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When to accept no … to yesterday's solutions

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As a professor in green chemistry it is interesting to look back and see how the green economy has evolved over the past decade and where it is heading. Despite challenging economic times, societies' demand for sustainable technologies continues to evolve and has refused to accept the status-quo. For example, numerous districts have either banned plastic bags or employed financial means to discourage their usage. Similarly, the use of Styrofoam™ containers for food packaging is being reviewed critically. These societal efforts have renewed the interest in developing sustainable packaging solutions. Accompanying these concerns, the development of second- and third-generation fuels has advanced significantly over the past decade. In the USA, +85% of the gasoline is ethanol blended and although cellulosic ethanol has not developed as rapidly as once proposed, several commercial/demonstration plants are now being constructed.

The fundamental science of biorefining continues to advance on several fronts

Along with these consumer-market-driven accomplishments, the fundamental science/engineering of biorefining continues to advance on several fronts. For example, although the natural diversity of plant biomass has been appreciated for some time, it is only in the last decade that sufficient resources have been applied to analyze this phenomenon on a broad scale for biorefining applications. Along these lines, Studer *et al.*[1] have shown that for undomesticated *Populus trichocarpa* trees, the lignin content varied from 15.7 to 27.9% and the syringyl:guaiacyl ratio varied from 1.0 to 3.0. Likewise, the recalcitrance of this feedstock to autohydrolysis at 160 °C followed by enzymatic deconstruction varied significantly from 28 to 92% of theoretical sugar release. It is reasonable to expect that commercial interests will readily use this natural variation to cultivate the next generation of productive, low-recalcitrance plants. From a more fundamental perspective, our growing body of knowledge on the biosynthesis of lignin and plant polysaccharides has begun to allow us to ask the question: how should the plant cell wall be constructed to yield a viable, productive plant while at the same time facilitating easy biological deconstruction to sugars. As reported by Chen and Dixon,[2] Fu *et al*.,[3] and others, part of this answer is by lowering the amount of lignin in biomass while at the same time altering the fundamental structure such that it enhances the effects of pre-treatment.[4] In addition, a deeper understanding of pre-treatment technologies and biomass characterization sciences has shown how pre-treatment technologies alters the structure of native biomass polymers and reduces the recalcitrance of biomass.[5] This knowledge is being used to tailor pre-treatment technologies to specific feedstocks and aid in more efficient reactor design. While some companies are developing translational technologies to yield sugars by chemical treatments, others are utilizing free cellulolytic enzyme systems to yield monomeric sugars to biofuels and/or chemical applications. Finally, the last few years have seen significant improvements in consolidated biomass processing (CBP) in which mildly pre-treated biomass can be converted directly to ethanol and/or related alcohols.[6] All these synergistic advances suggest that a new wave of biorefining technologies will significantly impact commercial practices.

Likewise, in the past, the conversion of biomass to biofuels by the biological route yielded a lignin-rich process stream that was viewed as a waste product to be burned for heating value.[7] Although, the energy needs for distillation and pre-treatment still necessitate this role, process improvements have diminished these overall energy demands and the excess lignin is being viewed as a promising resource for chemicals, fungible fuels, and/or materials. Catalytic lignin pyrolysis has been shown to be a promising resource for the generation of low-molecular-weight aromatics that needs further improvement to enter into commercial development.[8] Alternatively, several research efforts are ongoing to develop lignin into a high-performance feedstock for the production of carbon fibers.[9]

Perhaps most promising to biorefining endeavors, is a host of entrepreneurs, researchers, and students that refuse to accept yesterday's solutions to address the technical challenges of today and the future for sustainable solutions for humankind's energy, chemical, and material needs.

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