Chapter 6
Future Perspectives

Abstract Some major challenges in the area of lignocellulosic biomass pretreatment are presented. Future research required is also discussed.

Keywords Lignocellulosic biomass · Pretreatment · Future research · Challenges

The effect of greenhouse gasses on the climate change has been recognized as a serious environmental threat. Serious efforts are being made for the search of sustainable more efficient and environmental friendly technology to prevent such emission. Production of ethanol from lignocellulosics has received much attention since the last decade due to enormous potential for conversion of renewable biomaterials into biofuels. A major impediment in this technology is the presence of lignin, which inhibits hydrolysis of cellulose and hemicellulose. This has resulted in extensive research in the development of various pretreatment processes for the treatment of lignocellulosic biomass. The pretreatment step plays a very important role in a lignocellulosic biorefinery process.

Various research groups and companies at various levels, usually with financial support from national governments and public bodies (example Swedish Energy Agency, Danish Ministry of Energy, US Department of Energy/Agriculture, and Canadian Sustainable Development Technology Canada) and multinational institutions such as the European Union have developed several proprietary cellulosic ethanol production configuration and technologies. Chemical pretreatment of lignocellulosic biomass due to its high reactivity at mild conditions forms the basics of these technologies.

Table 6.1 gives profiles of some of the main projects undertaken or under construction/development underpinned by breakthrough pretreatment, hydrolysis, and fermentation technologies, as well as process integration and optimization. The pretreatment of feedstocks to improve biodegradability to simple sugars has been the subject of intensive research worldwide with a focus on maximizing sugar yields at high solid loads and at the lowest economic and environmental costs. Widely known and emerging chemical pretreatment methods have been reviewed with regard to process description, advantages, drawbacks, and recent innovations

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Table 6.1 Selected large-scale cellulosic ethanol plants based on chemical pretreatment

SEKAB Örnsköldsvik, Sweden Two stage dilute H_2SO_4/SO_2; pine chips
Abengoa bioenergy, Salamanca, Spain; York, NE, USA; Kansas, USA Acid impregnation + steam explosion; wheat and barley straw, corn stover, wheat straw, switchgrass
BioGasol Ballerup, Denmark Dilute acid/steam explosion or wet explosion; wheat straw and bran, corn stover, garden wastes, energy crops and green wastes
Procethol 2G, Futurol Pomacle, France Wheat straw, switchgrass, green waste, miscanthus, vinasses
Izumi Biorefinery Japan Arkenol; cedar, pine, and hemlock
INEOS Florida, USA Thermochemical; municipal solid waste and so forth
ZeaChem Oregon, USA Chemical; hybrid poplar, corn stover, and cob
Logos Technologies California, USA Colloid milling; corn stover, switchgrass, and wood chips
BlueFire Mississippi, USA Concentrated acid (Arkenol); wood waste, municipal solid waste
Weyland AS, Norway Concentrated acid; corn stover, sawdust, paper pulp, switchgrass
Borregaard Norway Acidic/neutral sulphite; wheat straw, eucalyptus, spruce
Queensland University of Technology, Queensland, Australia Acid, alkaline, steam explosion, ionic liquid; sugarcane bagasse
Praj Industries, India Thermochemical; corn cob, sugarcane bagasse
Lignol Energy Corporation, Canada Organosolv; wood, agricultural residues
Blue sugars, Wyoming, USA Acid, thermomechanical; pine
Petrobras/Blue sugars; Brazil Acid, thermomechanical; sugarcane bagasse
Dupont, Danisco Cellulosic Ethanol (DDCE), Iowa, USA NH_3 steam recycled; corn stover
COFCO/SINOPEC/Novozyme, Zhaodong, China Steam explosion (with acid impregnation); corn stover

Based on Bensah and Mensah (2013)

employed to offset inherent challenges. Cellulosic ethanol is close to commercialization but there are still technical, environmental, and economic challenges associated with biomass pretreatment, hydrolysis, and fermentation. No solvent has been found to work best for all biomass and such optimized methods and process conditions for various materials need to be examined and developed further. Some major challenges of the chemical pretreatment include the following:

- Requirement of extensive size reduction
- Handling biomass at high solids concentration
- Corrosion
- Solvent costs, and recovery
- Environmental pollution from solvents, by-products, and waste from reactions.

Nevertheless, the challenges mentioned above are being tackled via several interventions, particularly, the application of novel solvents and the combination of different chemical methods with physicochemical and biological pretreatments to obtain higher sugar yields, reduced use of costly solvents, lower enzyme dose, milder process conditions, recovery, and use of biomass components in pristine forms, and also improvements in environmental sustainability. Presently, several efforts are being made to develop new technologies to further reduce the cost of pretreatment and generate less toxic chemicals, higher sugar yield, and higher-value by-products. The choice of the pretreatment technology depends on several factors, such as the type of biomass, the value of by-products, and the process complexity (Chaturvedi and Verma 2013). The combination of different methods may yield more positive effects in the future. Extensive research has been done on the development of advanced pretreatment technologies to produce more digestible biomass in order to ease bioconversion of biomass into cellulosic ethanol. An ideal cost-effective pretreatment method should have the following characteristics (Hsu et al. 1996; Yang and Wyman 2008; Drapcho et al. 2008):

(1) Maximum fermentable carbohydrate recovery
(2) Minimum inhibitors generated as a result of carbohydrate degradation during pretreatment
(3) Reduced environmental impact
(4) Lower demand of post-pretreatment processes such as washing, neutralization, and detoxification
(5) Reduced use of water and chemicals
(6) Reduced capital cost for reactor
(7) Moderately reduced energy input
(8) Relatively high treatment rate
(9) Production of high value-added by-products.

Therefore, the future research on pretreatment should be focused on the following areas (Zheng et al. 2009):

(1) Reduction of water and chemical use
(2) Recovery of carbohydrates and value-added by-products to improve the economic feasibility
(3) Development of clean delignification yielding benefits of co-fermentation of hexose and pentose sugars with improved economics of pretreatment

(4) Basic understanding of pretreatment mechanisms and also the relationship between the biomass structure features and enzymatic hydrolysis
(5) Reduction of the formation of inhibitors such as furfural, 5-hydroxymethyl furfural and acetic acid which could significantly inhibit enzymatic hydrolysis and fermentation of biomass (Hsu et al. 1996; Yang and Wyman 2008).

Like most established industrial processes, a possible major step towards bioprocessing of lignocellulosics on an industrial scale is creating or finding markets for by-products of biomass pretreatment technologies (Agbor et al. 2011). Multiple or combinatorial pretreatments have the ability to enhance biomass digestibility and operate under various conditions to maximize selective product recovery, while reducing the generation of inhibitory carbohydrate degradation products. As pretreatment is the second most expensive unit cost in the conversion of lignocellulosic biomass to ethanol (NREL 2002), it calls for systematic analysis of pretreatment process dynamics and their by-products as means to reduce cost in designing a cost competitive process (Agbor et al. 2011). Lignol Innovations Burnaby, British Columbia, Canada has demonstrated its unique and economical integrated process technology for biorefining abundant and renewable lignocellulosic biomass feedstocks into fuel ethanol, pure lignin and other valuable co-products. Lignol's unique delignification pretreatment Organosolv process fractionates or separates woody biomass into cellulose, hemi-cellulose and lignin. The cellulose and hemi-cellulose are enzymatically hydrolysed into sugars. These sugars are fermented into ethanol which can be distilled and dehydrated to fuel-grade ethanol. The high purity lignin can be processed into a great variety of high value products. This innovation is a key solution for producing ethanol and high value products from low-value feedstocks, while providing an alternative to reliance on fossil fuels.

In the United States, at DOE bioenergy research centres, AFEX pretreated spent grains and lignocellulosics are being considered as feed for livestock. Although industrial production of biofuels has preceded a detail understanding of pretreatment, optimization of integrated biorefining processes requires strong coordinated research that will, delineate pretreatment chemistries and their effects on feedstocks and also fermentation yields of fuels and co-products.

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