Renewable Energy 67 (2014) 136–142

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Economic feasibility of algal biodiesel under alternative public policies

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ARTICLE INFO

Article history:
Received 10 October 2013
Accepted 14 November 2013
Available online 15 December 2013

Keywords:
Algae
Mass balance
Biodiesel
Economic feasibility
Public policy

ABSTRACT

The motivation for this research was to determine the influence of public policies on economic feasibility of producing algal biodiesel in a system that produced all its energy needs internally. To achieve this, a steady-state mass balance/unit operation system was modeled first. Open raceway technology was assumed for the production of algal feedstock, and the residual biomass after oil extraction was assumed fermented to produce ethanol for the transesterification process. The project assumed the production of 50 million gallons of biodiesel per year and using about 14% of the diesel output to supplement internal energy requirements. It sold the remainder biodiesel and ethanol as pure biofuels to maximize the rents from the renewable fuel standards quota system. Assuming a peak daily yield of 500 kg algal biomass (dry basis)/ha, the results show that production of algal biodiesel under the foregoing constraints is only economically feasible with direct and indirect public policy intervention. For example, the renewable fuel standards' tracking RIN (Renewable fuel Identification Number) system provides a treasury-neutral value for biofuel producers as does the reinstatement of the renewable fuel tax credit. Additionally, the capital costs of an integrated system are such that some form of capital cost grant from the government would support the economic feasibility of the algal biodiesel production.

1. Introduction

Renewable energy's potential to address the environmental problems posed by fossil fuels and contribute to addressing the energy security challenges are stimulating action in governments, businesses and research institutions. Public policies are being developed to facilitate the continued emergence and growth of the renewable energy sector. The success of these initiatives is reflected in the sector's global revenues topping $500 billion in 2011, representing a compound annual growth rate of about 3.7% between 2007 and 2011 [10].

Despite their promise, renewable energy production is not uncontroversial. Hydroelectric power development often impacts arable land availability and human communities that depend on it while wind energy development in certain places has been accused of destroying the vistas. For bioenergy, the controversy has centered around its effects on food prices resulting from diversion of food products to energy feedstock and the increase in input prices resulting from the increase in their demand for non-food feedstock production [15].

Bioenergy solutions to these controversies have focused on using cellulosic feedstock [24] and non-food oilseeds and plants [17]. Algae have been presented as a promising biomass feedstock for a long time [3,21]. Its advantages have been described by some to include reliability as a feedstock, higher energy yield per unit production area and year-round batch-wise harvesting that supersedes all other biomass sources [11]. At their most conservative oil content level, Mata et al. note that microalgae oil output per unit area is about 92 times that of soybeans. These extrapolations form the crux of the debate in the research community about algae's technical and economic feasibility as an effective biofuel feedstock [4,14,17,27].

This paper contributes to the debate from a different perspective. First, it seeks to develop a carbon-neutral production system for algal biodiesel, implying that the production system must not lead to an overall increase in carbon release to the atmosphere. Next, it evaluates the economic feasibility of such a production under prevailing public policies and plausible alternative policies. It achieves these objectives using a mass balance/unit operation approach [7] to ensure that carbon-neutrality is maintained, and assesses the economic feasibility using net present value approach

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http://dx.doi.org/10.1016/j.renene.2013.11.029

to capital investment decision-making. The next section provides an overview of the bioenergy policies in the U.S. against a backdrop of fossil energy's entrenched incumbency advantages. The assumptions driving the system dynamic model used are presented in the subsequent section and the penultimate section presents the results. The summary and conclusions are presented in the final section.

1.1. U.S. bioenergy policy overview

Public policies supporting bioenergy in the U.S. have only become prominent in the last two decades or so. At the forefront of these policies is the EPAct (Energy Policy Act) of 1992, which directed that more studies be conducted on biofuels and provided guidance for federal programs for increased implementation of biofuel programs. Title III of the EPAct (1992) amended the Energy Policy and Conservation Act of 1975 and directed the Secretary of Energy to acquire vehicles using alternative fuel for federal fleet, among other directives. Title IV of this EPAct (1992) also amended the Energy Policy and Conservation Act of 1975 to authorize appropriations from Fiscal 1993 through 1995 for alternative fuel commercial trucks application program. It also amended the Motor Vehicle Information and Cost Savings Act of 1972 to reflect the alternative fuel provisions of EPAct (1992). Title IV also authorized the Secretary of Transportation to establish a low-interest loan program to encourage small businesses to adopt vehicles using alternative fuel. Finally, it directed the Secretary of Energy to promote the use of alternative fuels through public education and information. The Federal Trade Commission was also directed under the Act to formulate regulations and guidelines for labeling alternative fuels and vehicles using such fuels. Thus, EPAct (1992) seemed to set the market development process in place in preparation for the development of the biofuel products.

The Energy Policy Act of 2005 put programs in place to encourage the use and production of biofuels, such as ethanol and biodiesel. It directed the pursuit of research and development of renewable energy using agricultural biomass as a feedstock and provided tax incentives for individuals and firms using and/or producing biofuels. There were specific instructions for the Secretary of Energy to ensure reduction in petroleum-fueled vehicles in the federal fleet. It also established compliance rules for the use of alternative fuels, with clear non-compliance penalties. Title VII of EPAct (2005) directed the establishment of programs to improve the commercialization of hybrid/flex fuel vehicles and plug-in/flex fuel vehicles. But Section D of Title IX focused specifically on research and development of agricultural biomass, directing the Secretaries of Agriculture and Energy to look into new feedstock for conversion into biofuels and bio-based products, including the development of technologies for converting cellulosic biomass into biofuel. The Secretary of Agriculture was also directed to establish education and outreach programs on bio-based fuels and bio-based products. Section D of Title XIII of EPAct (2005) established tax incentives for investments in alternative energy, including fuel cells and hybrid vehicles. Section 1342 provided a 30% tax credit for the cost of installing a commercial or residential refueling property to dispense fuels containing at least 85% ethanol or biodiesel up to a $30,000 maximum. Additionally, producers could claim a $1.00 per gallon tax credit for biodiesel produced from new agricultural feedstock, including biomass feedstock, and $0.50 per gallon for biodiesel produced from used feedstock, such as fryer grease. This tax credit was set to expire on December 31, 2009.

The EISA (Energy Independence and Security Act) of 2007 was an omnibus energy policy act with four of its 16 titles related directly to alternative fuels. Title I allow automobile manufacturers tax credits towards the production of alternative-fueled vehicles, extending such credits through 2019. It also allowed vehicles operating a blend of 20% biodiesel and 80% petroleum to be considered for CAFE (corporate average fuel economy) credits. Title II of the EISA specifically focused on increasing energy security through biofuels. It increased the original biofuel production target of 7.5 billion gallons originally established under the RFS (Renewable Fuel Standard) of the EPAct (2005) to 36 billion gallons by 2022. The revised standards, referred to as Renewable Fuel Standards II (RFS II), comprised 15 billion gallons of conventional biofuels, 4 billion gallons of advanced biofuels, 16 billion gallons of cellulosic biofuels and 1 billion gallons of biomass-based diesel. It also stipulated that an increasing amount of renewable fuels must be sourced from feedstock other than corn, with the expectation that these types of fuels will reach 21 billion gallons by 2022. Title IX of the law provided grants and loans for the development, construction and retrofitting of commercial scale refineries to produce biofuels. These specific policy initiatives provided an invitation to researchers to revisit algae as a potential feedstock in biodiesel production and for refineries and interested entrepreneurs to consider the technical and economic issues involved in using algae as a sustainable feedstock in biodiesel production. To ensure environmental sustainability, EISA required the application of lifecycle greenhouse gas performance to guarantee that renewable fuels produced lower levels of greenhouse gases than the petroleum fuels they replace.

In addition to the foregoing, three specific tax credits are stipulated under Title VIII of the Tax Relief, Unemployment Insurance Reauthorization and Job Creation Act of 2010. They are: $1.00 per gallon biodiesel mixture credit; $1.00 per gallon of biodiesel that is not in a mixture with diesel fuel; and $0.10 per gallon up to 15 million gallons of agri-biodiesel produced by small producers. These credits expired in December 2011, and a new legislation, Biodiesel Tax Incentive Reform and Extension Act (H.R. 2238), seeking to extend the $1 per gallon biodiesel tax credit to 2014 and change the tax incentive to a production excise tax credit remains with the House Committee on Ways and Means since June 2011 (Library of Congress, n.d.).

The RIN (Renewable fuel Identification Number) is a serial number assigned to each batch of renewable fuel, traveling with the fuel through the supply chain. The Environmental Protection Agency uses it to track the performance of manufacturers, refineries, blenders, and importers in fulfilling their renewable fuel sale obligations, and in consequence, progress towards the national mandatory biofuel targets under EISA (2007). The agency establishes an annual quota of biofuels based on total motor fuels consumed. Each manufacturer, refinery, blender or importer is then obliged to use a minimum of the specified biofuel quota in its operations. For example, the 2010 quota of 7.95% obliged firms to use no less than 7.95% of renewable fuels in their blends. Recognizing that there will be surpluses and shortages across the industry, the EPA allows firms to trade excess RINs to meet their renewable fuel quotas obligations. RINs have provided a treasury-neutral support for biofuel manufacturers who sell to manufacturers, refineries, blenders, and importers who need renewable fuel to meet their obligations.

The foregoing policy initiatives have contributed to increasing annual U.S. biodiesel production capacity to about 2.11 billion gallons as of September 2012, distributed across 105 biodiesel plants in 36 states, with an average production capacity of about 13.8 million gallons and a standard deviation of about 13.9 million gallons [25]. The nine-month total B100 production increased from 268 million gallons in 2010 to 648 million gallons in 2011 and further to 748 million gallons at the end of September 2012. Despite the consistent growth in production, this production level is only 61% of the 2013 biomass-based diesel volume established by the Environmental Protection Agency [26]. While it is true that the industry's current capacity can meet the target, the evidence of current monthly capacity utilization shows that the industry monthly output average about 3.06% of production capacity (Fig. 1). It is argued that the slowdown in production and growth in capacity utilization since the end of 2011 may reflect the effect of the expiration at the end of December 2011of the various programs designed to support the biofuels industry, including the renewable tax credit policy.

The dominant biodiesel feedstock in the U.S. is all food products. EIA [25] data show that soybean oil and canola oil account for 66.60% and 14.40% respectively of biodiesel feedstock. Animal fat's contribution is only about 12.30% of manufactured biodiesel in 2012. Because of the recent surges in commodity prices, policymakers have been attempting to encourage the use of non-food feedstock in biodiesel and renewable fuel production [15].

While algae's potential to contribute to biodiesel supply in the U.S. is high, its current contribution is negligible. According to *The Economist* [22], current commercial algae production in the U.S. is not directed towards biodiesel but to higher value products. For example, Solazyme, Inc. of San Francisco, California, had received funding from Dow Chemical to produce transformer oils and Aurora Algae of Hayward, California, with funding from the Australian Government, is focusing on omega-3 fatty acids for food supplements and pharmaceuticals. That biodiesel production is not the focus of commercial algae production is indicative of its lack of competitiveness against alternative feedstocks. So, what would it take to position algal biodiesel as a competitive alternative and enhance biodiesel production without significant risk in food price volatility?

1.2. Modeling assumptions

Total U.S. biodiesel production in 2011 was 0.967 billion gallons compared to total No. 2 petro-diesel consumption in excess of 36.16 billion gallons. This makes biodiesel vulnerable to petro-diesel's entrenched incumbency advantage. One of the manifestations of this advantage is pricing, which the incumbent industry establishes using its size and tenure. Therefore, biodiesel producers are assumed to be price takers and biodiesel prices are petro-diesel prices adjusted for energy content. The lower-heating value for biodiesel is 36.95 MJ/kg compared to 42.79 MJ/kg for petro-diesel.

The model of algae-based biodiesel production is conceived of as a technological model based on the traditional mass balance/unit operations approach of chemical engineers [17] as a foundation that is integrated in a dynamic overall economic model. Four overall operations are biomass production, oil extraction, diesel production from oil, and ethanol production to supply alcohol for the oil-to-diesel conversion. The technological study has been published (Pfromm et al., 2011) and a brief summary is given below. The study showed that sustainable diesel production using algae is feasible under optimistic yield assumptions, with sustainability violated only by natural gas-based fertilizer. An overall net export of saleable diesel is achieved while using about 14% of the diesel produced to conceptually satisfy the energy demand of the process.

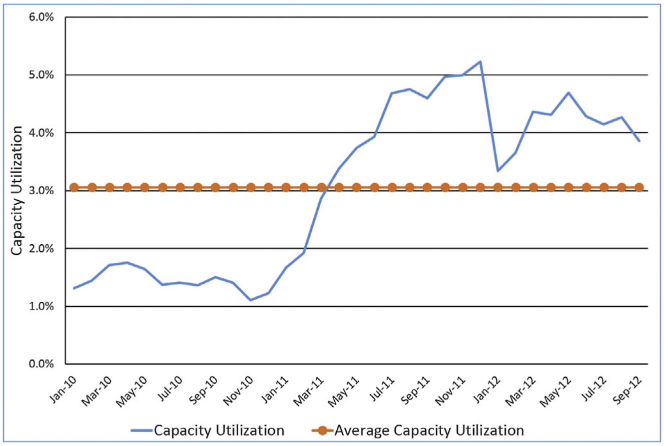

Fig. 1. Monthly B100 biodiesel production as a proportion of annual U.S. production capacity.

Fig. 2 lays out the implementing assumptions. The biomass feedstock unit is built to provide enough algae to produce the quantity of oil needed for the desired biodiesel output and enough residual biomass to produce the ethanol needed for the transesterification process. Its carbon neutrality implies that the number of carbon atoms in the first unit operation is equal to the number in the final unit operation. It is important to note that while self-sufficient in its feedstock and energy needs (carbon requirements), the system is not self-contained because it imports water, yeast, sodium and potassium hydroxide catalysts and nitrogen fertilizer.

The assumed technology for biomass feedstock production is an open raceway pond, with production assumed to occur in Southern Texas or Southern Arizona region, where appropriate temperature, insolation, humidity and water availability to allow for at least 305 days of production per year [28] are given. But probably equally, if not more, important is the fact that this region has the potential of providing the contiguous land mass of nearly 3950 ha needed to build the open raceway ponds, roads and buildings. It is assumed after Ryan et al. [2] that algae feedstock is harvested every other day once the ponds are in full production. Pond construction costs are extrapolated from Briggs' [1] estimates of $80,000/ha to $95,213/ha at 2.00% growth rate. Production operations costs are based on $18,000/ha estimated by Sass et al. [20] and extrapolated to $21,485 in 2012 at 2.0%.

There is an intense debate about the potential algal yield from commercial operations in the literature [17]. However, open pond trials at Roswell, New Mexico in the late 1980s showed that yield peaks of 500 kg/ha per day could be achieved [21]. Assuming this peak is attainable and can be maintained, it is obvious that it will not happen from day one of operations. Therefore, a maximum yield of 500 kg/ha per day is assumed and the open raceway ponds are built based on this yield assumption. This implies that for the 50 million-gallon diesel operation, a total production area of about 3289 ha is required. Yield is assumed to grow from 120 kg/ha per day in the first production year to the maximum of 500 kg/ha per day by the seventh year of operations. This is deemed realistic as management addresses the environmental and other operational challenges inherently associated with the operation of open raceway pond systems [23].

The second unit operation is oil extraction from the harvested algae. Again, significant debate exists about the quantity of lipids that can be extracted from different algae species primarily because of the significant interactions between the growing environment and the compositional structure of the algae as well as the extraction methods. Hu et al. [9] and Gao et al. [5] are followed in the assumption of 36.8 wt.% useable oil relative to dry cell weight used here. This is the product of the 46 wt.% of available lipids (dry basis) and 80% useable triglycerides in the oil. It is assumed the energy demand and technical complexity for triglyceride recovery from dry algal biomass are equivalent to oil recovery from soybeans, hence a hexane solvent extraction technology is applied. While this can certainly be debated, it is also a best case assumption. A 1% loss is assumed in the post-extraction lipid refining process.

The biomass remaining after the lipid extraction process in the second unit operation is fermented in the third unit operation to produce the ethanol required for the transesterification process, the final unit process. The ethanol yield from the fermentation process

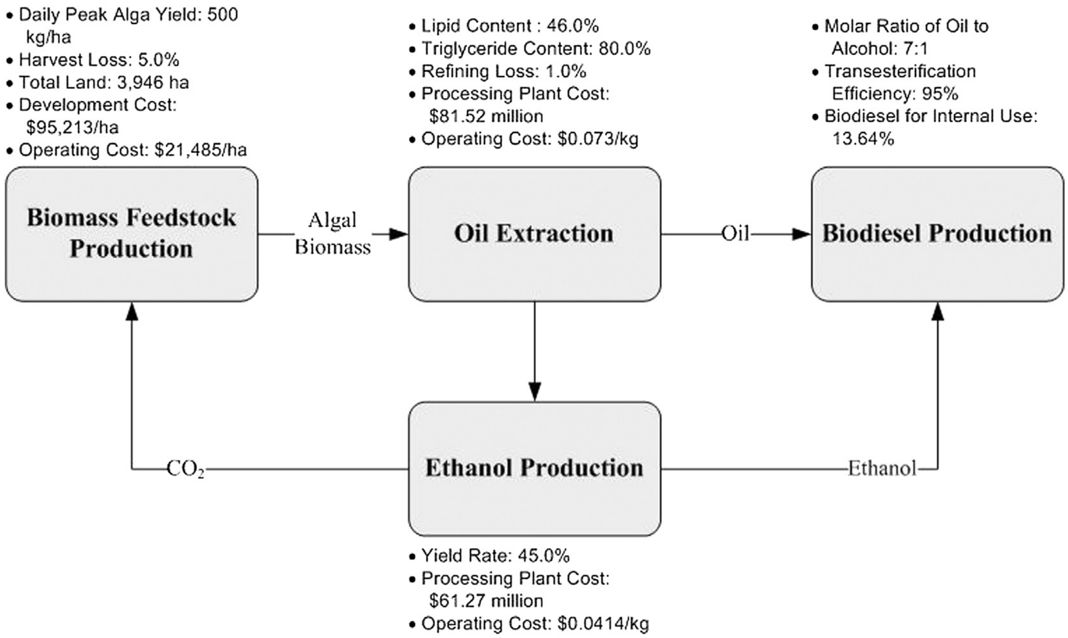

Fig. 2. Assumptions underlying unit operations of the biodiesel production model.

is assumed to be 45% [6,8]. The cost of operating the ethanol plant and the transesterification plant without internal transfers pricing for feedstock and oil are assumed at approximately $0.05/kg using calculations by Peters [16]. All the CO_2 by-product from the fermentation is captured and fed into the ponds to enhance photosynthesis while the distiller's biomass from the ethanol production and the glycerol from the transesterification process are utilized to supplement the 13.65% of manufactured biodiesel used to satisfy the production system's internal energy demand. Finally, in the transesterification process, it is also assumed that the required molar ratio of oil to ethanol for a complete transesterification is 7:1, and for every 100 kg of biodiesel produced, 10 kg of crude glycerol is generated [19]. The cost of operating the transesterification process is estimated at $0.08/kg, after Gerpen's presentation at the Oilseed and Biodiesel Workshop on January 9, 2008 in Billings, MT.

Both long-term ethanol and biodiesel prices, presented in 2011 dollars, are drawn from the Energy Information Agency's [25] long-range price forecasts. These prices are converted into dollars per kilogram of each product for use in the model. Historical ethanol and biodiesel prices from EIA were used with historical RIN values obtained from the Oil Price Information Service (OPIS, www.opisnet.com) to project future RIN values for both ethanol and biodiesel using a linear regression model. The regression coefficients for ethanol RIN were −0.0094 and 0.117 for the intercept and the ethanol price while the coefficients for biodiesel RIN were −0.0074 and 0.142. The coefficients of variation for both equations exceeded 0.8 and the regression coefficients were statistically significant at the 5% level in both cases. Carbon price is assumed fixed at about $0.09/kg, the highest price obtained at the California Air Resources Board's first auction for greenhouse gas under that state's cap-and-trade program, as reported by OPIS.

1.3. Scenarios

The simulation assumes deterministic conditions in yield for all outputs – algal feedstock, oil, biodiesel and ethanol. It also assumes that algal biodiesel and ethanol are sold to blenders so the producer is able to extract the full value of the associated RINs. Finally, it is assumed that operating costs for the different unit operations grow at a constant rate of 2.2% per annum to capture the inflation rate. Given the foregoing, five scenarios are investigated in this research (Table 1). The Base Scenario assumes that production mandates and targets stipulated under the EISA (2007) remain unchanged until 2022. This allows RIN values to be applied to EIA projected prices until 2022. Scenario I assumes that the $1.00/gallon tax credit is reinstated in 2014–2016. Scenario II assumes an incentive for petro-fuel users to move to lower carbon alternatives by instituting

Table 1
Simulated public policy scenarios.

Scenario	Product price	RIN value	Tax credit	Carbon subsidy	Comments
Base	X	X			RIN available from 2012 but ends in 2022. This is a treasury-neutral program.
I	X	X	X		RIN available from 2012 but ends in 2022. Tax credit is assumed reintroduced in 2014 and terminates in 2016. This is not a treasury-neutral program.
II	X	X		X	RIN available from 2012 but ends in 2022. LHV-adjusted carbon subsidy begins in 2014 and goes on to end of the simulation. This is a treasury-neutral program.
III	X	X	X	X	RIN available from 2012 but ends in 2022. Tax credit is assumed to begin in 2014 and continues until 2022. LHV-adjusted carbon subsidy begins in 2014 and continues throughout the simulation. This is not a treasury-neutral program.
IV	X				No public policy in effect for the industry.

a tax on carbon which is transferred to biofuel manufacturers, after adjusting for energy content of the biofuels with respect to petro-fuels. The carbon subsidy is assumed to become effective in 2014 and does not sunset. Scenario III assumes that the tax credit policy is implemented in 2014 in addition to the LHV-adjusted carbon subsidy in addition to RIN being in effect from 2012. However, both the RIN and the tax credit are terminated in 2022 but the carbon subsidy continues for the rest of the simulation period. Scenario IV assumes none of these policy options are available, and evaluates the plant's performance solely on its production and prevailing market prices.

Given the number of federal and state grants available for biofuel development, it is envisaged that building a plant of this magnitude may qualify for some level of capital grant from government. Three grant support options are evaluated: (i) No grant; (ii) 5% of total capital costs; and (iii) 10% of capital costs are covered by the grant. The results are analyzed under each of these support options.

2. Results and discussion

The system was designed to produce 50 million gallons of algal biodiesel, using 13.65% of it for its internal energy needs and selling the remainder as B100 biodiesel to blenders who need the biodiesel to meet their renewable fuel standard quotas.[1] Construction is assumed completed in 2012 and production begins in 2013 with an average biomass daily yield of 120 kg/ha. The total biomass produced at the system's steady state daily yield of 500 kg/ha is approximately 473.62 million kg per annum. In this production state, total biodiesel output is 163.10 million kg per annum and about 140.84 million kg is sold. Along with this is 114.51 million kg of ethanol of which 55.17 million kg is sold with the difference being used in the transesterification process.

There are five principal products emanating from the four unit processes: algal biomass; biodiesel; carbon dioxide; ethanol; and glycerol. Based on the molar masses of these products, their carbon contents are calculated and tracked through the production process. The peak biomass output produces about 210.04 million kg of carbon annually. The carbon content of the biodiesel produced at peak biomass production was estimated at about 126.24 million kg per annum, while that of ethanol and glycerol was respectively 59.71 million kg and 5.88 million kg per annum. About 17.18 million kg of carbon is harvested annually from the fermentation process in ethanol production for use in biomass production. The accounting shows that the total carbon from the downstream products – biodiesel, CO_2, ethanol and glycerol – was about 1.04 million kg (approximately 0.49%) less than the algal biomass carbon the system started with, with the difference accounted in the production losses at the biomass stage and incomplete fermentation. About 65.60% of the total carbon from the system is transferred outside the system in the form of biodiesel and ethanol. The treasury-neutral carbon subsidy is based on this portion of the system's carbon production.

Revenue in each scenario depends on the policy that is in effect. The average biodiesel sales revenue under the Base Scenario for the simulation period is about $147.95 million, with a standard deviation of approximately $36.93 million. For ethanol, average sales revenue under the Base Scenario is about $47.78 million with a standard deviation of about $11.50 million. The mean total revenue under the Base Scenario is about $187.91 million with a standard deviation of about $59.08 million. Scenario I assumed that the renewable tax credit is re-introduced for two years in 2014, resulting in average total sales revenue increasing by 2.48% to about $192.57 million, with a standard deviation of about $55.93 million. Tax credits are becoming an increasingly difficult policy option because of the federal government's fiscal situation. However, the treasury-neutral LHV-adjusted carbon subsidy defining Scenario II should be a more palatable policy program given that it is paid by transferred tax revenues on petro-fuel consumers. This policy initiative is shown to result in average revenue of about $197.03 million, a 4.85% increase over the Base Scenario. The standard deviation of average revenue under Scenario II is approximately $62.04 million. The carbon subsidy accounts for an average of about 4.68% of the average revenue under Scenario II, an average of approximately $9.50 million with a standard deviation of $2.40 million. Scenario III assumes a long-term tax credit policy that begins in 2014 and continues to 2022. It also assumes RIN terminates in 2022 but the carbon subsidy starts in 2014 and does not end for the simulation duration. The average total revenue under Scenario III is approximately $215.58 million, with a standard deviation of $67.36 million. The extended tax credit and carbon subsidy results in average revenue under Scenario III being about 14.72% higher than under the Base Scenario. The average revenue under Scenario IV, which assumes the absence of any policy support, is about $170.50 million with a standard deviation of about $54.36 million. This was about 9.29% lower than the Base Scenario's average revenue.

Gross margin is defined as total revenue from operations less total variable costs, which was the sum of operating costs at the algae production, oil extraction, ethanol production and transesterification unit operations. Biomass production accounts for the lion's share of operating costs, averaging about 67.49% of the average variable costs of $147.79 million. The average gross margin under the Base Scenario is about $45.98 million with a standard deviation of about $28.68 million. The average gross margin under Scenario I is about $50.84 million with a standard deviation of $27.91 million. Scenario II and Scenario III posted average gross margins of $55.48 million and $74.80 million respectively while their standard deviations are $30.56 million and $46.35 million. The introduction of the $1.00/gallon tax credit for only two years increases average gross margin by almost 10.56% while the carbon subsidy increased it by 20.66% in comparison to the Base Scenario. Gross margin under Scenario IV is nearly 40% below that under the Base Scenario.

Net revenue is gross margin less capital and fixed costs. Fixed costs are the same under all scenarios and are estimated at $499.47 million. They included land acquisition and development – open raceway ponds, roads and buildings – biodiesel and ethanol processing equipment and pipes to transport CO_2 to the ponds after biomass fermentation. Fig. 3 shows results of the average net revenues for the four scenarios under the three capital grant options. The results show that for each five percent increase in capital cost grant the firm receives, average net revenue increases by about a million dollars. Thus, the average net revenue under the Base Scenario is $24.17 million with the zero grant option compared to $25.16 million and $26.16 million with the 5% and 10% grant options respectively. The relative benefits of the grant are more pronounced under Scenario IV, where no other public policy was in effect for the biofuels industry, and least pronounced under Scenario III where all the policies considered in this paper are recognized.

The firm or industry hurdle rate defines the appropriate discount rate for cash flow in the estimation of net present value. The hurdle rate accounts for the opportunity cost of invested capital as well as the risk premium investors desire for the particular investment. Given the size of the investment and its duration, the

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[1] Fifty million gallons is equal to approximately 165.54 million kg of biodiesel at a density of 0.875 kg/l and 3.785 l/gallon. The results are presented in kilograms.

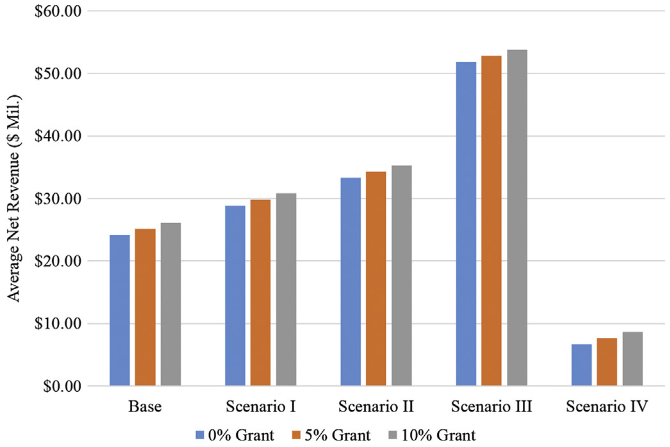

Fig. 3. Average net revenues by scenario and grant option.

opportunity cost of invested capital is assumed to be the average 10-year Treasury bond for 2002–2012, which was at 3.95% using Federal Reserve Board data. The industry's risk premium is assumed at 6% after Pyke [18]. Thus, an assumed hurdle rate of 9.95% was used as the discount rate for assessing the economic feasibility of a 50-million gallon integrated carbon-neutral algal biodiesel manufacturing plant.

The NPV (net present value) results for the different scenarios follow similar pattern as seen in Fig. 3. For a project to be considered economically feasible for investment, its NPV has to be positive at the given discount rate over the stated investment horizon. The investment horizon was 20 years for this project and the discount rate was 9.95%. The results show that none of the capital grant options under the Base Scenario, Scenario II and Scenario IV produced a positive NPV. Contrarily, all capital grant options under Scenario III produced positive net present values. For Scenario I, only the 10% capital grant option produced positive net present value of about $6.20 million and an internal rate of return of 10.12%. Increasing the carbon subsidy from $0.091/kg to $0.10/kg produces an economically feasible result under the 10% capital grant option of Scenario II. Its average net present value is about $2.39 million, with an internal rate of return of 10.01%. Given its treasury neutrality, the carbon subsidy is a promising incentive to both encourage biofuel production and discourage petro-fuel consumption.

Given that a legislative proposal to extend the renewable tax credit has been languishing in committee since June 2011, there is very little reason to expect Scenario III to be implemented. However, its results point to the importance of public policies in helping the biofuel industry translate its potential into reality in contributing to energy security and environmental sustainability. The entrenched incumbency advantage of the fossil fuel industry is evident under Scenario IV, where the absence of any policy support for the industry makes it impossible for it to be economically feasible, especially when constrained to operate under carbon mass balance conditions.

2.1. Summary and conclusions

The unintended consequences of the relationship between increased biofuel production and food prices have motivated interest in non-food feedstock for biofuel production. This interest has recently created a resurgence in algae's potential as a biofuel feedstock. However, debates about its technical feasibility, driven by its year-round yield in open raceway operations are ongoing. Using Sheehan et al.'s [21] work, an optimistic peak yield rate of 500 kg/ha per day was assumed, reaching that peak in seven years from an initial yield of 120 kg/ha per day. A system dynamic model was built for an integrated mass balance/unit operation system that produced all the required feedstock and energy resources necessary for the production of 50 million gallons of biodiesel.

The results showed peak biodiesel output of about 49.26 million gallons, 13.65% of which is used as part of the system's energy requirements. The biomass residue after lipid extraction is fermented to produce about 38.34 million gallons of ethanol, about 48.12% of which is used in the transesterification process to produce the biodiesel. Thus, at peak, 42.53 million gallons of pure biodiesel and 18.47 million gallons of pure ethanol are sold.

Some level of government support appears imperative if algal biodiesel is going to become a significant contributor to the biofuels supply in the U.S. For example, a reinstatement of the $1.00/gallon tax credit, a 10% capital cost grant under a program such as the Biorefinery Assistance Program, and the RIN-engendered biofuels value, can produce an economically feasible production system that is carbon neutral. Similarly establishing a carbon tax on petro-fuel consumption and using it to subsidize the carbon-neutrality of biofuels as designed in this paper shows promise. The paper confirms the need for some limited public support in order for the biofuels industry to overcome fossil fuels' inherent entrenched incumbency advantage.

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