The Fate of Estrogens Applied During Wastewater Irrigation
In my previous Resource column, I addressed how ASABE’s reconfiguration, for more efficient alignment of our technical divisions, will enable the growth and marketing of our profession and our Society. The value of our profession can only be communicated by marketing ourselves to the public and to policymakers. In particular, the reconfiguration treats agricultural engineering and biological engineering as common threads throughout ASABE, showing how both of these engineering fields benefit the people of the world by providing nutritious food, clean water, abundant energy, and a healthy environment. Our goal is to market these efforts—and thereby gain our profession’s rightful place in the global arena.

Retaining a greater proportion of our student members and attracting others to join us is another important challenge facing ASABE. The realignment and marketing effort will be critically important in meeting this challenge. The targeted audience should recognize our relevance and competence in working to solve the grand challenges that the world is facing. Whether we apply our expertise in agriculture to address food, water, and energy issues, or we conduct fundamental research in biological engineering to develop new products and processes, we must ensure that our efforts are recognized and understood. Engineers are usually not effective marketers, so we need marketing expertise to help us. The message needs to be: who we are, what we do, and how we are vital.

An effective marketing effort is critical to the future of our profession and ASABE. Retaining current members and attracting new ones is also a high priority, and we do not have time to waste. With potential members having many options to choose from, we need to provide the compelling value they seek in joining ASABE. Watch for the marketing deliverables—and help promote how you and ASABE benefit the people of the world!

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As concerns about the presence of unregulated compounds known as “emerging contaminants” (ECs) in drinking water sources continue to grow, alternative solutions for managing wastewater are becoming increasingly appealing. Irrigation with wastewater is commonly used for agriculture in developing countries. In contrast, land application of treated wastewater is being used in the United States as a way to artificially recharge groundwater aquifers and protect rivers and streams that would otherwise receive discharge from wastewater treatment plants.

Since the 1960s, Penn State University has been applying its treated wastewater to approximately 2.5 km² (600 acres) of agricultural and forested land, known as the Living Filter. This provides a great benefit to Spring Creek’s water quality, which had previously received effluent from the university’s wastewater treatment plant. However, more than 50 years later, it is now recognized that ECs, many of which are known endocrine disruptors, are not completely removed in conventional wastewater treatment and thus are being inadvertently introduced into the environment during this irrigation. Two research groups in Penn State’s Department of Agricultural and Biological Engineering are trying to understand the fate, transport, and threats of estrogens contained in the irrigated wastewater.

**Understanding the threat to groundwater**

Herschel Elliott and his graduate student, Senorpe Asem-Hiablie, recently completed an assessment of the potential for estrogens to reach the aquifer beneath the Living Filter. To study undisturbed soil profiles, cube-shaped steel casings (60 cm on a side) were driven into the ground, excavated, and used as lysimeters to evaluate the vertical transport of three estrogens. Effluent spiked with the estrogens and an inert tracer was applied to the lysimeters at the actual irrigation rate (5 cm per week), and the leachate was monitored for six months. Leachate estrogen levels were generally less than 10% of the applied concentrations, suggesting that sorption to soils significantly retards subsurface transport of estrogens. However, rapid appearance of estrogens in the leachate after application of less than one pore volume of effluent implies that the soil macropores serve as preferential transport pathways in structured soils. Since the water table beneath the Living Filter area is about 50 m below the surface, the likelihood of groundwater contamination by estrogens is low at this site. However, the impact of surface irrigation-applied estrogens on water quality may be greater for areas with coarse-textured or highly structured soils overlying shallow groundwater.
Assessing the impact on vernal pool ecosystems

Heather Gall and her graduate student, Odette Mina, are interested in understanding the fate of estrogens that are mobilized during surface runoff and their potential threat to nearby aquatic ecosystems. There are several vernal pools near the Living Filter that may be impacted by estrogens and other endocrine-disrupting compounds contained in the irrigated wastewater. Vernal pools are important habitats for amphibians such as frogs and salamanders, which are currently facing global population declines. Although some laboratory studies have been conducted to understand the impact of controlled exposure of amphibians to emerging contaminants, no data exist for the occurrence of the ECs in vernal pools.

Gall, Mina, and their collaborators in Penn State’s Department of Biology (Tracy Langkilde and her graduate student, Bradley Carlson) have identified seven vernal pool sites across an agricultural impact gradient, with the Living Filter sites among those most impacted by agricultural activities. They collected one round of samples in October 2013, when water levels in the pools were low, with the goal of establishing baseline concentrations prior to the pools filling up to normal levels. Of the seven sites, only one had detectable levels of estrogens. That is good news for the tadpoles that are developing at these sites, but the absence of estrogens was expected due to their short half-lives and because no recent stormwater runoff events had occurred.

These vernal pools receive their water primarily from surface runoff rather than groundwater, and Gall’s team hypothesizes that concentrations will increase following snowmelt and runoff events, which are expected to transport estrogens, pesticides, and other ECs. Therefore, more water samples will be collected in the winter and spring to assess the impacts of snowmelt and large spring rainfall events on the presence of estrogens in these vernal pools. These data will then be used to develop controlled mesocosm experiments, in which tadpoles are exposed to environmentally relevant “contaminant cocktails.” For more information on Penn State’s Living Filter, visit: www.opp.psu.edu/services/eng-resources/living-filter-fact-sheet.

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All feature photos courtesy of Tracy Langkilde.
Los Angeles County is home to nearly 10 million people, as well as at least 171 farms, 211 nurseries, 118 community gardens, and 761 school gardens. However, just 21 of the 88 incorporated cities in the county explicitly permit farms in some form. The other 61 cities do not mention the word “farm” anywhere in their zoning or municipal codes.

These facts encapsulate the findings of a collaborative research project on urban agriculture at the University of California-Los Angeles (UCLA) by 13 graduate students in urban and regional planning, one law student, and two graduate research associates, with facilitation by a doctoral candidate and two faculty advisors. The client for the project is the University of California Cooperative Extension in Los Angeles County (UCCE-LA). As part of the University of California’s Division of Agriculture and Natural Resources, UCCE-LA has worked with commercial farmers for the past century and hopes to work more closely with small urban farmers, using the UCLA study as a foundation.

**A more informed discussion on urban agriculture**

California is the most agriculturally productive state in the United States, but until recently most of the agricultural focus has been directed at large farms and ranches. Agricultural production in cities had been viewed as a niche activity practiced by alternative-lifestyle adults and school-children. Recently, though, the conversation about urban food production has become more complex. Advocates of urban agriculture assert that access to fresh foods can reduce obesity rates, that pesticide-free food is better for human and environmental health, and that growing food close to where it’s consumed just makes sense.

In order to facilitate an informed discussion about food and the city, the UCLA researchers sought to answer a few simple questions: What does urban agriculture look like? How is it regulated? Who engages in it? And how and where is city-grown produce sold?

To find out what urban agriculture looks like, the researchers scanned every census tract in Los Angeles County using Google Earth. They also visited selected farms, nurseries, and gardens and initiated thousands of phone calls to schools and unconfirmed agricultural sites. Confirmed urban agriculture sites were entered into a database and visualized in an interactive geographic information systems map. To analyze how agriculture is currently regulated, the researchers conducted keyword searches for 15 core agriculture activities within the zoning and municipal codes of all 88 cities in Los Angeles County. While mentions of farms,
gardens, and flora are sparse, animals are heavily regulated in many cities. For example, 75 cities permit fowl in some form (with varying regulations for chickens, roosters, turkeys, geese, and eggs), while just seven cities explicitly prohibit fowl. Fowl is referenced in 59 cities’ municipal codes and in 49 zoning codes—and sometimes both. Other fauna frequently mentioned in zoning and municipal codes are bees, fish, goats, heavy livestock, horses, pigs, and rabbits. Cities rarely regulate the same agriculture activities the same way. Making things even more complicated, Los Angeles County has its own regulations for certain activities. In some cases, the researchers found conflicting regulations within a single jurisdiction, and the regulatory language was often obtuse, outdated, or of questionable validity.

To gauge the effect of regulations and other factors on urban agriculture, the researchers visited sites around the county and conducted interviews with urban agriculturalists. The people who work at and manage the farms, nurseries, aquaponic systems, and community and school gardens tend to do so more in pursuit of health and community than in pursuit of money. Some farms and vineyards in less densely populated regions of Los Angeles Country are operated at a commercial scale and generate significant profits for their owners, but these are a minority. In general, urban agriculturalists reported being frustrated by complex regulations. Time and labor constraints and lack of effective distribution methods were the other difficulties frequently cited by people producing food in cities.

Farmers’ markets are operating successfully in thousands of diverse neighborhoods across the county, and they are where most of the outputs of urban agriculture are currently sold. The researchers visited dozens of farmers’ markets in Los Angeles County and conducted an in-depth study at the market in Altadena, an unincorporated neighborhood in a densely populated area of the county. Urban agriculture vendors transport their products (fruits, vegetables, eggs, jams,
spices, etc.) an average of 40 km (25 miles) and sell them for significantly higher prices than the same goods command in grocery stores.

Competition from commercial-scale farms outside of Los Angeles County is a constant threat to urban agriculture. At farmers’ markets, urban agricultural products are often sold adjacent to similar products produced for a fraction of the price at commercial-scale farms.

In Los Angeles grocery stores, including Ralphs and Whole Foods, fruits and vegetables grown anywhere within the state of California are labeled and advertised as “local.” In order to be successful, urban agriculturalists must differentiate their products from commercial-scale products and convince customers that their products have added value.

Urban agriculture in the balance

Whether or not local production adds value is a matter of perspective. Urban agriculture may be a trend, or it may be the beginning of a movement. Food advocates, scientists, policymakers, and ultimately the free market will determine how much food is produced and sold in cities like Los Angeles. The most tangible results of the UCLA students’ research are the interactive map of urban agriculture sites and the regulatory analysis. The researchers hope that this effort will help enrich urban agriculture’s academic and political standing. Staff members at UCCE-LA, the client agency, are already developing educational activities in response to the UCLA study, including updated materials to support school gardens, as well as an online database of resources and best practices for urban farmers. They also hope to partner with nonprofit agencies to assess vacant lands for their suitability for farming.

While the study did not address the engineering aspects of urban agriculture, some areas of future inquiry are apparent. Los Angeles still has available open space for urban agriculture, but as that changes, the engineering challenges of rooftop agriculture will need to be addressed. Engineering challenges also come with novel approaches to urban food production, such as aquaponics and vertical gardening, that are increasingly discussed as alternatives where space is limited.

The full project, including an interactive map of the agricultural sites, is located on the website at: CultivateLosAngeles.org.

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Editor's note: With this article, Marty Matlock begins a four-part series on biological and agricultural engineers in sustainable agriculture. This overview of the engineer's role will be followed by articles on the path forward for sustainable agriculture, the food and agriculture industry's leadership in sustainable agriculture, and the challenges and opportunities of global agriculture.

Our global population is just over 7 billion, but it is expected to approach 10 billion by 2050. We currently use over 40% of the Earth’s land for agricultural production. Future demands from the land for food, feed, fiber, and fuel will increase pressure for land transformation, habitat loss, and biodiversity loss. In addition, as much as 70% of human-appropriated water is used for agriculture, making water the Earth’s most valuable resource. Human prosperity requires a healthy and resilient biosphere, as well as prosperous agricultural communities, and that means agriculture must be sustainable.

Field to Market: The Alliance for Sustainable Agriculture (www.fieldtomarket.org) defines agricultural sustainability as meeting the needs of current generations while enhancing the ability of future generations to meet their needs. In practice, the goals of sustainable agriculture are to increase resource use efficiency, decrease environmental impacts, protect product safety, and ensure product quality. These goals all involve optimizing complex systems to achieve improvements in a variety of competing metrics, which in turn requires developing new processes and adapting to changing conditions within the entire supply chain. Clearly, agricultural sustainability is a broad and interdisciplinary topic.

The difference between agricultural sustainability and other continuous improvement strategies is the scope of the analysis. Sustainable agriculture strategies must consider impacts on the environment as well as the community and the economy. Fortunately, the knowledge and skills of biological and agricultural engineers are ideally suited for addressing these challenges. Biological and agricultural engineering integrates soil conservation, water quality and quantity, food production and processing, energy systems (including biofuels and on-farm efficiency), information technology, facilities design, and many other areas. This wide diversity has always been our strength, and in some cases our weakness.

As a discipline of generalists, we have sometimes struggled to find a focus and common definition. However, meeting the challenges of sustainability requires competent generalists. Biological and agricultural engineering is essential to successfully meeting the challenges of today’s agricultural producers while enhancing productivity, profitability, and environmental conservation in the future.
Agricultural sustainability frameworks

Sustainability programs are already being implemented in various agricultural production sectors and across the value chain for consumer package goods (CPGs). These programs are not being driven by governmental regulation or policy. Instead, they are being driven by corporate concerns over product quality, safety, and security. Retailers need to protect their reputations by managing the processes associated with their products. Sustainability is a big part of that corporate responsibility, and it’s good for business. Global consumer spending for CPGs exceeded $7 trillion in 2010, and global agricultural supply chains support more than 35% of total annual CPG sales. Unilever, a top-ten global CPG company with annual sales of over $69 billion in 2012, has committed to sourcing all of its agricultural products sustainably by 2020. Walmart, a global CPG retailer with annual food product sales in excess of $214 billion in 2012 (55% of total sales for the company), has committed to sourcing more sustainable agricultural products. In addition, Walmart is requiring its suppliers to improve nutrient management metrics across their product supply chains (www.walmarthsustainabilityhub.com).

Sustainability frameworks are a tool for managing continuous improvement. They have three stages: definition, measurement, and implementation. The definition stage consists of defining sustainability for the enterprise, identifying the key performance indicators (KPIs) that measure sustainability, and selecting the metrics that represent the KPIs. The measurement stage consists of benchmarking the KPI metrics to provide a comparison point, setting goals for each KPI, and developing strategies to meet those goals. The implementation stage includes implementation of the strategy, measuring and reporting results over time and space, and adapting the strategy to improve outcomes. Continuous improvement occurs through this adaptive approach. If something works, keep doing it; if not, try something else, but keep implementing, measuring, reporting, and adapting.

Life cycle assessment and benchmarking

Biological and agricultural engineers know that you can’t manage what you don’t measure, especially in complex agricultural systems. To effectively improve the metrics for the parameters that we care about, the KPIs must be outcome based, science driven, technology neutral, and transparent. The range of KPIs necessary to address the full range of sustainability issues must include environmental, social, and economic indicators as well. Fortunately, biological and agricultural engineers have been developing outcomes-based, science-driven solutions for agricultural processes for more than a century. We work with producers and processors to develop KPIs based on analysis of impacts and efficiency. We have a culture of close collaboration with our colleagues in agronomy, agricultural economics, and rural sociology. And we are often the leaders in defining and selecting KPIs across the environmental, economic, and social aspects of sustainability.

Life cycle assessment (LCA) is used for quantifying KPI metrics in agricultural sustainability, both for setting benchmarks and for performing assessments. The LCA method uses a rigorous systems analysis approach in which each discrete element of a supply chain is defined as a unit process, with inputs from nature and other processes and with outputs to nature and other processes. An agricultural activity can be defined as a system of these unit processes, which can be modeled with current or alternative inputs to evaluate the impacts of different scenarios. In addition, the mass and energy flows through the unit processes can be aggregated to quantify all the upstream impacts of a product or process. This approach gives us the information we need to make more informed decisions about the sustainability of supply chains. In this way, biological and agricultural engineers are systems analysts, because this approach is at the core of our expertise.

Benchmarking is the process of setting a baseline with which to compare future measurements. Without benchmarks, it is difficult, and often impossible, to evaluate the performance of a process. Benchmarks are usually temporal,
that is, a time period is selected for which adequate data exist for the KPI under study. The type of benchmark that is selected determines the content of the sustainability framework.

Setting goals for KPI improvement requires measuring a KPI and deciding how much to change it over some time period. The specific goal depends on the purpose of the sustainability plan, the type of KPI, and the limitations of the organization setting the goals. Goals can be aspirational, strategic, tactical, or operational. Each type of goal has a discrete scope and timeframe that communicates priorities to the decision maker. Biological and agricultural engineers work at each level of this process, from defining what is possible (aspirational goals) to identifying appropriate implementation strategies (operational goals). The result of this process is an understanding of the agricultural enterprise that informs sustainability efforts across the entire supply chain.

Sustainability is a defining concept in agriculture. It brings together the cultural land ethic with the economics of production, the commitment to conservation, the practice of innovation, and the underlying science of modern agriculture. The discipline of biological and agricultural engineering was born from the need to increase the efficiency and decrease the impacts of agricultural production. Sustainable agriculture is what we do, and it’s what we have always done. Now we must expand our view upstream and downstream in the agricultural supply chain and across the social, economic, and environmental impacts of agriculture to achieve prosperous, global sustainability. With another three billion people coming to dinner in the next 40 years, the demand for biological and agricultural engineers has never been greater, and the opportunities for our profession have never been brighter.

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Imagine a 10,440 ha (25,800 acres) contiguous drip-irrigated farm that has 1,000 km (620 mi) of buried mainline, 30,600 km (19,000 mi) of drip line, and 34 pumping stations with 110 pumps, all installed in an area more arid than the Kalahari Desert. Now add 21st century automation technology with 1,400 sensors and 1,800 controls to irrigate this farm, day and night, with no human interaction. To handle any detrimental hydraulic conditions, add sophisticated algorithms to provide enough computer smarts to meet the challenge. Now add remote access to the system so that no matter where you are, or which mobile device you carry, you can remotely override the computer and become the person in charge. This state-of-the-science “dream farm” actually exists. It’s GreenWood Resources (GWR) Boardman Tree Farm, located in eastern Oregon.

Boardman Tree Farm (BTF) is a real-world model for how technology can enable agroforestry to efficiently and economically produce fiber from one of the most renewable resources—trees—in a sustainable and ecologically friendly manner. BTF covers 104 km² (40 mi²), which makes it the world’s largest irrigated fiber farm and one of the largest contiguous drip-irrigated farms. In addition to the nine million Pacific Albus (hybrid poplar) trees, there are 2,225 ha (5,500 acres) of various high-value crops, including organic crops, under center-pivot irrigation. The extensive irrigation network consists of 1,000 km (620 mi) of buried pipe up to 183 cm (72 in.) in diameter—you could walk upright inside these pipes.

Single pump capacities range from 1,900 to 120,000 Lpm (500 to 32,000 gpm), with pump motors ranging in size from 22 to 746 kW (30 to 1000 hp). BTF’s peak pumping power of 28,400 kW (38,100 hp) can deliver more than 852,000 Lpm (225,000 gpm) with enough capacity to produce 1.2 billion Lpd (325 million gpd). This huge volume of water is fed to the trees by nearly 27 million drip emitters, with 30,600 km (19,000 mi) of drip line—that would reach about 3/4 of the way around the Earth. With 250 sand media...
filters in the irrigation system, BTF has one of the world’s largest sand media filter systems.

BTF produces high fiber yields through two approaches. First, BTF uses an advanced scientific irrigation management (ASIM) system, an irrigation supervisory control and data acquisition (I-SCADA) system, and an advanced hydraulic balanced irrigation scheduling (AHBIS) program, among other programs, to use water and energy resources efficiently. Second, BTF plants genetically superior (high-yielding, fast-growing, disease and pest resistant) tree stock that’s well suited to this particular environment.

The secret is mostly in the software

BTF uses the ASIM system to accurately predict future water demands for each age group of trees. This water demand prediction system uses localized hybrid poplar crop models, 25 years of local AgriMet hourly weather data for evapotranspiration (ET) and growing degree days, multiple independent extended weather forecasts, and real-time soil moisture sensors. Due to the high energy cost for pumping—more than $3,000,000—the ASIM system’s operational objective is to pump only what the trees actually need.

The I-SCADA system, which is one of the most advanced large-scale farm automation systems in the United States, displays the irrigation schedules and keeps track of real-time operation. Each field has three soil moisture sensors at three different depths, and these sensors can be read in real-time. The ASIM and I-SCADA systems together allow BTF to replace daily ET losses, thereby maintaining optimum daily soil moisture around the root zone. This daily replacement of lost soil water produces exceptional high growth in the trees. Measured height increases during peak growth are greater than 5 cm (2 in.) a day, and annual growth rings wider than 4 cm (1.5 in.) are common. This high growth and ET have led to high evaporative cooling, as observed by NASA’s thermal imaging satellite, between the irrigated trees and the surrounding pristine sagebrush habitat. The cooling ranges as high as 12°C (54°F), similar to the temperature difference between a rainforest and desert. As a result, the healthy, fast-growing trees at BTF benefit the neighboring towns and farms by increasing the humidity and moderating the temperatures of this semi-arid region.

The I-SCADA system has also allowed BTF to achieve an irrigation efficiency that is surpassed by no other large-scale irrigated farm in the nation, possibly even the world. The I-SCADA system “spoon feeds” the trees with precise amounts of water and fertilizer four times a day at different rates and start times. The 1,400 sensors and 1,800 controls in the system interact with 153 remote...
terminal units (RTUs). All communications to the RTUs are done by multi-spread spectrum radio telemetry on two independent licensed radio frequencies. The I-SCADA system is designed to control all devices within a radius of 30 km (19 mi) of the central office. All of the I-SCADA system’s remote field actions occur within two seconds of operator command, with full control acknowledgement within five seconds of command initialization.

The I-SCADA system includes auto-shutoff programs to shut down devices independently to mitigate a hydraulic problem and thereby maintain system integrity. The system can also be controlled remotely from any location that has internet or cell phone coverage. This is combined with a real-time alarm/pager system to alert operators of an irrigation situation that would adversely affect irrigation performance or efficiency.

BTF uses an original methodology for scheduling individual field irrigation events to maintain smooth and steady operation of the pumping stations. This methodology is incorporated into the AHBIS program, which optimizes irrigation scheduling so that no pump-
crops, and provide security. GIS assists in field layout for planting (each tree has a grid reference), irrigation system and road layout, inventory control, and general mapping. BTF also uses terrestrial laser imaging detection and ranging (LIDAR) for inventory and harvest purposes.  

**Groundwater recharge:** During winter and spring runoff, BTF’s irrigation system supplies river water to a groundwater recharge basin at the edge of the property. Excess water is also bypassed to the recharge basin during certain periods of the irrigation season. The goal of the groundwater recharge project is to reverse the declining water table in the area and thereby allow the local farmers to grow high-value crops and improve their economic returns.  

**Bioenergy, biofuels, and biochemicals:** Some of the fiber produced at BTF is used as feedstock for conversion into aviation fuel, ethanol, biochemicals (such as methyl acetate), acetic acid, and for bioplastics production. BTF’s high-yielding, fast-growing trees can provide a yield per hectare that is five times the ethanol yield of corn, at a production cost of less than one dollar per gallon of ethanol.  

**Water use and water rights:** BTF runs an unusual water rights program that involves irrigating only a 120 cm (4 ft) zone on either side of the 3 m (10 ft) tree rows while maintaining a 61 cm (2 ft) wide dry zone between the tree rows. This central dry zone allows BTF to meet its water rights obligation while drastically reducing weed growth between the tree rows. To our knowledge, this level of irrigation precision, on such a huge scale, is unique.  

**Breeding and cloning technology:** Besides using carbon isotope discrimination for selection of drought-resistant clone varieties, GWR’s world-renowned hybrid poplar breeding and research station also produces planting stock in the form of high-yielding, fast-growing, disease and pest resistant trees. Breeding is on-going to produce hybrid poplar trees that have lower lignin content for efficient biofuel and biochemical production. Breeding is also on-going to meet the increased demand for high-yielding, fast-growing planting stock for tree farms in other regions of the world.  

BTF’s goal is to develop an economically and environmentally sustainable agricultural system that can produce fiber for biochemical, biofuel, bio-energy, paper, veneer, and solid wood products and that can remain productive in the long run. The adoption of 21st century technology has so far allowed BTF to achieve this goal.  

**As reported on The Amusing Planet website ...**  
Boardman Tree Farm, an innovative poplar farm that employs more than 100 people locally, is located in Morrow County, Oregon, along Interstate 84, five miles west of the I-82 junction. Owned by the GreenWood Tree Farm Fund and operated by a Portland-based tree farm management group, its 10,117 ha (25,000 acres) consist of thousands and thousands of hybrid poplar trees. The trees are neatly arranged in evenly spaced rows, and they are about the same size, height, and thickness. It’s a surreal sight, one of the most eye-catching for miles along Interstate 84.  

The farm is just one of the many holdings of GreenWood Resources in North America, South America, and China, but clearly one of the most accessible, being located next to the interstate. The farm is broken up into 16 and 28 ha (40 and 70 acre) plots, with access roads separating the plots from each other on all sides. Each plot consists of about 600 trees per 0.4 ha (1 acre).  

For more pictures, visit: www.amusingplanet.com/2013/09/boardman-tree-farm-of-greenwood.html.
In a 2005 Resource article [“NSF Million for Virginia Tech,” Resource 12(1), 13-14], Kumar Mallikarjunan and I described the plans of a group of engineering and education faculty members at Virginia Tech who had received a five-year (2004-2009) grant through the Department-Level Reform (DLR) program of the National Science Foundation. Many faculty members from Virginia Tech’s Department of Biological Systems Engineering (BSE) and Department of Engineering Education participated in the funded project, and many faculty members in BSE continue to be involved. The goal of the project was to adopt the spiral curriculum approach to the bioprocess engineering option within the undergraduate BSE program at Virginia Tech.

**Bruner’s spiral**

The spiral curriculum approach is based on the work of Jerome Bruner. In his landmark 1960 book *The Process of Education*, Bruner proposed that education should include early participation in the important work of the student’s chosen discipline. More specifically, as we reported in a 2011 article:

“Bruner’s idea was that learners—even beginners—could engage successfully with the central questions inherent in any discipline if those questions could be presented in a manner that invites real experimentation and inquiry at the appropriate level. One key to this idea is that the learning curriculum could be arranged so that the central questions, or themes, in a discipline would be returned to again and again as the learners advance in their knowledge and intellectual capacity. The learning trajectory is thus represented as a spiral, rather than the linear pathway that is characteristic of traditional schooling” (from “Reformulating general engineering and biological systems engineering programs at Virginia Tech” by V. Lohani, M. L. Wolfe, T. Wildman, K. Mallikarjunan, and J. Connor. In Advances in Engineering Education 2(4). Available at: http://advances.asee.org/vol02/issue04/papers/acee-vol02-issue04-p11.pdf).

In engineering disciplines, the spiral curriculum must include opportunities for students to engage in solving problems that are representative of real engineering work from the beginning of their studies. With time, the problems become more complex and in-depth, and the students’ identity as engineers solidifies.

We viewed the curriculum development process as a design problem: “Design a spiral curriculum for bioprocess engineering.” The design process that we developed can be expressed in seven steps, which gives the appearance of a linear process, but it is actually iterative:

**Step 1.** Define overall outcomes: “What do bioprocess engineers need to be able to do when they graduate?” We defined four overall technical outcomes: (1) design a reactor, (2) design a process and optimize the process conditions, (3) select units in the process and design a plant layout, and (4) control the process—plus a fifth outcome that focused on professional skills, e.g., teamwork, ethical responsibility, and lifelong learning.

**Step 2.** Develop concept maps to identify knowledge areas, or subject matter expertise, related to each outcome.

**Step 3.** For each subject matter or knowledge area identified in step 2, identify the specific topics that the students need to know to attain each outcome.

**Step 4.** Develop spiral learning objectives to define the specific knowledge and skills that the students need to attain the overall outcomes. Increasing cognitive levels are included.

**Step 5.** Develop learning modules, i.e., combinations of learning activities, to facilitate student achievement of a set of learning objectives, as well as activities to assess student learning.
Step 6. Incorporate each learning module into existing courses, or:

Step 7. Develop new courses to include the learning modules.

We found that we implemented steps 5, 6, and 7 iteratively. We did not develop all of the learning modules and then incorporate them into existing courses or new courses. Rather, we developed a module and then implemented it. This helped guide our development of the next module. By the end of the project funding, we had developed and implemented several learning modules, and we were in the process of fully implementing a spiral curriculum. In the article quoted earlier, we presented a comprehensive description of the funded project and its results.

Change begets change

In the meantime, we have continued to develop and implement additional learning modules, and we have made other changes based on spiral theory. For example, the funded project focused on the bioprocess engineering area of the BSE curriculum. Since then, the faculty members who focus on the watershed science and engineering (WSE) area of the BSE curriculum have applied spiral theory to the WSE area. The group has essentially worked through steps 1 through 7 and revised and rearranged courses to be more consistent with spiral theory. In the first phase of the revisions, the group revised three courses; in the second phase, the group anticipates further course expansions and revisions.

During the funded project period, we implemented our first learning module in the sophomore-level “Introduction to BSE” course (course number BSE 2004). Since the project ended, we have further revised the learning objectives (what the students will know and be able to do by successfully completing the course) and the structure of the course to include learning modules (step 5) that introduce the fundamental concepts within the discipline. While a single instructor coordinates the overall course, different faculty members lead the different modules that introduce fundamental concepts such as mass and energy balances, microbial metabolism, and enzyme kinetics, as well as engineering design, engineering problem-solving tools and techniques, laboratory and field safety, communication skills, teamwork, and engineering ethics.

The most recent application of spiral theory occurred as we were ensuring that all of our major design experience projects incorporate appropriate engineering standards. Faculty discussion led to the realization that the concept of standards was not a theme in the curriculum, and it should be. So we identified opportunities to introduce standards early in the curriculum and to reinforce the use of standards throughout the curriculum—creating a standards spiral. The first draft of the standards spiral in BSE courses is the following:

BSE 2004 Introduction to BSE: Incorporate the use of ASTM standards in the Basic Measurements laboratory. Incorporate a section on citing standards in documents in the BSE Guide to Laboratory Reports (this guide is introduced in this course and used in laboratory courses throughout the curriculum). Explicitly require students to complete sophomore design exercises using standards.

BSE 3324 Small Watershed Hydrology: Use USDA-NRCS standards for the design of vegetated waterways.

BSE 3334 Nonpoint-Source Pollution Assessment and Control: Use USDA-NRCS standards for the design of best management practices.

BSE 3524 Unit Operations: Include ISO and ASTM measurement standards in laboratory exercises.

BSE 4524 Biological Process Plant Design: Students use SuperPro Designer software, which incorporates standard designs for process components (e.g., heat exchangers, fermenters, etc.). The standards on which these components are based will be included in the course material.

BSE 4125-4126 Senior Design: Require incorporation of appropriate standards in every project and in all project reports.

The funded project allowed BSE to begin the journey of implementing spiral learning into our curriculum, and we are very excited to continue this journey to improve the BSE education process, and to improve the learning experience of our BSE students. The impacts on student learning have been significant, and we expect continued positive impacts.

ASABE Fellow Mary Leigh Wolfe, Professor and Department Head, Department of Biological Systems Engineering, Virginia Tech, Blacksburg, USA, mlwolfe@vt.edu.
The “Threads” of Biosystems Engineering

Demetres Briassoulis

The core concepts, or threads, of biosystems engineering are variously understood by those of us within the discipline but have never been unequivocally defined due to the discipline’s early stage of development. This complicates the use and interpretation of terminology, as well as compatibility of the programs of study, compared to other well-established engineering disciplines. A common definition of the emerging discipline of biosystems engineering is clearly needed at the international level.

Defining BSEN

Traditionally, agricultural engineering has applied engineering science and technology to agricultural production and processing. Agricultural engineering combines the disciplines of animal biology, plant biology, and mechanical, civil, electrical, and chemical engineering with knowledge of agricultural principles. In the same way, biosystems engineering is a field of engineering that integrates engineering science with applied biological, environmental, and agricultural sciences. This emerging discipline has been described in various ways. In Europe, there is a consensus on the use of the term biosystems engineering, but various terms are used across the United States, such as biological engineering, biological systems engineering, and food engineering. In some U.S. institutions, biosystems engineering is synonymous with biological engineering. However, in other U.S. institutions, biosystems engineering is considered a broader term that includes both biological engineering and agricultural engineering.

In the framework of recent European and international projects, biosystems engineering, or BSEN, has become a common descriptor for the relevant programs of study in Europe, the United States, and internationally. The overarching mission of BSEN (encompassing agricultural, food, and biological engineering) is to “integrate life and engineering for the enhancement of complex living systems.” BSEN represents an evolution of the agricultural engineering discipline that applies to all living organisms but generally does not include biomedical applications. BSEN is also defined as “the branch of engineering that applies engineering sciences to solve problems involving biological systems.” Note that this definition excludes two related disciplines: biomedical engineering (which has a human biology background and is also referred to as bioengineering) and biotechnology (which is not an engineering discipline).

In Europe, the key objective for BSEN programs of study is to ensure that they offer essential fundamental engineering knowledge and competencies. With this in mind, a core curriculum for agricultural and biosystems engineering programs in Europe has been developed by the USAEE (University Studies of Agricultural Engineering in Europe).
The agricultural sciences part of the core curriculum includes a non-engineering component drawn from traditional programs in agricultural engineering. However, agricultural engineering is considered a subset of BSEN. Similarly, BSEN is also founded on environmental science, engineering and food science, and engineering. Thus, the biological sciences part of a modern BSEN curriculum may be more essential to this emerging discipline. To avoid confusion during the transition period from traditional agricultural engineering to the emerging BSEN discipline, and in accordance with the corresponding terminology of the core curriculum, the dual term agricultural/biological sciences is used.

Defining BSEN competencies

The BSEN core curriculum in Europe includes core competencies but does not include mid-level competencies, or specialization-dependent competencies, which are related to applied BSEN topics and are defined by the individual program of study. These mid-level competencies and learning outcomes, as well as advanced-level knowledge and skills, have been defined in a structured way in the framework of the EU-US Atlantis project.

For illustrative purposes, the mid-level competencies and learning outcomes for six specializations within BSEN, which were selected from all the various BSEN specializations, have been defined, and the domain-specific knowledge to be acquired for each outcome has been proposed. These six specializations are bioprocess engineering, bioenergy systems, bio-based materials, biosystems informatics and analysis, structural systems, materials and environment for biological systems, and water resources engineering. In the near future, this initial work will be extended to include the remaining BSEN specializations (e.g., mechanical systems, waste management, etc.). Once the proposed definitions have been adopted, these threads will be available for the global development of biosystems engineering as a program of study, as an engineering discipline, and ultimately as a profession.

For further explanation of the core competencies and learning outcomes that have been proposed for academic programs in biosystems engineering, see “The ‘Threads’ of Biosystems Engineering” in Transactions of the ASABE 57(1).

Demetres Briassouls, Professor, Department of Natural Resources and Agricultural Engineering, Agricultural University of Athens, Greece, briassou@aua.gr.
Sometimes it’s frustrating to do engineering. My own area of study is microbial processes, and the source of my frustration is the limited information that’s typically available whenever I’m trying to develop a new process. I hear the same complaint from my students, and I understand how they feel. Even worse, sometimes it’s not just a large chunk of knowledge that’s missing; there are often no formal rules to use in initiating the design.

Perhaps more engineers encounter this situation. Ancient engineers certainly did. Those who designed the first simple machines certainly lacked advanced tools and deep theoretical knowledge. Of course, early designs often focused on mechanical innovations for military advantage, such as the catapult, ballista, and counterweight trebuchet, but many innovations served civic needs. Aqueducts conveying water over long distances facilitated the expansion of agriculture and the growth of urban centers. These ancient systems were all “engineered” prior to any scientific understanding. Practical demands, like how to fend off an invasion, had to be addressed before that fundamental knowledge could be acquired. And, like me, early engineers often didn’t get it right the first time and had to refine their designs. Lead pipes, and more recently asbestos, come to mind.

As the Renaissance sparked scientific discoveries, technical innovations applied that new knowledge to meet growing societal expectations for security, health, comfort, and convenience. Even with burgeoning scientific knowledge, though, the science could still be incomplete for engineers who were merely trying to meet evolving societal needs. An empirical, practical understanding could allow progress without fundamental understanding, or even formal training. I am inspired by James Watt, who, with curiosity, intellect, and a wealth of experience in working with scientific instruments,
made key engineering improvements to the steam engine, which facilitated the Industrial Revolution. And he did this a century before the development of thermodynamics, which explained how the steam engine actually worked. It’s hard to overstate how important his developments were to the mechanization of agriculture, and many other fields.

**Emerging field, emerging hope**

Science seldom neatly precedes engineering and technological developments, and that’s the typical challenge faced by engineers. Perhaps there’s hope for me and others who work in the emerging field of biological engineering!

Biology has lagged behind other disciplines because the tools needed for its study required first the maturity of physics and chemistry. The quantitative description of biology has seemed particularly slow. Even for engineers in the recent past, the living world was often the source of system constraints: biology did not inform the design; instead, it was something that had to be dealt with. This perspective slowly began to change 60 years ago when the structure of DNA and its genetic code were elucidated. The very existence of a “code” implied the prospect of numerical representation, as well as the development of algorithms to interpret the code and create designs using its architecture. At last we have “engineering biology”—formal design rules with predictive power for developing, assembling, and synthesizing biological systems from scratch.

In my field, another breakthrough occurred in the 1980s when the polymerase chain reaction (PCR) was developed. Just as Gutenberg’s movable-type printing press allowed books to become widely available (with huge social consequences), so does PCR enable a new era in which the DNA code will become widely accessible. And just as the steam engine prompted the science of thermodynamics and new mechanical devices, new science and engineering will emerge from PCR technology as well.

**Biology-inspired engineering**

There is much engineering to learn from biology. In contrast to physics and chemistry, biology is uniquely self-designing, and it teaches us all about efficiency. I am in awe of the elegant designs found in biology. Consider the structure of proteins: a stunningly efficient architecture that uses only 20 building blocks (the amino acids) to assemble thousands of different catalysts, as well as structural components like collagen, and even gas carriers like hemoglobin. Wouldn’t it be remarkable if all our engineered products, from washing machines and tractors to toothbrushes and televisions, could be assembled from various combinations of only 20 parts? Moreover, imagine that once the useful life of a product was complete, it could be neatly disassembled back into its components, which would then be re-used in the construction of some other useful device. We are just beginning to articulate and formulate the fundamental design principles of biology, but efficient use of resources and total sustainability are two such principles that we can apply to engineering. It is exciting to watch the development of this biology-inspired engineering.

A new generation of engineers already draws inspiration from biology in many application domains. One such area is the design of new materials. For example, engineers have noted that insect cuticles and crustacean shells have remarkable strength, which is related to their complex structure of alternating...
layers of chitin and proteins. Engineered laminates made to mimic the cuticle have the strength and toughness of aluminum alloys with only half the density. In addition, because they can be easily transformed between rigid and flexible states, these biomaterials can be molded into fine structures, such as artificial blood vessels and scaffolds for tissue regeneration. As another example, engineers are conceiving entire manufacturing processes modeled on the organization of living systems. Such a process might emulate human cognitive behaviors: perception, reasoning, and execution, as well as cooperation, reactivity, and even pro-activeness. The same processes that arise in an ant colony through collective intelligence can be implemented to optimize technological processes. Such flexible systems are particularly useful in responding rapidly to process disturbances.

Innovative devices and processes that are inspired by biology will also be implemented in application domains that haven’t even occurred to me, or to anyone, yet. Whatever your own area of interest (or source of frustration, as the case may be), think about how new materials can be applied in ways that advantageously replicate biological functions. Can the systems you study be designed to leverage natural activities in some way, maybe to self-adjust or to evolve by design? Can engineered systems be designed to detect their own needs, and then initiate processes to provide for those needs? What are the formal design rules?

We are all engineers

The Institute of Biological Engineering (IBE) is a forum for engineers and scientists who are inspired by biology. IBE’s vision is to promote development of the principles of biological engineering, and to serve as a catalyst for applying these principles in meeting societal needs. Naturally, most members of IBE, like me, are also active members of professions in the application domains of biological engineering, such as applied microbiology, biomaterials, medicine, or agriculture. This diverse membership benefits IBE; our members collaborate across disciplines to articulate and advance the broad principles of biological engineering.

Collaboration with IBE also benefits professions that have a focus in application domains, by broadening their science base and sharing advances in our understanding of life processes. Our members are working to create in IBE a kind of biological system—adaptive as we struggle to formalize how biology can inspire our designs, and collaborative in networking with other organizations to advance engineering solutions to society’s challenges. Because biology is so intimately linked to the societal need for food, the opportunities for biology to inform the design of agricultural systems are particularly promising.

I believe that biological engineering will be the most important engineering discipline in the 21st century, and it will affect all aspects of our society. Biology is an integral theme in at least half of the fourteen “Grand Challenges for Engineering” identified in 2008 by the U.S. National Academy of Engineering. Meeting societal challenges such as sustainability, managing the nitrogen cycle, providing access to clean water, developing better medicines, and protecting our global environment will require partnerships between many scientists and engineers. Let’s work to build these linkages. As engineers, and as human beings, we’re all in this together.

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Offset design improves round-bale unroller

_In Brief:_ ASABE member John Wilhoit and Timothy Coolong of the University of Kentucky have introduced a new technology that can make the application of organic mulches more efficient. The team altered a conventional round-bale unroller and designed experiments to document its efficiency.

“We modified an unroller so that the new design would be offset, allowing the tractor to straddle a row and unroll the bale in the space between adjacent rows,” explained Wilhoit. “Then we tested the modified unroller with several types of organic mulches for between-row weed control in organic watermelon plots. Mulching between the rows can be an effective practice for controlling weeds. Our modification makes mulching with round bales of hay or wheat straw more efficient.”

For the experiments, the offset round-bale unroller was used to apply hay and wheat straw mulch to between-row areas of Crimson Sweet watermelons in 2009 and 2010. The mulches were also applied at two thicknesses by using one or two layers unrolled from round bales. “The results showed a significant interaction of mulch type and year for weed control,” Coolong said. “One-year-old hay had less impact on weed control in 2010 compared with new hay in 2009, but other mulches had improved weed control in 2010. One-year-old wheat straw and new hay had the lowest levels of weed biomass compared with new wheat straw and the no-mulch control.”

The experiments also proved that the thickness of the mulch affected weed control, with mulches applied in two layers resulting in significantly less weed biomass than those applied in one layer. “These results suggest that hay and wheat straw mulches can be an effective weed control when used in conjunction with cultivation,” Wilhoit stated. “Weed control with all of the mulches was significantly better than the control. Our results also indicated that adequate weed control could be achieved with a single layer of mulch, reducing costs for mulching with round bales. The hay and wheat straw mulches were all effective in weed control, even at application rates in the range of 15,000 to 20,000 pounds per acre.”

“Our results showed that an offset bale unroller can make mulching of vegetable crops more efficient. The mulches used in our study are commonly available and relatively inexpensive in Kentucky. However, our offset bale unroller design could likely be used with other mulches that may be more commonly available in other regions of the United States,” Coolong concluded. The researchers added that any conventional bale unroller can be modified like the one used in the study, provided that the clamping arms are open at the end where they pivot on the toolbar, allowing an additional length of toolbar to be welded on.

For more information, contact John Wilhoit, jwilhoit@bae.uky.edu, or Michael Neff, American Society for Horticultural Science, mwneff@ashs.org.
Cellulose nanocrystals are a “green” wonder material

In Brief: The tiny cellulose crystals that give trees and plants their high strength, light weight, and resilience have been shown to have the stiffness of steel. These nanocrystals may be used to create a new class of biomaterials with wide-ranging applications, such as construction materials and automotive components.

Calculations using precise models based on the atomic structure of cellulose show that the crystals have a stiffness of 206 gigapascals, which is comparable to steel, said Pablo Zavattieri, assistant professor of civil engineering at a Purdue University in West Lafayette, Ind. “This material has really amazing properties,” he said. “It is abundant, renewable, and produced as waste in the paper industry.”

The nanocrystals are about 3 nm wide by 500 nm long—or about 1/1000th the width of a grain of sand—making them too small to study with optical microscopes and difficult to measure with laboratory instruments. “It is very difficult to measure the properties of these crystals experimentally because they are so tiny,” Zavattieri said. “So, for the first time, we have predicted their properties using quantum mechanics.” The findings represent a milestone in understanding the fundamental mechanical behavior of cellulose nanocrystals.

“It is also the first step toward a multiscale modeling approach to understand and predict the behavior of individual crystals, the interaction between crystals, and their interaction with other materials,” Zavattieri said. “This is important for the design of novel cellulose-based materials, and other research groups are considering them for a huge variety of applications, ranging from electronics and medical devices to structural components for the automotive, civil engineering, and aerospace industries.”

Cellulose nanocrystals represent a potential green alternative to carbon nanotubes for reinforcing materials such as polymers and concrete. Potential applications for biomaterials made from cellulose nanocrystals include biodegradable plastics and textiles, flexible batteries made from conductive paper, new drug-delivery technologies, flexible displays for electronic devices, special filters for water purification, and new types of sensors and computer memory devices.

Cellulose can be extracted from a variety of biological sources, including trees, plants, algae, ocean-dwelling organisms called tunicates, and bacteria that create a protective...
web of cellulose. “With this in mind, cellulose nanomaterials are inherently renewable, sustainable, biodegradable, and carbon-neutral, like the sources from which they were extracted,” Zavattieri said. “They have the potential to be processed at industrial-scale quantities and at low cost compared to other materials.”

Biomaterials manufacturing with cellulose nanocrystals could be a natural extension of the paper and biofuels industries, using technology that is already well established for cellulose-based materials. “Some of the byproducts of the paper industry now go to making biofuels, so we could just add another process to use the leftover cellulose to make a composite material,” Zavattieri said. “Cellulose crystals are harder to break down into sugars to make liquid fuel, so let’s use them for other products, and build on the existing infrastructure of the pulp and paper industry.”

The surfaces of the crystals can be chemically modified to achieve different surface properties. “For example, you might want to modify the surface so that it binds strongly with a reinforcing polymer to make a tough composite material,” Zavattieri said. “Cellulose crystals are hard to break down into sugars to make liquid fuel, so let’s use them for other products, and build on the existing infrastructure of the pulp and paper industry.”

The surfaces of the crystals can be chemically modified to achieve different surface properties. “For example, you might want to modify the surface so that it binds strongly with a reinforcing polymer to make a tough composite material, or you might want to change the chemical characteristics so that it behaves differently in different environments,” Zavattieri said.

Zavattieri plans to extend this research to study the properties of alpha-chitin, a material derived from the shells of organisms including lobsters, crabs, mollusks, and insects. Alpha-chitin appears to have mechanical properties similar to those of cellulose. “As a waste product of the food industry, this material is also abundant and renewable, just like cellulose,” he said.

For more information, contact Pablo Zavattieri, zavattie@purdue.edu, Emil Venere, venere@purdue.edu, or Robert Moon, robertmoon@fs.fed.us.

Kitty litter: A new use for spent corn grains

In Brief: Processing the spent grains left over from corn ethanol production can produce a kitty litter that’s nearly 100% biodegradable. USDA-ARS plant physiologist Steven Vaughn and his colleagues have shown that litter made with these grains as the starting material may prove to be more environmentally friendly than popular but nonbiodegradable clay-based litters.

After use, clay kitty litters mostly end up in landfills. Spent grains, also known as dried distiller’s grains (DDGs), may provide a new and perhaps higher-value market for the tons of DDGs that corn ethanol refineries now primarily market as a cattle feed ingredient.

In preliminary studies, Vaughn’s group tested “x-DDGs.” These are DDGs that, after being used for ethanol production, are treated with one or more solvents to extract any remaining, potentially useful natural compounds.

The team’s laboratory experiments yielded a suggested formulation composed of x-DDGs and three other compounds: glycerol, to prevent the litter from forming dust particles when poured or pawed; guar gum, to help the litter clump easily when wet; and a very small amount of copper sulfate, for odor control. The resulting litter is highly absorbent, forms strong clumps that don’t crumble when scooped from the litter box, and provides significant odor control, according to Vaughn.

The idea of using corn or other grains as the basis of an environmentally sound cat litter isn’t new. But Vaughn’s group may be the first to extensively study the potential of x-DDGs as the primary component of a litter, and the first to make their results publicly available.

For more information, contact Marcia Wood, USDA Public Affairs Specialist, marcia.wood@ars.usda.gov.
Algae to crude oil: Million-year natural process takes minutes in the lab

In Brief: Engineers at the U.S. Department of Energy’s Pacific Northwest National Laboratory (PNNL) have created a continuous chemical process that produces useful crude oil minutes after they pour in harvested algae—a verdant green paste with the consistency of pea soup. The PNNL team combined several chemical steps into one continuous process that starts with an algae slurry that contains as much as 80% to 90% water. Most current processes require the algae to be dried—an expensive process that takes a lot of energy. The new process simplifies the transformation of algae into oil, water, and usable byproducts. A biofuels company, Utah-based Genifuel Corporation, has licensed the technology and is working with an industrial partner to build a pilot plant using this technology.

In the PNNL process, a slurry of green algae is pumped into the front end of a chemical reactor. Once the system is up and running, crude oil is produced in less than an hour, along with water and a usable byproduct stream. With additional conventional refining, the crude algae oil can be converted into aviation fuel, gasoline, or diesel fuel. The byproducts can be processed further to yield burnable gas and usable substances such as potassium and nitrogen, which, along with the cleaned water, can be recycled to grow more algae.

While algae have long been considered a potential source of biofuel, and several companies have produced algae-based fuels on a research scale, the resulting fuel has been projected to be expensive. The PNNL process harnesses algae’s energy potential efficiently and incorporates a number of methods to reduce the cost of producing algae fuel. “Cost is the big roadblock for algae-based fuel,” said Douglas Elliott, who led the PNNL team. “We believe that the process we’ve created will help make algae biofuels much more economical.”

The PNNL team simplified the production of crude oil from algae by combining several chemical steps into one continuous process. The most important cost-saving step is that the process works with wet algae. Most current processes require the algae to be dried—a process that requires much energy and is therefore expensive. The new process works with an algae slurry that contains as much as 80% to 90% water. “Not having to dry the algae is a big win in this process. That cuts the cost a great deal,” said Elliott. “And there are other bonuses, such as being able to extract usable gas and recycle the water and nutrients to help grow more algae, which further reduce the costs.”

While a few other groups have tested similar processes to create biofuel from wet algae, most of that work has been done one batch at a time. The PNNL system runs continuously, processing about 1.5 L (0.4 gal) of algae slurry in the research reactor per hour. While that doesn’t seem like much, it’s much closer to the type of continuous system required for large-scale commercial production.

The PNNL system also eliminates another step required in today’s most common algae-processing method: the need for complex processing with solvents such as hexane to extract the energy-rich oils from the rest of the algae. Instead, the PNNL process works with the whole algae biomass, subjecting it to very hot water under high pressure to tear apart the substance, converting most of the biomass into liquid and gas fuels.

The system runs at around 350°C (662°F) at a pressure of around 20.7 MPa (3000 psi), combining processes known as hydrothermal liquefaction and catalytic hydrothermal gasification. Elliott says such a high-pressure system is not easy to build, which is one drawback to the technology, although the cost savings on the back end more than make up for the initial investment. “It’s a bit like using a pressure cooker, only the pressures and temperatures are much higher,” said Elliott. “In a sense, we are duplicating the geological process that converted algae into oil over the course of millions of years. We’re just doing it much, much faster.” The products of the process are:

- Crude oil, which can be refined into aviation fuel, gasoline, or diesel fuel. In the team’s experiments, generally more than 50%, and sometimes as much as 70%, of the algae’s carbon is converted to energy in crude oil.
• Clean water, which can be re-used to grow more algae.
• Fuel gas, which can be burned to make electricity or cleaned to make natural gas for vehicle fuel in the form of compressed natural gas.
• Nutrients such as nitrogen, phosphorus, and potassium, which are key nutrients for growing algae.

Elliott has worked on hydrothermal technology for nearly 40 years, applying it to a variety of substances, including wood chips and other substances. Because of the mix of earthy materials in his laboratory, and the constant chemical processing, he jokes that his laboratory sometimes smells “like a mix of dirty socks, rotten eggs, and wood smoke”—an accurate assessment.

Genifuel Corporation has worked closely with Elliott’s team since 2008, licensing the technology and working initially with PNNL through The Department of Energy’s Technology Assistance Program to assess the technology. “This has really been a fruitful collaboration for both Genifuel and PNNL,” said James Oyler, president of Genifuel. “The hydrothermal liquefaction process that PNNL developed for biomass makes the conversion of algae to biofuel much more economical. Genifuel has been a partner to improve the technology and make it feasible for use in a commercial system.”

“It’s a formidable challenge, to make a biofuel that is cost-competitive with established petroleum-based fuels,” Oyler added. “This is a huge step in the right direction.”

A video about the technology is available at: http://www.youtube.com/watch?v=Qs0QZJ0rea0.

For more information, contact Tom Rickey, News and Media Relations, Pacific Northwest National Laboratory, tom.rickey@pnnl.gov.
Biodegradable packaging from cotton waste

In Brief: Proprietary agricultural waste blends provided by USDA scientists to industry partners are being used in a new process that literally grows custom packaging material to protect computers and other breakables during shipping.

The biodegradable blends were developed by ASABE member Greg Holt and his colleagues at the USDA-ARS Cotton Production and Processing Research Unit in Lubbock, Texas. His industry partner, Ecovative Design of Green Island, N.Y., developed the patented method that uses fungi to “grow” packaging material.

The process involves combining cotton gin waste and fungi inside a mold, called a “tool.” Woody cotton waste is blended, pasteurized, and embedded in the customized tool. Then the tool is injected with fungus, which grows onto, in, and around the cotton waste, eventually forming a new, consistently textured, solid mass. The two ingredients become one, resulting in a spongy-looking material similar in appearance to polystyrene foam.

When the tool is opened, the custom-shaped packaging material emerges. The material is biodegradable, compostable, and flame retardant, and it has the cushioning strength of synthetic packaging material. This new process provides a cost-effective “green” alternative to extruded polystyrene foam packaging—an estimated $2 billion market.

To learn which blends meet or exceed the characteristics of extruded polystyrene foam, the researchers evaluated the physical and mechanical properties of six different cotton byproduct blends as a substrate for fungal colonization. Each blend was inoculated with a single fungus strain using two different inoculation methods, for a total of 12 treatments. Overall, the treatments tested well, and the results indicated that the specific blend and inoculation method can be adjusted based on the intended end use of the material.

For more information, contact Rosalie Marion Bliss, USDA Public Affairs Specialist, rosalie.bliss@ars.usda.gov.

New technique may drive down biofuel production costs

In Brief: Researchers at North Carolina State University have developed a simple, effective, and relatively inexpensive technique for removing lignin from the plant material used to make biofuels, which may drive down the cost of biofuel production. They used protic ionic liquids (PILs) to dissolve lignin from biomass, leaving behind the energy-rich cellulose, which can be used to make biofuels. The lignin can then be removed from the PIL, allowing the PIL to be used repeatedly.

Lignin, nature’s way of protecting plant cell walls, is difficult to break down or remove from biomass, such as corn stover. However, lignin needs to be extracted in order to release the energy-rich cellulose that is used to make biofuels.

“Finding inexpensive ways to remove lignin is one of the largest barriers to producing cost-effective biofuels,” says Ezinne Achinivu, a doctoral student in chemical and biomolecular engineering at NCSU. “Our approach is very promising.”
The researchers began by making a number of liquid salts called protic ionic liquids, or PILs. These PILs are inexpensive to prepare and are made by mixing an acid, such as acetic acid, and a base (specifically, an amine). As part of the pretreatment process, a PIL formulation is mixed with biomass and then heated and stirred. The lignin dissolves into the PIL, leaving the cellulose behind as a solid. The cellulose, which is now much easier to process, is then easily filtered from the mixture for use in subsequent biofuel production steps.

The remaining PIL and lignin solution can then be heated to distill and recover the PIL, leaving the lignin behind as a black powder. The PIL can be re-used, and the lignin is also valuable because it can be used to manufacture polymers or other chemical products, which could supplement the cost of running the biofuel production facility.

“This PIL-based technique can be easily scaled up and is likely to be both more energy efficient and less expensive than existing biomass pretreatment techniques for removing lignin,” Achinivu says.

The researchers are currently working to apply the technique to wood and other biomass feedstock materials, as well as to fine-tune the interactions between PILs and lignin.

“If we can better understand how the PIL dissolves the lignin, we can make the process even more efficient by using less energy while extracting more lignin,” Achinivu says.

For more information, contact Ezinne Achinivu, ecachini@ncsu.edu, or Matt Shipman, NCSU News Services, matt_shipman@ncsu.edu.
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I Love Teaching, but I Hate Grading

William Kisaalita

It was one of those fall football Saturdays when our campus turns into one big tailgate party. Typically, faculty don’t come to campus on such days—a decision made easier by the university revoking our parking permits for the day—to accommodate the influx of visitors with game tickets.

This Saturday, though, I had a ticket for the game. Two hours before the kickoff, I went to my office in the engineering building to grade some papers that were two weeks overdue. I ran into a junior colleague in the hallway and jokingly inquired what he was doing in the building on a game day. His response was, “I love teaching, but I hate grading.” I offered a vague encouraging remark, which he didn’t seem to buy, and we both headed to our offices.

After reflecting on my colleague’s statement, I realized that I felt the same way, which probably explains why I’ve had to constantly devise strategies, sometimes with little success, to get my grading done in a timely manner. I decided to write this short piece to help my teaching colleagues—first, to know that they are not alone, and second, to help lower the “activation energy” required for getting on with the grading process. Following are a few strategies that have worked for me.

For engineering science courses like mechanics, for which right answers exist for assigned problems, I always request a teaching assistant (TA). With my guidance, the TA does all the grading. I use this relationship to mentor the TA to develop teaching skills, which sometimes involves the TA preparing and delivering lectures under my watch. This takes a load off me, and it benefits the TA. A 2011 study conclusively showed that graduate students who engage in meaningful teaching experiences improve their research skills (see “Graduate students’ teaching experiences improve their methodological research skills” by D. Feldon, et al., in Science 333(6045): 1037-1039).

I’ve recently been assigned to teach a graduate research methodology class that is required for all incoming graduate students. In this class, essay assignments are frequently used as teaching tools. Because such assignments have no right or wrong answers, and their quality is based on how well the students support their point of view, it is most appropriate that I do the grading. Creating a “grading key” in advance helps to improve the assigned question and also makes it much easier for me to get started on grading the completed assignments. This key also comes in handy for explaining my grading, especially when unhappy students demand to know why points were deducted.

To concentrate on grading, I step away from the office, which is full of things that are easier to do than grading. Responding to e-mails, talking with drop-in students and colleagues, reading journal articles, etc., are all much easier, and they become excuses to delay the grading chore. Going to the library is not a good idea either, because the library is full of books and magazines with inviting covers that shout “pick me up and read me.” Going to a place with few distractions, like the student cafeteria, and finding a corner table works best. Once I get there, I switch off my phone, get a cup of coffee, and focus on grading. I don’t leave until I’ve reached my target, which may be getting through half the papers in one sitting.

I’ve recently introduced peer evaluation in my classes. In engineering curricula, peer evaluation has been used in capstone design projects, and other classes have used it to assess individual contributions to group work. In the graduate class that I mentioned above, the students often make short presentations of about four minutes each. Each student is also assigned two peer presentations to evaluate anonymously. The students are asked to provide an assessment with respect to strengths, areas for improvement, and any other comments that they may want to add. Their comments have been very accurate. Most of the time, I don’t have to add any comments of my own. The students also take their peers’ comments very seriously. After receiving this peer feedback, many students have come to my office to discuss the comments and get suggestions on how to address their deficiencies.

Grading often seems a monotonous activity, but—if it’s done right—it is an integral part of enhancing student learning. By viewing grading that way, I am more motivated to adopt strategies that help me do it well and in a timely manner. The strategies that I’ve provided above may not be suitable for some classes. In such cases, more appropriate strategies have been devised by others. I hope that this short piece will start a conversation about grading, and I especially encourage sharing of grading strategies that have worked in different situations.

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