Looking at the impressive array of topics and experts who contributed to this issue of Resource, I asked what more I could contribute on the future of agricultural machinery. Let me just touch on a few of the changes where I see building blocks already in place.

Precision agriculture has the potential to change ag machinery even more than the application of hydraulics did fifty years ago. Until recently, precision ag meant guidance to prevent overlaps in field operations while planting in straight rows. In the future, precision ag technology will assist our stewardship efforts by applying inputs more precisely, with site-specific prescriptions, taking full advantage of cropland potential. As new sensors are developed, precision ag will mean seeding, application, and harvesting on a sub-meter scale, and an individual-plant scale may not be out of the question. This precision will increase production while reducing inputs.

Along with new sensors, the use of RFID tagging and data collection throughout the production chain will make seed-to-table tracking a reality. This technology will allow producers to benefit from their efforts, and it will inform consumers on product sources and production methods.

Autonomous implements are in the design stage today and will soon debut in commercial platforms, performing in ways that were once unimaginable by producers burdened with labor shortages—and by agricultural workers burdened with repetitive tasks. This technology will include master-slave units that operate in harmony over large areas; armies of small robots that weed, feed, and apply pesticides on a plant-by-plant basis; and simultaneous operation of multiple pieces of equipment in diverse locations—all controlled from the producer’s home office. Unmanned aerial vehicles will collect much of the needed data.

Finally, as the demand for clean water increases, the cost of water and the need to use it efficiently may soon be on par with energy. The progress in irrigation systems—from flood to center-pivot, to drip, to subsurface drip—has improved water use efficiency for crop production. However, while major improvements have been made, the challenge is still great. The International Fund for Agricultural Development estimates that 70% of freshwater worldwide is currently used for irrigation, and 22% is used for industry, which includes processing of agricultural products. Improved irrigation equipment, such as mobile drip technology (a combination of center-pivot and drip irrigation), has the potential to improve the water use efficiency of center-pivot systems as much as sprinklers improved on flood irrigation by virtually eliminating evaporative losses. At the same time, significant potential lies in water treatment technologies to improve water quality and reuse.

The next quarter-century will be a challenging—and rewarding—time for those involved in developing the agricultural machinery and associated technologies needed to feed our growing global population. ASABE members will be at the center of this effort.

Let me know your thoughts at mherron@myasabe.org.

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Bernard E. Romig
After two decades of ASABE membership, there are some who still consider me young. One of those people is my mom. However, she would also tell you that I was probably born a couple of generations too late. You see, although I’ve worked as an engineer helping to develop some of the most advanced agricultural equipment of our time, I still enjoy using the machines of yesteryear—machines like a husking peg to harvest corn and a pitchfork to clean manure from a livestock pen.

In its most basic form, a “machine” is defined as an instrument designed to transmit or modify the application of power, force, or motion, so my examples are indeed machines. In some parts of the world, this is “machine” state-of-the-art. In the United States, Canada, and Western Europe, a “machine” has for decades been known as an assemblage of parts that transmit force, motion, and energy from one to another in a predetermined manner, or as a piece of equipment with moving parts that does work when it’s given power from electricity or a combustible fuel source. This would be the “machine” that likely comes to mind for most of you.

Consider the image above. Would you consider this example of using a “machine” something from the past, from the present, or from the future? In some areas of the globe, and in some food and fiber production systems, mechanically applying pesticides or fertilizer is alien. In other areas, this form of application would be considered not only archaic but also unsafe. When thinking about the frontiers of agricultural machinery, many would like to conjure up images similar to that shown on the cover of Resource almost six years ago, in “The Farm of the Future” special issue of January/February 2011, where robotic machines were operating autonomously in a cornfield. However, autonomy is only one of many frontiers to consider.

With the gracious contributions of many ASABE members, I have attempted to gather articles to allow you, the reader, to consider the myriad of agricultural machine frontiers that we as agricultural and biological engineers need to consider. I have tried to cover the gamut from smallholder production to broad-acre production, from specialty crops to commodity crops, and from traditional horsepower to renewable horsepower. These articles tell of global efforts you might not have heard of before, and of regional efforts that could have global implications. Hopefully, some of the frontiers that our authors have highlighted will seem like old news, and others will surprise you. If so, then I’ve completed my task well, as old frontiers for some will be new frontiers for others.

Thank you for the opportunity to serve as your guest editor for this issue.

By the way, if you don’t remember “The Farm of the Future” special issue, pull it out of your stack of old magazines or download it from the ASABE website (http://www.asabe.org/media/222755/resource18-01janfeb2011.pdf). Compare the views on agricultural machinery from back then to the views expressed in this issue. You may be surprised by what has changed, and what hasn’t.
Smallholder agriculture is the backbone of food production capacity throughout the developing world and thereby represents one of the keys to ensuring long-term global food security. The global population is set to exceed 9 billion by 2050, so the need to produce more food is immediate and urgent. The world’s half-billion smallholder farms produce about 80% of our food, and they will be required to carry the burden of increasing food production by over 60% compared to 2007 levels in the next three decades. This production intensification will need to take place against a background of natural resource degradation, especially of soils. The majority of the world’s soil resources are in poor condition, with a third dangerously degraded due to erosion, salinization, compaction, acidification, and chemical pollution. In this situation, sustainable intensification will require natural resource-friendly production systems. Chief among these will be some form of conservation agriculture with reduced tillage (ideally none), permanent soil cover, and increased biodiversity brought about by crop rotations, associations, and sequences.

**Achieving sustainable intensification**

Increasing the labor and land productivity of smallholder agriculture will require greater access to farm power and mechanization—an often overlooked but nevertheless vital input. Increasing farm power means that increased areas can be sown to crops (or, indeed, made available for livestock production), but this option is not always available to individual smallholders. Other options to increase productivity include multi-cropping, precision agriculture, controlled-traffic farming, permanent raised beds with residue retention, and improving timeliness, as described below.

**Multi-cropping**

Where rainfall and/or irrigation permit, producing multiple crops per year on the same plot of land will clearly raise the overall productivity of the land. Mechanization can play a vital role in facilitating multi-cropping by increasing the rapidity and efficiency of harvesting one crop and ensuring that the land is prepared and the next crop established as soon as possible. One of the outstanding ways to reduce the turnaround time between harvesting one crop and establishing the next is the adoption of no-till or direct seeding. In this case,
crop residues are left on the soil surface, and direct seeders or planters place the seed and fertilizer at the required depths and positions after cutting through the surface mulch and without inverting the soil.

**Precision agriculture**

Carefully designed machines are capable of improving crop production, and consequently land productivity, through accurate placement of inputs. Examples that spring to mind include precision planters capable of placing seeds at precisely the right depth and spacing, and at the same time placing fertilizer to the side and below the crop line. Precision agriculture more generally has opened the door to crop (and animal) management systems that allow inputs to be precisely applied where they will maximize returns and keep costs to a minimum. Input use efficiency is optimized, environmental pollution is minimized, and profitability is increased.

**Controlled-traffic farming and raised beds**

Degraded, compacted soils lose productivity, and one particularly promising mechanization development is controlling the traffic on agricultural soils by means of controlled-traffic farming (CTF). CTF reduces soil compaction by vehicles (or animals) in the area where the crop is grown and confines the wheels (or hooves) to distinct and permanent traffic lines. Suitable CTF systems exist for smallholder farming, including the use of permanent raised beds with residue retention for crop production, preferably combined with conservation agriculture. Developed at the International Center for Maize and Wheat Improvement (CIMMYT), permanent raised beds with retained crop residues have proven to be a sustainable production alternative to conventional tillage, with its associated high cost, for both rainfed and irrigated agriculture. Not only are yields improved, but there are also savings in irrigation water use of about 30% when compared with flat-planted crops.

**Improving timeliness**

Insufficient farm power, especially at critical times of the cropping season, can lead to delayed operations with consequent yield penalties. Crops planted outside the permissible planting window will incur increasingly drastic yield penalties, which can exceed 1% for each additional day’s delay. Controlling weeds early in the season is crucial for achieving maximum yields. Weeds compete with the crop for light, water, and nutrients and will limit crop yields if they are allowed to interfere with crop canopy establishment. In the worst-case scenario, late or ineffective weeding can reduce yields to zero and is usually the result of a scarcity of labor or farm power at critical times. Planting crops in lines, raised beds, or CTF systems, and using weoders powered by draft animals to clean the crop, can have a dramatic effect on the timeliness of the weeding operation and, consequently, on crop yields.

**Equipment options for sustainable production**

Old traditions die hard, and there will inevitably be a prolonged transition period while conventional, plow-based tillage is replaced with climate-smart conservation agriculture practices. One incentive for change will come from the realization that the energy typically required for no-till production is about half that needed for conventional systems. Therefore, lower horsepower tractors will be more suitable, and mechanization costs will be reduced.

Four-wheel tractors (4WTs) of up to 60 hp are likely to fill the niche, and these are now widely available (particularly from manufacturers in India and China). However, equipment for conservation agriculture is available for all power sources, including human and draft animal power and two-wheel tractors (2WTs), typically in the 10 to 15 hp range. Implements start with direct seeders and planters equipped with chiseling or disc seed and fertilizer slot openers. For manual operation, various no-till jab planters are on the market.

Cover crop and weed management is achieved through mechanical means and herbicide application. Knife rollers and boom sprayers are available for human, draft animal, and small tractor applications. Examples of all these options and more can be found on the Conservation Agriculture website of the United Nations FAO (http://www.fao.org/ag/ca/).

**Other mechanization options**

It is important to realize that, for some time to come, there will still be substantial use of plows and harrows, and these will often be locally made by established manufacturers or in the artisan sector. These sources provide much needed skilled employment and are valuable repositories of local knowledge that should be tapped as more climate-smart technologies are promoted and demanded. It is also important to view mechanization needs and opportunities holistically and take in the whole agricultural produce value chain from production to marketing so that opportunities arise for value addition on the farm (for example in threshing and shelling) and in crop processing, which adds value to the produce and again provides employment. Finally, there is a huge need for transport to get the products (and people) to market, to transport inputs to the farm, and to move both produce and inputs around the farm.

**Increasing the demand for smallholder mechanization**

In order for smallholders to break out of the vicious cycle of poverty, low savings, low access to mechanization, and low productivity, they need to increase their labor and land productivity, and they need farm power and mechanization to realize that goal. Increasing demand will lead to greater productivity, stimulate the mechanization industry, and result in lower mechanization costs (i.e., a virtuous cycle). Mechanization inputs are usually large (especially for
resource-poor smallholders) and are required before any returns can be made, so a farmer with just a few hectares will be reluctant to invest in machinery. For these and other reasons, an attractive option that would improve access to mechanization is to offer services from well-equipped and well-trained local service providers. This option is attracting the attention of international donor organizations who can collaborate with both public and private sectors to ensure that suitable machinery is available, local manufacture is encouraged where suitable, and adequate technical and business training is offered. Demand can be encouraged in the early stages with schemes such as donor-funded e-vouchers, which can be redeemed for climate-smart mechanization services and other necessary inputs, such as quality seed and fertilizer. However, it is important that these incentive schemes are phased out as soon as possible to ensure sustainability.

Conclusions

Sustainable intensification. The smallholder farming sector is key to producing the food requirements of an increasing, and increasingly urban, population. Increased production must be accompanied by natural resource conservation if we are to have a future on this planet. Therefore, climate-smart conservation agriculture and productivity-enhancing practices are needed at a scale suited to smallholder production systems.

Local manufacture. Local manufacture of mechanization equipment is a desirable goal, as it helps to stimulate the local economy and provides an opportunity to adapt technologies to local conditions, be they crops, soils, climate, production systems, technical knowledge, manufacturing skills, or material supply, among other factors.

Policy guidelines. Local and national governments will need guidance on how to provide the best environment for nurturing a local agricultural equipment manufacturing industry and how to provide capacity for conservation agriculture mechanization services in the private sector.

Service provision. Given the problems of affordability and local availability of machinery and power sources, a promising solution is to equip and train entrepreneurial service providers. This will help to satisfy the demand from smallholders for more farm power and mechanization and will be key to lifting smallholders out of poverty and producing more food for the world’s burgeoning urban population.

ASABE member Brian G. Sims, independent consultant in tropical agriculture and agricultural engineering, Engineering for Development, Bedford, U.K., www.engineering4development.co.uk, BrianGSims@aol.com.

Focused on (but not confined to) the development of smallholder farming systems using on-farm participatory research and development methods and collaborative approaches to farm mechanization, Sims is past leader of the International Development Group at Silsoe Research Institute (SRI) in the U.K., where he advised on the identification, formulation, appraisal, management, and evaluation of agricultural development programs for the U.K. Department for International Development (DFID) and other governments and NGOs. He was a visiting researcher at Stanford University in 1985 and a recipient of the ASABE Kishida International Award in 2002. Since leaving SRI in 2003, Sims has continued to work, principally for the United Nations FAO, in development and emergency programs, mainly in sub-Saharan Africa.
When I tell people I’m going to a Club of Bologna meeting, I’m often met with a quizzical look and some version of “What’s that?” Some older or more knowledgeable people recognize the parallelism to the Club of Rome—famous for being a group of leaders who identify world problems and for their bestselling report *The Limits to Growth*—and want to know the difference. The Club of Bologna is specifically focused on studying and defining strategies for agricultural mechanization worldwide.

The genesis of the Club of Bologna goes back to UNACOMA, the Italian Association of Agricultural Machinery Manufacturers (now FederUnacoma), which started an annual (now biennial) exhibition called *Esposizione Internazionale di Macchine per l’Agricoltura* (EIMA) that has since become one of the world’s largest agricultural machinery exhibitions, with 235,000 attendees in 2014. There have been other activities concurrent with the EIMA machinery shows, most notably a 1987 international symposium entitled “Research and Information-Spreading on Innovations for Agriculture and Industry in the Year 2000.” During the closing session of that symposium, a proposal was made for the periodic exchange of information between countries on the state-of-the-art of agricultural mechanization. One of the objectives was to define the outlook for the future. Subsequently, Professor Giuseppe Pellizzi led the founding of the Club of Bologna and served as its first president. According to its internal rules, the Club was “established in 1988 for the study and definition of strategies for the development of agricultural mechanization worldwide, taking into consideration technical, economic, and social advances and changes on an international level.”

The Club did not want to duplicate what already existed. At the first meeting, Dr. Yoav Sarig said, “I do not think we need another form of conference, as there are enough opportunities for professional meetings … The idea is to benefit from the intelligence and experience of the people who are here … to be able to eventually come up with a series of guidelines for the future.”

The Club of Bologna is an independent nonprofit association sponsored by FederUnacoma under the auspices of the International Commission of Agricultural and Biosystems Engineering (CIGR) and in close collaboration with FAO, UNIDO, and the Accademia dei Georgofili (Academy of Georgofili). The Club usually meets annually at the largest machinery shows—EIMA in Bologna in even-numbered years and Agritechnica in Hannover in odd-numbered years. Membership is by invitation only to select individuals who have outstanding roles and experience in the agricultural mechanization sector. Members are expected to attend meetings and contribute meaningfully to the discussion. After presentations and discussions by the Club’s internationally diverse group, members have an obligation to transfer and disseminate their gained knowledge in their home countries. Incidentally, more than 30 members of the Club of Bologna are also ASABE members.

During the early years of the Club of Bologna, the presentations and transcripts of the formal discussions were published in book form after each annual meeting. Now the presentations and findings are available on-line. Recent meetings have dealt with such issues as electric drives, energy use of biomass, life cycle assessment, and robotics for agriculture.

For example, the 2013 meeting dealt with the topic of “International Standards: Opportunity or Problem.” There were presentations by individuals from organizations (FAO, CEMA, ASABE, etc.) and companies (AGCO, Deere, Kubota, and TAFE) and then discussions. Based on the pre-
sentations and discussions, the members submitted comments that were used to generate conclusions and recommendations. Some of the recommendations for this topic included increased dissemination of standards through the internet, more educational opportunities for smaller manufacturers, encouragement of governments in developing countries to emphasize standards, and efforts to prevent potential overregulation of engine emission standards.

I knew nothing about the Club of Bologna until I was asked to give my first presentation. But I found the different perspectives of the members and the high level of their knowledge and experience to be very informative. I seized the opportunity to join when I was offered membership, even though participation demands a significant commitment of time and finances—at least for someone far from Italy and Germany. The members come from 37 different countries and a variety of universities, agencies, and manufacturers. A 17-member Management Committee orchestrates the details under the current leadership of president Luigi Bodria (professor in the University of Milan’s Department of Agricultural and Environmental Science and past director of the Institute of Agricultural Mechanics) and technical secretary Marco Fiala (associate professor in the University of Milan’s Department of Agricultural and Environmental Sciences).

In addition to the meetings, which are conducted in a formal manner, the informal discussions during meals, breaks, and transportation have allowed me to establish professional relationships with machinery experts from around the world. It is interesting to get their perspectives. Not long ago, I shared a bus ride with a Club member who was working on alternative energy equipment, while NATO—led by my home country—was embargoing his country and bombing his facilities.

Every two years, on the occasion of EIMA International, the Club of Bologna and the Accademia dei Georgofili organizes the Giuseppe Pellizzi Prize. FederUnacoma sponsors this international competition for recent doctoral dissertations focused on agricultural machinery and mechanization. The biennial prize is given during the EIMA events to the top three dissertations completed within the previous two years. Club members can nominate candidates from any country for the prize.

The Club of Bologna developed the Milan Charter for Mechanization, which was appended to the Milan Charter given to the United Nations Secretary General at the World’s Fair in Milan last October. It emphasizes the strategic role of mechanization—and agricultural technologies in general—in meeting the food needs of the world. Two points are emphasized: the development of mechanization appropriate to local conditions in developing countries, and the evolution of mechanization to improve sustainability in industrialized countries.

The November 2016 meeting will concentrate on preparing a book—Evolution and Prospects of Agricultural Mechanization in the World—to celebrate 27 years of the Club of Bologna. This book will document the crucial role that mechanization has played in the past and will play in the future to produce the food needed to support an increasing population with limited resources. Individual chapters will document the historical, current, and future roles of agricultural mechanization in major countries and regions.

Because the goal of the Club is to generate and publicize information on agricultural mechanization worldwide, the meeting proceedings, member lists, and other documents are publicly available at www.clubofbologna.org.

ASABE Fellow John K. Schueller, P.E., Professor of Mechanical and Aerospace Engineering, Affiliate Professor of Agricultural and Biological Engineering, and Director of the Center for Manufacturing Innovation, University of Florida, Gainesville, USA, schuejk@ufl.edu.
I have worked over 30 years for three major agricultural equipment manufacturers (John Deere, Case, and CLAAS) in product development centers and production operations around the world. During my career, I have worked on a wide range of undertakings, from advanced engineering projects to production line maintenance within each company’s worldwide operations. Today, I lead CLAAS North American production operations as President of CLAAS Omaha in Omaha, Nebraska. The Omaha site is the North American headquarters for sales and production operations and where CLAAS’s North American team pursues the globalization process for its North American produced products.

The opinions expressed in this article are not supported by facts and figures but are rather my own views, based on intuition. This viewpoint, which I present for your consideration, was developed from years of experience in agricultural mechanization. In order to use the past to project a future vision, we need to recognize the factors that influence the trajectory. For agricultural equipment, those factors are labor availability, financial risk, and the global infrastructure.

First, labor availability is decreasing worldwide, so more work per person will need to be done regardless of whether that work is done in Asia or North America. Next is the need of original equipment manufacturers (OEMs) to improve the cost structure and reduce the financial risk of their products worldwide, which is being demanded by their shareholders. Additionally, the technology that supports precision farming is growing very quickly and will soon become a global demand. Future product designs will require consideration of each of these trends, which I believe will reduce the physical size of all wholesale equipment to a smaller scale.

**The trend toward smaller**

The point I want to make is that globalization’s impact over the next 25 years will cause a reverse trend in future ag equipment development. Historically, “big iron ag” has trended toward development of larger equipment. Moving forward, the ag equipment industry will start to reverse equipment size in the direction of smaller-scale machines, driven by the trends that I described above.

Up to now, the trend toward ever-larger equipment in North America and Europe has been based on the need to accomplish more work with less human labor because of the diminishing labor force available in the farming community. To operate one product (tractor, combine, etc.), only one person was needed at the controls. If that one person needed to do more, the machine just needed to get more powerful, wider, longer—in a word, bigger. This “build it bigger” trend has been lagging in Russian and China, but it’s now proceeding quickly as those countries, and others, have started to adopt Western countries’ product developments. This adoption comes naturally as communication has become faster and easier. In today’s hyper-connected world, all content can be shared anywhere in real-time. So, ag product developers can discover the latest trends almost instantly, and change in the future will proceed even faster than in the past.
In recognition of the shrinking labor force, indications are that each OEM has its own version of a smarter operating system in development. Based on these systems, future products will incorporate semi- and fully autonomous features that will eventually lead to partially or totally autonomous machinery. Therefore, each product’s architecture will be smarter, and each configuration will have a wider range of possible specifications. Our end customer, the farmer, will be able to operate multiple units simultaneously to complete more farming operations than today’s farmer. These multi-unit fleets will be tailored for the specific needs of global customers and will also contain more common components.

At the same time, OEM product costs per unit of work will need to be reduced—or better stated, optimized. Each OEM is continuously looking for lower-cost designs, taking advantage of common parts that are more frequently used and the lowest costs for production and logistics. Smaller platforms with smarter interfaces will allow global production in multiple localized configurations. Those configurations will be based on a core design that can be customized for each production site. The smaller platforms will have a range of smart technology depending on the local country and customer needs. This localization will allow manufacturers to produce high volumes of common parts in one or two factories and efficiently ship materials to other operations that produce lower volumes of assembled equipment. This strategy allows each company to reduce its foreign currency exchange risk and minimize its capital investment.

“In the future, our end customer, the farmer (I think this term will soon change to “operation manager”), will require more precision farming technology to increase the output per unit area. We usually think about precision farming as a North American or European practice, which is mostly true today. However, with all the social media and other means available for communication, precision farming is growing fast in the rest of the world. For example, think about how quickly the smart phone market grew to surpass landline communication. If we had to build our phone system over again, we wouldn’t bother with landlines at all! I think there is a lot of evidence to support the argument that farm labor, OEM financial risk, and global infrastructure are driving the future of agriculture equipment development—which will see a reverse trend to smaller, more versatile, and more economical machinery.”

In the global village, OEMs will build machines that fit diverse applications in crop management, production, and data collection. Due to the limited road and field infrastructure in many developing countries, smaller machines will be preferred for these applications because of their versatility, greater mobility, and lower cost.

ASABE member Maury V. Salz, President, CLAAS Omaha, Omaha, Neb., USA, maury.salz@claas.com.

The CLAAS Crop Tiger (India) on the left compared to the CLAAS Lexion (North America) on the right. In the future, will the smaller machine become more common than today’s behemoth?
The regulatory environment for American agriculture is changing and, depending on your vantage point, it isn’t for the better. Regardless of your opinion on the issue, production agriculture is getting more regulation, in more areas, and some would say, at an increasing velocity. As a result, whether related to the food, fiber, or fuel that agriculture produces or the equipment, inputs, or practices that it employs, don’t look for any return to the good ol’ days.

More oversight is expected

The American consumer, interest groups, and regulatory backers are seemingly giving a nod to more oversight in many areas: certification of crops, labeling of products and food-stuffs, supervision of production practices, and permitting of autonomous technologies. The stated reasons can be as varied as safety, health, environment, and sustainability—or simply precautionary principles.

As the ag industry moves increasingly into the world of global trade, the cost of access is more export scrutiny, which usually means more product certification and labeling. Up to now, North America has been an island in a sea of regulatory zeal, as the rest of the world mostly looks to legislation for directing industry (including agriculture). This regulatory burden will likely continue to expand into North American agriculture as more export markets and products are added. The present regulatory process derives, in part, from the birth of the European common market and its continuing development within the European Union (EU). The EU certification scheme (CE mark) provides the model for the rest of the world to emulate—and emulate they have. Throughout the world, under the guidance of the WTO, the EU model underpins most regulatory and certification schemes currently in use, regardless of the form of government. The compulsory certification system in China (CCC), the Eurasian Customs Union certification system (EAC) in Russia, and the Eurocentric leanings of South American countries—including Brazil and Argentina among others—all stand as examples.

For all the above reasons, it seems that American agriculture’s free-market advantage of producing what we want, where we want, and how we want is quickly slipping away. GMO crops, nutrient and chemical application, and machine structure and operation are increasingly being impacted by oversight at home and abroad.

As the public and the market continue to demand more in the areas of safety and regulatory compliance, the big question is: What strategy should production agriculture employ to ensure it has a voice in the direction that society is pushing the industry? Or more directly, how do we provide safe foods, safe inputs, safe environments, safe equipment, and safe practices in a cost-effective and equitable manner?

Finding our voice

The development of technical, product, and industry standards is a proactive approach in which the ag industry can provide viable, cost-effective solutions for the legislative, rule-making, and regulatory processes in North America and the world. Addressing regulatory oversight through a multi-
stakeholder standards development process provides an opportunity to deliver, in a non-adversarial setting, fact-based and consensus-based solutions. This approach can advocate for solutions that highlight good stewardship while sharing knowledge locally and globally. In free-trade discussions, well-constructed product and technical standards can also bolster the ag industry’s position, giving production agriculture more leverage in discussions of harmonization, conformity assessment, and equivalency.

Looking at the horizon, many of the grand challenges that we face go beyond standards for machine structure and function. The focus is rapidly moving into two areas: (1) the ecosystems in which machines are operating, and (2) the integrated cloud-based systems used to link suppliers, producers, distributors, customers, and regulators.

In the near future, areas of regulatory impact will include chemical use and drift, nutrient application and loss, soil health and erosion, and product traceability and labeling. Regardless of the issue, producers will be asked to validate their operational parameters, practices, inputs, and product content. Assessments of “potential” spray drift, nutrient loss, and soil loss will be required outputs and will become factors in real-time operational decisions. All this will require the ag industry to measure, assess, and document its status and progress in consistent, meaningful ways for each of these factors and report to the affected constituencies, including producers, end users, and regulators or other third parties.

Taking the lead in standards

Addressing these challenges will require more complex cross-functional standards development teams than typically have been formed in the past. Beyond equipment manufacturers, safety organizations, government agencies, and research communities, additional support will be needed from on-line forums, farmers, commodity and inputs trade groups, and e-business systems integrators.

Projects are underway today that leverage more collaborative relationships, including an innovative approach to addressing spray drift through the use of mechanistic modeling, as well as another avenue addressing sustainability of agricultural production systems. Given the increasing speed of technological and regulatory change, the formation of cross-functional standards development associations (and thereby innovative approaches) bodes well for production agriculture and will help achieve useful results in this dynamic environment.

Standards development requires that developers understand the market and act in a timely manner. Waiting until the market, the public, or regulators are demanding action only means that the standards development community is two or three years behind where due diligence says it should be. Our efforts shouldn’t be premature; more importantly, they shouldn’t come too late.

ASABE member Randy Renze, Principal, RJRenze Product Services LLC, Ankeny, Iowa, USA, renzerj@gmail.com.

"American agriculture’s free-market advantage of producing what we want, where we want, and how we want is quickly slipping away."
Specialty agriculture has its fair share of design challenges, with farmers comparing the technology of specialty ag equipment to other ag equipment, as well as to consumer products. In particular, in designing equipment for specialty crop harvesting, there are a myriad of challenges, and difficult decisions have to be made in order to design and market a high-quality harvester that will help farmers make money.

There is often a trade-off between the latest high-tech and the simple-to-operate and simple-to-service. Design cycles are often the result of a new technology in harvesting, control systems, or operator comfort. Recently, however, there has been a new demand for redesign based on environmental considerations. This includes Tier IV engine emissions and internal manufacturing processes.

For many manufacturers of specialty ag equipment, the additional cost of the new high-tech, lower-pollution engines has a direct effect on the cost of new equipment. Specialty ag manufacturers have looked to increase sale prices, but higher price tags can cause farmers to extend the use of their older equipment, rather than purchase new machinery. In addition, the new engine technologies often require more space for their functions, such as cleaner exhaust, which makes installing new engines into existing machinery almost impossible. As a result, manufacturers must redesign a larger portion of the machine, which adds to the development cost. Part of the redesign includes efforts to control the manufacturing cost, which helps to control the sale price.

Because of the higher price tags for new machinery, farmers want to know how these machines are more efficient, and how they can help keep operating costs—whether per acre or per hour—from climbing. In specialty agriculture, particularly in harvesting operations, increased efficiency for the end user has become a focus for many manufacturers. We look to increase the overall farm efficiency through the design of our equipment. In order to do this, we need to be in touch with our customers, to make sure we are meeting their needs. Our product leadership teams have the specific purpose to make personal contact with farmers and then bring the information together to make decisions that are best for both the company and the customer. As we continue into the 2020s, this process will be an ongoing challenge.

**The challenges of automation**

Automation is a new frontier in specialty ag equipment. Automation already exists in some forms, and it will make its way into harvesting equipment. Specifically, machine vision and robotics will increasingly appear in specialty ag systems. Reliability and cost, along with processing speed, will be the major hurdles. The new systems will be smaller and slower than larger, less precise, less automated machines—and more machines will be needed to harvest a farm. Driverless equipment will be adopted more slowly. Specialty agriculture, which often involves perishable products and high-value crops, will likely retain a human operator to oversee the machine and make on-the-go adjustments.

As we design machines that are more efficient, we will include more networked systems, so that the operator can monitor key performance indicators while the onboard controller adjusts other parameters to optimize machine operation. Challenging questions will arise from the end users: “What happens when something goes wrong?” and “Who can
fix this machine at a moment’s notice?” Technicians who can troubleshoot and repair high-tech machines are already in demand, and they will be in even higher demand in the future.

End-of-life for agricultural machinery will also continue to be a challenge for manufacturers and end users. As technology changes, the new technology is incorporated into new machinery. After all, why keep using a four-year-old computer controller when a faster, more powerful, and less expensive replacement is available? Parts availability will become increasingly difficult to sustain as machines become more complex. Many end users expect that parts will always be available for their 20-year-old (and older) harvesters. For many mechanical parts, that long-term availability does not seem daunting. However, with more and more sensors and electronics installed on machines, sourcing of parts becomes a challenge, especially when microchips are discontinued due to lack of demand, or due to the on-going advances in microchip design.

Big growth in small farms

I believe that small farms (5 to 20 acres) will increase in number as the trend toward community-supported agriculture (CSA) increases. Existing hobby farmers will find new opportunities in CSA. As a result, the market for hobby-size farms will increase, along with greater demand for towed and mounted equipment. Many of these farms already have a tractor and some other machinery, but they will look for easier, more automated methods for tilling and harvesting. Selective harvesting would be ideal for this type of farm, as well as reasonable costs for the new equipment.

At the end of the harvesting day, we all want our customers to be successful. Keeping abreast of their needs and finding ways to serve them will make our work rewarding and continue to advance the art and science of agriculture.

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The U.S. tree fruit industry is an important component of the nation’s agricultural sector, representing about 10% to 13% ($14 to $18 billion) of all crop production. Currently, fresh market fruits are harvested manually around the world, which makes the industry highly labor intensive and less sustainable due to rising labor costs and increasing labor shortages. In the Pacific Northwest region of the U.S., labor costs for harvesting fresh market fruit account for 20% to 30% of all on-farm variable costs.

Researchers in the past have investigated different technologies for mechanical harvesting of tree fruit. Despite wide differences in the specific mechanisms, almost all the investigated systems were designed to perform either shake-and-catch harvesting (mass harvesting) or pick-and-place harvesting (robotic harvesting). In principle, shake-and-catch harvesting applies vibratory excitation to the canopy, trunk, or a branch of a tree to create a detaching force on the fruit and uses some type of catching device to collect the detached fruit. Mechanical tree fruit harvesters based on this approach are used to harvest fruit destined for the processing market due to the high productivity of shake-and-catch harvesting. However, there has been limited success in fresh market fruit harvesting due to the high level of harvest-induced damage. For pick-and-place harvesting, the process includes locating target fruit, approaching and detaching the fruit, and then placing the picked fruit in a designated container. In general, robotic harvesting has achieved very limited success, primarily due to inadequate accuracy, speed, and robustness. Because none of the existing technologies has provided a satisfactory solution, mechanical harvesting of fresh market fruit remains a crucial problem for the long-term sustainability of the tree fruit industry.

To develop a roadmap for fully automated mechanical harvesting systems that would be practical for harvesting fresh market fruit, a joint task force consisting of an industry advisory group and a technology development group from Washington State University has specified that an ideal solution should be capable of harvesting more than 95% of the fruit with less than 5% harvest-induced cullage in SNAP (Simple, Narrow, Accessible, and Productive) fruiting wall orchard systems, using less than 20% of the current level of human labor. In addition, a system capable of achieving a harvest speed of one fruit per second should be economically competitive with current harvest methods. While fully autonomous harvesters navigating between tree rows are still years away, researchers at Washington State University’s Center for Precision and Automated Agricultural Systems (CPAAS) are working on the core technologies for fully automated mechanical harvesting systems, both for mass harvesting and robotic harvesting.

Shake-and-catch harvesting

Fully automated mass harvesting, using a shake-and-catch system that shakes only a targeted canopy region and catches the fruit directly beneath, could achieve high productivity at a relatively low cost if the harvest-induced fruit damage could be controlled within an acceptable tolerance, which is a crucial challenge for this technique. Developing this type of harvesting system with minimal fruit damage requires fundamental understanding of (1) the achievable productivity and fruit quality from a shake-and-catch process, (2) how to control the system parameters to achieve such a result, and (3) tree architectures that could optimize the horticultural attributes and be machine-friendly for automated mass harvesting.
Given the multi-faceted nature of the problem, the CPAAS team used a transdisciplinary approach to gain a comprehensive understanding of the physical and biological aspects, and then used that knowledge to create possible solutions for the recognized challenges. One of the important findings was that an appropriate combination of shaking pattern and rhythm could improve localized fruit removal from the targeted tree branch and also reduce harvest-induced fruit bruising. Field testing in a formally trained Gala apple orchard revealed that semi-selective shaking could achieve 88% fruit removal with less than 4% shaking-induced bruising.

Another test using a prototype fruit capturing device on a vertically trained Jazz apple orchard showed that it was possible to remove 92% of the fruit from the targeted canopy region, collect up to 99% of the removed apples under the shaken branch, and maintain 85% of the collected apples at the highest extra-fancy grade. By keeping the harvest-induced fruit damage rate to less than 15% for several varieties and about 5% for a few varieties, this research indicated the possibility of achieving the desired fruit quality with mass harvesting using appropriately designed fruit capturing devices.

**Pick-and-place harvesting**

Using a three-step process of locating, detaching, and placing of fruit, robotic pick-and-place harvesting offers the possibility of selectively harvesting individual fruit. This technology has been extensively studied since the 1980s, with numerous prototypes evaluated. However, very few systems are ready for commercial adoption, largely due to unsatisfactory productivity, robustness, and fruit quality. While all three steps affect the results, the technologies for fruit locating and placing have been well studied and validated, at least at a conceptual level.

The middle step—fruit detachment—is the most challenging task and remains the central challenge in robotic harvesting. Most studies have used a modified industrial robot to detach fruit, which could be one of the reasons for the resulting performance deficiencies. Fruit picking may require a more complicated grabbing and detaching motion than other industrial picking applications. Based on previously reported success, a robotic apple picker being developed by a CPAAS team has achieved a cycle time of six seconds to pick an apple from a formally trained fruiting wall tree canopy. However, this speed does not yet meet the desired productivity level.

To understand the effect of the fruit detachment method on picking productivity and fruit quality, CPAAS researchers conducted a study of fruit picking dynamics. The study found that the required grabbing force, on average, could vary by up to 100% for different grabbing methods while picking different varieties of apples, which resulted in picking-induced fruit bruising rates that varied from 0% to 60%. However, the grabbing patterns that required less force generally required a detaching motion that was more complicated than simply pulling the fruit off the branch.

**Other alternatives**

To make fully automated harvesting systems practical for fresh market fruit, a more creative approach is required, rather than simply adapting technologies from other applications. One area for innovation could be an overall system integration approach, including human-machine-tree interaction and improvement in horticultural systems. If we can create a technology that allows human operators to cooperate with robotic machines, then the human operator could simplify the tasks that the robotic machine would otherwise need to handle autonomously, which in turn could make the robotic harvesting solution more adaptable and affordable. For example, work is being done at CPAAS with machine vision systems that can detect and locate most of the fruit, but human operators can step in to identify the last 1% to 2% of the fruit that are obscured in the canopy and difficult for the machine to find.

In recent years, many companies and venture capitalists have been attracted to developing robotic solutions for fresh market fruit harvesting. For example, Abundant Robotics, Inc., a California-based company, is developing a robotic apple picker with support from the Washington Tree Fruit Research Commission. This project involves a vacuum-based picker that can avoid damaging the target fruit, adjacent fruit, or part of the tree—which a grasping machine might do—and it achieved a picking speed of one fruit per second. Other companies around the world, such as FFRobotics in Israel, are also putting development effort into robotic fruit harvesters. Based on the recent progress in agricultural technology, fully automated tree fruit harvesting systems could become commercially available for U.S. growers in the next three to five years.

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We’ve arrived at an exciting time in the crop production industry—what many are calling the Digital Age of Agriculture. While many may define “digital agriculture” in different ways, there’s no question that producers and other professionals in our industry are using data at an ever-increasing rate. In my opinion, using data to drive decisions in crop production, instead of experience alone, is a sure sign that digital agriculture is a real trend—a trend that began with precision agriculture over 25 years ago. What started with georeferenced soil sampling and yield monitors has evolved into sensors of all kinds available from a variety of platforms.

The number of sensors generating data in our fields today is remarkable. Modern tractors and implements have become mobile sensor suites that can wirelessly transmit machine or agronomic data to cloud-based storage platforms. Unfortunately, raw data alone holds little value, and that’s one of the biggest challenges we face today. Many in our industry have underestimated the challenges associated with agricultural data collection, processing, and analysis. In fact, I have spoken to many producers who have given up on trying to figure out how to get more out of their data. Several factors may have contributed to this conundrum, including data quality, security, transferability, and ease of analysis.

Data quality

For most users, as-applied and yield data are the most sought after datasets generated during the year, all of which rely on sensors. While most users want 100% accuracy in these datasets, we must temper their expectations because of the challenges associated with recording this valuable information. No matter the application, sensors always have some inherent error embedded in their output, and while we do our best to minimize this error, it is unavoidable. To use sensor data in agricultural applications, we must georeference the data, which requires additional information from global navigation satellite systems (GNSS). To achieve the highest accuracy possible, we often recommend real-time kinematic (RTK) GNSS correction, which can be costly and often limits adoption by potential users. The need for highly accurate GNSS data becomes even more apparent as as-applied datasets from field operations are layered with imagery collected from aerial platforms, including airplanes or unmanned aerial vehicles (UAVs). I have experienced such negative effects when combining as-applied and yield data with aerial images for on-farm research trials.

The future of sensors in agriculture is wide open, ranging from multispectral and hyperspectral sensing of plants or soils during the growing season to grain quality during or after harvest. Development of algorithms or models that incorporate sensor data to provide decision support to end users in near real-time continues to be a critical need in crop production. Changing cultural practices in which growers make decisions based on experience is challenging; however, demonstrating the potential of data-based decisions can pay off if it encourages producers to adopt a proven technology. In Nebraska, for example, sensor-based, real-time control of nitrogen and irrigation applications during the growing season is showing producers the potential for optimizing input use efficiency in their fields.
Data security

Data security has been a hot topic in recent years. In agriculture, producers see the data they generate as a valuable product, and they want to control and protect that product. Most producers focus on data generated from their field equipment, which can flow into either machine or agronomic data streams. Many companies have also noticed the value of producer-generated data. Data agreements are evolving to help protect producers' agronomic information while providing industry access to machine-related data, with the goal of improving equipment performance. I have been fortunate to be involved with the Ag Data Coalition (ADC), a diverse group focused on developing a data management platform that will put farmers in control of their data. This farmer-centric effort that the ADC has committed to will continue to drive the conversation about data ownership in a positive direction.

Data transferability

Data transferability has improved in recent years, but it can still pose a challenge in some cases. There has been a great deal of activity in this area, and good work has been accomplished by entities like Ag Gateway, the Open Ag Data Alliance (OADA), and the Agricultural Industry Electronics Foundation (AEF). Data standardization almost seemed like an unachievable task, but members of Ag Gateway have made great progress in the past few years toward this goal, and data exchange will be easier in the future because of it.

Along those lines, interoperability of agricultural equipment has been a major challenge for many producers who have to deal with multimanufacturer tractor-to-implement communication. AEF's work on ISO Bus standards has helped to alleviate many of these issues via the virtual terminal. Annual Plugfest events sponsored by AEF allow industry professionals from different companies to get together and test their latest electronic components. These efforts will have positive returns for end users and producers. Standardized datasets along with improved communication protocols will help accelerate innovations in machine automation and improve user confidence in the decision support systems that use the data.

Data analysis

Data analysis has always been challenging because we have to learn proper analysis techniques as well as how to use specific software to achieve our desired results. Geographic information system (GIS) software packages for agricultural data applications have matured over time, along with the rest of the industry. In the early days of precision agriculture, GIS software was not intuitive for most users. Farm management information systems (FMIS) software quickly evolved from basic GIS packages to improve the user experience and organize data in a structured format (e.g., grower, farm, field, year, operation, etc.).

Over the past two decades, many FMIS software options have been developed with impressive analysis capacities. Users can now easily build their own nutrient prescription algorithms or conduct multi-layer queries, which can be applied at the field or farm level. While we still have to scrutinize the data and ensure proper analysis techniques, there's no question that these tools are becoming easier to use. Each year, we offer training to hundreds of producers, crop consultants, and retailers through the Nebraska Extension Precision Ag Data Management Workshops, and it's clear that agricultural professionals want to learn how to gather actionable information from their data.

Many producers and other agricultural professionals continue to push forward with exciting applications for the data they're generating. Producers are growing more crops with fewer inputs, and they're using essential inputs like water and nitrogen more efficiently than ever, which is better for the planet. Through many different avenues, agricultural data has been helping to drive these improvements. The trend toward digital agriculture will continue to grow in the future, and I'm excited to see how this new piece will fit into the puzzle of feeding our growing global population.

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Manure Systems
A balancing act of animals, equipment, labor, and the environment

Andy Lenkaitis, P.E.

From the barn to the field, the equipment used to handle manure has improved dramatically in the past 30 years. Push scrapers and shovels are being replaced by sleek robotic machines that maneuver through the barn, while the old open-cab tractor and manure spreader tossing dry manure onto a field are being replaced by self-propelled machines that simultaneously work the soil and inject liquid manure with a precision-controlled supply system.

There are two major drivers of innovation in animal agriculture: making the animals more comfortable, and making tasks easier for the operator. In manure equipment technology, we also have a third factor: environmental impact. When we look inside the barn, the equipment and the approach vary among animal species; however, in the field, it doesn’t matter what animal created the manure—it all needs to be used properly.

In the barn, manure collection systems—both mechanical and robotic systems—operate alongside the animals to collect manure and clean the barn. Efficient manure collection is critical for controlling the gas and odor emissions from animal facilities. Many systems also strive to minimize freshwater use by reusing water several times for floor cleaning, bedding separation, and manure conveyance. Particularly on dairy farms, bedding recovery systems have been gaining popularity as a way to recover or produce bedding for the animals. Equipment development in the barn is driven by finding ways to replace manual tasks without disrupting natural animal behavior. Robotic systems will play key roles in cleaning stalls, distributing feed, and even moving and sorting the animals. Specialized products—such as environmental floors, aeration systems, and emissions recovery and treatment technology—will be adopted to find solutions that can pay for themselves through improved efficiency and economics.

Advanced manure treatment systems—such as decanter centrifuges, digesters, and filtration systems—provide additional options for manure treatment and handling. As livestock farms grow in one location, their manure and nutrients need to be distributed across greater distances. Often, concentrating the nutrients recovered from manure can allow an operation to transport the nutrients over greater distances, while the lower-nutrient liquid can be applied more cost-effectively close to home. Manure processing systems will continue to evolve to extract beneficial products from manure, including fiber for processing, gas for energy, and field amendments with nutrient levels tailored for specific farms and fields. Manure processing may be limited on swine farms, as their growth model is to build barns strategically on land capable of using all the manure produced.

Most operators are aware of the nitrogen, phosphorus, and potassium (N, P, and K) values of manure. Those of us involved in manure processing discuss N, P, K, and B, where B stands for the biological benefits of manure, which often go beyond the traditional nutrient analysis. To maximize the biological benefits, manure application technology has evolved along with other agricultural equipment. PTO-driven manure pumps at the edge of a storage lagoon have become manure...
boats which include a pump, power unit, and agitation nozzles floating across multi-acre lagoons to create a homogeneous mix of nutrients in the material applied to the field.

Liquid manure tankers with flowmeters and GPS mapping can precisely apply manure with a variety of tools that incorporate manure immediately into the soil, thereby reducing the odor and preserving the precious nutrients. When a large land area is available within a few miles of the farm, power units with booster pumps can feed manure from a lagoon directly to the applicators through a pipeline network at up to 4,000 gallons per minute with precise control of manure placement. Real-time nutrient readings with near-infrared sensors or similar technology will decrease the variability in nutrient applications. All this development in manure application equipment is driven by efficiency, measured in gallons per labor hour during the short application window.

Many of these advances in manure equipment are due in part to a shift toward more liquid manure systems on livestock farms. Handling manure as a liquid allows application with precise control and can adapt proven pump technology from other industries. Solid spreading systems in the poultry industry have also made advances in precise control of nutrient application. In either case—solid or liquid—efficient use of nutrients requires a consistent and homogenous manure product.

Manure handling has a dirty and smelly past. While the future is bright, the industry doesn’t smell like roses quite yet. Farm managers and operators—those who understand the needs of the animals, the value of manure, and the cost of labor—are continually pushing for innovative solutions to balance these demands. Engineers will continue to develop new technologies, new materials, and new methods to meet the challenge. One thing won’t change: manure handling will remain a major factor in the future of animal production systems.

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In the 1970s, the U.S. and other countries began commercial production of ethanol to supplement transportation fuels, especially gasoline. The production of ethanol from corn grain was slow until the early 2000s, when petroleum prices became volatile and the U.S. relied heavily on imports. To reduce this reliance and boost domestic production, federal and state governments legislated renewable fuel standards, such as the RFS2 established by the Energy Independence and Security Act of 2007. This legislation includes a cap on ethanol production from corn grain to minimize the impact on feed and food markets.

The graph below shows transportation fuel production in the U.S. based on the RFS2. The mandated 15 billion gallon plateau for corn ethanol was achieved in 2014. The remaining growth in biofuel production—more than 20 billion gallons by 2022—will be sourced from non-food crops and residues. Those 20 billion gallons of biofuel will require a minimum of 280 million dry tons of feedstock, assuming a conversion rate of 75 gallons per dry ton. This implies that an additional 40 million tons of biomass must be produced each year to reach the target of 280 million tons in 2022.

In addition to biomass for liquid biofuels, there has been fast growth in wood pellet production in the U.S., increasing from 1 million tons per year a decade ago to about 8 million tons per year in 2015. This growth is due to the demand for wood pellets to reduce the use of coal for power generation in Europe. The growing demand for pellets in Europe may push U.S. production up to 15 million dry tons per year by 2022. At the same time, domestic growth in pellet demand for power production may require another 9 million tons per year of lignocellulosic biomass when the EPA’s mandated Clean Power Plan is put in place in 2022. Using a factor of 1.2 dry tons of biomass to produce one dry ton of pellets, an additional 24 million dry tons of biomass will be needed for pellet production in 2022.

Harvesting, storing, and transporting these huge quantities of biomass will create opportunities for equipment manufacturers, construction contractors, the rural workforce, and a whole range of services to support this emerging biofuel economy. Our analysis estimates that the annual purchase of new and replacement equipment for harvest, handling, and transport of biomass could exceed $4 billion annually. This does not include the economic and social activities that would result from the demand for new processing and handling equipment.

However, industrial-scale biomass harvest and supply systems face challenges beyond those of traditional agricultural operations and require development of new technologies to improve efficiency, reduce environmental impacts, and maintain feedstock quality.

**Biomass ash content**

The biomass ash content—whether biogenic ash that is part of the plant matter or environmental ash that is picked up from the soil during harvest—can have significant impacts on biomass conversion. Excluding bark, the biogenic ash in woody
biomass is often less than 1% but may range from 2% to 10% in herbaceous species. Picking up soil particles during biomass collection adds to the overall ash content. With soil contamination comes undesirable levels of iron and manganese, which can catalyze reactions and reduce process efficiency.

Some soils neutralize the acids used in pretreatment. This can reduce the efficiency of the conversion process or increase the production cost because additional acid must be added to achieve the pH necessary for optimum processing. High ash content has been shown to reduce conversion of cellulose to sugars by 6% to 10%. The components of ash also affect machinery life and maintenance costs. Early experiences with logging equipment and pellet mills showed that excessive silica abrades steel surfaces. Sensing instruments, along with design and operational strategies, could be developed to avoid soil particles and/or shake excess soil from the plant matter during harvest. Post-harvest fractionation and washing strategies to reduce ash are usually not economically feasible.

Densification

Increasing the bulk density of biomass feedstocks significantly reduces the costs of transport and storage. Denser bales lower the cost of on-farm transport and stacking. Briquetting, cubing, and pelleting reduce the costs of long-haul transport and long-term storage. However, operations that increase density are power intensive and can be expensive. The power input required to make biomass denser increases exponentially with the increase in bulk density. Recent research shows that the density of current bales can be economically increased by 15%—beyond that, the power demand becomes excessive. The densification parameters, such as moisture content and particle size, are important factors. The lignin content in woody biomass provides natural binding to form durable pellets. In contrast, the low lignin in herbaceous biomass requires the addition of external binders to form pellets.

Lignocellulose content

The lignocellulosic portions of agricultural and forest materials are tough and more difficult to process than softer tissues, such as fruit pulp, green forages, and grains. Many processing machines, such as choppers, grinders, and densification equipment, exhibit early wear when grinding and pressing lignocellulosic materials. When working with dry residue that is contaminated with soil, this equipment can require more frequent service and even replacement. Future equipment should be able to handle abrasive lignocellulosic materials. Up to 80% of the dry matter in a mature plant consists of highly lignified cell wall materials. Corn stover, for example, has dry, thick, hard stalks with high resistance to shear and bending. Energy crops like switchgrass, miscanthus, and energy sorghum are also tough to cut, dry, and bale.

Soil compaction

Another challenge facing biomass harvest operations, especially in residue collection, is the potential for soil compaction. Frequent travel in the field tends to press the soil down, and dense soil is less productive. Collecting crop residue currently means bringing additional equipment into the field. For example, after grain harvest, additional vehicles are needed to bale, transport, and store the straw at the field edge. Soil compaction is exacerbated by the fact that the machines used for handling biomass are often heavier than conventional agricultural equipment. Likewise, forest equipment that gathers logging residue may lead to excessive forest floor compaction. These extra operations are often at the end of the season, when the soil may have become soft due to rain and low evaporation.

Machines can be designed to spread their ground force over a larger track area. In addition to developing lighter equipment, soil compaction can be reduced by combining operations to avoid repeated travel in the field. For example, grain and stover harvesting can be performed simultaneously without using an extra tractor to pull the baler. An added benefit of single-pass harvesting is less entrainment of soil particles in the biomass because the cut stover does not touch the ground.

Moisture content

Moisture is one of the most critical factors in handling agricultural and forestry materials. Researchers have established that the ultimate shear strength of herbaceous crops is inversely proportional to the moisture content and directly proportional to the dry matter density. Some technologies have been developed to harvest, process, and store high-moisture materials. Natural and artificial drying methods have been developed for food grains and other perishables. Wet storage methods, such as ensilage, have been adapted for animal housing. Unfortunately, our knowledge of handling high-moisture cellulosic materials is still limited. An early analysis of weather data indicated that almost 1/3 of the stover in the U.S. after grain harvest could have a moisture content greater than 40% (wet mass basis).

While machinery systems are widely used for harvesting and handling forage crops, similar systems for collecting crop residues and dedicated energy crops are yet to be commercially developed. The functionality of the equipment used for collecting, handling, and processing of biomass is affected by the variability of the biomass, including its morphology, composition, and physical properties. To overcome these challenges, agricultural and biological engineers must understand the factors that govern the interactions between biological materials and machines—as well as the environmental factors of traditional agricultural operations.

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There is clearly a market for organic and locally grown products. While agricultural professionals debate the merits of organic and local food production, grocery stores across the nation have added organic and local food sections. Consumers are buying organic and buying local, and demand for these products has increased substantially in recent years. The confluence of the organic and local food movements has led to a unique range of marketing opportunities—from local food sections in grocery stores to farmer’s markets and community-supported agriculture (CSA) programs. These venues provide more contact with customers and higher prices for producers who are able to meet the expectations of these customers.

Small vs. large production systems

Although CSA, farmer’s markets, and local food sections provide new markets for producers, they also place unique demands on production compared to more traditional systems. With CSA and local food, one big requirement is that farms must provide a diverse array of products (often vegetables) rather than specializing in only one crop. Keeping customers happy requires a variety of crops throughout the season. When you add the requirements of organic production, these operations begin to look considerably different from other agricultural systems.

If someone with a background in traditional wheat, corn, or soybean production visits these operations, it becomes immediately clear that the work and machine use are very different. In these small, diversified production systems, a tractor is used nearly every day, but only for a few hours at a time and often at relatively low load. Because they can’t use synthetic herbicides, organic producers have to rely on mechanical cultivation, plastic mulch, crop rotation, and even hand weeding to control weeds. All of this translates into highly variable machine tasks that occur every day and continue all season. Compare this to grain crop equipment that is often run for long periods (upwards of 16 hours a day) for a couple weeks until a particular task is completed, after which the machine is parked and the producer moves on to the next task.

In organic and local production systems, the available machinery is often ill-suited to the production requirements. It’s often older equipment repurposed from other production systems. However, the criteria for selecting machinery are very different between traditional production systems and these new applications. For example, machine capacity, which is the area that a machine can work in a given amount of time (e.g., acres per day), is critical in grain production systems and is often constrained by horsepower. In organic and local production, machine capacity is determined by the width of the production plot, the type of weeding performed, and the speed at which the task must be performed in order to be effective. The maximum area that a machine can cover in a day is generally unimportant, as this level is rarely reached. The traditional mantra that has driven farm machinery development—“bigger is better”—does not apply to local production systems.
Local production systems also vary significantly from other farming systems in their economics. In diversified vegetable production for CSA, the revenue is between $15,000 and $20,000 per acre per year for operations in the 30 to 100 acre range. Clearly, the total revenue of these operations can be quite high, but as with all agriculture, the expenses are also very high. In addition, the nature of the expenses is different. The largest expense for local production systems is generally labor, with a significant portion of that dedicated to weed control.

**Machinery for small producers**

There are challenges in developing new machinery for these producers. First, these operations are geographically dispersed. Without concentration in a single location, the traditional interactions, from producers discussing best practices to businesses offering specialized products and services, become more difficult. Additionally, their market requires diversified production; therefore, while total revenue may be high, the revenue from any single crop is limited. Both of these factors mean that the expensive, California-style automation that creates highly specialized machines—such as a dedicated harvester for paste tomatoes—will not be applicable. Instead, the machinery that supports these producers must be flexible and support a wide variety of crops.

Still, a growing market with significant revenue, high labor expenses, lacking a mechanical process for weeding, and ill-suited for current machinery options seems to be a perfect candidate for new types of machinery. Even more enticing is that these producers have considerable access to consumers. A machinery solution that improves the features of organic and local production in a way that consumers find appealing can be marketed directly to those consumers and provide a competitive advantage for producers.

So, what do these producers need from their machinery? Since one of the primary drivers of labor cost is weeding, that task is perfect for mechanization. The basics of weeding are similar across a wide variety of crops, and advanced weeding implements are already available. While row crop cultivation has declined in the U.S., European companies like Steketee, Einböck, and Kress have continued development and currently produce high-speed, camera-guided precision row-crop cultivators with finger weeding attachments that can provide both intra-row and inter-row weed control in a wide variety of crops. The machine that pulls these implements need only be low power and operate for short durations, but it needs to be precise and capable of frequent use. Preferably, to create further labor savings, the machine would also reduce the need for an operator.

**The solar electric solution**

Considering all these factors, we began investigating an autonomous, solar-powered tractor for weeding in diversified, organic, local vegetable production. Its autonomous operation makes the system ideally suited for its intended application because it targets a primary cost: weeding labor. The tractor must be precise to reduce the chance of damage to high-value crops, but it does not need to be highly intelligent (i.e., capable of handling unanticipated situations). The tractor is low power, which limits its ability to cause damage to external structures. Human operators will also be within a few minutes’ walk and able to provide assistance if anything unusual occurs. The tractor only needs to be able to drive precisely, and in the event of a problem, stop and wait for human assistance.

The operating duration and frequency, combined with the expectations of the target customers, make electricity an excellent option for powering this machine. After the oil embargo of the 1970s, agricultural engineers investigated using electrical power for agricultural field machinery. The findings at the time were that storage issues made electrical power impractical for general fieldwork, but that there were possibilities in utility work (frequent, short-duration tasks). Those findings have proven accurate. Indeed, modern farms have few electric vehicles; however, utility-type vehicles in other industries (e.g., fork trucks for material handling) have seen a shift from mostly internal combustion to electric drive trains. The duty cycle of our weeding machine closely matches the use of a utility vehicle. Operating for short durations requires batteries of a reasonable size and provides sufficient recharging time between tasks.
The ASABE Constitution establishes that “a Fellow shall be a member of unusual professional distinction, with outstanding and extraordinary qualifications and experience in, or related to, the field of agricultural, food, or biological engineering. A Fellow shall have had 20 years of active practice in, or related to, the profession of engineering; the teaching of engineering; or the teaching of an engineering-related curriculum. The designation Fellow shall have honorary status, to which members of distinction may be elected, but for which they may not apply. Admission shall be only after a minimum of 20 years as an active Member-Engineer or Member of ASABE.”

Election to Fellow is one of the highest distinctions that an ASABE member can achieve. Members who have been elected Fellow often say it is one of the most significant experiences of their career. At the Annual International Meeting in Orlando, Florida, on July 18, thirteen new fellows were recognized and honored. In the coming issues of Resource, we will shine a spotlight on these highly accomplished individuals, beginning with these four honorees.

Creating this electricity from solar power is the type of differentiation that customers of organic and local food would appreciate. Other researchers have established that direct power using vehicle-mounted solar panels is impractical, so a battery system makes more sense. A battery charger tied to the power grid might be all that is necessary to ensure that the tractor is operated with renewable energy, as many utilities provide options to purchase dedicated renewable energy. Another option is installing solar panels on the farm. Based on our tests, a 12 kW solar panel system (with a footprint of about 500 ft²) would supply enough energy to weed eight acres of diversified vegetable production, with enough excess energy to refrigerate the produce all year.

Is this the future of organic and local production? Only time and the markets will be able to determine that. These production systems can certainly benefit from mechanization to decrease their labor costs, and they have the revenue and pricing power to make changes to their operations. Assuming the demand for local and organic food remains strong, this is an opportunity for machinery manufacturers to fill an as-yet unmet niche in the market.

ASABE member Joe Dvorak, P.E., Assistant Professor, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, USA, Joe.Dvorak@uky.edu.

The tractor and weeder operating in a vegetable plot. The person sitting on the back of the machine is controlling the weeder for this experiment. When configured for human control, this weeding operation normally requires two people: one person steers the tractor, and another guides the weeder. The person guiding the weeder can be removed through the use of a readily available camera-control option, while the unmanned tractor design removes the tractor driver for additional labor savings.

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Meet the Fellows

David D. Bosch, Research Hydraulic Engineer, USDA Agricultural Research Service, Southeast Watershed Research Laboratory, Tifton, Georgia, was honored for his distinguished contributions to the science of watershed hydrology and development of hydrologic models. Bosch has profoundly improved understanding of hydrologic and water quality processes in agricultural areas and in specialized natural environments contiguous to agricultural areas. He was one of the first to identify vadose zone and groundwater flow rates through riparian buffers. Pictured here, David and Maria Bosch.
Honoring the Newly Elected

Robert T. Burns, P.E., Associate Dean, University of Tennessee Institute of Agriculture, was honored for his meritorious work in environmental stewardship of animal production worldwide. Burns is an international authority in the area of manure and nutrient management. He provided leadership in the development and maintenance of the USDA Natural Resources Conservation Service curriculum for training technical service providers in creating comprehensive nutrient management plans for animal feeding operations.

Pictured here, Robert Burns on the Canadian Trans Labrador Highway.

Gary A. Clark, P.E., Senior Associate Dean and Professor, College of Engineering, Kansas State University, was honored for his exemplary teaching, research, and extension work in irrigation, water management, academic administration, and leadership in the profession. Clark has focused on water conservation through improved irrigation system design, operation, and management. He helped create a cooperative program among state agencies, farmer irrigation associations, and Kansas State Research and Extension that promoted improved center-pivot irrigation management and tools, helping move ET-based irrigation scheduling to a common practice.

Pictured here, Gary and Barbara Clark with children Robert, Ashley, and Matthew.

Darrin J. Drollinger, ASABE Executive Director, was honored for his outstanding service to the equipment manufacturing industry and outstanding leadership in the non-profit sector of agricultural and biological engineering. Since 2010, Drollinger has led ASABE’s day-to-day operations, providing organizational and technical leadership, developing domestic and international partnerships within the Society and among professional groups, and energizing effective collaborations that support member-based priorities. Prior to ASABE, Drollinger gave 20 years of service to the Association of Equipment Manufacturers as a staff engineer and as vice president.

The ASABE Foundation supports the efforts of the Society in several ways, including numerous awards. In 2016, the Sukup Global Food Security Award was added as a major endowed award to “recognize enhancement of food security by innovative engineering or the application of engineering in the production and distribution of food, including the storage and handling of grains, oilseeds, and other food products.” The award was made possible by the generous endowment of Sukup Manufacturing Co.

ASABE Fellow Charles Sukup, P.E., is President of Sukup Manufacturing and received the Cyrus Hall McCormick Jerome Increase Case Gold Medal Award in 2016 that recognizes “exceptional and meritorious engineering achievement in agriculture.” Given these two significant events occurring in the same year, we invited Charles to share some of his thoughts about what motivated him to initiate an ASABE award and how it felt to be on the receiving end of one of those awards as well.

Charles said one reason he wanted to sponsor an award was that he is very thankful for what his company and family have been blessed with and was looking for an opportunity to continue to give back to the Society. He was the first degreed engineer to work in the family business, which was founded by his father over 50 years ago. The company has maintained a focus on grain drying and storage throughout its history. Charles has found value in the Annual International Meetings that he began attending as a student member at Iowa State University. As a 37-year member of ASABE, and having served as 2006-2007 Society president, on the Board of Trustees, and on the Foundation Board of Trustees, he has a deep understanding of the many roles that ASABE plays.

One of the motivations for an award focused on global food security comes from Charles’ opportunities to travel internationally and see the challenges faced by farmers around the world. His daughter Elizabeth has also focused on international agricultural projects and has worked with organizations including the UN World Food Program, traveling to Liberia, Ghana, and Ethiopia. A focus on food security is also consistent with the grain storage business, as Charles indicates that up to a third of the grain produced in the world does not get to the end users. The Sukup Global Food Security Award reinforces one of the missions of agricultural and biological engineers: to feed the world.

It is fitting that the first recipient of the award is ASABE Fellow Carl Bern, P.E., of Iowa State University, who has worked with smallholder farmers around the world in growing and storing their own food. The Sukup Global Food Security Award is unique in that it does not require the recipients to be ASABE members, and the award can be given to individuals, teams, or organizations. The idea is to not constrain possible recipients but rather to allow the award to highlight the most innovative and impactful efforts that address global food security.

As a recipient of the Case Gold Medal, Charles said, “I am very humbled to receive the Society’s oldest award that began in 1932, and I hope to live up to that legacy.” Charles expressed great appreciation for the efforts of everyone associated with the Society, including staff, trustees on both boards, and all of the volunteers that allow ASABE to thrive.

Perhaps there is a unique area that inspires or motivates you to create an award or recognition for ASABE programs—or to provide additional funds to an existing award or the KEYS fundraising initiative. Please contact Mark Crossley (crossley@asabe.org) or Darrin Drollinger (drollinger@asabe.org) for the many ways you can give back and promote the future generations of your profession.

ASABE member and Foundation trustee Edward M. Barnes, Senior Director, Agricultural & Environmental Research, Cotton, Inc., Cary, N.C., USA, EBarnes@Cottoninc.com.

ASABE member, Foundation trustee, and Development Committee chair Sylvia Schonauer, P.E., Principal Engineer, Advanced Innovation Global Breakfast, W. K. Kellogg Institute, Battle Creek, Mich., USA, sylvia.schonauer@kellogg.com.
RUTGERS UNIVERSITY
BIOENVIRONMENTAL ENGINEERING DEPARTMENT
NEW BRUNSWICK, NJ

Type of Position: Graduate Student or Post-doc

Start date: Available immediately

Description: The project involves the design, implementation and evaluation of innovative ventilation systems for high tunnels and small greenhouses. The main focus will be on environmental data collection and ventilation modeling using computational fluid dynamics (CFD) techniques. The project is grant-funded and offers up to three years of funding provided satisfactory progress.

Qualifications: Agricultural engineering degree (or equivalent) with experience in controlled environment agriculture, instrumentation, and CFD analysis.

Application Process: Please submit a cover letter, CV, college transcripts, and the names, e-mail addresses, and phone numbers of three references. Applications will be reviewed as soon as they are received.

Contact: A.J. Both, Dept. of Environmental Sciences, 14 College Farm Road, New Brunswick, NJ 08901. E-mail: both@aesop.rutgers.edu

TEXAS A&M UNIVERSITY
BIOLOGICAL & AGRICULTURAL ENGINEERING DEPARTMENT
COLLEGE STATION, TEXAS

Professor and Chair of Cotton Engineering, Ginning and Mechanization—Tenure Track. The Department of Biological and Agricultural Engineering at Texas A&M University and Texas A&M Agrilife Research seek qualified applicants for this position to establish an integrated teaching (45%), research (45%) and service (10%) program on cotton engineering. Applicants should possess an earned Ph.D. in Biosystems, Agricultural, Biological or other engineering discipline. Candidates should have demonstrated performance in research, teaching and outreach suitable for appointment as holder of the Chair of Cotton Engineering, Ginning and Mechanization and demonstrated success in grantsmanship. Additional expertise is desired in one or more of the following areas: sustainable systems, supply chain logistics, air quality, post-harvest processing, machine learning, cyber-physical systems, big data analytics or bio-manufacturing. The successful candidate will demonstrate an ability to both lead and collaborate within multidisciplinary teams and have excellent written and oral communication skills. Apply at http://greatjobs.tamu.edu, search for NOV #09873. Please send an e-mail notice of application to the search chair, Dr. Sergio Capareda, at scapareda@tamu.edu.

E-mail only applications cannot be accepted. The closing date for applications is January 14, 2017. Texas A&M University seeks individuals who are able to work with diverse students and colleagues, who have experience with a variety of teaching methods and curricular perspectives, and who will contribute to the diversity efforts of the University.

Assistant Professor—Post-harvest Process Engineering—Tenure Track. The Department of Biological and Agricultural Engineering at Texas A&M University and Texas A&M Agrilife Research seek qualified applicants for this position with a research (45%), teaching (45%) and service (10%) appointment. Applicants should possess an earned Ph.D. in Biosystems, Agricultural, Biological or other engineering discipline. Candidates should have demonstrated potential for leading a research and teaching program in post-harvest engineering. Expertise is desired in one or more of the following areas: air quality, supply chain logistics, machine learning, cyber-physical systems, big data analytics or bio-manufacturing. The successful candidate will demonstrate an ability to both lead and collaborate within multidisciplinary teams and have excellent written and oral communication skills. Apply at http://greatjobs.tamu.edu, search for NOV #09874. Please send an e-mail notice of application to the search chair, Dr. Sergio Capareda, at scapareda@tamu.edu.

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Your personal or company consultant business card could appear here. For information on rates ($95 and up) visit www.asabe.org/Advertise or contact Sandy Rutter, 269-932-7004, rutter@asabe.org.
This special Resource issue is dedicated to a look into the future of agricultural machinery. In closing with “the last word,” it seems pertinent to reflect on the ways engineering has changed in the last half-century and how it may well change going forward.

Fifty years ago, computers were rare, and those who used them wrote their own software. Most of the design decisions required for a new machine were based on a combination of hand calculation and experience. Development cycles were long, production of drawings and material specifications was time consuming, and what little accelerated-life testing that existed was based on experience rather than well documented material science. Today, computers are ubiquitous, and software for almost any discipline is readily available. This has fundamentally changed the way we approach engineering design.

It is now routine to explore a vast array of options, using mathematical models, early in the design of a new or revised machine. The first prototype can be much closer to a final design, even though the time from concept to prototype has been reduced. Well-documented, accelerated testing allows an expected machine life, measured in years, to be verified in a few weeks, further shortening the time from concept to production. As a profession, we are also learning to use new materials and fabrication techniques to produce designs that were almost impossible just a few years ago. These trends will continue and will promote the ever-increasing productivity and efficiency needed to support the world population of 2025 and beyond.

Even more important than the changes in the machines will be the changes in user experience as machines become more autonomous. Fifty years ago, machine operators had to decide the appropriate settings for multiple controls in an attempt to optimize performance. Feedback control loops—other than the engine speed governor and, where applicable, draft control of the three-point hitch—were nearly nonexistent. Today’s trends in machine autonomy began as science fiction. Early attempts at self-steering tractors and feed rate controls never reached production because the experimenters could find no practical way to observe the condition they were trying to control. With new sensors, and computing power to extract meaningful information from multiple sensors, we can design machines that require less second-by-second human input. In fact, the human operator has so little continuous involvement that distraction is becoming a problem!

Future semi-autonomous machines will require careful interface designs to ensure that the human remains in control while maximizing the use of machine intelligence to perform routine tasks. The human interface problem will eventually be solved, but that is one of the major challenges in improving the productivity of agricultural machinery.

While the quest for efficiency is nothing new, society is becoming ever more aware of sustainability. Life cycle analysis is well accepted in principle. However, as a profession, we still have a lot to learn as this practice develops. It is already apparent that life cycle analysis will require more systems engineering techniques. When the environmental impacts of building a machine and disposing of it at the end of its life are added to the impacts from machine operation, we have a complex trade space in which a global optimum will rarely coincide with the optimum for any segment of the machine’s life.

Another effect of this increasing awareness of sustainability will be a need for an in-depth look at our ultimate goals. The people who use agricultural machinery are primarily attempting to meet the food, fiber, and fuel needs of the world population. Current farming practices are working toward that goal, but there is little reason to believe that a more sustainable practice can’t replace any current practice. The moldboard plow has almost disappeared during the last fifty years. Similar changes will occur as we develop a better understanding of the optimal environments for growing crops and livestock.

So what should we expect in the years to come? First, the pace of change will continue to increase. Engineering will include more effective model-based design tools, more reliable methods for accelerated durability evaluation, and advanced electronics at a reasonable price point. These changes will result in shorter lead-times on new products. At the same time, new ways of farming will result from a new understanding of the needs of crops and livestock, combined with society’s increasing comfort with autonomous devices. Beyond that, it’s futile to attempt a more specific prediction, because our future course depends on many things yet to be realized.

ASABE member Bernard E. Romig, Principal Engineer, John Deere Fellow, Moline Technology Innovation Center, Moline, Ill., USA, RomigBernardE@JohnDeere.com.
Keynote Speaker
Dr. J. B. Penn
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