PV facilities: opportunities for conversion and re-use of semiconductor fabs

Nate Monosoff, CH2M HILL, Oregon, USA

This article first appeared in *Photovoltaics International* journal's second edition in November 2008.

ABSTRACT

Crystalline wafer and thin-film photovoltaics manufacturing have experienced dramatic expansion in recent years, but future growth requires increasingly effective strategies to reduce costs and increase the competitiveness of PV power. Reducing PV manufacturing costs has been a prime focus of the industry. In the current climate, cost reduction is especially critical given the industry shakeout that many analysts are forecasting. Now more than ever, it is important to bring manufacturing capacity online quickly and cost effectively. The vast majority of commercial-scale PV manufacturing capacity is new construction (greenfield), meaning it is purpose-built on an unused piece of land; however, there are alternatives. This paper will outline opportunities for re-use of existing obsolete semiconductor fabs, and the steps required to convert from one manufacturing strand to another. This is an approach that offers manufacturers the potential advantages of reduced costs, more rapid ramping of plants to produce finished product, and the superior sustainability achieved through the re-use of existing facilities.

Introduction

Siting, design, permitting and construction of a traditional greenfield PV facility is a process that can take 1-2 years and exceed USD$75 million for up to 100MW. This process can vary widely depending upon the specific PV technology, scale, location, and building design involved. While PV manufacturing equipment typically represents the lion's share of capital expense for manufacturing startup, the financial and schedule costs of facilities are also important factors in manufacturing scale-up.

The alternative to greenfield construction is to retrofit existing buildings and sites. Going this route is attractive to cut costs and schedule, but it is not easy to find an existing facility with systems suitable for PV manufacturing already operating and ready to go. One intriguing option is to re-use or retrofit existing semiconductor facilities. PV manufacturing in an old semiconductor building is not an obvious match, but this approach is proving appealing enough that a number of PV and semiconductor firms are conducting in-depth assessments.

The semiconductor industry and aging 200mm fabs

The semiconductor industry has been growing and improving exponentially for decades, lowering costs and increasing the performance of its devices in an increasingly competitive market. This mature industry is subject to significant cost pressure and volatile cyclicality. The very survival of semiconductor manufacturers depends on their ability to achieve regular technological leaps – often of major proportions – to meet the demands of the "Moore's Law" dictum that calls for a doubling of chip capability every 18 months.

Semiconductor process and device improvements drove production wafer sizes from 150mm to 200mm in the mid- to late-1980s, and eventually to the current state-of-the-art, 300mm. Many 200mm fabs, built mostly from the late 1980s until around 2000, are now facing challenges as their capacity is shifting to more cost-competitive 300mm fabs.

Semiconductor fabs are not general use buildings. They are highly customized with complex and elaborate mechanical, electrical, and process (water, chemicals, and gas) production and delivery systems. Many of these systems deal with hazardous

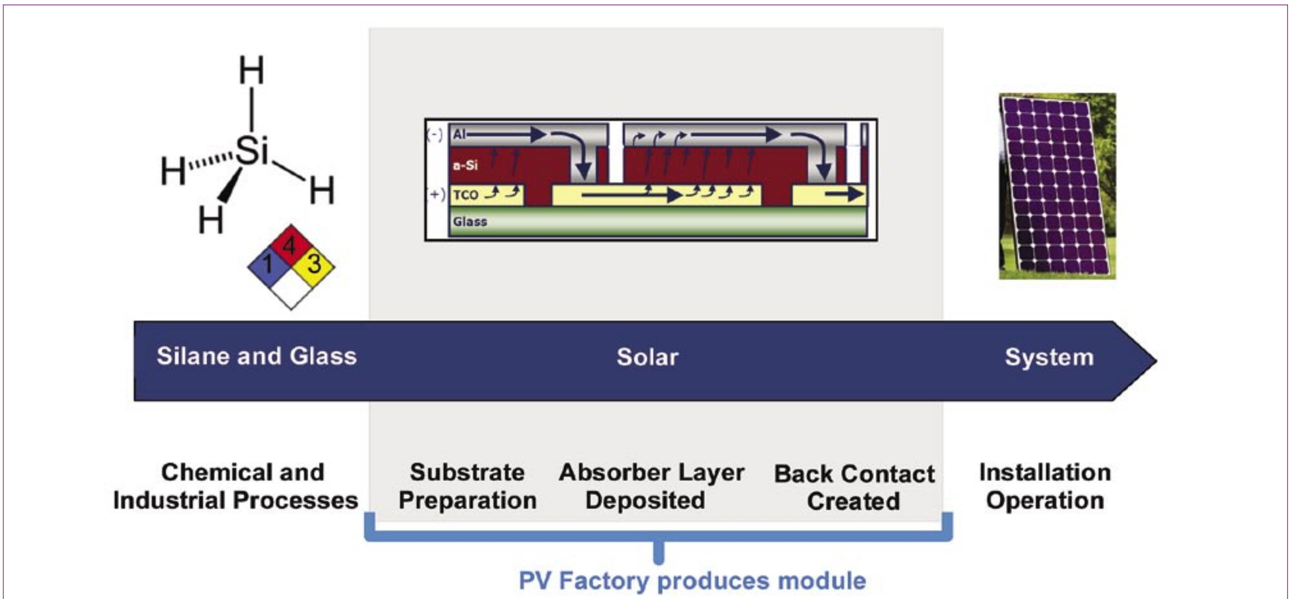

Figure 1. The processes, sequences, and materials related to PV manufacturing shown in this a-Si thin-film process diagram have many similarities to those of semiconductor manufacturing.

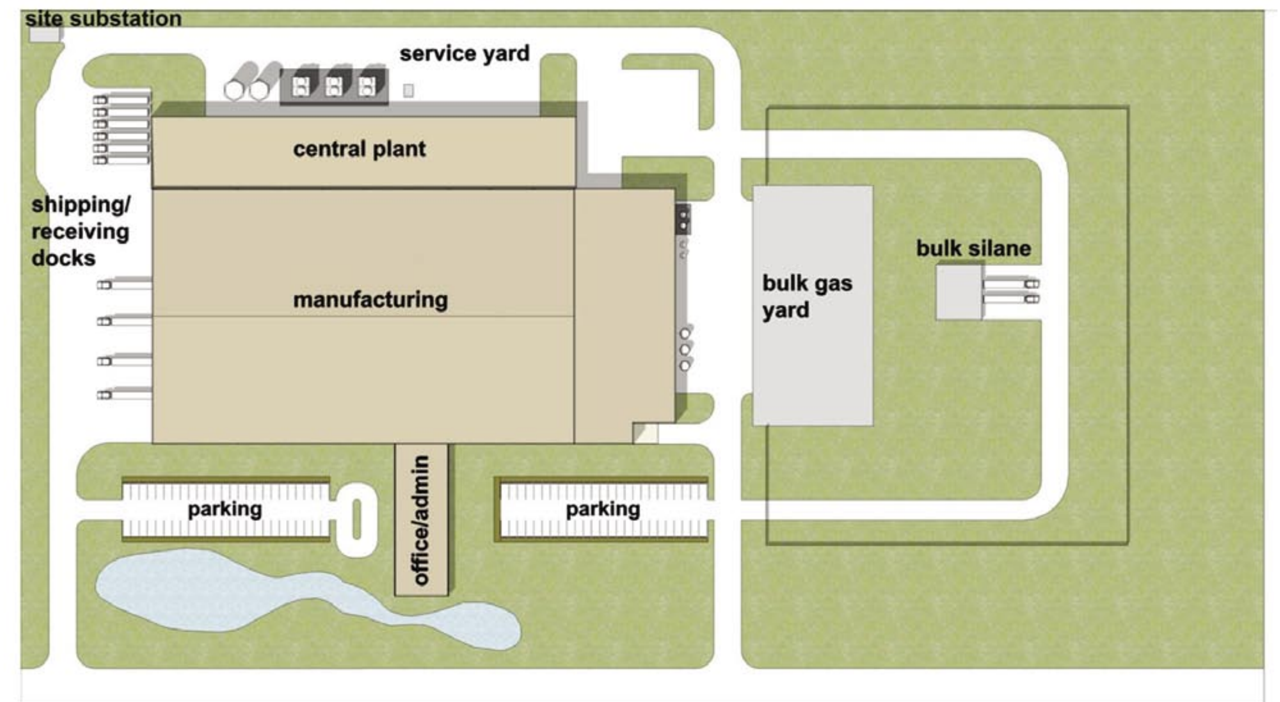

Figure 2. This typical hypothetical site plan for a 50MW PV manufacturing facility bears many similarities to that of a 200mm semiconductor manufacturing site.

and highly regulated materials. While this level of facility customization makes these fabs efficient facilities for producing specific types of semiconductor products, it also makes them very challenging to sell or convert to alternate uses.

Many non-competitive 200mm fabs are facing these challenges now, and many more will face these challenges over the next few years. Of the more than sixty 200mm semiconductor fabs forecast to be candidates for process technology upgrade conversions, CH2M HILL estimates that a quarter will be evaluated for PV. Which of these conversions succeed and which fail to meet expectations depends on how well PV manufacturers match their business strategies and capital improvement budgets to a potential fab conversion property.

The options for aging semiconductor facilities are few: convert the fab or mothball it.

In the past a reasonable option for those who needed the manufacturing capacity and had sufficient capital was to convert a 200mm fab to 300mm processes. Converting to 300mm is an expensive and difficult option that is not always a possibility due to limits of the building and facility support systems. Also, improvements in the efficiency of 300mm process technology have reduced the need for new 300mm facilities.

Mothballing a 200mm semiconductor facility has drawbacks. Moving equipment out and locking the doors creates the prospect of a non-productive and expensive-to-maintain building. To maintain value, the facility cleanroom and many of the facilities support systems must continue to be run even when the semiconductor fab is not in use. Operating these facility systems can cost millions of dollars annually. In addition to annual operating costs, idle or mothballed fabs also continue to incur property taxes and other liabilities. Government regulations may also require the owner to decommission systems containing hazardous material systems that are no longer in regular use.

"There is the potential opportunity for the PV industry to acquire these assets at a low cost and retrofit them into profitable PV manufacturing facilities."

Because converting to 300mm and mothballing a 200mm fab are difficult and expensive options, there is the potential opportunity for the PV industry to acquire these assets at a low cost and retrofit them into profitable PV manufacturing facilities (see thin-film example in Figure 1). According to analysis by CH2M HILL, there are a number of existing 200mm semiconductor fabs that are potentially good candidates for retrofitting into PV manufacturing.

PV manufacturing in a 200mm fab: a decent fit

At first glance, it may not appear that PV manufacturing is a good fit for such elaborate and complex facilities. No-one would build a new greenfield semiconductor fab-style building for wafer-based or thin-film PV manufacturing because this type of construction would not be cost-effective. However, CH2M HILL has identified a number of advantages and potential benefits of reusing these facilities, and determined that with careful planning and assessment, such a conversion is feasible from both an engineering and cost perspective.

The following is a review of specific issues to be evaluated when considering the viability of converting a semiconductor fab into PV manufacturing.

Business issues

Proximity to critical supply chain materials

PV manufacturing consumables can vary significantly depending on the manufacturing technology required for a particular PV product. The good news is that many materials and consumables required in PV manufacturing processes are also used in the semiconductor industry. Choosing a location with an existing semiconductor plant could be advantageous as there is usually already a supplier infrastructure that can safely and cost-effectively provide the bulk and specialty gases and chemicals required for PV manufacturing.

Access to affordable and skilled labour

A skilled workforce is an important component in justifying the business case of any PV manufacturing operation from both a cost and a quality perspective. Business plans for new manufacturing operations often depend on meeting efficiency, yield, and throughput improvement milestones. The availability of experienced engineers and managers who understand the materials, processes, and equipment

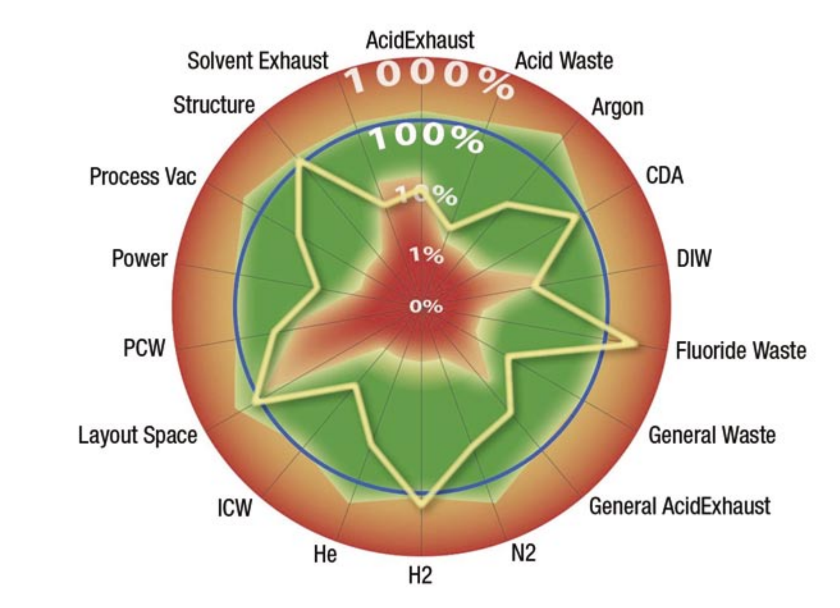

Figure 3. The chart above shows the results of a CH2M HILL study comparing the requirements for a generic 100MW a-Si manufacturing toolset (a composite of major tool vendor requirements) to facility and utilities available in a generic 200mm semiconductor fab. The green regions represent the extents of the "turn-up" and "turn-down" limits per system. Many PV system requirements are shown operating in the green regions, indicating that little effort is required to modify that system to support its new toolset.

common to semiconductor and solar manufacturing is critical to meeting aggressive solar manufacturing ramp plans. The workforce of a semiconductor plant is an excellent pool from which to draw upon in staffing a PV manufacturing plant.

Proximity to customers

Finished PV panels are bulky and heavy products. Freight and logistics costs required to transport them from plant to customer can be a significant factor in total delivered panel costs. Many existing 200mm semiconductor fabs are located in geographic areas that are in close proximity to potentially large PV markets.

Cost and availability of utilities

Semiconductor manufacturing is energy and water intensive. It is likely that existing semiconductor fabs are in locations with access to affordable power, water, and other critical utilities.

Accepting regulatory environments

Many of the gases and chemicals used in PV manufacturing are also used in semiconductor manufacturing. Regulatory agencies near existing 200mm fabs are likely to be more comfortable permitting facilities using these gases and chemicals than locations new to high-tech manufacturing. This built-in familiarity can translate into a smoother and more predictable permitting process.

Building issues

Manufacturing and support space

In general, a 200mm semiconductor fab is a two- to four-storey building with a clean core space on the top floor for clean manufacturing. The core level immediately below is typically a clean support space. The bottom storey and the rooms surrounding the core spaces on all levels are typically less clean support spaces. Separate buildings and areas nearby usually serve as a Central Utility Building (CUB), gas supply and distribution yard, and offices.

In the more modern fabs, 200mm cleanroom floor space (waffle slabs) should generally support 60-200MW of PV production depending on manufacturing technology. According to some recent analysis, this target range of annual solar manufacturing output could represent a potential "sweet spot" for efficient economies of scale. (Again, this is an assumption that is technology-dependant.) Site support areas in a semiconductor fab are typically many times this cleanroom area, and are suitable for reconfiguration into raw and finished goods storage and staging, spare parts storage, consumable storage and distribution, and human resources functions.

Depending on a fab's design, column spacing and other building features in support spaces can make conversion to certain PV requirements such as warehousing challenging, but not prohibitive (see Figure 2).

Structure and interior clear heights

200mm facilities should have sufficient structural strength and interior clear heights in the cleanroom to handle solar wafer or thin film equipment (up to around Generation 5 for typical glass form factors) from the major vendors. Clear heights and structural strength in support spaces can limit warehousing depending on configuration, but with some clever engineering and planning, these challenges shouldn't be prohibitive. PV requirements vary by toolset and technology, and a clear case for physical layout must be made before starting detailed analysis. For certain PV equipment, long clear spans and cranes can be required, and some shoring and structural reinforcement can be required in other retrofit activities. Inter-floor and general material transport issues arising from structural elements such as columns, sheer walls, shafts, and elevators can also be addressed with good planning and renovation design.

Utilities and facility systems

200mm semiconductor fabs have many of the same mechanical, electrical, and process systems required by both wafer and thin-film PV manufacturing. While semiconductor fab systems generally have huge excess capacities and many more points of connection than PV toolsets require, these systems can be "turned-up" or "turned-down" with good design to better meet the demands of the specific PV technology being applied. In most cases, systems must be "turned-down" to accommodate PV manufacturing, but there are exceptions to this norm.

If significant detuning of facility systems is required, the new configurations may operate outside of original equipment's design set-points. These systems may not operate at their highest efficiency, and operating costs will not scale perfectly with use.

Mechanical systems

Most 200mm fabs have huge excesses in air handling capacity, contamination control, and other facility specifications compared to PV requirements for the processing tools and the factory spaces that house them. However, this excess capacity can be "turned down" with relatively little effort by deactivating or removing redundant pumps, air handlers, compressors, sensible cooling coils, chillers, condensers, fans, boilers, and other mechanical equipment. There is also the potential to run the remaining equipment at reduced rates. To offset reconfiguration costs, pre-existing semiconductor-related equipment can be removed and sold on the relatively active global market, or at least be liquidated for its scrap value.

Electrical systems

While total electrical loads in semiconductor facilities are typically more than sufficient to supply PV processing tools, the location of loads must shift significantly from their former semiconductor processing positions. This can involve additional costs associated with removing, re-sizing, and re-installing existing distribution panels, cable trays, and cabling. However, these systems have

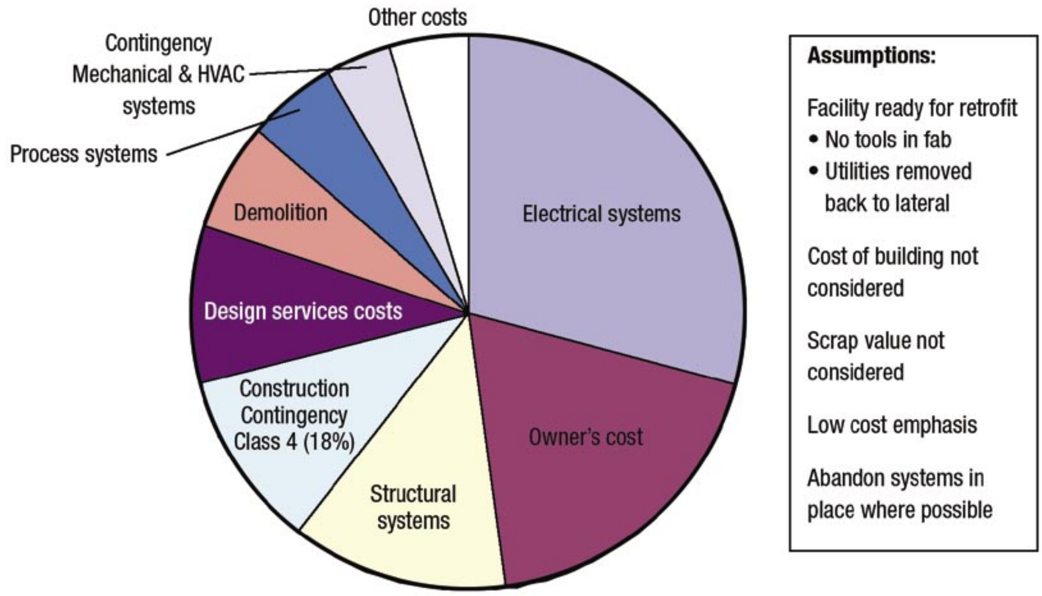

Figure 4. The chart above presents a breakdown of retrofit costs by area. Other costs include life and safety systems retrofit, instrumentation and controls retrofit, architectural systems retrofit, and fire protection retrofit.

a relatively high scrap value, creating the potential to offset the reconfiguration costs of a building's electrical infrastructure. In the CH2M HILL study example below, electrical costs are a significant portion of total direct retrofit costs, but scrap value is not considered. Total retrofit costs are still low compared to greenfield construction.

Water, wastewater, and process chemicals and gasses

Most of the bulk systems required by PV manufacturing exist in a 200mm semiconductor facility. As noted previously, these are among the systems that can often be "turned-down" significantly to align with PV requirements.

The chart in Figure 3 shows some of the results of a CH2M HILL analysis of the utility requirements and other attributes of a 100MW PV a-Si toolset (yellow line) compared to the "turn-up" and "turn-down" limits of a generic 200mm fab (green regions). Many building systems are in appropriate ranges and should entail minimal retrofit efforts.

Permits

Permits can pose significant lead-time constraints when planning greenfield PV manufacturing. Re-using an existing 200mm semiconductor fab and its existing permits can result in significant schedule advantage.

Wastewater permit limits in existing 200mm semiconductor permits should cover most of the waste products related to PV manufacturing, but careful and specific analysis should be conducted because wastewater constituents and volumes can vary widely depending on the manufacturing process, tools, and scale of operation. In the CH2M HILL analysis presented above, fluoride levels in wastewater is one area that should be closely examined to confirm that it will not exceed local discharge limits.

It is likely that existing storm water permits will not need to be modified for most PV re-use scenarios assuming that the project does not involve construction modification outside of the existing building shell. However, in all cases, existing stormwater permits should be reviewed to confirm that no modification will be required.

Air discharge permit conditions are facility-specific and should be considered on a case-by-case basis. However, having existing air discharge permits for a 200mm semiconductor fab may reduce the effort and schedule for permitting any new use.

Accidental release prevention also must be considered on a case-by-case basis, but many programs and protocols carried over from the semiconductor operations can have value in helping establish their equivalents in PV manufacturing. Some hazardous materials common to both types of operations can enable re-use of existing tanks and systems as well as their existing certifications.

Hazardous occupancy codes for 200mm semiconductor fabs vary around the world. PV manufacturing facilities tend to utilize fewer dangerous materials in lower volumes, and are typically classified in a lower hazard category. This has the potential to streamline the new permitting or permit re-classification process.

Summary

Aging semiconductor facilities are facing a dilemma, as they are increasingly being outperformed and displaced by 300mm fabs. The PV manufacturing industry may be able to take advantage of these underutilized facilities and transform them into profitable manufacturing centres. This strategy offers benefits for both the semiconductor fab owners and PV manufacturers; fab owners can extract new value from their outdated fabs, and PV industry manufacturers can significantly reduce project schedule and potentially reduce facility cost. This strategy also offers the satisfaction of knowing that the sustainability of these projects is being enhanced through the re-use of existing facilities.

According to the CH2M HILL study, PV manufacturers may be able to reduce facility costs by up to 50% compared to a greenfield approach, and reduce schedules by between 30-50%. While this scenario looks attractive, especially with a premium on reducing initial capital cost and speed to market, the details of specific fab re-use opportunities require a detailed analysis of retrofit and permitting requirements.

The success of any semiconductor to PV conversion or retrofit will depend on the ability to manage change in complex and fast-moving environments, something both the semiconductor and PV industries understand well. These industries have a shared heritage of ingenuity, adaptability, and reduction of costs per unit of performance that encourages exactly this type of creative solution for manufacturing cost and schedule challenges.

About the Author

Nate Monosoff is a Technologist with CH2M HILL's Industrial Client Group. He has extensive experience in early stage factory planning, industrial engineering, modelling, utility planning, tool layout, and consulting for manufacturing and technology development clients. His expertise spans photovoltaics, nanotechnology, FPD, MEMS and semiconductor manufacturing, and includes cost modelling, business start-up consulting, and strategic planning.

Enquiries

Website: www.ch2m.com/electronics