Supporting Online Materials

Capex: An Accounting Tutorial for the Scientist and Engineer

Five key financial terms are necessary to evaluate the impact of capex on PV module manufacturing cost & minimum sustainable price. This document provides a more foundational description of these five key financial terms, with PV-relevant examples. This tutorial is designed for scientists and engineers without a strong background in accounting, finance, or related subjects.

(1) First, the PV community is well accustomed to module or system costs presented in units of "dollars per watt" ($/W). In this case, the "W" relates to the peak output of the module or system tested under AM1.5 conditions. Module & system $/W impact profitability and levelized cost of electricity (LCOE), and thus reducing $/W is a focus of considerable R&D effort.

We often want to know what fraction of $/W is related to "capex," herein defined as "the plant, property, and equipment, including the engineering, procurement, and construction expenses of the manufacturing facility itself." To calculate this number, we need the following parameters:

(2) The total cost of plant, property, and equipment (PP&E) is given in units of $. (For modern "greenfield" (built from scratch) GW-scale factories, this cost today is on the order of 10^8 or 10^9 $.)

(3) To make a fair comparison between factories, we take the "$" number from (2) and normalize by the factory's nameplate annual manufacturing capacity, which has units of (W/yr). So, if a vertically integrated polysilicon-to-modules factory costs $2 billion upfront, and produces 2 GW of modules per year, the capacity-normalized capex is $1/(W/yr). This capacity-normalized unit allows us to quickly compare upfront investments in factories or technology generations. But the unit is awkward, so we simplify it from $/(W/yr) to $\$/W_{aCap}$ in our manuscript. Our bottom-up calculations yield 0.68 $\$/W_{aCap}$ for wafer, cell, and module manufacturing, and 1.01 $\$/W_{aCap}$ when polysilicon refining is included (Figure 2).

What's particularly confusing about capex, is that in non-technical writing, we often omit the "per year" when discussing manufacturing capacity. For example, one often reads "2 GW factory," instead of the more correct "2 GW/yr factory." While the former is ubiquitously used, the units don't work out when one starts doing math to calculate the impact of capex on PV module cost or minimum sustainable price.

(4) The simplest way to calculate the faction of PV module cost ($/W) that is capex-related is to take the total PP&E ($), look up a "depreciation schedule" (how many years it takes to fully "write off," or "amortize," our PP&E), and divide one by the other. In the United States, the Internal Revenue Service (IRS) defines how quickly a business owner can "depreciate" equipment, because equipment depreciation is treated as a "financial loss" for the company and thus reduces taxable income. This is called a "depreciation schedule." For PV, the depreciation schedule is 7 years for manufacturing equipment and longer for factory plant. Let's assume we have a straight-line depreciation schedule, which means we amortize a constant fraction of the initial $ each year (math is easier). To calculate the faction of module cost $/W related to capex, we first we take the initial factory $, split it into "equipment" and "facilities" buckets, and divide them by 7 or 25 years, respectively. (This is why each bar in Figure 2 has two different shades, for equipment and facilities.) Second, we consider the factory's nameplate annual manufacturing capacity (W/yr). Third, we divide one number by the other, to obtain the faction of module cost $/W related to capex. (We call this quotient the "depreciation expense.") Let's say we have a 2 GW/yr factory for which we paid $2.1 billion, and we'll make the super-easy (and grossly over-simplified) assumption that 100% of the capex is equipment-related (zero facilities). Assuming straight-line depreciation, the capex cost per module will be $(2.1\times10^9\ \$) / ((2\times10^9\ \mathrm{W/yr}) \bullet (7\ \mathrm{yr})) = 0.15\ \$/\mathrm{W}$. Note that this number is pretty close to our detailed bottom-up calculation in the Excel spreadsheet in the Supporting Online Materials, summarized in Figure 1.

(5) Notice we underlined the word "cost" in the first line of the previous section. This is to emphasize that calculating the module bottom-up cost and its minimum sustainable price are two related but distinct exercises. The minimum sustainable price reflects the minimum margin that the manufacturer needs to make, so that the "internal rate of return" (IRR) on their investment equals the "weighted average cost of capital" (WACC). In simple jargon-free terms, there's an interest rate associated with borrowing money, and the manufacturer must be sufficiently profitable to satisfy investors' interest rate (cost of capital). To calculate the effect of capex on PV module

minimum sustainable price ($/W), we need to insert all time-dependent costs into a net present value (NPV) calculator, at the bottom of our Excel spreadsheet in the Supporting Online Materials. Capex is one such time-dependent parameter — we borrow money today, and must pay it back in the future. Unfortunately for a manufacturer, money is much more valuable today than tomorrow (because of compounded interest), thus borrowing money today to make a factory means the margin on tomorrow's product must be high. The margin associated with capex explains much of the difference between the "cost" and the "minimum sustainable price" shown in Figure 1. As capex decreases, so does the difference between "cost" and "minimum sustainable price" (Figure 7).

Because the value of money is greater today than tomorrow, there's an incentive for manufacturers to amortize their PP&E faster than fixed "straight-line" depreciation. Thus, some tax jurisdictions allow for "accelerated depreciation"; as the name suggests, a declining percentage of PP&E is amortized each year.

In our work, accelerated depreciation is assumed to calculate the minimum sustainable price (right column of Figure 1), while straight-line depreciation is assumed to calculate module cost (left column of Figure 1). While this may appear inconsistent from the scientific point of view, this is consistent with first-pass financial decision-making in light of tax considerations.