U.S. House of Representatives
Committee on Science and Technology

Hearing on:
"E-Waste R&D Act"

February 9th, 2009

Testimony of:
Paul T. Anastas and Julie B. Zimmerman
Center for Green Chemistry and Green Engineering
Yale University

Presented by:
Paul T. Anastas

New Haven, CT

Chairman Gordon, Members of the Committee, I am pleased to testify today on the topic of the proposed E-Waste R&D program. My name is Paul Anastas and I am the Teresa and H. John Heinz III Professor in the Practice of Chemistry for the Environment and the Director for the Center for Green Chemistry and Green Engineering at Yale University.

The bill under discussion today centers on the problem of e-waste. My testimony focuses on considering solutions to this problem from a broader context. E-waste, like waste of any kind, is fundamentally an end-of-pipe problem. To truly address this issue in a meaningful and permanent sense, a research program should be designed to tackle it at its source – at the design-level of the products. Though creating the infrastructure and technologies necessary to manage and reuse waste materials is an important short-term goal, the enormous growth projected for the electronics sector is also an opportunity to re-imagine how these products are designed and attempt to eliminate not only the notion of waste, but also the environmental impacts of electronics on humans and the environment throughout their life-cycle. My testimony seeks to make the following key points:

1. E-waste is a serious and growing problem and yet it is only one aspect of the much larger issue as we seek to move toward sustainable electronics.
2. Waste is one egregious symptom of flawed design. With improved design, we can address not only the waste issue but also the important issues of energy usage, worker/assembler safety, depletion of scarce, rare, and precious metals, and the reduction of toxics use and replacement with benign alternatives.
3. Sustainable design frameworks exist to achieve these goals including the Principles of Green Chemistry and the Principles of Green Engineering.
4. Significant research challenges exist and can be addressed through thoughtful investment by the federal government in academic research in partnership with the private sector.
5. Advances in sustainable design of electronics can lead to improvements in overall environmental performance, including waste, while at the same time creating innovations in functional performance that enhances jobs and competitiveness.

Introduction

Electronic devices are a central feature of our daily lives. We rely on them for everything from communicating with our loved ones to monitoring our blood glucose to ensuring that our cars respond intelligently to changing road conditions.

Not only do electronics provide us with a vast array of personal benefits, but they also have a potentially significant role to play in sustainable development. For example, electronics could lead to greater environmental sustainability by significantly reducing the need for transport, leading to the dematerialization of certain products (such as the virtual provision of multimedia), or providing improved environmental monitoring capacity. With recent concern over global climate change, large-scale efficiency gains resulting from information and communication technology (ICT) use across sectors are seen as a key tool for transitioning to a lower-carbon world and facilitating low-carbon development.[1] On the social development side, ICT can facilitate general access to knowledge, build community-organizing capacity, and provide access to local and global markets. All of these are dramatically underserved needs in the developing world.

Sustainable development will require that the services provided by electronics continue to be made available to an ever-widening pool of consumers. The importance and value of electronics and their ability to offset other environmental problems are often used to excuse their own environmental impact. However, even a small impact subject to the scale of production that electronic devices will see in the coming decades would be unacceptably large. It is even more daunting to consider that electronics have one of the largest impacts per unit mass out of any product category. Electronic devices are inherently complex – they contain hundreds of materials, many of which are toxic, and require extremely precise structure and assembly on a minute scale, making them very resource-intensive to produce. As electronic devices become increasingly central to human life, we need to develop ways to sustainably provide their key services without tacitly accepting the problems they currently bring with them.

Thus far, industry's understandable initial response to these concerns has been to embark on a program of incremental improvement – making each generation of products slightly less toxic, slightly more energy efficient, slightly "less bad." However, in a time characterized by explosive growth in the worldwide use of electronics, a commitment to incremental improvement is not sufficient. Nor will even a reasonably effective end-of-pipe waste management system for the e-waste stream sufficiently address the material throughput or toxicity issues that are already apparent. We cannot solve an exponential increase in problems with a linear decrease in impact.

Our longer-term research priorities must be targeted toward the drastic reduction of both the volume and the toxicity of this waste stream through concerted efforts at *better design*. We need to clearly define the challenges we hope to tackle, and then address them in a more creative and innovative manner than has thus far been applied. This approach will also require efforts to build our long-term capacity for innovation, through the building of a sustainability knowledge base throughout our nation's engineering programs. The good news is that sustainable electronics are possible. We have the tools

---

[1] Smart 2020: Enabling the low carbon economy in the information age. The Climate Group, on behalf of the Global eSustainability Initiative. 2008.
ICT's potential role in mitigating climate impacts was the subject of the recently-published "SMART 2020" report, which concluded that ICT's potential for increasing the efficiency of other sectors is so great that it beyond offsets the use-phase emissions of the ICT sector itself., though the CO_2 emissions reductions needed to stabilize atmospheric greenhouse gas levels still exceed what those gains would represent.

and design frameworks required for getting on the right path. However, to overcome a challenge, we must first recognize it as a challenge – and define our targets appropriately.

The Electronics-Manufacturing Sector: Historic & Current Problems

The electronics-manufacturing sector is characterized by quick product turnover, complicated and globalized production chains, capital intensity, a high level of outsourcing, and a global material footprint. A typical computer contains over 1,000 components, whose raw materials draw on the majority of the periodic table. It's usual for these components to be manufactured and assembled in different parts of the world – for example, semiconductor chips made in Scotland, a disk drive made in the Philippines, an LCD monitor made in South Korea, circuit boards fabricated in China and assembled in Taiwan, and the final product assembled in Mexico.[2] In 2005, only 25% of production was done "in house," with 75% outsourced to contract manufacturers, primarily in Asia.[3]

Environmental concerns for electronic devices, can be broken down into three major categories:

- The use of hazardous and toxic substances
- Resource and energy intensity
- The loss of materials and their embedded value to the waste stream

The complexity of electronic products represents an investment of energy, water, and processing time that goes far beyond the basic value of their structural materials. For example, the production of a memory chip requires about 600 times its weight in fossil fuel. This is at least an order of magnitude higher than any other product category – for comparison: the production of a car requires 1 – 2 times, and an aluminum can requires 4 – 5 times its weight in fossil fuel.[4]

Many electronic products, especially older models, contain substantial quantities of hazardous substances. For example, older cathode ray tubes (CRTs) contain between four and seven pounds of lead.[5] In 2003, the High Density Packaging User Group (HDPUG) conducted an industry-wide survey of the material composition profiles of certain IT components. Using methodologies ranging from analytical testing to surveys and literature reviews, they categorized what they considered to be the environmentally relevant materials present in electronic equipment based on toxicity and volume. The chart below presents a summary of their findings.

---

[2] Example adapted from Schipper, Irene and de Haan, Esther. "CSR Issues in the ICT Hardware Manufacturing Sector" SOMO ICT Sector Report. September 2005.

[3] Schipper, Irene and de Haan, Esther. "CSR Issues in the ICT Hardware Manufacturing Sector" SOMO ICT Sector Report. September 2005.

[4] Environmental Science and Technology, "The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices," Williams, E. D.; Ayres, R. U.; Heller, M.; (Article); 2002; 36(24); 5504-5510. http://dx.doi.org/10.1021/es025643o

[5] EPA 67 FR 40509, June 12, 2002. California Environmental Protection Agency *Managing Waste Cathode Ray Tubes*, Fact Sheet August 2001. From the "Recycyling Technology Products" Paper.

Summary of Potentially Environmentally Relevant Chemicals[6]

Chemical	Primary Use	Environmental Relevance
Antimony	Solder, flame retardant	Concerns about toxicity
Arsenic	Dopant in semiconductor manufacturing	Concerns about toxicity
Beryllium	May be found in select connections	Concerns about toxicity
Bismuth	Solder	Contaminant to copper recycling
Brominated compounds	Flame retardants in printed circuit boards, ICs, and plastics	Concerns about incineration byproducts and toxicity
Cadmium	Identified as stabilizer additive to some cables; present in trace amounts in some telecom boards	Restricted by EU RoHS
Chromium	Found as chromium (III) in stainless steel. Chromium VI may be present in trace amounts	Chromium VI restricted by RoHS
Lead	Solder, stabilizer in cords	Restricted by RoHS
Mercury	Identified in bulbs used in backlighting of LCD	Restricted by EU RoHS
Nickel	Plating	Concerns about toxicity
Silver	Solder	Leachability at end of life

In addition to these substances of concern identified by the HDPUG group, many others are often highlighted, including: halogenated and other ozone-depleting substances (i.e. CFCs), plasticizers, refractory ceramic fibers, asbestos, lithium, and copper (which, along with arsenic and nickel, can catalyze the increase of dioxins during incineration).[7]

The loss of material to the waste stream is really a problem with three distinct sub-categories, which build on the problems already discussed:

- reducing the volume of waste entering landfills
- reducing pollution caused by the toxic content of disposed electronics
- closing material loops and recovering the economic value of materials

The disposal and recycling of waste electronics has become an international and multidimensional issue. A great deal of attention is often paid to the volume of e-waste entering the waste stream. The volume is significant - the US EPA estimates that more than 3.2 million tons of electronic waste enters US landfills every year[8] and that this volume will continue to grow rapidly in the coming decades, the more significant

---

[6] High Density Packaging User Group (HDPUG). "Material Composition Profiles of Select IT Components, A Design for Environment Project with the High Density Packaging User Group (HDPUG). 2003 IEEE International Symposium on Electronics and the Environment, Conference Record, pp. 125 - 130.

[7] WEEE and Hazardous Waste. A report produced for DEFRA. March 2004.

[8] Environmental Protection Agency. www.epa.gov/epaoswer/osw/conserve/plugin/index.htm

problem with e-waste relates to its qualitative characteristics. E-waste is expensive to manage properly because of its bulk, small components, and toxic constituents. This distinguishes e-waste from ordinary garbage, while simultaneously making it particularly important to manage properly. However, from an economic perspective, only some subsets of e-waste make financial sense to recover, while the bulkiest ones (plastics) must be dealt with at a cost.

The off-shoring and improper recycling of e-waste has resulted in unsafe working conditions for thousands of workers in the developing world. In a many cases, "recycling" of e-waste involves burning parts over open pit fires in order to melt solder and separate out valuable components. A recent study examining heavy metal contamination levels in Guiyu, China, a village heavily involved in e-waste recycling, found that levels of lead and copper in road dust were 371 and 155 times higher, respectively, than in a non-e-waste recycling site 30 kilometers away. The contamination levels in the village were likely to pose significant health risks, particularly to children, which the authors correlated with body loading studies done in the same region.[9] Exposure to high levels of heavy metals can result in both acute and chronic health conditions ranging from damage to the nervous system, and changes to blood composition, lung, kidney, and liver functioning.[10]

Rapid technological advances in the electronics sector result in quick product turnover. This rapid turnover is exacerbated by fashion- and software-driven hardware obsolescence. The average lifespan for a PC manufactured in 2005 was estimated to be two years.[11] Though demand for electronic devices in the industrialized world continues to grow, the most significant growth is occurring in developing countries. Today only 10% of China's population of 1.3 billion owns a computer. By 2020 that number is projected to rise to 70%. By that same year, half the world's population will own a mobile phone and almost a third of the global population will have a PC (currently one in 50).[12] This translates to over 4 billion PCs in active use worldwide.

Not only does this imply a massive increase in the production of electronic devices, but it will also necessitate greater network capacity to support their energy needs, more materials to allow for their manufacture, and the creation of an infrastructure for their end of life management.

The topics touched on here are likely to be covered in more detail in other testimonies. However, I would like to draw attention to a few areas, which I believe do not get

---

[9] Leung AOW, Duzgoren-Aydin NS, Cheung KC, Wong MH. "Heavy Metals Concentrations of Surface Dust from e-Waste Recycling and its Human Health Implications in Southeast China." Environmental Science and Technology. January 2008, in press.

[10] Ibid.

[11] National Safety Council, "Electronic Product Recovery and Recycling Baseline Report: Recycling of Selected Electronic Products in the United States," May 1999

[12] Smart 2020: Enabling the low carbon economy in the information age. The Climate Group, on behalf of the Global eSustainability Initiative. 2008.

sufficient attention, and which should guide the development of research priorities in this field.

The first is what I believe to be an insufficient focus on the toxicity of some of the material components of electronic devices. Many industry representatives point to the incremental improvements achieved in recent generations of electronic products and consider this a successful stopping point for the elimination of toxic and hazardous materials. However, the fact remains that electronic devices still contain many hazardous materials. What we should ultimately be aiming for is the total elimination of toxic and hazardous materials in these products. Only when products are truly benign will their mass production not pose a substantial threat to workers, users, and those handling the equipment at end of life. Truly benign products do not pose an inherent risk – they can be handled properly or mishandled without any threat to humans or the environment. This is not an easy or short-term proposition, but it is the goal that we should at least be aspiring to achieve. Perhaps, and likely, this cannot be achieved through the search for direct analogues of existing toxic materials. Instead, we can focus on shifting towards new technological avenues. For example, rather than replacing the lead in cathode ray tubes with a benign alternative, we instead replaced CRTs with an entirely different technology.

Another issue, which is only infrequently touched upon, is the question of material scarcity. The operating assumption within the high tech manufacturing industry is that sufficient material exists to continue satisfying the enormous and growing demand for electronics. However, these assumptions are not always grounded in firm data – because in many cases, the data does not exist. We generally have a very poor understanding of the material quantities that we consume, or how consistently we can expect those flows to continue. One example particularly relevant to the electronics sector is that of tantalum, a scarce metal that is essential for the manufacture of capacitors and resistors. At the very least we should attempt to better quantify the stocks and flows of various resources through the electronics sector to improve our capacity for impact assessment.

Finally, I would like to draw attention to the potential of emerging technologies. These nascent technologies including molecular self-assembly, nanotechnology and nano-materials, self-healing polymers, organic batteries and others, offer the promise of not merely meeting environmental goals but also dramatically increasing performance and competitiveness. Only though proper support for the basic research and development of these innovative new fields can the power and potential of these green chemistry and green engineering solutions be realized.

Frameworks for Sustainable Design

It has become widely accepted that any consideration of product sustainability should take into account the entire product life cycle – from raw material acquisition and manufacturing, through use, to disposal.

Looking at the entire life cycle helps prevent "problem shifting." For example, energy-saving compact fluorescent light bulbs save a great deal of electricity, but represent a life cycle trade-off because they contain mercury – thus shifting environmental burden from the use phase to manufacturing and end of life. Examining the whole life cycle also helps standardize the environmental burden against the unit of service provided – for example, a disposable cup may have a much lower environmental cost than a metal travel mug, but the metal travel mug is capable of providing hundreds of uses in comparison with the disposable's single use. A key step in optimizing any system requires an objective look at where the largest areas for improvement lie within the system as a whole.

Several frameworks for sustainable design, all of which take a life cycle perspective, have become well established over the past decade, among them the 12 Principles of Green Chemistry and the 12 Principles of Green Engineering.[13] Though it is unnecessary to go into the details of this design framework here, it implies some key approaches for responding to the problems outlined above through re-design:

1. **Eliminate or severely reduce toxicity (toward zero hazard)**
    - **Materials and energy sourcing –** By changing the nature of the materials and energy that are input into the process of making electronics, we can dramatically improve all aspects of the life-cycle stages of electronics including that of e-waste.
        - Reduce the use of hazards wherever possible (i.e. replacing toxic flame retardants, plasticizers, mercury, lead, and arsenic – containing substances, etc.).
        - Design new materials, plastics, composites and alloys that increase performance while reducing toxicity.
        - Ensure that the new materials are designed such that included as part of functional performance are things like non-persistence, non-bioaccumulation, degradability, non-mutagenic/non-carcinogenic, and non-endocrine disrupting.
2. **Close the material loop (achieve zero waste)**
    - **Design for reuse and end-of-life.** The primary goal for end-of-life design for electronics should be to retain the embedded complexity of these products because they are so resource-intensive to produce. Functional components should be re-used whole as a first priority, recycled for their raw materials as a second priority, and appropriately disposed of as a last resort.
        - Incorporate take-back schemes
        - Reduce material diversity
        - Improve the ease of product disassembly
        - Incorporate renewable/biodegradable materials wherever possible and advisable
    - **Think broadly about possible material synergies outside of the industry.**

---

[13] Anastas, P.T., and Zimmerman, J.B., "Design through the Twelve Principles of Green Engineering", *Env. Sci. and Tech.,* **37**, 5, 95 – 101, 2003. Anastas, P.T., Warner, J. C., Green Chemistry: Theory and Practice, Oxford University Press, 1998.

        - Can waste products be sold as feedstock to other industries? Example: IBM is reported to have recently begun selling its information-scoured silicon chips as a feedstock for solar panels.[14]
        - Can other industries' wastes be purchased as feedstock?[15] Example: University of Delaware Professor Richard Wool's chicken-feather-based circuit boards, which take an existing waste-stream (3 billion pounds of chicken feathers are disposed of annually) and use it as a feedstock to make a more efficient circuit board than the conventional version.[16]

3. **Optimize resource use at the design stage (for energy, materials, and time)**
    - **Determine and design for optimal product lifetime -** Extending useful product life for most electronics would lead to overall energy and resource savings. This is also supported by recent life cycle analysis studies that have shown that the use phase only comprises about 20% of total energy consumption over the lifetime of an electronic device.[17] However we must also balance this with the concerns of "locking-in" resources into technologies that may become obsolete or that may be perceived to be obsolete by style-conscious consumers.
        - Therefore, product lifetimes should be increased, but provisions should be made for adaptability and upgradeability.
        - Modular options could provide trend-conscious consumers with exchangeable components for a new product appearance. These style upgrades could largely go on within companies out of customer view.
    - **Select production methodologies that are as efficient as possible**
    - **Select materials that deliver functionality with minimal resource input**
    - **Expand the number of services delivered by any single device**

Specific Research Priorities

The high turnover in the electronics sector is often framed as a problem, but from a sustainable design perspective it can also be seen as an opportunity. With technology advancing rapidly, each new generation of products is the chance to try something new and truly break out of existing technological paradigms. However, there are certain problems that will need to be dealt with sooner than others.

---

[14] The Associated Press. "IBM to Recycle Chips for Solar Panels." *The International Herald Tribune.* 30 October 2007. <http://www.iht.com/articles/2007/10/30/business/ibm.php>

[15] De la Pena, N. "Sifting the Garbage for a Green Polymer." *The New York Times.* 19 June 2007. <http://www.nytimes.com/2007/06/19/science/19poly.html >

[16] Frazer, L. "Chicken Electronics – A Technology Plucked from Waste." *Environ Health Perspect.* **112(10):** A564–A567, July 2004.

[17] Williams, Eric. Energy Intensity of Computer Manufacturing: Hybrid Assessment Combining Process and Economic Input-Output Methods. *Environmental Science and Technology*. 2004; 38(22); 6166-6174. http://dx.doi.org/10.1021/es035152j

Innovations in areas ranging from chemistry and materials science to systems engineering and policy will be required to effectively address the problem of e-waste.

- **Short-term**
  - **Up-cycling historic wastes –**
    - Research on the transformation or destruction of current toxics.
    - Determine the applications for the direct re-use of electronics, component re-use, or recycling – with the goal of retaining as much embedded complexity as possible.
    - Nanotechnology has the potential to revolutionize a number of industries through the creation of materials with novel physical properties. This area needs to be thoroughly investigated in order to maximize its potential benefits in the electronics sector while designing through newly emerging Green-Nano programs to reduce the intrinsic of toxicity and eco-toxicity.
  - **Improve design for disassembly to enhance the reuse and recyclability of new products –** both through new recycling technologies and new product design.
    - Research new material joining options such as fasteners, welds, adhesives
    - Examine the potential for the use of new materials developed through bio-based and molecular self-assembly techniques
  - **Improve the recycling infrastructure**
    - Educate consumers about electronic waste
    - Facilitate the collection of electronic products
  - **Extend useful product life**
    - Determine the factors that lead to technological failure
  - **Conduct basic research on materials and life cycle impacts**
    - Support data-gathering programs that will allow for the completion of Life Cycle Analyses (LCAs) and Material Flow Accounts (MFAs)

The toxic materials contained in older electronic products that will hit the waste stream in the next 10 years are a potentially serious environmental problem. Effective ways of managing these legacy products remain an unresolved challenge. Improving recycling technology to be able to safely extract valuable materials from this waste stream will be one of the earliest priorities.

Plastics present another challenge because although they constitute a large part of the volume of the e-waste stream, however they represent a low fraction of the value, which does not create economic incentive for their recovery. In the near term, one of the solutions to this problem will be to research alternative uses for the mixed plastic stream that can be extracted from legacy electronics. A market for these materials needs to be established if we wish to successfully divert them from landfills and other disposal options.

To avoid these very problems with future generations of electronic products, an immediate, concerted research effort should be directed at designing components and materials that are easily separable and recoverable. For materials used in very minute quantities, advanced separation techniques should be explored. This is a key priority for putting an immediate dent into the future e-waste stream.

Historically, the "use phase" of electric and electronic equipment has been considered the most important energy-consuming phase of the product lifecycle. Though this holds true for large appliances such as washing machines and refrigerators, in the case of most personal electronic devices such as computers, the majority of resource consumption and energy usage occurs before the product even reaches the consumer. A now widely cited study found that the life cycle energy burden of a computer is dominated by the production phase (81%) as opposed to operation (19%).[18] This is one of the major reasons that extending the usable lifespan of ICT devices has been identified by many groups as a potentially promising approach to mitigating their environmental impact.[19]

An important problem for evaluating the environmental sustainability of electronic products is the lack of sufficient information on life cycle impacts. Because of insufficient data, we don't even know how much of certain materials (such as precious metals) we are using, and how quickly we are depleting our existing stock. It is estimated that the typical mobile phone made today contains approximately sixty chemical elements from the Periodic Table. Of these, we may have adequate data on the supplies and usage rates of eight of them. This is something that needs to be remedied through basic research.

- **Mid-term**
    - **Begin to phase out toxics**
    - **Investigate new materials and improve existing functionalities**
        - **Develop new display technologies**
        - **Improve energy storage capability**
    - **Basic material research on polymers, composites, and conducting organic materials.**

A central tenet in the 12 Principles of Green Chemistry is that we should strive to eliminate toxic and hazardous materials to the greatest extent possible throughout their life cycle. Though the ultimate goal of product re-design should be the elimination of

---

[18] Williams, Eric. Energy Intensity of Computer Manufacturing: Hybrid Assessment Combining Process and Economic Input-Output Methods. *Environmental Science and Technology*. 2004; 38(22); 6166-6174. http://dx.doi.org/10.1021/es035152j

[19] Ibid.

toxic and hazardous substances, this process will need to be carefully managed and not forced through by over-eager legislation. The trade-offs of eliminating certain toxic substances for alternative materials appear to be highly uncertain in some areas, and have often led to heated debates, particularly just prior to the adoption of definitive regulatory measures. Among several recent examples, one of the most prominent is the regulatory push to eliminate lead.

Consumer electronics constitute 40 percent of the lead found in landfills,[20] largely originating from cathode ray tube (CRT) monitors, but also present in significant quantities in printed circuit boards. Lead is well known to have neurotoxic effects and presents a particular risk for children. The recently adopted RoHS directive in the European Union, which has been in effect since July 1, 2006, has severely restricted the use of lead in any new electronic devices, particularly in solders, which forces manufacturers interested in continuing sales in the EU market to switch to alternatives.

Tin-lead solders have been used for over half a century, and shifting to alternatives has raised concern about the performance of the alternatives.

Therefore, it is important to innovate truly better alternatives to existing toxic products, and not prematurely stifle the process through legislative bans in the absence of the necessary research on the green chemistry alternatives. This fundamental research is essential to meeting the genuine goals of moving away from toxic materials in ways that don't cause unintended environmental, health, and economic consequences.

- **Long-term**
  - **Material basis of computers**
    - **Non-depleting**
    - **Non-rare, scarce, toxic metals**
    - **Non-persistent, non-accumulating, non-toxic materials**
  - **Focus on new dematerialized product conceptions**
    - Nano scale materials and components
    - Molecular self-assembly
    - Biomimetic devices
  - **Strive for holistic applications of green design**
    - Dematerialize – use fewer devices with less overall material to provide the same services
    - Close material loops – cease to design products whose components cannot be fully recovered for some kind of use

The ultimate message is that green chemistry and engineering principles can only lead to sustainability if they are applied systematically. Incremental improvements along specific problem trajectories are essential stepping stones, but the full-fledged, system-wide adoption of these design foundations calls for transformative breakthroughs – both in products themselves and in the logistical systems we have in place for managing them

---

[20] Silicon Valley Toxics Coalition, "Fourth Annual Computer Report Card," January 9, 2003 http://www.svtc.org/cleancc/pubs/2002report.htm

and their waste streams. This integrated approach to design is the only way to truly address the e-waste problem.

These key transformative innovations will likely rely heavily on dematerialization and will probably make use of technologies that are currently unknown or just emerging, such as nano-scale self-assembly, self-healing materials, programmed decomposition, biological mining and recovery (for minute quantities of valuable materials).

The ultimate goal is to create products that can provide increased benefits to our society and our economy – on energy that is renewable, made of materials that are benign, and based on renewable and reusable feedstocks. This vision is the goal of perfection we seek through green chemistry and green engineering and it is only through holding out goals of perfection – the "true north" - that we guarantee continuous improvement rather than settling for half-solutions and comprises.

The E-Waste R&D program that is ultimately established should be as visionary and broad looking as possible in its scope, and avoid treating the problem of E-Waste as a single, narrow challenge.

Program Structure

Research and Education - There are many models in the federal government that have been successful in ensuring the same general goals that are sought by this legislation:

1. Excellence in research
2. Partnership with industry
3. Integrating education
4. Sound science basis for policy inputs

Some of the outstanding models that could be considered in this research include the Industry – University Cooperative Research Centers that are funded out of the National Science Foundation; the Technology for a Sustainable Environment Program that until recently was funded out of the U.S. Environmental Protection Agency and part of an inter-agency Program with NSF had an excellent track record; and the Integrated Graduate Education and Research Training (IGERT) grants provide and excellent model that could be adapted to partnerships with industry. There are also the excellent examples of Engineering Research Centers (ERCs) and Science and Technology Research Centers (STCs) that have very productive industry/academic partnerships for research and education.

Leveraging research – In addition to the establishment of centers dedicated to this important area, it would also be worth considering how to leverage the portfolio of existing research that will greatly impact future electronics. Those projects in areas such as nanotechnology, polymers and materials, electrical engineering, product design, metallurgy, and others currently funded by federal research programs because of their direct and important relevance to electronics. By ensuring that the next round of program solicitations supporting this research contain requirements for the principal investigator to discuss potential environmental and human health benefits of their work and the use of this information as criteria in a funding decision. This could have a tremendous positive impact on funding for the field.

Policy Issues

The successful implementation of the outcomes of this endeavor will additionally need to be supported by innovative policy frameworks in order to function efficiently and to provide incentives for the adoption of environmentally superior designs.

It should be noted that "product stewardship" or Extended Producer Responsibility (EPR) concepts as implemented in existing e-waste legislation have not been effective, and seem unlikely to become effective, at changing product design. This is because, for both economic and environmental reasons, almost all product recovery and recycling systems are collective – they handle all manufacturers' products collectively. While manufacturers may pay for their share of the waste collected, or their share of products produced, no system has yet been developed to provide a financial incentive for individual manufacturers to make their products easier to recycle. In addition, the collective nature of both the end-of-life system and the component supply chain makes it difficult for individual electronics manufacturers to adopt dramatic innovations for the reduction of environmental impact.

Another big source of contention regarding electronics recycling has been the search for an appropriate financing system. State and local governments would like to see manufacturer-financed recycling programs because not enough funding is available for government-financed options.[21] However, the cost of compliance with even a single law can be a challenge for industry, and with the recent barrage of new regulations, industry has voiced that it cannot bear these costs alone. The National Electronics Product Stewardship Initiative (NEPSI) – a dialogue between stakeholders convened by the EPA in 2001 to devise a single national solution to electronics take-back and recycling was brought to an unsuccessful close when participants could not reach a consensus on the financing system for e-waste recycling.

The key challenge has been that all of the proposed industry funding schemes burden different manufacturers unequally, and in every case the burdened companies have vigorously opposed the specific scheme that would disadvantage them. In response to the lack of a national solution, many U.S. states have developed their own systems, creating a regulatory patchwork. This is in addition to the emerging international patchwork of regulations creating an uncertain regulatory environment making it difficult for the industrial sector to continue to innovate in a clear direction.

These are all overlying issues that need to be addressed to ensure the ultimate effectiveness of any proposal.

---

[21] from recycling doc – Oregon Department of Environmental Quality Federal Register comments in Appendix VII.

Conclusion

This bill provides a tremendous opportunity to address the important and growing issue of the impacts of electronics on our environment, our health, and our economy. It is essential that the legislation incorporate the following elements.

1. Do not focus merely on waste since the only effective and economically beneficial way to address the issue is through redesign of the life cycle of electronics.
2. Funding for research is essential on the green chemistry and green engineering solutions for the sustainable design of electronics. Initially this research will focus on removing some of the most problematic toxic, bio-accumulating, persistent substances and later can address the key systems approaches of biomimicry, organic energy storage, and dematerialization all fundamental to a sustainable ICT enterprise.
3. Models for government funding for successful industry-university partnerships exist and those should be considered.
4. Policy research to provide the incentives for the design, development, purchasing, recycling, reuse, and remanufacturing of electronics, is an important element.

Thank you for the opportunity to comment on this important legislation.

Paul T. Anastas, Ph.D.

Center for Green Chemistry and Green Engineering
Yale University
New Haven, CT 06520
203-432-6165 paul.anastas@yale.edu

EDUCATION

1989	**Ph.D.**	Organic Chemistry, Brandeis University
1987	**M. A.**	Organic Chemistry, Brandeis University
1984	**B. S.**	Chemistry, University of Massachusetts

PROFESSIONAL EXPERIENCE

1/2007 - present **Yale University, Teresa and H. John Heinz III Professor in the Practice of Chemistry for the Environment, School of Forestry and Environmental Studies; Lecturer, Chemistry Department; Research Associate, Department of Chemical Engineering; Director, Center for Green Chemistry and Green Engineering at Yale.**

6/2004 – 12/2006 **Director, Green Chemistry Institute -** American Chemical Society, Washington D.C. Directed the not-for-profit organization that promotes the design, discovery, development and implementation of material and energy sources that are benign to human health and the environment to advance sustainability through science with networks and chapters in twenty-five nations globally.

9/1999 – 6/2004 **Assistant Director, Environment (***previously NSTC Rep.***), White House Office of Science and Technology Policy, Executive Office of the President, Washington, DC**. Responsibilities included the development of science policy and budgetary planning in coordination with Congressional interests and Executive branch agencies on the wide range of environmental issues. Specific areas of focus include toxic substances, science for sustainability, green chemistry and engineering, climate change, water resources, and bilateral science and technology relationships between the U.S. and national and multinational governmental institutions. Additional duties include managing governmental and private research/science community relationships to coordinate input on diverse scientific issues of importance to the White House.

- Served as International Affair Coordinator for OSTP 2001-2002
- Served as OSTP/Interagency Science lead for COP – 7 Meeting on Climate Change – Marrakesh, Morrocco, UNFCCC, 2001.
- Served as OSTP/Interagency Science lead for COP – 8 Meeting on Climate Change – New Delhi, UNFCCC, 2002.
- Led interagency workgroup on Science and Technology for Sustainability
- Served as science lead on bilateral climate change negotiations with EU, Japan, Italy, and Australia
- Served on OSTP interagency working group on nanotechnology, subgroup for environment, health and safety
- Served as OSTP interagency lead on bilateral science and technology collaborations and negotiated with China, Japan, and S. Korea on collaborative activities.

1/1995 – 9/1999 **Director of the Green Chemistry Program and Chief of the Industrial Chemistry Branch. United States Environmental Protection Agency, Washington, DC.** Managed a staff of 25 Ph.D. level scientists who assess the chemistry and biochemistry of new substances in the environment with a focus on the hydrosphere, atmosphere, and biosphere. Direct academic/industrial research collaborative projects on the development of environmentally benign chemical products and processes. Additional responsibilities include conducting the chemical evaluation for regulation of all new and existing chemical substances and developing models for the underlying chemical properties for the flow of substances in aquatic, air, and terrestrial systems.

3/1992 – 1/1995 **New Chemical Section Chief of the Industrial Chemistry Branch. United States Environmental Protection Agency, Washington, DC.**

7/1989 – 3/1992 **Chemist. Industrial Chemistry Branch, United States Environmental Protection Agency, Washington, DC.**

ACADEMIC AFFILIATIONS

9/2005 – 9/2006 **Senior Research Fellow - Roy Family Fellow.** John F. Kennedy School of Government**.** Harvard University, Cambridge, Massachusetts

1/2005 – 1/2006 **Director.** Alliance for Global Sustainability, Center for Environment and Energy, Massachusetts Institute of Technology, Cambridge, Massachusetts

9/2002 - present **Visiting Professor.** Institut Universitat de Ciencia i Techologica, Barcelona, Spain.
8/1999 - present **Special Professor.** Chemistry Department, Nottingham University, Nottingham, United Kingdom.

BOARDS AND PROFESSIONAL AFFLIATIONS

- National Advisory Council for Environmental Policy and Technology – 2007 - present
- National Academy of Sciences Board on Chemical Sciences and Technology - 2004 - 2007
- NATO Science Committee – Environmental Security Panel – 2001-2004
- National Research Council's Chemical Sciences Roundtable – 2002 - present
- Department of Defense Strategic Environmental Research and Development Program (SERDP), Science Advisory Board - 2002 - 2004, 2007 - present
- ACS Green Chemistry Institute Governing Board - 2004-2006
- Mascaro Sustainability Initiative Board Member - 2004 – present
- Australian Green Chemistry Research Center, Advisory Board Member 2004 - present
- Environmental Science and Technology; Editorial Advisory Board Member 2002 -present
- Clean Technologies and Environmental Policy, Editorial Board Member – 1999 -2002
- Journal of Green Chemistry, Editorial Advisory Board Member - 2004 - present
- U.S.-China Center; Board Member - 2002 - present
- American Chemical Society, Committee on Environmental Improvement 1999-2004
- Green Chemistry Gordon Conference; Founding Chair and Executive Committee member
- NATO Consultant; Science for Peace (SFP) Expert Advisor 1999-2003
- Green Chemistry and Engineering Conference, co-founder and co-chair, 1997-2003
- IUPAC Working Party on Green Chemistry
- Joint Association for Advancement of Supercritical Technologies; Board Member, 1996-2000
- Federal Interagency Chemical Research Committee; Representative,1994-2000
- American Chemical Society; Organic, Environmental Chemistry and Education Division Member

ACHIEVEMENTS, HONORS, AND AWARDS

- Council of Scientific Society Presidents, 2008 Leadership in Science Award, 2008.
- John Jeyes Lectureship, UK Royal Society of Chemistry, 2007
- Honorary Doctorate of Science in Chemistry, Queens University, Belfast, Ireland, 2007
- Bayer Distinguished Lectureship, 2007
- The Heinz Award, Environment, 2006
- Scientific American 50 Award in Science and Technology, 2005
- Inaugural Canadian Green Chemistry Medal, Montreal, Canada, 2004
- Special Professor, Universitat of Vic, Barcelona, Spain, 2002
- Erskine Scholar, University of Canterbury, New Zealand, 2002
- Greek Chemical Society Award for Contributions to Chemistry, 2002
- Honorary Professor, Queens University, Belfast, N. Ireland, 2001
- Vice President's Hammer Award: Acute Exposure Guideline Levels Program, 2000
- Joseph Seifter Award for Scientific Excellence in Risk Assessment, 1999
- Nolan and Gloria Sommer Award - Distinguished Contributions to Chemistry, 1999
- EPA Bronze Medal - Development of Green Chemistry Expert System, 1999
- Vice-President's Hammer Award – Green Chemistry Program, 1998
- EPA Silver Medal - Design and Development EPA's Green Chemistry Program, 1997
- First Annual Office of Pollution Prevention and Toxics Award for Outstanding Branch Chief, 1995
- EPA Bronze Medal for Outstanding Service, 1995
- Two EPA Bronze Medals for Outstanding Service, 1994
- EPA Bronze Medal for Outstanding Service, 1993
- Sustained Superior Performance Award, 1991
- Presidential Point of Light Award, 1991
- EPA Assistant Administrator's Awards, 1991
- Sustained Superior Performance Award, 1990

NOTABLE SPEAKING INVITATIONS

- Master Speaker, GreenBuild, Boston, 2008.
- Plenary Speaker, Yale Day, Waseda University, Tokyo, Japan, 2008.
- Keynote Speaker, Green Chemistry/Environmental Health Sciences, Irvine, CA, 2008.
- Keynote Speaker, Blueprints for Sustainable Infrastructure, Auckland, NZ, 2008.
- Opening Keynote, 8th International Symposium on Green Chemistry in China, Beijing, China, 2007
- Opening Keynote, Asian Oceanic Network's Green Chemistry Conference, Tokyo, Japan, 2007
- Keynote, First Pan-African Green Chemistry Conference, Cape Town, South Africa, 2007
- Keynote, Case Western Reserve University, "Frontiers in Chemistry", 2006
- National Academy of Sciences workshop on Green Chemistry Education, 2005

- National Academy of Sciences workshop on Science and Technology for Sustainability, 2005
- Federation European Chemical Societies, Bordeaux, France Keynote Lecture 2004
- Beckman Foundation, Irvine, CA, Invited Lecture, 2004
- Heinz Center, Washington, D.C., Invited Lecture, 2004
- Sustainable Resources Conference, Boulder Colorado, Invited Lecture, 2004
- 1St Indian Conference on Green Chemistry, Delhi, India, Inaugural Address, Nov, 2003
- AIST National Symposium on Risk Management of Chemicals, Tokyo, Japan, Keynote Lecture November, 2003
- International Conference on Green/Sustainable Chemistry, Tokyo, Japan, Plenary Lecture, March, 2003
- 'Prestige Lecturer', University of Canterbury, Christchurch, New Zealand, 2002
- Federation of European Chemical Societies Conference, "Chemistry for a Sustaining World", Athens, Greece, Keynote Address, 2002
- International Conference on Environmental Catalysis, Tokyo, Japan, Plenary Lecture, 2001
- Chemrawn XIV World Congress on Green Chemistry, Plenary Lecturer, 2001
- Green Chemistry in China, - Jinan, China, Honor Speech, 2001
- Royal Society of Chemistry Green Chemistry Conference: Sustainable Products and Processes Swansea, Wales, Keynote Lecture, 2001
- Venice Summer School on Green Chemistry, Keynote Lecturer, 2000
- Chemistry Olympiad – U.S. Team, Keynote Address, 2000
- Italian National Academy of Sciences, Invited lecture, 2000
- AAAS National Meeting, Science for Sustainability Symposium, Keynote Lecture, 2002

PUBLICATIONS: BOOKS

- Anastas, P.T. and Parent, K., eds. Green Chemistry Education: Changing the Course of Chemistry, American Chemical Society Press, 2008.
- Anastas, P.T. and Lankey, R., eds. Advancing Sustainability Through Green Chemistry and Engineering, Oxford University Press, 2002.
- Anastas, P.T., Bickart, P. and Kirchhoff, M., Designing Safer Polymers, John C. Wiley and Sons, 2000.
- Anastas, P.T. and Tundo, P.,eds., Green Chemistry: Challenging Perspectives, Oxford University Press, 2000.
- Anastas, P.T. and Warner, J.C., Green Chemistry: Theory and Practice, Oxford University Press,1998.
- Anastas, P.T., Heine, L., and Williamson, T.C., eds., Green Engineering, American Chemical Society Press, 2000.
- Anastas, P.T., Heine, L., and Williamson, T.C., eds., Green Chemical Syntheses and Processes, American Chemical Society Press, 2000.
- Anastas, P.T. and Williamson, T.C., eds., Green Chemistry: Frontiers in Benign Chemical Syntheses and Processes, Oxford University Press,1998
- Anastas, P.T., and Williamson, T.C. eds., Green Chemistry: Environmentally Benign Syntheses and Processes, American Chemical Society Press, 1996.
- Anastas, P.T., Farris, C.A. eds., Benign By Design: Alternative Synthetic Design for Pollution Prevention, American Chemical Society Press, 1994.

PUBLICATIONS: Over 50 Peer-Reviewed Scientific Papers and Articles