The Clean Revolution:
Technologies from the Leading Edge

by Joel Makower

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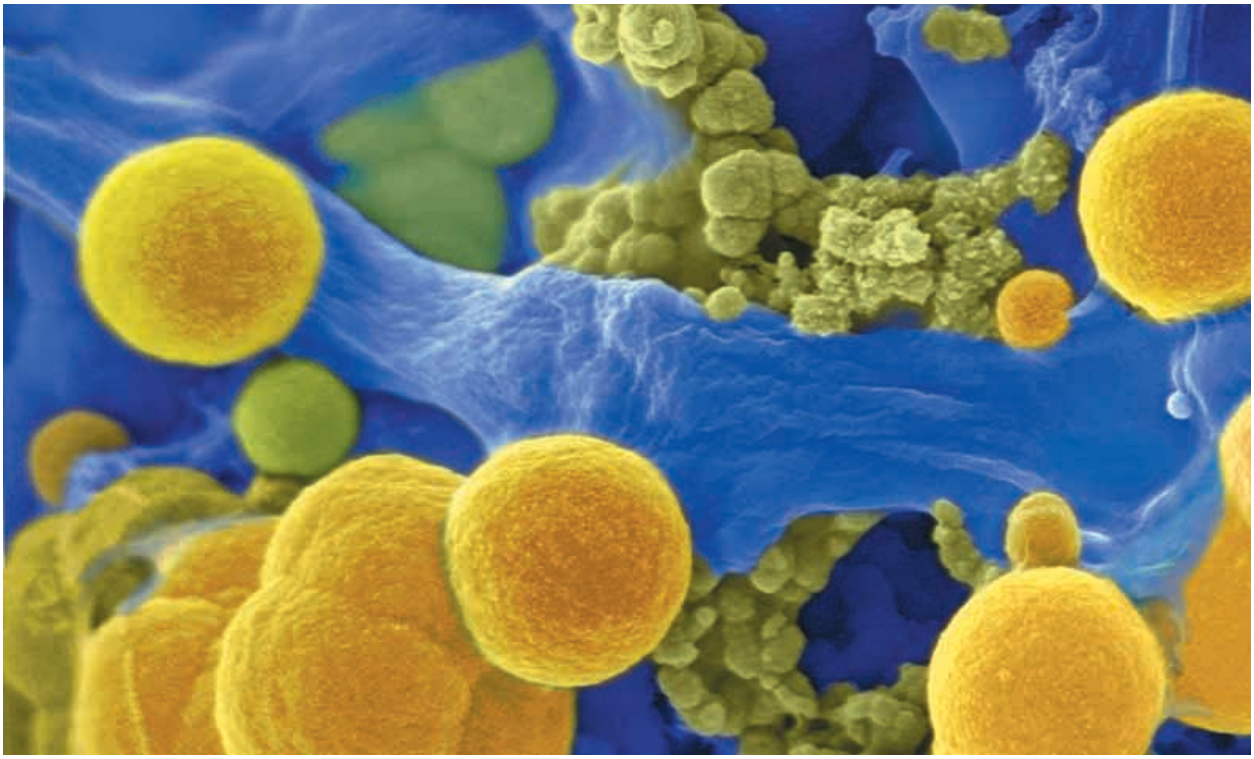

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Cover Picture
Sulfate-reducing bacteria. May assist in groundwater remediation and may play a role in the genesis of some ore deposits.

Is “clean technology” an oxymoron… or the future of our planet? Does it represent one of the great business opportunities of the new millennium… or will it rise and fall like so many over-hyped technologies of the past? Will it engender a revolutionary shift in how we live, work, and play… or a more evolutionary shift largely transparent to the masses?

When it comes to clean technology, questions far outnumber answers. To most business people, the very notion of “clean tech” itself begs any number of questions—from “What is it?” to “Can technology ever really be clean?” to “How clean does it have to be to be *clean*?” to “Isn’t all this simply a logical extension of business as usual?”

Clearly, this is not business as usual. Indeed, for all the hype about the New Economy—the irrationally exuberant e-world that dominated headlines and mindspace for the past few years—a real, and sustainable, new economy is emerging. It is based not on ephemeral (and dubious) products and services, but on providing clean energy, clean transportation, clean water, and other goods and services that embody the principles of industrial ecology, resource productivity, and natural capitalism.

This is no mere recasting of the ’70s “appropriate technology” movement, though the seeds of many of today’s burgeoning success stories were sowed during that period. The new clean-tech era is represented by a diverse and dispersed corps of companies, from start-ups to multinational giants, with support from forward-thinking investors, scientists, politician’s, and customers.

In May 2001, GBN—in partnership with Clean Edge, Inc., a consulting and publishing firm focusing on clean technology—brought together a remarkable assemblage of member companies, Network members, staff, and other resources to examine the world of clean technology. The goal was to pose, and attempt to answer, three critical questions:

What, exactly, is “clean technology”?

Why is it now coming to the forefront?

How can companies profit from these new markets?

Clean Tech: Then and Now

How is today’s “clean technology” different from 1970s “appropriate technology” movement? Here are some representative slogans of the two eras.

THEN . . .	**NOW . . .**
Return to Nature (Live Simpler)	Emulate Nature (Live Smarter)
Business Is the Problem	Business Is the Solution
Money Is an Implement of Destruction	Money Is an Implement of Creation
Be Off the Grid	Feed Into the Grid
Small Is Beautiful	Small Is Profitable (and Profitable Is Beautiful)
Be Self-Sufficient	Be Interdependent
Think Globally, Act Locally	Think and Act “Glocally”
Power to the People!	The People Need Power!

In the quest for answers, participants visited more than a score of clean-tech sites around the San Francisco Bay Area—a region at the epicenter of concern about environmental degradation, energy and water resources, and constrained mobility—to meet with a variety of experts on the promise and pitfalls of clean technology. Along the way, groups of participants "invented" a number of clean-tech products and services aimed at meeting the simultaneous goals of creating profitable new markets, reducing environmental impacts, and improving people's lives.

Clean-tech examples could be found throughout the member companies in attendance. Texaco has a significant stake in a leading fuel-cell company and is actively engaged in designing a global hydrogen infrastructure to power vehicles, homes, and businesses. Procter & Gamble recently introduced a new product system that makes water in developing countries germ-free and safe to drink, potentially improving the lives of the more than one billion denizens of the planet who lack potable water. Dow is partnering with Cargill to manufacture NatureWorks, the first mass-produced plastic made from corn and other annually renewable resources. DuPont is reinventing itself to deliver chemical services instead of products, simultaneously improving resource efficiency while better meeting customer needs. Hewlett-Packard recently launched an initiative focusing on sustainable business ventures that benefit the rural poor in developing countries. Herman Miller's Michigan headquarters building boasts some of the world's greenest designs and materials.

The meeting was endowed with a wealth of gifted resource people, including some of the leading voices on industrial ecology, natural capitalism, sustainable business, nanotechnology, renewable energy, "hypercars," green buildings, water resources, and technology and innovation management.

And so the stage was set: Is clean technology a driving force for a new "New Economy"? Can it be? Should it be?

We set off to find out.

What Is Clean Tech?

Given the wide range of things being showcased as "clean tech," how do we define it? Clean Edge proffered the following definition:

> **A diverse range of products, services, and processes that harness renewable materials and energy sources, dramatically reduce the use of natural resources, and significantly cut or eliminate emissions and wastes. Clean technologies are competitive with, if not superior to, their conventional counterparts. Many also offer significant additional benefits, notably their ability to improve the lives of those in both developed and developing countries.**

Such a broad-brush definition gives clean tech a pretty wide berth, which seemed disconcerting to some. Should a sport-utility vehicle that gets twice the fuel-economy of its competitors, thanks to an innovative hybrid-electric engine, be considered "clean technology"? (Or, as sustainable-business guru John Elkington so deliciously pondered: Is it progress if a cannibal eats with a fork?)

How about the alchemy of "cleaner coal," a process in which dirty coal is subjected to a 2,700-degree oven, yielding a cleaner-burning gas? Is it, as some claim, clean tech?

And what about nuclear power, which, in the wake of current energy market perturbations, is being touted as "the clean air energy" by industry proponents? Does it deserve the clean-tech moniker?

In the rough-and-tumble world of industrial marketing, there appears to be a fairly fine line separating clean tech, cleaner tech, and downright greenwashing.

Clean Tech's Four Domains
Select Examples

Energy	**Transportation**
Biomass	Battery storage
Fuel cells	Electro propulsion
Geothermal	Fuel-cell vehicles
Microturbines	Hybrid-electric vehicles
Photovoltaics	Solar-powered vehicles
Small-scale hydro	Stirling engines
Wave/tidal power	
Wind power	
Materials/Buildings	**Water**
Biobased materials	Biological water filtration
Biomimetics	Distributed systems
Green buildings	Small-scale desalination
Green chemistry	Ultraviolet purification
Phytoremediation	Wetlands restoration

Another reality of clean technology is that it defies easy classification. Because clean tech spans a variety of Standard Industrial Classifications, it was useful to divide it into four domains reflecting its principal applications. At the WorldView event, these four domains—energy, transportation, water, and materials and buildings—served as a basis for Learning Journeys as well as for innovating clean-tech businesses and business models.

But even this handy classification scheme is far from perfect. None of these domains exists in a vacuum; all are tightly linked. Energy, of course, pervades everything, and each of the other domains, in a variety of ways, is similarly critical to the others.

> **In the end, and perhaps fittingly, clean technology was seen to be much like an ecosystem: Far from a single, isolated entity, it is a diverse universe, tightly integrated with and dependent upon a myriad of other factors and forces.**

Why Now?

That same notion—clean technology as a complex part of a complex system—also underscores the answer to another key question: Why does clean technology seem to be taking off at this particular time? And to a corollary query: Is this truly a revolution or merely an evolution?

There seems little dispute that a critical mass of clean-technology companies, products, and markets has coalesced in just a few short years. As Clean Edge revealed in Clean Tech: Profits and Potential (http://www.cleanedge.com/reports.php), a report issued just prior to the WorldView event, markets for clean technology, while still relatively tiny, are growing dramatically, with steep trajectories forecast for some technologies. For example, Clean Edge projects the market for clean energy to grow more than tenfold over the coming decade, to more than $80 billion. Investment money is pouring into clean technologies at an accelerating rate—more than $2 billion of equity investments during 2000 in North America alone, according to Clean Edge, plus billions more in R&D investments by companies and governments, and venture investments in other parts of the world.

Much of this has been a long time in the making. Indeed, some of the most promising clean technologies are more than a century old.

Consider fuel cells. These clean and quiet devices, which generate electricity from hydrogen and oxygen, were first conceptualized by Sir William Grove around 1840. The technology advanced slowly for more than a century but took one giant leap for mankind in the 1960s, when General Electric produced fuel cells to power the Gemini and Apollo space capsules. Only recently have fuel cells been developed for commercial use. Today, at least nine major automobile makers plan to introduce fuel-cell vehicles to commercial markets by 2005, and dozens of other commercial applications are in the pipeline.

Or consider photovoltaics, the technology of turning sunlight into electricity. The concept is just as old, dating to 1839, when Edmund Becquerel realized that certain materials would create a very small amount of voltage. Not much happened until 1921, when Albert Einstein won a Nobel Prize for further explanation of the photovoltaic effect. Bell Laboratories created the first solar-cell silicon device in the 1950s; the space program used solar cells in the 1960s, and the OPEC oil embargo brought them to public light in the 1970s. Only in the late 1990s did they become efficient enough to be cost-competitive with some conventional energy sources.

Old as they are, fuel cells and photovoltaics are relatively new. Biological water filtration—which uses nature's powers to cleanse dirty water—and other clean technologies that harness nature's services are the product of billions of years of R&D on the part of Mother Earth. (The mere notion that we are just now learning to harness nature's power to cleanse our environmental misdeeds is an ironic touchstone to society's historical disconnection from the natural world.)

So, Why Now?

Today's clean-tech boom is the result of a confluence of environmental, technological, economic, and social forces. They include:

- **Changing markets**, from the globalization of suppliers and customers to the emerging markets of the developing world, are dramatically expanding the demand for goods and services around the globe. The challenge for companies and countries in the developing world is how to grow new busi-

nesses and economies without the concomitant growth of resource extraction and toxic emissions that have characterized economic progress in industrial societies. The newly opened markets of China, India, Africa, Latin America, and Eastern Europe have raised challenging new opportunities to build these countries' fast-growing infrastructures using cleaner technologies.

- **Changing business models**, including the growth of decentralized distribution systems and microenterprise. Both of these fit neatly with many clean technologies' smaller, localized scale: distributed energy, which makes power available close to where it is needed; and distributed water, which similarly shuns large, centralized processing plants in favor of smaller, localized filtration facilities. The mainstreaming of natural capitalism and industrial ecology—which challenge companies to mimic natural systems by harnessing closed-loop processes that do not deplete natural resources—have led companies to invent new, significantly cleaner products, services, and processes. The rise in global innovation and entrepreneurialism, and the growth of private-equity investment capital to support technology, also have accelerated clean-tech's development.

- **Changing technologies**, including continued innovations in microelectronics, biology, chemistry, and physics have significantly improved the performance of many clean technologies. Efficiency advances and declining costs of renewable-energy technologies, for example, have dramatically cut the cost of wind power and photovoltaics, making them cost-competitive with conventional energy sources in many cases. Emerging scientific disciplines, such as bioengineering and nanotechnology, are yielding breakthroughs in products and processes that dramatically cut waste and emissions and reduce resource use. A revolution in design, emphasizing dematerialization, similarly has produced products and processes that provide more value with less "stuff."

Navigating Society's Mental Maps

How people perceive and embrace clean technology depends in part on the mental maps they carry with them. Here is a representative sampling of attitudes and perspectives.

Eco-Geeks
- Clean tech is our only hope for saving the world.
- Business is our best chance to heal the planet.
- Clean technologies are inevitable.
- There is a technology fix for any problem.

Incrementalists
- Clean tech is a niche market for enthusiasts.
- Incremental improvements are the most cost-effective approach moving forward.
- Clean technologies are making their way into the marketplace and need no further help.

Sustainable Thinkers
- Clean technologies are only one part of a fundamental shift society needs to make.
- Clean tech is good, but we must also consider the social ingenuity required to solve global problems.

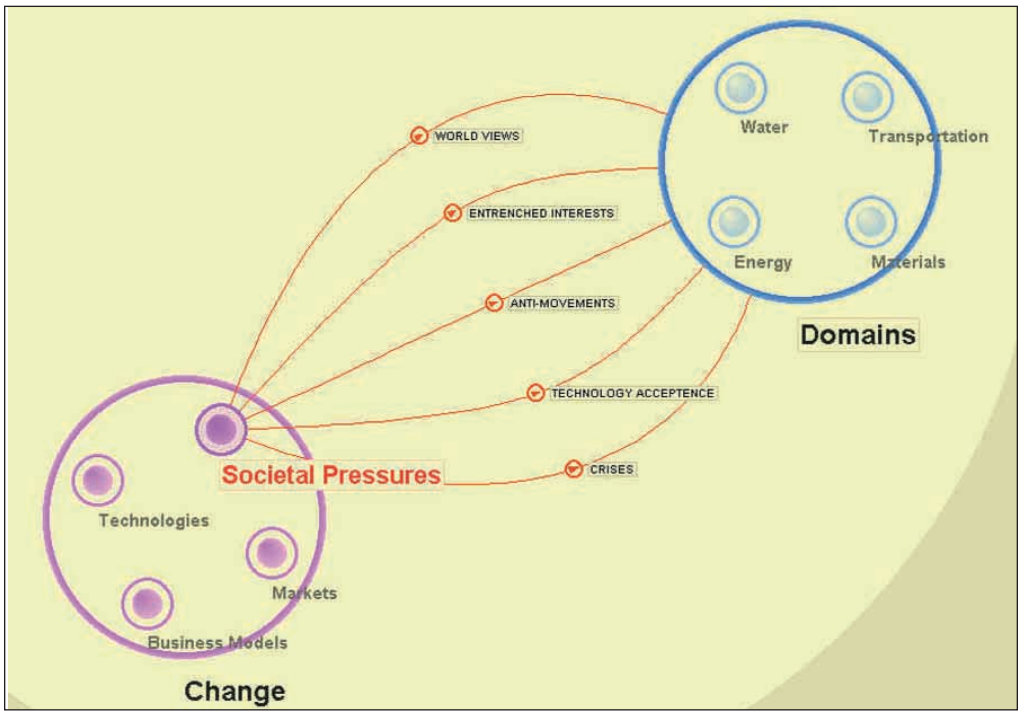
Technophobes
- Technology is part of the problem, and rarely the solution.
- Technology has outpaced our ability to control it.

Market Skeptics
- Big business is talking a good game, but as history has shown us, greed and fear will lead corporations to suppress or slow truly disruptive technologies.
- Most consumers don't really care about clean technologies and won't pay a premium for them.

Eco-Fatalists
- Clean technologies are an oxymoron.
- Clean technologies are too little, too late.
- Business will only do what it is forced to do, so we need new global governance regimes.

• **Changing social pressures** have pressed companies to address the needs of society and the environment as never before. Environmental concerns over global climate change, deforestation, air pollution, and inadequate supplies of clean water have stepped up pressure to find more environmentally benign ways to meet the needs of a growing world. The concern over climate change in particular has led to a new focus on alternative transportation and energy technologies. The increased attention paid to sustainable development—which aims to balance long-term environmental, economic, and social interests as a means of addressing the needs of the world's citizens as well as those of future generations—has increased the demand for clean, affordable, and resource-efficient technologies in developing countries. The anti-globalization movement, combined with activist demands for companies to be more accountable and transparent in their dealings, has led many firms to more proactively examine, and change, their products, processes, and policies.

Such forces have led a relatively small but growing corps of companies to pursue vast new business opportunities centered around clean technologies, and have prompted investors to pour billions into new clean technologies and the companies that can bring them to market.



At the WorldView meeting, participants worked with John Garn of ViewCraft to build a multidimensional KnowledgeMap ™ of the clean-tech universe, helping to track the relationships among the myriad players as well as the obstacles, barriers, and wildcards. The view pictured here illuminates the social drivers affecting the acceleration of clean-tech.

Will People Buy It?

So much for the supply side. What about demand? Will the market be ready, willing, and able to accept these innovative, cleaner goods and services?

That's a far cloudier picture. In the past, many environmental products have failed to gain market footholds, despite an endless parade of surveys indicating that consumers greatly prefer to buy things that are better for the earth. Are consumers misrepresenting their real intentions, are the products not living up to expectations, or are other forces contributing to this apparent disconnect between green concern and green consumerism? What does all this bode for the future of clean technology?

There are several good reasons why so-called "green" products didn't sell. Many of them didn't work well, were more expensive, or came from unfamiliar brands. Most weren't widely available, requiring shoppers to drive miles out of their way or resort to mail-order merchants. Some green products required consumers to adopt new, unfamiliar, and often-inconvenient habits. Several high-profile companies were lambasted by government officials for misrepresenting the environmental benefits of their products.

Given all this, it's little wonder green consumerism was largely a non-starter, at least in the U.S., where getting consumers to change their habits has historically been tough going.

To succeed, "environmentally preferable" must not be just cleaner, but better—and, ideally, cheaper. To become part of society's fabric, environmentally preferable products must be fairly invisible to the end user, much like so many automotive safety features. The dramatic improvements offered by antilock brakes, air bags, side-impact protection, and a host of other innovations generally don't change the way cars look or drive. They simply make cars better.

> **That's a key lesson for clean technologies. It's not enough to simply be "clean." To succeed in the consumer marketplace, they must yield additional benefits to a product or service, all while being relatively invisible, requiring few if any changes in the way something is purchased and used. For consumers, clean technology should be a no-brainer.**

Case in point: Hybrid-electric automobiles, which combine the best aspects of both electric and conventional engines to boost gas mileage to 70 miles per gallon or more. Other than their improved drivetrains, they are little different from their conventional counterparts. The two models currently being sold in the U.S. are both doing quite well, encouraging most other major auto makers to introduce hybrids in the U.S. market the next two-to-three years.

As GBN Chairman Peter Schwartz put it: "People won't choose to live thoughtfully. The only thing is to make the value proposition so great, by whatever consumer criteria, and lead them to do the right thing in spite of themselves."

Places to Intervene in a System

By Dana Meadows in *Whole Earth*,
via Hunter Lovins

9. Numbers (taxes, subsidies, standards)
8. Material stocks and flows
7. Regulating negative feedback loops
6. Deriving positive feedback loops
5. Information flows
4. Rules (incentives, punishments, constraints)
3. Power of self-organization
2. Goals of system
1. Mindset of paradigm

Things are different in the world of industrial and institutional buyers, where purchasing priorities often diverge widely from those of consumers. In B-to-B transactions, clean technologies can require dramatic changes in customer relationships, often leading one or both parties to retool manufacturing processes or even rethink product strategies altogether.

Consider "servicizing," the notion of selling a service instead of a product—warmth instead of energy; mobility instead of vehicles; clean clothes instead of washers. This is catching on in several sectors, notably chemicals, where firms are offering chemical management services, in which they retain ownership of the physical product but sell or lease their services. For example, DuPont now leases "sulfur services," rather than selling sulfur outright. By retaining ownership of goods and selling only their services, manufacturers retain control of—and responsibility for—the physical assets. Such arrangements radically alter business relationships, not to mention management practices.

Or take distributed energy technologies, which can enable companies to buffer themselves from energy-distribution disruptions or price spikes through the use of on-site, off-the-grid energy technologies such as microturbines and fuel cells. Such technologies can dramatically change companies' relationships with energy utilities and require wholesale changes in a firm's own internal electricity infrastructure—none of which may necessarily be a market barrier, given the business benefits the technologies engender. Indeed, the fact that these technologies are "clean" may be secondary at best.

Ultimately, whether clean technologies truly take off may hinge on any of a number of wildcards—energy crises, severe weather patterns, activist pressures, or political machinations, among others. Or it could be a "killer app"—a clean-tech application whose popularity boosts entire markets, much like the rapid uptake of e-mail helped build mass acceptance of the Web.

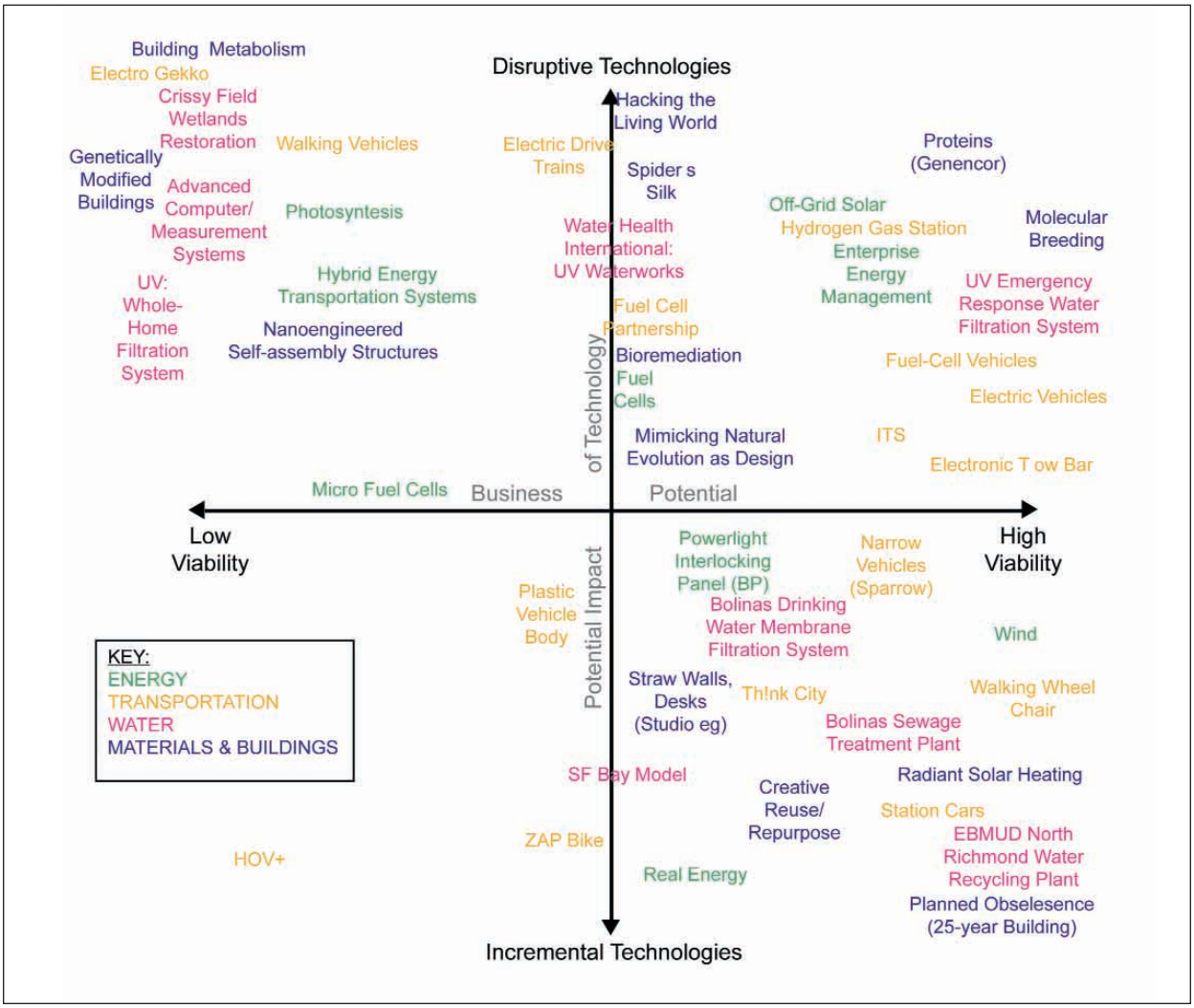
Actually, the Web may represent a poor metaphor for clean technology, given the volatility, poor performance, and infant mortality among Web-related firms. Indeed, clean-technology companies and advocates may find useful lessons from the irrational exuberance of the Internet business, which crashed and burned even quicker than it took off.

Which leads us to our third—and, ultimately, toughest—question: Can companies profit from clean tech?

How Can Companies Profit from Clean Tech?

Answering that question required an immersion in the clean-tech universe to understand the day-to-day realities of companies developing and marketing clean technologies. That immersion process was facilitated by four Learning Journeys—one each into the four principal clean-tech domains: energy, transportation, water, and materials/buildings. The WorldView participants fanned out throughout the Bay Area, from Sacramento to Palo Alto to Livermore. Each journey aimed to showcase innovations that are in the commercial pipeline as well as those whose likely commercialization was further into the future. All told, the four groups visited a total of 27 sites (see Appendix).

(It should be noted that the Bay Area, which provided a rich lode of Learning Journey opportunities—is by no means the center of the clean-tech universe. Learning Journeys could be organized in many parts of the U.S. and abroad, from Japan's photovoltaic manufacturers, to Denmark's wind-turbine companies, to solar-power water desalination plants in the Middle East, to the profitable new microenterprises of India and Bangladesh.)



During the post-Learning Journey debrief, each of the four groups placed each visit or technology they experienced on a matrix indicating its perceived impact and viability. The group's collective optimism showed through: Almost nothing was deemed to have both low viability and low impact.

In for the Long Haul

The Learning Journeys were only the beginning. A panel moderated by Peter Schwartz—including Hunter Lovins (Rocky Mountain Institute), Neil Jacobstein (Institute for Molecular Manufacturing), Rob Shelton (Arthur D. Little, Inc.), and Peter Warshall (*Whole Earth*)—looked further into the future at "Potential Surprises, Discontinuities, and Disruptive Clean Technologies on the Horizon."

The horizon, it turns out, isn't that far off in some cases. Take the "hypercar," the concept vehicle pioneered by the Rocky Mountain Institute that is part luxury sedan, part SUV, and part environmental wonder. Lovins likened the auto industry of today to the computer industry in the early 1980s. We are now seeing the earliest "PCs"—advanced, lightweight, hybrid-electric autos like the Honda Insight and Toyota Prius—enter the marketplace, with many more innovative vehicles to come.

But simply having greener transport isn't particularly disruptive. What's changed is the potential of such vehicles to become rolling power plants, feeding power into the electric grid when they are idle—which they are 99 percent of the time. Says Lovins: "The generating capacity running around on the roads today is roughly 14 times the current generating capacity of the grid."

Or consider nanotechnology, a shotgun marriage of chemistry and engineering in which manufacturing is done by manipulating individual atoms and molecules to build tools, materials, and products. Or (returning to the PC metaphor), "doing for matter what computing did for bits," says Jacobstein. Nanotech promises some truly disruptive technologies, such as nano-electrical machines (NEMs) that consume very little energy, or nanoassembly of carbon molecules into diamonoid configurations, yielding materials with tensile strength fifty times that of titanium. We have many examples of microelectrical machine systems (MEMs) today. We have examples of two-dimensional nanofabrication in semiconductor manufacturing. However, it will take 10–20 years to reach industrial strength molecular nanotechnology that can pick and place molecules with atomic precision and scale up to industrial applications.

Shelton warned that clean technologies' biggest impacts would likely come from a series of incremental technologies, rather than one or two disruptive ones. In determining which technologies to bet on, "companies should be looking to pick the complete deals, not just one technology," he says. The key is to take on solutions to a set of problems, "investing in people and the way they're organized and their ability to change and learn" rather than their ability to harness one particular tool. That, he says, will lead to "innovation for the long haul."

How Far? How Fast?

Neil Jacobstein, chairman of the Institute for Molecular Manufacturing, offered the following forecast of the role of nanotechnology in building clean-tech markets over the coming two decades.

	2 Years	**5–10 Years**	**10–20 Years**
Energy	Sensors	Nanotube membranes for fuel cells; nanotube hydrogen storage	Large-scale solar photovoltaic arrays
Transportation	Carbon composites; sensors; activators	Super strong light nano tube composites	Fabricate transport to order;extract and use local carbon vs. transport it
Water	MEMs and NEMs; sensors	Desalination membranes	Assembler separation and purification systems
Buildings and Materials	Carbon composite materials	Nanotube composites for specialized applications; diamond sheets and parts	Assembly of diamond bridges and organic buildings

The long haul—the next 20 years—is what Warshall describes as "the end of the linear mind," a time when global societies will begin to include such things as clean water and adequate energy among a base level of human rights. The key to pushing clean-tech forward, he says, is the restoration of natural capital—the resources harnessed by nature to cleanse the air and water, fertilize the soil, keep pests in check, and provide a wealth of other services vital to economies but virtually uncounted in national or corporate accounting systems. The ability of industry to harness clean technologies to adapt to changes in available natural capital—during a drought, for example—will be key to their future competitiveness. Says Warshall: "The whole business opportunity for natural capitalism is there for the taking."

Barriers, Uncertainties, Wildcards

The Learning Journeys and the ensuing discussions and exercises raised two key things: There is a great deal more going on in companies and laboratories than participants had realized, but the pace of development is much slower than that of, say, the e-business world. Interestingly, the GBN corporate members came away feeling more energized and excited than the advocates and resource people, who seemed unsettled by the relatively slow pace of progress in bringing clean tech to market.

Why is Clean Tech Happening NOW

Forces of Change	The Result	Barriers & Enablers Uncertainties & Wildcards	Outcomes and Opportunities?
• Globalization of markets, suppliers, labor • Newly deregulated markets • Decentralized distribution systems • Servicizing of physical goods • Emerging markets in developing regions • B24B opportunities	Changing Markets	• Customer acceptance, willingness/ ability to change • Customer demand • Environmental needs • Infrastructure changes • Standards and specifications • Educational efforts • Media awareness and response • Financial mechanisms	New Markets
• Rise in innovation/entrepreneurialism • Shift to knowledge-intensive economy • Infusion of private-equity investment capital • Growth in industrial ecology/natural capitalism • Emergence of microenterprise • Distributed and open source movements	Changing Business Models	• Economic stability & growth • Government support/incentives/subsidies • Standards and specifications • Entrepreneurial support • Acceptance/willingness of new business models • Industry leadership/resistence	New Business Models
• Efficiency advances • Declining costs • Technological breakthroughs (faster, better, cheaper, lighter) • Design revolution • (some) Dematerialization • New disciplines, new tools: bioengineering, nanotech, biomemetics, etc.	Changing Technologies	• Technological advances and setbacks • Prices of conventional resources—oil, gas, trees, etc. • Government commitments to R&D • Private investment capital	New Technologies
• Declining resources (trees, energy, water) • Overtaxing earth's carrying capacity • Growing concern over climate change, clean air and water, biodiversity • Population growth and shifts • Growth of NGOs • Demands for corporate responsibility, accountability, transparency • Changing generational and cultural attitudes • Mainstreaming of environmental movement, and sustainable development concept	Changing Societal Pressures	• Differing world views • Entrenched interests (political, corporate, NGOs) • Anti-corporate/anti-globalization movement • Acceptance of technology as a solution • Weather perturbations, wars, crises	New Solutions

Source: GBN/Clean Edge, 2001

It became clear to all involved that the road to a clean-tech future, however promising, is replete with speed bumps, roadblocks, and uncharted territory. To succeed in the marketplace, clean technologies will have to traverse these obstacles and, whenever possible, transform them into opportunities. Four realizations emerged:

- **The clean-tech universe of players is highly fragmented and disconnected from one another**. This contrasts with, say, the world of telecommunications, where there are a great deal more standard-setting organizations, partnerships, and collaborative projects. The Learning Journeys illuminated the lack of connectivity among the various players working in similar fields. Even inside many companies, a sort of "Clean Wall" appears to exist between scientists and engineers on one side and the finance and marketing folks on the other. (This coinage owes deep gratitude to Rob Shelton, one of our resource people, who in the early 1990s pointed out the existence of a Green Wall between environmental professionals and the rest of the company, which prevented the environment from becoming a source of business value and competitive advantage.) Says Shelton today: "The clean-tech development community does not communicate well and does not learn from itself. If the community only knew what the community knew."

- **Inconsistent government support represents a potent force working against the development of clean-tech products and markets**. In the U.S., government R&D for clean technology has been a political football, and has been growing and shrinking with less regard for funding needs than for the shifting political winds. This lack of consistency, even at a relatively low level of funding, has been a stumbling block for many firms' R&D efforts, with support withering away at critical junctures. Meanwhile, while the U.S. faltered in funding clean tech, other governments picked up the slack, with the result that markets for several U.S.-developed technologies—most notably, renewable-energy technologies—have been co-opted by the Japanese, Danes, Germans, and others.

- **It isn't just the technologies that need help; it's also the underlying markets**. For example, creating a market for fuel cells—whether for vehicles, businesses, homes, or portable electronics—will require building a new hydrogen infrastructure. While a great deal of R&D effort is pouring into developing fuel cells, much less effort is focusing on how to make the societal transition from hydrocarbons to hydrogen. Will that slow the uptake of fuel cells as a principal power source? It certainly could. So, too, with distributed water technologies, such as biofiltration. How do you integrate a water-cleansing process relying on natural systems into an infrastructure based on large-scale water-treatment facilities? Will employing such technologies require water users to go "off the grid"? If so, will that present a roadblock to these technologies' deployment?

- **Clean technologies will be slower to develop than many people had hoped**. This was perhaps the most sobering realization by the group: The rise of clean technology represents both revolution and evolution. That is, while we are likely to see periodic bursts of dramatic growth and the rapid uptake of a few disruptive technologies, most clean technologies will likely unfold incrementally over the longer term—roughly the next five to fifty years. Developing products, building infrastructures, and marketing them to the point that they reach critical mass will take money, resources, ingenuity—and more than a little patience.

Ultimately, this revolution-evolution scenario for clean tech, however unsatisfying to some, may be the more sustainable path, one in which hype will run a lower risk of outpacing tangible progress. That delicate line between technological promise and marketplace reality has hamstrung the world of e-business. It caused irrationally exuberant investors to mindlessly pour billions into dubious business propositions,

then just as quickly (and, some say, just as mindlessly and irrationally) pull the proverbial plug when short-term profits proved elusive. A similar phenomenon plagued solar energy during the 1970s and 1980s, as investors were lured by the promise of breakthrough technologies—and disappointed when they failed to materialize quickly enough.

Says science-fiction writer Bruce Sterling: "Incremental change is better than a boom-or-bust cycle, which stymied development that could have saved our bacon in the '70s. Slow but steady performance is ideological, and we should aim for it. We're not going to Brainiac our way out of these problems."

Some will cavil that while building clean-tech markets will mandate taking a longer view, it's not really all that long. After all, 50 years is a relative blip, chronologically, compared with other major industrial shifts. Most people forget that petroleum was just emerging as a dominant industry 50 years ago. It took decades for it to grow into the behemoth force it is today. What will be the behemoth forces of tomorrow? (Hint: The oil giants are placing their bets on fuel cells, solar, wind, and biomass.)

All of this will be extremely challenging for the financial community, for which the "long-view" tends to be measured in a months or years, not decades. Shining a light on the huge markets waiting to be built while tempering investors' congenital impatience may be clean-tech's most formidable challenge.

> **Will investors once again pull the plug on clean technologies that fail to yield short-term results? Or will the financial community view the longer horizon of clean-tech's payoff? The answer to that question could be key to all that comes next.**

New Products, New Markets, New Visions

There certainly is no shortage of ideas. GBNovate—an innovation exercise in which players are dealt cards representing technologies, societal challenges, enablers, and other factors, and then asked to brainstorm new business opportunities—yielded a wealth of innovations. The more fanciful included a hydro-powered spaceship RV to transport the elderly to visit their families, complete with the motto: "If we can go to the moon, we can go to Tucson." Others were extremely functional, such as an inexpensive, durable portable display device for use by those in developing countries. This device would be owned at the village level and used on a per-transaction basis to enable the poorest of the poor to receive money transfers or photos from distant relatives, conduct commerce, access the Internet, and pay bills, among other things. Many of these business ideas involved not just products or services, but complex social systems that showcased clean technologies' ability to improve lives as well as pocketbooks.

Such ingenuity helped punctuate the vision of clean technology that was emerging: a vast portfolio of tools that could transform society and engender vast new opportunities, assuming they are wielded with skill, swiftness, and grace. "My definition of clean technology was too limited," concluded one GBN member. "I've started to see there is a connection between all of them." Said another: "This is more real than I thought."

Will clean tech yield the next Big Idea? Will it come from harnessing cars to generate energy for homes and offices? From "hacking the biological code" to produce cleaner materials and products, as one Learning Journey host described? Will we be doing "landfill mining" for resources to build our new economies, "consuming earlier waste" to build the societies of the future, as Bruce Sterling forecast? Will it involve bridges made from hyperstrong spider's silk, or bio-based buildings grown on the spot from organic ingredients, or biological water filtration systems built into every home?

The future, when viewed through a clean-tech lens, looks promising—and profitable.

But amid all this optimism and creativity, other questions loom large: Will clean-tech's bounty arrive in time to avert the potential weather catastrophes of global warming, or to provide food and clean water to mushrooming populations of the poorest of the poor? Will it materialize in time to stem deforestation and its domino effect of ecological impacts? Will it provide jobs and better lives to those who need it most? Or will it be too little, too late?

Indeed, given all the potential that clean tech offers, these may be the most important questions of all.

Appendix

The Energy Learning Journey

The Water Learning Journey

The Materials & Building Learning Journey

The Transportation Learning Journey

Eight Clean-Tech Memes: A Cheat Sheet

Reading List

Resources

The Energy Learning Journey

Stop 1:
UC Berkeley, Renewable and Appropriate Energy Laboratory—RAEL
ist-socrates.berkeley.edu/~rael/aboutrael.html

Stop 2:
Altamont Pass
Green Ridge Associates—Division of FLPL Energy
www.fplenergy.com

Stop 3:
Silicon Energy
www.siliconenergy.com
Nth Power Technologies
www.nthfund.com

Stop 4:
UC Berkeley, Department of Chemistry
www.cchem.berkeley.edu/~chemgrad/faculty/fleming.html

Stop 5:
Pleasanton Power Park
Real Energy
www.realenergy.com
BP Solar
www.bpsolar.com

Stop 6:
Dinner/Debrief
Bruce Sterling with a Story from a Clean-Tech Future

The Water Learning Journey

Stop 1:
Bay Model
www.spn.usace.army.mil/bmvc/model.htm

Stop 2:
Bolinas Community Public Utility District
Sewage Treatment Plant

Stop 3:
Bolinas Community Public Utility District
Drinking Water Membrane Filtration System
www.memtec.com
www.bcpud.org

Stop 4:
East Bay Municipal Utility District
www.ebmud.com

Stop 5:
Water Health International
www.waterhealth.com

Stop 6:
Dinner/Debrief
Bruce Sterling with a Story from a Clean-Tech Future

The Materials & Building Learning Journey

Stop 1:
Ecological Design Institute in Sausalito
www.ecodesign.org

Stop 2:
Genencor
www.genencor.com

Stop 3:
Studio eg
www.studioeg.com
Indigo Development
www.indigodev.com

Stop 4:
Molecular Sciences Institute in Berkeley
www.molsci.org

Stop 5:
California College of Arts and Crafts
www.savingsbydesign.com/awards/2000awards.html

Stop 6:
Dinner/Debrief
Bruce Sterling with a Story from a Clean-Tech Future

The Transportation Learning Journey

Stop 1:
Corbin Motors
www.corbinmotors.com

Stop 2:
Partners for Advanced Transit and Highways PATH
www.path.berkeley.edu

Stop 3:
California Partnership for Fuel Cells Demonstration Facility—CaFCP
www.cafcp.org

Stop 4:
UC Berkeley, PolyPedal Lab Advanced Mobility Systems
polypedal.berkeley.edu

Stop 5:
National Station Car Association
www.stncar.com
Hertz Rent-A-Car—Ford TH!NK at Fisherman's Wharf
www.thinkmobility.com
ZAP Bikes
www.zapworld.com

Stop 6:
Dinner/Debrief
Bruce Sterling with a Story from a Clean-Tech Future

Eight Clean-Tech Memes: A Cheat Sheet

> **Meme (mēm), n. 1.** a contagious information pattern that replicates by parasitically infecting human minds and altering their behavior, causing them to propagate the pattern. Oxford zoologist, Richard Dawkins, originally coined this term in his book, *The Selfish Gene*, by making the analogy to evolutionary processes and playing off the word "gene." Individual slogans, catchphrases, melodies, icons, inventions, ideas, and fashions are typical memes.

In the emerging field of "memetics," some people argue that we may be able to influence, and even predict, the spread of "good memes" that push our evolutionary buttons and force us to pay attention to them.

For your reference, here are eight "memes" we see propagating and influencing the clean technology sector. In addition to these, what other important memes should we think about, create, and spread to accelerate the shift to clean tech markets?

B-to-4B

"Business selling to the four billion of the world's poorest citizens," a term coined by C. K. Prahalad, professor of business at the University of Michigan Business School, and Stuart Hart, professor at the University of North Carolina's Kenan-Flagler Business School. Most corporations ignore this large population because their business models, economic assumptions, infrastructure are barriers for making these markets profitable. They write: "The bottom of the pyramid presents a new managerial challenge—one potentially as powerful as the challenge presented by the proliferation of the Internet and e-business. The transformation of the bottom of the pyramid and the creation of a new and emerging market, like the opportunity in e-business, requires a total transformation of managerial practices in established [multinational companies]. It will also transform public policy debates in both developed and developing countries." What creative, sustainable offerings can we think of that could overcome some of these barriers? See "Beyond Greening: Strategies for a Sustainable World" by Stuart Hart in *Harvard Business Review* (Jan–Feb, 1997).

Biomemetics

Also referred to as "biomimicry" (from bios, meaning life, and mimesis, meaning to imitate), it is a new science that studies nature's best ideas and then imitates these designs and processes to solve human problems. Studying a leaf to invent a better solar cell is an example. Says Janine Benyus, author of *Biomimicry*: "The core idea is that nature, imaginative by necessity, has already solved many of the problems we are grappling with. Animals, plants, and microbes are the consummate engineers. They have found what works, what is appropriate, and most important, what lasts here on Earth. This is the real news of biomimicry: After 3.8 billion years of research and development, failures are fossils, and what surrounds us is the secret to survival."

Corporate Social Responsibility

Refers to a broad range of business activities generally linking "doing well" to "doing good." The CSR agenda encompasses a vast array of topics. Business for Social Responsibility, in its online resource center, lists no fewer than 116 topics and subtopics that comprise the CSR agenda, from carbon offsets to child labor, ethics training to employing underutilized workers, green product design to global community involvement. And while there's no single definition of what constitutes corporate social responsibility, BSR defines it as "operating a business in a manner that meets or exceeds the ethical, legal, commercial, and public expectations that society has of business. CSR is seen by leadership companies as more than a collection of discrete practices or occasional gestures, or initiatives motivated by marketing, public relations, or other business benefits. Rather, it is viewed as a comprehensive set of policies, practices, and programs that are integrated throughout business operations, and decision-making processes that are supported and rewarded by top management."

Distributed

As with the Internet, which puts power and control into individuals' hands wherever they work or live, the "distributed" model is playing a key role in a number of clean technologies, especially energy. Distributed generation refers to the production of electricity at or near where it is needed, as opposed to shipping electricity hundreds of miles from a central power plant. In both the developed and developing worlds, the trend is toward decentralized solutions that do not depend on the grid, though they often are connected to one.

Industrial Ecology

A science in which industrial systems are modeled after natural systems. According to Tom Graedel and Brad Allenby in *Industrial Ecology*, the concept requires that "an industrial system be viewed not in isolation from its surrounding systems, but in concert with them." One key concept is that, like the biological system, industrial ecology rejects the notion of waste. Dictionaries define waste as useless or worthless material. In nature, however, there is no waste; all materials are reused, generally with great efficiency, because acquiring new materials can be costly in terms of energy and resources. Industrial ecology views materials and products that are obsolete not as wastes, but as residues we have not yet learned to use efficiently.

Natural Capitalism

Refers to the natural resources and ecosystem services that make possible all economic activity. The notion was introduced in a book of that title by Paul Hawken, Amory Lovins, and Hunter Lovins, describing a future in which business and environmental interests increasingly overlap, and in which businesses can simultaneously satisfy their customers' needs, increase profits, and help solve environmental problems. Natural capitalism's four precepts promote: radical resource productivity (using resources more efficiently); biomimicry (redesigning industrial systems along biological lines); service and flow economy (a shift from an economy of goods and purchases to one of service and flow); and investing in natural capital (restoring and expanding stocks of natural capital to promote more abundant ecosystem services).

Sustainable Development

Means different things to different people, but the most frequently quoted definition is from the 1987 report *Our Common Future*: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." According to the International Institute on Sustainable Development: "Sustainable development focuses on improving the quality of life for all of the Earth's citizens without increasing the use of natural resources beyond the capacity of the environment to supply them indefinitely. It requires an understanding that inaction has consequences and that we must find innovative ways to change institutional structures and influence individual behavior."

Servicizing

The notion of selling a service rather than a product—warmth instead of energy; mobility instead of vehicles; clean clothes instead of washers. This is catching on in several sectors, notably chemicals, where firms are offering chemical management services, in which they retain ownership of the physical product but sell or lease their services. By retaining ownership of goods and selling only their services, manufacturers retain control of—and responsibility for—the physical assets. "In a servicizing environment," writes the Tellus Institute, "the notion of straightforward buying and selling softens and diversifies into a spectrum of property rights arrangements, including leasing, pooling, sharing, and take-back. Value is increasingly created and measured by the function provided, and for the manufacturer, the product increasingly becomes a means of delivering this function, rather than an end in itself."

Reading List

We recommend these books as good sources of information on clean-tech issues.

Biomimicry: Innovation Inspired by Nature, by Janine M. Benyus

Deep Design: Pathways to a Livable Future, by David Wann

Made to Measure, by Philip Ball

Natural Capitalism: Creating the Next Industrial Revolution, by Paul Hawkin, Amory Lovins, and Hunter L. Lovins

Power Surge: Guide to the Coming Energy Revolution, by Christopher Flavin

Powering the Future: The Ballard Fuel Cell and the Race to Change the World, by Tom Koppel

The Sacred Balance: Rediscovering Our Place in Nature, by David T. Suzuki

State of the World 2001, Worldwatch Institute

The Sun, the Genome, and the Internet: Tools of Scientific Revolutions, by Freeman J. Dyson

Upsizing: The Road to Zero Emissions—More Jobs, More Income, and No Pollution, by Gunter Pauli

Resources

Energy

American Bioenergy Association
www.biomass.org

American Wind Energy Association
www.awea.org

Green Energy News
www.nrglink.com

Green Power Network
www.eren.doe.gov/greenpower

Hydrogen and Fuel Cell Investor
www.h2fc.com

Rocky Mountain Institute
www.rmi.org

SolarAccess.com
www.solaraccess.com

Sustainable Energy Coalition
www.sustainableenergy.org

Water

Water Environment Federation
http://www.wef.org

WaterInvestments.com
www.waterinvestments.com

Transportation

Electric Vehicle Association of the Americaswww.evaa.org

EV World
www.evworld.com

Innovative Transportation Technologies
faculty.washington.edu/jbs/itrans

Manufacturing

Bio/Environmentally Degradable Polymer Society
www.bedps.org

Carbohydrate Economy Clearinghouse
www.carbohydrateeconomy.org

Consortium on Green Design and Manufacturing
www.me.berkeley.edu/green/cgdm.html

Green Chemistry Program
www.epa.gov/opptintr/dfe/greenchem

International Cleaner Production Information Clearinghouse
www.emcentre.com/unepweb/index.htm

Zero Waste Research Institute
www.zeri.org