IC KNOWLEDGE LLC

Packaging Cost and Price Model User Manual

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Version 2019 model

Introduction

This manual presents an overview of the Assembly and Test Cost and Price Model and the basic workings of the model. The revision number for the manual does not align with model revisions, so for example we might have 5 model revisions in a year but only 1 manual revision if the model revisions didn't add features that needed to be reflected in the manual. Conversely, we will sometimes revise the manual to add additional explanation or details.

Model description

The Assembly and Test Cost and Price Model is designed to calculate the manufacturing cost and selling price of testing and assembly of most low power packages/semiconductor products. Examples of specific package types covered in the model are leadframe packages, organic substrate packages including EMIB, wafer level packaging and InFO.

Please note that our cost models are cost of goods sold (COGS) models and do not include below the line costs such as research and development (R&D) or selling, general and administration costs (SG&A). Our pricing calculations are cost plus gross margin (GM). R&D and SG&A costs are absorbed in GM as well as operating income.

Support and updates

As a licensee to the Assembly and Test Cost and Price Model you will receive all updates made to the model for twelve months from the date of purchase emailed to your email address of record. If you change your email address it is your responsibility to notify us. Reasonable levels of phone and email support will be provided for twelve months from the date of purchase of the model. On-site or other forms of support are not provided. For more information, please see our Support Policy.

Our "Support Policy" and other model support information is available in the gray bar on the right side of the Packaging Cost and Price Model page here:
http://www.icknowledge.com/products/packagingmodel.html

Known Excel bugs and limitations

- We occasionally see issues with dropdown menus not working properly in the model. If you click on a dropdown menu and can't see the dropdown list, right click in the cell, choose "Pick from Drop Down list" and then left click in the cell and the dropdown should appear. This is an Excel bug and not something we can address ourselves.
- Number formatting must use a decimal point to indicate decimals, e.g. 1.0. If you set up Excel to use a coma to indicate a decimal, e.g. 1,0 the model will not function correctly. This setting is an Excel option under advanced and you can set "Use system separators" for a "Decimal separator" to be a .

or ,. It is common practice in Europe to use a , but that will prevent the model from working correctly.

- We use a lot of dropdown lists in the model. Excel 2007 does not support dropdown lists that reference other sheets in the model. We have currently designed the model to work around this issue but at some point we will cease to support Excel 2007 because there is a lot of overhead involved in accommodating this.

Model conventions

There are several conventions used throughput the model.

The gray areas on each model sheet contain the model inputs and outputs. The inputs that can be directly changed by the user are white areas within the gray, the gray areas are labels and model driven outputs and cannot be directly changed by the user.

Throughout the model there are red dots indicating comments. Moving the cursor over the red dots displays information explaining input or outputs.

In this manual, regular, bold and underlined text describe the model and model features. Italic text provides background on the inner workings of the model.

Common Questions

- How do I model an SOC - we get this question a lot. There is a perception that SOC specifies what something is, it doesn't. SOC stands for System On a Chip and is vaguely defined industry buzz word that can be applied to many different types of devices. Things like cell phone applications processors are commonly referred to as SOCs, but most microprocessors, most microcontrollers and many other products meet the definition of SOC as well. You can model an SOC in the model but you need to model the product based on what it is.
- What package do I select for Chip Scale Packages (CSP) - this is similar to SOC described above, CSP basically means a package is roughly the size of the die or chip it contains. Many package types can be CSPs, simply select the package type of interested, BGA, QFN, etc.

Worksheet overview

The following is a brief description of the model worksheets and the purpose of each sheet. The sheet tabs are color coded, gray is informational (these sheets may in some cases be editable but do not drive the model results), red are the main drivers (these sheets are editable), brown are results (these sheets are not editable), blue modifies the processes or performs comparisons or calculations (these sheets are editable).

Please note that there are many sheets in the model and scrolling between them can be a slow process. If you right click in the area where the scrolling arrows are (bottom left part of Excel) you will get a sheet list and you can directly select the sheet you want to go to.

- <u>License (Gray tab)</u> – the model software license. This sheet is not editable.
- <u>Introduction (Gray tab)</u> – a brief introduction to IC Knowledge and our cost modeling product line as well as disclaimer and warrantee information. This sheet is not editable.
- <u>HELP (Gray tab)</u> – a listing of the various ways to get help with the model. This sheet is not editable.
- <u>Configuration (red tab)</u> – configures the overall model. This sheet is user editable.
- Wafer Definition (red tab) – defines the different wafer types that feed into the test and assembly operations.
- <u>Database (red tab)</u> – defines pre-defined and user defined packages that can be used to populate the model by running macros.
- <u>Wafer Sort (blue tab)</u> – configures the wafer sort calculations and displays the costs.
- <u>Assembly (blue tab)</u> – configures the assembly calculations and displays the costs.
- <u>Class Test (blue tab)</u> – configure the class test calculations and displays the costs.
- <u>Cost Summary</u> - a summary of the model results.
- <u>Materials Usage</u> - a summary of the material quantities and costs used for the defined package.
- <u>Yearly Data (brown tab)</u> - sets utility, labor, material and margins by year, company and country.
- <u>Lookups (grey tab)</u> – provides information on what test setting to use and provide a hndy calculator of cost versus volume.
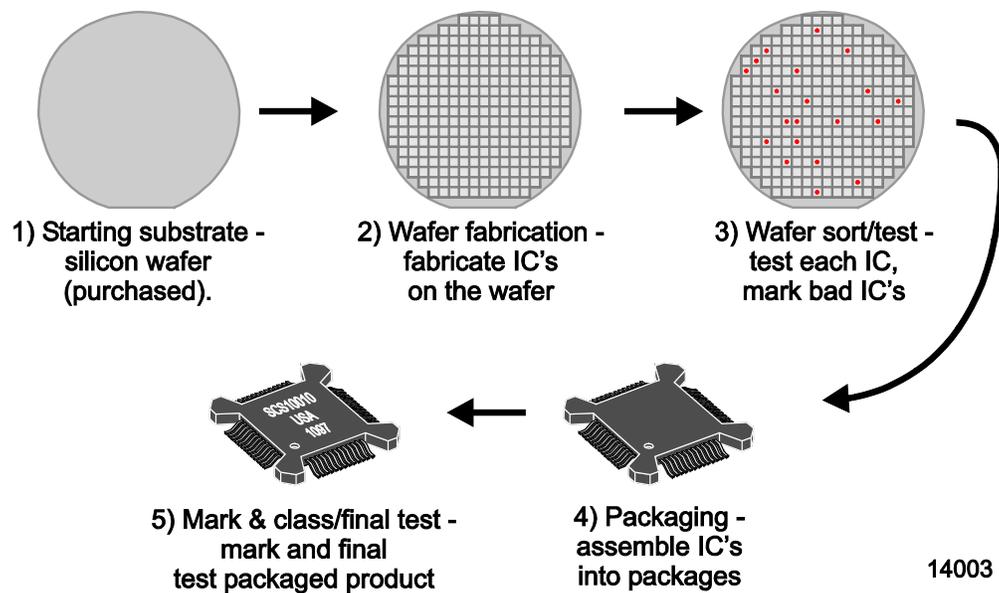- <u>Revisions (grey tab)</u> - lists the changes in the current version of the model.

Detailed worksheet descriptions

In this section the "active" worksheets are described in more detail. Worksheet such as 'License', 'Introduction', 'Help', 'Revision History' worksheets are expected to be self-explanatory.

The following are the main steps in the IC manufacturing flow:

- *Starting wafer – this is purchased by all IC manufacturers. Wafers come in a variety of sizes and types. When you select a process the appropriate wafer size and type is automatically selected.*
- *Wafer fabrication – anywhere between tens to tens of thousands of integrated circuits are fabricated on the surface of the wafer. The wafer yield is the number of wafers that complete fabrication process divided by the number of wafers started into the fab.*
- *Wafer sort (also called wafer test or wafer probe) – the ICs on the wafer surface are tested and the bad ICs are mark with an ink dot or in an electronic map so they won't be packaged. Die yield is the number of die that pass wafer sort divided by the total number of die on the wafer. Wafer sort may be a single pass test or may include multiple passes at different temperatures, or before and after bakes and burn-ins.*
- *Packaging – the individual ICs on the wafer are cut up and put into protective packages that provide electrical connections to the IC.*
- *Class test (also called final test) – the packaged ICs are tested to insure the ICs were correctly packaged without damage. For some ICs they can't be fully tested until they are packaged and this may be the first full test. Class test may be a single pass test or may include multiple passes at different temperatures, or before and after bakes and burn-ins.*

1) Starting substrate -
silicon wafer
(purchased).

2) Wafer fabrication -
fabricate IC's
on the wafer

3) Wafer sort/test -
test each IC,
mark bad IC's

5) Mark & class/final test -
mark and final
test packaged product

4) Packaging -
assemble IC's
into packages

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IC Manufacturing Flow

Configuration (red tab)
These values configure the overall model:

- Year to model – sets the year being modeled for the entire model. This setting effects labor rates, utility rates, margins and materials costs.
- OSAT – select the OSAT of interest or internal operations by country. This set the gross margin and country where the operation is located. For internal operations gross margin is zero and only the country is set.
- Volume - this is the volume of business the company does with the OSAT and increases or decreases the gross margin applied to determine the price. If the company does <$100k per year of total packaging volume with a provider, the volume is very low, >=$100K to <$1M is low, >=$1M to <$10M is average, >=$10M to <$50M is high and >=$50M is very high. If an internal option is selected above no gross margin is applied and this setting has no effect.

For rows 4 through 7 the configuration for Wafer Sort (row 5), Assembly (row 6) and Class Test (row 7)

- Column B - allows you to activate or deactivate each operation, wafer sort, assembly and class test.
- Column C/D - display the default country based on the OSAT selection.
- Column E/F - allows you to override the default country individually for each operation.
- Column G - displays the default gross margin based on the year, OSAT and volume selected in row 1 through 3 above.
- Column H - allows you to override the default margin for each operation. Simply select the margin you want from the drop down.
- Column I - displays the default year each facility was built. Currently it is assumed each facility is five years old so that data is the current year from row 1 minus 5. Currently the percent of equipment that is fully depreciated is embed in the model calculations and not user adjustable.
- Column J - allows you to override the year the facility was built.
- Column K - is the number of years the equipment is depreciated over. This is solely used to calculate the depreciation rate for undepreciated equipment and does not affect when the equipment is fully depreciated. This column has 5 entered when the model is shipped but you can enter any value you want.
- Column L - is the depreciation rate applied to the undepreciated equipment. This is one over the number of years entered in column K.
- Column M - allows you to set the uptime for assembly in cell M6, the uptime for wafer sort and class test is set on the wafer sort and class test sheets because it is product type specific.
- Column N - allows you to set the utilization for assembly in cell N6, the utilization for wafer sort and class test is set on the wafer sort and class test sheets because it is product type specific.
- Column O - sets the operating hours per week for each operation. The model ships with 168 hours entered in these cells but you can enter whatever value you want.
- Column P - sets the weeks of operation per year for each operation. The model ships with 52 weeks entered in these cells but you can enter whatever value you want.

Wafer Definition (red tab)
This sheet defines the wafers that are entered into the test and assembly operations.

Rows 5 through 10 allow the user to define their own wafers and rows 12 through 16 list pre-defined wafers.

- Column B - lists the wafer definition. For rows 5 through 10 the values are user entered. If you aren't using a row it is recommended that you enter "NA".
- Column C - allows a wafer price to be entered for each user defined wafers. This is not a required field but if you want to get a total product cost including the wafer cost at the end of the model you need to enter the wafer cost here. We recommend our IC Cost and Price Model, Strategic Cost and Price Model and Discrete and Power Products cost and Price Model to determine the wafer prices. For the pre-defined "Bridge die wafer", "Interposer – no TSV" and "Interposer – TSV" wafers the wafer price fills in automatically. The values that fill in here are from the 'Yearly Data' sheet for the wafer type and year. These values may be edited on the 'Yearly Data' sheet. For "InFO wafer" and "Integrated passive device" the wafer cost is built up in the model.
- Column D - allows the user to select the wafer size for user defined wafers and displays the wafer size for pre-defined wafers.
- Column E - allows the user to select the wafer type for user defined wafers and displays the wafer type for pre-defined wafers. The wafer type determines the saw speed.
- Column F - allows you to enter the die width for each die. Entering a value in a row in this column "turns on" that die type for the model. You must populate this for any die you are using and we recommend you leave it blank for any die you aren't using.
- Column G - allows you to enter the die height for each die. Entering a value in a row in this column "turns on" that die type for the model. You must populate this for any die you are using and we recommend you leave it blank for any die you aren't using.
- Column H - allows you to enter the edge exclusion for each wafer type. Edge exclusion is used to calculate gross die.
- Column I - allows you to enter the street width between die to accommodate wafer sawing.
- Column J - displays the calculated whole gross die per wafer based on the wafer size, die size edge exclusion and street width selections for each row.
- Column K - allows you to enter a die yield for each row. We recommend our IC Cost and Price Model, Strategic Cost and Price Model and Discrete and Power Products cost and Price Model to determine the die yield.
- Column L - displays the net die per wafer. This is the gross die multiplied by the die yield.

<u>*Background on die size and number of die per wafer*</u>

When entering the die size – the die width and height in millimeters should be entered. The model takes the die size, adds street width and calculates the number of die that will fit onto a wafer based on wafer size and edge exclusion. If a supplier will not tell you the die size (this is very unusual) and x-ray of the package can be performed, or the package can be decapped to measure the die size. We recommend TechInisght for this service.

There is more than one way to describe die size and it is important to understand the differences. The following figure illustrates three die in a row on a wafer. Notice that there is the physical die size and then between each die there is a blank "street". The street provides an area for the saw cut used to separate the finished die. The model assumes that the die size that is entered is the physical die size of the die and by default the model adds a 75 micron street width when calculating the whole die on a wafer. Sometimes die sizes are specified using the stepping distance from the middle of a street to the middle of the next street. In this case you need to override the street width and set it to zero. Another situation that you may encounter is where a die size is measured after sawing, you need to make sure the measurement is the die only and not some remnant of the street still attached to the side of the die. The street is made wider than a typical saw cut to leave some room for misalignment and saw damage around the cut.

Die Size
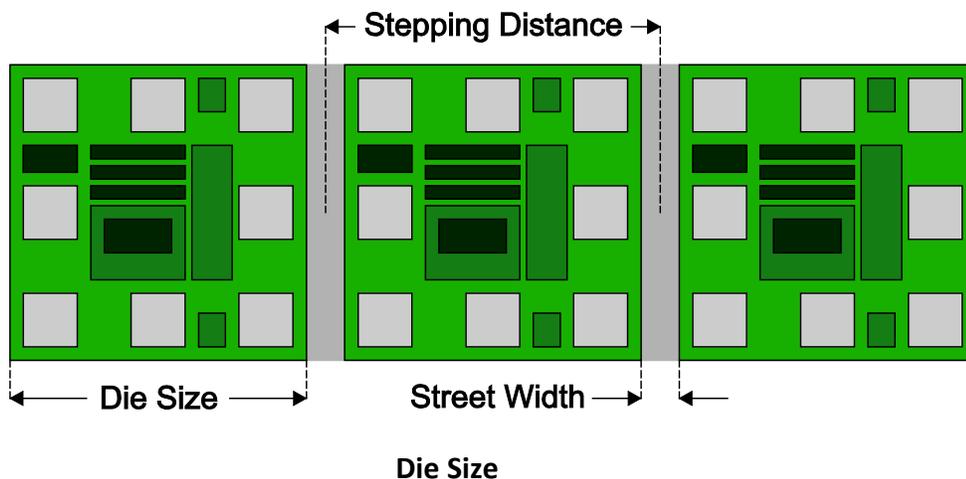
Other factors to take into when determining the number of whole die on a wafer are the edge exclusion.

- *Edge Exclusion – due to issues with maintaining prefect process uniformity all the way to the edge of a wafer there is an edge exclusion area at the edge of the die where no good die exist. By default the model leaves a 2mm edge exclusion but you can override that if necessary on the 'Global Values' sheet.*

Background – Cost Accounting

Cost accounting practices break out manufacturing costs in three categories:

1. *Material – material only includes materials that become part of the final product that is shipped. Materials consumed in product are included in overhead and do not count as materials.*
2. *Labor – labor only include direct or "touch" labor, basically the operators who make the product. Indirect labor such as engineers, technicians, managers and supervisors are included in overhead.*
3. *Overhead – everything else.*

The following table summarizes what is included in each category for different phases of IC production.

Category	*Wafer Fabrication*	*Packaging*	*Test*
Material	*Starting Wafer*	*Substrates, Leadframes, Wire, Mold Compound*	*None*
Labor	*Operators*	*Operators*	*Operators*
Overhead	*Depreciation, Equipment maintenance, Indirect labor, Monitor wafers, Facilities costs, Consumables*	*Depreciation, Equipment maintenance, Indirect labor, Facilities costs, Consumables*	*Depreciation, Equipment maintenance, Indirect labor, Facilities costs, Consumables*

<u>Database (red tab)</u>
This sheet has pre-defined products (rows 5 through 24) and user defined packages (rows 25 through 34).

This sheet is unlocked to allow the macros to run, you can change the data in rows 5 through 34, pick a product to model in cell A36 and trigger the macros by pressing the buttons in cells B38, B40, B42, B44 and B46. Any other changes on other rows or clls or inserting rows will break the macros.

Rows 5 through 24 will be used by IC Knowledge to pre-define products although you can override the values if you wish. Not all rows may be populated in the current model, we left space for future additions. Columns B through LI have values that will transfer to the 'Wafer Definition', 'Wafer Sort', 'Assembly' and 'Class Test' sheets when the macros are run. The settings here do not include every setting from those sheets but rather the typical setting a user would change to define a product. These cells are in grey but are not locked.

Rows 25 through 34 are left for users to define their own product scenarios. Columns B through LI have values that will transfer to the 'Wafer Definition', 'Wafer Sort', 'Assembly' and 'Class Test' sheets when the macros are run. The settings here do not include every setting from those sheets but rather the typical setting a user would change to define a product.

To use this sheet:
• If you want to use a user defined product populate the row(s) you wish to use. For a pre-defined product, you can skip this step although in some cases you may want to use a predefined product but change a few values.
• Select the product to model from the drop down in cell A36.
• Press the "Populate Wafer Definition" button to run the macro to populate the 'Wafer Definition' sheet.
• Press the "Populate Wafer Sort" button to run the macro to populate the 'Wafer Sort' sheet.
• Press the "Populate Assembly Wafers" button to run the macro to populate the wafer assembly portion of the 'Assembly' sheet.
• Press the "Populate Assembly Package" button to run the macro to populate the package assembly portion of the 'Assembly' sheet.
• Press the "Populate Class Test" button to run the macro to populate the 'Class Test' sheet.

<u>Wafer sort (blue tab)</u>
This sheet configures the wafer sort calculations.

Rows 3 through 8 configure the user defined wafer sort. Rows 9 through 13 configure the pre-defined wafer sort (if applicable). Rows 15 through 26 display the resulting costs.

<u>Display only columns</u>
- Column B displays the wafer description from the 'Wafer Definition' sheet.
- Column C displays the wafer price from the 'Wafer Definition' sheet.
- Column D displays the wafer size from the 'Wafer Definition' sheet.
- Column E displays the wafer type from the 'Wafer Definition' sheet.
- Column F displays the die width from the 'Wafer Definition' sheet.
- Column G displays the die height from the 'Wafer Definition' sheet.
- Column H displays the edge exclusion from the 'Wafer Definition' sheet.
- Column I displays the street width from the 'Wafer Definition' sheet.
- Column J displays the gross die from the 'Wafer Definition' sheet.
- Column K displays the die yield from the 'Wafer Definition' sheet.
- Column L displays the net die from the 'Wafer Definition' sheet.

<u>Active columns</u>
- Column M - allows the user to select the product type for test for the user defined wafers and displays the values for the pre-defined wafers. the product type determines default test times and the type and cost for the test equipment. Many standard product types are pre-defined here.
  - <u>CMOS Image Sensors</u> - select CIS and the number of pixels.
  - <u>Logic</u> - if the device is a DSP, Embedded Processor, Microcontroller or Microprocessor simply select the appropriate device and configuration (number of cores, embedded memory, etc.). For all other logic devices select ASIC with the appropriate device performance and complexity. To help with ASIC type selection there is an ASIC type lookup on the 'Lookups' sheet. See the section on 'Lookups' for how to use the ASIC lookup.
  - <u>Memory</u> - for memory simply select the memory type: DRAM, NAND, NOR, SRAM and the memory density.
  - <u>Mixed Signal</u> - ICs combining a significant amount of analog with digital are mixed signal. Select mixed signal and the appropriate complexity. We do not currently have help for selecting the complexity of mixed signal ICs.
  - <u>RF</u> - RF testing is very expensive because of the frequencies involved. For RF products select RF with the appropriate complexity for the device We do not currently have help for selecting the complexity of RF ICs.
- Column N - allows you to select the "Product level", options are "Aerospace" (burn-in and three temperature testing), "Automotive" (three temperature testing), "Commercial" (single temperature testing), "Military" (burn-in and three temperature testing).
- Column O - allows you to enter the electrical connections fo reach wafer type, this is used to calculate tester equipment costs.
- Column P - displays the calculated test time.
- Column Q - allows the user to enter a test time. The entries here do not change anything unless you select "User" in column R in the same row.
- Column R - allows you to select default value or user value for the test time.
- Column S - displays the default die tested in parallel.

- Column T - allows the user to enter a units tested in parallel. The entries here do not change anything unless you select "User" in column U in the same row.
- Column U - allows you to select default value or user value for the units tested in parallel.
- Column V - displays the default parallel test efficiency. The setting drives the test time increase as the number of units tested in parallel increases.
- Column W - allows the user to enter a parallel test efficiency. The entries here do not change anything unless you select "User" in column X in the same row.
- Column X - allows you to select default value or user value for the parallel efficiency.
- Column Y - displays the default system cost.
- Column Z - allows the user to enter a test system cost. The entries here do not change anything unless you select "User" in column AA in the same row.
- Column AA - allows you to select default value or user value for the test system cost.
- Column AB - displays the default utilization.
- Column AC - allows the user to enter a utilization. The entries here do not change anything unless you select "User" in column AD in the same row.
- Column AD - allows you to select default value or user value for the utilization.
- Column AE - displays the default uptime.
- Column AF - allows the user to enter a uptime. The entries here do not change anything unless you select "User" in column AG in the same row.
- Column AG - allows you to select default value or user value for the uptime.
- Column AH - displays the default sort 1 time as a percentage of the test time.
- Column AI - allows the user to enter a sort 1 time. The entries here do not change anything unless you select "User" in column AJ in the same row.
- Column AJ - allows you to select default value or user value for the sort 1 test time. In rows 17 through 27 the costs for wafer sort 1 are displayed.
- Column AK - displays the default wafer bake time.
- Column AL - allows the user to enter wafer bake time. The entries here do not change anything unless you select "User" in column AM in the same row.
- Column AM - allows you to select default value or user value for the wafer bake time. In rows 17 through 27 the costs for wafer bake are displayed.
- Column AN - displays the default sort 2 time as a percentage of the test time.
- Column AO - allows the user to enter a sort 2 time. The entries here do not change anything unless you select "User" in column AP in the same row.
- Column AP - allows you to select default value or user value for the sort 2 test time. In rows 17 through 27 the costs for wafer sort 2 are displayed.
- Column AQ - displays the default sort 3 time as a percentage of the test time.
- Column AR - allows the user to enter a sort 3 time. The entries here do not change anything unless you select "User" in column AS in the same row.
- Column AS - allows you to select default value or user value for the sort 3 test time. In rows 17 through 27 the costs for wafer sort 3 are displayed.
- Column AT - displays the aerospace cost adders in rows 17 through 27.
- Column AU - displays the total wafer sort costs for each wafer type.
- Column AV - displays the total wafer price (cost plus gross margin) for each wafer type.

Background - Parallel testing efficiency

Testing multiple devices in parallel is an important technique for reducing test costs by spreading expensive test hardware costs out over more units. However, the more units tested in parallel the longer the test time characterized by the test efficiency given by the following formula.

$$M = 1 - \frac{(T_N - T_1)}{(N-1)T_1}$$

Where T_1 is the time to test one unit, N is the number of units tested in parallel and T_N is the test time for N units.

The ITRS has defined M and N by product and by year and we use those values to calculate the test time in parallel based on our estimates of T_1.

Background – Test and Burn-In Usage

Testing of integrated circuits is typically performed at wafer level as wafer sort or probe and at product levels as class or final test.

At wafer sort testing is typically single pass testing with the exception of Flash where testing is done followed by wafer bake and then a second testing pass. The two testing passes enable the number of units that went bad during wafer bake to be calculated. Automotive product testing may require multiple tests at different temperature, for example hot, cold and room temperature. For automotive multiple temperature testing in sort would be for die that will be used as flip chips in modules or other die used directly. If the die will go through the normal packaging process, then multiple temperature testing would likely be deferred until class test.

At class test products are typically tested, burned-in and tested again with the exception of lower end parts that are single pass tested with no burn-in. Automotive parts may once again be tested hot, cold and at room temperature. Aerospace and Military add additional test and inspections.

<u>Assembly (blue tab)</u>
This sheet configures the Assembly calculations.

Rows 5 through 10 configure the user defined wafer assembly. Rows 11 through 15 configure the pre-defined wafer assembly (if applicable). Rows 17 through 27 display the resulting costs.

At a high level, columns A through AD are the wafer level operations and columns AF through BO are the die/package level operations. Rows 4 through 15 define the operations and rows 17 through 27 present the costs.

Rows 5 through 10 display the user defined wafers from the 'Wafer Definition' sheet.

Rows 11 through 15 are predefined wafers with limited ability for the user to edit how they are processed. In columns B through AD some selections are set and cannot be edited by the user (grey background) and some can be edited by the user (white background).

The predefined wafers supported in the model are:
1. <u>Bridge die wafer</u> - bridge die are used to connect die together in the Intel EMIB process.
2. <u>InFO wafer</u> - TSMC process where a wafer is used as a package for one or more die.
3. <u>Integrated passive device</u> - typically used in cell phones, resistors, capacitors and inductors are integrated on a single device.
4. <u>Interposer - no TSV</u> - interposer wafers without TSVs.
5. <u>Interposer - TSV</u> - interposer wafers with TSVs.

Working left to right and top to bottom the following is the detail of the sheet operation.

Wafer processing (columns C through AD)
This section defines the wafer level processing and costs. The results of this section may be used by themselves and, or to feed into the die/package process section.

<u>Display only columns</u>
- Column B displays the wafer description from the 'Wafer Definition' sheet.
- Column C displays the wafer size from the 'Wafer Definition' sheet.
- Column D displays the wafer type from the 'Wafer Definition' sheet.
- Column E displays the die width from the 'Wafer Definition' sheet.
- Column F displays the die height from the 'Wafer Definition' sheet.
- Column GJ displays the gross die from the 'Wafer Definition' sheet.
- Column H displays the die yield from the 'Wafer Definition' sheet.
- Column I displays the net die from the 'Wafer Definition' sheet.

<u>Active columns</u>
- Column J - sets whether the wafer is background. Rows 5 through 15 set backgrind "yes" or "no" and rows 17 through 27 display the resulting cost per wafer.
- Column K - sets the backgrind thickness. This is used to determine mold thickness for certain package types.

- Column L - sets the number of redistribution layers (RDL) added to the wafer with 0 to 4 layers supported. Rows 5 through 10 allow you to set the RDL layers for the user defined wafers. Rows 17 through 27 display the resulting cost per wafer.
- Column M - displays whether an integrated passive device (IPD) is used. Integrated passive devices are being increasingly used in cell phones and combine passive devices such as resistors, capacitors and inductors onto a single device. Although the fabrication of these devices uses technologies you would normally see in a wafer fab, OSATs such as STATS ChipPAC have started fabricating these devices. This is driven from the 'Wafer Definition' sheet. Rows 13 displays whether an IPD is used and row 25 displays the cost per wafer.
- Column N - selects frontside wafer bumping with "copper", "NA", and "solder" as the options. Rows 5 through 15 are where you make the selections and rows 17 through 22 display the cost per wafer. Bumping includes under bump layers.
- Column O - allows the user to enter the number of solder balls to be applied to the backside of the wafer or if solder pre-forms are used on the front side this is the number of front side pre-forms. The number entered is per die and can be entered for the six user defined wafers in rows 5 through 10 and for the InFO wafer in row 12. Rows 17 through 22 and 24 display the resulting cost per wafer.
- Column P - allows copper pillars to be selected for the InFO wafer in row 12. For InFO wafers copper pillars are used to connect to additional packaged parts mounted above the substrate. Row 24 displays the cost per wafer.
- Column Q - allows the user to select wafer coating for the 6 user defined wafers, a protective wafer coating is sometimes used on bumped die. Rows 5 through 10 allow wafer coating to be selected and rows 17 through 22 display the cost per wafer.
- Column R - lets the wafer level build layers for InFO wafers to be set in row 12. Row 24 displays the cost per wafer. Wafer level buildup layers are used for interconnect for the InFO process and off by default for all other wafer types and not user editable.
- Column S - lets the wafer mold for InFO wafers to be set in row 12. Row 24 displays the cost per wafer. Wafer mold is used for the InFO process and off by default for all other wafer types and not user editable.
- Column T - lets the planarize for InFO wafers to be set in row 12. Row 24 displays the cost per wafer. Wafer mold is used for the InFO process and off by default for all other wafer types and not user editable. Planarize is used to expose electrical contacts after wafer mold for the InFO process.
- Column U - lets the carrier removal for InFO wafers to be set in row 12. Row 24 displays the cost per wafer. Wafer mold is used for the InFO process and off by default for all other wafer types and not user editable. Planarize is used to expose electrical contacts after wafer mold for the InFO process. A carrier is used for the InFO process and then removed.
- Column V - allows first pass wafer sawing to be set for the six user defined wafers in rows 5 through 10 and for InFO wafers in row 12. The cost per wafer are displayed in rows 17 through 22 and 24.
- Column W - allows second pass wafer sawing to be set for the six user defined wafers in rows 5 through 10 and for InFO wafers in row 12. The cost per wafer are displayed in rows 17 through 22 and 24. Wafers are sometimes sawed in two passes and this allows the user to reflect this.
- Column X - allows saw type to be selected between "1 spindle", "2 spindle" or "3 spindle" standard saw or laser (single head). For standard saws increasing spindle counts increases throughput. Rows 5 through 10 allows the saw type to be set for user defined wafers and row 12 allows it to be set for InFO wafers. Rows 17 through 22 and 24 display the cost per wafer.

- Column Y - allows reconstructed wafer to be set for the 6 user defined wafers. A reconstructed wafer is when a wafer is built on a film carrier and made up of only good tested die. Rows 5 through 10 allow reconstructed wafer to be set and rows 17 through 22 display the cost per wafer.
- Column Z - allows wafer backside laser mark to be set for the 6 user defined wafers. Backside laser marking is sometimes used for die that will be wafer level packaged. Rows 5 through 10 allow reconstructed wafer to be set and rows 17 through 22 display the cost per wafer.
- Column AA - allows tape and reel to be set for the 6 user defined wafers. Rows 5 through 10 allow reconstructed wafer to be set and rows 17 through 22 display the cost per wafer.
- Column AB - allows visual inspect to be set for the six user defined wafers in rows 5 through 10 and for InFO wafers in row 12. The cost per wafer are displayed in rows 17 through 22 and 24.
- Column AC - displays the total cost per wafer for all the wafers in rows 17 through 27. This is the wafer processing cost and does not include the cost of the input wafer.
- Column AD - displays the die cost for all of the wafers. The die cost is the cost from column AC divided by the net die per wafer.

Die/package processing
This section defines the die/package processes and costs. The die costs from the wafer level section feed into this section.

- Column AF - cells AF5 through AF15 define how many die are used from each wafer defined in the wafer processing section. If 0 is entered here the costs from the wafer on that row in the wafer processing section will not be included in the die/package calculations. For packages with multiple die from various wafers you can use as many die from each wafer as you want. For example for a leadframe package you might have 2 die from wafer 1. For an organic substrate with EMIB die you might have 1 die from wafer 1, 1 die from wafer 2 and 6 die from the EMIB wafer to interconnect them. For an InFO part you would have 1 InFO die and then multiple die you are attaching to it. Cells AF17 through AF27 display the total cost for die from each respective wafer type. This is the die cost from cells AD17 through AD27 multiplied by the number of times each die is used in cells AF5 through AF15. In cell AF28 a total of all of the die costs for the die being used is displayed.
- Column AG - select InFO, Leadframe or Organic Substrate to set the package type for this section. Wafer level packaging is not an option here because it is completed in the wafer level processing section. You select the package type in Cell AG5.
- Column AH - if you select "Leadframe" in cell AG5 then cells AH5 through AJ15 turn white so you can define the leadframe. Cell AH5 is a dropdown where you select the leadframe. For "InFO" or "Organic Substrate" packages this section is inactive.
- Column AI - for Leadframe packages you select "Etched" or "Stamped" for the leadframe type in cell AI5.
- Column AJ - in cell AJ5 you select the alloy type used to make the leadframe.
- Column AK - for stamped leadframes you can select whether to spot plate it in cell AK5. In cell AH17 to AK17 the cost for the leadframe based on the leadframe defining selections is displayed. This cost also appears in cell AH28 to AK28 for the total of the entire package process.
- Column AL - if cell AG5 is set to "Organic Substrate" then cells AL5 through AQ15 turn white so you can define the organic substrate package. In cell AL5 you enter the organic substrate package width in millimeters.
- Column AM - in cell AM5 you enter the organic substrate height in millimeters.

- Column AN - in cell AN5 you enter the number of core layers for the organic substrate. See "*Background – package layers"* following this section for more information on layers.
- Column AO - in cell AO5 you enter the number of input/outputs for the organic substrate
- Column AP - in cell AP5 enter the number of buildup layers for the organic substrate.
- Column AQ – in cell AQ5 you can select "BGA" or "LGA" to set whether the organic package has solder balls (BGA) or gold plated pads (LGA). This is new in release 2019 – revision 01.
- Column AR - if you enter a number greater than 0 for the EMIB wafer (Bridge die wafer) die used in cell AF11, then cell AR5 will display a "Yes' to indicate additional organic substrate processing is active for EMIB die. In cell AL17 through AR17 the cost for the organic substrate is displayed and it is also added into cell AL28 to AR28 for the package total.
- Column AS - select the die attach type for each of the user defined wafer/die types in cells AS5 through AS10. If you select "Flip chip" here then wire bonding is disabled from that die. Also supported are "Epoxy", Gold Eutectic" and Solder. Cells AS17 through AS22 display the die attach cost for each die. Cell AS28 displays the total die attach costs and adds into the overall package cost.
- Column AT - if any active die are epoxy mounted then cure is automatically turned on in cell AT5. The cure cost is displayed in cell AT17 and added into cell AT28 for the total package cost.
- Column AU and AV - in cells AU5 through AU10 and AU13 you can enter the number of bypass capacitors used on the packages and in cells AV5 through AV10 and AV13 you can enter the number of power supply capacitors used on the package. The cost for bypass capacitors is displayed in cells AU17 through AU27 and summarized in cell AU28 and the cost for power supply capacitors is displayed in cells AV17 through AV27 and summarized in cell AV28.
- Column AW through AY - in cells AW5 though AW10 you can turn on aluminum heat spreaders, for each row that you turn on aluminum heat spreaders the corresponding width (column AX) and height (column AY) cells will turn white and you need to enter the height and width. The aluminum heat spreader cost for each die is displayed in cells AW17 to AW27 and the total cost is displayed in cell AW28.
- Column AZ - in cell AZ5 you can select "Yes" or "No" to activate or deactivate plasma cleaning. The cost for plasma clean is displayed in cell AZ17 and added into cell AZ28 for the total package cost.
- Column BA - in cells BA5 through BA10 and BA13 select the wire type for wire bond with "Aluminum", "Copper" and "Gold" options. Wire bond is disabled for any die where "Flip chip" is selected for die attached or where 0 is entered for number of die in column AF.
- Column BB - in cells BB5 through BB10 enter the number of wire bonds for each die. Wire bond is disabled for any die where "Flip chip" is selected for die attached or where 0 is entered for number of die in column AF.
- Column BC - in cells BC5 through BC10 enter the length of the wire bonds for each die. Wire bond is disabled for any die where "Flip chip" is selected for die attached or where 0 is entered for number of die in column AF. Cells BC17 through BC27 display the cost for wire bond for each die and cell BC28 totals up the wire bond cost for the final package costs.
- Column BD - in cells BD5 through BD10 and BD13 select "Yes' to enable visual inspection and select "No" to disable visual inspection. The cost for visual inspection for each die is displayed in cells BD17 through BD27 and added together in cell BD28 for the package cost.
- Column BE - select "Yes" in cell BE5 to enable molding and "No" to disable mold. If you disable mold then the thermal lid definition cells will turn white and allow you to define a thermal lid. Cell BE17 displays the molding cost and it is added into cell BE28 for the package cost.

- Column BF - if mold is turned off in cell BE5, then you will have the option to turn on a thermal lid by selecting "Yes' in cell BF5.
- Column BG - if a thermal lid is used enter the lid width in millimeters in cell BG5.
- Column BH - if a thermal lid is used enter the lid height in millimeters in cell BH5. Cell BH17 displays the cost of the thermal lid and the cost is added into cell BG28 for the package cost.
- Column BI - for leadframe packages you can select Singulate in cell BI5. InFO and organic substrates are sawn up and that is defied in the wafer section for InFO or incorporated into the substrate formation process for organic substrates. The cost for singulation is shown in cell BI17 and added into cell BI28 for the package cost.
- Column BJ - select "Yes" in cell BJ5 to add laser mark to the package. The cost for laser mark is displayed in cell BJ17 and added into cell BJ28 for the package cost.
- Column BK - select "Yes" in cell BK5 to add tape and reel to the package. The cost for tape and reel is displayed in cell BK17 and added into cell BK28 for the package cost.
- Column BL - select "Yes" in cell BL5 to add a visual inspection step. The cost is displayed in cell BL17 and added into cell BL28 for the package cost.
- Column BM - to add open/short testing enter the open/short test time in cell BM5. The cost for open/short testing is displayed cell BM17 and added into cell BM28 for the package cost.
- Column BN - cell BN28 sums up all of the packaging costs to get a total package cost.
- Column BO - cell BO28 displays the package selling price after applying the gross margin from the 'Configuration' sheet.

Background – package layers
Organic substrate packages have layers to provide the ability to support a large number of connections.

The basic organic substrate fabrication process is:
1. *A sheet of glass fiber impregnated with BT resin.*
2. *Metalize the sheet.*
3. *Drill alignment holes.*
4. *Apply and pattern polyimide and metal runs.*
5. *Align and glue together multiple layers. Drill holes and plate to create metal filled vias.*
6. *Apply and pattern solder mask.*
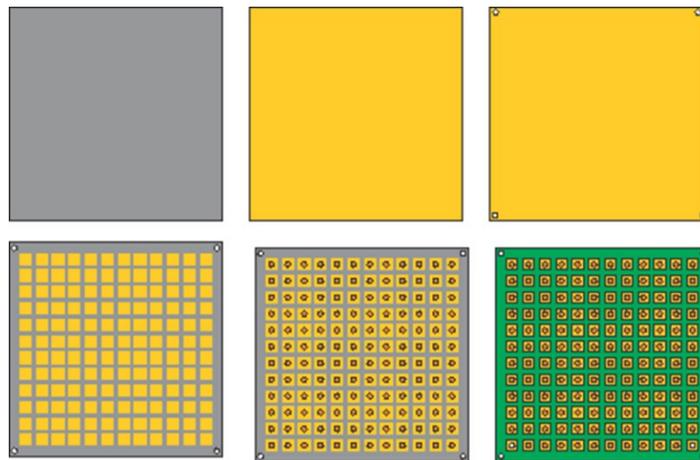
Organic substrate at the various steps in the fabrication process.

The number of layers created in this process are the organic substrate "core layers".

Built up substrates are used where greater precision is required than can be achieved by the process illustrated in the previous section.

Build up is very common for flip chips where pitches =< 100 microns are needed.

Build up utilizes deposited polyimide by screen printing or dry films followed by laser etching of vias and metal deposition and etching to "build up" layers on top of the core substrate.
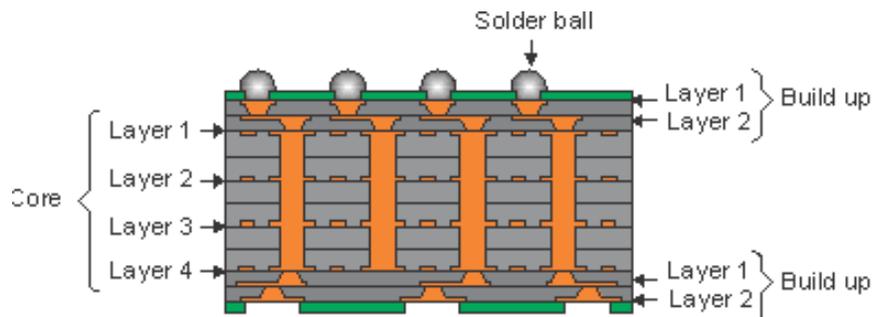
Cross section of an organic substrate with 4 core layers and 2 build up layers.

<u>Class Test (blue tab)</u>
This sheet configures the class test calculations.

Rows 3 through 8 configure the user defined wafer class test. Rows 9 through 13 configure the pre-defined wafer class test (if applicable). Rows 15 through 26 display the resulting costs.

<u>Display only columns</u>
- Column B displays the wafer description from the 'Wafer Definition' sheet.
- Column C displays product type from the 'Wafer Sort' sheet.

<u>Active columns</u>
- Column D - allows you to select the "Product level", options are "Aerospace" (burn-in and three temperature testing), "Automotive" (three temperature testing), "Commercial" (single temperature testing), "Military" (burn-in and three temperature testing).
- Column E - allows you to enter the number of balls/pins for the product. This is used to calculate the test equipment cost.
- Column F – displays the default class test yield. This is estimated based on the number of package balls/pins from column E.
- Column G – enter the class test yield. This entry has no effect unless you select "user" in column H.
- Column H – select "default" to use the default class test yield from column F or user to use the user entered class test yield from column G.
- Column I – select the year the class test equipment came on-line.
- Column J - displays the calculated test time.
- Column K - allows the user to enter a test time. The entries here do not change anything unless you select "User" in column R in the same row.
- Column L - allows you to select default value or user value for the test time.
- Column M - displays the default parts tested in parallel.
- Column N - allows the user to enter a units tested in parallel. The entries here do not change anything unless you select "User" in column O in the same row.
- Column O - allows you to select default value or user value for the units tested in parallel.
- Column P - displays the default parallel test efficiency. The setting drives the test time increase as the number of units tested in parallel increases.
- Column Q - allows the user to enter a parallel test efficiency. The entries here do not change anything unless you select "User" in column R in the same row.
- Column R - allows you to select default value or user value for the parallel efficiency.
- Column S - displays the default test system cost including the handler.
- Column T - allows the user to enter a test system cost. The entries here do not change anything unless you select "User" in column U in the same row.
- Column U - allows you to select default value or user value for the test system cost.
- Column V - displays the default utilization.
- Column W - allows the user to enter a utilization. The entries here do not change anything unless you select "User" in column X in the same row.
- Column X - allows you to select default value or user value for the utilization.
- Column Y - displays the default uptime.
- Column Z - allows the user to enter an uptime. The entries here do not change anything unless you select "User" in column AA in the same row.
- Column AA - allows you to select default value or user value for the uptime.

- Column AB - displays the default pre burn-in test time as a percentage of the test time.
- Column AC - allows the user to enter pre burn-in test time. The entries here do not change anything unless you select "User" in column AD in the same row.
- Column AD - allows you to select default value or user value for the sort 1 test time. In rows 17 through 27 the costs for pre burn-in test are displayed.
- Column AE - displays the default burn-in 1 time.
- Column AF - allows the user to enter the burn-in 1 time. The entries here do not change anything unless you select "User" in column AG in the same row.
- Column AG - allows you to select default value or user value for the burn-in 1 time. In rows 17 through 27 the costs for burn-in 1 are displayed.
- Column AH - displays the interim test time as a percentage of the test time.
- Column AI - allows the user to enter an interim test time. The entries here do not change anything unless you select "User" in column AJ in the same row.
- Column AJ - allows you to select default value or user value for the interim test time. In rows 17 through 27 the costs for interim test are displayed.
- Column AK - displays the default burn-in 2 time.
- Column AL - allows the user to enter the burn-in 2 time. The entries here do not change anything unless you select "User" in column AM in the same row.
- Column AM - allows you to select default value or user value for the burn-in 2 time. In rows 17 through 27 the costs for burn-in 2 are displayed.
- Column AN - displays the room temperature test time as a percentage of the test time.
- Column AO - allows the user to enter a room temperature test time. The entries here do not change anything unless you select "User" in column AP in the same row.
- Column AP - allows you to select default value or user value for the room temperature test time. In rows 17 through 27 the costs for room temperature test are displayed.
- Column AQ - displays the hot test time as a percentage of the test time.
- Column AR - allows the user to enter a hot test time. The entries here do not change anything unless you select "User" in column AS in the same row.
- Column AS - allows you to select default value or user value for the hot test time. In rows 17 through 27 the costs for hot test are displayed.
- Column AT - displays the cold test time as a percentage of the test time.
- Column AU - allows the user to enter a cold test time. The entries here do not change anything unless you select "User" in column AV in the same row.
- Column AV - allows you to select default value or user value for the cold test time. In rows 17 through 27 the costs for hot test are displayed.

Aerospace and Military
Aerospace and military parts require extra testing and paperwork that is configured in columns AX through BJ. For commercial and automotive parts the defaults in these columns is zero.
- Column AX – lists the usage for each row in the rest of the columns out to column BJ. In each column row 3 is the default value, row 4 allows for a user entered value but this value has no effect unless "User" is selected in row 5, row 5 allows "Default" to be set to use the default value or "User" to be set to use the use value. Row 6 displays the value used.
- Column AY – sets the lot size for processes.
- Colum AZ – sets the internal visual inspection cost.
- Column BA -sets the nondestructive bond pull cost.
- Column BB – sets the serialization cost.

- Column BC – sets the temperature cycling cost.
- Column BD – sets the constant acceleration test cost.
- Column BE – sets the particle impact noise test cost.
- Column BF – sets the fine and gross leak test cost.
- Column BG – sets the radiographic test cost.
- Column BH – sets the external visual inspection cost.
- Column BI – sets the document costs.
- Column BJ – repeats the row descriptions from column AX.
- Column BK – displays the total class test cost.
- Column BV – displays the total class test price with gross margin added.

<u>Cost Summary (brown tab)</u>
This sheet summarizes the costs for wafer sort, assembly and class test from the previous sheets. This sheet is not user editable but rather is driven by the settings on the previous sheets.

The cost summary sheet summarizes the costs in a set of cells organized by columns and rows.

The columns are:
- Column B – description of each cost factor
- Column C – the value for the 1st wafer or die, this corresponds to the first user defined wafer.
- Column D – the value for the 2nd wafer or die, this corresponds to the second user defined wafer.
- Column E – the value for the 3rd wafer or die, this corresponds to the third user defined wafer.
- Column F – the value for the 4th wafer or die, this corresponds to the fourth user defined wafer.
- Column G – the value for the 5th wafer or die, this corresponds to the fifth user defined wafer.
- Column H – the value for the 6th wafer or die, this corresponds to the sixth user defined wafer.
- Column I – the value for the 7th wafer or die, this corresponds to the pre-defined bridge die wafers used for EMIB processing.
- Column J – the value for the 8th wafer or die, this corresponds to the pre-defined InFO wafer used in the TSMC InFO process.
- Column K – the value for the 9th wafer or die, this corresponds to the pre-defined integrated passive device (IPD) wafers.
- Column L – the value for the 10th wafer or die, this corresponds to the pre-defined interposer without TSV wafers.
- Column M – the value for the 11th wafer or die, this corresponds to the pre-defined interposer with TSV wafers.

The rows apply to all columns and are:
- Rows 9 and 10 present the wafer prices for the wafers input into the process. For the user defined wafers this is the wafer price entered by the user on the 'Wafer Definition' sheet if entered. For the pre-defined this is the values the model assigns from the 'Yearly Value' sheet.
- Rows 12 through 19 presents the wafer sort costs for sort 1, wafer bake, sort 2, sort 3 and aerospace costs if applicable. This section is driven by the 'Wafer Sort' sheet.
- Rows 21 through 41 presents the wafer level assembly costs from the 'Assembly' sheet.
- Rows 43 through 64 present the die/package level assembly costs from the 'Assembly' sheet.
- Rows 66 through 75 takes the wafer prices from row 10, adds wafer sort costs from row 19 and then uses the net die from the 'Wafer Definition' sheet to calculate cost per die. The die usage from the 'Assembly' sheet is then used to add up all the die costs in the package.
- Row 77 and 78 add the package and die costs together to get a total packaged die cost.
- Rows 80 through 103 presents the class test costs from the 'Class Test Sheet'.
- Rows 105 and 106 present the class test yield and final total product cost.

Background – Product Cost Calculation
The product cost calculations are made as follows:

The packaged die cost calculation is by default based on packaging being performed by an outside contractor (this default may be changed on the 'Defaults' worksheet. When an outside contractor is used the contractor is only paid for good packages.

Packaged die cost = cost per tested good die/packaging yield + package cost

If the default is changed to in-house packaging then:

Packaged die cost = (cost per tested good die + package cost)/packaging yield

Product cost is calculated by:

Product cost = (packaged die cost + class test cost)/class test yield

Background – Gross Margin

Gross margin is the selling price minus the cost of goods sold. Gross margin percentage is the gross margin divided by the selling price for example:

If a product has a cost of goods sold (COGS) of $0.70 and sells for $1.00, then the gross margin (GM) is $0.30 making the gross margin 30%.

To convert from COGS to selling price for a given GM% use the following:

GM%	Divisor
20%	0.80
30%	0.70
40%	0.60
50%	0.50
60%	0.40
70%	0.30

For example, if COGS is $1.40, then a 60% GM would give a selling price of $3.50. A number of our customers have incorrectly made these calculations.

Cost is what it costs to make a product; price is what the market is willing to pay for the product. If you produce and sell a product the hope is always that the price will be greater than the cost by a significant margin but this is not always that case. Profit is gross margin minus below the line costs such as research and development, and general, selling and administrative Gross margins need to typically be greater than the high teens percentage to actually make a profit.

Price = cost + gross margin

If the cost is known (and that is primarily what this model calculates) and gross margin is known or can be estimated, then selling pricing is known and or can be estimated.

Material Usage (brown tab)
This tab displays the material usage for assembly. This sheet is not user editable and is driven by the 'Configuration', 'Wafer Definition', 'Assembly' and 'Yearly Data' sheet entries/selections.

- Column B lists every material type supported by the model.
- Column C displays whether the usage is per part, per wafer or a combination of the two.
- Column D displays the amount of usage.
- Column E displays the units of usage.
- Column F displays the cost of the material, this is based on the material and the current year and comes from the 'Yearly Data' sheet.
- Column G displays the units for pricing, for example a material might be used in grams but bought in kilograms.
- Column H displays the material cost, this is the usage multiplied by the price after adjusting for differences in usage and purchasing units.

<u>Yearly Value (brown tab)</u>

This sheet presents user editable values by year from 2010 for 2030 for the following input factors:

- Direct labor rate by country.
- Electric rate by country.
- Engineers salary by country.
- Margin by OSAT provider.
- Material costs by material type.

Lookups (gray tab)

The lookups sheet provides six lookups to help determine what value to use elsewhere in the model. The lookups page suggests values to use but doesn't drive the model results.

ASIC test type

This lookup gives a rough idea of what ASIC test type to select in the product type for test dropdown on the 'Wafer Sort' and 'Class Test' sheets. You select the node and select a die area that is the next larger size than your die. For example, if your die is $100mm^2$, then it is bigger than 64mm2 and smaller than $128mm^2$ so you pick $128mm^2$.

Selling price

This is a calculator for selling price. The product cost calculated by the model is automatically filled in, you can then enter a gross margin and a selling price is displayed. You can also enter a product price and volume and have a price volume curve displayed. This is useful for example if you go on a distributor site and get a one thousand (1k) piece price, you can enter that price and see what the price will be at higher volumes.