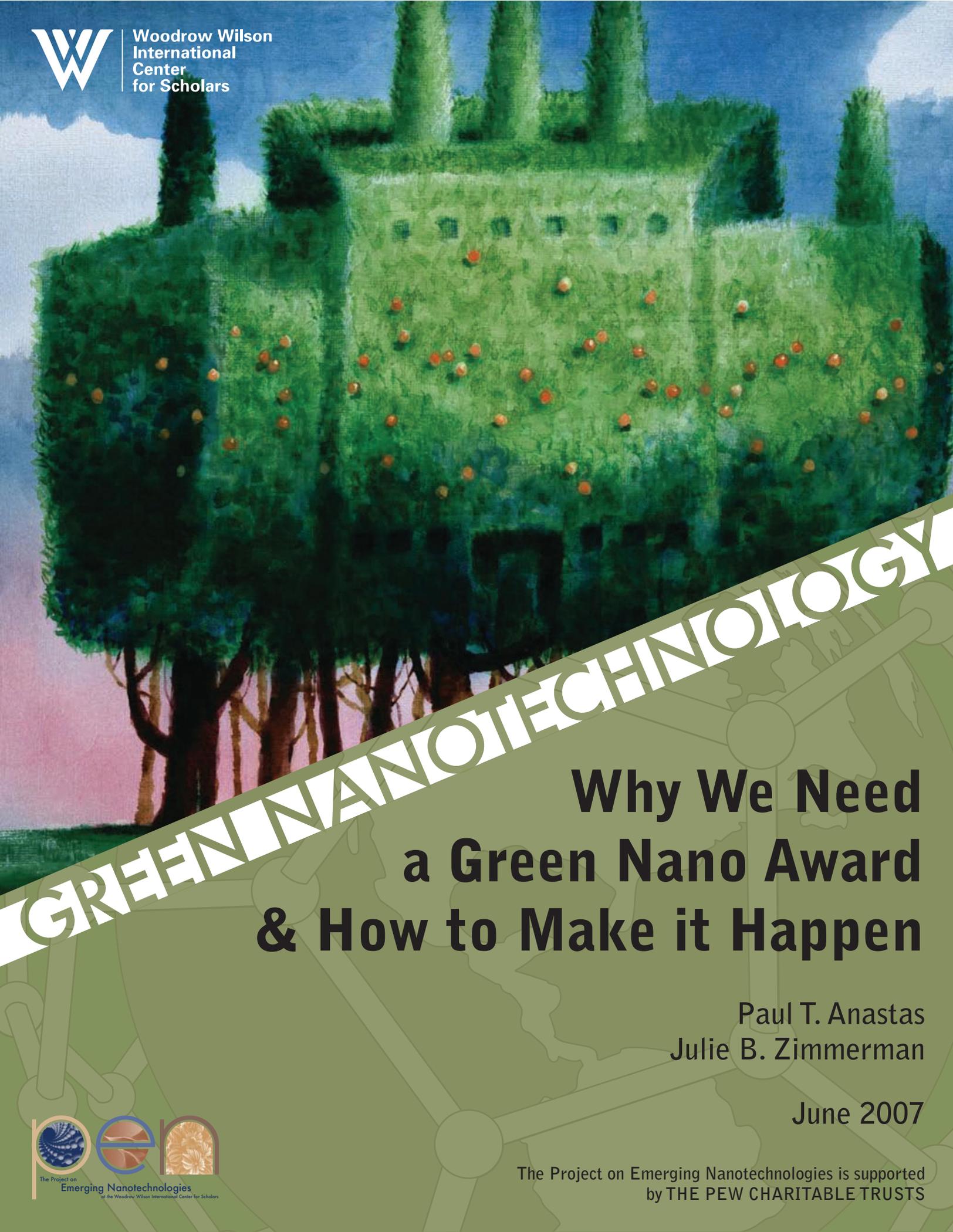




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GREEN NANOTECHNOLOGY

Why We Need a Green Nano Award & How to Make it Happen

Paul T. Anastas
Julie B. Zimmerman

June 2007



The Project on Emerging Nanotechnologies is supported
by THE PEW CHARITABLE TRUSTS

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The opinions expressed in this report are those of the authors and do not necessarily reflect views of the Woodrow Wilson International Center for Scholars or The Pew Charitable Trusts.

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PREFACE

Many have termed nanotechnology—the ability to manipulate matter at an atomic scale—the next industrial revolution. Nanoscale science and engineering will change the way in which we make just about everything, from materials to chemicals, and will have long-lasting impacts on almost every sector of our economy. Such fundamental changes in our industrial infrastructure are rare, occurring only every 20 to 30 years.

Given the nature of this transformation, we have an unprecedented opportunity to “green” this emerging production infrastructure in order to minimize emissions, reduce waste, and cut energy requirements. This opportunity, however, will not last long. As production systems for nanotechnologies are ramped up, flexibility will be reduced because of large capital investment in facilities, intellectual property arrangements, and supply-chain relationships.

Key production choices that industry makes over the next 5 to 10 years will become effectively “locked in” and may be difficult to modify with either policies or economic incentives. In 30 years, our legacy to the planet could be either business as usual—with increased and new risks to humans and the environment—or a new set of industries with a radically smaller environmental footprint. We must act aggressively now to ensure the emergence of nano-based processes and products with reduced environmental impacts.

Given the stakes, it is interesting that not a single nation has identified green nanotechnology as a national priority. No government program in the United States focuses resources on the development of green nano, and the topic has been largely a sidebar discussion at the hundreds of workshops and conferences on nanotechnology. While substantial research is being devoted to developing new applications of nanotechnology, relatively little research attention is being directed to understanding potential risks or to fundamentally avoiding them. This imbalance needs to be addressed.

The Project on Emerging Nanotechnologies has commissioned this paper as a discussion piece in order to facilitate the launch of a Green Nano award. Our hope is that such an award would elevate green nano to a visible national and international priority, recognize innovative approaches to reducing or eliminating risks, and reward scientists and engineers working in this emerging area. This paper reviews the key issues that need to be considered before establishing an award for achievements in green nano. We hope that others will join us in this important endeavor as we begin the stakeholder process to develop and launch the award.

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Washington, DC
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ACKNOWLEDGEMENTS

The authors acknowledge invaluable input from the experts at conferences including Safer Nano 2007 (Eugene, Oregon); 1st Asian-Oceania Conference on Green and Sustainable Chemistry (Tokyo, Japan); a Harvard/Yale Green Chemistry Institute Workshop called Impediments to Implementing Green Technologies (Cambridge, Massachusetts); and the American Chemical Society's National Meeting symposia on Green Nanotechnology in Atlanta (Spring 2006) and San Francisco (Fall 2006). Special thanks go to Dr. James Hutchison at the University of Oregon, Dr. John Warner at the University of Massachusetts-Lowell, and Kazu Hiyoshi of the Japanese Chemical Innovation Institute. Finally, thanks to the Project on Emerging Nanotechnologies, a partnership between The Pew Charitable Trusts and the Woodrow Wilson International Center for Scholars, for commissioning this report and for editing, designing, and producing this document.

BACKGROUND AND INTRODUCTION

People have been talking about nanotechnology in one form or another since 1959, when Richard P. Feynman gave his now-famous lecture entitled "There's Plenty of Room at the Bottom." It is, however, only since the establishment of the National Nanotechnology Initiative (NNI) in 2001 that nanotechnology has experienced rapid growth and become an increasingly important research area. In the last few years, several scientific journals specifically focused on nanotechnology have arisen in the United States and in other nations. Nanotechnology investments by the U.S. government exceeded \$1 billion in 2006, more than double the initial 2001 investment in the NNI. An estimated \$9 billion globally from both public and private funds in 2005 significantly augmented this recent growth.

Perhaps the most important reason for the current interest in nanoscience and nanotechnology is its ability to exploit unique properties and to generate new capabilities based on the size of the materials. The idea of complementing the traditional route of controlling properties through composition of matter with controlling properties through size has powerful implications. Using this newfound ability, companies and research groups around the world are aggressively pursuing the applications of nanomaterials. As of June 2007, more than 500 commercial products claim to incorporate nanotechnology, as shown in the Project on Emerging Nanotechnologies' Consumer Products Inventory (<http://www.nanotechproject.org/44>). These range from clothing to medical devices to sports equipment. The projected annual market for nano-based products is estimated to reach \$1 trillion by 2015 (Nel 2006).

While cutting-edge science is being used to develop new applications for nanomaterials, a number of studies and scientific analyses have looked at the potential implications of nanomaterials for human health and the environment. Several of these studies have raised concerns about the ability of nanomaterials to cross certain biological barriers in ways that may be harmful, and others have raised environmental concerns,

including the possible mobilization of nanomaterials in groundwater and the ability for nanomaterials to “escort” other toxic substances along various environmental or biological pathways.

One area that is beginning to emerge conceptually is the idea of green nanotechnology (green nano). Green nano refers to the design of nanomaterials and processes through green chemistry and green engineering that results in the development of new performance characteristics (including beneficial environmental applications) without adverse consequences to humans and the biosphere. It has been said that green nano preserves or improves the *applications* while minimizing or eliminating the *implications* of nanomaterials or nanoproducts. By designing nanotechnology upfront to address potential issues of concern to human health and the environment and reducing uncertainty, green nano may even protect the development of the field as a whole from public fears, real or perceived, and the legislative and regulatory backlash that might follow that fear.

Risk perceptions associated with emerging technologies and industries can be damaging, as was demonstrated by the introduction of genetically modified organisms (GMOs) into the marketplace. A strong opposition movement to GMOs developed in the late 1990s in many countries, especially in Europe, even though this technology was presented from the outset as highly promising and its advantages were often highlighted (Bonny 2003). Several risk-perception studies have been conducted in the United States and Europe to explore the reasons for public opposition to biotechnology. Some early studies found that the risks of DNA technology were perceived as extremely unknown, with very negative consequences that were delayed and not directly observable (Slovic 1987). There is substantial evidence that public perception of and attitudes about risk appear to drive beliefs about the acceptability level of emerging technologies such as genetic modification, although these factors have not to date been incorporated into regulatory processes and activities (Frewer et al. 2004). By asking the right questions and addressing issues of environmental and health concern proactively, industry and government can assure the public that nanoscience and nanotechnology are being pursued responsibly and that risks will be reduced or eliminated early.

Even though the pursuit of green nano promises significant advantages, it remains a very small area of research. The budget for government-funded nanotechnology research in the United States allocates approximately 95% for applications of nanotechnology, 4% for implications of nanotechnology, and less than 1% for green nano broadly defined (Dunphy Guzman et al. 2006). Nonetheless, while green nano may be growing slowly in some respects, there are leading groups that have enunciated and illustrated its major concepts. Recent conferences and symposia have highlighted some of the excellent work being conducted on green nano, including the Wilson Center’s Project on Emerging Nanotechnologies’ Green Nano forums,¹ the American Chemical Society’s Nanotechnology and the Environment symposium at its 2006 National Meeting, and the University of Oregon’s Safer Nanotechnology conference. Box 1 illustrates a few examples of this work.

¹ See <http://www.nanotechproject.org/116/4262007-green-nanotechnology-its-easier-than-you-think>.

Box 1: Examples of Green Nanotechnology Applications

- New manufacturing processes that are more selective and specific so as to minimize waste and by-product formation
- Separation and purification methods for nanoproducts that significantly reduce the solvent and energy usage currently associated with the isolation and purification of nanomaterial
- Design of nanomaterials that provide performance in the target application with greatly reduced or eliminated toxicity, bioavailability, or persistence

WHY AN AWARDS PROGRAM?

There are many ways in which to motivate people to engage in particular endeavors. These motivational forces may be positive, such as the provision of research funding, or negative, such as the threat of legal action for noncompliance. Another technique for motivating behavior is to provide an award and recognition (the “carrot” approach). The word *award* is applied in different contexts. In work on patent races, for example, the first firm to take out a patent might be seen as winning a prize (e.g., Grishagin et al. 2001). Prizes may reward previous work, as do the Nobel or Pulitzer Prizes, or they may promote future achievement.

Awards break down into two basic types: inducement and recognition.

Inducement prizes, or incentive prizes, are offered to individuals or groups who provide the best entry in a contest or who are the first to meet a specified technical goal. Such prizes may or may not include a cash reward. The prizes are prospective, intended to induce people to do something better than others, or to do something that has not been done before (National Academy of Sciences 2000). Historical examples include a 1714 prize offered by the British government for the first practical method to determine longitude at sea and an early 20th century set of aviation prizes, including the prize for the first nonstop flight from New York to Paris. More-recent inducement prizes include a private-sector prize for super-efficient refrigerators, a prize-like program at the Federal Communications Commission in the early 1990s for wireless personal communications services and low-Earth orbit communications, two new private-sector prizes for innovative space launch vehicles, and several prizes offered for achievements in computing (National Academy of Sciences 2000).

Recognition prizes are awards offered to recognize past achievement. The Nobel Prizes in science are the most famous examples. The Draper Prize, given by the National Academy of Engineering, recognizes significant accomplishment in engineering. As with

inducement awards, these prizes may or may not include a cash component (National Academy of Sciences 2000). The number of recognition prizes in science and technology is large and growing. As of 1992, some 3,000 science prizes were available in North America alone, five times as many as 20 years earlier (Zuckerman 1992). Some of the newer awards are in the same fields as the Nobel Prizes, while others are conscious attempts to create prestigious awards in fields not covered by the Nobels.

Recently, the World Health Organization and the World Bank proposed the use of prizes to induce the development of vaccines that would otherwise not be developed or distributed widely enough (Kremer 2000). Others have suggested the use of prizes to promote innovation to increase Third World agricultural productivity (e.g., Kremer and Zwane 2002, Masters 2003, Kalil 2006) and for energy and climate change research (e.g., Kalil 2006). In 1990, the \$100,000 Loebner Prize was offered for the invention of a computer whose responses to questions cannot be distinguished from a human's. In memory of physicist Richard Feynman, the Foresight Institute has sponsored a grand prize worth at least \$250,000 to spur scientific and technical progress in nanotechnology. The \$10 million "X Prize" was created in 1996 to stimulate a new generation of launch vehicles to carry passengers into space (National Academy of Sciences 2000, <http://www.xprize.org>).

Prize programs such as these are demonstrating their ability to focus the attention of policymakers, entrepreneurs, and the attentive public—as well as researchers—on the goals of an innovation program (National Academy of Sciences 2007). These types of programs can stimulate a high degree of competition among the participants pursuing the award and are likely to attract a diverse array of organizations with new perspectives and approaches to the desired target. Another benefit is the creation of incentives for use and leveraging of financial resources toward the intended goal. These programs also ultimately lead to information sharing about lessons learned and best practices, and they advance the state of knowledge in a direction that has been identified as relevant and significant by the award program organizers.

WHY HAVE A GREEN NANO AWARD?

Establishing an award program could motivate green nano accomplishments, that is, achieving applications of nanotechnology without negative implications for human health and the environment. There are a number of reasons why an awards program in green nano could engage a greater number of people in green nano and catalyze this emerging and important field.

One primary reason for such an award is to recognize an accomplishment and to give credit where credit is due. This kind of recognition can be very powerful in an emerging field, especially within the scientific and technical disciplines. Emerging fields often do not have well-established support or reward systems. The peer-review systems, market awareness, tenure committees, industry analysts, and trade and technical journals may not have the perspective and history to adequately appreciate outstanding work

being done in a nascent research area. In an emerging field, external validation can be critical. It is essential to the growth of a field since it can strengthen, and in some cases protect, the strongest champions for advancing the field, its early adopters: the leaders at the vanguard who are often the most vulnerable. Therefore, giving credit where it is due is an important strategic element that needs to be considered when constructing an awards program.

Another motivation for creating an awards program in green nano is to gather data on industrial processes that improve human health and the environment that are currently very difficult to obtain. One reason for this is that a company may fear that its suggested innovations will lead to criticism of its practices. That is, if a company discovers a new, “green” alternative and seeks recognition for this accomplishment, the prior process, with its flaws, may be examined more closely. Even within academic research laboratories, there is often no driver to quantify the potential value of many new improvements from the perspective of human health and the environment. Yet the ability to get these data—these success stories—out to the public is an important part of advancing the field of green nano. An awards program would provide the platform and incentive to encourage individuals and organizations to release information on their technologies in a relatively safe way. While it should not be expected that information on highly proprietary technologies would necessarily be released merely for an award, a very important database could still be built from the collected nominations submitted to the awards program.

In the absence of an awards program or a similar mechanism, there is little knowledge about who the leaders or laggards are in a particular field and little incentive for one company, group, or institution to step forward. An awards program can be used to create a competitive dynamic whereby there is a “race to the top” —a race to see who can excel in this area. This type of competition can be seen in analogous award programs ranging from total quality management to customer satisfaction, as well as in awards for environmental performance.

Measuring progress within a given field can also be achieved through an awards program where the key players willingly volunteer information in hope of receiving recognition for substantive accomplishments. The evaluation process of even the initial batch of nominations for the proposed award can provide a benchmark for the current state of nanotechnology in terms of designs that address its human-health and environmental impacts. This analysis will obviously have limitations and cannot be overinterpreted. Nevertheless, it will provide increased insight into important questions concerning how nanotechnology can be applied with reduced or eliminated negative impacts to human health and the environment.

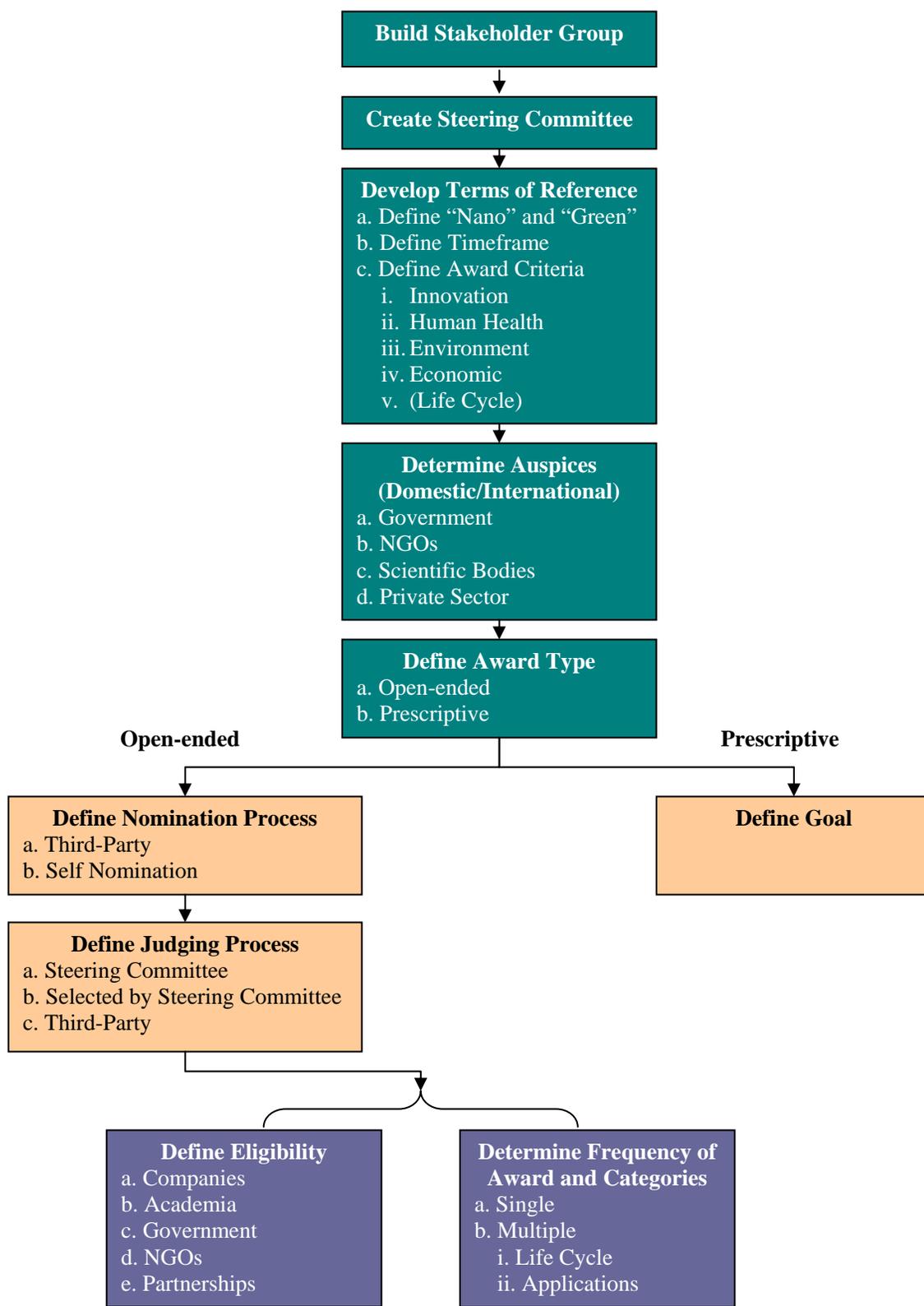
After several iterations of the awards program, the data set will also allow for some rudimentary trend analysis covering what topics are emerging as key foci in the field, what breadth of sectors are getting involved, and where problem areas are arising. Using the awards results for public benchmarking and trend analysis will help increase

the value of the award, not only to the award recipients but also to other businesses, the government, and the public as a whole.

Finally, one of the very important reasons to launch an awards program in green nano is the opportunity it provides to increase the visibility of this important area. Green nano has received little coverage in the popular media, and an award could make the topic more newsworthy. An awards program will bring attention to the challenging issues that green nano is seeking to overcome as well as to the excellent solutions that those working in the field are developing. An awards ceremony could be a nucleating event that would bring together the best ideas in the field, high-profile individuals from various organizations, and the media. Used correctly, awards programs have been shown to increase the interest and investment in a field or endeavor (National Academy of Sciences 2000).

The following diagram provides a decision road map for the issues that need to be considered for developing a Green Nano Awards Program. These are discussed in the following sections.

Green Nano Award Decision Road Map



WHAT PROCESS SHOULD BE USED TO DEVELOP THE AWARDS PROGRAM?

The success or failure of an awards program is often dependent on its very first steps. If the process that is used to develop the program is not carried out in an inclusive, respected, transparent, and organized manner, the program may be doomed to failure before it is even launched. Because of this danger, it is important that anyone considering launching an awards program consider factors such as the following at the earliest stages.

- **Involvement of stakeholders.** A careful analysis should be undertaken to identify the groups that consider themselves to be important stakeholders regarding green nano. These stakeholder groups should be invited through some mechanism (e.g., meeting, workshop, and/or written comments) to participate at an appropriate level in the development of the awards program. Being overly inclusive at the beginning of the process is certainly less dangerous than not being inclusive enough. However, the more stakeholders involved in the process, the more difficult it may ultimately be to come to agreement.
- **Terms of reference.** It is legitimate for the convening group—those that are driving the initial idea of an awards program—to identify terms of reference or ground rules for the planning discussion. Otherwise, the discussions may quickly become so diffuse and off-topic that they are non-productive. The danger of being overly prescriptive with these ground rules is that the stakeholders may not feel that they have an adequate say in the development of the award and that they have been invited solely to give their stamp of approval of a fait accompli. An appropriate balance must be struck. For example, in the case of a Green Nano award, it is appropriate to define what is meant by “nano” and what is meant by “green,” and other fundamental decisions, prior to convening stakeholders.

Defining what is not on the table for discussion can be very useful in developing the terms of reference. Rather than appearing to have laid out all the issues ahead of time, the facilitator might say that everything is on the table with the exception of x, y, and z. For example, several awards on pollution prevention would specify that waste treatment and remediation technologies would not be appropriate for the discussion.

- **Steering Committee.** Because only a certain number of individuals can be included to maintain the effectiveness of the group, it will be necessary to create a smaller group, or steering committee, to review and discuss the input from stakeholders and then make and implement final decisions. The importance of balance on this committee, for both the initial success and the long-term health of the awards program, cannot be overemphasized. While keeping the number of sub-committee members small and balancing

qualifications of the individuals is challenging, it is both possible and necessary. Attracting individuals of note with diverse backgrounds can make the task easier. Ensuring representation from industry, government, academia, and environmental and public health groups is important. The inclusion of major funding source(s) should be considered for representation on the steering committee. Most important, no individual should be part of the steering committee if he or she would negatively impact the standing of the award, either as a result of individual issues or a conflict of interests due to an association with other organizations. In either case, it is important that representation on the steering committee be considered carefully given the potential for these conflicts of interest due to advanced knowledge of criteria, competitors, or funding opportunities.

SCOPE OF THE AWARD

Having secured broad input from numerous stakeholders, the steering committee will outline the scope of the award. The statement of scope basically answers the question “What is this program recognizing?”

An important element will be defining “nano.” While it is possible to create new definitions that are tailored to the program, it would be advantageous to adopt a definition of nano from well-established and well-respected sources. Using the NNI’s definition or one cited in statutory language is one defensible choice. Using a definition set forth by a scientifically respected source such as the National Academies or a major science journal would also be very defensible. Introducing a new definition of nanotechnology for the purposes of this award is highly discouraged.

A definition of “green” can be more complex, since there are many perspectives on what makes something “green.” One possible definition of green nano is: “nanoscience and nanotechnology that have been designed to reduce or eliminate adverse consequences to human health and the environment while performing its intended application.” Important questions to address are whether the concept of “green” should address the entire life cycle of the technology, including the origin of the materials used, the manufacturing process, the impacts of the use phase, the nature of the product itself and what happens to the product after its commercial life is finished, or just certain parts of the life cycle.

If the award will recognize “sustainable” nanotechnology or nano-enhanced environmental technologies (e.g., for energy storage, renewable energy, pollutant removal), the task of assessing the impacts of a particular technology on the environment, the economy, and society is much more complex. Currently, there is considerable debate about the state of sustainability metrics. Using a set of existing metrics would be possible but controversial since there is no agreement on the best approaches to these types of measurements. Developing new metrics would be potentially time-consuming, expensive, and no less controversial, as this is likely a project onto itself. It would be

very disadvantageous for a new award to start out being the subject of debate on the validity of its approach. A new award must build consensus and community, and anything that undermines that goal, such as introducing new, potentially controversial, sustainability metrics, should be undertaken with caution.

A good option would be to rely on definitions of the term that are in the current scientific literature. The term *green nanoscience* was coined by McKenzie and Hutchison, who first used and defined it in a 2004 paper by the same name. In that seminal paper, the authors say, “Green nanoscience brings together the methods and approaches of both green chemistry and nanoscience to develop green products, processes, and applications” (McKenzie and Hutchison 2004). There is legitimacy in adopting original terminology as a basis for definitions.

In addition to ensuring that the nominated projects are indeed both “nano” and “green,” it is important to consider the timeframe in which the technology was introduced. This is important for several reasons. First, the award should be associated with innovation. This is critical since a major goal of the program is to drive continuous improvement toward greener nanotechnology. (This will be discussed in more detail later in this report.) In order to achieve this goal, a relatively short timeframe between developing the technology and applying for the award should be a part of the award scope. It is also useful to have a set timeframe for logistical reasons as a protection against nominations being submitted repeatedly. If there is concern about overlooking some older advances in green nanotechnology because of this timeframe restriction, that can be dealt with through a “lifetime achievement” award or similar special category that may be reserved for pioneering people or technologies. The balance between being inclusive and encouraging recent advances means that the timeframe is a somewhat arbitrary determination, but a range of three to five years would be appropriate. The hard time line can be made more inclusive by associating it with “major milestones” for the technology, ranging from discovery to development to commercialization, as indicated by publications, patent filings, and profits/market share, respectively.

CRITERIA FOR THE AWARD

The criteria for the award are the most critical aspects of the entire initiative. The first task is to decide on the criteria elements; the second is to make those elements more specific. Clear, unequivocal, objective criteria will make judging the applicants very straightforward. However, this approach does not take into account intangible considerations that may be extremely important to a judging panel and to the awards program as a whole. Assessment criteria elements that are too strict may face the unintended consequence of recognizing only technologies that lend themselves to statistical measure. The important caution attributed to Einstein—“Not everything that can be counted counts. And not everything that counts can be counted”—is a useful admonition in considering the award criteria. A continuum is advisable, wherein the judging panel may consider objective measures as well as more qualitative measures.

The criteria elements of a Green Nano award should reflect the purpose of the award and may include the following:

- **Innovation.** The nominated technology should show significant and substantial improvement over the current state of the art of nanotechnology or of the area of technology that it is seeking to displace. The measures could be new performance, capabilities, or efficiencies, and may be illustrated through patents, publications, testimonials, or demonstrations. Transformational technologies that bring about “Factor 4” (or greater) advancements could be explicitly rated more highly than incremental improvements.²
- **Human health.** The technology should demonstrate either beneficial impacts on human health or reduced adverse impact on human health. For this criterion, the nomination should include an analysis of why this technology is believed to have the potential to have a positive impact on human health, either in absolute terms or relative to a current technology that it is displacing.
- **Environment.** The technology should demonstrate either beneficial impacts or reduced adverse impact on the environment. The nomination should include an analysis of why this technology is believed to have an overall positive impact on the environment, either in absolute terms or relative to a current technology that it is displacing.
- **Economic.** In order for the technology to benefit society, it will need to possess an economic viability or the potential for economic viability (depending on the stage of development of the technology). In some cases, evidence of economic viability can include actual profit and market share statements for fully commercialized and mature products. Other emerging technologies may need to present an analysis that is more speculative, yet based on sound economic models.
- **Life cycle.** If life cycle is included in the awards program’s definition of green, the nomination should address the impacts of the technology throughout the life-cycle stages. While a full life-cycle analysis is not required, a presentation of the important life-cycle impacts and implications must be included.

Within these above criteria elements, it is possible to introduce further refinements by specifying what data elements need to be provided in the nomination package. Data elements must be specified carefully, since they will narrow the nomination pool prior to consideration or review by a judging panel. It may be beneficial to list suggested “useful evidence” for meeting particular criteria rather than making the supply of certain data a “toggle switch” that defines a potential nominee as either in or

² The idea behind “Factor Four” is that natural resources can be used more efficiently in all domains of daily life, either by generating more products, services, and quality of life from the available resources, or by using less resources to maintain the same standard (Weizsäcker et al. 1997).

out of the award process. Since one of the goals of a Green Nano award is to build a database of technologies and products, it is advisable to encourage the submission of as many new nominations as possible.

AUSPICES OF THE AWARD

One major factor that will determine how the award is valued by the scientific community, the business world, non-governmental organizations (NGOs), the media, and the general public, is under whose auspices the award is given. Certainly, a disreputable organization would make it difficult for the award to succeed from the start; while an organization of high repute and regard would greatly enhance the value placed on the award. Most awards fall somewhere between these two extremes. However, it is important to note that certain entities, even if they are reputable, may be perceived as having a bias. The auspice of the award must be carefully considered in that light, even if the auspice is not directly involved in the award-selection process.

For a domestic award based in the United States, there are a number of governmental options to consider, including:

- Federal Government Agencies
 - National Science Foundation
 - Environmental Protection Agency
 - National Institute of Standards and Technology
 - Department of Energy
- U.S. Congress
- White House
 - Office of Science and Technology Policy
 - NNI
 - Council on Environmental Quality
- State and Local Governments

For an international award, the governmental options may include:

- Organization for Economic Cooperation and Development
- United Nations
 - Secretary General
 - United Nations Environment Program
 - G-8
 - Carnegie Group of Science Ministers

For a domestic or an international award, the non-governmental/scientific/professional organizations options are plentiful and have a variety of trade-offs. Possibilities include:

- Environmental Groups
 - Natural Resources Defense Council
 - World Resources Institute
 - Environmental Defense

- Greenpeace
- Scientific Groups and Professional Societies (and their journals)
 - National Academies
 - American Association for the Advancement of Science (*Science*)
 - American Chemical Society (*Environmental Science and Technology*)
 - Massachusetts Institute of Technology (*Technology Review*)
- Research Organizations and Institutes
 - Wilson Center Project on Emerging Nanotechnologies
 - Union of Concerned Scientists
 - Public Interest Research Groups
 - Science in the Public Interest
 - Green Electronics Council

For a domestic or an international award, the private-entity options are plentiful and have a variety of trade-offs.

- U.S. Business Council for Sustainable Development
- U.S. Chamber of Commerce
- Intel Corporation³
- NanoBusiness Alliance

WHAT TYPE OF AWARD?

It is important to consider whether the award will be more open-ended or more prescriptive with respect to the type of work that will be rewarded. Open-ended awards tend to be recognition-type programs for significant accomplishments in a broad field, while a more prescriptive program would more closely resemble an inducement prize, in which the desired outcomes are stated and the award is given only for achieving those outcomes.

Open-ended

An open-ended prize provides an award (financial, honorary, or both) for work that has already been done. This type of award is useful in recognizing and validating significant research and can bring more attention to the field. As awareness of the award program grows, it can spark innovation and investment in emerging green nano aspects.

Prescriptive

A prescriptive award is usually desirable when a technological threshold or target is specified before the research begins. This type of award induces innovations, rather than awards past breakthroughs. This requires that the goal or target be established ahead

³ Intel Corporation was called out as an individual company due to its sponsoring role of the nationwide Science Talent Search, America's oldest and most highly regarded pre-college science contest. The contest is designed to reward innovative, cutting-edge, independent research.

of time and that it be specific enough to ensure that there is no uncertainty as to when the desired results have been achieved. The goal-setting process itself may require a significant amount of time, energy, and resources. Also, this type of award will likely exclude environmental, advocacy, and policy-type NGOs and governmental organizations from being recognized by the award program. This is an important consideration, as these types of organizations may play vital roles in advancing the field and growing the community in green nano.

HOW MANY AWARDS TO GIVE EACH YEAR

All other factors being equal, the fewer the awards given out each year, the greater prestige the awards confer. However, a small number of awards can make it difficult for a new award program to garner broad support and recognition. In addition, if the number of awards is too small, the pool of nominees may also be small. That, in turn, would make it harder for the program to reach its goal of creating a database of green nanotechnologies. On the other hand, a larger number of awards may dilute the distinction given to fewer winners and could in turn make it more difficult to get media coverage.

Single Recipient Awards for an Individual or Group

There is often a relationship between the exclusivity of an award and the prestige associated with it. A number of awards are given annually to a single recipient or possibly two recipients in the fields of environment and/or sustainability. They include:

- the Tyler Prize for Environmental Achievement (premier award for environmental science, energy, and medicine conferring great benefit upon mankind; \$200,000 cash award; administered by the University of Southern California);
- the Blue Planet Prize (to help preserve Earth's beauty for future generations; \$400,000 cash award; administered by the Asahi Glass Foundation); and
- the Clarke Water Prize (recognizes outstanding research scientists who have implemented better water-science research and technology; \$50,000 cash award; administered by the National Water Research Institute).

By limiting the number of Green Nano awards, it is possible to create a highly desirable and esteemed award with the potential for a larger monetary prize, if one is given, since it will not need to be divided among multiple winners. However, limiting the number of awardees may be discouraging to potential applicants and may pose a barrier to the goal of building a green nano community.

Another model for creating a single-recipient award is to create an "inducement prize." In this case, a competition is established that awards a prize, often monetary, for the accomplishment of a feat that often extends the current limits of human ability. Inducement prizes are distinct from recognition prizes, such as the Nobel Prize. There is one inducement prize in the field of nanotechnology: the Foresight Institute is offering a

\$250,000 Feynman Grand Prize for the first person(s) to design and build two nanotechnology devices—a nanoscale robotic arm and a computing device that demonstrates the feasibility of building a nanotechnology computer.

While inducement prizes have been highly successful in encouraging the accomplishment of specific goals (e.g., the Orteig Prize for the first solo flight across the Atlantic, won by Charles Lindbergh), the approach has pros and cons. With an inducement prize, there is certainty that the goal established by the award committee will be achieved; however, reaching this goal could take an extremely long time. This means that the award could be announced, but not given, for many years, resulting in a loss of momentum, interest, and media coverage for the interim years. In addition, the goal-setting process itself could require a significant amount of time, energy, and resources, since the steering committee, with input from stakeholders, would have to come to consensus on a single, long-term vision for the most important achievement in green nano. Finally, those seeking to accomplish the stated goal will need a sustainable, long-term, and potentially significant source of research funding. While this would not be the responsibility of the awards program, it is important to consider that it may be a challenge for many would-be contenders.

Award Programs with Several Categories

Another common structure for awards programs is to give multiple awards in different categories on an annual basis. This type of program can recognize a larger portion of the community each year and encourage broader participation by providing multiple opportunities for recognition. However, if too many awards are issued each year, it could dilute the prestige associated with a newly established awards program. This multiple-award structure, when pursued with a moderate number of awards, is very popular, with examples ranging from the Nobel Prizes to the Baldrige National Quality Awards for organizational performance excellence to the Presidential Green Chemistry Challenge Awards. In each case, the awards are given for significant advances that range across fields or across categories within a single field. In this case, the pool of nominations can remain large but there is reduced competition for any single award, which can be supportive and encouraging for the community. It is also important to note that the categories selected for the award can often define who will be eligible for it. For example, if “Policy Tools” or “Advocacy” is not recognized within any of the selected categories, it is possible that NGOs, particularly environmental organizations or think tanks, will not be eligible.

For a Green Nano award, there are several options for creating awards in multiple categories. Below are some suggested options for offering multiple awards.

Option 1: Life-cycle stages

- Synthesis
- Manufacturing
- Use
- End of life

Option 2: The “Ps”

- Production
- Products
- Processes
- Policies

Option 3: The “Ds”

- Design
- Discovery
- Development
- Demonstration

Option 4: Applications

- Water
- Energy
- Health care
- Consumer products

Option 5: Eligibility

- Global/multinational companies
- Small businesses
- Academia
- NGOs

Option 6: A hybrid of the above options

NOMINATION PROCESS

The nature of the nomination process can dramatically affect the number of nominations that are received for the award. In many programs that require independent, third-party nominations, there are often very few nominations to consider. While this would alleviate pressure on the reviewers, it also may limit the ability of the awards program to build a viable green nano community and to secure the necessary buy-in for the award.

One strategy utilized by certain award programs is to tap into a body of pre-identified individuals who are respected and knowledgeable in a field and to solicit nominations from them. As a program progresses, these individuals are increasingly comprised of previous award winners.

If the award is to be international and coordinated with national interests around the world, there could be a system whereby national committees choose a nominee to forward to an international review board. In this way, the awards program can build

multiple national awards programs, thereby multiplying its impact while also establishing an organizational structure for soliciting nominations globally.

Finally, a fourth option is to open the award-nomination process broadly to allow anyone to nominate, including self-nominations. This can work well for awards programs that are honorary in nature or that have only a nominal monetary prize. Generally, self-nominations would not be encouraged for awards that have significant monetary value, as this could result in overwhelming response to the program and a significant (and possibly unreasonable) burden on the review process.

HOW TO RUN THE JUDGING PROCESS

The integrity of the judging process is an important factor not only for selecting the most worthy recipient but also for maintaining the respect and perceived legitimacy of the award by the target community and the public. In order to achieve this, other award programs have used a number of strategies, as detailed below.

Judges are the steering committee

Since the individuals selected for membership on the steering committee will be, by design, representative of those organizations and stakeholders of highest relevance and importance to a Green Nano award, it is reasonable to assume that they possess the same breadth of perspective that would be needed to comprise an appropriate judging panel. However, some members of the steering committee may not have sufficient time to devote to a judging process, or, more important, may have a bias that could affect the impartiality of the process.

Judges selected by the steering committee

A second option is that the steering committee selects the judging panel directly. Like the first option, this one continues to give the steering committee direct involvement in and oversight of the awards process. It also gives the committee an opportunity to ensure the quality and breadth that it wishes to see in the review and judging process. The steering committee would invite highly regarded individuals to serve on the judging panel, thereby allowing flexibility in achieving the desired diversity of represented sectors, expertise, and perspectives. The downside of this option is that the members of the steering committee, or those individuals whom they select, may have a bias that affects their ability to judge impartially.

Partnerships with technically credible organization to handle judging

Instead of being directly involved in the judging process, the steering committee could appoint an independent, third-party group to handle the review and judging functions. This model has worked successfully for other awards programs. Since a Green Nano award would have a strong technical and scientific orientation, it may make

sense to engage a respected scientific organization such as the National Academies or a professional scientific society. This third-party process visibly emphasizes the independence of the judging panel as not being an agent of an organization responsible for administering the awards. It can have the additional advantage of tapping into existing organizational structures and staffing, rather than having to create an infrastructure for this specific purpose.

WHO SHOULD BE ELIGIBLE FOR THE AWARD?

The eligibility criteria will determine the character of the award. Decisions regarding whether the award is recognizing the accomplishment—that is, the technology itself—or the company, individual, or organization that created the technology is a fundamental distinction to be considered by the award program.

Companies

In considering whether or not to allow individual companies to be recognized, it is useful to consider potential trade-offs. Recognizing a corporate entity can be viewed as an endorsement of the company as a whole rather than of a particular achievement. Global companies in particular often have a breadth of operation that is less than homogeneous, and it may be possible that the award program does not wish to endorse all activities and actions of the company. Likewise, the award program may not want to appear to be endorsing all the company's products. It is also important to consider the role that small businesses often play in emerging fields such as green nano and the unique challenges that small businesses face when conducting high-risk research and development. For reasons such as these, it may be useful to acknowledge the contributions of small businesses separately, thereby leveling the playing field of those eligible for the award.

In sum, while there are many reasons that companies, rather than individuals, should be eligible for the award, the program should think seriously about how the award is characterized.

Academics

The eligibility of academics bears directly on how forward looking the award seeks to be. Since the work of academics will likely not have commercially demonstrated data and will instead largely be focused on research breakthroughs, the steering committee must decide whether the award program should recognize only “real-world accomplishments” or whether advancing the science and technology of the field also fits with the mission of the award. In addition to strengthening the field, allowing academics to be eligible for the award will provide necessary validation for these pioneering researchers whose work may not be highly valued by their peers or by the current reward systems in higher education.

At a time when many academics—especially those working in innovative areas such as nanotechnology—are forming independent, start-up businesses, it will be important to make it clear that the work of the start-up would be considered a corporate nomination and not an academic one. This is sometimes difficult since the lines between these two endeavors are blurred. Fairness and integrity of the awards program would dictate clarity regarding such distinctions.

Government

There are two main options to consider regarding government entities. If the awards program wishes to create an award category for policy that advances the state of green nano in a broad context, the government clearly would need to be eligible for the award. The second, and not mutually exclusive option, would be to allow governmental organizations to compete in the technology categories with the other sectors. It is worthwhile to consider the wide range of government laboratories—within the National Institutes of Health, National Institute of Standards and Technology, Environmental Protection Agency, U.S. Department of Agriculture—and laboratories that are contract facilities of the government—particularly those associated with the National Aeronautics and Space Administration and Department of Energy—conducting important nanotechnology work for inclusion in the awards program.

Non-governmental Organizations (NGOs)

Like many emerging fields, green nano needs support from many different organizations. The NGO community represents many different types of groups, including environmental advocacy, policy think tanks, and research institutes. While NGOs conducting research may be eligible under many of the categories discussed earlier, many other NGOs may not. If NGOs are to be eligible for a Green Nano award, it will be necessary to create an appropriate category where they can compete. In addition, by allowing NGO eligibility, it is possible that the Green Nano award will not be based strictly on scientific or technical advancement, making an inducement prize a more difficult choice for award structure. However, if NGOs are eligible and there is not an appropriate category for many of them, it may alienate a very important group of organizations from the green nano community.

Collaborative Partnerships

Given the relationship between eligibility and the award categories, it is important to consider that some of the most significant research in emerging fields comes from partnerships between industry and academia or among industry, government, and academia. This allows for the highest-quality individuals with unique expertise to come together on a project that often carries a higher degree of risk than can be supported by any single entity. As the categories are established, it is important to decide whether such partnerships will be eligible for the Green Nano award. By acknowledging this category, the Green Nano award can further encourage the formation of these types of collaborations.

SHOULD THE AWARD BE INTERNATIONAL?

There are both advantages and disadvantages to launching a Green Nano award as an international award. While an international award would reach out to significantly larger audiences and attract greater exposure, as well as a larger population of potential nominees, the logistics of coordinating the scope, criteria, funding, and press for the award would be a major undertaking. That said, there are several options to consider.

Awards are designed, developed, and implemented by an international group

The steering committee could choose to involve experts and relevant stakeholders in the international nanotechnology community to be part of the Green Nano Awards Program from the outset. There is active research on green nano in the European Union (especially in the United Kingdom), Japan, India, and elsewhere. The steering committee could coordinate efforts of the international community to develop the foundation for an international Green Nano award that would be open to companies and individuals from around the world.

Many nations have national awards and then select one international winner from the national winners

A second option would be for each nation to develop its own approach to and criteria for the award, reflecting its own industry, values, and infrastructure. An international winner would then be selected from among the country winners. This model has the potential not only to strengthen the national initiatives but also lend credibility to the international award. A major downside to this approach is that not all countries can compete equally on the international level.

U.S.- only model with efforts to duplicate elsewhere

Another option would be to launch the award as U.S.-based. The steering committee would then focus on developing a model in the United States for a Green Nano award. Once successfully established, the U.S. program could be used as a model for other nations that could modify it, adopt it, or build on it in developing an award for green nano in their own national contexts.

INCREASING VISIBILITY OF THE AWARD

Someone once said that, “If one discovered absolute truth and it was written in a book that gathered dust and no one read it, it would be as if it were never discovered.” If the Green Nano Awards Program is launched and succeeds in all its logistical and organizational tasks, and yet is invisible to the community it seeks to motivate and the public it seeks to inform, it will be for naught. The awards program could take several steps to enhance visibility.

Press involvement at outset

Steering committee members should be selected not only on the basis of their expertise but also on what they can bring to the program in terms of press coverage and public outreach. This can be accomplished through engaging journalists who are leaders in press coverage of nanotechnology or sustainability, officers of professional societies that have a large journal readership, or simply individuals with extensive press networks and experience.

Emphasize nanotechnology in everyday life

If the program emphasizes the positive impact of the award-winning technology on people's daily lives—perhaps even including such a factor in the judging criteria—it will be easier to garner press coverage. Also important is emphasizing the human-health benefits achieved or mitigated with this technology, particularly if they are relevant to vulnerable populations such as children.

Involve organizations with notable communications network

By including organizations that have an established infrastructure for communication and outreach, the Green Nano award will benefit in terms of increased efforts by those organizations that feel some ownership for the success of the award. These organizations will be promoting their participation in this newly established award, thereby promoting the award itself. Furthermore, these groups are more likely to accurately describe the processes and goals of the award with an inside perspective, minimizing the opportunity for misinformation in the media. Two other potential benefits of this arrangement are reduced costs to the Green Nano program for services the participating organizations will handle and dissemination to participating organizations' stakeholders, which may not have been reached otherwise.

Tie into established high-profile awards

In order to save time, money, and resources, the award program may find it worthwhile to connect to an established and respected awards program. This will allow leveraging of existing infrastructure in terms of communications, outreach, and award ceremony logistics. The new award program will also benefit from the credibility and prestige of the existing award. There are also drawbacks to this type of approach; for example, the Green Nano award would have to give up some ownership of the awards and would risk being seen as a subset of existing pursuits rather than as an important and distinct emerging field. The merits of connecting to an existing program should be weighed carefully, as the benefits may be short-term gains in time, money, and effort while limiting the ability of the Green Nano award to expand and have an independent identity in the future.

LOCATION OF THE AWARD CEREMONY

The location of the award ceremony, although not a huge factor in the success of the program, can determine the extent of press coverage and prestige to the Green Nano Awards Program.

Recognized and valued by the winners

If the venue for the awards ceremony is immediately recognizable and highly perceived by the award winners, receipt of the award carries an additional benefit. Awards that are presented at the White House are considered very valuable and prestigious on the basis of location alone. To the scientific community, the National Academies offers significant value. The venue should be selected so as to strengthen the prestige of the award and its value to the recipient.

Good visuals

In order to attract and encourage press coverage that includes photographs, film, or video elements, the steering committee may want to select a venue for the awards that is aesthetically pleasing. While there are exceptions, most indoor venues do not fill these requirements. Outdoor venues can be selected to emphasize the “green” message and real purpose of the Green Nano award.

Ability to accommodate growth and success

If the ceremony is to be held at the same site each year, the program may wish to select a venue that can accommodate growth in the award. If the venue can accommodate only a very small number of participants, it may be difficult to continue at this venue as the award grows in stature and in public interest.

FINANCIAL SUSTAINABILITY OF THE AWARD

The amount of funding needed to carry out the Green Nano Awards Program will vary considerably depending on the scope of the program and whether the prize is one of recognition or of inducement with a monetary award. The annual cost of implementing award programs in similar fields runs as low as \$150,000 for programs such as the P3: People, Prosperity and the Planet Student Design Competition for Sustainability (<http://es.epa.gov/ncer/p3/>) to as high as \$400,000 for the Presidential Green Chemistry Challenge Awards (<http://www.epa.gov/greenchemistry/pubs/pgcc/presgcc.html>). The P3 Award Program cost does not account for the significant internal staff time and internal resources dedicated to the program; if these expenses were added, the program cost would be at least twice that amount. The P3 Awards also offer a possible \$75,000 grant. The Green Chemistry Award cost does not account for internal time, use of external contractors, or significant donations by the American Chemical Society, which

helps with the reviews and judging for the award. If monetized, these contributions would add \$50,000 to \$100,000 to the annual program cost.

We estimate that an annual Green Nano Awards Program would cost a minimum of \$250,000; a very solid program involving external support (especially for judging), marketing, and operational and logistical infrastructure would cost \$500,000. The program could cost two to three times this amount if the steering committee elects to develop a program with high visibility, impact, and engagement. It is important to remember that these costs can be brought down with significant and well-structured partnerships that bring in strategic in-kind contributions.

Given the tremendous interest in anything related to nanotechnology and the groundswell of recent interest in environmental and sustainability issues, it may be relatively straightforward to find the initial funding to launch an awards program for green nano. The more important question in the longer term is how to translate initial enthusiasm into sustained financial stability. There are several strategic elements that the awards program should consider.

At outset, seek perpetual endowment of the award

Organizers of the award should take advantage of the moment when enthusiasm is high to ensure the program's future financial stability. This long-term strategy could be reliably accomplished through an endowment mechanism. Pursuing funding from a philanthropic foundation whose mission aligns with the goals of a Green Nano award would be a viable option.

Involve foundations in the planning

By including foundations in the planning of the Green Nano award, there will be a direct connection to and potential commitment from those who have an opportunity to provide financial support for the award. If foundations feel some ownership for the award, they will be interested in seeing the award succeed and thrive over the long-term.

Maintain balance of involved organizations

It is imperative that the organization involved in developing and administering the award represent a balance of perspectives and goals. This will ensure that the award is respected and valued by the maximum number of organizations and will help maintain transparency, fairness, and objectivity in administering the award. It is important, particularly when working in the "green" arena, to maintain balance to prevent the perception of "green-washing" for industry or "industry bashing" for environmental-advocacy organizations. A balance of organizations will provide the highest likelihood of success for the newly established Green Nano award.

RECOMMENDATIONS

The report authors make the following recommendations for the launching of a Green Nano Awards Program.

- The launching of an awards program in green nano could be a catalyzing, empowering idea and should be developed in the near term.
- An independent organization, such as the Woodrow Wilson International Center for Scholars, should convene a small group of leaders (i.e., 5 to 10 individuals from government, NGOs, academia, and industry) to act as an initial steering committee that would identify (1) the best individuals and groups to be involved in a larger stakeholder process in developing the award, and (2) the individuals who should be part of the permanent steering committee.
- The program should adopt the definition of nano used by the NNI to minimize confusion and debate about this issue when so many other critical decisions need to be made with respect to establishing a Green Nano Awards Program.
- The program should adopt the definition of green nano put forward by MacKenzie and Hutchison. This definition has been peer reviewed and published and is widely accepted within the community, making it a good choice to minimize the inevitable “What is green?” discussions.
- Nominations should be accepted for accomplishment milestones of significant discovery, development, or commercialization within a timeframe of the past five years. Explicit emphasis can be placed on “Factor 4”-type advances. This will ensure a motivation for continuous improvement among researchers competing for the award. Also, an open-ended award seems more consistent with the goals of establishing a Green Nano award in that the entire emerging field can engage and strive for green design rather than targeting a single product or process.
- The steering committee, with extensive input from the stakeholder group, should select specific criteria for life-cycle-based accomplishments in:
 - Innovation
 - Health
 - Environment
 - Commercial competitiveness.

If governed by a steering committee mechanism, the Green Nano award will gain credibility and will benefit from the perspectives of people in many sectors who will have ownership of and interest in its success.

- The program should seek to be a Presidential award administered by the Office of Science and Technology Policy and the Council on Environmental Quality, in close coordination with the NNI. If this is not possible, a diverse consortium should act as the foundation for the award. If administered as a Presidential-level award, the competition will benefit from the objective, third-party standing of the federal government and minimize any potential conflict-of-interest issues with organizations administering and competing for the award.
- The number of awards should be small (i.e., five or fewer). This will ensure that the award maintains a high level of prestige while allowing for multiple

recognition opportunities that meet the goal of growing the green nano community.

- To keep financial requirements lower, no monetary prize should be associated with the award. However, efforts should be taken to assure high visibility and recognition.
- Self-nominations should be allowed. This will contribute to collecting the highest number of best practices from the community and the greatest number of green nano examples and success stories. This will prove to be invaluable as others seek information and knowledge about how to “do” green nano.
- The program should have a third party judging panel to process and review the nominations. The first choice is the National Academies. If that is not possible, the steering committee may wish to select a professional scientific society such as the American Association for the Advancement of Science. Again, the intention is to maintain an objective, rigorous process for selecting winners. This is vital since industry is likely to be a nominee and it is important that the awards program not appear to be biased to one sector.
- All sectors should be eligible for the award. This includes NGOs since policy innovations are likely to be a vital component of the success of green nano.
- The award should start as a U.S.-based program that can be duplicated or modified in other countries. Launching a program of this type internationally would be difficult, given the need for agreement from so many stakeholders. But perhaps most important, a domestic award would give the United States a leadership position in this emerging field and a competitive advantage in a global marketplace, where green nanotechnology may be seen as more acceptable.
- Major foundations should be approached at the outset to determine their interest in providing basic operational funding to launch, or even endow, the awards program. Additional funding sources, if needed, should be sought from government and relevant industries.

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