

Breaking biomass

Research into pre-treatment of energy crops will hopefully lead to more efficient production of liquid biofuels, thus meeting growing energy demands.

Global interest in renewable energy has grown over the last decades driven both by efforts to mitigate the effects of climate change and fuel security concerns. Renewable energy, however, is not a new concept, being the only form of energy available to mankind until the use of fossil fuels became widespread during the last few centuries. Biomass was the first fuel of any kind; the invention of fire to combust biomass provided a means of warmth, protection and nutrition for early humans. Biomass can be used as a source of heat but, additionally, both electricity and transport fuels can be produced from it.

Energy use in Ireland is divided almost equally between heat, electricity and transport fuel usage, and biomass is currently used in Ireland to generate heat in open fires and biomass stoves and boilers; to generate electricity in Edenderry power station, where it is co-fired with peat; and, to power vehicles, as petrol and diesel sold in Ireland have to contain a minimum percentage of either biodiesel (in diesel) or ethanol (in petrol).

Liquid biofuels from biomass

Woody biomass can be burnt to generate heat and electricity. However, it is much more difficult to convert woody biomass into liquid biofuels, because woody biomass consists of a tightly bound mixture of lignin, cellulose and hemicellulose, which needs to be broken down first before the conversion process can begin. This initial breakdown process is called a pre-treatment step. This is an expensive step, which adds considerable extra cost to the production of liquid biofuels from woody (ligno-cellulosic) feedstocks. As a consequence, liquid biofuels are generally made from waste or food crops. Current bioethanol (ethanol manufactured from biological sources) production comes from food crops such as corn, sugar cane and sugar beet, while biodiesel is manufactured from crops such as oilseed rape and soybeans. However, the use of food crops for the production of liquid biofuels has negative consequences.

Food crops are generally grown on the most productive soils and the use of good land to produce feedstocks for liquid biofuel production makes it more difficult to meet the growing demand for food. Additionally, the

use of food crops for liquid biofuel production has often distorted food prices. Consequently, as demands for liquid biofuels increase, alternatives to food-based liquid biofuels are needed. Liquid biofuels produced from ligno-cellulosic biomass can offer an alternative if the cost of the pre-treatment step can be reduced, particularly if the ligno-cellulosic biomass can be produced on land that is not used for food production. Fast-growing energy crops produced on marginal land could supply a significant amount of biomass to supply the growing demand for liquid biofuels without compromising global food production, but only if the technology for cost-efficient biomass pre-treatment can be developed.

Pre-treatment research

Research at the Institute of Technology, Carlow, has sought to increase the efficiency and reduce the cost of biomass pre-treatment. Biomass contains ~45-50% cellulose, 25-35% hemicellulose and 15-20% lignin. Thermochemical techniques can be used to manufacture second-generation biodiesel or bioethanol from biomass; such techniques generally produce a char together with a gas, which can be synthesised into a range of fuels. Bioethanol can also be produced from ligno-cellulosic biomass by biological methods in which enzymes are used to convert cellulose and hemicellulose to sugars, which are then fermented to ethanol. Pre-treatment is necessary to achieve high yields of sugar from the cellulose and hemicellulose present in biomass. Effective pre-treatments disrupt cell walls and crystalline structures to allow enzymes to access the biomass structure. Pre-treatment can be classified into several categories: physical (milling, grinding); biological (use of microorganisms and fungi); chemical (use of acid or alkaline reagents or organic solvents); and, physico-chemical (steam explosion/autohydrolysis and wet oxidation). This research has concentrated on the use of chemical pre-treatments applied to a range of energy crops that can be grown in Ireland.

In this research, four different energy crops (willow, miscanthus, hemp and switchgrass) were treated with a range of concentrations of four different pre-treatment chemicals (sodium hydroxide, methanol,



sulphuric acid and ammonia). The optimum pre-treatment chemical was found to be crop specific. Pre-treatments employing ammonia proved most effective for willow and hemp. Sulphuric acid pre-treatment generated highest yields from miscanthus, while methanol pre-treatment generated the highest yields from switchgrass. The efficiency of a range of enzymes for converting cellulose to simple sugars was also tested, and the enzyme with the highest efficiency was also dependent on the feedstock. To maximise conversion efficiency, it is important to match both the pre-treatment chemical and the enzyme to the crop being used as a feedstock for the production of second-generation ethanol. Critically, it was also found that the efficiency of the conversion of cellulose and hemicellulose to ethanol could be significantly enhanced if the conversion of cellulose/hemicellulose to simpler sugars could be combined and done in the same step as the fermentation of these sugars to ethanol. The combination of these two steps is referred to as simultaneous saccharification and fermentation, saccharification being a term used to describe the conversion of polysaccharides such as cellulose and hemicellulose to simpler sugars.

The use of different pre-treatment chemicals has also to be considered from an environmental perspective, as the use of pre-treatment chemicals can affect different aspects of the environment such as the quality of the air, water and soil. Our study used life cycle assessment techniques to quantify the impact of pre-treatment choice on a range of environmental receptors, global warming potential, eutrophication, acidification, photochemical oxidation demand, and marine and human ecotoxicity. The results showed that no one pre-treatment chemical provided a minimum impact across all of these environmental receptors, although organic solvents such as methanol had the lowest global warming potential. In many respects, this is the most critical environmental receptor to be considered when comparing bioenergy processes, as the primary driver for bioenergy is climate change mitigation.

Second-generation biofuels can offer an alternative to first-generation biofuels without competition between food and fuel. The economics of

second-generation biofuels need improvement but this research has shown that the cost and efficiency of the costly biomass pre-treatment step can be significantly enhanced to lower the overall cost of the conversion of ligno-cellulosic biomass to ethanol.

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