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developed during hypothetical dissolution reactions and could compare interface chemistry both with and without solution flow.

In essence, Lis *et al.* show that the immediate products of dissolution are not held at the interface if there is sufficient shear induced by rapid laminar flow of fresh solution. In this case, the surface field is controlled by the immediate chemical composition of the interface and does not include contributions by the dissolution products near the interface. This result is not unforeseen, but it has not been measured directly until now. The difference between the high shear and static solution cases can change the surface charge enough to flip the average water dipole orientation 180°, which likely changes the positions and density of field-dissipating ions within the EDL. The consequences of flow effects on surface charge may be widespread.

The flow regimes used by Lis *et al.* are large compared with typical geochemical processes but could be reached near injection sites used for carbon dioxide sequestration or perhaps during fracking processes. In this case, modeling of interfacial charges and reactions may be inaccurate unless shear rate is considered. High fluid shear near pores in separation filters is another case where even small amounts of dissolution could create sensitivity to flow rates. Lis *et al.* also measured astonishingly long response times (tens to hundreds of seconds) for the interface to reestablish a steady state once the flow has been stopped. It may be possible, using pulsed flow experiments, to identify particular stages in the dissolution process. These times result from slow dissolution and finite solution diffusion rates and can be used to explore their kinetics, for example, as a function of time after the flow stops. These new observations ought to inspire others to examine molecular aqueous interfacial processes with renewed curiosity and ingenuity. ■

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PLANT SCIENCE

Best practices for biofuels

Data-based standards should guide biofuel production

By **Heather Youngs**[1] *and* **Chris Somerville**[1,2]

One reason for the use of biofuels is to reduce the greenhouse gas (GHG) emissions associated with liquid transportation fuels. However, the large amount of land needed to displace a sizable fraction of fossil fuel use has raised concerns that land will be used to produce fuels instead of animal feed and food, and that ecosystems may come under additional pressure. In considering the many different ways of producing such fuels, it is possible to envision both good and bad outcomes, depending on the approach (*1*). Thus, comments about biofuels in recent reports from Working Groups 2 and 3 (WG2 and WG3) of the Intergovernmental Panel on Climate Change (IPCC) (*2*, *3*) and a recent report by Liska *et al.* (*4*) have a special weight in the public discourse.

Since the positive treatment of biofuels in the 2007 IPCC report, a number of economic and life-cycle analysis (LCA) modeling studies have raised concerns. In particular, the use of an economic model to assess effects of indirect land-use change on GHG emissions (*5*) identified the possibility that biofuels may endanger ecosystems by stimulating expansion of agriculture but accomplish little or no reduction in GHG emissions. Subsequent studies have reduced the original estimates of such effects by an order of magnitude while accepting the basic premise (*6*). The IPCC WG3 carried out a detailed analysis of the impacts of biofuels in a special report in 2011 (*2*), which was abstracted into a series of out-of-context comments in the current IPCC WG2 report (*3*) that triggered recent criticism of biofuels. Indeed, the 2011 report emphasizes that, on the basis of LCA, biofuels can help reduce GHG emissions. However, it notes that production of biofuels must be carefully managed to prevent negative effects on food production, biodiversity, and social equity. In these and other respects, the 2011 report mirrors the academic literature, which abounds in hypothetical scenarios about possible negative effects of continued biofuel expansion. The abundance of such concerns highlights the importance of implementation, by both importing and producing nations, of standards based on verifiable sustainability criteria and good governance (*7*, *8*).

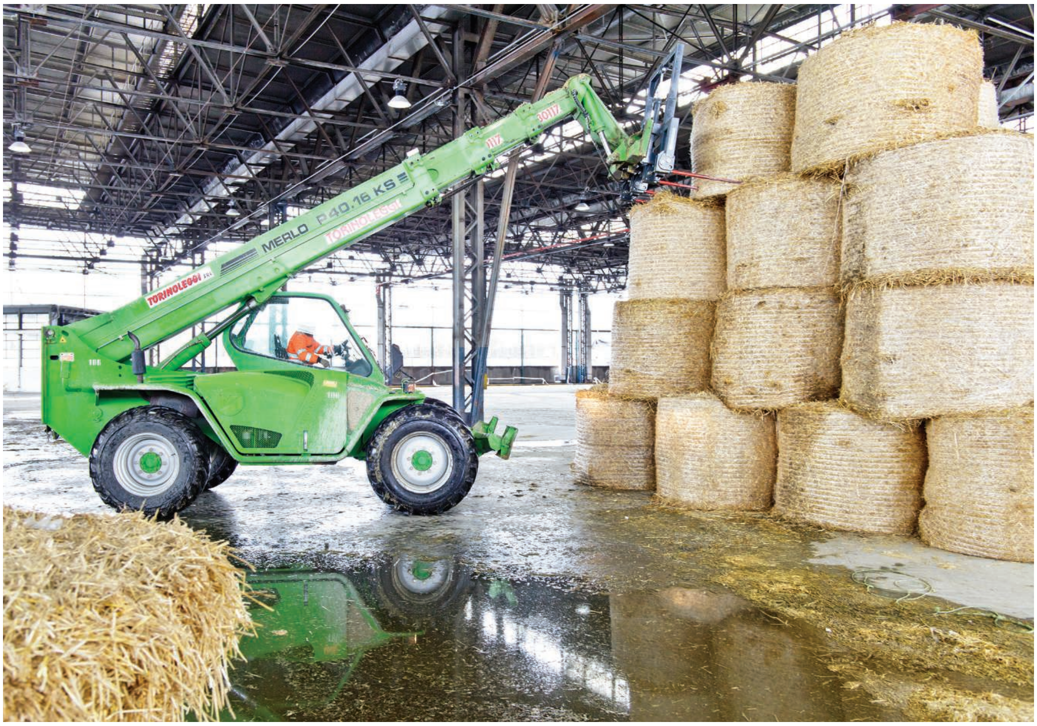
Many of the concerns about potential food-versus-fuel conflicts appear to be muted with regard to the pending development of cellulosic biofuels—liquid fuels made from the inedible body of plants. Several small commercial facilities in Europe and the United States recently began production, and several more are under construction in the United States and Brazil (see the second photo). Many of these facilities are using, or plan to use, crop residues such as wheat straw or corn stover (i.e., cobs, leaves, and stalks). Such sources

Polyvinylchloride rings are installed to facilitate GHG measurement in a corn field site in Iowa.

PHOTO: LORI ABENDROTH/IOWA STATE UNIVERSITY

seem attractive because they do not lead to land-use change or reduce the availability of grain. Thus, a recent claim by Liska *et al.*, on the basis of modeling results and a partial LCA, that the use of corn stover is unsustainable and does not result in fuels with reduced GHG emissions relative to gasoline has attracted attention.

Crop residues protect against erosion from wind and water, replenish mineral nutrients, and are the source of soil organic carbon (SOC) that supports soil ecosystems and contributes important physical qualities to soil. For decades, proponents of residue use (e.g., for animal feed, bedding, or biofuels) have grappled with understanding how much, if any, residue is required to provide such benefits. A recent study,



Biofuel bales. Wheat straw is readied for producing lignocellulosic ethanol at an advanced biofuels facility in Crescentino, Italy.

PHOTO: FABRIZIO GIRALDI/ WWW.FABRIZIOGIRALDI.COM AND VALENCIA RASETTO/BETA RENEWABLES

supported by the U.S. Department of Agriculture, reports the first 239 site-years of data collected from 36 research sites under various production systems such as no-till or conventional plowing (*9*) (see the first photo). Another study indicates that some residue can be sustainably removed from some locations, depending on factors such as biomass productivity, soil characteristics, soil management, water availability, and surface topography (*10*).

Liska *et al.* attempt to predict the SOC implications of stover removal for the entire U.S. corn crop using a model parameterized with measurements of the mineralization rate of various types of materials ranging from polysaccharides and polyphenols to microbial cells and plant residues from various locations around the world. The model correlates (within 20% error) with measurements of SOC from a single irrigated no-till continuous corn field, although the relevance of the parameters obtained in this way to corn stover at different locations around the United States is uncertain. The model output agrees with the view of soil scientists that removing all residues is detrimental; however, the story is more complicated at lower levels of removal, because of the high error ascribed to the model. One could interpret the output to indicate that 25 to 50% removal rates show no statistical difference from no removal, although a clear negative trend is evident; by contrast, the authors interpret the model to predict that removing any amount of stover tested (i.e., from 25 to 100%) will lead to soil carbon loss.

The LCA model used by Liska *et al.* does not incorporate GHG credits for using residual lignin for energy production in the bioconversion facilities, a point acknowledged by the authors, who also recognized that SOC loss might be offset by planting a fall cover crop or other management practices. Thus, ethanol from stover has not been shown to have higher GHG emissions than gasoline as reported in the general media (*11*). However, the most important unanswered question seems to be how well the model actually predicts what would happen under the diverse conditions that prevail in the corn belt soils. Soil scientists doing empirical studies emphasize that the outcome of stover removal is highly variable (*10*). It is possible that the single study site used by Liska *et al.* may not be suitable for stover removal.

Liska *et al.* also report that SOC decreased on a test site in which no stover was removed. Presumably this reflects the possibility that some corn-belt soils have not yet achieved SOC equilibrium after conversion from pre-agricultural conditions. By contrast, some high-yielding perennial grasses planted on former corn land substantially increase soil carbon, even when all aboveground biomass is removed (*12*).

The public attention associated with the report of Liska *et al.* exemplifies a disturbing trend in the treatment of model predictions as equivalent to knowledge or data based on actual measurement. Models are important tools, but they are often built on a partial state of knowledge and reflect assumptions and simplifications. Modern computing has enabled the creation of complex models with large underlying data sets, which reflect the intellectual contribution of many disparate disciplines, complicating, and possibly compromising, the peer review process of academic research. Because the model of Liska *et al.* predicts something that can be measured, the prediction will be tested by empirical studies that should ultimately settle the matter. In the interim, it is useful to bear in mind that much of the public discourse regarding biofuels is politically charged because biofuels have become a large disruptive activity that may benefit some sectors of society at the expense of others (e.g., the fossil fuels industry). It is therefore important that the scientific community remain clear about the relative power of measurements versus model predictions. ■

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