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Process Simulation-based Net Energy Analysis for Future Bioethanol Production as Commercial Biofuel from Waste Rice Straw in Sri Lanka

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Abstract

As the staple food crop in Sri Lanka, paddy rice occupies around 34% (over 0.87 million hectares of land) of the total arable area in the country, corresponding to an average rice production of 3,774,344 t/year. Rice straw is the major biomass waste from rice cultivation, which approximates to an average of 2,830,758 t/year generation at a theoretical straw/grain ratio of 0.75. Open burning of rice straw in paddy fields is the common practice, which could result in an average GHG emissions of 92 kg CO_2 eq/t of dry rice straw and other harmful airborne emissions. Application of rice straw into soil as an organic fertiliser is also an inefficient practice, compared to bioenergy generation using rice straw. The average composition of the Sri Lankan rice straw (i.e. 30.0 wt.% cellulose, 3.9 wt.% hemicellulose, 38.2% lignin, 16.1 wt.% wax, and 12.3 wt.% silica) shows the possibility to be used as a second-generation bioethanol feedstock. Existing studies indicate that bioethanol production from rice straw is more environmentally-benign, compared to alternative options, such as gasification for combined heat and power and dimethyl ether (DME) production. This study analyses the net energy indicators of a possible bioethanol production process from rice straw in Sri Lanka. Chemical process simulations using Aspen Plus software were utilised to evaluate the bioethanol production process from rice straw, with a plant output capacity of 1,000 litres/hr of dehydrated bioethanol (99.7 vol.% ethanol) that can be blended with gasoline as a commercial fuel (e.g. E10: 10% bioethanol+gasoline) without any vehicle engine modification. The cradle to gate bioethanol production process from waste rice straw, considered for net energy analysis consists of three major stages: 1. Rice straw preparation, 2. Rice straw transportation, and 3. Bioethanol conversion. The results show that the considered bioethanol production process has a positive net energy gain and increased renewability factor. Detailed analysis indicates that only around 8% of the total process energy consumption is utilised for the bioethanol dehydration operation that is favourable for converting any existing rice straw ethanol plant into commercial gasohol production plant. The sensitivity of bioethanol yield and process energy parameters for the net energy indicator results are further analysed and discussed. The findings from this study can support decision making for a future waste-to-biofuel plant using waste rice straw in Sri Lanka.

Keywords: Rice straw, Bioethanol production, Net energy analysis, Process simulation, Waste-to-biofuel