Sustainable Design— Not Just for Architecture Any More

real inspiration

SUMMARY

Environmental, economic, and competitive market conditions make sustainable design a desirable approach to engineering today. Dozens of savvy worldwide companies have already put years of effort into incorporating sustainable design elements into their products, in a broad range of industries. With an ever-growing list of cost and regulatory issues complicating the choice of materials and geometry, designers need tools that automate and simplify material decisions. SolidWorks® simulation and analysis tools can help you to lower costs and comply with new standards to make positive environmental impacts.

SolidWorks

Introduction

What is sustainable design?

Sustainable design is a comprehensive, holistic approach to creating products and systems that are environmentally benign, socially equitable, and economically viable: environmentally, such that the design offers obvious or measurable environmental benefits; socially, so that it fills the needs of everyone involved in its production, use, and disposal or reuse; and economically, so that the design is competitive in the marketplace.

All products have the potential to be designed with sustainability in mind if engineers really think about making products better while using materials that positively affect the environment.

Fuel-efficient cars, solar-heated buildings, clean-burning power plants, recyclable packaging, and low-voltage lighting are dramatic examples of products that help balance consumer needs with good environmental stewardship. Yet realistically, all products have the potential to be designed with sustainability in mind if engineers really think about making products better while using materials that positively affect the environment.

Implementing the practical aspects of sustainable design involves the following considerations:

- **Minimal material use:** Can you change the wall thickness of a part from half an inch to three-eighths of an inch without compromising its functionality? (ex: housing for a wide-screen TV)
- **Improved material choices:** Is there a plastic that wasn't available 10 years ago, that would make this part easier to produce, recycle, or transport, for the same cost? (ex: specify recyclable high-density polyethylene (HDPE) instead of acrylonitrile butadiene styrene (ABS))
- **Design for ease of disassembly:** Can the product be designed to be taken apart, either for repair or selective recycling? (ex: use tabs to connect parts, rather than glue)
- **Product reuse or recycling at end of life:** Can the product be designed in a modular fashion, so that one part can be replaced to upgrade its function (ex: rethink throwaway cell phones by selling a consumer-replaceable slide-in memory/function board)
- **Minimal energy consumption:** Is there a different method or machine for building or operating the system that uses less energy to run? (ex: redesign oxygen-flow mask so it uses lower-pressure, less expensive pump system at the consumer end)
- **Manufacture without producing hazardous waste** (ex: the successful elimination of lead-based solder)
- **Use of clean technologies as a fundamental mindset** (ex: hybrid automotive engines)

But why is a new way of thinking so economically important? The answer is that demand for natural resources is growing faster than the available supply, driving up their costs, at the same time that new environmental directives must

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also be met. Fortunately, small design changes—based on optimized amounts of carefully chosen, modern materials, manufactured with minimal energy/resource usage—generate large ripple effects in the overall sustainable life-cycle, and offer the extra benefit of an improved competitive edge in the global market.

Europe is leading the way to achieving this change in mindset, having recently proposed an Integrated Product Policy (IPP) that not only promotes but pushes sustainable development. In a recent report, Cyon Research Corporation analyzes this approach: "At the heart of IPP is the principle that the biggest improvements in environmental impacts of products can be made during the design phase (front-of-pipe), rather than through process efficiency, cleaner production, or pollution management (end-of-pipe). The European Union estimates that over 80 percent of all product-related environmental impacts are determined during the design phase."

Consequently, companies that prioritize finding tangible, methodical ways to reduce material costs and improve processes will be leaders in maintaining profit margins.

Sustainable goals, directives, and tactics

Current economic/environmental policies
Although Europe, with its more limited land and resources, leads the way in suggesting and enacting programs aimed at sustainability, American manufacturers aiming for those markets will have to take heed and comply. A number of EU regulations already in place will radically impact the way products are designed and marketed, from cell phones to sports cars.

For example, the Waste of Electrical and Electronic Equipment (WEEE) and End of Life Vehicles (ELV) Directives are both based on the principle of extended producer responsibility. WEEE requires that circuit boards must not only be manufactured through nonhazardous processes but also designed for disassembly, sorting, and safe recycling/disposal. And the ELV states that automobiles designated for the European market (27 EU states) must be designed with the same tasks in mind, with producers paying "all or a significant part" of the costs of treating negative/nil-value vehicles at treatment facilities.

Legally, these rules mean manufacturers must meet the costs of take-back and recycling of their own products. Economically and environmentally, those manufacturers who are smart about designing their products for ease of reclamation should actually reap financial benefits from doing so.

Other directives aimed at reducing energy consumption during both manufacturing and usage are in the early stages of adoption. The Energy Usage Products (EuP) policy imposes energy-use limits on a wide range of products, and even extends to components and subassemblies sold as spare parts. Compliance with EuP will be verified through the European CE Marking program alongside established safety and electromagnetic compatibility standards.

A lifecycle approach to product design

Human nature believes it's easier to keep things as they are, even against persuasive arguments to the contrary. Often new products merely reflect a progression of incremental changes based on legacy designs and procedures. Think how a car is assembled: although robotics has played a huge role in the past few decades, the overall assembly process still follows the structure laid down by Henry Ford. Worse yet, steps such as gluing and welding have replaced screwing or bolting in many areas, such that subassemblies cannot be opened for repair, but must be trashed and completely replaced.

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At the same time, traditional material costs are rushing upwards: the price index for nonmanufactured goods rose from less than 70 (representing the actual price when compared to an average value set to 100) in 1995 to more than 170 (a 70 percent increase over the norm) in 2005. Rising prices for steel and crude oil are also reflected in manufacturing and shipping costs, and yet consumers keep demanding lower prices. Car manufacturers frequently must raise the price of their models just to pay for end-of-life compliance expenses. So, what can be done to balance or lower these cost issues?

The United States leads the way in product design, so to maintain this leadership as both economic and social pressures for sustainable design grow stronger, the traditional reluctance to change basic principles can and must fade. Kishore Boyalakuntla, national technical manager, analysis products for SolidWorks, observes, "Challenge drives innovation; thus, Ford, and every other car manufacturer, is now thinking differently about every piece of plastic that goes into its vehicles." They're asking themselves:

- What do the raw materials cost?
- How environmentally benign is the processing and handling?
- What energy does it take to use this material?
- Is there a material that costs the same but is easier to recycle?
- Is there a new material that is so strong we can now use less of it to make an existing part with the same durability?

At the same time, many different industry and government groups have developed numerical methods for evaluating the relative environmental impact of different material, processing, and transport choices. Boyalakuntla points out, "Universities, too, such as MIT, are not only looking at energy methods and new design methods, but are starting up whole new departments that combine different disciplines for sustainable development."

Lifecycle analysis and planning

Looking at the big picture is a great way to identify specific product design tasks that can be reevaluated to lessen their contributions to the overall environmental impact. For a product manufacturing process, a lifecycle analysis (LCA) identifies the energy and waste (solid, airborne, and waterborne) associated with each relevant stage, including:

- Raw material extraction
- Material processing
- Component manufacturing
- Assembly and packaging
- Distribution and purchase
- Installation and use
- Maintenance and upgrading
- End-of-life:
  - material recycling
  - component reuse
  - product reuse
  - landfilling
  - incineration

Dozens of savvy, worldwide companies have already put years of efforts into incorporating some or all of these design elements in industries ranging from furniture and flooring to telecommunications and tools.

One interesting and very timely attempt to quantify such factors for design decisions comes from a partnership between the Industrial Designers Society of America and the US EPA. Their project, called Okala, is currently updating its list of calculated "impact" values for hundreds of materials and processes. For example, one assigns a value of 140 to a product if the material used is aluminum, while switching to the use of ABS plastic (which takes less energy to process in the raw form) brings the impact down to 47. (For more information, visit www.IDSA.org.)

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- IKEA has made a science of the design of its assemble-it-yourself furniture such that the packaging for most pieces comprises flat boxes that stack efficiently in delivery trucks for minimum trip/fuel expenses.
- BASF helps automotive manufacturers save time and money with its hybrid UV/thermal coatings that greatly cut back on outgassing and thus minimize volatile emissions or possible defects from bubbling during the paint-curing process.
- IBM started implementing a formal, ISO 4001 environmental management system across all of the company's global manufacturing and hardware development operations and all its business units more than ten years ago, building on previous efforts to ensure environmental considerations are a routine part of all business decisions.
- Whirlpool has been named ENERGY STAR® Partner of the Year seven times, and has been internationally recognized for its commitment to environmental packaging, production, and design.
- BMW's recycling center takes new car models and dismantles them, testing the effectiveness of the disassembly process, as some parts are designed for re-use and others for recycling. The group feeds information back to the design center.
- The DeWalt family of industrial power tools uses a modular design approach such that a single model of rechargeable 14.4-volt battery fits into all the tools in the 14.4-volt product line (e.g., drill, power saw, flashlight).

Specific product design efforts

Since the term sustainable design can refer to many different areas of product design, as well as end applications, following are details of several companies and their products, stepping through the thought processes that produced improved products with better financial and environmental impacts.

Medtronic

In physiology, "perfusion" is the term for quantifying how much of a necessary nutrient (such as oxygen) a person's blood is actually delivering into a patient's system. Medtronics Perfusion Systems group manufactures a line of products, used during cardiopulmonary bypass surgery, that help control this factor by providing circulation, temperature control, filtering, and supplemental oxygen. The systems must operate with consistent, efficient gas transfer, minimized blood shear, low priming volume, and low blood-side pressure drop.

Perfusion Systems has incorporated design-for-the-environment (DfE) procedures into its complete design-control methodology. This process has already generated a 75 to 85 percent reduction in chemical use and wastewater loading for a coating process during manufacturing, with an annual savings of $2.1 million. In addition, the company plans a 30 to 35 percent reduction in material use and a 90 percent reduction in industrial solid waste generated in a battery-manufacturing process. The potential annual savings with the latter approach is over $200,000.

THE COSTING PROCESS USED FOR THIS OXYGENATOR MANUFACTURED BY MEDTRONIC, INC. WAS OPTIMIZED DURING THE DESIGN STAGE, RESULTING IN SIGNIFICANT COST SAVINGS.

Apple Power Mac G4 Desktop Computer

A case study in 2000 of the Apple Power Mac G4 Desktop Computer described the company's systematic approach to sustainable product design.

APPLE DESIGNED ITS POWER MAC G4 DESKTOP COMPUTER TO INCORPORATE MANY ELEMENTS THAT REDUCED PART COUNT, MADE REPAIRS EASIER, AND ALLOWED DISASSEMBLY FOR RECYCLING.

This process has already generated a 75 to 85 percent reduction in chemical use and wastewater loading for a coating process during manufacturing, with an annual savings of $2.1 million.

Here are just a few of the improvements achieved by making changes in the following design attributes:

Energy conservation—reduced thermal profile allows fans to turn off during sleep; sleep-mode power usage is less than five watts (just 17 percent of the ENERGY STAR 30-watt requirement)

Materials conservation—compared to previous products, the Mac G4 used 50 percent fewer components on the universal motherboard; eliminated sliders and skids for attaching zip drives and CD ROMs to chassis

Hazardous constituents—lithium battery contains no heavy metals; no chlorofluorocarbons (CFCs) or other ozone-depleting compounds used in manufacture

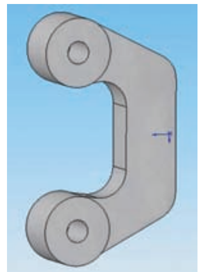
Design robustness—continued use of standard modular components across different products; also incorporated industry-standard components

Ease of service, repair, and upgradeability—all components accessible via swing-open enclosure side door; processor easily removable, replaceable, and upgradeable; key components changeable in one minute

Ease of disassembly/recycling—screw count reduced from 11 to two for mounting motherboard to chassis (reduces time and cost); metal chassis and polycarbonate plastic skin enclosure easily separated for recycling

Automotive material reductions

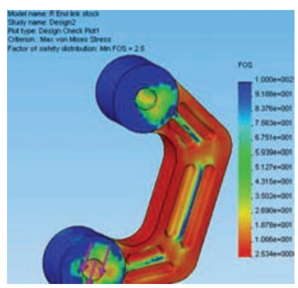
Low cost and improved safety are two factors that can coexist in product design with excellent results, given a detailed, accurate analysis of mechanical form coupled with material properties. One automotive company recently used FEA to assess the design of an end-link bracket that connects the sway bar and control arm in a vehicle suspension system to possibly cut down on material use. The ripple-effect implications would involve saving money by allowing the purchase of smaller quantities, as well as using less energy to produce the material.



ORIGINAL DESIGN OF SOLID REINFORCED NYLON SUSPENSION END-LINK

The ripple-effect implications would involve saving money by allowing the purchase of smaller quantities, as well as using less energy to produce the material.

SUSPENSION END-LINK REDESIGNED WITH SLOTS TO MINIMIZE MATERIAL USAGE WHILE MAINTAINING SAFE OPERATING STRENGTH



STRESS DISTRIBUTION ON REDESIGNED END-LINK, WITH ACCEPTABLE SAFETY FACTOR OF 2.5

Made of reinforced nylon, the mostly solid, injection-molded part as originally designed had a minimum safety factor of 3.4, and cost $0.65 each. The company analyzed the resulting stresses and functional limits when redesigning the part to have six through-cut slits, reducing its mass from 0.234 kg to 0.205 kg. The CAE stress analysis showed it would still operate with an acceptable minimum safety factor of 2.5, while saving $0.09 per part. The material savings with the new design translated into a cost savings of more than $32,000 per year without compromising safety.

Dell

The humble fastener takes on a very important role when considered from a design-for-disassembly point of view. Why use three types of screw-head when one will do? A single part is easier to order, buy in quantity, and assemble/disassemble with a single type of screwdriver.

THIS DELL COMPUTER COVER IS OPENED BY SIMPLY PUSHING TWO BUTTONS ON EITHER SIDE OF THE COVER. NO TOOL IS REQUIRED AND THE CONNECTORS ARE INTEGRAL TO THEIR CORRESPONDING PARTS.

Snap-fits eliminate the need for screws and screwdrivers altogether, make for easier repairs and replacements, and permit ready separation of materials at end-of-life compared to traditional gluing processes.

THE LEVER ON THIS DELL COMPUTER CIRCUIT BOARD RACK NOT ONLY ACTS AS A CONNECTOR BUT ALSO SERVES AS A HANDLE.

A DART CONNECTOR, WHICH REPLACES THE USE OF AN ADHESIVE, HOLDS ACOUSTIC FOAM SECURELY IN PLACE ON THE INSIDE OF A COMPUTER FRONT PANEL.

At the same time, snap-fits eliminate the need for screws and screwdrivers altogether, make for easier repairs and replacements, and permit ready separation of materials at end-of-life compared to traditional gluing processes. Dell computer designs employ several clever approaches to fastening, all of which save on materials, time, and effort:

- A Dell computer-cover is removed by simply pushing two buttons on either side of the cover; the connectors are integral to the unit.
- A lever on a circuit-board rack not only serves as a connector but also as a handle.

Even the design of a flexible plastic snap-fit fastener can be optimized with analysis software: for example, a tapered, cantilevered hook is more likely to withstand repeated disassembly and assembly than a hook with a rectangular cross-section.

Optimization means designing parts and assemblies with as little mass as possible, yet with just enough to resist failures under normal operating conditions.

SolidWorks case studies

With an ever-growing maze of cost and regulatory issues complicating the choice of materials and geometry, designers need tools that automate and simplify material decisions. Boyalakuntla sees an essential role for such software. "To come up with a product that has a positive impact throughout its lifecycle," he observes, "you've got to test many ideas, and the only way you can do that is by doing virtual design and virtual testing. Engineers can contribute to the sustainable process by using tools where analysis drives design."

Analysis software such as SolidWorks Simulation and SolidWorks Flow Simulation, accessed from pull-down menus within SolidWorks 3D CAD software, helps designers make qualified evaluations of the impacts of their design choices, and quickly run through multiple "what if" scenarios to optimize various user-defined factors.

Optimization means designing parts and assemblies with as little mass as possible, yet with just enough to resist failures under normal operating conditions. Software-enabled studies that can result in significant payoffs include:

- Analyzing complex weight-saving geometries, suggesting the use of tubes and I-beams instead of solid prisms
- Comparing the mechanical properties of a part when made from different materials, by simply clicking on an embedded material-properties library to change parameters
- Testing multiple functions for a part, using the Configuration Manager

Such studies offer a low-cost alternative to physical prototyping of each design iteration, allowing designers to aggressively pursue options that would otherwise be too costly and time-consuming to build and test.

User profile

SolidWorks user Commuter Cars (Spokane, WA, www.commutercars.com) applied sustainable concepts from the ground up when they designed their unique two-passenger vehicle, the Tango. This battery-powered car moves through traffic like a motorcycle, yet its racecar-style roll-cage design and low center of gravity provide safety performance on a par with typical midsize sedans.

COMMUTER CAR, TWO-PERSON URBAN TRANSPORTATION VEHICLE BASED ON RACECAR SAFETY DESIGN ELEMENTS

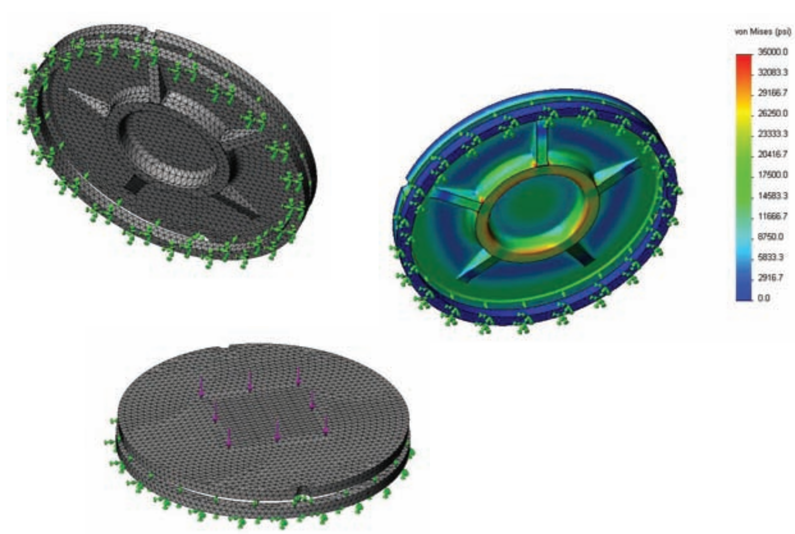
President Rick Woodbury explains that his staff tried to design every aspect of the car to serve more than one purpose. For example, the battery box provides the torsional strength of the car, and the motors themselves provide the structure of the differential. The chassis has been designed to accommodate multiple body designs and therefore reap the benefits of modularity down the road.

SIDE PANEL OF COMMUTER CAR. REINFORCED ENGINEERING-ANALYSIS-BASED DESIGN, RESULTING IN MAXIMUM STRENGTH FOR MINIMUM WEIGHT

Not only does the company's approach make good business sense, but, at a finer level of detail, Commuter Cars also supports sustainable design by using fasteners that permit easy disassembly, and takes care to avoid hybrids (glued/welded dissimilar materials) so that everything can be recycled in a pure state.

Material reduction

Optimizing the weight and volume of a part not only lowers the cost of raw materials but also reduces shipping expenses and can make the difference between complying with European Union material-standards or losing out on a potential market.



LEBARON FOUNDRY USED SOLIDWORKS SIMULATION TO IDENTIFY AREAS OF CAST-IRON MANHOLE-COVER DESIGNS WHERE THICKNESSES COULD BE REDUCED WITHOUT COMPROMISING SAFETY PERFORMANCE. MATERIAL SAVINGS WERE 25 PERCENT BY WEIGHT, AND MORE THAN $500,000 PER YEAR.

Changing the geometry while keeping the same material can offer surprising cost savings even with low-tech, taken-for-granted products. Consider the manhole cover; driven over, walked upon, and occasionally pried open, this mainstay of city utility systems past and present is one of the best-selling products of LeBARON Foundry of Brockton, Massachusetts. Yet, several years ago, with sharply rising scrap-metal prices pitted against the terms of locked-in municipal contracts, the company needed a way to recover some costs.

Having just purchased SolidWorks Premium, including SolidWorks Simulation, the company felt it could speed up its testing process by efficiently sifting through various design geometries prior to strength-testing samples. With the help of the software analysis, LeBARON discovered that many of its products were over-designed—thicker than need be for safety and performance—and therefore redid the geometries, at less than two days each.

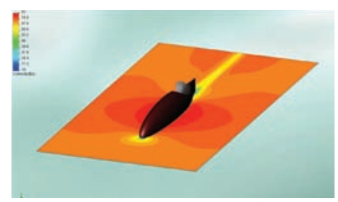
Optimizing the weight and volume of a part not only lowers the cost of raw materials but also reduces shipping expenses.

The process shaved as much as 50 pounds of cast iron from a typical manhole cover, saving up to 25 percent by weight; the cost savings more than covered the projected shortfall of $500,000 per year.

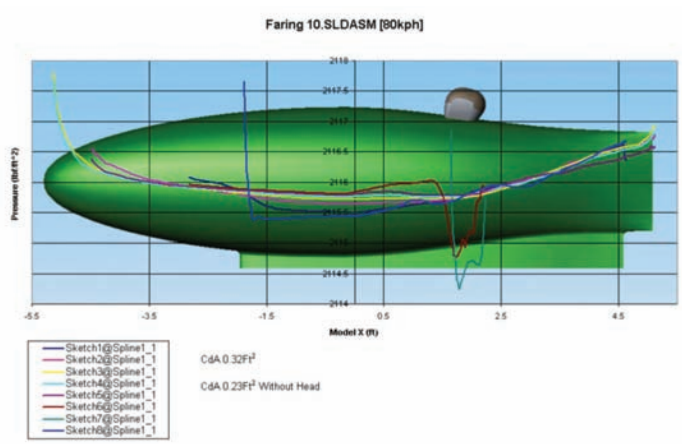
Product function optimization

The goal of functional optimization is to tailor parts and assemblies so that all aspects of the design (weight, functional performance, durability, aesthetics) come together to make that part(s) the best for the job at hand. Sometimes observing how nature solves a similar problem offers a starting point, and that's just what happened for consultant Ben Eadie of MountainWave Design Services (Calgary, Alberta, Canada; www.mountain-wave.ca).

KOLODZIEJZYK DESIGNED AND BUILT A CUSTOM RECUMBENT BICYCLE SURROUNDED BY A LIGHTWEIGHT SHROUD.



AIRFLOW VELOCITY AROUND FAIRING



PRESSURE DIAGRAM FOR DIFFERENT DESIGN SHAPES OF BIKE FAIRING (SHROUD)

Eadie had been talking with Greg Kolodziejzyk, a retired entrepreneur who set out to break the existing 24-hour human-powered distance record of 1021.36 km set in 1995. No wind or stored energy of any kind was allowed, so Kolodziejzyk designed and built a custom recumbent bicycle surrounded by a lightweight shroud. However, he knew from physical tests that the carbon-fiber shroud (called a fairing) could probably benefit from a redesign to slice through the air more efficiently.

Having worked with SolidWorks CAD packages since 1999, Eadie combined his expertise in aerodynamic system design with the capabilities offered in two additional SolidWorks products: SolidWorks Simulation for structural analysis and SolidWorks Flow Simulation for computational fluid dynamics. His structural analyses were very helpful for determining just where the rider should sit, and his research into the shapes of animals that move through fluids at speeds comparable to that desired by Kolodziejzyk (an average of 50 kph) pointed the fairing design towards a fish shape.

Sometimes observing how nature solves a similar problem offers a starting point.

Although not an expert in SolidWorks Flow Simulation, Eadie was able to create five different fairing designs, based on 20 to 30 different analysis runs, with individual runs averaging six hours. He points out that this should be contrasted with the time to build a physical prototype, which could take two years for a single model, and could not then be easily reworked for improvements.

Testing the design in the software became the rule. Whenever the team considered the slightest design change, they evaluated it on the computer model, making sure there was a gain that made it worth changing. Eadie comments that there was no point in building anything until it had been proven on the computer. The final single-build, streamlined design enabled Kolodziejzyk to break the 24-hour human-powered distance record, clocking in on July 20, 2006, having pedaled 1046.94 km.

Reclamation and disposal considerations

Making a design easy to reuse, disassemble, and/or recycle not only extends the useful lifetime of a product but permits sorting by material-type and thus simplifying disposal issues. One example that touches on these and most other aspects of sustainable design comes from a dynamic design workshop held during the summer of 2006 at the Massachusetts Institute of Technology in Cambridge, Massachusetts.

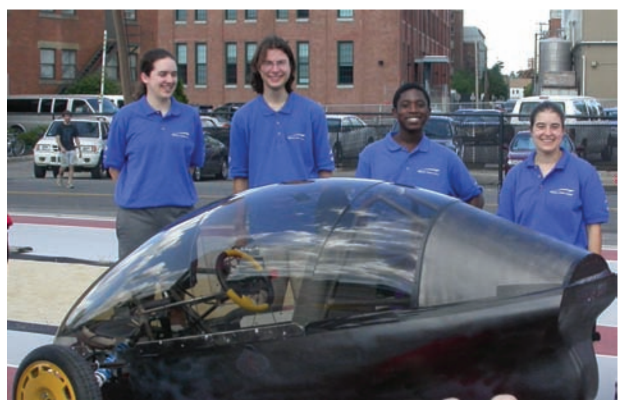
MIT's Dean for Undergraduate Research, Dr. Kim Vandiver, counseled the student-proposed, student-run project dubbed the Vehicle Design Summit (VDS) 1.0—a serious effort aimed at revolutionizing personal transportation through alternative propulsive technologies. Four mixed teams of approximately 12 students each (including participants from 21 universities in 13 countries) worked on the following four approaches:

- Fuel Cell Electric Vehicle - a hydrogen fuel cell generates electricity that is stored in a battery which operates an electric motor
- Biofuel Vehicle - runs a converted diesel engine on pure vegetable oil

- Assisted Human-Power Vehicle (AHPV) - a combination of human bicycle motion plus solar power
- Pulse Electric Vehicle - operates on pure electric power

Making a design easy to reuse, disassemble, and/or recycle not only extends the useful lifetime of a product but permits sorting by material type and thus simplifying disposal issues.

FINAL ALTERNATIVE-FUEL VEHICLES DESIGNED AND BUILT IN NINE WEEKS BY THE FOUR TEAMS PARTICIPATING IN THE VEHICLE DESIGN SUMMIT AT MIT, SUMMER 2006. FROM LEFT, THE FOUR DESIGNS ARE: BIOFUEL, ASSISTED HUMAN POWER VEHICLE, PULSE ELECTRIC, AND HYDROGEN FUEL CELL. (IMAGE COURTESY MIT VDS 1.0)



STUDENT LEADERS OF 2006 MIT VEHICLE DESIGN SUMMIT, L TO R: ROBYN ALLEN, MATT RITTER, NII ARMAR, AND ANNA JAFFE. (IMAGE COURTESTY MIT VDS 1.0)

The students worked to understand the whole system of the car plus its environmental impacts, then tailored and built each vehicle to operate on a specific energy source, keeping in mind all aspects of sustainable design.

From initial concept to final construction, many of the students used SolidWorks and SolidWorks Simulation for 3D CAD and part/assembly analysis. For example, the Pulse team used the materials analysis capability to investigate the chassis-design behavior given the properties of chromolly steel; the software identified weak points and deflections under specified loads. The Biofuel vehicle team used the CAD software to optimize the car to be as light and aerodynamic as possible, and the Fuel Cell team made a point of using recyclable materials, making their chassis aluminum and their body polypropylene. In fact, the latter group believes its car is on the order of 80 to 90 percent recyclable. All four vehicles were built on time (nine weeks from concept to driving) and functioned very much as planned.

A follow-up VDS 2.0 program started in January 2007, with the goal of designing and building a four-passenger vehicle with the following performance specs:

1. Minimize energy during design, manufacture, use, and recycling (with a factor of 20 reduction over typical 2006 commercial sedan lifecycle costs)
2. Achieve 200 mpg and 150-mile range
3. Run 0 to 60 mph in 10 seconds, with a 120-mph top speed

As part of this effort, as many as 50 university teams designed and built a subsystem of a single vehicle, then came for final assembly and test driving. The teams tested their vehicles, built 40 copies for crash testing, and most recently began their search for a manufacturer to begin production.

The Biofuel vehicle team used the CAD software to optimize the car to be as light and aerodynamic as possible, and the Fuel Cell team made a point of using recyclable materials, making their chassis aluminum and their body polypropylene.

Conclusion

Athough there may always be tradeoffs when evaluating the details of sustainable designs, the long-term benefits (and we must look long-term) are undeniable:

- Reduced impact on the environment
- Use of clean technologies for everyday living, construction, and manufacturing
- Reduced water treatment costs
- Less waste going to landfills
- Soil, air, and water pollution prevention
- Preservation of forests and biodiversity
- Reduced climate change
- Product reuse or recycling at end of life

Tradeoffs are best analyzed with precise software products, whose results can be repeated, shared, and analyzed by all departments in an organization, from design and manufacturing to marketing and transportation. Forward-planning companies are more profitable than reactive, defensive companies, and those that improve their competitive position may also keep jobs from going overseas. Software that enables sustainable design processes at all stages of a product's lifecycle is a critical tool for successfully operating in today's design environment.

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