Designing Successful Products with Plastics with Sustainability as a Design Consideration

For most every plastic product or part design project, the design engineer will begin with a set of requirements for the product or part and will proceed to create the initial design solution concepts using a few well-known considerations. These considerations are often referred to as the “Four Pillars” of plastic part design [1] and include the material(s) to be used, the process(es) to be used to fabricate the part(s), the tooling required for the process(es) selected, and, the actual detailed part design(s). Any plastic product or part designed with these four considerations utilized for every design decision throughout the design process will typically perform and function as expected and should be easily manufacturable. Missing from these four primary considerations, although sometimes implied, is a regard for sustainability.

Designers and engineers practicing in the art of plastic part or product development will generally be versed in the concept of energy efficiency. In fact, one of the driving forces in the selection and use of plastics as a material choice for many products and parts is the overwhelming energy efficiency that can be achieved, resulting in lower costs. As designers, if we can save one single gram of material in a part, then that is one less gram that needs to be produced as a raw material, one less gram that needs to be transported from the raw material manufacturer through distribution to the processor, one less gram that needs to be heated for processing, one less gram that needs to be cooled during processing, one less gram that needs to be transported from processing to final assembly and packaging, one less gram that needs to be transported from final pack out through distribution to the retail shelf or to the final destination, and one less gram to be reclaimed at end-of-life for the part or product. Energy savings are realized at every step for each single gram we can remove during the concept and design stage of development, resulting in less fossil fuel use, less greenhouse gas emissions, and a lower overall carbon footprint. As important as these energy savings are, they do not make the part or product truly sustainable. Hence there must also be a desire to include sustainability in the primary considerations utilized by the design engineer when creating concepts or solutions for any new product or part to be manufactured utilizing plastics materials.

How then, does the design engineer begin to include sustainability in those primary considerations? What specific requirements or metrics are used for this consideration? When can the sustainability characteristics be evaluated and validated during the development process? These are not easy questions to resolve as every development project has different functional and environmental situations which determine the complexity of the sustainability component to be considered. However, there should be some broad-spectrum characteristics, and some means of comparative analysis for the design engineer to use during development, much like the considerations for materials, processes, and tooling. Our goal in this article is to explore just how the design engineer can implement a consideration for sustainability throughout the design process, from concept development through to final detailed design ready for implementation and manufacture.

Sustainability is a broad term and can possess different meanings in different settings, hence let's first frame a definition of sustainability that we intend to consider during our design and development process. The root word "sustainable" is defined by Merriam-Webster as "of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged." [2] It follows that sustainability is therefore the ability to be sustainable, or to remain sustainable. For our creative design thinking, during considerations for a new or revised concept for some part or product, the ability to be sustainable creates considerations in two directions, that is, upstream and downstream.

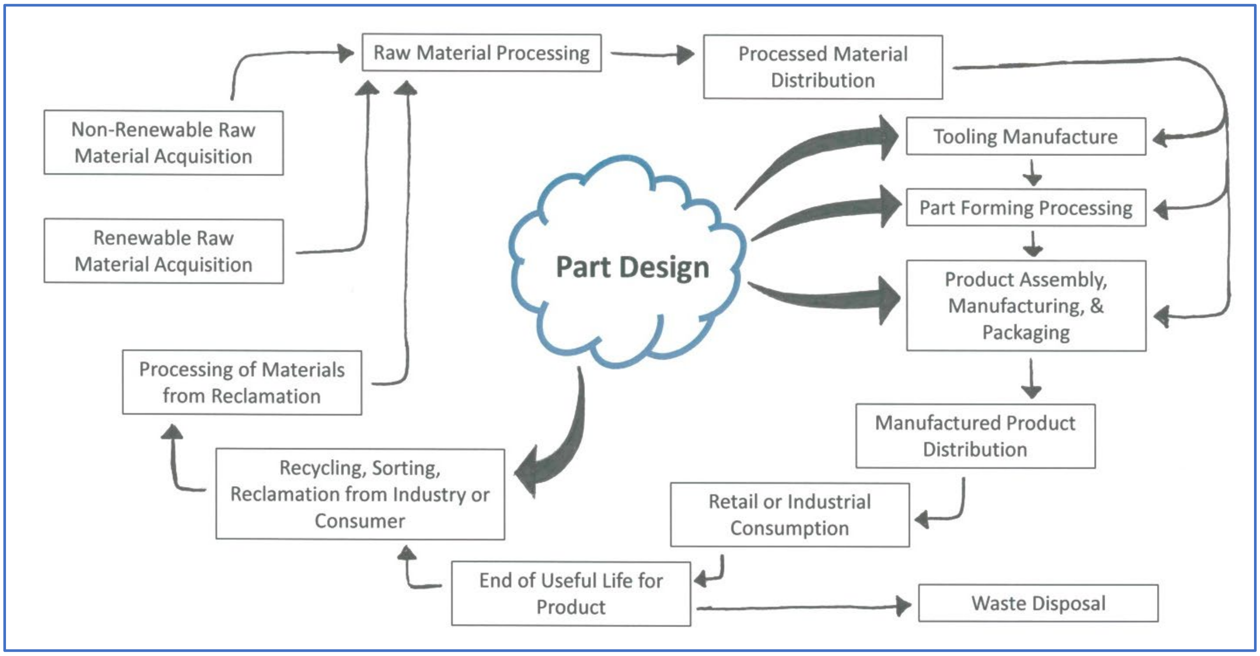

Figure 1: A high-level representation of the life cycle for a manufactured part or product, illustrating the upstream and downstream stages where design choices can impact the sustainability result for the part or product being developed. Image courtesy of and copyright by M-B&A, Inc., 2021

Upstream considerations include the resources available that will be required to produce the part or product being conceived, such as raw materials for the product, raw materials for the tooling, energy used for the processing, tool construction, transportation, etc. Downstream considerations include the use and lifespan of the actual product itself, including transportation through the distribution channel to the market, useful lifespan by the user, energy required for use by the user, disposal or reclamation means, etc. Another downstream factor will be the user experience, which can determine the lifespan and affect the sustainability result. In other words, the end-user determines whether the product value is worthy of retention and proper long-term care or, alternatively, if the user-experience deems the product unsatisfactory, then the product is discarded prematurely. The implementation of this new sustainability consideration during the design conceptualization stage of development causes the design engineer to think holistically about the entire life cycle of the intended product, from raw materials creation through to end-of-life recovery, to be truly able to validate the ability to be sustainable for the concept being developed and evaluated. No product we create will be perfectly sustainable, however, our goal is to create both product and part designs intended for manufacture that have the greatest chance of being sustainable or the least opportunity of becoming non-sustainable.

Implementing a sustainability consideration in the design process will require two distinct steps or stages. The design engineer will first need to think about the discreet characteristics of the materials, the process proposed for forming the materials, the tooling to support the process, the end use of the part or product, and the anticipated end-of-life for the part or product, including what alternative(s) may be considered for these regarding the overall sustainability of the finished product. Secondly, the design engineer will need to determine exactly what metrics can be used to compare the alternatives or decisions required during the design process with respect to sustainability. This is simple to conceive, but not so simple to implement.

To simplify the implementation, the consideration for sustainability might be best included as a sub-consideration for each of the four pillars (materials, process, tooling, and design) considerations. In this manner, the sustainability consideration can be focused within each of the four main categories, helping the designer to break the broad sustainability category into smaller, more specific groups during each design decision required. Hence, this article will present the four main considerations in two distinct development process steps, the conceptual creation step, and the detailed design for manufacture step. It will follow each of the four main considerations through each of these development steps and investigate the means and methods for implementing the sustainability sub-consideration within each.

While perhaps an understatement, it must be understood that design decisions made early in the development process carry enormous weight in shaping the remainder of the design process. This is a statement of fact borne out of experience and the school of hard knocks. Hence, while reading the remainder of this article, keep in mind that the early decisions may well be the most important – especially when the sustainability considerations are given appropriate review and weight in those early decisions. The environmental impact of a part or product can be almost entirely determined by the early conceptual design decisions – these are extremely important decisions – be certain to invest the time and brain power to ensure they set the project on the proper trajectory from the onset.

1.0 Concept Creation Stage of the Development Process

The following four sections review the application of the sustainability sub-consideration within each of the four pillars (materials, process, tooling, and design) considerations used for every decision made during the concept creation stage of the development process.

1.1 Concept Creation Main Consideration One - Materials

One of the toughest decisions any designer or engineer will make when creating a concept solution is to select the "best" material for the product or part. Entire books have been written on the subject, whether the material was ferrous metals, non-ferrous metals, wood, or plastics. However, our scope is limited to selecting the correct or best polymeric or plastics material for a given concept to be developed. Given this scope, the selection task is still extremely difficult with well over 85,000 different grades and formulations of thermoplastics and thermosetting materials available. However, given the functional requirements for a part or product to be developed and, given a preliminary guess as to the process to be used, the experienced designer will jump to a select plastics family, or perhaps two, based on similar products or parts that have previously been successfully used in similar end-use applications, in similar environmental conditions. This is understood and there is nothing new about this general decision/selection process during initial concept generation, but how do we implement a consideration for sustainability at this early stage? Secondly, what metrics can we use to compare alternate selections to enhance or maximize sustainability?

One can argue that the material characteristics themselves would be the first place that the designer might find some useful comparatives. For example, if the material selection possibilities included two thermoplastics, the process selected was injection molding, and the functional requirements for the product or part was required to be able to withstand boiling water (for say a kitchen appliance or tool), then the designer might jump to a material like polypropylene, or alternatively might consider a higher order material like a copolyester or maybe a polysulfone. These materials can easily be processed by injection molding, and they all will satisfy the thermal requirements. However, if the designer considers the sustainability resulting from either selection, what is the outcome?

In this example looking upstream, the polypropylene choice will render a lighter part that requires far less energy input for transportation and processing. Yet, looking downstream, the copolyester or polysulfone choice might render a finished part that has a much longer service life, resulting in fewer replacements over an extended period of time, thereby using far less material with less transportation and processing energy required over the same service life. The selection of any of these materials might be satisfactory for the functional requirements, but the sustainability question becomes tied to anticipated useful life and might also be impacted by end-of-life means for reclamation or reuse. Recycling streams for polypropylene are commonly in use globally whereas recycling of copolyester and polysulfone materials is more of a specialty in much of the global marketplace.

As the example illustrates, the materials selected will have an impact upon the sustainability of the product or part and the impact may be different when looking upstream (lighter material weight, lower transportation impact, lower processing temperatures, etc.) than when looking downstream (lifespan might be severalfold the alternate).

Products made up of multiple parts can be a challenge but also an opportunity for designers that can think and group like materials together to increase the ability for reclamation or recycling at the product end-of-life. Product packaging, which tends to be single use, such as containers and closures for cleaning agents, soaps, shampoos, and the like can be designed and developed to use containers and closures of similar materials to simplify the end-user's job of recycling. Assemblies made from differing materials, for example a trigger sprayer package which includes metal components (compression spring, check valve ball, etc.) are hard to deal with in the recycling stream. However, if the sprayer body were to be developed so it could be broken or disassembled easily at end of life, the end-user could remove the metal components and recycle the molded plastic remainder as a whole (provided the remaining materials were all compatible). Assemblies which have sealing components, for example O-rings or compression seals of elastomeric materials, will often be a mix of thermosets (elastomer) and thermoplastic materials. Designing the seals from thermoplastic materials, like a TPV or a TPO, instead of thermosetting materials, like EPDM or Buna-N, could be one solution implemented to simplify the downstream reclamation process, resulting in a more sustainable solution. Once again, early in the concept generation thinking, the designer must consider each of these facets, including user experience, while creating the solution concept. Only through this broad conceptual thinking method by the designer can sustainable influences become in situ in the final concept solution to be developed.

Another upstream sustainability consideration could be to research and use materials with renewable feedstocks, or bio-based materials instead of fossil-fuel based polymers. Many new formulations are available from the manufacturers and from compounder suppliers for many forming processes, and more are developed and available every year. These are new materials and do not have the track record of other polymers, but they certainly deserve a review to see if they can satisfy the requirements for any given part development project. Compostable formulations and bio-degradable formulations deserve equal scrutiny if the application allows, perhaps especially with short use or single use parts, as in food service or potential patient care use items.

1.2 Concept Creation Main Consideration Two – Process to be Utilized

Given the scope of the “need” for which a solution is desired and given the basic knowledge of the intended market size along with the estimated annual capacity required, the experienced design engineer can make an early and quick initial determination as to the preferred process(es) for the product or part. At the conceptual stage, the determination of the preferred process allows the designer to continue to broadly think through the concept solution. The sustainability sub-consideration must enter into this initial process determination early, as different processes can result in wildly different sustainability results for a given product or part. For example, if the injection molding process is selected, the part produced is near net shape and most often in the correct surface finish and color required. As compared to thermoforming or pressure forming where secondary operations will be required for trimming and scrap reclamation will be required. Conversely, a part thermoformed from a UV stabilized thick-wall PVC sheet may perform and last far longer in some outdoor applications than a thin-wall injection molded part, resulting in a service life for the thermoformed part which might equal two or three times the service life of the injection molded part. Obviously, there are many other factors utilized in determining the final selection, but early consideration of the sustainability consequences for a process decision are highly recommended.

When thinking about sustainability during the initial process considerations, what does the designer need to consider? How does the sustainability issue affect the following development considerations and how are they then vetted and/or validated? Normally, part functional requirements and anticipated annual production volumes will be the main factors to determine a suitable process for a given part. Even so, there are opportunities to consider the downstream sustainability results of the process under consideration. The upstream factors still apply, that is raw material manufacture, raw material transportation, etc., however, the downstream factors can determine different outcomes when evaluating sustainable results. These include such factors as in-process waste generated, ability to reclaim or reprocess the generated waste, energy required for waste regrinding or reclamation, energy required for secondary operations, energy required for transportation of in-process parts for secondary operations, and so on. Once the project is underway and geometry is created based upon the initial process selected, it will become more difficult to alter the process selection, hence, invest the time to evaluate the selection thoroughly before beginning geometry creation.

One process that has become more prevalent in the manufacturing of plastic parts is Additive Manufacturing (AM). This process has matured from use in rapid prototyping to use as a viable production process for certain parts in certain applications. New materials and processes are being developed and refined at a rapid pace so this process will find more and more applications for use in full scale manufacturing. One particular benefit from the AM process is the ability to customize each part produced easily. It is ideal for short run manufacturing of specialized or individualized parts and assemblies. Since there is no forming tooling required, the AM equipment can produce geometries that no other plastics forming process can produce, parts within hollow portion of parts, parts with undercuts or fastening features without the required coring or tooling complexities, and so on. From a sustainability standpoint, the AM equipment used can be local to the market where the product is used, reducing energy used for transportation and reducing the inventories required as the parts can be produced on demand rather than warehoused (further reducing energy for warehouse climate control, etc.

The design engineer should always consider the upstream and downstream effects on the sustainability of a concept solution during the initial consideration for the process(es) to be utilized for a given product or part to be developed. Consideration as early as possible of these effects during the initial concept solution thinking will help the designer be more effective in the decision process, resulting in better decisions as the project progresses with less downstream changes resulting in a more efficient project timeline.

1.3 Concept Creation Main Consideration Three – Tooling Required for the Selected Forming Process

For any selected process there will be some tool, mold, program, or die that will be required to form the plastic material into the desired shape and geometry. The sustainability impacts from the tooling may be premature at the initial concept creation stage of the project, but it should still be considered. Since the tool geometry is dependent upon the part design, the question of sustainable tooling might be better raised during the part design stage of the project. However, as with the process selection consideration, the tooling effect on sustainability can be understood and reviewed during concept creation once the process selection has been determined. For example, if we know that our part in question will be injection molded and then a secondary operation is required for a vent hole to be drilled for some functional requirement, the designer might weigh the sustainable attributes for the secondary operation against the cost of a more expensive, larger (more raw materials) mold that has a self-actuating core to form the hole. From the sustainability standpoint, which method results in a more favorable outcome? The self-actuating core method produces less waste, but may require a larger mold opening stroke, taking more time, and using more energy for each cycle. However, the secondary operation itself takes additional energy input, takes some transportation of the parts from primary to secondary operation equipment, requires perhaps additional quality inspection steps, etc. Hence, the ability to determine the sustainability impacts for tooling are complex and rely on the decisions made in process selection and on the part geometry of the finished part design.

If the part to be injection molded was a low volume requirement, for example 5,000 pieces per year, then we might choose to simplify the mold design and add the hole by the secondary operation method. In addition, for a mold built for low-volume production, alternate tooling materials might be selected that could result in a more favorable sustainability outcome for the projects. Lighter and easier to machine tooling materials take far less energy and time to fabricate, lower the raw material transportation impact, lower the in-process energy required and, depending upon the thermal conductivity of the materials (aluminum vs. steel), can decrease cycle times (faster cooling with higher conductivity materials) as well as lower the molding process energy requirements. Alternatively, for higher volume production capacities, tool durability will be a primary requirement, driving the tooling materials decision. The use of premium tool steel for the cavities and cores will permit the tooling to run enormous quantities of parts without requiring additional maintenance, reducing potential additional energy input for maintenance and transportation over the life of the tooling.

Similar tooling design complexity, tool material selections, and secondary operation alternatives will be found in most any plastics processing method. In fact, most plastic processing methods will require some secondary operation for excess material removal, trimming for features, trimming to length, etc. Injection molding and some blow molding processes are the exceptions where a net shape final part can be produced with little or no secondary finishing operations required.

When considering tooling sustainability aspects, one must consider Additive Manufacturing (AM), since there is virtually no tooling required. Couple this zero-tooling impact with the ability to produce the parts from AM on demand and to produce them local to the intended market and there becomes a real and present case for the sustainability result that can be achieved with the AM process.

1.4 Concept Creation Main Consideration Four – Design of the Product or Part to be Developed

As the design engineer is formulating and creating solutions to the design problem at hand, they will be "thinking" about many different potential geometries and forms which the solution might take. Environmental impact and sustainability considerations during this active generation of the conceptual final part/product form might branch out in several directions, for example on durability for extended service life, or on ease of disassembly for recycling, or on light-weighting to reduce transportation energy requirements, and so on. This is high-level thinking, and it drives the rest of the development project, hence it is highly recommended to invest the time and resources necessary to ensure that the final selected design solution has been carefully evaluated from a sustainability vantage point.

The actual part design must fulfill the functional requirements for the intended "user" and the "need" for which a solution is required. However, upfront thinking by the design engineer from a holistic part or product lifespan perspective can allow the solution to not only satisfy the functional requirements and user experience, but to also drive the solution to be a more sustainable overall solution. Product and part designs that are well thought out and are created with consideration for sustainability will often stand out as excellent values when compared to similar solutions once manufactured and placed into the stream of commerce.

Considerations in the concept creation design stage for the design geometry or features might include:

- Can the design consolidate parts of similar materials into sub-assemblies that can be separated for recycling or reclamation?
- Can the design satisfy the functional requirements with the lowest energy input for the material and process selected?
- Can the design be durable enough to function longer than similar solutions for the instant "need" and user?
- Does the user experience promote intuitive care and long-term use for the product?
- Can the design promote longevity, or does the design encourage wasteful behavior?
- Can the design foster intuitive use to prevent premature discarding due to user frustration?
- Can the design be distributed without excess additional packaging? Can the package be durable for storage and care of the product as well?
- Can the design reduce energy use or lower additional energy input during manufacture and transportation to the end-user?
- Can the part/product have other usefulness at end-of-life? Is repurposing possible and encouraged?
- Can a circular operational mode be established wherein the packaging, or the product can be returned and reprocessed into the next lot of products? (Think of milk bottles from the 1960's, or soda pop bottles from the same era.)

Many other considerations for sustainability could be utilized, and every different development project will generate other possibilities. However, there is no benefit unless the design engineer actually invests the time and brain cells to really think through these considerations right up front, not after the concept has been formed. Once the development project moves from this conceptual stage to the actual part/product design stage the ability to influence the sustainability characteristics is reduced with every decision made and design feature developed.

1.5 Review and Validation of the Initial Concept and Decision to move to Development

Once the initial concept is complete most project teams will have a formal review process prior to investing time and resources to begin the development of the detailed design for manufacture. This early review of the concept is usually to verify that the concept satisfies the functional requirements for the solution requested but can also serve as an opportunity to discuss the sustainability intent for the concept with the team assembled for the review. Better yet, a fully documented functional requirements document should contain a section dedicated to the design intent for sustainability. This one document should follow the development and be utilized as the basis for every decision made throughout development. Hence having a well written description of the sustainability intent included in the functional requirements document should be a prerequisite for every development project.

Functional Requirements for Project 52145						
Item No.	Function	Value	Type of Value	Verification Method	When to Verify	Sustainability Comments
1	Contain volume of fluid above Freezing and below Boiling Temp.	1	Liter	CAD Calculation and prototype verification	During design and at prototyping	Look at stretch blow mold process and compare with laminated film pouch vessel
2	O2 Permeability of container and closure means	4 x 10^-6	Liter/cm^2/min	Permeabilty testing at independent lab	Production quality parts	Single material is desired over multi-layer alternate
3	Drop strength from distance to hard floor above freezing and below Boiling	5	Feet	Drop test with H2O at temperature extremes	Prototyping and again with production quality parts	N/A
4	Closure torque to achieve leak free seal	10	In - Oz	Torque several units to specification and several to 2 In-Oz above and below spec. invert and set for 15 days	Prototyping and again with production quality parts	N/A
5	Decoration and labeling	Must	Must Have	Provide samples with decoration or labeling means for evaluation by quality control team	Production quality parts	Decoration means to be similar materials to container for ease of recycling/reprocessing

Figure 2: A representative Functional Requirements document showing the relationship of the sustainability comments for each applicable functional requirement listed. These comments remain visible during the entire design and development process if added early in the conceptual creation process, allowing anyone that references the document to be reminded of the potential for enhanced sustainability outcomes for the project. Image courtesy of and copyright by M-B&A, Inc., 2021

2.0 Design for Manufacture Stage of the Development Process

The following four sections review the application of the sustainability sub-consideration within each of the four pillars (materials, process, tooling, and design) considerations used for every decision made during the detailed design for manufacture stage of the development process.

2.1 Detailed Design Main Consideration One - Materials

In most instances, a material class, or perhaps two, will have been identified as primary possibilities during the concept generation stage and these will be the first to be reviewed for suitability in the detailed design stage. First, the material selection must satisfy the functional requirements for the product or part being developed. However, with so many material classes, and so many different formulations available within each class, the designer can choose several options that satisfy the functional requirements. Considerations for sustainability can be used to further refine the range of possible materials from this initial selection listing and identify those with the lowest impact to sustainability for both the upstream and the downstream characteristics. Upstream characteristics might include the feedstock or raw materials acquisition methods and energy required therefore, as well as the processing of the raw materials into useable resins and compounds, and the transportation energy required to deliver the useable resins and compounds to the final processing locations. Other upstream considerations might include the ability of the selected material(s) to contain some quantity of recycled or post-consumer reclaimed material. Additionally, the ability to use bio-based feedstock materials or plastics formulated from renewable raw materials like those formulated from corn starch (PLA) and the like. Downstream characteristics might include the durability or longevity of the part or product in the selected material in the anticipated environment. It might also include the ability of the selected material to be easily identified and recycled by the uneducated end-user, or the potential for reducing the decoration or additives to facilitate a cleaner recycled material when reprocessed, not to mention the downstream effects on energy utilization that might be required for processing the differing materials included in the selection pool.

2.2 Detailed Design Main Consideration Two – Process to be Utilized

As with materials, the process to be utilized has already been identified during the initial concept generation stage. However, the good design team will always reconsider the selection and the basis for the selection to verify that it still meets the criteria for the part or product to be developed. In many instances there is simply no other selection that can compete, but in some cases, there will be another process which might be suitable. Hence, reconsideration and validation of the decision is necessary. For this detailed design stage, the downstream characteristics to be considered for sustainability become more focused and somewhat easier to quantify and compare since we have a material class identified and we understand what the design concept looks like and how it might function in use. Given the selected forming process, the designer might be thinking about many different factors, such as:

- Total energy required during processing
- Final product part weight that needs to be transported

- Collection and reuse of trim waste or regrind of in-process waste material(s)
- Reduction of parts through consolidation or combined features on individual parts
- Reduction of assembly fallout through robust part design for assembly, and more.

2.3 Detailed Design Main Consideration Three – Tooling Required for the Selected Process

The molds or tooling required will be a function of the process selected and the anticipated annual capacity of parts that will be required from any given tool. As for sustainability considerations, these are focused on the tool design features like number of cavities, materials used to fabricate the tool and longevity thereof. Others include the thermal transfer properties of the tool materials to facilitate rapid heat up or cool down to gain energy efficiency, and the mass of plastic materials used that will not become finished parts. Examples of materials used that will not become finished parts include runners for injection-molded parts, trimmed sheet waste for thermoformed and pressure formed parts, pinch off waste for extrusion blow-molded parts, trimmed features for rotational-molded parts, and so on. Regarding injection molded parts, tooling cavitation is an interesting discussion point on the topic of sustainability. Each processing cycle will require some defined energy input and if a single cycle produces 32 parts, then the energy per unit required would be far less than if the cycle only produces 4 parts per cycle.

Certainly, other considerations for sustainability exist when dealing with the tooling and will be contemplated on a project-by-project basis, but the designer should always be thinking about these kinds of characteristics when determining the tooling to be used for the process selected. In some projects the designer will not be part of the tooling development team so it is the designer's responsibility to accurately and concisely annotate the part or product specification that will be given to the processor or tooling development shop so that the design intent is understood. This is simple and easy to accomplish with notes added to the 2D specification drawing for every part of any project under development.

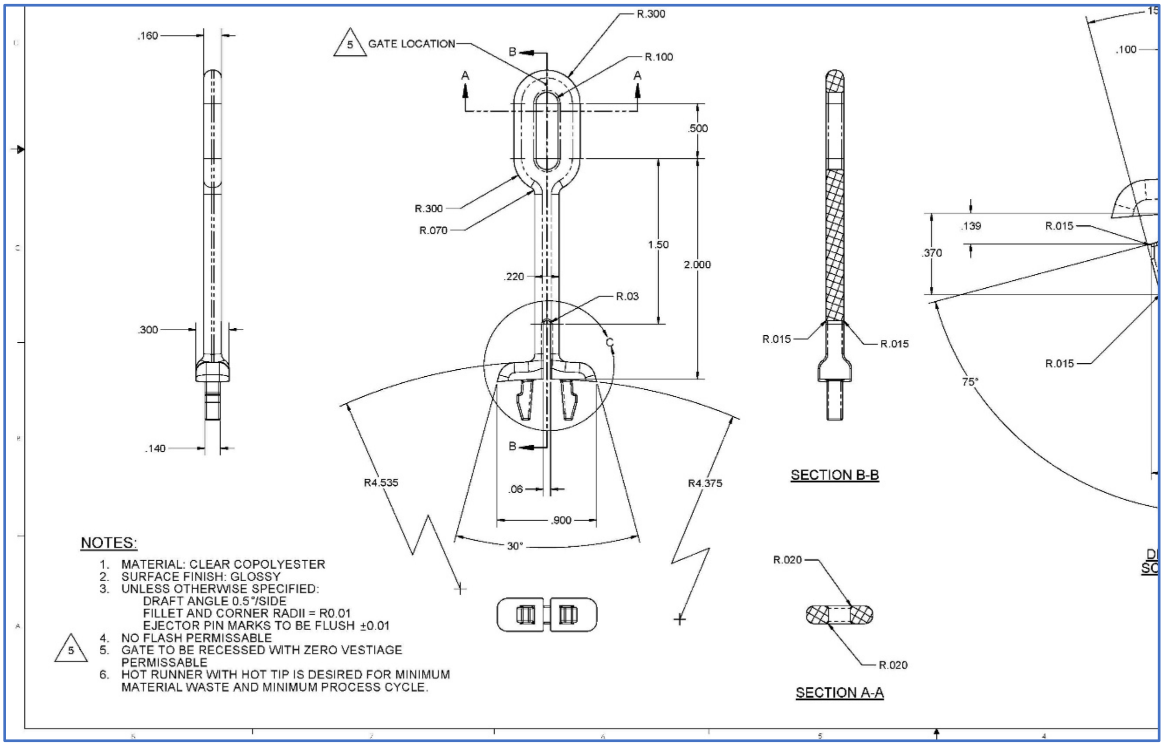

Figure 3: A sample illustration of a 2D specification drawing for an injection molded part. Note 6 is shown to advise the tooling design source that the design team desires a certain tool feature, in this example a hot runner system, to aid in reducing material waste and in optimizing the processing cycle for maximum efficiency. Image courtesy of and copyright by M-B&A, Inc., 2021

2.4 Main Consideration Four – Design of the Product or Part to be Developed

The design of the detailed features required for functionality and performance are paramount to satisfying the design intent. High level concept philosophy determined during the initial concept design will drive the detailed design for manufacture so long as the design intent is preserved. Among these high-level goals should be some degree of characteristics specific to the sustainability targets or goals of the proposed concept for development. During this detailed design for manufacture effort, the designer must retain focus on these goals, as it is extremely easy to be distracted by opportunities to reduce costs, or reduce project timelines, as these are highly visible to the business and marketing teams working on the project. The ability to foster careful decisions about design features that affect the ability for the finished part or product to meet or exceed the end users' needs while remaining sustainable is difficult but an important requirement for the design team.

Creating detailed geometry and features on a given part may not seem like an opportunity for applying sustainability ideas or principles, but every feature defined can lead to a finished product that fulfills the goals well, or alternatively it does not. The drive and desire for mindful creative design cannot be overstated. Learning this sustainable mindfulness and applying it during every design effort is a process, but once part of the everyday design considerations, it becomes second nature and ingrained in our design thinking.

3.0 Qualification of the potential Sustainability Outcome of the Concept

Methodologies have been developed and proposed to allow the designer to evaluate a given concept with respect to sustainability [3]. Products developed with mixed materials, like consumer electronics, require the analysis for each different material and each different manufacturing process utilized. This results in an enormous volume of data to be considered, evaluated, categorized, entered, and analyzed. The complete analysis requires a substantial investment of resources and time which for many development projects will not be justified and hence cannot be allocated or authorized. When used correctly, the methodology produces a numerical scoring for each material and process that allows the design team to make informed decisions prior to starting the detailed design work.

For the reduced scope of this article, to include plastics part or product development, a different less time-consuming methodology, similar to an FMEA analysis, has been conceived to be used on a design concept. The proposed methodology uses scoring for each different possible concept relative to metrics for sustainability, such as energy utilization, actual product use during the product lifespan, and intended end of life disposition.

For a given design concept, the analysis requires the team to evaluate the proposed concept with respect to three sustainability categories. The first category for analysis focuses upon energy utilization, including transportation energy inputs, both upstream and downstream. Review of the concept from a total energy input and from a total energy required over the lifespan of the part or product, is required wherein the scoring is from 1 to 10. A concept with a low total energy input would score at the low end with a 1 and a concept having a high energy input would score at the high end with a 10. Those concepts having a total energy score somewhere in between would be scored accordingly within the range. The second category for analysis focuses upon the actual use and lifespan of the part or product, which includes the downstream functions of distribution to the end-user and the lifespan once in the hands of the end-user, wherein the scoring is again in the range between 1 and 10. A concept that is a durable long-life robust part or product would score a 1 and a single use disposable would score a 10, and products falling in between would be scored accordingly on the spectrum. The third category for analysis focuses upon the end-of-life disposition intended and implemented for the concept, including the ability for reuse of the materials through recycling or other reclamation, or the ability for composting or biodegradable disposal, wherein the scoring is again between 1 and 10. A concept that provides means for end-of-life total reclamation of the materials would score a 1 and a concept which is destined for a landfill only would score a 10, and concepts falling in between would be scored accordingly.

Sustainability Scoring Comparison of Piece Part Alternatives									
Item No.	Title/Part No./ Issue	Function and/or Operation	Material	Process	Potential sustainable benefit	Overall Energy Utilization	Anticipated Lifespan of Service	Intended end-of-life Disposition	Score Product
1a	Body Molding	Structural frame used to enclose and assemble the finished product, and to hold the electronics safe from hazards	ABS	Injection Molding	Reduction of parts	3	3	4	36
1b			ABS	Thermoforming	Longevity	6	2	4	48
1c			ABS	3D Printing	Reduction of storage and transportation energy needs	1	3	4	12
2a	Cover	Structural cover assembled to protect contents of the Body molding	ABS	Injection Molding	Reduction of secondary operations	3	2	4	24
2b			Aluminum	Stamping	Longevity	5	1	2	10
2c			ABS	Thermoforming	Longevity	6	2	4	48
2d			ABS	3D Printing	Reduction of storage and transportation energy needs	1	3	4	12
3a	Cover Gasket Seal	Provides weathertight seal to required specification	EPDM	Compression Molding	Longevity	6	2	8	96
3b			TPV	Injection Molding	Energy savings and Reprocessing ability	3	3	4	36
4a	Battery compartment	Isolates and protects the electronics from the rechargeable batteries	PP	Injection Molding		3	3	4	36
4b			TPV	Injection Molding		3	2	4	24

Figure 4: This example illustrates the analysis of four different parts of an assembly. Each part is reviewed in different processes and materials and is scored based upon the process and material combination. Based upon the scoring methods taught, the lowest score product should represent the best sustainability outcome of the available choices. Hence for part number 1, the best selection should be line item 1c – using ABS and an additive manufacturing process. Image courtesy of and copyright by M-B&A, Inc., 2021

Once each potential concept variation is scored the three scores for each are simply multiplied to get a final score product for each possible concept variation. Hence, a concept with three scores of 1 will have a final score product of 1 and a concept with three scores of 10 will have a final score product of 1000. Just as in golf, the lowest score is the winner. Well, that is not exactly the case here, but the lower the score the better. On many projects a balance is required between the functional requirements, the estimated base factory cost, the intended end-user experience, and the desired sustainability. As such, the balance may require the team to choose the concept variation that best suits all the requirements which may not be the concept variation with the absolute lowest sustainability score product. For example, if there were four different concept variations being evaluated, and two have final scores below 100, one with a final score of 500, and one with a final score of over 700, then the team would consider either concept variation with the scores below 100 and discard the two high scores. In this manner, the team has selected the most appropriate concept variations from a sustainability vantage, as well as from the functional requirements vantage.

4.0 Conclusions

The addition of the sustainability consideration within each of the “Four Pillars,” that is the four major considerations used during the development of a plastic part or product (materials, process, tooling, and design) is recommended as a means for enhancing every part or product designed for manufacture. Careful contemplation during both the initial concept generation and the detailed design for manufacture stages of development for the upstream and downstream factors contributing to the environmental impact or sustainability of the final product have been proven to result in superior finished product quality and end-user experience. The use of a simple, easy, and quick methodology to rate and provide comparative scoring between concept variations with respect to the sustainability can guide the design towards the concept variation that has the greatest opportunity to result in the highest level of sustainability for the intended product being developed. Integration and use of these recommended considerations and methodologies for every plastics part or product project developed will lead to ever better uses of the natural resources required for manufactured goods.

References:

1 M.T. MacLean-Blevins, *Designing Successful Products with Plastics - Fundamentals of Plastic Part Design*, first ed., Elsevier, Oxford, 2018

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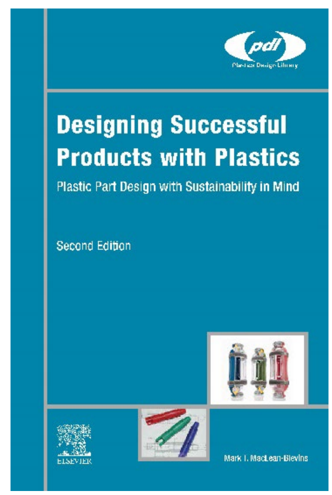
Further Reading:

You can learn more in the book Designing Successful Products with Plastics, available at the following link: https://shop.elsevier.com/books/designing-successful-products-with-plastics/maclean-blevins/978-0-443-16114-8



About the author: Mark MacLean-Blevins, founder of M-B&A, is an independent product design consultant in practice since 1993 with fifty-five patents issued for innovations developed as a result of his creative work. Mark and Kim MacLean-Blevins, parents of eight children, live and work in Westminster, Maryland.

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