Thin-Film Batteries: Current and Future Markets 2009-2016

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Executive Summary

E.1 Introduction

New electronic products that are small, portable, flexible and "smart" are emerging for applications that range from entertainment to retail automation to military devices. These products may be displays, RFID tags, medical devices, sensors or a variety of other kinds of devices. They have little in common except the need for a power source—typically one that is inexpensive (because price points of the devices themselves may be critical) and long lasting, and in accordance with the product itself, (possibly) flexible with a small footprint.

Today, many of the products listed above are powered with conventional batteries—AAA, button/coin cells, etc. These batteries are very inexpensive as they are manufactured in hundreds of millions, and are relatively long lasting. There are, however, limits to what can be achieved with these conventional power sources. In particular, the footprint and flexibility issues are challenging. A triple-A battery cannot be bent or put in a wallet. This suggests a need for "thin" batteries that are better matched to the need of the latest thin-film and printable electronics products.

More than aesthetic design is involved here. In some cases—powered smartcards are an example—battery "thinness" is so critical to the success of the product that "thin" batteries can be seen as a key enabling technology. Flexibility may have a similar importance in the case of certain products and the fact that "thin" batteries can be created in various sizes and shapes makes them well suited to the paper and plastic film substrates that this new type of electronics will use. As we discuss throughout this report, however, the problem for all types of thin batteries is cost; it is hard to compete with products such as button cells that are manufactured in such huge volumes.

There is also the question of what we really mean when we talk about "thin" batteries. What is included in this category? In its reports, NanoMarkets has made a fundamental distinction between "printable batteries" and "thin-film" batteries. Typically, printable batteries have printed electrodes and a liquid electrolyte. Their selling proposition is that where the products being powered use a substantial amount of printing (or at least could) in their manufacture, cost can be reduced by creating a complete product in an integrated functional printing plant. It is also hoped that the relatively low cost of printing machinery may help reduce the cost of thin batteries. These propositions certainly sound plausible but have yet to be proven.

NanoMarkets has analyzed the market specifically for printed batteries in another report ("*Printable Battery Markets: 2009 and Beyond"*). This report deals with "thin-film" batteries. Purists define "thin film" in rather specific terms, namely that thin-film batteries are those based on technology developed at Oak Ridge National Laboratory (ORNL). ORNL's technology specifically defines a thin-film battery as a lithium cell with a thickness no greater than 6 microns that is fabricated by depositing successive layers of the cathode, electrolyte, and anode using direct-current and radiofrequency magnetron

sputtering and thermal evaporation. Instead, our category of thin-film batteries is broader, and includes the ORNL technology-based batteries, but also other batteries with similar characteristics. Thin-film batteries—in the sense that we talk about them here—are typically solid-state giving them the potential of being just another layer in a product created from layered thin films. Associated with this solid-state quality is typically a very good performance with regard to health and safety issues.

E.2 Summary and Comparison of Thin-Film Battery Chemistries

Most of the solid-state, thin-film batteries available today use lithium chemistry. Lithium batteries have the ability to withstand high temperatures, which could be useful in certain manufacturing environments, such as when batteries are used with smartcards that have to endure a high-temperature lamination process. Variations of the lithium chemistry used for thin-film batteries are shown in Exhibit E-1.

Exhibit E-1
Thin-Film Lithium Battery Constructions

	Anode	Cathode	Electrolyte
Lithium Manganese Dioxide	Lithium metal	Manganese dioxide	Organic
Lithium phosphorus oxynitride	Lithium metal	Lithium cobalt oxide ($LiCoO_2$)	Lithium phosphorus oxynitride ceramic
Lithium Thionyl Chloride	Lithium metal	Porous carbon filled with liquid thionyl chloride	Porous carbon filled with liquid thionyl chloride acts as cathode and electrolyte
Lithium Oxygen	Lithium (typically w/ another metal)	Atmospheric oxygen	

Several thin-film battery firms are using the chemistry developed at ORNL—a lithium anode, lithium oxide cathode and lithium phosphorous oxynitride polymer (LiPON) for the electrolyte. The elements are then fabricated onto a variety of substrates including ceramics, semiconductors, metal foils and plastics. One drawback to this technology is that it relies on sputtering and thermal evaporation, which is complex, expensive, and difficult to scale to high volumes. Companies using this technology include Cymbet, Excellatron, Front Edge Technology, Infinite Power Solutions, and Oak Ridge Micro-Energy.

A different approach, one that is being taken by Solicore, is the use of lithium as the anode, manganese dioxide as the cathode, and a polymer matrix electrolyte (PME). The company claims that its proprietary PME enables the battery to perform like a liquid-based battery but without the safety concerns. For this battery technology, Solicore does not use the sputtering and evaporation as do those companies that rely on the ORNL technology. Instead, Solicore uses a coating process, which gives high yields and can be scaled up to high volumes.

E.3 Summary of Main Opportunities in the Thin-Film Batteries Market

The great leap forward since NanoMarkets published its first report in this area in 2007, is that thin-film battery firms have actually started to ship products. Many are still sampling, but a few firms actually have real products that they can now ship:

- Solicore announced that it has produced over 1 million batteries in the first quarter of 2009.
- Cymbet's thin-film battery technology, which is sold under the name of EnerChip, became commercially available in the fall of 2007.
- Infinite Power started to serve its customers at the end of 2008 from a new 36,000 square-foot-facility, which it says is the world's first, and only, volume manufacturing facility for solid-state thin-film batteries.
- ORME says it has manufactured its batteries in limited quantities and has produced samples for potential customers. It also says that it is seeking a relationship with a third party manufacturing partner that will be able to scale up ORME's manufacturing process and produce large numbers of batteries for high-volume markets

E.3.1 Strategic Options: Performance, Niches and Manufacturing

Obviously, this kind of news provides credibility for thin-film batteries and suggests the possibility of economies of scale soon to come. However, NanoMarkets does not believe thin-film batteries, in their current form, are likely to reach price points where they can compete head to head with coin batteries. In any case, most manufacturers of these batteries would not want to compete on price—small firms, which most of them are, seldom can succeed with price.

Each company has its own approach. One strategy is to just improve on performance measures in an incremental and evolutionary way—longer lifetimes, or longer times between charging, for example. This is a strategy for creating a premium product that will not be significantly impacted by price sensibilities.

Another approach is to (as it were) take the high road and create batteries that are intended for high-value applications, where price is not the major issue, or at least competing with button batteries is not the major issue. What this tends to mean in practice are batteries aimed at the medical or military market. This may entail the use of novel technologies; Biophan Technologies, a medical device company, is developing a long-life power source based on biothermal power for use in implants. Firms following this strategy have generally moved themselves well away from the part of the market where they have to compete with button batteries or on price. (The important counterexample here is in the hearing-aid sector.) But inevitably in adopting this strategy, thin-film battery firms have moved into niche markets where volumes will always be quite low.

Yet another strategy adopted by thin-film makers is to look to innovative manufacturing techniques as a way of distinguishing themselves in the marketplace. In a sense, printable batteries are a special case of using this strategy. However, more within the scope of this report, we note that Solicore has emphasized the proprietariness of its approach to manufacturing thin-film batteries and that Cymbet's batteries are manufactured using a cold method, which enables films to be deposited at 100°C rather than the 700°C used in the original ORNL process. Lower temperatures would enable the use of a greater variety of substrates, particularly flexible substrates. Meanwhile, NanoEner has developed a proprietary technology for the production of nanostructured thin and thick coatings. The company's proprietary process, called Vapor Deposition Solidification (VDS), offers the advantages of traditional vacuum, plasma and laser technologies in controlling film structure at the atomic level while providing for "outstanding" rate of evaporation and deposition up to 1,000 times higher than existing methods, according to the company. Yet another strategic direction that is based on novel manufacturing/materials platforms is Enable IPC's nanostructuring of the cathode for its battery.

E.3.2 Strategic Options: New Applications Markets

Most of the Web sites of thin-film battery makers are full of potential applications for which their batteries *could* be used. However, we have the sense that most of these firms are simply listing all the applications they can think of rather than telling us where they really see the opportunities for their particular battery technologies. In most cases, thin battery firms will take a completely pragmatic approach once they can manufacture in volume, focusing on a shotgun sales approach and taking whatever orders come their way.

This seems a reasonable approach. But it should also be seen in a broader context. Many of these battery firms were formed with the idea that there would be plenty of opportunities for them in the near future in the RFID space and this is not really how things have turned out. As so often happens with a new technology, it has proved more difficult and costly to implement RFID and the need for specifically thin batteries from this sector is not yet entirely clear. In addition, to the extent that RFID adopts new battery technology there may be more attraction to the printable batteries than to the thin-film batteries discussed in this report; the reason being that RFID tags are probably going to have to be printed to make them cost effective in a world in which barcodes are the "product" that RFID plans to replace. All the issues surrounding the use of thin-film batteries in the RFID space have only become more acute since the worldwide financial meltdown in the fall of 2008.

Given these trends, thin-film battery makers have been in search of better opportunities. NanoMarkets believes they will ultimately find them—or are already finding them—in two applications markets: sensors and smartcards. Our projections of the market opportunities for thin-film batteries suggest that as much as 60 percent of the sales of thin-film batteries during the eight-year forecast period considered here will come from these two applications.

As we have already mentioned, powered smartcards are a natural application for thin batteries; anything else makes the cards too bulky to fit into a pocket. A lot of printing goes into making a

smartcard so there may be a tendency to choose a printable battery for these products. On the other hand, the thin-film batteries discussed in this report may be better able to withstand the high temperature lamination that goes into making these cards.

The sensor application is more interesting, or at least more complex. The sensor industry is very fragmented in terms of end users, technologies and product type; however, we expect this industry to rapidly expand in response to a number of key socioeconomic drivers such as an aging population in the developed world (medical diagnostic sensors), environmental concerns (sensors for environmental monitoring), and security concerns (biohazard and gas sensors). Many of the most prominent of the trends and applications seem to call out for highly distributed sensors, which can be created in the form of wireless sensor networks or sensors fabricated on large-area, flexible substrates. In many cases, these distributed sensors cannot be powered from the grid and must be run from batteries.

This new kind of sensor could in many cases be powered by a completely conventional battery, as the key performance requirement for battery-driven sensors is likely to be longevity rather than small footprint. However, there will certainly be instances where footprint will matter and thin, flexible batteries seem like an obvious fit with thin, flexible sensor arrays. In addition, a new role is emerging for batteries in the sensor market. In this conception, the sensor or sensor array is powered by energy harvesting or PV (which is really a form of energy harvesting). These energy sources are never used up, but vary considerably over time; adding batteries as a buffer can help smooth out the energy supply. Several thin-film battery firms see this kind of application specifically as an opportunity. For example, at the time of writing, Cymbet had just introduced its EnerChip EH CBC5300 Energy Harvesting Module. This module is used with small photovoltaic cells from Konarka to power devices using ambient solar energy harvesting. Several years ago, Front Edge Technology entered into a joint-venture agreement with Advanced Power Solutions to develop an energy/battery source that combined APSI's thermo-electro generator with FET's thin-film battery technology. It is also possible to imagine thin-film batteries being used in conjunction with piezoelectric or inductive energy generation.

Yet another sensor opportunity may emerge as the result of the high thermal resilience of certain thin-film batteries. Thus, Oak Ridge Micro-Energy (ORME) has already developed a prototype for a high temperature, thin-film battery that could be used for down-hole drilling sensors and other sensor applications that operate in harsh environments, and as back-up of high temperature non-volatile memory and semiconductor diagnostic wafers.

Medical devices are also the target of some of the thin-film and printable battery makers, the latter are targeting smart bandages and cosmetic/pharmaceutical patches, which is something close to a smart fabric application in which printing might be expected to play an important role. The part of the medical market where the makers of the thin-film batteries considered in this report seem to be focusing their efforts is on the implant market. For example, in its financials, Biophan specifically says that one objective of its majority-owned subsidiary TE-Bio is to "reduce or eliminate the need to

remove pacemakers or other implants simply to replace their aging batteries." It is also easy to see that a battery with a small footprint would be an advantage for an implant; small implants are good implants. The good news here is that the medical implant market is relatively price insensitive and has strong growth potential, given both the aging populations in industrial countries and the growth in implantable medical technologies. A very long-lived battery would have key advantages in this context, since it may be a way to reduce surgeries—an obviously desirable goal. The bad news here is that the implant market is relatively small. By far the largest part of the market is the hearing-aid segment, which accounts for about five or six million units each year. At (say) 30 cents per battery, this is not much of a market.

Even though we think a lot of the opportunities for thin-film batteries are going to be found in the sensor and smartcard sectors, NanoMarkets does not think there is going to be one "killer app" for this technology. Some revenues can be expected from a wide range of applications. These include all the areas mentioned above and more: RFID, smart packaging, medical and cosmetic devices, and batteries for real-time clocks and SRAMs in computers.

E.4 Firms to Watch in the Thin-Film Battery Business

In this report, we profile the following thin-film battery firms: Biophan, Cymbet, Enable IPC, Excellatron, Front Edge Technology, Infinite Power Solutions, ITN, NanoEner, NEC, Oak Ridge Micro-Energy, Planar Energy Devices, Solicore and Ultralife. We also provide brief profiles of the printable battery firms. NanoMarkets believes that the firms profiled here are a fairly complete list, although there may be other firms operating in this space under the radar.

E.4.1 Where the Money is Coming From

While there is a strong business case for thin-film batteries, at least in certain areas, it is not completely clear yet where the money is coming from to fund this case. Many of the companies, including some that apparently have very big plans for the future, don't appear to have the money to make those plans happen. In addition, one obvious source of funding for this technology—large battery firms—seems to have little interest in thin-film batteries at the present time, but this could change.

For the time being, most of the private investments in thin-film battery firms seems to be in small amounts from second-tier VCs; a few million here, a few million there seems typical. There are a few big name firms that have some strategic involvement in this business, but usually (once again) the involvement is very small and it is sometimes fairly indirect. Thus, the (Israeli) Millennium Materials Fund has a small stake in Cymbet and this fund has money from Siemens, Bayer and Schott Glass, among others. Dow and Intel are also involved in this company through their VC arms.

But there are few other firms in the thin-film battery business that can claim such an impressive line up of investors. And in the current economic climate, it will not be easy to get new money for this area, unless the whole sector can be linked with "clean technology" in investors' minds or if some thin-

film battery company gains notoriety for a new application or (better still) a large contract with a major customer. Even the small public companies in this space do not seem to be doing terribly well. Enable IPC, for example, was recently downgraded to a "Pink Sheets" company.

Another source of funding for thin-film battery companies is government grants, but these are intended primarily for R&D. Thus, Excellatron has received a $1.44-million grant from the Advanced Technology Program (ATP) of the National Institute of Standards and Technology (NIST) to develop a high-rate deposition technology. But such grants are not intended to enable the firms to move to the productization stage. The industry is, apparently, not without its hopes for future funding. For example, Planar Energy Devices says that it will seek $20 million in funding in 2010 to scale its manufacturing facilities and then do an IPO in 2012. However, it is obviously impossible to be sure that such ambitions will succeed, especially given the poor economic climate. In the absence of a sudden appearance of substantial funding, the firms that need to be watched for leaps forward in this market from a commercial perspective are those few that have raised substantial capital in the recent past.

If we exclude Power Paper, which is a printable battery firm and which is discussed more fully in NanoMarkets' report on that topic, there are really only two companies that could be said to fit into the well funded category: Infinite Power Solutions and Solicore. Infinite Power Solutions has received funding of almost $50 million in the last three years, and has used much of that money to build substantial manufacturing facilities. In addition, the company is known to be shipping devices to Lockheed Martin—probably not a potential high-volume customer but a good start and one that establishes credibility. Meanwhile, Solicore has also raised substantial amounts of funding. This firm has long standing ties to Air Products and (arguably more importantly) it has real customers. In particular, about 18 months ago, Solicore entered into a multi-year, multi-million unit purchase agreement with Innovative Card Technologies.

Many—most, really—of the other companies in the thin-film battery space are nowhere near commercialization. The companies using technology developed at ORNL, for example, have a great chemistry, which results in a high-performing battery, but there's no proof that their technologies can scale up to commercial volumes. It's like the world's best mousetrap that no one can build. These companies will need to prove commercial viability by demonstrating the ability to scale up these complex, expensive manufacturing processes.

E.4.2 Partnerships and Alliances

Many of the thin-film battery producers have entered into partnerships to accelerate the use of their batteries in commercial products. Typical partners include: display makers, companies that supply digital security, such as smartcards and e-passports, smart packaging producers, and others that are involved in applications that these thin-film battery producers are targeting. In addition, several of the thin-film battery firms are working with government agencies, including the Army, Navy, DARPA and NIH.

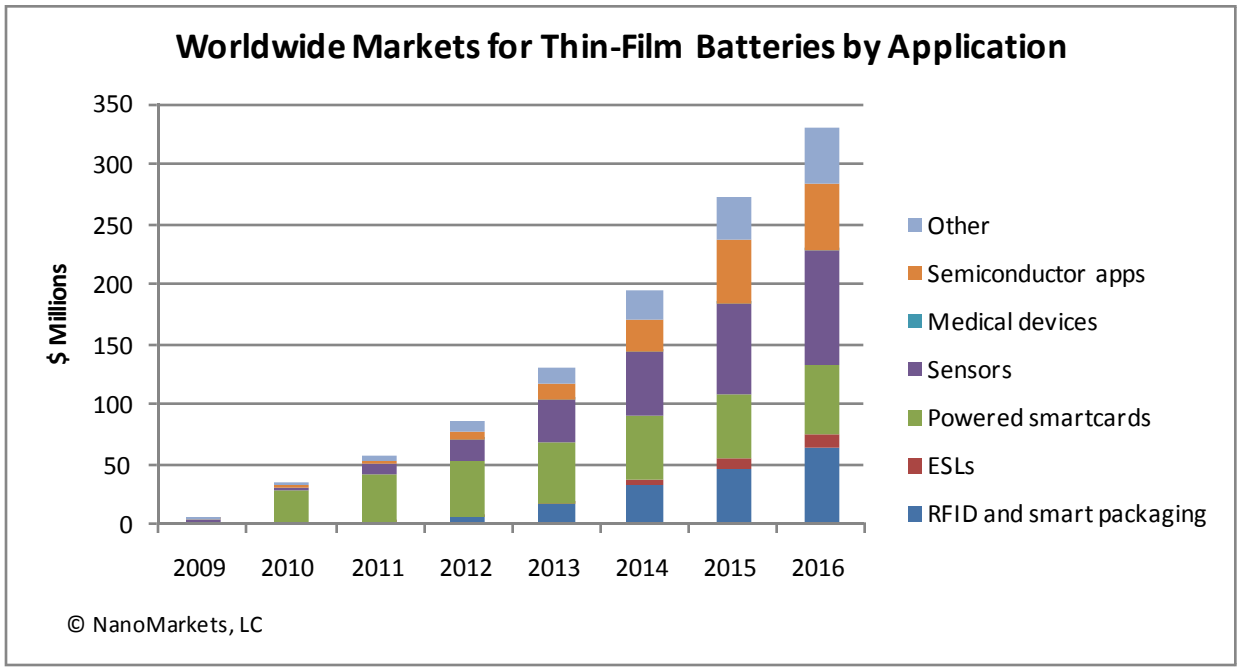
Enable IPC, for example, is working with a major credit card manufacturing company to integrate its battery technology into a smartcard. In addition, Enable IPC is working with another company to integrate its battery technology into sensors for truck tires.

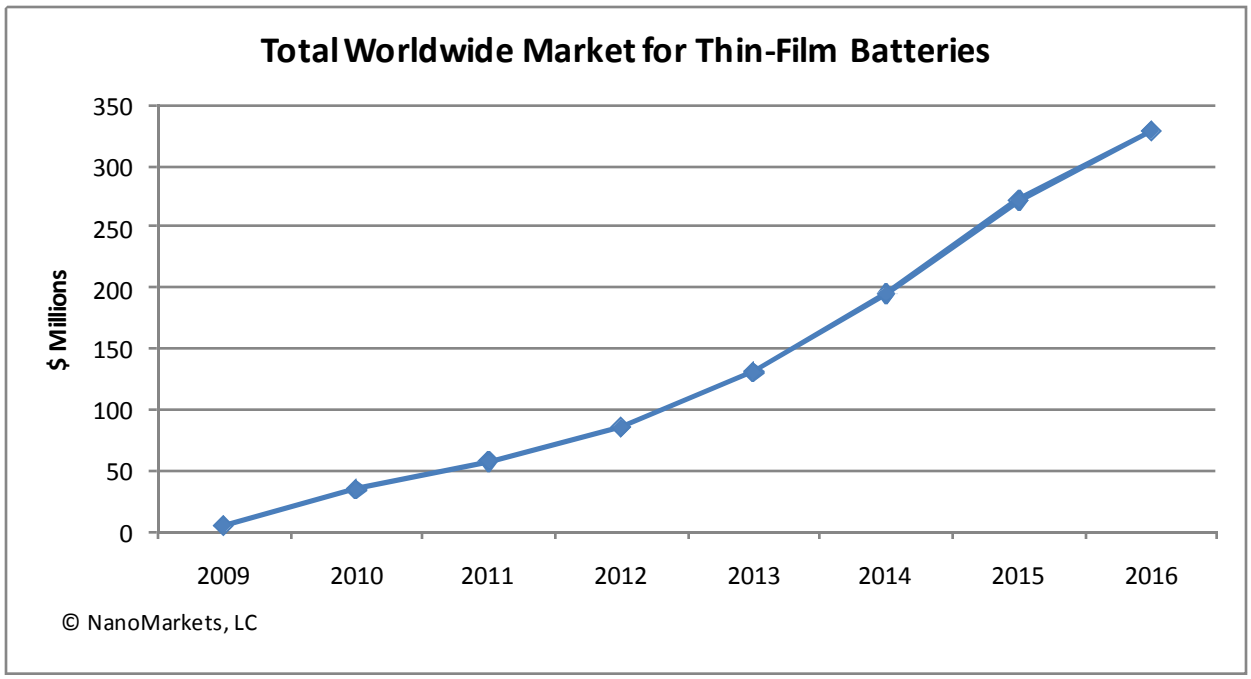
Infinite Power has several partners in the electronics industry. These include an unnamed integrated circuit producer, a partner in the printed circuit board space, and (as we have already mentioned) Lockheed Martin. The company's collaboration with Lockheed was initiated in October 2008 to apply Infinite Power's battery technology to military and civil applications that Lockheed is developing. This collaboration is targeting low-power, wireless sensor applications.

Solicore has announced several partnerships over the past few years, most of which are with product distributors. These include strategic partnerships with Japanese distributors of smartcards, including Asia Industry Development (AID) and Tomoe Engineering Co. Ltd.; HierStar, a leading Chinese contract manufacturer, to provide Solicore's Flexion battery for use in display card applications such as one-time password (OTP) cards; Semicom-Lexis Ltd for the exclusive distribution of Solicore's Flexion batteries in Israel; and Ineltro AG, a leading Swiss distributor of electronic components, power solutions and embedded computers, to supply Solicore's Flexion batteries throughout Switzerland and Liechtenstein.

E.5 Summary of Eight-Year Forecasts for Thin-Film Batteries

Exhibit E-2 shows NanoMarkets' latest forecast for the thin-film battery market. They are significantly more modest than those we produced a few years ago. The reason for the downgrading of our numbers is our expectation that economic growth for the next few years is not going to be spectacular. More specifically, RFID does not seem likely to provide the market size that had generally been hoped some years back.





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