CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

This thesis gives real insight on the environmental and energy benefits of biofuel in India. The environmental evaluation of the life cycle of ethanol produced from sugarcane molasses and rice straw is performed by adopting different technological approaches. A comparative assessment of different rice straw utilization practices is also conducted in order to find preferable utilization practices so as to avoid the burning of straw in country. Green house gas (GHG) emissions, net energy ratio (NER), production cost are found to be dependent on the feedstock yield, conversion technology, system boundaries, allocation approaches and assumptions used in study.

The thesis makes possible to assess existing 1G and selected 2G technologies and feedstock, determine the improved 2G pathways and generate useful and novel information to facilitate the stakeholders involved in bioenergy sectors. It is worthy to note that although the LCA is a powerful tool for the evaluation of the environmental effects of a product/process, however, results are dependent on the data quality, system boundary, process modeling, time horizon and geographical location. The intended audiences of this thesis are policy makers, private investors, researchers and other stakeholders who are interested and motivated enough to consider making concerted and unified efforts toward the production of sustainable biofuels in developing countries.

The insight provided in this thesis could help national/regional governments and international development organizations to accelerate the development agenda on the promotion of bioenergy services needed for transition to a low carbon development path.

Following conclusions are drawn from the research work of the present thesis:

1. LCA of fuel ethanol from sugarcane molasses concludes that emissions are released at each process during production chain. Sugarcane farming is the unit that contributes largest to the GHG emissions and energy consumption. If the allocation of GHG emissions and energy is not done for co-products, than on stand-alone basis, ethanol is more polluting and gives very little NER benefit as compared to gasoline. The overall results vary with different allocation approaches and MA and EA are best for this study. MPA allocation gives higher GHG emissions and lower NER as there lies difference in the price of co-products and product. Lower GHG emissions and higher NER is obtained in WR which is due to higher sugarcane yield, sugar recovery, lower consumption of inputs in farming, sugar production and molasses transport in WR.
2. Depending upon the pretreatment process, the 2G ethanol production from rice straw shows GHG emission reductions of 77% in DA and 89% in SE with respect to gasoline and hence, meets the specification set by the US EPA for advanced biofuel. NER for ethanol are in the range of 2.3 and 2.7. The contribution analysis indicates that enzyme production is a significant contributor to the GHG emissions followed by chemicals use. SE process resulted in higher environmental and energy benefits than DA due to higher ethanol and co-product yield. The study identifies the production and use of enzymes as the major GHG emission generating unit. The study concludes that lignocellulosic ethanol is a sustainable and renewable fuel. Utilization of rice straw for ethanol not only provides the solution for its management in the field, but also reduces pollution by avoiding burning, provides cleaner source of renewable fuel and enhances the socio-economic status of rural people.
3. The modified pretreatment method developed by the Centre, which uses soaking of biomass in alkali prior to pretreatment helps in reduction of enzyme dosage from 25-40%. Moreover, ethanol yield has also improved and cost has reduced from 0.87$/L to 0.70 $/L.

Therefore, the modified pretreatment process is beneficial to follow in future.

4. The utilization of agricultural residue such as rice straw for different purposes is a sustainable way to avoid harmful impacts from burning. The LCA of five rice straw utilization systems results show that straw utilization for electricity, ethanol and biogas results in the highest environmental benefits in GWP, AP and POCP and utilization for fodder results in the highest benefit in EP. Therefore, use of straw can provide clean energy to ever increasing demand of energy in India.

8.2 RECOMMENDATIONS

1. At many instances, the data of emission and other inputs in agriculture has been taken from scientific literature as this kind of data is not available in India. Therefore, Government of India should emphasize to develop a program to produce these kind of databases specific to India which might give more realistic picture of LCA. Moreover, Government of India should emphasize on integrating sugar industry and distillery, which will provide substantial reduction in GHG emissions and will give more energy benefits. It has been observed that farming is the most energy intense process of fuel ethanol production, which is primarily because of the higher use of coal and fossil fuels in electricity generation. Therefore, bio-based electricity production can change the landscape of energy mix in India and, hence, can further reduce the GHG emissions and increase the NER.
2. It has been identified that enzyme production is the emission and energy hotspot in the 2G ethanol production chain. Therefore, it is recommended that either recycling of enzyme or on-site production of enzyme can further reduce the environmental load of the process. Further research on improving and modifying the process should be conducted, so as to have minimum requirement of chemicals, higher sugar recovery and reduction in the enzyme dosage for the process.
3. The issues regarding the policy for encouraging the utilization of agricultural residue for electricity production in rice cultivating areas

should be analyzed in depth in the near future. The local community should also invest in expanding the number of biogas plants in the villages.

4. The incorporation of straw into the soil as fertilizer does not positively contribute to a net reduction of GWP impact as compared to others, due to increased biogenic emissions of CH_4 and N_2O, but improvement in yield and soil organic matter is obtained. However, long term benefits such as improvement in yield and soil carbon stock may also be taken into consideration in future. For the better performance of straw incorporation and use as fertilizer, it is recommended to combine the straw together with the organic fertilizer, green manure, cattle manure and inorganic fertilizer so as to increase the SOM.
5. Awareness of farmers must be raised so as to promote the use of straw instead of burning it. There is an enormous quantity of nutrients and energy embodied in this low cost nutrient and therefore, should be used as an energy source.