### Arburg Devises an Informative Product Carbon Footprint Calculation

# $CO_2$ Footprint of Injection Molding Machines

Arburg has been dealing with the issue of sustainability and resource efficiency for a very long time. The injection molding machine supplier is being integrated more and more by its customers into evaluations of climate-change activities along the supply chain. Drawing on ISO TS 14067:2015, which specifies how to quantify the carbon footprint of a product, Arburg studied ways to determine the product carbon footprint (PCF) and specific energy requirements of its injection molding machines.

Raw materials extraction through to delivery account for just 5 % of the $CO_2$ emitted by an injection molding machine over its entire life cycle. © Arburg

Under the European Union's "Green Deal", companies are being actively encouraged to reduce the carbon emissions from their activities and products. In order to meet strict legal requirements and the goal of zero net emissions of greenhouse gases from production by 2050, companies will have to significantly increase their energy and resource efficiency in the future. Accordingly, sustainability is a major strategic issue for many European plastics converters at the moment.

The German Climate Change Act goes one step further in legislating for a 65 % reduction in $CO_2$ emissions by 2030 and for greenhouse gas neutrality by 2045. The Greenhouse Gas Protocol, an internationally recognized accounting standard for greenhouse gas emissions, classifies emissions into three areas called "Scopes". Injection molding machines are considered Scope 3 assets, which cover indirect emissions from upstream and downstream business activities. As a machine manufacturer, Arburg actively engages in carbon accounting in order to obtain reliable and comparable indicators and help achieve the ambitious climate targets. Its commitment here is borne out by the above-average "B" grade which the company earned in the Carbon Disclosure Project (CDP).

## *Bulk of PCF Arises in the Use Phase*

In contrast to the annual corporate carbon footprint (CCF), the product carbon footprint (PCF) addresses the quantities of greenhouse gases emitted and removed over the entire service life of a product. Reported in units of $CO_2$ equivalents, PCF is an important metric in life cycle assessment. The guidelines on quantifying and reporting it are set out in international standard ISO TS 14067:2018.

For injection molders, the first relevant question is the machine's carbon footprint, from when it is being made to when it arrives at the plant. In its cradle-to-gate analysis, Arburg examined the period from extraction of raw materials to the manufacturing phase through to the machine leaving the factory gate. However, this period accounts for only 5 % of the machine's $CO_2$ emissions. On a cradle-to-grave basis, i.e. over the ma-

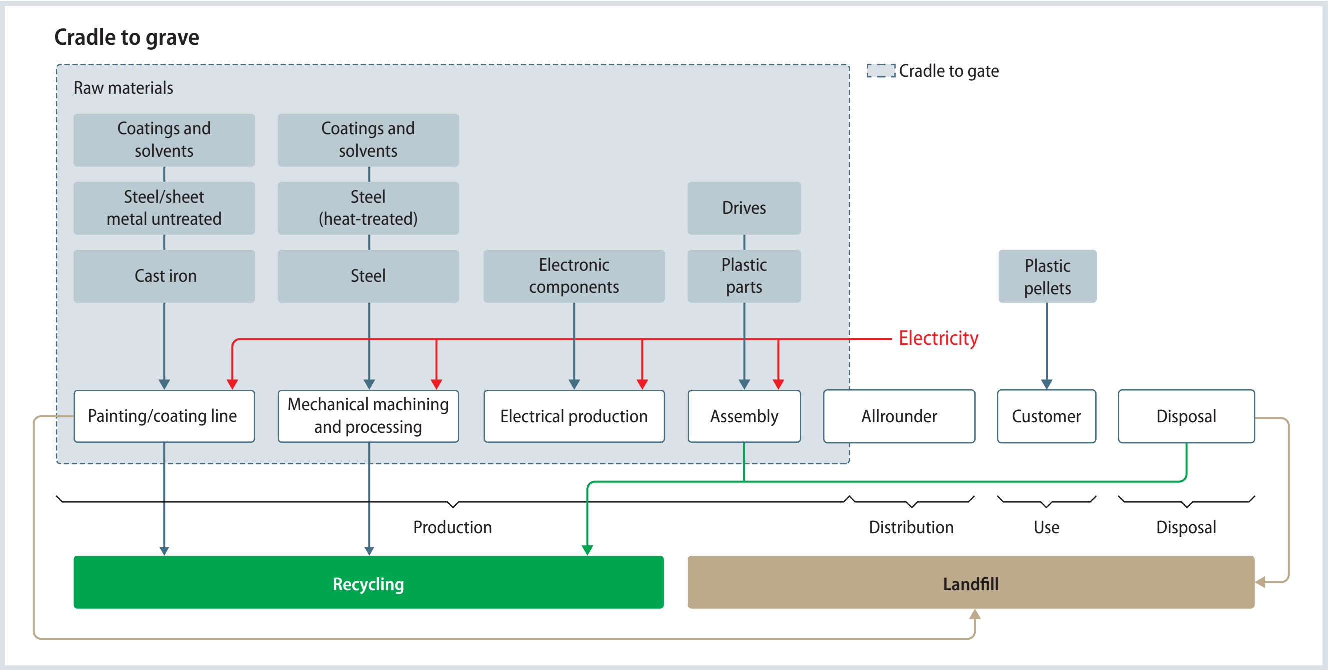

**Fig. 1.** Arburg's cradle-to-gate analysis determines the $CO_2$ emissions associated with its injection molding machines, from the constituent raw materials and the manufacturing process right through to delivery. Source: Arburg; graphic: © Hanser

chine's entire life, the bulk of PCF is generated during the use phase at the customer's factory, plus emissions that arise during its distribution and disposal. Arburg records the $CO_2$ emitted in four process steps that lead to the finished machine:

- painting or coating,
- mechanical machining and processing,
- electrical production, and
- assembly.

The raw materials used and the requisite electric power can be apportioned to the various steps in this process sequence and the other phases in the product life cycle (**Fig. 1**).

## *Raw Materials Emissions*

The parts list for an injection molding machine could number up to 11,000 individual items if every screw were to be accounted for. To help it better manage this figure, Arburg divides the raw materials into eight materials groups. On this basis, an Allrounder injection molding machine consists of over 55 % plastic-coated cast iron and a further 35 % of steel and sheet metal (whether heat-treated, painted, plastic-coated or untreated). Plastic parts, drives and electronic components account for just 7 % of the total weight.

These materials groups differ substantially in terms of the $CO_2$ emissions generated during their production. However, a weighted average value or emissions factor can be determined commensurate with the distribution. The emissions factor for an Allrounder is 1.83 [kg $CO_2$ equivalent per kg product]. The $CO_2$ equivalent for the complete injection molding machine therefore is obtained by multiplying the emissions factor by the product weight specified in the data sheet (**Table 1**).

This means that the manufacture of a hybrid Allrounder 570 H with a clamping force of 2000 kN and a net weight of 8300 kg generates raw materials-related emissions of around 15,190 kg $CO_2$. The corresponding figure for a 3300-kg Allrounder 370 with a clamping force of 600 kN is around 6040 kg.

## *Electricity-Related Emissions during Production*

Electricity consumption during the production phase also contributes to the PCF. Standardized calculations are based on an electricity requirement of 878.94 kWh per 1000 kg of product and an emissions factor of 0.366 [kg $CO_2$ equivalent per kWh] for the German electricity mix in 2020 (**Table 2**).

On that basis, the electricity requirement is 2900 kWh for the Allrounder 370 H, with a $CO_2$ equivalent of about 1160 kg. The corresponding figures for the Allrounder 570 H would be an electricity requirement of 7295 kWh and emissions of 2670 kg $CO_2$.

However, this calculation cannot be directly applied to Arburg. The reason is that the company manufactures around 60 % of its own machine »

| Series* | Weight [kg] | Emissions factor** | $CO_2$ equivalent of raw materials [kg] |
|---|---|---|---|
| Allrounder 370 H | 3300 | 1.83 | 6040 |
| Allrounder 470 H | 4700 | 1.83 | 8600 |
| Allrounder 570 H | 8300 | 1.83 | 15,190 |

* Hybrid Hidrive series with clamping force of 600 kN (370 H), 1000 kN (470 H) and 2000 kN (570 H)
** Weighted average [kg $CO_2$ equivalent/kg product]

**Table 1.** The $CO_2$ emissions of an injection molding machine in terms of raw materials are simply calculated by multiplying the net weight by the emissions factor 1.83 as determined by Arburg. Source: Arburg

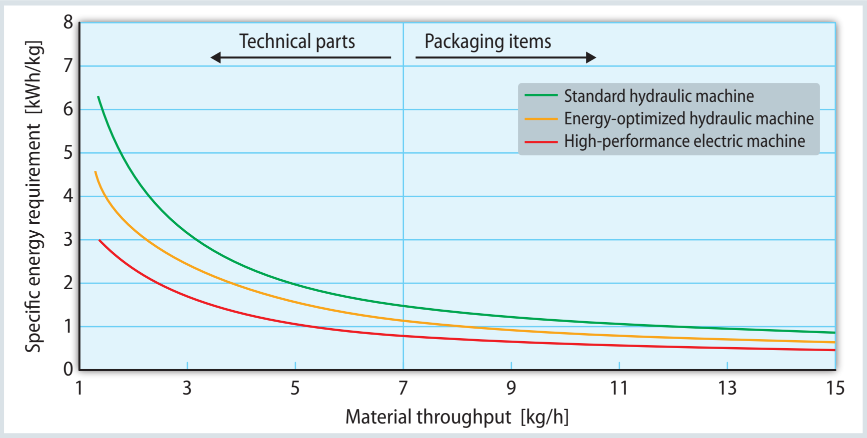

**Fig. 2.** The specific energy requirement of an injection molding machine in the use phase depends on the equipment, type of application and material throughput. In general, the better the machine is utilized, the better is the carbon footprint. Source: Arburg; graphic: © Hanser

| Series | Weight [kg] | Electricity requirement* [kWh] | Emissions factor** | $CO_2$ equivalent of manufacture [kg] |
|---|---|---|---|---|
| Allrounder 370 H | 3300 | 2900 | 0.366 | 1160 |
| Allrounder 470 H | 4700 | 4130 | 0.366 | 1510 |
| Allrounder 570 H | 8300 | 7295 | 0.366 | 2670 |

* Standardized electricity requirement: 878.94 kWh/1000 kg product
** Basis: German electricity mix (in 2020)

**Table 2.** Electricity-related $CO_2$ emissions arising from the manufacture of an injection molding machine can be calculated on the basis of the German electricity mix (emissions factor 0.366 for the year 2020). Source: Arburg

components exclusively at its central production site in Lossburg, Germany, using a mix of carbon-neutral renewable energies such as photovoltaic, wind and geothermal energy as well as combined heat-and-power plants. Since 2016, the electricity purchased regionally has come entirely from sustainable sources. The emissions factor for Arburg's electricity mix is just 0.17, instead of 0.366.

In concrete terms, this means that the electricity-related $CO_2$ equivalent for the Allrounder 370 H is actually just 490 kg, instead of 1160 kg, and, similarly, 1240 kg, instead of 2670 kg, for the Allrounder 570. Thus, as a result of the company's high degree of vertical integration and the sustainable electricity mix, the electricity-related emissions generated by an Arburg machine during its manufacturing phase are some 53 % lower than the German average.

Adding the raw materials- and electricity-related emissions together yields a total $CO_2$ equivalent for a "cradle-to-gate" analysis of 6530 kg for the Allrounder 370 H and 16,430 kg for the Allrounder 570 H (**Table 3**). By comparison, each person in Germany generates an average $CO_2$ footprint of around 12,000 kg per year, with this figure varying according to such factors as personal consumption, mobility, housing and nutrition.

## *In-Use Footprint*

Some 95 % of an injection molding machine's PCF arises during its use phase. However, the level of emissions it actually generates in daily use depends on numerous factors. Crucial determining factors are the choice of polymer, the product design and the construction of the injection mold. A key parameter here is the specific energy requirement, which is the quotient of power consumption and material throughput and is expressed in units of kWh per kg. As a rule of thumb, the shorter the cycle time and the higher the shot weight, the lower is the specific energy requirement and the better is the $CO_2$ equivalent.

The specific energy requirement is critically affected by the type of drive, i.e. whether electric, hybrid or hydraulic. Other contributory factors are whether single- or dual-circuit pump technology or hydraulic accumulators are used and whether options such as servo-electric metering or ejection are included.

Any feature which enables simultaneous, dynamic and fast movements and thus shortens cycle times benefits the carbon footprint in use. The same applies to the screw diameter and installed power: the greater the shot weight and the lower the power consumption, the better. In summary, machine equipment tailored specifically to the requirements and processes can substantially reduce the energy requirement. Arburg supports its customers in this area through its wealth of expertise in application technology and process engineering and by exploiting the advantages of modular machine technology.

## *Measuring the Energy Requirement under Euromap 60.2*

The Euromap 60.2 Recommendation is used for determining the energy consumption of an injection molding machine in a customer-specific process. It facilitates objective comparisons of different machine designs by measuring and documenting the average power consumption under standard conditions for a defined accounting period. The readings depend both on the machine technology and on the utilization rate and the type of application. For example,

| Series | $CO_2$ equivalent of raw materials [kg] | $CO_2$ equivalent of manufacture* [kg] | $CO_2$ equivalent of cradle to gate [kg] |
|---|---|---|---|
| Allrounder 370 H | 6040 | 490 | 6530 |
| Allrounder 470 H | 8600 | 700 | 9300 |
| Allrounder 570 H | 15,190 | 1240 | 16,430 |

* Based on emissions factor 0.170 (Arburg electricity mix)

**Table 3.** The carbon footprint (PCF) of the machines up to delivery to the customer is the sum of the raw materials- and electricity-related $CO_2$ equivalents ("cradle to gate"). Source: Arburg

| **Machine** | | **Product** | | | |
|---|---|---|---|---|---|
| **Size** | **Drive** | **Technical item** | | **Packaging item** | |
| | | Material throughput [kg/h] | Emissions [kg $CO_2$/kg PA66] | Material throughput [kg/h] | Emissions [kg $CO_2$/kg PP] |
| 370* | Hydraulic T2 | 4.2 | 4.43 | 10.08 | 2.87 |
| | Electric Comfort | 4.2 | 2.13 | 10.08 | 1.58 |
| 570** | Hydraulic T2 | 16.2 | 2.6 | 41.04 | 2.3 |
| | Electric Comfort | 16.2 | 1.39 | 41.04 | 1.23 |
| 820*** | Hydraulic T2 | 45.6 | 1.72 | 115.2 | 1.69 |
| | Electric Comfort | 45.6 | 0.93 | 115.2 | 1.07 |

* Clamping force 600 kN, injection unit 170, screw D30 ** Clamping force 2000 kN, injection unit 800, screw D50
*** Clamping force 4000 kN, injection unit 2100, screw D70

**Table 4.** Arburg studied the $CO_2$ emissions from three sizes of injection molding machine and two types of drive during measurements conducted in accordance with Euromap 60.2. One technical part and one packaging item were produced.
Source: Arburg

the specific energy requirement for small production runs of technical molded parts is significantly greater per se than for the production of fast-moving packaging items (**Fig. 2**).

The results show that electric machines require around 50 % less energy than standard hydraulic machines. And the lower the material throughput, the more significant the differences are. But energy-optimized hydraulic machines, too, can significantly reduce the carbon footprint.

## *Practical Example*

While working on a practical application, Arburg examined various scenarios involving hydraulic and electric machines from the S and Alldrive series in three sizes – 370, 570 and 820 – and clamping forces of 600, 2000 and 4000 kN. A distinction was made between an hydraulic drive featuring dual-circuit pump technology (T2) and an electric drive from the "Comfort" performance range.

Two items were produced, namely a PA66-GF30 technical item in a cycle time of 30 s at 50 % plasticizing capacity and a PP packaging item in a cycle time of 5 s at 100 % plasticizing capacity (**Table 4**). The $CO_2$ emissions were calculated on the basis of the German electricity mix.

The electric Allrounder 820 A, operating at a throughput of 115.2 kg/h, emitted 1.07 kg $CO_2$ per kg plastic when molding the packaging item. The 370 electric model emitted almost twice as much (2.13) when injection molding the technical item at a throughput of 4.2 kg/h. For the hydraulic Allrounder 370 S, this value was as high as 4.43.

These figures apply to the practical example. Other applications may yield different figures. The actual power consumption depends in each case on the duty cycle, capacity utilization and the efficiency of the connected consumers. These factors are influenced in turn by the injection molding process. In general, however, it may be said that the energy requirement for both types of drive decreases as material throughput increases. In any event, an electric machine generates around 50 % fewer $CO_2$ emissions. The same result is obtained when the $CO_2$ emissions are all calculated on the basis of material throughput.

Not included in this analysis are the $CO_2$ emissions generated in the production of the plastic pellets or other consumers such as peripheral equipment for providing mold-temperature control or shop air-conditioning (waste heat and cooling). The energy requirements and thus the $CO_2$ emissions from the peripheral equipment increase sharply, particularly for technical items, and even exceed those of the injection molding machine on a proportional basis. A further interesting parameter is the carbon footprint of a single molded part.

## *Conclusion*

An informative "cradle-to-gate" carbon footprint can be calculated for injection molding machines. Raw materials have a roughly tenfold greater impact on the product carbon footprint during the manufacturing phase than does electricity consumption. Local supply chains, a high degree of vertical integration and the use of renewable energies can positively influence the footprint.

As the PCF during the use phase depends on many factors,individual case studies are required here. As a rule, the specific energy requirement of an injection molding machine decreases as its utilization rate increases. In addition, electric machines generate up to around 50 % fewer $CO_2$ emissions than their hydraulic counterparts, the exact amount depending on the equipment and material throughput.

The goal for the future is to be able to determine a scientifically sound, holistic life cycle assessment for injection molding machines. This will require much greater effort. This is precisely what Prof. Dr.-Ing. Hans-Josef Endres and his team at the Institute for Plastics and Circular Economy (IKK) at Leibniz University in Hanover, Germany, are working on, in collaboration with Arburg and others. ■

## Info

### Text

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