**1.INTRODUCTION**

**1.1 GREEN ENGINEERING:**

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| |  |  |  | | --- | --- | --- | | Green Engineering is the design, commercialization and use of processes and products that are feasible and economical while: | | | |  | | | |  |  | * Reducing the generation of pollution at the source. | |  | | | |  |  | * Minimizing the risk to human health and the environment. * Green engineering embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process or product. | |
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The principles of green engineering are as follows:

1. Engineer processes and products holistically, use system analysis and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well being.
3. Use life cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs areas inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography aspirations and cultures.
8. Create engineering solutions beyond current and dominant technologies; improve, innovate and invent (technologies) to achieve sustainability.
9. Actively include communities and stakeholders in development of engineering solutions.

**1.2 NANOTECHNOLOGY**

Nanotechnology is the engineering of functional systems at the molecular scale. This covers current work and concepts that are more advanced. In its original sense, nanotechnology refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, highly advanced products. Nanotechnology is often referred to as a general-purpose technology. That’s because in its mature form it will have significantimpact on almost all industries and all areas of society. It offers better built, longer lasting, cleaner, safer, and smarter products for the home, for communications, for medicine, for transportation, for agriculture, and for industry in general. Like electricity or computersbefore it,nanotechwill offer greatly improved efficiency in almost every facet of life. Butas a

general-purpose technology, it will be dual-use, meaning it will have many commercial uses and it also will have many military uses -- making far more powerful weapons and tools of surveillance. Thus it represents not only wonderful benefits for humanity, but also grave risks.

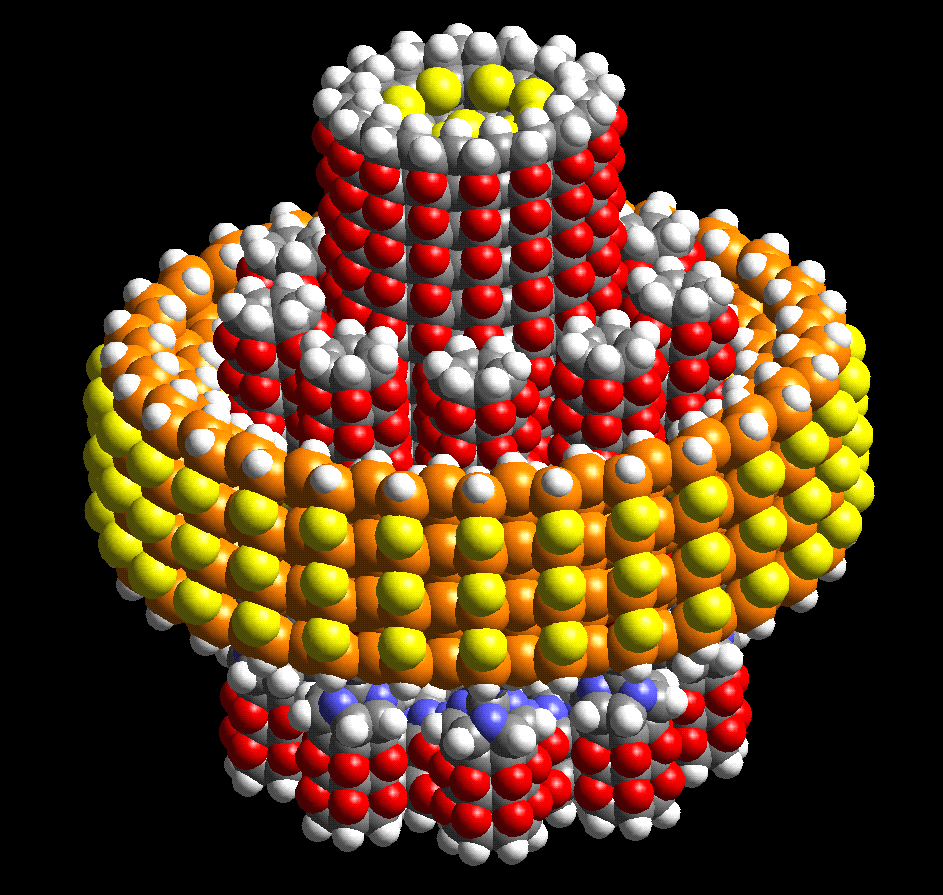


Figure 1

A key understanding of nanotechnology is that it offers not just better products, but a vastly improved means of production. A computer can make copies of data files -- essentially as many copies as you want at little or no cost. It may be only a matter of time until the manufacture of products becomes as cheap as the copying not only will allow making many high-quality products at very low cost, but it will allow making new nanofactories at the same low cost and at the speed. This unique (outside of biology, which is) ability to reproduce its own same rapid means of production is why nanotech is said to be an exponential technology. It represents a manufacturing system that will be able to make more manufacturing systems -- factories that can build factories -- rapidly, cheaply, and cleanly. The means of production will be able to reproduce exponentially, so in just a few weeks a few nanofactories conceivably could become billions. It is a revolutionary, transformative, powerful, and potentially very dangerous -- or beneficial – technology.

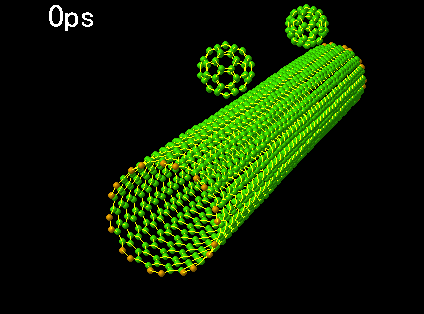


Figure 2

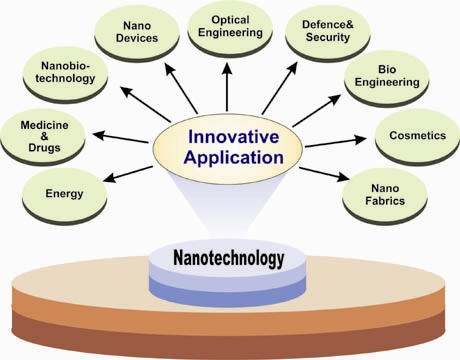


Figure 3

It is important to recognize some unique features about nanotechnology. First, it is the amalgamation of knowledge from chemistry, physics, biology, materials science, and various engineering fields. It epitomizes the concept of the whole being greater than the sum of theparts.

Second, nanoscale science and engineering span different scales. Nanostructures and nanoscale phenomena are generally embedded in micro- and macrostructures, and their interactions are important. The connection between scales—nano to micro to macro—is also a critical aspect of integration.  
  
In addition, it is often difficult to isolate nanoscale phenomena as we do at customary scales. That is, thermal, electronic, mechanical, and chemical effects are often related to each other. By changing one, it is possible to influence the others. This, of course, emphasizes the need for interdisciplinary knowledge.

**1.3 GREEN NANOTECHNOLOGY**

Green nanotechnology is the development of [clean technologies](http://en.wikipedia.org/wiki/Clean_technologies), "to minimize potential environmental and [human](http://en.wikipedia.org/wiki/Human) health risks associated with the [manufacture](http://en.wikipedia.org/wiki/Manufacture) and use of [nanotechnology](http://en.wikipedia.org/wiki/Nanotechnology) products, and to encourage replacement of existing products with new nano-products that are more environmentally friendly throughout their [lifecycle](http://en.wikipedia.org/wiki/Product_lifecycle)."

Nanotechnology is an emerging field that has great potential for use in commercial, defence and security applications. Nanomaterials and the manufacturing techniques used to create them, however, may pose adverse environmental, health and safety effects. One of the challenges facing this new industry is the design of nanomaterials and nano-manufacturing methods that provide maximum efficiency while minimizing these hazards. Merging green chemistry and nano-science will provide opportunities to meet these challenges and to develop sustainable technologies and materials.

Our goals are to implement the principles of green nano-science to:

(1) Design environmentally benign nanoparticles, test for putative toxicity and redesign as necessary; we are developing methods to prepare libraries of functionalized metal nanoparticles in which the size, shape and functionality can be widely varied. We will study the accumulation of nanoparticles within organisms and the impacts of these nanoparticles on viability, gene expression and development. These data will be used to guide the development of more benign nanoparticles for a wide range of applications. The surface of these nanoparticles will be modified which will direct self-assembly, tune electronic or optical coupling, and further enhance the biologically safety of these nanoparticles.

(2) Develop greener methods for large-scale nanoparticle production through green nano-manufacturing technologies; we will identify acceptable nanoparticle formation reactions that can be carried out in a single solvent phase and that will permit control of particle size. From these studies we will scale up production and develop an integrated micro-reactor platform for deploying the single solvent phase chemistries. We are also exploring gas-phase production of ceramic nanoparticles in micro-reactors to produce materials that should expand our capabilities to produce novel devices for sensors and medicine.

(3) Discover efficient approaches for using nanoparticles in the development of novel nano-devices; Nanomaterials are driving innovation in optical and electronic devices, however, realizing the full potential of nanoscale matter in device technologies requires the integration of the nanoscale building blocks with other components of the device. Nanostructures can also be important precursors in the low-cost and greener manufacture of more traditional micro scaledevices and to exotic new materials. Thus, developing environmentally-benign assembly methods and identifying approaches to interface nanomaterials with macroscopic structures are being explored to produce greener, high-performance devices and nanostructured materials.

A marriage of nanotechnology with green engineering serves two important purposes.

First, emerging nanotechnologies could be made clean from start. It would be foolhardy to develop a new nanotechnology infrastructure from an old industrial model that would generateanother set of environmental problems. While nanotechnology will never be as green as Mother Nature, approaching a new nano approach to the technology’s development ultimately promises to shift society into a new paradigm that is proactive, rather than reactive, when it comes to environmental problems.

Second, green technologies that benefit the environment could use nanotechnology to boost performance. In other words, nanotechnology could help us make every atom count-for example, by allowing us to create ultra efficient catalysts, detoxify wastes, assemble useful molecular machines and efficiently convert sunlight to energy. It could potentially contribute for long term sustainability for future generations, as more green products and processes replace the old harmful and wasteful ones.



Figure 4

A huge amount of research and development activity has been devoted to nano-scale related technologies in recent years. The National Science Foundation projects nanotechnology related products will become a $1 trillion industry by 2015 [1]. Nano-scale technology is defined as any technology that deals with structures or features in the nanometer range or that are less than 100 nanometres, about one-thousandth the diameter of a human hair, and larger than

about 1 nm, the scale of the atom or of small molecules.

Below about 1 nm, the properties of materials become familiar and predictable, as this is the established domain of chemistry and atomic physics. It should be noted that nanotechnology is not just one, but many wide ranging technologies in many technical disciplines including but not limited to chemistry, biology, physics, material science, electronics, MEMS and self-assembly. Nano-structures have the ability to generate new features and perform new functions that are more efficient than or cannot be performed by larger structures and machines. Due to the small dimensions of nano-materials, their physical/chemical properties (e.g. stability, hardness, conductivity, reactivity,

optical sensitivity, melting point, etc.) can be manipulated to improve the overall properties of conventional materials. At nanometer scales, the surface properties start becoming more dominant than the bulk material properties, generating unique material attributes and chemical reactions. More fundamentally, the electronic structure of materials becomes size-dependent as the dimensions enter the nanoscale.

Delocalized electronic states as in a metal or a semiconductor are altered by the finite dimensions. Hence, the optical properties, including light absorption and emission behaviour, will be altered, the fact that nanoscale features are smaller

than the wavelength of visible photons also impacts light scattering, enabling the design of nanocrystalline ceramics that are as transparent as glass. Changes in the bonding at the surface of a nanoparticle will affect the electronic structure as well, and the implications for the reactivity of the surface can be significant. Beyond the electronic structure, nanostructuring can also affect transport properties markedly.

Nanoscale features that are smaller than or comparable to the wavelengths or mean-free paths of phonons (quanta of lattice vibrations) or electrons permit the design of materials with thermal and electrical conductivity that may be outside the range accessible with ordinary materials. The most significant nano-structures investigated to date are made from single atomistic layers of carbon. These structures include hollow ball shaped “Bucky balls” (Fullerene - C60), carbon nanotubes (CNTs) and graphene sheets which have a very interesting range of mechanical, thermal and electrical properties. It should also be noted that even though the environmental and health effects of nano-scale structures are poorly understood at this time, nano-scale-based technologies are already being used in some industrial applications. A series of nano-materials, including metal nanoparticles and nano-powders, magnetic fluids, nano-adhesives, nanocomposite polymers, and nanocoatings (anti-fog, antireflective, wear and scratch resistant, dirt repellent, biocide, etc.) are being introduced for potential application in the automotive market.

Metal nanoparticles are being considered for potential use in catalytic converters since the catalytic reactivity is significantly enhanced due to the increased surface area and altered electronic structure of the metal nanoparticle.

Coolants utilize nanoparticles and nano-powders to increase the efficiency of heat transfer and potentially reduce the size of the automotive cooling equipment. Some manufacturers are currently using nanomagnetic fluids in shock absorbers to increase vibration control efficiency. Wear-resistant, hard surface nano-coatings are being investigated for applications in bearings, cylinders, valves, and other highly stressed areas.

Nano-layers of semiconducting materials provide high efficiency electronic components and systems with a longer lifetime. Sensors based on nanolayer structures are used in engine control, airbag, anti-lock brake and electronic stability program systems. Nanoparticles also support the optimization

of conventional components like batteries, catalysts, solar cells or fuel cells.

The most promising automotive applications of nanotechnology include the following:

**•** Improved materials with CNTs, graphene and other nanoparticles/structures

**•** Improved mechanical, thermal, and appearance properties for plastics

**•** Coatings & encapsulates for wear and corrosion resistance, permeation barriers, and appearance

**•** Cooling fluids with improved thermal performance

**•** Joining interfaces for improved thermal cycle and crack resistance

**•** Metal alloys with greater mechanical strength

**•** Metal matrix and ceramics with improved mechanical properties

**•** Solder materials with crack resistance or lower processing temperature

**•** Displays with lower cost and higher performance

**•** Batteries for electric vehicles and fuel cells with improved energy capacity

**•** Automotive sensors with nano-sensing elements, nanostructures and nano-machines

**•** Hybrid electric vehicles using electrical interconnects for high-frequency and high-power applications

**•** Electrical switching including CNT transistors, quantum transistors, nano-electro-mechanical switches, electron emission amplification, and more efficient solar cells

**•** Self-assembly using fluid carriers

**2.THE ROLE OF MECHANICAL ENGINEERING IN NANOTECHNOLOGY**

Itis fair to ask what the role of mechanical engineering in nanotechnology will be. In fact,quite abit of nano scale science and engineering is already performed by mechanical engineers.   
  
For example, mechanical engineershave been essential in developing instruments such as nano indenters and atomic force microscopes, which are used for mechanical testing, nano scale imaging, and metrology. Issues of feedback control of such systems are unique because of the nano scale precision required in positioning and the ability to measure forces down to piconewton levels.

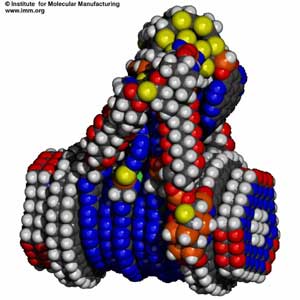


Figure 5

Mechanical engineering issues extend to instruments for nanoparticle and aerosol detection and characterization, as well as to various forms of nanoscale imaging. Magnetic data storage technology already has many features that fall well into the nanometer size range, and requires mechanical engineering knowledge and expertise to further its development.  
  
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There are many concepts in mechanical engineering that are critical in the development of nanotechnology. It is incumbent upon mechanical engineers to provide depth in these areas.

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| http://www.memagazine.org/supparch/nanosept04/ewolimit/n5.jpg  ***Figure 6***  ***At present, nanotechnologists can create simple structures, like this silicon carbide tower.*** |

One of the most important issues related to nanotechnology is systems integration and packaging. Researchers have been able to study individual nanostructures and have even synthesized building blocks such as nanoparticles and nanowires. But how do we integrate these building blocks in a rational manner to make a functional device or a system? This step requires design based on the understanding of nanoscale science, and on new manufacturing techniques.



Figure 7

One of the biggest challenges in nanotechnology is manufacturing. Assembling large quantities of nanostructures in a rational and rapid manner requires tooling, imaging systems, and instrumentation, sensors, and control systems. After nanostructures are assembled into functional devices, they need to be packaged so that they can interact with their environment and yet retain the nanoness that provides the unique function and performance.  
  
These concerns are similar to those found in conventional manufacturing, though there is a call for a level of precision that is not required by macroscale designers.

**3. NANOPARTICLE THERMALMATERIALS**

In spite of advances in efficiency of vehicle powertrainsystems and electronics, the removal of waste heat continuesto be an important challenge. With increasing focus onreduced component size and mass, the traditional approach ofincreasing the area available for heat exchange with a coolingfluid (air, water/ethylene glycol) to manage higher heat loadsis not acceptable. Increasing thermal power densities requiresinnovations in new coolants and thermal coupling materials.The concept of using nano-fluids as a means of improvingcoolant performance was proposed over a decade ago [2].Reports of up to 100% increase in liquid thermal conductivitywith the addition of nanometer scale particles motivated alarge amount of scientific/technical inquiry in the ensuingyears [3].

Nano-fluids are a solid-liquid composite containingnanoparticles with sizes in the 1-100 nm range dispersed andsuspended in a liquid. A variety of nanoparticle solids havebeen used as additives, including metals such as copper andgold, alumina, SiC and CuO ceramics and carbon nano-tubes.Thesurprisingly large increases in liquid thermalconductivity have been reported for relatively small particleloadings (<10% by volume). In addition, there have also beenreports of higher critical heat flux (dry-out) for nano-fluidsused in liquid-vapour phase cooling applications. Theseobservations have been made for a number of liquids,including water/ethylene glycol, alcohols and oils. The resultsdefy conventional experience which requires much highervolume loading of larger particles to produce slurries withcomparable increases in effective liquid thermal conductivity.These observations have stimulated numerous theoriesattempting to understand and describe the phenomena, but thenature of the thermal enhancement mechanism still remainscontroversial. This situation is further aggravated byinconsistent results from different laboratories, and someclaims that if carefully measured, the enhancements aresmaller and explained by established theories.

Nevertheless, the potential for significantly improvedcoolants may provide impetus for further improvements inengine efficiency and reduced size and weight of coolingsystem components. In addition, there are efforts to examineimprovements in the thermal and rheological properties oflubricants with the addition of nano-scale particles [4].

In automotive electronics, the use of thermal interfacematerials (TIM) to thermally couple electronic devices to heatsinks for waste heat removal is common practice. Althoughthe thermal resistance of TIM has been reduced over theyears, these materials still represent a major bottleneck in thethermal stack-up between semiconductor die and the coolingmedium. As a result, components capable of handling higherpower densities often operate at de-rated performance levelsto mitigate high temperatures and to compensate for the harshautomotive environment. This problem is especially criticalin hybrid electric vehicle power control systems, whereswitching transistors can operate at power densities in excessof 300 W/cm2.Spurred by enhanced nano-fluid thermal properties,investigators translated the nano-composite ideas into therealm of TIM. It is common practice to boost the thermalconductivity of silicone oils, polymer gels, phase-changematerials and thermoplastics by the addition of solid particlesof micrometer scale size. Research has shown that optimalparticle loading achieves improved thermal conductivity andlow modulus (to accommodate thermal expansion mismatchof components) with a variety of materials and particleshapes/sizes [5].

Mixtures of nano- and micro- scale particlesadd another dimension for controlling thermal, rheologicaland mechanical properties [6].Of particular interest is the use of carbon nano-tubes for TIMapplications. The CNT is essentially a single atomic layer ofgraphite (graphene) which is rolled up onto itself. There aresingle- and multi-walled versions of CNT which can exhibitthermal conductivity in excess of 1000 Watts/meter ° Kelvin(for comparison, Cu = 400W/mK) and high tensile strengthalong the axis of the tube. Applications to TIM have involvedtwo basic approaches:

**1.** Simple addition of CNT to the TIM matrix (grease, gel, etc.)

**2.** Growth of vertically aligned CNT ‘carpets’ on theheatsink or device package.

In the former approach, CNT loading is increased untilpercolation of fibres provides a thermal path from matingsurfaces. In the latter growth method, the individual CNTprovide a direct high-conduction path between surfaces [6, 7].

In this case, tantalizing reports of low thermal impedance (∼0.05 cm2C/W) have motivated continuing development ofgrowth methods more amenable to high volume, low costelectronics production. At this point, efficient growth of highquality CNT is still time consuming and requirestemperatures in excess of 500°C on catalyzed surfaces.In spite of the prospect that nano-composite materials offerimproved thermal conduction, several issues need to beresolved. Dispersing nanoparticles to avoid aggregation canbe crucial to improving performance. In many cases thedispersions are not stable and over time lead to degradedthermal performance. In the case of liquids, maintaining atime-stable suspension can be problematic, since manycandidate particle materials are denser than the liquid andtend to settle out. As it turns out, it is the nanometer-sizedparticles that can mitigate this problem. The intrinsicBrownian motion of liquid molecules surrounding theparticles can maintain a dispersion/suspension.

Although the thermal properties of CNT are impressive, theperformance gains in CNT composites are not as large asanticipated. High-interface thermal resistance in both CNTfillers and vertically aligned CNT tips severely impedescoupling between the CNT and the matrix or mating surface.Work continues on materials and methods to functionalize theCNT surface to improve the thermal coupling.As composite technology progresses, we would expect to seethe eventual penetration of nanoparticles into the realm ofthermal management materials. The final issues to beconfronted will be the value of performance gains achievablein a high volume, low cost automotive market.

**4.DISPLAYS USINGNANOTECHNOLOGY**

Displays with improved performance and unique features aremade possible by nanotechnology. Additionally, lower costlight emission sources, such as lasers are possible in the nearfuture. Display technology, under rapid development forconsumer electronic devices and home entertainmentsystems, is also being pursued for automotive applications.

Improved performance, longer life, higher energy efficiency,unique presentation features, reduced package size andinnovation become the value proposition for implementingthis new technology.

Automotive displays are expected to directly utilize nanotechnologyin a variety of ways. Light emitting devices, suchas LEDs, OLEDs (Organic Light Emitting Diode),fluorescent or field-emissive displays, electro-luminescentand perhaps lasers, are utilizing nano-phosphors and nanolayerto improve their performance. For example, silvernanoparticles on the cathode surface allow surface Plasmon localization. This provides a strong oscillator decay channelthat generates a two-fold increase of intensity for flexibleOLED displays. Optical thin films, non-linear holographicreflectors, micro-lenses, and light conversion films areexamples of materials that modulate or redirectelectromagnetic radiation. Light projection systems, flatpaneldisplays, including cameras and other optical detectorsthat provide the input signals are all expected to benefit fromnanotechnology developments.One particular area of interest is nano-phosphors, since thesematerials possess strikingly different absorption and emissioncharacteristics while operating with better efficiencies andlife times than their related bulk phosphors. Since the particlesize determines the band-gap energy, coupling nano-phosphorswith new semiconductor materials (with andwithout doping) means that a wide variety of designedphosphors and new devices will likely be developed.Although many materials under consideration are somewhatexotic and expensive, inexpensive materials, such as zincoxide, and titanium dioxide are also used in the nano-world.Considerable work is being done but much of it is in therealm of industrial secrecy.Most first generation nano-phosphors, Q-dots included, arebased on toxic elements such as cadmium and lead.Alternative materials (manganese or copper-doped zincsulphide, D-dots) are coming onto the market. Although thesematerials are still relatively expensive, the cost will reduce asapplications are identified and escalate the demand formaterial. Today nano-phosphors have many applications indisplay devices and more are being discovered.Photonic properties of these materials are indicative of theirelectrical properties. The arrangement of the electrons,dictated by energy states, sets the rules for how a materialwill interact with incident photons. In this regard, conductors,insulators, and semiconductors each have unique valance andconduction electron energy band arrangements. A dielectricor insulator material will absorb a photon when a valenceband electron can be excited to a higherconduction band, the energy being greater than the band gapof the material. Most dielectrics are transparent to visiblelight since the energy of photons at these wavelengths areinsufficient to promote the electrons. A conductive material isopaque since it will either absorb or reflect photons due to themany energy bands available for electrons to be promotedwithin the conduction band (intraband). It is thesemiconductor materials (especially with doping) that allowcontrollable interaction with incident photons due to free

electrons in the partially filled conductive band and theenergy states available in the “adjustable” band gap energy.Coupling these electrical properties with the dimensional sizeof the material, we now have the ability to break up theenergy bands into discrete levels; that is, we can widen theband gap by controlling the physical size of the particle.Semiconductor particles at the size and scale where this ispossible are known as quantum dots, and the smaller thequantum dot, the larger its corresponding band gap. Quantumdots can absorb photons over a broad wavelength interval.Conversely quantum dots emit photons over a very narrow,temperature insensitive wavelength band, since the quantumconfinement of the energy states in three dimensionsapproximates that of an atom having discrete atomic levels.Quantum dots are also called artificial atoms.In general, the area of nano-optics operates on differentprinciples than bulk optics. Nano-optic elements consist ofnumerous nano-scale structures created in regular patterns onor in a material. Depending upon the optical function, theycan be created with metals, dielectrics, non-metals andsemiconductors, epitaxial grown crystals, glass and plastics.In whatever form, creating the nano-structured material is transformative. Nano-optic devices can perform their opticalfunctions in very thin layers, often less than a micron inthickness. The optical effects can be achieved in a shorterfocal length compared to bulk optics because the subwavelength-size structures of nano-patterns interact with lightlocally, involving quantum effects as well as classical opticalperformance.

This feature of nano-optics allows for verycompact form factors.

The ability to understand how a material will interact withphotons for generating a display or display element isprimarily dependent upon the energy states of the electrons.The nano-scale interaction of photons and materials, termednano-photonics, is a field still in its infancy with plenty ofroom to grow. This term encompasses a very broad field ofmaterials, processes, and potential applications. For example,a new emerging roadmap targeting development of concepts,technologies, and devices has been released within theframework of the Photonics21 strategic research agenda. Thisroadmap is promoted by the EU Network of Excellence onnano-photonics (PhOREMOST), composed of 34 partnersand over 300 researchers. ([www.phoremost.org](http://www.phoremost.org))The majority of the developing technologies referenced byPhOREMOST are not directly applicable to futureautomotive emissive optical displays, projection systems, orimagers. Many anticipated nano-photonic materials will becoupled with silicon-based wafer processing to generatedigital information processing and communication lightbasedfeatures (plasmonics) to increase processing speedwhile greatly reducing the power dissipation associated withtoday's electron-based metal and semiconductor materials.However, other processing developments such as materialprocessing using sols and self-assembly techniques areexpected to indirectly advance display technology as theyprovide the means to create these new propertieseconomically.

Nanotechnology is engineering and it is all about practicalapplications of physics, chemistry, and materials science.Nano-photonics is that specialized region of study where theeffects of light interacting with matter on a very small scalewill be the engine to generate new products and featuresalmost unimaginable today.

**5. NANO-COMPOSITES**

Nano-composites are materials that incorporate nano-sizedparticles into a matrix of standard material such as polymers.Adding nanoparticles can generate a drastic improvement inproperties that include mechanical strength, toughness andelectrical or thermal conductivity. The effectiveness of thenanoparticles is such that the amount of material added isnormally only 0.5-5.0% by weight. They have properties thatare superior to conventional microscale composites and canbe synthesized using simple and inexpensive techniques. [8]

A few nano-composites have already reached themarketplace, while a few others are on the verge, and manycontinue to remain in the laboratories of various researchinstitutions and companies. The global nano-compositesmarket is projected to reach 989 million pounds by the end ofthe 2010, as stated in a report published by Global IndustryAnalysts, Inc.Nano-composites comprising nanoparticles such as Nanoclays(70% of volume) or nano-carbon fillers, carbon nanotubes,carbon nano-fibers and graphite platelets are expectedto be a major growth segment for the plastics industry.

**5.1 HOW NANO-COMPOSITES WORK**

Nanoparticles have an extremely high surface-to-volume ratiowhich dramatically changes their properties when comparedwith their bulk sized equivalents. It also changes the way inwhich the nanoparticles bond with the bulk material. Theresult is that the composite can be many times improved with

respect to the component parts.

**5.2 WHY NANO-COMPOSITES?**

Polymers reinforced with as little as 2% to 6% of thesenanoparticles via melt compounding or in-situ polymerizationexhibit dramatic improvements in properties such as thermomechanical,light weight, dimensional stability, barrier

properties, flame retardancy, heat resistance and electricalconductivity.

**5.3 CURRENT APPLICATIONS OF NANOCOMPOSITES**

Applications of nano-composite plastics are diversified suchas thin-film capacitors for computer chips; solid polymerelectrolytes for batteries, automotive engine parts and fueltanks; impellers and blades, oxygen and gas barriers, foodpackaging etc. with automotive and packaging accounting fora majority of the consumption. [9] The automotive segment isprojected to generate the fastest demand for nano-compositesif the cost/performance ratio is acceptable. Some automotiveproduction examples of nano-composites include thefollowing: Step assist - First commercial application on the2002 GMC Safari and Chevrolet Astro van; Body SideMolding of the 2004 Chevrolet Impala (7% weight savingsper vehicle and improved surface quality compared with TPOand improved mar/scuff resistance); Cargo bed for GM's2005 Hummer H2 (seven pounds of molded-in-colornanocomposites);Fuel tanks (Increased resistance to permeation);under-hood (timing gage cover (Toyota) and engine cover(Mitsubishi).

**5.4 KEY CHALLENGES FORNANOCOMPOSITES FOR FASTER**

**COMMERCIALIZATION**

**•** Develop low cost and high production volume to meet fastto market needs.

**•** Develop fast, low cost analytical methods with smallquantity of samples which can provide a degree of exfoliationand degree of orientation, (TEM, XRD, Rheology consideredtoo expensive and time consuming) for example, IR candetect silicon-oxygen bond in clay, which can help toevaluate degree of clay dispersion.

**•** Develop in-line testing of nano-composites.

**•** Develop alternative nano-clay treatments for better adhesionof nano-filler to polymer.

**•** Improve understanding the effect on performance byblending nano-fillers with conventional reinforcements suchas glass fiber.

**•** Prediction of orientation / flow modeling.

**•** Understand the rheology and chemo-rheology of thepolymer composites.

**•** Cost/performance ratio to substitute HIPS (High impactpolystyrene), PC/ABS (Polycarbonate/Acrylonitirile-Butadiene-Styrene) and PC (Polycarbonate) with TPO(Thermoplastics Polyolefins).

**•** Fine dispersion, full exfoliation and interfacial adhesion.

**•** High stiffness without affecting impact properties.

**5.5 OPPORTUNITIES AND FUTURETRENDS FOR NANO-COMPOSITES**

Nano-fillers are expensive compared to conventional fillers,so one must use them wisely depending on the final partperformance requirements. In many cases, it may be costeffective to use nano-filler where it is needed such as on thetop layer of a part surface or middle layer of thickness orlocalized areas of the part (nano-composite pre-moldedinserts).New nanotechnology applications are being demonstrated byR&D engineers, but the commercial officers balk at increasedcosts. The nano-clays cost about $3/lb and are used inloadings of 3-4 percent. The conventional competitor materialis talc, which costs 30 cents/lb and is used at loadings of10-15 percent. Another issue: Widespread replacement withnano-composites may require extensive re-tooling because of

differences in shrinkage rates.Recent news of an innovative method of growing carbonnano-tubes may revolutionize the implementation ofnanotechnology. Use of Nano-polypropylene (PP) for valueadded substitution such as high cost engineering plastics ordevelopment of molded-in-color nano-composites to replaceglass-filled, painted PP for interior applications such asinstrument panels will see major growth. Functional nanocompositesdevelopment is underway such as functionalizedclays which add properties to clay including anti-static andmoisture repellent characteristics and selective chemicalbarriers. Ultraviolet-curable nano-composites (electronics)and foaming and nucleating effect of nano-fillers (improveproperties, desirable cell size and density, use of

microcellular processes such as MuCell) will becommercialized soon. There is potential for body panels andlarge moldings to substitute for steel, aluminum, magnesiumand Sheet-Molding Compound (SMC), where thermoplastics

are currently excluded due to inadequate physical ormechanical performance.

There is a need to develop a low cost, carbon nano-tube basedcomposite for high-end engineered plastics. For designers,there is a need to develop flow simulation software with orwithout a hybrid fiber-filled system (including orientationeffect and warpage) so output can be used directly forstructural analysis.There are also many opportunities for development of newfillers and improvements such as nano-composites of a newnano-ceramic fiber, titanium dioxide (TiO2), magneticparticles, carbon nano-tubes and other molecularly reinforcedpolymers. Mixtures of different nano-materials orcombinations of nano-materials with traditional additives areincreasingly being considered.

**6. FUEL AND NANOTECHNOLOGY**

Nanotechnology can address the shortage of fossil fuels such as diesel and gasoline by:

* Making the production of fuels from low grade raw materials economical
* Increasing the mileage of engines
* Making the production of fuels from normal raw materials more efficient

Nanotechnology can do all this by increasing the effectiveness of catalysts. Catalysts can reduce the temperature required to convert raw materials into fuel or increase the percentage of fuel burned at a given temperature. Catalysts made from nanoparticles have a greater surface area to interact with the reacting chemicals than catalysts made from larger particles. The larger surface area allows more chemicals to interact with the catalyst simultaneously, which makes the catalyst more effective. This increased effectiveness can make a process such as the production of diesel fuel from coal more economical, and enable the production of fuel from currently unusable raw materials such as low grade crude oil.

Nanotechnology, in the form of genetic engineering, can also improve the performance of enzymes used in the [conversion of cellulose into ethanol](http://money.cnn.com/magazines/fortune/fortune_archive/2006/02/06/8367959/index.htm). Currently ethanol added to gasoline in the United States is made from corn, which is driving up the price of corn. The plan is to use engineered enzymes to break down cellulose into sugar, is fermented to turn the sugar into ethanol. This will allow material that often goes to waste, such as wood chips and grass to be turned into ethanol.

**6.1 FUEL: NANOTECHNOLOGY APPLICATIONS UNDER DEVELOPMENT**

* [Conversion of coal to diesel and gasoline](http://www.htigrp.com/data/upfiles/pdf/DCL%20Technology%2023Feb05.pdf)
* [Reducing the cost of converting crude from oil sands to fuel](http://www.refineryscience.com/sites/refineryscience/files/ColdLakeBitumenTest.pdf)
* [Increasing mileage of diesel engines](http://news.com.com/Nano+firm+reduces+diesel+fumes,+improves+mileage/2100-11395_3-6106117.html)

Nanosphere based catalyst that [reduces the cost of producing biodiesel](http://www.nanowerk.com/news/newsid=2161.php)

[**Modifying enzymes**](http://www.iogen.ca/cellulose_ethanol/what_is_ethanol/process.html) to convert cellulous into sugar, making the production of ethanol from cellulous material cost effective.

[**Modifying crops**](http://www.technologyreview.com/Energy/18741) to allow cellulous material, such as corn stalks to produce enzymes that are triggered at elevated temperatures to convert the cellulous to sugar, simplify the production of ethanol.

[**Modifying bacteria**](http://www.rochester.edu/news/show.php?id=2803) to cause the production of enzymes that will convert cellulous material to ethanol in one step, rather than converting cellulous to sugar which is than fermented into ethanol.

**6.2 FUEL CELLS AND NANOTECHNOLOGY**

**6.2.1 How can nanotechnology improve fuel cells?**

Catalysts are used with fuels such as hydrogen or methanol to produce hydrogen ions. Platinum, which is very expensive, is the catalyst typically used in this process. Companies are using nanoparticles of platinum to reduce the amount of platinum needed, or using nanoparticles of other materials to replace platinum entirely and thereby lower costs.

Fuel cells contain membranes that allow [hydrogen ions to pass through the cell](http://www.mtimicrofuelcells.com/technology/how.asp) but do not allow other atoms or ions, such as oxygen, to pass through. Companies are using nanotechnology to create more efficient membranes; this will allow them to build lighter weight and longer lasting fuel cells.

Small fuel cells are being developed that can be used to replace batteries in handheld devices such as PDAs or laptop computers. Most companies working on this type of fuel cell are using methanol as a fuel and are calling them DMFC's, which stands for direct methanol fuel cell. DMFC's are designed to last longer than conventional batteries. In addition, rather than plugging your device into an electrical outlet and waiting for the battery to recharge, with a DMFC you simply insert a new cartridge of methanol into the device and you're ready to go.

Fuel cells that can replace batteries in electric cars are also under development. Hydrogen is the fuel most researchers propose for use in fuel cell powered cars. In addition to the improvements to catalysts and membranes discussed above, it is necessary to develop a lightweight and safe hydrogen fuel tank to hold the fuel and build a network of refuelling stations. To build these tanks, researchers are trying to develop lightweight nanomaterials that will absorb the hydrogen and only release it when needed. The Department of Energy is estimating that widespread usage of hydrogen powered cars will not occur until approximately 2020.

**6.2.2 FUEL CELLS: NANOTECHNOLOGY APPLICATIONS**

* [**Increasing catalyst surface area**](http://www.physorg.com/news11654.html)and efficiency by depositing platinum on porous alumina
* [**Increasing storage capacity**](http://www.understandingnano.com/graphene-hydrogen-storage.html) for hydrogen fuel tanks using graphene.
* [**Replacing platinum catalysts**](http://www.qsinano.com/apps_fuelcell.php) with less expensive nanomaterials
* Increasing the [**reactivity of platinum**](http://www.understandingnano.com/fuel_cells-platinum-reactivity-lattice-strain.html), by adjusting the atomic spacing, to significantly reduce the amount of platinum needed in a fuel cell.
* Using [**hydrogen fuel cells to power cars**](http://automobiles.honda.com/fcx-clarity/how-fcx-works/v-flow)

**6.3 NANOTECHNOLOGY BATTERY (NANO BATTERY)**

**How can nanotechnology improve batteries?**

Using nanotechnology in the manufacture of batteries offers the following benefits:

* Reducing the possibility of batteries catching fire by providing less flammable electrode material.
* Increasing the available power from a battery and decreasing the time required to recharge a battery. These benefits are achieved by coating the surface of an electrode with nanoparticles. This increases the surface area of the electrode thereby allowing more current to flow between the electrode and the chemicals inside the battery. This technique could increase the efficiency of hybrid vehicles by significantly reducing the weight of the batteries needed to provide adequate power.
* Increasing the shelf life of a battery by using nanomaterials to separate liquids in the battery from the solid electrodes when there is no draw on the battery. This separation prevents the low level discharge that occurs in a conventional battery, which increases the shelf life of the battery dramatically.

**6.3.1 BATTERIES: NANOTECHNOLOGY APPLICATIONS UNDER DEVELOPMENT**

* [**Battery anodes with silicon nanowires**](http://www.understandingnano.com/battery-nanowire-silicon.html) that can increase the capacity of Li-ion batteries.
* Battery small enough to be implanted in the eye and [**power artificial retina**](http://www.understandingnano.com/battery-artificial-retina.html)
* [**Long shelf life battery**](http://www.understandingnano.com/batteries-nanograss-mphase-technologies.html) uses "nanograss" to separate liquid electrolytes from the solid electrode until power is needed.
* Lithium ion batteries with nanoparticle (Nanophosphate™) electrodes that meet the safety requirements for [**electric cars**](http://www.understandingnano.com/batteries-a123systems-automotive-nanophosphate-electrode.html)while improving the performance.

Battery anodes using[**silicon nanoparticles coating a titanium disilicide lattice**](http://www.understandingnano.com/battery-anode-silicon-nanoparticles-lithium-ion.html) may improve the charge/discharge rate of Li-ion batteries as well as the battery lifetime.  
  
[**Thermocells using nanotubes**](http://www.understandingnano.com/nanotube-thermocells.html) that generate electricity.

**7. NANOTECHNOLOGY APPLIED TOSOLDERING SYSTEMS**

Due to the European Union environmental legislation, theelectronics industry is being forced to eliminate lead from thetraditional solder alloy system of tin-lead (SnPb). Theindustry has developed new solder alloys to replace SnPbeutectic alloys, but the required processing temperature mustincrease by about 35°C to accommodate the alloy (tin silvercopper family, SAC). This increase in processingtemperatures to about 235°C to 245°C, results in additionalunwanted thermal stress on the electronic components beingassembled as compared to tin-lead assembly temperatures ofabout 210°C.Research is being conducted in the realm of nano-particlesizedsolder alloys. Metals undergo a melting pointdepression when the particle size is reduced to nano-scale.Preliminary work by an iNEMI Nano Solder Project Team[10] has worked towards demonstrating that a reduction inmelting temperature of a solder alloy is feasible as a functionof particle size. (see Figure 2)



***Figure 8. Melting point of solder as a function of particle size***



***Figure 9. DSC scans depicting the melting depression fora Sn sample (courtesy of John Koppes, Purdue) [***11***]***

It may be possible to develop a solder paste system usingnano-sized solder particles (or alloying elements) to takeadvantage of this melting point suppression. This would be atechnology enabler for upcoming high-density electronicsthat are heat sensitive, thereby improving reliability of thefuture electronic systems.The first phase of the iNEMI project work was to producenano-scale tin, silver and copper particles to test for themelting depression phenomena. The team used DifferentialScanning Calorimetry (DSC) to demonstrate a reduction inthe melting and subsequent solidification of the test materials.By repeating the temperature scan cycle many times, a recordof the response is obtained. Figure 3 shows a typical DSC runon a sample of tin particles. The blue line includes the heatabsorption (endothermic reaction) of the flux carrier thatvolatizes and reacts on the first thermal cycle combined withthe melting of the nano-tin particles. By repeating the DSCthermal scan, one can demonstrate that the tin is no longermelting after the first cycle because it is no longer a nanosizedparticle. This method has demonstrated the meltingpoint suppression of the first cycle.Future work in Phase II of this iNEMI project will addressincreasing the metal density of the nano-solder paste and thedevelopment of a flux system that supports the coalescence ofthe particles. Solder paste printability and solder jointreliability tests would then follow.

**7.1 NANO-REACTIVE FOILS**

One promising application of nano-technology to thesoldering process is in the use of nano-reactive foils. Thesefoils are comprised of thousands of alternating nano-scalelayers of aluminum and nickel that are placed between thetwo surfaces to be joined. For instance, a nano-reactive foil isplaced between two solder performs to ultimately bond asemiconductor device to a Printed Circuit Board (PCB) asshown in figure 4.

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Figure 10

When activated with a small amount of energy, the nanoreactivefoil rapidly reacts chemically in an exothermicreaction. The energy in the form of released heat, melts the adjacent solder and, in this example, bonds the IC to thesubstrate. The amount of energy released is directlyproportional to the number of Al-Ni layers present in thenano-reactive foil.There are several advantages to using this technology for thesoldering process. It is not only quick, but it also eliminatesthe need for solder flux, thereby minimizing voiding and alsoeliminating the need for cleaning to remove any flux residue.Another significant benefit of this technology is that thereactive heat stays localized and does not subject thecomponent to prolonged high temperature exposure found inthe traditional PCB solder reflow process.The superior quality of solder joints produced by using thesenano-reactive foils is a big advantage when it comes tosoldering high-power devices to heat sinks. This nanoreactivefoil process is well suited for electric vehicle andhybrid power control applications. A small drop in thermalresistance goes a long way in increasing the performance ofthese components.

**8. ENVIRONMENTAL HEALTH &SAFETY**

The unconventional size, crystalline structure, large surfacearea and physical/chemical properties of nano-materialspromise unprecedented technological advances; howeverthese same properties also present significant challenges tounderstanding, predicting and managing potential health,safety, and environmental risks. The toxicologicalcharacteristics of familiar chemical compositions becomeuncertain when reconfigured at the molecular level in theform of nano-materials. Nanomaterials may differ from theirlarger particle counterparts with regard to viable routes ofexposure, movement of the material once in the body andinteraction of the materials with the body's biologicalsystems; all data which are essential for predicting healthrisks.Preliminary data indicate nanoparticles have the potential tobe absorbed into the body via inhalation, ingestion, andthrough the skin. Occupational exposure is most likely tooccur via inhalation or skin contact. While personalprotective equipment (PPE) is often the preferred choice forminimizing employee exposures, the efficacy of traditionalPPE toward specific nanomaterials is largely unknown.

A critical feature of nanoparticles is their high surface-areato-mass ratio. This property provides additional sites forbonding or reaction with surrounding material and results inunique characteristics such as improved strength or heatresistance. Similarly, evidence suggests that when inhaled,the large surface area of insoluble nanoparticles creates thepotential for greater biological activity [13, 14, 15]. Althoughdependent upon their effective size in the body and otherphysio-chemical characteristics, studies have also shown thatwhen nanoparticles are inhaled they may penetrate cellsallowing direct access to the bloodstream and possiblycircumventing the blood-brain barrier or depositing in otherorgans of the body [16, 17].Several studies have noted an increased risk of biologicalresponses from exposure to carbon nano-tubes [18, 19, 20,21]. Both single-walled (SWCNT) and multi-walled(MWCNT) carbon nano-tubes are non-biodegradable andresemble needle-like, carcinogenic asbestos fibers in size,shape and cellular persistence. Until recently several studiesonly suggested a potential link between inhalation exposureto long MWCNTs and cancer, but had not demonstrated thatinhaled MWCNTs could actually pass from the lung and intothe surrounding tissues [22, 23, 24].

The National Institute forOccupational Safety and Health (NIOSH) researchers havereported new data showing that MWCNTs can indeedmigrate intact from the lungs of mice and into the tissuesurrounding the lungs where asbestos induces a form ofcancer known as mesothelioma [25].Significant absorption of nano-material through the skinappears unlikely. Passive diffusion appears to be the primarymechanism for transport across the stratum corneum. Thecomposition of this outer layer of the skin creates an effectivebarrier to dermal absorption of both chemicals. Althoughsome studies have indicated that penetration of particles inlow micron diameter size range is possible, penetration islikely to be slow and not present an acute hazard [26].

There is very limited information describing the behavior ofnanoparticles once released to the environment. The fate ofmost nanoparticles in air, water, and soil is unknownparticularly with respect to persistence and potential forbioaccumulation (wildlife toxicity). It is possible thosemicroorganisms in soil or water could bioconcentratenanoparticles within their cells, and that nanoparticles couldconsequently bioaccumulate up the food chain.Because of these issues, it is important to adhere to safepractices for the handling, use and disposal of these materials.It is also essential that a comprehensive environmental andhuman health risk assessment accompany all new nanomaterialsand their proposed uses. Attention to each phase ofan applications lifecycle is warranted due to the uncertaintiesand paucity of scientific data regarding toxicity andenvironmental impact.

**9.CONCLUSIONS**

The automotive industry will be influenced by thedevelopment and implementation of nanotechnology. It is ourhope to raise the awareness that nanotechnology willpositively influence the business of the automotive industry

over the next several years.Due to the small size of nano-materials, their physical/chemical properties (e.g. stability, hardness, conductivity,reactivity, optical sensitivity, melting point, etc.) can bemanipulated to improve the overall properties of conventionalmaterial.Metal nanoparticles are being considered for potential use incatalytic converters since the catalytic reactivity issignificantly enhanced due to the increased surface area ofthe metal. Coolants utilize nanoparticles and nano-powders toincrease the efficiency of heat transfer and potentially reducethe size of the automotive cooling equipment. Somemanufacturers are currently using nano-magnetic fluids inshock absorbers to increase vibration control efficiency.Wear-resistant, hard-surface nano-coatings are beinginvestigated for applications in bearings, cylinders, valves,and other highly stressed components.High efficiency nano-layers of semiconducting materialsprovide electronic components and systems with a longerlifetime. Sensors based on nano-layer structures findapplications in engine control, airbag, anti-lock brake andelectronic stability program systems. Nanoparticles alsosupport the optimization of conventional components likebatteries, catalysts, solar cells or fuel cells.Nanotechnology is science and engineering, and it is all aboutpractical applications of physics, chemistry and materialproperties. Nanotechnology will influence the auto industryinitially on a very small scale, but will certainly be developedto deliver features, products and processes that are almostunimaginable today.

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**11.DEFINITIONS/ABBREVIATIONS**

**CNT**

Carbon Nano-tube

**CuO**

Cupric oxide

**DSC**

Differential Scanning Calorimetry

**DSL**

Domestic Substance list

**EPA**

Environmental Protection Agency

**EU**

European Union

**FIFRA**

Federal Insecticide, Fungicide, Rodenticide Act

**IC**

Integrated Circuit

**iNEMI**

International Electronics Manufacturing Initiative

**MEMS**

Micro Electro Mechanical Sensor

**MWCNT**

Multi-Walled Carbon Nano-tube

**NIOSH**

National Institute for Occupational Safety and Health

**NSNR**

New Substances Notification Regulation

**OLED**

Organic Light Emitting Diode

**PCB**

Printed Circuit Board

**PMN**

Pre Manufacturer Notice

**PP**

Polypropylene

**PPE**

Personal Protective Equipment **SMC**

Sheet-Molding Compound

**SnPb**

Tin-Lead

**SWCNT**

Single-Walled Carbon Nano-tube

**SNUR**

Significant New Use Rules

**TIM**

Thermal Interface Materials

**TSCA**

Toxic Substances Control Act