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EFFECTIVE POLICY DESIGN FOR PROMOTING INVESTMENT IN ADVANCED ALTERNATIVE FUELS

Kristine Bitnere and Stephanie Searle

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

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International Council on Clean Transportation
1225 I Street NW, Suite 900
Washington DC 20005 USA

communications@theicct.org | www.theicct.org | @TheICCT

PREFACE BY THE EUROPEAN CLIMATE FOUNDATION

In December 2015, world leaders agreed to a new deal for tackling the risks of climate change. Countries now need to develop strategies for meeting their commitments under the Paris Agreement, largely via efforts to limit deforestation and to reduce the carbon intensity of their economies. In Europe, these climate-protection strategies will be developed via the European Union's (EU's) 2030 climate and energy framework, with a view to ensuring an integrated single market for emissions-reduction technologies.

Existing EU energy policy for 2020 foresees an important role for bioenergy as a means of reducing carbon emissions from heating, power, and transport, and yet there are concerns that this has led to a number of negative consequences related to the intensification of resource use. If bioenergy is to continue to play a role in EU energy strategies for 2030, it seems wise to learn from the past to ensure that this is done in a manner that is consistent with the EU's environmental goals, including the objective of limiting temperature rise to no more than 2°C.

With this in mind, the European Climate Foundation (ECF) has convened the BioFrontiers platform, bringing together stakeholders from industry and civil society to explore the conditions and boundaries under which supply chains for advanced biofuels for transport might be developed in a sustainable manner. This builds on work developed in the ECF's Wasted platform in 2013–2014, which focused on waste- and residue-based feedstocks for advanced biofuels. This time around, there is an additional focus on considering land-using feedstocks and novel fuel technologies.

As the name BioFrontiers suggests, this discussion enters new territory and is faced with numerous gaps in knowledge. To facilitate a transparent and constructive debate between industry and civil society, the ECF has commissioned a number of studies to help fill such knowledge gaps. This is one such study. It does not represent the views of the members of the BioFrontiers platform; it is merely an input to their discussions. If this research also helps inform the wider debate on the sustainability of bioenergy, that is a bonus.

Pete Harrison
Programme Director, Transport
European Climate Foundation

EXECUTIVE SUMMARY

Low-carbon fuels produced from non-food feedstocks have the potential to deliver deep greenhouse gas (GHG) reductions in transport fuels, but their commercialization has been slow despite a decade of policy support across the European Union (EU) and United States (U.S.). Policies in both the EU and U.S. envision a transition over time from first-generation, food-based biofuels to alternative fuels using non-food feedstocks and emerging technologies that offer greater GHG savings. In this study, we consider these alternative fuels under the umbrella term *advanced alternative fuel* (AAF). AAF includes technologies such as cellulosic ethanol, biomass gasification, and pyrolysis. The transition to AAF has been regarded as a key element in achieving climate goals over the next decade or two. It is clear that the AAF industry has faced challenges in scaling up from successful laboratory- and pilot-scale facilities to commercial production, and these barriers must be addressed to realize a transformation of the alternative fuel supply in the EU and U.S.

The EU and U.S., as well as other countries including Canada, are currently developing plans for biofuel policies for the decade from 2020 to 2030. All of these jurisdictions have something to learn from the combined policy experience of the past decade, and they can improve the effectiveness of biofuel policy in fostering a transition to lower GHG fuels.

This study seeks to understand why the past decade of alternative fuel policies has not led to commercialization of AAF and how we can apply lessons learned to developing proposals for fuel policy over the coming decade. First, we discuss key economic barriers that impede the commercialization of AAF. We then review existing and past policies in the EU and U.S. that have promoted AAF and assess the effectiveness of these policies in improving the economic viability of AAF projects and leading to actual AAF production.

By comparing the experiences in different jurisdictions, we identify elements of alternative fuel policy that are most successful at addressing the key barriers for AAF commercialization, as well as elements that have reduced the effectiveness of policies in supporting AAF. We conclude with principles for policy design to provide effective support for AAF. Although many studies have commented on the slow pace of AAF commercialization, to the best of our knowledge none have analyzed the role of policy in contributing to that outcome across these jurisdictions.

AAF generally relies on complex technologies with unique challenges compared to first-generation biofuels. In particular, AAF facilities typically have much higher capital costs than do first-generation biofuel plants. Although lower feedstock costs in some cases can offset the higher capital costs over the long run, attracting sufficient investment to fund facility construction can be difficult for new AAF companies. Because capital costs are so high, more years of operation and profit are required to pay a return on investment for AAF facilities compared to those for first-generation biofuels. Thus, the first lesson learned in our analysis of policy experience is that guaranteed long-term policy support is necessary to provide certainty that AAF investors will achieve a return on investment. Policies in the U.S., both at the federal level and in the state of California, provide greater long-term support for AAF than first-generation technologies. In contrast, the EU first introduced specific incentives for AAF in 2015 for a policy target in 2020, providing only 5 years of support. As a result of this and other factors, the U.S. has greater AAF capacity, especially for cellulosic ethanol, than does the EU.

Another key lesson learned from our analysis is that effective AAF support requires dedicated targets and incentives, separate from support measures for first-generation technologies. The EU introduced biofuel targets in 2009; several member states began providing incentives for biofuels prior to that year, but these measures universally applied equal treatment to AAF as first-generation biofuels. Prior to 2015, the EU provided no incentive for the use of AAF over first-generation biofuels, and since first generation biofuels have lower technology risks and much lower capital costs, they have been the primary compliance option for biofuel mandates compared to AAF.

Sustainability challenges have had a surprisingly large impact on public confidence in EU biofuels policy, affecting both food-based biofuels and AAF. The EU postponed proposing measures to address the impact of indirect land use change (ILUC) on the full lifecycle greenhouse gas emissions of biofuel pathways. As a result, a long and contentious legislative debate about ILUC measures introduced high uncertainty about the future direction of EU policy, including support for AAF. In contrast, the U.S. and California addressed ILUC accounting when biofuel policies in these jurisdictions were first introduced, and they have consistently provided a signal of stronger support for lower GHG pathways with relatively little controversy. Dealing with sustainability challenges at the beginning of biofuel programs, to the extent possible, is important to protecting policy stability in future years.

A few other policy elements identified in our analysis can have a substantial impact on the effectiveness of AAF support. Supporting offtake, either through government procurement contracts or blending mandates, can strengthen the certainty for AAF companies that there will be a market for their product. An example is the government offtake agreement with Gruppo Mossi Ghisolfi in Italy, leading to the first successful commercial-scale cellulosic ethanol plant in Europe. Cost containment is a necessary element for many policies to prevent a biofuel mandate from imposing an undue burden on obligated parties and consumers, but it must be carefully designed to allow adequate support for AAF development. The cellulosic waiver credit in the U.S. is an example of a cost ceiling that was set too low and thus limits the effectiveness of U.S. federal policy in driving the blending of AAF. California's cost-containment mechanism allows for a higher ceiling that was determined through a stakeholder process, providing a stronger signal for AAF in that market.

AAF is incentivized by a variety of policy frameworks in different jurisdictions, including blending or GHG targets, tax incentives, or government grants. There is no single ideal policy design, and the framework used depends on other policies in place and the market conditions of each country or region. The lessons learned from the past decade of policy experience that we identify and analyze in this study can help inform the design of many policy types that may be implemented in the future. Table 1 provides a summary of these key policy design principles identified with specific recommendations for how they could be applied in various AAF policy frameworks.

Table 1. Principles for effective AAF support in various policy frameworks

Policy design principle	Renewable energy Mandate	GHG reduction Target	Price guarantee	Fuel tax reduction/ production tax credit	Investment tax credit	Grants and loan guarantees
Long-term support	Binding mandate for at least 10 years		Contracts for at least 10 years	Duration of at least 10 years	Duration of at least 5 years	N/A
Avoid competition with first-generation biofuels	Separate target for AAF		Dedicated fund for AAF			
Deal with sustainability up front	Accounting for indirect emissions and other environmental concerns in policy design		Eligibility restriction to sustainable fuels			
Support offtake	Requirement for fuel suppliers to supply/blend fuel		Government offtake contracts			
Cost containment	Credit price ceiling and potentially floor		Maximum reimbursement	Tax credit phase out after certain volume achieved		Set amount of funding available

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INTRODUCTION

The transportation sector is one of the largest contributors to global greenhouse gas (GHG) emissions. Several countries have promoted biofuels as a key strategy in decarbonizing the transport sector, along with other measures, such as efficiency improvements and electrification. Within biofuel support, the EU and U.S. have indicated that a transition to advanced biofuels produced from non-food feedstocks is necessary to achieve deep decarbonization because these pathways can deliver greater GHG reductions compared to first-generation, food-based biofuels. The focus on advanced biofuels has increased particularly in the European Union (EU) because of concerns around indirect land use change (ILUC) caused by food-based biofuels (EC, 2012, EC, 2016a). In 2015, the European Commission (EC) proposed the gradual phase out of food-based biofuels and replacement by advanced biofuels, such as cellulosic biofuel, and other low-carbon alternative fuels, including renewable power-to-liquids and waste-based fossil fuels (EC, 2015). However, at present, few commercial-scale advanced biofuel and other low-carbon alternative fuel facilities are in production.

This study seeks to understand why policy support for these advanced technologies has not resulted in greater deployment of facilities and scale-up in production. For the purpose of this study, we focus on alternative fuels, including both biofuels and non-biological low-carbon pathways, that rely on emerging technologies and non-food feedstocks and that can offer high GHG savings compared to petroleum; we refer to these pathways as advanced alternative fuel (AAF).

The first section of this report briefly reviews barriers to commercialization of AAF, in particular economic and market challenges. The second section reviews existing EU and U.S. policies promoting AAF and evaluates the effectiveness of policy elements in scaling up production capacity. We analyze a number of policy frameworks, including renewable energy targets, GHG emission reduction targets, tax incentives, subsidies, and grant programs at the EU level and in member states, and at the U.S. federal level as well as in the state of California. The third section summarizes and discusses the lessons learned from the experiences of these jurisdictions in promoting AAF. The fourth section introduces principles for effective policy design for supporting investment in AAF production developed from these lessons learned.

ECONOMIC CHALLENGES FOR ADVANCED ALTERNATIVE FUEL (AAF)

AAF technologies have developed substantially over the past 1–2 decades as various government jurisdictions have actively supported research and development (R&D). Several pathways have been demonstrated (EC, 2016b). However, commercial deployment of AAF production technologies at large scale has been slow because of a number of barriers, including financial, economic, regulatory, and scale-up challenges.

AAF technologies differ from those used to produce conventional biofuels, mainly because of the feedstocks used. AAF is typically produced from waste, residues, and energy crops, which require more complex processes to convert to fuel. For example, feedstocks high in starch and sugar, such as corn or sugar beets, can be easily fermented to produce ethanol. The lignocellulose in feedstocks such as corn stover, on the other hand, must first be converted to sugar through hydrolysis before fermentation (Wyman, 1999). Pyrolysis is used to produce drop-in diesel and gasoline from lignocellulosic wastes and residues via thermochemical processing in the absence of oxygen. The process creates bio-oil that must further be refined into transport fuel (Furimsky, 2013). Fischer-Tropsch diesel synthesis includes feedstock gasification, gas cleaning and processing, and catalytic conversion into liquid (Tijmensen, Faaij, Hamelinck, & van Hardeveld, 2002).

Although these technologies have been developed and used to produce fuel at demonstration scale, the design and construction of commercial-scale production facilities has lagged behind. A key factor is that such facilities require much higher capital investment (CAPEX) compared to first-generation biofuel plants (Peters, Alberici, & Passmore, 2015). Operation costs (OPEX) of AAF on a per-gallon basis are typically lower than costs for first-generation biofuels because of lower feedstock prices, but they may still be significant because of the chemicals (enzymes, catalysts) required for AAF production (Peters et al., 2015). Figure 1 shows illustrative CAPEX and OPEX for a variety of first- and second-generation biofuel conversion technologies using data from the UK Transport Energy Task Force (2015). It is important to note that feedstock prices could increase if demand for AAF rises. Although some studies estimate that AAF could be cost competitive with petroleum when fully commercialized and produced at nth-of-a-kind facilities, at present AAF is likely substantially more expensive to produce (Pavlenko, Searle, Malins, & El Takriti, 2016). Even at nth-of-a-kind facilities, the time required to achieve a return on investment is expected to be around 8 to 20 years (Peters et al., 2015).

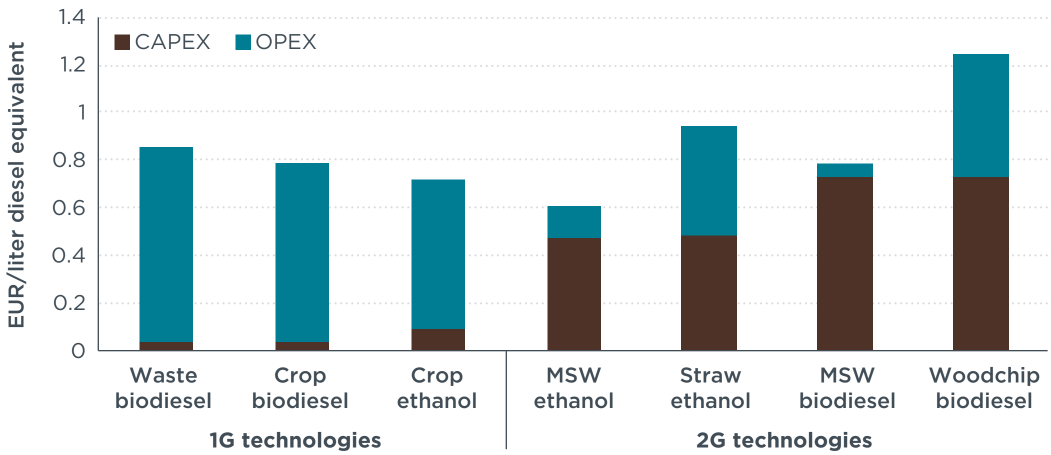

Figure 1. Illustrative capital and operating expenses for first- and second-generation biofuel-conversion technologies. Data from the Low Carbon Vehicle Partnership (2015).

High capital costs, poor historic performance, and the long period required to realize a return on investment have all contributed to the slow commercialization of AAF technologies. Funding for AAF facilities is sourced from governments, private company funds, large corporations, and investment banks (Peters et al., 2015). Non-private funding requires interest rate payments that accumulate during the years of construction and ramp up, before the facility is operating at scale. Investors must have some degree of confidence that the lifetime profit from these projects will be sufficient to repay these loans in order to finance them. While AAF production costs are currently higher than the market price for transport fuel, policy support is necessary to support competitive pricing. Investors must be able to expect policy support to be stable over a timeframe that is long enough to realize a return on investment.

Table 2 summarizes the technical and economic challenges for the commercialization of AAF, focusing mostly on the economic barriers to financing AAF projects. These challenges occur in scaling up production, in supplying AAF at commercial-scale facilities, and in selling fuel in the market.

Table 2. Technical and economic factors affecting AAF commercialization

	Factors affecting AAF industry	Description
R&D and Demonstration		Technical challenges in scaling up production from laboratory- or pilot-scale to commercial-scale facilities
Supply	**Capital costs**	High and upfront
	Interest rate	Difficult to pay due to long construction and ramp-up times
	Feedstock costs	Variable
	Feedstock supply	Difficult to ensure a stable supply chain
	Other input costs (catalysts, enzymes, etc.)	Variable
Price	**AAF price**	Uncompetitive compared to fossil fuel and food-based biofuel prices
	Fossil fuel prices	Variable fuel prices contribute to uncertainty
Demand		Lack of strong and long-term demand given current and expected production prices

Because of these technological and economic barriers, AAF does not have a natural competitive advantage in the marketplace. The demand and competitive advantage of AAF largely depends on policy drivers. It is clear that policy tools, such as GHG reduction targets, AAF blending targets, and fiscal measures, are currently necessary to support AAF production.

POLICY EXPERIENCE IN PROMOTING ADVANCED ALTERNATIVE FUELS

Some jurisdictions have been promoting renewable fuels, including AAF, since the early 2000s. This section reviews the experience and lessons learned from AAF policy implementation in the EU and select member states (i.e., Finland, France, the Netherlands, Sweden, and the UK), as well as in the U.S. and in the state of California. We assess effectiveness based on how well policies improve the financial viability of AAF projects, and generally on actual AAF production in various jurisdictions.

EUROPEAN UNION

This section reviews the policy measures that have been applied at the EU level to promote the production and demand for AAF. The next section will review how the EU-level policies and other measures have been implemented at the member state level for select countries. The EU policy framework for AAF promotion is based on a set of legislative acts requiring member states to fulfill certain policy goals as indicated:

1. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/ EC and 2003/30/EC (Renewable Energy Directive, RED) (European Parliament and Council of the European Union, 2009a)
    - 10% renewable energy share target to be achieved by 2020 starting from 2009
    - A 7% cap on the share of biofuels produced from food and other land-based crops that can be counted toward the 10% renewable energy share
    - Double counting of biofuels produced from non-food feedstocks and used cooking oil and animal fat
    - 0.5% flexible target for AAF excluding fuels produced from used cooking oil and animal fat (introduced by the Directive [EU] 2015/1513 [European Parliament & Council of the European Union, 2015])
2. Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC (Fuel Quality Directive, FQD) (European Parliament and Council of the European Union, 2009b)
    - 6% lifecycle GHG emission-reduction target from energy used in transportation sector to be achieved by 2020 starting from 2009
3. State aid for environmental protection and energy (Energy Taxation Directive; Official Journal of the European Union, 2003)
    - Excise duty reduction/exemption upon the European Commission's approval
    - Direct subsidies to biofuels plants
4. FP7, Horizon 2020, NER 300 (European Commission, 2015; 2017a)
    - EU direct grant program for demonstration of AAF technologies at large scale

With the exception of the EU grant program, member states are required to implement these measures with supporting action at the national level.

Renewable Energy Directive

In 2003, the EU introduced an indicative 5.75% share target for biofuels in the transportation sector to be achieved by 2010 (European Parliament & Council of the European Union, 2003). The share was not met, in part because the target was not mandatory (European Commission, 2013).

In 2009, the EU approved the RED, setting a mandatory 10% renewable energy share target for energy consumed by transportation to be achieved by 2020. Member states are obligated to fulfil the target. Fuel eligibility requirements include sustainability criteria to prevent the use of land with high biodiversity and carbon stock, as well as a requirement that lifecycle GHG emissions savings cannot exceed a certain threshold. Many first-generation biofuel pathways qualify toward the target since GHG emissions from ILUC are not accounted for in the RED.

The RED allowed member states to double count biofuels produced from non-food feedstocks (using both first- and second-generation technologies) toward the 10% renewable energy share target. This measure aims to create a competitive advantage for feedstocks assumed to deliver higher GHG emission savings than food-based biofuels. Otherwise, there is no additional incentive for pathways that deliver GHG savings above the required threshold.

Double counting has been implemented in most member states, including the Netherlands and the UK, and it has been very effective in promoting the use of used cooking oil and animal fat, which have constituted 57% (Department for Transport, 2016) and 71% (Werther, 2017) of all feedstocks used for RED compliance so far, respectively. These feedstocks are typically processed into biodiesel using first-generation technology similar to that used for food-based biodiesel with low capital costs. There has been little production of AAF using energy crops, agriculture and forestry residues, and waste in these countries.

When the RED was approved in 2009, ILUC accounting was not included. Instead, the RED required the European Commission to study the issue and later propose a solution for addressing concerns around ILUC. The Commission commissioned a study that found that first-generation biodiesel pathways are associated with high ILUC emissions and thus do not contribute to the RED's GHG reduction goals (Laborde, 2011). The Commission later introduced a proposal to account for ILUC in the RED and FQD, using the results from Laborde (2011) (European Commission, 2010; 2012). By this time, the food-based biofuel industry had already ramped up production considerably and lobbied strongly against the proposal. The proposal led to a prolonged public debate about ILUC and the role of food-based biofuels in EU renewable fuel policy that did not conclude until an amendment to the RED was finally passed in 2015. The final amendment that was passed, commonly referred to as "the ILUC Directive," did not include ILUC accounting and instead introduced the following measures to reduce ILUC impacts from food-based biofuels:

- 7% cap on biofuels produced from food- or other land-based crops in 2020;
- 0.5% non-binding mandate for cellulosic and other advanced biofuels sourced from non-food feedstocks (AAF) excluding first-generation technologies, such as waste biodiesel (European Parliament and Council of the European Union, 2015).

This amendment also introduced reporting of ILUC emissions, but not accounting of ILUC when assessing the GHG performance of biofuel pathways against the required GHG savings threshold in the RED. For installations in operation at the time the RED was introduced, the threshold started at 35% and increases to 50% in 2018. For new installations beginning operation in 2015 or later, the GHG threshold is 60%. Thus, food-based biofuels may still qualify under the GHG reduction threshold if they offer relatively high direct carbon savings from feedstock and fuel production, process, and transport. If ILUC accounting had been introduced, AAF would have had a somewhat stronger competitive advantage in the fuel marketplace because all food-based biodiesel pathways would have become ineligible to be used for compliance with the RED.

Member states should aim to meet the 0.5% subtarget for advanced biofuels but may set lower targets if:

» There is a limited potential for the sustainable production or production at a cost-efficient price of biofuels sourced from feedstocks listed in the RED,
» Specific technical or climatic characteristics of the local fuel market limit advanced biofuels blending possibilities, and
» Member states apply other policies (energy efficiency or electric vehicles) to reduce GHG emissions.

Member states thus have different ways for opting out of the 0.5% advanced biofuel target. The flexible nature of this mandate as well as its late introduction is unlikely to bolster public confidence in the AAF industry.

Fuel Quality Directive

In parallel to the RED, the EU approved changes to the FQD, introducing a mandatory target for fuel suppliers to reduce lifecycle GHG emissions by 6% for energy supplied for transportation in the year 2020 (Article 7a). This mandate applies directly to fuel suppliers, but member states are required to provide implementing provisions.

The 6% GHG reduction target is expected to be met largely with first-generation biofuels together with upstream emission reductions. Although the 7% cap on food-based biofuels in the RED (see above) does not apply to fuels used for compliance with FQD (member states have the option to introduce a cap on food-based biofuels in the FQD, but it is unlikely any will choose to do so), blending constraints for ethanol and biodiesel may limit the use of first-generation biofuels. Diesel can contain up to 7% biodiesel by volume, and petrol can contain up to 10% of ethanol by volume for use in most road vehicles depending on the oxygen content of the fuel. Some member states further restrict biofuels blending; for example, Latvia allows only 5% biodiesel blending, and the majority of the EU member states have not allowed the distribution of 10% ethanol in petrol. The viscosity of biodiesel increases in cold temperatures, and this may provide physical limitations to biodiesel consumption in some member states. Blending constraints may limit the contribution of food-based biofuels to the FQD, but they simultaneously will limit the market penetration of advanced ethanol.

The decision not to include ILUC accounting in the RED, discussed above, also applies to the FQD and drastically affects the incentive in the FQD to consume AAF. All types of food-based biofuel are estimated to have significant ILUC emissions. Similar to the RED, if ILUC factors were required for accounting, food-based biodiesel would not qualify for FQD compliance at all. Food-based ethanol could still qualify, but the GHG savings that could be claimed for FQD compliance for these pathways would be reduced by around 15%. No AAF pathways would be assigned ILUC emissions, and so the relative value of using these pathways compared to food-based biofuels would increase, providing a competitive advantage over first-generation biofuels.

Lastly, electricity and upstream emission reductions (UERs) from petroleum production, such as venting and flaring reductions at oil drilling sites, can also contribute toward the FQD target (Official Journal of the European Union, 2015) and may reduce the demand for AAF until 2020. It has been estimated that UERs have the potential to deliver a significant fraction of the FQD target cost effectively (Malins, Searle, Baral, Galarza, & Wang, 2014). Thus, AAF may not be necessary to meet the 6% GHG reduction target in the FQD in all member states, and there are no specific incentives within the FQD to drive the production and consumption of AAF.

State aid for environmental protection and energy

Many member states reduce taxes on biofuels as a measure of fiscal support, but there are EU-level rules governing how they can do this. In 2003, the EU revised the legal framework for energy taxation and approved Directive 2003/96/EC (Energy Taxation Directive; Official Journal of the European Union, 2003), allowing member states to reduce excise duties on biofuels. Depending on the country, the excise duty can greatly affect fuel retail prices. In June 2016, taxes and duties accounted for a weighted average of 65% of retail prices for unleaded petrol and 60% of retail prices for diesel in the EU-15 (European Environment Agency, 2016). Refineries or traders can claim these tax reductions when they blend biofuel into transport fuel for consumption, and they are expected to pass on this benefit to the final consumer. Thus, this measure is meant to prevent fuel suppliers from transferring the costs of compliance with biofuel mandates to the final consumer. In member states that choose to reduce excise taxes on biofuels, if the value of this incentive is passed on to consumers, this measure should have a major impact on the market competitiveness of biofuel blends.

The allowance for excise duty reductions applies equally to first-generation biofuels and AAF. As a result, first-generation biofuels have been the main beneficiaries of the excise duty reduction.

In addition to the Energy Taxation Directive, EU member states are required to follow certain guidelines (European Commission, 2008) when granting fiscal support for biofuels and must request the EC's approval. This procedure aims to ensure that member states do not overcompensate producers for biofuel through tax benefits or direct funding. In 2014, the EC introduced new guidelines (European Commission, 2014) that limited member states' fiscal support options for food-based biofuels. Beginning in 2014, these guidelines prohibit direct subsidies or tax benefits for investment in new food-based biofuel capacity. Fiscal support may still be provided for the production of food-based biofuels at existing installations, but such funding may not continue beyond 2020. Theoretically, the 2014 guidelines should result in a competitive advantage for AAF, since non-food feedstocks are not subject to these same rules. However, similar to the cap on food-based biofuels, the state aid limitations might have been introduced too late to significantly increase investment in AAF by 2020.

Direct funding for demonstration of AAF production

There have been two major grant programs at the EU-level that provide funding for AAF projects. From 2007 to 2013, The EU 7th Framework Program (European Commission,

2015) provided grants for emerging technologies in all fields, including small AAF facilities in the demonstration phase. Starting in 2014, this program was renamed "Horizon 2020" (European Commission, 2017a). These grants are limited to emerging technologies requiring further research and development. The guidelines limiting financial support for new food-based biofuel facilities described above also apply to the Horizon 2020 program.

The other program is the New Entrants' Reserve fund (NER300) (European Commission, 2017b). Two rounds of funding were approved in 2012 and 2014. In contrast to Horizon 2020, NER300 offers funding for the demonstration of technologies that have already been proven at the laboratory scale. The level of funding awarded to a project is capped at 50% of investment and operating costs and thus should not result in over-compensation for a project. The grant funding can only be received once the plant has been constructed and has begun operation. The amount of funding provided is based on actual production relative to the production capacity and should be paid out over the first 5 years of operation.

Out of five projects in the first round funded by NER300, two have been canceled (Ajos BTL and UPM Stracel BTL), and there is no information about developments of a third (CEG Plant Goswinowice). These two projects were cancelled due to difficulties in sourcing funding for plant design and construction and difficulties paying interest during the start-up period when the plants were partially operational. These experiences illustrate how the structure of the NER300 grants, in combination with other policy incentives, may not provide sufficient financial support, and that this may be due to the timing of the grant payments. These two projects likely failed because of financial stress in the early stages, before significant grant payments had been made. Had the funding been available earlier to help finance the design and construction of plants, as well as the early stages of operation, these outcomes might have been different.

Summary of EU-level policies

Table 3 summarizes major lessons learned about the effectiveness of these EU policy measures in supporting AAF. These lessons are organized by the policy measure or by major elements of the policy measures. Table 3 lists the obligated party and the applicable timeframe of each policy. Key lessons that can be learned about the effectiveness of these policy measures in promoting AAF are described.

Table 3. EU-level policy experience in promoting AAF

Policy measure	Obligated party	Timeframe	Lessons learned in promoting AAF
RED: 10% renewable energy target for energy in transportation	Member states	2009–2020	• Target achieved through most cost-effective existing technologies rather than supporting advancement of new technology
Double counting of non-food based biofuels toward 10% renewable energy in transport target	Member states	2009–2020	• Effective at promoting non-food-based biofuels, but only pathways using mature technologies • Ineffective at supporting advancement of new technology
7% cap on food-based biofuels	Member states	2017–2020	• Cap too high and introduced too late to significantly change industry direction
0.5% flexible mandate for AAF	Member states	2017–2020	• Introduced too late to drive investments in AAF technologies with high capital costs and long construction and start-up times; • Target is non-binding, making investments in AAF is vulnerable to political change
FQD: 6% lifecycle GHG emission-reduction target for energy used in transportation	Fuel suppliers	2009–2020	• Failure to include ILUC accounting undermines incentive premium for high-performing pathways
Excise duty reduction/ exemption	Member states	2003 until present	• Equal treatment of AAF and first-generation biofuels results in support mostly given to mature technologies
EU direct grants through FP7, Horizon 2020, and NER300	None	2007–2020	• Targeted funding for AAF can be effective at supporting those projects • Timing of payments late in project ramp-up not always sufficient to attract investment
Guidelines on state aid support to food-based biofuels from 2014	Member states	2008–2013 2014–2020	• The EC's approval requirement diminished the possibility of member states overcompensating producers for biofuel • Limitation for support of food-based biofuels was introduced too late to spur investments in AAF • Efficiency in promoting AAF is determined by policy promoting these fuels

EU MEMBER STATES

The section reviews member states' implementation of the EU-level legislation described above to promote biofuels and the effectiveness of implementation in promoting AAF in particular. The RED and FQD set policy goals that member states agreed to achieve. Every member state is then free to decide how to transpose the EU-level directives into national law to achieve those goals as long as they follow the single market principle, which aims to prevent any regulatory obstacles to free movement of goods. In particular to implement the RED target for renewable energy in transport, certain member states introduced various supportive policy measures, such as blending mandates, a carbon tax exemption, and double counting of biofuels produced from wastes and residues. This section describes the experiences of select countries whose biofuel markets are among the largest in Europe: Finland, France, Germany, Italy, the Netherlands, Sweden, and the UK.

Finland

In 2008, Finland approved a biofuel blending obligation on fuel suppliers with an annual target of 6% in 2011–2014, increasing to 20% in 2020 (Finlex, 2007, 2013). Biofuels produced from waste, residues, and cellulosic and lignocellulosic material can be double counted toward the biofuels obligation. If the retailer fails to fulfill the quota, a fine is levied. This penalty is calculated based on the amount by which the retailer has failed to fulfill the quota, where each mega joule (MJ) of renewable energy not supplied leads to a charge of € 0.04. The quota has not changed since it was approved.

Finland also gives biofuels preferential tax treatment. The carbon dioxide (CO_2) tax (of EUR 58/tCO_2 since 2014) treats most biofuels as providing a 50% reduction in CO_2 and double counts biofuels as zero carbon. In 2011, Finish energy tax policy was reformed in a way that further improved the treatment for biofuels (Finlex, 2016). This reform changed the calculation of fuel taxes from a volume basis to an energy basis, as well as adding a CO_2 tax. Ethanol and biodiesel have lower energy densities compared to fossil gasoline and diesel, and so this change allows taxes to be applied to fuels equally on the basis of energy used.

Setting policy direction beyond 2020, in 2016, the Finish government approved its Energy and Climate Strategy, setting a 30% renewable energy target in transportation by 2030 (double counting not included), including a 200,000 electric vehicle target, which is approximately 10% of the fleet. The government has not yet defined feedstocks that will be eligible for the target.

France

Since 2005, there has been a biofuels incorporation obligation in France, set by the Energy Code Article L641-6 (Legifrance, 2017b). The level of this obligation increased annually until 2010 for diesel replacements and until 2009 for gasoline replacements. It has remained at 7% blending for both fuel types since then, except for a one-time further increase in the target for diesel replacements to 7.7% in 2014. The biofuels obligation is renewed annually. In 2015, the incorporation target was extended to non-road diesel (Ministry of Ecology, Sustainable Development and Energy, 2015). The biofuels obligation allows double counting of advanced biofuels. Eligible feedstocks include used cooking oil, animal oils and fats (Categories 1 and 2), wine-making byproducts, cellulosic materials of non-food origin, and lignocellulosic material. In 2014, France published an order limiting the double counting of biofuel made from used cooking oil at 0.35% by energy content and from advanced bioethanol at 0.25% toward the biofuel quota to limit potential fraud (Legifrance, 2014). The Customs code establishes a fine in the form of the General Tax on Polluting Activities (TGAP) that fuel suppliers must pay for failing to comply with the biofuels quota (Legifrance, 2017a).

In 2015, France set long-term renewable energy targets in transportation with the approval of Law 205-992: 10% by 2020 and 15% by 2030 (Legifrance, 2015). The following year, France approved a Decree introducing targets for advanced biofuels of 1.6% by 2018 and 3.4% by 2023 for gasoline blends and 1% by 2018 and 2.3% by 2023 for diesel blends (Legifrance, 2016). Double counting is not allowed toward these targets, and the government still has to determine which feedstocks are eligible.

From 2002 to 2015, the French Customs Code granted a partial reduction from the domestic consumption tax to approved quantities of biofuels on an annual basis. The level of this tax reduction ranged from 15% to 21% depending on biofuel type in 2009 and decreased to 3%–7% in 2015. Starting in 2016, the tax reduction was abolished.

Germany

From 2007 to 2014, Germany required fuel suppliers to blend biofuels under the biofuel obligation in the Federal Emission Control Act (German Federal Ministry of Justice and Consumer Protection, 2017b). Required blend levels increased annually from 2007 to 2010 and remained at 2.8% by energy content for gasoline and 4.4% for diesel through 2014. Certain types of wastes and residues, as well as cellulosic and lignocellulosic material, were double counted toward the quota.

In 2015, the government switched to a GHG reduction quota, requiring fuel suppliers to reduce the GHG intensity of the fuel mix they supply by 3.5% in 2015–2016, 4% in 2017–2019, and 6% from 2020 onward. Fuel suppliers and biofuel producers may trade certificates for GHG emission reductions to achieve their obligations, and they are fined if they do not meet these obligations. ILUC accounting toward the GHG emission reduction target is not required.

Germany completely exempted biofuels from excise duties from 2002 to mid-2006. From that point onward, Germany gradually increased excise duties on biofuels. Since January 2013, conventional biofuels have been subject to the same tax rate as fossil fuels to prevent overcompensation (German Federal Ministry of Justice and Consumer Protection, 2017a). An exception is that certain types of AAF, including synthetic hydrocarbons and cellulosic ethanol produced from biomass (biomass-to-liquids, BtL fuels), qualified for full tax exemption through 2015. In addition, suppliers of E85 (85% ethanol blended in gasoline) could apply for an excise duty reduction through 2015.

Italy

Italy introduced a biofuels obligation in 2006, requiring a minimum share of biofuels of 4.5% in transport fuel by energy content for 2012–2014. This obligation was extended for 2015 and onward by a Ministerial Decree signed in 2014, with annual blending targets increasing to 10% in 2020 and beyond (Gazzetta Ufficiale, 2014). The 2014 decree also introduced an obligation for 1.2% AAF blending in 2018, increasing to 1.6% in 2020 and 2% in 2022, and remaining at 2% thereafter. The obligation for AAF may be achieved solely through feedstocks listed in RED, Annex IX, Part A (which specifies lignocellulosic material and certain types of wastes and residues). Used cooking oil and animal fat are not on this list, but they can be double counted toward the general obligation. The government established a certificate-trading scheme to enable compliance with these mandates; failure to comply results in a fine. The Decree includes a provision that the obligation for advanced biofuels may be revised once a year ahead of the reference year to take into account technology development.

In 2013 and 2014, the Italian government made an offtake agreement for AAF with a private business group "Gruppo Mossi Ghioslfi," fostering the deployment of second-generation biorefineries in Italy. This agreement covers three cellulosic ethanol plants in the South of Italy. The first plant was built by Biochemtex (Cobror, 2015).

From 1995 to 2010, Italy allowed tax reductions for limited amounts of biofuels according to the Decree 504/1995 and the Annual Finance Act. From 2007–2010, this was a 20% excise duty reduction for an annual quota. The quota decreased every year, and the tax reduction expired in 2011 (Italian Ministry of Economic Development, 2010).

The Netherlands

In 2006, the Netherlands introduced an excise duty exemption on 2% biofuel blends, intended to cover the difference in production costs for biofuels compared to petroleum (European Commission, 2005). This tax benefit was in place for only 1 year. In 2007, it was replaced by a 2% biofuel blending quota by energy content for fuel suppliers (European Commission, 2005). This quota increases annually to 10% blending in 2020. In 2009, the Netherlands introduced double counting for advanced biofuels through a ministerial regulation. In 2013, the list was amended to exclude distillers dried grains with solubles (DDGS), animal fats Category 3, pulp sugar, untreated tall oil, grass, industrial wastewater, and others (Ministry of Infrastructure and Environment of the Netherlands, 2011). The Netherlands set the food-based biofuel cap at 5%, lower than the 7% cap required by the ILUC Directive. A certification trading scheme was introduced in 2015, using Renewable Energy Units (HBEs), each representing 1 gigajoule (GJ) of renewable energy, to demonstrate compliance with the biofuels quota. A penalty applies for noncompliance.

Sweden

Unlike many other EU member states, Sweden has not introduced a biofuel blending requirement. Instead, biofuels are only promoted through tax exemptions, along with a requirement that fueling stations of a certain size offer at least one type of renewable fuel (The Swedish Parliament, 2010). Because there is no biofuels target, Sweden does not apply double counting.

Prior to 2013, Sweden exempted all biofuel blends from the energy tax and the CO_2 tax. From 2013 onward, Sweden imposed an energy tax on low biofuel blends (5% by volume, max) as a result of overcompensation of producers for first-generation biofuels. In 2015, this tax was applied to all blends up to 10% ethanol and 7% biodiesel by volume. As of 2016, the taxation scheme is as follows:

- 74% energy tax reduction for low ethanol blends (E10)
- 8% energy tax reduction applies for biodiesel blends (B7)
- 50% energy tax reduction for high-level biodiesel blending
- 73% energy tax reduction for high-level bioethanol blends (E85)
- 100% energy tax exemption for hydrogenated vegetable and animal oils and fats (HVO)

Biofuel producers must apply for the tax exemption and demonstrate that the biofuel is produced at a plant that began operation in 2013 or earlier (Swedish Statute Book, 1994). All biofuels are exempted from the CO_2 tax.

The UK

In 2007, the UK established the Renewable Fuel Transport Obligation (RTFO), requiring obligated fuel suppliers to blend 2.5% biofuels in transport fuel in 2008/2009, increasing annually to 4.75% in 2013/2014; the mandate has remained constant since then (Legislation.gov.uk, 2007). Obligated parties may comply using tradeable renewable transport fuel certificates or by paying into a buy-out fund for the shortfall. Since 2011, biofuels produced from waste/non-agriculture residues, non-food cellulosic material, and lignocellulosic materials have been double counted. The legislation was revised in 2009 to introduce sustainability criteria and to adapt the targets.

The UK also provided a fuel duty reduction of 20 pence per liter for biofuels until 2010. The duty reduction for biodiesel from used cooking oil remained in place until 2012 (Nationalarchives.gov.uk, 2009).

State of AAF capacity in the EU

Table 4 lists select AAF facilities currently producing in the EU with capacities of 1,000 tonnes per year or greater. Three of these facilities produce cellulosic ethanol from agricultural residues. The EU light-duty vehicle market is dominated by diesel fuel, and therefore there may be a larger market opportunity for second-generation renewable diesel in future. This is not a comprehensive list of AAF facilities in the EU.

Table 4. Select operating advanced biofuel plants in Europe

Member State	Company	Fuel type	Feedstock	Capacity (tonnes/year)	Year of first production
Denmark	Inbicon, DONG Energy	Cellulosic ethanol	Agriculture residues	4,300	2009
Finland	UPM Lappeenranta Biorefinery	Renewable diesel	Tall oil	100,000	2015
Germany	Clariant - Sunliquid®, Germany	Cellulosic ethanol	Agriculture residues	1,000	2012
Italy	Beta Renewables, Biochemtex in Crescentino	Cellulosic ethanol	Agriculture residues, dedicated energy crops	60,000	2013
Sweden	Preem Petroleum, Sweden	Renewable diesel	Tall oil	130,000	2011

Source: Adityabirla (2017), Baltic Transport Journal (2016), Betarenewables (n.d.), The bioliq® Project (2014), Clariant (2014), ETIP Bioenergy (2016), UPM Biofuels (2017).

Summary of EU member state experiences

The table below summarizes selected EU member states' experiences in promoting AAF, including presenting key policy measures, their timeframes, and a description of the effectiveness of these measures in promoting AAF. The table reflects the RED and FQD only where member states have transposed these directives into national legislation. Although there is some capacity to produce AAF in the EU, it is very low compared to the 0.5% advanced biofuel target for 2020. Many member states have not yet implemented the ILUC Directive and do not yet have sufficient policy mechanisms in place to provide targeted promotion for AAF. Italy, in particular, has provided relatively strong policy support for AAF and is home to the EU's largest cellulosic ethanol facility.

Table 5. Selected Member States' Experiences in Promoting AAF

Country	Policy measures	Timeframe	Effectiveness in promoting AAF
Finland	Biofuels obligation	2011–2020	Strong support for biofuels overall No competitive advantage provided for AAF
	Double counting	From 2011	
	Excise duty reduction for double-counted biofuels only	2012–present	
France	Biofuels obligation	2005–2016 (renewed on an annual basis)	Annual renewal of the obligation creates uncertainty for investments
	Double counting with a cap	2010–2020 From 2014: cap	Cap limits investment in emerging technologies
	AAF target	2016–2023	Positive signal to investors Target introduced too late to drive investments in AAF for RED/FQD targets in 2020
	Excise duty reduction	2002–2015	No competitive advantage provided for AAF
Germany	Biofuels obligation	2009–2014	No competitive advantage provided for AAF
	Double counting	2009–2014	
	Lifecycle GHG emissions savings target (no ILUC accounting)	2015–2020	
	Excise duty reduction	2004–2015	Restrictive list of eligible technologies limits support to emerging technologies
Italy	Biofuels obligation	2012–2020	Government offtake agreement followed by the target for AAF provided investment security and was effective in supporting the EU's largest cellulosic biofuel facility Target may have been introduced too late to be met
	Double counting	2012–2020	
	AAF target	2018–2022	
	Government offtake agreement for AAF	2014 and 2015	
	Excise duty reduction	2007–2010	No competitive advantage provided for AAF
The Netherlands	Biofuels obligation	2007–2020	No competitive advantage provided for AAF Investment depreciation option addresses only fuel distributors
	Double counting	2009–2020	
	Excise duty reduction	2006–2007: 2% of fuels	
	Investment depreciation	2012–present	
Sweden	Pump law	2005–present	No competitive advantage provided for AAF
	Excise duty reduction	2007–present	
The UK	Biofuels obligation	2008–present	No competitive advantage provided for AAF
	Double counting	2011–2020	
	Excise duty reduction	Until 2010 for all biofuels Until 2012 for used cooking oil biodiesel	

THE U.S. AND THE STATE OF CALIFORNIA

This section reviews policy measures set at the U.S. federal level as well as in the state of California.

U.S.

Renewable Fuels Standard

The U.S. Renewable Fuel Standard (RFS) program was established by the Energy Policy Act (U.S. Congress, 2005) and required ethanol blending in gasoline from 2006–2009 (U.S. EPA, 2009). The RFS was amended and extended by the Energy Independence and Security Act (U.S. Government Publishing Office, 2007) to include other types of biofuel, along with additional changes; the revised program began in 2010 and is ongoing. Obligated parties (fuel refiners, blenders, and importers) must supply increasing amounts of biofuel in road transport. The RFS covers four nested categories of biofuel, defined by feedstock and fuel type and by lifecycle GHG performance, including ILUC accounting:

- Renewable fuel, including all types of biofuel (must reduce GHG by 20% compared to gasoline)
    - Advanced biofuel, a subset of renewable fuel (reduce GHG by 50%)
        - Biomass-based diesel, a subset of advanced biofuel including biodiesel and renewable diesel (reduce GHG by 50%)
        - Cellulosic biofuel, a subset of advanced biofuel including biofuels made from cellulose, hemicellulose, and lignocellulose (reduce GHG by 60%).

Cellulosic biofuel has its own sub-mandate within the RFS. EISA specifies an annually increasing volume schedule for all four categories of biofuel through 2022, but grants authority to the U.S. Environmental Protection Agency (EPA) to revise those volumes in years when supply is unlikely to meet those targets. EPA has revised the cellulosic biofuel volume downward in all applicable years because of insufficient supply. EPA also has authority to set volumes for all categories for all years after 2022 (Searle, 2015).

The RFS has a credit-trading system. One Renewable Identification Number (RIN) is awarded for each gallon of ethanol-equivalent biofuel. Obligated parties must submit the required number of RINs to the EPA each year or face a penalty. There are several RIN categories corresponding to the different fuel categories, and in the case of cellulosic biofuel, to two different fuel types: ethanol and diesel. These different RIN types tend to carry different prices on the market; cellulosic RINs are generally more expensive than advanced biofuel and biomass-based diesel RINs, which are in turn more expensive than renewable fuel RINs.

In years when EPA revises the cellulosic biofuel volume downward, it also makes cellulosic waiver credits (CWCs) available for purchase. Obligated parties can submit a CWC plus an advanced RIN in lieu of a cellulosic RIN. The price of CWCs depends on the price of gasoline; for example, in 2015, the CWC price was $0.64 (U.S. EPA, 2015).

When the revised RFS program began in 2010, a list of eligible feedstocks was provided. For the cellulosic category, this included crop residues, forestry residues, and perennial grasses, among other feedstocks. Since then, EPA has evaluated a number of new feedstocks for inclusion in the program on the basis of lifecycle GHG performance and other criteria. In 2013, EPA approved new pathways for biogas produced from cellulosic materials, including landfills and dairy waste (U.S. EPA, 2014). This biogas can be used as compressed natural gas (CNG), liquefied natural gas (LNG), or as biogas-derived electricity in electric vehicles. Although cellulosic biogas offers high GHG reductions, for the purposes of this study, we do not consider it to be AAF because it does not use an emerging technology.

The amounts of cellulosic biofuel used for compliance with the RFS have been lower than even the revised cellulosic volumes in many years. The statutory volumes for cellulosic biofuel set in EISA, EPA's revised volumes, and actual production are shown in Table 5. Cellulosic biogas is a subset of the cellulosic biofuel category; biogas volumes are shown in parentheses.

Table 6. Original and revised required volumes and achieved volumes for cellulosic biofuel under the RFS, millions of ethanol-equivalent gallons per year (EPA, 2017a, 2017b)

Cellulosic biofuel	Statutory RFS2 requirement	Revised RFS2 requirement	Actual Production (cellulosic biogas)
2010	100	6.50	0.00
2011	250	6.00	0.00
2012	500	10.45	0.02
2013	1,000	6.0	0.42 (0.42)
2014	1,750	33	33 (32)
2015	3,000	123	142 (140)
2016	4,250	230	189 (185)
2017	5,500	311	72 (69) as of June 10

Excise Tax Credit

At various points, the U.S. has provided income tax credits to ethanol, biodiesel and renewable diesel, and cellulosic biofuel. At least one U.S. tax incentive has been in the form of a reduction in the fuel tax, a common type of tax incentive in the EU. Other U.S. biofuel tax incentives have instead reduced the total amount of income tax that a company or individual must pay. As of July 2017, there are no active tax credits for biofuel production or blending. Past tax credits include the following (U.S. Department of Energy, 2017):

» Biodiesel and renewable diesel tax credits. An income tax credit of $1.00 per gallon was available to blenders and to consumers of B100 (100% biodiesel) from 2006–2016. Over that period, the biodiesel tax credit has several times expired and been extended, sometimes retroactively, for one or more years by different legal acts (Searle, 2014).

» Volumetric ethanol excise tax credit (VEETC). The VEETC applied from 2006–2011 and consisted of a $0.45 credit per gallon ethanol against a blender's fuel tax liability; any excess tax credit available could be applied to income tax.

» Second-generation biofuel producers tax credit: From 2009–2016 (Miller, Christensen, Park, Baral, Malins, & Searle, 2013), an income tax credit of $1.01 per gallon is available to producers of biofuel made from lignocellulose, hemicellulose, algae, cyanobacteria, or lemna. Like the biodiesel and renewable diesel tax credit, the second-generation biofuel producers tax credit has a history of frequent expiration and extension, sometimes retroactively.

The VEETC was effective in helping build the corn ethanol industry in the U.S. The biodiesel and renewable diesel tax credit has been effective at growing the biodiesel and renewable diesel industry in the U.S. as well. However, the second-generation biofuel producers tax credit has been less effective in supporting cellulosic biofuel industry compared to other fuels. Beneficiaries of this tax credit, similar to those of the biodiesel and renewable diesel tax credits, face the political uncertainty of frequent expiration and renewal. However, this issue may affect cellulosic biofuel producers more strongly because cellulosic biofuel production requires high capital investments, long construction times, and a long period required to generate a return on investment, whereas first-generation biodiesel typically has low capital costs and a short period of time required to generate a return on investment.

Another problem with the second-generation biofuel producers tax credit is that it can only be claimed against a producer's income tax liability in the same year. A positive tax liability is only incurred during years of profit, and losses from earlier years can be deducted from this profit. In the early years of construction and startup before cellulosic biofuel producers are profitable, they can be expected to have zero tax liability, and thus the tax credit cannot be claimed (Miller et al., 2013). This is unlike the biodiesel and renewable diesel tax credits, for which the U.S. government will pay the value of the tax credit to eligible parties even if they have zero tax liability (U.S. Department of Energy, 2017). In this aspect, U.S. tax policy actually treats some types of first-generation biofuel more favorably than AAF.

Loan Guarantee for Investments and Direct Funding

In the U.S., the Department of Energy (DOE) and the U.S. Department of Agriculture (USDA) have had grant programs providing loan guarantees as well as direct funding. With a loan guarantee, the government commits to paying a company's investment loans if that company is unable to pay them. This incentive is meant to reduce investment risk and encourage private investment in emerging technologies.

DOE's Loan Guarantee Program was created by EPAct for projects with high technology risks that "avoid, reduce or sequester air pollutants or anthropogenic emissions of greenhouse gases; and employ new or significantly improved technologies as compared to commercial technologies in service in the United States at the time the guarantee is issued" (U.S. Department of Energy, 2016). These loan guarantees are meant for early commercial-stage projects and are generally not provided for research and development. This program supported Project LIBERTY, the country's first commercial-scale cellulosic ethanol plants sponsored by POET, LCC.

Additional loan guarantees as well as grants are issued by the U.S. Department of Agriculture Biorefinery Assistance Program (renamed the Biorefinery, Renewable Chemical and Biobased Product Manufacturing Assistance Program) in 2008 (USDA, 2016). This program supports the development, construction, and retrofitting of commercial-scale biorefineries and facilities for biobased product manufacturing. As of 2014, the maximum loan guarantee was $250 million and the maximum grant funding was up to 80% of project costs. The second round of the call expired in April 2017.

California

While the federal incentives described above apply in the state of California, California further encourages the use of AAF and other low-carbon fuels through its Low Carbon Fuel Standard (LCFS) program, established in 2010 (ARB, 2017b). The LCFS has annual GHG reduction targets, leading to a 10% reduction in the lifecycle GHG intensity of road fuel supplied in the state of California in 2020 compared to a 2010 baseline (ARB, 2015). The standard is technology neutral and can be met using any type of fuel. The lifecycle GHG intensity of biofuels includes ILUC accounting.

LCFS has a credit trading system, and credits are retired to show compliance. Credits are awarded not on a volumetric or energy basis (as in the RFS and some EU policies) but rather based on the carbon intensity savings of the fuel. This mechanism provides greater policy value to lower carbon fuels and should in principle better support AAF compared to food-based biofuels (Miller et al, 2013, Pavlenko et al., 2016). There is also a cost-containment mechanism, the Credit Clearance Market (ARB, 2016). At the end of each compliance year, parties may sell excess credits; these are pooled and distributed to parties with shortfalls in their obligations at a maximum price of $200 per ton CO_2e.

The LCFS target has been mainly fulfilled by food-based ethanol, natural gas, and food-based biodiesel. It has been criticized as providing insufficient support to AAF because the mandate can be met using first-generation fuels; it is not necessary for regulated parties to purchase AAF. In addition, as with the RFS program, fluctuating credit prices reduce the certainty of the value of future policy support (Pavlenko et al., 2016).

State of AAF capacity in the U.S.

The U.S. has a number of AAF facilities, the bulk of which produce cellulosic ethanol. Table 6 highlights some of these facilities, presenting the fuel type, main feedstock, capacity, and year of first production; this is not a comprehensive list of all AAF facilities in the U.S.

Table 7. Select operating AAF facilities in the U.S.

State	Company	Fuel type	Feedstock	Capacity (tonnes/ year)	Year of first production
Georgia	LanzaTech, mobile demo plant	Ethanol	Woody biomass	70	2014
Iowa	DuPont	Cellulosic ethanol	Corn stover	90,000	2015
Iowa	QCCP	Cellulosic ethanol	Corn kernel fiber	12,000	2014
Iowa	Poet	Cellulosic ethanol	Corn stover	60,000	2014
Oklahoma	ENVIA Energy	Drop-in diesel and gasoline	Landfill gas and natural gas	13,000	2017
Various	Various companies using Edeniq technology	Cellulosic ethanol	Corn kernel fiber	3,000 (total)	2016

Source: Daily Energy Insider Reports (2016), Lane (2017), U.S. EPA (2017b)

Summary of U.S. experience

Table 7 summarizes the experience of the U.S. and state of California in promoting AAF. The table is organized by policy measure and time frame and describes the effectiveness of each policy measure. Overall, the U.S. has significantly greater AAF capacity than the EU. This relative success may be due to the combination of multiple policies available in the U.S., as well as the competitive advantage given to AAF by each of these policies (the dedicated cellulosic mandate in the RFS, the greater credit value given to very low carbon fuels in the LCFS, the dedicated tax credit for cellulosic fuel, and loan guarantee and grant programs available only to AAF). At the same time, AAF production in the U.S. has been much lower than anticipated, particularly compared to the statutory volumes in the RFS. It is likely that a combination of factors, including the economic recession, contributed to this gap. Certain policy design elements have also contributed to uncertainty, including the fluctuating credit prices in the RFS and LCFS and the frequent expirations and reinstatements of the tax credit.

Table 8. U.S. and California's experience in promoting AAF

Country	Policy measure	Timeframe	Effectiveness in promoting AAF
U.S. (federal level)	Cellulosic mandate in RFS	2010 onward; revised on an annual basis	• Provides a competitive advantage for cellulosic biofuels over first-generation biofuels • Original targets too ambitious to be met • Target revisions have led to uncertainty • Fluctuating credit prices have contributed to uncertainty • CWCs price may be too low, incentivizing CWC purchase instead of cellulosic biofuel blending
	Tax credit for cellulosic biofuel production	Currently expired; usually renewed every 1–2 years	• Provides targeted support for cellulosic biofuel but not other kinds of AAF • Has never been active for a long enough period to provide sufficient policy certainty for investment in new AAF production • Tax credit can only be claimed in years of profit
	Loan guarantees and grants	Programs renewed on a 3- to 5-year basis	• Large resources directed toward AAF • Lengthy approval process and strict requirements for self-funding • Supports attracting investment and building up production capacity • Does not support production
California	LCFS	2010–2020	• Direct competition between AAF and conventional biofuels leads to compliance using mainly conventional biofuels • Low credit prices in early years did not provide sufficient support for investment in AAF • ILUC accounting creates a value differential between food-based biofuels and AAF • Fluctuating credit prices have contributed to uncertainty

DISCUSSION: WHAT WORKED AND WHAT DID NOT?

The EU and U.S. have made renewable fuels a central strategy in achieving GHG reductions in the transport sector, and both regions have identified AAF as key to enabling deep decarbonization over the long term. Across these jurisdictions, several different types of policy incentives have been introduced to promote AAF, with different countries attempting variants on the same policy framework. After nearly a decade of AAF policy implementation, we can learn lessons about policy elements that have been more or less effective at driving AAF commercialization.

Although the AAF industry, at its forefront cellulosic ethanol, has not reached widespread commercialization anywhere in the world, some jurisdictions have made markedly more progress than others. The U.S. in particular, followed by Italy, has successfully supported the development of AAF companies and the construction of a few commercial-sized facilities. The U.S. has two large, commercial-scale cellulosic ethanol facilities that are still in the process of ramping up production, while Italy has the EU's largest existing cellulosic ethanol facility. These two countries were the first to introduce dedicated AAF mandates; the U.S. cellulosic biofuel mandate as part of the revised RFS was announced in 2007, and the Italian AAF mandate was announced in 2014. Both countries have provided other forms of targeted support to AAF. The Italian government's offtake agreement with Gruppo Mossi Ghioslfi has arguably been more important in building its AAF industry than the sub-target so far. Providing clear, dedicated support to AAF in a long-term policy narrative has been at least partially successful in supporting the AAF industry to date in these two countries.

Yet, even in the U.S.—the country with the strongest combination of cellulosic biofuel incentives of any reviewed here—the cellulosic industry has fallen far short of expectations. There are several likely contributing factors to this outcome: overly optimistic expectations, the recent economic recession, and potentially a failure to understand realistic capital and production costs of cellulosic biofuel (Pavlenko et al., 2016; Pavlenko, Searle, & Nelson, 2017). But there are also attributes of U.S. cellulosic biofuel incentives that have likely weakened the value of these incentives to biofuel companies, in particular, their ability to attract private investment. In the remainder of this section, we discuss how policy elements in the EU and U.S. have succeeded or failed to promote AAF through targeted support, timeliness of that support, and policy stability.

The U.S. and Italy's case studies suggest that providing dedicated support for AAF is an important policy element in successfully promoting these fuels. Many studies have projected that various types of AAF could be cost competitive with first-generation biofuels and perhaps even with petroleum once the industry has fully scaled up (e.g., Humbird et al., 2011; Peters et al., 2015 UK Transport Energy Task Force, 2015), but at present AAF is likely more expensive than many types of first-generation biofuels and faces the particular challenge of high capital costs (Pavlenko et al., 2016, 2017). Thus, mandates that treat first-generation fuels and AAF equally, including those in all EU countries reviewed here except Italy and France, will be met entirely or almost entirely with first-generation technologies. Double-counting incentives for RED compliance provide an advantage for AAF over food-based biofuels in EU countries that have implemented them, but these incentives still put AAF in direct competition with first-generation technologies using non-food feedstocks, such as used cooking oil biodiesel.

Furthermore, double-counting incentives may not increase their value enough to overcome the cost challenges associated with first-of-a-kind AAF facilities.

GHG reduction targets can provide stronger support to AAF compared to food-based biofuels because they reward lower carbon fuels. California's LCFS assigns lower carbon intensity scores to cellulosic fuels compared to most types of food-based biofuel, with a correspondingly higher incentive value (ARB, 2017c). Although there are no AAF facilities in the state of California, the LCFS likely contributed to the development of facilities in other parts of the U.S., Canada, and Brazil (U.S. EPA, 2017c) that would be able to produce LCFS credits for fuel imported into and consumed in California. On the other hand, only a very small percentage of the total fuel used for LCFS compliance is cellulosic ethanol or other AAF; to date, the policy is primarily driving biofuel production using first-generation technologies (ARB, 2017a). Furthermore, a GHG reduction target only gives greater support to AAF if ILUC accounting is included. Without ILUC accounting, efficient first-generation facilities can claim carbon intensities equally low as AAF and are thus treated the same. The GHG reduction target in the FQD is therefore not likely to be a very stronger driver for AAF. Although Germany has some AAF production, it seems likely that AAF in the country has been driven more by signals of policy stability from the government (e.g., it is the only EU country reviewed here that has implemented the GHG reduction target in the FQD) than by the GHG target itself.

Because AAF facilities typically require high capital costs and long construction and start-up times, the timing of policy support can be very important. Having long-term policy certainty is generally more critical for AAF, for which facilities may require 10 years or more after the project start date to pay back capital loans (Pavlenko et al., 2016, 2017). We compare these AAF facilities to first-generation facilities with relatively simple and inexpensive technologies and much shorter payback periods. Perhaps the most apt example of a policy that fails to provide this long-term certainty is the U.S. tax credit for cellulosic biofuel, which has expired and has been reinstated every 1–2 years since it was first introduced. An investor considering a new cellulosic biofuel facility that will take years just to design and construct will not consider the U.S. tax credit to be reliable enough to support production. Although the EU's 0.5% advanced biofuels sub-target introduced with the ILUC Directive is embedded in a narrative of long-term policy support, this target was likely not introduced early enough to be met. This sub-target was decided in 2015, and member states have not been required to implement it until 2017, leaving only 3 years before the target applies in 2020. Importantly, member states have considerable flexibility in meeting this target and, in principle, can avoid meeting it altogether. Although Italy's sub-target was first announced in 2014, providing 6 years for the industry to meet it, France did not announce its sub-target until 2016. As far as we are aware, no other member states reviewed in this study have implemented the advanced biofuel sub-target. Because member states are not strictly obligated to implement the sub-target, AAF companies and investors in many countries have no guarantee that they will receive this form of support by 2020.

The timing of grants and loan guarantees matters also. The NER300 program provides financial support only after production has begun, offering no concrete assistance for companies in covering high capital costs. Conversely, grant and loan guarantee programs provide support for capital costs, but not for production. Although capital costs are a major barrier to attracting investment, it is likely that even if capital costs are financed, additional support is still needed for the production phase (Pavlenko et al., 2017).

Perhaps the most difficult problem to solve in supporting AAF is achieving policy stability. The U.S. tax credit is a perfect example of an unstable policy; similarly, EU tax credits have been reduced over time. Although the cellulosic biofuel mandate in the RFS has a long-term trajectory, there are several elements of this policy that reduce the certainty with which investors can count on its support in future years. The first is the fact that the mandated cellulosic volume has been reduced in every year of RFS implementation. This is largely a result of setting volumes that were too high when the program was introduced. Now the problem is that there is no certainty of what the mandated volumes will be in future years, contrary to the intent of the original volume schedule. EPA may soon be required to reset the cellulosic volume schedule through 2022, which may rectify this problem (U.S. EPA, 2017c). The second issue with the RFS is the availability of CWCs. Because CWCs have a price cap and because an equivalent number of CWCs are available as gallons of the cellulosic mandate in any given year, this feature both caps the effective level of financial support provided by the RFS to cellulosic biofuel production and allows obligated parties to avoid blending any cellulosic biofuel at all. The final problem discussed here is common to California's LCFS as well as the RFS and any other policy with a credit market: variable credit prices. The benefit of credit markets is that they allow these policies to be met in the most cost-effective way possible, avoiding overcompensation of alternative fuels. The downside is that variable credit prices detract from the stability of the policy. Investors considering supporting an AAF facility that will begin production in 5 years will have little certainty of the value of a policy at that time given a variable credit market. Credit markets for alternative fuel policies tend not to implement price floors (a guaranteed minimum level of support); price floors could help rectify credit value uncertainty.

Finally, we have learned that AAF requires fundamentally different policy support characteristics compared with first-generation biofuels. Because AAF production tends to involve complicated technologies, it requires high capital costs; long construction and ramp-up times; and, at least for first-of-a-kind facilities, a relatively high level of price support. Designing a policy that provides a sufficient level of support at all stages of construction and production as well as enough long-term stability to ensure a return on investment is not simple. In the next section, we discuss principles for solving these policy design problems.

PRINCIPLES FOR EFFECTIVE POLICY SUPPORT FOR INVESTMENT

There are number of potential policy options that governments could apply to effectively promote AAF commercialization. Although policy measures to promote capital investments in AAF may vary from GHG emission reduction targets to blending obligations or other mechanisms, these elements of policy design should be considered with any measure that is implemented.

Guarantee long-term stable support. The timeframe of a policy should align with the timeframe over which support is needed. Investors must expect a project to turn a profit for enough years to pay back capital and start-up costs—and, in the case of AAF technologies with high CAPEX, it can take a long time to do so. Thus, to be effective, AAF policies should guarantee support for at least 10 years. First-of-a-kind plants will typically have hiccups that slow ramp-up times, or even result in shuttering of the facility. Investors in the industry will wait for success and lessons learned from first-of-a-kind plants before supporting the next wave; thus, alternative fuel policies should be embedded in a narrative of even longer-term support in order to guide the industry from startup to widespread commercialization.

Avoid direct competition with first-generation technologies. In blending or volume mandates or GHG reduction targets, each eligible pathway is competing with the others for support. Given the choice, investors will tend to support safe, first-generation biofuel pathways over riskier technologies that have not yet been proven at commercial scale. Providing AAF with added incentives, such as double counting or the higher value provided to lower carbon fuels under a GHG reduction target, is not enough to promote investment when first-generation biofuels are still a compliance option. To ensure that investment is directed to emerging technologies, those technologies alone should be eligible for support under a target or sub-target. This principle does not apply to tax incentives with unlimited potential spending, although the value in supporting first-generation technologies with direct fiscal support may be questioned.

Deal with sustainability challenges up front. Waiting to address critical sustainability issues increases policy uncertainty. In such instances, it is clear that the policy will change in the coming years, but it is unknown what those changes will be and how they will affect the alternative fuels industry. This lesson was learned in particular during the ILUC debate in the EU, when support for food-based biofuels changed only a few years before the target year. Potential sustainability challenges for second-generation feedstocks should be addressed as early as possible to provide policy stability.

Support offtake. Product demand is essential for the viability of any industry, including AAF. The strongest form of offtake support is government procurement contracts that guarantee purchase of fuel. Requiring private industry, such as fuel suppliers, to consume alternative fuel also provides effective support.

Design cost containment carefully. Cost-containment mechanisms are a necessary component of any alternative fuels policy in order to prevent undue burden, whether it is a cap on government spending through tax incentives or a maximum purchase price for alternative fuels by fuel suppliers. However, setting a cost cap too low can undermine the policy by allowing the targets not to be met. In tandem, a price floor for credit markets may be necessary to provide policy certainty. Pavlenko et al. (2016) outlined a program that would provide a long-term price floor for AAF through a contracts-for-difference approach. The right balance is a fine line between what the government or fuel suppliers can afford and the level of support that is necessary to incentivize new AAF projects.

It may not be possible to fulfill all of these recommendations in the same policy, but these principles and the problems they aim to address should at least be considered in the early stages of new AAF policy design. AAF is incentivized by a variety of policy frameworks in different jurisdictions, including blending or GHG targets, tax incentives, or government grants. There is no single ideal policy design, and the framework used depends on other policies in place and the market conditions of each country or region. The lessons learned from the past decade of policy experience that we identify and analyze in this study can help inform the design of many policy type that may be implemented in the future. Table 8 lays out policy design principles that can be applied to a variety of policy frameworks, including renewable energy mandates, GHG emission reduction targets, "price guarantees," tax incentives, and government grants. The "price guarantee" policy option refers to the contracts-for-difference approach proposed in Pavlenko et al. (2016), in which AAF companies compete for a minimum price floor that is then guaranteed by the government in long-term contracts.

Table 9. Principles for effective AAF support in various policy frameworks

<table>
<tr><th>Policy design principle</th><th>Renewable energy Mandate</th><th>GHG reduction Target</th><th>Price guarantee</th><th>Fuel tax reduction/ production tax credit</th><th>Investment tax credit</th><th>Grants and loan guarantees</th></tr>
<tr><td>Long-term support</td><td colspan="2">Binding mandate for at least 10 years</td><td>Contracts for at least 10 years</td><td>Duration of at least 10 years</td><td>Duration of at least 5 years</td><td>N/A</td></tr>
<tr><td>Avoid competition with first-generation biofuels</td><td colspan="2">Separate target for AAF</td><td colspan="4">Dedicated fund for AAF</td></tr>
<tr><td>Deal with sustainability up front</td><td colspan="2">Accounting for indirect emissions and other environmental concerns in policy design</td><td colspan="4">Eligibility restriction to sustainable fuels</td></tr>
<tr><td>Support offtake</td><td colspan="2">Requirement for fuel suppliers to supply/blend fuel</td><td colspan="4">Government offtake contracts</td></tr>
<tr><td>Cost containment</td><td colspan="2">Credit price ceiling and potentially floor</td><td>Maximum reimbursement</td><td colspan="2">Tax credit phase out after certain volume achieved</td><td>Set amount of funding available</td></tr>
</table>

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