Eight Bio-Based Technologies for 2050

JIM LANE, Editor & Publisher, Biofuels Digest

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Wonder how the world will ever produce enough energy and cut back enough carbon? Here are eight technology platforms for 2050 that could make the difference.

Over the past several weeks, we have been exploring the topic of transformative technologies, and readers are busy at work this week and through September 23rd in the voting process. That is now. Looking ahead, we explored a few years down the road in our 10-part series The Bioenergy Project of the Future [1], published last fall.

Now we are looking at the longer term. What kind of technologies will evolve in the 2030s and even the 2040s to transform our fuel, food and materials choices, and lead us towards some of the fuel targets outlined for 2050 by the International Energy Agency?

In looking that far down the line, we have some long term trends to guide us.

The Scary Trends

1. Population growth. The UN says that the global population will increase to 9 billion by 2050, up from 6.6 billion today (although population is expected thereafter to stabilize).

2. Increasing wealth and energy intensity in the developing world. Not only will

the developing world have a lot more mouths to feed, but they will also be more wealthy and increasingly have the buying power to achieve what is generally known today as the energy-intensive Western lifestyle. This has disquieting implications. Global energy use totaled 472 exajoules in 2008 [2], but if everyone had used the same amount of energy as is annually consumed in the U.S., energy demand would have been 2,078 exajoules. If population and demand trends hold, that would be 2,834 exajoules by 2050, an increase of roughly 500 percent. Not that everyone is expected to have an energy-replete U.S. lifestyle, but it frames the problem, especially when we are trying to reduce overall carbon emissions 80 percent below existing levels. It could require as much as a 97 percent decrease in carbon intensity.

3. Scarcity of key materials. Growing demands for energy and materials? Well, there are occasional imbalances even today in vital materials, such as crude oil, water, grains, oilseeds, which could be expected to only be magnified, and include supply constraints for rare metals, chemical feedstocks and phosphorus.

4. Build-up of waste streams. An energy-intensive society is a waste-producing one. Not only municipal solid waste, but liquid wastes, greenhouse gases, hazardous materials, and residues from manufacturing, energy production, food and other industries.

The Friendly Trends

1. Energy efficiency. The U.S. and Europe have been relatively neutral in terms of energy intensity since 1990. Though population increase still affects overall demand, energy-efficient design in buildings, vehicles and manufacturing can be expected to have a strong impact on retarding growth in energy demand. The opportunities for telecommuting and more efficient urban design offer even more substantial savings in, say, fuel demand.

2. Moore’s Law. The continuation of a Moore’s Law environment in transistor size is a situation in which the number of transistors that can be affordably placed on a standard chip doubles every two years. The trend, which has held up for 50 years, is expected to continue through 2020 at this time. Even 10 more years represents a 32-fold increase.

3. Moore’s Law, synthetic bio-style. The cost of sequencing a human genome has been decreasing for 20 years at a rate exceeding Moore’s Law rate — from $100 million in 1990 to $12,000 as of March 2011, according to the National Human Genome research Institute. At the present rate, the cost would be around $11.70 in 20 years or substantially less than the expected cost of, say, a movie ticket.

How do those trends help? Synthetic biology and computer science are drivers of the bio-based revolution in fuels, chemicals and materials. As the *Economist* observed in 2006, “At the moment, what passes for genetic engineering is mere pottering. It means moving genes one at a time from species to species … True engineering would involve more radical redesigns … In the short run, such engineering means assembling genes from different organisms to create new metabolic pathways or even new organisms. In the long run, it might involve re-writing the genetic code altogether, to create things that are beyond the range of existing biology.”

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What are some of the breakthroughs in technology that we may see, over the longer term, that may address some of our pressing issues in energy demand?

1. Waste capture. Today we capture just a fraction of the total output of greenhouse gas emissions, not to mention industrial, municipal, agricultural, animal and forest residues. Expect this figure to change radically, as rising costs of virgin materials, plus breakthroughs in biology and catalysis open up new opportunities to turn waste streams into value streams. Carbon capture is just one element here — think conversion, capture and repurposing all industrial wastes as an industrial goal for 2050. The Kalundborg symbiosis is a good start. [3]

2. Breakthrough in carbon fixation and solar efficiency. Today organisms capture between 1 and 4 percent of solar energy, and fix CO_2 and nitrogen slowly, if at all. In the future, expect that synthetic biology will build organisms that can capture as much as 30 to 40 percent of solar energy through completely redesigned metabolic pathways. Last year, a scientific team headed by Drs. Craig Venter, Hamilton Smith and Clyde Hutchison [4] announced completion of the final step in their quest to create the first synthetic bacterial cell. Her formal name is M. mycoides JCVI-syn1.0 — you can call her Syndi. She’s the start of a long journey towards redesigning pathways from the ground up.

3. Development of symbiotic communities of enhanced organisms. Today we work generally on one organism at a time when it comes to optimizing performance. We make better corn, switchgrass, E. coli or what have you. But everything around us exists in symbiotic, or competing, communities. For example, nitrogen fixation is not performed by soybean genome, but by the bacteria that exist in its ecosystem. And much of human biological process is performed by hosted bacteria. By 2050, expect that synthetic biology will not only be designing improved genomes, but also using advances in biology and computing to understand and design in terms of symbiotic communities of organisms. Think symphony, as opposed to melody.

4. Off-the-shelf parts inventory in synthetic biology. The BioBricks group shows

the way here. [5] "We envision a world in which scientists and engineers work together using BioBrick parts — freely available standardized biological parts — to create safe, ethical solutions to the problems facing humanity." In their formulation, "each distinct BioBrick standard biological part is a nucleic acid-encoded molecular biological function (e.g., turn on/off gene expression), along with the associated information defining and describing the part." Off-the-shelf parts will mean everything when it comes time to develop simplified metabolic pathways, possibly based on E. coli bacteria or yeast fungi, that will have specialized, completely synthetic pathways for the creation of fuels and target chemicals.

5. Shift from freshwater to saline water. Whether it is companies like Ceres [6] developing salt-tolerant switchgrass, or groups like the Seawater Foundation [7] developing salicornia (sea asparagus) as a salt-tolerant bio-feedstock, expect to see all agriculture move off freshwater (excepting rainfall) by 2050, and utilize brackish groundwater or seawater.

6. Rooftop bio-systems. Here, Joule Unlimited's radical engineering designs point the way [8] . In the future, bioprocessing will be increasingly based on small-scale, solid-state systems that look more like solar panels than industrial manufacturing plants. There will always be room for the big industrial biotech plants with their monster fermentation tanks, and huge systems for biomass supply and product distribution, but rooftop bio is entirely going to be in the mix by 2050 — competing with solar panels for space on the rooftops of industrial plants, homes, schools and hospitals, utilizing all that solar energy instead of reflecting or absorbing it.

7. Super-light, super-strong materials. Carbon-based fibers stronger than steel, more flexible than plastics will emerge — durable, yet adjustable. The bio-based revolution will have as much impact on materials as feed or fuel. Lightweight, super-strong materials are the path towards deployment of low-cost, lightweight diesel-electric hybrids — the most efficient and effective platform for off-grid transportation yet developed.

8. Bio-processors built into biomass. Syngenta is getting down this track [9]: inserting corn amylase code into its proprietary corn seeds, delivering enzymes for pre-treatment and breaking down biomass right into the genome, and growing them with solar energy instead of industrial inputs. Well, it's a grand start, but just a start. By 2050, look for smart, complete, consolidated bioprocessing systems embedded into biomass. And they won't just be switched on to create fuels — think chemicals or even precursors for electric power. And they might just be switched on using mobile technologies, and perhaps even processed in the field, without a need for aggregation. Just turn on the embedded systems, and add nutrients, water, etc. from delivery systems in the field, and collect product remotely.

Far out? Could be, but think of where computing was 40 years ago … or genomics. You may even see the beginnings of a real convergence of bio-based systems and computer science itself, with developments like a bio-based quantum computer [10]. In the even more distant future, we may well see entire computing systems cheaply embedded into bio-materials or even fuels.

Think of that — fuels that talk back and control their response to conditions from within the fuel stream. That's science fiction today, but so too was the computer in the 1930s.

Links:
[1] http://biofuelsdigest.com/bdigest/2010/10/05/the-biorefinery-project-of-the-future-part-x-of-10-bringing-it-all-together/
[2] http://en.wikipedia.org/wiki/World_energy_consumption
[3] http://www.symbiosis.dk/en
[4] http://biofuelsdigest.com/bdigest/2010/05/21/god-loses-monopoly-synthetic-genomics-creates-first-synthetic-bacterial-cell/
[5] http://biobricks.org/
[6] http://www.ceres.net/
[7] http://www.seawaterfoundation.org/
[8] http://www.jouleunlimited.com/
[9] http://www.syngenta.com/country/us/en/Enogen/Newsroom/Pages/SyngentasCornAmylase.aspx
[10] http://nextbigfuture.com/2010/05/protein-computing-bio-based-quantum.html
[11] http://biofuelsdigest.com/bdigest/2010/10/11/the-top-100-people-in-bioenergy-2/