Appendix 1

Examples of Results from the EPA/NSF
Technology for a Sustainable Environment (TSE) Grants Program

TSE Grant Example 1: In the first few years of the TSE program, research focused on environmentally benign solvents. Organic solvents are often toxic substances with widespread use as intermediates and final products. The early TSE research focused on identifying environmentally benign alternatives to toxic solvents such as liquid or supercritical CO2, water, and ionic liquids. CO_2 became the primary focus of TSE research when EPA and NSF received numerous, high-quality proposals that addressed the key scientific questions related to the use of CO_2 as an alternative solvent. In 2003, EPA funded a "State of the Science" report on the use of CO_2 as a solvent that outlined the scientific progress and growing commercial interest in CO_2. The report noted that the "use of CO2 as a solvent is fast becoming 'mature', an achievement due in large part to sustained funding in the area from EPA and NSF."

TSE-funded research has resulted in the development of CO_2-based processes as alternatives to organic or halogenated solvents for cleaning, treating, and coating surfaces. This work resulted from a 1997 grant awarded to Dr. Joseph DeSimone at the University of North Carolina-Chapel Hill. His research led to the development of specialty detergent systems that easily dissolve in CO_2. A small business was then created and funded by EPA under its Small Business Innovation Research (SBIR) program to advance this technology as an alternative to traditional dry cleaning. Implementing this technology in the dry-cleaning sector has resulted in significant reductions of perchloroethylene (perc) emissions (a suspected carcinogen) and the associated burdens of environmental regulations. This technology is now being used in five states and over 100 dry cleaning establishments.

These same technological advances used to develop CO_2 as an alternative solvent led Dr. DeSimone to develop a process to manufacture polytetrafluoroethylene (Teflon) using CO_2. This process replaced previous processes that used chlorinated chemicals or millions of gallons of water that needed to be treated before they entered the public water system.

DuPont, the manufacturer of Teflon, adopted this innovative process and announced that it would invest $275 million to build and operate a world-class manufacturing facility in Fayetteville, North Carolina, using this new technology.

The potential for CO_2 as an environmentally preferable solvent is now being realized in several additional areas, including separation processes in the food industry, coatings in the automotive and furniture industries, polymer production and processing, and cleaning processes for the garment care (dry cleaning) and microelectronics industries. The cost of ownership associated with the continued use of organic solvents is no longer a minor issue and CO_2 presents a unique, cost-effective, benign alternative to utilizing a potential environmental pollutant as a feedstock.

For more information, see (http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/905/report/0).

TSE Grant Example 2: A critical component of waste minimization in fine chemicals manufacture is the substitution of classical organic syntheses using stoichiometric amounts of inorganic reagents with cleaner, catalytic alternatives. New and improved catalysts will enable important chemical reactions to be conducted under milder conditions, with less energy expenditure, in a shorter time, using less reactive and more environmentally friendly chemicals and solvents. For these reasons, catalysis is another area of research focus under TSE.

A TSE grant awarded by EPA in 1996 to Dr. Terrence Collins at Carnegie Mellon University, Pittsburgh, Pennsylvania, led to the development of oxidant activators based on iron. These activators promise extensive environmental benefits including a significant reduction in chlorinated pollutants. In addition, these alternative catalysts provide superior technical performance and significant cost and energy savings across a wide range of oxidation technologies.

Uses for these oxidant activators range from pulp and paper bleaching to fuel desulfurization to water disinfection, and most recently, biological or chemical decontamination for homeland security. In the case of pulp and paper bleaching, these activators proceed rapidly and efficiently at ambient temperatures with competitive performance while completely eliminating chlorinated pollutants.

More than 85 percent of recalcitrant sulfur compounds in refined automotive fuels can be easily removed using these powerful, environmentally friendly catalysts. Further development of this technology has the potential to provide an attractive alternative to existing methods that remove sulfur contaminants from fuels. Sulfur is associated with human health impacts, contributes to acid rain, and causes engines to burn less efficiently. This innovative technology demonstrates immediate environmental benefits by simultaneously reducing sulfur emissions from fuel combustion and improving fuel efficiency.

Given the widespread applicability of this technology and its demonstrated environmental and economic benefits, Dr. Collins is currently negotiating with several companies to manufacture these oxidants on a metric-ton scale for widespread use.

For more information, see (https://www.fastlane.nsf.gov/servlet/showaward?award=9612990).

TSE Grant Example 3: Another area of research concentration in the TSE program has been the use of renewable, bio-based feedstocks for chemical production. Use of renewable resources reduces the reliance on petroleum and has significant long-range strategic benefits for the US. Bio-based feedstocks also do not have environmental impacts associated with petroleum refining and processing. A “State of the Science” report on the development of this process and the contribution of TSE research is currently in progress

A TSE grant awarded by EPA in 1998 to Dr. John Dorgan at Colorado School of Mines in Golden, Colorado, contributed to the development of the first family of polymers derived entirely from annually renewable resources that can compete with traditional fibers and plastic packaging materials on a cost and performance basis. These polymers are based on polylactic acid (PLA), a fully biodegradable and completely recyclable material, which is produced by fermenting and distilling corn sugar. PLA production also uses internal recycle streams to eliminate waste, resulting in over 95% yields and preventing pollution at the source.

This technology is the basis for the world's first global-scale manufacturing facility capable of making commercial-grade plastic resins from annually renewable resources such as ordinary field corn. Cargill-Dow opened this facility in November 2001 after a $750 million investment. The plan now produces more than 300 million pounds of PLA annually and employs close to 100 people. From the corn plant to the retail counter, PLA has a lifecycle that reduces fossil fuel consumption by up to 50 percent. In addition, the process to make PLA generates 15 to 60 percent less greenhouse gases (GHG) than the material it replaces. Research also shows that technology advancements in PLA could allow up to 80 to 100 percent reduction in GHGs. This unique technology offers a new material alternative that competes on performance and price, while also reducing impact on the environment.

For more information, see (http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/967/report/0).

Appendix 2

Intramural Research, Development, and Implementation at EPA

As a result of EPA intramural research, several significant scientific and technical advances in green chemistry and engineering have been developed and implemented including:

- A novel process reactor, called a "Spinning Tube-in-Tube" or STT Reactor, has been used by EPA research staff to enhance the effectiveness of new catalysts. The STT Reactor, developed by Kreido Laboratories, consists of a small cylinder spinning within a hollow tube at speeds beyond 5500 rpm. This creates a well-stirred medium for chemical reactions such that mass transfer limitations can be either minimized or eliminated. The SST Reactor embodies the idea of process intensification through its potential for high throughput while maintaining a small physical footprint. Utilizing a CRADA with Kreido, EPA obtained an operating STT reactor for in-house experimentation. Employing the newly created EPA-designed catalysts, and using identical reaction conditions, researchers have been able to decrease the reaction time for partial selective oxidation of cyclohexane from 4 hours in a traditional batch reactor to below 25 minutes in the STT reactor. Currently, additional experiments with the STT Reactor are being negotiated under CRADAs to allow EPA researchers to develop other green chemistry applications for chemical production where significant toxic releases occur.

- Over the years, EPA's Green Metal Finishing program has evolved through close interactions with the regulatory programs in the offices of Water and Air Quality and Planning and Standards (OAQPS) in the Office of Air and Radiation. One project evaluated the use of fume suppressants for emissions control in hard chrome plating operations, an industry dominated by small businesses. Using this work, OAQPS revised their newly promulgated maximum achievable control technology (MACT) emission standards to include the results of the EPA demonstration of fume suppressants. The adoption of this technology resulted in multi-million dollar cost savings to industry, as well as major improvements in both EPA and Occupational Safety and Health Administration compliance. EPA was also involved with the metal finishing industry under the Common Sense Initiative (CSI) program involving industry, stakeholder groups, and the Agency's program offices including Office of Water, OAQPS and Office of Solid Waste. Ultimately, the CSI's Metal Finishing Committee developed a research agenda that was jointly implemented by EPA's laboratory and industry groups. EPA and the American Electroplaters and Surface Finishers Society jointly sponsor an annual conference to insure that the results of this research are transferred between the research office, program offices, and industry.

- Researchers in EPA developed a novel process reactor called a Corona Reactor. This reactor can be effectively and efficiently used in industrial oxidation processes, such as in the oxidation of alcohols and hydrocarbons for the production of value-added products. It can also be applied in advanced air and water cleaning processes. The Corona Reactor (patent pending) uses an oxidation protocol that has the advantage of the high oxidizing power of ozone formed within the reactor, as well as the photo-oxidation capability of UV light generated during ozone formation. This research has been conducted in collaboration with Washington University at St. Louis and a small business supported by EPA's SBIR program, Ceramatec, of Salt Lake City, Utah. The cleaning of indoor and airline cabin air are two potential applications of this. Other applications include the cleaning and partial and deep oxidation of waste gas streams from kraft pulp and paper mills. This ongoing study is being done in collaboration with Miami University and the Mead Westvaco Pulp and Paper Company of Chillicothe, Ohio.

As a result of EPA intramural research, several significant tools in science and technology for sustainability have been developed and implemented including:

- Program for Assisting the Replacement of Industrial Solvents (PARIS II): EPA is working to find cost-effective alternatives for industrial solvents that raise concerns for worker health and toxins in the environment. PARIS II is a software tool created to address this need by identifying pure chemicals or design mixtures that can serve as alternatives to more hazardous substances currently in use. The "greener" solvents formulated by PARIS II have improved environmental properties and can perform as well as the solvents they were designed to replace.

- Tool for the Reduction and Assessment of Chemicals and other environmental Impacts (TRACI): The most effective way to achieve long-term environmental results is to use a consistent set of metrics and a coherent decision-making framework. The EPA developed TRACI, a software package that characterizes the potential effects of specific chemicals or processes on ozone depletion and global warming, human health and the ecosystem. TRACI's modular design allows the most sophisticated impact assessment methodologies to be compiled. TRACI can be used in life cycle assessments, to improve design, set corporate environmental goals, plan a path to meet those goals, and then measure environmental progress.

- Waste Reduction Algorithm (WAR): In traditional chemical process design, attention is focused primarily on minimizing cost while the environmental impact of a process is often overlooked. This could, in many instances, lead to the production of large quantities of waste materials. It is possible to reduce the generation of these wastes and their environmental impact by modifying the design of the process. EPA recently developed a method to reduce wastes that is based on a potential environmental impact (PEI) balance for chemical processes. The PEI is a relative measure of the potential for a chemical to have an adverse affect on human health and the environment. The result of the PEI balance is an impact (pollution) index that provides a measure of the impact of the waste generated by a process. The goal of this methodology is to minimize the PEI for a process instead of minimizing the amount of waste (pollutants) generated by a process. The impact estimation algorithm is sophisticated and flexible enough to allow users to emphasize or de-emphasize different hazards as needed for particular applications. The result is a robust process design that integrally incorporates environmental impact reduction. The first version of the WAR Algorithm has been integrated into the commercial simulator ChemCAD IV under a Cooperative Research and Development Agreement (CRADA) between the EPA and Chemstations, Inc. A number of other CRADAs are being negotiated that involve further development of the WAR algorithm.

Appendix 3
Success Stories in Pollution Prevention from
EPA's Small Business Innovation Research Program

SBIR Example 1: EnerTech Environmental, Atlanta, Georgia, has successfully developed an innovative process that chemically converts municipal sewage sludge, municipal solid waste, and other organic wastes into a high-energy, liquid fuel that is cleaner to combust than most fuels. This process eliminates the need to burn or bury organic wastes and begins to address the environmental burdens associated with combustion and landfills. Instead it produces E-fuel, a valuable and cleaner supplement or substitute for conventional fuels such as coal or oil

For more information, see (http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/1517/report/0).

SBIR Example 2: Creare Incorporated, Hanover, New Hampshire, has designed a novel cutting tool-cooling system (CUTS) that eliminates the need for cutting fluids by indirectly cooling the cutting tool. Many companies use these costly and often environmentally problematic cutting fluids during machining operations. CUTS meets or exceeds current machining performance, including tool life and final product quality, when compared to traditional cooling systems that use cutting fluids. This technology uses a prevention-oriented approach that alleviates the human and environmental health and safety issues associated with cutting fluids

For more information, see (http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/6098/report/0).

SBIR Example 3: Lynntech, Incorporated, College Station, Texas, is working to commercialize a fundamentally new, inorganic conversion coating that is chromium free and will protect aluminum from corrosion. Potentially toxic chromium conversion coatings are used extensively to protect aluminum parts for the aerospace, automobile, construction, and consumer products industries. Lynntech's newly developed protective coatings meet rigorous corrosion protection standards and also eliminate chromium exposure in the workplace and the environment

For more information, see (http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/1375/report/0).

Appendix 4

Examples of Collaborative Networks with the Private Sector Related to Green Chemistry, Green Engineering, Pollution Prevention, and Sustainability

American Chemical Society (ACS): EPA and the ACS have partnered for the past eight years to host an annual Green Chemistry and Engineering Conference on issues that include global awareness, innovation, homeland security, and sustainability. A key objective of these conferences is to extend and strengthen the community of scientists, engineers, government officials, and the public in support of green chemistry. Conferences and symposia provide important opportunities for peer review, network building, increased awareness, and general development of a Green Chemistry community.

National Environmental Performance Track: This voluntary partnership program recognizes and rewards private and public facilities that demonstrate strong environmental performance beyond current requirements. The program is based on the premise that government should complement existing programs with new tools and strategies that not only protect people and the environment, but also capture opportunities for reducing costs and spurring technological innovation. Performance Track encourages participation of small, medium, and large facilities and its members are located throughout the United States and Puerto Rico.

All major industries are represented in Performance Track, with manufacturers of chemical, electronic and electrical, and medical equipment composing nearly 40 percent of the 344 members. Performance Track also provides recognition, regulatory flexibility, and other incentives that promote high levels of environmental performance and provide a learning network where best practices can be shared. The program encourages continuous environmental improvement through the use of environmental management systems. Public outreach, community involvement, and performance measurement are also important components of the program. Performance Track works within the business environment to encourage industry to reduce environmental emissions below regulated levels through approaches that are cost-effective.

For more information, see http://www.epa.gov/performancetrack.