Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States

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Abstract

Background:
The availability of feedstock options is a key to meeting the volumetric requirement of 136.3 billion
liters of renewable fuels per year beginning in 2022, as required in the US 2007 Energy Independence and Security Act. Life-cycle greenhouse gas (GHG) emissions of sorghum-based ethanol need to be assessed for sorghum to play a role in meeting that requirement.
Results:
Multiple sorghum-based ethanol production pathways show diverse well-to-wheels (WTW) energy use and GHG emissions due to differences in energy use and fertilizer use intensity associated with sorghum growth and differences in the ethanol conversion processes. All sorghum-based ethanol pathways can achieve significant fossil energy savings. Relative to GHG emissions from conventional gasoline, grain sorghum-based ethanol can reduce WTW GHG emissions by 35% or 23%, respectively, when wet or dried distillers grains with solubles (DGS) is the co-product and fossil natural gas (FNG) is consumed as the process fuel. The reduction increased to 56% or 55%, respectively, for wet or dried DGS co-production when renewable natural gas (RNG) from anaerobic digestion of animal waste is used as the process fuel. These results do not include land-use change (LUC) GHG emissions, which we take as negligible. If LUC GHG emissions for grain sorghum ethanol as estimated by the US Environmental Protection Agency (EPA) are included (26 g CO2 e/MJ), these reductions when wet DGS is co-produced decrease to 7% or 29% when FNG or RNG is used as the process fuel. Sweet sorghum-based ethanol can reduce GHG emissions by 71% or 72% without or with use of co-produced vinasse as farm fertilizer, respectively, in ethanol plants using only sugar juice to produce ethanol. If both sugar and cellulosic bagasse were used in the future for ethanol production, an ethanol plant with a combined heat and power (CHP) system that supplies all process energy can achieve a GHG emission reduction of 70% or 72%, respectively, without or with vinasse fertigation. Forage sorghum-based ethanol can achieve a 49% WTW GHG emission reduction when ethanol plants meet process energy demands with CHP. In the case of forage sorghum and an integrated sweet sorghum pathway, the use of a portion of feedstock to fuel CHP systems significantly reduces fossil fuel consumption and GHG emissions.
Conclusions:
This study provides new insight into life-cycle energy use and GHG emissions of multiple sorghum-based ethanol production pathways in the US. Our results show that adding sorghum feedstocks to the existing options for ethanol production could help in meeting the requirements for volumes of renewable, advanced and cellulosic bioethanol production in the US required by the EPA’s Renewable Fuel Standard program.