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Water management planning for photovoltaic manufacturing facilities

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ABSTRACT

Various economic and political influences continue to push high-volume manufacturing of semiconductor and PV devices into relatively arid and water-constrained geographies. As the social, economic and political focus on water resources and sustainability increases daily, the need to address the supply, use and disposal of water at manufacturing facilities is growing increasingly more complex. Historically, PV manufacturing has not been considered a major water consumer so there has been little scrutiny of water management. As the costs of water and wastewater disposal spiral upwards, water resource management becomes a significantly more important factor in the capital and operating costs of PV manufacturing. This paper outlines the preparation of a water management diagram (WMD) with reference to the development of water systems for new PV manufacturing plants, and discusses some cautionary design considerations.

Introduction

Like other modern industries, PV manufacturers are using multiple criteria for selecting new manufacturing sites. Typically, water supply (and discharge) and associated costs of water are not at the top of the list, and sites are often selected with unique water management constraints. An increasing volume of PV manufacturing is being planned for regions where water has become a critical resource. Many oil-rich Middle Eastern nations are looking to establish non-petroleum industries for their future generations; since solar power generation is well suited to these geographies, PV manufacturing facilities are being targeted.

In order to most effectively manage the cost of water operations and the complexities of environmental permitting and social benchmarking, a comprehensive water management plan should be adopted for the facility or site, if not for the corporation as a whole. A primary tool for development of the water management plan for a given site or facility is the water management diagram (WMD). The WMD should be developed as early in the facility design as practical, with the understanding that there may be adjustments during the course of facility design. More frequently nowadays, initial planning permits require estimates of water consumption and wastewater discharge, as well as definitions of measures used to reduce consumption and recycle water internally.

A typical WMD should include:

- all known and projected water users, with supply water criteria and wastewater characterization;
- offsite water sources, flows and quality;
- onsite water treatment systems, with input chemicals, output residuals, output water and quality;
- offsite effluents and residuals from treatment.

This discussion focuses on the general types of information required to prepare the WMD and some caveats to be considered in developing water systems related to designs for new PV manufacturing plants.

Water use requirements

The core water needs for a PV manufacturing plant begin with the specific aqueous processes used in manufacturing, and then propagate into the manufacturing support systems and energy utilities that utilize water. Domestic water needs, e.g. potable water supply and sanitary wastewater, are a function of the site population and related demands, and add to the facility water requirements. The heart of the WMD for the facility will be the process requirements, with support requirements stemming out from this core.

Process water

In the case of silicon wafer PV, the processes requiring water typically include various cooling and cleaning steps associated with bricking, cropping, wafer sawing, wafer removal and cleaning; chemical make-up and rinsing associated with feedstock etching, silicon reclaim, texture etching and isolation / PSG etching; and miscellaneous processes such as glass cleaning. For CIGS on glass the wet processes may only include glass cleaning, cadmium deposition and in situ equipment-cleaning operations. Larger silicon-based plants are more aggressively pursuing cost reduction practices with kerf reclaim and carbide slurry reclaim. Inclusion of these types of system increases the set of process-water requirements. Regardless of PV type, each process should have its water quality and use rates established and in line with the manufacturing process technology.

One of the challenges to water treatment system design is obtaining the specific level of water quality required for each process, especially in emerging PV technologies. The manufacturing process for each step may come from the process equipment supplier, from internal development by the PV manufacturer, or from a third-party process technology supplier. A given project may have a combination of all of these, further complicating the resolution of the number of different water qualities required for the various processes.

Users are accustomed to referring to 'city water,' 'RO water' and 'DI water,' since those are the systems they had in development in previous manufacturing facilities, without realizing that none of these three systems has any industry-accepted quality parameters. Simultaneously, equipment suppliers give resistivity specifications for deionized water that might range from 5 to 15MΩcm, without realizing that this range is not normally available with conventional deionization technology (e.g. mixed-bed ion exchange, which generally delivers more than 17MΩcm when operated effectively).

In the end, from a practical standpoint, the three categories of water quality mentioned do generally work their way into the PV facility design. City water is set as the quality level for incoming supply water, which generally meets USEPA drinking water standards (with some exceptions to be discussed). This water is used to supply relatively dirty processes such as saw coolant, brick rinsing and other front-end rinsing. Deionized water, with nominal resistivity greater than 17MΩcm, is used for all steps requiring a consistent supply of clean water for chemical processing and critical cleaning. RO water is an intermediate quality that is generally hard to define in terms of specific quality parameters. It is often used for a

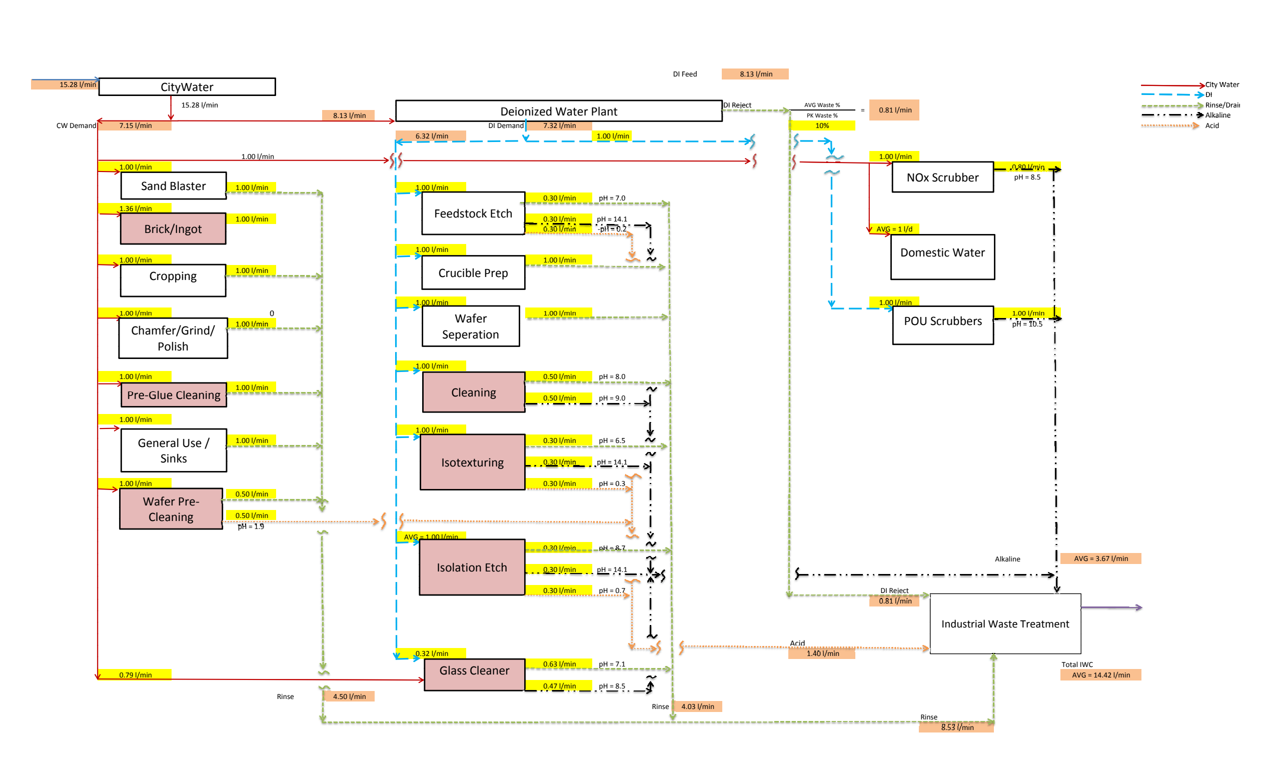

Figure 1. Base WMD for a silicon PV factory.

few manufacturing steps, but is more often specified for facility support systems.

Process-water requirements are a direct function of the processes performed in specific types of equipment and are therefore not at the discretion of facility design. In order to prepare a good WMD, the specific criteria for water supplies should be established early in the project.

Process and facility support systems

One step away from the direct processing of the product are a number of systems designed to support the manufacturing process. These may be supplied along with the process equipment or provided by a centralized system in the facility. It is easy to underestimate the significance of the design of some of these systems for water management.

Scrubbers

Any PV manufacturing facility that utilizes wet etching, plating and vapour deposition processes is likely to require abatement of one or more process exhaust streams. Depending on the facility size and tool set, air abatement may involve a point-of-use (POU) system connected to dedicated tools, or a plant-wide system with a network of collection ducts distributed to multiple tools with similar exhaust contaminants.

The use of packed-bed towers using water for scrubbing of acid and ammonia vapours is reasonably well understood and provides adequate protection for most aqueous cleaning processes. The water requirements are dependent on the scrubber capacity and make-up water quality. The use of chemicals to control pH in these scrubbers is a common practice, but has its pros and cons when weighing water use, chemical consumption and wastewater disposal.

In the fairly common case of silicon etching with acid mixtures, including nitric and hydrofluoric, a significant amount of nitrogen oxides ($NO+NO_2$, or NO_x) is liberated. NO_x is regulated by the USEPA and many other international authorities and requires more aggressive chemical management in the scrubber. If an NO_x scrubber is required, it will have its own make-up water demand, but more importantly a more complex wastewater blow-down. Though not specifically regulated, the silicon etch process may produce silicon tetrafluoride in the exhaust, along with NO_x and hydrofluoric acid fumes. Significant levels of silicon and fluoride in the NO_x scrubber can lead to increased chemical consumption and scaling if not planned for appropriately.

PECVD and similar deposition tools typically require abatement of a mixture of corrosive and flammable/pyrophoric

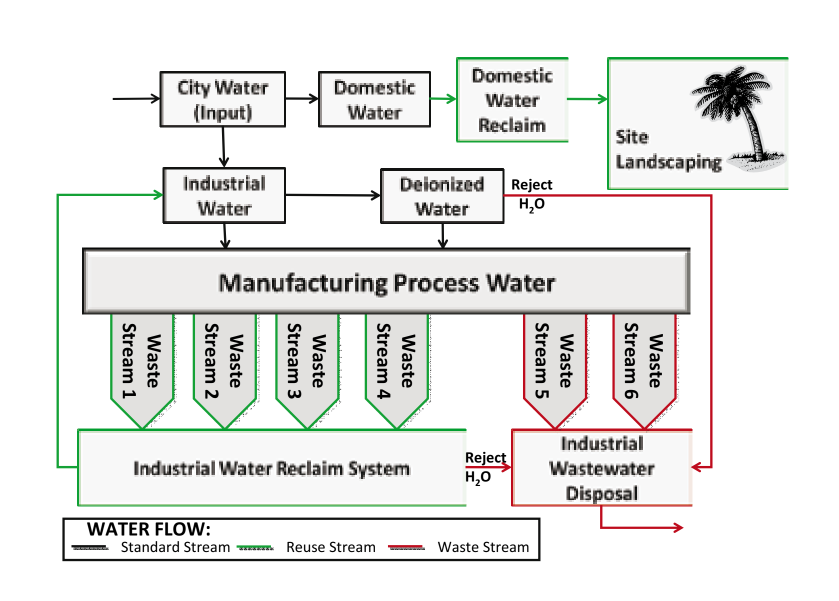

Figure 2. Water reuse scenario for a >120MW PV manufacturing facility.

gases. The most common abatement for these processes is a POU unit with a combustion chamber followed by a wet quench/scrubbing chamber. Due to the high level of fluoride and high temperature of this liquor, hard water will tend to form calcium fluoride and other calcium salts, which deposit in the workings of the scrubber, reducing capacity and eventually clogging it.

Due to scaling concerns in both the NO_x and POU scrubbers, they are often specified to receive RO water. It is likely that, in most cases, simply softened water would be adequate for these. Likewise, scrubbers offer a good opportunity to utilize relatively low-quality reclaimed water, as long as the scaling issues are addressed.

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For purposes of WMD development, it is important to note that wet scrubbers fundamentally evaporate a continuous quantity of pure water into the atmosphere. While the total volume may not be large, this effect contributes to increased concentrations of chemicals in the wastewater.

Cooling water

Most manufacturing facilities have some requirements for cooling of process and facility equipment. In the case of silicon wafering, furnace cooling water becomes a high-use, manufacturing-critical system. Emergency cooling water for furnaces can introduce another level of complexity in water management. Critical cooling of furnaces in the event of power failure can be supported in a number of ways, including expanded water storage capacity.

Typical process cooling water (PCW) systems consist of closed-loop water circuits that provide water at a specified temperature to the tool and reject transferred heat from the PCW to a secondary system. The secondary system may consist of an evaporative cooling system (cooling tower), a CFC-based chilled water system (which in turn rejects its heat to a cooling tower), or some other type of cooling cycle.

Independent of direct-connected PCW cooling, a significant amount of heat from process tools is rejected into the air recirculating in the building. In this case, the tool heat is rejected to the chilled water portion of the building air-conditioning system. In large facilities, this would include chillers and cooling towers, but may simply involve air-cooled direct expansion units that are much less energy efficient.

The industry-standard concept for cooling systems design includes rejection of heat through evaporative cooling in cooling towers. The water quality and related management within cooling towers is a discussion in itself, but the fundamental concept of evaporating pure water to reject heat from a plant significantly complicates the overall water management of the facility. Regardless of water quality considerations, every calorie of heat rejected results in removing unrecoverable pure water from the site, increasing water demand and raising the concentration of all of the constituents in the site wastewater. This impact is exacerbated in hot climates, where a significant cooling load is required just to cool make-up air to the required indoor temperature.

Cooling towers are often considered a good opportunity for reusing lower quality water. While this may be of merit, it is critical to evaluate the impact of the concentration effect of the tower on wastewater discharge. For a recent project in Saudi Arabia, the design included ammonia refrigeration-based cooling, which utilized air-cooled condensers. The capital cost was considerably more than the industry standard, and energy efficiency slightly less, but in the context of water supply limitations, it was a major factor for project success.

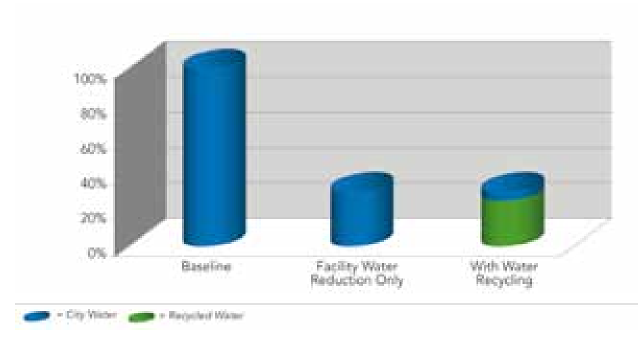

Figure 3. Potential reduction forecast of incoming water – reduction and recycling impacts.

Domestic water

Planning and design of sanitary water systems is a fairly well-defined practice, based on such simple factors as site population requirements for office, food, recreational, healthcare and other personnel facilities. There is little flexibility in the ability to optimize domestic water use, as system designs are heavily dictated by plumbing and sanitation codes.

In remote or developing areas, there may be no sanitary-waste infrastructure for connection. Packaged sanitary-waste treatment systems are readily available, but depend on not being loaded with process wastes. Onsite-treated sanitary effluent may be made suitable for reuse in agriculture. It is not conventional to return sanitary waste to reclaimed process-water systems, as the sanitary use is small compared to process systems usage levels and the potential contamination risk is moderately high. With the increased use of reclaimed tertiary effluent from municipal treatment plants, as with Singapore's NEW water and Fremont's purple pipe systems, consideration of onsite reuse of sanitary waste may become more popular.

Miscellaneous uses

There are always a number of assorted water uses that are not specifically identified or tied directly to processes. Analytical labs, parts cleaning, product conveyance and similar activities use unpredictable amounts of water and can inadvertently contribute unplanned contaminants to a wastewater or reclaim-water treatment system. Some of these minor uses may not be identified in early planning, but it is important to include them in the final water management scheme.

Supply water

Water supply to a manufacturing site is generally limited to the existing resources and infrastructure in the area of the site. Although the specific nature and cost of water are not primary site-selection criteria, the availability of a reliable water supply usually is. Most domestic water supplies are regulated to quality standards, but the actual quality delivered to a site will vary greatly within these standards.

Of course, the availability of adequate supply water volume is most important, but the quality of that water has a major impact on its use in the process, on the cost and complexity of process-water treatment systems and on wastewater disposal. In general, the higher the total dissolved solids or salinity and the higher the hardness, the more costly will be pretreating for process-water uses. Variability of water quality year-round must be reviewed to assure treatment systems are robust enough.

In parallel with the concentrating effect of cooling towers and scrubbers, the dissolved material in the incoming water significantly affects the total dissolved solids (TDS) of the wastewater from manufacturing. This is readily tracked in a WMD where the quality of the incoming water is allowed to be entered into a balancing model.

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Increasingly, alternative sources of water are being made available to industry from regional water reclaim activities. Treated municipal wastewater can be clarified and sanitized to a level that is quite suitable for onsite use in manufacturing and cooling systems. A new PV plant in California was required to show in its permitting documents how the future 'purple pipe' reclaimed water would be integrated into the facility upon its arrival in the near future; of course, there is little data available on the long-term water quality from this source. These options can have significant offsite resource management implications and should be considered on a local basis. One factor to consider is the impact of the wastewater from the new PV plant, in terms of influencing the quality of the reclaimed water derived from the very wastewater system to which the plant discharges.

Site effluent constraints

Surprisingly, the main constraints to increasing internal reclaim in manufacturing facilities are the limitations on wastewater discharged from the site. Fundamentally, a PV manufacturing facility brings in water from offsite, adds chemicals to it during processing, then evaporates away pure water in scrubbers, cooling systems and humidification systems. From a site balance perspective, the resulting wastewater will be significantly higher in concentration than the incoming supply water. Add to this efforts to treat and return process and domestic wastewater back to process water, and the effluent rises in concentration of contaminants proportionally to the rate of reclaimed water.

The principal constituents in wastewater can be categorized as dissolved solids (salts and minerals), dissolved organic matter, and suspended solids (both organic and mineral). Treatment processes are available to destroy some and remove all of these contaminants, but with varying degrees of cost and practicality. Organic matter can be degraded biologically and suspended solids removed with clarifiers and filters, resulting in solids for offsite disposal. However, dissolved solids are a different challenge. Specific regulated substances such as cadmium and fluoride can be targeted for treatment, but this usually results in further chemical addition, leading to an increase in TDS. The TDS limits for wastewater vary by site, but are becoming more challenging in the light of increased TDS in supply water, use of softeners in local residential use and the ultimate discharge point of the wastewater (sea, river or other).

In the extreme case, variations of 'zero liquid discharge' (ZLD) can be pursued at significant capital and operating costs. Such systems typically target membrane and thermal separation technologies to increase the salt concentrations up to brine or crystallization states. Use of solar evaporation in brine ponds is a common element in arid climates where land area is available for large ponds.

Conclusion

In the end, the choice of water treatment strategies is developed from a complex set of criteria, many of which are mutually interactive. Development of a water and material balance model estimating water use rates, contaminants and treatment efficiencies is required to evaluate the available alternatives within the constraints defined by incoming and effluent water. Invariably, capital and operating costs become significant decision drivers. The question is, what cost does one put on the future value of water?

About the Author

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