NanoMarkets Report

Dye Sensitized Cell Markets—2014

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SUMMARY

The recent announcement of dye sensitized cells (DSCs) based on perovskite material that provide a 15 percent efficiency shows that DSCs could be about to hit the PV mainstream. With such new developments in mind, this new report forecasts and analyzes the market for DSCs over the next eight years. NanoMarkets has been covering the ups and downs of the DSC sector for the past five years and we believe that DSC is entering into a new era. DSC technology will soon be able to provide efficiencies close to those of commercial thin-film solar panels. And, for the first time for years, DSC will be competing in a stable market environment for solar panels.

In the report, we examine how the leading players in the DSC space plan to generate revenues in this new business environment and how their addressable markets will grow in the next decade. Our analysis covers all the product/market areas that are being seriously suggested for DSC and shows how these markets are likely to evolve.

Because of its huge revenue potential we are especially interested in the building-integrated photovoltaics (BIPV) sector and we also take a serious look at the opportunity for selling DSC products into the developing world; a market that several DSC firms have specifically targeted. This report also appraises the commercial significance of recent technical developments in the DSC space, especially the development of improved electrolytes both solid-state and liquid.

As always with NanoMarkets' reports, this report also contains granular, eight-year forecasts of DSC panel and materials shipments in volume and value terms, broken down by application wherever possible. Materials covered include the critical components of the cells and modules; host, dye, and electrolyte materials; transparent and nontransparent electrode materials; and encapsulation materials.

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Chapter One: Introduction

1.1 Dye-sensitized Solar Cell (DSC) Technology

NanoMarkets has been keeping a keen eye on DSC photovoltaics for some years now. As stated in the previous report, the last couple of years have been quite interesting for third-generation photovoltaic PV technology. Significant advances have taken place not only with respect to lab-scale cell efficiencies, but also on the commercialization front. As a result, a number of commercial providers have the potential to supply DSC panels in the near future.

However, the financial difficulties faced by the PV industry in recent times have cast suspicion on the long-term viability of both large and small firms. Nevertheless, there is scope for further improvement in the efficiency of lab-scale DSCs that already are competitive with amorphous silicon (a-Si) cells (~15 percent).

The changing dynamics in the global PV industry have led DSC manufacturers to seek solace in more economically resilient off-grid applications. Building-integrated photovoltaic (BIPV) applications and low-light driven DSC solutions for consumer electronics are increasingly being seen as the largest potential markets for DSC. In fact, the first commercialized DSC products were flexible keyboards and portable battery chargers.

1.1.1 A Ray of Hope: Effect of China and Improved Cell Efficiency

Respite in the form of consolidation and subsidy rationalization in China: In the last five years, the global PV industry, particularly in the U.S. and Europe, has suffered from pricing pressures caused by PV panel manufacturers from China. Subsidy-supported production led to an oversupply of solar PV panels and a subsequent drop in prices from the level observed in 2007.

As a result, even large Chinese PV panel manufacturers such as Suntech incurred losses. Based on current trends, the Chinese government is not expected to extend further subsidies to the numerous financially troubled solar firms.

Consolidation or closure will be the only options for less resourceful Chinese solar PV panel manufacturers over the next two years and is necessary if balance in the global solar PV space is to be restored.

European manufacturers have also been faced with reductions in government subsidies, which have further increased the pricing pressure on these firms.

Emerging PV technologies such as DSC have not been spared either. The DSC industry suffered as early entrants in the DSC space, including G24 Innovations (now a part of G24 Power Ltd., U.K.) and Dyesol (Australia) were acquired or left to suffer dwindling revenues respectively.

The good news is that the consolidation of smaller firms and a more reasonable government subsidy scheme in China will put a check on cheap solar PV panels in the coming years. In addition, the growing significance of protectionist measures, such as anti-dumping laws, should provide the DSC industry much needed relief.

However, the industry must make a conscious effort to ease commercialization barriers, and adequate financial support by governments and the private investment community is also needed.

With these developments, innovative DSC-centric firms in the U.S. and Europe can gain a fresh lease on life over the next three to five years by guaranteeing solutions with extended lifetimes.

DSCs looking to shed the 'jinxed' label: When the efficiency of DSCs hovered near 10 percent in 2010, the PV industry lost interest in this technology, and it was considered to be a niche market segment like organic PV (OPV). At that point, DSC was expected to remain in a permanent R&D phase or at best be suitable only for use in the low-end applications. Such an outlook was not entirely misplaced, as DSCs were obviously a type of organic cells because they contain organic dyes.

What changed in the last couple of years is that DSC PV witnessed a number of technological breakthroughs that helped the technology overcome previously stagnated efficiency numbers. More importantly, the industry embarked on a path towards solving critical lifetime-related issues that were a major stumbling block to its success in the past.

1.1.2 Challenging Path to Commercialization

Changing solar industry dynamics in China, combined with protectionist measures taken by the U.S. and European nations, is good news for new solar PV entrants. However, established DSC players such as G24i and Dyesol will need to figure out ways to stay financially viable.

Rebirth of G24i: One of the earliest entrants in the DSC space, G24i ran into financial trouble in December 2012 but then reemerged as a new entity under the name G24i Power Limited. The reasons behind the revival of this relatively new PV firm are interesting given the pricing pressures faced by the entire PV industry over the last couple of years.

A private investment team led by the Martin family (U.S.) and Innovation Management Limited (Isle of Man) saw the potential to commercialize DSC technology. With G24i Power's roll-to-roll (R2R) process, which has significant potential to reduce the unit cost of DSC modules, this gamble seems to be paying off.

In addition, the strategy of the restructured G24i Power is different from that envisaged by the original owners. The focus of the new entity is to:

- Engage in process improvement initiatives to enhance product quality, lifetime, and conversion efficiency in order to offer competitive alternatives in the consumer electronics sector;
- Develop new DSC solutions, including solid-state flexible cells; and
- Target a wider range of applications, such as mobile chargers in the developing world. Others include computer accessories, washroom products, healthcare solutions, and lighted point-of-purchase displays.

The intention of the new owners is to provide the financial support needed to smoothly reach the final stages of commercialization and help the firm regain its position in the industry. As a matter of fact, G24i Power re-started its production and research programs in November 2013.

NanoMarkets believes, however, that while G24i Power might trigger the DSC commercialization process, only consumer response and the ability to develop market relevant products on a regular basis will determine the firm's success. And this proof is still a long way from appearing.

Fate of Dyesol: Recently, Dyesol's revenues and profitability have been dwindling because liquid-state materials are going out of favor in comparison to solid-state materials. However, a couple of strategic moves initiated by the company might work in its favor:

- The transition from expensive liquid-based materials to relatively cheaper solid-state materials including perovskite sensitizers and the Spiro solid-state electrolyte–a significant move considering the higher efficiency, lower cost, and better scalability prospects for solid-state DSCs.
- The intent to diversify beyond the materials space into licensing for access to IP royalties and the manufacturing of modules.

The move to strengthen its solid-state material IP portfolio and progress toward commercialization can be strengthened through Dyesol's recent tie-up with Nanyang Technological Institute (NTU, Singapore).

Dyesol's acquisition of an equity stake in Printed Power Pte Ltd, a spinoff of NTU, in April 2013 will enable the company to enter the new market for fully printed Combined Energy Generation and Storage (CEGS) solutions.

If everything falls into place, Dyesol should be able to commercialize a DSC-based low indoor light sensor network within the next two years. Funding support from SPRING (an enterprise of the Singapore government) will be the lifeline for the project. In addition, this tie-up will further aid the shift in Dyesol's research activities from liquid-state to solid-state DSCs.

Separately, Dyesol's long association with École Polytechnique Fédéral de Lausanne (EPFL, Switzerland) will pave the way for the introduction of mass production techniques for solid-state DSCs in the next three to four years. Such methods will be primarily targeted at the production of DSCs for BIPV applications involving steel and glass.

However, the big question is if Dyesol can keep its investors convinced that it has strong future prospects. Dyesol's business model mostly hinges on its ability to translate pilot production capability to larger scale deployment. Thus, it is essential that the company puts long-term supply agreements and project financing in place.

Doing so, however, has been a concern for Dyesol recently; despite the completion of pilot projects for a majority of its partners, large-scale deployment has been lagging behind schedule. The delays have been mainly due to funding-related negotiations with some of its major partners, such as Tata Steel (Europe), Pilkington (part of NSG, Japan), and Timo (South Korea).

At this juncture, it is important to note that Dyesol does have a chance to speed up things in the coming year. The disclosure in November 2013 by Tasnee (Saudi Arabia), one of Dyesol's biggest investors and collaborators, to extend its funding support is a big source of relief for the firm.

The company will have immediate access to AU$10 million and receive a further AU$6 million by January 2014 provided it receives shareholder approval. Dyesol thus has the opportunity to

leverage these additional financial resources to achieve commercialization and mass deployment of solid-state solar cell technology in BIPV applications.

In addition, as of November 2013, Dyesol became an industrial partner in the $19 million SPECIFIC (Sustainable Product Engineering Centre for Innovative Functional Industrial Coatings) project, which should also help the firm recover from its financial woes to some extent. The five-year project with established industrial partners such as BASF (Germany), Pilkington, and Tata Steel (Europe) was formed to promote solid-state DSCs in BIPV applications.

Overall, NanoMarkets believes that Dyesol's success will largely depend on its ability to convince investors of the value proposition of solid-state DSCs and its capability of achieving mass scale deployment of commercial solutions.

For other small and innovative firms, success in the DSC space will hinge upon their ability to muster financial support on a regular basis. In addition, these companies must make a concerted effort to identify potential technological and financial partners that will be willing to commit to long-term supply agreements that will enable economies of scale.

Role of Tata Steel (Europe): Despite developing the world's largest DSC panel for steel-based BIPV applications in collaboration with Dyesol in 2011, large-scale production has not yet occurred; however, there are rumors that the company experienced technical difficulties that have apparently now been overcome.

At present, the Colors division of Tata Steel (Europe) is involved in various partnership projects on DSC research to assess the performance and commercial potential of DSCs. For instance, it is one of the partners of the Low Carbon Research Institute (LCRI), which is presently exploring ways to commercialize low-cost DSCs in the U.K.

The $7-million funding support for the project will be crucial for facilitating the commercialization of industrial DSC applications in collaboration with Tata Colors and Dyesol.

Successful technology development and production planning for the commercialization of DSC-enabled steel roofing and building facades is in the cards. *However, given Tata's cautious approach in the DSC commercialization space, NanoMarkets believes that large-scale production of DSC-based BIPV solutions may not materialize in the immediate future.*

Fujikura's (Japan) intention to commercialize low-light solutions: DSCs have played a significant role in the company's strategic roadmap. In April 2013, Fujikura started shipping samples of its DSC modules that are capable of generating twice the electric power generated by conventional amorphous solar cells under indoor light conditions.

What sets apart Fujikura's light-harvesting DSC solutions is the flexibility options offered to consumers. The ability of the modules to optimally convert light to electric power in response to changing lighting conditions (both amount and type) is also seen as a consumer-friendly move.

At present, Fujikura is delivering small volumes of its DSC-based panels (business card and passport-sized) for evaluation. This DSC initiative is partially supported by the New Energy and Industrial Technology Development Organization (NEDO), Japan.

NanoMarkets believes that Fujikura can emerge as a key DSC player in the low-power consumer applications segment given the less competitive nature of the energy harvesting consumer electronics market and the growing consumer demand for technologies that can promise reduced recharging frequencies. Given that increasing numbers of samples of similar DSC modules are being produced and evaluated, commercial products might well be hitting the market within the next two years.

Potential of specialty chemical firms: Providing support to the PV panel manufacturers are the specialty chemical firms that supply different components, including electrolytes and other performance-enhancing additives.

BASF (DE) and IoLiTec Ionic Liquid Technologies (Germany) are active in ionic liquids (ILs), which serve as DSC electrolytes. Sigma Aldrich (U.S.), an established life science and chemical firm, is a key player with a wide range of dyes and nanoparticles for DSC applications.

Merck is another major chemical firm that supplies materials for DSC applications and is active in DSC-related R&D efforts. For instance, it received funding (€3 million) in May 2013 from Germany's Federal Ministry of Education and Research for project COBRA (organic cobalt-based low-cost printable large-area photovoltaics). The three-year project with partners 3GSolar (Israel) and Colour Synthesis Solutions (U.K.) seeks to improve efficiencies and lifetimes through the use of a novel redox systems and non-volatile electrolytes.

NanoMarkets believes that there is opportunity here for such established chemical firms such as Merck, BASF, and Sigma Aldrich, which are active across multiple DSC materials markets, to collaborate on research efforts to further move up the DSC value chain.

1.1.3 What Changed in the Last Year?

Given the dynamic economic and technological environment in the DSC market, it is important to take note of some key developments.

- Efficiency has always been a widely discussed issue for DSCs, although DSC performance is not solely decided by cell efficiency. Nevertheless, what could not be achieved over the past decade was achieved in July 2013 at the EPFL–researchers effectively replaced a liquid electrolyte with a solid-state perovskite material to achieve a cell efficiency of 15 percent under standard AM 1.5 test conditions.
- This development could be the precursor to the commercialization of solid-state DSCs, given the nature of the pioneering work at EPFL, which is where modern-day DSCs took shape.
- The use of other materials has also gained traction in the past year. For instance, the University of Basel (Swiss) and Merck are currently working to replace traditional DSC electrolytes with a cobalt-based electrolytic system. The use of cobalt is expected to increase the stability of next-generation DSCs while remaining cost-effective.

NanoMarkets believes that these early successes with solid-state DSC technology and new material sets hold real promise for the future commercialization of DSCs and could very well garner more investor interest that may, consequently, further accelerate innovation and drive real product development efforts.

1.1.4 Market Opportunities in the DSC space

The move into new territories: Chinese overcapacity and the accompanied crash in conventional silicon prices did not provide enough time for solar companies to adapt and reconfigure business operations. Aggressive consolidation, particularly of mainstream PV technology firms, was the result. DSC firms have also has been finding it difficult to compete in a space where comparison on the basis of $/W reigns.

In the recent past, DSC firms have been quick to realize that the way to establish a presence in the PV market is to target niche applications that can be commercialized within the next three-five years and benefit from the superior features of this technology with respect to good indoor performance, flexibility, robustness, and color tenability.

BIPV to the rescue: In this regard, BIPV is an attractive market for DSCs given its ability to deliver semi-transparent glass. The market potential is huge, particularly in Europe where legislation is likely to push for the construction of near zero-emission buildings. However, large-volume production of DSC modules with lifetimes of around 20 years remains a challenge.

If Dyesol can achieve the incorporation of longer-lifetime DSC modules into glass and metallic BIPV solutions in the next two-three years, it may have a real chance to revive its fortunes to some extent.

G24i Power Ltd could also make an impact in the BIPV space provided some of its recent technological developments are effectively incorporated in its product line. Whether or not the company has access to the funds needed to ensure commercialization remains to be seen, however.

Meanwhile, Exeger's (Sweden) pilot production plant, which is expected to begin commercial operation in 2014, will enable the firm to realize potential economies of scale. Notably, the €1.8 million in financial support the company received from the EU through a LIFE financial instrument may enable Exeger to gain prominence in the next two-three years.

In the meantime, the industry is also making serious investments to resolve scale-up related issues and ramp up production capacity in order to serve the large-volume BIPV market within the next three-five years. By that time, DSC technology will mature and the stability and lifetime-related issues that are still present today should be resolved at the R&D level.

NanoMarkets believes that with a few years of successful commercialization experience behind it, the DSC industry will be ready to emerge as a major contender in the BIPV space. On-grid and utility-scale generation is not on the radar at the moment; however, this situation could change if any technological breakthrough manages to significantly improve the long-term stability of DSCs in outdoor conditions.

Further opportunities in energy-harvesting applications: Energy harvesting is another attractive market, particularly for indoor applications, which have recently experienced rapid growth. Here DSC can differentiate itself based on its substantially reduced performance gap. The indoor energy-harvesting market includes applications such as power supplies for various sensors (temperature, humidity, CO_2 concentration, etc.), remote control units, and charging devices. Power sources for information management systems in smart homes and large warehouses are longer-term opportunities.

In this space, Fujikura could emerge as a key player given the fact that the firm has recently advanced into the evaluation stage for its low-light enabled DSC solutions. It remains to be seen whether G24i Power will be able to make a comeback in this space with its new management.

In short, DSC manufacturers are once again retooling their strategies and looking for target niche markets where they can deliver unique value at a reasonable price and thus remain profitable.

1.1.5 Can DSCs Cross the Commercialization Hurdle?

There are compelling technological and economic reasons to be optimistic about the future of DSC PV.

As a fundamentally superior technology, DSC possesses the maximum probability of converting an incident photon into electrical current. A well-established material knowledge base and the availability of standardized manufacturing equipment should, therefore, enable high production yields in the coming years.

For instance, it is known that DSCs are relatively stable at higher temperatures. Therefore, the use of non-vacuum deposition techniques is possible and would do away with the need for expenditures on capital-intensive infrastructure.

In addition, the ability of DSCs to efficiently operate across a wide range of the visible spectrum, including in low indoor lighting conditions, makes it superior to other competing technologies.

Furthermore, the ability to produce DSC modules that are semi-transparent, semi-flexible, and have longer lifetime modules makes this PV technology very attractive for applications in the BIPV segment.

To top it all, NanoMarkets believes that the recently improving efficiency trend and better price to performance ratio will drive DSC commercialization in the coming years.

1.1.6 Challenges?

Growth of the DSC PV market in the next decade is likely to meet today's cautious forecasts. However, it is not going to be easy sailing, at least for the next couple of years.

Technical bottlenecks: There is a need to remove technical bottlenecks, such as degradation upon exposure to ultraviolet (UV) radiation and poor absorption in the red part of spectrum. In addition, the tendency of hazardous volatile organic solvents to escape from the liquid electrolyte must be resolved.

Apart from these hurdles, there are scale-up related issues; it is often challenging to reasonably replicate lab-scale small area efficiencies on large area modules. Fortunately, a majority of current research efforts are focused on successfully replacing liquid electrolytes with conducting polymers or ionic solids without compromising efficiency. Such developments should solve all of the liquid electrolyte related issues, including scale-up concerns.

Researchers are also working to improve the spectral absorbance of DSCs*. If early results are to be believed, most of the mentioned issues are likely to be resolved sooner rather than later.*

Economic issues: The impact of the economic slowdown is evident in the reduction of government subsidies and tax incentives that supported the PV industry for so long. The lack of such assistance will take a toll on the investment climate, although emerging technologies with unique benefits will remain within the investment radar.

In addition, because DSC PV currently competes in off-grid applications and sees its future in BIPV applications, the impact of declining subsidies may not be felt to a significant degree.

In summary, NanoMarkets believes that given the technical and economic advantages that DSC PV presents, notwithstanding a few critical technical hurdles that are likely to be resolved, DSC should be able to prove itself in the market.

1.2 Objectives and Scope of this Report

This report examines the opportunities and challenges for the DSC industry over the next eight years. The purpose of this report is to present a critical assessment of recent developments in the realm of DSC PV. Based on our unbiased assessment of recent technology and market trends, we present a forecast of how things are going to pan out for DSC PV over the next eight years.

The report looks into the broader issues in the global PV industry that might impact the DSC industry. Emphasis has been made to identify the right target markets, such as BIPV and indoor energy harvesting applications. We have further highlighted the potential factors that might improve the prospects for DSC technology in these markets. We also make a conscious effort to explore the ramifications of the revised strategies adopted by the key players in the industry.

In addition, technological developments that are likely to shape the future course of the industry are discussed with regard to the use of electrolyte, electrode and encapsulation materials. Initiatives to improve cell efficiency and achieve cost-effectiveness have also been investigated.

1.3 Methodology of this Report

1.3.1 Forecasting Methodology

The basic forecasting approach involved identification and quantification of the underlying markets for DSC and the corresponding materials needs. The technological and market pressures that can affect the growth prospects for DSC modules and the mix of materials used to produce those modules were also considered.

In addition, the competitive landscape was assessed to determine the suitability and likely volume of DSC devices that will be produced over the next eight years. The broader economic developments that may impact DSC PV and materials development and commercialization were also considered.

This report is international in scope. The forecasts herein are worldwide forecasts and we have not been geographically selective in the firms that we have covered in this report or interviewed in order to collect information.

1.3.2 Data Sources

This report is the latest from NanoMarkets that looks closely at the PV industry, which is a key area of expertise for NanoMarkets.

- The information for this report is derived from a variety of sources, but principally comes from primary sources, including NanoMarkets' ongoing interview program of entrepreneurs, business development and marketing managers, and technologists involved with PV, PV materials, and emerging electronics of all kinds.

- We also used information from secondary sources, such as relevant company and industry organization websites, commercial databases, trade press articles, technical literature, SEC filings, and other corporate literature.

Some background information for this report has been taken from the previous version of this report, "*Dye-Sensitized Cells: Materials, Applications, and Opportunities*" from April 2012.

Where information from an earlier report has been used, it has been reconsidered in light of current developments and updated accordingly.

1.3.3 Alternative Scenarios

While we take a realistic approach to the global dye sensitized cell market and the direction of the worldwide economy, other scenarios are possible. At the time of this writing, the U.S. economy has been registering slow, yet steady, growth, but reasonable economic growth in Europe will take time to register. The Japanese economy is also expected to improve in a few years, provided it is able to overcome certain minor hurdles, such as the increase in sales tax introduced in April 2013.

Overall, however, the emerging economies led by China will serve as the major engine of global economic recovery from the recessionary phase experienced in the recent past.

Unfortunately, if certain macroeconomic events, such as a delayed economic recovery in the key DSC markets of Europe and Japan, occur, they would have a negative impact on the prospects for DSC technology. Because the DSC industry has been mired in technology- and investment-related issues, any adverse economic event would likely dampen the spirits of innovative DSC firms with limited resources.

On the other hand, there is always the possibility—although an uncertain one—that an overall high-growth economic scenario will develop across the primary DSC markets. By high-growth we mean a sustained, rapid recovery in developed economies along with consistent strong growth in emerging economies, particularly China, Brazil and India, which could enable a relatively faster adoption rate for DSCs.

1.4 Plan of this Report

In Chapter Two, we discuss recent technological improvements in DSC PV, including important breakthroughs in electrolyte and electrode materials, recent trends in substrate and encapsulation materials, and novel performance enhancement strategies with potential future importance, such as the use of quantum dots. We also examine how DSC compares to other types of thin-film PV technologies.

In Chapter Three, we look at the prospective markets for DSCs, including different segments of the off-grid PV market (indoor, retail, sensors, automotive, and military) and the potentially game changing BIPV market. Our overall eight-year growth forecasts for these markets and break up of

these forecasts by product and material type are also presented here, as is a discussion of some of the emerging opportunities for DSC in developing countries.

In Chapter Four we review the latest developments and strategies of key DSC firms, including those that provide value-added products (modules, chargers, etc.) and specialty chemical firms that supply materials with a focus on the revised strategic roadmaps adopted by several firms in response to current market conditions.