Packaging Cost and Price Model User Manual

IC Knowledge LLC, PO Box 20, Georgetown, MA 01833
Tx: (978) 352 – 7610, Fx: (978) 352 – 3870, email: info@icknowledge.com

Version 2018 model

Introduction
This manual presents an overview of the Packaging Cost and Price Model and the basic workings of the model.

Model description
The Packaging Cost and Price Model is designed to easily calculate the cost and price of most low power semiconductor packages. 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 profits.

Support and updates
As a licensee to the Packaging 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", "Add process request form" and other support items for this model are available in the grey bar on the right side of the Packaging Cost Model page on our web site 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.

- License (Gray tab) – the model software license. This sheet is not editable.
- Introduction (Gray tab) – a brief introduction to IC Knowledge and our cost modeling product line as well as disclaimer and warrantee information. This sheet is not editable.
- HELP (Gray tab) – a listing of the various ways to get help with the model. This sheet is not editable.
- Global Values (red tab) – configures the overall model. This sheet is user editable.
- Packaging (blue tab) - this is the sheet that defines the packaging process and displays the costs, price and materials usage.
- Yearly Data (brown tab) - sets utility, labor, material and margins by year, company and country.
- Revision (grey tab) - lists the changes in the current version of the model.
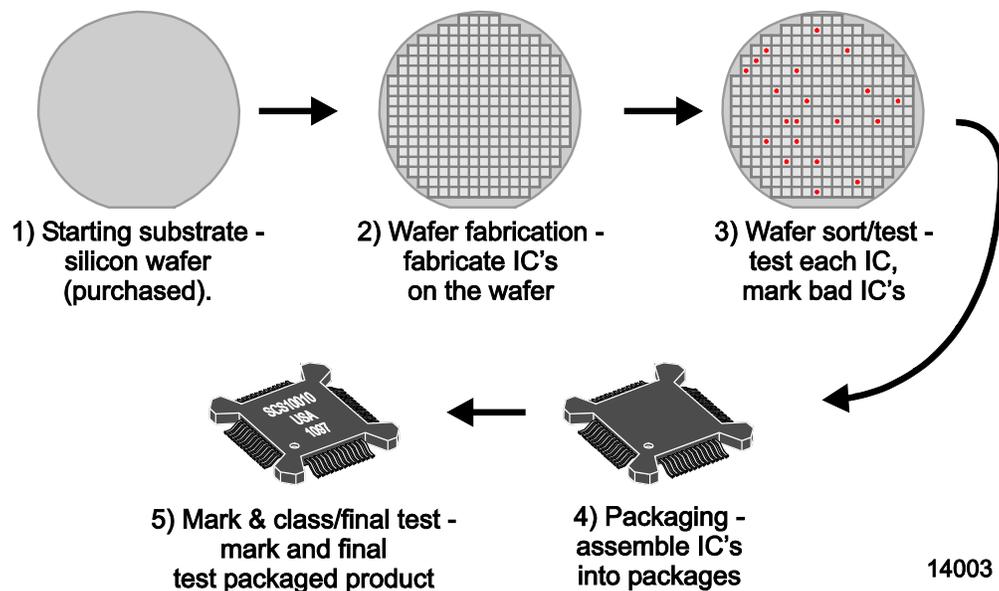
Detailed worksheet descriptions

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

<u>Global Values (red tab)</u>
These values configure the overall model.

- <u>OSAT (cell B1)</u> - sets the outsourced assembly and test provider running the packaging process. This selection determines the country and sets the default gross margin. The country and gross margin can be overridden to model OSATs or packaging locations not available in this list.

For the rest of the page for each item column C is the default value, column C selects default or override values and column D presents the value being modeled.

- <u>Year being modeled (row 3)</u> - year being modeled is used to select the yearly values on the 'YearlyData' sheet and also is compared to the year the equipment came on line value to determine if equipment is still depreciating.
- <u>Country (row 4)</u> - the country the packaging facility is located in. The default is set by the selected OSAT. The country selected sets what labor and utility rates to use from the 'YearlyData' sheet.
- <u>Volume/margin (row 5)</u> - when you select an OSAT in row 1 and average gross margin fill in as the default. You can override the gross margin by selecting "Very low", "Low", "Average", "High" or "Very High" here in in each case an override margin will fill in based on the volume selected and OSAT. You can also select a margin %.
- <u>Street width (row 6)</u> - the street is the space between die left for sawing (see the Background on die size and number of die per wafer information below).
- <u>Edge exclusion (row 7)</u> - the width of the area at the wafers edge where no good or whole die are printed (see the Background on die size and number of die per wafer information below).
- <u>Oversaw (row 8)</u> - when sawing up a wafer the saw travels past the edges of the wafer, this is called oversaw and the amount of oversaw effects the wafer sawing time.
- <u>Equipment set years to depreciate over (row 9)</u> - sets the depreciation rate for equipment.
- <u>Equipment depreciation (display only) (row 10)</u> - displays the equipment depreciation rate (one divided by the years to depreciate the equipment over).
- <u>Percent depreciated (row 11)</u> - the percentage of the equipment set that is fully depreciated. We recommend this be set to 95% for leadframe based packages, 50% for organic substrate packages and 0% for wafer level and InFO packages.
- <u>Year the facility was built (row 12)</u> - by default this is set to 5 years before the date being modeled so the facility is still depreciating.
- <u>Building systems years to depreciate over (row 13)</u> - the number of years to depreciate the building systems over. Building systems make up 70% of the facility construction costs and are the HVAC systems, high purity piping systems, cleanroom, etc.
- <u>Building years to depreciate over (row 14)</u> - the number of years to depreciate the building over. the building makes up 30% of the facility construction cost.
- <u>Building system depreciation rate (display only) (row 15)</u> - displays the depreciation rate being applied to the building systems. If the year to model minus the year the facility was built is greater than the years to depreciate the building systems over this is 0. If the year to model minus the year the facility was built is less than or equal to the years to depreciate the building systems over this is set to one divided by the years to depreciate the building systems over.
- <u>Building depreciation rate (display only) (row 15)</u> - displays the depreciation rate being applied to the building. If the year to model minus the year the facility was built is greater than the years to depreciate the building over this is 0. If the year to model minus the year the facility was built is less than or equal to the years to depreciate the building over this is set to one divided by the years to depreciate the building over.

- <u>Hours per week of operation (row 17)</u> - by default 168 hours (24 hours a day 7 days a week).
- <u>Weeks per year of operation (row 18)</u> - by default 52 weeks per year.
- <u>Uptime (%) (row 19)</u> - the average percentage of time the equipment is up and available for use.
- <u>Utilization (%) (row 20)</u> - the average percentage of time that equipment is being used when it is up.
- <u>Calculated machine hours (hrs/yr) (row 22)</u> - this is the hours per week multiplied by the weeks per year multiplied by the uptime multiplied by the utilization and represents the productive machine hours per year.

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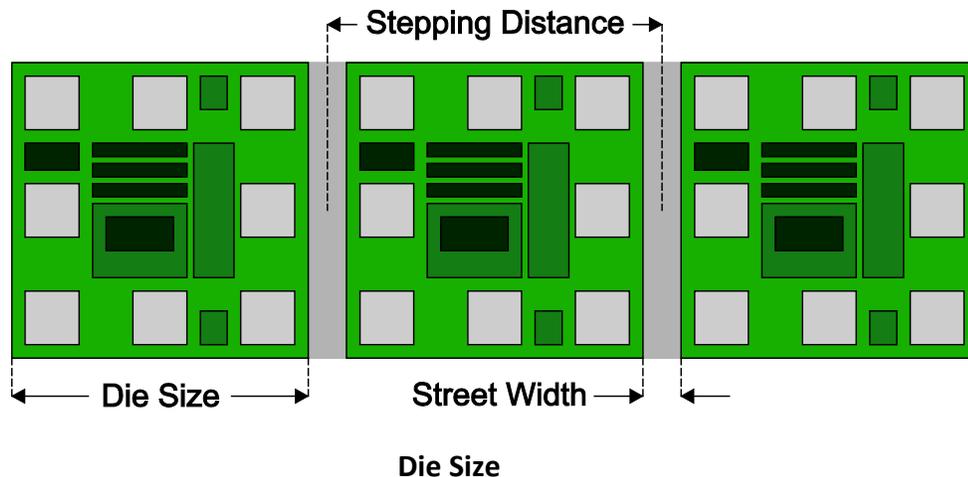
Other factors to take into when determining the number of whole die on a wafer are the edge exclusion.

- *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.*

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>Packaging (blue tab)</u>
This is the main sheet of the model and is where the package is defined and the cost, price and material usage are all displayed.

At a high level, columns A through AA are the wafer level operations and columns AC through BE are the die/package level operations. Rows 4 through 14 define the operations, rows 15 though 26 present the costs and rows 27 through 70 present the material usage.

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

Wafer processing
This section defines the wafer level processing and costs. The results of this section may be used by themselves and also feed into the die/package process section:
- <u>Wafer # and description</u> - The model allows for up to 6 user defined wafers and 4 pre-defined wafer types to be used in the packaging process. Each wafer can supply 1 die per package or many die per package. Cells A5 through A14 number the wafers 1 through 10 and cells B5 through B14 describe the wafers. Cells B5 through B10 are user editable and you can enter whatever wafer description you want.
- <u>Wafer size</u> - cells C5 through C10 allow the user to select a wafer size for the user defined. For any wafers you aren't using you should set this to "NA". The predefined wafers have wafer sizes set in cells C11 through C14 and these are not user editable.
- <u>Die size</u> - the die width and die height are set in cells E5 through F14. You must fill this in for any wafer you are using and **should be left blank for any wafer you are not using**. For the user defined wafers if you select a wafer size other than NA these matching die size cells will turn red unless you enter die size values. See the " Background on die size and number of die per wafer" for information on die size.
- <u>Gross die</u> - cells G5 through G14 display the calculated whole gross die per wafer based on the wafer size selected in column C, die sizes from columns E and F and street width and edge exclusion set on the 'Global Values' sheet.
- <u>Die yield</u> - enter a die yield in cells H5 through H14 for any wafer types being used.
- <u>Net die</u> - the gross die multiplied by the die yield is displayed in cells I5 through I14.
- <u>Backgrind</u> - in cells J5 through J14 set whether the wafers are going through Backgrind. In cells J16 through J25 the cost per wafer for Backgrind is displayed.
- <u>Wafer thickness (mm)</u> - in cells K5 through K14 enter the die thickness after Backgrind. This thickness is used to determine mold epoxy thickness to cover the die.
- <u>RDL</u> - Redistribution Layer used to rout bond pads to wafer bumps for flip chip. In cells L5 through L10 you can select whether to perform RDL or not. RDL is off for the predefined wafers and is not user editable. In cells L16 through L25 the RDL cost per wafer is displayed.
- <u>Frontside wafer bumping</u> - in cells M5 through M14 select NA if no frontside bumping is done or copper for copper bumping or solder for solder bumping. Cells M16 through M25 display the cost per wafer from frontside wafer bumping.
- <u>Backside solder balls</u> - cells N5 through N10 and N14 enter the number of solder balls applied for backside wafer bumping. In cells N11 through N13 solder balls is off by default for certain predefined wafers and is not user editable. In cells N16 through N25 the cost per wafer for solder ball bumping is displayed.
- <u>Copper pillar formation</u> - copper pillars are used for the InFO process and are off for all other wafers by default and not user editable. For InFO you can turn on or off copper pillars in cell

O14. Copper pillars are an option in the InFO process to provide interconnect to die mounted to the backside of the InFO package. The cost per wafer to form copper pillars is displayed in cells O16 through O25.

- Wafer coating - a protective wafer coating is sometimes used on bumped die. Select yes or no for wafer coating in cells P5 though P10. Wafer coating is off by default for the predefined wafers and is not user editable. The cost per wafer for wafer coating is displayed in cells P16 through P25.
- Wafer level buildup layers - 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. In cell Q14 enter the number of buildup layers for the InFO wafer. The cost per wafer for the selected buildup layers is displayed in calls Q16 through Q25.
- Wafer mold - wafer mold is used for the InFO process and off by default for all other wafer types and not user editable. Select "Yes" in cell R14 to activate wafer mold for the InFO wafer. The cost per wafer for wafer mold is displayed in calls R16 through R25.
- Planarize - planarize is used to expose electrical contacts after wafer mold for the InFO process. Planarize is off by default and not user editable for all non-InFO wafers. Cells S16 through S25 display the cost per wafer for the planarize step.
- Carrier removal - a carrier is used for the InFO process and then removed. Carrier removal is off by default and not user editable for all non-InFO wafers. Cells T16 through T25 display the cost per wafer for the carrier removal step.
- First pass - selects "Yes" or "No" to turn on or off the first pass wafer sawing. Cells U5 through U14 select first pass sawing for each wafer. Cells U11 through U13 are on by default and not user editable. Cells U16 through U25 display the wafer cost for sawing for each wafer.
- Second pass - selects "Yes" or "No" to turn on or off the second pass wafer sawing. Cells V5 through V14 select first pass sawing for each wafer. Cells V11 through V13 are on by default and not user editable. Cells V16 through V25 display the wafer cost for sawing for each wafer.
- Saw type - select "1 spindle", "2 spindle" or "3 spindle" standard saw or laser (single head) for the saw type in cells W5 through W14. Cells W11 through W13 are set to "2 spindle" by default and are not user editable. The selections in these cells are used for both first and second pass sawing of applicable.
- Reconstruct wafer - after test only good die are picked and placed onto a frame to create a new wafer of all good die. Select "Yes" or "No" to activate or inactivate reconstructed wafer in cells X5 through X14. Reconstruct wafer is off by default for the predefined wafers and is not user editable. The cost per wafer for reconstruct is displayed in cells X16 through X25.
- Visual inspect - select "1 times", "2 times" or "3 times" for 1, 2 or 3 wafer visual inspections respectively or "NA" for no inspection in cells Y5 through Y14. By default the EMIB and interposer wafers have 1 inspection and that is not user editable.
- Wafer cost - in cells Z16 through Z25 the total cost for processing of each wafer type is displayed. This is a summary of columns J though Y.
- Die cost - in cells AA16 through AA25 the cost per doe for wafer processing is displayed. This is the wafer costs from column Z divided by the net die for each wafer from cells I5 through I14.

Die/package processing

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

- Die usage - cells AC5 through AC14 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 AC16 through AC25 display the total cost for die from each respective wafer type. This is the die cost from cells AA16 through AA25 multiplied by the number of times each die is sued in cells AC5 through AC14. In cell AC26 a total of all of the die costs for the die being used displayed.

- Type - 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 AD5.
- Leadframe - if you select "Leadframe" in cell AD5 then cells AE5 through AH13 turn white so you can define the leadframe. Cell AE5 is a dropdown where you select the leadframe. For "InFO" or "Organic Substrate" packages this section is inactive.
- Etched or stamped - for Leadframe packages you select "Etched" or "Stamped" for the leadframe type in cell AF5.
- Alloy - in cell AG5 you select the alloy type used to make the leadframe.
- Stamped plated - for stamped leadframes you can select whether to spot plate it in cell AH5. In cell AF16 the cost for the leadframe based on the leadframe defining selections is displayed. This cost also appears in cell AF26 for the total of the entire package process.
- Width - if cell AD5 is set to "Organic Substrate" then cells AL5 through AN13 turn white so you can define the organic substrate package. In cell AI5 you enter the organic substrate package width in millimeters.
- Height - in cell AJ5 you enter the organic substrate height in millimeters.
- Core layers - in cell AK5 you enter the number of core layers for the organic substrate.
- I/O - in cell AL5 you enter the number of input/outputs for the organic substrate
- Buildup layers - in cell AM5 enter the number of buildup layers for the organic substrate.
- EMIB processing - if you enter a number greater than 0 for the EMIB wafer (Bridge die wafer) die used in cell AC11, then cell AN5 will display a "Yes' to indicate additional organic substrate processing is active for EMIB die. In cell AK16 the cost for the organic substrate is displayed and it is also added into cell AK26 for the package total.
- Type - select the die attach type for each of the user defined wafer/die types in cells AO5 through AO10. If you select "Flip chip" here then wire bonding is disabled from that die. Also supported are "Epoxy", Gold Eutectic" and Solder. Cells AO16 through AO21 display the die attach cost for each die. Cell AO26 displays the total die attach costs and adds into the overall package cost.
- Cure - if any active die are epoxy mounted then cure is automatically turned on in cell AP5. The cure cost is displayed in cell AP16 and added into cell AP26 for the total package cost.
- Plasma clean - in cell AQ5 you can select "Yes" or "No" to activate or deactivate plasma cleaning. The cost for plasma clean is displayed in cell AQ16 and added into cell AQ26 for teh total package cost.
- Wire type - in cells AR5 through AR10 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 AC.

- Number of bond wires - in cells AS5 through AS10 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 AC.
- Wire length - in cells AT5 through AT10 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 AC. Cells AT16 through AT21 display the cost for wire bond for each die and cell AT26 totals up the wire bond cost for the final package costs.
- Inspect - in cells AU5 through AU10 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 AU16 through AU21 and added together in cell AU26 for the package cost.
- Mold - select "Yes" in cell AV5 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 AV16 displays the molding cost and it is added into cell AV26 for the package cost.
- Used - if mold is turned off in cell AV5, then you will have the option to turn on a thermal lid by selecting "Yes' in cell AW5.
- Width - if a thermal lid is used enter the lid width in millimeters in cell AX5.
- Height - if a thermal lid is used enter the lid height in millimeters in cell AY5. Cell AY16 displays the cost of the thermal lid and the cost is added into cell AY26 for the package cost.
- Singulate - for leadframe packages you cans elect Singulate in cell AZ5. 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 AZ16 and added into cell AZ26 for the package cost.
- Laser mark - select "Yes" in cell BA5 to add laser mark to the package. The cost for laser mark is displayed in cell BA16 and added into cell BA26 for the package cost.
- Inspect - select "Yes" in cell BB5 to add a visual inspection step. The cost is displayed in cell BB16 and added into cell BB26 for the package cost.
- Open/short test time - to add open/short testing enter the open/short test time in cell BC5. The cost for open/short testing is displayed cell BC16 and added into cell BC26 for the package cost.
- Total package cost - cell BD26 sums up all of the packaging costs to get a total package cost.
- Total package price - cell BE26 displays the package selling price after applying the gross margin from the 'Global Values' sheet.

- Wafer level material usage - the material usage by material type and wafer for wafer processing is displayed in cells C28 through Q52. These values are per wafer.
- Die/package material usage - the material usage by material type, broken out into leadframe, organic substrate and die/package and wafer for die/package is displayed in cells AE28 through AI70. These values are per die or package.

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

This sheet presents user editable values by year from 2010 for 2025 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.