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The Status Quo of Taiwan's Photovoltaic Industry

(I) Supply and Demand of the PV Industry

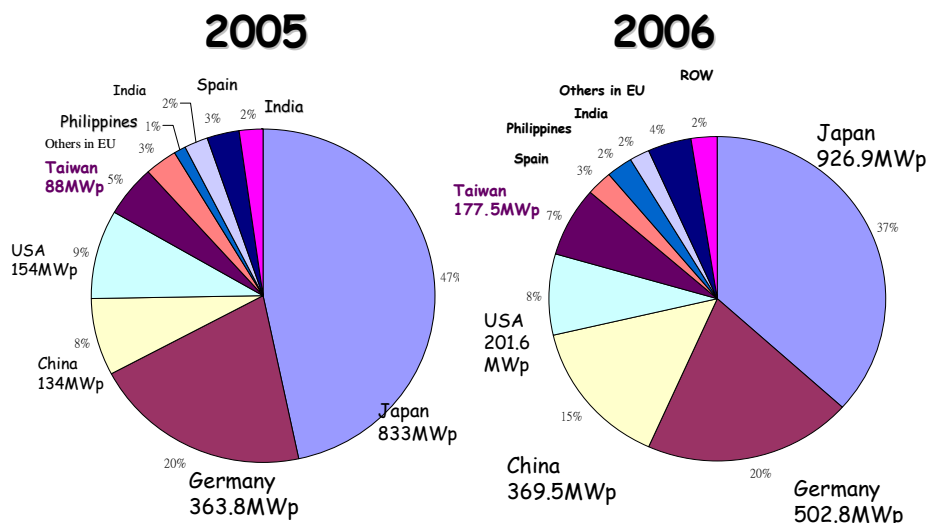
➤ Production capacity of solar cells in Taiwan

The solar industry in Taiwan started in 1987 with the production of amorphous silicon cells. The solar industry experienced an investment boom in 2003 as a result of the market demands in Europe and Japan. Startup companies covered various fields of supply chain in the solar industry, such as wafers, cells, modules, and system installation.

The PV industry in Taiwan has shown a rapid growth in sales revenue as reported by IEK/ITRI. The industry's revenue achieved NT\$7 billion in 2005 while in 2006, it had over NT\$21.2 billion with a growth rate of 300% (2% in global share). New reports revealed that the revenue for 2007 reached NT\$53 billion. An optimistic forecast for 2008 was estimated to reach over NT\$100 billion, NT\$150 billion in 2010 (6% in global share), and NT\$400 billion in 2015 (7% in global share). The investment in PV industry in Taiwan is still a hot topic. PV companies in Taiwan are also expected to exceed their total production capacity of over 2 GWp in 2008, although some existing companies are suffering from the shortage of poly-silicon supply. While newcomers are still expected, there will be new investments particularly on thin film solar cells including silicon thin films, CIGS, and CdTe.

The cell production from Taiwan reached 88 MWp in 2005, while a significant growth in cell production was reported in 2006 at 177.5 MWp. Taiwan has showed remarkable performance in the global markets. In fact, the cell production for 2007 achieved 360 MWp, placing Taiwan the 4th in

global output. PV News reported that Taiwan had a global share of 10%, with Motech achieving 176 MWp in production capacity, thereby ranking 6th in worldwide production (after Q-cell, Sharp, Suntech, Kyocera, and First Solar). Since Taiwan's solar cell industries are facing the shortage problem of poly-silicon supplies, companies such as CPC, Taiwan Polysilicon Co., Universal Semiconductor Co., and Muto Silicon Co. have announced to start the business of poly-silicon production. These enterprises will need some years for such a transition to be successful and fully operational. The supply of solar wafers is the major business for Green Energy Co., Sino American Silicon Products Co., and Wafer Works. Mospec Semiductors Co. has started the production recently. It is evident that cell production depends heavily on the supply of silicon.



Source : ITRI(2007) & PV NEWS (2007/06)

Global cell production in 2005~2006

Source: ITRI (2007) / PV NEWS (June 2007)

➤ **Crystalline silicon solar cell industry**

The supply of poly-silicon is the major concern for wafer manufacturers in Taiwan. MEMC, Hemlock, Solargiga, and DC Chemical Wafer suppliers are the main sources for Green Energy, Sino American, and Wafer Works with a total demand of over 700 MWp. The solar cell business dominates the solar industry in Taiwan, both in crystalline solar cells and thin film solar cells. The investment on Si solar cells began in 2004 with turnkey solutions from Germany. Intensive research and development to improve efficiency of localized production equipment will also be encouraged. The total production capacity reached a historic record of 1.7 GWp for crystalline cells and 198 MWp for thin film solar cells. Module capacity was around 228 MWp in 2007. The total capacity of Taiwan's PV industry is estimated to reach over 4 GWp in 2010.

The production of equipment and facilities are capital intensive in the solar industry. While local equipment providers are striving hard to survive in this field, local suppliers occupied only a small percentage in the total revenue. In 2004, more than 12 companies started their activity in the production of solar cell equipment, such as Mirle Automation Co., Delta Electronics Inc., CS Manufacturing Ltd., Contrel Technology Ltd., Gallant Precision Machining Co., Kenmec Mechanical Engineering Co., Ching-Hung Machinery & Electrical Industrial Co., Song Jaan Technology Co., Marketech International Co., Atma Champ Ent. Co., Schmid Automation Asia Co., Youtech Corporation. They focus on the development of diffusion furnace, cutting machines, etching stations, plasma etching machines, IR back furnace and laminators. Cooperation with foreign partners in technology development will help expedite certain R&D procedures and will therefore result in cost reduction.



Thin film solar cells and concentrated photovoltaic system

The investment on thin films started in 2005. In 2008, 10 companies, namely Sinonar Solar, Formosun Technology, Next Power, Nano Win Tech, Green Energy Technology, Sunner Solar, Sun Well Solar, Kenmos Photovoltaic, Arima, and Chi-Mei, launched their mass production. Most of them introduced well-established technology and turnkey solutions from Applied, Ulvac, Oerlicon, and Nano PV. However, they still put a lot of efforts to build their own know-how. The expected output in 2008 was over 198 MWp. As the market outlook for thin film cell occupies over 20% of the total market (2 GWp), the technological development to improve cell efficiency will be a great challenge for these companies.

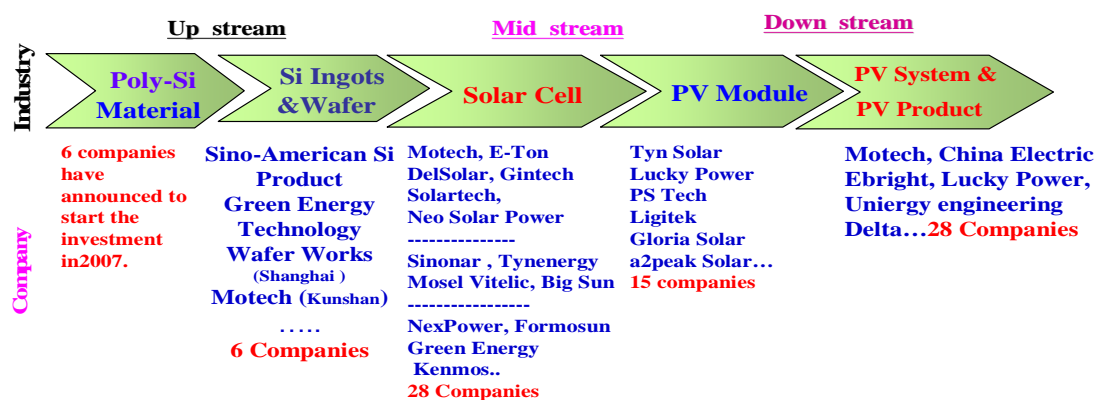
Taiwan has small activities in concentrated PVs in comparison with crystalline solar cells. Investments focus on GaAs wafers, concentrated modules, and tracking systems. Winfoundry Co., Arima EcoEnergy Tech.Co., and Compound Solar Technology Co. have started the GaAs wafer production business. Everphoton Energy Co., Arima EcoEnergy Tech. Co., and Delta Electronics Inc. focus on components, tracking systems, and parts.

(II) Gap in Industry Supply Chain, Investment Niche and Prospective Foreign Investors

More than 70 PV companies generated a sales volume of NT\$53 billion (USD1.65 billion) in 2007. These businesses cover wafer processing, multi-crystal growth furnace, wire sawing, wafer polishing, crystalline cell production, thin film cells, modules, and system installation (as shown in the following table). Cell production dominates the PV industry in Taiwan. The total revenues for cell production increased from NT\$1 billion in 2003 to NT\$14.8 billion in 2006. The revenues will reach over NT\$100 billion in 2010 and over NT\$240 billion in 2015 (BAU). The revenues for poly-Si

increased from NT\$50 million in 2003 to NT\$10 billion in 2007. Its growth is anticipated to reach up to NT\$31 billion in 2010. Only a small growth in module business has been observed with only about NT\$100~300 million is needed for investments. However, sales increased from NT\$200 million in 2003 to NT\$3.7 billion in 2007, expecting to achieve NT\$18.2 billion in 2010 and NT\$45 billion in 2015, if the market still remains in momentum. The growth of the system installation industry depends on government incentive programs. It is expected to achieve over NT\$2.5 billion in 2010.

Analysis results of the supply chain in PV industry shows that poly-Si and wafer supply are the key issues to the growth of momentum of Taiwan's PV industries. Intensive innovative technology improvement and efforts to bring down the cost are the major challenges.



Source : PVTC/ITRI (2007/11)

Supply Chain of PV Industry in Taiwan

Taiwan still has limited self-made PV equipment although PV manufacturers have been expanding their capacity dramatically. Over 50% of the equipment can be supplied by local equipment providers, however, the market share is not significant. For example, the equipment investment for production line of 30MWp could be in the range of NT\$250 million. For 30 production lines, the revenues will be over NT\$7.5 billion. In the investment for thin film solar cells, the cost for each new production will be over NT\$1.5 billion (30MWp per line).

Sales Revenue for PV Industry in Taiwan

Supply chain	2004	2005	2006	2010(f)	2015(f)
Ingot/Wafer	2.0	6.4	46.0	310	771
Solar Cell	26.0	55.0	148.0	1,000	2,488
PV Module	1.1	4.4	12.0	182	453
PV Product	4.0	4.4	4.8	7	11
PV System	0.5	1.0	1.2	25	307
Total Value, 100 million NTD	33.5	70.0	212.0	1,524	4,031

Source: ITRI (2008/April)

The investment boom in Taiwan has resulted in production expansion and growth in revenues. However, security of silicon supply, cell efficiency improvement, local supply of equipments for Si cells and thin film production should be resolved to meet the requirements of the global market demands and boost companies' competitiveness. The gap in industry supply chain includes the production of Poly-Si materials, with potential investors like Tokuyama, REC, Hemlock, MEMC, Wacker Chemie, Elkem, DC Chemicals, LDK, Mitsubishi, and Sumitomo. These companies have technological know-how and dominate the supply for Si worldwide. Most of the Taiwanese cell makers have signed long term contracts with these suppliers to secure Si materials.

Another gap in the supply chain is the acquirement of equipment for whole production line with turn-key solutions. Cooperation with leading companies in the directional crystalline furnace, block cutter, wire saw machines, diffusion furnace, PECVD, simulators for efficiency measurement. The major suppliers for these equipments are GT Solar, Spire Solar, Schmid for directional crystalline furnace; Meyer Berger, HTC for block cutters, wire saw machines, Centrotherm, Semco, Despatch for diffusion furnace, Shimadzu, Roth & Rau for PECVD, Berger Lichttechnik, NPC, Spectra-Nova for simulators for measurement efficiency.

Equipment for module production needs less capital (NT\$60 to 80 million for 10MWp). The leading companies are Schmid and GT Sola, etc. The investment in equipment development will benefit not only from the cost for local cell makers but is also a good way to penetrate into the world equipment market.

(III) Major Suppliers in Taiwan

1. Taiwan's Mature Industrial Infrastructure

The outstanding infrastructure of IT, display and optical disk industries in Taiwan has contributed to the civilization of human beings. Taiwan is the inevitable partner in the world industry. These imbedded characteristics in Taiwan such as global logistics management, scale up capability and marketing management provide the best bases for the investment of the PV industry. The current players in Taiwan, which have excellent experiences in semiconductor are Green Energy Tech. Co., NeoSolar, Dell Solar, Next Power, Chi-Mei, etc., have played major roles in the industry. Some of the companies have different strategies with cooperation with well known

research institutes such as UNSW in Australia. Another example is that Dell is working with Delta Electronics (its parent company) for the improvement of cell efficiency.

2.Vertical integration of supply chain

To solve the problem of poly-Si supply, the PV industries apply versatile strategies such as establishing long term contracts and integration of upstream and downstream supply chain. It is also the global trend to integrate the benefit inherent in each sectors of supply chain to keep the global competitiveness. Meanwhile, the early research for the next generation solar cell is another alternative for sustainable operation.

The globalization of PV companies has been accelerated due to severe competition in world markets and cost pressure. Companies like Motech and E-Ton have diversified their business into poly Si field. Motech invested on AE Poly Silicon company for silicon supply. E-Ton focuses not only on crystalline solar cells but also developed joint ventures with partners for thin film solar cells. E-Ton's acquirement of Adema (USA) for module production is also one example of an integrated supply chain. Green Energy has also invested in thin films and will launch its production soon.

A strategy to secure the poly-silicon has been developed through long-term contracts, joint ventures, stock shares, and alliances. The high dynamic activities of the PV industry will be the basis for cost advantage to occupy high global market share. For poly-silicon production, Siemens process (Silane&TCS) is still the main stream. The Siemens process occupiers over 90% of the market share. Fluid bed reaction (FBR) method shares only 9% of the silicon market. Newly developed methods such as physical metallurgical method will be expected with cost benefits and may take over 7% of the market in 2010.

3.Evaluation of the production capability for poly-silicon :

Siemens process starts with silane & TCS. It is a mature process but with mass investments on equipments and facilities (an investment for 1,000 tons needs at least US\$100 million). The handling of the byproducts is also an issue. The leading companies are HemlockWacker, REC, Tokuyama, and MEMC. Curently, the possibility for technological transfer to Taiwan is low. However, companies in Taiwan such as Universal Semiconductor Co. and Taiwan Polysilicon Co. (invested by San Fu Chemical Co.) have started the project for plant building.

Fluid bed reaction (FBR): Silane or TCS will be processed into granulate. Trace impurities contamination is one of the main issues. The process provided lower poduction cost (30 USD/Kg). However, FBR is still in the pilot production stage throughout the world. Wacker reported that FBR needs less electricity for production (only 1/3 of Siemens process). Major companies are MEMC, REC, and Wacker. The AE Polysilicon (USA), invested by Motech , is working on the process.

Silicon reduction method: The process started with silicon halide and with sodium or zinc as reduction agents. The process shows great cost advantage. Reduction with sodium has been in the pilot production stage. However, the safe handling of chemical active sodium has to be solved before mass production. Major companies, which are Silicon Research Inc., Taiwan Semiconductors Co., and Muto Silicon Co., have production projects in Taiwan as well. Chisso in Japan focused on zinc reduction method but is currently still in the pilot stage.

Physical metallurgy: The process integrated a wet chemical method with physical casting process. The process is low in cost (20~40 USD/Kg). Many

companies and research institutes in EU, Russia, and China are working in this field. However, real mass production is not reported due to the difficulty in controlling trace elements. Companies like Elkem Solar, JEF, Dow Corning, and Nippon Steel are very aggressive in the process. Big Sun Co. in Taiwan is working with Russian team to secure long term supply of silicon.

In 2010, the cell production capacity will be over 4,000 MWp. The consumption of silicon will be lowered to the range of 7~10 g/Wp. If the consumption of silicon was based on 10 g/Wp, Taiwan needs about 400 k tons of silicon (by utilization of 70%, it needs 280 k tons). Even the 7 companies in Taiwan have been successful in mass production, the total silicon capacity for Taiwan can not meet the needs from local cell makers. It has been reported that the supply and demand of silicon will be balanced in 2010. However, the balance will be affected by high oil price and the decreasing of installation cost. For Taiwanese PV suppliers, the supply of silicon will be a nightmare if the security of silicon supply can not be solved in the future. Cooperation with world leading companies through joint ventures and alliances should be considered. Silicon production technology with environmental friendly process will be especially encouraged in Taiwan

Another important sector in the PV industry will be the establishment of equipment development capability. Taiwan has established good and fine machinery industry that could be applied for PV production. Companies such as Mirle Automation Co., Delta Electronics Inc., CS Manufacturing Ltd., Contrel Technology Ltd., Gallant Precision Machining Co., Kenmec Mechanical Engineering Co., Ching-Hung Machinery & Electrical Industrial Co., Song Jaan Technology Co., Marketech International Co., Atma Champ Ent. Co., have been successful in penetrating into the global equipment market. The investment in the development of core equipments

(PECVD, diffusion furnace, solar simulators) are still attractive for foreign partners in the global markets.