Photovoltaic Modules
Photovoltaic modules are interconnected assemblies of photovoltaic cells (solar cells) packaged in a weather tight housing. Modules are rated and called out by their wattage as measured under factory controlled Standard Test Conditions (STC is equal to 1000 W/m² at 25°C and 1.5atm). In addition, every module has a maximum voltage (Voc) and current (Isc). These characteristics are used by solar designers to create an efficient PV system. Commercially available photovoltaic modules come in three primary types:

Monocrystalline: These modules are made up of cells that are created from slices of single (mono) grown silicon crystals. Each cell typically produces .5 volts. Cells are wired in series to create higher module voltages. Typical 24 volt nominal modules will have 72 monocrystalline solar cells. Monocrystalline modules have the highest efficiency (14-17% typically).

Polycrystalline: These modules are made up of cells that come from molten silicon poured in blocks and sawed into plates. The resulting crystal structure varies in size and number (poly). Polycrystalline cells typically have slightly lower efficiencies (13-15% typically), but less voltage drop off at higher temperatures.

Amorphous (thin film): Thin film modules are made by depositing thin layers of silicon onto a substrate. The layer is frequently only 1µM thick (a human hair is 50-100µM thick). Amorphous panels are much cheaper to manufacture, however their efficiencies are also substantially lower (5-7% typically). They have very good low light and high temperature characteristics.
Inverters
Inverters convert the module DC voltage into grid matching AC power. They typically accept multiple strings of modules and utilize “power point tracking” (PPT) to maximize the energy produced by modules. PPT locates the point of maximum power on the photovoltaic modules current/voltage curve:

![Typical Grid-Tied Inverter](image)

On the AC side, grid-tied inverters supply AC power, synchronized to the grid frequency, while matching the grid voltage and maintaining the ability to instantaneously shutdown if the grid voltage goes away. Inverters are characterized by their input power capabilities (2000W, 3000W, etc.). They have a minimum DC voltage at which they turn on and a maximum DC voltage they can handle. There is another range of voltages within which they can power point track. Solar designers match module characteristics and string sizes to inverter’s characteristics using local ambient temperature considerations. This maximizes the power produced in all conditions. Modern grid-tied inverters convert solar power to grid power at efficiencies of 92-97%.

Racking and Balance of System Hardware
Solar modules are usually either roof or ground mounted. Commercial racking systems are available for both applications. These systems provide strong, durable, lightweight solar array mounting. Roof orientation, shade factors, available open ground space, access, and distance to service entrance location are all considered factors.

Roof Mounts: Roof mounts add 3-5 lbs per square foot of dead load to a roof. (this is typically less than an additional layer of roofing…since modules last 20-30 years, it is generally wise to assure that the underlying roof will not need replacing much sooner). Roof attachments are achieved via lag bolts into the underlying rafters. Mounting feet are designed to sit on top of composition roofs. Also available are standoff mounts that can be flashed into a new roof. These keep modules slightly cooler (by increasing airflow underneath) which improves output. The number of attachment points required is determined by the length of the mounting rails (typically 1 mount ever 6 feet) and the local wind conditions dictated pull off forces.
**Ground Mounts:** Ground mounting of solar modules is another option. Available racking requires 1½ to 2 inch pipe mounts anchored in cement. Aluminum rails for mounting the modules are then clamped to these uprights. Ground mounts under 6 feet high require no additional engineering, but do require septic review for the permit process. Ground mounting provides easy access to the modules and, although slightly more expensive, is a great way to go if appropriate space is available.

![Ground Mounted Solar Array](image)

**Balance of System Hardware:** Unique solar Multi-Conductor (MC) cables are used to connect modules together in strings and make required wire runs to a junction box. High voltage DC disconnects are used to isolate modules for inverter replacement or repair. AC power is fed into the main service entrance via a back fed breaker (typically 20 or 30 amps). Solar module grounding is achieved via special module to rail grounding clips. Ground lugs are then attached to each rail and wired together in a run back to the primary inverter ground.

![Typical Main Service Entrance](image)  ![DC Disconnect](image)  ![Solar Module Grounding Clip](image)  ![Solar Rail Grounding Lug](image)