Frontier Technologies and the Human Future

Sustainability Solutions

Dennis M. Bushnell

ABSTRACT: Technological revolutions have contributed to societal issues with potentially existential impacts. As we leave the IT Age and enter the Virtual Age, society will require frontier technologies and systems-level approaches to address, mitigate, and possibly reverse these serious concerns, redirecting our focus from economic growth to sustainability. This article offers an overview of emerging frontier technologies, major ongoing and prospective societal issues, and the potential for new solution spaces, including renewable energy and storage, the gig and DIY economies, tele-living, cyborgism, electric transportation, energy-generating buildings, halophytes for energy and food production, and the combination of AI, robotics, and autonomous technologies.

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Major Frontier Technologies

Artificial intelligence, computing, autonomy, and robotics. The IT revolution has transformed society into a world of "tele-everything," introducing extraordinary capabilities for learning AI via neural nets. Scientist/inventor Dr. Stephen Thaler, president and CEO of Imagination Engines Inc., has shown the way for machine creativity with his Imagination Engine, enabling machine ideation and creativity via the very rapid system-level evaluation of large numbers of quasi-random combinatorials, analogous to human ideation and creativity.[1] Many researchers worldwide are pursuing quantum computing in a quest for the most stable qbit to delay decoherence. Such computing could offer fantastic capabilities, possibly replacing many physical activities with computations. Work is also continuing to progress toward robotics that operate via trusted autonomy and direct brain–machine communications. Big data is evolving as a fourth engineering design approach, joining theory, experiment, and computation. And multisensory virtual reality is increasingly providing an alternative to the physical world.

New materials and printing. The frontiers of materials development include printing at the nanoscale level for

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superb microstructures that offer much improved material properties; rigidified smart membranes for a large panoply of inflatables and other uses; material processing approaches that provide enhanced multifunctionality; nanotubes as an ultimate multifunctional material; and associated nanotubes for structures as a replacement for composites. The result will be significantly better materials at less cost, enabling enhanced functionalities. Additive manufacturing, along with the AI-enhanced, open-collaborative Web, is enabling enhanced invention around the world, along with reduced weight and part count and home tele-manufacturing.

Biological technologies, genomics, and synthetic biology. The impacts of the ongoing biological revolutions include life extension, improved health, designer humans and life forms, bioproduction (manufacturing using biological process), bio-functionalism (what is manufactured contains biological products), reinvented agriculture, biomining, and biomaterials.

Major Societal Issues

Climate and energy. The Industrial Age was largely a result of understanding and mastering thermodynamics and exploiting fossil fuels. Due to the resulting carbon dioxide and other emissions, these fossil fuels have precipitated a serious developing climate crisis. Near- to mid-term impacts involve floods, storms, disease, sea-level rise, droughts, species extinctions, tidal waves, ocean acidification, and ocean circulation changes, among others. As paleontologist Peter Ward has pointed out, the farther-term impacts are truly existential for humans and nearly all species, and involve major reductions in the ozone layer and anoxic ocean conditions leading to an atmosphere poisoned by hydrogen sulfide.[2]

The technological solution spaces for climate and energy challenges include conservation approaches and the many flavors of renewable energy. Renewable energy technologies, along with the rapidly developing storage technologies, are now at or below cost parity with fossil fuels. Further, their capacity is immense, their capabilities are still improving, and their costs are still dropping. Some 25 percent of the world's electrical generation now comes from renewable sources, which also represent about 65 percent of new generation. Storage technology is also advancing rapidly. In a few decades, observers project, renewables will largely decarbonize the energy landscape. Batteries will be capable of shifting transportation from heavy hydrocarbon fossil fuels to renewably generated electrical energy.

The renewable energy capacity is massive, estimated at some 20,000 exajoules (20,000 EJ) or more, compared with the 500 EJ we currently use. Renewable sources include wind (terrestrial, offshore, high altitude), solar (photovoltaic, thermal, hydrogen fuel, hydrocarbons from CO_2), biomass (including halophytes—salt plants grown on deserts or wastelands using brackish water or seawater), heat exchangers in the Gulf Stream, osmotic power, ocean (currents, waves, tidal), hydro, and geothermal including using abandoned oil/gas wells.

This ongoing shift to increasingly inexpensive renewables will not stop climate change, because there is much change already "baked in" and experiencing positive feedback. However, decarbonization of energy should enable us to mitigate perhaps the most dire climate impacts. Given the huge investments in carbon fossil fuels and their utilization, this relatively rapid shift to renewables will result in "stranded assets," along with shifts in energy winners and losers globally, with major economic impacts likely.

Historically, energy consumption per capita has been a measure of the wealth of societies. As energy becomes renewable and less expensive, many millions will no longer die early from pollution due to fossil fuel use. The current subsidies for fossil fuels could be utilized for more positive societal purposes. Thus far, employment is increasing due to the energy shift. As this trend continues, the cost of living will likely fall while standards of living improve and the multitudinous effects of climate change are mitigated.

Technologies have contributed to climate problems, and technologies are now being developed and applied to mitigate their impacts and improve the collective human weal. Although renewable energy approaches are necessary for climate change mitigation, their development was slow until several technologies, collectively targeted at reducing cost and increasing performance, have reached below-cost-parity with fossil fuels. Currently, coal and nuclear plants are closing due to economic costs. (Nuclear is a clean, green energy except for the waste issues.) Largely speaking, technologies that mitigate serious societal issues will be utilized if they are also economically favorable.

Ecosystems, population, and water. The increasing numbers of humans and their usual profligate nature have caused the ecosystem to degrade in nearly all aspects. Manifestations include freshwater shortages, climate change, pollution, loss of topsoil and wildlife habitat, despoiled countryside due to mining, deforestation, crashing fish stocks, species extinctions, and the emergence of fragile monoculture biomes. Evolution of just about everything is now human-engendered, and it is occurring at rates that

exceed natural evolution by an estimated six orders of magnitude. This includes the evolution of the human species.

Some have stated that the current overwhelming issue is to prevent ecosystem collapse. We are already short some 50 percent of a planet's worth of resources. As the rest of the world begins to attain Western living standards, we will be short by three or more planets' worth of resources. We have reached the ecosystem's carrying capacity and exceeded it in many aspects. The longstanding "sustainability" movement seeks to replace the current economic growth mantra with sustainability for those aspects of growth that affect the ecosystem.

The pace of utilizing renewable energy was slow, even in the face of obvious and serious climate change impacts, until there was an obvious financial driver (lower costs) for a shift to renewables. There is a wealth of approaches for improving the sustainability of the ecosystem, usually with some localized adoption and depending upon activism, but as yet there has been no appreciable major shift toward sustainability and away from growth. The many lifestyle and economic upsides to sustainability have not yet been assembled into a package of overwhelming financial benefits and approaches that will alter the centuries-old fixation on growth.

The fundamental upside of sustainability is avoiding the many downsides of continued ecosystem degeneration. Because the growth that underlies much of the current economy provides employment and investment opportunities, sustainability solutions should offer additional financial upsides that replace these. Growth per se is fine as long as it does not further degrade the ecosystem. Without financial incentives to do so, shortsighted humans find it hard to change in order to ensure a prosperous long-term future for their progeny. Economic short termism has thus far usually prevailed over longer term viability considerations with regard to the ecosystem and climate problems, and ecosystem concerns raise major economic issues when they involve alterations in the status quo.

There are many frontier and other technologies that could be efficacious for the ecosystem, but the challenge is to develop and apply those that are economically advantageous. Technologies making homes energy-generating versus energy-using are now state-of-the-art and improving; they are becoming economically advantageous to the homeowner but not to the power companies. Recycling technologies, including at-home recycling and products that last far longer, are possible, but they are not particularly advantageous to manufacturers in terms of selling more new products.

In agriculture, improving the ecosystem would involve shifting to wholly new planetary resources such as halophytes—plants grown using saltwater in deserts and wastelands—to address vital resources such as land, water, food, energy, climate, and trace minerals in the human diet. Such technologies would "green" the deserts and wastelands, create freshwater rain, and to a large extent replace current agricultural practices that result in increasingly salinated soil, loss of trace minerals, shortages of freshwater and arable land, and huge investments.

Overall, a shift to saline-water cultivation of halophytes would create vast wealth in the longer term, but as in the case of the stranded fossil fuel assets, there are economic issues in the tactical, shorter-term solutions. The massive scale and serious nature of the climate and ecosystem issues actually require revolutions in approach as well as technology. Quick fixes are insufficient, because the problems are worse than initially recognized. Many positive climate feedbacks are kicking in, which some suggest could nearly double the projected changes going forward. A modified, business-as-usual approach will not be sufficient to address this crisis.

Humans have been inordinately successful in inventing and developing technologies to delay the Malthusian predictions of the population outgrowing the planet's resources. However, the magnitude of the overall effects of humanity's growing ecosystem requirements calls for many serious technology shifts, which can have near-term economic issues. The long view, addressing the many serious and confounding issues concomitantly, needs to prevail going forward.

Employment, wealth distribution, and AI. The ongoing development of artificial intelligence has produced a blizzard of books and commentaries about AI's potential impacts on employment. Most of the early studies suggest major employment reductions as machines attain increased capabilities and lower costs. There are many reasons machines are in fact better than humans for much current work. Thus far, early days yet, there have been job losses, with the development of a growing gig economy—workers taking on tasks as temporary contract labor rather than as full-time employees with wages (and benefits).

Some studies, based on the historical record, indicate AI will have minimal effects on employment going forward, suggesting that as technology advances, new employment opportunities have been and will be created. But this time may be different. As Marshall Brain, author of *The Second Intelligent Species*,[3] has said, we have never before invented

and deployed an intelligent species to compete with ourselves. To compound this apparently diminishing overall employment situation is the major increase in wealth disparity, mainly as a result of digitization. As technologies have developed, ever fewer numbers of more highly trained and specialized workers can create vast amounts of capital, resulting in a situation of wealth disparity that has become notorious. This double whammy of machines taking jobs and increasing wealth disparity is giving rise to societal tensions that may become worse going forward. Many nations and regions are experimenting with a guaranteed annual income to maintain standards of living and defuse societal tensions.

The IT revolution has resulted in tele-everything—employment, shopping, travel, education, medicine, commerce, manufacturing (with at-home 3D printing), politics, and so on. The technologies have enabled an increasing DIY culture that further reduces employment for some professions, including teachers, health-care providers, travel agents, and sales clerks. Less human labor is required because cheaper machines and the Web can increasingly do the tasks, or, with help from the Web, individuals can do it themselves.

Even with a guaranteed annual income, supported by machines put to work in a global commons, there will be issues regarding what humans do all day. One possibility is a "back to the future, high-tech, DIY on steroids" scenario, in which a pre–Industrial Revolution model prevails. Instead of jobs, individuals would have holdings of perhaps a half acre, using tele-everything technologies to independently provide their own food, energy, education, medicine, and manufactured goods.

Potential additional societal issues. Several of the following planetary and societal issues are statistically near certainties over the long term:

• **Solar storms.** The powerful Carrington event of 1859 dramatically illustrates the effects of a serious solar storm upon electrical systems and networks. At the time, electrical systems were rudimentary; most mechanisms were still mechanical, but telegraph and other devices were seriously affected. Observers today believe we are due for another such strong solar storm event, just as society is fundamentally and increasingly dependent upon electrons for nearly all functionalities. In its final report, the Congressional EMP Commission examined the potential the effects of nuclear electromagnetic pulses, which are analogous to the effects of strong solar superstorms. The report states that the devastation to electronics would have huge national consequences within a year, including hunger, disease, and societal reversion.[4] With

early-warning satellite technology, we could have some minutes of warning of a major solar storm and attempt to shut down the grid and reduce its impacts. We could also stockpile large transformers, which are a major vulnerability for the grid.

• **Asteroid impact.** Due to closing velocity, it would not take a very large asteroid to create a very serious impact upon the planet's climate, as demonstrated by the asteroid in eastern Mexico that purportedly wiped out the dinosaurs. Effective technological mitigation for this threat, including redirection by various means, could be applied if an incoming asteroid were identified at far enough distance from Earth.

• **Biological threats, biohacking.** This threat derives from the ongoing biotechnology revolutions, especially synthetic biotechnology and the increasing ability to change and perhaps even create life. Of concern is biohacking, the accidental or deliberate production of a pathogen for which we do not have a treatment. In the earlier days of genomics, scientists at the 1975 Asilomar conference on recombinant DNA in California considered the potential occurrence of biohacking and its impacts, and agreed upon certain procedures to minimize its chances of happening.[5] Today, with the synbio technologies writ large, the possibilities are much greater for inadvertent or intentional biohacking, with possibly serious consequences for humans and/or the ecosystem. The controls to avoid this possibility need strengthening.

• **Machines surpassing human intelligence.** As machines have become more capable, enabling the development of initial versions of AI, knowledgeable people have raised "what if" questions about machines becoming smarter than humans. Complicating the issue are several ongoing technologies such as quantum computing, which researchers are now beginning to apply to AI. Also, we are rapidly developing brain–machine communications and implanting brain chips. The future thus will likely see ever more intelligent machines and humans bonding with them. The consequences of machines becoming smarter than humans are yet to be determined, depending upon details of the ways in which they are smarter and what effective software controls are instituted, if any. Going forward, machines will be ever more incorporated into and intertwined with the human brain, leading the way to brain uploads.

Evolution of Humans by Humans

The ongoing development of medical technologies are enabling humans to increasingly become cyborgs. The panoply of non-biomedical implants we are inserting into our bodies include cochlear implants; artificial retinas, hearts, and limbs; and printed

organs. Then there are the brain chips already alluded to. We are basically wet electrochemical beings on the way to becoming cyborgs as the technologies develop. Health-related technologies, including the biotechnology revolutions, have increased life expectancy by about 0.25 years per year, and some observers project that medical implants and CRIPSR (gene editing technology) could increase life expectancy by one year per year.

Overall, humans have become responsible for our own species' ongoing evolution—and much else—and doing it more than a million times faster than natural evolution, but with little planning or consideration of potential outcomes.

The cost reductions of reusable rockets bring huge areas of space closer to our reach, allowing us to seriously consider colonizing the Moon, Mars, and space habitats both safely and affordably. In that process, humans will be subjected to conditions of microgravity and radiation, which will change us, as has been observed among crew on the International Space Station. But what will we become? In addition to the natural, classically Darwinian environmental adaptations observed in space crews, we'll have the cyborg technologies and medical implants, brain chips, and merging with the machines, perhaps evolving differently on Earth than on Mars or other space environments.

Whither humans going forward—here, there, and anywhere? The time scale for major changes in the physiological makeup of humans will be decades, not centuries or longer, given the changes in the environment and the developing technologies writ large. Far more consideration is needed of the impacts and mitigation possibilities of frontier technologies interacting with each other, of humans' adverse impacts on the environment, of natural evolution, and of some existential issues. And we need to consider where we want to go and in what state, and then map how to get there from here.

Such a process is awash with concomitant societal issues and lacking viable solution spaces. A coordinated approach is vital for ensuring successful outcomes, economies of effort, and minimization of adverse effects during the resulting "get-well" campaign.

Perspectives on Resulting Futures

To recap, the trends we are seeing include increasing life spans; humans merging with machines; global sensor grid; global mind; space colonization; shift to the Virtual Age;

electric transportation; low-cost space access; synbio and CRISPR; increasing do-it-yourself capabilities; inexpensive renewable energy and energy storage; the synergistic benefits of saline agriculture (halophytes) on land, water, food, climate, energy, and trace minerals; increasing AI and autonomous operation; and brain–machine interfaces.

Major societal concerns of climate, the ecosystem, and wealth distribution may be on an existential path due to increases in population and standards of living and the effects of current technologies—trends that will compound natural threats such as asteroid impacts and major solar storms. The solutions typically considered are often tactical, inadequate, and largely protective of the economic status quo.

What's needed is a well-grounded analysis and documentation of the long-term trends among the many interrelated societal issues, with a defined problem and solution space to holistically address future human health, wealth, and happiness. The solutions must also be economically favorable. Some options include:

• Web-based AI agents could be incorporated into free motivational adult education programs addressing societal issues and potential ways to solve them, individually and in combination. This approach could be very efficacious for an informed body politic and improved decision making at the individual and societal level. The content of such adult education will be enhanced by the ongoing development of a global sensor grid and a global mind.

• Halophytes could be grown on deserts and wastelands for food and biomass using saltwater irrigation. The capacity of saline agriculture is truly massive, inexpensive, achievable in the near term, and financially beneficial. It would release for direct human use the 70 percent of freshwater that is now used for agriculture, and it would employ the 44 percent of landmass that is wastelands and deserts. Halophyte cultivation thus rapidly and inexpensively provides solutions to land, water, food, energy, and climate at the requisite scale.

• More people could adopt a live-off-the-land, do-it-yourself lifestyle. This would consist of growing their own food, collecting water, adopting distributed-energy generation to "cut the cord" with utilities, manufacturing via 3D printing on site, and leveraging "tele-everything" options for services such as education and medicine. This lifestyle emulates a pre–Industrial Revolution model of fewer jobs and more independent living, but now we benefit from the ongoing technology revolutions that

make such DIY living much more efficient, effective, healthy, pleasant, and inexpensive writ large.

• Applying more cost-effective energy storage and increasingly inexpensive renewable energy options to distributed generation could put us well on the way to mitigating climate issues. However, there are some worrisome economic speed bumps along the way: Phasing out fossil fuels will have to be managed carefully, as they currently are major industries and economic powerhouses.

• Replacing the current dominant economic growth mantra with a sustainability ethic is the key to addressing ecosystem issues. Sustainability solutions for individual issues and combinations of problems have major favorable economic benefits, starting with overcoming the many negative financial effects of continued ecosystem degeneration. For instance, using recycled materials in manufacturing is usually less expensive and less energy intensive than using primary inputs drawn from the most ecologically destructive human activity—mining. The move from growth to sustainability solutions will require a financial win-and-loss column diagram analyzing the various approaches to ecosystem issues, ranging from doing nothing to proactively mitigating them. This would help guide future, discussions, decisions, and actions.

• The so-called gig economy, which has grown massively in recent years, offers a partial solution to machines taking over human tasks. It also has potential to lower living costs. The concepts of DIY applied to employment and income are evolving, including performing Web-based tasks and making things to generate income, usually on an individual basis. At-home manufacture via 3D printing will support some gig activities as well as help reduce costs of durable goods. As well, the tele-everything lifestyle should reduce living costs associated with a panoply of household expenses, including transportation, education, and health care. Material substitutions, major efficiency improvements, and automation are also sources of reduced costs of living.

Notes

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