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Implications of U.S. biofuels policy for sustainable transportation energy in Maine and the Northeast

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ABSTRACT

Drop-in biofuels that are compatible with the existing vehicle and retail infrastructure continue to receive great attention due to their promise in addressing climate change and energy security concerns stemming from use of petroleum-based fuels. In this paper we discuss current drop-in biofuel production technologies and assess relevant biofuel policies in the U.S., particularly those impacting forest biomass in Maine and the Northeast. In this context, we examine the Renewable Fuel Standard (RFS) policy and its definition of biomass which favors biomass from plantations regardless of actual ecological impacts on biodiversity, soil and water quality. We argue that the Environmental Protection Agency (EPA) should consider revising the definition of biomass eligible for renewable fuel credits to include sustainably managed natural forests.

1. Introduction

The Energy Independence and Security Act of 2007 (EISA, P.L. 110–140) addresses multiple policy goals including moving the US towards greater energy independence, increasing the production of low-carbon renewable fuels, increasing the efficiency of products, buildings and vehicles and promoting research on carbon capture and storage. EISA expanded the scope of the Renewable Fuel Program (RFS) authorized by the Energy Policy Act of 2005 (Energy Policy Act of 2005, P.L. 109-58) to the new Renewable Fuel Standard (RFS2) program. RFS2 is aimed at the challenging goal of expanding the production and use of liquid fuels that can replace petroleum fuels used in transport. First generation biofuel such as corn-grain ethanol production has been successful, reaching approximately 15 billion gallons by 2015 due to stable and consistent policies [15]. Second generation biofuels such as cellulosic ethanol, however, face challenges due to policy uncertainty. This uncertainty is mostly reflected in volumetric requirement obligations set by the EPA [16,19]. As of early 2016, about a dozen companies are producing or proposing to produce cellulosic biofuels. In addition to policy uncertainty, cellulosic ethanol production also faces challenges from feedstock availability, cost, and various environmental and societal constraints (Chen et al., 2016). Among other cellulosic biofuels, particularly interesting are drop-in biofuels that are compatible with the existing vehicle, distribution and retail infrastructure and are ready to use in vehicles without upgrading or blending with other fuels. This technological breakthrough can develop cost-effective conversion pathways and lead to a commercial production of next-generation biofuels from woody biomass [31,51].

As highlighted by previous assessments [15,20,55] cellulosic biofuels including drop-in fuel are not commercially produced due in part to the inadequate supply of cellulosic feedstock such as woody biomass. The US Northeast region[1] and particularly the State of Maine has great potential to produce cellulosic biofuels. Northeast states including Maine can produce significant amounts of advanced biofuels due to their high forestland coverage [19]. Furthermore, potential sustainable production in the Northeast alone can account for a large share of the goal for nation-wide cellulosic ethanol production mandated by the U.S. Congress.

One of the overarching goals of drop-in biofuel is to reduce greenhouse gas emissions and high dependence on imported petroleum by developing renewable energy from domestic feedstock. But an important question arises to this end – i.e., can forest-based drop-in biofuel meet these expected goals while maintaining the socio-economic and environmental integrity? If this fuel is to be produced as part of a transition toward a sustainable energy pathway, then what is the current status of policies that guide biofuel production, and what are the consequences of commercial drop-in biofuel production for the economy, society and environment? The answers to these questions largely hinge on the policies formulated to regulate and evaluate biofuel production. While the U.S. Department of Energy (USDOE) and

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[1] The Northeast includes the following states: NY, ME, PA, WV, OH, NH, VT, MA, MD, NJ, CT, DE and RI.

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Department of Agriculture (USDA) continuously investigate possibilities to make biofuels economically, socially and environmentally sustainable, these organizations regularly formulate and update policies to guide biofuel production [17,61,62].

A fundamental requirement to achieving sustainable production of forest-based drop-in biofuel is to evaluate current drop-in biofuel production processes and associated policies and improve them as needed. It is essential to design policies that overcome technological barriers and address social, economic and environmental challenges in parallel [28]. These challenges include constraints imposed by production costs, feedstock availability, and economic benefits including subsidies, social values, and ecosystem and biodiversity impacts. Responding to these challenges effectively requires analyzing policies that directly or indirectly affect biofuels production. Biofuels produced from forest biomass face conflicting definitions of renewable biomass that adversely impact the viability of biofuel production in Maine's and other northeastern forests despite a long history of using those same forests for pulp and paper production. Previous studies have provided overview of RFS [20,53,57] and assessed the challenges linked with implementation of RFS [15,20,49,66]. To our knowledge no previous study has looked into the definitions and terminology within this policy which has long-term impact on development of biofuels industry.

In this study, we review the current status of RFS policy and its environmental and economic implications, with focus on drop-in biofuels produced from woody biomass in Maine and the Northeast. We provide an evidence-based provision to be included in revised RFS regulations. Our proposal in revising the definition of 'biomass' in current RFS policy provides a consistent and sustainability driven approach that will allow the biofuels industry to overcome the biomass availability challenge while maintaining the forest diversity, soil and water quality. We pose the following research questions:

1. What is the current status of RFS policy and what are potential challenges in implementing this policy?
2. What is the potential of drop-in biofuel from forest biomass in the state of Maine and the Northeast?
3. What are the broader environmental, economic and social implications of drop-in biofuel production, in particular looking at RFS policy and forest biomass availability, in Maine and the Northeast?

The analysis begins by reviewing the current status of RFS policy, then the paper provides a review of drop-in biofuel production technologies with focus on how these technologies can be relevant to ongoing renewable bioenergy production. The paper then discusses an important flaw in the definition of renewable biomass in RFS. This discussion provides evidence based metrics in the context of Maine that support our argument for potential revision of the current biomass definition in RFS.

2. Renewable fuel standard

The Renewable Fuel Standard (RFS) is a program developed by the Environmental Protection Agency (EPA) to comply with the Clean Air Act and the Energy Policy Act of 2005. The RFS mandated the production of 7.5 billion gallons of biofuels by 2012, with an incremental production over subsequent years [22,53]. In 2007, under the EISA, the RFS was updated, which increased mandated biofuel volumes and extended targets to the year 2022. These revised mandates – referred to as RFS2 – required the annual use of 36 billion gallons of biofuel by 2022, with at least 16 billion gallons coming from cellulosic feedstocks [23].

RFS2 recognizes four types of biofuels, each with its own per-year production requirement (Table 1). The categories include: (1) advanced biofuels; (2) biomass-based diesel; (3) cellulosic biofuels; and (4) total renewable fuels. Further, biofuels qualifying under each category must achieve a certain minimum threshold of life cycle greenhouse gas (GHG) emissions reductions compared to the petroleum baseline (Table 1). These biofuels should be produced from feedstocks that meet the EPA's definitions of renewable biomass.

The total renewable fuel is the combination of the first three biofuel types and corn-starch based biofuel. As is seen in Table 1, most biofuel produced in the U.S. is still ethanol derived from corn (i.e., total renewable minus other fuel categories). The contribution of cellulosic ethanol in the total volume of biofuels is still quite limited (about 700,000 gallons out of 14.3 billion gallons produced in 2014 [23]. The production of corn-starch based biofuel is capped at 15 billion gallons/year after 2015, and focus thereafter is directed toward cellulose-based biofuels.

Pursuant to RFS2, the EPA is required to set cellulosic biofuels standards for every year that it estimates commercially available quantities will be less than the targets set in the statute. Due to a lack of US production, the EPA lowered the cellulosic, biomass-based diesel and advanced biofuel standards from 2010 through 2017 below statutory targets (see Table 1) [10,25]. The most recent targets, 2015–2016 (and 2017 for biodiesel) represent progress over historic levels given the lowered actual target levels. The standard for advanced biofuel mandated volume at 3.61 billion gallons is nearly 1 billion gallons greater than the 2014 standard of 2.67 billion gallons. The 2016 cellulosic biofuel requirement rises from 123 million gallons in 2015 to 230 million gallons in 2016. By statute, however, the 2016 standard for advanced biofuels and cellulosic biofuels was set at 7.25 and 4.25 billion gallons. The difference between statutorily set volumes and final yearly required volumes have been met with EPA created waiver credits whose prices are set based on statute but vary with the price of gasoline [27].

The ramp-up in the required cellulosic fuel volumes by the EPA has been limited by a number of factors including technical costs and challenges of producing cellulosic biofuels, access to financing, uncertainty in the way that EPA sets future volume standards, and the uncertainty in approved feedstocks. The relatively low cellulosic waiver price and the low prices of petro-gasoline and petro-diesel fuels also are major barriers to expanding the cellulosic fuel industry.

Under RFS2, the EPA assigns petroleum importers and refiners called "obligated parties" a Renewable Identification Number (RIN) for every gallon of biofuel produced. These RINs can be separated from the renewable fuel and bought and sold by the parties. The RINs are used by obligated parties as a means of demonstrating compliance with their renewable volume obligations.[2] Importantly, RIN credits provide an additional source of market value to producers of renewable fuels beyond the value of the fuels themselves used for combustion.

RIN market values are determined by their supply and the need of petroleum fuel suppliers and importers to have RIN credits to demonstrate compliance with RFS2. RIN prices can vary greatly depending on complex market interactions that involve petroleum fuel markets, tax incentives for biofuels, expectations of RIN availability, and EPA's actions to set future advanced biofuel volume targets [52]. The price of corn ethanol RIN credits ranged between $0.01 per gallon to $0.05 per gallon, whereas biodiesel RIN prices ranged between $1.00 and $1.50 in 2013 [21]. RIN prices of cellulosic biofuel RIN were between $0.38 and $0.46 in September of 2015 [48].

3. Drop-In Fuels

The 2016 volume of traditional corn (starch)-based ethanol was lowered in 2016 to 14.5 billion gallons from its statutory level of 15 billion gallons. This reduction reflects recognition of the declining sales

[2] The law allows for some exemptions. Producers of less than 10,000 gallons per year are not required to participate. Similarly, new producers who make less than 125,000 gallons per year and are in their first three years of operation are also exempt from RIN compliance. The intention of this exemption is to allow pilot or demonstration plants to focus on developing the technology [22,54].

Table 1
EISA renewable fuel requirements [24].

	Biofuel types and production mandates				
	Total renewable	Cellulosic-based	Biomass-based	Advanced	RIN Price (cellulosic ethanol)
GHG Reduction[b]	20%	60%	50%	50%	
Year	Billions of gallons, numbers in parentheses represent revised mandates.				Dollars per RIN credit
2008	9.00	NA	NA	NA	NA
2009	11.10	Na	0.50	0.60	NA
2010	12.95	0.10	0.65	0.95	1.56
2011	13.95	0.25 (0.0065)	0.80	1.35	1.13
2012	15.20	0.50 (0.006)	1.00	2.00	0.78
2013	16.55	1.00 (0[c])	1.28	2.75	0.42
2014	18.15 (15.93)	1.75 (0.0008[d])	1.63	3.75 (2.68)	0.49
2015	20.50 (16.3)	3.00 (0.033)	1.70[a]	5.50 (2.9)	0.64
2016	22.25 (17.4)	4.25 (0.106)	1.80[a]	7.25 (3.4)	a
2017	24.00	5.50 (0.206)	1.90[a]	9.00	a
2018	26.00	7.00 (a)	a	11.00	a
2019	28.00	8.50 (a)	a	13.00	a
2020	30.00	10.50 (a)	a	15.00	a
2021	33.00	13.50 (a)	a	18.00	a
2022	36.00	16.00 (a)	a	21.00	a

NA refers to data not available; all volumes are ethanol-equivalent, except biomass-based diesel which is actual.
[a] Proposed volume requirement. a = EPA will propose in the future.
[b] GHG emission reductions relative to petroleum baseline.
[c] In a January 2013 decision, the D.C. Circuit Court vacated the 2013 cellulosic standard.
[d] EPA reduced the 2013 cellulosic standard in the Direct Final Rule in April 2014.

of gasoline and, therefore, a reduced ability to blend ethanol with petro-gasoline. Significantly, however, the total volume requirements are now designated to go beyond the blend wall. The blend-wall reflects the limit to the use of 10% ethanol in gasoline given the existing vehicle and retail infrastructure. That is, the mandated volume of ethanol will be 10.10% of the volume of gasoline sold in the U.S. EPA [26]. This requires greater use of flexible fuel vehicles and fuel retail facilities that can dispense ethanol in higher blends.

Going beyond blending additional ethanol or biodiesel into petroleum fuels will require the continued development of “drop-in” renewable fuels, which can be used directly in the vehicles, and are substantially similar to gasoline, diesel and jet fuels. One of the major benefits of drop-in fuel over other biofuels (e.g., ethanol, biodiesel) is that it can be ready to ‘drop-in’ to existing petroleum transportation and distribution networks as well as without modification of vehicles. This addresses the infrastructure compatibility issue which is considered a major barrier to fast commercialization of biofuels like ethanol and biodiesel [51]. Furthermore, this overcomes the transportation and distribution limitation of ethanol.

While there are nearly 15 running commercial plants that produce cellulosic ethanol from various feedstocks in the US [5], drop-in fuels, however, are still in their early phase of development. A number of studies have been carried out to convert biomass into drop-in fuels, and research has rapidly grown in recent years (see Table 2). Pyrolysis and catalyst development/upgrading are among the cross-cutting technologies researched thus far for drop-in biofuel production [65]. Pyrolysis oil (bio-oil), unlike crude oil, contains a significant amount of oxygenated compounds before being upgraded to a drop-in fuel. Oxygenated pyrolysis (bio) oil compounds are unstable, and thus the oxygen must be released to make oil compatible with existing petroleum infrastructure. Several approaches have been explored to deoxygenate and dehydrate oil including catalytic pyrolysis [12], hydrotreating-hydrocracking [32,35,64], HydroDeOxygentaion [4,58], and ThermalDeOxygenation [63].

Carlson et al. [12] developed a process to produce gasoline-range aromatics from solid biomass feedstocks using a catalytic fast pyrolysis process. The “bio-oil” produced from fast pyrolysis is catalytically upgraded to drop-in fuels. The process uses zeolite catalysts in the pyrolysis process to convert oxygenated compounds generated by pyrolysis of the biomass into gasoline-range aromatics [12]. Balakrishnan et al. [4] examined a process for the flexible production of jet fuels and lubricant base oils from Brazilian sugarcane. The drop-in jet fuel conversion involves conversion of sugars in a sugarcane-derived sucrose and hemicellulose to ketones using a combination of chemical and biocatalytic processes. Boyajian et al. [8] developed a new “gas-to-liquid” technology that converts syngas to high-quality gasoline, diesel, and jet fuel through a catalytic thermochemical process. Syngas is produced by several commercially available technologies from a wide variety of feedstocks (e.g., natural gas, biomass and municipal waste). This conversion technology is proprietary and is not available publicly. The thermochemical catalytic conversion of sugars into diesel range fuels has gained momentum. Sreekumar et al. [58] developed a process to convert sugarcane into drop-in diesel range fuels. This process converts sugarcane into furfural, which is then distilled and sent for hydrogenation and aldol condensation. Finally, the product is hydrodeoxygenated to produce alkane products.

The Pacific Northwest National Laboratory (PNNL) designed a pyrolysis-based drop-in fuel production pathway using forest residues as feedstock [35]. Wright et al. [64] also examined a biomass-based fast pyrolysis pathway to produce drop-in diesel from corn stover. The drop-in diesel production design cases by Jones et al. [35] and Wright et al. [64] require a 3-stage stabilization and upgrading of bio-oil – (1) stabilization at low temperature and pressure via hydrogenation; (2) further stabilization via hydrodeoxygenation; and (3) upgrading via hydrotreating and hydrocracking.

A new drop-in fuel production pathway developed at the University of Maine uses forest residues as a feedstock to produce ThermalDeoxygenated (TDO) oil as an intermediate oil product. TDO oil is then upgraded into drop-in diesel or other similar products. In comparison to previously described processes, TDO drop-in fuel production uses hydrotreating and fractionation to upgrade oil into drop-in fuel, and requires a lower quantity of catalyst and externally supplied hydrogen for these processes as compared to pyrolysis. For details about this pathway, see Case et al. [13]. Mawhood et al. [44] reviewed six promising conversion pathways for renewable bio-jet fuels – i.e., (1) biomass to liquids or BTL; (2) hydrotreated depolymerized cellulosic jet or HDCJ; (3) alcohol to jet or ATJ; (4) fermentation to jet or FTJ; (5) aqueous phase reforming or APR; and (6) lignin to jet or LTJ. They concluded that drop-in jet production pathways vary considerably in terms of their technological and commercial maturity.

Table 2
Comparison of different pathways to produce drop-in fuels.

Components	Balkrishnan (2015)[a]	Wheeler [63]	Jones et al. (2010)	Pray [51]	Carlson et al. [12]	Wright et al. (2011)
Biomass feedstock	Sugarcane	Forest residues	Forest residues (poplar)	Sugarcane	Biomass	Corn stover
Process overview	Depolymerization/dehydration, hydrotreatment and hydrodeoxygention	Hydrolysis/dehydration, separation and neutralization, TDO, upgrading	Fast pyrolysis, hydrotreating, hydrocracking	Fermentation, separation, distillation and hydrodeoxygenation	Catalytic fast pyrolysis, hydrogen reaction	Fast pyrolysis, hydrotreating, hydrocracking
Catalysts	MgAlO and Nb2O5	Nickel	Transition metals and sulfides	"NA"	Zeolite	Transition metals and sulfides
Oxygen removal	During hyrdodeoxygentation process	During TDO process	During stabilization/ hydroprocessing	"NA"	"NA"	During stabilization/hydroprocessing
Intermediate products	Furfural and 2-methylfuran	TDO-oil	Bio-oil	Sucrose, farnesene	Bio-oil	Bio-oil
Hydrogen for upgrading	Yes	Yes (low)	Yes	Yes	Yes	Yes
Products	Jet fuel	Gasoline, diesel, heavy fuel oil, furfural, char	Gasoline and diesel, char	Farnesane, jet fuel	Gasoline range products, coke	Diesel and naptha range products, char, fuel gas
Yield	0.4 l/kg of feedstock	0.14 l[b]/kg of feedstock	0.35 l[c]/kg of feedstock	0.21–0.33 l[d]/kg of feedstock	NA	0.36 l[e]/kg of feedstock

[a] The study presents multiple pathways to produce jet fuel and lubricants. Jet fuel from hemicellulose via 2-methylfuran is presented here.
[b] Fuel density was assumed 3 kg/gal [2].
[c] Reported yield was 28% [36]. Density of fuel was assumed to be 3 kg/gal.
[d] Density of farnesene was assumed to be 3 kg/gal [14].
[e] Reported yield was 29% [36]. Density of fuel was assumed to be 3 kg/gal.

With the current pathways discovered, the overall yield for drop-in biofuel production is relatively low (between 0.14 to 0.4 liter per kg of feedstock) compared to established technologies such as corn-based ethanol production. One significant challenge remains to identify a cost-effective way to convert feedstock into drop-in fuel with competitive yields. Potentially mitigating to low fuel volume is the potential to produce biochemicals as a bioproduct of liquid fuel production. Additionally, the availability of federal renewable fuel credits (RIN credits) from EPA certified renewable fuel pathways is essential.

4. Biomass definitions

Over the last years, the concept of biomass has grown to include diverse sources such as algae, municipal solid wastes, energy crops, crop residues, and animal manure. Individually, these biomass types cannot be used as a sustainable source of fuel as they are limited in supply and are not available throughout the year [9]. Woody biomass is more promising due to continuous availability. In the state of Maine and the Northeast, woody biomass has received special attention given its widespread availability. When biomass remaining after timber harvest is used as a feedstock for biofuel production, it can generate additional jobs and value-added products. However, in order to qualify under the policy provisions in the RFS2 program, woody biomass must meet key criteria.

A significant issue is that "renewable biomass" has been defined in various ways in U.S. energy policy [9,52]. Of the many biomass definitions, two are used by policy-makers, scientists, and program managers as the most comprehensive for energy production purposes – (i) the definition in Title IX of the 2008 Farm Bill; and (ii) the definition in Title II of EISA. While these laws provide detailed definitions of renewable biomass, each differs in substantive ways which can affect the overall availability and qualification of forest-based biomass when applied to of northeastern forest that are naturally regenerating. The 2008 Farm Bill defines renewable biomass as 'materials, precommercial thinnings, or invasive species from National Forest System land and public land as defined in the Section 103 of the Federal Land Policy and Management Act of 1978 (43 U S C. 1702. In addition to various organic matters, this definition includes biomass obtained from the following activities: forest thinning materials, forest harvest slash (e.g., branches and tops), post-disaster debris, hardwood chips, softwood chips, and bark. However, it excludes as ineligible the biomass obtained from mulch, wood pulp, and other finished wood products such as lumber, pellets and paper products [60].

On the other hand, EISA's definition of renewable biomass limits the types of biomass and types of land from which the biomass may be harvested to include 'planted trees/crops and residues from agricultural and forest land cleared prior to December 19, 2007 and actively managed on that date.' In contrast to the Farm Bill definition, to be eligible for RFS under EISA, biomass cannot be harvested from federal lands and naturally regenerated forests. Furthermore, unlike the Farm Bill definition, the EISA definition makes other finished wood products such as lumber, pellets and paper products eligible. Additionally, the Farm Bill defines "renewable biomass' in a very unrestrictive way, giving permits to woody biomass regardless of whether the biomass comes from planted or natural forests, and federal or non-federal lands.

4.1. Eligible forest biomass for drop-in biofuel in Maine

The Northeast region of the U.S. has a high potential to supply biomass as the majority of this region is forested {Neupane, 2011 #107}. Dilekli and Duchin [18] reported that the Northeast region can produce up to 5.37 billion gallons of cellulosic biofuel per year from advance feedstock in the form of net forest growth and woody wastes. This volume of biofuel could displace nearly 12.5% of the gasoline that is now used in the transportation sector in the region [18].

Northeastern states have about 92 million acres of forestland, 87 million acres of which is classified as timberland [59]. Maine and New Hampshire in particular have high percentages of forestland (90% and 83%, respectively), whereas states with greater population densities are less forested (e.g., Delaware is only 31% forested). Maine and the Northeast are uniquely positioned when it comes to EISA's 2007 renewable biomass definition. In Maine, over 90% of Maine's forests are naturally regenerated [41], and the vast majority of harvest is carried out using partial harvesting methods (about 95% of total volume), whereas clearcutting comprises less than 5% [42,43]. Since most forest biomass harvested in Maine is not from planted trees, it is unclear how much of the Maine's forest biomass may qualify as renewable biomass under RFS2. EISA's forest biomass definition favors planted trees over naturally regenerated forest. According to the current EPA definition, only a very small percentage of Maine forestland would qualify as renewable biomass. However, from the current definition of forest biomass under RFS2, Maine's forest biomass would be eligible under the following clauses -

> "…Slash and pre-commercial thinning from non-federal forestlands that are neither old-growth nor listed as critically imperiled or rare by a State Natural Heritage Program"

where forestland is defined as "land that is at least 10% stocked by forest trees of any size, or land formerly having such tree cover, and is not currently developed for a non-forest use. The minimum area for classification as forestland is one acre" [45]. Slash can be defined as "the residue, e.g., treetop and branches, left on the ground after logging or accumulating as a result of a storm, fire, girdling, or de-limbing" [30].

This portion of the renewable biomass definition indicates that most of the tree tops and branches removed as a result of timber harvesting in Maine may qualify as renewable biomass under the RFS2 if the biomass qualifies as slash or as pre-commercial thinning – even if the forestland does not qualify as an actively managed tree plantation [52].

However, whole trees that could be used for pulp or other purposes, unmerchantable trees harvested via clearcut, and any product harvested from an old growth forest, a late successional forest or a forest with at risk ecology would not qualify as renewable biomass. Maine's forests have a unique position in terms of maintaining their harvest and growth ratio. Historically, the growth and harvest ratio of Maine's forests are maintained at one. Forest management activities, including commercial thinning and harvesting are carried out in a sustainable way by practicing Best Management Practices (see next section). Considering these ecological factors, Neupane [47] estimated biomass availability in Maine and concluded there are about four million dry tons of total forest biomass (including tops and branches, saplings, and rough and cull trees) that can be harvested annually from Maine's forest. Out of this total, tops and braches comprise about 27%. If only tops and branch components of biomass qualify from Maine's forest, the total RFS2 eligible biomass availability would be just 108,000 dry metric tons per year. This significantly reduces the availability of RFS2 compliant biomass in Maine. Contrary to EPA's goal to promote cellulosic biofuel production, its RFS2 eligible biomass definition limits the domestic production of biofuels from Maine's forests.

Furthermore, as found in a life cycle assessment study, the drop-in biofuel produced from Maine's forests significantly reduces the greenhouse gas emissions (by more than 75%) compared to its petroleum counterpart [47]. Similar GHG reductions are found in other life cycle studies of forest-based drop-in biofuels. For example, Han et al. [29] performed an LCA of pyrolysis-based drop-in fuel production from forest residues and found that at least 60% GHG emissions reductions compared to the petroleum fuels. Hsu [31] found at least 53% GHG emissions reductions from pyrolysis-based drop-in biofuels and subsequent hydroprocessing of forest residues. Therefore, if EPA's goal is to promote renewable fuels that replace fossil-based fuel, and if it wants to address inadequacy of cellulosic fuel production as mandated in RFS2, it should revise the current definition of biomass in favor of naturally regenerated forests such as Maine's forests.

5. Harvesting policies to maintain biodiversity, and soil and water quality

While woody biomass is a promising source of biofuel, ensuring the long-term integrity of forest ecosystems is equally crucial. Indeed, an environmentally responsible, socially acceptable and economically viable forest harvesting procedure is important for sustainable energy development.

5.1. Soil and site productivity

Forest productivity is highly dependent upon soil organic content (SOC). As a result, preserving soil quality by maintaining SOC is important [33]. A number of studies have assessed the impact of timber harvesting on soil quality. For example, Johnson and Curtis [34] found that in general, there was no clear change in soil organic content except under conditions with intense mechanical disturbance. When whole-tree harvesting was used, Paré et al. [50] and Johnson and Curtis [34] found a decline in soil nutrients. The level of soil impact, however, varied depending on soil type [39], trees species mix [33], and topography.

Benjamin et al. [7] developed guidelines for biomass harvest operations in Maine and suggested leaving more fine woody material on-site during harvest operations in order to maintain long-term soil productivity. In particular, the following these guidelines suggest: (1) except where scarification of the soil is important for regeneration, leave the litter layer, stumps, and/or roots intact to the extent possible, and (2) minimize removal of fine woody material on low-fertility sites, shallow-to-bedrock soils, coarse sandy soils, poorly drained soils, erosion-prone sites (i.e., exposed soil, longer and steeper slopes). Janowiak and Webster [33] offered a guiding principle to maintain soil quality during harvest. The principles include: increase forested land where feasible, adapt management to site conditions, evaluate the role of fertilization and wood ash recycling, and retain organic legacies for soil productivity. Maine's Best Management Practices (BMPs) suggest minimizing disturbance of the forest floor during harvest, and stabilizing areas of exposed soil to prevent soil from eroding post-harvest [39].

In general, soil quality can be maintained only when the approaches discussed above are used to retain soil organic content and increase nutrient availability. Specific guidelines may vary depending on site conditions. For forest-based drop-in fuels in Maine, it is imperative to follow Maine's BMPs [39] and the guidelines proposed by Benjamin et al. [7]. Given that these guidelines and best practices are followed, we believe that forest lands can be sustainably managed to provide feedstock material for biofuel and biochemical production.

5.2. Water quality and best management practices

BMPs contain a wide range of techniques that can be used pre-harvest, during harvesting, and after harvest operations in order to preserve water and soil quality, as well as forest biodiversity. BMPs are recommended procedures that, when used appropriately, result in the greatest protection of the environment over the course of the operations [39]. These recommendations have been established across the country to serve as guidelines to protect soils, water quality, and overall forest ecosystem health. The State of Maine developed BMPs in 2005 to provide guidelines for loggers, foresters, landowners and other stakeholders to plan forest operations that minimize adverse impacts on forest soils, water quality, and biodiversity. BMPs provide specific plans for various types of equipment, material and experience across a range of situations, including site factors such as terrain, slope, soil type, and forest type.

BMPs protect shoreland vegetation, maintain the natural flow of water in streams and wetlands, and minimize the risk of sediment and other pollutants getting into water bodies [39]. Impacts of BMPs have been noticeable in Maine. An effectiveness of BMPs was assessed by the Maine Forest Service, which found that lake sedimentation results were improved by 4% between 2005 and 2008 [40].

Technically speaking, most BMPs are voluntary guidelines, but in some situations – depending on the site and location – state laws may make them mandatory [39]. Aust and Blinn [3] reviewed BMP water quality recommendations across a number of states and summarized their findings as follows – (i) careful planning and construction of roads; (ii) minimization of exposed soil; (iii) quick re-vegetation; and (iv) maintenance of buffers adjacent to streams. In Maine, forest harvesting operations typically follow the State's BMPs. These guidelines, important today, are of even greater consequence under future scenarios that envision higher demands for biomass.

6. Public participation

Increased use of biomass for energy has caught the attention of many stakeholders. Along the biofuel supply chain, primary stakeholders include forest landowners, loggers and truckers, and processors. These stakeholders potentially have different views and interests in forest biomass harvesting [6,38]. Unlike other companies and government agencies that have a hierarchical structure for decision-making, the first stage of biomass production involves many decision-makers – i.e., landowners. The multi-faceted nature of landowner involvement suggests the need to better understand decision-making processes and reactions to policy [37].

Maine' forestlands are owned both publicly and privately. The public owns roughly 6% of the total forestland, whereas the rest has private ownership. The large portion of public forestlands includes state parks, state wildlife management areas and public reserve lands. The private ownership includes: non-industrial private landowners, industrial landowners, large non-industrial landowners, and investment companies. The industrial landowners include paper mills, sawmills and other wood processing facilities, which own about 28% of the forestland. MTF [46].

In Maine, non-industrial private forest landowners – also known as NIPFs or family forest owners – comprise an estimated 100,000 individuals and own about 30% of forest land [11] while they produce 50–60% of all harvested timber [1]. Understanding NIPF's intent to harvest wood for bioenergy, along with the factors that influence these intentions, would improve the efforts of policy-makers, loggers, and processors. Silver et al. [56] studied how NIPF landowner values affected attitudes and willingness to harvest biomass from their land. They found that 63% of private landowner respondents expressed a willingness to supply wood fiber for biomass, but reported that a large number of landowners are unsure about the desirability of harvesting biomass for energy.

Views of forest managers, loggers and landowners to adopt BMPs and knowledge about woody biomass for bioenergy generation are crucial in determining the development of biofuel industry. Effective implementation of regulations and voluntary guidelines such as BMPs rely on public acceptance of these policies. Without support, it is difficult to execute programs designed to minimize detrimental impacts to forest ecosystems. Benjamin et al. [6] argue that given this need for public support, efforts are needed to understand and quickly respond to forestry sector stakeholder concerns as they emerge.

7. Final remarks and paths forward

The key to success for the biofuels industry relies on the policies formulated that nurture and guide the industry. In the short-term, such policies should be designed to promote biofuels by assuring resource availability, efficient harvesting mechanisms, and clear and consistent terminology within regulations. Over the long-term, policies should guide the industry towards assuring overall system sustainability. The EPA's current definition of “renewable biomass” is unclear, especially in the case of naturally regenerated forest biomass such as that typically found in Maine and other states. In contradiction to EPA's goal to promote renewable fuel, it is limiting the domestic supply of forest-based biofuel in Maine through its current definition under RFS2.

Considering the unique nature and forest management practices in Maine, the EPA and Congress should consider revising this RFS2 definition to allow more naturally regenerating forests lands to qualify as renewable biomass. If feedstock constraints are relaxed by the introduction of the biomass definition we propose in this study, a significant increase in potential biofuel production can be expected. Though drop-in biofuels are a promising next generation fuel, efficient conversion technologies with higher fuel yield and subsequent lower production cost are key to commercial production of these fuels.

Further research is needed to assess the large-scale deployment of forest-based drop-in biofuel, including its effects on land use, biodiversity and hydrology. In this regard, BMP guidelines can be adapted to preserve soil and water quality and maintain the forest biodiversity. Moving forward, biofuels policies should be designed to promote biofuels by assuring resource availability, efficient harvesting mechanisms, and clear and consistent terminology within regulations.

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