Next Generation Materials:
Technology Assessment

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1. Introduction to the Technology/System

1.1 Overview

The term “next generation materials” refers to major innovations in the properties, manufacturing processes, and market applications of many materials vital to the U.S. economy, including metals, polymers, ceramics, composites, and coatings. In particular, next generation materials can be thought of as those that lead to step changes in the economic, engineering, and environmental performance of materials across their entire life cycles (i.e., manufacturing, use and reuse, and end of life) as compared to historical performance improvement rates within specific materials classes. Furthermore, materials innovations can occur at many different scales, including improved structural properties at the nanometer scale, novel surface geometries at the micrometer scale, and creation of new materials markets and applications at the global scale. Key examples include new catalysts for more profitable and sustainable fuels and chemicals, advanced surface coatings and geometries for improving materials durability and reducing friction, lightweight metal alloys and composites for more fuel efficient vehicles, and near net shape techniques for less wasteful and more profitable materials processing. A recent in-depth report estimated that 54 such “breakthrough” materials innovations could save the United States over 2.8 quadrillion British thermal units (Quads) at cost savings of $65 billion across the U.S.

economy.[1] In other words, innovations in materials hold great potential for improving the nation's energy security and economic competitiveness.

Given the vast landscape of different materials, markets, and end use sector applications (e.g., infrastructure, consumer products, transportation, appliances, and so on), it is helpful to discuss next generation materials in terms of specific innovation opportunity areas. Table 1 summarizes the innovation opportunity categories used in this chapter, which were identified by a panel of experts on breakthrough materials innovation areas convened by The Minerals, Metals & Materials Society (TMS) on behalf of the Advanced Manufacturing Office (AMO) as part of a 2011 *Innovation Impact Report*.[2] The representative materials innovations listed under each category were further informed by expert elicitation data obtained by Oak Ridge National Laboratory (ORNL). Finally, Table 1 summarizes the potential segments of the U.S. energy-economic system that could be impacted by innovations in each category.

Quantifying the potential energy, emissions, and economic benefits of next generation materials is difficult for several reasons. First, the rapid pace of innovation and the myriad classes and applications of materials targeted by such innovations create an enormous opportunity space that is intractable to analyze as a whole. Second, the nascent state of many materials innovations means that credible data on their performance are not yet available. Third, when such data are available, they are often at the lab or pilot scale, and therefore difficult to extrapolate to industrial scale conditions. Fourth, materials innovations can have significant life-cycle effects—including changes in the types and structures of raw materials supply chains, changes in application product performance, and changes in viable end of life options—which makes benefits analysis an uncertain and analytically challenging exercise. Therefore, this chapter focuses on providing quantitative data for specific case studies within materials innovation categories drawn from the literature rather than attempting to derive (highly uncertain) estimates of the potential societal benefits of innovation categories as a whole. However, the qualitative summary of impacted economy segments in Table 1 underscores the broad reach and importance of next generation materials for improving the economic and environmental performance of the U.S. economy.

Table 1: Materials innovation categories and sectors of likely impact

		Energy Generation						Energy Storage		Energy Use	
Category	**Subcategories**	**Solar**	**Wind**	**Biomass**	**Nuclear**	**Oil & Gas**	**Coal**	**Batteries**	**Fuel Cells**	**Industry**	**Transport**
Functional surface technologies	Catalysts			X		X	X	X	X	X	X
	Separations			X		X	X	X	X	X	X
	Coatings	X	X	X	X	X	X	X	X	X	X
Higher-performance materials	Thermoelectrics	X		X			X			X	X
	Phase-stable metals			X	X	X	X				
	Surface treatments	X	X	X	X	X	X	X	X	X	X
	Bio-based materials			X						X	X
	Lightweight high-strength materials	X	X			X	X	X		X	X
New paradigm manufacturing processes	Net-shape processing		X		X	X	X			X	X
	Additive manufacturing	X								X	X
	Composite materials		X							X	X
	Magnetic field processing									X	X
	Low-carbon cements									X	
	Energy-efficient metals processes									X	X

1.2 Public and private roles and activities

Two high profile public and private partnerships in the United States related to next generation materials are the Materials Genome Initiative (MGI) and the Integrated Computational Materials Engineering (ICME) movement. The MGI is a U.S. Federal government multi-stakeholder initiative designed to develop an infrastructure to accelerate and sustain domestic materials discovery and deployment, primarily through funding of research in the areas of computational tools, experimental tools, data management, and collaborative networks.[3] The MGI has invested over $250 million in research to date. ICME refers to the development of multi-scale modeling of materials systems to capture the nexuses between structure, properties, processes, and performance. The need for ICME to accelerate the development and deployment of next generation materials was stressed in a 2008 U.S. National Research Council report, and further underscored in a 2013 study led by the TMS on ICME implementation in key U.S. industries.[4, 5] The European Commission is aggressively funding capacity and network building for ICME, while in the United States the TMS has been a key convener of conferences and roadmaps to promote ICME leadership domestically.[6, 7] In addition to these partnerships, there are many funding programs and collaboration networks that have been established to facilitate progress in particular materials and/or process domains, including the public-private U.S. Manufacturing Innovation Institutes focused on additive manufacturing, battery materials, and composites.[8] A key to the success of all of these initiatives is a sharp focus on the materials innovation opportunities with high impact potential, including efforts to overcome development and adoption barriers as discussed in the previous section.

2. Technology Assessment and Potential

2.1 Performance advances

Ongoing innovation and focused research in each materials innovation category are leading to steady improvements in their engineering, economic, and market performance in various applications. In particular, to realize the greatest benefits from next generation materials and build competitive advantage, the United States should encourage and invest in next generation materials initiatives that accelerate performance gains beyond historical improvement rates, and/or usher in new eras of performance through disruptive materials innovations. Table 2 summarizes key “stretch” performance summaries and targets for each materials innovation category that would lead to substantial national energy and economic benefits, as identified by the blue ribbon panel of experts within the 2011 *Innovation Impact Report*.[2] Reaching these targets will require significant financial investments, extensive research across the public and private sectors, and favorable policy incentives and conditions as discussed further in Section 4.

Table 2: Target performance advances for next generation materials [2]

Category	**Subcategories**	**Next generation performance targets**
Functional surface technologies	Catalysts	Greater than 91% selectivity and expanded feedstock capabilities by 2020, leading to more efficient conversions and greater applications to bioprocesses.
	Separations	5x-10x improvements in scale and flux of ceramic, metallic, polymeric, and composite membranes by 2020.
	Coatings	Greater thermal stabilities for higher temperature applications; higher wear and more reparable coatings.
Higher-performance materials	Thermoelectrics	Future figure of merit (ZT) of 1.8, compared to 1 in 2011, leading to greater conversion efficiencies; thermal stability up to 1000 C.
	Phase-stable metals	Thermal stability up to 1200 F by 2020 (next generation steels) and up to 1425 F (nickel-cobalt); irradiation-resistent steels up to 80 years lifespan by 2020.
	Surface treatments	5x improvement in material durability by 2020.
	Bio-based materials	Increased use of bio-based feedstocks for fuels and chemicals to offset fossil fuel use
	Lightweight high-strength materials	25% weight reduction by 2020
New paradigm manufacturing processes	Net-shape processing	20% improvement in energy efficiency of powder metallurgy by 2020; 8% reduction in energy intensity of casting by 2016.
	Additive manufacturing	Buy-to-fly ratio of 2 to 1 for additive manufacturing by 2020;
	Composite materials	Fiber processing costs reduce by one-half by 2026; 6x improvement in tooling cycles for composite matrix manufacturing by 2020.
	Low-carbon cements	Net-zero carbon emissions or closed carbon cycles for elimination of calcining emissions during thermal processing of clinker.
	Energy-efficient metals processes	33% reduction in energy intensity of aluminum production by 2020; 66% reduction in energy intensity of metals recycling by 2020; 70% reduction in titanium powder costs by 2020.

2.2 Potential Impacts

The potential positive impacts of next generation materials on the U.S. economy are vast, and can be realized across different stages of the materials life cycle. As discussed in Section 1, analyses of the life-cycle benefits of next generation materials are complex and quantitative data to support these analyses for the myriad innovations underway in each materials innovation category are scarce. However, the following examples underscore the potential benefits of next generation materials based on the availability of credible quantitative data from the literature.

2.2.1 Functional surface technologies

Functional surface technologies refer to advances in the interactions of materials with their environments and service conditions, and include catalysts, functional surface geometries, and coatings. These technologies influence the performance of every sector of the U.S. economy, from catalysts producing fuels and chemicals, to coating protecting structural steel in buildings and bridges, to the surface geometries of drives, pistons, and bearings in vehicles and machinery. Examples of benefits of next generation materials in this category include:

- Next generation catalysts and process pathways for production of olefins, ammonia, methanol, and other commodity chemicals such as catalytic crackers, catalytic oxidative dehydrogenation, and electrolysis could reduce the energy intensity of commodity chemicals production by 20%-40%, leading to global savings of 13 exajoules (EJ) globally by 2050. [9]

- Improved coatings that reduce corrosion-related losses and costs in the US petroleum refining, chemicals, and pulp and paper industries by 10% would save these three industries about $1.1 billion each year. [2]

- Surface treatments and coatings for reduced friction losses in the engine, drivetrain, and fuel systems enabled by advancements in tribology and computational design could reduce the fuel used by U.S. cars, light trucks, and heavy-duty vehicles by up to 12%, or 1.4 million barrels of petroleum per day. [10]

- Novel surface geometries can influence the hydrophobicity of materials, thereby reducing drag in solid-liquid interactions. Applications of this new class of specially “wettable” materials include reducing aerodynamic friction in transport vehicles and drag friction in fluid transport pipes across the economy. Additionally, such materials hold promise for harvesting of water from fog, which might be used to as a source of water supply in various world regions. In one study, a wettable mesh harvested 3-10 liters per square meter of mesh per day from fog. [11, 12]

- According to the 2011 *Innovation Impact Report*[2], “An economically viable gas-to-liquids process enabled by the development and manufacturing of advanced catalyst materials can eliminate some of the 2.1 billion cubic meters (bcm) of natural gas that is flared and vented in the United States each year,8 resulting in energy savings and reduced CO2 emissions and fuel costs. For example, eliminating 10% of natural gas flaring (0.21 bcm) through the increased use of gas-to-liquids processing would save 8 TBtu of energy, 0.4 MMT of CO2 emissions, and $15 million in fuel costs each year.”

2.2.2 Higher performance materials

Higher performance materials include a broad swath of opportunities across metals, polymers, ceramics, and composites that improve strength and engineering performance in various applications, leading to both energy and economic benefits across the US economy. Examples of benefits of high performance materials in this category include:

- Advancements in high-strength, lightweight materials for automotive applications such as magnesium alloys, aluminum alloys, high strength steels, and polymer composites can lead to massive energy savings in the U.S. transport sector through lighter weight bodies, chassis, and drivetrains and more efficient engines. For example, a 10% reduction in vehicle mass can lead to 6-8% improvement in vehicle fuel economy. Using lightweight components and high-efficiency engines enabled by advanced materials in one quarter of the U.S. fleet could save more than 5 billion gallons of fuel annually by 2030.[13]

- High-ZT thermoelectric materials that convert waste heat into electricity at an efficiency of 15% could be applied to the estimated 1.5 Quads of unrecovered waste heat in the U.S. industrial sector each year could save U.S. manufacturers more than $3.6 billion in annual energy costs.[2]

- The calcining processes that occurs in cement kilns is a major contributor to the greenhouse gas (GHG) emissions footprint of the U.S. manufacturing sector. Novel substitute materials for producing cement, including magnesium silicates or carbonates, and/or carbon-cycling processes, such as the Calera or Calix process, can reduce or eliminate GHG emissions from calcining. Such an improvement would provide US cement plants with a competitive advantage as the world seeks lower-carbon alternatives to traditional cement (one of the world's largest volume materials) while lending progress toward national GHG emissions reduction targets. [14]

- According to the 2011 *Innovation Impact Report* [2], "Incorporating advanced phase-stable metallic materials capable of withstanding elevated inlet temperatures and harsh operating environments into the design of these turbines could greatly improve the efficiency of U.S. electricity generation. For example, a 1% reduction in fuel consumed by U.S. power-generating gas and steam turbines would save 348 TBtu of energy and $400 million in fuel costs."

2.2.3 New paradigm manufacturing processes

New paradigm manufacturing processes are a critical opportunity for several reasons. First, novel materials innovations may require entirely new production processes, such as a shift from sputtering-based coating applications to colloid-based applications for new electrochromic window coatings for energy efficiency [15]. Second, improvements to high-volume processes for producing metals, polymers, and other bulk materials in more energy- and materials-efficient fashion can reduce both the operating costs and the energy, resources, and waste footprints of US industry. Third, next generation manufacturing processes such as nanofabrication, synthetic biology, and additive manufacturing can lead to dramatic improvements in manufacturing flexibility, lead time, and productivity while also opening up opportunities for new materials innovations to support the processes (e.g., advanced powders for additive manufacturing).

In one example, next generation metals industry processes, including intelligent casting, improved controls, blank geometry optimization, inert atmosphere melting, and higher strength alloys can substantially reduce yield losses in the production of metal products. For example, in the steelmaking industry, advanced processes for minimizing yield loss could reduce the overall energy intensity of the U.S. steel industry by around 10%. [16]

3. Program Considerations to Support R&D

There are several key areas of research and deployment support needed to the aggressive performance improvements goals for next generation materials, such as those summarized in Section 2. The necessary support mechanisms span the entire technology life cycle, and involves significant investments of research funds, new forms of public-private collaborations, new tools and methods for materials discovery, greater policy incentives for high-risk, high-reward materials innovations, and pilot and demonstration projects to verify marketplace performance and reduce barriers related to perceived risk among early adopters.

Clearly, large investments in basic and applied science are needed to accelerate the availability and performance of next generation materials, given that performance advancements often rely on improved fundamental understanding of materials properties, chemistry, and physics, often at very small scales. Such research typically requires high-end equipment for materials imaging, synthesis, manipulation, and measurements, all of which can require substantial capital investments. Ongoing support is further needed for staffing research teams and the (sometimes) lengthy experimental and computational processes that lead to materials breakthroughs. Therefore, continued federal investment in basic and applied research will be critical. However, large scale collaborative public-private partnerships, such as the National Network for Manufacturing Innovation Institutes [8], and shared user facilities, such as Lawrence Berkeley National Laboratory's Advanced Light Source, can facilitate collaborations while maximizing the reach of public and private investments in capital equipment. Such initiatives require not only significant financial investments, but also strong commitments to collaboration and shared agendas for research priorities across private companies, universities and research labs, federal and local government agencies, and federal and local policy makers.

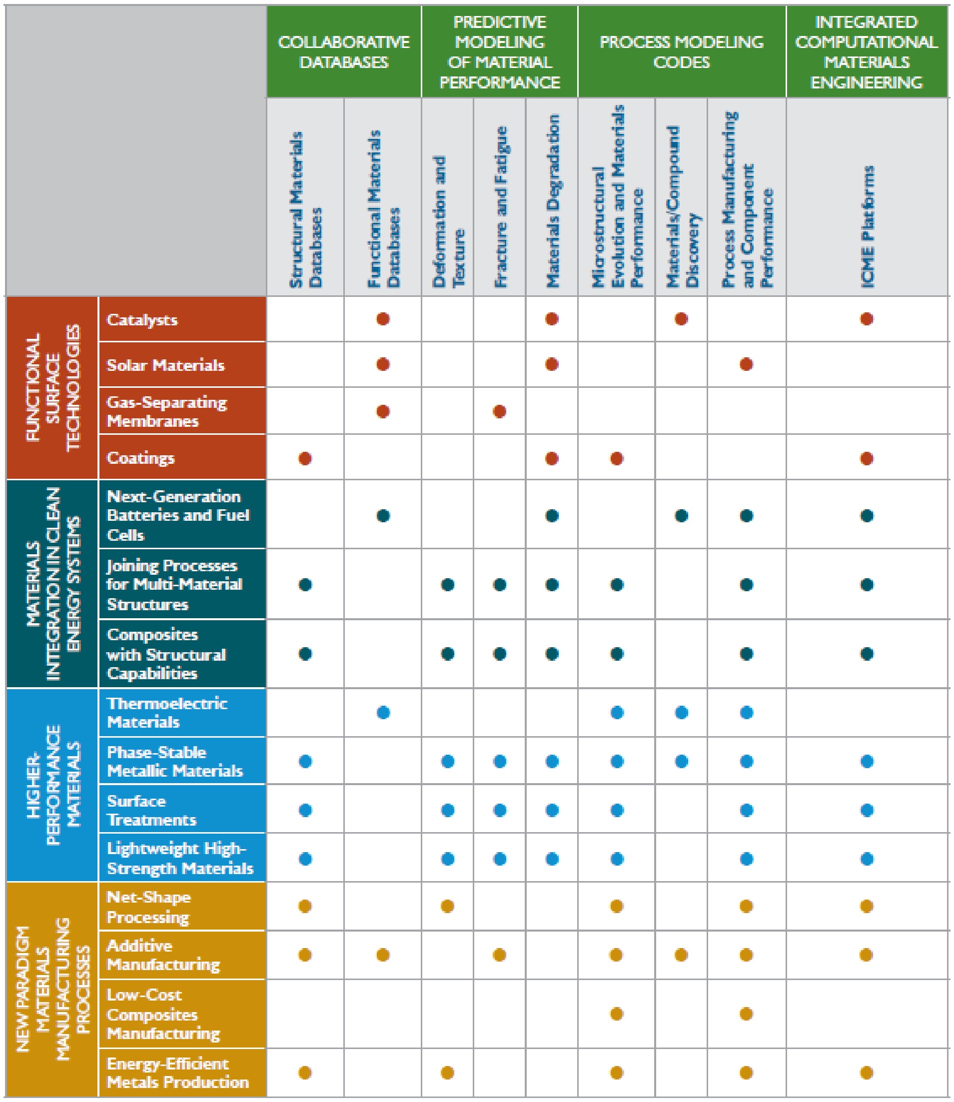
In addition to increased investments in physical laboratory facilities necessary to perform basic and applied science, substantial investment and new collaborations are also needed to further develop computational methods, tools, and databases that enable better discovery and prediction of materials properties and processing attributes. Such advancements include better collaborative databases of materials and process properties, manufacturing process simulations, and methods for predicting performance. Additionally, the Integrated Computational Materials Engineering (ICME) movement seeks to develop such computational capacity by developing and linking models and data for multi-scale simulation of materials performance. Because general ICME methods can apply to any materials innovation category, they can accelerate discovery and optimization of materials affecting every sector of the U.S. economy. Figure 1 summarizes the potential impacts of improved computational resources across materials innovation categories, as determined by the 2011 *Innovation Impact Report*.[2]

Materials breakthroughs at the laboratory scale can also face major barriers related to manufacturing process scale-up and eventual market acceptance and uptake, which can significantly limit a material's potential for large-scale impact on the nation's energy and economic systems. Continued and increased investments in market readiness programs, pilot and demonstration projects, and public outreach are needed to help usher such technologies through the so-called "valley of death" that exists between proof of concept and market adoption. For small businesses, the Small Business Research Innovation (SBIR) program was designed to address this need through several billion dollars in assistance each year, but increased investment will be critical to reach the stretch goals laid out in Section 2. Similarly, the U.S. DOE has funded numerous demonstration projects for materials innovations, energy technologies, and manufacturing processes as a way to test ideas, learn by doing, and, most importantly, to prove out technologies in controlled trials to help overcome the initial market reluctance and perceived risk that often inhibits the adoption of novel technologies.

Table 3 summarizes some major R&D opportunity areas for each materials innovation category, based on expert elicitation and conclusions in the 2011 *Innovation Impact Report*.[2] While not exhaustive of all needed areas of R&D support, Table 3 provides a comprehensive overview of targeted opportunities that could lead to significant national benefits.

Table 3: Summary of R&D priority areas for next generation materials innovation categories [2]

Category	Subcategories	R&D Priority Activities		
		0-2 years	**2-5 years**	**5-10 years**
Functional surface technologies	Catalysts	Lab scale integration of catalysts in membranes	Large-scale integration of catalysts in membranes;	Identify catalysts for alternate feedstocks
	Separations	Investigate tradeoffs between flux and stability in membrane systems; real-world degredation studies	Increase flux of dense ceramic membranes; identify selectivity issues in polymers to reduce thickness	
	Coatings	High-wear coatings; advanced research in in-situ defect monitoring	Non-vacuum coating applications; identify materials for high temperature, conductivity, and oxidation	
Higher-performance materials	Thermoelectrics	Develop a range of thermoelectric polymers for weight optimized components	Develop highly conductive materials compatible with additive manufacturing, polymer designs with integrated circuits	Develop capacitance materials compatible with additive manufacturing to enable stucturally integrated energy storage; oxidation barrier
	Phase-stable metals	High-strength, low alloy steels for deep well drilling; corrosion resistant zirconium alloys with reduced hydrogen pickup	Stress, corrosion, and cracking resistant stainless steel; high pressure steels; irradiation resistant steels; physics-based models for lifetime prediction	Alternate fuel cladding materials; oxidation and corrosion resistant refractory alloys; materials databases for ICME
	Surface treatments	User facility for remanufactured parts testing; lower-cost coating materials	Low-cost laser processing; high accuracy non-planar surface treatments	Ceramics for gas turbines; ultra-high temperature thermal barrier coatings for oxy-combustion turbines
	Lightweight high-strength materials	Low-cost improved processing for metal-based composite casting; improved wear resistance; custom optimized hybrid/gradient metallic systems	New alloy designs with higher retention for better recyclability; improve damage detection techniques; increase corrosion resistance of alumimum or magnesium	
New paradigm manufacturing processes	Net-shape processing	Use innovative joining methods to improve dimensional control and enable forged and formed components to replace machined components	Increase closed-loop spring back controls and strain-distribution controls; improved room temperature formability for non-ferrous alloys; nanomaterial tooling; direct consolidation of titanium powder; high magnetic field metal casting; Use innovative joining methods to improve dimensional control and enable forged and formed components	Processes for simultaneous improvements of shape and materials properties; use innovative joining methods to improve dimensional control and enable forged and formed components to replace machined components
	Additive manufacturing	Automated spark plasma sintering; closed-loop hardware/software for improved yields; develop families of polymer nano-filled compounds; new inks and slurries for direct writing systems; regional additive manufacturing stations	Continuous process for production of titanium powder; increased process throughput; new inks and slurries for direct writing systems; new file formats; larger chambers for metals deposition; improved sensing and controlling of	Develop large-scale printed energy storage batteries; new inks and slurries for direct writing systems; develop additive system techniques to integrate additive manufacturing systems seamlessly
	Composite materials	New autoclave-free processes; develop automated panel lay-up forming to improve production rates	More energy efficient fiber manufacturing processes; high-volume production technologies	Develop low-cost fiber feedstocks
	Energy-efficient metals processes	Improve instrumentation for aluminum reduction cells	New electrode materials for aluminum reduction cells; continuous process for titanium powder; develop a titanium molten metal delivery system	Direct reduction of iron ore using electrolytic hydrogen; novel electrochemistry processes for aluminum or magnesium production; continuous casting processes for high-end alloys; advanced scaling of melt facilities; low-cost, high-prperty magnesum system for high-volume casting



		COLLABORATIVE DATABASES		PREDICTIVE MODELING OF MATERIAL PERFORMANCE			PROCESS MODELING CODES			INTEGRATED COMPUTATIONAL MATERIALS ENGINEERING
		Structural Materials Databases	Functional Materials Databases	Deformation and Texture	Fracture and Fatigue	Materials Degradation	Microstructural Evolution and Materials Performance	Materials/Compound Discovery	Process Manufacturing and Component Performance	ICME Platforms
FUNCTIONAL SURFACE TECHNOLOGIES	Catalysts		●			●		●		●
	Solar Materials		●			●			●	
	Gas-Separating Membranes		●		●					
	Coatings	●				●	●			●
MATERIALS INTEGRATION IN CLEAN ENERGY SYSTEMS	Next-Generation Batteries and Fuel Cells		●			●		●	●	●
	Joining Processes for Multi-Material Structures	●		●	●	●	●		●	●
	Composites with Structural Capabilities	●		●	●	●	●		●	●
HIGHER-PERFORMANCE MATERIALS	Thermoelectric Materials		●				●	●	●	
	Phase-Stable Metallic Materials	●		●	●	●	●	●	●	●
	Surface Treatments	●		●	●	●	●		●	●
	Lightweight High-Strength Materials	●		●	●	●	●		●	●
NEW PARADIGM MATERIALS MANUFACTURING PROCESSES	Net-Shape Processing	●		●			●		●	●
	Additive Manufacturing	●	●		●		●	●	●	●
	Low-Cost Composites Manufacturing						●		●	
	Energy-Efficient Metals Production	●		●			●		●	●

Figure 1: The impact of computational tools and advances on next generation materials innovation [2]

4. Risk and Uncertainty, and Other Considerations

As with any research area, investments in next generation materials developments are not with substantial risks and uncertainties. Given that many materials innovations are based on the discovery of fundamental new structures, interactions, and properties at the lab scale, there is always a significant risk that such discoveries may not ultimately translate into new materials that can be manufactured at levels of acceptable cost or meet other performance requirements dictated by their market application, such a strength, durability, resistance to corrosion, aesthetics, and non-toxicity, to name a few.

The development of integrated computational tools and models that can help predict materials and market performance can reduce these risks to some extent, but uncertainties are always present. The materials innovation process can also demand enormous investments in capital equipment for experiments, measurements, and testing, which represent a major up-front cost barrier to many research institutions. Moreover, even when such investments have been made, it can be very expensive to maintain ongoing research activities, especially when the processes of discovering and engineering new materials innovations can take many years. Therefore, there is a risk that the materials innovation process is not sustainable or accessible to many capable researchers, which represents a bottleneck in our research infrastructure as well as the potential for innovation directions being determined by a relatively small population within the research community, which can limit the opportunity space.

Another significant risk is the strong coupling between energy prices and the market for new materials across all materials innovation categories, such as high-strength, lightweight materials for transport vehicles, materials for clean energy applications, and new processes for reducing manufacturing energy use and waste in key materials industries such as iron and steel and chemicals. When energy prices increase, as happened over roughly the last decade, continuous pressure is placed on U.S. businesses and consumer to reduce energy costs through greater efficiency, which accelerates demand for novel, more energy efficient, materials and processes. However, recent significant drops in the prices of US natural gas and transport fuels may serve as disincentives for greater energy efficiency, and reduce the market attractiveness economic viability of such technologies. Such vulnerability to energy market fluctuations can be overcome through strong national policies and commitments to next generation materials as part of local and national energy policies, in the interests of long-term energy and resource securities, and as a means of bringing competitive advantage to the United States by manufacturing and supplying next generation materials to global markets.

5. Case Studies

Table 4 summarizes several case studies within advanced materials research areas funded by the US DOE and AMO, along with quantitative estimates of benefits. While the potential energy and economic benefits of materials innovation can vary widely and are highly case specific, the quantitative data in Table X underscore the life-cycle savings that might be realized across the US economy through next generation materials.

Table 4: Case studies of U.S. DOE advanced materials research benefits

Category	**Subcategory**	**Description**	**Benefits**
Functional surface technologies	Catalysts/coatings	A novel catalytic coating is being developed for ethylene crackers, which greatly reducing coke formation in furnace coils. Less coke formation contributes to longer run times and lower decoking frequency, leading to savings in energy use and corresponding air pollutant emissions. [17]	• 15-25% energy reduction (fuel savings) might be achieved in the ethylene cracking process. • Energy savings for the U.S. petrochemicals sector as a whole would range from 4%-6%.
New paradigm manufacturing processes	Net-shape processing	An improved lost foam casting process has been engineered by General Motors, which more accurately measures the size and shape of sand used in casting and better characterizes rheological properties to reduce casting defects. [18]	• Commercialized in 2004, this technology saved an estimated 2.3 Trillion Btus of cumulative energy in the United States as of 2009. • Significantly reduces aluminum and sand scrap rates during production of the complex General Motors L61 engine.
Functional surface	Separations	A novel ceramic membrane technology has been developed to replace rubber-	• Prevents fuel vapor escape from a gasoline storage tank, thereby

technologies		based polymer membranes for separating volatile organic compounds from air at fueling stations. [18]	potentially saving 180 million gallons of gasoline per year domestically.
Higher performance materials	Bio-based materials	New process technologies have been developed to yield semi-crystalline polylactide particles derived from biomass feedstocks that have improved physical properties, thereby offering a viable replacement to fossil-fuel derived polymers. [18]	• Consumes up to 68% less energy in the form of fossil resources compared with producing products from petroleum. • Competes in a market based on price and performance, with a better environmental profile than today's plastics. • Reduces the nation's dependence on foreign resources and oil for products such as clothing, food packaging, and carpets.

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