecom, electro-medical, and industrial. Power-One has extensive sales channels across the US, offering distributor as well as OEM sales, and an international distributor channel. Power-One's sales and distribution networks are one of its major strategic strengths.

**Power-One's Management Team**

Dennis Roark, executive vice-president and vice-president of research and development at Power-One, Inc., has over 20 years of experience in power conversion engineering and power supply manufacturing. Prior to joining Power-One, he co-founded and co-owned California D.C. Power Supplies, Inc., a power supply manufacturing company. He is responsible for all of Power-One's research and development operations, and is continuously abreast of innovations and technological advances in the power conversion industry. Mr. Roark received his B.S. in Engineering from California Polytechnic University, Pomona.

Dave Hage, vice-president of sales and marketing at Power-One, Inc., is responsible for the direction and management of the marketing, sales, and promotion of the organization's products and services. With over 20 years of experience in sales and marketing, he joined Power-One in 1993 after working at Honeywell, SGS-Thomson Semiconductors and Power Convertibles Corporation, a subsidiary of Burr/Brown, Inc., where he was executive vice-president. Mr. Hage received his B.S. in Engineering from Northern Arizona University, and his MBA from Arizona State University.

Together with their staff of engineers, marketing analysts, sales representatives, and technicians, Mr. Roark and Mr. Hage will direct and implement Power-One's commercialization of the Aerocapacitor.
**Power-One Strategic and Business Profile**

Power-One is recognized as one of the top three power supply companies in North America. Our brand name is one of the most recognized and respected in the power supply industry. Our name is our most important asset. We will maintain and improve its reputation. Every product that is labeled with the Power-One name must be indicative of our commitment to quality and value.

Our goal is to be the recognized leader in our industry at supplying products from "Customer to Concept to Customer".

**Strategy Statement for Power-One**

* A full line power supply manufacturer
  * servicing diverse customers
    * with flexible, cost effective, quality products
      * which are readily available.

This Strategy Statement outlines the way the company operates and makes decisions. The Strategy Statement is detailed in the following manner:

**A Full Line Power Supply Company**

Power-One offers a broad range of products to meet our customers' requirements for standard power supplies. Since many customers require several different types of power solutions, Power-One offers flexible products to meet a variety of customer needs. Our present line consists of AC-DC products from 5-2500 watts.

*The Aerocapacitor will augment the power supply portfolio. These products will utilize our brand name and distribution channels to our advantage.*
Diverse Customers

Power-One has over 10,000 customers. Distributor sales account for more than one-half of our revenue.

*It is believed that the Aerocapacitor can be marketed through our existing distributors.*

Flexible Products

We will aggressively pursue modifications to our product line and will thoroughly research customer and market needs to offer simple and flexible power conversion solutions. We will design products for manufacturability and strive for elegantly simple solutions. We will avoid overly complex products.

*The Aerocapacitor meets these requirements, while much more investigation of customer needs is required.*

Cost Effective Products

All new products will have pre-defined cost objectives, and we will drive to achieve those target costs. We will understand the cost objectives for new products before attempting to enter a new market.

*For the Aerocapacitor, this is TBD.*

Quality Products

The Power-One name is synonymous with quality. Our customers receive the highest quality products and services at a competitive price. Quality metrics have been established and will be maintained.

All worldwide Power-One manufacturing facilities and suppliers will be measured against our quality standards. Continuous quality monitoring and improvement is a requirement for all Power-One manufacturing sites, subcontractors, and suppliers. We will maintain ISO-9000 certification for all of our facilities and will encourage our suppliers to achieve this certification.

We will hold sub-contractors accountable for meeting Power-One quality standards and will provide them with the necessary support to achieve quality objectives. Power-One personnel will regularly visit critical off-site locations/facilities and communicate clearly with headquarters to ensure that quality levels are maintained.

Readily Available

Our emphasis on being a standard products manufacturer allows us to have products available "off the shelf". This also allows us to sell the majority of our products through our extensive distribution channel. The Aerocapacitor can be sold both on a direct basis, as well as through distributors.
Implementation of Strategy Statement

In addition to the Strategy Statement, Power-One has determined the best way to achieve many of its goals are in the following areas:

New Product Introductions

Power-One is a “product-driven” power supply company that will be the recognized leader in achieving the goals set by our new product development program. New product introduction cycles will be measured in days rather than months.

We intend to fully understand our customers' needs so that we can conceptualize and design products that effectively serve the market and meet our cost/performance objectives. We will gain this understanding in part through the "Vision-One" program, wherein customer input on design concepts is solicited. We want customers intimately involved, not only in the conceptual phase, but through the alpha, beta and production launch.

In terms of the Aerocapacitor, as products are developed, we will use our Vision-One approach and discuss customer needs to determine future requirements, as well as ways to market to them for current products.

Customer Service

Power-One must make it easy for customers to do business with us. We will consistently measure customer perception and satisfaction levels, and will implement corrective action programs to improve service.
Power-One’s Marketing Strategy

**Driving Force**
Definition: Something pushing, propelling, or driving an organization forward. *Driving force* or *strategic drive* is the one element or component of a business which drives the organization toward certain products, markets, and customers and thus determines the organization’s “look” or profile. This concept sets the organization apart from any other corporate structure and gives it its particular identity.

Power-One’s Driving Force: A "Product Driven" Company
Primary driving force: Power-One is a "product driven" company. A product driven company is one that has tied its business to a single product. As a result, the company’s future products will greatly resemble its current and past products in "look" and "function". Power-One’s entire business is based on delivering power conversion products that meet customers' needs. In the context of Super-capacitors, this definition fits.

Secondary driving force: Power-One's secondary driving force is our distribution network. Companies that have a unique way of getting their product or service from their place to their customer's place are pursuing a "distribution-driven" strategy. For Super-capacitors, these same distributors can be used as a marketing channel.

**Core Competencies and Areas of Excellence**
Definition: A *core competency* or area of *excellence* is two or three organizational strengths that are critical to the success of the company. These areas must be fueled with more resources in order to develop a level of proficiency greater than any competitor's. This will significantly differentiate us from our competitors and provide a unique value for our customers. In good times, these are the areas to which additional resources should be given. In bad times, these are the last areas that should be cut. A "core competency" should meet these three tests:

1. Which of our competencies could allow us to enter into a new market?
2. Which competency significantly contributes to the end product's benefits to the customer?
3. Which of our competencies would be hard for a competitor to imitate?

*Primary "Core Competencies" (listed in order)*

1. Name Recognition
Positive brand name preference has allowed Power-One to develop one of the most impressive customer bases in the industry, including many of the top 1000 electronics companies. Due to our diverse customer base, we are not highly vulnerable to economic cycles. Since its founding in 1973, Power-One has earned a reputation within the industry and with its customers for producing products of the highest quality. In independent market surveys, the company is recognized as one of the top three U.S. power supply manufacturers known for the quality and stability of its products.
2. Distribution Channels

Power-One has the largest domestic distribution network in the power supply industry. Power-One has utilized distributors for over 10 years, which is longer than any other power supply manufacturer. The strength of Power-One’s network of distributors is unmatched in the industry for a variety of reasons, including the company’s annual sales volume, its customers’ loyalty to the Power-One brand, and its long-standing relationships with the distributors. Over 50% of Power-One’s sales are via distribution. The electronics distribution community recognizes Power-One as the premier line to sell.

The Company is suitably positioned to utilize the Power-One brand name and distribution channel to promote and sell the Aerocapacitor.
### Characteristics of Market Segments (External Environment)

#### Geographic Markets
Common Characteristics of Geographic Markets
- North America and U.S. (presence and support)

<table>
<thead>
<tr>
<th>Successful Geographic Markets</th>
<th>Unsuccessful Geographic</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>Europe - Lack of presence and focus</td>
</tr>
<tr>
<td>East coast, Midwest industrial sector, (markets where price is less critical), Southern California.</td>
<td></td>
</tr>
</tbody>
</table>

#### Market Segments

<table>
<thead>
<tr>
<th>Successful Market Segments</th>
<th>Unsuccessful Market Segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>Computer - PC markets</td>
</tr>
<tr>
<td>Medical (Hi-End)</td>
<td>Central Office Switching</td>
</tr>
<tr>
<td>Test Equipment/Instrumentation (Hi-End)</td>
<td>Segments that require multiple product lines</td>
</tr>
<tr>
<td>Communications</td>
<td></td>
</tr>
</tbody>
</table>

#### Characteristics of Distributors

<table>
<thead>
<tr>
<th>Successful Distributors</th>
<th>Unsuccessful Distributors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong Product Knowledge</td>
<td>Limited Product Knowledge</td>
</tr>
<tr>
<td>Strong Inventory Position</td>
<td>Weak Inventory Position</td>
</tr>
<tr>
<td>Good Internal Systems</td>
<td>No Internal Systems</td>
</tr>
<tr>
<td>Motivated Sales Force</td>
<td>Unmotivated Sales Force</td>
</tr>
<tr>
<td>Synergistic Line Card</td>
<td>No Synergistic Line Card</td>
</tr>
<tr>
<td>World Class Customer Service</td>
<td>Weak Customer Service</td>
</tr>
<tr>
<td>Good Working Knowledge of Competition</td>
<td>Limited Knowledge of Competition</td>
</tr>
<tr>
<td>Superior Communication Channel s with Field Sales</td>
<td>Weak Communication Channels with Field Sales</td>
</tr>
<tr>
<td>Financial Stability</td>
<td>Unstable Financially</td>
</tr>
<tr>
<td>Knowledge of Customer Base Within Territories</td>
<td>Lack of Knowledge of Customer Base</td>
</tr>
</tbody>
</table>

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Market Opportunities for Capacitors and the Aerocapacitor

**Capacitors -- Continued Strong Electronics Demand**

**Market Situation**

Passive electronic component companies have been riding high over the past year, thanks to generally strong conditions in the electronics industry. Passive electronic components, which include capacitors, resistor, inductors, and transformers, are found in virtually every electronic device. While demand (and pricing) for these products is affected by economic cycles, the steady growth of the electronics industry and rapidly increasing consumption of integrated circuits over the past 10 years have continued to push passive electronic component unit volumes higher. In addition, the growing complexity of today's electronic devices, such as the shift to more powerful microprocessors in personal computer, has boosted overall passive electronic component content. The structural changes in passive electronic component demand, coupled with the continued strength of the global economy, have created some of the most favorable industry conditions in recent memory.

Growth has been particularly impressive, in two of the fastest-growing segments of the passive electronic components business-tantalum capacitor chips and multi-layer ceramic capacitor (MLCC) chips. Industry wide, lead times for tantalum capacitor chips and MLCCs have lengthened, due to tight capacity and strong demand. Pricing has held firm and, in some instances, selected price increases have been passed through on some capacitor chips in short supply. Typically, unit prices for capacitors decline on average around 5%-6% annually.

Currently, a handful of large industry players dominate the passive electronic components business, including several Japanese-based companies. In the case of tantalum capacitors and multi-layer ceramic capacitors, what was at one time a fragmented market in the 1950s and 1960s is very much a rationalized industry in the 1990s.

By way of background, capacitors, along with resistors, are among the most common form of passive component found in electronic circuits. Capacitors store, filter and regulate electrical entry and current flow. These devices provide instantaneous current to integrated circuits and other active components. Capacitors consist of conducting materials, which are separated by some form of insulating material (dielectric) such as tantalum, ceramic, aluminum, film, paper and mica. The choice of capacitor dielectric is determined by the specific physical and electrical performance characteristics of that dielectric.

Tantalum capacitors and MLCCs, which are found in more new design applications, are generally used with integrated circuits in applications that require low to medium capacitance values. Generally, ceramic capacitors are more cost-effective at lower capacitance values and tantalum capacitors are more cost-effective at medium capacitance values.

The worldwide capacitor market is estimated at $14.6 billion - the largest segments of which include ceramic, aluminum, film, and tantalum capacitors. Essentially commodity items, capacitors are inexpensive, with average unit prices typically well under $0.20.
BREAKDOWN OF ESTIMATED $14.6 BILLION CAPACITOR MARKET

<table>
<thead>
<tr>
<th>Capacitor Type</th>
<th>Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>43%</td>
</tr>
<tr>
<td>Multi-layer Ceramic</td>
<td>20%</td>
</tr>
<tr>
<td>Film</td>
<td>15%</td>
</tr>
<tr>
<td>Single Layer Ceramic</td>
<td>11%</td>
</tr>
<tr>
<td>Tantalum</td>
<td>9%</td>
</tr>
<tr>
<td>Other</td>
<td>2%</td>
</tr>
</tbody>
</table>

COMPETITION (TANTALUM CAPACITORS)

Kemet is believed to be one of the two largest factors in the tantalum capacitor market. Excluding Japan (which is essentially a closed market for domestic manufacturers of passive electronic components), we estimate that Kemet has roughly 35% of the estimated $900 million market for solid tantalum capacitors. This is roughly on par with Vishay, which we believe has approximately 25%-30% of the market (including wet and foil tantalum capacitors). Other large players in the solid tantalum market (outside of Japan) include AVX (estimated at about 18%), which was acquired by Kyocera in 1990, and NEC Corp. (at around 7%).

Kemet is particularly strong in the U.S. market in solid tantalum capacitors, with its share of this estimated $400 million market estimated at around 35%-37%. Vishay, through its Sprague subsidiary, is second in the U.S, followed by the Japanese-based companies. In the European tantalum capacitor market, which is estimated to be around $200 million in size, we believe that Kemet has about 20% of the market, behind Vishay.

LARGEST PLAYERS IN THE WORLDWIDE MARKET FOR SOLID TANTALUM CAPACITORS (ESTIMATED MARKET SIZE $1.3 BILLION)

<table>
<thead>
<tr>
<th>Company</th>
<th>Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kemet</td>
<td>18%</td>
</tr>
<tr>
<td>Vishay</td>
<td>18%</td>
</tr>
<tr>
<td>NEC</td>
<td>14%</td>
</tr>
<tr>
<td>Kyocera/AVX</td>
<td>10%</td>
</tr>
<tr>
<td>Panasonic</td>
<td>9%</td>
</tr>
<tr>
<td>Hitachi</td>
<td>8%</td>
</tr>
<tr>
<td>Matsuo</td>
<td>8%</td>
</tr>
<tr>
<td>Nichicon</td>
<td>8%</td>
</tr>
<tr>
<td>Others</td>
<td>7%</td>
</tr>
</tbody>
</table>
PACKAGING
Capacitors feature two major package designs - traditional leaded devices (which have wire at opposite ends of the capacitor that are mounted through holes on the printed circuit board) and surface-mount capacitors (which are soldered directly and on the PCB without leaded wires).

Surface-mount tantalum chips and MLCCs represent the fastest-growing segments of the capacitor business, having increased at compound annual rates of 20% and 25%, respectively, over the last five years. Surface-mount technology is being used widely in advanced electronic applications because they can be mounted to both sides of a PCB, which is particularly important in the smaller-size boards found in today's smaller electronics products such as laptop computers and cellular phones.

The shift to surface-mount technology is likely to continue to spur demand for tantalum and multi-layer ceramic capacitors. Other type of capacitors-namely, aluminum, film and paper-do not lend themselves to surface-mount technology due to production issues (primarily producing a product capable of withstanding the heat associated with soldering a surface-mount device to a PCB board).

Ceramic and tantalum capacitors are estimated to constitute about 75% of the U.S. capacitor market and roughly 29% of the worldwide market.

WORLDWIDE TANTALUM AND MULTI-LAYER CERAMIC CAPACITOR CONSUMPTION BY REGION

<table>
<thead>
<tr>
<th>Tantalum Capacitors</th>
<th>Multilayer Ceramic Capacitors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Size MKemet Share</td>
</tr>
<tr>
<td>U.S.</td>
<td>402</td>
</tr>
<tr>
<td>Europe</td>
<td>191</td>
</tr>
<tr>
<td>Japan</td>
<td>358</td>
</tr>
<tr>
<td>ROW</td>
<td>303</td>
</tr>
<tr>
<td>Total</td>
<td>1,254</td>
</tr>
</tbody>
</table>

MULTI-LAYER CERAMIC CAPACITORS

The worldwide MLCC market, estimated at about $2.8 billion in 1994, is dominated by Japanese manufacturers, including market-share leader Murata (with an estimated market share of around 32%), Kyocera/AVX (25%), and TDK (19%). Kemet and Vishay (through its acquisition last year of Vitramon) each have around 7% of the worldwide market. Excluding the Japanese market, Kemet's share of the multi-layer ceramic capacitor market stands at around 10%. Kemet's market share in MLCCs in the U.S. is estimated at about 18% versus approximately 8% in Europe and 4% in the rest of the world.
GROWING COMPLEXITY OF ELECTRONIC DEVICES FUELS CAPACITOR DEMAND

Among the key drivers is the growing content of passive electronic components in computers and peripheral devices, telecommunications equipment, and communication device (such as cellular phones, pagers, and fax machines) automobiles, and virtually all sophisticated electronic devices. Worldwide, the electronics industry is in the midst of a major boom that began in mid-1992 and which has been fueled by robust demand for PCs and communications products in the U.S. and the opening of new markets in emerging economies in the Far East and eastern Europe and Latin America. During this time, not only have volumes surged, but integrated circuits have become much more complex. It is the growing complexity of IC design that has helped create the current favorable industry fundamentals for passive electronic components manufacturers.

The number of passive electronic components needed to support integrated circuits has steadily risen in recent years. This is particularly true in the case of capacitors. For every one integrated circuit used today, about four capacitors are required on average, whereas only a few years ago the ratio was under 3:1. Moreover, this ratio appears headed upward over the next several years.

Capacitor content in electronic device continues to increase across the board. For example, the average cellular phone has more than 100 tantalum and multi-layer ceramic capacitors (valued at about $4.00), while automobiles have in excess of 2,000 tantalum capacitors and MLCCs (valued at around $50). PCs are also a clear illustration of the example of this trend, as the migration to more powerful microprocessors has dramatically increased the content for capacitors. A typical 486-based system contains an average 22 MLCCs and four tantalum capacitors. Moreover, demand for Pentium-based systems has ramped faster than many industry analysts envisioned. Indeed, estimates are that roughly half of the estimated 55 million-plus PCs expected to ship in 1995 will be Pentium machines. This would translate to 1.3 billion MLCCs just for Pentium-based machines. MLCC and tantalum capacitor requirements should increase further with the next-generation P6 microprocessor.

The Electrochemical Or “Super-Capacitor”

Electrochemical capacitor is a generic term encompassing all device usually referred to as a double layer capacitor, supercapacitor, ultracapacitor and/or pseudocapacitor. The main features of the electrochemical capacitor are an ability to store several hundred times as much energy on a weight and volume basis as a conventional electrolytic capacitor and a cycle life in excess of 100,000 cycles.

The electrochemical capacitor stores energy through a combination of charging at a solid electrode an electrolyte interface (e.g., double layer capacitance, DL) and Faradaic reactions occurring at or near a solid electrode surface (pseudocapacitance, PSC). Devices based on DL most prominently are based on high surface area carbon electrodes, while PSC devices most frequently involve redox, intercalation or similar reactions.

The electrochemical capacitor can replace a battery in those applications requiring high power
density and discharge rates in the time range of minutes to less than seconds. It can also be used with a battery to reduce peak power demands and thereby extend battery life.

**Key Issues**

There are several key issues which will determine the future of the electrochemical capacitor.

**Technology**

Present research efforts are focusing on the development of cost effective, high energy and high power devices using high surface area carbons, mixed metal oxides, conducting polymers and other interesting materials in aqueous and non-aqueous electrolytes.

Energy densities of 5-10 Wh/kg and power densities of 500 W/kg have been achieved in the laboratory. The technical challenge is to design cost competitive devices with materials which will produce high energy density without sacrificing power performance. This report list the major device and material developers and the technologies they are investigating.

**Markets**

The present electrochemical capacitor products are used primarily for memory back-up power in consumer electronic equipment. The worldwide market for present generation device in 1992 is estimated to have been 130 million units equivalent to a dollar value of $52-78 million. This market is projected to grow 5-7% annually over the next three years. The U.S. sales in 1992 were approximately 3 million units, 4% of the world production, with a value of $3.6 to $5 million. US. unit sales increased 40-50% in 1993 and further rapid growth is anticipated as design engineers become more familiar with the device and new applications develop.

The development of high power, greater energy density, more rapid discharge rate electrochemical capacitors has opened a wide range of possible markets. The following new and expanded potential applications have been identified.

- Hybrid and electric vehicles
- Automotive subsystems
- Medical
- Actuators
- Motor drives
- Utility load leveling
- Robotics
- Military
- Power Supplies

The largest market opportunities are in electric and hybrid vehicles and automotive subsystems. Assuming the anticipated success in achieving present technology goals, the growth rate for the market should increase dramatically over the 1994-2000 time frame. An addressable market volume of approximately $1.35 billion is possible by the end of that time period.

The market outlook is optimistic, but it will take the combination of improved technology, reasonable cost and intensive marketing to achieve these goals.
Competitive Environment

It is too early to tell which companies will dominate the future electrochemical capacitor markets. The competitors will require the technical, marketing and financial resources to pursue the important new applications. The European and U.S. efforts are focused on the electric vehicle application. The U.S. programs are being supported primarily by the DOE as parts of their EV development program, although there are other confidential activities in progress at several important companies.

The Japanese have a broader view recognizing as well the potential for a small, reliable, high power source in a growing world of portable products. The Japanese also have the advantage of a long-standing history in the field and the commitment of major industrial groups.

The strength of the Japanese position is apparent from the patent situation. 78.8% of all issued patents pertaining to the electrochemical capacitor are from Japan as compared to only 8.6% from the U.S. Recent novel technical approaches by U.S. and European groups provide indications of a strong competitive market environment in the future.

Conclusion

The technology and market outlooks for the electrochemical capacitor are optimistic. The competition will likely increase as the scope of the opportunity is more widely recognized. The device stands an excellent chance of fulfilling the initial expectations of its early developers.

THE ELECTROCHEMICAL CAPACITOR

Overview

The electrochemical capacitor is a relatively new energy storage device based on electrochemical principles discovered in the late 1800s. H.I. Becker at General Electric is credited with the first true electrochemical capacitor patent, a double layer capacitor (DLC) in 1957. It wasn't until 1969 that the DLC was introduced commercially with some fanfare by Standard Oil Co. (Ohio) (SOHIO), but it failed to attract any substantial interest in the U.S. SOHIO finally licensed their patents to NEC Corp. in Japan in the late 1970s. The electrochemical capacitor has become Japanese product manufactured by NEC and others since then, being first commercialized in 1978 for low discharge rate applications, typically measured in hours, with capacitances of the order of 0.1 farads at five volts. The major use has been as a substitute for the battery in memory protection circuits for electronic consumer applications. However, as will be discussed in this report, applications for electrochemical capacitors have broadened in recent years.

It has been only in the last five years that the electrochemical capacitor has been “rediscovered” in the U.S. and elsewhere as a potentially valuable power source for a variety of important, high discharge rate uses.
The renewed interest in the electrochemical capacitor has been spurred by:

- **Technology** - Exciting new research directions using higher surface area carbons, mixed metal oxides, conductive polymer electrodes and electrolytes, and other interesting systems.

- **Markets** - A series of new, major applications with significant market potential.

The main attraction of the electrochemical capacitor is its ability to store considerably greater amounts of energy on a weight and volume basis than conventional electrical and electrolytic capacitors. For example, electrochemical capacitors can typically store up to several hundred times as much energy on a weight and volume basis compared to an aluminum electrolytic capacitor.

**APPLICATIONS AND MARKETS**

**Overview**

The vast majority of electrochemical capacitors are sold in the form of small devices used primarily for low discharge rate power backup for CMOS RAM memories. The international market for electrochemical capacitors in 1992 is estimated at approximately 130 million units. The average cost of these devices is in the range of $0.40 to $0.60 each, placing the dollar-value world market at $52-78 million. The market for the present product line is projected to grow 5-7% annually over the next three years.

Almost all these device are manufactured in Japan by companies with a complete line of conventional capacitors. The electrochemical capacitor has been integrated into the overall capacitor product lines of these companies, in contrast to the U.S. where capacitor companies have generally ignored the product.

The U.S. electrochemical capacitor market in 1992 was approximately 3 million units, or about 4% of the world production. Average unit cost was $0.90 to $1.00, equivalent to a value of $3.6 to 5 million. The higher U.S. unit cost compared to the world average probably reflects the present generally lower volume usage in this country. U.S. unit sales have increased 40-50% in 1993. Continued rapid growth is probable as cellular telephones and other new applications develop. It is important to recognize that the total sales are small and that any significant new use will markedly impact the rate of growth.

The largest effort to develop improved electrochemical capacitors exists in Japan. This is reflected by their numerous major development programs, the large number of Japanese electrochemical capacitor related patents and the continued entry of major companies to the field. This interest stems primarily from the fact that not only are most of the device sales presently in the Far East, but also because there may be a greater recognition of the potential role of improved electrochemical capacitor technology in that country.
There is very little private money currently being invested in U.S. electrochemical capacitor development. This situation probably results from the relatively small size of the existing market for presently available devices and the failure of large companies to recognize the broad new application potential of the next-generation devices. The support and impetus is coming from the U.S. government, primarily the DOE. Even then, the total U.S. government expenditure on electrochemical capacitor programs will be less than $5 million in 1994.

The comparatively low level of government financial support may be a result of the present concentration on the development improved battery systems, as illustrated by the program of the US Advanced Battery Consortium (USABC), as much as a lack of understanding and skepticism about the electrochemical capacitor. There are some indications that the U.S. situation may be changing.

Motorola has recently licensed electrochemical capacitor technology based on mixed metal oxides. Since Motorola is not considered to be involved in the EV market, the company's interest in capacitors appears to indicate that they visualize important major applications for the capacitor within its communications product lines.

Westinghouse Naval System Division has entered into a tentative joint venture agreement with Pinnacle Research Institute to manufacture “ultracapacitors” in North America. The joint venture plans to release product by mid-1994.

The attendance lists from the electrochemical capacitor seminars reflect global interest from a number of major companies.

There is one certainty about the electrochemical capacitor market. The Japanese will continue to be active in development of these devices with or without the commercial emergence of the electric vehicle. The present major producers are focusing on consumer and special industrial applications where memory back-up or sudden burst power are required, as well as the EV.

The use of the electrochemical capacitor is growing, but the total dollar volume remains relatively small. New applications will continue to provide increased market opportunities for the small electrochemical capacitor in such areas as auto subsystems, but costs will have to meet the strict requirements of major automobile manufacturers even if regulatory measures (e.g., if the federal government mandated the use of electrically-heated catalysts) establish some of the applications.

The development of successful electrochemical capacitor technology and the actual implementation of proposed new applications over the next several years will determine whether the device remains mainly a Japanese product for consumer applications or will develop into an interesting, high value, energy storage/power source with a greatly expanded market.
Applications for Electrochemical Capacitors

The applications for the electrochemical capacitor fall into four broad categories, although it should be noted that there are often overlaps in application and differing segmentation schemes have been proposed. The applications can be most easily defined in terms of the discharge rate requirements for the application.

- Pulse power applications typically require very short bursts of energy, usually on the order of a few milliseconds or less. These applications are most often military-or SDI-related. Commercial and industrial applications are now developing in what is referred to as pulse applications, though these applications tend to have somewhat longer discharge times than traditional pulse applications.

- Bridge power applications, which are typically less than 5 seconds in pulse duration. The most common uses for capacitors with such discharge characteristics are in smart weapons and automotive subsystems.

- Load leveling applications, where the discharge requirements are in the range of up to about two minutes. Capacitors used in this mode are found in automotive subsystems.

- Standby power applications, which are often referred to as memory backup. In these applications, as distinct from those of the first three categories, the capacitor need only deliver relatively low power. Discharge times are typically hours, with the most common applications being memory protection.

New and Expanded Applications

The development of high power electrochemical capacitors has opened up a whole range of application possibilities. Most of these new applications under consideration and/or under development require the capacitor to operate at relatively high discharge rates (e.g., as compared with the memory back-up capacitors). The following applications were identified in the survey which was carried out in support of this report and through discussions with developers:

- Hybrid and electric vehicles
- Automotive subsystems
- Medical
- Actuators
- Power supplies
- Motor drives
- Utility load leveling
- Robotics
- Pulse power for medical devices
- Portable X-ray machine power
- Bridge power in military systems
- Memory back-up
Competitive Situation

The EV market is attractive worldwide. For example, there are substantial activities in Japan, Europe, Korea and elsewhere. MITI (Japan) has recently suggested a joint U.S.-Europe-Japanese EV development program. Fiat is working with Alsthom Alcatel in Europe. Varta and ABB have a joint EV program in Germany. EV programs are being supported by the government in Korea. As a result, the electrochemical capacitor developers must be aware of efforts everywhere, if they are not to miss this opportunity.

Power Supplies

It is interesting that the application of the electrochemical capacitor to power supplies, the major focus of the early SOHIO activity, may finally come to fruition albeit as a power hold up rather than a filtering component.

The electrochemical capacitor as a backup for short interval power interruption was mentioned in a number of the questionnaire responses. At present both Lambda Electronics and Zytec Corp. are interested in this application.

There appear to be both low (7-60 volts) and high voltage (400 volts) commercial power supply applications. In the low voltage application, the electrochemical capacitor will serve as the output capacitor for AC-DC power supplies and as a 48 volt buss capacitor for DC-DC supplies. Cost is an important consideration. The present approach provides hold up time of 20 ms for a power supply at 400 V at a cost of approximately $3 per 300 watts. The trend is to provide buss hold up with capacitors for a few cycles of power drop (i.e. 20 ms.).

The high voltage application is for an electrochemical capacitor in an uninterruptible power supply. The requirement is for 300-400 volts and power levels up to 1 KW for several seconds with energy storage to several kilojoules at operating temperatures of 0-40°C and storage of -20 to 65°C. Leakage can be high, on the order of 10 ma. The capacitor must be charged at approximately the same rate as it is discharged. This specification cannot be met with present electrochemical capacitor technology, because of the high voltage and energy density requirements.

It is estimated that the low voltage power hold up market can be $10 million within 3-5 years.

The high voltage electrochemical capacitor market is much larger, because of its broad applicability to uninterruptable power supplies. A market of $10 million for the electrochemical capacitor is conceivable, if the device can meet the operating specifications. However, since this application does not appear realistic for the electrochemical capacitor at this time, the dollar estimate for this market is not included in the total market opportunity summary to follow:
Total Market Potential 1994-2000 ($Millions)

| Present Applications | $80  |
| EV/Hybrid Systems   | 350  |
| Automotive Sub-Systems | 895  |
| Medical             | 20   |
| Power Back-up       | 10   |
| Military            | --   |
| **Total**           | **$1,355** |

**Market Development**

The U.S. and European electrochemical capacitor efforts have focused on the EV application. The Japanese have taken a broader view, recognizing the potential for a small reliable power source in a growing world of portable products. The present annual unit sales volume of electrochemical capacitors is small, but there is a large potential opportunity. The challenges are to combine the necessary technical and marketing skills and to marshal the required financial support to develop and market a successful device.

Over the next five years a target market opportunity exists in excess of $1.3 billion annually for the electrochemical capacitor. A large number of interesting applications, particularly in the automotive area, have been discussed. Market estimates are attractive but they refer only to the potential opportunity; but the future is not assured. There are problems that must be solved.

The electrochemical capacitor is either unknown or a curiosity to many system designers, procurement engineers and electronic device manufacturers. This is true even for those, such as the capacitor companies, for which the product might be considered a “natural”. Education of OEM equipment designers is an absolute necessity for the successful marketing of the device.
The Competitive Situation

It is too early to conclude which companies will dominate this field. The Japanese are off to a head start, but significant progress has been made in the U.S. and Europe, all spurred by the EV requirement.

There is an important distinction between the Japanese and U.S. efforts. In Japan the electrochemical capacitor projects are being supported by major electronic companies as well as some battery groups and carbon suppliers. In the U.S. the activity is mostly government supported and even that has been limited compared, for example, with the funds being spent on batteries.

The U.S. activity is dominated by small companies, such as Evans and Pinnacle. Maxwell is the only major capacitor manufacturer currently actively involved in this area. These are activities, or at least interest, at some large companies as can be seen from the attendance list at recent electrochemical capacitor seminars. Development programs at these companies, if any, are often shrouded in secrecy with very little evidence revealed in the patent literature. Even the major auto companies have no obvious major commitment in the field, though they appear to invest relatively freely in new battery technologies.

*Power-One Aerocapacitor Based Products*

[to be completed at a later date when products are identified and proven to meet the needs of the market segments selected]

Tentatively products being considered are:

- Linear Power Supply with improved holdup (comparable to a Switching P.S.) -- Low voltage application
- DC/DC converter output capacitors (low voltage)
- Output bypass capacitors for switching P.S.

*Promotional Activities*

Promotional activities will focus on using Power-One’s core strengths and its infrastructure to capture business. These core strengths are:

- Brand-name recognition and preference
- Distribution Channel
- Quality systems
- Customer Base
- Technical Support
Technical Selling

The promotion will consist of a "technical sell" to the engineering community, as well as a "purchasing" and "management" sell. To promote the technical sell the following are options that will be used, depending on the budgets established:

- Application notes and "white papers" showing the applications, features, and benefits of the Aerocapacitor
- Seminars given to engineers
- Video presentations
- Trade show participation in appropriate electronic venues, such as Wescon and Electro
- Advertising to the engineering community via electronic magazines and editors

Advertising Strategy, Including Media Used:

The advertising strategy is to continue to develop the Power-One brand name recognition and preference. The tactic is to re-enforce the Power-One name in a consistent advertising format. Media used is the electronic magazines that focus on the design engineer, e.g., Electronic Products, Electronic Design, Electronic Design News, and Electronic Engineering Times.

Power-One has been selected as a Preferred Supplier in the Electronic Buyers News in 1993 and 1994. This is a select list of suppliers that have been voted by the readers of the magazine, and is a prestigious award. This is especially a good award, as Power-One spends very little advertising dollars in this purchasing magazine.

The company also uses "card decks" to generate leads. Here, the company buys mail lists and sends out small advertisements.

Selling will be done through existing sales groups, i.e.:

- Manufacturers Representatives
- Direct Sales Force (Regional Mgt)
- Distributors
- A registration program will be created to protect distributors business

Support for customers, Reps, and distributors will be provided through:

- Product Marketing function
- Technical Support/Application Engineering
- Training Programs for Sales Groups
Selling Strategies

*Overview Of Selling Organization And Sales Force*

Power-One's sales network includes five domestic Regional Managers, approximately twenty domestic Manufacturer's Representatives, twenty domestic Distributors, and ten International Distributors. Since over 50% of the revenue is from smaller customers, the distributor channel must be properly trained and motivated by the Regional Manager and Rep organization. This requires a dedicated customer service group, as well as a technical support/application support organization.

While 50% of the revenue comes from the Distributors, the other 50% comes from the larger OEM. The Rep sales force handles these direct customers, with support from the Regional Manager and Product Marketing personnel.

*Strategic Selling*

Selling Strategy to OEM's: The company has developed a strategic selling process, including a company-wide database and forecasting system called IMPACT (Integrated Marketing, Prospects And Customer Tracking). Any opportunity over $25K is tracked and pursued. The strategic selling model is similar to the Miller-Heiman concept. The Reps, who are responsible for most of the direct contact for the major OEM's, are driven to increase sales by offering incentives to surpass their sales budgets. Regional Managers use IMPACT and review with the Reps continually to manage the selling process.

Selling Strategy to Distributors: Power-One is the premier power line for any distributor. Distributors want one power-supply company rather than many, and Power-One with its broad product portfolio offers this capability. In addition, the Reps are paid commission by Power-One for Point of Sales though our distributors. This encourages their support in training and driving sales through distributors. The following are a list of the Power-One distributors:
**Power-One Distributors**
Allied Electronics
Bell Industries
CAM/RPC
Capstone Electronics (Arrow)
Carlton-Bates
CED Baldwin
Classic Components
Deeco Inc.
Digi-Key
Farnell
FLW
Future Electronics
Gerrie Electric Wholesale Ltd
Greene Shaw (Coghlan)
Industrial Automation Supply Inc
Kent Electronics Corporation
Pioneer Electronics
Radar Electric
RS Electronics
Sterling ELectronics
Steven Engineering
Voyager Electronics
Zeller Electronics
ACAL (Europe)
Marubeni (Japan)

International: Prior to 1994, European business was treated as an incremental sales approach. In 1994, some study was made of the current Distributor make-up and business potential. In 1995, we are in the process of revamping the network. Three distributors have already been replaced and a pan-European distributor will be signed by June. This pan-European distributor, ACAL, is an experienced power supply distributor. Additionally, we have started working with Marubeni, a $150 Billion trading company in Japan. They will distribute our product in Japan. Agreements are expected to be finalized in May/June. Already, much training has occurred as well as Marubeni displaying and advertising Power-One in trade shows and trade publications.

The basic strategy for selling is consistency. Power-One provides dedicated people to support this business and does not try to move business from Distribution to OEM. The company consistently offers relatively good margins and good service. Reps and Power-One Regional Managers are also involved in the selling process.
Selling Organization

Power-One has continuously used Manufacturer’s Representatives to sell its products. The Rep organization follows the traditional geographical territory alignment of the Electronic Representative Association (ERA). The number of Representatives has remained constant over the last 5 years. These Reps are managed by the 5 Power-One Regional Managers. The Regions are: Southwest, Northwest, Northeast, Southeast/Midwest, and Central. The Reps are further supported by Customer Service Reps of Power-One. The following are a list of the Power-One Representatives:

**Power-One Representatives**
- B-P Sales Inc
- Datcom Inc
- Eastern Components Sales Inc
- Eltron Technologies Inc
- Electrocraft
- Harvey King, Inc
- M. Gottlieb Associates Inc
- Midwest Technical Sale Inc
- M-Squared Inc
- Nycom Inc
- Pacific Marketing Specialists
- Parsons Technical Marketing
- Phase II
- Quorum 3
- Rathsburg Associates Inc
- Shepard & Associates
- Stan Clothier Company
- System Sales of Arizona
- Varigon Inc
- Victory Sales Inc
- Weiss Company Ltd.
Power-One's Strength, Weaknesses, Opportunities and Threats (SWOT)

<table>
<thead>
<tr>
<th>Unique Strengths</th>
<th>Weaknesses</th>
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<tbody>
<tr>
<td>Distribution Channel</td>
<td>High dependency on key personnel</td>
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<tr>
<td>Application Engineering/Service</td>
<td>Inability to purchase materials at low cost (Asian price) for high volume applications</td>
</tr>
<tr>
<td>Financial Stability</td>
<td>Higher G &amp; A than Asia Pacific competition (G &amp; A as a percentage of gross margin)</td>
</tr>
<tr>
<td>Quality - (ISO Certifications at all facilities (Only 7% of US mid-size manufacturers ISO certified) - Need to exploit this.</td>
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<tr>
<td>Broad product line</td>
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<tr>
<td>Team approach to problem solving</td>
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</table>

External Environment (Competitors)

<table>
<thead>
<tr>
<th>General Strengths</th>
<th>General Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Resources for large competitors</td>
<td>Industry standards are limited</td>
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<tr>
<td>Strategic Alliances between established partners</td>
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<tr>
<td>Asian Presence</td>
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<tr>
<td>- Labor/material/Eng/Mfg Capabilities/automation</td>
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<tr>
<td>Technology</td>
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Opportunities and Threats

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<tr>
<th>Opportunities</th>
<th>Threats</th>
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<tr>
<td>Expand product offerings through Distribution</td>
<td>Competitors broadening product lines</td>
</tr>
<tr>
<td>Expand volume niches - lower cost</td>
<td>Competitor Consolidation</td>
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<tr>
<td>Geographical expansion</td>
<td>Technology/Packaging</td>
</tr>
<tr>
<td>New markets</td>
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Product Requirements and Issues:

[TBD]
Financial Overview (Product Income Statement)

[to be completed when the following are identified:]

- Products are finalized, complete with all specifications
- Costs are provided (manufacturing, price breaks by quantity, distribution mark-ups)
- Average Selling Price (market price for similar units)

Manufacturing

[TBD]

Production Requirements and Scheduling

[TBD]

Product Technologies

[TBD]
Supercapacitor Competitors
Manufacturers and Major R&D Groups

The following provides a brief summary comment about some of the major electrochemical capacitor device and material researchers and developers. This listing is not inclusive of all R&D activities presently in progress in the world.

The material in this report has been taken from a variety of sources. It is not meant to be all inclusive, but rather to demonstrate the current state of the art based on recent published available information.

Japan

Asahi Glass Co. Ltd/ELNA - Yokohama, Japan (U.S. Sales office - Cypress, CA)

The company sells its product in the U.S. through ELNA. The emphasis of their efforts appear to be on improved carbon and organic electrolytes.

A complete catalog of the ELNA electrochemical capacitor product line is available.

Isuzu Motors - Japan (U.S. office - CA)

The company publicly entered the electrochemical capacitor field several years ago with the announcement of a joint activity with Fuji Electrochemical to develop an electrochemical capacitor for automotive and EV applications. Despite being a relative newcomer to the field, the company has the second largest number of electrochemical capacitor patents in the world.

The Isuzu objective is to use an electrochemical capacitor in an environmentally safe power system for the next generation of vehicles. The company has openly discussed the use of the electrochemical capacitor for ignition starting and regenerative braking as well as hybrid and electric vehicles.

Japan Storage Battery - Japan -

The company is known to have an electrochemical capacitor activity, but no details of their activities have been published to date. There is one reference in the patent section.

Kuraray - Japan

The company makes carbon for electrochemical capacitors. They have several patents in the field.
Matsushita Electric Industrial Co. - Japan (U.S. Sales office - Panasonic Industrial Co., Secaucus, NJ)

Matsushita has manufactured electrochemical capacitors since 1978 and sells them for use in VCRs, cameras, appliances, battery-less watches, actuators and similar applications. Initially the company made only coin size products, but in recent years larger, wound electrochemical capacitors have been developed. They have an active electrochemical capacitor development program based on improved activated carbon electrodes, organic electrolytes and wound structures. The company has developed 500 F and 1500 F devices, both being studied by the DOE for EV use. The 500 F device is available commercially and the company is finalizing its specification on the 1500 F capacitor.

Matsushita has had more electrochemical capacitor related patents issued than any other company in the world. A complete catalog of the Matsushita electrochemical capacitor product line is available from Panasonic.

Murata - Japan

The company has discontinued its electrochemical capacitor product line after many years in the business. The company has extensive patents in the field.

NEC Corp., - Tokyo, Japan (U.S. - NEC Corp., Mountain View, CA)

NEC licensed the SOHIO patents and has been manufacturing electrochemical capacitors since 1978. The company distributes its products in the U.S. through its California office and by private label through Ceswid, Inc. (formerly Carborundum). The development emphasis has been on activated carbon, aqueous electrolytes, and general programs to improve performance.

NEC has recently developed a carbon, carbon composite electrochemical capacitor that has one of the highest energy densities reported to date. Recent advances in the structure of their electrodes improving electrolyte access makes the frequency response of their 150F, 5.5 volt capacitor comparable to other large electrochemical capacitors.

NEC is one of the leaders in the number of patents issued in this field. A complete catalog of the NEC electrochemical capacitor product line is available.

Osaka Gas - Japan

The company makes activated carbons in a number of forms for the electrochemical capacitor. Some of their product is being distributed in the U.S. by Spectracorp.

Seiko Instruments - Japan - (U.S. Sales office - CA)

The company is offering small polyacene based capacitors for sales. There is no indication that they are working in the EV area.
Yamaguchi University - Japan

This university group has been active in the electrochemical capacitor materials development area for some time. They are pursuing complex solid polymer electrolytes of polyethylene oxide grafted methyl methacrylate or poly acrylonitrile with carbon electrodes. These device have given 0.6F/cm² or 20 F/g and good cyclability.

North America

Alupower - Toronto, Ontario, Canada

The company is owned by Alcan Aluminum Ltd. The company has been involved in the development and commercialization of Al/air and Al/oxygen batteries for a variety of applications including the EV (as a range extended). They have a part ownership in Unique Mobility, a company which is involved in the development of advanced electric propulsion systems.

Alupower has developed a “low cost” electrochemical capacitor using both aqueous and non-aqueous electrolytes for EV use. They have built a 12 volt prototype for hybrid use with a lead acid battery and have plans for a 108 volt module.

Cesiwid, Inc., - Niagara Falls, NY

Cesiwid, Inc., a German company, has purchased the component division of The Carborundum Co. The latter has been marketing private branded NEC electrochemical capacitors. They will continue the capacitor operation and maybe even become more aggressive in the field. A complete catalog of the Carborundum electrochemical capacitor product line is available.

Econd International - Houston, TX

This company is the U.S. distributor for “Econd-Souz”, the Moscow based Russian company. The company has been working in the field for 8-10 years with the initial activity being to assist in the starting of diesel engines in mobile missile systems for the Russian military. The product is designed to delivery pulse power over short periods of time. The devices are being manufactured in Russia and imported to the U.S. Their principal activities are in automotive subsystems and medical applications, i.e. portable X-ray and secondary backup power for hospitals. The Russian company is already selling their devices to the Russian railroad systems for diesel locomotive starting.

EG&G, Idaho/Idaho National Engineering Lab - Idaho Falls, ID

This laboratory is doing the testing and evaluation of electrochemical capacitors for the DOE, and monitoring the DOE electrochemical capacitor development contracts. INEL has been a leader in the promotion of the electrochemical capacitor for EV and Hybrid applications.
Eglin Air Force Base, WL/MNMF - Eglin AF Base, FL

Eglin Air Force Base has supported a joint effort with Illinois State University to study high surface area polypyrrole electrodes for use in the electrochemical capacitor. In addition, Eglin has issued an SBIR request for further studies of high surface and polymer electrodes for application including the electrochemical capacitor.

The Electronic and Power Sources Directorate, Army Research Lab - Ft. Monmouth, NJ

The Army has monitored the development of electrochemical capacitors, but has spent little R&D money in the field. Their present interest is related to the potential for use by the Tank Command for electric vehicle drives.

Emtech - Toronto, Ontario, Canada

This group has the rights to certain Ukranian electrochemical capacitor technology. It is believed that they plan to license the technology to others. Little is known at this time about the performance of their electrochemical capacitor.

The Evans Co. - Providence, RI

The company manufactures the "Capattery", the only commercially available carbon based electrochemical capacitor presently being manufactured in the U.S. They specialize in high reliability, hermetically sealed, custom electrochemical capacitors for military and space application. More than two million part-test house have been obtained in the laboratory and in the field with some Capattery models without a single failure.

The company recently demonstrated a 120 V electrochemical capacitor, which stored 35 kilojoules of energy. This device is probably the world's largest electrochemical capacitor. Test results at up to 20 kW discharge power have been reported for their prototypes.

A complete catalog of the Evans Capattery product is available.

Federated Fabrics - Andover, MA

The company supplies activated carbon fibers, fabrics and net shaped electrodes in which the pore size is tailored to the electrolyte. R&D efforts are focused on increasing the capacitance of activated carbon fibers and fabrics. They have provided sample material to Maxwell Laboratories.
General Electric - Schenectady, NY

The company has been doing development work under a DOE contract to develop advanced driveline electronics for the EV. The goal is to have available full scale hardware in 1995 for use with the Ecostar driveline.

G.E. has expressed an interest in the use of electrochemical capacitors as “electrical flywheels” for electric and hybrid vehicles. If the technology is successful, G.E. Capacitor and Power Protection group could conceivably manufacture and market the devices.

Giner, Inc. - Waltham, MA

This is a contract R&D group which has done extensive work for the government. They have used solid electrolytes with both carbon and mixed metal oxide devices. They have reported mixed metals oxide capacitance of 400 F/g.

JME, Inc. - Shaker Heights, OH

JME is a small consulting firm that specializes in electrochemical capacitor development, evaluation and system engineering. JME has worked with many different device manufacturers, material suppliers an capacitor users. Recently, JME was commissioned by DOE to develop the test procedures needed to evaluate the performance of high power electrochemical capacitors presently being developed for the EV application.

Johnson Controls, Inc. - Milwaukee, WI

The company is investigating the application of electrochemical capacitors to cold starting, electrically heated catalytic converters and the electric vehicle. No recent public information has been made available about the status of their activity.

Lawrence Livermore National Laboratory - Livermore, CA

This group has been developing the carbon aerogel foam material for use in electrochemical capacitors. This material shows considerable promise. ARPA has recently granted LLNL a $1.9 million contract of which some part will be spent to pursue the further development and study of the aerogel type electrochemical capacitor.

Maccor, Inc. - Tulsa, OK

This company provides the only commercially available capacitor charge/discharge test equipment.
Maxwell, Corp - San Diego, CA

Maxwell is a manufacturer of a standard line of capacitors. The company is developing an improved carbon based electrochemical capacitor for EV applications under a five year $2.5 million per year contract with the DOE. The work is being carried out in conjunction with Auburn University. The company has been a capacitor manufacturer for many years, but only recently became involved in electrochemical capacitor activities.

Motorola - Ft. Lauderdale, FL

The company has licensed the electrochemical capacitor technology covered by the Dwight Craig patent issued in Germany. The purpose and goal of the Motorola activity are not known. However, it is possible that they are developing a power source for mobile communications, i.e., pulse signal transmission to satellites for phones. This application requires a high pulse power source such as an electrical capacitor. The plausible applications could include an electrochemical capacitor combined with a battery.

Mound Laboratories - Miami, OH

This group is making activated carbon foam material for Sandia.

NASA Jet Propulsion Laboratory - Pasadena, CA

NASA recently released information regarding a pyrrole-based conductive polymer electrochemical capacitor. NASA does not have a continuing program and is seeking to license the technology.

Pinnacle Research Institute - Cupertino, CA

Pinnacle Research Institute was formed on dissolution of the electrochemical capacitor group at The Continental Group. The latter carried out extensive development work on mixed metal oxide electrochemical capacitors.

Pinnacle has been the most successful group in obtaining government contracts. Much of the information about their work may have been classified, since limited papers were found in the open literature. There are no electrochemical capacitor patents issued in the name of either Pinnacle Research or Continental Group.

Support for this activity has come primarily from the Department of Defense (DOD) and Defense Advanced Research Agency (DARPA) and is estimated to be about $13 million since the inception of the work. The DOE has also been negotiating an EV electrochemical capacitor contract with Pinnacle. Initially directed to SDI applications, the effort is now more closely focused on medical, hybrid and electric vehicles, electrically heated catalyst and the potential commercial applications.

As noted earlier, Westinghouse Naval System Division has entered into a tentative joint venture agreement with Pinnacle Research Institute to manufacture “ultracapacitors” in North America. The Joint venture plans to release product by mid-1994.
Sandia National Laboratory - Albuquerque, NM

This group has been working on microcellular carbon foam materials with an emphasis on surface modification. The activity has shown promising results.

Spectracorp Ltd. - Lawrence, MA

This company does R&D and supplies carbonaceous materials for electrochemical capacitors and fuel cells. The products include porous carbon/carbon materials and activated carbon fibers and beads. The materials are being evaluated by electrochemical capacitor groups around the world.

Technautics - Cleveland, OH

This company is offering the all-solid Hypercap electrochemical capacitor based on old rubidium silver oxide technology. A complete catalog of the Hypercap product line is available.

University of Ottawa (Professor Brian Conway) - Ottawa, Ontario, Canada

Professor Conway has been involved in electrochemical capacitor R&D since 1975. At that time he was working with The Continental Group, Inc. whose mixed metal oxide technology was eventually taken over by Pinnacle Research Institute. Professor Conway continues to be one of the leading R&D workers in the field.

Westinghouse - Pittsburgh, PA

See Pinnacle.

Westvaco Corp. (Carbon Department) - Covington, VA

This large carbon manufacturer is developing high surface area active carbons for electrochemical capacitors. No other details are publicly available about their activities.

Europe

Alcatel Alsthom - France

The company has been developing an electrochemical capacitor for the EV in cooperation with their battery company, SAFT, Innovision (Denmark) and Fiat (Italy).

Dornier GMBH - Friedrichshafen, Germany

The company has been developing electrochemical capacitors for space applications, such as power supplies for pulse power and computer memory back up. Both mixed metal oxides in acid electrolyte and nickel electrodes in an alkaline electrolyte have been used.
Russia

Econd-Souz - Moscow

See Econd Intl., - Houston, TX

ELIT Stock Co. - Kursk, Russia

The company, formerly MP “Pulsar”, is offering product similar to that of Econd Souz. A complete catalog of the ELIT Stock product line is available.