ETHANOL PRODUCTION POTENTIAL AND COSTS FROM LIGNOCELLULOSIC RESOURCES IN CALIFORNIA

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ABSTRACT: Recent California legislation and policy is likely to have substantial impact on the production and use of biofuels in the state. These new policies include standards for greenhouse gas (GHG) vehicle emissions and carbon content in the fuel, statewide reduction of GHG to 1990 levels by 2020 and goals for in-state biofuels production. The in-state biofuels production goals are: by 2010, 20% of state's biofuel consumption should be produced in-state, increasing to 40% by 2020, and 75% by 2050. Though none of these current laws and policies establish alternative fuel or biofuel usage requirements (such as a renewable fuel standard or RFS), they are likely to increase the use of biofuels in the state. California reformulated gasoline currently contains 5.7% ethanol which represents a 3.4 Gl y^{-1} market. Current in-state fuel ethanol production capacity is approximately 265 Ml y^{-1} from imported corn grain, surplus beverage sugars, and cheese whey. Although grain and sugar crops constitute a large share of California's agricultural production, they are not currently used for in-state fuel ethanol production. Various plans exist for increasing starch and sugar production, including the introduction of sugar cane into the southern interior valleys of the state, but lignocellulosic feedstocks are much more abundant in the state and likely to remain the dominant biomass available for biofuel production. Furthermore, ethanol derived from these resources should realize lower lifecycle greenhouse gas (GHG) emissions compared with ethanol from grain. Based on resource assessments conducted for the state, lignocellulosic ethanol production potential from California was estimated at about 6.9 Gl y^{-1} from 23 Tg y^{-1} of agricultural residues, forest thinnings, and woody and paper material in the municipal solid waste (MSW) landfill stream and another 2.3 – 5.1 Gl y^{-1} could be produced from 600,000 ha of energy crops. A California lignocellulosic ethanol facility could produce ethanol for about \$0.44 per liter assuming delivered feedstock cost of \$44 Mg^{-1} (dry basis), 292 liter Mg^{-1} yield, enzyme costs of \$0.066 l^{-1} ethanol, and plant capital cost of \$0.76 per liter-annual-capacity.
Keywords: liquid biofuels, resource potential, economic aspects

1 INTRODUCTION

Recent California legislation and executive branch policy may have substantial impact on the production and use of biofuels in the state. New legislation in California includes standards for reduced global warming emissions from vehicles (AB 1493 [3]), and establishment of a goal to reduce statewide GHG emissions to 1990 levels by 2020 (AB 32 [4]).

Policies articulated by executive order set statewide GHG emission reduction targets for 2010, 2020, and 2050, set goals for in-state biofuels production and electricity generation from biomass, and established a goal to reduce the carbon intensity of transportation fuels which includes development of a low carbon fuel standard (LCFS).

Executive Order S-06-06 and the Bioenergy Action Plan articulated goals for in-state share of biofuel production; by 2010, 20% of the state's biofuel consumption should be produced in-state, increasing to 40% by 2020, and 75% by 2050 [5],[6]. The biofuel production goals do not establish a renewable fuel standards (RFS) as they do not address actual biofuel usage.

Though none of these current laws and policies establish alternative fuel or biofuel usage requirements (such as a renewable fuel standard or RFS), they are likely to increase the use of biofuels in the state. Other pending legislation proposes an RFS for diesel consumed in the state (starting at 2% renewable diesel followed in two years by 5% renewable diesel content, SB 140, Kehoe) [7].

This paper estimates the potential for ethanol production from in-state lignocellulosic resources and provides initial comment on production costs and economic impacts.

2 LIGNOCELLULOSIC ETHANOL POTENTIAL

2.1 Current ethanol use and production in California

Nearly all gasoline in California contains 5.7% ethanol by volume as an oxygenate, for octane enhancement, as well as to supplement the limited petroleum refining capacity. California currently consumes about 60 Gl y^{-1} of gasoline[8]. California ethanol use, therefore, is some 3.4 Gl y^{-1} blended with gasoline. Ethanol consumption in the US in 2006 was 20.3 Gl [9].

Current in-state fuel ethanol production capacity is approximately 265 Ml y^{-1} from imported corn grain, surplus beverage sugars, and cheese whey. Although grain and sugar crops constitute a large share of California's agricultural production, they are not currently used for in-state fuel ethanol production. Various plans exist for increasing starch and sugar production, including the introduction of sugar cane into the southern interior valleys of the state, but lignocellulosic feedstocks are much more abundant in the state and likely to remain the dominant biomass available for biofuel production.

2.2 Lignocellulosic resources in California

Existing lignocellulosic resources in California include forest operation and wood product residues, urban mixed paper, wood, and green wastes currently landfilled, and certain crop and agricultural residues. Technically recoverable amounts are estimated to be about 23 to 27 dry Tg y^{-1} (Figure 1).

Energy crops, such as switchgrass,[1] grown

[1] Switchgrass is used as an example and may not be the preferred crop for California although field experiments are beginning. The best mix of energy crops that are agronomically and otherwise sustainable

specifically for ethanol feedstock on 600,000 ha of idle or marginal lands could add another 6 to 12 dry Tg y^{-1}.

Potential ethanol production from cellulosic residues in California could be as much as 6.9 Gl. Energy crops could add another 2.3 to 5.1 Gl of ethanol potential depending on crop and ethanol yield. Total ethanol production from in-state lignocellulosic feedstock material could approach between 9.1 and 12 Gl (between 6.1 and 8 Gl of gasoline equivalent or 10-13% of current gasoline use; see Table 1)

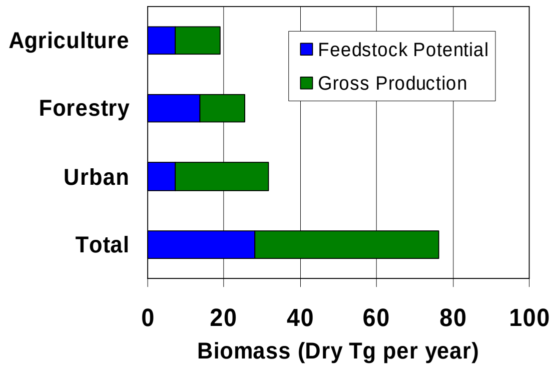

Figure 1: Total annual residue biomass in California and estimated technically recoverable feedstock potential [2]

Table 1: California lignocellulosic ethanol potential* [1]

Biomass Source		Potential Feedstock (dry Tg y^{-1})	Potential Ethanol ($Ml\ y^{-1}$)	Potential Ethanol ($Ml\ y^{-1}$, gasoline equivalent)
Field and Seed		2.1	606	397
Orchard/Vine		1.6	473	314
Landfilled Mixed paper		3.6	1211	806
Landfilled wood & greenwaste with ADC		2.4	818	545
Forest thinnings		12.9	3748	2498
Totals- Current California		**22.6**	**6,855**	**4,561**
600,000 ha Dedicated Energy Crop				
Low Yield (11.2 dry Mg ha^{-1}, 334 l Mg^{-1})		6.8	2,270	1,514
High Yield (20.2 dry Mg ha^{-1}, 418 l Mg^{-1})		12.2	5,110	3,407
State potentials with 600,000 ha energy crop	**Low Yield**	**29**	**9,138**	**6,076**
	----------	----------	***Range***	----------
	High Yield	**34.5**	**11,977**	**7,968**

*Assumes a conservative ethanol yield of 292 liters per dry tonne (Mg) for field and seed crops, orchard and vine prunings and removals, and forest and range thinnings. Assumes 334 liters per dry tonne (Mg)for landfilled paper and woody/green wastes considered to be available for utilization. Nearly 70% of the state estimate is due to the large potential for forest and rangeland thinnings. The estimate assumes no competition for the resource such as biopower, mulch, compost, etc

in California is the subject of on-going and proposed research.

3 COST ESTIMATES

The cost of corn-ethanol production in the US mid-West is currently about \$0.46 l^{-1} (based on corn at \$3.50/bushel.[10]

Using cost factors derived from studies by the National Renewable Energy Laboratory, ethanol production cost from a 265 Ml y^{-1} facility using co-current dilute acid prehydrolysis and enzymatic hydrolysis of lignocellulosic feedstocks in California is estimated to be \$0.43 l^{-1} in the near to midterm (3- 8 years) if the technology is sufficiently commercialized [11] (table 2).

Delivered feedstock cost for this analysis was assumed to be \$44 Mg^{-1} (dry) ton and cellulase enzyme cost to be \$0.066 l^{-1} ethanol. Capital cost is \$200 million (\$0.755 l^{-1} annual-capacity). The project internal rate of return is 15%.

The economic model assumes a yield of 292 litres of ethanol per dry tonne of biomass feedstock which is expected for enzymatic hydrolysis with improvements in yield to 420 l Mg^{-1} (dry) possible [12]. Facility operation is around the clock for 350 days per year consuming 2585 Mg d-1 (905,000 Mg y-1). With enzyme costs at \$0.0264 per liter as anticipated by recent biotechnology developments, ethanol might be produced for \$0.40 per liter. With yield improvement to 420 l Mg^{-1} and enzyme costs at \$0.0264 per liter, ethanol production cost would be about \$0.33 l^{-1}..

Table 2: Breakdown of lignocellulosic ethanol production cost estimate.

	(US\$/litre)	(US M\$/year)
Feedstock Cost (\$44 Mg^{-1} (dry))	0.151	39.6
Cellulase	0.067	17.5
Labor (includes Administration)	0.013	3.4
Maintenance	0.009	2.3
Insurance/Property Tax	0.007	1.8
Other Operating Exp.	0.030	7.8
Total non Fuel Expenses	0.125	32.8
Total Operating Expenses	**0.276**	**72.4**
Equity Recovery	0.140	36.8
Taxes	0.048	12.5
Electricity Revenue	-0.032	-8.3
Revenue Requirement	0.433	113.3

5 DISCUSSION

Lignocellulosic derived ethanol offers several advantages over ethanol produced from sugar/starch feedstocks. These include the potential for higher per acre ethanol yields and lower agronomic inputs for purpose-grown energy crops, improved product life-cycle environmental performance, GHG balances and net-energy ratios, the potential to utilize marginal and out of production lands which reduces competition with food crops, and the potential to utilize the diverse and large existing lignocellulosic biomass residue streams found in urban waste, forest thinnings, and agricultural residues.

As the US will not be able to make enough biofuels (e.g., bioethanol) from conventional feedstocks (starch and sugar sources) to substantially reduce petroleum imports or lower GHG emissions from the transportation sector, lignocellulosic routes to biofuels will be needed [13, 19, 20].

Existing lignocellulosic resources in California include forest operation and wood product residues, urban mixed paper, wood, and green wastes currently landfilled, and certain crop and agricultural residues. Technically recoverable amounts are estimated to be about 23 to 27 dry Tg y^{-1} .

Energy crops, such as switchgrass,[2] grown specifically for ethanol feedstock on 600,000 ha of idle or marginal lands could add another 6 to 12 dry Tg y^{-1}.

Potential ethanol production from cellulosic residues in California could be as much as 6.9 Gl. Energy crops could add another 2.3 to 5.1 Gl of ethanol potential depending on crop and ethanol yield. Total ethanol production from in-state lignocellulosic feedstock material could approach between 9.1 and 12 Gl (between 6.1 and 8 Gl of gasoline equivalent or 10-13% of current gasoline use; see Table 1).[3]

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[2] Switchgrass is used as an example and may not be the preferred crop for California although field experiments are beginning. The best mix of energy crops that are agronomically and otherwise sustainable in California is the subject of on-going and proposed research.

[3] Ethanol is not the only biofuel that can be made from lignocellulosic biomass. Butanol, mixed alcohols, Fischer-Tropsch liquids, and others can serve as gasoline and diesel fuel replacements.

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