PERSPECTIVES on Science and Christian Faith

JOURNAL OF THE AMERICAN SCIENTIFIC AFFILIATION

Theme Issue: Responsible Technology and Issues of Faith

"The fear of the Lord
is the beginning of Wisdom."
Psalm 111:10

VOLUME 64, NUMBER 1 **MARCH 2012**

(US ISSN 0892-2675) (CPM #40927506)

Perspectives on Science and Christian Faith
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Perspectives on Science and Christian Faith (ISSN 0892-2675) is published quarterly for $40 per year by the American Scientific Affiliation, 55 Market Street, Ipswich, MA 01938-0668. Phone: 978-356-5656; Fax: 978-356-4375; asa@asa3.org; www.asa3.org

Periodicals postage paid at Ipswich, MA and at additional mailing offices. POSTMASTER: Send address changes to: *Perspectives on Science and Christian Faith*, The American Scientific Affiliation, PO Box 668, Ipswich, MA 01938-0668.

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3. Use endnotes for all references. Each note must have a unique number. Follow *The Chicago Manual of Style* (16th ed., sections 14.1 to 14.317).
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Editorial

It Takes a Team

James C. Peterson

The ASA Executive Council had twenty questions for me to answer in writing, and many more in a personal interview. Considering as well my *curriculum vitae*, references, and work to date with ASA/CSCA, the council brought my name to the annual meeting as the new editor of *PSCF*. The process was emblematic of the rigorous and good-natured teamwork so characteristic of ASA/CSCA and the production of this journal. There is a small army of people that work diligently with marked expertise and good judgment to make *PSCF* happen. Most of them are all but invisible to *PSCF* readers. This editorial cannot mention each one crucial to creating the journal each quarter, but here is a start.

It is Lyn Berg as managing editor who finds a way to winsomely present the content in a certain number of pages on precise deadlines. Esther Martin checks every word for the slightest error. In the midst of all his other duties as executive director, Randy Isaac often supports the journal—as, for example, in recent internal discussions of copyright issues. Frances Polischuk tracks the accounts and mailing list. Terry Gray and Jack Haas make *PSCF* available on the ASA website.

As to content, each year over forty reviewers explain and critique the contribution of new books. It is the subject area editors, Patrick Franklin, Arie Leegwater, Don MacDonald, and Robin Rylaarsdam, who find these experts to evaluate the most relevant and important books out of the hundreds of thousands that are published each year. The resulting reviews are honed to be well written, informative, and prompt. Franklin comes to the task from his post as professor of theology and ethics at Tyndale Seminary in Toronto and will be moving this summer to Providence Theological Seminary in Otterburne, Manitoba. Leegwater taught chemistry at Calvin College and edited this journal. MacDonald is a professor in the social sciences at Seattle Pacific University, and Rylaarsdam is a professor of biology at Benedictine University. Franklin takes the further step of coordinating the book choices since the subject areas often interact. He then marshals the readied reviews into categories to help readers find the ones that match their interests. He also maintains a database of potential reviewers. If you would like to lend your expertise to this helpful service of reviewing (and get free books!), do send him your contact information and a brief description of your expertise (psfranklin@gmail.com).

Essential to the journal are the twenty or so authors each year who contribute articles that ring true, bring fresh insight, and fit our journal's mission. Sometimes the required blind peer review discovers a young scholar's first important insight for publication. Often blind peer review recognizes yet further contributions by accomplished scholars. We appreciate the luminaries from a wide variety of fields and with contrasting views who have written for us, including (not by any means an exhaustive list) Elving Anderson, Robert Benne, John Hedley Brooke, Richard Bube, Francis Collins, William Dembski, Calvin DeWitt, Owen Gingerich, Joel Green, Malcolm Jeeves, Robert Kaita, Donald MacKay, George Marsden, J. P. Moreland, Nancey Murphy, Ronald Numbers, Clark Pinnock, Alvin Plantinga, Walter Thorson, Thomas F. Torrance, Charles Townes, John Walton, Bruce Waltke, Jennifer Wiseman …

Twenty-one editorial board members volunteer sage advice and generously serve in the peer review process. Since *PSCF* articles are usually to some degree interdisciplinary, each article considered for publication requires several reviewers drawn from the interacting disciplines. That requires the commitment of the editorial board and many more scholars as well. Peer reviewers for 2011 are listed in this issue with profound thanks. We will miss the service, ending with 2011, of editorial board members Charles Adams and Walter Thorson. Allan Harvey, an engineer with the National Bureau of Standards, and Heather Looy, an Alberta professor of psychology, have ably stepped in to carry on that work.

For four years now, inspiring and holding it all together from title page, masthead, and editorial, through articles and reviews, to the always lively letters to the editor at the end of each issue, has been Arie Leegwater. He has carried on the legacy of ever raising the standards and service of the journal and is graciously following through by finishing the editing of articles he started for this issue and continuing as one of our book review editors. On behalf of the readers of *PSCF*, I extend a heartfelt thank you to Arie for his skilled, thoughtful, and effective work. The journal, ASA/CSCA, and we the readers, are better for it.

The Christian tradition is the largest and most global people movement in the world. Science is ever increasing in its influence. What an opportunity to work where the two meet. *Perspectives on Science and Christian Faith* is a strategic service, encouraging, testing, learning, guiding that interaction. It is well worth the best attention and contribution that so many give to make it possible. Thanks to all who, by our Lord's grace, make it so.

James C. Peterson, *Editor* ✦

In This Issue

In this special theme issue devoted to "Responsible Technology and Issues of Faith," seven authors address a diversity of topics which provide Christian assessments of, and approaches to, technology and its practices. Similar concerns about contemporary engineering practices are also found in recent secular engineering magazines. For example, articles in the March and September (2011) issues of *Mechanical Engineering,* the magazine of the American Society of Mechanical Engineers, have advocated a more humanitarian approach to design and have promoted the design of technologies with an eye to the rest of the globe. Many engineering schools are urging their students to consider *Engineers without Borders*, and engineering departments at Christian colleges have long promoted service learning.

The seven articles in *PSCF* can be broken down into three groups:

1. Two articles written by philosophers of technology: Albert Borgmann (University of Montana) explores the character of contemplation in a technological era by examining what we can glean from the wisdom of Thomas Merton. Marc J. de Vries (Delft University of Technology) details the presence of utopian thinking in contemporary technology and contrasts this with the need for responsible technology in an imperfect world.

2. Two articles written by Calvin College engineers: Steven H. VanderLeest distinguishes between science and technology and argues that an interplay model, rather than a primacy model, best describes the engineering design of technology. Gayle Ermer examines the complexity of technology and provides a rationale for a connectionist approach to engineering design.

3. Three articles written by a former energy research lab director, a biology professor, and a physicist detail specific practices, respectively—renewable energy generation, agrarian agriculture, and solar cooking, all practices that demand attention: Kenell Touryan (recent vice president of R&D at the American University of Armenia) champions renewable energy for a sustainable future, David Dornbos Jr. (Calvin College) argues for a normative consideration of sustainable agricultural practices in agrarian systems, and Paul Arveson (board member of Solar Household Energy) promotes solar cooking as an underutilized solution for the poor of the earth.

May this theme issue promote reflection and give us a more informed understanding of how we can live technologically responsible lives, responding in faith to God's call in Genesis to be culturally engaged in his world.

Arie Leegwater *and* **Jack Swearengen**
Theme Issue Co-Editors
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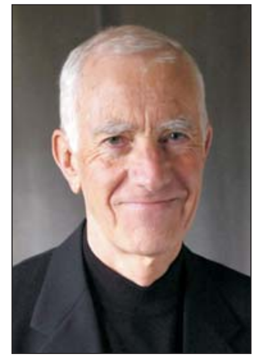
Article



Albert Borgmann

Contemplation in a Technological Era: Learning from Thomas Merton

Albert Borgmann

Thomas Merton was an insightful observer of contemporary culture. In his writings, an ever-sharper picture of the technology emerges as well as a more and more resourceful answer to the cultural ailments – the counsel of contemplation. A philosophical response to Merton has to sustain the depth of his insights while articulating the systematic force of technology and the concrete reforms that provide a secure and practicable role for contemplation.

Contemplation is a word that few people use although it has a fairly definite meaning. Technology is a word that a lot of people use although its meaning is far from clear. In the life of Thomas Merton, contemplation at first was a definite goal, but gradually lost its sharpness, though not its force, whereas technology was at first an implicit and unspoken presence that toward the end of Merton's life assumed definite and troubling contours.

Thomas Merton was a prophet, a seer and a warner. As a seer, he had an intrepid openness that allowed him to see things the rest of us are too timid or too lazy to envision, and as a warner, he wrote with a supple vividness that captivated his readers. Prophecy and philosophy are kindred disciplines. Both are devoted to seeing and telling, but there is a division of emphasis. The prophet is passionate and topical; the philosopher should be dispassionate and systematic. The prophet challenges the philosopher. The philosopher questions the prophet. The prophet is the pioneer. The philosopher is the settler. The pioneer's work is exciting and inspiring, but it can't be final. We have to settle down eventually and come to terms with everyday life. However, the settler has to be careful not to level down and disfigure what the pioneer has discovered. My goal then is to examine some of the things Merton has said about contemplation and technology and to suggest how they can be ordered into a vision that both meets the challenges of Merton and allows us to cope with everyday life.

Merton challenges philosophy to show how contemplation can have a fruitful place in the culture of technology. The first task then is to explicate technology as a cultural context or, to be more precise, to comprehend technology as the shape of contemporary life. Merton has always been keenly attuned to the promises and liabilities of his cultural setting.

Albert Borgmann *is Regents Professor of Philosophy at the University of Montana, Missoula, where he has taught since 1970. His special area is the philosophy of society and culture. Among his publications are* Technology and the Character of Contemporary Life *(University of Chicago Press, 1984),* Crossing the Postmodern Divide *(University of Chicago Press, 1992),* Holding On to Reality: The Nature of Information at the Turn of the Millennium *(University of Chicago Press, 1999),* Power Failure: Christianity in the Culture of Technology *(Brazos Press, 2003), and* Real American Ethics *(University of Chicago Press, 2006).*

Technology became for him a central term and concern only in the later years of his life. Once he had an explicit grip on the technological cast of his time, his insights, however terse, were probing and disturbing.

Much like Jacques Ellul with whom he was familiar, Merton feared that technology was becoming an autonomous and destructive force.[1] It threatened to reduce life to a process of production and consumption; it led to a disintegration of traditional structures; and it left us with "a transient and meaningless sense of enjoyment" and "the contrived and obsessive gyrations of its empty mind."[2] But Merton was no Luddite or romantic. He admired the accomplishments of science and technology, and he maintained his hope that technology could be changed from the ruler to a servant of contemporary life.[3]

Now the task before us is to fit Merton's insights into a theory of technology. At times Merton got impatient with theory. It seemed too leisurely and abstract in a time of urgent and visceral issues. Philosophical theorizing does, too often, have the traits that offended Merton. But we can perhaps avoid them if we think of philosophical theory as the enterprise that helps us clear a space in our lives for occasions of grace. This is quite in Merton's spirit when he approvingly quoted Clement of Alexandria: "The word prepares the way for action and disposes hearers to the practice of virtue."[4]

The force that overlies and often suffocates those occasions is technology, as Merton realized. He also captured in a vignette the crucial shape of technology and the powers and dangers that are consequences of that shape. Early in *Conjectures of a Guilty Bystander* (1965), Merton said,

> Technology is not in itself opposed to spirituality and to religion. But it presents a great temptation. For instance, where many machines are used in monastic work, (and it is right that they should be used), there can be a deadening of spirit and of sensibility, a blunting of perception, a loss of awareness, a lowering of tone, a general fatigue and lassitude, a proneness to unrest and guilt which we might be less likely to suffer if we simply went out and worked with our hands in the woods or in the fields.[5]

The crucial feature of the technological culture is the insertion of machinery between humanity and reality. Merton might have been thinking of plowing. There was a time when it was done with a single plow that was drawn by a mule with a monk guiding it, mule and man pacing the field up and down, turning one furrow after another. What prompted Merton's observations could have been an array of four plows, pulled by a tractor moving half again as fast as a mule and a man, thus enabling the monk and the machinery to do six times the plowing that the monk used to do with the mule.

It is right that the tractor should be used; we are inclined to say with Merton. It frees up time in the life of the monastery. It dispenses with the mules that need to be fed morning and evening, summer and winter, that are prone to laming and kicking, that need to be trained and groomed and have their hooves trimmed and shod. And yet the monk on the tractor does not see the soil turn, does not smell the earth, does not feel the clods under his feet, does not hear the meadowlark, does not talk to the mule and appreciate her work.

It's reasonable in the immediate setting of the monastery to employ machinery, and it is necessary in the wider setting of society at large. If the monastery is to survive, it has to come to terms with the world as Merton realized.[6] Coming to terms with the economy is part of that task. A monastery has to be reasonably efficient in its operations. It cannot afford to waste time and cling to practices that lead to starvation. It must look for niches of comparative advantage to earn the money that's needed for the purchases of the goods and services it cannot produce within its borders.[7]

We can generalize the pattern of technology that begins to emerge from Merton's observations. Plowing used to be a practice that was embedded in the competence and circumstances of a community. There was the shop and the skill of the blacksmith who could repair a plow. There was the knowledge of how to get mules from mares and jacks. There were the hayfields that got the mules through the winter, and there was much else besides.

It all fell away when the tractor appeared. Not everything disappeared. The field, the soil, the furrows, the seed, and the harvest remained. The alteration of a practice can be a gradual affair. "Each year the new tractors get bigger and bigger, louder and louder," Merton observed.[8] The driver gets enclosed in a cab; the cab gets air-conditioned. The driver can communicate with anyone and everyone. Agriculture and cyberspace begin to merge, and the world we knew when "we simply went out and worked with our hands in woods or in the fields" is receding ever more.

Some practices have detached themselves entirely from their contexts. For morally troubled Catholics, the custom and context of seeking help used to be the confession. The confessor knew the sinner's community. He was immersed in the world of sacrament and theology. Today troubled priests and bishops are sent to a psychologist rather than a confessor. The machinery of expertise has replaced the context of the church. Help is no longer a gift. It has become a commodity you have to purchase.

For most of us, the practices of agriculture have entirely disappeared into the machinery of production. The commodities of food appear on supermarket shelves as if from nowhere, with fake reminders of the farms we know from children's books. And thus the pattern of technology becomes visible in its stark and general two-sidedness of commodification and mechanization. Commodification is the detachment of things and practices from their traditional contexts, and it is the conversion of things and practices into freely available commodities. Mechanization is the replacement of traditional contexts and competencies by increasingly powerful and concealed machineries. As workers we indenture ourselves for the requirements of the machinery. As consumers we revel in the abundance of unencumbered pleasures.

Let's turn to contemplation. It first became a definite moral concern in Aristotle's ethics. Contemplation for him was nothing less than the loftiest and best kind of human activity. It was the exercise of the highest human faculty, viz., reason, devoted to the noblest objects, viz., those that are perfect and immutable, the laws of reality, the order of the cosmos, the divinities. It was said to yield the greatest pleasure and to lift humans most nearly to the level of divinity. Thus for Aristotle, the contemplative by far outranked the active life as well as the pleasurable life.

Aristotle's concept of contemplation became influential for Christianity through the work of Albert the Great and Thomas of Aquino. Thomas could easily accept the exalted finality of contemplation, but for him, of course, it was attainable only in heaven—the blessedness of being face to face with God. There could be foreshadowings of the beatific vision here on earth. But earthly life for most of us, most of the time, had to be one of active engagements. The question of how the contemplative life and the active life were to be related to one another has been an enduring one for Christians (the life of pleasure playing a subordinate role at best). These schematic accounts of technology and contemplation suggest a ready way of connecting them, or rather, of seeing them disconnected. The active and the pleasurable lives line up with machinery and commodity, with production and consumption, with labor and leisure. But contemplation, whether Aristotelian or Thomist, seems to have no place in the culture of technology and constitutes, if anything, a rebuke to technology. But how can we get beneath such schemata to the real challenges of the day? Those challenges have been set before us by Merton, and we now have to respond to them. There are three major ones.

The first is this. Merton shows us, more urgently and irrecusably than any writer I know, how deeply the glory and the misery of being human are intertwined, and not only with one another but also with our circumstances, and how hard it can be in this thicket of entanglements to hear the Good News. That humans are poised between greatness and failure is the obvious lesson of history. There are inspiring and humbling feats of generosity, forgiveness, ingenuity, and fortitude, and then there are the terrors of cruelty, cowardice, and indifference. For Christians, glory is the nearness of God; misery is the painful experience of inadequacy.

The second challenge Merton holds before us is to look into the depths of modernity. Technology, as we think of it here, is the character of the modern era. It surfaces most clearly in research and development, in industry and commerce, and in appliances and utilities. But technology exerts its power not only in what it does and enables, but also in what it abandons and disables, in the ways in which it withdraws vitality from institutions and customs, leaves the former as pretentious shells and inflames the latter to a last show of arrogance.

The third and final major challenge is the task of understanding clearly how human ambivalence and the modulations of technology interact, and of working out the lessons Merton has been teaching us about those interactions.

Beginning then with the first epiphany of the technological culture, we see Merton depicting it in the unlikely place of southern France and the early part of the twentieth century. On the first page of *The Seven Storey Mountain,* Merton says,

> Neither of my parents suffered from the little spooky prejudices that devour the people who know nothing but automobiles and movies and what's in the ice-box and what's in the papers and which neighbors are getting a divorce.[9]

Three pages farther into the book, Merton turns to the authority that stands in judgment of "the little spooky prejudices." It's the medieval monastery that's been moved from St. Michel-de-Cuxa and reassembled in northern Manhattan. "Synthetic as it is," Merton says, "it still preserves enough of its own reality to be a reproach to everything else around it, except the trees and the Palisades."[10]

Here is the pivotal contrast between technology and contemplation, seen as malaise and salvation. The ailment is the attenuation of everyday life by the fascination with the products of technology—cars, movies, refrigerated food, and mass communication. Those look like tame and old-fashioned technologies by today's standards. But Merton could already see the flimsy and distracting unreality of the emerging technological culture. Merton saw salvation in the reality of the monastery, displaced and displayed, to be sure, but commanding none the less.

Though his parents immunized Merton against the popular manifestations of the culture of technology, he vividly experienced the hidden injuries of it, the loss of rightful authority in the cultural institutions of his time. Outwardly, Merton received the best education imaginable, the elite school of Oakham, then Cambridge, and finally Columbia. He was widely traveled, fluent in French and English, able to read Greek and Latin. Though Merton was hard on his study habits and quiet about his accomplishments, there was evidently enough diligence and more than enough intelligence to make him an outstanding student. Merton did not generally object to the subjects and texts he was taught. What angered him was the lack of institutional conviction in all this teaching. Cambridge traded on its faded glory, and Columbia was driven by a mindless busyness. Individual teachers, with exceptions gratefully noted by Merton, were moved by vanity or fads.

Deprived of moral guidance and favored by material benefits, young Merton gloried in his scornful individualism, and even when at Columbia, and seemingly on his way to a successful career as a writer and critic, the glamour of his accomplishments overlay an emptiness and despair that drove him close to a nervous breakdown. Merton ardently desired to escape this glorious misery and reach a world of spiritual authority and peace.

After many struggles, Merton found order and solace in the Catholic church; and after more struggles, in the Trappist Order. Monastic contemplation, emerging toward the end of *The Seven Storey Mountain,* appeared to be the solution to the moral and intellectual decay that the advancing culture of technology had left in its wake. Merton was sincere and eloquent in his professions of peaceful happiness at the several stations of his conversion and devotion. But when his journey to peaceful contemplation appeared to have reached its destination in Our Lady of Gethsemani Monastery, Merton found himself immersed in another kind of struggle.

Merton at times seemed to say that contemplation is merely the rejection and not the redemption of the technological culture.

> Do everything you can to avoid the amusements and the noise of the business of men. Keep as far away as you can from the places where they gather to cheat and insult one another, to laugh at one another, or to mock one another with their false gestures of friendship. Do not read their newspapers, if you can help it. Be glad if you can keep beyond the reach of their radios. Do not bother with their unearthly songs or their intolerable concerns for the way their bodies look and feel.
>
> Do not smoke their cigarettes or drink the things they drink or share their preoccupation with different kinds of food. Do not complicate your life by looking at the pictures in their magazines.[11]

Merton, ever circumspect and generous, goes on to qualify his Abraham a Sancta Clara sermon. In particular, he warned against the turn to solitude and "the untroubled presence of God" as an escape only.

He was well aware of the conventional objection to contemplation, especially to the kind of contemplation sought by mystics, the objection, i.e., that contemplation dispenses with the community and the teachings of the church. He declared that contemplation is at heart communal, doctrinal, and active.[12] These declarations had the ring of mere assertions. Merton's reflections seemed more immediate and moving when they mourned the concealment of God and testified to the pain of fruitless searching. Often he went on to say that God's absence is God's presence and that in pain there is joy.[13] But these assurances seem strenuous and severe.

For all the miserable glory of Merton's early experiences of contemplation, there are two necessary lessons we must take from his reflections. The first is the need for a clear-eyed recognition of the power of technology. For most people, the misery of the human condition does not take the form of Merton's painful sensitivity to the failings of ourselves and of society. On the contrary, it is mindlessness, either the sullen mindlessness of unloved work and pointless consumption or the hyperactive mindlessness of frenetic work and conspicuous consumption. The second lesson concerns the need of a resolute search for the center of our lives, for a final presence that will not play us false.

Though necessary, these lessons are not quite equal to the problem of technology. A deeper and more articulate awareness of technology is needed and with a more generous understanding of contemplation. In *Conjectures of a Guilty Bystander*, Merton sets an example of this sort of insight and liberality. He saw that the stark contrast between the technological culture and the grace of redemption obscures the force both of technology and of grace. Let me first explain the hidden injuries of technology and then turn to the unforethinkable moments of grace.

Technology is more than the obvious adversary of contemplation. To the careful observer it says: *Et in Arcadia ego*—In the midst of religious devotion, here I am. Technology infects contemplation and insinuates itself into the monastery and the church when they seem resolutely opposed to the culture at large; for mere opposition inflames, cramps, and cripples the pious. The opposition may begin with "certain refusals which are noble, which are affirmations of a higher truth, epiphanies of reality, witnesses to God," as Merton notes. But when the emphasis falls entirely on the refusal, the self gets constricted in a cramp, and when someone "has reduced himself, narrowed himself down to the point where he is nothing but this miserable cramp clutched on to itself, when the cramp destroys itself, it destroys him."[14]

It's not only the pious who are reduced to defeat, and worse, to self-defeat, by the uncomprehending refusal of the dominant culture. The same fate can befall a young black who sees nothing but racism in contemporary culture, even in the pleasures the culture has left for young African-Americans, "the humor, the song, the behind-the-back pass." As the young Barack Obama began to suspect,

> At best, these things were a refuge; at worst, a trap. Following this maddening logic, the only thing you could choose as your own was withdrawal into a smaller and smaller coil of rage, until being black meant only the knowledge of your own powerlessness, of your own defeat.[15]

The culture of technology leaves us with blind resistance and nowhere to go while it makes its presence felt everywhere, as Merton sorrowfully observed. Taped recordings invade the refectory, "official fluorescent light" dispels the majesty of the sunrise, the noise of tractors and chain saws offends the quiet of the cloister.[16] Most troubling, the church gets used as a machine that produces self-righteousness.[17] The shell of its administration consists of "baroque seals and Renaissance chanceries" while its soul has been commandeered by "IBM machines."[18]

Real contemplation finally opens up for Merton in the unforethinkable moments of grace—the innocent beauty of dawn, the splendor of nature on the Vigil of Pentecost, or "sunlight falling on a tall vase of red and white carnations and green leaves on the altar of the novitiate chapel."[19] Grace comes to pass in "the splendor of the simple," as Heidegger says. The setting of contemplation has a splendid rather than an austere simplicity. "The simplicity that would have kept these flowers off this altar," Merton says, "is perhaps less simple than the simplicity which enjoys them there, but does not need them to be there."[20] Similarly, the contemplative life should not be the strenuous clinging to an idea of sanctity, but the celebration of resurrection and creation.[21]

Such moments of grace are the redemption of Aristotelian contemplation. Aristotelian contemplation suffers from two major defects. First, it is abstract as a practice and in its objects; second, it is solitary. Merton's mature conception of contemplation cures these defects and redeems Aristotelian contemplation. At the same time, Merton's contemplation shares two features with Aristotle's *theoria*. The first is the proximity of the divine, "this flower, this light, this moment, this silence: *Dominus est*. Eternity."[22] The second is the disclosure of the cosmos. The affirmation of grace in good action "integrates us," Merton says,

> into the whole living movement and development of the cosmos, it brings us into harmony with all the rest of the world, it situates us in our place, it helps us fulfill our task and to participate fruitfully in the whole world's work and its history, as it reaches out for its ultimate meaning and fulfillment.[23]

As his quotations show, Merton's contemplative moments go beyond Aristotle's contemplation in two ways: first, they are grounded in the immediacy and concreteness of life; and second, they include responsibility for the human community.[24] Thus, in reply to a deeper recognition of the technological culture, contemplation comes into focus as the moment of grace that is close to divinity and discloses the cosmos, but is also immediate and concrete and responsible for the welfare of all people.

Conjectures of a Guilty Bystander was written nearly half a century ago. Technology since has not stood still. We can summarize both the trajectory of Merton's thought and the trajectory of technology since Merton's death by considering the phenomenon of distraction. Young Merton was torn asunder by the conceits of the high culture that had its vitality and authority drained by technology. He reveled in pretentious individualism first and all but spent his vital energy in fashionable intellectualism. He was distracted beyond his awareness.

In the early years of his monastic life, Merton must have experienced the acuity of distraction that has classically assaulted contemplatives in the midst of their solitude and devotion, the kind of aggressive distraction that St. Anthony suffered memorably on Mathias Grünewald's Isenheim altar. Fantastic beasts have knocked down the venerable saint. They are tearing his hair, biting his hand, and are setting on him from all sides. The spectacular and offensive nature of these distractions was an artifact of the kind of contemplation Merton was to leave behind. It's also a revealing foil of contemporary distraction.

Merton finally came to recognize that distraction today is not a dramatic assault in the midst of contemplation, but part of the normal fabric of reality, of the affluence of the well-to-do and of the publicity that was a constant invitation for himself.[25] In either case, the simplicity and peace of the moments of grace are imperiled.

There were computers and IBM machines in Merton's lifetime. But he could not have imagined the cultural revolution that was caused by the rise of the most recent phase of technology, by IT, information technology. The revolution by now is all but forgotten. We are living under the regime that the revolution of the late seventies and early eighties has established and that is now so well entrenched that today "technology" simply often stands for information technology.

Distraction might have been like a long rainy season, as it was for young Merton, or like the occasional hurricane that the monastic Merton knew. Today it is like a permanent, if attractively glamorous, fog. It's the atmosphere we live in. It has, to be sure, "the phantasms of a lewd and somewhat idiotic burlesque," but for many today it's no longer "fabricated in their imagination."[26] It is worked out in the graphic details of video games, YouTube, and pornography.

Those distractions are morally offensive, of course, but they are at least marked off by their unsavory explicitness. The kind of distraction that displaces the moments of grace more inconspicuously and effectively comes in the guise of the plausible, the understandable, and the increasingly normal. It's the email that announces itself and may well be important, the twitter that could be urgent, the news that might tell us how a crucial decision has come down. Any one of these messages could plausibly have a legitimate claim on our attention. But these bits of information don't come as definite and single events. They are droplets in the endless mist of cyberspace, one bumping into another and all of them composing a fog that envelopes and occupies the spaces and times that were formerly the places and moments of contemplation or at least of conversation—the family dinner, the staff meeting, the vacation cottage, quiet reading, daydreaming, leisurely walks. These devastations have not gone unnoticed. But they are often chronicled with nostalgia and resignation.

Let me conclude by aligning Merton's prophetic pronouncement with philosophical analysis. Technology, Merton has said, furnishes "a transient and meaningless sense of enjoyment" and leaves us with "the contrived and obsessive gyrations of its empty mind."[27] Even within the monastery, it can lead to "a deadening of spirit and sensibility, a blunting of perception, a loss of awareness, a lowering of tone, a general fatigue and lassitude, a proneness to unrest and guilt."[28]

Transcribing this into more contemporary and systematic language, we can say that the culture of technology has finally depressed the glory and the misery of the human condition to distraction and indecision. For most people in this country, the overt challenges of global warming and global justice are uncertain specters in the distant background. The profound challenge of the good life is an ever-postponed task. The foreground of life is occupied with worries about the stability of work and the little and quickly fading thrills of consumption. As members of the technological society, we have systematically uprooted the relations that once had grounded our lives in a certain community, a definite place, and an overarching time. The machineries that now support us fail to engage us, and the commodities that are supposed to please us have turned out to be joyless. Misery has become a low-grade headache, and glory has been transmuted into fugitive pleasure. We have become insensitive to the Good News.

Though he was harsh in his view of the technological culture, Merton was never merely severe. His basic understanding of the world was generous and graceful, and he would have applauded the decency of people and the moments of affection and celebration that still animate their lives. The one thing that Merton perhaps did not appreciate fully and explicitly is the importance of the setting of moments of grace. He was often critical of the confinements and conceits of the monastic life though he never repudiated it. But it was the enclosure of the chapel or the disclosure of the fields and woods that occasioned for him the nearness of divinity. We have to give such occasions a secure place and a regular time in our lives. Contemplation needs a cloister, a space where the splendor of the simple is secure from mindless distraction and busyness.

We have to learn to adopt and adapt the cloister to the conditions of technology. Just as the cloister used to be surrounded and supported by the buildings of the monastery, and the monastery by the fields and woods, so we need to clear, within the supporting structures of technology, places and times in our lives for the celebration of what finally matters. Most important, we have to make time and room for the family dinner. We can't leave moments of grace to the vagaries of luck or accident. The culture of the table needs to have the central and firm location in our lives that the cloister used to have within the monastery.

We must follow Merton in joining all people of good will in the work of establishing sites where the sacred and the tangible are regularly reconciled and celebrated in communities small and large. Contemplation today has to be celebration. But, as Christians, we cannot forget that, however splendid and fulfilling a particular celebration may be, it will have its final affirmation in eternal contemplation.

What Thomas Merton finally teaches us is that today we need the steady and world-affirming Christianity that Obama had found in his own life:

> It was because of these newfound understandings—that religious commitment did not require me to suspend critical thinking, disengage from the battle for economic and social justice, or otherwise retreat from the world that I knew and loved—that I was finally able to walk down the aisle of Trinity United Church of Christ one day and be baptized. It came about as a choice and not an epiphany; the questions I had did not magically disappear. But kneeling beneath that cross on the South Side of Chicago, I felt God's spirit beckoning me. I submitted myself to His will, and dedicated myself to discovering His truth.[29] ✦

Notes

[1]Thomas Merton, *Conjectures of a Guilty Bystander* (1965; reprint, New York: Doubleday, 2009), 59, 70, 254.

[2]Ibid., 71 and 286.

[3]Ibid., 67, 71, 222, 252.
[4]Ibid., 88.
[5]Ibid., 18.
[6]Ibid., 177.
[7]Ibid., 19–21.
[8]Ibid., 231.
[9]Thomas Merton, *The Seven Storey Mountain* (1948; reprint, Garden City, NY: Garden City Books, 1951), 3.
[10]Ibid., 6.
[11]Thomas Merton, *Seeds of Contemplation* (Norfolk, CT: New Directions Books, 1949), 60–1.
[12]Ibid., 48–9, 56, 87, 115.
[13]Ibid., 138, 153, 155–6, 176–7.
[14] Ibid., 225; see also 118, 150, 154, 208.
[15]Barack Obama, *Dreams from My Father: A Story of Race and Inheritance* (1995; reprint, New York: Three Rivers Press, 2004), 85.
[16]Merton, *Conjectures*, 33, 177, 231, 307.
[17]Ibid., 112.
[18]Ibid., 251–2.
[19]Ibid., 128, 143, 175, 297.
[20]Ibid., 144.
[21]Ibid., 157–8.
[22]Ibid., 143.
[23]Ibid., 114. See also 300–5.
[24]Ibid., 95–6.
[25]Ibid., 224, 273.
[26]Merton, *Seeds*, 142.
[27]Merton, *Conjectures*, 71, 286.
[28]Ibid., 18.
[29]Barack Obama, *The Audacity of Hope: Thoughts on Reclaiming the American Dream* (New York: Crown Publishers, 2006), 20.

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Marc J. de Vries

Utopian Thinking in Contemporary Technology versus Responsible Technology for an Imperfect World

Marc J. de Vries

In several contemporary technological developments, the expectations people have of the new technology is framed in terms of the prospect of an ideal world. This utopian thinking is featured in at least three technological domains, namely, medical nanotechnology, virtual realities, and sustainable technologies. Some authors have ascribed this to Christian sources, but there are strong arguments against this claim. This kind of utopian thinking denies the influence of sin and its consequences on human thinking and acting, ideas that are significant in Christian thinking. A more balanced approach is needed, one which takes into account the nonideal state of reality, a condition present until the end of time.

In the rhetoric accompanying several contemporary technologies, we find clear traces of utopian thinking: namely, the idea that an ideal world can be realized by means of new technologies.[1] According to David Noble, the origin of this kind of thinking in technology is attributable to the Christian concept of Paradise.[2] In Christian thinking, however, paradise cannot be restored by humans. It is God who will create a new heaven and earth in which the brokenness that characterizes our current world will no longer be present. Until then, responsible technology means having technology that operates in an imperfect world.

Christian Origins of Utopian Thinking?

The meaning of the word utopia stems from the Greek: it denotes nonplace (*ou topos*).[3] The term was used by Thomas More as the title of his book of 1516 in which he described an ideal state. Since then, the term is used for any ideal world one can imagine but that does not exist (hence the term, nonplace).

Francis Bacon in *The New Atlantis* (1627) promoted experimentation in the natural sciences since this would bring about endless new opportunities for controlling nature, enabling humans to create an ideal world. One of the means by which humans have tried to create these ideal worlds is technology.[4] The development of technologies has always been and still is driven by promises and expectations.[5]

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In his book *The Religion of Technology*, David Noble argues that the Christian concept of Paradise is the origin of utopian thinking in technology.[6] Christians, according to him, have learned from the Bible that there was an original ideal world in which there was no disease, no pain, no human death, nor any other form of suffering. But this Paradise was lost when humans sinned, and ever since, we have lived in a broken world. However, the ideal of restoring Paradise motivated people to create artifacts of various kinds in order to recapture this ideal world of Paradise. In the first part of his book, Noble takes his readers on a historical tour. He shows how utopian thinking in the Middle Ages raised the status of technology. Since then, the Paradise ideal has motivated people through the ages to develop ever-new technologies. In the second part, Noble uses a thematic approach to argue that, in all the major domains of technology, we find this utopian thinking. It is striking that he also includes non-Christians as examples of people who were influenced by this thinking. In particular, the fact that he mentions Auguste Comte, as such an example, makes clear that the Paradise ideal can remain active in a secularized form even when people have turned their back on their Christian past.

Although at first sight Noble's arguments seem plausible, there is one major aspect of Christian thought that he completely ignores. One can question if this was done on purpose, because in some cases, his selection of persons to illustrate the Christian origin of utopian thinking in technology is quite peculiar. A case in point: one of the historical chapters is devoted to the Reformation era, but nowhere in that chapter does Noble discuss the contribution of John Calvin. Since Calvin wrote extensively about the value of culture for Christians and non-Christians, the reader would have expected that he would be featured in this chapter. But Calvin definitely does not fit into Noble's argumentation. Calvin always pointed out that sin has thoroughly pervaded all human thinking and acting, and makes it entirely impossible for us to restore Paradise by ourselves.[7] It is only through the work of Jesus Christ that restoration becomes possible, and even then, it is only fully realized when Christ returns at the end of history. Instead of Calvin, Noble refers to movements such as those begun by Anabaptists to support his argument. At that time, the possibility of restoring Paradise and realizing the New Jerusalem on Earth was quite real for them. But one doubts that they were in the mainstream of Reformation era thought.

Noble's attack on Christian thinking as the origin of an unlimited and relentless effort to realize Paradise on Earth, at whatever cost, is similar to Lynn White's accusation that Christian thinking was the cause of the irresponsible exploitation of resources.[8] He, too, is selective in his references. He suggests that mainstream Christian thought originates from the biblical notion that humans have been given the task of exploiting the earth and ruling over all living and nonliving beings. White, however, fails to notice that throughout history, there have been theologians who have emphasized that the term "rule over" in Hebrew has the meaning of "taking care of someone else's goods" rather than exploiting these goods for one's own interests. In a way, White, like Noble, suggests that Christians still have Paradise (and the permission to exploit that place) in mind when developing culture in general and technology in particular. But, as with Noble, White has to be selective in calling for witnesses, since many mainstream Christian thinkers do not comply with this image of the Christian attitude toward the concept of Paradise. Rather, it is a secularized form of the Paradise ideal that moves people in a direction to assume that there are no limits to its motivating force; this assumption causes people to develop technologies in often irresponsible ways.

An example of this can be found in the science fiction television series *Star Trek*. This series has many strong utopian references. Thanks to almost unlimited technological possibilities, humans can travel over unimaginable distances, heal the most life-threatening diseases and wounds by simply moving an electronic device over their body, communicate with other beings without any language barrier so that peace can be established between all species, and create any desirable meal by telling a replicator to produce it instantaneously. The series was conceptualized by Gene Roddenberry, who explicitly stated that he was driven by a humanistic approach to life.[9] Human beings are good in principle. In the end, if they release their creative powers in technology, all will be well; all suffering and war will be no more.

The value of Noble's and White's writings and of Roddenberry's television series, however, is that they are right in identifying utopian thinking as a driving force behind technological developments. As I will show in the following sections, this kind of thinking seems to be gaining popularity today, at least when we consider the rhetoric that accompanies many contemporary technological developments. I will show the presence of this thinking in three important domains in current technology and then show what a Christian response could be. I will argue that the biblical foundation for such a response includes not only the notion of human responsibility, but also the imperfection due to sin and the perfection to be realized only after Christ's return.

Utopian Thinking in Medical Technology

One of the emerging new technologies of our time is nanotechnology. This is a technology about which many moral issues have already been discussed.[10] Actually this is not one technology, but an umbrella term for many technologies, all of which, in one way or another, aim at manipulating particles at the nanolevel, that is, at the level of nanometers (one nanometer is one billionth of a meter). Among existing applications is the production of materials with layers of particles that are only a few nanometers thick, for example, suntan lotion or toothpaste with a layer of nanoparticles which has special protective properties. The long-term aim of nanotechnology is the manipulation of individual atoms and the ability to build structures by connecting atoms one by one (molecular nanotechnology).[11]

One of the most important application areas is in health care. Here we can find several examples of a striving for perfection or utopian thinking.[12] Current speculations suggest that one day engineers will be able to build or repair human tissue by manipulating individual atoms. It would then be possible to undo the damage done by the aging process. By repairing brain tissue at a sufficient speed, humans would be able to keep ahead of the point at which the dying process begins. Thus a person's lifespan could be extended by decades or centuries, and perhaps as long as a person chose to go to the nanodoctor. This would mean a sort of eternal life, although the term eternal dying would be more appropriate since brain tissue keeps degrading and will always need periodic repair. The promise or hope is that humans can eradicate death by means of technology. This hope was already expressed before the coming of nanotechnology, by transhumanists. Now they see nanotechnology as a possible means for realizing this ideal. Ray Kurzweil is a famous example of this "school" of thinking.[13]

This hope differs fundamentally from a biblical view of human life and death. In a biblical perspective, human death[14] is part of the curse caused by sin and can be removed only through the work of Christ after his return to Earth at the end of history. Until then, death is the gateway to life in heaven for those who have committed themselves to the redemptive work of Christ. The road to the tree of life in Eden's garden is blocked by an angel with a sword. The claim of nanotechnology suggests that humans have found a way to get around that angel and reach the tree of life without God's intervention. In other words, Paradise will be regained by means of nanotechnology.[15] Many nanoscientists refuse to take this claim seriously as it is extremely speculative, but the rhetoric certainly is there and even plays a role in acquiring funding for nanotechnological research. In addition, in the biblical story of the building of the tower of Babel, we read that God himself described the possibilities of human endeavor by saying that "nothing will be restrained from them, which they have imagined to do" (Gen. 11:6b, KJV). This is confirmed by the many wrong predictions made about the limits of what humans can accomplish, for instance, the assumed impossibility of air traffic or of placing a human on the moon. The utopia of eternal life will be sought, and we cannot be sure how far humans will be able to go on this road.

A similar utopian aim in medical nanotechnology is to acquire a continuous and complete knowledge of our health status, made possible by using "lab-on-chip" technologies. These allow for a complete blood and DNA analysis, using as little as a drop of blood and at a price that anyone can afford. These analyses would enable people to monitor not only their current condition, but also the chance of developing diseases in the future. Having this knowledge gives a person at least a feeling of control, even though not all diseases can be avoided by making lifestyle changes. But coupled with the expectation that nanotechnologies can also be used to manipulate DNA, nanomedicine holds the promise that hereditary diseases can be avoided by repairing the section of the DNA strand that contains the threat. This would mean the abolishment of all diseases, which again is a promise of utopian character. In a biblical view, diseases are, like human death, the effect of the curse humans have brought upon themselves by sin. For this, too, humans now claim to have found an antidote that does not require redemption by Christ.

A third example of utopian thinking in nanotechnology is the creation of human-machine integrated beings, or "cyborgs." By creating seamless transitions from human tissue to artificial materials, the boundaries between humans and machines seem to blur. A person cannot tell where the human part ends and where the artificial part begins, because the atoms in place do not reveal whether they are of natural or artificial origin. Geertsema has shown that this blurring only holds in a materialist view of reality, and therefore cyborgs will remain a myth.[16] But even given the impossibility of creating a cyborg in the sense of a perfect human-machine integration, we already know that human bodies can be enhanced by technologies (prostheses, for example). Nanotechnologies could extend these possibilities enormously. Direct connections between brain tissue and computers could allow physicians to read the electrical signals in the brain much more immediately and precisely than we can do now with scans or EEGs. We can also stimulate the brain directly and thus bring in new signals from the outside. As the neurosciences reveal more and more connections between the signals in the brain and mental activities, these signals will, no doubt, have an impact on the "enhanced" human being's thinking. The concept of cyborgs almost by necessity contains the promise of a super-being that has capabilities beyond our imagination. Here, again, we see utopian promises being made by means of anticipated technological developments.

Utopian Thinking in Virtual Worlds

A second domain, in which we find utopian ambitions in emerging technologies, is that of virtual realities or virtual worlds.[17] Probably the best-known example of this is Second Life, a virtual world that contains almost every aspect of real life. We can create our own avatar, give it the properties we want (male or female, desired moods, appearance, etc.), and enter the virtual world to meet other avatars, to shop, to study, to start a business, and to perform many other activities. This virtual world has certain utopian features. For instance, the possibility of choosing our own character is something impossible in "First life." We can alter our character only by great effort. But the avatar in Second Life can be changed at will, which gives a person a flexible identity.[18] This means that the natural "laws" in the human psyche (studied in psychology) can be overcome in the virtual world, at least, so it seems.

Another constraint in the real world is that our acts cannot be undone, and we have to take responsibility for our deeds.[19] In a virtual world, however, once we have committed something we regret, it is a simple matter to remove our avatar and start all over again with a new one, walking away from the consequences of what we have done. We can also question if acts in the virtual world have any consequences in the real world. This was a matter of importance when the first rape was committed in Second Life.[20] The person behind the raped avatar really felt raped, but the person behind the avatar raping her claimed that no real rape had occurred because no physical act had taken place. The fact that the raped person (and not just her avatar) felt raped shows that it is an illusion to think that we can escape the real world by entering the virtual world. Behind our avatar is our own "First life" mind that cannot but obey the "First life" order that God has created.

The above was humorously illustrated by the makers of the television series CSI: NY, in an episode in which the crime investigators tried to solve a murder committed in real life by trying to find the avatar of the murdered person in Second Life. Mac Taylor, the male detective, tried to approach the murderer by using an attractive female avatar. However, his female colleague, Stella Bonasera, soon had to take over, because, as a male, Taylor simply was not able to make his avatar behave in a female manner. Trying to negate this fact is an attempt to break away from a protection that God built into the created world. Clearly, it is not healthy to keep shifting from one character to the other. In the first place, there is a danger that we may become uncomfortable with our "First life" character, but we are still confronted with it each time we return to the real world. In the second place, we can become confused about our real identity after having changed identities so frequently.[21]

Utopia Thinking Even in Sustainable Technologies

The term "sustainability" was coined by the Brundtland Commission and was defined as follows: sustainable developments are those that "meet present needs without compromising the ability of future generations to meet their needs."[22] This seems to be something that should always be strived for, given the ecological problems we are faced with today. It should definitely be advocated by Christians, as it relates directly to the biblical notion of stewardship.

There seems to be, however, a utopian notion in this definition that is hardly ever noticed. The definition suggests that every next generation ought to have the same resources as the current generation. If this is taken literally, it contains a perspective of eternity, similar to the one we noted in nanomedicine. It would mean that all decay is compensated for technologically, and no loss of resources ever takes place. We could perhaps say that this was never consciously included in the Brundtland definition. However, in the Cradle-to-cradle approach to sustainability developed by William McDonough and Michael Braungart, it seems to be taken in that literal sense indeed.[23] The Cradle-to-cradle slogan is "waste is food." This means that waste from one process can always be used as the input ("food") for another process.

In a television documentary (aired in 2006 by the Dutch broadcasting company VPRO), we can hear Braungart say literally that it is fine to produce waste, as it is a positive action because it provides food for a subsequent process. This seems to contradict not only all previous policies aimed at preventing waste, but also the second law in thermodynamics that tells us that there is always a loss of quality in energy conversion. When people produce waste in a careless way, expecting all waste to be reusable, they enhance the environmental problems substantially, and the utopia soon turns into a dystopia.[24] It also contradicts the biblical word that the earth "shall wax old like a garment" (Ps. 102:26). This wearing away and decay of the earth is a consequence of the curse we have brought about.[25] But again and again, we see technological claims that humans can overcome the effects of this curse.

The Utopias Appear to Be Nonplaces

For each of the domains discussed in the previous sections, we can see the first signs of the anticipated utopias actually being nonplaces. Karl Popper argued that the whole idea of utopias in society is flawed, and even though his argument may not be entirely correct, he still should be taken seriously, given his importance as a philosopher.[26] For each of these domains, utopian promises are disturbed by experiences of undesired effects caused by efforts to realize the utopia. We have already mentioned a few when we discussed the virtual worlds and the sustainability ideals.[27] Also, in the domain of the application of health care, first concerns about dystopian effects have been expressed.

The idea of extending our lifespan indefinitely may sound attractive at first, but it raises fundamental questions about how we view human beings. It seems that much of what we do is driven by an awareness that we have only a limited time to accomplish our goals in life. Are we still motivated to take initiatives, given the prospect of endless time? Do we have the courage to start a study knowing that we still have hundreds of years to go? And if that endless life is without diseases, what will that do to our character? It is known that physically we grow stronger by being engaged in a constant battle against viruses and bacteria and that we become vulnerable when we are constantly protected from these attacks on our health. But, mentally and spiritually, having to struggle with setbacks helps us to develop character. What will happen if we can find easy solutions for any problem we encounter? Furthermore, some of the technologies with utopian promises bring about threats to the values of human integrity and human identity.

Nanochips that are implanted with the utopian promise of enhancing our brain capacities will influence our thinking in ways that we do not as yet know. We already know that drugs can have a strong impact on our personality. How much more could this be the case with electronic devices that have been designed to do just that? How can we guarantee that we have control over these devices, not only before, but also after they have been implanted and begin to influence us?

The same value of human identity is at stake when we attempt to reproduce human life. Cloning may result in two human beings with identical memories. Will they, or we, be able to sort out who was the original and who is the clone? In the movie *The Fifth Day,* this problem is played out in a fairly convincing way. So the utopia of creating human beings with enhanced capacities may turn into a dystopia of loss of identity. Similarly, a utopia of human enhancement may result in a dystopia of loss of integrity. Nanorobots invading our human bodies may seem an attractive way of repairing damage within the body that would otherwise require surgery, but when control over these devices is lost, they may do more harm than good. The same holds for nanocoated drugs that fall apart only where chemical substances which indicate tumors or infections are present. How can we know that the coatings, once removed, do not pervade other parts of the body and become a new asbestos problem, perhaps even more serious than the original one? These are some of the examples of how utopias can suddenly become dystopias.

Several authors have pointed out the dangers of utopias turning into dystopias. Already in 1943, the famous Christian apologist C. S. Lewis warned in his book *The Abolition of Man* that the utopia of creating superhumans in Nazi ideology would mean the loss of human values.[28] The next (genetically manipulated) generation would in fact have less, rather than more, control, as they would have no say in the manipulations that made them into what they would be. Similar warnings (but not from a Christian perspective) were uttered by Günther Anders, first in the 1940s and 1950s, with respect to the atomic bomb and other applications of nuclear energy, and later with respect to mass production and television.[29] Bill McKibben, in his book *The End of Nature,* warned that utopian striving for improvement through biotechnologies will, in the end, lead to the destruction of human life.[30]

However, even when a utopia does not turn into a dystopia, it can prove to be a nonplace. It is known that women who have had cosmetic surgery soon "discover" that they need another body improvement to reach the happiness they desired when entering the world of cosmetic surgery. True happiness is always one cup size or face lift away. In the meantime, a lot of money is invested in pursuing an ideal that is often not realized.

A Christian Response: Responsibility in Brokenness

It is striking that the theme of utopian thinking in technology has long been featured in the history of philosophy of technology. In a recent survey of the history of philosophy of technology in the Netherlands, I was struck by the fact that several inaugural lectures of professors in philosophy of technology contained this theme in a prominent way. Dutch philosopher of technology Hans Achterhuis even made it a main theme in his whole philosophical oeuvre.[31] He particularly points out the danger of pursuing utopias, in that they make people forget to take into account constraints that safeguard the responsible development of technologies. Or, as van de Poel and Royakkers formulate it, human technological enthusiasm has the inherent danger of easily overlooking possible negative effects of technology and the relevant social constraints.[32]

In fact, this is what Noble accused Christians of doing, in his book *The Religion of Technology*.[33] Earlier, I refuted Noble's claim by pointing out that Christians are, or at least should be, aware of the fact that fallen humans are unable to bring about a perfect world. However, there is a second element in a Christian response to Achterhuis' concern, that Noble also overlooked. In a biblical perspective, there is an awareness of boundaries that hold in reality and limit our human interventions. In part, these are given with the natural order that God has imposed on reality. These boundaries are the cause of some of the "cracks" in the surface of utopias such as virtual worlds.

As we saw, nature does not allow us to alter personality in an unlimited way, just as we cannot ignore the law of gravity and other regularities ("laws") that hold for the behavior of created reality.

These laws do not require our obedience (gravity works regardless), but we are obliged to take them into account when developing new technologies. A second component of the boundaries limiting our human endeavor comprises laws that do require our obedience. Probably the best-known examples of these are the Ten Commandments. In general, they are the expressions of God's will graciously offered to advance human flourishing. Among these expressions are those that relate to personal identity and integrity. Although we do not find these exact terms in the Bible, the way that the creation of humans is described, as well as many other statements about the nature of humans, makes it clear that humans have a special position in reality and that the human personality is something that we should not tamper with, whether it be our own personality or that of others.[34]

Instead of trying to realize a utopia, a Christian perspective should be aimed at developing technologies for an imperfect world. In a way, this is what engineers normally do. In that respect, all this utopian rhetoric must often sound strange to engineers, since they know by experience that, at the very heart of a problem in engineering design, a designer must deal with conflicts in the list of requirements and make appropriate trade-offs. This is what engineers learn in their education, and in practice, they find out the importance of these considerations. Here we see confirmation of what C. S. Lewis claimed in his book *Mere Christianity,*[35] namely, that the Christian approach is the most rational one. It is an illusion to believe that we can realize a utopia through technology. Rather, we should learn to deal with the imperfection of reality.[36]

There are at least two types of imperfections that engineers (and users of technology) should consider, rather than ignoring them in an utopian approach. First, the natural aspects of reality are imperfect, but so also are the human aspects. We have seen that utopias can turn into dystopias if we try to go against natural laws, such as the relative stability of our personality in "First life" or the unforeseen effects of nanoparticles in our body. These natural laws at first sight may seem to hamper the engineers' work because they limit human freedom. But at the same time, these laws are necessary conditions for life and for engineering. No devise could be designed without the certainty that the law of gravity, and indeed that all other natural laws, would hold in the future. The ordered behavior of reality is what makes design possible, and, indeed, life in general. This order was created and is still maintained by God in order to make reality a place we can live in. Trying to abrogate these rules in order to claim autonomous freedom is likely to result in a loss of safety and control. Utopias based on this are not only places that do not exist ("nonplaces") but are also places that were never meant to exist as long as God's curse pertains to this reality.

There is a second type of imperfection, namely the one that resides in our human nature. Humans are imperfect beings in a moral sense. In spite of the high moral expectations assumed in a humanistic approach, reality shows time and time again that humans will abuse technologies in some way or other. Even when we start out by developing and using technologies with the best of intentions, sooner or later our motives will form a hybrid: good and bad intentions will mix, and the result will be irresponsible behavior to a greater or lesser degree. When designing, engineers normally take for granted that users will deal with their products, honoring the aims they were designed for. This is what we call a "proper function."[37] But the designers' control over the users' handling of the artifact is limited. There are also "accidental functions." A screwdriver is designed for getting screws into and out of a surface, but many do-it-yourself enthusiasts use it for opening tin cans. Although this simple example of an accidental function seems innocent, damage caused by the screwdriver or the tin can's lid can be one of the results.

Users can also deliberately employ accidental functions for an evil purpose. Airplanes were designed to transport people over large distances. The 9/11 terrorists, however, used an airplane as an extreme weapon against Americans. It is almost impossible for a designer to foresee all the possible abuses of his or her design. Yet, designers should at least make a serious effort to think about possible abuses, rather than to take for granted that they can create a utopia in which no evil user exists. Such a utopia was sketched by Gene Roddenberry when he conceived his Star Trek television series. In *The Original Series*, the first series of this television show, we can see this very clearly. The Enterprise crew was tempted to respond to evil with evil, but they always exercised their good intentions, enabled by supportive technologies. But engineers do well not to assume this; rather, they should work from the assumption that there will always be someone who will use the device in unintended and evil ways.

An important aspect of this second type of imperfection has to do with our limited knowledge of the possible effects of new technologies. Not only has sin pervaded our intentions, but it has also affected our knowledge. This contributes to our limitations, in that we are creators and do not have the Creator's knowledge. This latter limitation, or epistemic opacity, carries with it a moral obligation to be careful in our decision making.[38] We can estimate the effects of a search for utopias only to a limited extent. Undesired side effects cannot be predicted. The greater the distance between the current situation and the desired utopia, the more we will be confronted with the Collingridge dilemma: the earlier in the process, the more we can decide, but the less we know about possible effects; the later in the process, the more we know but the less we can yet decide.[39] Many of the utopian ambitions we discussed are in a very early stage of realization. The tendency to give absolute priority to this realization can make people blind to possible undesired side effects. Instead, we should bear in mind the limitations of our knowledge. In addition, we have to take into account that, in the context of our ambitions, sin influences our knowledge in such a way that what we may hold to be true is that which we desire to be true.

Thus we need to develop "technologies for an imperfect world." This is what God calls us to do. Before Adam and Eve fell into sin, God called them to take care of a perfect garden. Cultivating this garden would have cost them no sweat, blood, or tears, since it would have naturally flourished. After sin, God spread a curse over the earth so that it brings forth thorns and thistles. Now cultivating the earth does cost sweat, blood, and tears. But this cultivation is still what God calls humans to do.[40] He wants us to take up the hoe and weed out the thorns and thistles, knowing full well that they will always come back.

We need not sit still and be silent until God restores everything. Until he comes back, he wants us to develop technologies that enable us to find shelter and food, to travel and communicate, to heal the sick, and to help the blind to see and the lame to walk. But we have to keep in mind that in spite of all our efforts, what we accomplish is not his perfect future world. For that, we await his coming in glory. In the meantime, we set up imperfect and temporary signs of the eternal and perfect world that he will inaugurate at the end of history. The Bible begins with a perfect garden and ends with a perfect city. It is not the garden that will return, but, rather, a city which comes down from heaven. Granted, this is an image used in the Book of Revelation, but still it is an image that refers to technology and not just to nature. In this city, nature and technology are in perfect harmony. Trees grow unhampered in the presence of golden paving bricks.

In conclusion, responsible technology is technology that takes into account the imperfection of our current reality, rather than our striving for a human-made utopia. Building utopias is like erecting new towers of Babel. As Schuurman has pointed out, the intentions lying behind technological developments often are similar to those behind building this famous tower in the plain of Shinar.[41] The motives for building these towers may seem morally good from a humanistic perspective. But from a biblical perspective, they do not do justice to the fact that God has given us only one way out of the impact of the curse that we have brought over this world, namely, reconciliation through Christ. Sixteenth-century church reformer John Calvin had a high appreciation for the culture developed by both Christians and non-Christians.[42] However, he emphasized that our culture does not restore a lost paradise. Only God can and will bring into being the new perfect city that will replace the old perfect garden. Until then, we must gratefully use our capabilities to develop responsible technologies which weed the imperfect garden and build imperfect cities. ✦

Notes

1There are, of course, also nontechnological utopias. Thomas More's *Utopia* (1516; reprint, Stilwell, KS: Digireads.com, 2005) was largely a political utopia.

2David Noble, *The Religion of Technology: The Divinity of Man and the Spirit of Invention* (New York: Penguin Books, 1999).

3Nonplace is the literal translation of the Greek word. I have used it here only in that sense and not in the way it is used by Marc Augé in his 1995 book called *Non-Places*. In that book, it has the meaning of places that we occupy so briefly that they lack significance as "places" for us.

4Alex Hall, "'A Way of Revealing': Technology and Utopianism in Contemporary Culture," *The Journal of Technology Studies* 35 (2009): 58–66.

5Mads Borup et al., "The Sociology of Expectations in Science and Technology," *Technology Analysis and Strategic Management* 18 (2006): 285–98.

6David Noble, *The Religion of Technology.*

7Alister E. McGrath, *A Life of John Calvin: A Study in the Shaping of Western Culture* (Oxford: Blackwell, 1990).

8Lynn Townsend White Jr., "The Historical Roots of Our Ecologic Crisis," *Science* 155 (1967): 1203–7.

9David Alexander, *Star Trek Creator: The Authorized Biography of Gene Roddenberry* (New York: Penguin Books, 1995).

10M. C. Roco and S. Bainbridge, *Societal Implications of Nanoscience and Nanotechnology* (Dordrecht, the Netherlands: Kluwer Academic Publishers, 2002); M. J. de Vries, "Analyzing the Complexity of Nanotechnology," in *Nanotechnology Challenges: Implications for Philosophy, Ethics and Society*, ed. Joachim Schummer and Davis Baird (Singapore: World Scientific, 2006), 165–79; M. J. de Vries, "A Multi-Disciplinary Approach to Technoethics," in *Handbook of Research on Technoethics*, ed. Rocci Luppicini and Rebecca Adell (New York: Information Science Reference, 2008), 20–31.

11Eric Drexler, *Engines of Creation* (New York: Anchor Press, 1986).

12Catherine Larrère, "Ethics and Nanotechnology: The Issue of Perfectionism," *HYLE – International Journal for Philosophy of Chemistry* 16 (2010): 19–30.

13See, for instance, Ray Kurzweil and Terry Grossman, *Fantastic Voyage: Live Long Enough to Live Forever* (Emmaus, PA: Rodale Books, 2004).

14Personally I am convinced that this refers both to the physical and spiritual death. In the context of evolutionary thinking, some theologians argue for physical death having been there from the beginning of human existence. The theological consequences of this in my view are, as yet, insufficiently analyzed.

15The idea of using science to control nature by technology goes back to Francis Bacon and his *Nova Atlantis* (1627).

16Henk Geertsema, "Cyborg: Myth or Reality," *Zygon* 41 (2006): 289–328.

17The first domain was medical technology.

18Sherry Turkle, *Life on the Screen: Identity in the Age of the Internet* (New York: Simon and Schuster, 1997).

19This holds, at least, for emotionally and spiritually healthy persons.

20J. Dibbell, "A Rape in Cyberspace: How an Evil Clown, a Haitian Trickster Spirit, Two Wizards, and a Cast of Dozens Turned a Database into a Society," *Village Voice* (1993): 36–42.

21This concern was expressed by Cristina Botella et al., "Cybertherapy: Advantages, Limitations and Ethical Issues," *PsychNology Journal* 7 (2009): 77–100 in the context of psychotherapeutic use of virtual worlds; and by Tsung Juang Wang, "Educating Avatars: on Virtual Worlds and Pedagogical Intent," *Teaching in Higher Education* 16 (2011): 617–28 for educational use.

22United Nations World Commission on Environment and Development, *Our Common Future* (Oxford: Oxford University Press, 1987).

23William McDonough and Michael Braungart, *Cradle to Cradle: Remaking the Way We Make Things* (New York: North Point Press, 2002).

24A dystopia is the opposite of a utopia.

25This raises the question of whether the second law of thermodynamics is also the result of sin because of the effect of decay. I do not want to discuss that question here, but only point out that the decay is more than the effect of this law. It also has to do with the fact that humans display careless behavior in dealing with this garment.

26Roger Paden, "Popper's Anti-utopianism and the Concept of an Open Society," *The Journal of Value Inquiry* 34 (2000): 409–26.

27In the case of virtual worlds, we mentioned the possibility of identity problems, and in the case of sustainability, we mentioned the possibility of people creating waste in a careless way, assuming that all waste can be reused.

28C. S. Lewis, *The Abolition of Man* (London: Oxford University Press, 1943).

29Günther Anders, *Die Antiquiertheit des Menschen 1. Über die Seele im Zeitalter der zweiten industriellen Revolution* (München: C. H. Beck Verlag, 1956); and Günther Anders, *Die Antiquiertheit des Menschen 2. Über die Zerstörung des Lebens im Zeitalter der dritten industriellen Revolution* (München: C. H. Beck Verlag, 1980).

30William McKibben, *The End of Nature* (New York: Random House Trade Paperbacks, 1989).

31See, for example, H. Achterhuis, *De erfenis van de utopie* (Amsterdam: Ambo, 1998).

32Ibo van de Poel and Lambèr Royakkers, *Ethics, Technology, and Engineering: An Introduction* (Chichester: Wiley-Blackwell, 2011).

33Noble, *The Religion of Technology.*

34Although the use of psychoactive drugs for psychiatric patients can be defended in certain cases, the dignity of the human personality should make us very guarded in this effort.

35C. S. Lewis, *Mere Christianity* (London: Collins, 1952).

36M. J. de Vries, "Technology for the Imperfect Life: The Development of Evil-Proof Technologies," in *Different Cultures, One World: Dialogue between Christians and Muslims about Globalizing Technology*, ed. Henk Jochemsen and Jan van der Stoep (Amsterdam: Rozenberg Publishers, 2010), 53–62.

37M. J. de Vries, "Teaching About Technology," in *An Introduction to the Philosophy of Technology for Non-philosophers* (Dordrecht, the Netherlands: Springer, 2005).

38Mark Coeckelbergh, "Imagining Worlds: Responsible Engineering under Conditions of Epistemic Opacity" in *Philosophy and Engineering: An Emerging Agenda* (Dordrecht: Springer, 2010), 175–87.

39David Collingridge, *The Social Control of Technology* (New York: St. Martin's Press, 1980).

40Jack Clayton Swearengen, *Beyond Paradise: Technology and the Kingdom of God* (Eugene, OR: Wipf & Stock Publishers, 2007), shows what this means in practice.

41E. Schuurman, *Faith and Hope in Technology* (Toronto, ON: Clements, 2003).

42McGrath, *A Life of John Calvin,* 1990.

Article

Engineering Is Not Science

Steven H. VanderLeest

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Engineering is not merely the application of science. While science is certainly an important factor in the engineering design of technology, subsuming engineering and technology under the umbrella of science obscures important differences. Following a structure suggested by Paul Forman, the two are distinguished, exploring the primacy of science in the modern era and the primacy of technology (and engineering) in the postmodern era. However, placing either practice above the other does not do justice to both: a symbiotic or interplay model is more appropriate. Recognizing the distinctive yet interdependent activities of science and engineering produces better insights. This interplay also suggests some benefits related to the exercise of Christian faith: providing multiple modes of worship, avoiding idolizing "-isms," and understanding our roles as stewards.

The act of categorizing illuminates certain characteristics but obscures others. Many academic disciplines can be divided into "lumpers," combining similar things into larger categories, and "splitters," dividing dissimilar things into smaller subsets. Categorization is a helpful mental model, but either strategy carried to extreme loses its value. Lumping everything in a unified category is too bland to make useful inferences; splitting everything into singular categories is too fragmented to provide helpful insights.

More than a simple cognitive aid, cataloging represents political power. Insensitive men have lumped both genders under the label "mankind." Disrespectful whites split off persons of color into a separate category of blacks (or more derogatory terms) in order to deny rights and even to deny personhood. Categories and labels become terms of respect and justice—or the lack thereof. This article examines the importance of the categories and the names of science and engineering.

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This article's structure follows Paul Forman's division of history in the year 1980. He tips the scales to favor science prior to, and technology after, that date.

> Liberation of our conception of technology from the functional dependence and cultural inferiority implied by "applied science" was a principal constitutive program of the discipline of the history of technology … When the historians of technology first began to revolt against "the linear model" and its view of science as originative source, as unmoved mover, of technological progress, they were setting themselves against prejudices deeply entrenched in modern culture … In the epochal global transformation from modernity to post-modernity that has been taking place in recent decades, technology has acquired, beginning about 1980, the cultural primacy that science had been enjoying for two centuries world-wide, and in the West for two millennia.[1]

The first two sections of this article employ the split categories of science and technology to examine Forman's claim. After following Forman's pendulum swings, the third section lumps these categories to provide a balance. The final section suggests some benefits that accrue, particularly for Christians honoring this balance.

Primacy of Science in Modernity

Forman claims that prior to 1980, modernism lumped technology and engineering in with science. Science covered all technical disciplines. It was not simply an umbrella term for a collection of related categories; it was a hierarchical term, signifying that science was the sole basis of technology. Technology was subservient to science. Arie Leegwater describes this approach: "Technology is seen as being, at best, applied science … the conventional view perceives science as clearly preceding and founding technology."[2] He then identifies the genesis of this viewpoint to be historians of science, though he notes that recent "studies in the history of technology have begun to challenge this assumed dependency of technology on science."[3]

Henry Petroski illustrates the subservient relationship by examining media coverage that is often positive for scientists and negative for engineers. When Wen Ho Lee is alleged to have stolen nuclear security data, he is an "engineer," but he is a "scientist" when defended as a victim of bias. When a scientist does work that draws controversy, the headline reads, "Engineering by Scientists on Embryo Stirs Criticism." When radio contact with the Mars Pathfinder mission is disrupted, engineers scramble to solve the problem, but scientists get attention when the problem is fixed. In the 1950s, engineers protested that when a rocket launch was successful, it was a "scientific achievement," but if not, it was an "engineering failure."[4]

Petroski's lament is not a new phenomenon. Shapin describes how the gentleman scientist Robert Boyle relied largely on servant technicians:

> … it is more than likely that very few … of Boyle's experiments involved the laying of his hands upon experimental apparatus or materials. A very substantial proportion of Boyle's experimental work was done on his behalf by paid assistants.[5]

Yet Boyle gives no recognition to their work, considering them largely invisible servants—unless there was a problem.

> Boyle was frequently absent from his laboratory on other business for extended periods, during which he devolved the whole responsibility for managing and recording experiments to his assistants … when the outcome accorded with expectation, no observing agent was customarily specified … Technicians' roles as observers and recorders were alluded to mainly when inconsistent or problematic results were obtained.[6]

The modern primacy of science has vestiges in our postmodern world. A remnant is found in many high schools, colleges, and universities that still reflect the former dominance in the names of their programs and departments. At my home institution, the Division of Natural Sciences and Mathematics omits engineering from its name despite the fact that engineering accounts for a plurality of division majors (and, combined with nursing, accounts for more division majors than all the natural sciences and mathematics combined).

A remnant is also found in the name of this journal's parent society, the American Scientific Affiliation (ASA), which presumes that its name encompasses both science and engineering, both scientific knowledge and technology. The ASA website provides a self-description which first centers on integrating Christian faith with science, describing science as a "way of knowing about [God's natural] order in detail." It then acknowledges a second task: examining "how best to use the results of science and technology."[7] This is a telling juxtaposition of knowledge for edification of the saints with a functional definition that makes science a means to practical ends—and suddenly the word technology appears with the apparent actor being the scientist and no mention of the engineer. The subsumption of technology into science is not simply an artifact of past ASA tradition. Even today, the executive director describes "sciences" to inherently include "all science and engineering and technology vocations."[8]

Primacy of Technology in Postmodernity

Philosophers of technology do not consider their subject to be merely applied science, and many philosophers of science have come to share this opinion. "Certainly the view … that science discovers and technology applies will no longer suffice."[9] Forman claims this shift occurred after 1980, resulting in a postmodern hierarchical ordering. Now technology subsumes and encompasses science. In this section, we will observe the transition from several perspectives: definitions, ordering, knowledge concepts, goals, constituent components, and comparison to other disciplines.

Definitions

Erasmus said that "every definition is dangerous." Typical descriptions of the scientific method (the practice that results in scientific knowledge), such as "systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses,"[10] are virtually unrecognizable as descriptions of engineering (the practice that results in technology). Science as an umbrella term is thus problematic:

> … science is commonly understood to include medicine, engineering, and high technology. "Science" is clearly a useful shorthand for a wide range of activities, but it also obscures the differences between them. It gives science a primacy that it may or may not deserve.[11]

Definitions of engineering do not resemble those of science. Vincenti says engineering is

> the practice of organizing the design, production, and operation of an artifact or process that transforms the physical world to some recognized human end.[12]

Dym describes engineering as

> a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints.[13]

The president of the National Academy of Engineering defines engineering succinctly as "design under constraint."[14] None of these definitions mentions science nor restricts engineering to only science. By contrast, Van Poolen's definition states,

> Whereas science discovers the laws of what is embedded in natural, created reality, design embeds into reality the "laws" of various tools and products. In short, science describes the natural while design develops the artificial.[15]

One aspect that all of these definitions omit is a consideration of design as a problem-solving activity, problems that are typically underconstrained, so that trade-offs are necessary and optimization is possible.

The phrase "science and technology" is awkward: science is a practice; technology is a tangible object.[16] The scientist performs the activities of science, experimenting, theorizing, hypothesizing, and so forth. These activities result in scientific knowledge, theories, or, simply termed, science. The engineer performs the activities of design, trade-offs and optimization under constraint, and invention. This activity results in technical artifacts, products, processes, or, simply termed, technology. Not all philosophers of technology hold to a merely material definition. For example, while observing that most definitions of technology include physical attributes (pointing to their status as objects), Van Poolen expands the identity of technology to include attributes of relationship.[17] In doing so, he consciously follows Bruno Latour, who considered technology not to be a thing, but rather a quasi-object—a concept Latour later developed into actor-network theory.

Sequencing

Modernism considers science to be prior to technology in the sequence of development of cultural artifacts (including an assumption that science produces technology); postmodernism assumes a more fluid, nonlinear relationship. Leegwater is helpful here in identifying three ways that science relies on technology. Two are important: (a) providing metaphors for understanding, and (b) use of technological instruments and apparatuses. The third is decisive: (c) "use of technologically developed objects in scientific work." He observes that many significant technological achievements of the Middle Ages

> ran far ahead of the limited scientific knowledge of the time … it was technical, practical machines that preceded and stimulated such scientific theories.[18]

This reversal, to have technological products spur scientific discovery, stands in opposition to modernism's view. Watt's steam engine preceded much of our scientific theory in the field of thermodynamics; indeed, it spurred later scientific research to develop theories explaining the extant engine. Astronomy flourished after the invention of the optical and radio telescope.

Martin Heidegger pushes the reversal even further.

> It is said that modern technology is something incomparably different from all earlier technologies because it is based on modern physics as an exact science. Meanwhile we have come to understand more clearly that the reverse holds true as well: Modern physics, as experimental, is dependent upon technical apparatus and upon progress in building of apparatus.[19]

He goes on to surmise that while modern physical science began chronologically before "machine-power technology," technology precedes science in its "essence holding sway within it."[20] William Lovitt, in translating Heidegger, attempts to explain this phrasing in his introduction to the book:

> *Techné* was a skilled and thorough knowing that disclosed, that was, as such, a mode of bringing forth into presencing, a mode of revealing.[21]

Science might then be more aptly called applied technology.

Writing just after Forman's chronological division of 1980, Leegwater presciently envisions both interpretations of sequencing. He suggests that an examination of engineering science and scientific technology can provide helpful insights into the interaction between science and technology. Even though he provides an example of technology preceding development of the associated scientific principles (Watt's steam engine), he downplays it, saying that while Watt might not have used scientific knowledge, he still used scientific methods to experiment systematically with engine designs.[22] Later, Leegwater notes the mathematical proportions provided in an 1842 book on the engineering and design of waterwheels, describing them as

> certainly not derivable from the principles of mechanics—that is, from abstract scientific theories and knowledge—but they are the result from borrowing and utilizing the methods of science to found new technological sciences.[23]

In attempting to explain technology developed without direct scientific knowledge as its basis, Leegwater points out the more tenuous connections between the two.

However, is it not curious that Watt uses so-called scientific methods to produce not science, but technology? For Watt the engineer, his use of the scientific method was no more definitive than his use of a wrench, blueprint, mathematical formula, or chemical recipe. If the use of a tool defines the user, then teachers would be called applied chalk artists and scientists would be called applied mathematicians or even applied technologists. Later, Leegwater is more sympathetic:

> Science cannot be viewed as the father of technology. Technology is not reducible to the application of prior scientific knowledge. The doing of technology builds up its own repository of knowledge—knowledge of skills, methods, techniques, and designs that do or do not work. The knowledge often precedes and transcends scientific knowledge and explanation.[24]

While one might expect scientists themselves to consider science primary, why would historians of science, whom we might expect to be more objective about science as a social phenomenon, also fall into an indiscriminating sequencing of science before and over technology, despite clear counterexamples? Petroski offers one explanation:

> … our Western Platonic bias has it that ideas are superior and prerequisite to things. Hence, scientists who deal in ideas, even ideas about things, tend to be viewed as superior to engineers who deal directly in things. This point of view has no doubt contributed to the mistaken conclusion that science must precede engineering in the creative process. In fact, … the engineer can go a long way in creating what never was without a fully formed science of the thing."[25]

Leegwater comes to a similar conclusion, noting that liberal arts support of science was of a theoretical nature that disdained "vulgar mechanics" and idealized the "life of the mind."[26]

Body of Knowledge

Engineering has its own body of knowledge independent of science: heuristics, rules of thumb, design processes and procedures—all targeted at optimizing practical value to meet human needs. Joseph Pitt argues that this knowledge is more reliable, implying a primacy for technology.

> On the very grounds on which the claim of superiority is made for scientific knowledge, engineering

> knowledge is shown to be far more reliable than scientific knowledge—thereby exposing the lie in the traditional view that science is our best and most successful means of producing knowledge.[27]

Even for those most opposed to a postmodern primacy of technology over science, Forman observes that they defend the purity of scientific knowledge and justify its truth by validating it thus: "science works."[28] But this defense undermines their position, shading science under the canopy of technology's practical approach.

Purpose

If the purpose of science is the "acquisition of knowledge," as *Responsible Technology* puts it, and the purpose of engineering science is only the "creation of objects,"[29] then science appears more sublime. But most engineering is not merely mass production of bric-a-brac. Technology is always a means to an end. Engineers do not develop devices whose only purpose is to exist. They pride themselves on practical application, on meeting human needs. They test their prowess by the market: those products that sell because they meet a need are considered successful; those that do not are failures. Considering these distinctive incentives, Louis Bucciarelli concludes, "Because their motivation (and rewards) and subject matter differ, engineers think in ways different from those of scientists."[30]

Science eschews subjective values, but values are the objective of engineering. A scientist does not study a new species or subatomic article in order to make it fit some need or solve some problem—in fact, bringing self-interest into the study would be considered a loss of objectivity and thus unscientific. By contrast, "unlike the scientific method, design methodology intentionally incorporates the values of the constituencies."[31] The engineer searches for the best means to solve a problem, inherently self-interested in practical application.

Forman quotes scientist Joseph Henry, saying, "We leave to others with lower aims and different objects to apply our discoveries to what are called useful purposes," and then he concludes,

> Today, in postmodernity, Henry's cynosure of for-its-own-sake science is without cultural understanding or support. Consequently, those who identify themselves as scientists have, overwhelmingly, no other ambition than to place themselves in the service of "useful purposes." To be sure, cosmic-discovery science and history-of-life-on-earth science continue, but less as exceptions than as "useful" to an increasingly credulous, "spirituality"-oriented, romantic-illusionary, postmodern culture.[32]

This reversal goads science to adopt the means-directed, purpose-driven practicality of engineering. Indeed, applicants for today's scientific grants are judged largely on anticipation of utility. Leegwater perceives it so: "The technological needs and desires of society often set the agenda for scientific research."[33] The search for pure knowledge for its own sake may have once been sufficient, but such lofty yet esoteric goals rarely get funding these days. In the decades before Forman's turning point from the dominance of science to that of technology, perhaps there was more room for pure science. But surely, even in the prior decades, government funding came at the cost of showing practical value. Even research with no apparent application that resulted in new knowledge could be held up for national pride. The superpowers' race to space was for patriotic ego as much as it was for national defense. Americans were wrenched into an avid pursuit of science because of the embarrassing bleep of Sputnik circling above—humanity's first artificial satellite produced by the Russians. Thus the cold war provided a purpose even for pure science: it was part of the competition to surpass the other superpower.

Science as One Tool of Many

Engineers do not rely solely on science to ply their trade. They use whatever works. When science provides vague or contradictory guidance, engineering develops its own predictive models and its own guidance to produce technology that performs the needed function. Because science is simply one tool among many, reliance does not indicate subservience. "Science is a tool of engineering, and as no one claims that the chisel creates the sculpture, so no one should claim that science makes the rocket."[34] Engineering even dares to disdain science as impractical—project managers admonish engineers to focus on the end goal without wasting time, by saying, "Don't make it a science project" (with the implication that science takes too long to arrive at a useful result).

The technologist's predilection for practicality has seeped into other professions. A recent issue of *The Atlantic,* concerning the apparent success of some alternative medicine therapies despite no evidence in controlled scientific experiments, notes,

> Rather than going ballistic when they hear that patients believe themselves to benefit under the care of alternative practitioners, argues the Mayo Clinic's Victor Montori, doctors ought to be praising, or at the very least tolerating, alternative medicine for the way it plugs gaping holes in modern medicine. "Who cares what the mechanism is?" he says. "The patient will be healthier."[35]

Montori works in the clinic's Knowledge and Evaluation Research Unit. For him, the reliability of knowledge is about utility: what works is true.

Closer Comparisons

Is science the most similar discipline to engineering? Leegwater points out some similarities between "engineering science" and "basic science" that include conformance with physical laws, tenets "built up and disseminated through similar cultural means such as textbooks,"[36] and cumulative structures built on previous knowledge. It is interesting that "engineering science" rather than the whole body of engineering knowledge is used for the comparison. Furthermore, these same similarities could be used to describe the similarity of engineering to mathematics, medicine, or even music. Besides scientific knowledge, engineering also leverages economics, mathematics, psychology, politics, law, and sociology, to name a few. Petroski has identified these closer cousins (and notice the echoes of Montori):

> Both medicine and engineering do use scientific knowledge and methods to solve relevant problems, but neither of them is simply an applied science. In fact, the practices of medicine and engineering are more like each other than either is like unqualified science: medical doctors and engineers both welcome all the relevant science they can muster, but neither can wait for complete scientific understanding before acting to save a life or create a new life-saving machine.[37]

Because technology has public safety implications, engineers are often licensed in order to practice, placing engineering closer to professions such as medicine or law than to science.

Science and Technology as Improvisational Duet

Both modernism and postmodernism provide all-encompassing historical narratives. Consider Latour. He identifies a shift away from compartmentalized disciplines with their own definitions and priorities toward a more interactive, interconnected network of actors. Simultaneously, he reinterprets historical events, no longer viewing them as simple, pure science, but rather as socially constructed knowledge largely dependent on practical technological devices. For example, he praises a historical study of Boyle that brings

> universal application of a law of physics back within a network of standardized practices. Unquestionably, Boyle's interpretation of the air's spring is propagated—but its speed of propagation is exactly equivalent to the rate at which the community of experimenters and their equipment develop. No science can exit from the network of its practice.[38]

Revisioning Boyle in postmodern (or perhaps anti-modern) terms, Latour makes the claim that forms the title of his book, namely, that we were never modern in the first place.

While Latour develops the idea of social constructivism by expanding the network out from science and technology to "facts, power, and discourse," my focus remains on the concomitant interplay of science and engineering, and their respective results, scientific knowledge and technology. Leegwater acknowledges this relationship:

> Scientists sometimes do technology, and technologists sometimes do science. The contemporary interaction between basic science and technology has therefore resulted in a diversity of activities.[39]

The social constructivists also see this, but recognize that the boundary is fuzzy—a matter of cultural definition:

> Science and technology are both socially constructed cultures and bring to bear whatever cultural resources are appropriate for the purposes at hand. In this view the boundary between science and technology is, in particular instances, a matter for social negotiation.[40]

Don Ihde describes a reframing of the primacy question that "will examine a more symbiotic technology/science direction." [41] He uses the term "technoscience" to name this new détente. However, Forman believes technoscience describes the entanglement of science and technology but does not anticipate their possible equality, suggesting the need for a better label than symbiosis provides.

What name do we give to this interplay? One possibility comes from the National Science Foundation (NSF). Created in the modern era (1950), the NSF of yesterday subsumed engineering and technology, but today recognizes them as equal partners, stating that its mission includes "fundamental fields of science and engineering"[42] and in a strategic focusing on STEM (Science, Technology, Engineering, and Mathematics) education. While the acronym distinguishes the terms, the STEM Education Coalition then lumps these different vocations back together under the technology rubric, in a postmodern move, with its mission to represent "all sectors of the technological workforce—from knowledge workers, to educators, to scientists, engineers, and technicians."[43]

Although STEM is an easy acronym to capture the disparate but related areas, it provides little insight into the relationship. If neither science nor engineering is superior to the other, if neither contains the other, then how do we describe the connection? As early as 1934, we see suggestions that the two are in a collaborative and roughly equal partnership. Historian Arnold Toynbee characterized the association of science with technology (embodied by the Industrial Revolution):

> Since the Industrial System, in its non-human aspect, is based on Physical Science, there may well be some kind of "pre-established harmony" between the two; and so it is possible that no violence is done to the nature of scientific thought through its being conducted on industrial lines.[44]

Toynbee adds a footnote:

> Physical Science and Industrialism may be conceived as a pair of dancers, both of whom know their steps and have an ear for the rhythm of the music. If the partner who has been leading chooses to change parts and to follow instead, there is perhaps no reason to expect that he will dance less correctly than before.[45]

This analogy of dancing partners is picked up thirty years later by Derek J. de Solla Price, a historian of science, who mentions the Toynbee quote;[46] thirty years later still, Arie Rip, a philosopher of science and technology, makes use of the idea.[47] (I am thus a little early to repeat it after only twenty years.) The dancing partners analogy is apt, but limited. Latour mentions the analogy of divided government: the branches of legislative, executive, and judicial form a single institution but interact in a balanced tension to produce, one hopes, the best governance.[48] We might also describe the two as musicians in a jazz band—though accomplished on their own and capable of a solo performance, they combine to produce a musical duet that is richer than the individual strains.

Dance, government, jazz duet—whatever we call the relationship—our label should suggest the nature of the connections between science and engineering (and between their respective results, scientific knowledge and technology). Rip suggests three aspects:

> a laboratory effect or method is exploited for another purpose, … Or a new domain of nature is opened up in the laboratory, and then also available for technical exploitation … [or] science may be a source of powerful heuristics for technological search processes.[49]

Ihde suggests that the interplay between science and technology would be a reframing that

> ends up being multicultural, occurring in many different places and times, and is developmental, particularly with respect to the refinement and progression of the technologies used in producing the knowledge entailed.[50]

It is also worth noting that our dancers or musicians can occasionally swap roles: "… if the natural scientist does have the ability to shape the object of research, and does so, then he or she is doing engineering."[51] Thus we see that the two are not completely distinct; either can carry the melody or harmonize with the other. However, this overlap ought not lead us back to considering one primary.

> Although there may be commonalities in principle and similarities in method, neither science nor engineering can completely subsume the other. This is not to say that self-declared or designated scientists cannot do engineering, or that engineers cannot do science. In fact, it may be precisely because they each can and do participate in each other's defining activities that scientists and engineering—and hence science and engineer—are so commonly confused.[52]

This interchangeability may mean that Van Poolen's line between the natural and the artificial is rather fuzzy.[53]

Why It Matters—Particularly for Christians

This final section offers a few reasons why the interplay of science and engineering is important, especially to Christians. From an engineering viewpoint, this section is about practical design: how are these tools means to a desired end? From a science viewpoint, this section is about inquiry: how do these practices lead to deeper knowledge?

Van Poolen writes that the Enlightenment has pushed us to reductionism, splitting complex meaning into simpler and simpler building blocks. But in interpreting technology, he says we have moved up levels of complexity (e.g., from bolts sitting on a shelf to bolts fastening together a complex bridge[54]), looking at the complex whole, leading to a unity in Christ.

> Ultimately, we can view technological things in a meaningful way because of the overall structure of relational unity given in the divine/human Word, the Logos. In this larger relational unity, the relational character of the quasi-object, hermeneutical text, and localized logos point us towards a Christian theory of technological things as containers for information about ourselves: who we are and what we value.[55]

While unity in Christ is certainly a biblical principle, it is not obvious that the three relational traits named by Van Poolen lead singularly to this conclusion. The characteristics are not necessarily distinctive to Christian faith. However, the author is clear that this is simply a starting point, hinting that this distinction is found in the connections:

> … meaning is found more in relationships between and within things than in the things themselves. This is suggested as an area ripe for further investigation within a Christian perspective.[56]

I hope that the following thoughts contribute to that investigation, focusing on three benefits that derive from recognizing the interplay of science and engineering: (1) the dance suggests diverse ways to worship God, (2) the dance helps us avoid idolizing "-isms," and (3) the dance helps us understand our roles as stewards.

More Ways to Worship God

Simply recognizing the distinct and equal partners is a point of respect and thus justice, so that the dance itself can be a form of worship.

We worship by appreciation. Scientific discoveries extend our understanding of the natural creation, which can lead us to better value its beauty and complexity, which in turn lead us to appreciate the Creator. When we discover a new space object or a new chemical or a new species, we worship. When we discover new elements of creation, we are unwrapping the gift of creation a bit further, providing us with new opportunities to give God the glory for the wonder of the world he created. So whereas Forman declares that science for its own sake in pursuit of knowledge has become "depreciated,"[57] Christians can, on the basis of their faith, redeem the scientific pursuit of pure knowledge, restoring a sense of wonder and awe of God's creation.

We worship through stewardship. Called to care for creation, we are the protectors and preservers of the natural world around us. Proper care requires appreciation, understanding, and judgment, so that we know how to be stewards of natural resources. This understanding comes largely from science. Yet, passive knowledge is not sufficient. We are not called to keep creation in a static, untouched state. As stewards, we are called to cultivate the creation, to develop culture that thoughtfully and appropriately uses the gift of creation. Creation is sometimes like the gift of a beautiful painting that we are free to observe but ought not touch. More often it is like the gift of an Erector Set™ or Lincoln Logs™ that we appreciate not only by reading the instructions, but also by building new and interesting designs from the basic elements it provides.

We worship through development. Technical development is part of God's mandate to develop culture (Gen. 1:28). When discovery turns to development of features that do not occur naturally, then science has morphed into engineering and our results are not simply the understanding of an existing aspect of creation, but a wholly new invention. Rather than take credit, we give God glory for providing raw materials that can be combined in new ways. This, too, is an unwrapping of the gift of creation. From the simplest cultivation of a garden on a hillside to the most complex genetic engineering, from the crudest hammer made with stone tied to wood to the most sophisticated medical instrument, we unfold the creation when we create. Our human ability to create is a reflection of our Creator. Made in his image, we are given a special gift to create, though limited to reworking existing matter and energy, rather than creation *ex nihilo*.

Avoid Idolizing "-isms"

Besides leading us toward God in worship, the dance can also keep us from straying toward philosophical idols. The interplay of science and technology helps us to avoid putting our faith in science or technology (scientism or technicism). Either could serve as an idol, and their combined power could be more alluring yet. Distinguishing between science and technology helps us reframe our trust by the interplay of primacy. Which came first? Which drives which? This fluid relationship between the two provides a healthy corrective, lest we settle into a comfortable trust in science as the ultimate arbiter of truth or in engineering as the ultimate test of what works. Instead, we place fundamental trust in God to uphold his creation providentially.

The interplay of science and technology can help us avoid technical neutralism. The scientist is supposed to be objective and disinterested when performing experiments to prove or disprove a hypothesis; science is supposed to be pure and free of bias. In reality, scientists have certain cultural dispositions: power and politics and money can sway the direction of research. Likewise, the engineer is supposed to be neutral; technology is supposed to be an unbiased means to an end. In reality, the engineer is designing according to values that are self-identified or driven by a customer; the technological product has built-in bias that can have a subtle influence on what the tool can do.[58] The separate but overlapping identities of science and engineering are best distinguished by their purpose. Uncovering motivation and goals highlights underlying values. Once brought to light, we can evaluate research directions and strategic technological developments on the basis of scriptural principles.[59]

The interplay helps us avoid determinism. If we believe that we are simply cogs in the gears of science or industrialism, then we easily abdicate responsibility. Today's enterprise prizes niche skills, producing a factory-like narrowing of scope.

> Inventors, industrial scientists, engineers, managers, financiers, and workers are components of but not artifacts in the system. Not created by the system builders, individuals and groups in systems have degrees of freedom not possessed by artifacts. Modern system builders, however, have tended to bureaucratize, deskill, and routinize in order to minimize the voluntary role of workers and administrative personnel in a system.[60]

Science may be objective (or at least appear so), but the scientist is not a helpless minion deterministically pursuing a prearranged fate. Choices can be made, and this becomes clearer in engineering design. The dance between science and technology can help us reestablish our human freedom to direct our own steps, so that we take back responsibility for the direction of development.

The interplay helps us avoid modernism's conceit. The allure of science—that can turn to positivism—and the temptation of technology's power—that can turn to arrogance—are tempered because science needs technology and technology needs science. There is no simple, sequential process that leads to progress. To avoid the danger of the combined dance leading to hubris, it is important that the two partners act as a check and balance on each other. Science explores the full implications of technological products; technology helps us focus on the truly good ends to which we direct our means.

The interplay helps us avoid postmodernism's despair. Relativism and deconstructionism hurl us into rough seas with no anchor and no solid landmarks by which to navigate. Our science and technology are both called into question as social constructions. However, like Samuel Johnson's famous refutation of Berkeley's immaterialism, "striking his foot with mighty force against a large stone, till he rebounded from it, 'I refute it thus.'"[61] Technology provides evidence of its own veracity as well as for the scientific principles it embodies, by virtue of the fact that it works. Engineers and scientists do not deconstruct the design of a bridge nor tolerate every design as equally valid social interpretations. Some bridges work and others do not.

Understand Our Role as Stewards in Directing Science and Engineering

Science and engineering can be pursued for a variety of reasons: pursued for their own sake, their beauty, and their lasting endurance; pursued as a job and a source of income; pursued for glory, fame, or power. What is our proper role as Christians in these vocations? Consider an analogy from technology, using Carl Mitcham's framework for the modes of the manifestation of technology: technological objects (or artifacts), technological activities (making and using), technological knowledge, and technological volition.[62]

In naming volition, or will, as an aspect of technology, Mitcham recognizes the culture-making potential of technology, and furthermore, the power of the tool that extends our desire—physical and also political power. Technology as prideful volition, as the metaphoric tool in our hand, makes us the captain of our own fate. Masters of our own destiny, we scoff at a higher power, finally shaking off the fates that capriciously control our lives. We are the tool-maker and the tool-wielder. We can rationalize that objectivity and neutrality make our cause obviously right because it is scientific, yet, in reality, science and engineering too easily become our means to power and control over nature—and over each other. But our faith speaks otherwise. We are the tool. Our Creator God made us; he is the Potter, and we are the clay. We are thus instruments of his peace. As God's steward of God's creation, we are the means to God's ends for the creation to flourish, acting as his hands. Scientific knowledge and technology amplify our ability to be good stewards. Just as they can check and balance each other to prevent pride, they can also help guide our cultural development, giving us clear-eyed assessments of our impact on the environment and on each other.

Conclusion

Modernism and postmodernism both get it wrong. Science and engineering are related, but distinguished, activities that, when done well, can reinforce and invigorate one another, to God's glory. Let neither science nor engineering be a slave to the other, because when they dance as equal partners, the result is deeper insight and richer worship. Shall we continue to dance together? ✦

Notes

[1]Paul Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," *History and Technology* 23, no. 1 (2007): 2.

[2]Arie Leegwater, "Technology and Science," in *Responsible Technology: A Christian Perspective,* ed. Stephen V. Monsma (Grand Rapids, MI: Eerdmans, 1986), 78. Arie Leegwater is one of the coauthors of this edited book. Where the authorship of a particular section is known, the specific author will be listed.

[3]Ibid., 79.

[4]Henry Petroski, *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems* (New York: Alfred A. Knopf, 2010), 26–8.

[5]Steven Shapin, "The Invisible Technician," *American Scientist* 77 (1989): 557.

[6]Ibid., 558.

[7]"About ASA," http://www.asa3.org/index.php?option=com_content&id=86.

[8]Randall D. Isaac, Executive Director of the ASA, private communication, 14 Sept. 2011.

[9]Trevor Pinch and Wiebe Bijker, "The Social Construction of Facts and Artefacts: Or, How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," *Social Studies of Science* 14, no. 3 (1984): 403.

[10]http://oxforddictionaries.com/definition/scientific+method.

[11]Petroski, *The Essential Engineer*, ix.

[12]Walter G. Vincenti, "Engineering Knowledge, Type of Design, and Level of Hierarchy: Further Thoughts about What Engineers Know," in *Technological Development and Science in the Industrial Age: New Perspectives on the Science–Technology Relationship,* ed. Peter Kroes and Martijn Bakker (Dordrecht: Kluwer Academic, 1992), 18–9.

[13]Clive L. Dym et al., "Engineering Design Thinking, Teaching, and Learning," *Journal of Engineering Education* (January 2005): 104.

[14]William Wulf, quoted in Fiona Clark and Deborah L. Illman, "Portrayals of Engineers in 'Science Times,'" *IEEE Technology and Society Magazine* (Spring 2006): 14.

[15]Lambert Van Poolen, "A Design Philosophy," in *Responsible Technology,* 166.

[16]We commonly think of technology as an object or device, but it is true that some nonphysical developments are also technology, such as an encryption algorithm or a manufacturing process. The authors of *Responsible Technology* define it as a "cultural activity" rather than the objects we commonly call technology. I prefer to call the activity, "design" or "engineering," and call the result, "technology."

[17]Lambert Van Poolen, "Towards a Christian Theory of Technological Things," *Christian Scholar's Review* 33, no. 3 (Spring 2004): 367–8.

[18]Leegwater, "Technology and Science," 86–7.

[19]Martin Heidegger, "The Question Concerning Technology," in *The Question Concerning Technology and Other Essays,* Martin Heidegger, trans. William Lovitt (New York: Harper and Row, 1977), 14.

[20]Ibid., 22.

[21]William Lovitt, "Introduction" in *The Question Concerning Technology*, xxv.

[22]Leegwater, "Technology and Science," 90.
[23]Ibid., 92.
[24]Ibid., 94.
[25]Petroski, *The Essential Engineer*, 24.
[26]Leegwater, "Technology and Science," 81.
[27]Joseph C. Pitt, "What Engineers Know," *Techné* 5, no. 3 (2001): 17.
[28]Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," 13.
[29]Leegwater, "Technology and Science," in *Responsible Technology: A Christian Perspective,* 93. The author compares the goals of science with engineering science, rather than engineering more broadly (the goals of which are never explicitly identified).
[30]Louis L. Bucciarelli, "Engineering Science," in *A Companion to the Philosophy of Technology*, ed. Jan Kyrre Berg Olsen, Stig Andur Pedersen, and Vincent F. Hendricks (Chichester, UK: Wiley-Blackwell, 2009), 67.
[31]Jack C. Swearengen, *Beyond Paradise: Technology and the Kingdom of God* (Eugene, OR: Wipf & Stock, 2007), 194.
[32]Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," 11.
[33]Leegwater, "Technology and Science," 94.
[34]Petroski, *The Essential Engineer*, 45.
[35]David H. Freedman, "The Triumph of New-Age Medicine," *The Atlantic* (July/August 2011): 99.
[36]Leegwater, "Technology and Science," 93.
[37]Petroski, *The Essential Engineer*, ix.

[38]Bruno Latour, *We Have Never Been Modern*, trans. Catherine Porter (Cambridge, MA: Harvard University Press, 1993), 24.
[39]Leegwater, "Technology and Science," 94. Leegwater implies that technology is a practice (since one can "do" it), while I prefer to use the more commonly understood usage, making technology the object and result of the practice of engineering.
[40]Pinch and Bijker, "The Social Construction of Facts and Artefacts," 404.
[41]Don Ihde, "Technology and Science" in *A Companion to the Philosophy of Technology,* 57.
[42]"US NSF—About the National Science Foundation," http://www.nsf.gov/about/.
[43]Home page of STEM Education Coalition, http://www.stemedcoalition.org/.
[44]Arnold J. Toynbee, "Introduction: The Geneses of Civilizations," *A Study of History*, vol. 1 (first ed., 1934; New York: Oxford University Press, 1962), 2–3.
[45]Ibid., 3, footnote 1.
[46]Derek J. de Solla Price, "Is Technology Historically Independent of Science? A Study in Statistical Historiography," *Technology and Culture* 6, no. 4 (Autumn 1965): 553–68.
[47]Arie Rip, "Science and Technology as Dancing Partners" in *Technological Development and Science in the Industrial Age,* ed. Peter Kroes and Martijn Bakker (Dordrecht: Kluwer Academic, 1992), 231–70.
[48]Latour, *We Have Never Been Modern*, 13.
[49]Rip, "Science and Technology as Dancing Partners," 236–7.
[50]Ihde, "Technology and Science," 57.
[51]Bucciarelli, "Engineering Science," 67.
[52]Ibid., 26.
[53]See Rip, "Science and Technology as Dancing Partners," who models both scientific knowledge and technological objects as search processes so that knowledge and artifact are on one continuous spectrum.
[54]Van Poolen, "Towards a Christian Theory of Technological Things," 371.
[55]Ibid., 376–7.
[56]Ibid., 377, footnote.
[57]Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," 11.
[58]For further analysis of technological bias, see my paper, Steven H. VanderLeest, "The Built-in Bias of Technology," *Proceedings of the 2004 American Society for Engineering Education (ASEE) Conference* (Salt Lake City, UT: June 2004), 1417–27; also refer to chapter 3, "Is Technology Neutral?" of *Responsible Technology*.
[59]Steven H. VanderLeest, "Virtuous Design," *Proceedings of the 2006 Christian Engineering Education Conference* (Bourbonnais, IL: June 2006).
[60]Thomas P. Hughes, "The Evolution of Large Technological Systems" in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology,* ed. Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge, MA: MIT Press, 1987), 54.
[61]James Boswell and Christopher Hibbert, eds., *The Life of Samuel Johnson* (New York: Penguin Classics, 1986), 122.
[62]Carl Mitcham, *Thinking through Technology: The Path between Engineering and Philosophy* (Chicago, IL: University of Chicago Press, 1994), 159–60.

Article

Gayle E. Ermer

Technology, Complexity, and Engineering Design: A Rationale for a Connectionist Approach

Gayle E. Ermer

The recent Fukushima Daiichi power plant failure has pushed nuclear system safety to the foreground of public awareness. Nuclear power plants are examples of the complexity of the engineered products that undergird contemporary civilization. The avoidance of technological failure depends heavily on accurately predicting, as part of the engineering design process, how complex technological systems and the individuals and societies with which they interact will behave. This article will recommend a connectionist rather than a reductionist approach to engineering design, in order to better compensate for the complexities and uncertainties inherent in technological activity. This approach is based on a Christian perspective of technology as a cultural, and therefore value-laden, activity.

Contemporary society depends on many large-scale technological systems to enable our everyday lives, including electric power transmission grids, roadway and building infrastructures, chemical processing factories, and air traffic control procedures. These systems often remain beyond our awareness, taken for granted as long as they function reliably. The six nuclear reactors at the Fukushima Daiichi facility on the eastern side of the island of Honshu, Japan, comprised just such a system. At 2:46 p.m. on March 11, 2011, normal operation was proceeding at the site, with reactors 1–3 active and reactors 4–6 on shutdown for routine maintenance.[1]

At that time, an earthquake of unprecedented magnitude (at least according to modern records) reverberated through the sea-bed to the east of the plant. Upon detection of the earthquake, the working reactors were immediately shut down in accordance with design plans. However, the earthquake also generated a tsunami that surged through the area approximately an hour later. The wave's destructive power devastated the region surrounding the plant, resulting in great loss of life, severe structural damage to buildings and infrastructure, and the loss of electrical power. The height of the wave exceeded the design capacity of the plant's flood protections, resulting in inundation of the backup diesel generators used to power the cooling water pumping systems. Even in shut-down mode, nuclear reactors generate considerable amounts of latent heat that needs to be dissipated. Without circulating fluid, reactors 1, 2, and 3 began overheating. As water

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evaporated from the reactor cores, exposed fuel rods partially melted down and generated hydrogen gas explosions within the containment buildings. Despite strenuous efforts to contain the situation, significant amounts of radioactive material were released into the environment.

After years of relative complacency about the safety of nuclear power, this incident has generated a serious reconsideration of the benefits and consequences of future reliance on this technology. Responses so far have been mixed. The following May, the environmental minister of Germany announced that his country would discontinue all nuclear power generation by 2022, challenging industry to replace it with renewable alternatives.[2] The United States and Japan both vowed to take a close look at safety improvement, without committing to future decreases or increases in nuclear electricity production rates.[3] Nigeria and India, on the other hand, announced their intention of increasing nuclear generating capacity, despite the risks highlighted at Fukushima.[4]

What principles should guide engineers and scientists as they seek to design new reactors and promote safe nuclear policies? Developers of technology need to understand why technological disasters such as Fukushima Daiichi happen, not only to prevent future disasters, but also to improve the effectiveness of all technology in promoting the flourishing of God's human and nonhuman creation. For a Christian, a vocation as an engineer or scientist includes creatively participating in the furthering of Christ's kingdom and serving creation through technological development. Our motivation in creating and implementing technological solutions is not simply to generate profit or to play with powerful toys. Rather, we are committed to glorifying God by using our skills and knowledge to provide for the needs of our fellow humans, reducing their suffering and enriching their lives. We also are committed to protecting the nonhuman aspects of creation, both because we recognize the extent to which human flourishing is dependent on the ecosystems surrounding us, and because we accept our role as stewards of the beauty and diversity of everything God has created.

The avoidance of technological failure depends heavily on accurately predicting how technology, and the individuals and societies with which it interacts, will behave in the future. This article will recommend a connectionist rather than a reductionist approach to engineering design that is based on Christian principles that guide us toward specific ways of understanding the role of technology in contemporary society. This approach explicitly takes into account the different levels of complexity present in engineered systems. The following section develops some definitions and concepts related to the nature of technology as viewed from a Christian perspective. The next section describes and illustrates several of the complexities inherent in technological systems. The last section suggests improvements to engineering design, and recommends a connectionist approach.

Technology as Cultural Activity

The complexities of technological design can be better understood from an appropriately broad definition of technology. Technology is often assumed to refer to a collection of hardware or tools, objects that are entirely subject to our will in using them to achieve our ends. In this conception, engineering is a rather "thin" activity, involving only scientific laws and deterministic behavior. In contrast, a Christian perspective can inform a more robust framework for understanding and guiding technological work. This framework arises from a holistic and contextual understanding of technology and supports the need for a connectionist approach to engineering design.

Creativity and Cultural Mandate

Central to Christianity, Judaism, and Islam is the recognition of an all-powerful Creator God who initiated and sustains everything that is in existence. This includes ourselves and the materials that we manipulate as engineers and scientists. Scripture reveals that God has created human beings in his image as responsible developers and caretakers of his creation. We are capable of doing technology because God has gifted us with that ability. Thus, our creativity in engineering design reflects the creativity of our Maker, although our efforts are limited by our finiteness and tainted by our sinfulness. We have been gifted with the ability to abstract concepts and analyze conditions, using logic and creativity. Throughout history, engineers and scientists have made great strides in developing an understanding of various aspects of the creation in order to better predict the effects of our engineered systems. Technology is also one of the ways we as Christians respond to the cultural mandate of Gen. 1:28, "Be fruitful and increase in number; fill the earth and subdue it." As Steven Bouma-Prediger interprets Gen. 2:15, we are "to serve and protect the garden that is creation—literally to be a slave to the earth for its own good, as well as for our benefit."[5] God intends that we should cultivate the earth, develop it responsibly, and creatively participate in the unfolding of his creation. Doing technology is central to what God calls us to be and to do as humans.

Nonneutrality

Within this context, it becomes clear that technology is not value free. The authors of *Responsible Technology* recognized this distinction in the following definition:

> We can define technology as a distinct human cultural activity in which human beings exercise freedom and responsibility in response to God by forming and transforming the natural creation, with the aid of tools and procedures, for practical ends or purposes.[6]

Jack Swearengen, in his more recent book, *Beyond Paradise*, concludes,

> Engineering design projects cannot be value-neutral because they are developed with integral values, principles, and goals in mind. In other words, the worldview of the designer influences the design.[7]

Carl Mitcham also emphasizes the broad scope of technological activity and its relationship to society in his book *Thinking through Technology.* He points out that engineers themselves often define technology too narrowly. In defining engineering, he writes,

> Engineering as a profession is identified with the systematic knowledge of how to design useful artifacts or processes, a discipline that (as the standard engineering educational curriculum illustrates) includes some pure science and mathematics, the "applied" or "engineering sciences" (e.g., strength of materials, thermodynamics, electronics), and is directed toward some societal need or desire. But while engineering involves a relationship to these other elements, artifact design is what constitutes the essence of engineering, because it is design that establishes and orders the unique engineering framework that integrates other elements. The term "technology" with its cognates is largely reserved by engineers for more direct involvement with material construction and the manipulation of artifacts.[8]

Mitcham goes on to set up a framework for analyzing technological pursuits that distinguishes four aspects: (1) technology as object, (2) technology as knowledge, (3) technology as activity, and (4) technology as volition.[9] A holistic view of technology as a cultural activity should take into account the whole process of conceiving, designing, building, producing, implementing, maintaining, disposing of, refining, and regulating technological objects and processes, in which many values interact as decisions are made.

Through this cultural activity, values become embedded in the technological artifacts themselves, causing them to be "biased" toward certain uses and behaviors.[10] Charles Adams emphasizes that

> … the designers, manufacturers, and marketers of technological artifacts are responsible not only for the physical or biotic properties of such artifacts, but also for the values that, inherent in the design process, are transmitted by those products. Thus, computer programmers designing recreational software for the mass market must consider the psychological, pedagogical, and sociological implications of their products.[11]

An interpretation of technology as a value-laden cultural activity highlights the challenges that engineers face in designing systems that are effective and safe, and suggests the complexities generated, not just by artifacts, but also by interactions between people and materials at each step in design implementation.

The Complexities of Contemporary Technology

One of the challenges in predicting and controlling technological system behavior is the increasing complexity of contemporary systems. Clearly, many physical systems being designed are becoming more complicated, containing ever larger numbers of components and subsystems. The sheer number of products produced is increasing as well. Perhaps more importantly, interactions are multiplying within systems, as well as between technological artifacts and the humans and societies who create and use them, and between the technological artifacts and the living world in which they are embedded. All of these factors increase the risk of engineering disaster, whether large or small; Charles Perrow has documented that disaster most often happens when multiple failures interact in ways that are not anticipated.[12]

The term complexity encompasses a variety of concepts and interpretations. Popular usage of the term rarely goes beyond the idea of complicatedness, the sense that technological systems have many interacting parts whose function is difficult for users to comprehend. While complicatedness is an aspect of technology that needs to be addressed in design, clarifying the other senses in which technology demonstrates complexity can help encourage a more complete approach to design and a better anticipation of possible risks. These complexities can be characterized in three ways: (1) Complexities of human finitude relate to the inability of humans to adequately predict how technological objects will behave in real life situations, and how to cope with that limitation; (2) Complexities of societal fallenness focus on the systemic effects of sin on the cultural and social landscape within which engineered designs are implemented; and (3) Complexities of personal sinfulness encompass the unethical choices and sinful dispositions of people as they interact with technology.[13] An appreciation of each of these types of contributions to technological system failure will result in more perceptive preparation for risk avoidance. This article will also consider the relationship between complexity and system boundaries, and the identification of truly complex systems.

Complexities of Human Finitude

The recognition of human finitude is often overlooked by Christians as a primary contributor to the risk of failure in today's technological systems. (These Christians often identify sinfulness or natural evil as possible explanations.) The creation accounts in Scripture clearly indicate that humans were created as finite beings. Simple reflection on the history of engineering reveals that our power over the resources God has entrusted to us for our creative activity has never been complete. Scripture and our own observations reveal the inexhaustible complexity of God's creation, within which we are challenged by the finiteness of our models as we attempt to describe creation and discover its usefulness.

Complicatedness. As was mentioned previously, one aspect of complexity that contemporary technological systems demonstrate is complicatedness. Engineered products contain many individual components and connections that need to be analyzed correctly in order to predict system behavior. Engineers rely primarily on reductionism and deterministic models to divide highly complicated systems into smaller pieces that can be more easily understood, simulated, and controlled. The assumptions required to reduce complicated behaviors to simple ones imply that our mathematical models do not completely capture the way things actually behave.

To allow engineers to better predict the behavior of systems that are too complex to be handled with explicit equation solutions, numerical modeling techniques have been developed. Numerical solutions allow engineers to simulate the behavior of systems that are too complicated to be modeled with straightforward explicitly derived equations. A complicated geometry can be subdivided into many elements of simpler geometry whose behavior and interactions are better understood and predicted. A digital computer can then be used to solve simultaneously the many equations used to represent the system connections and externally applied constraints. The danger of these models is that they tend to promote a black box approach to behavior prediction. It is difficult to determine whether predicted results obtained in this way are reasonable, unless a parallel modeling method is available or a significant level of experience with the systems being modeled has been obtained. The more complicated the system, the more difficult it becomes to identify a possible error in the model or to recognize when the system is operating outside the model's assumed range of behavior.

Uncertainty. The recognition that some system variables exhibit unpredictable or random variation in values suggests the need for incorporation of statistical modeling into the engineering design process. Stochastic models can aid in predicting system behavior in situations in which a specific state may not be known, but the anticipated range of states can be estimated. Of course, decision making based on different sets of responses, which might occur with different levels of probability, adds another level of complexity to the design process.

The mischaracterization, based on historical data, of the probability and magnitude of possible earthquake events was one of the contributing factors to the Fukushima disaster.

Trade-offs. All engineering design is based on compromises between multiple and often incommensurable requirements. Safety considerations must be balanced with other goals. Prioritization of these requirements is a complex and challenging task. Ranking various design alternatives relative to the different requirements amounts to comparing apples and oranges. For example, in considering safety levels in a nuclear plant versus the cost of redundant backup systems, all of the stakeholders need to come to a consensus about what is just. Unfortunately, the processes currently used to adjudicate these issues are often hidden from the general public and therefore lack accountability. Engineers may be tempted to focus on purely technical specifications in order to avoid the controversies and politics that surround the "nontechnical" constraints.

Interactions. According to Perrow, the defining features of technology in the developed world today are its complexity and tight coupling.[14] These features make the anticipation of interactions difficult and often limit our options for responding to failures once certain conditions have occurred. For Perrow, these factors make it almost inevitable that disasters, which he identifies as "normal accidents," will occur in some technological systems, including nuclear power electricity generation. This can be interpreted as another manifestation of human finitude. Some technologies may have outstripped our own abilities as designers to understand and control them.

Complexities of Societal Fallenness

Implementing engineering designs is also risky because humans live in societies whose institutions have been impacted by the Fall. Cultural development has been corrupted in many ways because of our spiritual estrangement from our Creator. This has resulted in what Plantinga describes as "… spoiling of shalom, any deviation from the way God wants things to be."[15] The corruption of culture and social institutions contributes to engineering failures; these systemic problems contribute another level of complexity to the problem of predicting how well technology systems will work. For example, in a capitalistic economic system, the tendency to increase profits by cutting corners to reduce costs is a constant presence. In a socialistic economy, the lack of direct rewards for additional work can contribute to negligence. Whether in a democratic or a totalitarian political system, there is a strong incentive for those in control to place the risks of technology disproportionately on those who have little representation.

It is difficult to predict how cultural factors will influence design decisions, and conversely, how new technologies will influence societal practices. L. J. Van Poolen rightly describes engineering as "prophetic activity," recognizing the complexity of the technology/society interaction and the difficulty in predicting the future.[16] The potential for not recognizing the importance of societal influences is increased by the fact that we live within a current cultural context that has been described as given over to "technicism"[17] or"technopoly."[18] These terms express the realization that contemporary North American culture overly relies on technical solutions to problems, and has too much faith in science and engineering. The tendency to idolize technology increases the risks of technology. Without a respect for the limits of technology, technological development can take place at a pace that leaves no time for careful risk assessment.

Complexities of Personal Sinfulness

The risks in technology are also magnified because of personal choices. Occasionally, people design, manufacture, or use technology to deliberately hurt other people. Often, they negligently make choices in their own interests rather than those of others. Users of technology sometimes apply technological artifacts in ways the designers never intended. The ability of human beings to make their own choices complicates our predictions about how they will interact with technological artifacts, and opens up possibilities for unanticipated modes of failure. This should not surprise Christians who recognize the relative "free will" of humans. Humans are not machines that can be programmed to behave only in desired ways. Instead, we need to recognize and compensate for the reality that all persons have been endowed by our Creator with the ability to make choices for which they need to be held accountable.

Complexity and System Boundaries

The nature of the models necessary to analyze a given design is dependent on the specification of system boundaries. Consider a nuclear power plant, which consists of many interacting subsystems. An engineer working on the design of the diesel backup generator might draw a system boundary that isolates the generator from the rest of the plant. This engineer would use mathematical models of the combustion reaction and associated generator behavior as the focus for optimizing the design. If the goal of the engineer is to design or choose an efficient, low-cost generator, then a reductionist mathematical model that describes the relationship between fuel input and voltage output is very helpful. The model will predict the behavior of the generator, thus optimizing the functioning of this system subcomponent toward better satisfying design constraints. However, if the ultimate goal of the designer is consistent reliable operation of the overall nuclear plant under all conditions, then the system boundaries would need to be expanded to account for the complexities of other possible interactions.

As the Fukushima incident made clear, the interaction between the generator and cooling water pumping (or the lack thereof) is critical to the safe functioning of the reactor. Would widening the system boundaries to include the water pumping system and reactor flow requirements, and perhaps to include the possible interactions between the generator and water influx from flooding, have influenced the engineer to design a different generator configuration which would have avoided the overheating that affected the Fukushima reactors? Without making a serious attempt to anticipate these interactions and to integrate additional requirements into the subcomponent design process, predictions or tradeoffs in the design of that subcomponent may compromise the integrity of the system as a whole.

Complex Systems and Emergent Behavior

Many complicated technical systems can be successfully modeled with reductive strategies. The macroscale behavior is essentially equal to the sum of the behavior of the parts, even if the scope and scale of the system present challenges in finding solutions and interpreting results. On the other hand, the interdisciplinary field of complexity theory has recently been bringing to light systems that are impossible to model reductively. These types of systems, particularly biological systems, are described as "complex" in a narrower sense of the term. More than in individual component behavior, the dynamic configuration of connections determines the response of the system to changing environmental conditions. This phenomenon has been described as "irreducible complexity."[19] Even seemingly simple systems, such as metal alloys and convection cells in boiling liquids, can be described as exhibiting this sort of behavior.

Most authors working in this field admit that it is difficult to form an explicit definition of such a complex system. Instead, general characteristics of complex systems are identified in order to distinguish them from merely complicated systems. Melanie Mitchell notes that these characteristics imply system behaviors that are collective, i.e., they arise from the combined actions of many relatively simple interacting elements without central control. Her definition of a complex system is

> a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behavior, sophisticated information processing, and adaptation via learning or evolution.[20]

These behaviors are often described as self-organizing. The term "emergent behavior" is also used. Examples of this kind of behavior include ant colonies, the human brain, and the national economy. While traditional engineering approaches might capture some of these characteristics (e.g., feedback loops), many characteristics (e.g., operating under nonequilibrium conditions) are contradictory to the assumptions typically made in engineering approaches.

Complexity theory has been, until now, a somewhat esoteric scientific enterprise that has remained peripheral to engineering work. These concepts are just beginning to filter into other domains where the prediction of system behavior is important. For example, Swilling and Annecke have recently appropriated a complexity approach for determining ways to respond to the need for global sustainability.[21] The approach has also been used for analyzing homeland security systems.[22] The power of complexity theory lies in its nonreductive approach to evaluating and solving problems. The focus is often situation specific, based on narrative and analogy, rather than exclusively on global, abstract principles. In this sense, complexity theory applies a postmodern sensibility, rather than the modernist viewpoint that underlies reductive modeling of traditional engineering analysis. As an example, Paul Cilliers cites the postmodern philosopher Jean-François Lyotard by describing knowledge "as the outcome of a multiplicity of local narratives."[23] As opposed to thinking about knowledge as a repository of isolated, objectively determined principles, he suggests that knowledge is determined by trying "to find meaningful relationships among the different discourses."[24] In other words, knowledge must include the connections between things and people. The next section will suggest that an emphasis on connections, rather than on system boundaries, is an appropriate response to the various types of complexity that have been described in this section.

Connectionism in Engineering Design

The introduction to this article posed a question related to the design of large-scale technological systems: What principles should guide engineers and scientists as they seek to design new reactors and promote safe nuclear policies? This section will focus on several approaches that I will refer to as "connectionist" approaches,[25] which, based on the understanding of technology and complexity that has been developed so far, should help to improve the safety and functionality of engineering designs. Before addressing these topics, two inappropriate approaches to risk analysis will be pointed out.

Some Christians (and others) who identify themselves as strongly "pro-life," that is, committed to the sanctity of human life as a precious gift of God, might reject nuclear technology altogether because of its potential for harm. While this might seem like a consistent position, those who think this way need to be reminded that no technology is risk free. We all currently (and without much concern except when it impacts us personally) participate in an automobile transportation system which predictably results in almost 40,000 deaths per year in the United States. We do not insist on perfectly safe cars because reducing the risk involves other costs, which introduce issues of distributive justice (e.g., poor people could not afford to buy such a vehicle) and stewardship (i.e., a safe car is typically heavier, and therefore less fuel-efficient). This illustrates that our perception of risk is easily skewed.[26] For example, people seem to be much more willing to participate in risky systems if they believe that events are under their own control. This may explain why people tolerate the possible harms of driving, while overestimating the possible dangers of nuclear power.

Christian engineers working in nuclear technology need to recognize that it is not feasible to implement safety systems that mitigate all conceivable risks, since there are costs associated with those systems. For example, building a 100-foot-tall wall around a nuclear reactor might mitigate possible damage from a tsunami, but doing so would significantly increase costs and introduce new safety issues, e.g., the possibility of structural collapse. A concern for the sanctity of human life should not result merely in a call for the rejection of certain technologies that are perceived as too dangerous, but, rather, a call to invest more resources in careful analysis so that risk can be reduced in all areas of our lives.

The opposite extreme would consist of accepting an entirely economic view of human life (and often of the environment, as well). Although levels of victim compensation might sometimes drive the evaluation of risk within particular industries, safety and risk of death cannot be evaluated by purely economic factors. The loss of a precious human life or the contamination of an ecosystem cannot be reduced to a dollar cost. When all of creation is viewed from a technical, utilitarian perspective, the value of human life is diminished, and inappropriate risks are encouraged.

The engineering design process needs to be approached from a different perspective in order to open up the imaginations of stakeholders to the required complexity of system models and to appropriate ways of balancing design requirements. The reductive engineering design approach is conceptualized in figure 1. This is the approach inculcated in engineers in their training and practiced in their professional work. In order to predict system behavior (and therefore to make choices about appropriate design for a given system), the system is subdivided into chunks that can be understood and mathematically modeled. The overall system boundaries are relatively fixed and impermeable, in the sense that few interactions from outside the system are allowed to impact the model of what goes on within the system. Each subsystem or component (A) has system boundaries which de-emphasize context. Thus "soft" effects are isolated so that they do not "corrupt" the objective technical perfection of the analysis and design. The required functions and attributes, that engineers commonly refer to as design criteria (1, 2, 3), are established based on conditions from within the system boundaries. These are the only constraints that are considered as potential trade-offs in optimizing the subsystem.

In the case of nuclear plant design, system A could be composed of the backup power generation system for the cooling pumps. The cooling pump system (C) would determine the power needed from the generation system (specification 1), the physical configuration of surrounding subsystems would determine the area footprint available for the system (specification 2), and other design criteria such as cost, reliability, and fuel efficiency requirements might be dictated by other subsystems. The danger in isolating subsystem A from the whole is that it is possible to model and optimize subsystem A while missing complex interactions that might compromise the performance of the system as a whole. If the engineers who designed the backup generator system had been more involved in discussions of flood potential or the local possibilities of power or personnel disruptions following a natural disaster, they might have made different decisions for locating or protecting the backup generator system.

The connectionist approach is illustrated in figure 2. Rather than starting with a top-down approach that establishes hard system boundaries, the process starts by looking outward from the specific subsystem to be designed; it expands system boundaries to absorb additional design constraints and modeling techniques both from other subsystems and also from the environment in which the system will operate. The new design criteria are derived by anticipating possible interactions caused by the complexity of the subsystem itself, as well as by interactions with the rest of the system.

The engineering design method of figure 2 is predicated on the cultural activity model of technology development. A nuclear plant is not just a collection of hardware (a reactor, a pumping system, a power generation system, etc.), but it has a history of events by which it has been actualized and is embedded in a context of geographical, economic, legal, and political constraints. We need to recognize this complexity, moving beyond the black-and-white, thumbs-up and thumbs-down choices that our society gravitates toward. We need action pursued via dialog within particular contexts, recognizing that humans, nonhumans, and their connections are constantly evolving.[27] Evolving, in this context, implies that new technologies are derived from combinations of previous technological components along with the appropriation of understandings of new phenomena.[28]

One particular modeling technique that is already available to the engineering community but not commonly taught, and can be used as a tool to stimulate

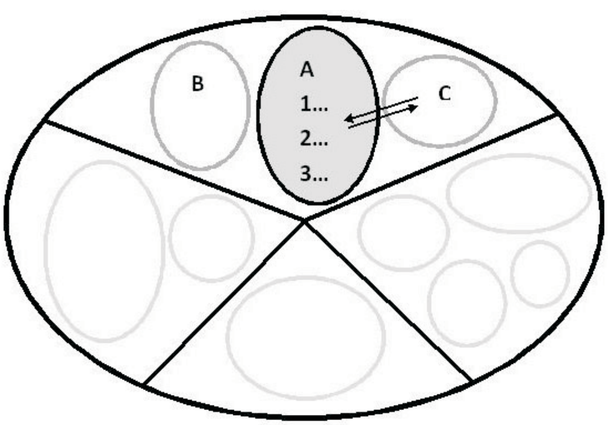

Figure 1. Reductionist Design Process

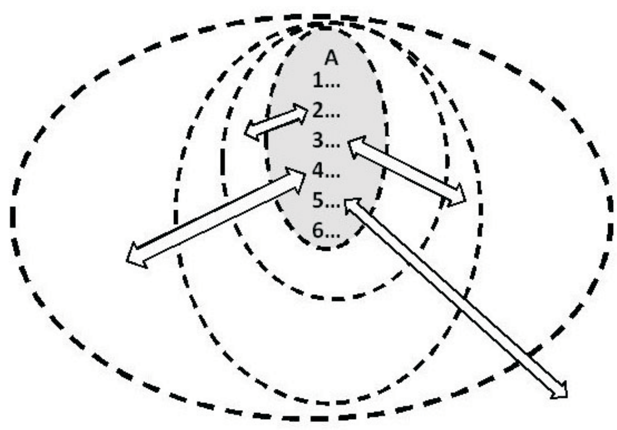

Figure 2. Connectionist Design Process

creativity in anticipating interactions, is Failure Mode and Effects Analysis (FMEA).[29] FMEA works by specifying a structured imaginative approach to predicting possible ways a design could fail, as well as calculating the probability and consequences of each failure. FMEA is currently required for safety-critical electronic systems (e.g., aircraft controls), but is not often taught or used systematically in other disciplines of engineering. Its primary advantage occurs in prioritizing responses to identified failure modes, in order to ensure quality of design. An FMEA analysis can be perceived as a series of check boxes and calculations that must be completed before a design can be approved, but, if applied rigorously, it should encourage out-of-the-box thinking related to how a particular design could be influenced by environmental effects or other interactions in a way that could degrade the performance of the system. Divergent thinking is necessary in order to anticipate modes of failure that have not been experienced in the past. We need to ask all the right questions during the design process. This creativity should be directed toward developing innately safe designs. Rather than focusing on the introduction of additional redundant safety systems, processes could be redesigned in ways that eliminate risk potential. For example, using a passive cooling system in a nuclear plant could eliminate the need for backup generators entirely.

Conclusions

In conclusion, recognition of different levels of complexity in technical systems pushes engineers beyond the use of reductive physical models in design analysis. Better safety may be gained, not by narrowing the focus onto every small system component, but by reaching out to connect a particular component to others, both within the system and with the environment surrounding the system. In the case of nuclear power, this means that engineers working on backup generator design and placement should consider not only the cost and efficiency of their particular subsystem, but they should also intentionally search for and investigate the interactions between the generators and the environment in which they are situated.

Modeling techniques from complexity theory, including chaos theory and neural networks, may provide useful tools for real progress in scientific analysis and engineering design. Perhaps the greatest gain from this approach will come, not from particular sets of equations, but from an ethos that serves as a corrective for modernist tendencies. Engineers and business leaders are bred within a modernist paradigm. Perhaps it is time to produce a new breed of postmodern engineers, by adopting a connectionist approach, driven by complexity theory. ✦

Notes

1Details of the event are taken from Ian Hutchinson, ed., *Christian Engineers and Scientists in Technology Newsletter* 18 (Spring 2011) and 19 (Summer 2011), and from the *New York Times* summary website, http://topics.nytimes.com/top/news/international/countriesandterritories/japan/index.html.

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3Malcolm Foster, Associated Press, "Contender for Japan's Top Post Vows to Phase Out Nuclear Power," *Virginian-Pilot*, August 28, 2011: A9.

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[14]Perrow, 97.
[15]C. Plantinga Jr., *Engaging God's World: A Christian Vision of Faith, Learning, and Living* (Grand Rapids, MI: Eerdmans, 2002), 51.
[16]L. J. Van Poolen, "A Philosophical Perspective on Technological Design," *The International Journal of Applied Engineering Education* 5, no. 3 (1989): 319–29.
[17]E. Schuurman, *Faith and Hope in Technology* (Toronto, ON: Clements, 2003), 66.
[18]See Neil Postman, *Technopoly: The Surrender of Culture to Technology* (New York: Vintage Books, 1992).
[19]Michael Behe defines and explores the concept of irreducible complexity in the context of evolutionary theory and intelligent design. See *Darwin's Black Box: The Biochemical Challenge to Evolution* (New York: Free Press, 1996). This paper is not as concerned with the origins of complexity in natural systems as it is with responding to the impact of irreducible complexity on designed systems and predictions of their behavior.
[20]Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2009).
[21]Mark Swilling and E. Annecke, *Just Transitions: Exploring Sustainability in a Unfair World* (Cape Town, South Africa: University of Cape Town Press, 2010).
[22]Alfred A. Marcus and Zachary Sheaffer, "Analogical Reasoning and Complexity," *Journal of Homeland Security and Emergency Management* 6, no. 1 (2009): article 82.
[23]Paul Cilliers, *Complexity and Postmodernism: Understanding Complex Systems* (New York: Routledge, 1998), 114.
[24]Ibid., 118.
[25]Ibid., 3–5. The language of connectionism is used by Cilliers, although he promotes this as a technique within the context of modeling of complex systems. My use of the term is more broadly focused on identifying and including interactions in engineering design.
[26]"How Americans Are Living Dangerously," *TIME*, Nov. 26, 2006, http://www.time.com/time/magazine/article/0,9171,1562978,00.html. This article presents a journalistic take on risk perception and how Americans respond to different risks (some of them technologically generated).
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[28]W. Brian Arthur, *The Nature of Technology: What It Is and How It Evolves* (New York: Free Press, 2009), 187. The author refers to the process of technology development as "combinatorial evolution."
[29]As an introduction to this topic, see the American Society of Quality Engineering website, http://asq.org/learn-about-quality/process-analysis-tools/overview/fmea.html.

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We wish to thank the following people for their helpful work in reviewing manuscripts.

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Charles F. Austerberry
David Bartholomew
Robert C. Bishop
Thomas Boogaart
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Walter L. Bradley
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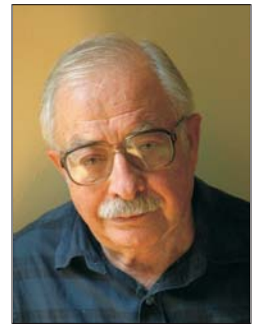

Kenell Touryan

Renewable Energy for a Sustainable Future: A Christian Imperative

Kenell Touryan

As a scientific affiliation that explores any and every area relating to Christian faith and science, ASA members should proactively face the challenges of determining sound energy policies, practicing energy conservation, and developing renewable energy sources. The mandate God has given us, to be good stewards, should be an imperative for seeking after every avenue leading to a sustainable future for humankind. Five significant converging trends have enhanced the penetration of renewable energy and energy efficiency in the world market. This, in itself, should give us an impetus to utilize energy resources such as solar power, water, wind, and biomass in residential, commercial, and industrial sectors.

The word "anthropocene" is a term coined by ecologist Eugene Stoermer and popularized by the Nobel Laureate atmospheric chemist Paul Crutzen.[1] It is an informal geologic chronological designation that serves to cover human activities that have had an impact on the global ecosystem. A more recent designation by Mark Lynas identifies humankind as "the God species."[2] In a previous article in *Perspectives on Science and Christian Faith*,[3] the author reminded the reader that the dazzling light shed by science has led to technological achievements unequaled in human history. The successes, which bear on nearly every aspect of human endeavor, have eclipsed contributions from the humanities.

In the optimism of the Enlightenment, technology assumed an exalted position in Western societies. In fact, science and technology have become the twin gods of the past century and no doubt will continue to remain entrenched in their lofty positions throughout the twenty-first century.

Technological optimists do not fret about the "two-edged sword" of technology, namely, the environmental, social, aesthetic, and spiritual impact on modern civilization. Most technological optimists—and apparently all economic determinists—believe that the boundless potential of human intellect will overcome problems of physical limits, thus making the earth's physical resources essentially inexhaustible. Edward Teller wrote, "Technology has opened the possibility of freedom for everyone."[4]

Nonetheless, archaeological evidence tells us that whole populations have

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disappeared due to the exhaustion of accessible resources. The long-running debate in journals and in the media between economist Julian Simon of Harvard University and bioscientist Paul Ehrlich of Stanford University included wagers over evidences supporting their convictions.[5] Simon cited historical evidence to argue that human ingenuity will remove all limits to growth, whereas Ehrlich insisted that we are on a course of resource exhaustion and ecological catastrophe. Their wager was settled in Simon's favor during his lifetime. But today the scale of human activity is so large that the impact on the earth's systems is becoming global, and recovery times could be measured in centuries, requiring a careful life-cycle assessment of all activities. Critical among these activities are the increasing global demand of energy and the earth's dwindling fossil fuel supplies. The curves shown in figure 1 represent the estimated availability of all known fossil fuel sources worldwide over two centuries, plotted against the rising world demand of energy. Although the data shown in figure 1 were prepared in 1985, *there have been no dramatic changes in these predictions over the past twenty-five years*.

Five Converging Factors

Over the past decade, five converging trends have emerged that are beginning to shape the energy future of this country and of the world.[6] These five trends are as follows:

1. *World Energy Demand Growth.* The world energy demand rate shows a steady, average upward trend of 2%, with China and India leading the developing countries. If we continue exploiting our nonrenewable resources, such as fossil fuels, this will inevitably lead to a global crisis in midcentury (barring the economically and technologically successful extraction of oil/gas from vast oil shale deposits). The United States constitutes only 5.5% of the world's population but consumes 26.5% of the world's energy. What will happen if China and India, which together constitute 35% of the world's population, attain the same level of prosperity by midcentury?

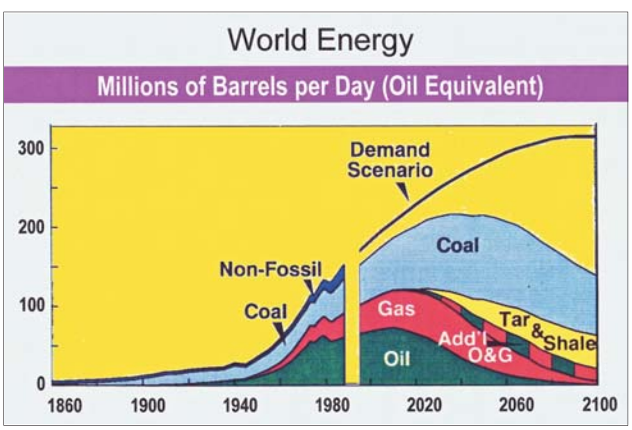

Figure 1. World Energy Sources since the Industrial Revolution
From John F. Bookout (President of Shell USA), "Two Centuries of Fossil Fuel Energy," International Geological Congress, Washington, DC, July 10, 1985, published in *Episodes* 12 (1989): 257–62.

2. *Global Environmental Awareness.* Accidents such as the Chernobyl nuclear power plant disaster of 1986, the more recent catastrophe in Japan, the 2009 oil spill in the Gulf, and a factor-of-three increase in greenhouse gases in our atmosphere since the start of the Industrial Revolution have created something akin to an ecoshock. As responsible stewards of planet Earth, it is high time for everyone, and most of all the ASA members, to start looking at renewable technologies to provide a significant portion of our energy budget to fulfill our future energy needs.

3. *Energy Security.* Security risks associated with the unequal distribution of fossil fuel resources throughout the world pose major destabilization threats. Renewable energy resources on the other hand (solar, wind, biomass, mini-hydro, organic waste utilization, and geothermal) are quite equitably distributed, with one or more of these resources available to *every country* in the world. In addition, the *distributed* nature of renewable technologies provides an inherent security against terrorist attacks. Large power stations operated by fossil fuels or nuclear power plants are vulnerable to sophisticated terrorist attacks.

4. *New Energy Technology Options.* The new emphasis placed on alternate energy resources and serious efforts at energy conservation in developed countries, and even in developing countries, has led to the creation of new technologies such as more efficient gas turbines, better insulation of buildings, energy-efficient appliances, and a number of renewable technologies (such as solar hot water, run-of-the-river small hydropower plants, wind farms). All these are becoming economically viable and have begun to make a noticeable impact on the world's energy budget.

5. *Increasing Business Interest.* Power production in the electricity sector, fuel production in the transportation sector, and thermal energy applications together have become a trillion-dollar business throughout the world. All this has led to a competitive market and opened up potentially lucrative business opportunities in the world's energy sector, including the development of renewable technologies.

To repeat, the convergence of these five trends mentioned above has given renewable energy technologies a significant boost as an economically feasible alternative to fossil fuels and nuclear power. These technologies can provide greater independence to countries devoid of fossil fuel resources; they will stand for a cleaner alternative; and finally, they will provide greater energy security against sophisticated terrorist attacks. For these reasons, the European Council in March 2006 called for European Union (EU) leadership on renewable energies and asked a commission (established by the EU) to produce an analysis of how best to expand renewable energies over the long term, for example, by raising their share of gross inland consumption to 15% by 2015.[7] The European Parliament, by an overwhelming majority, called for a 25% target for renewable energies in the EU's overall energy consumption by 2020. To this end, the commission in 2006 prepared the framework for a renewable energy road map for all EU countries to employ as part of their ten-year strategy for achieving these targets.

Similar initiatives have been taken by Australia, Russia, and the USA. For example, in the USA, the Solar America Initiative (SAI) is part of the Federal Advanced Energy Initiative, whose purpose is to accelerate the development of advanced photovoltaic materials—with the goal of making it cost competitive with other forms of renewable electricity by 2015.[8] Other countries, such as Georgia, Turkey, and even Azerbaijan and Iran, have also started to pay serious attention to renewable energy, even though they are major producers of oil and gas.

Both eastern and western European countries have responded to this initiative, and their road maps can be found on the internet. It is beyond the scope of this article to provide a comprehensive review of all these road maps. However, it will be instructive at this point to look at two small countries, Armenia and Switzerland, as they look ahead to the coming decades in an attempt to meet their energy needs with minimum reliance on imported fuels. The reasons for selecting these two countries and not others are as follows:

1. The author was involved in preparing a road map for Armenia, based on the strategic plans for energy production in Switzerland by 2050;
2. Both are small countries with no fossil fuel reserves;
3. Both rely heavily on large hydropower for electricity generation;
4. Switzerland is a developed country, whereas Armenia is borderline between developed and developing country, often characterized as a "misdeveloped" country (under the Soviet System);
5. The political climates of Armenia and Switzerland are very different from each other in dealing with renewable technologies;
6. Switzerland ranks as one of the least corrupt countries, whereas Armenia ranks as one of the worst;
7. Finally, Armenia considers itself a Christian country in the Orthodox tradition dating from AD 301, and Switzerland is serious about their Reformed and Roman Catholic tradition.

Before we go into the details of describing the two road maps, it is important to define what is meant by *alternative and/or renewal energies* and to take a look first at *conservation and energy efficiency* before finally turning our attention to renewable energy resources.

The Terms Used—Alternative Energy versus Renewable Energy

Alternate or alternative energy is a term used to describe all energy sources *other than* energy from fossil fuels. Alternate energy by definition includes nuclear energy and fusion energy in addition to renewable energy sources.

Renewable energy, on the other hand, deals with the sun, wind, and water as the primary sources. Some add geothermal energy and energy from organic wastes to the list (geothermal can be considered renewable when used as a "hot-dry-rock" system in which water is injected into the rock formation through a central well, and steam is obtained from adjoining production wells). Renewable energy sources can lead to technologies via two separate paths (see figures 2–4). The first path (figure 3) is called thermoconversion. When *heat* is absorbed as by materials such as solids, liquids (e.g., water), or gas (e.g., air), then thermoconversion leads to solar thermal power, hydropower, wind, waves, and ocean currents. The second path (figure 4) is called photo-conversion that depends on *light* from the sun (electronic excitations rather than molecular excitations) and leads to photovoltaic power, photo-electro-chemistry, photosynthesis (which is responsible for all plant life), and synthetic chemical compounds that can store solar energy.

Both diagrams exhibit the steps that each conversion path takes from a primary process to a primary product, followed by the specific technology and finally to the useful product. The two morphologies show the wide range of basic and applied sciences involved in the development of renewable energy technologies.[9]

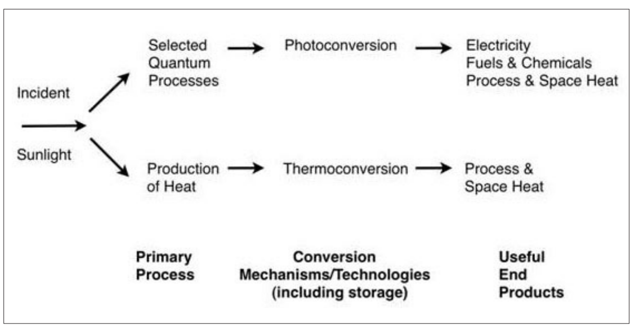

Figure 2. Solar Radiation Processes and Conversion

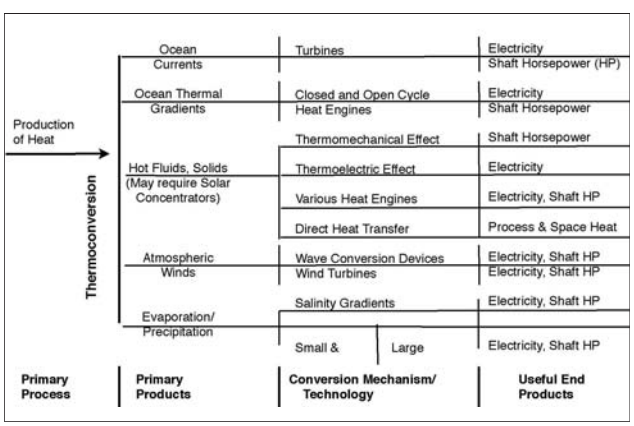

Figure 3. Detailed Morphology for Solar Thermoconversion Paths

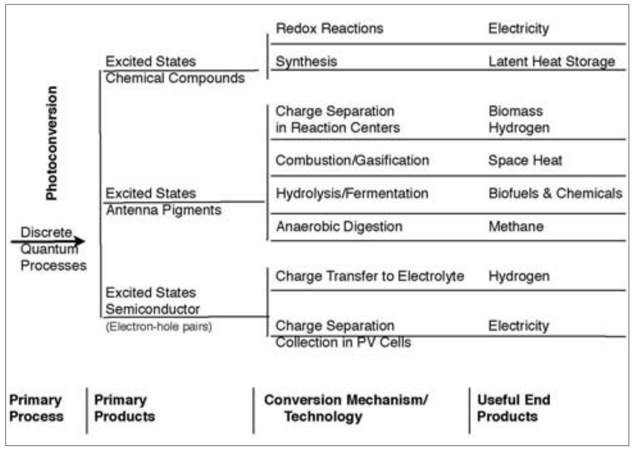

Figure 4. Detailed Morphology for Solar Photoconversion

Conservation and Efficient Use of Energy

The National Renewable Energy laboratory prepared a chart for global energy versus wealth relationship in 2002 (figure 5). What is significant in this figure is the apparent correspondence between GDP and Energy Consumption for each country: the higher the GDP, the higher the energy consumption. It is an accepted fact that all developing countries have *the desire* to reach the level of GDPs of the developing countries. Should that happen, countries such as China, which has already moved up the chart toward Japan, the USA, and Europe, could eventually exhaust most of the world's oil and gas resources, unless they too move toward well-planned conservation and energy-efficiency measures and follow the targets set

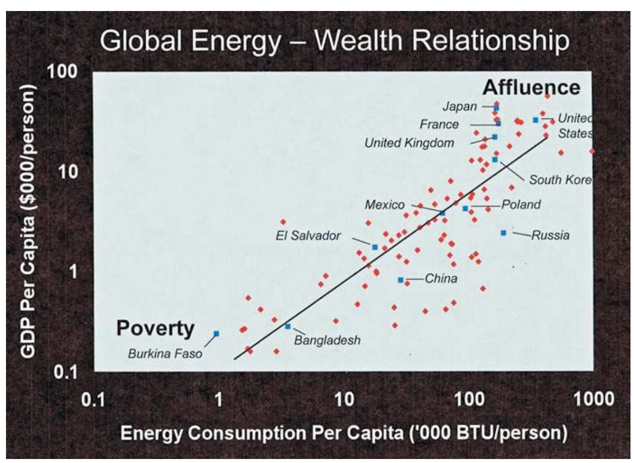

Figure 5. Global Energy and Wealth Relationship, prepared by NREL Staff. Originally published in Kenell J. Touryan, "Renewable Energy: Rapidly Maturing Technology for the 21st Century," *Journal of Propulsion and Power* 15, no. 2 (March–April 1999): 163–74.

by the European Commission. Needless to say, conservation measures and efficient energy use are less expensive to achieve than developing a new renewable energy technology. For example, retrofitting a building to make it energy efficient, whether residential or commercial, will cost about $2 per watt as compared to a cost of $3 to $5 per watt for small hydro stations, providing solar thermal heating or generating electricity from wind. (In 2010 dollars, costs for new energy range from $3 to $5 per watt.) Building-energy efficiency measures include, but are not limited to, proper insulation, electric lighting that uses compact fluorescent halogen bulbs, and efficient electric appliances.

Priority sectors in which energy savings can be obtained include production and distribution of electricity, irrigation and water supply, electric lighting, transportation, and food production. In industry, for example, losses in an electricity value chain (described as the sequence from energy production to energy consumption) using fossil fuels can amount to 80% between primary energy production and final industrial production. These losses can be reduced to 60% or less when using efficient gas turbines and smart grids that include demand-side management.

The Swiss Plan from 2010–2050

Historically, Switzerland's longest-serving and most important source of renewable energy has been hydropower; the same is true for Armenia. But the new renewable resources, including solar thermal, solar photovoltaic (PV), wood, biomass, wind, and geothermal, also play an increasingly important role in today's Swiss energy mix. For economical reasons, wood, biomass, solar thermal hot water, small hydropower, and wind are available now to a modest extent and, in some cases, are also economically attractive. The potential for PV and geothermal is large, but only in the longer term (2030). One of the goals of Switzerland's energy policy for 2030 is to increase the proportion of electricity production from renewable energy by an amount equal to 10% of the country's present-day electricity consumption. Since 2007, approximately 55.6% of the overall electricity production in Switzerland comes from renewable resources, with hydropower providing 53.6% of this amount and the rest coming from other renewable resources, of which the largest portion is biomass (wood and biogas). It should be noted that 39% of the electricity production comes from three aging nuclear power plants which the Swiss have decided to phase out by 2025. Three main forms of renewable resources are considered:

1. Electricity from hydropower, wind power, PV, and biomass;
2. Thermal energy from heat pumps, solar thermal heat, geothermal, and biomass;
3. Transportation from gas and liquid fuels extracted from biomass.

The Swiss calculate that their electricity consumption will increase by about one quarter to one third and that, by the middle of this century, a certain share of electricity production from fossil fuels will remain inevitable. This will be the case even in the event that the road map's recommendation of 10% from PV by midcentury is implemented. This is not the case for thermal requirements, which are anticipated to fall by 40% by 2035 compared with current levels. With the implementation of the road map, it will be possible to cover 40% of heat requirements with wood, biomass, and solar thermal by midcentury.

Besides electricity, the second major problem is the energy policy in the transport sector. Although the Swiss anticipate the energy demand to decrease by a third by 2035 (more efficient cars and public transport), only 16% of transport energy requirements can be met by gas and liquid fuels extracted from biomass—unless, of course, an all-electric vehicle system is instituted in the country by 2035.

However, it is noteworthy that Switzerland is very seriously considering instituting a drastic cut in energy consumption by 2050, down to 2,000 watts per capita, which represents a major cut from the 3,000 watts per capita at the current level of energy consumption. Energy supply that would rely mainly on indigenous sources of renewable energy is only possible given a far lower level of energy consumption than today. Thus, a "2,000-watt society" is being promoted at the level of the Swiss Department of Environment, Transport, Energy, and Communication.[10] To accomplish this reduction in energy consumption, an effective energy policy is required now, and in the years to come, to ensure, in the long term, an adequate, economical, and ecologically friendly supply of energy based on renewable sources.

The Armenian Strategy for the Next Decade (2010–2020 and beyond)

Unlike Switzerland, Armenia to date has not yet been ready to adopt renewable energy technologies (RETs) for its energy budget. It has no fossil fuel resources in the country and relies on nuclear power for 35% of its electricity production and on large hydropower for 30%, not unlike Switzerland. The balance comes from fossil fuel imports. In December 2010, the World Bank selected the Danish Energy Management to work with a team of Armenian engineers and scientists to prepare a ten-year strategy plan for bringing renewable technologies to Armenia. The road map was prepared along the same lines as the requirements set forth by the EU Parliament for their member countries, and as was done in Switzerland. The team completed its plan in June 2011, and presented it to all branches of the government.

The plan showed that the country can group RETs into three categories, as in the Swiss case:

1. Electricity production, from small hydropower (less than 10 MW per run-of-the-river project), wind power, PV, and biomass;
2. Thermal energy using heat pumps, solar thermal heat, geothermal, and biomass;
3. Transportation using gas and liquid fuels extracted from nonfood-related biomass (such as stover, switchgrass, algae); the eventual use of hydrogen fuel cells.

Findings of a comprehensive review of the renewable energy potential in Armenia have ranked small hydropower using run-of-the-river sources, and solar hot water, as the most advanced and economical sources for Armenia in the short- and mid-term (by 2016), followed by grid-connected wind farms and the use of heat pumps by 2020 (see figure 6). The wind farms will be located in several mountain passes with the potential of supplying 20% of the electricity for the country. PV and cellulosic biomass from Jerusalem artichokes planted in arid regions will become economical after 2020. Although the prediction for the growth of RETs is modest in Armenia, their use can increase five-fold by 2020 (not including large hydropower), forestalling the necessity for another nuclear power plant. However, Armenia compares very poorly with Switzerland in energy conservation and in energy efficiency. Japan is ranked the most efficient user of energy among developed countries. The road map prepared above for Armenia makes it clear that Armenia needs to increase its energy conservation and efficiency *before* it invests large sums in RETs.

Sadly, unlike Switzerland, Armenia has no formal plan for reducing energy consumption by 2020. In addition, implementing large scale RETs in Armenia, as with any other country, depends more on political measures than on technical capabilities. Furthermore, unlike Switzerland, which has decided to phase out their existing three nuclear power plants by 2025, the issue is complicated by the fact that the Armenian government is keen on replacing the present, aging nuclear power plant with new 1,000 MW ones, using Russian technology. The location of these plants is on earthquake fault lines which require special design features to secure their safety, thus making the proposed nuclear power plants a more expensive project than using RETs by a factor of three or more.

To be diplomatic in our approach, the author and a team organized by the Danish Energy Management presented two scenarios to the Armenian

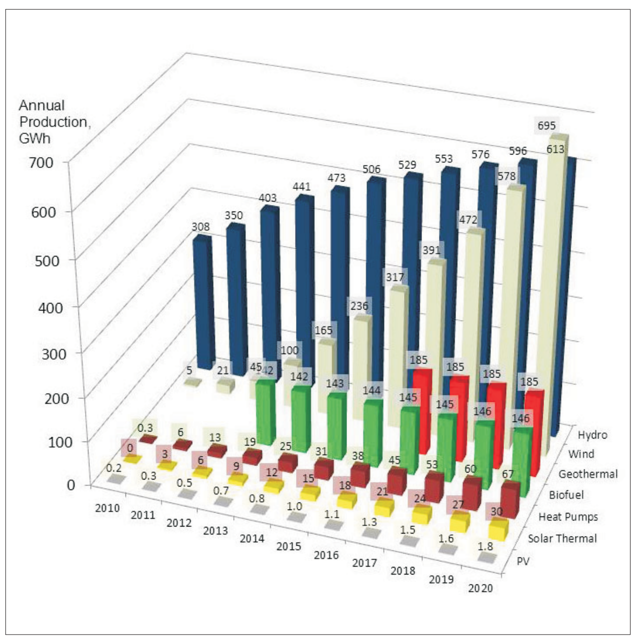

Figure 6. Renewable Energy Production over the Decade 2010–2020.

government. One scenario was with a new nuclear power plant; the other, without one. If a nuclear power plant becomes a reality after 2020, there will be *excess electricity* which then can be used to power electric cars in Armenia and/or generate hydrogen for cars running on hydrogen fuel cells. Armenia has eliminated tramways, but still uses electricity-operated buses. Unlike Switzerland, Armenia has very limited rail transport and is too poor to invest funds in an extensive rail system.[11]

Nuclear Power and RETs

Nuclear power has been an important part of the world's energy budget. Its advantages are several. It is nonpolluting, uses ten-thousand-fold less fuel (uranium or plutonium vs. fossil fuels) and makes an excellent base-load power plant. However, unless built with strict safeguards, the risks could be catastrophic in the event of a serious accident as, for example, the Three Mile Island accident, the Chernobyl event, and the recent Japanese tsunami. In addition, disposal of the rapidly accumulating high- and low-level radioactive wastes is becoming the "Achilles' heel" of the industry, along with the ever-existing fear of nuclear weapons proliferation (namely, the concern that so-called rogue states such as North Korea or Iran may go nuclear).

People are often incredulous when they learn that in spite of the author's thirty-year involvement with RETs, he still supports nuclear power plants, albeit cautiously. After spending fifteen years on nuclear power technology and fusion energy, the author appreciates the importance of such systems as part of an overall energy budget of the world. He does not subscribe to the present panic against nuclear power plants. But as stewards of this unique planet, and especially as Christians, we have been given the responsibility of using its resources wisely and at minimum risk to the environment and to humankind as a whole. After all, the sun, a nuclear-fusion power plant, has been placed at a safe ninety million miles away from Earth, and the planet itself has been provided with two types of filters to minimize destructive rays from the sun: a magnetic field that filters out the deadly solar wind that flows from the sun, and the ozone shield which moderates the flux of the sun's dangerous UV radiation, limiting the UV radiation to beneficial uses.

Scaling Up Renewable Energy Technologies

Having presented a favorable picture for renewable technologies, it is important to note some of the problems inherent in the *large-scale* use of these technologies. In a special section in *Science,* this problem was graphically illustrated (see figure 7).[12] First, it should be noted that the world population consumes 15 TW of electric power (1 TW is one trillion watts). The *potential* for the worldwide use of biomass is 9 TW; for wind, 20 TW; for hydroelectric power, 1.6 TW; for geothermal, 3.8 TW; and for solar, more than 50 TW.

All that is well and good; however, one needs to consider the land, water, and material demands of some of these technologies. The article gave an illustration of how much land is needed for San Jose, CA, to provide *all 740 megawatts* of its power from renewable technologies. To supply that power, coal mines and coal power plants would need 3,800 hectares of land; a wind farm would need 53,000 hectares, which is bigger than the area of San Jose itself. However, unlike coal mines, the land occupied by the wind farms would allow crops to grow and cattle to graze beneath the erected turbines. Solar would require 7,500 hectares; hydroelectric, 1,300 hectares (where abundant rain is available); and biomass, a whopping 270,000 hectares, unless algal biofuels were used for fuel from the lipids in the algae. The energy density of algae, compared with that of cellulosic biomass, is higher by a factor of three or more. These conditions make it clear that renewable energy cannot *by itself* meet *all* the energy consumption required by a given country. Another reason for this

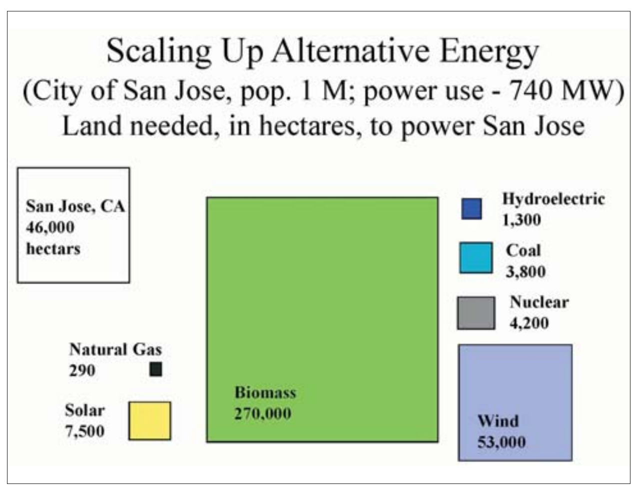

Figure 7. Scaling Up Issues for Renewable Energy

is that energy from the sun and the wind are intermittent, and energy from the use of hydropower can be seasonal. A backup base-load power plant, using fossil fuels or nuclear power, may be required.

Lastly, nuclear energy production would cover an area of 4,200 hectares. In fact, the *material needs* for solar thermal and solar photovoltaics could exceed the material needs for constructing a nuclear power plant that would produce the same amount of electric power. Another interesting number to consider is the use of water. Solar thermal, for example, will need 70% more water than an equivalent coal power plant, but not as much as a nuclear power plant would.

One solution to this large-scale application issue is to plan *distributed systems* in which each community uses its own mixture of RETs tied to the city's main power grid (see appropriate technology section below). Clearly then, one has to consider a *mixture* of energy sources to meet the growing energy needs of the world's population.

Finally, we look at a more economical option: *conservation and the efficient use of energy*. In fact, as mentioned above, before a country contemplates the development of renewable resources, it should first consider conservation measures such as proper insulation or less-energy-consuming appliances for residential, commercial, and industrial applications. A careful analysis shows that it is less costly to install such measures than to provide new renewable energy sources. The former would require expenditures on the order of two cents per watt, whereas the lowest cost for wind or solar energy subsystems would be in the range of five to seven cents per watt.

Renewable Energy and Energy Efficiency within the Scope of Appropriate Technology

In 1955, the British economist E. F. Schumacher came up with criteria for technologies that were small-scaled, decentralized, and not energy intensive. He also emphasized that technologies should be environmentally sustainable, based on renewable resources.[13] In one of the most famous essays in his book entitled *Buddhist Economics*, he blended *spiritual values* with economic progress in order to achieve "right livelihood" that would value people over tools and progress. This he thought would preserve the environment, and foster simplicity and nonviolence. What Schumacher called intermediate technology is now called appropriate technology.[14] The appropriate technology movement grew out of the energy crisis of 1970. It focuses on environmental and sustainability issues, both of which are fully applicable today. Although it is commonly discussed in its relationship to economic development of third-world countries, this movement can be found in both developing and developed countries.

Amory Lovins expands the definition of appropriate technology to "appropriate renewable energy."[15] Unlike the problems mentioned above that will arise when facing large-scale utilization for RETs, appropriate energy technologies are especially suited for isolated (off the grid) or small-scale energy needs. With these, electricity can be provided using PV panels, solar thermal collectors, small wind turbines, mini- or micro-hydro, etc., some of which are already being used in villages in Armenia and Switzerland. One curious experiment was conducted by students from the American University of Armenia. A German company donated simple, low-cost parabolic dish cookers which were taken to various villages in Armenia for demonstration purposes. One of the unexpected problems that arose was the complaint from some villagers that solar-cooked food did not taste as good as food cooked on wood stoves!

To avoid problems inherent in the large-scale use of renewable technologies, *distributed systems* may be more practical for use in large cities. These could loosely be classified as "appropriate renewable energy" networks. In distributed systems, each community in a large city installs its own electric power generation system, using renewable technologies such as PV, and connects its system to the main power grid of the city. All this could materialize once digitized, smart power grid systems are installed, and demand-side management becomes practical.

Finally, the other practical use of RETs is in locations where no power grid is available, and electric power is obtained through diesel generators. The hybrid system consists of a small wind turbine and/or PV modules with a diesel generator as backup. The system automatically shifts from wind or PV to diesel power when the renewable resource is un-available (cloud cover, night-time use). Such hybrid systems may be classified as appropriate technologies and are being installed on small islands and in villages where no power grid exists, for example, the islands of Indonesia and several fishing villages in Mexico and Brazil. Figure 8 is a sketch of a typical hybrid system. Let me sound a word of caution though. In each village where a hybrid system is installed, the villagers should *take ownership* of the system to ensure the operation and maintenance needed to keep the system running. Another important point to consider is that before large numbers of such hybrid systems are installed, there should be trained operation and maintenance staff accessible to these locations in order to ensure their smooth operation.

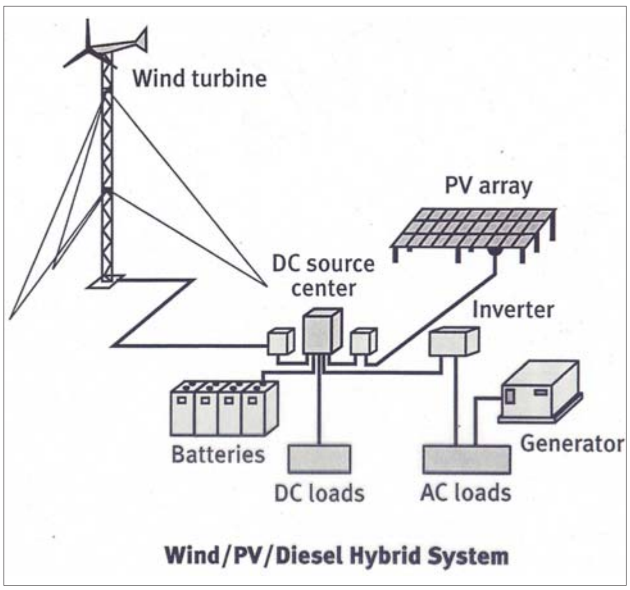

Figure 8. Micro-Grid System Architecture. This is a typical structure of a hybrid system with a diesel generator as backup.

Our Rare Earth and Concluding Remarks

The term "rare earth" was coined by Peter Ward and Donald Brownlee in a recent book with the same title.[16] In this book, the two professors from the University of Washington have joined with a number of astronomers and astrophysicists to show that, in spite of the possible existence of myriads of other planets throughout our universe, the chance for another planet like ours that can sustain life is indeed remote. They base their argument on a careful statistical evaluation of one hundred plus parameters that must be fulfilled with great precision before an earth-like planet can be formed. Such calculations, first started by the Cornell University astronomer Frank Drake fifty years ago, have led to the conclusion that there may be only *one* earth-like planet in the universe.[17] Decades of search for extraterrestrial intelligence (SETI) via radio telescopes have so far received no extraterrestrial signals to indicate their existence.

For those who believe in a God who created the universe, creating life elsewhere in the universe should not be a problem. On the other hand, why would God place such importance on *our planet,* and feel compelled to make a soft landing on Earth, through his Son's incarnation, to reconcile us with the Father?

In summary, let us note that as of today, no signals indicating intelligent life have been received from outer space. In addition, recent analyses seem to indicate that the probability of a "just right" planet like ours to exist more than once is highly unlikely, and that our Earth has a privileged position in the universe, described in detail by Guillermo Gonzalez and Jay Richards.[18] If we add to these considerations God's special concern for planet Earth, it becomes imperative for us to use appropriate technologies in a responsible manner. This will include encouraging the use of renewable resources, fuel-efficient cars, and energy-saving appliances. Many secular people are taking this issue seriously. We as Christians should be far more proactive in determining how to respond to limited resources, and energy and technology challenges. We *should lead* in making the necessary changes. In so doing, we can fulfill the Apostle Paul's exhortation to Timothy, in being satisfied with less, not more (1 Tim. 6:6–8). Living this way then becomes our "reasonable service" (see Rom. 12:2–3) and permits us to become good stewards in doing our best, individually and collectively, in sustaining and enriching our earthly home. ✦

Notes

[1]Paul J. Crutzen and Eugene F. Stoermer, "The Anthropocene," *IGBP Newsletter* 41, May 2000, http://www3.mpch-mainz.mpg.de/~air/anthropocene/. See also, "Welcome to the Anthropocene," *The Economist* (May 26, 2011).

[2]Mark Lynas, *The God Species: How the Planet Can Survive the Age of Humans* (London: Fourth Estate, 2011) (published in the USA by National Geographic as *The God Species: Saving the Planet in the Age of Humans*). For a review of the book, see *The Economist* (July 14, 2011): 86.

[3] Kenell J. Touryan, "ASA in the 21st Century," *Perspectives on Science and Christian Faith* 56, no. 2 (June 2004): 82–8.

[4] Edward Teller, *Better a Shield than a Sword* (New York: Free Press, 1987), 50.

[5] Julian L. Simon, ed., *The State of Humanity* (Oxford, UK: Blackwell, 1995); Julian L. Simon, "'Finite' Doesn't Fit Here," *The Oregonian* (Portland), February 11, 1997; Julian L. Simon, "Earth's Doomsayers Are Wrong," *San Francisco Chronicle,* May 12, 1995; Paul Ehrlich, *The Population Bomb* (New York: Ballantine Books, 1971); and Paul Ehrlich and Stephen Schneider, "A $15,000 Counter-Offer," *San Francisco Chronicle*, May 18, 1995.

[6] Kenell J. Touryan, "Renewable Energy: Rapidly Maturing Technology for the 21st Century," *Journal of Propulsion and Power* 15, no. 2 (March–April 1999): 163–74.

[7] Commission of the European Communities, Renewable Energy Road Map, Brussels COM (2006) 848 final.

[8] Solar America Initiative (SAI) concluded in 2009, incorporated into the US Dept. of Energy's Solar Energy Technologies Program.

[9] For more information, see Touryan, "Renewable Energy: Rapidly Maturing Technology for the 21st Century," 165–6.

[10] For details see Swiss Federal Office of Energy (SFOE) at www.bfe.admin.ch/themen/00490/index.html/.

[11] For the executive summary, see http//r2e2.am/wp-content/uploads/2011/07/Roadmap-11pdf/.

[12] Adrian Cho, "Energy's Tricky Tradeoffs," *Science* 329 (13 August 2010): 786–7.

[13] E. F. Schumacher, *Small Is Beautiful: Economics as if People Mattered* (New York: Harper & Row, 1977).

[14] Barrett Hazeltine and Christopher Bull, *Appropriate Technology: Tools, Choices, and Implications* (New York: Academic Press, 1998), 3.

[15] Amory B. Lovins, *Soft Energy Paths: Toward a Durable Peace* (San Francisco, CA: Harpercollins, 1979).

[16] Peter D. Ward and Donald Brownlee, *Rare Earth: Why Complex Life Is Uncommon in the Universe* (New York: Springer Verlag, 2000), chap. 12.

[17] Frank Drake's equation to predict how many civilizations might exist in our galaxy is given in Ward and Brownlee, "Rare Earth," 257. See also John D. Barrow and Frank J. Tipler, *The Anthropic Cosmological Principle* (New York: Oxford University Press, 1986).

[18] Guillermo Gonzalez and Jay W. Richards, *The Privileged Planet: How Our Place in the Cosmos Is Designed for Discovery* (Washington, DC: Regnery Publishing, 2004).

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Article

How Should Christians Promote Sustainable Agriculture in Agrarian Systems? A Normative Evaluation

David Dornbos Jr.

David Dornbos Jr.

Empowerment of the very poor to produce sufficient, healthful food for personal consumption and trade is critical to the reduction of chronic hunger and poverty. To produce food in a sustainable way that does not jeopardize environmental quality is important, allowing Christians to fulfill the Gen. 2:15 command "to serve and protect" creation. Application of sustainable agricultural practices in the agrarian systems of small farmers in poorer countries, as they are practiced in industrialized systems, implies the adoption of an inherently unsustainable industrialized process. Industrialized systems could harm ecological processes and damage community structures in poorer countries, jeopardizing their future production capacity. The purpose of this article is to distinguish principles of sustainable agriculture from specific practices in order to advance agricultural development that is economically, socially, and environmentally sound. Biblical norms justify the principles of sustainable agriculture, and these principles can inform place-based practices that have the potential to both honor God and sustain creation. Better agricultural development will result from an extended dialogue between industrialized and agrarian producers, each striving to adapt practices that achieve the principles of sustainable agriculture.

Global hunger and poverty are difficult, intertwined, and multifaceted problems that have persisted for centuries. People who do not receive an adequate diet are much more likely to suffer from a range of ailments and exhibit significantly shorter life expectancy. Chronic hunger, as distinguished from acute starvation, develops gradually as a result of a person receiving slightly insufficient calories and/or improper nutritional balance over an extended period of time. Children with weakened immune systems are vulnerable to a plethora of parasites and waterborne diseases, possibly leading to dehydration and death. While exact numbers are unclear, experts estimate that 800 million people suffer from chronic hunger globally.[1] Malnutrition

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disproportionately hurts children. The World Health Organization estimated that 112 million children, 26% of whom are under age five in developing countries, were underweight.[2] In fact, chronic hunger may kill as many as thirty-four thousand children under age five daily, or twelve million children per year.[3]

Hunger is inextricably linked with poverty, perpetuating the so-called "poverty trap." Agrarian (subsistence) farmers often lack the financial resources to invest in improved seeds, chemical fertilizers, pesticides, and water management systems. Of the 6.2 billion people inhabiting Earth in 2005, the World Bank estimates that 1.4 billion were living in extreme poverty, defined as having an income of $1.25 per day or less; 852 million of these were undernourished.[4] With recent increases in food prices, they further estimate that one billion people will go hungry while another two billion will be malnourished.[5]

Such statistics have long inspired spirited efforts by the faith community to increase food production capacity both for consumption and for sale in the market. On at least nine occasions, the biblical narrative calls us to "love your neighbor as yourselves."[6] The Bible makes clear that "the poor you will always have with you" (Matt. 26:11; Mark 14:7), and yet we are called to help them by giving of our possessions while seeking our true treasure in heaven (Matt. 19:21; Mark 10:21). We live in a time when the goods and services of global ecosystems are shared (including the air we breathe) or traded in the context of a global economy, making all of the earth's inhabitants our neighbors. To love our neighbors we must also assure access to, or at least not impede access to, daily water and bread just as Jesus did when he fed the five thousand (Matt. 14:13; Luke 9:10).

Sustainable help to neighbors, however, requires a careful response. We should not create a state of welfare or cause unintended harm.[7] Advocacy of appropriate principles and practices should do no harm to people or to the environment on which they depend for food and water. One approach of significant merit is that of the Christian Reformed World Relief Committee, which seeks to empower impoverished communities to be self-sustaining. It provides holistic support for their long-term physical and spiritual development by facilitating community transformation.[8] Knowing what specific actions to take, however, is not a simple matter. Westerners involved in development work usually have a natural tendency to use those systems with which they are familiar and which brought them a measure of success. Thus, it might seem very reasonable to empower farmers in developing countries by having them forego their agrarian practices and instead adopt the industrialized agricultural practices to which we are accustomed. This, however, may not be a wise plan.

One objective of this article is to provide a clear affirmation of the principles of sustainable agriculture (SA) while also illustrating that deployment of the SA practices used in the industrialized food production process of developed countries could, in fact, be harmful to people and their environment in poorer countries with high populations of small farmers. A second objective is to suggest that people in industrialized countries may gain insights about how to produce food in a more agroecologically sound way by learning from agrarian practices.

Steven Hall presents SA as a redemptive and restorative process of food production consistent with the biblical vision of sustainability reflected in creation care and the command to love God and our neighbor.[9] While the principle goals of SA are biblically supported and appropriate to maintain food production capacity, the SA practices associated with industrial agriculture make less sense when applied in the context of very poor, small shareholder farmers in poor countries. The sort of efficiency gained by industrial agriculture is not the efficiency primarily needed by small farmers. More specifically, industrialized efficiency rewards the most calories produced per unit of labor, rather than the quality calories produced per unit of water, nitrogen, or energy. Small, poor farmers lack access to costly technologies such as pesticide application, irrigation systems, and hybrid seeds because they are also frequently among the world's impoverished; however, they often have access to human labor. Secondly, the poor lack the infrastructure required to address soil erosion, water quality, and health issues that eventually arise from the industrialized food system and associated diet. More "appropriate technologies,"[10] a different set of SA practices consistent with SA principles, are required in support of poor, small shareholder farmers.

Sustainable Agricultural Practices Improve, But Do Not Fix, the Industrialized System

It might seem that people in industrialized countries have solved the food production challenge. We do produce a lot of food. One way to empower less fortunate global neighbors might be to share the knowledge and technology we used to increase food production capacity. Industrialized food production systems are incredibly efficient in producing large quantities of food with a minimum of labor. By integrating the use of tractors, improved genetics, fertilizers, and pesticides in a complex monoculture system, one US farmer can produce enough food annually to feed 140 people.[11]

However, serious tradeoffs challenge the sustainability of this industrialized food system. In a *Science* article, Peter Raven lists a number of global concerns: we treat agricultural lands with three million metric tons of pesticides per year; we fix more chemical nitrogen fertilizer, using natural gas via the Haber-Bosch process, than all natural processes combined; we have already lost 20% of the world's topsoil; 20% of agricultural land is now so degraded that it is no longer able to support food production; and species extinctions are three orders of magnitude higher than the geologic baseline.[12] Most of the grain that is produced is fed to livestock or distilled to produce ethanol for automobiles. The global grain supply is now consistently below demand as evidenced by the high commodity prices and "rice riots" of recent years. Even though industrialized agriculture can produce some impressive food yields and is labor efficient, costs to the environment and the persistence of hunger suggest that this food production system is unsustainable.[13]

Most farmers using industrialized systems are aware of these environmental issues, but they are trapped in the larger food system and must do what is required to stay in business. Farmers adopt a technology that balances the environmental protection mandated by law and the Farm Bill, against the maintenance of high-yield levels required by the commercial market to stay solvent. Farm Bill and market constraints require farmers to increase fertilizer use, install irrigation systems or drainage tile, and utilize pesticides to maintain high-yield levels. The number of farms fell dramatically from its peak of nearly seven million in 1935 to 1.9 million farms in 1997; eight percent of these very large family or nonfamily farms account for 68% of production today.[14] Whereas more than one-half of Americans farmed in the 1940s, fewer than two percent of Americans farm for a living today, and only seventeen percent of Americans now live in rural areas.[15] Therefore, while economically sustainable, industrialized food production systems are environmentally and socially unsustainable.

Sustainable Agriculture Is …

Sustainable agriculture represents a number of approaches or techniques developed to improve these economic, environmental, and social problems. The US Department of Agriculture defines SA as

> an integrated system of plant and animal production practices having a site-specific application that will, over the long term: satisfy human food and fiber needs, enhance environmental quality … and enhance the quality of life for farmers and society as a whole.[16]

The breadth of this definition is helpful at one level because it suggests that economic, environmental, and social concerns must be considered together, but it provides little specific insight into what needs to change. Consequently, perceptions of what SA is vary widely when viewed from the perspective of farmers, economists, environmentalists, or rural sociologists. To some, SA represents small changes to an industrial food production system intended to reduce environmental impact while still protecting profitability. For others, SA represents a radically different concept of food production, namely, an agroecological system typified by highly integrated polycultures.

The mainstream perspective of SA in the USA is to make small modifications to the industrialized food production system aimed at improving the triple bottom line by optimizing economic profit, minimizing environmental damage, and maintaining social acceptance. New practices minimize soil erosion, increase fertilizer efficiency, reduce fertilizer runoff, increase irrigation water use efficiency, and reduce pesticide exposure. Economic calculators, or weed, insect, and disease fact sheets, and numerous other decision tools, help farmers select practices that protect economic health while minimizing environmental damage.[17] For example, while

Integrated Pest Management (IPM) does not abrogate pesticide use, it does not account for important externalized costs, real and indirect costs (e.g., healthcare, reintroduction of biodiversity) that are not accounted for in the purchase price of a product. The voluntary use of IPM has reduced pesticide use by encouraging farmers not to apply pesticides unless it is necessary to protect the real economic potential of a crop field. A second example is the adoption of no-till or minimum tillage to reduce soil erosion. Seed quality, farm equipment, and pesticide options have improved sufficiently for farmers to now achieve comparable yields, or at least minimal losses, when adopting a no-till system. These SA practices which dominate in the US food production system represent gradual improvements of a problematic system.

Another competing perspective of SA is agroecology. An "agroecological" approach encourages the application of ecological principles in agricultural environments. Stephen Gliessman refers to agroecology as the integration of the broader ecology into the agricultural process to create an agroecosystem.[18] Agroecological producers actively promote the use of natural predators or integrated cropping systems and polyculture as a replacement for pesticides and chemical fertilizers. Agroecological operations tend to be small in size and rely heavily on human labor. Gliessman argues that agricultural systems can no longer be viewed as strictly production activities driven primarily by economic pressures. They should consider all inputs and outputs with the surrounding environment and community. The agroecological approach represents a significant paradigm shift from the industrialized systems that most of us are accustomed to. Arguably, such a shift is necessary to achieve true sustainability.

While it is generally agreed that present industrial agriculture is unsustainable, there are very different opinions about what SA should look like within developed countries. For example, the advice of the International Assessment of Agricultural Knowledge, Science and Technology for Development,[19] which encouraged agroecological practices, was largely rejected several years ago, possibly because it either represented a significant shift from the current industrialized approach or challenged the potential to market high-value industrialized technologies. If SA means broadly different things to different people in developed countries, it should not be a surprise that confusion exists around the question of what sorts of agricultural practices should be exported to people in developing societies. Therefore, careful discrimination between *SA principles* and biblical norms that support those principles, and the *SA practices* required to instantiate the principles, are necessary. We need a guide to help us identify which SA practices to advocate among small agrarian farmers in poorer countries, as well as among stakeholders relying on the industrialized system.

Side Effects of the Industrial Food Production System Conflict with Creation Care Norms

As responsible stewards of God's creation, we should promote production systems that create a minimal disturbance in order to protect productivity and resilience. At least four biblical norms inform the Christian worldview of crop production practice and promote good environmental stewardship. First, *God claims ownership over all elements of creation, so as humans we should seek to protect the diversity that God created.* The Old Testament narrative claims that everything in heaven and on Earth belongs to God (Deut. 10:14, 1 Chron. 29:11, Job 41:11, and Ps. 24:1) and that God cares for all the diversity he created (Job 38–40). Therefore, as garden caretakers, we are responsible to promote the biodiversity that produces resilience.

World Resources Institute reports that agroecosystems cover more than one-quarter of the global land area, with much of the remainder unsuitable for food production.[20] Industrialized production systems mainly use monocultures to optimize productivity in a labor-efficient manner. Monocultures (fields are planted with one crop type and individual plants of identical genetic composition) are maintained with the use of pesticides and tillage to prevent weeds from competing for resources. While the use of some land resources for food production is reasonable, conversion of virtually all native ecosystems, such as tall-grass prairies to corn and soybean monocultures, seems excessive. These behaviors signal a problem with our stewardship. We have replaced much of God's created diversity with monocultures in order to produce feed for livestock and ethanol for automobiles. A paradigm shift to an agroecosystem approach, on the other hand, employs biodiversity to produce food and to protect ecosystem resilience. David Kline argues that to stop and move the chipping sparrow nest when plowing a field in the spring not only preserves the life of one of God's creatures, but it also provides a natural way to control insect crop pests, owing to the large appetite of these insectivorous little birds.[21] It should be intuitive that one aspect of the goodness of God's creation is that all created creatures, not only humans, have a role in the natural process of agroecosystems.

Second, *humans and natural systems require a rest period.* "For six years you are to sow your fields and harvest the crops, but during the seventh year let the land lie unplowed and unused" (Exod. 23:10–11a). A similar command in Lev. 25:3–4 is accompanied by God's promise, "If you follow my decrees and are careful to obey my commands, I will send you rain in its season, and the ground will yield its crops and the trees of the field their fruit" (Lev. 26:3–4), and "you will eat all the food you want and live in safety in your land" (Lev. 26:5b).

Agricultural land seldom receives a fallow period these days with current agricultural practices. That was not always the case. In the pursuit of maximum profits, every year crops are planted in each field, and even in what were once fencerows. Some fields are planted with the same crop type every year, mostly as continuous corn production which prevents the sort of rest associated with crop rotation. One way of adhering to biblical instruction might be to provide agricultural land "rest" by building a fallow period into a crop rotation, by the use of "green manures" in which biomass is returned to the soil as a form of carbon sequestration, or by the adoption of polyculture that minimizes soil exposure. "Rested" soils can recover and regenerate, regaining native fertility and reversing degradation.

Third, *we are commanded "to serve and protect" God's creation.* A production system that pollutes the land conflicts with the "goodness" of the created order (Genesis 1) and represents an imbalance of the dual command "to serve and protect" (Gen. 2:15).

As a consequence of the heavy use of fertilizers, pesticides, and irrigation water required to maintain productivity in monocultures, it is clear that we have extensively polluted the soil and our fresh water. The substantial sediment load in streams following rainfalls stems largely from agricultural fields. Negatively charged soil particles also carry a load of nutrients and chemicals into the watershed where they drive an eutrophication process unhealthy for aquatic systems. Topsoil loss contributes to lower soil fertility, compensated for by higher fertilizer application, which further exacerbates the degradative cycle. Poor freshwater and coastal ecosystem health is significantly rooted in the food production process and represents one of the biggest threats to global health.[22]

Fourth, *God sustains, holds together, and has ultimate power over creation.* The psalmist wrote that God cares for the land, waters it, and enriches it abundantly in order to provide grain for people (Ps. 65:9). The created order is held together by God (Col. 1:17), who also retains the ability to shut up the heavens, producing drought, or unleashing locusts which eat crops (2 Chron. 7:13). God has declared this creation "good" (Genesis 1) and actively maintains it through God-ordained natural systems.

Much of industrial agricultural practice relies on a reductionist approach in which individual components of an agroecosystem are controlled or managed without regard to the overall health of the system. For example, the availability of nitrogen for annual crop plants is maximized by applying chemical fertilizers such as anhydrous ammonia or urea, without regard to fossil fuel cost, carbon footprints, downstream effects, soil microflora health, or soil pH levels. In contrast, this norm argues for a holistic system approach in which biodiversity provides insect control support, nitrogen-fixing crops are either rotated or grown in polyculture to provide naturally produced nitrogen, and disease and insect life cycles are broken. A properly constructed agroecosystem, one modeled after the holistic principles of ecology ordained from the beginning of creation, has great potential to provide sustainable food resources and ecological services. A paradigm shift toward agroecosystems, structured to complement natural systems rather than fighting them, could afford a sustainable supply of the variety of goods and services required by all beings.

Biblical Norms Support Principles of Sustainable Agriculture But Not Specific Practices

In his article, "Toward a Theology of Sustainable Agriculture," Steven Hall provides a broad biblical framework of SA with three foci: the environment, economy, and community.[23] The first biblical theme supporting the environmental component of sustainability is found in Genesis 1, which proclaims the goodness of God's creation and gives humans the responsibility to keep and preserve the land, allowing it to recover after use (Gen. 2:15; Exod. 23:11; and Lev. 25:4–7). Secondly, Hall argues that money-valued resources, such as land (Exod. 12:44) and the food that can be produced on it, can represent appropriate economic sustainability rather than the love of money (1 Tim. 6:10). Use of land or food production systems that rely upon unsustainable practices in the quest of an egregious lifestyle would reflect an inappropriate use of money. Third, multiple Old and New Testament passages illustrate that people who are concerned about the well-being of their neighbors as much as themselves encourage the development of healthy communities (Lev. 19:18; Matt. 19:19, 22:39; Mark 12:31, 12:33; Luke 10:27; Rom. 13:9; Gal. 5:14; James 2:8).

The consolidation of small family farms into large agricultural operations in recent decades has virtually created modern ghost towns in many midwestern states, representing a loss of community. A persistent perception of farmers as unrefined, backward, or uneducated people, by those who have little sense of where their food comes from or what it takes to produce that food, reflects a lost sense of community. Yet farming and nonfarming people are inherently interconnected via the environment, economy, and communities at local and global levels. All people, whether they realize it or not, depend on healthy ecosystems to provide goods such as food and fiber, and services such as filtered water and clean air—resources that we take for granted. An alignment of sustainable agricultural systems with basic food needs, while maintaining healthy ecosystems capable of providing the goods and services required for healthy and prosperous communities, should be a primary goal of political and faith communities.

I consider Hall's theological principles of SA to be wholly consistent with the biblical norms commonly associated with creation care. But in order for Christians to be responsible actors in the food system and to be able to advocate for appropriate food production practices, these principles need to be connected with place-appropriate practices. In the following sections, SA practices of industrialized food systems will be compared with the practices and the appropriateness of agrarian systems, with reference to each of the SA principles.

Reduce Soil Erosion

The top eight inches of soil, the "skin of the earth" on which life depends, according to a recent National Geographic article, is one of humankind's most limiting nonrenewable resources.[24] Once lost, the genesis of new soil requires millennia. Wind and water erosion remain a major concern in food production. Because healthy soils are required to provide the water, nutrients, and oxygen that plants need to produce a maximum food yield, soil erosion represents a significant threat to food security. Industrialized agriculture is extremely hard on soil.

> The average corn farmer who never rotates crops loses around twenty tons of soil per acre per year with conventionally tilled corn. This is the equivalent of 2.3 bushels of soil lost per bushel of corn harvested.[25]

Crop plants grown in rows during three months of a calendar year provide little resistance to the erosive power of water flowing through a field. Consequently, 20% of the soil has already been lost, resulting in siltation in rivers and reservoirs, the creation of a dead zone in the Gulf of Mexico, and the red-brown color of rivers that should actually run a clear, amber color following a rain.

The good news is that farmers using industrialized systems continue to adopt SA practices such as no-till and minimum tillage, construction of terraces, and maintenance of grassy waterways that have reduced soil erosion by 40%. The bad news is that erosion still exceeds the soil genesis rate by two to one. As long as row crop systems persist with monoculture crops such as corn and soybeans, it will be hard to bring the rate of soil loss into equilibrium with soil genesis.

Low soil quality is also a problem for growers in agrarian systems, yet they lack the financial resources to augment degraded soils with fertilizer and irrigation. Agrarian or subsistence producers may have other options. Practices which incorporate compost, instead of burning crop residue after harvest, will reduce erosion by providing a barrier to water flow and will enhance soil quality by adding organic carbon. Small shareholder farmers with animals may have the opportunity to incorporate crop residues, add soil nutrients as manure, and rotate a greater number of crops. Use of perennial crops preserves soil by maintaining year-round root systems that effectively hold soil in place. Finally, communities with greater labor availability may use a polyculture system, utilizing a menagerie of perennial (fruit trees) and annual crops positioned to optimize light, water, and nitrogen cycling, while holding soil in place. The goal of each of these practices is consistent with the SA principle of conserving soil. The practices of each system to achieve this goal differ widely, reflecting not merely a difference in economic circumstances but also a fundamental difference in the underlying paradigms of industrial and agrarian agriculture.

Reduce Pesticide Use

In Gen. 3:17–19, we read,

> Cursed is the ground because of you;
>   through painful toil you will eat of it
>   all the days of your life.
> It will produce thorns and thistles for you
>   and you will eat the plants of the field.
> By the sweat of your brow
>   you will eat your food
> until you return to the ground,
>   since from it you were taken;
> for dust you are
>   and to dust you will return.

Industrial agriculture relies primarily upon pesticides to control weeds that compete for sunlight, water, and nutrients, or to control the insects and diseases that consume crops. Pesticide control has effectively protected crops, providing large yields. While the benefit of greater productivity and lower food prices are obvious, there are negative tradeoffs from pesticide use. First, pests eventually develop resistance to pesticides, requiring higher doses or new active ingredients. Just fifteen years after introducing crops engineered to be resistant to Roundup™ herbicide, weeds are already becoming resistant.[26] Second, many pesticides kill unintended targets; most insecticides kill both crop pests and beneficial insect predators. Third, pesticides are responsible for the numerous poisonings and chronic illnesses of agricultural workers.[27] Effective pest control will remain a challenge as predicted by the "sweat of the brow" curse that followed the Fall. While the use of pesticides allows people in industrialized systems to avoid some of the work described in this curse, its benefits are accompanied by a number of challenges.

While pest control is critical to achieving high and reliable food yields, SA practices of industrialized systems make less sense in agrarian systems. Pesticides are expensive, they are not always effective, some are toxic to humans, and pests become resistant. The lowest cost pesticides, no longer protected by patents, are often used by the small farmers. These are frequently older broad-spectrum compounds which are more toxic to humans and the environment.[28] In Carchi, Ecuador, adoption of these pesticides doubled potato yields initially, but pests soon developed resistance. Carchi farmers responded by applying higher concentrations more frequently in order to maintain high yields. A community health concern developed when some Carchi farmers, who were applying pesticides without protective clothing or sound hygienic practices, experienced disabilities and premature deaths, along with their family members. "Ecosalud" developed as a successful movement of farm widows who promoted natural control methods coupled to safer pesticide use (only when it was absolutely necessary).

Fostering biodiversity can reduce, and in some cases replace, the requirement for pesticides, even in surprising ways. Consider, for example, the Amish farmer who preserved the nest of his insectivorous chipping sparrow.[29] While modern insecticides are more selective than their predecessors, they often kill beneficial insects, too. High populations of ladybugs, lacewings, and wasps help to keep plant pests in check. Crop polyculture provides both spatial and temporal diversity that disrupts the life cycles of insect and fungal pests. While there may be appropriate times and places to use pesticides, preferential adoption of agroecological approaches to disrupt pest life cycles, to encourage prognosticators of pests, or to use native crops with natural defense mechanisms, should be a first line of defense.

Because IPM focuses on economic sustainability, it may underestimate social and environmental costs as reported in the Carchi case study. Use of highly diversified polyculture systems and human labor in agrarian environments can mitigate some pesticide use by engaging a variety of ecological advantages.

Optimize Water- and Fertilizer-Use Efficiency

Water and nitrogen fertilizer are critical to optimizing yields. 2.3 billion of the earth's 6.4 billion inhabitants (41% of the human population) lack access to adequate water.[30] Nearly one-fifth of global food production lands rely upon irrigation water to maintain high yields. While water is critical to food production capacity, optimizing water use efficiency (WUE, the quantity of food produced per unit of water) is an important metric. SA techniques of industrialized systems are focused on optimizing WUE by transitioning from gravity or high-pressure sprinkler systems that lose a large percentage of water to evaporation, to low-pressure systems. Low-pressure systems are more efficient in delivering water, but are expensive. Soil erosion is indirectly related to the problem of insufficient water because eroded soils store less water and nutrients with which to support plant growth, driving the need for more irrigation.

Crop plants in agrarian systems also require large volumes of water, but farmers in these systems cannot access irrigation technology even if water were available. Jeffrey Sachs advocates that wealthy industrialized nations ante up to the UN in support of large infrastructure development such as dams and irrigation canals to supply water for irrigation.[31] On the other hand, Paul Polak of International Development Enterprises advocates empowering small shareholder farmers with a variety of low-cost solutions such as treadle pumps and trickle irrigation systems.[32] For $25–$50, the poorest of farmers with access to fifty gallons of water per day can support a vegetable garden. In Cambodia, groups such as Resource Development International develop, produce, and sell novel home use water filters for consumption and merry-go-round water pumping systems to enable people to access irrigation water.[33] Access to even a small amount of water using such technology can enable a family to grow enough vitamin-rich vegetables to augment a rice-based diet and reduce vulnerability to water-borne pathogens. While large, expensive infrastructure and technology might have its place, simple approaches can often replace the need for expensive technological solutions.

A number of mineral nutrients (the largest quantity of which is nitrogen) are required as well as water to optimize crop yield. Cereal grains commonly produce ~40% yield increases when nitrogen fertilizer is applied. In the industrial paradigm, chemical fertilizers are the main way nitrogen is delivered to corn, wheat, and rice. Nitrogen fertilizers are expensive, however, because the Haber-Bosch process requires large amounts of fossil fuels to create the conditions of 500°C, 200 atmospheres of pressure, and a catalyst, to produce ammonia nitrogen from nitrogen and hydrogen gases. SA practices, such as the use of slow-release fertilizers, the placement of fertilizer near the crop, and multiple applications of fertilizer, optimize nitrogen use efficiency by crop plants in industrialized systems. Nonetheless, the energy, environmental, and economic cost of nitrogen fertilizer is very high and is sustainable only as long as fossil fuel energy is available to drive the Haber-Bosch process. In contrast, rotation of cereals with nitrogen-fixing legumes, such as beans, peas, or forage crops such as clovers, provides a natural source of organic nitrogen by taking advantage of symbiotic relationships between certain plants and bacteria.

Agrarian farmers have minimal access to nitrogen fertilizer due mainly to cost. Integration of animal manure in their production system and the rotation of nitrogen-fixing crops can sustainably replace the need for nitrogen fertilizer. Farm animals can be used to glean unharvestable grains or plant biomass while spreading their waste in the field. Nitrogen-fixing shrubs such as *Sesbania*, legumes, or *Azolla-Anabaena* (the water fern) may be used as off-season crops to accumulate nitrogen in soils for its eventual use by grain crops. Polyculture offers the potential of interplanting nitrogen-producing crops with those requiring nitrogen. In Luke 19, Jesus told a parable about a man of noble birth who invested resources with his servants. After returning, two servants reported that they invested their minas in a way that earned more minas. God provides people with many resources of different types with the expectation that we are to use these resources wisely. By analogy, water and nitrogen can be viewed as resources that we should invest. If we do so wisely, we not only produce the meaningful outcome of a food crop, but we also improve soil quality by building organic matter such that the water from future rains will be stored in quality soils, enabling the sustained production of ever greater crop yields.

What Kind of Agriculture Should People in Developed Societies Promote?

It is tempting to believe that Western affluence is tied to the efficiency and productivity of the industrial food production model, and then to advocate adoption of the industrial model in developing countries as a solution to both poverty and hunger problems. Before boldly advocating such a change, however, we as foreigners and strangers should remind ourselves of Paul's exhortation to the Philippians, "Do nothing out of selfish ambition or vain conceit, but in humility consider others better than you. Each of you should look not only to your own interests, but also to the interests of others" (Phil. 2:3–4). Those of us from industrialized countries tend to be arrogant because we have been successful by some measures. We often go to poorer countries for a temporary stay to advocate our way of life, having all the power plus a safety net back home to fall back on.

Whereas industrial food production systems use labor efficiently and do produce high yields of a single crop, wholesale adoption of this model could be very harmful to small shareholder, agrarian farmers. First, promoting an industrial production system would be prohibitively expensive. Industrial systems rely on equipment, pesticide, fertilizer, and seed technologies that are expensive, and small shareholder farmers lack large cash reserves. Second, industrialized systems drive labor efficiency. While labor is cost prohibitive in industrialized systems where less than 2% of the population farm, more than 80% of people farm in many agrarian cultures, and consequently labor is valued differently in such places. The main point of this argument is that we should actively promote the adoption of SA principles and facilitate the development of place-appropriate SA practices in support of those principles.

Simply put, many industrial SA practices are irrelevant to the needs of small shareholder farmers in agrarian systems. Sustainable practices such as no-till farming, precision placement of nitrogen fertilizer, and low-pressure irrigation systems are conflated with the industrialized system. To adopt these SA practices requires agrarian farmers to adopt the entire industrialized system, a system that fails to provide the outputs required by the very poor, does not utilize well the resources that the poor do have, and that even in industrialized countries needs considerable reform!

In Cambodia, for example, there is plenty of human labor, with approximately 80% of the population working as rural farmers, each managing a few hectares. Adoption of large modern equipment such as planters and combines would replace the livelihoods of much of the population. Small shareholder farmers need a different sort of efficiency, more quality calories per unit of time, and high-use efficiency of limiting resources such as water, fertilizer, and pesticides. The use efficiencies of water, fertilizer, and pesticides tend to be low in industrialized systems in deference to human labor costs. For example, industrialized food production requires ten kilocalories of fossil fuel energy to produce one kilocalorie of supermarket food, much of which is corn and soybean.[34] Much of the ten kilocalorie energy cost is invested in nitrogen fertilizer which is applied to corn in one application before planting instead of in many small doses throughout the growing season. Nitrogen use efficiency ranges from 15–16%, with most being lost to the atmosphere or ground water. The corn produced is used for animal feed, high fructose corn syrup, or ethanol—hardly quality calories. Alternatively, people in agrarian systems can gain yield advantages even by using practices such as trickle irrigation, fertilizing with lower doses of nutrients more often, or growing crops in polyculture to take advantage of nitrogen-fixing plants while disturbing pest life cycles, thereby reducing the need for pesticides. Recognizing how efficiency is defined and rewarded is extremely important.

Since at least the 1980s, SA practices have been and continue to be adopted by growers who use the industrialized production process. These practices essentially represent incremental improvements to the industrialized process that developed from the 1950s to the 1980s, in an effort to reduce damage caused by the system. To advocate that agrarian farmers change their production practices to an industrialized system would certainly produce for them the same kinds of environmental degradation experienced here.

While agrarian systems are certainly not immune to the potential to degrade environmental resources, it seems more sensible to develop SA practices for existing systems. The opportunities and constraints of small shareholder farmers are unique. A clear understanding of the goals and principles of SA that is fully aware of the current opportunities and challenges of small farmers in poorer countries is required. Micah 6:8 offers us a great reminder that we are to "serve humbly" when making particular recommendations from a position of power. These small farmers who are completely reliant on their land for virtually all of their subsistence may have something to teach us about ecological literacy and long-term sustainability.

Apply the Principles of Sustainable Agriculture to the Very Poor

Food production practices of industrial and agrarian food production systems reflect principles of SA and biblical norms, informing us how we should serve and protect our environment. However, these practices differ from place to place, because they represent place-contextualized approaches of meeting creation care objectives. A reduction or elimination of pesticides and minimal use of fertilizer reduces the pollution load on the land. No-till farming, terraces, or grassy waterways decrease soil erosion, protecting our soil resources. Crop rotation and green manure renew soil. Greater biodiversity improves agroecosystem resilience, provides predators to crop-damaging insects, and increases production potential. While the particular practices of industrial SA may or may not apply to agrarian systems or vice versa, the principles and biblical norms supporting them certainly do.

A comparison of industrialized and agrarian food production systems helps to identify opportunities and threats in both situations. Neither is fully sustainable, yet the practices of one can inform the other in valuable ways. If we are to truly engage the "serve humbly" spirit of Micah 6:8, small- and industrialized-system farmers could empower one another in mutually supportive ways. A vital exchange of ideas, technologies, and practices consistent with the principles and biblical norms of SA has the potential to drive the development of contextually meaningful food production systems that are more economically, socially, and environmentally sustainable. Such an exchange has the potential to create a paradigm shift in both systems, enabling the development of an agroecology that is optimally sustainable and consistent with the dual command of Gen. 2:15 "to serve and protect" God's creation. ✦

Notes

[1]Peter Uvin, "The State of World Hunger," in *The Hunger Report: 1995*, ed. Ellen Messer and Peter Uvin (Amsterdam: Gordon and Breach, 1996), 1–17, Table 1.6.

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to conventional corn growers in the US Midwest, can be accessed at the following University of Illinois Extension website: http://ipm.illinois.edu/fieldcrops/insects/european_corn_borer/index.html. Integrated pest management (IPM) is a sustainable agriculture technique designed to ensure that pesticides are applied only when economically necessary. To determine if an insecticide should be sprayed on a cornfield to kill European corn borer larvae, the number one insect pest of corn, farmers input an expected yield of a crop, level of infestation, potential for yield preservation, and crop value in a calculator. The output of this financially based model will produce a "spray" or "no-spray" recommendation that optimizes profitability for that particular situation.

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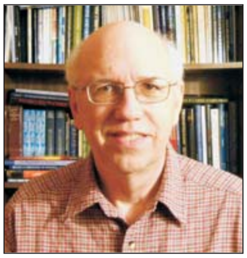
Article



Paul Arveson

Integrated Solar Cooking: An Underutilized Solution

Paul Arveson

Forty years ago, Francis Schaeffer challenged Christians to set an example of care for the environment. Now, as the earth has a population of more than seven billion, how well have we responded to this challenge? What have we done about global stewardship? This article describes a low-cost technology available to the poor of the world—not a "high tech" electrical device or a new energy source, but simply a technique to cook with the sun—using a fuel-free, labor-saving device, the solar cooker. The author's own experience and that of NGOs is reported. Solar cooking requires not only a radical shift in thinking about how we cook our food, but it also has many potential environmental, economic, and social benefits for billions of people.

In 1970, Francis Schaeffer published a paperback with the depressing title, *Pollution and the Death of Man*.[1] Although Schaeffer is widely known among evangelical Christians, this is not one of his more widely known books. It was one of the first books by an evangelical on the subject of "ecology" (actually, environmental ethics or what today is often called "creation care"). In it, Schaeffer recognized the serious problems of environmental damage in modern life, which cry out for solutions that can harness our Christian zeal in order to reduce pollution and rescue the environment. I was reminded of Schaeffer's book while reading Jack Swearengen's comprehensive book, *Beyond Paradise: Technology and the Kingdom of God*.[2] Schaeffer challenged the church to act as a "pilot plant," to set an example of environmental stewardship to the world. Stewardship should inspire Christians to practical action, both locally and globally,[3] and it should lead them away from eschatological fatalism.[4]

As an undergraduate, **Paul Arveson** *became a Christian in 1963. He received a BS in Physics from Virginia Tech and an MS in Computer Systems Management from the University of Maryland. He served as a civilian employee in the Navy, conducting research in acoustics and oceanography, and designed systems for signal processing and analysis. In 1998 Paul cofounded the Balanced Scorecard Institute, a management consulting firm. Paul has maintained a lifelong interest in issues of faith and science through his work with the ASA; he now serves as Secretary of the DC Metro Section. Paul facilitates a Sunday adult class at his church and was a cofounder of the C. S. Lewis Institute. Recently he has joined the Board of Solar Household Energy. He also currently serves on the Board of Managers of the Washington Academy of Sciences.*

The Challenge of Environmental Stewardship

It is not just about us. As Americans, our thinking about creation care naturally tends to focus on issues close at hand. We consider the fuel economy of cars and the cost of utilities for our homes. We worry about contamination of our food, excessive use of pesticides, and the reliability of electric power for our freezers and computers. These are the problems of a developed country. Meanwhile, there are billions of people around the world who live in comparative poverty. They are vulnerable to their environment in many ways, they suffer greatly, and we live alongside them on the same planet. This is an area in which scientists and technologists can intervene to offer innovative and appropriate solutions—especially when motivated by an ethic of *other-centered* Christian compassion.[5] But to be appropriate, interventions need to be carefully considered from the *bottom-up* viewpoint of the recipient. Thus, a first step in planning aid programs is to visualize in some detail the actual situation of the person in need. Constructing scenarios of people different from ourselves may lead to a better understanding of their needs. Such a scenario is provided in the example below, based on a compilation of field data.

A Day in the Life of Sarah

Sarah lives in a very sunny and warm part of the world. She lives with her husband in a stick-and-board house in a small village. It has a bedroom and a kitchen. They grow enough food to subsist, including beans, squash, and tomatoes, and Sarah trades some of these for corn and meat at the village marketplace. The family has to drink water from a muddy creek, because they often cannot afford to buy water from the tank truck that occasionally comes through the village. Sarah cooks in the traditional way. She moves three large stones together, then lights a fire in a pile of sticks and sets a pot over it. Sarah and her children are always coughing due to cooking smoke from burning sticks and dried dung. One of her children died of a lung disease last year.

Sarah's husband works in a field all day. For this, Sarah is grateful; many men have either left their wives or spend the day drinking and hanging out. They have four children. The older children stay around home and play; they cannot afford to buy the uniforms required to go to school.

Sarah gets up about 5:00 a.m. and lights a fire of sticks. She boils some water and makes hot cereal for breakfast. Sarah also makes a lunch for her husband to bring to the fields. Next she feeds her children, and then herself. After cleaning up, Sarah gathers clothes that need cleaning and walks to the creek to wash them, with one child strapped to her back and escorting a toddler. She brings home the wash and hangs it up to dry in the hot sun.

Her children help in gathering sticks for firewood. They sometimes have to walk several miles to find sufficient wood, and then they must carry the load back on their heads. All the local wood has been gathered already, and nearby landowners are scaring away poor people from gathering on their land. Often children get injured by thorns and insect bites. And it is always dangerous for women and children to be out in the woods alone.

Sometimes Sarah runs out of wood for the fire, because her children could not walk far enough to find a sufficient quantity. At these times she has to trade food for firewood. In the hot afternoon, she prepares lunch for the children and herself, by once again cutting up some sticks and starting the three-stone fire. After lunch she has some time to gather vegetables from her garden; she shells some beans and puts them into a soaking pot.

By late afternoon her husband returns home, tired and hungry. Sarah has prepared a meal of vegetables and rice over the fire. She feeds the children, scrubs out the cooking pots, and goes to bed—exhausted, coughing, and hot.

Billions of Sarahs

It is estimated that 2.5 billion people depend on food cooked indoors over open fires with biofuels, much as humans have done for hundreds of thousands of years.[6] According to the World Health Organization, this practice leads to respiratory diseases, accounting for nearly two million deaths per year, mostly of women and children.[7]

In rural Peru, for instance, a typical household will burn 3.6 tons of wood per year for heating and cooking.[8] Such consumption of firewood has many ripple effects. This wood must be either gathered by hand or purchased—one of the major household expenses. Fuel and food preparation consume so much time that women cannot earn extra income. They cannot send their children to school because they do not have enough money for school uniforms, and they need the children to gather wood and do other chores.[9] So, in many areas, the education level is not improving. These are chronic lifestyle habits that are not affected much by short-term government or NGO interventions.

The cumulative effect of a billion cooking fires (as well as slash-and-burn agriculture and other fires) adds significantly to the amount of black carbon,[10] aerosols,[11] and carbon dioxide in the atmosphere. Pollution of air, water, and earth (soil erosion) are evident in many places. The constant gathering of living and dead wood leads to deforestation and habitat loss. For example, in Haiti, the contrast between its barren land and the forests of the Dominican Republic can be seen clearly on satellite maps.[12]

The Energy-Poverty-Climate Nexus

In the year 2000, the United Nations announced eight global goals that must be achieved to meet the needs of people like Sarah.

The Millennium Development Goals

Goal 1: Eradicate extreme poverty and hunger.

Goal 2: Achieve universal primary education.

Goal 3: Promote gender equality and empower women.

Goal 4: Reduce child mortality.

Goal 5: Improve maternal health.

Goal 6: Combat HIV/AIDS, malaria and other diseases.

Goal 7: Ensure environmental sustainability.

Goal 8: Develop a global partnership for development.[13]

In reaching these goals, we need not assume that development in the less developed nations will take the same path that Western civilization took—along with its excesses. It is not necessarily desirable that the solution for them is to have what we have. The ultimate consumer "dream" may not be to have a big home with a dishwasher, a freezer, and an electric stove (along with all the resource demands, infrastructure costs, and environmental impacts that these products entail). In the colonial era, the USA was powered by wood. In the twentieth century, petroleum and its plastic and chemical products dominated. But with the advent of technologies such as the Internet, cell phones, satellites, fiber optics, vaccines, and nanotechnology, it is becoming possible for developing countries to "leapfrog" over energy-intensive products and to develop by more efficient paths. In some cases, it only takes a small amount of technology transfer to achieve significant economic impacts. This article will describe one such technology.

Daniel Kammen, a climate expert at the World Bank, noted that there is a "nexus" between energy, poverty, and climate change.[14] All three challenges are complementary; they impact each other. For example, as the story of Sarah's lifestyle indicates, reducing the need for firewood can also have an impact on poverty and climate change. Cooking over a fire is a major part of daily life, primarily of women. Moreover, the cost of fuel, or the labor in collecting firewood, is often a significant fraction of total household costs.[15] Because biomass fire-based cooking takes so much time and labor every day, it robs women and children of other opportunities such as education and small business. Hence, inefficient, fire-based cooking is one of the main causes of many social, health, economic, and environmental problems.[16]

The Solar Cooker

For many regions of the world, one approach to address the "nexus" is solar cooking. A *solar cooker* is a device that uses concentrated sunlight to cook foods. It does not require photovoltaic (PV) or other complex technologies; the only innovation required is a polished metal surface such as aluminum foil or metalized plastic film. Although it is "high tech" in terms of manufacturing, metalized film is very inexpensive and is now widely used as food packaging.

There are three basic types of solar cookers (figure 1), with many variations available:

1. Parabolic cookers, which use curved reflectors to focus sunlight onto a small area where a pot or teapot is mounted. Some designs include a sun-tracking device.
2. Panel cookers, in which flat sheets of shiny metal are arranged to focus sunlight on a black pot.
3. Box cookers, in which an insulated box covered with a transparent window captures sunlight to heat a black pot in the box.

There is a continuum from devices that heat by concentrating sunlight (parabolics) to devices that cook simply by retaining heat. Thus fuel-free cooker designs may be arranged in this order:

1. True parabolics with a high light concentration factor;
2. Modified parabolics (e.g., troughs);
3. Panel cookers with a transparent enclosure to reduce convective heat loss (This also includes evacuated tubes and solar hot water collectors.);
4. Boxes with shiny reflectors internally and externally;

5. Boxes with shiny external reflectors and black internal surfaces;
6. Boxes with no reflectors and black internal surfaces; and
7. Retained-heat insulated containers (no light input).

Solar cookers can also be characterized by three physical parameters:

- food and container mass
- light concentration factor
- net heat loss factor

The time it takes to heat food or water can be obtained from Newton's law of heating and cooling. The cooking time is directly proportional to the mass of the food and the pot, and the mean specific heat of the food and the pot, and inversely proportional to the reflector area and light concentration factor. Typically, a solar cooker takes from 1.5 to 2.5 hours to cook a meal. It performs like the slow cooker or "crock pot" in many American kitchens.

The maximum temperature achieved by a solar cooker is also dependent on the rate of heat loss; at equilibrium, the losses will equal the solar input. To reduce cooking time, the cooking pots and container walls are usually painted black. But at equilibrium, radiation loss will equal incoming solar radiation energy (Kirchhoff's law). Convection is also an efficient cause of heat loss, so box cookers must use a tightly sealed box. Of course, for water-based foods such as rice, polenta, or stews, the maximum internal temperature is self-limited to around 100°C.

Thus the main cooking requirements—quantity of food and cooking time—lead to solar cooker design requirements. Each type and size of cooker has its appropriate uses. For frying foods, parabolic or other curved reflectors can attain very high temperatures by concentrating sunlight on a small spot where a pot or frying pan is placed. These devices cook food in a short time, although the reflector must be turned frequently to keep it aligned to the sun direction.

For emergencies, and in refugee situations, a low-cost cardboard-and-aluminum panel cooker called the CooKit has been developed by Solar Cookers International (SCI). Tens of thousands of these devices have been distributed in camps in Africa.[17] The CooKit design is simple and can be made locally with existing materials such as cardboard and any kind of shiny material, e.g., aluminum foil, or even potato chip bags, candy wrappers, or cigarette packs.[18] The reflective panel can be used with any black pot, as long as it is enclosed in a roaster bag to reduce convection. It can reach temperatures around 120°C.[19] In addition to cooking food, the CooKit is used for pasteurizing water and milk, because experiments have shown that to pasteurize water it is only necessary to achieve a temperature of 65°C; it is not necessary to boil the water.[20]

A more durable general-purpose panel cooker is the HotPot, which includes a polished aluminum reflector, a glass bowl and cover, and an inner black enameled steel pot. The glass bowl acts to prevent convective heat loss. This product is well made and will last for many years. The author has personally used a HotPot cooker for a couple of years to cook

Parabolic Cooker **Panel Cooker ("HotPot")** **Box Cooker (Sun Oven™)**

Figure 1. Solar Cooker Types.

vegetables, rib roasts, hot dogs, hamburgers, and cakes. He is one of many people in Washington DC, and other places around the USA who cook frequently with a solar cooker (figure 2).

Figure 2. Solar cooking on a snow day in DC, Feb. 2010.

Box cookers can be made of plywood, cardboard, or molded polymers. A simple box cooker design tested in Guatemala achieved 120°C in 30 minutes.[21] One commercial product, the Sun Oven™, claims to achieve temperatures of over 180°C.[22] Panel and box cookers do not need to be turned or adjusted frequently, and the pot does not need to be tended during cooking. These realities free up time for other activities. The American Society of Agricultural Engineers has published a standard for performance measurements of box cookers; international standards for solar cookers are currently being developed.[23]

Integrated Solar—Biomass Cooking

What does a solar cook do on cloudy days, or after dark? To provide for this, a modern *fuel-efficient stove* is recommended. Many designs have recently been developed. They are small and lightweight, typically made of clay or steel with insulated walls. They are efficient because of carefully designed air flow and reduced thermal mass. They can cook a meal quickly with only a small handful of wood or other biomass. Within the past year, a major effort has been launched to scale up the introduction of fuel-efficient stoves, the Global Alliance for Clean Cookstoves (GACC). Funded by hundreds of partners, the GACC seeks to distribute 10 million efficient stoves (including LPG stoves).[24] With widespread recognition, celebrity endorsements, and numerous meetings, the GACC has rapidly succeeded in focusing government and NGO efforts, primarily aimed at improving indoor air quality.

If food is cooked on a sunny afternoon in the solar cooker, how is it kept warm for the evening meal after sunset? For this purpose, a third component is required: a *large insulated basket or box*, which is lined with a thick insulating material such as straw or wool to reduce the heat loss factor. If a pot of hot food is stored in such a container, it will continue to cook and stay warm for hours.

The combination of these three simple devices—a solar cooker, a fuel-efficient stove, and a heat storage container—provides a complete "*integrated cooking solution*" for people in sunny regions all over the world, particularly in northern Africa and the Middle East, Central America, India and central Asia, Australia, and western South America. Haiti, for example, is dry for at least half the year—an excellent candidate for solar cooking.[25]

Fuel-efficient stoves reduce firewood requirements significantly. But solar cookers use *no fuel at all*. Thus, solar cookers can serve to drive down fuel costs for the poor, as well as reduce the environmental and health impacts from burning fuels.

Ongoing Solar Cooking Projects

Solar cooking devices are in widespread use in India, and production of solar cookers is growing rapidly in China.[26] For instance, there is an institution that feeds 30,000 people each day from a large solar cooker installation in India.[27] Solar Cookers International (SCI) has distributed tens of thousands of CooKits and other cooker products to African countries and Haiti.[28]

Solar Household Energy (SHE) is a nonprofit organization located in the Washington DC area to build awareness and support for solar cooking. (The author joined the board of this organization recently.) SHE has conducted field projects in El Salvador, Mexico, the Dominican Republic, Bolivia, Haiti, Senegal, and Chad. These projects are being evaluated to assess long-term acceptance by cooks in these countries. SHE also conducts research on cooker designs and is partnering with other US non-profit organizations to collect detailed measurements to improve cooker performance.

This year SHE established or advanced several important relationships, and provided technical assistance to these new partners. The United Nations High Commissioner for Refugees (UNHCR) contracted with SHE to train 48 women in the Gaga refugee camp in Chad to solar cook, and to distribute HotPot solar ovens for them to use (figure 3). UNHCR was interested in this project as a pilot to determine if a larger-scale program of solar ovens is warranted in the camps. The preliminary results are positive. The following description of the project is excerpted from SHE's final report to UNHCR:

> The preliminary results indicate that introducing solar cooking has caused them [the participants] to reduce their wood use by an average of 25–40% after only two months. These savings are likely to grow over time and could be further increased by additional measures. The users are extremely enthusiastic about their new HotPots and have adapted their cooking to use them every midday meal.[29]

Figure 3. Women solar cooking in refugee camp in Chad.

These results indicate that cultural acceptance and lifestyle changes are feasible. However, the scale of the projects so far has been small. SHE and SCI hope to scale up the size and duration of these projects, and many plans need to be prepared in order to be ready for this. SHE is currently working on ways to develop and test microfinancing practices, so that in-country entrepreneurs can enable solar cooking practices to grow organically within a country. This is a challenging, multidisciplinary long-term effort.

Challenges to the Introduction of Solar Cooking

It is gratifying to see the beginning of a large-scale introduction of more fuel-efficient biomass and LPG stoves around the world. However, fuel-efficient stoves of any kind still use fuels, they still generate CO_2, they reduce but do not eliminate deforestation, and they still require users to pay fuel costs and fuel distribution costs. In sunny regions, solar cooking can drive down costs, labor, pollution, and deforestation still further. But scaling up of solar cooker use faces several serious challenges. As Steve Jobs has said, "A lot of times, people do not know what they want until you show it to them."[30]

Many people in developing countries do not recognize solar cooking as a potential solution because it is such a paradigm shift in their thinking about how food is cooked. This is certainly understandable, and it implies that adequate training and careful adaptation to the local cooking practices is necessary for effective acceptance. However, based on recent pilot field projects, there is ample evidence that many users do accept solar cookers, especially as they begin to realize the economic, labor, and health benefits.

Despite the great potential benefits, currently there is little recognition of solar cooking in the USA. Field projects are small, because there are few significant sources of funding, either from nonprofit organizations or government agencies. Many people in developed countries, accustomed as we are to gas, electric, and microwave cooking, are unfamiliar with the *concept* of solar cooking. This is indicated in some common objections or misconceptions, such as the following.

"Two hours is too long to cook a meal." This objection is based on a misconception. Although solar cooking takes more "wall clock time," it takes much less actual labor time because food does not have to be stirred, as it does over a fire. Panel or box cookers work like an oven or slow cooker in a developed-world kitchen. You put the food in, then go away and do some other productive work. Moreover, solar

cooking significantly reduces the labor and time for wood gathering, cutting, preparing the fire, and other tasks. By visualizing "a day in the life" of the solar cook, one can begin to recognize more benefits that follow from this labor-saving use of the sun.

"Solar cookers don't get hot enough." Of course they do; people cook with them all over the world. But like any technological product, a solar cooker must be "the right tool for the job." Selection of the product must begin from the end user's requirements (including food types, latitude, climate, etc.) to derive design parameters such as those suggested above. Users need to know how to orient the cooker to the sun angle, anchor it properly, and so forth. Some well-intentioned interventions have reported poor performance because the products were not appropriate for the conditions, or because users were not properly trained in their use.[31]

"Solar cookers cost too much for the poor." It is true that the initial product cost may be prohibitive—for clean cookstoves as well as for solar cookers—but microfinancing methods are being implemented to reduce initial cost, and the reduction in fuel cost over time will decrease total cost of ownership. The economic rationale is parallel to that for fuel-efficient cookstoves. But more research is needed in order to design cookers that use lower-cost materials and reduced manufacturing labor, and to refine funding methods.

A key challenge is the lack of long-term evaluations of previous field projects. Often interventions begin with great enthusiasm, but follow-up reports are inadequate. Cooking is a daily routine that varies widely around the world; the appropriateness of a technological solution needs to be carefully matched to the "cooking facts" of a particular region or village. This requires anthropological data (e.g., "a day in the life of Sarah") as well as feedback from users, in order to optimize the fit for maximum usage. Video ethnography is a new technique that could be very helpful in this regard.[32]

There are numerous challenges of solar cooking that can be discouraging—until we are reminded of the large potential benefits of this technology for many people, as well as for the global environment. In fact, solar cooking has benefits that directly or indirectly cover *every one* of the eight Millennium Development Goals.

The Role of Christians in Meeting the Challenges

Christian organizations are playing a key role in achieving the Millennium Development Goals. Faith-based NGO's have advantages over government-sponsored programs in ensuring environmental sustainability. In a recent white paper, Amy Gambrill, a USAID official quoted advice from the findings of the African Biodiversity Collaborative Group as follows:

> Reach out to faith communities for dialogue and collaboration. The global urgency for a sustainable world demands multidimensional approaches and a persistent push for ideals based on innovative and pragmatic strategies. Faith-based communities comprise the largest social organizations in Africa, representing a repository of opportunities to spread the cause for sustainability in the continent. Conservation leaders should reach out to religious communities to collaborate in implementing these recommendations, with a view to enhancing the capacity for value-based sustainability decisions that link nature and human well-being.[33]

Gambrill notes that a purely technical approach to environmental challenges may overlook human values and motivations in the local culture, which frame the worldview of the people we intend to reach with interventions. Government-based aid programs typically have a short lifespan and cannot sustain long-term efforts. But mission organizations are often more trusted than governmental agencies, and they are going to be around for the long term to encourage adoption of new methods and products. Hence, some mission organizations are learning to partner and "piggyback" each other's programs to provide better care for the whole person's physical and spiritual needs.

Summary: The Sun Is Manna from Heaven

During the Exodus in the wilderness, the Israelites became hungry, and they suffered and grumbled to Moses (Exodus 16). God gave them manna. In the dryer areas of the earth, the sun is energy "manna" from heaven. It is distributed freely each day and almost every day. Like manna, each one can gather as much as she needs. Like manna, it cannot be stored but must be used on a daily basis. But until recently, it has not been possible to gather this "manna." One bit of new technology has changed that: metallized film and aluminum foil—materials that are now available cheaply everywhere, and are often considered trash. With this shiny material and other low-cost materials, the Sarahs of this world can obtain appropriately designed solar cookers and start gathering the "manna," cease gathering so much firewood, and immediately begin to enjoy the many benefits of solar cooking. ✦

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[29]Solar Household Energy Annual Report, FY 2011, http://she-inc.org/ar2011.pdf.

[30]Quoted in *Bloomberg Business Week* special issue, October 10, 2011.

[31]D. M. Kammen and W. F. Lankford, "Cooking in the Sunshine," *Nature* 348 (November 29, 1990): 385–6.

[32]J. H. Schaeffer, "Videotape: New Techniques of Observation and Analysis in Anthropology," in *Principles of Visual Anthropology*, ed. Paul Hockings (Berlin: Mouton de Gruyter, 1995).

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The Grand Design's Unintended Arguments for the Existence of God

Let me add to the book review of *The Grand Design* by Stephen Hawking and Leonard Mlodinow (*PSCF* 63, no. 2 [2011]: 132–3). The book actually provides strong positive evidence in support of the existence of God. In chapter 7 entitled "The Apparent Miracle," the authors make the following assertions:

> Most of the fundamental constants in our theories appear fine-tuned in the sense that if they were altered by only modest amounts, the universe would be qualitatively different, and in most cases unsuited for the development of life. (p. 160)
>
> The laws of nature form a system that is extremely fine-tuned, and very little in physical law can be altered without destroying the possibility of the development of life as we know it. Were it not for a series of startling coincidences in the precise details of physical law, it seems, humans and similar life-forms would never have come into being. (p. 161)
>
> The universe and its laws appear to have a design that both is tailor-made to support us, and if we are to exist, leaves little room for alteration. (p. 162)
>
> [For example,] if protons were 0.2% heavier they would decay into neutrons, destabilizing atoms. (p. 160)

These facts are examples of what is sometimes called an anthropic principle.

Hawking and Mlodinow then assert, "Many people would like us to use these coincidences as evidence for the work of God" (p. 163). I myself am one of those many people, since it seems like the most reasonable conclusion to draw from these facts. Indeed, Hawking and Mlodinow should be thanked for providing us with such a clear and concise exposition of this presently available scientific evidence in support of the existence of God.

There is also a logical inconsistency in Hawking and Mlodinow's argumentation. Near the beginning of the first chapter, they propose a "model-dependent realism" theory of what they claim is the best characterization of reality that is available for us. They assert,

> But there may be different ways in which one could model the same physical situation, with each employing different fundamental elements and concepts. If two such physical theories or models accurately predict the same events, one cannot be said to be more real than the other; rather, we are free to use whichever model is more convenient. (p. 7)

They then apply this approach to general explanations of the universe. For example, a typical physicist model (TP-model) of the universe would encompass all of the known and experimentally verified laws and theories of physics such as the laws of thermodynamics and electromagnetism, the theories of relativity and quantum mechanics, and the standard model of elementary particle interactions. Hawking and Mlodinow would doubtless agree with the wisdom of adapting this TP-model.

Let us go one step further and consider two somewhat enhanced TP-models which accept all verified laws and theories of physics, but which add a judgment about the existence of God. Consider an atheistic (ATP-)model of physical reality which denies the reality of a god, and a deistical (DTP-)model which affirms God as the Creator. Since belief in God has no effect on the outcome of an experiment in physics, both models agree equally well with observation, and one is therefore at liberty "to use whichever model is more convenient." According to "model-dependent realism," any one of these three models is just as appropriate for use, and just as well "conforms to reality." This means that the argumentation against the existence of God found throughout their book is, in reality, a denial of the central postulate of "model-dependent realism." To be logically self-consistent, Hawking and Mlodinow are obliged to accept the TP-, ATP-, and DTP-models as equally authentic representations of reality. Their decision to espouse the ATP-model and repudiate the DTP-model is a flagrant rejection of the central claim of "model-dependent realism."

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It Is Time for Advocates of Evolutionary Origins of Information to Use a More Balanced Approach

I have read with interest the three articles published in the December 2011 issue of *PSCF* on biological information, and the evolutionary origins of genetic information. All three authors have taken special care to demonstrate that complex systems such as living cells need not involve an intelligent source. Those arguments, however, leave me with an uneasy feeling as a Christian who is committed to upholding truth claims that can be learned from God's two books: nature and scripture. The reasons for my concern are as follows:

1. Whether done consciously or unconsciously, there *seems to be a tendency* to give special homage to Darwinian evolution at the *expense* of biblical insights. It seems as if the book of nature is primary and scripture is secondary. This is particularly apparent in Freeland's article, where he describes the evolutionary origin of genetic information with great erudition, but ends his treatise with what seems like a *perfunctory* allusion to "a loving creator God." No effort is made to show in what ways God expresses himself in his creation, other than by the author himself *choosing* to believe that he does. There is no way for me to distinguish such a position from what can be called "functional deism."

2. In my encounter with college youth, I have found most of them to be *unable* to distinguish between methodological naturalism and ontological naturalism. As most atheists and agnostics do, they confuse the mechanical/scientific theory approach of Darwinian or neo-Darwinian evolution with its comprehensive worldview implications. Thus, Dawkins's notorious statement that *"Darwin made the world safe for atheism"* is gaining foothold everywhere. No wonder so many young people end up losing their fragile faith in

Christian truth claims. Should we not, as ASA members, be more careful in emphasizing this point to the younger generation, and uphold in higher esteem the wonders of the Creator's work as seen in living systems, rather than in what Darwin claims?

3. I have been an applied physicist and a research engineer all my life. In my discussions with nonbelievers, I can question *any and all theories* in the physical sciences, whether it is the second law of thermodynamics or Einstein's theories of relativity, but if I raise a question regarding the problems inherent in the theory (dogma?) of macroevolution, I am quickly dismissed as an ignoramus. What seems ironic is that both the second law and the laws of general relativity have been *demonstrated to be accurate* to 10+ decimal places, and yet the problem of biogenesis, which is the very starting point of Darwinian evolution, has evaded all explanations for over 150 years.

4. Do we, as ASA members who adhere to our Statement of Faith, have a responsibility to be more careful in mediating grace to our ID members instead of belittling their valiant efforts to integrate the Creator more directly into his creation? At present, we face virulent and persistent attacks from neo-atheists (I would rather call them *miso-theists)* such as Dawkins, Harris, Hitchens, Dennett, and Stenger. To this we should add the increasing hostility, both subtle and open, exhibited by academe toward any and all practicing Christians, no matter what their professional credentials are. In fact, *I have yet to see an ontological naturalist take seriously the best BioLogos position, in spite of how well argued the effort might be.*

Again, should not we, as members of ASA, help strengthen the faith of our younger colleagues in the face of relentless opposition from academe, by uncritically defending a theory that is the *sine qua non* of the nonbeliever? I wonder if it is time to have a more balanced approach to how God weaves in his creation the *supernatural with the natural in a seamless manner, without gaps,* which *he* has done throughout history, an observation that is cogently argued by C. S. Lewis in his book *Miracles.*

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Biological Information and Carbon

In "Information, Intelligence, and the Origins of Life," (*PSCF* 63, no. 4 [2011]: 219–30), Randy Isaac wrote, "Without a clear understanding of all possible historical paths, no credible probability of occurrence can be determined,"[1] and "… probabilities and improbabilities cannot be reliably assessed unless all historical pathways and processes are well understood."[2] These statements exemplify fiat science, for which no supporting data are needed. They trump all scientific data, logic, and sound reason. Because they cannot be falsified, they are scientifically meaningless but very dangerous.

Isaac does not consider that biological information is inextricably linked to carbon. Only carbon-based information units explore sequence space, and the information is not prescient. Carbon is the ink of life, and it is finite. The upper 35 kilometers of Earth's crust contains about 10^{46} carbon atoms. For any given number of carbon atoms, enzymes are more information dense than DNA or RNA. The 10^{46} carbon atoms can assemble into fewer than 10^{43} units of information composed of 400 amino acid residues.

Each family of proteins has a unique protein-folding motif containing amino acids, which are specific in type and sequence. A selector cannot select for an enzyme until it is functional, and an enzyme is not functional until each specific amino acid is properly sequenced. The rules of probability are in play during their initial sequencing, because they have no history. The protein-folding motif of an average-sized family of proteins contains between 54 and 108 amino acids that are specific. The probability of their proper sequencing would range between 1 chance in 10^{70} and 1 chance in 10^{140} per try for L-isomer biological amino acids that are independent and identically distributed. So, are carbon-based information units potent in the exploration of this sequence space?

If each of the 10^{43} units of information were to alter its structure, and therefore its information, once per second for 3 billion years, fewer than 10^{60} unique units of information would have been existent. These units fall short in the exploration of the sequence space for one average-sized, protein-folding motif by a factor ranging between 10^{10} and 10^{80}.

The primordial soup contained a mixed bag of amino acids including nonbiological amino acids and D- and L-isomers. Sparking experiments produce nine biological amino acids but add 26 nonbiological amino acids to the mix. Meteorites transport 60 nonbiological amino acids to the mix. Eleven biological amino acids are not produced in sparking experiments or transported to Earth by meteorites and are "rare." If 10% of the amino acid residuals are glycine, the probability that an average-sized, carbon-based information unit would be composed of only L-isomers is about 1 chance in 2^{360} or less than 1 chance in 10^{108} per try. The integrity of the information contained within such units would be highly corrupted through the addition of nonbiological amino acids and D-isomers and through the infrequent insertion of "rare" biological amino acids. Several might escape corruption, but the probability is that these few would be written as gibberish. Unplanned carbon-based information is impotent in assembling the protein-folding motif of average-sized proteins.

The protein-folding motifs of 500 average-sized or larger protein families have a total of far more than 27,000 amino acids specific in type and sequence.[3] The probability of their correct sequencing would be far less than 1 chance in $10^{35,000}$ per try. A single alteration would remove an entire protein family from existence. The carbon-based information units from 10^{500} universes would be inadequate to investigate this sequence space.[4] The unplanned origin of life and the unplanned assembly of the first cell are highly speculative scientific hypotheses masquerading as scientific theories. *Scientific American* labels them "mysteries."[5] They do not belong in a natural science curriculum.

However, all this is irrelevant for Isaac, because, "… all possible historical paths …" and "… all historical pathways …" have not been investigated. He checkmates every reasoned objection. Isaac's fiat science undermines natural science and science education, and it allows adherents of an exclusive unplanned biological origin to get rid of God for all time.

Notes

[1]Randy Isaac, "Information, Intelligence, and the Origins of Life," *Perspectives on Science and Christian Faith* 63, no. 4 (2011): 228.

[2]Ibid.

[3]Each of 500 average-sized or larger proteins would have a minimum of 54 amino acids specific in type and sequence.
500 proteins x 54 specific amino acids/protein = 27,000 specific amino acids.

[4]10^{60} information units investigating sequence space/planet x 10 planets/star x 10^{24} stars/universe x 10^{500} universes = 10^{585} information units investigating sequence space.

[5]Philip Ball, "10 Unsolved Mysteries," *Scientific American* 305, no. 4 (October 2011): 48–9.

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Calculating Probabilities of Carbon-Based Biomolecules

The quotations from my article cited by Nelson are not statements of "fiat science" but of practical reality. If a calculation of a reaction rate fails to include all relevant reaction paths, the result of the calculation will be in error. Perhaps it would have been clearer if I had added the adjective "… all *relevant* historical pathways …" to indicate that the omission of a plausible path would lead to an erroneous result. I did not mean to imply that everything must be known before anything can be said.

As Nelson points out, all known biological information is carbon-based. In principle, it may be possible for life to be based on other elements, but this is not yet our experience.

The probability calculations that Nelson provides for various proteins are reasonably accurate for the scenario he assumes. The path he considers is essentially a collection of amino acids, from 54 to 27,000 for various protein families, coalescing in a random single-step assembly into the proper sequence. As he concludes, this is virtually impossible. However, it is not relevant to any evolutionary theory, none of which postulates such a path. All evolutionary theories hypothesize some type of step-by-step approach rather than a single step.

A macroscopic analogy may help illustrate the difference. Two blocks from the ASA office in Ipswich, MA, is a dam on the Ipswich River. Fish from below the dam can be observed upstream from the dam even though the dam is significantly higher than any of these fish can jump. Before we infer that a fisherman is catching the fish and transporting them upstream from the dam, we need to ensure we have considered all possible paths. On the far side of the river, we find a fish ladder that enables the fish to proceed step-by-step to reach the upstream side of the dam. What was impossible has become a feasible journey for the fish.

Wilf and Ewens have shown mathematically that while the probability of a single-step random assembly of a collection of elements scales *exponentially* with the number of elements, a step-by-step random assembly of those elements scales *logarithmically* with the number of elements.[1] That is the difference between impossibility and feasibility.

Nelson is correct to point out that we have not discovered the "fish ladder" that would account for the formation of the earliest complexes of biomolecules that could reproduce themselves and begin the chain of continuity of what we call life. But there is no reason to conclude that such a step-by-step process does not exist. No law or principle from information theory or any other discipline precludes such a scenario.

In evolutionary biology, probability calculations may have some value in determining whether a particular path to an event was feasible, but they are of little value in determining whether that event happened. The set of possibilities is too large. The fundamental flaw in every argument based on irreducible complexity is that only one or a few possible paths are analyzed. Upon finding those paths to be virtually impossible, the conclusion is drawn that no path is possible. Darwin encouraged some of this thinking by insisting on fine gradualism as a necessary feature. He did not have the benefit of the genetic research of the last few decades that shows the rich palette of pathways by which nature can proceed. We now understand that the number of possible paths is far greater than can be reasonably assessed.

Nelson is concerned that the units of biological information "fall short in the exploration of the sequence space for one average-sized, protein-folding motif by a factor ranging between 10^{10} and 10^{80}." However, a recent study by Burke and Elber suggests a finite number of networks of protein-folding configurations so that "a model of evolution with only a few sequences evolving to fill out sequence space is plausible. The sequence space is well connected and allows for sequence migration between folds."[2]

In summary, we must approach probability arguments with a great deal of humility. It must be acknowledged that we know too little of nature's options to derive a credible probability. The search for the pathway to life goes on.

Notes

[1]Herbert S. Wilf and Warren J. Ewens, "There's Plenty of Time for Evolution," *Proceedings of the National Academy of Sciences* 107, no. 52 (2010): 22454–6.

[2]Sean Burke and Ron Elber, "Super Folds, Networks, and Barriers," *Proteins: Structure, Function, and Bioinformatics* (2011), doi:10.1002/prot.23212.

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Volume 64, Number 1 **March 2012**