UC DAVIS
World Food Center

Water Conservation, Food Distribution, and Ag Production Digitization

Input from 17 UC Davis Experts

Compiled by Dan Flynn, College of Agricultural & Environmental Sciences Dean's Office Representative for Strategic Initiatives, on behalf of the UC Davis World Food Center

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Jay Lund

Jay Lund is Professor of Civil and Environmental Engineering in the Department of Civil and Environmental Engineering. He also serves as Director for the Center for Watershed Sciences. His research focus areas: application of systems analysis, economic, and management methods to infrastructure and public works problems

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

I tend to look at broader problems. There are two approaches:

- Use less water for the same agricultural production; which is happening over time as crops more productive. There is also apparent conservation from higher irrigation efficiencies.
- Use the same water we are using and split between crops and aquifers. Some irrigation methods that are commonly seen as waste are actually not waste because they are recharging the aquifer, e.g., flood irrigation. However, percolating water will take nitrate and salt from agricultural soils into the groundwater, so that speaks to needing to use higher efficiency irrigation systems. One solution is to use efficient systems, and alternate in wetter and dryer years between inefficiency and efficiency, as well as using water systems management.

We will need to tighten up regulations as they relate to water use, e.g., meters will be required, which requires a need for cheaper meters that are easier to estimate use.

Or maybe remote sensing is the way to do it, have the water meter in the sky. That research is underway at UC Davis in the Center for Watershed Sciences and the Department of Land, Air and Water Resources. Idaho uses remote sensing to estimate water use to some degree. Needs to be transparent between companies as to the estimation of water use.

What are some challenges that these technology startups are facing?

As we move into broader accounting systems then we need more non-proprietary services at the larger water district and regional scales: what the water use is and what people are entitled to, which will facilitate water credits.

Aggregrate transactions need to be public, individual transactions can continue to be private.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

I think that the water conservation impact of effluent reuse would be medium. GHG and energy use could potentially increase in managing the effluent from additional pumping, processing, etc.

For Aerial Imagery there is some value in having a consistent methodology; estimates of use need to more public and there has to be a way for farmer to appeal. If we use meters you can get a variance on the estimates, the remote sensing errors might be just as big but at least they should be more systematic and standardized.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

There is a value in having Predictive Maintenance and Analytics that integrate field data and operations. For example, when fish are around you can turn on different pumps, thereby minimizing impacts on fish and agriculture. Another example: California farmers modified rice agriculture by flooding at some times of the year, which helped rice straw decompose while increasing the bird population.

Isaya Kisekka

Isaya Kisekka is Assistant Professor in the Department of Land, Air and Water Resources and in the Department of Biological and Agricultural Engineering. His research focus is in agricultural water management, irrigation engineering, agricultural hydrology, crop modeling and decision support, modeling of evapotranspiration and soil water measurement.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

I have had the benefit of working with various types of growers around the United States. My view is that we have the technology for irrigation efficiency but we have a deficiency in management of these systems. For example, farmers have invested in drip irrigation and variable-rate irrigation, only to abandon the systems in a couple years because they did not manage them well. Drip irrigation can break down from clogging and rodents chewing through the lines. Soil-moisture sensors send a lot of data but the farmer doesn't know what to do it. How do you bridge the gap?

The Natural Resources Conservation Service (NRCS, in the USDA - United States Department of Agriculture) is subsidizing the farmer to go to efficient irrigation systems. With these systems you have to understand the soil, the plant, the market, not just for maximum yield but also for maximum profit. Sensor information could optimize whether to irrigate today or the day after. It's pretty complex with all this information. CropManage (a system that provides guidance to field crop growers in the Salinas Valley, overseen by local farm advisors in the University of California's Division of Agriculture and Natural Resources) does a good job but we need to integrate it with sensor data and simulation models. Maybe the farmer should not have to figure this out due to the complexity, perhaps they could contract with companies to advise them (farmers already use crop consultants.)

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

I am developing a risk-management tool (iCrop) to predict the end-of-season impacts of crop-management decisions. He'd like to write a paper about it and then the technology would be open for entrepreneurship. With this tool the farmer could predict the impact from the interaction between genetics, management and environment. The farmer would select different variables and determine crop profitability. This tool looks at irrigation as a complete system, incorporating water allocation, crop selection, sensing, fertigation and site. With this tool you can draw the area to be planted, and the area that you draw would be populated with weather (from California CIMIS data) and soil info (from USDA mapping), using a test model DSSAT developed some years ago.

What are some challenges that these technology startups are facing?

Inconsistency in USDA policies may be working against it, for example if using regulated deficit irrigation you wouldn't qualify for crop insurance, because you wouldn't have an average historical yield.

There is also a high failure rate of ag-tech companies, which often are developing solutions for which there are not actual problems. They should talk to the farmers more. Some of these ag-tech companies talk to me and they do not have a good knowledge of farming.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

If there were more investment in large irrigation infrastructure and more delivery systems, e.g, pressurizing the distribution network, on-demand irrigation would permit farmer to do high-frequency irrigation and fertigation. Pressurized systems perform better than the old irrigation-canal systems.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

Water management, Infrastructure and water reuse that is suitable for the crop.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

If you can predict demand you can optimize management and optimize supply and demand.

Andre Daccache

Andre Daccache is Assistant Professor in the Department of Biological and Agricultural Engineering. His research focus areas: water resources management, irrigation engineering. crop and climate change modeling and hydraulic engineering.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

A lot of studies have been done on saving water in agriculture but there is a big gap between the results of this research and what is happening on the ground. The majority of farmers don't know anything, they are not using remote sensing, they are not using what has been developed already.

We need to tighten the link between the farmers and researchers. We could have training to translate complex technology into more understandable language. Need researchers who could translate data into simple means for farmers. Decision support tools are needed to translate complex science into actionable information.

Before coming to UC Davis I was benchmarking data for tomato growers on how much water they were using. I was expecting that neighboring farmers would have similar experiences, but found that there was a great level of variation between growers. So the question is, do the growers know where they stand compared to other growers? My experience is that they don't know. I was also surprised that farmers either don't collect data or if they do they don't know what to do with it. So the way we did it with the tomato growers was we issued a scorecard which showed where they stand compared to the other growers, and the scorecard included diagnosing their problems. It was not science, it was simple, but this had more impact than studying more science. We need to link technology to what is apparently happening. We need technology but also basic knowledge.

If you want to measure soil moisture, there are different methods, but most of them need to be calibrated and validated before you get valid results. It would be useful if there was an entity that could compare technology (e.g., like consumer reports). This could start with a literature review -- even he as a researcher cannot keep up with all that is being done, nobody has time to read all of these published papers. Target the relevant papers in a Google Scholar review and look for the commonalities and differences. Use a systematic review, based on key words, to be much more directed on whether more research is needed or not. They use systematic review in medicine research a lot, e.g., is a medication bad on stomach.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Renewable energy for irrigation pumping, using hybrid technology to run the pumps. If you have a hydraulic pump in the middle of nowhere is expensive and the power lines are a source of fire hazard. Combining solar and diesel power, could reduce emission and costs, use solar during peak period to reduce cost. Not sure if anyone is doing it.

Smart card sfor agricultural water (like for transit systems). Water agency can load the cards, farmer uses to their limit, and if wanted to use more would need to, it is not that innovative, using in Italy for 10 years, each farmer has own hydrant, at end of season how much is used is recorded on the card and the farmer pays the water agency. We could use this technology to manage groundwater. Farmers would not like it, but it would allow the water authority to track withdrawls, would tell the water manager where water is used in real time. Could use this not necessarily to penalize the farmer but to better manage sustainability.

What are some challenges that these technology startups are facing?

Growers are pragmatic, so the first thing that you need to do is provide evidence that what you are proposing actually works. The technology cannot be too complex or expensive, and it needs to pay off. Sometimes a farmer does not believe until they see it. Show me, do a demonstration program at UC Davis with extension.

Water quality, such as when using wastewater for irrigation, which would make a huge impact in countries without much water, such as in the Middle East. What are the health consequences of using treated urban wastewater, which could be used with urban farmers? What are the nutrients, what are the environmental benefits compared to typical disposal systems? If using for agriculture you don't need to separate the wastewater effluent, and separation would be expensive. Could kill pathogens with UV.

There are a lot of companies that that try to meet the farmers' needs but how much science is behind the product that they are selling? I am skeptical. Need to look not just at technology but also why the grower is not adopting the technology.

Shrinivasa Upadhyaya

Shrinivasa Upadhyaya is Professor in the Department of Biological and Agricultural Engineering. Research focus areas: Precision agriculture or SSCM, Sensor development, Instrumentation, Machinery design, Variability and mapping, GIS, Mathematical Modeling of biological and physical processes, Soil dynamics, Tillage, Traction, Soil compaction, and Infiltration and irrigation management.

To get to 90% of a research goal takes a couple years. Getting to 95+% of the goal takes much longer. For example, we have researchers who have been using a light bar that can take measurements under the tree, riding on a Kawasaki Mule, to determine canopy coverage and thereby estimate production. A second objective of this work is water management – can we detect the plant water status and respond by properly irrigating the tree? If you know the canopy coverage you can determine a crop co-efficient for evapotranspiration. This technology works pretty well and been used for a few years in walnuts, grapes, pistachios and almonds. We found that a grower could save irrigation water, which was 90% of the goal.

We are now trying to determine how the tree acclimates to the conditions in the field, which is the 95+% level that is difficult to determine. Something that a plant does in the beginning of the season is not the same that a plant will do at the end of the season. To pursue this goal we first needed to create irrigation management zones based on soil conditions and other factors. We are getting data remotely from monitors in the trees and we are working with a few farmers to collect data, the company that has the sensor licenses the technology from the university. Energy requirements and poor cellular connectivity create problems with transmission of the data. Both will ultimately be addressed, such as by solar power and better cellular coverage. I am trying to come up with a way to solve the acclimatization issue and to demonstrate to early adopters that this project is working like it is supposed to.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

Sensors to indicate plant water status, to replace the pressure bomb. Development of a decision support system once the data is acquired, deep learning (e.g., neural network with multiple layers). Method of analyzing the data to make irrigation decisions.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Andrew McElrone in the Department of Viticulture and Enology has technology to make irrigation decisions in the vineyard. There are people at Cornell putting a probe directly into the xylem of the trunk, a sensor that measures water flow in the xylem. Israel has a dendrometer that measure the change in the diameter of the trunk. There is a Zim probe looking at the thickness of the leaves. All of these are looking at the plant water requirement.

What are some challenges that these technology startups are facing?

Private companies have a hard time finding funding to get early adopters for them to resolve issues and bugs in the technologies. I have been working with early adopters to work out the issues with the technology. They are not putting out money for the researcher to try out their system. Demonstrating it to the growers is a challenge. There might be products on the market that have not had enough ground truthing. The Small Business Innovation Research program (SBIR) is one way to do this so that the companies can hire someone with research capability.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

Planting and growing have high energy-reduction potential, but not how much can be minimized. Certainly water is an input with potential to be minimized. Fertilizer application could be reduced to reduce energy input, by minimizing resource input.

Are there any missing segments on that are not shown in this chart?

Post harvest is an area to save energy.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

Precision agriculture has potential to reduce inputs, when he thinks of robots he thinks of labor reductions.

FOOD DISTRIBUTION SUMMARY

Technology areas currently underfunded

- Energy-efficient drying technologies (Bradford)
- Gene editing (Bradford)
- Efficient distribution systems to feed demand for local food (Bradford)
- More understanding of the spoilage initiation point (Nitin)
- Understanding consumer demand and the dynamics of how they change in the market (Nitin)
- Storage and distribution (Nitin)
- Membrane filtration to isolate components (de Moura Bell)
- Refrigeration systems in transportation and storage (Brigham)
- Sensors that detect pathogens, excessive temperatures and over-ripeness (Brigham)
- Cold chain management, especially in the initial stage of cooling (Donis-Gonzalez)
- Repurposing food byproducts to make new food products (Simmons)
- Small-scale anaerobic digesters located at the site of waste generation (Simmons)

Emerging early-stage technologies

- Drying technologies using renewable energy and desiccants rather than heated air (Bradford)
- Hermetic storage for dry products in ship containers (Bradford)
- Cloud-based tracking to promote traceability and optimize energy use (Nitin)
- Sensors in smart refrigeration technology (Nitin)
- Integrating multiple data sources (Spang, de Moura Bell)
- Sensors that detect pathogens (Brigham)
- Dry chain technologies, enhancing methods with current equipment and evaluating new methods (e.g., dessicant, infrared) (Donis-Gonzalez)
- Sensors and communication for both the dry and cold chains (Donis-Gonzalez)
- Translating the “internet of things” to food processing to improve energy efficiency (Simmons)
- Anti-microbial coatings to avoid the need for cold-chain or dry chain (Siegel)

- Separation and drying of liquid food products to reduce cold-chain transportation costs (Siegel)

Challenges for start-up companies

- Sunk costs in old technology make prospective buyers reluctant to invest in new more- efficient technology (Bradford)
- Making solutions cost-effective when you don't have access to mass-scale (Nitin, Siegel) This is the problem with the biofuel sector, hard to get to scale
- Growers want to protect primary market from being adversely impacted by a secondary market (e,g., imperfect produce) (Spang)
- Getting water and energy utilities to share their data (Spang)
- Unknowns about imperfect produce: quantity, annual variability, potential consumer demand (Spang)
- Water and energy costs are too low to incentivize efficiency (Brigham)
- Lack of traceability and accountability for improperly handled food (Brigham)
- The economics of agriculture is not as appealing as other fields (Donis-Gonzalez)
- Ag is not cool like other tech (Donis-Gonzalez)
- Ag has a slow return (Donis-Gonzalez)
- Ag often requires specialized technology for each crop (Donis-Gonzalez)
- There is resistance from the industry to do something new (Donis-Gonzalez)
- Hard to get funding for research in cold chain (Donis-Gonzalez)
- Unfamiliarity by investors (Simmons)
- Companies may be reluctant to divulge data (Simmons)
- The timeline and return for ag-tech doesn't fit most venture capital models (Siegel)
- The pathways to market are not clear for ag-tech start-ups (Siegel)

Missing segments in food distribution value chain

- Dry chain (Bradford, Donis-Gonzalez)
- Harvest (Bradford)
- Postharvest (Bradford)
- Processing (Bradford, Spang, de Moura Bell, Brigham, Donis-Gonzalez, Simmons)

- Cold chain should include storage (Nitin, Spang, Brigham, Donis-Gonzalez)
- Sanitation (Nitin)
- Packaging should include grading and sorting (Spang)
- Secondary use (Spang)
- Waste prevention (Spang)
- Consumption and Disposal should include reutilization, bio-digesters, alternative energy sources (Donis-Gonzalez) and management at the wholesale level (Nitin)
- Product development (Siegel)

Kent Bradford

Kent Bradford is Distinguished Professor in the Department of Plant Sciences, Director of the Seed Biotechnology Center, and Interim Director of the World Food Center. His research focus areas: all aspects of seed biology, from the genetics, molecular biology and physiology of seed development, dormancy and germination to the production, storage, enhancement and utilization of seeds for agricultural purposes

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

Energy-efficient drying technologies. Gene editing, which is not going to be regulated by the federal government.

Water supply and conservation: We need the California delta tunnel project and much more, more groundwater storage and much more, cheaper desalinization for urban uses. Northern California is way behind Southern California in conservation.

The desire for local food and the challenges of efficient distribution. Subscription farming is very inefficient – could we develop distribution hubs that could be more efficient?

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

One-third of the energy in the food industry is from taking out water. An emerging early-stage technology relates to drying technologies using renewable energy and desiccants rather than heated air.

Hermetic storage for dry products. For example, California nuts arrive in Europe with aflatoxin, even though they were shipped free of aflatoxin. Shipping nuts through Panama Canal exposes them to high humidity and warmth and then goes to the north where there is condensation that introduces moisture and fungi. We need to seal the cargo hold to keep it dry, or put the product in a liner (grainpro makes a warehouse-size liner) or dry the product further.

What are some challenges that these technology startups are facing?

Sunk costs in old technology make prospective buyers reluctant to invest in new more- efficient technology

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

The value chain overlooked the impact of drying, large unquantified losses on the front end for the US, left in the field, not included in the value chain analysis on slide 5. Plant breeding is also missing from the value chain – we need to breed plants that would not allow E.coli and other pathogens to grow.

Are there any missing segments on food distribution that are not shown in this chart?

Need to start this slide with a new category: dry materials have a more-complicated food chain than non-dry materials.

Need to add Harvest and Post-Harvest.

Another potential packaging question; anaerobic packaging could prevent oxidation.

Storage (does the slide mean bulk storage or packaged storage?)

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

Add drying technology, investment will be low with high impact in energy reduction and GHG reduction.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

Add dry chain chain (drying costs for corn can be as much as all the other growing, harvesting, and post-harvest costs for corn prior to drying). If it can dry in field they are fine but if the weather is not conducive to drying (as in the Midwest) then you need to dry some other way.

For most grains they would store better if we dried them more, but producers aim for just below the threshold where fungi would grow. If dried further it would cost more.

Nitin Nitin

Nitin Nitin is Professor and Engineer in the Department of Food Science and Technology. Research focus areas: interdisciplinary approaches encompassing biomolecular engineering, mathematical modeling, material science and molecular imaging to study food engineering and biological/biomedical research.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

Waste in fresh produce, meat and seafood. Everybody is passing the buck. We need more understanding of the spoilage initiation point and what can be done to address spoilage. Initiation is probably starting on the farm, not very visible, so you need sensor, process, packaging and transportation technologies.

Understanding the consumer aspect; we understand little about consumer demand and the dynamics of how they change in the market. We think that food is a staple but consumers don't buy the same things every time. Just because a consumer buys kale doesn't mean they are going to eat it.

Storage and distribution are parts of the value chain with little research.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Water-free or efficient cleaning and sanitation would save a lot of water and energy. We may use ten times the weight of produce to clean it and this water is chilled.

Water treatment technology at the point of use, for example could treat water to reuse at the facility rather than sending it off for treatment by a municipal system.

Looking at cloud-based tracking to promote traceability and optimize energy use, for example, people would leave fridge door open while taking something to the loading dock.

Samsung has a smart fridge technology with smart sensors that are promising but the appliance is very expensive.

What are some challenges that these technology startups are facing?

Biggest challenge is making solutions cost-effective. The industry tells us that any solution has to cost less than 10 cents, which might work at mass scale but not for a start-up with fewer customers. There is a disconnect between the return expected by investors and the need for startups to keep product cost low.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

Freezing and refrigeration are the biggest energy sinks in home, retail and the cold chain. Easiest to make changes at the wholesale and retail level because they have fixed facilities. The longer you hold something in a freezer the bigger the energy sink it is.

More efficient cooling technologies could contribute to conservation of energy and greenhouse gases in agriculture, for example, temperature zoning in refrigerators since everything doesn't need to be held at same temperature. Could get two weeks of shelf life out of produce with better refrigerator technology.

Are there any missing segments on food distribution that are not shown in this chart?

Processing should be included, and cold chain should go beyond transportation.

Sanitation should be reflected, and it could go through the whole chain. The Food Safety Modernization Act now requires trucks to be sanitized.

Disposal management at the wholesale level is not reflected, this waste could go to biodigester, biofuel, composting facility, etc.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

Thinks Waste Prevention is correct.

Cold Chain Transportation: California is requiring trucks to have some level of renewable energy (maybe 25%), which could eventually impact the requirements in other states.

Less familiar with Logistics Software, sees it more as a short-term gain because once you figure out what you are not doing right you change and you don't need to keep doing it again and again.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

Processing. Also, waste prevention could come from packaging and other segments that are on this slide. On his slide some of the companies in packaging and logistics are also focused on waste. Most of these topics are aiming to give consumers the best quality product.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

Agree with most of this. Waste Prevention and the Cold Chain are missing the impact on the quality of the food. This is the most significant impact that people get from eating food. Should be included among the potential impacts besides energy/GHG/water, it will make it more compelling for government to fund research in this area.

Edward Spang

Edward Spang is Assistant Professor in the Department of Food Science and Technology and Associate Director, Center for Water-Energy Efficiency. Research focus areas: energy efficiency; water conservation; food waste; clean technology; systems analysis; sustainability; GIS

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

I don't know what is currently underfunded but there are definitely more startups in food loss and waste recently.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Putting info together: information technology, digitized supply chain, blockchain, internet of things, making known what was previously unknown. If we have a better sense of seasonality, composition of waste production, etc., it allows us to design models to give a solution based on each producer's situation.

What are some challenges that these technology startups are facing?

Growers know that the secondary market (imperfect produce for example) could eat into their primary market.

Challenges to getting water and energy utilities to share their data, gets more complex in the food chain.

How much imperfect produce is there – we don't know how much there is, or how consistent it is annually, or how much the consumer wants it. We don't have the ability to pinpoint more.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

In Packaging I would include grading and sorting in there.

Processing should be included.

My work is ongoing to losses in the field. Walmart and Blue Apron are trying to get more of the edible produce out of the field. Some trends, such as eating more vegetables, can feed into this goal, e.g., cauliflower "rice" allows farmers to take the stem and grind it up and have a new product. There products are changing people's perspective on eating less-desirable produce.

The California Energy Commission is also interested in switching modes of energy, for example switching from gas to electricity to reduce GHG, which affects processing energy, such as choosing microwave or infrared processing.

Are there any missing segments on food distribution that are not shown in this chart?

Cold chain should include storage. Some of these cold chain info companies, such as BT9, take technology to the field because for example, the lettuce picked in the morning is different from the lettuce picked in the afternoon, and the afternoon lettuce needs to be cooled more quickly. Lineage Logistics has been buying up cold storage warehouses and is upgrading the efficiency of these facilities by monitoring these facilities at high-resolution and making continuous improvements.

Processing is missing.

Secondary Use should be included such as food upcycling, for example taking juice pulp and making into a high-fiber food. Regrained take brewers grain and making it a flour and I think that they are working with the federal Department of Energy on a new technology for drying the grain. Also coffee cherry grinding into a flour. There are potential food-safety issues in producing these products, but there are companies that can fill that step. Closing the Loop is a broader area of this Secondary Use, for example, food byproducts often are provided to animals but there is a lot of room for more analysis to get higher value, a clear comparison is not well known. A company that specializes in this analysis could do it more methodically than the producer. Each producer comes up with their own solution but a company could be the one that consulted and manages this issue for food companies.

Waste prevention: Lean Path, helps companies measure their food loss in foodservice. Full Harvest gets imperfect produce into the market.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

This is the type of analysis I do. Without the data I can't say. If Cold Chain expanded the water conservation impact could be high if you are saving produce.

Logistics hardware: energy and GHG tend to go hand-in-hand.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

For waste prevention and waste recycling: From an economic and environmental perspective the place to have the most impact is the farthest down the chain, e.g., reducing consumer waste. The food is at its highest economic value further down the chain, but it is not necessarily the easiest to change. That is his goal of reducing food loss and waste, but if you are avoiding loss in cold chain you are gaining the dividends earlier.\

AB 1826 (2014) is a California law that will require businesses that generate four cubic yards or more of commercial solid waste per week to arrange for organic waste recycling services. This requirement, will begins January 1, 2019, creates opportunity for new companies to manage this waste.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

Logistics makes sense, no primary impact on water. But if logistics are optimized, and if it keeps more produce in the supply chain then it would have an impact, but maybe this is a secondary impact.

Food waste: significant GHG savings by landfill avoidance, wouldn't put transportation as a major impact for water.

Cold chain: Agree if improvements create less waste.

How are you quantifying/measuring the potential water conservation/energy/GHG reduction impact?

CalRecycle has a conversion factor for the landfill avoidance issue identified above.

If you are not wasting something then you need to quantify all the inputs along the chain, which gets complex. There is a tradeoff between having a really good number and devoting the time to develop the number. You could use a model from the Water Footprint Network, and use this as a placeholder for primary crops unless higher resolution data is needed. The Water Footprint Network has a Bluewater Footprint for irrigation water, a Greenwater Footprint for rain, and a Greywater Footprint for wastewater. It gets more complicated when you quantify inputs for processed foods such as a can of vegetable soup.

Juliana de Moura Bell

Juliana de Moura Bell is Assistant Professor in the Department of Food Science and Technology. Research focus areas: extraction and fractionation of food components, functional food, bio-processing, conversion of agricultural waste streams, enzyme-assisted extraction, supercritical and subcritical extractions.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

Use of membrane filtration to isolate components, which have been adopted by some food-processing industries already, but these could be used much more to isolate the compounds. We need the research developed for this purpose, we need to develop and optimize the process.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

The need is for more integration rather than adding something unique.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

Processing is an area missing from the value chain, need to add a column to the left of Packaging:

Value Chain Activities Description: post-production processing of products (e.g., drying, pasteurization, slicing, crushing, mixing, etc.)

GHG Reduction Activities: Membrane filtration (which allows working at ambient temperatures, minimize microbial contamination, cleaner effluent, microwave extractions allow reducing extraction time aqueous extraction and enzyme extraction could also provide benefits (e.g., not using flammable solvents)

Energy Use Reduction Activities: same as GHG

Are there any missing segments on food distribution that are not shown in this chart?

Processing, for example, manufacturers of non-thermal processing equipment; add new companies that are producing new ingredients (Repo Foods). To get other examples Google "plant-based proteins"

Jill Brigham

Jill Brigham is the Executive Director of the Sustainable Wine & Food Processing Center. Research interests: water and energy minimization, rainwater recovery and treatment, alternative energy generation, and byproduct recovery.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

The trend of direct-to-consumer foods drives the importance of increasing the efficiency of the logistics chain. I have the sense that there would be overall increase in impacts on GHG, energy and water from this growing area. Amazon Prime has had a net increase in GHG and energy use for getting products to the consumer.

The things that are not sexy are underfunded; refrigeration systems whether in a building or in transportation, tend to be inefficient from the perspective of insulative properties of the container and the cooling system itself. I would agree that the cold chain needs to focus also on storage. A warehouse in the cold chain is easier to address than trucking and transportation, for example, you can outfit the warehouse with solar panels. We see some leaders like Walmart and Target that have turned to these sources, which are fairly dominated by cooling.

Sensors that detect pathogens, excessive temps and overripeness. If you had better capability at the processing plant to sense pathogens you could extend the shelf life. There are now inks that change color when product exposed to a certain temperature. NASA would use discs that show if something got too hot. It would be good to know when in time that foods were exposed to excessive temperatures. A wireless temperature logger would be $3, could use one per pallet. Blockchain would be an area to integrate environmental sensors, GPS location. We need to ask what data is needed and how we obtain it so that the sensors are correct and not expensive, we need to decrease the cost of sensors and automation of the data.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Sensors, work being done in the Department of Food Science and Technology. Nitin Nitin and Maria Marco are trying to commercialize a pathogen sensor technology, they are partnered with the Electrical Engineering Department.

What are some challenges that these technology startups are facing?

Cost of energy and water are low enough that there is not a huge driver for efficiency.

If food is improperly handled there is a lack of traceability and accountability, which allows people to get away from food safety and quality issues.

What part of the value chain represents the biggest energy and GHG saving potential?

Trucking and cooling. The distribution part is hard to improve due to our reliance on trucking, which is very inefficient, partly due to centralized production in areas of high efficiency. So that requires more energy to get it to the consumer, so we need to drive efficiency in transportation.

What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

Cooling: new materials for insulation, more efficient cooling technology, heat exchange mechanisms. Transportation: optimization for routing, power source, aerodynamics, but not much impact in all of these.

I agree that processing should be at the front end of this one.

Are there any missing segments on food distribution that are not shown in this chart?

If you include Processing in the value chain you would add sensors, processing equipment (automation/robotics, computer systems, e.g., Johnson Controls, Allen-Bradley, Siemens) and data systems.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

If Processing is added to the value chain then in Waste Prevention water conservation could have potential to go to high from medium.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

If you had processing you would add sensors, processing equipment (automation/robotics, computer systems, e.g., Johnson Controls, Allen-Bradley, Siemens), data systems.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

I don’t have issues with what is on there, but they overlooked processing.

Irwin Donis-Gonzalez

Irwin Donis-Gonzalez is Cooperative Extension Specialist in the Department of Biological and Agricultural Engineering. Research focus areas: postharvest engineering, handling (storage, drying, etc.), traceability, and processing of agricultural commodities with a goal of reducing energy consumption while ensuring food quality and safety.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

People think that cold chain is fully developed and not much can be done, but we believe that more can be done in cold chain management, especially in the initial stage of cooling. We could also do more in training personnel. There are a lot of unknowns. There are a lot of manufacturers in this segment. We could make minimum contributions that would be significant.

I have submitted SBIR applications, one in dry chain has been approved, and one in initial cooling is still pending consideration. Dry chain is more modern and appealing and is a bit easier to find funds in this area. Both cold and dry chains have their place, dry chain cannot replace cold chain.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Dry chain: emerging technologies include enhancing methods with current equipment and evaluating new methods of drying, e.g., dessicant drying, infrared drying, sensing and communication technology.

Sensors and communication for both the dry and cold chains

What are some challenges that these technology startups are facing?

- The economics of agriculture is not as appealing as other fields, e.g., CA almonds 3% revenue of the iPhone, start-ups want to make money
- Ag is not cool like other tech
- Ag has a slow return
- Ag has variability (e.g., need different tech for tomatoes, almonds)
- There is resistance from the industry to do something new
- Hard to get funding for research in cold chain, e.g., forced-air cooling.

- We should look at food more as a health issue

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

Processing is an area missing from the value chain, so you need to add a column to the left of Packaging. Dry chain (dried fruit – 40 % of the energy is just removing moisture). Cold chain should not just be about transportation, it's also cold warehouse storage, and other steps in the chain.

Value Chain Activities Description: post-production processing of products (e.g., drying, pasteurization, slicing, crushing, mixing, etc.)

GHG Reduction Activities: developing different controllers to use ambient air (e.g., desiccant drying through hydroscopic salts, magnesium chloride, drying beads)

Energy Use Reduction Activities: same as GHG, could reduce 30% with ambient air

Water Conservation: better means of sensing water usage, modifying process (e.g., walnuts go through the hulling process using water but we believe we can remove it mechanically); cherries are chilled with water but could use forced-air cooling such as in the Chilean industry);

Are there any missing segments on food distribution that are not shown in this chart?

Need to add Processing, company examples: Grossi Fabrication (manufacturer of drying for walnuts in CA), Applied Instrumentation (dehydrator design, testing), Weco (sensing equipment); Kramer Corp (design and construction of silos and other ag equipment); cold chain: look at the Post Harvest Tech Center Yellow Pages for examples.

Consumption and Disposal should include reutilization, biodigesters, alternative sources of energy

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

Looks accurate, although water conservation in Logistics software could go from Low to Medium.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

Dry Chain: Impacts would be High, High, Low, analogous to cold chain

Internet of Things (may be part of Logistics Software) Low, Low, Low, could potentially be High, High, High

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

Would change the focus segment for waste prevention; in developed countries is more related to consumers and retailers, need to better understand consumers. In developing countries it is a lack of technology that leads to food waste.

How are you quantifying/measuring the potential water conservation/energy/GHG reduction impact?

Agrees with Chris Simmons on life-cycle assessment: Should look at life-cycle assessments when quantifying

Christopher Simmons

Christopher Simmons is Assistant Professor in the Department of Food Science and Technology. Energy, water use and quality, food processing, genetics, microorganisms, soil science, sustainability, metagenomics, metatranscriptomics, microbial communities, lignocellulose deconstruction, biofuels, bioenergy.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

Repurposing waste to other products. We have some homegrown start-ups that are looking at new products, e.g., Renew Foods takes high-quality waste streams (e.g., cucumber pulp, banana skins) and using them to create new products. These types of companies are unfamiliar to investors and new products have a low success rate even for the most established companies (e.g., Pepsi), return rate variable because there is not an accepted investment model (in terms of sourcing, transport, etc.). Challenges: you are transporting water for the most part, also got to worry about spoilage, fermentation and oxidation.

Small-scale anaerobic digesters Located on the site of the waste production which would then contribute to the energy needs of the facility. Microsoft does this with their dining commons. I have a project with Ned Spang to do this, funded by the California Energy Commission, we are constructing and deploying a pilot unit that they would compare to the cost of a central larger digester.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Translating the "internet of things" to food processing. Processing plants have little ability to monitor their energy demands for each step of processing using real-time data. There are opportunities to monitor inefficiencies. Would require developing systems with sensors and infrastructure with software to monitor and enable decision-making, for example, when you see that a boiler is working harder because steam trap is stuck, the plant manager can take corrective action that would prevent energy losses and possibly cause a plant shutdown. Hard to optimize processing when you don't have the whole story. If you have this kind of data over several years than you have a platform for benchmarking for that industry that can be valuable to all companies in that industry. The brewing industry has gone further than most industries, but still could go further.

What are some challenges that these technology startups are facing?

Unfamiliarity by investors and companies may be reluctant to divulge data.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

Processing is an area missing from the value chain, need to add a column to the left of Packaging:

Value Chain Activities Description: post-production processing of products (e.g., drying, pasteurization, slicing, crushing, mixing, etc.)

GHG Reduction Activities: Thermal processing is the largest GHG emitter, so waste-heat recovery would reduce GHG, as would using non-thermal processing (high-pressure, post-electric field, cold plasma) could reduce emissions.

Energy Use Reduction Activities: same as GHG

Water Conservation: contingent on product, but if you use less energy you use less water (steam is heating medium for food processing so if you could reduce heating that you need by recovering heat or capturing condensed water and recycling it.)

Are there any missing segments on food distribution that are not shown in this chart? (By missing segments do you mean Packaging, Storage, Distribution, Retail, Consumption/disposal etc?)

Processing, e.g., manufacturers of non-thermal processing equipment

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

How they are defining medium and high as it relates to water conservation, direct v. embedded savings, for example, animal products require a lot of embedded water, so if you have alternatives that would save that embedded water.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

Processing, and you could call out non-thermal processing.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

Looks accurate.

How are you quantifying/measuring the potential water conservation/energy/GHG reduction impact?

Should look at life-cycle assessments when quantifying (for example stressed and non-stressed water source such as groundwater in overdraft.

AG PRODUCTION DIGITIZATION SUMMARY

Technology areas currently underfunded

- The interaction between the environment and biology (Slaughter)
- Education of the agricultural community on the benefits of new technology and how to use it to maximize benefits (Jenkins)
- An adequate workforce trained to operate, diagnose and maintain sophisticated agricultural machines (Slaughter)
- Integrating big data to provide actionable information to the farmer (Mitloehner, Ustin, Vougioukas, Upadhyaya)
- Harvest technology (Vougioukas)
- Tree architecture design to facilitate mechanical harvest (Vougioukas)
- Plant breeding that focuses on the harvestability of the crop (Vougioukas)
- Larger drones that would be more useful in agricultural operations than is currently the case (Ustin)
- More sophisticated drone and satellite instrumentation to provide better data (Ustin)
- Rapid genotyping or phenotyping of crops to respond to rapidly changing climate (Ustin)
- Predictive weather data based on today's weather (Ustin)
- Better methods for measuring actual evapotranspiration (Ustin)

Emerging early-stage technologies

- Integrating big data to provide actionable information to the farmer (Slaughter, Jenkins, Mitloehner, Vougioukas)
- Manure management with anaerobic digesters (Mitloehner)
- Opportunities from mechanization (e.g., etching bar codes on each piece of produce, not necessarily needing to plant in rows) (Vougioukas)

Challenges for start-up companies

- They don't have the breadth of disciplines, especially when dealing with the complexity of the food/energy/water nexus (Slaughter, Vougioukas)

- Lack of technical service network for anaerobic digesters in California due to the European base of the industry and the comparatively small market in California (Mitloehner)
- Conflicting state agency policies on digesters (Mitloehner)
- Revenue potential not there for mechanization of smaller crops (Vougioukas)
- Farmers don't want to give away their data (Vougioukas)
- Lack of standardization in data collection (Siegel)
- Need for consensus on which data to collect based on the goal you are seeking to achieve (Siegel)
- The timeline and return for ag-tech doesn't fit most venture capital models (Siegel)
- Pathways to market are not clear for ag-tech start-ups (Siegel)

Missing segments from digital agriculture technologies value chain

- Processing (Jenkins)
- Plant breeding (Slaughter, Vougioukas)
- Information management (Jenkins)
- Decision support (Jenkins)
- Established agricultural companies (Jenkins)
- Information flow across the value chain (Slaughter)
- Animal agriculture (Mitloehner, Vougioukas)
- GMOs and gene editing (Mitloehner)
- Postharvest (Vougioukas, Ustin)

David Slaughter and Bryan Jenkins

David Slaughter is Professor in the Department of Biological and Agricultural Engineering and Director of UC Davis' Smart Farm initiative. Research focus areas: agricultural robotics; machine learning; automation and control for agricultural machines; nondestructive sensors for quality and composition of biological materials; instrumentation and postharvest engineering for biological materials; packaging, handling, storage and transportation of agricultural commodities.

Bryan Jenkins is Professor in and Chair of the Department of Biological and Agricultural Engineering. Research focus areas: energy systems in agriculture, biomass fuel production, thermal conversion, and environmental impacts; combustion and gasification of biomass fuels; properties of fuels; system models.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

DS: The low-hanging fruit is getting a lot of attention (such as monitoring soil moisture). These areas are relatively straightforward. More complex areas, which examine the interaction between the environment and biology, are not getting attention. For example, when looking at soil moisture you should also look at other things such as the dew point in the air, other examples? Biological systems learn from prior experience. For example, when there is a mild spring and then a sudden heat event the plant will react dramatically, but if this happens again the plant will not react as dramatically, so you cannot use the same algorithms as on the first event. Another example: if an orange grove has a sudden freeze the oranges will have an off-flavor like grapefruit, but you if have more of those events the tree will not react in the same way. That is why you need a place like UC Davis, which can form multi-disciplinary teams to look at the complexity. Silicon Valley has computer expertise but often not biological expertise.

BJ: Education of the agricultural community needs to have more investment. Get info to people that need it, enlighten people who can use the info and understand that there is a better way to do it.

DS: For example, with tomato-grader systems, we are having trouble getting people who understand the equipment because they have no background in analytics. To advance smart-agricultural infrastructure you will need to train people to repair this equipment and diagnose problems. Advancement in agriculture has economic implications and social implications.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

DS: A lot of people are working in big data, which is also happening in other parts of society such as entertainment. The opportunity is that agriculture is data-rich and has multi-disciplinary complexity, and big data approaches could have a benefit. For example, there was a recent lettuce outbreak caused by weather events that allowed cracking of the leaves and pathogens to get in, while at the same time other weather events were pushing air from a upwind dairy to this lettuce-growing area. Would have been beneficial to the industry to predict when this event would occur. Could have sensors and an analytic piece. Labor shortages, resource issues and climate change are other complexities where this capability would be useful.

BJ: We are where weather forecasting was 50 years ago.

DS: There is a huge problem with converting sensor data to farm management. There is a problem with integration. There are smart technologies that can have applications for integration.

BJ: Other opportunities are new ways to use to electric technologies, new ways to desalinate water, new ways to achieve traceability in the food system. The nexus of food, energy and water are widely explored now, for example Andre Decacche and Isaya Kisekka are working on a USAID project on water in Egypt.

What are some challenges that these technology startups are facing?

DS: They don't have the breadth of disciplines, especially when dealing with the complexity of the food/energy/water nexus. They have a need for more of a systems approach that is more multi-disciplinary, with more biology. Start-ups are not equipped to have that breadth, they might have depth in one area. For example, there is one project in New Jersey, a football-field-sized indoor facility to supply lettuce to the East Coast, yet they don't have a plant pathologist on staff.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

DS: The biggest gains will be found in taking a systems approach to interactions. There is a problem with de-coupling these issues into segments as on the slide. The answer will change with the question. If the question is labor, biggest impacts will be in harvesting, pruning and thinning. There will be a food shortage in the next 30 years, one approach is to put more land in production, another approach is get more production from underperforming agricultural areas. You are missing opportunities by just focusing on these segments.

BJ: Processing is not on this slide.

DS: Breeding is not on the slide either. For example, walnuts need a lot of chilling, can you breed walnuts to need less chilling? Another example: there is a lot of breeding in corn, which is a resource-intensive crop, but there is not a lot of breeding in sorghum, which is more drought tolerant.

BJ: Organizing these issues into digestible segments is one thing but you also don't want to miss the point.

Are there any missing segments on digital agriculture technologies that are not shown in this chart?

BJ: How would this slide look if you put the current companies in agriculture. Where is information management, where is decision support on this slide?

DS: Information would come out of planting that would have an impact on harvesting. Need information flow across the process to be reflected in this slide. The opportunity in this slide would be a start-up that would span the whole value chain.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

DS: Simulation/modeling can have high impacts in water conservation. Robotics/machinery can also have high impacts in water conservation because smart machinery is not restricted to humanoid robots, you can also have machinery that can increase water efficiency. It depends on how they are defining robotics/machinery, you could have sensing, defining, action parts. It would be a mistake to define robotics/machines solely as those that replace humans. The future is moving toward smart machines that will be broadly addressing all of agriculture, not just replacing labor but controlling irrigation systems and all aspects of agriculture.

BJ: Does Farm intelligence include Data and Information? If you are making decisions you need good data and info. You could also characterize energy differently – for example, you could increase energy use on the farm but use more renewable energy sources such as solar.

DS: Need breeding to be reflected in this theme of Ag Production Digitization, you can't ignore the biology. For example, sorghum is more drought tolerant because it uses C3 rather than C4 photosynthesis. There are not that many C4 crops that use the more efficient process. This is a breeding issue. Smart machines would have high impact on water conservation in that they have the capability to deliver irrigation on an individual plant basis. Weather & climate have a high energy impact in drying for example.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

BJ: "Information" should be set out very distinctly.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

DS: Ag digitization has not been well-funded. There has been growth in data collection but a complete lack of getting past the data. Farm management platforms have not been successful in making an impact in agriculture. There is not field monitoring beyond aerial imaging.

BJ: I don't think that precision fertilizer application represents the highest GHG impact potential. Impact needs to be characterized by crop, and by input. If you consider animal agriculture – which is missing from these slides, precision fertilizer might not be the most impactful on GHG. The water impacts of robotics is wrong if considering water recycling and water treatment.

Frank Mitloehner

Frank Mitloehner is Professor in the Department of Animal Sciences. Research focus areas: air quality research related to livestock production, especially quantification of ammonia, dust, and odor emissions in dairies, beef feedlots, and poultry operations. Main objective is to help establishing environmentally benign livestock systems. Environmental physiology research, focusing on effects of air emissions on animal health.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

All of this technology is exhausting the ability of the farmer to interpret data, most farmers don't have capability to process the data to its best extent. We need to have big data capabilities. A lot of new technologies are on the horizon:

- Ear tags and rumination collars for cows that record bodily functions; e.g., when the cow is in heat ready and ready to be inseminated, as well as telling the farmer that the animals are stressed and needs to be treated.
- There is drone technology that can help with identifying cooling area for cows.
- Facial recognition for cows, so the cow steps into milking parlor and all the info on the cow's identity and health. For example, the info would note whether the animal is sick or on medication and either should not be milked or the milk should go into a lot to be set aside from the other milk.
- Virtual fences, which allows a rancher to move a finger on a computer screen to identify grazing areas for the next day, and the cow has an ear tag that that will make an annoying sound if the cows stray from the designated area. It makes it possible for farms to not have fences in the future.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Largest challenge in animal agriculture is dealing with new regulations, e.g., SB 1383 in California requires a 40 percent reduction of farm methane in the next 12 years. This will be difficult to accomplish and it begs the question for the farmer: what am I emitting right now? And once you achieve benchmarking how do you manage emissions?

The most promising source of impact in the food/energy/water nexus is in manure management. Manure contains nutrients and energy. One solution is anaerobic digesters, which is a large tank where you put biomass in that tank, cap it, make it anaerobic, and as a result anaerobic microbes will digest and produce methane within about 20 days, and when you burn it you produce power or fuels such as compressed natural gas, ethanol or hydrogen. When you burn the methane it converts to CO2, which is 25 times less potent as GHG than methane. You don't need to use water to get manure into the digester. Dairies also add food waste, dead animals, fats, oils and grease to the digester. In CA there are two dozen anaerobic digesters, in Germany 8,500. So California is supporting the construction of hundreds of anaerobic digesters at dairies, with an investment of $500 million. This sends a strong signal to investors that this is an emerging part of the mix in California. Here is the challenge: many of the companies in Germany are folding because public support is being cut back. They are aving a hard time competing on price with coal or something else. California is thinking of requiring public utilities to have this source as part of the energy mix.

Newtrient, a company for which I am a consultant, has a webpage with 250 different manure treatment technologies. Manure can be an asset to the farmer, providing additional income. My home town in Germany has a central digester producing a lot of biogas, which is burned and made into power, and residual heat is used to heat a large water tank, so that the entire village of 1,000 has heated water and energy that is off the grid. We can do this in California – we have the nation's leading dairy industry here, 1,700 dairies with abundant manure. At the same time we are producing so much byproduct from crops that could go into digesters. Forty percent of all food produced goes to food waste, we could easily digest that. It is likely that most of this energy won't be burned into power but put in the pipeline or put into vehicle fuels, which could be exempt from certain taxes and generate carbon credits, which could be sold.

What are some challenges that these technology startups are facing?

There are currently 20 digesters in California and half of them are not operational. The digester technology providers are European, and the market is not very big here so there is no service network in the US. If the digester goes down you are out of luck.

Often the state agencies regulating agriculture don't talk to each other. One agency is pro-digester, and one is not. There was one case where a dairy was grandfathered in by regulators to manage manure in a lagoon, which releases emissions. When the dairy invested in a cleaner option of biogas, which provides emissions from a tailpipe, the state started regulating. One of the best dairymen in California almost went out of business due to regulatory issues and digester failures. There was also a dairyman asked by UC Davis to collaborate on a project to determine how much in nutrients from manure leached into groundwater. The dairyman did this to help with the science. The California Water Board found out about it and required dairy to supply them the data, and when the board found out that one well was high in nitrate and salt it issued a cease-and-desist notice unless he put in a liner that cost $800,000.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

Animal agriculture is much larger than plant agriculture in GHG emissions, and is more water-intensive than plant crops. Animal agriculture also consumes a lot of crops, it is tightly interconnected with plant agriculture. You lose efficiency along the chain with animals.

While animal agriculture is more resource-intensive than plant agriculture, it is also more nutrient dense. You shouldn't compare calories or weight of a kilo of beans to a kilo of beef because animal products are very nutrient dense. There is no plant that can come close to the nutrient content of an egg. So if you do this calculation the metric is different. A gallon of cow milk can't be compared to a gallon of almond milk.

Currently we are very wasteful in the whole supply chain. Forty percent of the food produced is wasted. Think of all the nutrients and water that we are sending to landfills. That by far is the greatest liability that we have.

The byproduct of animals is a fertilizer, or a fertilizer and a fuel, or a feedstock. For example, lagoon water from animal waste can be used in a system for worm production. Worm castings can be worth $400 per yard. We could reduce GHG, because instead of methane emissions from the lagoon, you are applying to this filter, which is an aerobic process, and the microbes that produce methane cannot tolerate oxygen. You get a 90 percent reduction in ammonia from the lagoon water when applied to this filter. With this technology you are also taking the nitrogen from the lagoon water and converting it to nitrogen gas rather than nitrate that can leach into groundwater. Biofiltro, a company in Davis, is working on this. These type of applications are new, I worked on one of the three research projects in the world with this technology. So there are new technologies that can generate significant income and environmental benefits.

Are there any missing segments on digital agriculture technologies that are not shown in this chart?

GMOs and gene editing (which is an upcoming breakthrough technology) have a big impact with GHG/energy/water.

You would have an equal number of companies in the animal agricultural sector as the plant agricultural sector. For example, there are 700 companies in feed production, which fits in the nexus of food/energy/water. Also the slaughterhouses and rendering sectors are huge, they are recycling all the stuff that has no other use, into soap, clothes, etc. For example, Darling Industries, the largest renderer in the world, has a major environmental impact, because they are getting the last amount of energy out of those by-products.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

Simulation/Modeling: Could have high impact on Water Conservation.

Robotics/machinery: if anaerobic digesters, could have high impact in all three.

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

Simulation/Modeling would have an impact in all three segments if focused on nutrition cycling: how much of the nutrients make it into products, how much are byproducts, and how much are pollutants because they cannot be controlled.

There are carbon footprint calculators and other tools that are used like TurboTax; in animal agriculture you have software that can tell you where you are benchmarking, where you have liabilities, and what you can do to mitigate. Can have impact beyond these three categories.

Labor is the greatest sustainability issue for farmers. I'm dealing with this all the time. If you don't have the time to attract high-quality workers then you are falling short in all your sustainability issues.

Stavros Vougioukas

Stavros Vougioukas is Associate Professor in the Department of Biological and Agricultural Engineering. Research focus areas: agricultural robotics, mechanization and automation for specialty crops. He focuses on the design, development, and testing of actuators, sensors and control systems for optimal management of inputs and products.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

Harvest technology. Most of the investment has been in aerial imaging, harvesting has been underfunded. The question is whether venture capitalists are skeptical of company proposals, or are there not many companies? I think that it may be the latter for specialty crops.

Tree architecture. Abundant Robotics is working on an apple harvester, the only reason they came along is that the tree architecture changed. The tree architecture changed to make hand-harvest easier (if it is easier for people it is easier for machines). Need to make the trees two-dimensional. If trees are more standardized then you can have a harvester used for multiple crops. If you can make the tree uniform mechanization can follow.

Breeding. Breeding has not focused on harvestability of the crop, it has been focused on other things such as disease resistance. There has been some limited breeding to aid harvestability for field crops (e.g., tall broccoli by Monsanto).

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Integration of Big Data. Now that there are so many modalities of big data, how do you use it to create irrigation prescriptions in a scalable way, so you don't people analyzing the data but algorithms do it. There are many data services available and there are people available who will look at the data for your operation. But as more data comes in for multiple growers, that is a lot of data for humans, a lot of potential of data-based learning that would need to be done by machines because the data will be too much. Most people have focused on getting data, aerial, weather stations etc., but not much effort to linking those data to actionable information that the farmer can use.

I like modeling, as an engineer, but there are issues with calibration to local conditions. The model would need to be calibrated for local conditions over multiple years. Instead of a simulation model you could have a black-box model in which the mass of data will provide the outputs that are tailored to local conditions. Kind of like a computer chess program that beats the chess masters, it plays millions of games against itself, with a learning program, and it learns. You could contract with a company to provide a service or could contract with a company like Monsanto who would control the data.

In indoor ag you can control the conditions for models. E.g., roses in NL

There are also opportunities from mechanization. When you have machines harvesting we have the ability to know where a certain fruit came from on a tree. What if you could etch a bar code on a fruit as it is harvested, with shelf life, damage, etc. and a lot of info can go back to the farm? The technology is available to a limited degree in packing-house operations in Europe.

With smaller robotic machines, you would not necessarily need to plant in a row, or plant in monocultures, which could reduce weeds, pests, and disease, which then could reduce chemical use. Could reduce compaction with lighter machines, could run them on solar energy. Small tractors without a cabin - robots that can do many of the tasks as a tractor such as plow and spray. Europe is more advanced due to smaller farms and smaller machines, and one could use more of these smaller machines for bigger operations.

What are some challenges that these technology startups are facing?

Start-ups are not equipped for some of these issues. For example, a start-up could develop a smaller agricultural robot but if they want a compatible cropping system they would need to engage plant scientists and other technical experts that start-ups typically would not have.

Revenue potential also is important – the return needs to be there to make it worthwhile for equipment fabricators to invest in harvest technology. Only crops that are big enough and have a long enough harvest window would be suitable. Also an issue is the harvest season for some crops is limited weighed with the cost of the machine and whether used as a service or owned

Banks won't want to pay for research but they might want to invest in UC Davis Smart Farm to advance ag digitization and mechanization.

Farmers don't want to give away their data.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

Growing should be the largest, with the longest period, and the most inputs. Some trends responding to this are: electrification/hybrids in ag equipment, smaller robotic machines that reduce the need for energy and operator for bigger machines.

Are there any missing segments on digital agriculture technologies that are not shown in this chart?

Post-harvest Processing, such as peeling with methods other than steam.

No mention of Animal Agriculture, a lot of crop that we grow is for cattle; lots to do in monitoring of animals, yield and feed.

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

Robotics: If Energy impact is high then GHG could be high as well. For example, if we use smaller electrical machines then maybe we could use solar.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

Field Monitoring/Analytics; how much is allocated to advanced analysis of the data and correlating the data to production, providing actionable info to the farmer.

What is the quality of the data, how close is it to the ground truth? Does the aerial image on temperature have high positive correlation with the actual temperature? Is there a way to provide calibration services?

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

Simulation/Modeling: Energy impact is hard to quantify given the challenges of calibrating at the local scale. Depends on what they mean by simulation/modeling – if it is at local scale I am skeptical because calibration applicability might not be there. For a broader scale, could be useful for academia or government but not necessarily a grower.

Robotics/Machinery: Not just reducing emissions because of the direct production activity, could be even higher energy/GHG impacts with smaller robots and new cropping systems

How are you quantifying/measuring the potential water conservation/energy/GHG reduction impact?

You ould need to commission a study to develop the data on the answer to previous question, unless a study has been done and I am not aware of it.

Susan Ustin

Susan Ustin is Professor of Environmental and Resource Science in the Department of Land, Air and Water Resources. Research focus areas: Remote sensing of environmental properties and landscape analysis utilizing optical, microwave, and thermal scanners; radiation interactions in plant canopies and application to hydrological and ecological problems.

What technology areas do you think are currently underfunded that would benefit from more early stage investment?

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

What are some challenges that these technology startups are facing?

Larger drones._Currently the drones are too small (less than 10 lbs.) to carry much payload and have too little range. The Federal Aviation Administration (FAA) allows drones of up to 55 lbs. Technology is available for larger drones, but they have not been developed and marketed.

Better aerial and satellite data._The quality of the aerial and satellite data is not very good yet. Need the drones to carry a more sophisticated instrument. Moving into the next level of platform. There are small satellites that work with less-expensive instruments (e.g., Dove, RapidEye, SkySat) but the data is not that great. Currently a lot of information is based on visual data, but the human eye can discern over 17 levels of gradation between black and white while some instruments can provide thousands of gradations. We need to get more sophisticated information on what is happening in the field. See Planet.com, could be a job for a crop consultant

Integration of crop data._Lots of data services are available but there is little that ties together data sources into actionable information for the farmer. Climate Corporation is providing for commodity crops, need for other crops.

Rapid genotyping or phenotyping. More rapid breeding of crops is an important response to the rapidly changing climate, a new area (she had not heard of it until three years ago) that is worthy of more investment. Mostly using thermal sensors, or spectrometers, or multi-band sensors, or LIDAR (LIDAR are instruments that emit signals in near infrared, which bounce back and tells how far away an object is, so by sending out a bunch of pulses you know how far the ground is and the top of the canopy, using it with phenotyping experiments. For example, rapid genotyping or phenotyping (phenotyping is the growth form of different genotypes) of lettuce varieties is being done to improve the efficiency of breeding and examine the nutrient composition of the plants, and could look at ones that took up more nitrogen, or have a higher chlorophyll and low water so maybe this type would be useful for determining drought tolerant.

Predictive weather data. A subset of one of the target investment areas (Simulation/Modeling). You could take the weather data from today, and use the info to predict weather in the following days, seems feasible to do at a scale.

Currently we predict evapotranspiration (ET) by using weather stations and satellite data (which adds the spatial component), and we measure things like relative humidity, net radiation, surface temperature. We are transitioning to new satellites which have 500 x 500 meter pixel capability (formerly the capability was 2km x 2km), with all this data, we can predict potential ET. This is feasible but has not been done yet. This is the technology we are going to have through the 2030s.

We want to move from measuring potential ET to actual ET. The California Department of Water Resources (DWR) has not decided to do the research on this. There are companies looking to market to individual farmers but their methods are not real accurate. A number of companies use a program called Metric, which takes a measurement every two weeks that they then need to translate. Using something like the Wharf model (which is based on the physics of how these processes work) would be better. This is a problem that needs some research -- you need an agency like DWR to provide the model that is always going to be there, unlike a company that could go out of business, or could also be a private company. If the farmers would move to Wharf they would get better information.

What part of the value chain represents the biggest energy and GHG saving potential? What specific technologies and/or practices can contribute to energy and GHG conservation in agriculture?

What happens to the residue after harvest, so we need another category of the value chain called Postharvest. For example, the wood from orchards could assist with carbon sequestration, or you store the carbon in the trees for 20 years, which is not a long period of time. What other ways would be profitable to keep the wood intact?

Are there any missing segments on digital agriculture technologies that are not shown in this chart?

Postharvest

Do you agree with the Energy, GHG, and Water impact ranking? What changes would you make?

Simulation/Modeling has high impact for Water Conservation, possibly also for Robotics/Machinery. A lot of potential savings for not having to move pipes around the field.

What other segments would you recommend prioritizing? Please describe how each of your chosen segments contribute to water conservation, GHG, and energy reduction.

Postharvest could go into farm management segment, almost all segments rely on information management (is this farm intelligence)

Do you agree with the Energy, GHG, and Water impacts for the chosen segments? What changes would you make?

Simulation/Modeling: energy would also take into account the life span of the crop, and year-round management, not just pre-planting.

How are you quantifying/measuring the potential water conservation/energy/GHG reduction impact?

Need to determine how much of the carbon is sequestered. If you could predict the weather for the next week, you would save on water, GHG and energy. For example, Paramount overwaters to some degree because they have a high risk in lower yield, and they manage water with more sophistication than most growers.

Justin Siegel

Justin Siegel is Assistant Professor in the Department of Molecular Medicine in the School of Medicine, Department of Chemistry and the Genome Center; he is also the Interim Director of the Innovation Institute for Food and Health. Research focus areas: computational enzyme design, biochemistry and molecular recognition, computational and theoretical biology.

Can you describe any emerging early stage technologies within the food/energy/water nexus that you are aware of? What type of opportunities are they trying to address?

Using anti-microbial coatings and peptides to avoid the need for the cold-chain or dry chain. For example, Apeel developed a clear coating from plant byproducts, extends shelf life significantly for fresh produce, avocados and strawberries.

Fairlife is doing separations of milk, fat, sugars, protein, minor components, drying them, and recombining the milk in different proportions (e.g., more protein, less sugar) using the local water source and it is cost-effective because not shipping water and no cold-chain

What are some challenges that these technology startups are facing?

The timeline and return don't fit with most venture capital models so you are really looking at impact investors for example, environmental and social justice funds or philanthropic investors. The returns are not great: two of the most successful were ClimateCorp, which had a $900 million exit with a $100 million investment and Blue River with a $60M investment and sold for $300M, these returns are not great for a venture model and both were five-year efforts.

Pathways to market are not clear for start-ups, whereas in biomedical the pathway is really clear, so it makes these companies high-risk investments. Who is the customer, who is paying, what is the incentive for them to put money into this new technology? Who is the customer, will it be the consumer, the company? If you are relying on farmers to be the customer that is a tough business.

Making solutions cost-effective when you don't have access to mass-scale. This was the problem with the biofuels sector, it is hard to get to scale.

We don't know what data needs to be collected or what variables to identify, collecting in a standardized way, and is machine readable, data quality is important, otherwise it is just noise. Perhaps the National Institutes for

Standards and Technology could work on this. The goals will drive the measurements: drought resistance, soil health, etc., all require different measurements.

Are there any missing segments on food distribution that are not shown in this chart?

Innovative consumer-purchased goods that would envision a new generation of products with the goals of reducing water, energy and GHG. Fairview Dairy uses desert land for milk production that is not useful for other agricultural production, and they do so in a manner that saves water and energy. Consumer-purchased goods have a clear path to market and there can be an excellent return. For example, RX Bar had a $600M exit, which was a 10X return on investment.