DIGITAL TRANSFORMS PHYSICAL

Designing for Sustainability: How Cummins Made Changes to Optimize Product Designs for the Environment

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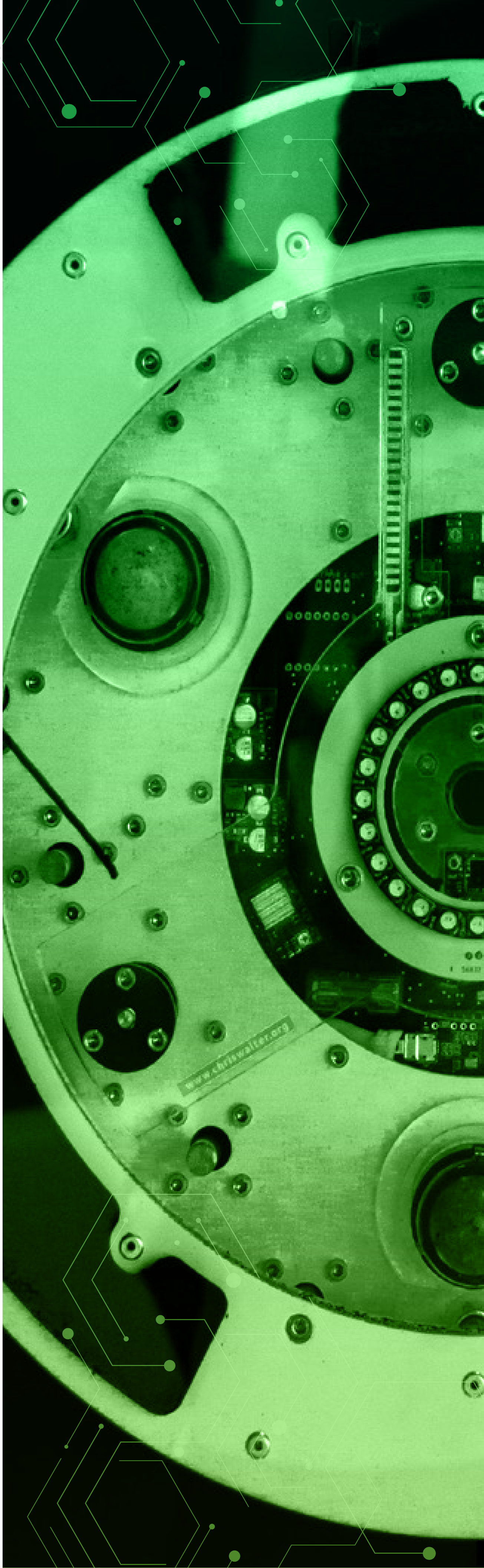
WHITE PAPER



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As a global leader in social and environmental responsibility, Cummins is committed to doing their part to create a more sustainable, prosperous world. That is why Cummins launched **PLANET 2050**, an aggressive sustainability strategy that has long-term aspirations, but by 2030 includes significant milestones such as:

- Reducing absolute greenhouse gas emissions from facilities and operations by 50%
- Creating a circular lifecycle plan for every part
- Generating 25% less waste in facilities and operations

The goals Cummins has set are ambitious, especially given that the business produces more than one million end-user engine products per year. Such a large production output requires a significant amount of material and natural resources, as well as compliance with environmental regulations. Also, unlike other power systems, certain Cummins products are designed to be used for longer than 25 years (or more than 120,000 hours) of rigorous operation. Cummins' power systems go through multiple rebuilds to achieve such longevity, emphasizing the importance of considering sustainability over a product's lifecycle.

Pictured: Cummins QSK95 diesel engine, which works in Mining (4400 hp), Locomotive, and Power Generation applications (3.5 MW back-up power)

With sustainability in focus, Cummins set out to rethink the processes it uses to design its internal combustion and fuel cell engine systems. About 70% of an item's lifecycle CO2 footprint is set early within the design phase of an item, meaning that if Cummins' goal is to minimize a product's environmental impact over its full lifecycle, Cummins' engineers need to design products specifically for sustainability.

What is Designing for Sustainability?

Designing for Sustainability (DfS) is far more than just light-weighting. Instead, it's a holistic approach that minimizes a design's impact on the environment over its entire lifecycle.

Although Designing for Sustainability is a broad topic, this paper concentrates on the process of:

- Designing an item with no more material used than necessary to meet its strength and stiffness requirements.
- Making a mindful selection about component material from an environmental perspective.
- The importance of having a documented, actionable plan for item re-use, recycling, and remanufacturing.
- Designing a product from a near-net perspective, minimizing the energy and water required to post-process an item (e.g., machining after casting or forging an item).

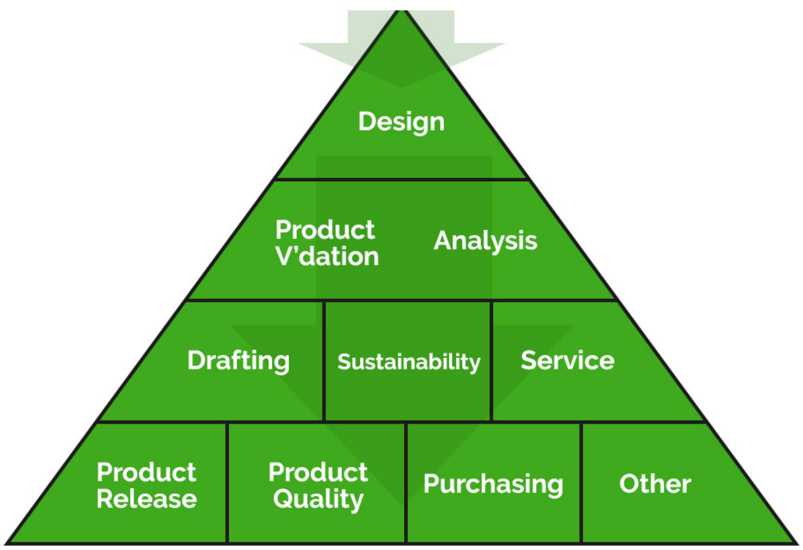
Business Benefits Associated with Designing for Sustainability

When committing to complete DfS work up-front (or very early in the design process), and with the appropriate cross-functional infrastructure and senior leader advocacy, DfS can bring significant business benefits, including:

- Products having a lower environmental impact due to using less CO2-intensive material and water in extraction and processing of the material;
- Products having an improved ability to be reused, remanufactured, or efficiently recycled, leading to greater aftermarket marketability;

- Products having reduced weight, with compounding CO_2 savings when considering the impact of shipping and vehicle fuel economy ;
- Reduced product cost due to the elimination of non-value-added material;
- Improved job satisfaction (and retention) for Design Engineers, who have more tangible ways of showing their bottom-line value to the business, and Expert Analysts, who can use their unique skill set to focus their efforts on more complex analysis challenges;
- Reducing the potential for re-work by improving the potential of designing the product right the first time (see chart below).

REQUIREMENTS / DESIGN CONSIDERATIONS



Many companies underestimate the number of times an item needs to be touched (or redesigned) in some way between the time an item is initially released and the time an item is launched into production. Redesign work is a tremendous source of inefficiency across engineering disciplines and other functions supporting the design of a new product.

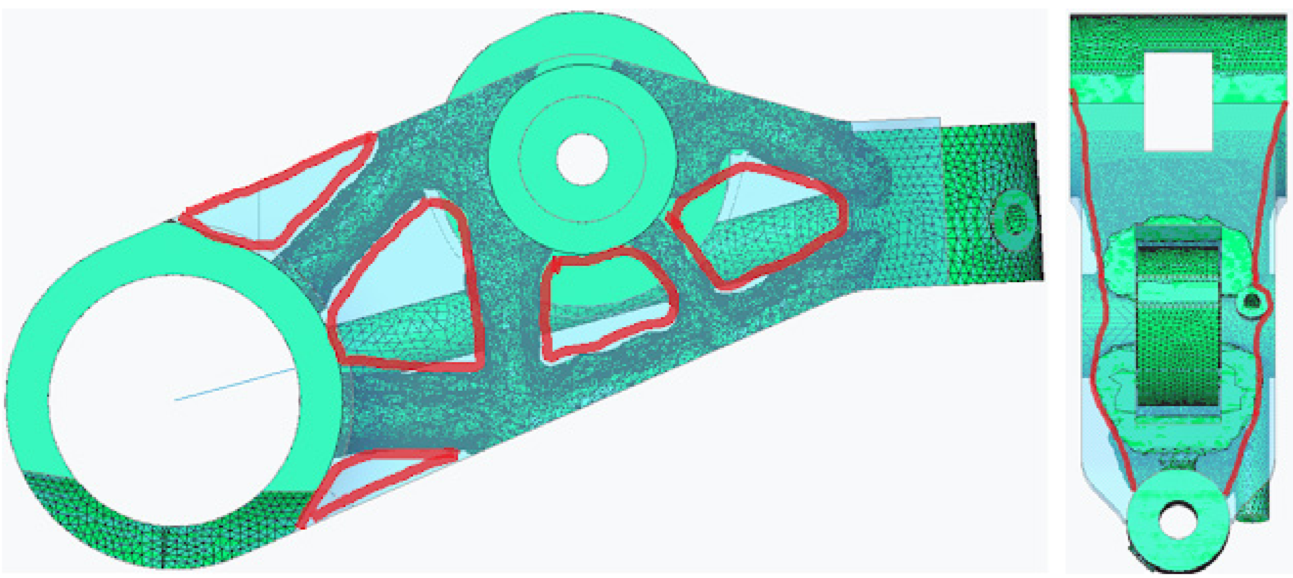
In other words, needing to perform some level of re-design also leads to the re-detailing of drawings, re-releasing of models and product structure, re-quoting with suppliers, the cost and complexity of re-tooling, the time to re-analyze, the cost and time to re-validate and re-test, etc. Hence, any reduction in "re-work" will have a significant impact on improving the overall efficiency of an engineering organization. Once a commitment is made to optimize a product in any way (instead of following a check-list approach to overcome a series of design margin thresholds), waste is removed from the product and the need to redesign is minimized.

Overcoming the Perception that DfS Requires "Extra Work"

Making DfS the culture in which new products are designed at Cummins has taken some time to implement. Perceptions that "heavier components were more robust" or that "time or people didn't exist to perform such additional tasks" presented tough challenges for the business to overcome. However, once DfS techniques were put in place and practiced by those proficient at performing topology optimization, it was shown that a **10-15% reduction of the material used to design a product could be achieved** without adversely affecting its structural integrity. In some instances, the item that was material-optimized was even more robust than the heavier part it was replacing.

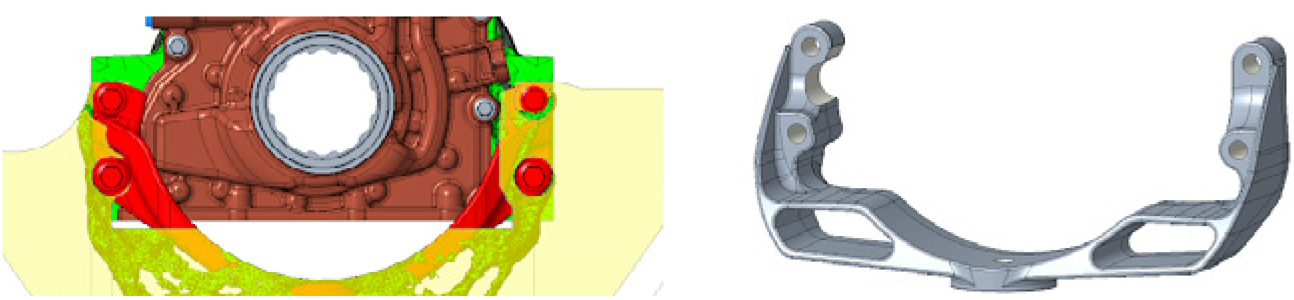
The following images demonstrate how topology optimization has helped Cummins reduce material use for its engine systems.

Rocker Lever



The marked-up red areas show material that can be removed due to its lack of added value from a strength or stiffness perspective.

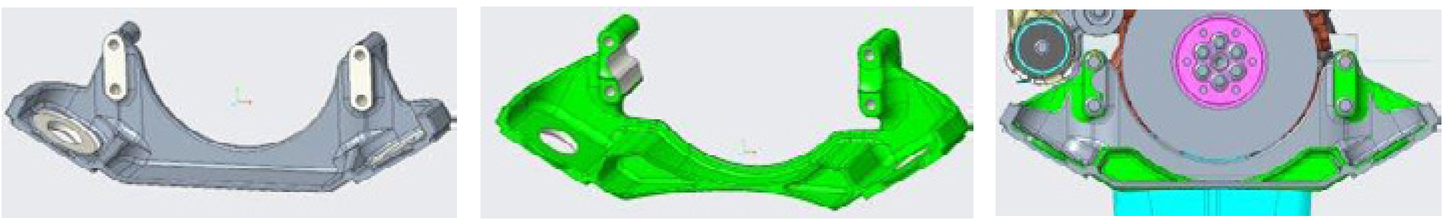
Front Engine Mount



The topology overlay (green) provides a greater strength and design margin.

Front Engine Mount Options

Choosing this design option for the front engine mount would enable Cummins designers to reduce its mass by 23%.



Choosing this design option for the front engine mount would enable Cummins designers to decrease its mass by 16%.

Also, when aligned with resources proficient at performing such analysis techniques, the time to perform such work can be completed without requiring additional time to design the product. When coupled with the other benefits that came from a commitment to performing DfS, Cummins had further incentive to change its culture to implement DfS on all new product designs.

Making Changes to Embrace DfS at Cummins

As PLANET 2050 declarations state, environmental stewardship at Cummins is not an optional activity. To realize its DfS goals, Cummins had to put several changes into place. These changes were not about "working smarter", but instead, removing inefficiencies associated with the existing design process. The changes included:

- Migrating from a culture that predominantly adheres to time-tested design standards to one that still adheres to the same standards, but also focuses on "optimizing" how each design margin target is achieved (including lifecycle material-use);
- Improving the proficiency of the Design Engineering workforce to construct

high-quality solid models quickly, and then refine their design concepts through up-front structural analysis work;

- Utilizing individuals with proven efficiency at optimization-based techniques to pilot supporting the new product design process;
- Migrating to a newer version of PTC's CAD software, **CREO**, which enables Design Engineers to proactively iterate on design concepts (and structurally optimize them) before they're sent to the analyst for final checking;
- Defining DfS expectations within the overarching Corporate Standards that govern New Product Development.

Quantifying the benefits from a CO2, bottom-line savings, and resource payback perspective, along with getting top-down support from Cummins' CEO, were critical to having DfS embraced across Cummins. Although the changes made were focused on CO2 reduction and helping to sustain the planet, other business benefits became apparent once the DfS initiatives were implemented.

Integrating DfS Principles into Cummins' Design Process

To ensure DfS principles became part of the DNA of its design process, Cummins found each of the following steps to be necessary.

1 Take a Top-Down Approach to Environmental Leadership

Tom Linebarger, CMI's Board Chairman (and former CEO), publicly announced aggressive PLANET 2050 expectations around designing new products with less material and documenting evidence for plans to recycle, reuse, and remanufacture newly designed products.

Cummins' CEO also spent significant time with each leader of the PLANET 2050 team discussing progress made to achieve their respective goals, and more importantly, to know where his influence could be applied to overcome obstacles hindering implementation.

On one occasion, the topic of DfS "seeming like extra work" for the engineering teams to complete was discussed. To overcome this obstacle, the CTO approved the request to hire two head count to focus specifically on completing topology optimization (by using tools such as CREO Generative) and other multi-disciplinary optimization techniques in the design concept phase.

Active engagement from Cummins' CEO was necessary to promote the priority of this work, to cascade the importance of DfS to leaders around the business, and to use their influence within the company to help overcome hesitancies. Receiving the CEO's first-hand advocacy and support of PLANET 2050 was the first critical step to achieving goals relating to Designing for the Environment.

2 Upgrade Corporate Standards to Reflect DfS Expectations

Once the priority had been set by senior management, Cummins' Corporate Standards had to be upgraded to reflect new DfS expectations. At Cummins, the Release Phase Code (RPC) Standard defines the design maturity (or readiness level) of an item, and the Corporate Cross-Functional Design Review Standard defines the cross-functional evidence that must accompany each released item, documenting that a phase code's design stability claim has been attained. Documenting DfS expectations as they related to each Release Phase Code was critical to ensuring the DfS work was communicated in detail to all levels of the company and ensuring that DfS tasks were performed consistently across the business.

To ensure products are repeatedly released to a high-quality standard, Cummins, like many large companies, is bound by various industry certifications that require adherence to Corporate Standards. For that reason, embedding DfS expectations within them was necessary to ensure that DfS work would be consistently performed across different parts of the business. For DfS to take root, Cummins' Corporate Standards needed to clearly articulate how DfS expectations align with PLANET 2050 goals.

Designing for Sustainability is one of many categories within the Design Review Standard that requires evidence and a documented cross-functional review before releasing an item to a phase code level. There are four DfS elements that require evidence, which are reflected in a Design for Sustainability Scorecard (shown below).

Design for Sustainability Scorecard

*When complete, submit scores using **this form** for tracking against PLANET 2050 goals.*

Fill out cells with blue shading.

Item Description / Part Number(s):

Design for Sustainability Criteria	Ranking (0, 3, 9)	Design for Sustainability - Ranking Criteria	Evidence for Scoring	Contact Person/ Team
Material / Process Specification (Material approved by Material Science & Engineering Functional Excellence)	9	**0** = Approval NOT received by Material Science FE. **9** = Material and process specification approved by Material Science FE representative.	**Example:** Material and process specs approved by Material Science Engineering from a sustainability perspective.	xxx.cummins.com
Material-Use Optimized (Material-use optimized to obtain required strength and stiffness)	9	**0** = NO EVIDENCE minimizing material-use. **3** = Material-use minimized using "design experience" ONLY. **9** = Material-use minimized using optimization-based methods such as topology optimization, Generative Design, MDO, etc.	**Example:** Topology optimization used to minimize material use, and approved by MSD function.	xxx.cummins.com
"Near-Net" Principles Applied (Manufacturing post-processing minimized)	9	**0** = NO EVIDENCE of using "near-net" principles. **3** = Manufacturing processing minimized using "design experience" ONLY. **9** = Post-processing / machining stock minimized using supplier engagement and approved by manufacturing specialist.	**Example:** Machining stock minimized through supplier engagement and DVA - approved by Manufacturing function.	xxx.cummins.com
Lifecycle Plan - "Closing the Loop" (Reuse, Reman, Recycle)	9	**0** = Evidence does NOT exist for a remanufacturing, reuse, or recycling plan. **9** = Aftermarket plan approved by New and Recon parts representative.	**Example:** Design for Aftermarket Scorecard completed - approved by NRP representative.	xxx.cummins.com
	100	**>80** - Strong Design for Sustainability Plan Exists **70-80** - Moderate Design for Sustainability Plan Exists **<70** - Weak Design for Sustainability Plan Exists		

First, approval must be received from the Corporate Material Science department, acknowledging that the material selected was the most appropriate to use when considering carbon intensity.

Without this step in the process, new components would often be made of the same material as the legacy component that designers were replacing. This was especially true for newer designers that were not as familiar with the origin of the 'parent' parts they were working to replace or update. This also ensured that mindful trade-offs were being made between possible materials that the item could be made from. With the designer knowing that they were going to need Material Science approval, this led to proactive engagement between the two entities up front, leading to designers using the material and process specification that would be most likely selected from a strength, stiffness, and carbon-burden perspective from the design's onset.

Second, evidence shall exist that the amount of material used for a given item was minimized while attaining its required strength and stiffness.

At a minimum, the designer was now aware that adding extraneous material to an item would adversely impact the environment. They received a low scorecard value if they had evidence that "designer intuition" was used to minimize the amount of material. On the flipside, they received the highest score if evidence existed that optimization techniques (such as CREO Generative Design) were used to minimize the amount of material used when achieving their design margin thresholds.

In addition, a C02 impact calculator was provided to the Design Community to quantify the impact of their material savings techniques while also estimating the annual cost savings. This provided Designers with a tangible way to quantify the value of their work to the bottom-line.

Third, evidence of designing an item so it would have a minimal amount of processing (or machining) after forming was needed.

This was referred to as "near net," which could take many different forms, including using Dimensional Variation Analyses to minimize the amount of machining stock on a casting or forging. If evidence existed that Manufacturing Engineering was engaged to effectively minimize the amount of post-processing, including an assessment of alternate manufacturing techniques, a full score would be reflected in the scorecard.

Lastly, evidence is required that the item has been effectively designed for its end-of-life (or end of its first life).

This work included completing a sub-scorecard (Design for Aftermarket Scorecard) to adequately document plans for an item's reuse, ability to be remanufactured, and/or recycled at the end of the engine system's first useful life. This could mean threaded bosses were enlarged to allow for thread inserts to encourage reuse, methods to minimize the challenges associated with disassembly, and dedicated plans to harvest CO2-burdensome alloys at the item's end of useful life.

The completed DfS scorecard would then be cross-functionally reviewed with the potential of using Business Intelligence to track DfS progress at the Design Review and program-levels. The details would then be uploaded into the Corporate Design Review database to monitor a New Product Introduction Team's performance on each of the four items. The details included within the Design Review presentation could then tally CO2 and other savings stemming from the DfS work. If poor scores existed on the scorecard, the presentation would highlight where additional support was required to improve future DfS performance.

DfS Scorecard Example: Exhaust Manifold

It should be noted that the Design Review Standard defines "the minimum required work to align with an item's RPC's design stability claim." To indicate that DfS work was part of the set of minimum expectations was only possible with the top-down support received from Cummins' leadership. When all content of the Design Review material has been reviewed and approved by the program team's cross-functional leaders, the status of an item would only then be elevated to the next RPC.

3 Integrate Dedicated Design Optimization Experts

Despite having the CEO's support and embedding DfS expectations within Corporate Standards, it was still challenging to get Cummins' engineering groups to embrace the completion of the scorecard tasks. This led to the hiring of two individuals who had proven expertise in the use of design optimization techniques. These two individuals comprised a pilot group called the DfS Design Center. Their exclusive responsibility is to work with the business to find projects that can use their design optimization expertise to ensure material use is minimized and provide support needed to achieve a full score on the DfS Scorecard.

At first, the business was hesitant to use this resource, until they found that the time-burden of the Design Center resources would not be charged against their program's budget, but instead charged to a Corporate initiative. So, essentially, the program teams that use these optimization experts receive their support free-of-charge. This allows the Design Center to help their team achieve DfS goals, including designing their products with the minimal amount of material, without impacting their program budget, which had not accounted for this work up-front. Offering the support of the Design Center in such a way was key to supporting the team as an outside corporate entity.

Each project the Design Center supports provides a way to gather data on how much material is saved by applying optimization techniques, identifying how much bottom-line cost is affected, and understanding how likely the DfS work helps avoid an inevitable redesign. The projects the Design Center were able to support over the first year helped to quantify the business value of these dedicated DfS resources, including:

- **10-15% material reduced from designs** when applying optimization techniques. The CO2 benefit is calculated and dependent upon the material selected.
- **$1.4 million in bottom-line cost savings** reaped from material reduction **– five times the total financial investment** for the two resources used to lead this work.
- An assurance that suboptimal (legacy) material and process specifications were not used in the new design without mindful consideration.

- An ability to identify and overcome inherent weaknesses of the 'parent' product through optimization techniques (note that many of the older legacy parts were designed before optimization tools like Creo Generative Design existed).
- An assurance that near-net techniques were used to minimize post-processing waste after forming.
- Documentation for the lifecycle of an item to ensure it could be reused (if possible), streamlined for remanufacturing, and efficiently recycled.

With support from the Design Center resources, Cummins' New Product Development teams were able to:

- Show stakeholders that DfS-specific work could be completed within the normal timeline allotted to design new products when using the right skill set.
- Provide real-time opportunities for Design Center experts to train individuals they were supporting on how to apply optimization techniques.
- Highlight design deficiencies associated with 'parent' products that were being used as design references or being updated with new functionality.
- Provide cross-functional experts from various departments the opportunity to review and comment on the design early on, even within the concept design phase, when designers have the freedom to act upon their comments.
- Normalize the performance of designers with varying levels of experience through up-front support and cross-functional mentorship.

These results were presented to the CEO, who shared the findings with other business leaders to show, objectively, how much CO2 and bottom-line savings could be achieved by applying these optimization techniques, as well as the payback that resulted from dedicating resources to this type of design work.

4 Improve Designer-Level Analysis Using PTC's Creo Tool Suite

In the past, one obstacle to completing DfS work was the amount of Analysis resources needed to do the optimization work. There simply were not enough Analyst resources available to complete the work, so the work needed to be performed by Design Engineers when they

In collaboration with PTC, Cummins devised a plan to provide all Creo users with access to analysis-based tools embedded within PTC's CAD software. By embedding multiple Creo tools like Generative Design, Creo Flow Analysis, Simulation Live, and Creo Simulate, Cummins' Design Engineers now had an innovative tool set to enable the optimization expectations called out in the DfS scorecard.

With expectations that Design Engineers would complete the upfront analysis work, most back-and-forth inefficiencies between Design and Analysis were avoided, making both groups more productive. Analysis experts could focus their time on tasks that required their unique and advanced skillset. With Design Engineers completing their own analysis work, they developed a newfound intuition for their craft that was difficult to attain without performing some level of their own analysis on the products they were designing. The analysts became more frequently challenged with work that required their unique skillset, further motivating them as well. Beyond being able to get more work done with the same level of resources, both functions felt that their skillsets were better used, further motivating them to grow in their respective roles.

When a product is designed with the primary goal of eclipsing time-tested design margins that exist within Design Standards (or Engineering Standard Work), there is often a sense of complacency that stems from having to follow a checklist-like approach to design. In contrast, when a commitment is made to "optimize" a design, where an intentional effort is made to achieve each threshold using a minimal amount of material and other requirements, a mindset shift (or culture change) occurs, requiring an enhanced understanding of how a design's structure is used to achieve its functions. This enhancement in functional understanding very early in the design process greatly improves the potential to design right the first time and avoid downstream re-work.

5 Utilize PTC's Creo Learn Training Program

It was critical that Cummins and PTC work together to develop a training regimen that incentivized Cummins' Design Engineers to grow in their modeling proficiency and analysis capabilities. Creo Learn was the training program that enabled Cummins' Design workforce to take such a step.

Creo Learn provides online, instructor-led training for each module within the Creo suite of tools. During the first year this training approach was used at Cummins, 45 individuals gained their Creo Fundamentals Certification (proving their basic proficiency of Creo techniques), and 13 individuals received their Professional Certification, showing a level of mastery across a broad array of Creo design and analysis modules.

Perhaps even more impressive than showing an improvement in their Creo proficiency, Creo users at Cummins (even very experienced users) became aware of functionality they previously were unaware of or were not incentivized enough to consider using.

Creo users who were predominantly using the CAD tool suite for its ability to create solid models are now using analysis-based tools embedded within the software, including generative design, to assess the integrity of their designs and optimize their designs from a material-use perspective.

Minimizing the Environmental Impact of Cummins' Products

Cummins has committed to designing new products in ways that minimize their environmental impact from a material-use perspective. When using the five steps stated in this paper, completing the DfS tasks proved to have several benefits to Cummins' bottom line, while also improving the efficiency of Cummins' engineering organization.

Designing for Sustainability is not only the right thing to do to protect the health of the planet. When pursued using these steps, including a healthy partnership with PTC, it can expedite a company's sustainability journey while yielding similar business benefits and further minimizing the impact that products have on the environment.

Amplifying the Value of Design Engineers

In addition to the environmental and bottom-line benefits, the changes Cummins made to implement DfS highlight how the Design community can bring much more tangible value to a business. Designers are always a valuable resource for taking a series of varied requirements and translating them into something tangible that performs against the set parameters. This is an important skillset that involves innate capabilities that mature over a Design Engineer's career. However, in many companies, Design Engineers are compartmentalized and viewed as just "modelers".

When committing to DfS benefits, the value of a strong and ever-growing Design Engineering organization becomes much more apparent to a company's overall success. Bottom-line metrics like CO2 savings, weight savings, cost savings, and the likelihood of designing an item right the first time are all a direct function of how effectively a Design Engineering workforce is utilized.

With Creo Generative and the optimization techniques that design teams can implement, Designers can now say that they are responsible for a certain amount of cost savings (or CO2 savings) per year. Therefore, Designing for Sustainability is about much more than "making models and drawings". It's also about protecting the planet and achieving the most cost-effective products.

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