Simulation-Driven Product Development Enables Breakthrough Sustainable Energy Innovation

CIMdata Commentary

Key takeaways:

- Industry thought leaders have identified pursuit of global sustainability as not only good for the environment, but also good for business because new product innovation drives growth and minimizes total lifecycle costs
- Wall Street has also recognized the positive correlation between financial performance (expanding market share, earnings growth and market leadership) and breakthroughs in sustainable energy innovation
- The complexity of products is exponentially increasing due to software and electronics content which requires that companies evolve to a simulation-driven product development process to achieve energy sustainability goals, speed time to market, minimize product costs, and reduce warranty costs
- Market leaders are increasingly adopting systems-based, multi-physics modeling and simulation technology to rapidly evaluate many more innovative systems concepts early in the design cycle and optimize product performance for energy sustainability throughout the lifecycle of products

Introduction

Although global initiatives such as reduction of greenhouse gas (GHG) emissions and the Circular Economy for resource conservation can appear to be purely a cost-burden, industry leaders have begun addressing these environmental issues in ways that create real business value.[1] [2] Over the past two decades, the concept of corporate sustainability has become part of mainstream business for many corporations—both large and small. Sustainability drives companies to explore new product innovations that use fewer resources and meet specific social needs as well as lead to increased market share and business value.

This paper will address some of the capabilities needed by companies who are pursuing leadership in sustainability and related energy conservation issues.

Political Drivers: Global Initiatives for Energy Sustainability

At the 21st Conference of Parties (COP21) meeting in Paris in late 2015, ministers from 195 countries adopted an agreement to fight climate change that included a commitment to limit global temperature rise to no more than 2°C above pre-industrial levels. A more aggressive goal of no more than 1.5°C is also actively being pushed for by countries who are potentially more vulnerable to climate change—called the “one point five to survive” initiative. The ongoing, complex debate on climate change is attempting to balance multiple social perspectives and business constraints, including achieving environmental commitments while ensuring access to energy as a precondition for sustainable economic growth and global social development.

[1] Bonini, Shiela and Anne-Titia Bové. Sustainability’s strategic worth: McKinsey Global Survey results. McKinsey & Company. July 2014.
[2] Bonini, Shiela and Steven Swartz. Profits with purpose: How organizing for sustainability can benefit the bottom line. McKinsey & Company. 2014.

Bridge Strategy for Greenhouse Gas Control

The International Energy Agency (IEA) subsequently proposed a bridge strategy for countries to achieve their intended nationally determined contributions (INDCs) to the 2°C goal while maintaining the same level of currently planned gross domestic product growth. As shown in Figure 1, this bridge strategy identified that two-thirds of the GHG goal could be achieved through two macro technology areas: energy efficiency (49%) and investment in renewable energy sources (17%).

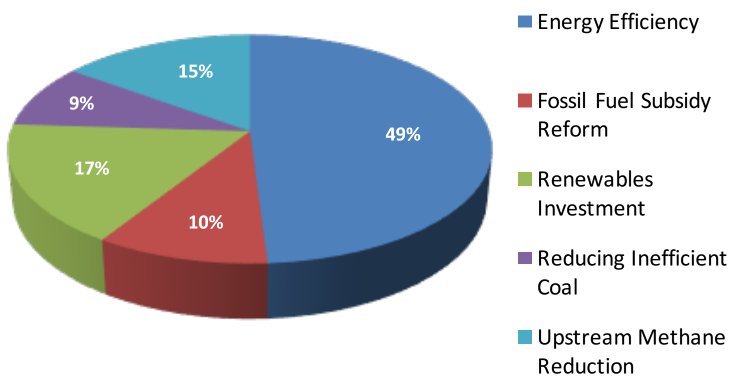

Figure 1—66% of Target GHG Emissions Deduction for the Bridge Scenario Would Come from Energy Efficiency (49%) and Investment in Renewables (17%)[3]

Business Driver: Achieving Profits with Sustainable Energy Innovation

The new business challenges and constraints imposed by sustainability foster cross-company, multi-disciplinary problem solving and innovation in products, processes, and business models to the extent that these positively impact stock performance. For example, annual analysis of companies that have achieved leadership positions on climate performance indices (CPLI) or disclosure indices (CDLI) suggests that companies that achieve leadership positions in climate change generate superior stock performance (see Figure 2). Since 2005, CDLI companies delivered total returns of 82.8%, outperforming the Global 500 (delivering 49.6%) by more than two-thirds. Moreover, CPLI companies generated average total returns of 31.9% since 2010, outperforming the Global 500 (at 24.8%) by more than a quarter.

The paradigm change triggered by energy sustainability and the Circular-Economy demands considerable rethinking of traditional engineering, design and manufacturing processes, and associated best practices to deal with greater product complexity and tighter design constraints. As such, breakthrough energy innovation demands a much larger amount of experimentation than usual to gain new insights into key product performance parameters. Such design iterations are much more efficiently and rapidly performed using computer simulations versus traditional “build and test” processes.

Further, the faster that new engineering technologies for energy sustainability can be brought to market in innovative new products, the quicker the time to business profits and return on capital. Achieving the targeted energy sustainability goals will not only result in near term energy savings but also will mitigate the future need for more extreme measures.

[3] Data extracted from: Energy and Climate Change. International Energy Agency. 2015

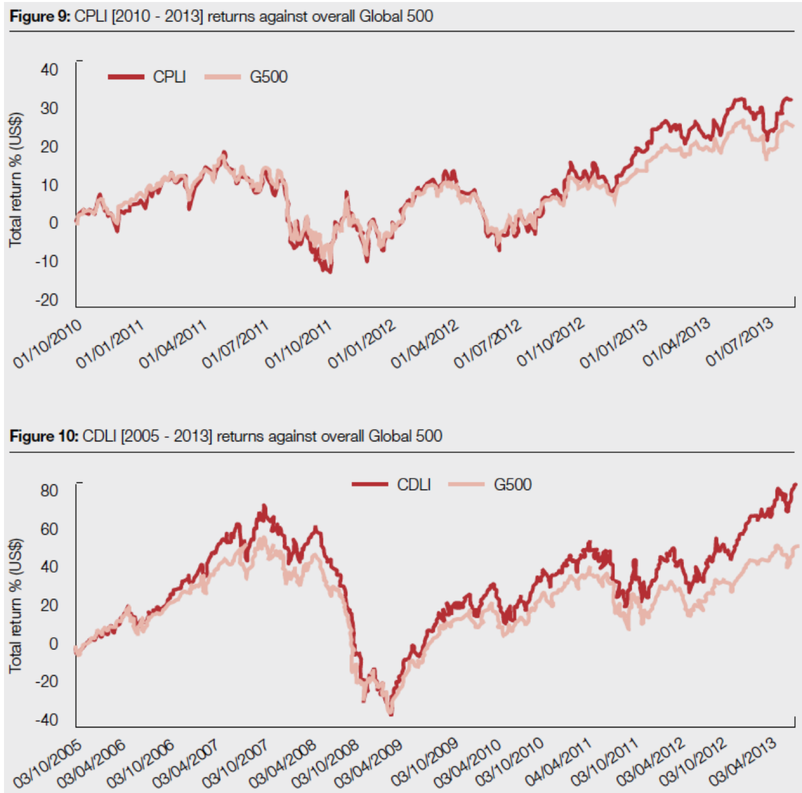

Figure 2—Stock Performance of Carbon Disclosure Project Leaders[1]

Simulation-Driven Engineering for Sustainable Energy Innovation

The engineering solutions to support breakthrough energy-related innovation will come from several key technology areas. These include: electrification, fuel efficiency, machine efficiency, thermal management, aerodynamics, light-weighting, new materials, and resource conservation. Energy efficiency can be increased through improved electrical motors, refrigeration, household appliances, building insulation, and vehicle fuel-economy, as well as through the application of variable speed drives, low temperature heat pumps, LED lighting, compact fluorescent lamps, etc. Existing products need to be even further optimized or, in most cases, significantly re-designed to meet new market competitive requirements, as well as global energy efficiency and sustainability goals. Increasing energy efficiency in diverse industries demands considerable engineering innovation and “out of the box” thinking.

This is where multiple levels of digital “physics-based prototypes” can be employed to simulate, analyze, and optimize the performance of new systems and components at all stages of the design cycle, especially during early concept development. Additionally, the added product complexity now introduced by cyber-physical systems that include hardware, electronics, software, and controls can be most effectively dealt with by addressing these multiple engineering domains and multiple physics phenomena using systems modeling and simulation solutions based on an integrated product innovation platform.[4]

Today’s simulation-driven product development platforms are designed to enable engineers to optimize product designs to achieve these market requirements for competitive

[4] The Next Step in PLM’s Evolution: Its Platformization. CIMdata Position Paper. March 2015. http://www.cimdata.com/en/resources/complimentary-reports-research/position-papers

performance and reduced risk of product failures, while also achieving societal goals for energy sustainability, conservation, and re-use of scarce resources such as water, energy, and materials. In fact, recent studies have shown that best-in-class companies are 53% more likely than their peers to use multi-physics simulation technology to achieve competitive advantage by meeting design targets for product launch dates, product cost, and quality; as well as financial metrics such as product revenues and profit margins. The contrast is indeed substantial and compelling between companies that have successfully leveraged simulation technology as a strategic part of their product development process versus those companies that have not adopted a simulation-driven product development approach.[5]

In short, profitable product innovation demands the creative use of physics-based modeling and simulation technology that enables engineers to rapidly analyze and solve real world issues related to breakthrough sustainable energy innovation.

Three industry applications are profiled below that highlight the engineering complexity that needs to be dealt with to create such energy-related design breakthroughs:

- Electric propulsion for on-road vehicles
- Combustion efficiency for off-road vehicle diesel engines
- Water conservation in residential shower use

These applications highlight large, well established, publicly traded, global companies, as well as a new venture-backed U.S. start-up company with fewer than ten employees. All demonstrate that the business drivers and related engineering technologies required to achieve sustainable energy innovation are relevant and realizable for all types of enterprises.

Application 1: Enabling Electric Propulsion for Automobiles

The transportation sector today is the second-largest emitter of CO_2 after the power sector, accounting for more than 20% of global energy-related CO_2 emissions.[6] Passenger and freight road vehicles are the primary cause of the increase, accounting for over 80% of the growth, due primarily to a heavy reliance on fossil fuels.

Under the long-term “450 Scenario,” the proportion of electric and plug-in hybrid electric vehicles (BEVs, PHEVs) is expected to be ~40% of all on-road vehicles, reducing global oil demand by six million barrels per day in 2040. BEVs and PHEVs will need to become comparable with today’s gasoline vehicles in terms of drive range and lifetime costs to attain much higher sales volumes.

Battery performance is a critical design element of an electric vehicle. Smaller and lighter batteries will significantly reduce the weight of the vehicle and improve its fuel economy, as well as reduce operational costs. Unfortunately, today’s state-of-the-art rechargeable battery technology (i.e., lithium-ion batteries) has much lower performance in terms of expected operating range for all-electric vehicles versus gasoline powered or hybrid vehicles. Further, in electric vehicles, many hundreds of individual battery cells need to be connected together as part of a much larger battery pack system to power the vehicle. Major automakers and

[5] Why Engineering Simulation is Critical to Your Smart Products Success in the Internet of Things. The Aberdeen Group. 2016. http://resource.ansys.com/Resource%20Library/White%20Papers/Why+Engineering+Simulation+is+Critical+to+Your+Smart+Products+Success+in+the+Internet+of+Things

[6] Bonini, Shiela and Steven Swartz. Profits with purpose: How organizing for sustainability can benefit the bottom line. McKinsey & Company. 2014.

their suppliers have been working together, along with the U.S. Department of Energy (DOE), to meet the ambitious goal of reducing energy costs to US$125/kWh by 2022.[7]

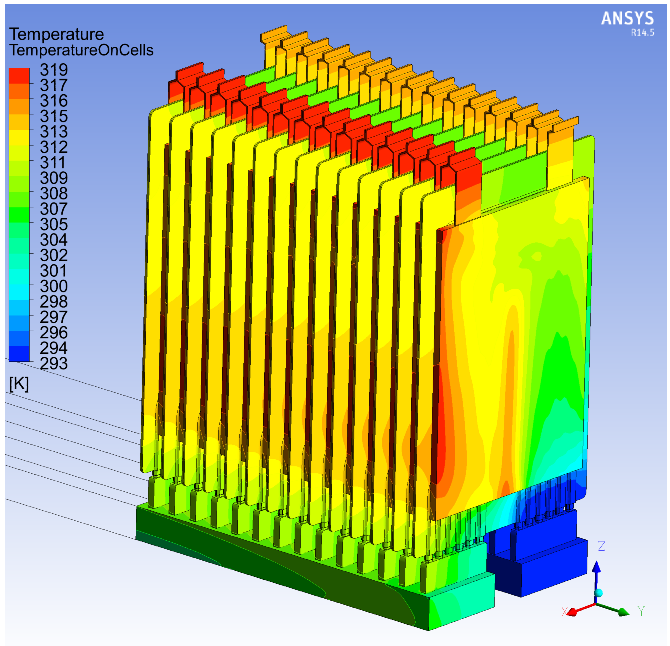

Figure 3—System Level Thermal Model of a 24-Cell Reference Battery Module
(Courtesy of ANSYS)

One excellent example of such collaboration is between General Motors (GM), DOE's National Energy Laboratory (NREL), ANSYS Inc., and ESim LLC, which is focused on Computer-Aided Engineering for Electric Vehicle Batteries. The main objective of the project is to develop design tools for battery packs by leveraging and extending the capabilities of systems-level thermal performance simulation packages. One major challenge related to electric vehicle battery packs is the maintenance of optimum system operating conditions for avoiding material degradation and loss of capacity given the strongly coupled electrochemical and thermal behavior of its hundreds or even thousands of cells. For electric vehicle makers, designing an efficient and robust cooling system for the battery pack is a key technology goal required to achieve affordable energy production.

In the longer term, further enhancements to this battery performance simulation technology will include the addition of battery-life modeling to predict the capacity fade of cells over an extended period of use, and expanding the capability to examine individual cells in more detail by replacing selected units in the system model with full 3D cell models, as well as reduced-order models. The design insights provided by this systems-level simulation approach will be especially critical for trade-off studies regarding key performance parameters, such as air cooling versus liquid cooling, battery form factor or effects of battery management system control logic. These types of critical design issues must be answered before auto manufacturers commit to building costly prototypes and production tooling.

Application 2: Improving Diesel Engine Efficiency

Medium- and heavy-duty vehicles currently account for about 20% of greenhouse gas emissions and oil use in the U.S. transportation sector, but only account for about 5% of the

[7] Ye, E., T. Han, T. and S. Kher. Automating Battery Pack Design. ANSYS Advantage, Vol. IX, Issue 2. 2015.

vehicles on the road.[8] Globally, GHG emissions from heavy-duty vehicles are growing rapidly and are expected to surpass emissions from passenger vehicles by 2030.

The EPA and National Highway Traffic Safety Administration (NHTSA) estimate that Phase 1 GHG emission rules will save 530 million barrels of oil over the life of vehicles built for the 2014 to 2018 model years. Certain combination tractors (also known as semis) will be required to achieve approximately a 20% reduction in fuel consumption and GHG emissions by model year 2018. This could save up to 4 gallons of fuel for every 100 miles driven.

The proposed Phase 2 program would cut GHG emissions by approximately 1 billion metric tons and conserve about 1.8 billion barrels of oil. The standards phase is beginning in model year 2021 and will culminate in model year 2027. The biggest impact will be in combination tractors designed to haul freight. The target is to reduce carbon dioxide emissions and fuel use by 24% compared to Phase 1 standards. Technologies being explored include combustion optimization, improved air handling, reduced friction loss within the engine components, improved emissions after-treatment technologies, and waste heat recovery.

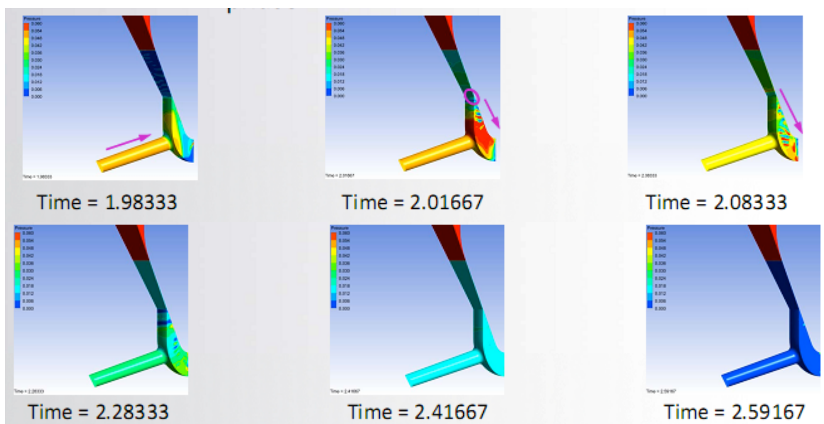

Figure 4—Conditions in the Injector Sac and Spray Hole During the Fuel Injection Cycle
(Courtesy of ANSYS)

The internal fluid dynamics of diesel engine fuel injectors can have a major impact on engine performance. The flow inside the fuel injector influences the pattern with which fuel is sprayed into the combustion chamber (Figure 4), that in turn, can impact combustion performance and emissions. Likewise, internal flow patterns affect fuel injector losses so optimizing these can improve fuel economy and engine performance.[9]

Cummins Inc., a global leader in the production of diesel engines for both on-road and off-road vehicles, as well as for power generation sets, makes extensive use of computational fluid dynamics (CFD) technology to simulate internal fluid dynamics of fuel injectors, paying particular attention to cavitation behavior, sac filling and pressure, and spray-hole velocity and momentum. Application of the CFD software enables Cummins engineers to evaluate many design alternatives and iterate to an optimized fuel injector design with lower losses and a superior spray pattern, resulting in significant improvements in engine performance.

Cummins states it has reduced engine emissions for their North American on road vehicle class diesel engines by an amazing 99% over the past 15 years through fuel injector

[8] Benink, C. Push to Cut Diesel Exhaust Emissions Is Far From Over for Heavy-duty Trucks. For Construction Pros, February 2016. http://www.forconstructionpros.com/article/12161711/heavy-duty-diesel-trucks-face-greenhouse-gas-ghg-emissions-challenge
[9] Husmeier, F. Cummins Uses Simulation to Reduce Injector Losses and Improve Spray Pattern for Performance. ANSYS Journal. 2013.

optimization and other innovations such as combustion thermal modeling, piston lubrication modeling, electronic control systems software modeling "in the loop," turbocharging, and exhaust gas recirculation techniques. In less advanced parts of the world, Cummins engines now actually clean up and improve the ambient air quality as they are operating in the environment. Based on these major virtual prototyping successes within its core engine application areas, Cummins simulation-driven product development strategy called Analysis-led Design is now a core element of their corporate-wide engineering process and is seen as a significant competitive differentiator for all of their business units in the power generation domain—vehicles, rail, standby power, and aftermarket engine treatment systems.

Application 3: A Water Conserving Showerhead Design

Saving water not only reduces stress on natural water systems, but it also produces substantial energy savings and greenhouse gas reductions. Treating and pumping water through cities appears to contribute as much as 2 to 3% of global GHG emissions and municipalities spend 25 to 60% of their budgets to supply energy to their water infrastructure.[10]

In the United States, the energy needed for collection, distribution, and treatment of drinking water and wastewater is estimated to result in approximately 116 billion pounds of carbon dioxide (CO_2) per year, which is the equivalent of the global warming produced by 10 million cars.[11] The energy-water connection is particularly strong in the driest regions of the world, such as the U.S. Southwest, where significant amounts of energy are used to import water.

Nebia, an innovative Kickstarter-funded start-up founded in August 2015, is addressing the challenge of water conservation and GHG emissions reduction through the design and development of an innovative showerhead that achieves a 70% reduction in water usage while delivering an improved personal showering experience.[12] Nebia's showerhead design reduces water usage in the typical 8-minute shower from 20 gallons (76 liters) of water to just 6 gallons with an improved user experience that is a result of optimum thermal design.

While developing its innovative new showerhead (see Figure 5), the company's engineers prioritized the thermal performance characteristics to ensure that while using much less water than normal; the Nebia shower experience will still be warm and comforting to the consumer.[13] Nebia engineers used advanced CFD solutions to analyze the thermal effects of hundreds of thousands of variables in the showerhead design to predict the relative performance of many different showerhead designs and achieve the right balance of water temperature, flow rates and directions, droplet patterns and sizes, and other characteristics to create the ideal shower experience. Using the simulation models, Nebia engineers studied the thermal performance of 12 design iterations per day, instead of spending a week on one physical test of a single physical prototype. Eliminating the need to build and test numerous early-stage prototypes significantly compressed the research and development time and engineering costs. In fact, research activities that previously took nine months were accelerated to just one month.

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[10] Zhou Y, B. Zhang, H. Wang and J. Bi. Drops of Energy: Conserving Urban Water to Reduce Greenhouse Gas Emissions. Environmental Science & Technology. 47(19). 2013.
[11] Ibid.
[12] Water Efficiency Saves Energy: Reducing Global Warming Pollution Through Water Use Strategies. Water Facts. www.nrdc.org. March 2009.
[13] Parisi-Amon, G. and C. L. Murphey. Full Steam Ahead. ANSYS Advantage. Vol. X, Issue 1. 2016.

Figure 5—Nebia's New Shower Head Design
(Courtesy of Nebia)

As a result of implementing a simulation-driven product development process from the outset, Nebia will now begin shipping its initial showerhead products to customers starting in the fall of 2016, approximately 14 months after incorporation of the company.

Conclusions

The corporate executive suite should no longer see achieving global energy sustainability and green and conservation goals as obstacles to business competitiveness, but rather as enablers of growth and operational efficiency as well as a superior way to generate return on capital and build brand equity. In other words, thinking green means money as well as sustainability.

The financial markets are now rewarding companies that excel in leveraging energy sustainability and Circular Economy principles in driving their businesses. In fact, companies that have sustainability as a significant part of their corporate strategy now account for more than 11% of all assets under management in the U.S.

While this paper highlights a very small sample of how physics-based modeling and simulation is being used today, the three applications herein demonstrate that engineers can now explore and better understand a wide variety of complex multi-physics design characteristics to develop innovative new concepts for many future "green" products—faster and much more efficiently with simulation-based engineering tools and processes.

The implementation of a simulation-driven product development platform as offered by engineering technology providers, such as ANSYS, is able to make a significant impact on producing breakthrough energy innovations to address the world's concerns about the long-term sustainment of energy, resources, and human life, as we now know it on this planet.

For more information on the customer application use cases highlighted in this paper and the ANSYS solutions for Simulation-Driven Product Development, please see www.ansys.com.

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