

## Tracking in PV Production: Part 1 Traceability from A to Z

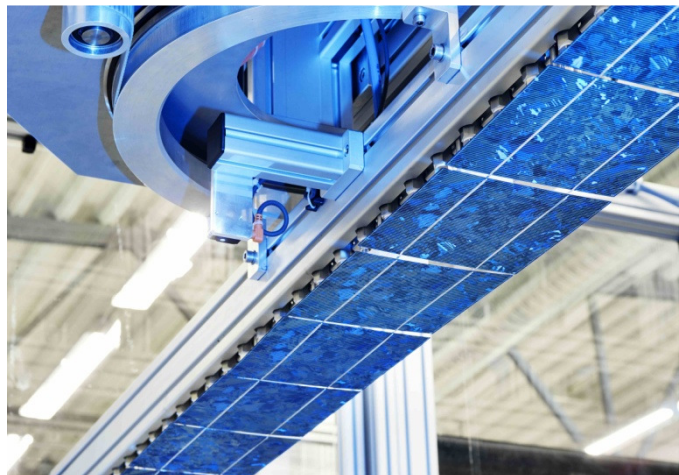
This is the first article in a series entitled “Tracking in PV Production”, from Prediktor. These articles cover all aspects of tracking in PV production and the series is divided into 4 parts. This 1<sup>st</sup> part defines the meaning of tracking in PV production and provides some examples of the benefits of tracking.



The ISO 8402 standard defines traceability as “The ability to trace the history, application or location of a product by means of recorded identifications”. This is a broad definition, and in practice it is possible to have an operational tracking system with different levels of coverage. The important point is to decide the depth, breadth and precision of the tracking needed.

### Tracking depth

**Depth** in tracking is related to how far forward and backward the system should track information. Wafer production can be tracked internally in a production unit from ingot to wafer delivered to customers. The tracking depth is increased if the wafer is tracked further, until its use in cells and further still to produced modules and PV systems. The depth can also be increased backwards in the production chain by tracking back to the polysilicon used as raw material for the ingot production.



*Traceability is an important function in cell production*

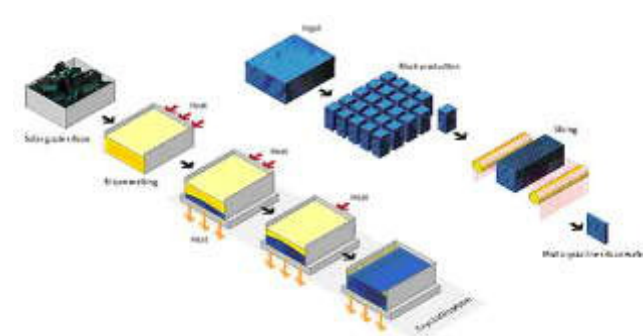
If the tracking depth spans several production units and transportation stages, as well as several business units, this is usually called **production chain tracking**. This creates additional challenges because the business units must mutually agree on a protocol for exchanging tracking information, and because some of the data to be exchanged may be commercially sensitive.

## Tracking breadth

**Breadth** in tracking describes the amount of information that is collected and associated with material while it is moved, processed and transformed from raw material to finished product. In the production of silicon wafers, if only information on ingot identities and quantity throughout the process is collected, then the tracking breadth will be small. However, if additional information on ingot analysis and process conditions such as temperatures, pressures, set points, and test results are collected, then the tracking breadth is increased.

Tracking breadth is important if the information is to be used for quality assurance and process optimization.

## Tracking precision



Tracking **precision** refers to the level of accuracy with which a tracking system can ascertain a material's movement within a process. To illustrate, we will use an example from the production of silicon wafers. The production process is shown in the figure.

### *Production and tracking of silicon wafers.*

A high level of precision is obtained if each individual wafer can be identified and tracked backward through the production process, including the wafer's position in the block it was sawed from, and that block's position in the ingot it was made from. The precision would be considerably lower if we only tracked back from boxes of wafers or produced batches. With low tracking precision, the factory will not be able to benefit from tracking information to optimize the production processes.

A high level of precision is obtained if each individual wafer can be identified and tracked backward through the production

Tracking precision may also be limited by process conditions. For example, if large volumes of intermediary products are mixed, precise tracking of materials through this process step will be difficult.

Tracking precision is also reduced by recycling of material within the process, as some material in one production step will be mixed back in at an earlier production step. A high-quality MES can help keep track of the recycled materials in a factory. For example, with ingot production, when the tops, tails, sides and pot scrap are recycled back in the process to make new ingots, the MES can keep track of important information about these recycled materials. By keeping track of the electrical resistance of the recycled material, the MES can calculate the correct doping amount to be added to the crucible when the recycled materials are mixed together with new polysilicon to be melt down to form the ingot.

## Tracking technologies

To suit different manufacturing practices, a tracking system can be simply implemented without machine based data technology. Such a system would be based on paper reports and manual registrations. However, the scope of registrations will be limited and it will be time consuming to search through the manual data. Significant improvements could be made if

modern computer technology is implemented at the factory to make full use of the tracking system and optimize the factory processes.

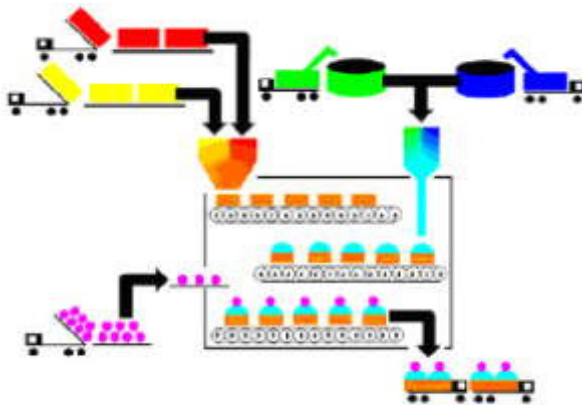
The main functions in a tracking system are data collection and data storage/data modeling.

### Data collection

The tracking system must be fed with data indicating which raw materials, at what time, enter the production and how these are transported and transformed throughout the process. In addition, data which can be related to the different material units, processing stages and buffer points are also collected.

Data collection is normally done with the help of different methods: **automatically** with PLCs, control systems, online analytical instruments and RFID units, or **manually** with operator screens, barcode readers or similar. Tracking systems can read some tens to several thousand signals per seconds, depending on the breadth and precision of the tracking.

### Data storage and data modeling

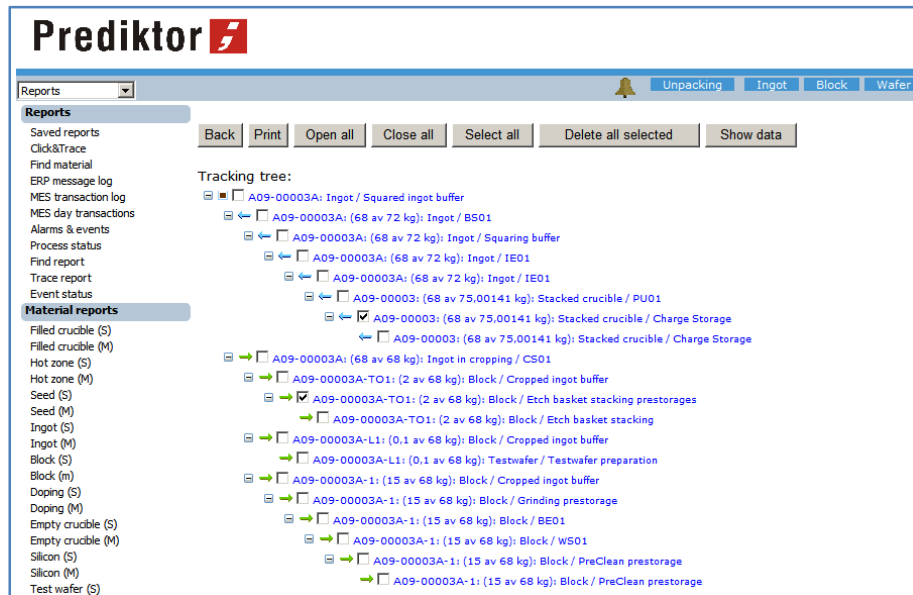


*Example of material genealogy: This figure represents material transformations and mixing*

Historical data in a tracking system is normally saved in a relational database. This database should model aspects of the production that are relevant for tracking. Below are some important elements for saving data in such a database:

- **Process units** are units where material is processed or stored, and represents a process unit or a storage space in the plant. An example is a wafer saw for cutting blocks into wafers.
- **Batches** are processed in process units. One example could be a batch run for etching and texturizing wafers. In a continuous process, such as polysilicon production, the material stream can be divided into "mass plugs" to simulate a series of batches passing through the process unit.
- **Material units** are tracking units that are generated in process units or when raw materials enter the system from a warehouse. The term is used to identify raw materials, WIPs, finished products and waste. All material units in the tracking system will be connected through the material genealogy. A material unit can have several "parents"/"children". The genealogy represents material transformations or splitting/mixing and describes how the material units have been transported and transformed through the process. The genealogy is used to produce reports for tracking and other compilations of data where it is interesting to see the history of

a material through the process. The genealogy can be illustrated as in the figure below.



*Tracking tree*

- **Material carriers** are containers for material such as wagons, baskets, cassettes etc. that can contain material units and are used for storage and/or transportation.
- **Data values** are values that can be presented individually or aggregated in reports. Data values are associated with process runs, process units, materials or periodical reports. Data values are used to store such data as laboratory results, process values or calculated values.
- **Material classes** define various types of material units for classifying raw materials, WIPs and products.

In addition to a relational database, a tracking system could include a time series database. This is particularly important for using the tracking system for quality control, root-cause analysis and process improvements. The time series database should be connected to the relational database so that time series can be associated with material progression and related data in a simple and seamless way.

The data model in the tracking system should preferably be based on ISA S95. S95 includes the model of the data flow and information for integration with production systems and ERP systems.

### Reporting and presentation

A tracking system has no value if the user cannot navigate the data and report on desired data compilations. The tracking system must be able to generate various kinds of reports. Examples of useful reports are:

- **Backwards tracking report:** provides main data for a product, including utilized process units, important process parameters and raw materials. In such a report, the user should be

able to drill down in the details, such as the position in the block where the wafer originates.

- Forward tracking report: provides all products that contain parts from a chosen raw material batch. For example, the forward tracking report can indicate all the wafers that were produced from a certain lot of polysilicon.
- Process report: Assembles a chosen set of process data (raw material data, temperature, additives, pressure, resulting product parameters/quality, etc.) for a chosen set of process units. Process reports are useful for process analysis and process optimization work.

These are only examples. It is important that it is easy to navigate through the data and that the user can specify formats and content.

### **Value of a Tracking System**

Tracking systems realized with the use of computer technology will rarely only have visual tracking functionality. The database system contains information about the historical running of the process and relations between the data. This provides the basis for many valuable uses:

#### **Quality improvement and process optimization**

The tracking information is vital for using the data to improve and optimize production. An example from one of Prediktor's wafer manufacturing customers can be used to illustrate this point. A quality problem with the produced wafers was discovered immediately in Real-time with the alarm function. The problem was tracked backwards to one particular wire saw and to one specific location in this saw. Identifying this problem quickly prevented loss of quality production and increased the earnings for the company. To achieve this level of responsiveness and detailed level of data analysis, it was necessary to have a tracking system with sufficient depth and breadth.

#### **Minimize work-in-progress (WIP)**

A tracking system will at any time be able to report on the status of work-in-progress. An increase in WIP in production is binding up capital. Only by having an overview of such parameters will the factory have the opportunity to identify bottlenecks and gain knowledge to balance the production.

#### **OEE calculations**

Tracking data are especially suitable for estimating various efficiency parameters in production. Today, many talk about OEE (Overall Equipment Effectiveness) in order to measure how effectively the equipment resources are being utilized. OEE is also a valuable metric for benchmarking the performance of the many pieces of equipment used in a factory, to identify low-performing units and the need for repair/optimization. It is unwise to consider OEE calculations separately from the tracking systems. A tracking system, based on a suitable data structure such as in ISA95, is particularly suitable as a basis for OEE calculations. It is therefore important that the implementation of a tracking system and an OEE system be considered together.

#### **Recall/backorder defective products.**

The higher the precision in the tracking system the more precisely products can be recalled. However, a precise recall requires that the reason for the defect has been localized to a specific batch of raw material, to a specific process unit or to some other reason. The more

precisely the reason is identified, the higher the precision in the recall. A precise recall reduces the direct costs and reduces the damage to company image in the market.

To be able to track from raw material to product and back again is also important in many industries. We frequently read in the newspapers that car owners with car models of a certain brand or production series must report to their mechanic workshop. Or we hear that one particular battery charger or other electronic gadget must be handed in to be replaced. Such incidents damage a manufacturer's brand name and reputation. A precise tracking system would limit the consequences of such incidents in terms of time and scope. Warranty costs would be reduced as well, which in such corporations could often equal as much as 5% of the turnover. In the car industry, the recall cost alone is estimated to 60 billion NOK per year.

In production companies with lower public and media exposure, such as the PV industry, there will also be great savings in having a precise and functional tracking system. For example, a wafer company that discovers a problem with their wafers that will reduce cell efficiency, can send a notification only to the specific cell companies that have been sold the compromised wafers, rather than a general recall notice to all cell customers. A precise and functional tracking system would be able to provide detailed information about which single wafers have been compromised, rather than scrapping entire lots of wafers already sold to the customers. Thus damage control is provided, making the best out of an unfortunate situation.

The "Tracking in PV Production" articles are written by Steinar Saelid, C.E.O of Prediktor AS and professor in technical cybernetics at Norwegian University of Science and Technology (NTNU). Saelid has wide experience with process data systems, model based control, soft sensor technology and the control of quality in processes. Prediktor develops and delivers MES solutions for data collection, storage, analysis and reporting.

