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Biomass at the shale gas crossroads

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Research and development in the conversion of biomass is in a period of rapid growth with academic and commercialization efforts expanding every year. The urgent need for sustainable carbon-based resources has elevated biomass conversion into fuels and chemicals to one of the most important scientific challenges of the 21st century. The core research problem is the selective conversion of highly functionalized sugar and lignin-derived chemicals to infrastructure-compatible aliphatic fuels and aromatic chemicals, which are identical to those already produced from petroleum. Heterogeneous catalysis remains the dominant tool for controlled transformation of biomass in biorefineries to meet the requirements of high throughput, negligible environmental impact and competitive cost. The past ten years of fundamental catalysis research has utilized existing knowledge of petroleum research to expand the capability of biomass processing, primarily with conventional catalytic materials used in the petrochemical industry. Research in the next two decades aims for major discoveries by developing new catalytic materials, combined with new computational and experimental techniques, that are specifically designed for biomass conversion. In this special issue of *Green Chemistry*, we have collected over 40 contributions from international leaders in catalysis for biomass applications, including fuels and chemicals, providing a snapshot of the state of the art.

Now is an opportune time for a themed issue specifically addressing biomass catalysis. In the past decade, the number of peer reviewed publications addressing both 'catalysis' and 'biomass' has risen by two orders of magnitude.[1] In 2002, fewer than 20 peer reviewed publication were published on this topic (Fig. 1), but within a decade, peer-reviewed publications have increased to over 400 in 2012. These articles continue to address major fundamental catalysis challenges related to biomass and demonstrate ever-increasing efficiency in biomass utilization to a wide range of fuels and chemicals. With no lack of research problems, the future for research in biomass catalysis looks promising.

In this climate of burgeoning biomass research, the rapid expansion of North American shale gas comes at a critical moment for development and implementation of biomass technology. Will this energy revolution help or hinder the biomass conversion effort? While emerging energy sources are frequently viewed as market competitors, shale gas and biomass are actually complementary feedstocks. The products of shale gas, a feedstock rich in methane and small (<C4) hydrocarbons, are different than the larger targets from conversion of biomass, a feedstock comprised of larger sugars (C5 and C6) or fatty acids (>C14). Biomass carbon is also highly oxidized, necessitating the use of upgrading technologies, such as hydrotreating and hydroprocessing, to achieve aliphatic hydrocarbons needed for liquid fuels. For this reason, techno-

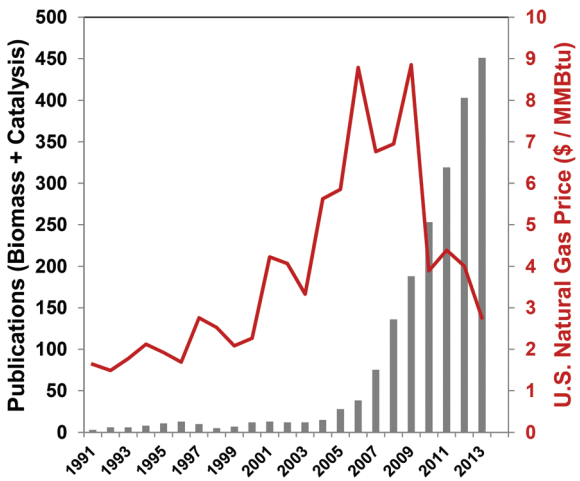

Fig. 1 Rapid changes in the past decade in the research of biomass catalysis and U.S. natural gas prices.[1,3]

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economic analyses have repeatedly identified hydrogen (H_2) as a major economic cost for implementation of catalytic biomass processes.[2]

While the *long-term* need of hydrogen for biomass hydroprocessing can eventually come from sustainable hydrolysis of water powered by solar and wind energy, the shale gas boom is providing cheap hydrogen *right now* that can serve as a bridge to future renewable hydrogen sources. In the last two decades, U.S. and world natural gas prices have dramatically grown in cost, with U.S. prices increasing by a factor of four from 1991 to 2009.[3] However, world and U.S. natural gas prices have diverged since 2009 due to North American shale gas production, and the U.S. natural gas prices have collapsed to US$ 2–3 per MMBtu, as shown in Fig. 1. Cheap natural gas equates to cheaper hydrogen, providing an economic boost to biomass processing ventures.

The confluence of cheap hydrogen and biomass processing has not been missed by the catalysis community, which has aggressively taken up the task of delving into the fundamental challenges of catalytic hydroprocessing and deoxygenation. In this issue, over two-thirds of the articles address research problems related to hydropyrolysis, hydrodeoxygenation, hydrotreating, or preparation/characterization of new hydrogenation catalysts. Of the remaining articles, most contributions address chemistries occurring in series with catalytic reduction including: aldol condensation, Diels–Alder cycloaddition, and dehydration. The dominant focus on catalytic reduction raises an important question: at the crossroads with booming shale gas, will biomass technologies thrive with cheaper hydrogen? The answer to this question will likely depend on the success of the next generation of catalytic biomass technologies, such as those in this issue of *Green Chemistry*.

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