World Future Review
1–25
© The Author(s) 2016
Reprints and permissions:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/1946756716659650
wfr.sagepub.com
SAGE

Alternative Futures for Forest-Based Nanomaterials: An Application of the Manoa School's Alternative Futures Method

David N. Bengston[2], Jim Dator[1], Michael J. Dockry[2], and Aubrey Yee[1]

Abstract

Forestry and forest products research has entered into a robust research agenda focused on creating nano-sized particles and nanoproducts from wood. As wood-based materials can be sustainably produced, the potential of these renewable products could be limitless and include high-end compostable electronics, paint-on solar panels, and lightweight materials for airplanes and cars. Others warn about potential serious negative health and environmental consequences. Either way, wood-based nanomaterials could disrupt forestry as we know it. This article is a summary and analysis of a collaborative research project exploring the futures of wood-based nanomaterials within the context of the futures of forests and forest management within the United States. We start by describing the history of forestry through the lens of the U.S. Forest Service, then describe nanotechnology in general and wood-based nanocellulose specifically. Next, we outline the Manoa School alternative futures method, and how we used it to design and carry out a "complete futures of x" project. Following the Manoa School approach, we describe four alternative futures for forestry and forest management. We conclude with implications for the future of forestry, forests, and forest-based nanomaterials, as well as a discussion on the implementation of a complete "futures of x" project.

Keywords

nanotechnology, nanomaterials, forestry, forest products, Manoa School

Introduction

> The vast possibilities of our great future will become realities only if we make ourselves responsible for that future.
>
> —Gifford Pinchot, First Chief of the U.S. Forest Service

Humans have used forests for millennia for heat, shelter, transportation, ceremony, and community. Foresters are professionals who grow and manage forests in response to society's needs. Foresters view forest products as sustainable because harvested trees can be replaced by new trees. Harvested timber is used for paper, building materials, furniture, and other wood products. Over time and through technological advances, foresters have

[1]University of Hawaii, Honolulu, HI, USA
[2]U.S. Forest Services, St. Paul, MN, USA

Corresponding Author:
David N. Bengston, 1992 Folwell Avenue, St. Paul, MN 55108, USA.
Email: dbengston@fs.fed.us

Downloaded from wfr.sagepub.com by guest on August 9, 2016

used wood at smaller and smaller scales: from whole logs (e.g., log cabins and dugout canoes), lumber, plywood, particleboard, paper, and chemicals. Over the last several centuries, foresters have provided these products by learning and adapting forestry techniques to reflect societal needs, technological changes, and the underlying ecological systems. Today, cutting-edge forest products research is centered on creating nano-sized particles from wood. The potential of these new renewable products could be vast and include high-end compostable electronics, paint-on solar panels, and lightweight materials for airplanes and cars. Others warn about possible serious negative health and environmental consequences of all nanotechnologies. Either way, forest products scientists believe that forest-based nanomaterials could disrupt forestry as we know it. There could be dramatic changes in the forests themselves, our societies, and our relationships to the forest and each other as a result of emerging nanotechnologies.

This article is a summary and analysis of a collaborative futures research project exploring the futures of wood-based nanomaterials within the context of the futures of forests and forest management generally in the United States. We start by describing the history of forestry through the lens of the U.S. Forest Service (USFS), then proceed to describe nanotechnology in general and wood-based nanocellulose specifically. Next, we outline the Manoa School alternative futures method, and how we used it to design and carry out a "complete futures of x" project (where "x" is the subject of the futures inquiry). Following the Manoa School approach, we describe four alternative futures for forestry and forest management. We conclude with implications for the future of forestry, forests, and forest-based nanomaterials, as well as a discussion on the implementation of a complete "futures of x" project.

The Project Team

The project team included two social scientists and environmental futurists David Bengston and Michael Dockry from the U.S. Department of Agriculture Forest Service, Northern Research Station, Strategic Foresight Group, St. Paul, Minnesota, and two futures researchers Jim Dator and Aubrey Yee of the Hawaii Research Center for Futures Studies, Department of Political Science, University of Hawaii at Manoa, Honolulu. The project is noteworthy not only because of what the "complete futures of x" approach of the Manoa School of Futures Studies illuminated about the futures of nanoforestry but also because of the way in which the project was organized and run.

In addition to the substantive focus on four alternative futures of nanoforestry, one of the goals of the project was to help forestry futurists to acquire mastery of the alternative futures of x method itself by using it to guide research into an area of substantive concern to the Forest Service. This is very much in keeping with the preference of the Hawaii Research Center for Futures Studies to help enable clients to become futurists themselves—to learn how to engage in rigorous study of alternative futures and then to actually incorporate futures theories and methods into their ongoing work—rather than merely hiring some outside futures group to "tell" them what "the future" "will be."

Jim Dator has had a lifetime of experience in futures studies at the most local and most global levels, theoretical and applied. Aubrey Yee is completing writing her PhD dissertation after four years of graduate study in the Alternative Futures Option of the Department of Political Science; she also has experience with the practical application of futures research as a team member of various projects of the Hawaii Research Center for Futures Studies of the University of Hawaii at Manoa.

At the same time, neither David Bengston nor Michael Dockry is new to futures studies. Both have been members of the Strategic Foresight Group within the Forest Service for several years, and have published reports of their work in both futures and forestry literature. They desired to add knowledge of and experience with the theories and methods of the Manoa School to the bag of theories and techniques they had already mastered.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

The research on the project began in September 2014 and ended in July 2015. Except for two days when three of the four researchers gave a joint progress report on their work at a meeting of the World Future Society in San Francisco in July 2015, the four researchers never met face-to-face. Instead, the four held virtual meetings of about two hours each about every week or two via Adobe Connect throughout the project period. Each worked on research assignments related to the project during the week and reported on the results during the virtual meetings. New tasks were then identified and reported on subsequently. While Jim Dator directed the flow of work overall, because of the experience and expertise of all four members, the process was quite collaborative.

Introduction to the U.S. Forest Service and Forestry

The USFS is an agency within the Department of Agriculture with the motto: "Caring for the Land and Serving People." Its stated mission is "To sustain the health, diversity, & productivity of the Nation's forests and grasslands to meet the needs of present and future generations." The USFS is the largest agency within the Department of Agriculture, with over thirty thousand employees.

USFS Organization

There are three branches within the USFS. The largest and best-known branch is the National Forest System. There are 155 national forests in forty-four states and Puerto Rico that manage about 193 million acres of forest and grassland. Another branch of the USFS is State and Private Forestry. This branch works with all nonfederal forest lands. It works closely with American state foresters, private forest land owners across the country, and tribes and tribal forest lands. Finally, there is the Research and Development branch of the agency. It is one of the largest forestry research organizations in the world, doing research on everything from forest ecology to urban watershed management to paper chemistry and now to wood nanotechnology materials and futures research.

USFS History

All good futures research starts by understanding the history of whatever the object of study is. We started this project by looking to the past of U.S. forestry to understand the historical drivers of change influencing forestry, the USFS, and how those drivers influenced our current understanding of forest products.

The USFS was founded in 1905 on the basis of progressive ideals and science-based management beliefs of the time.[1] Specifically, the USFS was founded for two basic reasons. The first was to provide sustainable timber supplies for the United States. The second was to protect watersheds and prevent flooding caused by massive cut and run logging operations that were common at the turn of the last century.[2] Indeed, in 1911, the Eastern National Forests were formed with a goal of restoring the land to its earlier conditions.

Fire has always been a driving force within the agency.[3] One of the best-known American icons is Smokey Bear with his famous admonition that "only *you* can prevent forest fires." Smokey's campaign against wildfires is perhaps the most successful public information program of all time.[4] With the considerable increase in forest fires caused by the increasingly apparent effects of climate change, a massive buildup of biomass fuels in forests due to many decades of aggressive fire suppression, and growing forest insect and disease problems, controlling forest fires is consuming an increasing amount of the Forest Service's resources, prompting new ideas about the role of wildfires and humans' response to them.[5]

With its early focus on science-based management, conservation, and later on forest products development, the USFS has always been at the forefront of technological change in forestry and forest products. Technological innovations have ranged from transportation and logging technologies that led to advancements in civil engineering (roads and bridges) to developments in chemicals and even in the early use of communication technologies because of the range and remoteness of the agency's responsibilities. Forest Service ranger stations were often communication hubs because they were the only places with phone or telegraph lines for hundreds of miles.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

The early decades of the USFS are often referred to as the "custodial era," which emphasized restoration of devastated forests in the East and a caretaker role for the national forests in the West.[6] World War II marked a watershed for the Forest Service, as the demand for timber and wood products in a rapidly growing economy catapulted the agency into a new role as a major supplier of lumber and pulpwood.[7] At the same time that timber production grew rapidly on the national forests, an outdoor recreation boom flooded the forests with users who were out of sync with large-scale production of timber and clear-cutting. The rise of the modern environmental movement in the 1960s and 1970s set the stage for a series of major clashes between those who favored preservation and proponents of industrial forestry.[8] Eventually, the Forest Service, other resource management agencies, and legislation began to respond to changing societal values, growing scientific knowledge, and evolving resource management experience to usher in the current era of ecosystem management on the national forests.[9]

Finally, while many, perhaps most, organizations have short time horizons, the USFS is naturally oriented toward the long run as the lifetimes of most trees is many decades or centuries, and forests persist for eons. The USFS has a long history of carrying out long-term forecasts and assessments.[10] One consequence was that the Forest Service was among the first U.S. agencies to experience and seek to deal with the consequences of global warming and climate change. It, thus, is natural for the Forest Service to understand the utility of futures studies, and to incorporate some of its theories and methods into its routine.

Nanotechnology—A Potential Game Changer

The origins of the idea of nanotechnology can be traced to a 1959 lecture by Nobel Prize winning physicist Richard Feynman,[11] in which he described what could result from learning how to control single atoms and molecules. Feynman did not use the term *nanotechnology* in this visionary talk, but he described many possibilities, including manufacturing nanoscale devices ("infinitesimal machines"), manipulating individual atoms, the miniaturization of computers, a mechanical surgeon that could be swallowed, "a billion tiny factories" that would work together as a system, and many other ideas.[12] Feynman's lecture was a vision of a scientific field that did not exist, but today we call nanotechnology. Feynman's ideas were viewed as ridiculous at the time: Paul Shlichta of Crystal Research in San Pedro, California, then a materials scientist at the Jet Propulsion Laboratory, heard the talk. "The general reaction was amusement. Most of the audience thought he was trying to be funny," he recalls."[13]

In 1986, Eric Drexler published a book that moved Feynman's vision forward: *Engines of Creation: The Coming Era of Nanotechnology*.[14] Nanotechnology is truly small. The word "nano" means "one-billionth," so one nanometer is one-billionth of a meter. A sheet of paper is about one hundred thousand nanometers thick. And one nanometer is about as long as your fingernail grows in one second.

In *Engines of Creation*, Drexler described the potential power of tiny self-replicating machines that could be created at the size of a molecule, and then set loose to do whatever they were designed to do, free from human intervention. The subheadings of Drexler's book show what he considered to be the potential of nanotechnology: *Engines of construction—Engines of abundance—Thinking machines—Engines of healing—Dangers and hopes—Engines of destruction.*

From the very beginning, Drexler recognized the potentially Faustian nature of nanotechnology—for construction and abundance, or for destruction and a world of nothing but "gray goo" (a term used to describe what life on Earth might become if self-replicating nanomachines got out of control and consumed all matter while building more of themselves). Drexler created the Foresight Institute to encourage research into nanotechnology. However, his ideas were initially scorned and viewed as a ridiculous fantasy (which is the way that all powerful new ideas about the future are initially viewed).

Downloaded from wfr.sagepub.com by guest on August 9, 2016

The journal *Science* is perhaps the most authoritative source for cutting-edge science in the United States. The first time nanotechnology was mentioned in *Science* was in 1989.[15] In 1991, *Science* published several articles about nanotechnology. One, about Drexler, quoted him saying that nanotechnology "will bring changes as profound as the industrial revolution, antibiotics, and nuclear weapons all in one."[16]

The U.S. Office of Technology Assessment, created by Congress to examine the possible social and environmental consequences of emerging technologies, published a report titled "Miniaturization Technologies," also in 1991.[17] But it was not until 1999, when President Clinton called for greatly increased research in nanotechnology, along with a $500 million budget—and especially when President Bush signed the "21st Century Nanotechnology Research and Development Act" in 2003, which provided even more substantial funding—that many scientists turned their attention to nanotechnology. The strategic plan that accompanied the National Nanotechnology Initiative in 2014 further encouraged nanotech research and applications in all areas—including forestry.

Critics of nanotechnology express urgent health and environmental concerns similar to those about asbestos, genetically modified organisms (GMO), and synthetic biology. Nanotechnologies are growing rapidly in commercial applications, including medicine, cosmetics, electronics, and environmental cleanups. Estimates of the number of nanotechnology-based consumer products currently on the market range from 1,600[18] to more than 2,800[19] and growing. But little is known about potential adverse effects on human health and the natural environment. Nanotoxicology is an emerging and rapidly developing discipline with the goal of evaluating the safety of engineered nanostructures and nanodevices.[20] But many safety questions remain unanswered. Nanoparticles are more biologically active than larger-sized particles of the same chemistry because they have greater surface area per mass. But if the traditional larger particle has already been assessed for adverse effects, it may not require further testing by regulators in nano form, causing many nanomaterials to slip through the cracks.[21]

In 2013, Drexler hit the news again with his latest book, the title of which sums up the revolutionary potential of nanotechnology: *Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization*.[22] The term *radical abundance* refers to producing radically more of what people want at a drastically lower cost, using atomically precise manufacturing. If Drexler-type nanotechnology proves feasible, anything and everything is a resource, nothing is a waste, and the old world of scarcity will be over, as will be the old ways of producing . . . everything—food, clothing, automobiles, buildings, people—well, everything. As the originator of the idea of nanotechnology, Richard Feynman said many years ago, "there is plenty of room at the bottom."[23] This is grassroots, decentralized, individualized development at its finest and most powerful—or at its most utterly dangerous and irresponsible.

Or perhaps it is nothing but really cool engineering at very small scales, and neither especially dangerous or transformative at all.

The Challenge and Opportunity of Nanotechnology for Forestry

In 2006, the Forest Products Laboratory, part of the USFS Research and Development branch, joined twenty-seven other U.S. federal agencies in the National Nanotechnology Initiative, and began to lead the forest products industry into a new field of research that was dominated by nanomaterials derived from sources other than wood, such as metals and petroleum. The 2005 Roadmap outlined the direction that the forest products industry should take to transform itself into becoming leaders in nanoproducts derived from wood.[24]

Figure 1 is a diagram of the scale of wood, decreasing from the whole tree down to the nanometer scale. We first used whole trees (and roughhewn planks) for construction such as for dugout canoes, ship masts, and log cabins. Then, we developed sawmills and other wood processing technology that created first lumber, then plywood, and then particleboard.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

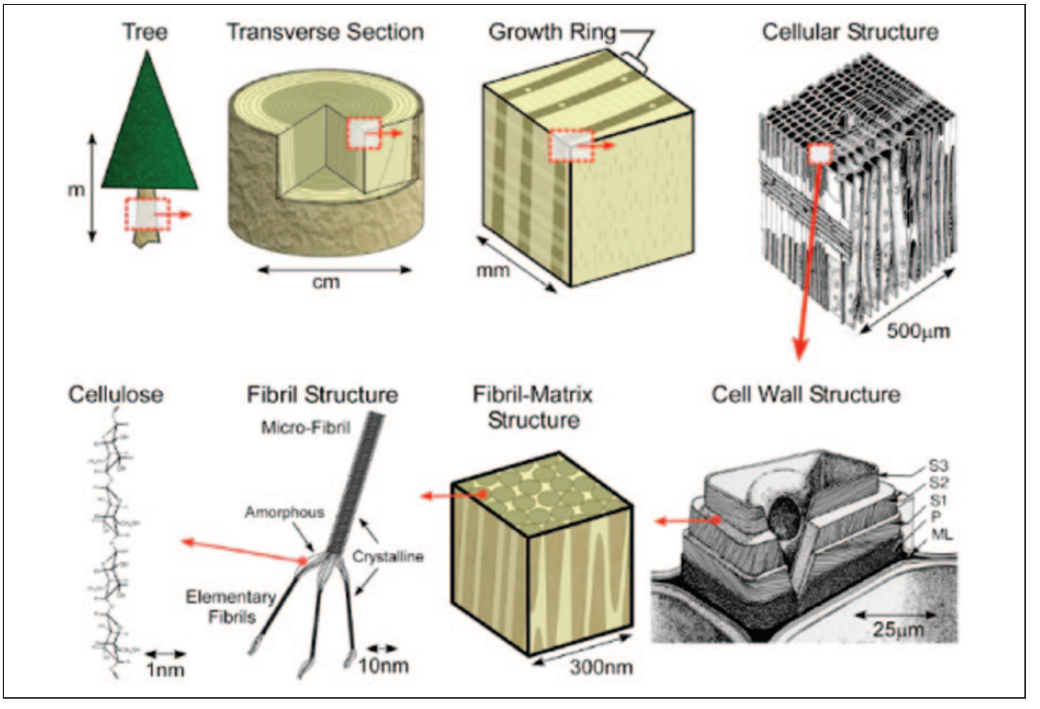

Figure 1. Wood from the whole tree to the nanoscale.
Source: http://www.nano.gov/sites/default/files/usforestproductsindustryandnanotechnology-usda.pdf)

We have made paper from wood cells, as well as chemicals from wood and tree extracts. Alston[25] refers to the long-term process of technological change in forest products leading to breaking wood down into smaller and smaller pieces as the "pulverization" principle. And now we have wood products being created from nano-sized particles. This can simply be viewed as the next logical extension of this process of invention, utilization, and miniaturization.

In 2012, the Forest Products Lab unveiled a congressionally funded pilot plant to produce nanomaterials that are now used by scientists around the world.[26] Wood nanomaterials are seen as a way to make myriad products with a cheap and renewable resource. It is also seen as an environmentally friendly material, naturally occurring, and easily recyclable or compostable.

Wood nanomaterials are lightweight, and yet have high strength and stiffness properties. They can be produced sustainably if forests are managed well—just like all forest products. Wood nanomaterials have the potential to transform the forest products industry and impact almost every aspect of our economies. Wood nanomaterials are being looked at for sustainable 3D printing. They are also being studied for printable and flexible electronics. They are being used in the medical and cosmetic fields. Scientists are even working on paintable solar panels and paintable liquid crystal display (LCD) screens made from wood nanomaterials.

Wood nanofilters can function at the molecular level.[27] They have implications for industrial processes and medicine. Military applications are widespread, including super lightweight and strong body armor. Automotive and aerospace applications for flexible, strong, cheap, lightweight materials are many, and should improve safety while increasing fuel efficiency. Finally, wood nanomaterials permit flexible electronics such as flexible, waterproof, recyclable, compostable cell phones, and compostable solar panels.[28]

Thus, when wood products scientists talk about wood-based nanomaterials, they see the

Downloaded from wfr.sagepub.com by guest on August 9, 2016

sky is the limit, and that this technology does have the potential to change almost every aspect of our lives. We have known that nanotechnology had this potential for decades, but wood-based nanomaterials are rather new and underappreciated within the larger nano research world. And, of course, one of the biggest appeals of wood nanomaterial is its sustainability—trees can grow and grow and grow, providing many ecosystem services while facilitating the development of nanomaterials.

At the same time, opposition to nanotech research and development is growing, and along the same lines of opposition to genetically modified materials. There are potential human and environmental health and safety issues. Most of the research on potential health and safety concerns of nanomaterials has focused on carbon nanostructures, but a growing body of literature examines cellulosic nanomaterials. For example, exposure to some types of cellulose nanofibers may result in decreased cell viability and reductions of algal growth,[29] DNA damage,[30] and inflammatory responses in the lungs.[31] The potential adverse effects of wood-based nanocellulose have received little attention; most studies to date have examined the health and environmental effects of cellulose nanofibers isolated from cotton, not wood fiber.

Alternative Futures within a "Complete" Project on the Futures of "X"

As stated above, one of the goals of this research project was to enable Bengston and Dockry of the Strategic Foresight Group of the USFS to learn about the theories and methods of the "Manoa School" of Futures Studies of the Hawaii Research Center for Futures Studies within the Department of Political Science of the University of Hawaii at Manoa. Additionally, the authors wanted to describe the entire futures of "X" method in this paper to make it accessible to researchers and futurists for use in their own projects. The Hawaii Research Center for Futures Studies was established in 1971 and is one of the world's oldest futures research centers. The Manoa School of alternative futures teaches a wide variety of futures methods, but a few steadfast, tried and tested rules guide our work in forecasting alternative futures. The first is that the future does not exist. Rather, there are always alternative futures with an emphasis on the "s." Because the future does not exist, it is not possible to predict anything. So while you cannot in any way accurately predict the future, you can forecast alternatives.

In addition to alternative futures, it is essential to consider, envision, and plan for preferred futures. This collective and participatory process is where futures becomes empowering, enabling communities, organizations, governments, and individuals to think first about possible futures and then the collectively desired future in a way that supports action toward realizing that preferred image of the future. This is a process that is iterative and can be embedded in any organization as a repeated process, one that you learn from, revisit, revise, and support.

What we call Dator's 2nd law of the future is perhaps the most famous Manoa School export. This is the rule that in a situation of rapid social and environmental change, "any useful idea about the futures should appear to be ridiculous." This is often followed by the caveat that not all ridiculous ideas will necessarily be useful. Once upon a time, generations could assume that their children's lives and their grandchildren's lives after that would be fairly similar in many ways. Change happened quite slowly. In the twenty-first century, this is no longer true. Change is happening at an increasingly rapid pace. We can barely keep up with the pace of technology. And, as change increases, so does uncertainty. So if you are thinking fifty years into the future, you have to imagine that the world may be quite different, and that most things you imagine in that future will quite likely appear ridiculous by today's standards. Our values, behaviors, and beliefs change with time, and it is the futurist's job to think about what these changes might look like and what they might mean. In today's world, we can see that what is one day considered ridiculous, may tomorrow be old news.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

One of the techniques of the Manoa School is called "researching the complete futures of 'x,'" where "x" represents an organization, corporation, nonprofit, church, community, nation, concept, concern, process, activity, technological innovation . . . anything.

A complete set of research activities aimed at determining the preferred futures of x should follow this sequence, more or less in this order:

1. Articulation of a theory of social stability and change that will guide research on the futures of x. The theory may be based on biology, environment, culture, technology, decisions/actions/events, or many, many other assumptions. In this study, we assume that technological change is a major agent of social stability and change. Other futures researchers might use a very different theory. But no one should attempt to make a statement about the future of x that is not based upon some kind of an articulated theory of social stability and change. The theory underlying this study is explained in greater detail in *Mutative Media*,[32] which focuses on changing communication technologies, from the origins of speech to electronic communication technologies and beyond.
2. Identification of the major driving forces ("drivers") according to the theory that are important for the creation and evolution of x. According to our theory of social change and stability, "technology and technological change" (as we define it) are the primary agents of social stability and change, and then such things as population, resources, energy, environment (natural and artificial), culture, language, myths, political economy, and other drivers, which currently are strongly influenced by technological change, become independent drivers on their own.
3. Research the history of the driving forces in relation to x. This is a crucial part of the research. Historical research will show that the main drivers in the past explain why x began, how and why it was structured the way it was, and how and why it changed (or did not change) over time. Very importantly, this also means that one does not study just x itself, but rather those aspects of the environment of x that contributed to the origin, mission, structure, change, and continuity of x. Both x and the environment are dynamically interrelated and must be studied as such.
4. Description of the present condition of x and of the environment of x in relation to those drivers. Current literature and thinking about x may contain clues about possible directions in which it could develop in the future.
5. Review what others have written about the futures of x. It is important to know what others think about the futures of x so one may learn from and improve upon their work. No sense in reinventing the wheel, or to presume/pretend that you are the first person ever to have studied the future of your x. In this project, we conducted an extensive review of the literature on the future of forestry and forest products. Our bibliography on this topic is available upon request to interested readers.
6. Identification of significant drivers (also called trends) of the future. These trends exhibit possible future values of the historical driving forces. These trends show in the future what the specific values of the past and present driving forces might be. However, it is impossible to "predict" what the specific futures values of these drivers will be. Different assumptions about how the world works lead to different conclusions about the future values of each of the drivers. Thus, each driver is projected with different values as appropriate for each of the four generic alternative futures (discussed in Item 8, below). This is perhaps the key feature of the Manoa School approach to studying the futures of x, in contrast to the approach of many other futurists.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

7. Identification of emerging issues that might interrupt the trends and/or create new ones. This is extremely important. It is the major contribution that a futurist should bring to a forecast. Relying on trends to anticipate the futures is never sufficient. Identifying as many significant emerging issues as possible should make the forecasts more useful and robust. Emerging issues are similar to what other futurists may call "wild cards," "black swans," or "weak signals." However, identifying likely emerging issues, via a method originally proposed by Graham Molitor,[33] is a central feature of the futures of x technique.
8. Creation of alternative futures, according to the four generic images of the futures as identified by the Manoa School.[34] The four futures (explained in the next section) include Grow, Collapse (New Beginnings), Discipline, and Transformation. The different values for each of the driving forces into the future, and the different impacts of emerging issues, are what make each of the four alternative futures different. Do not include anything in any of the four futures that is not either the future trend of a previously identified driver, or an emerging issue. There is a specific set of different assumptions about drivers and emerging issues for each of the four generic images of the future. The four futures were determined as the result of intensive empirical research[35] and, thus, should be followed carefully. They are the "factual" basis of the forecast. However, many of the details of each of the four futures are a consequence of choices the futurist makes in describing the futures. Nonetheless, there should be a "factual" basis underlying every feature of each future. That is, there must be some research paper or other evidence supporting each detail of each of the four futures. The futurist does not "make them up," as a fiction writer might.
9. Exercise in envisioning one or more preferred futures. When possible and appropriate, preferred futures visioning is a group process, involving everyone (or representatives of everyone) who will be impacted by the actual futures of x. The wider the participation, the better. Sometimes, if the futures of x process involves only a single futures researcher or research group, and perhaps a few people currently active in or concerned about x, futures visioning is done by only one or a small group of people. But the entire point of the futures of x process is to arrive at a dynamic vision of a preferred futures of x that will be used to guide decisions concerning x.
10. Description of preferred futures. There are two basic ways the description of a preferred future of x can be generated. If the study is done by a futurist or futures research group for his or her own purposes, or simply to understand the futures of x, then the futurist or futures group will create the description of a preferred future of x on their own.
11. If the research was being done by a futurist or group for, and with the participation of members of, the organization, then, after the general contours of a preferred future for x have been identified, a small representative group of people within x will work together (preferably with but possibly without the futurist) to craft a relatively detailed description of that vision, so that designers, planners, and policy makers can then create designs, plans, and policies that can be used to guide x toward the preferred future.
12. Development of a strategic design or plan and sector designs, plans, and potential policies based on the preferred futures so that they are robust/resilient in regard to all four alternative futures as well. This should be done by professional designers, planners, and policy makers who have been actively involved in the prior futures process so

Downloaded from wfr.sagepub.com by guest on August 9, 2016

that they fully understand the rationale behind the preferred future. Otherwise, latecomers may sabotage the entire effort by ignoring parts or all of the preferred future. Ideally, the futurist/futures group should be involved in the designing/planning/policy-making process, and sometimes a futurist organization is able to devise designs, plans, and policies on its own without additional professional assistance.

13. Identify specific personnel, policies, and funds for carrying out the plans and policies, with appropriate oversight and review. When these steps are not taken to begin moving x toward the preferred future, the process often becomes a paper exercise only and does not move the institution toward the goal of the preferred future.
14. Day-to-day management of the process to carry out the plan to move toward the preferred future. Achieving the goals resulting from the futures process work best when the process of moving toward the preferred future becomes the general responsibility of everyone involved with x, and the specific responsibility of personnel working within x.
15. Periodic evaluation of the preferred futures and plans by both internal and external participants. Futures are highly volatile. What seemed like a preferred future (or features of the alternative futures) at one time, for certain people, may not be preferred later, or by different personnel. A preferred future is a guiding vision in relation to the four alternative futures, it is not an ironclad blueprint that must be followed without further consideration. While the process of determining a preferred future for x must be respected and the outcomes followed, opportunities for reevaluating the alternative and preferred futures of x must be provided with sufficient frequency and influence that personnel affiliated with x become neither tired of the futures process, nor feel unable to make significant change when it is needed.
16. Institutionalization of futures research, continuing scanning, and periodic repeating of the entire process. This is also one of the most important elements in the entire process. Unless futures scanning and reevaluation of preferred futures is a routine, rewarded, and respected part of x, it might be fun for the few involved in a futures of x process, but will probably have no lasting impact on x itself.

For this ongoing project, we have to date completed the first eight steps in the sequence.

The Four Generic Images of the Futures

The idea of alternative futures embraces the possibility of infinite alternatives, all of which are possible, not one of which is truly more probable than any other. We often want to think that one future is more probable, but we need only look to history to realize how often things turn out quite differently than we expected. To help us manage all of these infinite possibilities and create useful scenarios, Dator developed four futures archetypes. The archetypes resulted from analyzing a huge number of images of the future in media and story. He saw that consistently these images tended to fall into one of four general categories. These categories or archetypes are not meant to constrain a scenario, but rather to guide the scenario, and to help us as futurists to get out of the "tyranny of the present" to envision truly different alternatives.

The first archetype is Continued Growth (or, simply "Grow"). This future anticipates a significant amount of change for the better in many aspects of life. Those things that some people might consider to be negative problems are seen instead as new opportunities for growth in new areas. Grow is the most common way that almost all organizations, governments, and even individuals envision their future—mostly the same as the present, but more and potentially better. While Grow typically implies

Downloaded from wfr.sagepub.com by guest on August 9, 2016

increased economic development, it also very much includes the diffuse challenges enlivened by increasing growth. Getting people to envision a future other than Continued Growth can often be one of the most important and difficult aspects of being a futurist as most institutions of modern society (especially education, governance, and, of course, the economy) are aimed at promoting growth, usually economic growth and population growth.

The second archetype is Collapse, and it is based in the belief that economic, environmental, government, and social systems as we know them are seriously unsustainable and will partially or fully collapse. While apocalyptic images of the future are popular today, collapse scenarios are not inherently negative, bad, or strenuous. As easy as it is to imagine various ways in which humanity might go extinct, it seems hard for some people to imagine ways in which humans might in fact thrive following catastrophe and crisis, even though history certainly offers many examples. We call this positive version of collapse "New Beginnings." Many people and organizations argue that a collapse of current systems could allow us to start fresh and reimagine how we might better coexist with one another and with the planet.

A third archetype is Discipline. One version of the Discipline archetype is based on the idea that we can and might avoid environmental, social, economic, or cultural collapse by restraining our behaviors so that we become sustainable in all these areas. However, while sustainable futures are inherently disciplined, not all disciplined scenarios are sustainable. Other versions of a disciplined image of the future say that even if continued growth can be made sustainable in terms of resources and the environment, continued economic growth by its very nature destroys certain basic values that should instead be the basis of a good life. Discipline may imply authoritarianism, but a discipline society can also be designed so that educational, institutional, structural, and similar systems encourage people to live peaceful, meaningful lives without the ceaseless demand for growth. Indeed, even now, many people willingly join communities, such as churches and religious orders, believing that by disciplining themselves, they achieve higher values than they will if they live "freely" without self and external restraints.

The fourth archetype, Transformation (or "Transform"), is based on the idea that a technological and/or spiritual revolution will produce a future so profoundly different from anything humans have ever experienced that the world as we know it now will seem unrecognizable. According to transformational images of the future, humanity experiences a total metamorphosis—the caterpillar becomes a butterfly. Old-fashioned *Homo sapiens* may no longer be at the center of life, or perhaps even survive in their present form. Instead, various forms of humans, post-humans, cyborgs, and artilects coexist: the singularity is realized.[36]

By doing historical research, horizon scanning for trends and emerging issues that provide a deepened understanding of the specific issues potentially facing the USFS and nanotechnology research, we collectively designed four alternative futures of nanotechnology in forestry. The resulting scenarios are not intended to represent any of our "preferred futures," although we may choose elements of them to become part of a preferred future. At this point in the research, we are most concerned with exploring truly alternative futures. The scenarios follow, written from the perspective of the year 2050.

Scenario 1: Grow Future

In retrospect, the relative ease with which events have unfolded and stayed on track is probably the most surprising and striking feature of the past several decades. From the economic low point earlier in the twenty-first century, the turnaround in the U.S. economy was slow at first but eventually picked up momentum and just kept rolling along. Growth in the United States and global economies was fueled by an unstoppable energy revolution made possible by opening vast new petroleum sources in the warming Arctic and Antarctic, by deep seabed drilling, shale gas fracking, and expanded nuclear fission. At the same

Downloaded from wfr.sagepub.com by guest on August 9, 2016

time, clever entrepreneurs were quick to learn how to profit handsomely from what once was called "alternative" or "renewable" energy sources, such as solar, wind, geothermal, ocean thermal energy conversion (OTEC), and the like. These are all now part of a single, dynamic, global energy grid.

Abundant and once again relatively cheap energy provided the stimulus needed to finally shake off the last vestiges of the Depression of the late 2010s and early 2020s and get the economy moving forward. At the same time, steady technological progress in many fields resulted in the creation of tens of millions of direct and indirect jobs in the late 2020s.

Balancing steady economic growth enabled by cheap energy with environmental sustainability has been a continuing challenge. There has been increasing pollution of Earth and air, along with wave after wave of harmful and costly nonnative invasive species, accelerating extinctions, degradation or exhaustion of some natural resources, severe local water shortages, less reliable food systems due to more volatile weather and climate, and more. More sprawl in the ever-growing wildland-urban interface continues to gobble up natural areas. There has been a steady increase in atmospheric CO_2 and accelerating climate change. No one now denies that the climate is changing—the historic sea level rise of the 2030s and massive damage to coastal areas put an end to that debate!

By 2050, climate change reached the high end of past projections and continues to accelerate due to melting permafrost in both polar regions, releasing growing amounts of methane.

But this has not led to doom, gloom, and despair! Neither has it been a damper on continued economic growth. To the contrary, private enterprise and an exuberant entrepreneurial spirit have enabled us to grasp these developments as new opportunities for even more spectacular economic growth and prosperity.

For example, there have been many different plans for geoengineering to reduce the greenhouse effect—or, better yet—to use the "pollutants" as resources for further growth. Some schemes have been successful immediately, while others are taking longer to become effective. But massive geoengineering projects are clearly one of the success stories of recent decades and the probable future.

At the same time, very rapid and substantial sea level rise has proven to be a continual spur to innovative responses, leading to miles of megastructures that hold back the rising tides in some parts of the world, and to coastal development that is built so as to welcome the advancing water, either by floating above it or sinking below the billowing waves. American entrepreneurs are leading the way in utilizing the oceans and especially the ocean floor as a vast field of abundant resources and a new venue for human settlement, habitation, and exploitation.

Even more important than the developments relying on mega-engineering are advances in micro-miniaturization: biotechnology, nanotechnology, artificial intelligence, synthetic biology, artificial photosynthesis, and other areas that opened new avenues for economic growth, creating vast new industries and revitalizing old ones. Moore's law continues. This is one reason why past fears about massive technological unemployment have proven to be unfounded—new labor-saving technologies do displace large numbers of workers in many fields and many types of occupations, but entirely new industries and many entirely new jobs are created. More intrusive technologies (and larger human populations) disrupt ecosystems, evoking the necessity of active and proactive human management of once "natural" processes. Sustainability and resilience science has matured to deal with unanticipated technological impacts on environments that are now recognized as being almost entirely artificial.

In the United States, population growth, greater personal wealth, growing multiple and seasonal homeownership, amenity migration, and interregional population shifts away from the warming West and Southeast to the more temperate climates in the Midwest and Far North have created new challenges for forest management, as has continued fragmentation of private forest ownerships resulting in ever-smaller parcels of forest land. The share of

Downloaded from wfr.sagepub.com by guest on August 9, 2016

urban and suburban populations has grown to more than 90 percent of the United States total, with about 50 percent of the population living in megaregions or megalopolises—gigantic chains of roughly adjacent metropolitan areas stretching from north to south, east to west, and everywhere else throughout the nation.

Endless waves of large homes were built in the wildland-urban interface (WUI), greatly complicating wildland firefighting and conservation of biodiversity. Globally, tropical deforestation continued in the most ecologically important, biologically rich forests, even as world forest cover remained constant due to massive expansion of plantation forestry.

The area burned by wildfires in the United States and globally is considerably larger than anticipated at the start of the century and the extent of annual damage continues to escalate. Indeed, firefighting consumed so much of Congress's appropriations for the Forest Service that a separate continental firefighting agency was created with the United States, Canada, and Mexico as climate change combined with urban sprawl to multiply the frequency, size, and intensity of wildfires.

When research at the USFS Forest Products Lab and elsewhere finally pushed the cost of wood-based nanomaterials below $3/pound in 2025, the effects on forestry and the forest products sector were profound. The shift from nonrenewable petroleum-based materials to renewable wood-based materials in everything from cars to computers was slow at first but has grown relentlessly. The applications of cellulose nanomaterials seem to be endless: composites and foams for automotive, aerospace, and building construction; plastics alternatives; additives for paper, packaging, paints, plastics, cement, food, and pharmaceuticals; textiles for health care and clothing; insulation; coatings; viscosity modifiers; oil and gas drilling fluids; cosmetics; flexible and compostable electronics; and much more. 3D printing with wood nanomaterials has meant that almost anything can be custom made on demand. An explosion of planting fast-growing, genetically modified trees to satisfy the demand for wood fiber took place in the 2030s.

Human modification of the environment is not new—not something that Western civilization alone has done. The evidence is abundantly clear that environmental modification is a defining feature of humanity from the very beginning. What is new now is simply the large numbers of humans on the planet and the increasing sophistication of technology that humans have created—and, most important of all, the growing realization that, because we created it, we are now responsible for managing and recreating our garden. Biotechnologies, nanotechnologies, and artificial intelligence greatly assist us in fulfilling our responsibilities here.

The secret to humanity's success has been its knowledge of science and technology, with mathematics the language of both. Science has shown us the vision forward while technology has enabled us to move toward the vision—whereupon science then unveils newer, even more compelling visions that new technologies enable us to achieve.

So, yes, there have been many people opposed to the developments that science and technology of recent decades made possible—mega-engineering on one hand and micro-miniaturized bionanotechnologies on the other. There have been concerns about new and renewed diseases, social inequity, irreversible damage—and, in truth, we all have had our share of problems. But, overall, most of us are more than content to be caretakers in the new gardens of our creation, and visionaries of newer ones, instead of barely surviving while cowering in the caves of our innocent childhood's wilderness.

Sources for the Grow Future are in the appendix.

Scenario 2: Collapse (New Beginning) Future

> I went to the woods because I wished to live deliberately, to front only the essential facts of life, and see if I could not learn what it had to teach, and not, when I came to die, discover that I had not lived. I did not wish to live what was not life, living is so dear; nor did I wish to practice resignation, unless it was quite necessary. I wanted to live deep and suck out all the marrow of life, to live so sturdily and Spartan-like as to put to rout all that was not life,

Downloaded from wfr.sagepub.com by guest on August 9, 2016

> to cut a broad swath and shave close, to drive life into a corner, and reduce it to its lowest terms.
>
> —Henry David Thoreau, *Walden: Or Life in the Woods*

The new beginnings scenario follows the threads of crises currently facing humanity at the start of the twenty-first century. From climate change (both gradual and abrupt), increasing food and water insecurity, threats of bioterrorism, overpopulation pressures, worldwide species extinction, rapidly converging disruptive technologies such as nanotechnology and synthetic biology, humanity currently faces massive tsunamis of potentially catastrophic change. Indeed, if the fears of runaway reproductive nanotechnology materialize, rendering everything in the planet potentially nothing but "Gray Goo," nanotechnology itself could become the prime driver of collapse without any help from anything else.

If even only *some* of these converging crises continue unabated, or increase in scope and scale, we will face a very different world in 2050. Future generations may inherit a planet with intensely decreased worldwide populations, scarce natural resources, severely hostile climates. The collapse of many social and economic institutions that exist today is clearly in the realm of possibility for the future. This is a low-tech future and the technology and society that fostered the collapse have been transformed from a global economic model to a more localized sharing and needs-based economy. Manufacturing is done at small scales, with local resources, and limited to bare necessities.

This collapsed world, while in many ways bleak, need not spell the end of humanity and in some ways can be seen as an opportunity for a new beginning, a clean slate from which humans can rebuild and learn from our previous mistakes. With forests and forest creatures threatened, their protection in this future will not only be more critical than ever but it will be more difficult than ever because the institutions that once managed and conserved these areas and precious resources have largely been disbanded after falling into disarray. Forests in most parts of what was the United States have been cleared for attempted agriculture or cleared for wood and other resources that were needed to survive. Pressures to save forests and forest creatures as climate induced extinctions mounted led many to accept the necessity of genetic engineering of flora and fauna. This move to accelerate genetic engineering (GE) technologies was met with equally strident resistance, and, in many places, the resistance turned violent. The nanotechnology labs of the USFS were attacked many times by radical anti-GE and anti-Nano activists. As the funding for the Forest Service dried up, protecting and maintaining the labs became logistically and financially impossible, and all research was halted. But that did not mean the effects of these technologies just disappeared. Today, remnants from the biotech and nanotech boom in the early to mid-twenty-first century still haunt the planet. These are creatures big and small created from the best science had to offer before we realized how much harm they could do to people, nonhuman life, and the environment as a whole. These animals, bacteria, and nanoparticles still roam, procreate, mutate, and live alongside remaining humans.

As peak oil was reached, a rush for wood biomass to replace oil further degraded remaining forests faster than they could be replaced. This happened globally, but because of the energy intense nature of travel and transport, there is more competition for locally derived wood than world-wide competition. Energy in this future is scarce and unreliable, making many formerly common activities and lifestyles nearly impossible. The former United States central government failed in a progressive series of collapses of multiple social and economic systems. Because wood became one of the main energy sources after peak oil, the termination of the Forest Service along with the central government was followed by severe degradation of forest ecosystems through unregulated timber harvests and myriad environmental changes.

The still critical Forest Service mission—to protect and safeguard precious resources while maintaining sustainable use of those resources—now rests in the hands of a dedicated, passionate group of community members who patrol highly

Downloaded from wfr.sagepub.com by guest on August 9, 2016

localized regions of the last remaining forests. They call themselves the Community-Based Foresters Guild and operate from an ethos of stewardship and deep commitment to the forests. It is not uncommon that these dedicated volunteers face serious danger in the form of fire, poaching, or bandits. They are loosely organized and struggle to counter the increasing pressures of wildlife poaching and illegal timber harvest taking place at the hands of often desperate people. It is a difficult and dangerous commitment, but with so little of the natural world remaining and survival a daily reality, passion and purpose drive the volunteers to protect what remains for the future.

Efforts such as those of the Community-Based Foresters are the foundation for rebuilding society in this brave new world. With communication and travel across distance much more difficult than before, highly localized communities are the basis of governance, and the healthy functioning of a community determines the health of the forest and natural resources available to that community.

Sources supporting this Collapse Future are listed in the appendix.

Scenario 3: Discipline Future

The United States has become less a collection of states and more of a collection of autonomous city-states. In the early twenty-first century, civil strife, violent social protests and rioting, breakdown of local police and civil order, environmental disasters, and other mega-disturbances, including floods, droughts, wildfires, and hurricanes, have caused the people of the United States to come together under a new governmental structure focused on strict adherence to order, discipline, and sustainability. The Forest Service led the transformation to a twenty-first century system of government based on efficiency, science, and renewable technologies based on trees and plants. Gifford Pinchot's axiom of the greatest good for the greatest number in the long run and objective scientific truth serve as national mottos.

This is a decentralized society, much like the earliest years of the USFS. There is a centralized government but its control over the city-states relates more to providing cultural and social norms rather than strict enforcement. While there continues to be diversity in cultures, size, and location within the new city-states, they share the common belief that order and discipline are required to maintain healthy human communities and a stable environment. People in these societies work together collaboratively, and governance is decentralized. Order and discipline are espoused by the central government and actively administered, applied, and enforced at the local level.

Agriculture is radically different from the inefficient production of the early twenty-first century. Agriculture is thousands of times more efficient in producing protein, calories, and nutrients needed to sustain population centers. Most people eat plants supplemented with the occasional wild harvested animal. Protein from plants is indistinguishable from farm raised meat and poultry, and most people are vegetarians. Farm raised fish and algae are also common. Range animals such as cows are no longer raised due to cheaper replacements for meat, cultural attitudes, and the energy costs to produce.

Because agriculture has intensified and because human population has decreased and moved together into self-sustaining communities, forests are beginning to recover after once nearing the brink of extinction. Land previously used for agriculture and suburban sprawl has now returned to forest, with food grown in highly organized and concentrated grow-zones and housing consolidated to provide maximum density in an urban core. Communities and forests exist in close proximity. Agricultural production, agroforestry, and trees are all integrated into the new cities. The forests now include many introduced species, genetically modified or synthetically born species, as well as "native" plants and animals. There is a decrease in biodiversity of old but an increase of genetic diversity as GMOs mix with non-GMOs. Wildlife such as white-tailed deer, eastern cotton-tail rabbits, and various rodents are plentiful but not too abundant because they are heavily hunted and regulated by the local government. Wood is used for almost everything, and forests and tree farms are heavily

Downloaded from wfr.sagepub.com by guest on August 9, 2016

managed and intensively used for food, energy, and materials by each city's population.

This is a high-tech future, and the technology has fostered the transition from global economics to a localized sharing and collaborative economy. Manufacturing facilities that are small scale and local allow communities to manufacture the things they need. Communities trade with one another for specialty items. Renewable wood-based nanomaterials combined with improved 3D printing technologies have helped make this transition because, now, things can be made on the spot and on demand. Forest and bio-based nanomaterials provide the means of generating electricity, maintain interconnected communications, and are used to produce lightweight materials for transportation, clothing, computers, and medicine.

Forestry has become both a science and a sort of religion. This is an era that mirrors the early twentieth-century progressive era where the principles of scientific regulation, scientific truth, and government control are paramount to bring order, meet material needs, and regulate social and spiritual lives of the citizens. Local control is strict in this scenario, with community leaders bringing harsh punishments for infractions of the rules. The local control has merged religion with science and sustainability. This future mirrors the early years of the USFS in terminology, emphasis on local decentralized governance, and the scientific control of nature. "District Rangers" are the ultimate enforcers of both social and environmental rules. This scenario is all about coming together, setting strict limits, and collaborating to make local communities thrive and avoid collapse. People have banded together to provide for their own food (intensive permaculture), energy (locally produced solar, wind, water, biomass from trees), and economy. Nanotechnology has played a major role in shaping this future.

Sources for this Discipline Future are listed in the appendix.

Scenario 4: Transform Future

Welcome to Akua, a vast, lifelike networking system composed of Terra, Luna, and Mars. The main features of Akua are material abundance, instantaneous mobility, and dynamic intelligent complexity, made possible when the nanotechnology projects of the USFS and many others not only met, but vastly exceeded, Drexler's wildest dreams.

Akua is an entirely artificial environment, the result of nanotechnologically and biosynthetically modified, geoengineered everything, designed and managed by a variety of cooperating and conflicting autonomous intelligences ranging from *Homo Ludditus* to *Homo Machinus*.

By harnessing, via synthetic adenosine triphosphate (APT), the fundamental electrical processes of life, energy is free and abundant.

Participation in the governance of Akua—rather than in economic production and consumption—is a main focus of human and posthuman life.

Given its history of environmental care and management, the USFS joined with similar agencies in the United States and around the world as the old nation-states disappeared. They took the lead in creating and maintaining this complex and dynamic world. Called "The Sylvans," they act on the basis of a few fundamental decisions that are made by consensus after lengthy discussion.

As strict requirements are few, while preferred values and behavior are many, the numerous resulting conflicts are resolved not by "laws," but by quorum-sensing and compromise. This system takes a lot of time—which everyone has—and does not always go smoothly, but most sentients prefer it to the old systems of oppressive "laws" decided by "majority rule" and imposed by privileged rulers empowered with killing force.

Preserving and restoring old cultures and environments is a major focus for most Homo Ludditus. They pride themselves in doing the trivial and arcane things that the other, newer Homo do not do or cannot do—including engaging in diverse religious practices, strenuous physical competition for meaningless prizes, mastering obscure languages and academic disciplines, and the like.

Akua is the Anthropocene Epoch on steroids.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

Akua is a Hawaiian word that is frequently translated as "god." However, an old *Vocabulary of Words in the Hawaiian Language*, published in 1836, stated, "Akua. The Deity, God, any supernatural being, an object of religious homage, applied also to artificial objects, the nature or properties of which Hawaiians do not understand, such as a watch, a compass, etc."

That is the meaning of "Akua" here. Akua is an "artificial object, the nature or properties of which" we today "do not understand," but, just as a watch or a compass makes sense to present-day Hawaiians, so also will Akua make complete sense to all of us as it becomes reality in the future.

Sources for the Transform Future are listed in the appendix.

Conclusion and Implications

The four specific futures described in this study—Grow, Collapse (New Beginnings), Discipline, and Transform—illustrate the range of possible futures for forestry and wood-based nanomaterials that could unfold in the coming decades, as well as possible roles that wood-based nanotechnology could play in helping to shape those future contexts. It should be reiterated that identification of the four archetypal scenarios (by Dator) and the details of our specific scenarios (by the research team) were determined through intensive empirical research.

The four futures themselves were derived from the collection, analysis, and reanalysis of actual images of the future that are exhibited in laws, policies, plans, pronouncements, futures research, religious texts, stories, poems, movies, games, and many other sources over many years and across many cultures. The four images of the future are considered to be the basic, irreducible, fundamental, contrasting, generic images of the future found within all so-called "developed" communities in the world today. All of the myriad conflicting images of the future that exist in all communities can be viewed as specific examples of one or more of the four generic images.[37]

Guided by the profoundly differing logic of each of the four generic types, actual examples of the main drivers, trends, and emerging issues illustrative of each of the four futures were identified using a scanning technique created by Graham Molitor.[38] Thus, there is a factual basis underlying every feature of each future, that is, a research paper or other credible bit of evidence supporting each detail of each of the four futures (see the appendix for references). The specific examples given of each of the four generic futures were derived from a rigorous effort in horizon scanning. This concluding section explores several broad and interconnected implications that cut across the set of scenarios, as well as some unique to one or two of the futures.

First and most fundamentally, an implication suggested by all four scenarios is that the future context and range of possibilities for nanocellulose and forestry are much more expansive than typically assumed in forestry planning and policy, especially when we look out many decades. The continued growth scenario is considered by most people to be the most likely. But as futurist Herman Kahn said, "The most likely future isn't."[39] In other words, even what is considered to be the most likely future is a low probability event given the complex nature of social-ecological systems and the frequency of discontinuous change and surprise. There is a long history of long-range forecasting in forestry.[40] But these forecasts and assessments are limited to a narrow range of business-as-usual, continuation of current trends futures; they project trends from the past and ignore the possibility of emerging countertrends, nonlinear developments, discontinuous change, and other types of surprise. They are missing the possibility of major shocks and structural changes that are plausible but unexpected. Scenarios and other foresight methods (e.g., horizon scanning, the futures wheel) are tools for uncovering and planning for surprises. Three of the four images of the future that we discuss are intended to open up thinking about a much wider range of long-run possibilities than are those of continued growth—even those that consider varieties of possible growth, such as "high, medium, and low"—and are based upon actual statements about the futures found in society today.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

Second, and following from the first implication, the wide range of possible futures and surprising developments suggests the need for strategies to promote or strengthen institutional and social-ecological resilience.[41] In ecological definitions, resilience is the ability of a system to absorb or accommodate disturbances without experiencing fundamental changes.[42] But the impacts of potentially disruptive technologies such as nanotechnology are so significant that they may cause significant changes in forest ecosystems, the forest products industry, and beyond. Fundamental changes to the system may be inevitable. Therefore, the classic ecological definition of resilience may be less appropriate for forestry in the twenty-first century than standard dictionary definitions of resilience that include notions of adaptation and adjustment, that is, "the ability to adjust to or recover from change," "the ability to adapt successfully in the face of change or threats," or "the capacity to absorb disturbances, self-organize, learn and adapt." Key characteristics of resilient systems include diversity, ecological variability, modularity, acknowledging slow variables, tight feedbacks, social capital, innovation, overlap in governance, and ecosystem service.[43]

Indeed, rather than contemplating the futures either in terms of "sustainability" or "resilience," it might be better to say that systems should strive for "evolvability"—successful emergence from one form and set of functions to another on the basis of responses to environmental pressures over time.[44] Thus, "The Forest Service" of the future may not look like or act like the Forest Service of the present but still be understood to have evolved into its future form and function on the basis of its successful responses to environmental, social, and technological challenges.

Third, potentially transformative technologies such as nanotechnology typically produce an array of unintended and unanticipated consequences, both direct and higher order impacts.[45] For example, there is a strong potential that many members of the public and other stakeholders may regard nanomaterials the same way they now regard GMOs, genetic engineering, nanoscale machines, and other controversial technologies, thereby provoking strong social opposition. This kind of opposition could stop wood-based nanomaterials in their tracks. Lessons that nanotechnology advocates can learn from biotechnology regarding social acceptability have been explored in recent years.[46] Key lessons include the following: (1) concerns about new technologies often reflect wider public concerns (e.g., terrorism), (2) greater public knowledge and awareness about the technologies may not diminish concerns and may even move the public toward a more skeptical view, and (3) an open model of innovation with extensive public discussion throughout the process is required. In addition, it seems that unintended consequences of the technology need to be transparently explored. In the GMO case, for example, an open discussion of increased pesticide use with GMO crops could have possibly avoided a fair share of the backlash while opening space for a shared public-private path forward.

Another possible unanticipated consequence is the occurrence of significant human or environmental health impacts of wood-based nanotechnology. Once again, serious health or safety impacts could stop the development and diffusion of nanomaterials if they ultimately prove to be nonviable from a public safety standpoint. This implies the need for intensive and balanced research on potential human health and ecotoxicological effects to investigate and prevent this potential development. Another related unanticipated consequence could be deleterious health effects on other living organisms (humans are not the only species that could have their health impacted by nanomaterials) or impacts to the ecosystem itself. In addition, if twigs and sticks can be turned into high-end electronics, the demand for forest-based materials could exceed the ecosystem's ability to produce those materials.

Unintended consequences such as these suggest the need for forest planners and policy makers to proactively identify possible consequences of wood nanomaterials and other major innovations produced by research and design strategies to encourage positive impacts and discourage negative impacts. The Futures

Downloaded from wfr.sagepub.com by guest on August 9, 2016

Wheel is a foresight tool specifically designed to do this.[47] Most analyses of the implications of change do not go beyond the obvious direct consequences. But the higher order consequences are less obvious and may be the most significant. The smart group process, graphic structure, and nonlinear thinking of the Futures Wheel make it a powerful tool for identifying and evaluating possible implications of change.

A fourth interconnected implication is that major and potentially disruptive and transformative technologies such as nanotechnology may create or contribute to a special category of high impact unintended consequence, often referred to as wild cards or black swans. The collapse and transform images of the futures could be considered as constructed by emphasizing various wild cards—drastically different futures that contain multiple individual wild cards. Emerging wild cards are difficult to identify and interpret, but several strategies have been proposed. Markley[48] described a four-level typology and a related method for monitoring emerging awareness of wild cards and their credibility, and Mendonça et al.[49] proposed a method based on the type of wild card, the subject area affected (e.g., economic, environmental, technological), and the nature and magnitude of potential impacts. Petersen[50] maintains that there are always early warnings of impending wild card events, but we frequently miss them because we tend not to think about such events and the precursors that might signal their approach.

This way of thinking about the future is problematic, however. It stems from a time when it seemed reasonable to think of a "normal," "most likely" future, and to see "wild cards" as largely unanticipated and perhaps unlikely events that might perturb the normal future. The alternative four futures approach suggests there is no "normal" future anymore from which "wild cards" might produce rare and unexpected deviations. Rather, there is ample evidence, which the four futures uncover, to support the likelihood of each of the four futures coming to pass. The four futures approach requires us to treat each of the four futures as potentially equal in possibility, and equal also in terms of desirability or undesirability. There is no "best case scenario" or "worst case scenario." There is no "most likely" or "least likely" future. Preferred futures represent our best shot and what we hope will be with a rational and rigorous plan to get there. But ultimately the point is, through exploring alternative futures, to evolve successfully regardless of what "the future" turns out to be, rather than assuming that one can only thrive in one future alone.

A final implication that follows from all the preceding implications is the importance of institutionalizing foresight capacity. Futures research is a transdisciplinary field of inquiry that uses a variety of methods to explore alternative possible, plausible, and preferable futures. Bell[51] further characterizes futures research as an "action science," with an orientation to informing decision-making and action. One goal of futures research is to produce strategic foresight, defined as "the ability to create and maintain a high-quality, coherent, and functional forward view and to use the insights arising in organizationally useful ways; for example, to detect adverse conditions, guide policy, shape strategy."[52] Institutionalizing foresight capacity into routine planning and policy making is critical to have a lasting effect. A single foresight exercise like this one quickly loses its value no matter how skillfully done and widely embraced. Institutionalizing foresight capacity in forestry and forest products would help identify continuing and new driving forces and trends, novel emerging issues, and a range of plausible alternative futures. Most important, it would stimulate ongoing strategic conversations about the futures.[53]

There are three main strategies for institutionalizing foresight. An in-house strategy would involve creating a futures unit that would be responsible for regular horizon scanning and high-priority projects exploring possible, plausible, and preferable futures using a range of foresight methods. An alternative strategy is to have one person assigned specifically to contract with futures research organizations and think tanks, purchasing scans and futures surveys on a regular basis, and working closely with planners, managers, and policy makers to incorporate the findings into decision-making and strategies. Outsourcing

Downloaded from wfr.sagepub.com by guest on August 9, 2016

foresight activities is a common approach in corporations, but it is important to ensure that foresight developed by outside consultants is relevant and incorporated into strategic planning and decision-making.[54] A hybrid approach to institutionalizing foresight, involving both an in-house futures unit and regular use of outside experts, is often most effective. In-house foresight champions know the culture and the ways of the organization or field, and outside experts bring new ideas and perspectives.

One of the main implications of the four scenarios is that nanotechnology may be far more transformative than we may now imagine. With nanotechnology, and the other transforming sciences and technologies such as artificial intelligence, robotics, biotechnologies, new materials, brain research, and space exploration and settlement, humanity presently may be like a caterpillar building a cocoon around herself with no notion of the butterfly that may emerge. Wood-based nanotechnology has the potential to produce a paradigm shift in forestry and forest products that would redefine forest resources. At the same time, the collapse and discipline futures caution us to proceed carefully and ethically. If our thinking is stuck in the old paradigm, we will not be successful in any new one. More broadly, each has the potential to accelerate the Anthropocene era of significant anthropogenic change by making all wood cellulose a material that can be made into countless high-value products. Our hope is that this study will stimulate further forward-looking debate and discussion about the futures of wood nanomaterials and forestry so that we can make the best possible decisions for the common good of all our futures.

Appendix

Selected References for Each of the Four Futures

Sources for Grow Futures

Asafu-Adjaye, John, Linus Blomqvist, Stuart Brand, Barry Brook, Ruth DeFries, Erle Ellis, Christopher Forman, David Keith, Martin Lewis, Mark Lynas, Ted Nordhaus, Roger Pielke, Jr., Rachel Pritzker, Pamela Ronald, Joyashree Roy, Mark Sagoff, Michael Schllenberger, Robert Stone, and Peter Teague. 2015. *An Ecomodernist Manifesto*, April 2015. http://www.ecomodernism.org/ (accessed July 1, 2016).

Bailey, Ronald. 2015. *The End of Doom: Environmental Renewal in the Twenty-First Century*. New York: Thomas Dunne Books.

Colvile, Robert. 2015. *The Great Acceleration: How the World Is Getting Faster and Faster*. Bloomsbury.

Cowen, Tyler. 2014. *Average Is Over: Powering America beyond the Age of the Great Stagnation*. New York: Dutton.

Defense Advanced Research Projects Agency. 2015. *Breakthrough Technologies for National Security*. www.darpa.mil (accessed July 1, 2016).

Diamandis, Peter, and Steven Kotler. 2012. *Abundance: The Future Is Better Than You Think*. New York: Free Press.

Ip, Greg. 2015. "The World's New Population Time Bomb: Too Few People." *Wall Street Journal*, November 23, 2015. http://www.wsj.com/articles/how-demographics-rule-the-global-economy-1448203724 (accessed July 1, 2016).

Land, George. 1986. *Grow or Die: The Unifying Principle of Transformation*. Random House.

Morton, Oliver. 2015. *The Planet Remade: How Geoengineering Could Change the World*. Princeton, NJ: Princeton University Press.

Peterson, Rachelle, and Peter Wood. 2015. *Sustainability: Higher Education's New Fundamentalism*. Washington, DC: National Association of Scholars.

Ridley, Matt. 2010. *The Rational Optimist: How Prosperity Evolves*. Harper.

Simon, Julian. 1998. *The Ultimate Resource 2*. Princeton, NJ: Princeton University Press.

Sources for Collapse and New Beginnings Futures

Dartnell, Lewis. 2014. *The Knowledge: How to Rebuild Our World from Scratch*. New York: Barnes & Noble.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

Dator, Jim. 2014. "'New Beginnings' within a New Normal for the Four Futures." *Foresight* 16 (6): 496–511.

Joy, Bill. 2000. "Why the Future Doesn't Need Us." *Wired* 8 (4). http://www.wired.com/wired/archive/8.04/joy.html (accessed July 1, 2016).

Lovelock, James. 2009. *The Vanishing Face of Gaia: A Final Warning*. New York: Basic Books.

Meadows, Dennis, Jorgen Randers, and Donella Meadows. 2004. *Limits to Growth: The 30-Year Update*. White River Junction, VT: Chelsea Green Publishing.

Rawles, James Wesley. 2009. *How to Survive the End of the World as We Know It: Tactics, Techniques, and Technologies for Uncertain Times*. New York: Plume.

Rees, Martin. 2003. *Our Final Hour: A Scientist's Warning: How Terror, Error, and Environmental Disaster Threaten Humankind's Future in this Century—On Earth and beyond*. New York: Basic Books.

Sheridan, Sam. 2014. *The Disaster Diaries: One Man's Quest to Learn Everything Necessary to Survive the Apocalypse*. New York: Penguin Books.

Stein, Matthew. 2008. *When Technology Fails: A Manual for Self-Reliance and Planetary Survival*. White River Junction, VT: Chelsea Green Publishing.

Ward, Peter. 2009. *The Medea Hypothesis: Is Life on Earth Ultimately Self-Destructive?* Princeton, NJ: Princeton University Press.

Sources for Discipline Futures

Alperovitz, Gar, James Speth, Jane Mansbridge, Gerald Hudson, Annie Leonard, Robert Reich, Dean Baker, Barbara Ehrenreich, Jeffrey Sachs, Gerald Torres, Larry Cohen, Julie Matthaei, Leo Gerard, John James Conyers, Jr., Bill McKibben, Saskia Sassen, Frances Fox Piven, Manuel Pastor, J. Phillip Thompson, Oliver Stone, Medea Benjamin, Timothy Wirth, Sarita Gupta, Noam Chomsky, Van Jones, Lawrence Mishel, Roxanne Dunbar-Oritz, Daniel Ellsberg, Herman Daly, Ralph Nader, Ai-jen Poo, Anna Galland, Danny Glover, Tom Morello, Jill Stein, and Nancy Fraser. 2015. *The Next System Project: New Political-Economic Possibilities for the 21st Century*. thenextsystem.org.

Barnosky, Anthony. 2014. *Dodging Extinction: Power, Food, Money, and the Future of Life on Earth*. Berkeley: University of California Press.

Bostrom, Nick, and Milan Cirkovic, eds. 2008. *Global Catastrophic Risks*. New York: Oxford University Press.

Brown, James, William Burnside, Ana Davidson, John Delong, William Dunn, Marcus Hamilton, Norman Mercado-Silva, Jeffrey Nekola, Jordan Okie, William Woodruff, and Wenyun Zuo. 2011. "Energetic Limits to Economic Growth." *Bioscience* 61 (1): 19–26.

Dator, Jim, and Seongwon Park. 2012. "Korea as a Conserver Society." *Social Business* 2 (3): 181–204.

Dong, Leilei, Hao Liu, and Saffa Riffat. 2009. "Development of Small-Scale and Micro-Scale Biomass-Fuelled CHP Systems—a Literature Review." *Applied Thermal Engineering* 29 (11): 2119–26.

Fernholz, Kathryn, Jeff Howe, Jim Bowyer, Steve Bratkovich, Matt Frank, Adam Zoet, and Sarah Stai. 2013. *The Next 100 Years of Forests in the U.S.: Growing the Forests We Want and Need*. Minneapolis: Dovetail Partners, Inc.

Floyd, Joshua, and Richard Slaughter, eds. 2014. "Descent Pathways: Special Issue." *Foresight* 16 (6): 485–95.

Laarman, Jan. 2000. "2050: A Scenario for People and Forests." *Journal of Forestry* 98 (2): 4–9.

Monbiot, George. 2014. *Feral: Rewilding the Land, the Sea, and Human Life*. Chicago: The University of Chicago Press.

Odum, Howard T., and Elisabeth Odum. 2002. *A Prosperous Way Down: Principles and Policies*. Boulder: University Press of Colorado.

The Pontifical Academy of Sciences and The Pontifical Academy of Social Sciences, ed.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

2014. *Sustainable Humanity Sustainable Nature Our Responsibility, Proceedings of a Workshop*. Vatican City. http://www.casinapioiv.va/content/dam/accademia/booklet/booklet_sustainable.pdf (accessed July 1, 2016).

Seddon, Philip J., Christine J. Griffiths, Pritpal S. Soorae, and Doug P. Armstrong. 2014. "Reversing Defaunation: Restoring Species in a Changing World." *Science* 345:405–12.

Steffen, Will, Paul Crutzen, and John McNeill. 2007. "The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?" *Ambio* 36 (8): 614–21.

Sources for Transform Futures

Bostrom, Nick. 2014. *Superintelligence: Paths, Dangers, Strategies*. Oxford: Oxford University Press.

Brain, Marshall. 2015. *The Second Intelligent Species: How Humans Will Become as Irrelevant as Cockroaches*. Cary, NC: BYG Publishing, Inc.

Church, George M., and Ed Regis. 2012. *Regenesis: How Synthetic Biology Will Reinvent Nature and Ourselves*. New York: Basic Books.

Dator, Jim, and Yongseok Seo. 2005. "Korea as the Wave of a Future: The Emerging Dream Society of Icons and Aesthetic Experience." *Papers of the British Association for Korean Studies* 10:1–21.

Drexler, K. Eric. 2013. *Radical Abundance: How A Revolution in Nanotechnology Will Change Civilization*. New York: Public Affairs.

Dunagan, Jake. 2004. "Neuro-Futures: The Brain, Politics, and Power." *Journal of Futures Studies* 9 (2): 1–18.

Enriquez, Juan, and Steve Gullans. 2015. *Evolving Ourselves: How Unnatural Selection and Nonrandom Mutation Are Changing Life on Earth*. New York: Penguin.

Goonatilake, Susantha. 1999. *Merged Evolution: Long-Term Implications of Biotechnology & Information Technology*. London: Gordon & Breach.

Kurzweil, Ray. 2005. *The Singularity Is Near: When Humans Transcend Biology*. New York: Viking.

Roden, David. 2015. *Posthuman Life: Philosophy at the Edge of the Human*. New York: Routledge.

Steffen, Will, Wendy Broadgate, Lisa Deutsch, Owen Gaffney, and Cornelia Ludwig. 2015. "The Trajectory of the Anthropocene: The Great Acceleration." *The Anthropocene Review* 2 (1): 1–18. doi:10.1177/2053019614564785.

Varho, Vilja, Pasi Rikkonen, and Saija Rasi. 2016. "Futures of Distributed Small-Scale Renewable Energy in Finland—A Delphi Study of the Opportunities and Obstacles Up to 2025." *Technological Forecasting & Social Change* 104:30–37.

Authors' Note

Authors are listed in alphabetical order and contributed equally to the project and manuscript.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by Research Joint Venture Agreement 14-JV-11242315-077, titled "Forest-based Nanocellulose Futures," between the US Forest Service, Northern Research Station and the University of Hawaii.

Notes

1. Char Miller, *American Forests: Nature, Culture, and Politics* (Lawrence: University Press of Kansas, 1997).
2. Gifford Pinchot, *Breaking New Ground*, Commemorative ed. (Washington, DC: Island Press, 1998), 1947.
3. Stephen J. Pyne, *America's Fires: Management on Wildlands and Forests*, Forest History Society Issues Series (Durham: Forest History Society, 1997).
4. R. E. Rice and C. K. Atkin, eds., *Public Communication Campaigns*, 3rd ed. (Thousand Oaks: Sage, 2001).

Downloaded from wfr.sagepub.com by guest on August 9, 2016

5. Robert L. Olson, David N. Bengston, Leif A. DeVaney, and Trevor A. C. Thompson, *Wildland Fire Management Futures: Insights from a Foresight Panel*, Gen. Tech. Rep. NRS-152 (Newtown Square: U.S. Department of Agriculture, Forest Service, Northern Research Station, 2015), http://www.treesearch.fs.fed.us/pubs/48581.
6. Gerald W. Williams, *The USDA Forest Service—The First Century*, FS-650 (Washington, DC: USDA Forest Service, 2000), http://www.foresthistory.org/ASPNET/Publications/first_century/index.htm.
7. Paul W. Hirt, *A Conspiracy of Optimism: Management of the National Forests since World War Two* (Lincoln: University of Nebraska Press, 1994).
8. Hirt, *A Conspiracy of Optimism*.
9. H. J. Cornter and M. A. Moote, *The Politics of Ecosystem Management* (Washington, DC: Island Press, 1999).
10. R. W. Guldin and D. N. Bengston, "Strategic Foresight Activities in the United States of America: A Brief History and Focus on Forest Sector." Presented at the IUFRO Forest Foresight Scoping Meeting, Vienna, Austria, February 26–27, 2015.
11. Tim Appenzeller, "The Man Who Dared to Think Small." *Science* 254 (November 29, 1991): 1300–301.
12. Chris Toumey, "Plenty of Room, Plenty of History." *Nature Nanotechnology* 4, no. 12 (2009): 783–84.
13. Appenzeller, "The Man Who Dared to Think Small," 1300.
14. K. Eric Drexler, *Engines of Creation: The Coming Era of Nanotechnology* (New York: Anchor Press/Doubleday, 1986).
15. A. M. Cruickshank, "Gordon Research Conferences," *Science* 243, no. 4895 (March 3, 1989): 1201–218. Nanotechnology was mentioned in the title of a conference paper, on p. 1207.
16. Ivan Amato, "The Apostle of Nanotechnology," *Science* 254, no. 5036 (November 29, 1991): 1310–311. Quote is from pp. 1310–11.
17. U.S. Congress, Office of Technology Assessment, *Miniaturization Technologies*, OTA-TCT-514 (Washington, DC: U.S. Government Printing Office, 1991), http://ota.fas.org/reports/9129.pdf
18. M. E. Vance, T. Kuiken, E. P. Vejerano, S. P. McGinnis, M. F. Hochella Jr., D. Rejeski, and M. S. Hull, "Nanotechnology in the Real World: Redeveloping the Nanomaterial Consumer Products Inventory." *Beilstein Journal of Nanotechnology* 6 (2015): 1769–780, doi:10.3762/bjnano.6.181.
19. Linda Fulps, "Lungs May Suffer When Certain Elements Go Nano." *Phys.org*, January 28, 2014, http://phys.org/news/2014-01-lungs-elements-nano.html#inlRlv.
20. Gunter Oberdorster, Eval Oberdorster, and Jan Oberdorster, "Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles." *Environmental Health Perspectives* 113, no. 7 (2005): 823–39.
21. Maxine McCall, "Nanoparticles and Nanosafety: The Big Picture," *The Conversation*, February 6, 2014, http://theconversation.com/nanoparticles-and-nanosafety-the-big-picture-22061.
22. K. Eric Drexler, *Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization* (New York: Public Affairs, 2013).
23. Toumey, "Plenty of Room, Plenty of History."
24. Nano materials can also be made from plants other than trees, like agricultural crops and crop residue. One advantage of forest-based nano materials is they do not typically require chemical inputs like fertilizers, pesticides, and herbicides which are often derived from petroleum. Rajai Atalla, James Beecher, Robert Caron, Jeffrey Catchmark, Yulin Deng, et al., "Nanotechnology for the Forest Products Industry: Vision and Technology Roadmap." Sponsored by the American Forest and Paper Association, U.S. Department of Energy's Pacific Northwest National Laboratory, Technical Association of the Pulp and Paper Industry, and the U.S. Department of Agriculture Forest Service, Forest Products Laboratory, 2005, http://www.tappi.org/content/pdf/nanotechnology_roadmap.pdf.
25. R. M. Alston, "Are Sustained Yield and Sustainable Forests Equivalent?" Proceedings of the 1991 Society of American Foresters National Convention, San Francisco, CA, August 4–7, 1991 (Bethesda: Society of American Foresters), 310–15.
26. USDA Forest Service, *Nanocellulose Pilot Plant* (Madison: USDA Forest Service, Forest Products Lab, 2012), http://www.fpl.fs.fed.us/research/facilities/nanocellulose_pilot-plant.php.
27. JoAnne Shatkin, T. W. Wegner, E. M. Bilek, and J. Cowie, "Market Projections of Cellulose Nanomaterial-Enabled Products—Part 1: Applications." *Tappi Journal* 13, no. 5 (2014): 9–16.
28. Mitch Jacoby, "Nano from the Forest: Tiny Cellulosic Particles are Poised to Make Big

Downloaded from wfr.sagepub.com by guest on August 9, 2016

Impact on Materials Technology." *Chemical & Engineering News* 92, no. 26 (2014): 9–12, http://cen.acs.org/articles/92/i26/Nano-Forest.html; Emil Venere, "Cellulose Nanocrystals Possible 'Green' Wonder Material." *R&D Magazine*, December 16, 2013, http://www.rdmag.com/news/2013/12/cellulose-nanocrystals-possible-green-wonder-material; Matt Safford, "These New Computer Chips Are Made from Wood." *Smithsonian.com*, June 3, 2015, http://www.smithsonianmag.com/innovation/these-new-computer-chips-are-made-from-wood-180955471/#r5mqDFhK4Jwyfmcx.99; Bernard Kippelen, Canek Fuentes-Hernandez, Yinjua Zhou, Robert Moon, and Jeffrey P. Youngblood, *Recyclable Organic Solar Cells on Substrates Comprising Cellulose Nanocrystals (CNC)*, US Patent 9,203,030, filed March 21, 2014, and issued December 1, 2015.

29. M. M. Pereira, N. R. B. Raposo, R. Brayner, E. M. Teixeira, V. Oliveira, C. C. R. Quintão, L. S. A. Camargo, L. H. C. Mattoso, and H. M. Brandão, "Cytotoxicity and Expression of Genes Involved in the Cellular Stress Response and Apoptosis in Mammalian Fibroblast Exposed to Cotton Cellulose Nanofibers." *Nanotechnology* 24, no. 7 (2013), Article 075103; M. M. Pereira, L. Mouton, C. Yéprémian, A. Couté, J. Lo, J. M. Marconcini, L. O. Ladeira, N. R. Raposo, H. M. Brandão, and R. Brayner, "Ecotoxicological Effects of Carbon Nanotubes and Cellulose Nanofibers in Chlorella Vulgaris." *Journal of Nanobiotechnology* 12 (2014), Article 15.
30. R. de Lima, L. O. Feitosa, C. R. Maruyama, M. A. Barga, P. C. Yamawaki, I. J. Vieira, E. M. Teixeira, A. C. Corrêa, L. H. C. Mattoso, and L. F. Fraceto, "Evaluation of the Genotoxicity of Cellulose Nanofibers." *International Journal Nanomedicine* 7 (2012): 3555–565.
31. N. Yanamala, M. T. Farcas, M. K. Hatfield, E. R. Kisin, V. E. Kagan, C. L. Geraci, and A. A. Shvedova, "In Vivo Evaluation of the Pulmonary Toxicity of Cellulose Nanocrystals: A Renewable and Sustainable Nanomaterial of the Future." *ACS Sustainable Chemistry & Engineering* 2 (2014): 1691–698.
32. James A. Dator, John A. Sweeney, and Aubrey M. Yee, *Mutative Media: Communication Technologies and Power Relations in the Past, Present, and Futures* (New York: Springer, 2014).
33. Graham T. T. Molitor, "How to Anticipate Public-Policy Changes," *S.A.M. Advanced Management Journal* 42, no. 3 (1977): 4–13.
34. Jim Dator, "Alternative Futures at the Manoa School." *Journal of Futures Studies* 14, no. 2 (2009): 1–18, http://www.jfs.tku.edu.tw/14-2/A01.
35. Dator, "Alternative Futures at the Manoa School."
36. Ray Kurzweil, *The Singularity is Near: When Humans Transcend Biology* (New York: Penguin Books, 2005).
37. Dator, "Alternative Futures at the Manoa School"; Neil MacDonald, "Futures and Culture," *Futures* 44, no. 4 (May 2012): 277–91.
38. Molitor, "How To Anticipate Public-Policy Changes." See also Dator et al., *Mutative Media*, chap. 5.
39. Herman Kahn, *The Coming Boom: Economic, Political and Social* (New York: Simon & Schuster, 1982), quote at p. 82.
40. Guldin and Bengston, "Strategic Foresight Activities in the United States of America," February 26–27, 2015.
41. B. Walker and D. Salt, *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* (Washington, DC: Island Press, 2006).
42. D. J. Davidson, "The Applicability of the Concept of Resilience to Social Systems: Some Sources of Optimism and Nagging Doubts," *Society & Natural Resources* 23, no. 12 (2010): 1135–49.
43. B. Walker and D. Salt, *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* (Washington, DC: Island Press, 2006).
44. The concept "evolvability" comes from Jan Huston, *A Passion to Evolve, Doctoral Dissertation* (Honolulu: University of Hawaii, May, 2000).
45. Dator et al., *Mutative Media*.
46. K. David and P. B. Thompson, eds., *What Can Nanotechnology Learn from Biotechnology? Social and Ethical Lessons for Nanoscience from the Debate over Agrifood Biotechnology and GMOs* (Burlington: Academic Press, 2008).
47. D. N. Bengston, "The Futures Wheel: A Method for Exploring the Implications of Social-Ecological Change." *Society & Natural Resources* 29, no. 3 (2016): 374–79, http://treesearch.fs.fed.us/pubs/50218.
48. O. Markley, "A New Methodology for Anticipating STEEP Surprises," *Technological Forecasting & Social Change* 78, no. 6 (2011): 1079–1097.
49. S. Mendonça, M. P. Cunha, J. Kaivo-oja, and F. Ruff, "Wild Cards, Weak Signals and Organizational Improvisation." *Futures* 36, no.

Downloaded from wfr.sagepub.com by guest on August 9, 2016

2 (2004): 201–18.
50. J. L. Petersen, *Out of the Blue: Wild Cards and Other Big Future Surprises* (Arlington, VA: The Arlington Institute, 1997).
51. W. Bell, *Foundations of Futures Studies, Volume 1: History, Purposes, and Knowledge* (New Brunswick, NJ: Transaction Publishers, 1997).
52. R. A. Slaughter, "Futures Studies as an Intellectual and Applied Discipline," in *Advancing Futures: Futures Studies in Higher Education*, ed. J. Dator (Westport, CT: Praeger, 2002), 91–107, quoted at p. 104.
53. P. Schwartz, *The Art of the Long View: Planning for the Future in an Uncertain World* (New York: Currency Doubleday, 1991).
54. G. S. Day and P. J. H. Schoemaker, "Scanning the Periphery," *Harvard Business Review* 83, no. 11 (2005): 135–48.

Author Biographies

David N. Bengston is an environmental futurist and social scientist with the US Forest Service, Northern Research Station, Strategic Foresight Group in St. Paul, Minnesota. He is also an adjunct professor in the Department of Forest Resources and the Conservation Biology Graduate Program at the University of Minnesota, USA.

Jim Dator is professor and director Emeritus, Hawaii Research Center for Futures Studies, Department of Political Science, University of Hawaii; professor, International Space University, Strasbourg, France; adjunct professor, Korean Advanced Institute of Science and Technology, Daejon, Korea; and former president, World Futures Studies Federation.

Michael J. Dockry is a research forester with the US Forest Service Northern Research Station, Strategic Foresight Research Group, an adjunct assistant professor at the University of Minnesota, and an associate editor of the *Journal of Forestry*. He earned a BS in forest science and a PhD in forestry from the University of Wisconsin Madison and an MS in forest resources from the Pennsylvania State University, USA.

Aubrey Yee is a PhD candidate in Political Science/Alternative Futures and research associate at the Hawaii Research Center for Futures Studies at the University of Hawaii at Manoa. She also works with the Hawaii Leadership Forum to implement and teach futures studies and systems thinking for social change.

Downloaded from wfr.sagepub.com by guest on August 9, 2016