WEEK 5: BIOENERGY

THEORY

CELLULOSIC ETHANOL

Biomass is the largest contributor to the renewable energy production. Traditional biomass utilization has the largest share (9%) among all renewable sources such as hydropower, solar, wind and biomass used for the production of liquid transportation fuels. Traditional use of biomass refers to the use of fuelwood, animal manure and agricultural residues in simple stoves with very low combustion efficiency.

Liquid biofuels can be broadly categorized as first- and second-generation biofuels. Biofuels which are derived from starch, sugars, and plant oils are termed as first-generation biofuels. These include bioethanol derived from food crops such as sugar beet, cereals, sugarcane and biodiesel obtained from rape, sunflower, soya, and palm, respectively. Biofuels derived from lignocellulosic biomass such as hard/soft wood, agricultural wastes are called as second-generation biofuels. Consequently, cellulosic etanol is a second-generation biofuel.

Contribution of cellulosic to the reductions in the greenhouse gas (GHG) emission is significant. Relative to petroleum gasoline, ethanol from corn, sugarcane, corn stover, switchgrass and miscanthus can reduce life-cycle GHG emissions by 19–48%, 40–62%, 90–103%, 77–97% and 101–115%, respectively.

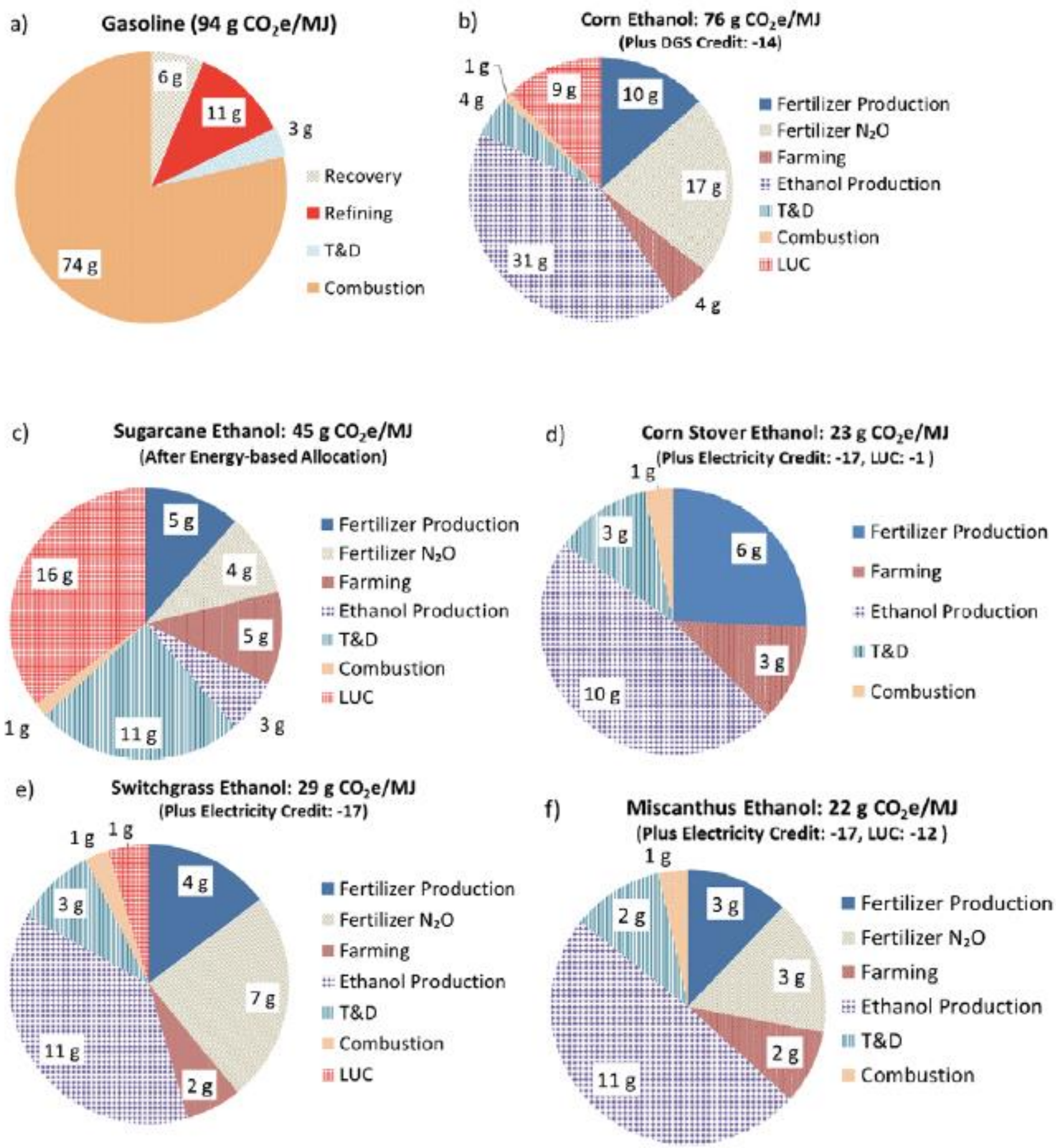

Figure 1. Shares of GHG emissions by activities for (a) gasoline, (b) corn ethanol, (c) sugarcane ethanol, (d) corn stover ethanol, (e) switchgrass ethanol and (f) miscanthus ethanol (Wang et al. ,2012).[1]

Lignocellulosic biomass is made up of three major components, cellulose, hemicellulose and lignin. The strong association of these components in the structure challenges its hydrolysis to fermentable sugars. Thus, conversion of lignocellulosic biomass to ethanol via biochemical routes requires a pretreatment step prior to enzymatic hydrolysis (Figure 2).

Biomass pretreatment, which introduces chemical and physical changes in the biomass structure, facilitates the conversion of the biomass to fermentable sugars. Several options – pretreatment methods are introduced to open the robust lignocellulosic biomass structure and enhance its enzymatic digestibility.

The second step which is enzymatic hydrolysis releases fermentable sugars (mainly glucose) from cellulose via enzymatic attack (attack of cellulases). The last step is fermentation in which glucose is fermented to ethanol via the yeast, *Saccharomyces cerevisiae (*Figure 3).

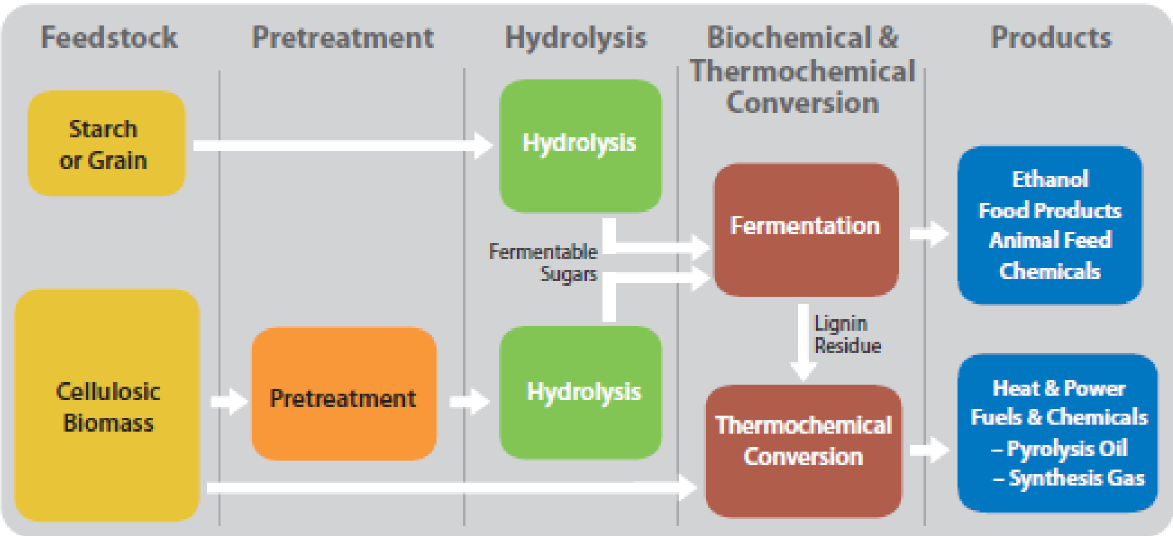

Figure 2. Major steps followed for ethanol production from grain, starch and lignocellulosic feedstocks through either biochemical or thermochemical routes.[2]

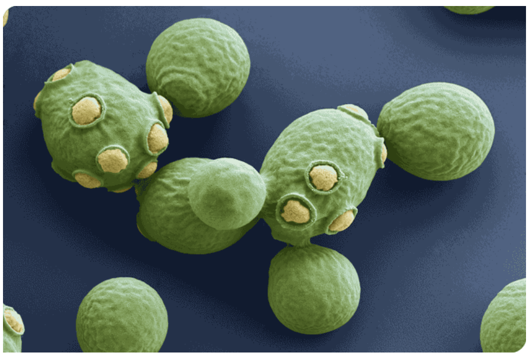

Figure 3. The yeast, *Saccharomyces cerevisiae.*[3]

Fermentation is a biochemical conversion process which is conducted in the absence of oxygen. In fact, fermentation has been defined as energy generation without electron transport chain. The metabolic pathway shown in the figure represents the anaerobic reaction mechanisms conducted during ethanol production from glucose (Figure 4). In the absence of oxygen, pyruvate generated through glycolysis accepts hydrogen from NADH. The produced NAD+ is then converted to NADH again with the formation of ethanol and CO_2 from pyruvate.

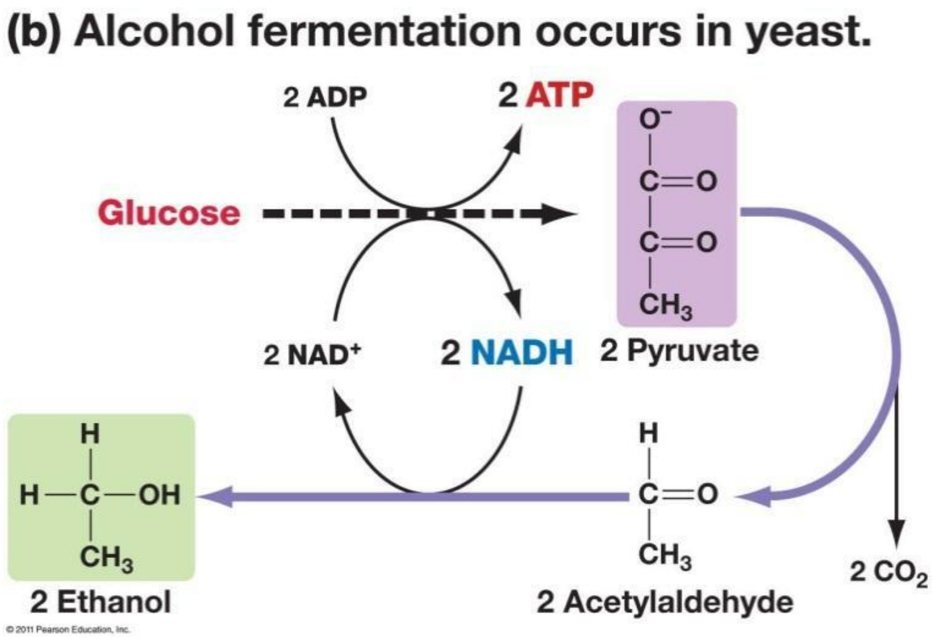

Figure 4. Ethanol fermentation in yeast and many bacteria.[4]

S. cerevisiae has been generally regarded as safe (GRAS). It is recognized for being one of the first eukaryotic organisms whose genome has been completely sequenced. It has been also shown to be more tolerant to the growth inhibitors released upon pretreatments which are conducted at severe conditions such as steam explosion.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 2\ ATP$$

Based on the stoichiometry of the reaction given above, the theoretical ethanol yield over glucose is 0.51 g/g. Ethanol yields, which have been reported in the vast majority of literature studies, are calculated on the basis of this conversion factor.

The use of ethanol is widespread, and more than 97% of gasoline in the U.S. contains some ethanol. The most common blend of ethanol is E10 (10% ethanol, 90% gasoline). Ethanol is also available as E85 (or flex fuel)—a high-level ethanol blend containing 51%-83% ethanol depending on season and geography—for use in flexible fuel vehicles. E15 is defined by the Environmental Protection Agency as a blend of 10.5%-15% ethanol with gasoline. E15 is an approved ethanol blend for use in model year 2001 and newer light-duty conventional gas vehicles in US.

A gallon of ethanol contains less energy than a gallon of gasoline. The result is lower fuel economy when operating your vehicle. The amount of energy difference varies depending on the blend. For example, E85, which contains 83% ethanol content, has about 27% less energy per gallon than gasoline. Gasoline vehicles, including flexible-fuel vehicles (FFVs), are optimized for gasoline.

Though ethanol possesses remarkable benefits, it has some disadvantages considering its use in vehicles. Ethanol is hygroscopic, **it means that it absorbs water from the air and thus has high corrosion aggressiveness.** That is why it is transported only by auto transport or railroad. Pure ethanol is also difficult to vaporise which can make starting a car in cold weather difficult.

In Turkey, Turkish Petroleum once used ethanol from wheat and corn as an additive to gasoline at 2%. Currently, there are only three companies TARKİM, TEZKİM and Konya Şeker, which produce high purity ethanol. Some sugar refineries are also known to produce bioethanol. In the sugar refineries, ethanol is produced from the co-product molasses.

References:

1. Wang M., Han J., Dunn J.B., Cai H., Elgowainy A. (2012). Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. *Environmental Research Letters,* 7(4).
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