Yield losses in electronics production are significant to LCA

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Problem Description

In LCAs of electronic products and components the direct material demand of the product is often assessed by looking at the materials *remaining* in the final product (eg. Reichart and Hischier 2001, IZT 1998, Hofstetter 1989). This shortcut inventory procedure gives a fairly good assessment *if* waste rates in production are low, i.e. most of a material input into production will end up in the product. However, in electronics production this assumption does often not hold true.

The reject or fail rate in the quality control step of electronic component production can be rather high. Cumulative losses can amount to significant changes in material and energy demand of production.

Examples

For modern silicon microchips the typical overall fail rate of production from silicon disks (wafers) is between 84% at technology introduction and 22% for mature production (data for Ultra-Large Systems Integration ULSI chips like eg. the 486 or Pentium processor given by Van Zandt 1997). Usually the flawed products cannot be directly fed back into production and need to be disposed of as waste (where some recycling may or may not occur).

Figure 1 The total losses of highly purified silicon during wafer and microchip production are not negligible.

Additionally, producing *rectangular* microchip dies from *circular* silicon wafers will have a waste rate (waste material per input) of at least around 15% *for geometric reasons alone*.

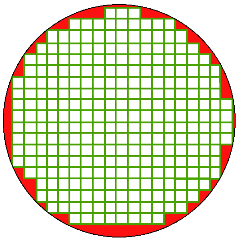

Figure 2 Cutting rectangular microchip dies from circular silicon wafers leads to geometric losses (in red).

Further upstream in the process chain, wafers are produced sawn from crystalline silicon columns (Czochralski column). With current wafer thicknesses of approx. 250nm and sawing gaps of approx. 150nm the sawing losses of silicon are *at least* 37.5% (typical figures). These and similar material losses and associated waste streams and energy demands are often not heeded in the LCA of electronic products and components, but they are probably a not negligible part of the burden from production. In the example of microchip production the overall loss of silicon from Czochralski column to shipping of functional ICs is between 92% and 58% (or yields are 8.5% to 42%). These losses increase the high-purity silicon material demand by a factor of 12 to 2.4.
Due to the highly progressive electronics market situation with ever shorter production cycles there is often an increasing lack of time to optimize component production and minmise fail rates. Higher mature yield demands exponentially higher fabrication costs as shown in figure 3 (Jensen et al. 1998).

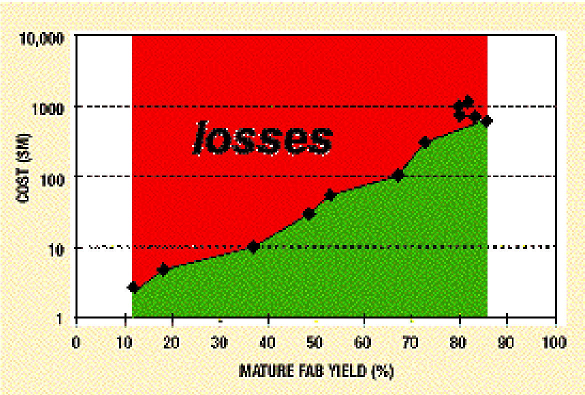

Figure 3 Fabrication cost vs. mature fabrication yield of Very Large Systems Integration VLSI microchip production (Jansen et al. 1998). Note that these are **mature** fabrication yields that go as low as 12%.

For simpler electronic components losses are probably lower than for complex microchips, but might still be relevant to include in the assessment.
Example 2: Production of thin-film-transistor liquid-crystal displays (TFT-LCDs) has high defect rates. Current production has typical defect rates (quality control reject) of 50% to 70%. The input to TFT-LCD production are large format glass substrates of various sizes of approximately 60 cm by 72 cm. From one glass substrate six LCD displays with 13.3- or 14.1-inch diagonals are produced. Hence there is a purely geometric loss of 15% to 23%. The material loss from glass

substrate to shipping of functional displays is hence between 40% and 62% (or yields are 60% to 38%). These losses increase the material demand by a factor of 1.7 to 2.6.
Apart from these material losses the *use of auxiliary materials in production*, which do not remain in the product (eg. solvents; masking, etching and cleaning agents etc.) or *direct emissions from production* are completely neglected by only assessing the materials in the final product. However, direct energy input to electronics production is usually heeded.

Conclusions

With respect to these special circumstances the often encountered inventory procedure of *assessing what materials remain in the product* needs to be reconsidered for LCAs of electronic products and components. Ignoring production yield needs to be verified since it can significantly underestimate the environmental burden from the infrastructure of electronic products, i.e. overemphasize the relative importance of burdens from the use phase. Electronics infrastructure might be environmentally more important than current studies suggest.

References

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