Reclaimed Municipal Wastewater for the Production of Bioenergy in the United States — A Resource Assessment

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ABSTRACT

The production of bioenergy requires a significant amount of freshwater to be withdrawn and consumed to irrigate conventional crops and be used in the conversion process in the biorefinery. Reclaimed wastewater has long been seen as an alternative to water and nutrient sources because it contains low levels of nitrogen and phosphorus. In drought-prone areas in the Western United States, reclaimed wastewater has been widely used to irrigate agricultural crops. The key issue in developing bioenergy feedstock is to consider the reuse of reclaimed wastewater to reduce the need for freshwater. This study assesses the large-scale potential for using reclaimed wastewater as the resource for biofuel feedstock production in the United States. Geospatial analysis was applied to estimate reuse potential at the county level. Technical and infrastructural challenges are highlighted.

KEY WORDS: Reclaimed municipal wastewater, effluent, discharge, irrigation, bioenergy

INTRODUCTION

It is anticipated that the demand for freshwater for producing food and energy and meeting basic human needs will continue to grow as the world's population increases and people's economic status improves. Enabling the long-term viability of the energy system thus requires the development of energy resources that protect natural resources and achieve environmental sustainability. The production of bioenergy (particularly with regard to conventional starch-based or oil-seed-based feedstock, such as corn or soybeans) requires a significant amount of freshwater to be withdrawn and consumed for irrigation (USDA 2008). Freshwater is also needed for the conversion process in the biorefinery. To that end, a key challenge is to invest in the technologies and develop the management programs that could increase the use of alternative water resources (Wu et al. 2009; Wu 2013). Energy demand will increase as populations continue to grow in the world. In parallel, wastewater treatment capacity will grow following the same trend. Thus using reclaimed water as an additional water resource for energy production is a key strategy for addressing the energy demand and water security issue. Such a reclaimed water application has been already explored for power generation (Veil 2007; Santos et al. 2015). Bioenergy is a critical component in the overall energy profile and also a major player in the current renewable energy portfolio. By incorporating the reuse of water in integrated water resources planning and energy and water policies, the long-term sustainability of bioenergy development can be achieved.

Reclaimed wastewater has long been seen as an alternative to water and nutrient sources because it contains low levels of nitrogen and phosphorus – necessary nutrients to support crop growth. Its potential applications range from irrigating pastures to augmenting potable water supplies. The main suitable user sectors are the agricultural irrigation (Kalavrouziotis, et al. 2015) and urban recreation sectors (Zhang et al. 2014). Climate change poses opportunities and threats to wastewater reclamation industry (Vo, et al. 2014). In drought-prone areas in the Western United States, the practice of irrigating agricultural crops by using reclaimed wastewater has been carried out. One project is reported to reuse all of the high-quality water produced by the Howard F. Curren advanced wastewater treatment plant, providing 113,000 m^3/d of reclaimed water for irrigation as well as maintaining the required minimum flows in the Hillsborough River and Tempa Bypass Canal (Metcalf et al. 2006). In the Pacific Northwest, a system of three small satellite reclaimed water plants was developed to generate Class A reclaimed water by using a membrane bioreactor (MBR) (Fowler and Kuzma 2007). The feasibility of wastewater reuse was investigated in Gloucester County, New Jersey, for crop and landscape irrigation, groundwater recharge, and recreational purposes (Walker et al. 2006). The Fort Worth water department prioritized for reclaimed water implementation by capital cost and customer base (Crumb and Martin 2010). Liu, Jilai, et al. (2011) developed groundwater model to evaluate the feasibility of using reclaimed water for irrigating crops in Beijing. That study concludes a 50% reduction of freshwater use and recommends a ground water table depth of 6 m from surface to prevent wastewater from reaching the water table due to irrigation. Based on a simulation of alternative wastewater reuse for Beijing (Yang and Abbaspour 2007), it was suggested that wastewater treatment plants would be more economically efficient in providing treated wastewater for onsite operation than offsite facilities. In 2005, the U.S. Environmental Protection Agency (EPA) developed criteria for reclaimed wastewater reuse (Crook and Surampalli 2005).

Despite the fact that water reclamation and reuse are practiced in many countries around the world (Kalavrouziotis, et al. 2015), the current level of reuse constitutes a minor fraction in the total volume of municipal wastewater effluent generated (Miller 2006). One major concern associated with reclaimed water reuse is public health. There is a large body of research that has analyzed the effects of using reclaimed wastewater to irrigate vegetables and fruits on soil and on human health (Aiello et al. 2007; Gori and Caretti 2008; Chiou 2008; Becerra-Castro et al. 2015) as a result of microbial contamination and heavy metal accumulation on soil surface. General risk assessment approaches were used to determine the acceptable contaminant concentrations in reclaimed wastewater used for irrigation in Weber et al. (2006) and Chiou (2008). Results show a range of contamination potential, but the risk to human health is either acceptable or can be limited to certain level. A 50% to 25% dilution ratio for irrigating a rice paddy was recommended in Chiou (2008). A study on the long-term impact of reclaimed wastewater irrigation on agricultural soils conducted based on 3 to 20 years of field data in California (Xu et al. 2010) indicates that reclaimed wastewater irrigation increases soil organic matter and nutrient level while it causes the soil to accumulate metal; this could lead to soil deterioration and affect the quality of the groundwater. Another study recommended disinfecting the reclaimed wastewater for reuse (Gori and Caretti 2008). It was suggested using reclaimed wastewater for irrigation when water scarcity is a major issue. Industrial reuse was recommended when poor water quality is a major issue (Yang and Abbaspour, 2007).

Conventional bioenergy crops may require a certain level of irrigation depending on the region and soil in which a crop is grown (Wu et al. 2012). Although about 70% of current conventional feedstocks are cultivated in regions where irrigation is well below 13%, there are regions that demand an elevated level of irrigation (USDA 2008; Wu et al. 2012). In recent years, due to draught and warming summers, freshwater supply became less available and its use for energy crop is likely to be restricted in these regions. Therefore, alternative water resources are needed. Chiu and Wu (2013) evaluated using reclaimed wastewater effluent (primary and secondary) as an alternative wastewater source for algae biofuel production for the Southern States. In the development of a long-term energy profile, especially when it involves renewable energy planning, an assessment of alternative water resources can play a critical role in achieving sustainable energy production.

This study examines the potential of using reclaimed municipal wastewater as an alternative water resource for bioenergy production in the contiguous United States. This resource assessment quantifies the benefits and constraints associated with applying conventional feedstock production with a geospatial spatial resolution at county level. Current efforts in cellulosic biofuel development emphasize using a feedstock that requires little irrigation; thus, this study focuses on conventional biofuel produced from corn and soybeans. It is designed to give policy makers the information and analysis they need to better understand alternative water resources for energy and food.

METHODOLOGY AND SCOPE

A geospatial analysis was performed to quantify water demand and reclaimed wastewater resource availability at a national scale and at a county-level resolution. This study is limited to publicly owned wastewater treatment (POWT) facilities. Municipal wastewater effluent data were collected and processed based on the EPA's Clean Watersheds Needs Survey (USEPA CWNS 2008) database. Because a CWNS data survey is conducted every four years and the latest data year available was 2008, we selected 2008 as our data year for this analysis. Thus crop production, land use, and irrigation data from 2008 were processed. Initial data collecting, screening, and processing incorporate climate, hydrology datasets and current agricultural land use. Corn and soybean harvesting and land use data were obtained from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) database. Climate analysis was conducted based on 30-year historical climate data from the National Oceanic and Atmospheric Administration (NOAA). Crop growth, evapotranspiration, and irrigation requirements were estimated from a water footprint framework WATER (Argonne National Laboratory). Withdrawal for irrigation at a county level was verified by an irrigation survey conducted by the USDA (USDA FRIS 2008) and U.S. Census Bureau data, and irrigation water consumption was further estimated (Chiu and Wu 2012). POWT effluent data were retrieved, sorted by facility and by type of treatment, and aggregated to county level. The facility-unit process-level data were sorted, screened by treatment type, and compared. This study considers only the reclaimed wastewater that is currently available; thus, it excludes the effluent that is already being applied for irrigation, domestic, and industry uses.

A future production scenario for a projection of biofuel feedstock that was commissioned by the U.S. Department of Energy (DOE 2011) was selected from category BLY+EC1_BLT - USDA baseline $55 per dry ton of cellulosic feedstock in 2022. The scenario was implemented in the reclaimed wastewater analysis framework to estimate volume of irrigation water can be replaced at a county level for the United States.

RESULTS

Municipal Wastewater Treatment Capacity

Historically, POWT facilities have received municipal wastewater primarily, with only a limited amount of industrial discharge flow. Nationwide, a majority of the POWT facilities are secondary wastewater treatment facilities. A spatial characterization of the current municipal wastewater infrastructure and reclaimed wastewater resources was developed to identify areas where the freshwater used could potentially be replaced with reclaimed municipal wastewater. Figure 1 shows the distribution of POWT facilities in the United States. The facilities are largely clustered in the middle of the country, with small clusters on the East Coast and in the North. The volumes of the effluent from primary or preliminary treatment and from secondary treatment are illustrated in Figures 2 and 3. The flow from secondary treatment spread further geographically than the flow from primary treatment, and the treatment intensity (volume of water treated per year) from secondary treatment facilities is relatively higher. . (Note that Alaska, North Dakota, and Rhode Island did not report data for the 2008 CWNS. These data indicate that a secondary treatment process is the dominant wastewater treatment scheme for the nation.

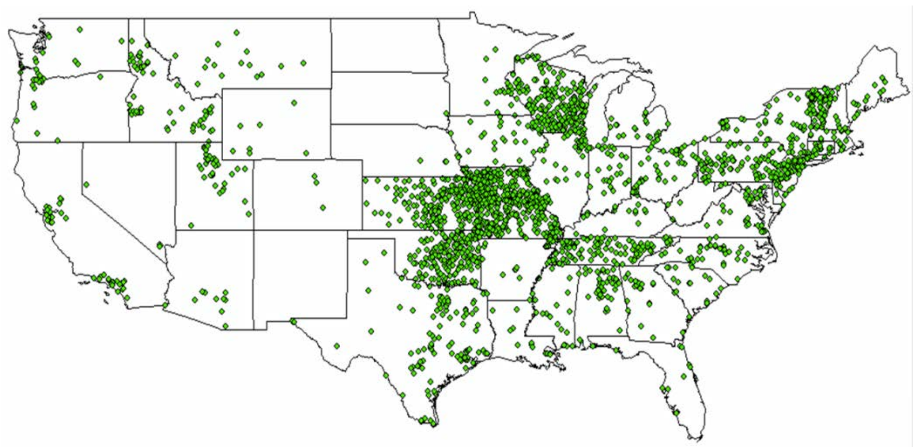

Figure 1. Number of municipal wastewater treatment facilities and their geographic distribution in the United States

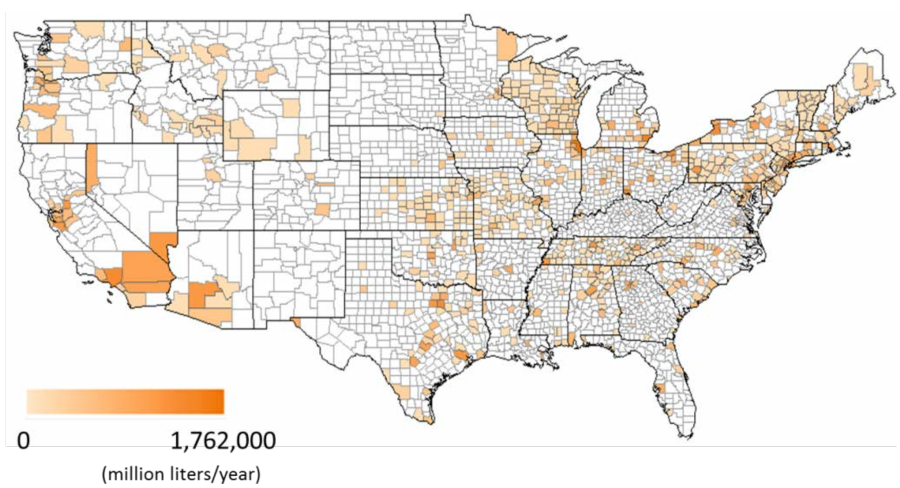

Figure 2. Volume of municipal wastewater that receives primary or preliminary treatment at the county level in the United States

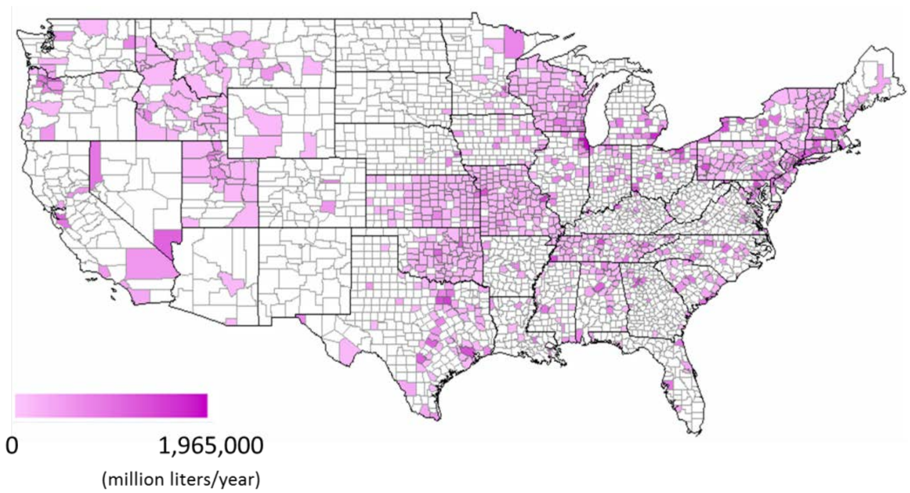

Figure 3. Volume of municipal wastewater that receives secondary treatment at the county level in the United States

Irrigation Demand

USDA conducted irrigation survey every five years. According to the 2008 survey, the states with the largest area of irrigated land are: Nebraska, California, Texas, Arkansas, and Idaho (USDA FRIS 2008). In 2008, the volume of U.S. water consumed in irrigating corn and soybeans used in the production of biofuels totaled 3,616 billion liters for corn and 620 billion liters for soybeans (Chiu and Wu 2012). The amount of water consumed represents approximately 30% of the corn production and 12% of the soybean production (Chiu and Wu 2012). The major portion of the corn (~60%) was used for animal feed. Geographically, the locations of the irrigation water consumed for corn were spread across United States, while those for soybean production were limited to the Eastern half of the nation (Figures 4 and 5). As expected, the intensity of the irrigation water requirement increased in the Western regions as a result of climate patterns (Figure 4). A comprehensive analysis of the water footprint shows that producing a kilogram of corn consumes less water than producing a kilogram of soybeans in most regions of the United States (WATER). However, the acreage used for planting corn has increased consistently since 2004, according to the USDA NASS; this has led to an increased total volume of irrigation water consumed. This trend is in sharp contrast to that for the less volatile soybean acreage; irrigation is used for about one-sixth of the acreage for soybeans as that needed for corn.

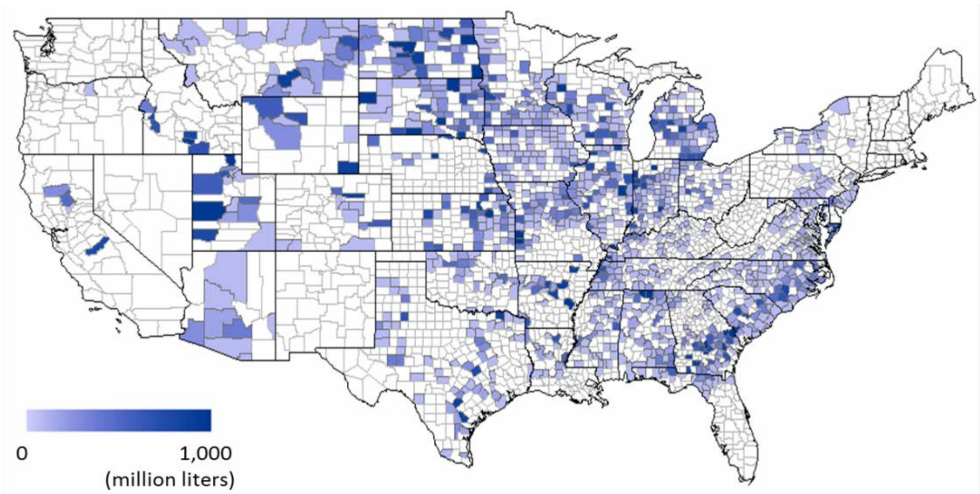

Figure 4. Irrigation water consumed for growing corn in 2008 in the United States

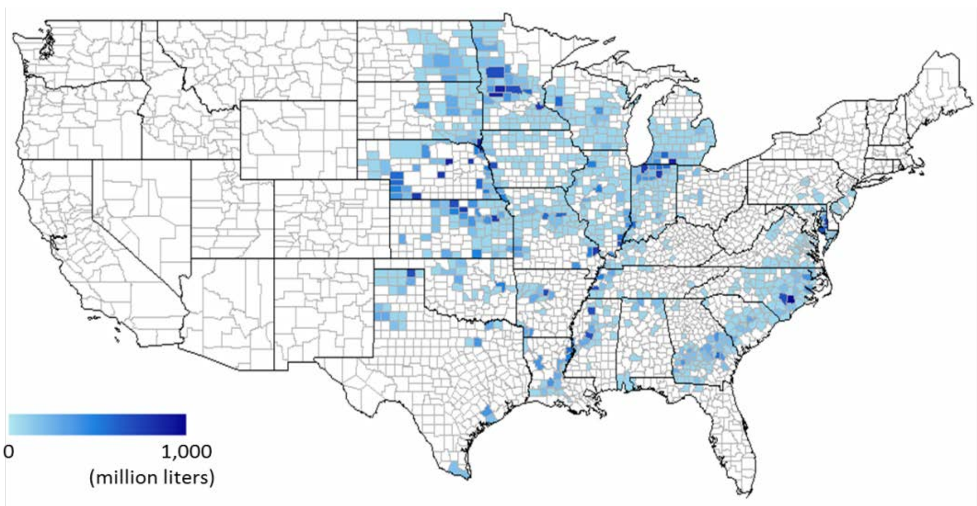

Figure 5. Irrigation water consumed for growing soybeans in 2008 in the United States

Irrigation Water Replacement by Reclaimed Wastewater

Effluent from the POWT facilities can be discharged (a) directly to surface water, (b) for industrial and/or domestic reuse, or (c) for well injection. The amount of effluent that outfalls to surface water is deemed available for reuse. In 2008, the amount of available reclaimed wastewater from secondary wastewater treatment facilities totaled 19.5 trillion liters per year in the United States. This amount far exceeds the 3.6 trillion liters of irrigation water required to grow corn for fuel, and it is 31 times higher than that required to grow soybeans for fuel (i.e., 0.62 trillion liters). However, wastewater facilities are not always located near crop farmland. In fact, large POWT facilities are often located near cities with dense populations. On the other hand, the farm regions where irrigation is needed typically have sparse populations and may not have POWT facility effluent available to them. Therefore, we performed a geospatial screening analysis to examine county-level irrigation demand and potential supply by reclaimed secondary effluent. We assumed the effluent could be used for irrigation within a county boundary. As illustrated in Figures 6 and 7, we found that if the available reclaimed wastewater from every POWT facility was applied to irrigate corn in the same county, up to 34,500 million liters of irrigation water could potentially be displaced each year in the county (Figure 6). A total freshwater savings of 587,254 million liters could be realized in the United States. This amount of displacement is significant, representing 16% of all irrigation water consumed for corn in 2008. In most farming counties where POWT facility effluent is available, approximately 100% of the irrigation requirements could be substituted (Figure 7). The State of Kansas stands out as potentially being the largest beneficiary of using reclaimed wastewater for irrigation: more than 80% of its counties could be covered by this. Missouri ranks second. Overall, the volume of wastewater reuse accounts for 3% of the total available reclaimed secondary wastewater. The potential for meeting irrigation needs gets higher when the cross-county boundary transportation of reclaimed wastewater is considered.

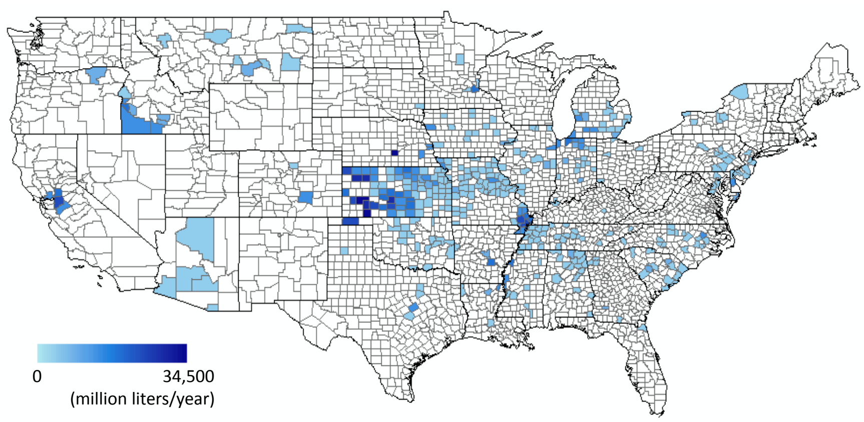

Figure 6. Estimated volume of irrigation water consumption could be displaced by reclaimed secondary wastewater for the production of corn at the county level in the United States

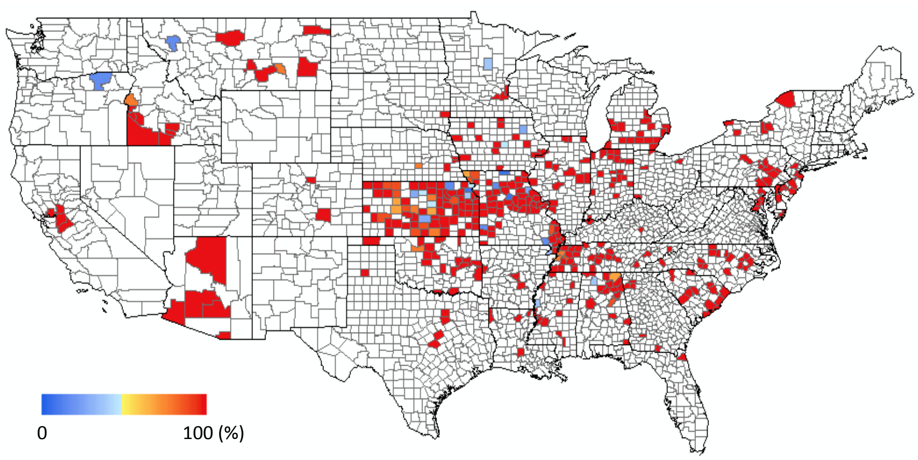

Figure 7. Estimated percent of irrigation water consumption could be displaced by reclaimed secondary wastewater for the production of corn at the county level in the United States

Future Bioenergy Production Scenario

DOE commissioned a major bioenergy resource assessment in 2005 and an update in 2011 (DOE 2011). That study estimated that a billion tons of bioenergy feedstock could be made available in the United States by the year 2030. The study laid the groundwork for determining the conventional and cellulosic resources available for bioenergy development beginning from 2012 till 2029. Figure 8 illustrates a scenario, BLY+EC1_BLT, in which corn production increases at a USDA-projected baseline rate by year 2022. Compared with year 2008, there is a slight increase (3.3%) in land use for corn; the amount goes up from 78 million acres in 2008 to 80 million acres by 2022. The production intensity increases in some counties in the Corn Belt where the irrigation requirement is minimal (USDA FRIS 2008, Wu et al. 2012). In 2008, about 15% of the harvested corn acreage was irrigated. Based on the assumptions that this percentage would remain and that the irrigation rate per acre for corn cultivation would also remain for the same climate region, we calculated the volume of irrigation water for the future scenarios. We estimated that 3.7 trillion liters of irrigation water would be consumed, a slight increase over the 2008 amount. Of this volume, 608 billion liters could be geographically suitable for substitution by the wastewater effluent, meeting 16.3% of the irrigation demand nationally. (Note that this figure is conservative because it does not include population increase projections.)

A critical hurdle in reclaimed wastewater reuse is the mismatch between the wastewater industry's infrastructure and the geospatial distribution of the crops that require irrigation. The land used for agricultural crops is quite limited to land that meets climate and soil conditions due to yield and economic considerations. Further, the POTW must be located near large population, e.g. cities, to provide its primary service. Because reclaimed wastewater contains nutrients and carbon sources which can induce microbial growth leading to microbial induced corrosion in pipelines or storage containers, transporting reclaimed wastewater requires an infrastructure that is specifically designed to be corrosion resist. Technologies and materials that could adapt the wastewater characteristics and effectively transport the reclaimed effluent are thus highly desirable.

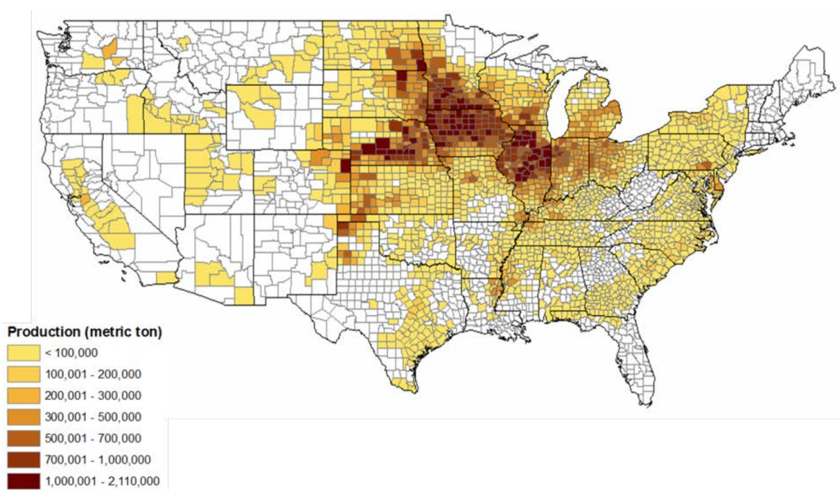

Figure 8. Projected corn grain production for biofuel by year 2022 (Source: DOE 2011)

CONCLUSION

Choices regarding the production of bioenergy feedstock are affected by various factors, including the regional climate, soil, type of feedstock, and local water resource availability. A vast volume of reclaimed wastewater from POWT facilities is available for reuse in the agricultural sector and the bioenergy sector. It is feasible that in the United States, up to 16% of current corn irrigation water could be displaced by the reclaimed wastewater from POWT facilities. At county level, the replacement can range from zero to 100%. The reuse of wastewater for irrigation could potentially save 590 to 610 billion liters of freshwater with regard to corn cultivation alone. However, a major constraint in using reclaimed wastewater as an alternative water resource for irrigation is the unique geographical disparity between the areas with reclaimed wastewater sources and the areas that need water for bioenergy production. This study estimates that the reuse is limited to 3% of available reclaimed water; reuse is crippled by a lack of infrastructure that connects the wastewater industry and agricultural farm lands. The framework established in this study and the study results can help policy makers understand the complex systems and evaluate the effects of the key factors that influence the potential for wastewater reuse. The study can support the wastewater and bioenergy industries in identifying synergies as they develop projects designed to improve profits while preserving the nation's water resources.

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