Thin-Film and Printable Batteries: 2010

Chapter One

April 2010

NanoMarkets, LC | PO Box 3840 | Glen Allen, VA 23058 | TEL: 804-360-2967 | FAX: 804-270-7017

Chapter One: Introduction

1.1 Background to this Report

1.1.1 Thin-Film and Printable Batteries: What Are They Good For?

A new class of electronic devices, often associated with the "Internet-of-things" concept, is emerging and includes RFID tags, electronic shelf labels (ESLs), active cosmetic/drug delivery patches, low-cost medical diagnostic products, remote sensor arrays, powered smartcards and smart packaging of various types. Although these devices may be powered to some extent by an energy harvesting approach or by an inductive field generated by some kind of reader system, battery power installed in the electronic device itself usually enables such devices to provide a much higher level of functionality. For example, battery-powered smart cards can have their own displays for one-time password and other applications—something that would be hard to achieve any other way.

A variety of small, low-cost batteries have powered electronics for generations and with considerable success. Today, the power sources used for the devices listed above are mostly button/hearing aid/coin batteries, or sometimes even larger batteries. In many cases, these batteries are quite suitable for the task in terms of power output and longevity. They are also very inexpensive, long-lived, have decent energy densities, and are based on very mature technology. Given all this, there is—on the face of it—no good reason why anyone should spend time developing new kinds of batteries for these devices. At least, there is no good reason why a firm should spend time in this way and expect to make money!

Nonetheless, a growing number of firms are supplying thin-film and printable batteries, which they claim are better suited to the applications discussed above. Such companies typically cite the following advantages of their products:

- **Size:** Thin-film (TF)/printable batteries are often better suited by virtue of their form factor than any other kind of battery for powering the kind of electronic devices listed above. This is perhaps best illustrated again by the powered smart card, which could not easily be powered by conventional coin/button batteries. The use of these conventional batteries would make the card much too thick to easily carry in a wallet. By contrast, the thin-film batteries now being commercialized are typically just a few millimeters thick. The bottom line is that while very small by the standards of (say) a car battery, these traditional batteries (notably button/coin batteries) are still quite large and bulky compared to what is needed for the large-area/flexible/disposable electronics sector.

- **Shape:** These batteries can be formed to fit in almost any shape, depending on the application.

- **Flexibility:** Potentially, and to some extent actually, TF/printable batteries can be fabricated on a flexible substrate. This makes them highly suitable for use in medical patches, smart bandages, smart packaging and smart clothing. In the future, these new kinds of batteries may be also be used in flexible displays (a product category that does not really exist as yet).

- **Environmental and safety superiority:** Compared to conventional button batteries, thin-film batteries (but not printable batteries) are typically entirely solid-state devices; as a result, these batteries are intrinsically safe and do not pose the risks of spilling, boiling or gassing associated with traditional batteries. While safety is really not a major threat with conventional batteries, the exploding laptop battery scare of a few years back has sensitized the consuming public that batteries can be a threat. There is also a potential health and safety issue from conventional batteries in that they often use hazardous chemicals, including lead, mercury, and cadmium. These are not materials that anyone wants in smart packaging for food or even pharmaceuticals. Solid-state thin-film batteries are also more likely to be considered environmentally friendly.

- **Temperature stability:** Most existing rechargeable batteries lose performance at high temperatures. Several producers of thin-film batteries claim that their technologies demonstrate superior temperature stability and can operate up to about 150° Celsius. This makes them suitable for applications/products where high thermal processes—such as lamination—are used.

- **Manufacturability:** Depending on the specific battery, various kinds of manufacturing processes are put forward by suppliers of TF/printable batteries as providing advantages of which the most important is cost savings. Printing batteries is the most strategically important of these manufacturing strategies and is a key theme throughout this report.

1.1.2 Cost Problems and Cost Strategies

The product/market strategies of the firms that are discussed in this report all amount to building a business case for TF/printable batteries around the advantages of these batteries that are listed above. However, despite all of these advantages, such strategies are subverted to some extent by the fact that the current generation of thin-film and printable batteries are more expensive than existing button/coin batteries. This is because:

- There is a need to recapture development costs over a relatively short period of time, while development costs for conventional batteries have long since been recovered.

- The production volumes for button/coin batteries are huge, while for TF/printable batteries they are very small. Thus for TF/printable batteries, economies of scale seldom if ever apply; at least not today.

Not that any TF/printable battery firm would want to compete on price alone and many of them clearly do not have the resources to do so. Most manufacturers of these new kinds of batteries are relatively small firms and it is a long standing finding of research into business strategies that smaller firms never do well when they have to compete on price.

There are really three ways to address this price problem, and they are not mutually exclusive:

- To essentially route around the pricing problem with the battery company creating its own high-value-added products in which the batteries are used. Cosmetic patches are the main example here. The problem with this approach is that firms must develop new skill sets and acquire new resources if they are to sell the whole of the product, not just the battery.

- To predict and rely on future, major economies of scale that will make the price points for TF/printable batteries much more comparable with conventional batteries. Every firm in the TF/printable battery space believes this to some extent, but it is important to realize that this hope is predicated on some kind of "take-off" application.

- To adopt a strategy that consists in searching for lower cost methods for manufacturing batteries. Often, but by no means always, as we have already noted these new production modes involve printing.

1.1.3 The Business Case for *Printable* Batteries

For the purposes of this report, we define printed batteries as any battery that uses printing technology in its manufacture. Most, if not all, printed batteries today use printing only for the electrodes and then utilize a liquid electrolyte between the electrodes. (Liquid electrolytes have a viscosity similar to water and therefore need a solid in which to contain them; they are typically absorbed into a "separator" material.)

There are several chemistries currently being used by companies that have developed printable battery technology, but they are usually zinc manganese dioxide or zinc carbon. These are relatively low-cost materials when compared with the various lithium chemistries used in many of the thin-film and conventional batteries. They are formulated into inks, which are then printed via screen printing onto a variety of substrates.

The argument for printing batteries is mostly the one that is always used for printable electronics, namely that printing machinery is relatively inexpensive and printing processes are well understood and not costly in themselves. In addition, it is hoped that the printed battery manufacturing can be integrated on the same manufacturing line with the device being powered and on the same substrate, allowing fixed production costs that can be allocated to both battery and device. The thinking here is best exemplified in the concept of printed packaging, where batteries could become just another printed layer.

In fact at the current stage of product evolution, none of the advantages of printing have completely been validated, although there *are* some encouraging signs from the industry that printing will have an important role to play in the future of battery manufacture. However, we also note that printable batteries face special challenges:

- In their current form, printable batteries are not solid-state batteries. This means that they do not offer the benefits that solid state confers, such as the ability to withstand high temperatures.
- In addition, many in the battery industry believe that only a fully printed battery will be able to compete with conventional batteries. Where they are not entirely printed, the manufacture of these batteries will obviously not get all the cost benefits associated with printing.

1.1.4 Thin-Film Battery Chemistries, Materials and Technological Alternatives

There are many technology directions that are being taken to build solid-state thin-film batteries of the kind discussed above. How these are likely to shape up, which applications these technologies will ultimately serve and which technologies may ultimately fade away is a major theme of this report. As applications mature, some of the chemistries and materials used in thin-film batteries will likely prove to have a certain level of general applicability, some will find niche applications where special conditions apply (such as in medical implants) and others will disappear entirely.

Today, the majority of thin-film batteries are lithium based and are fairly similar to the batteries used in mobile phones and laptop/notebook computers, at least from a chemical point of view. The next stage in thin-film battery evolution from lithium-ion is to lithium-ion-polymer (LiPo), which relies on a solid electrolyte (sometimes gel) instead of a porous substrate that has been soaked with a liquid electrolyte. These batteries offer improvements in terms of lower cost manufacturing and robustness, and can be as thin as one millimeter. Yet other variations of the lithium battery theme that are being commercialized are lithium metal, lithium manganese dioxide, lithium thionyl chloride and lithium oxygen.

Lithium phosphorus oxynitride (LiPON), which was originally developed by Oak Ridge National Laboratory, is frequently used as the electrolyte in thin-film batteries today, but other types of electrolyte are being developed. As well, some companies are developing thin-film batteries using chemistries other than ones based on lithium. And some of the leading edge chemistries are much more exotic:

- A few researchers have been working on using biomaterials; this is mostly work being done in universities and research institutes, of course, but Sony is also involved.
- Yet another research direction is radioisotope batteries.

Most of the more exotic materials really have no chance of becoming a mainstream battery technology within the eight-year time frame being considered in this report. They may be at the very beginning of a development cycle that will not result in mass-market products for another twenty years. But they could have specialist applications in medical and military markets well before that time

All of the major chemistries that are currently being commercialized for volume applications of thin-film batteries have been well researched for many years, so there are unlikely to be insurmountable barriers to progress in this area. Nonetheless, products at this early stage of development often encounter teething problems; thin-film batteries are unlikely to be the exception to the rule. And while the batteries that we focus on in this report are "newbie" technologies trying to take a share of the battery market from older technologies, there may also sometimes be other, even newer, battery technologies that represent a challenge to thin-film batteries. These might include certain kinds of energy harvesting technologies, batteries that use novel nanomaterials, or even thin-film fuel cells.

1.1.5 TF/Printable Battery Strategies and Changing Applications

So, are the benefits mentioned above really sufficient to make people pay more for their batteries? And do the current limitations of printable batteries, still allow for their use? In certain limited cases the answers to these questions already appear to be yes. We expect these new kinds of batteries to target applications where the current battery technology is deficient in some way that is indicated by the list of TF/printable batteries advantages given above. The main products in which such applications are important were already mentioned above, although there are others that don't quite fit into the Internet-of-things concept, such as certain kinds of computer memory.

Still, the immediately addressable markets for TF/printable batteries are quite small, limiting the revenues available to the makers of these batteries in the immediate future. Some of these TF/printable battery manufacturers are, however, capturing value by moving up the chain and selling complete products—such as cosmetic patches—in which their batteries are used. This strategy serves both as a way to make some more money in the short term and to demonstrate the use of the firm's thin-film technology, which in turn—it is hoped—will lead to more orders.

Eventually, the prices for TF/printable batteries can be expected to come down and the market for these batteries will grow. Of considerable importance with regard to this evolution is the likelihood of:

- Improved marketing, leading to larger orders, which in turn will lead to economies of scale
- The development and use of better manufacturing technologies. Printable batteries are, in a sense, an example of this strategy. So is integrating the manufacture of the battery with that of the product that it will power, which carries with it obvious cost savings.

Neither the printable or thin-film battery will ever be a panacea, however. We do not expect thin-film batteries to represent the next generation of batteries for mobile electronics, for example. In the distant future, thin-film batteries may have much wider applicability; there are experiments suggesting they could be used to power cars, for example. But, in this report, we are not primarily concerned with the more futuristic applications that have been proposed and at this point they seem more curiosity than money-spinners.

Changes in addressable markets: In the meantime, TF/printable batteries face many challenges apart from cost. One of these is that many of the applications at which their new technologies are aimed are themselves new technologies that have generally not done well in the current recession. Most notable among these is RFID. Not so long ago this was seen as a "killer app" for TF/printable batteries, but the recession is not likely to be a good time for retail and wholesale firms and others to implement what is, in effect, major new IT systems. In addition, RFID is not coming down in price fast enough to really make significant penetrations at the item level; at least not as fast as hoped and, of course, most RFID tags derive their power inductively and don't need batteries anyway.

With all this in mind, makers of TF/printable batteries have turned elsewhere for first revenues. Powered smartcards are seen as one good prospect, because they can potentially provide very high security at a time when ID theft and other forms of abuse cost credit card companies billions of dollars. NanoMarkets sees this as a better bet than RFID at this point in time, but it remains an opportunity that is only just beginning to open up. (Smartcards have been around for many years, but they have been of a type with relatively low functionality and therefore do not need batteries.)

1.1.6 The Future

The discussion above describes the current state of the TF/printable battery market. It seems likely that printable battery firms in the future will focus on:

- Further developing their battery technology to meet specifications of important applications and increase energy density
- Improving manufacturing processes used to make the batteries, possibly employing printing for all parts of the battery
- Establishing relationships with device manufacturers (customers), especially those that are developing devices made via printing and especially those that could lead to early volume production.

More capacity will also need to be put in place to manufacture cells with emerging chemistries. As we have already mentioned, thin-film batteries are not likely to grow into a substantial and profitable industry until high-volume production can be justified. But this will mean a call on equity investors and/or bankers for significant amounts of capital. This will be especially challenging in the current economic environment, although we note that there has been some VC money going into the TF/printable battery sector in the past year. Still, so far investments in this sector have mainly been small and the new generation of batteries discussed here does not seem to have attracted the attention of the best-known VC firms, although there are a few important strategic investors in this space.

1.2 Objectives and Scope of this Report

The main goal of this report is to determine in which applications a substantial business case can be made for thin-film and printable batteries. In order to reach this goal we have:

- Analyzed and quantified the opportunities for TF/printable batteries in a broad range of applications for which they are claimed to be suited. For each of these applications, we examine the requirements for power sources and compare current and future performance of TF/printable batteries with the other power sources that may be used for each application.

- Examined critically, the business case "stories" being told by the leading manufacturers of TF/printable batteries to ascertain the degree to which they jibe with market realities

- Analyzed the likely evolution of materials and battery chemistries used in the novel batteries discussed in this report. This analysis covers both the electrodes and electrolyte. We have also reviewed the progress being made with manufacturing processes.

This report brings together NanoMarkets' deep experience in the thin-film, organic and printable electronics sector with its analysis of the latest developments in the battery field including new products, technology breakthroughs, new licensing, financial and marketing arrangements and recent M&A activity. And while the main objective of this report is to focus on the evolving opportunities in TF/printable batteries, it will also seek to explain where there have been apparent failures and analyze why these have occurred.

Applications and technologies covered: In terms of applications, in this report we have looked primarily at RFID, smart packaging and labels, smartcards, biometric ID, point-of-presence displays, sensors, medical diagnostic devices, medical implants and drug delivery systems, games and novelties, cosmetic devices, battery backed-up computer memory and embedded chips. We have given special attention to RFID and powered smartcards because these seem to be getting widespread attention in the TF/printable batter sector. However, a few firms have settled on a somewhat different focus, such as specialized computer memory, and there is substantial discussion of the more niche-like areas as well.

In addition to the technologies that clearly belong in the thin-film or printable categories—that is the main battery chemistries—we have also discussed some of the other novel small-scale storage technologies that are emerging at this time and which either compete or synergize with thin-film batteries.

Companies profiled: In this report, we have presented an account of the roles and strategies of important firms in the market and their apparent successes and failures. It is far too early in the evolution of the thin-film battery market to begin to talk about "market shares."

However, where a firm has some kind of current dominance in a market covered, we have identified it as such. We believe that this report profiles all of the major firms currently producing or close to producing thin-film or printable batteries.

It is important to note that the focus of this report is on batteries designed to power mostly thin-film and disposable electronics, not mobile electronics. A somewhat different group of companies and technologies are focusing on the mobile power space, although the issues in both sectors overlap and there is some discussion of powering mobile electronics contained in this report. Mobile electronics can cope with much larger footprints for batteries, however, and have very different power requirements.

Geographies covered: The report is based on a worldwide view of the market, and we have not favored companies from any particular geographic region. We strive to cast as broad a net as possible in our efforts to research the information for this report both in terms of applications and in terms of the national origins of the technologies being reviewed.

1.3 Methodology of this Report

As with all NanoMarkets' reports, our assessment of the business prospects for TF/printable batteries is based on analysis of the underlying needs for the features and capabilities that thin-film batteries can potentially offer. We therefore believe it is vital to understand where the actual demand will come from and what type of capabilities the market is looking for.

We have used both primary and secondary research in this report to determine where TF/printable battery technology is headed:

- The primary research came from NanoMarkets' ongoing interview program in which we conduct regular interviews with key executives throughout the entire thin-film, organic and printable electronics value chain—including manufacturers of equipment and materials and of devices and subsystems themselves. As part of that process we have interviewed many of the main firms offering printable and thin-film batteries.

- The secondary research drew on the World Wide Web, commercial databases, trade press articles, government reports, SEC filings and other corporate literature to fill out what is going on in this sector. NanoMarkets' researchers have also been frequent attendees and speakers at important trade shows and conferences of relevance to this study.

The forecasting methodology is discussed more fully in the main body of this report. However, it is based largely on our expectation of penetration of the important application sectors by TF/printable batteries. In making that assessment, we have taken into consideration current expectations for both TF/printable battery technology and the applications into which they will fit. This includes the likely impact of the current recessionary environment. In the forecasting section, we have also discussed how our projections may vary under various scenarios and how likely those scenarios are to occur.

1.4 Plan of this Report

Chapter Two of this report analyzes the main technology trends in the TF/printable battery space, while Chapter Three provides an account of the many markets in which thin-film batteries compete and where the novel battery types that we discuss in this report are likely to generate money. Chapter Three also includes NanoMarkets eight-year forecasts for TF/printable batteries. In Chapter Four, we provide profiles of the leading technology developers and suppliers of TF/printable batteries.

Table of Contents

Chapter Two: Evolution of Thin-Film and Printable Battery Technology

Chapter Three: Applications and Forecasts for Thin-Film Batteries

Chapter Four: Profiles of Leading Thin Battery Firms

Thin-Film and Printable Battery Markets: 2010

Released: April 20, 2010

Pricing: $2,795 Advanced Version (up to 5 users)
$3,295 Group Version (up to 10 users)
$3,795 Enterprise Version

To order: Please visit the NanoMarkets Store online at www.nanomarkets.net/store.cfm

Order by phone (804) 360-2967 or by email at sales@nanomarkets.net.