BUILDING THE PERFECT BEAST: DESIGNING ADVANCED ALTERNATIVE FUEL POLICY TO WORK

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ABSTRACT: Since the year 2000, grand aspirations have been set for the development of a new advanced alternative fuel industry, but targets have repeatedly been missed and deployment of new facilities has delivered only a tiny fraction of the fuel production forecast by the most ambitious policies. This paper argues that one of the main reasons for this shortfall between goals and achievement is the use of policy frameworks that have not been designed to provide long-term value certainty. The setting of energetic targets for the supply of advanced alternative fuels was intended to give the market the flexibility to choose the lowest cost solutions. Instead, the value-uncertainty built into such policies as a feature has contributed to an investment environment in which high capital expenditure projects using new technologies are profoundly disadvantaged compared to high operational expenditure fuel production at first generation plants. The market has thus failed to deliver the best value long-term solutions. An alternative policy framework is proposed in which credits would be awarded for advanced alternative fuel production, and fuel suppliers would be required to support that production by buying all available credits at the end of the year at a prescribed price. That price would be fixed up to an annual supply target; beyond that annual supply target, the per-credit price would be scaled down in proportion to the degree of over-achievement in supply, allowing a firm cap to be set on the cost of support to fuel consumers. While the market would be able to expand supply until the adjusted credit price reflected marginal production costs, the high levels of price variability in existing biofuel credit markets would be avoided. It is argued that such a framework could be much more effective at driving investment than a simple mandate, while avoiding excessive costs for fuel suppliers or consumers.
Keywords: biofuel; economics; policies; cellulose; second generation.

1 INTRODUCTION

By some measures, the rise of biofuel mandates as a climate policy tool since the early 2000s has been a renewable energy success story. Between 2000 and 2016, global biofuel production rose from 15 million tonnes (almost entirely ethanol) to 110 million tonnes (80 million of ethanol and 30 million of biodiesel), more or less entirely from first generation technologies. This rapid growth in fuel production is illustrated in Fig. 1 and Fig. 2 [1]. The great majority of this growth has occurred under biofuel consumption mandates such as the Renewable Fuel Standard in the U.S. and the Renewable Energy Directive in the EU – as of 2015, some sort of biofuel mandate was in effect in 33 countries [2]. While there are significant questions about whether net environmental benefits have been delivered by expanding the use of some first generation biofuels [3]–[7] and about the impacts of biofuel demand on food markets [8], there is no question that volumes have dramatically increased, as intended.

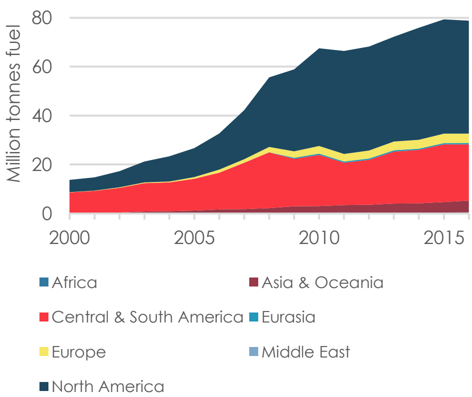

Figure 1: Growth in global ethanol supply since 2000.

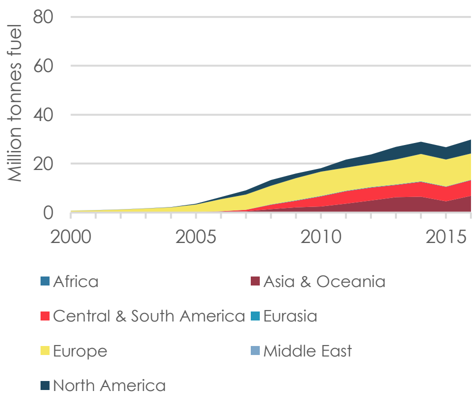

Figure 2: Growth in global biodiesel supply since 2000.

While renewable fuel mandates have been broadly successful in increasing the consumption of first generation biofuels, the same cannot be said about the commercialization and deployment of advanced alternative fuels (henceforth AAFs) (1). In 2016, Bloomberg New Energy Finance reported global cellulosic ethanol capacity of 700 million litres – but little of this capacity was utilized [9]. In 2015, only around 2.0 million gallons of cellulosic ethanol and 0.2 million gallons of cellulosic renewable hydrocarbons were produced in the U.S. [10].

From an investment viewpoint, the history of cellulosic biofuel production is one of mothballed plants, dropping share value, unresolved bottlenecks and unmet promise [11]. Expectations for algal biofuel production have been drastically dampened over the past decade due to “exorbitant” production costs [12] and several companies have sought higher value lower volume markets [13]. Power-to-liquids technologies remain limited by high production costs driven by the price of electricity [14]. As shown in 0, to date both voluntary and mandatory targets that have been set for

AAF show no prospect of being met. In 2011, Bloomberg New Energy Finance reported $2.9 billion of investment in next generation biofuels and biochemical – by 2016 this had fallen to $650 million [9].

To quote one commentator writing in Nature in 2017, “A robust second-generation biofuels industry based on inedible cellulosic biomass available as wood, grass, and various wastes was widely expected to be in place by now,” and, “the biofuels landscape today is a pale shadow of what was imagined a decade ago” [13].

Table I: Targets for advanced alternative fuel deployment.

Name	Target	Notes
Renewable Energy Directive	0.5% AAFs in EU transport energy	Unlikely to be achieved in most EU countries.
Renewable Fuel Standard cellulosic standard	16 billion gallons (ethanol equiv.) cellulosic fuel by 2022	Original annual targets missed by orders of magnitude, most current supply consists of biomethane, original targets will not be achieved.
European advanced biofuels flightpath	2 million tonnes of aviation biofuel by 2020	Very unlikely to be achieved, hydrotreated lipids provide only significant volumes.

In short, the government interventions that have been made over the past two decades with a view to commercializing AAF technologies have failed, at least when compared to the dramatic aspirations for the industry that are evidenced by the cellulosic standard under the Renewable Fuel Standard and other ambitious targets. This paper asks whether the design of the policies that have been rolled out in the hope of kick-starting the AAF industry is partly to blame for its underperformance, and presents a novel proposed policy framework that it is claimed could be more effective in delivering commercialization.

2 THE CASE FOR ADVANCED ALTERNATIVE FUELS

Given that there is already a large first generation biofuel market, one question that immediately presents itself is why there should policy makers be concerned with developing AAF technologies? Various answers have been given to this question, and the answer depends somewhat on how one ranks the different potential goals (environmental, social and economic) of biofuel policy.

For the purposes of this paper, the primary advantages of AAFs over first generation fuels are considered to be the following:

1) The potential to deliver significant GHG emissions reductions through the displacement of fossil fuels (2);
2) The long-term potential to be cost competitive with liquid fossil fuels, and less costly than first generation fuels [15];
3) The potential to use materials that have little current value to the ecosystem or economy, and thereby avoid impacts on food and biodiversity [16];
4) The potential to deliver economic value to the rural economy from resources with little current value [17];
5) The potential for some AAF technologies to deliver fuels whose use in existing vehicles and aircraft is not limited by blend walls under fuel quality specifications.

It is taken as axiomatic for the purposes of this paper that the potential to produce AAFs that deliver these benefits exists. Other papers have discussed at length the scale of the resource potential, the sustainability concerns associated with using those resources, and the potential cost of converting those resources to alternative fuels – no review of that literature is attempted here. There are legitimate policy questions that can and should be asked about how the benefits of AAF development compare to the costs (to taxpayers, fuel consumers, fuel suppliers and society in general). For the sake of this paper, the case is considered in which a political decision has been taken that AAF commercialization is a policy goal and any associated sustainability requirements on feedstock acquisition have been put in place. The question then becomes: given that there is a policy imperative to develop an AAF industry, how can a policy mechanism be designed to efficiently deliver that goal?

3 CHALLENGES IN ADVANCED ALTERNATIVE FUEL DEPLOYMENT

In considering what form of policy support might be effective it is important to have an understanding of the barriers that have contributed to the delays in commercializing AAFs to date.

3.1 Technology development

In some respects, the most fundamental barrier to wider deployment of AAFs is that the technologies needed are still in development – and, indeed, will only be optimised at commercial scale through experience of operating commercial plants. Many of the constituent technologies required for AAF production processes are already well understood, but the application to commercial scale remains challenging.

A good example is gasification of biomass followed by Fischer-Tropsch hydrocarbon synthesis. The Fischer-Tropsch process for synthesising hydrocarbons from syngas (CO and H_2) is approaching its hundredth anniversary, and has been applied at commercial scale in the context of coal-to-liquids and gas-to-liquids processes for many decades. Nevertheless, handling the impurities in biomass resources and making the technology cost efficient at a scale appropriate to biomass resources introduce novel challenges to commercial operation. The process for biofuel production has been characterised as at technology readiness level 6-8 [18], meaning that the necessary technologies have been demonstrated but the full system is yet to be demonstrated, especially in an operational commercial environment. Operational difficulties, materials handling challenges and bottlenecks have beset ‘first of a kind’ AAF facilities, and contributed to their limited fuel production to date.

The technological barriers should not be overstated –

the technologies have been demonstrated at pilot scale and the wrinkles could be ironed out given time to learn from experience and an adequately supportive policy environment – but they should also not be ignored. Both the reality and perception of technology risk contribute to making it more challenging to finance AAF production facilities, making investors seek high returns from projects compared to ventures considered less risky [11], [15].

One observer has argued that advanced biofuels policies, "were designed assuming that deployment, rather than technology, was the limiting factor" [13], and that this resulted in policy that was not well suited to the reality of commercialising an industry from scratch. The framework of fuel production mandates, that has been so effective in increasing volumes of production for biofuels that have well-understood production costs, has fallen short when applied to novel production processes not yet commercially applied.

- Policy hypothesis 1**:** AAF policy should be explicitly designed for the context of commercialisation of novel production processes with significant perceived technology risk.

3.2 Capital requirements

The cost profiles of AAF production technologies are generally marked out from the cost profile of first generation biofuel processes by lower operational expenditures at the expense of significantly higher capital expenditures [15], [17], [19].

The defining difference in operational costs comes due to the use of lower value feedstocks. Biodiesel production, for instance, is reliant on the use of lipids that already have significant value in other markets, even in the case of lipids sometimes characterised as 'residues' or 'wastes' [20]. If nothing else, biodiesel feedstocks could be substituted for fuel oil in heating applications, which sets a minimum price for these feedstocks that is already close to the price of diesel. In contrast, AAF technologies enable the utilization of lower value resources such as cellulosic biomass. In the case of wastes that would otherwise incur disposal costs, such as landfill waste, the cost of feedstock may even be negative. If AAF processes are able to deal with the materials handling challenges that come with these materials, the feedstocks may be available at zero or negative cost [17].

The difference in capital cost reflects three related issues. Firstly, AAF production processes are more complex than first generation processes, and thus the industrial equipment required is naturally more expensive, especially for first-of-a-kind plants. Secondly, because of the higher cost of equipment, economies of scale are required to improve cost competitiveness. These economies reduce cost per tonne of output, but further increase the absolute initial investment required for a new plant [21]. Thirdly, the various risks perceived by investors as associated with the sector increase the cost of capital [11]. Project financing therefore becomes a much more fundamental challenge than it is for first generation facilities, especially for first-to-nth of a kind (3) facilities.

- Policy hypothesis 2: supporting investor confidence must be at the heart of AAF policy.

3.3 Market uncertainty

Having managed to raise the capital to construct a new AAF facility, and having dealt with all the technological challenges that are associated with scaling up production at an industrial scale chemicals plant, AAF producers must confront entering an unpredictable fuel market in which they are likely to need two decades of sales at or above production costs in order to recoup investments. Even assuming a firm and long-term policy framework (see next subsection), as with any other business the viability of AAF facilities will be determined by their competitiveness with other market players – in this case a combination of the petroleum industry, the first generation biofuel industry and the rest of the AAF industry.

The AAF industry has little prospect of competing directly on price with petroleum in the near term (excluding policy interventions to impose external costs of GHG emissions on petroleum fuels), and thus AAF producers must compete for space in the government-supported alternative fuels market [15], [22]. Due to the elevated costs of capital and operations for novel technologies, "at present AAF is likely more expensive than many types of first-generation biofuels and faces the particular challenge of high capital costs. Thus, mandates that treat first-generation fuels and AAF equally … will be met entirely or almost entirely with first-generation technologies" [23]. It is therefore important to provide bespoke support for AAFs [16], [24].

Further, even within a long-term defined mandate that gives preferential status to AAFs over first generation fuels, there is always the risk of being outcompeted by lower-cost technologies. In the long term, it is of course necessary to eliminate inefficient technologies in favour of more efficient ones. In the short term, however, the difficulty of predicting production rates and cost profiles for competitor processes and companies is a further barrier to raising capital, especially if the value of support policy may be very sensitive to the level of AAF production. Given annual volume targets that reflect only a handful of operational plants in the early years of an AAF supply mandate with a credit market, one can easily imagine a situation in which having a large competitor facility open six months ahead of schedule could flood the credit market, temporarily collapsing the value of support.

- Policy hypothesis 3: AAF's need to be given specific support not available to first generation fuels.
- Policy hypothesis 4: AAF policy should seek to minimise the sensitivity of the value of policy support to level of supply.

3.4 Policy uncertainty

Uncertainty in alternative fuel support frameworks is repeatedly invoked on both sides of the Atlantic by industrial stakeholders to explain the lack of progress in AAF commercialisation. One commentator asserts that, "slow progress can mostly be attributed to the widely gyrating public policy that injected not only a great deal of uncertainty into the marketplace regarding the future of cellulosic ethanol, but also elevated financial investment risks for the willing investors" [25]. Long term policy certainty is repeatedly called for in recommendations for effective biofuel policy making [23], [26]–[28].

In considering uncertainty, it is important to recognise that it can arise for several quite different reasons. At the most basic level, government may fail to create confidence that a measure has any longevity. For instance, “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” [23]. This type of fundamental uncertainty can be alleviated by adopting policies that have defined and ideally long-term duration, and by adopting policies in ways that are robust against political interference – for instance, a support scheme that is in place for a decade and can only be amended through legislative action may be understood as more robust than a support scheme like the aforementioned tax incentive that must be actively reinstated each year.

Uncertainty can also arise through political opposition to support policies. For biofuel policies, opposition has come on the one side from environmental campaigners concerned about indirect land use change and other sustainability issues e.g. [29], and on the other from vested industrial interests seeking to avoid having [excessive] costs imposed on them e.g. [30]. While some stakeholders would undoubtedly like to see AAF policies set in stone for 15 years and protected from any political interference, this is not realistic when political opponents have legitimate concerns. If AAF policy were to be demonstrated to have politically unacceptable environmental or social impacts, or to cause politically unacceptable increases in fuel prices, any policy no matter how clearly defined would be vulnerable to amendment. It is the opinion of the author that this type of political uncertainty can best be reduced by setting clear, comprehensive and effective rules governing sustainability of feedstock procurement [27], and by including clear measures from the start to manage the costs of compliance so they remain politically acceptable [31].

- Policy hypothesis 5: AAF policy should be set with clear long-term support mechanisms.
- Policy hypothesis 6: Potential sustainability issues for supported AAF technologies should be identified in advance and dealt with effectively.
- Policy hypothesis 7: Cost-containment mechanisms should be used to avoid excessive program costs in future market conditions.

3.5 Understanding the value proposition

As noted above, the challenge of expanding AAF production can be thought of as primarily a challenge of project financing. There are technology developers out there with technologies demonstrated at least at pilot scale, ready to build facilities if only they could demonstrate a strong enough value proposition to bring in investment. This can be simplified in investment terms to the need to convince investors that a project has a positive net present value, given required rate of returns to investment (4).

Given that, at least for first-to-nth AAF facilities, fuel output will not be cost competitive with fossil fuels, showing a positive net present value requires assigning a value to the policy support available in order to bridge the gap between the production cost of the AAF and the price for which that fuel could be sold independent of policy support (i.e. it’s value as an energy carrier). This is, on one level, an easily framed analytical problem – calculate the value of the support mechanisms available, calculate expected production costs, predict future petroleum prices, and compare the three over the course of the lifetime of the plant. In practice this is a rather difficult calculation. Even ignoring the perennial difficulty of predicting oil prices and of correctly forecasting production costs for new processes, depending on the type of policy the value of the support available may be anything but clear.

At one end of the spectrum, some policy mechanisms provide a very clear value proposition. The U.S. Second Generation Biofuel Producer Tax Credit [32] provided a defined incentive of $1.01 per gallon of qualifying fuel supplied. However, this value clarity is undermined by the fact that nobody knew (or knows) how long the credit would be available for, so that while the current value was certain the future value was completely uncertain (and likely to be treated as zero by investors). Providing a potential pathway to value certainty on a longer-term basis, a policy mechanism suggested for AAF commercialisation in California called a ‘contract for difference’ [28], [33] would provide value certainty by guaranteeing to successful bidders that the State of California would provide direct funding for a specified period to close any gap between the expected production cost of AAF and the value of that fuel in the market (including from other policies).

At the other end of the value-certainty spectrum, you have programmes that set targets and allow the value of support to be determined by the market. Under the U.S. Renewable Fuel Standard (RFS), for instance, “RIN [renewable identification number] prices are sensitive to a variety of factors, including constraints on feedstock supply (e.g., drought), concerns about ethanol volumes approaching the ethanol blend wall for gasoline, and importantly, policy developments surrounding the future direction of the RFS program” [28]. In principle, setting an ambitious volume target for cellulosic biofuel under the RFS should have created a guaranteed market in which the value of the D3 or D7 RIN (the AAF credits under the RFS system) would cover the price premium to produce qualifying fuels. In practice, the value of the RIN is variable and is capped by the RFS’s cost containment mechanism, the cellulosic waiver credit [34].

Under the EU Renewable Energy Directive (RED), the value of compliance with the AAF target (0.5% of transport energy by 2020, 0) is even harder to parse. Whereas the cellulosic waiver credit under the RFS (cost containment mechanisms are discussed further below) can be thought of as a defined penalty for non-compliance with supplier AAF targets, which thereby provides an indication of the value of a RIN [11], the EU has 28 Member States, each of which may have a unique implementations of the 0.5% target, may have implemented a lower target, or may not yet have implemented it. The supply of AAFs is also counted double against overall targets for renewables in transport – but this simply doubles the considerable uncertainty on the value of compliance from single-counted biofuels. In any event, the RFS has a defined compliance schedule only to 2022, and the RED only to 2020, making it essentially impossible to come to a clear prediction of the value of these policies for the operational lifetime of an AAF facility. In short, it is difficult to make a clear case for an investor about how much these policies are worth to future production.

- Policy hypothesis 8: AAF support mechanisms should be defined in such a way that producers and investors are able to estimate future value of support.

4 CHALLENGES IN RENEWABLE SUPPORT POLICY DESIGN

The previous section reviewed some of the challenges faced by AAF technology developers in financing commercial scale projects, and considered the implications of these issues for policy design. This section reviews some of the policy decisions and policy design options that regulators are faced with when developing a new AAF support mechanism.

4.1 Balancing cost with outcomes

For any government intervention, one of the most basic questions is how the benefits expected to be delivered compare to the societal costs of implementation. This paper will not attempt to quantify the benefits of AAF deployment and predict the costs, which is left as an exercise for the reader. From a policy design perspective, the basic requirement is for the costs imposed to be proportionate to the benefits sought.

In existing biofuel mandates, cost minimisation is approached in two primary ways. Firstly, by avoiding active choices about which specific technologies and feedstocks to use, policy makers seek to allow the market to choose the most cost-effective compliance options [35]. In principle, given flexibility to choose compliance options to meet an overall target, the market should minimise compliance costs. An important caveat on this assumption is that different policy framing will result in different levels of discounting of future costs and benefits in the market. A policy that provides only short-term confidence will favour short-term solutions, i.e. pathways with lower capital expenditures but potentially higher operational expenditures. To put it another way, the market may choose different compliance options to meet 20 consecutive one year targets than it would to meet one predictable 20 year target; “The long-term risk associated with commercializing new fuel technologies reduces the effectiveness of existing, shorter-term financial incentives and incentives with an uncertain value proposition” [28]. To put it another way, given the wrong sort of policy the market can be expected to fail to deliver compliance options that deliver the best long-term value.

The second standard mechanism to limit costs in biofuel policy is the application of some kind of cost-containment mechanism, i.e. a safety valve to allow targets to be unmet if compliance costs cross some threshold, for instance by allowing a defined penalty to be paid as an alternative to supplying qualifying fuel. Such systems, which effectively cap compliance costs, are discussed further below.

Any support system that imposes fixed targets without some kind of safety valve makes itself open to accusations of imposing unreasonable costs. For instance, the very high nominal cellulosic biofuel targets under the RFS have never been met, but the use of waivers allowed by the legislation has prevented drastic penalties being imposed on fuel suppliers. While some commentators believe the use of these waivers has undermined the investment signal to AAF producers, without some form of waiver it seems certain that congressional action would have been taken to revise down the over-ambitious volume targets set in the original standard, thus adding to political uncertainty.

- Policy hypothesis 9: The maximum potential future costs of an AAF support scheme should be kept well within social tolerance.

4.2 Who pays? Taxpayers vs. consumers

In the 90s and early 2000s, most biofuel support in Europe was given through discounts on fuel taxation [36], while in the U.S. the rapid growth of ethanol supply in the mid-2000s was driven by the volumetric ethanol excise tax credit (VEETC), which replaced previous favourable tax treatments for ethanol [37]. Excise tax exemptions for biofuels in the EU were reported to have reduced tax take by €3 billion in 2006 [36], while VEETC reached a cost to U.S. taxpayers of $6 billion (not including additional tax credits for biodiesel blending) [38]. Under a system of defined tax advantages, the cost to taxpayers increases as supply of eligible fuels increases, and the rising cost to the exchequer of biofuel support in the late 2000s provided the context for a general shift from tax incentives to mandates in both North America and Europe.

Under a mandate, fuel suppliers are required to supply a certain amount of alternative fuel each year (or under credit systems to acquire credits to show they supported the supply of alternative fuels) and are subject to penalty if these targets are missed. The cost of compliance is therefore shifted from the taxpayer to the fuel supplier, and is then expected to be passed through to fuel consumers [39]. In general, the companies obligated in such mandates are the companies currently supplying petroleum fuels to consumers, sometimes with exemptions for niche players and small suppliers. There are several potential advantages to a mandate structure rather than tax incentive structure for biofuel policy.

Environmentally, the most important of these is that a mandate imposes additional cost on fuel consumers, whereas a tax incentive tends to reduce costs. A tax incentive is therefore likely to increase overall fuel consumption, undermining environmental benefits from the policy [40], [41]. Economically, a tax incentive structure is also arguably more likely to result in over-compensation (5) than a mandate, because the value of the tax incentive is set by government rather than by the market. Politically, a mandate has the considerable advantage that the cost to consumers can be hidden within retail fuel prices that are already subject to considerable fluctuation, whereas the budgetary cost of a tax incentive must be explicitly declared [42].

- Policy hypothesis 10: The costs of developing AAF supply should ideally be placed on fuel consumers rather than taxpayers.

4.3 Avoiding over-compensation

As noted above, one of the reasons that alternative fuel mandates with market-determined support value have been increasingly favoured over systems with defined levels of support value is that regulators are keen to avoid ‘overcompensation’ of fuel producers.

Overcompensation describes the situation when a producer receives significantly more value from a support system than is necessary to make the business viable. The European Commission advises that for renewable energy support schemes, “Under the Environmental aid guidelines, Member States can grant investment and/or operating aid to cover the difference between the production costs and the market price of the energy” [43]. One source suggests in the context of EU renewable energy support that overcompensation has occurred if the internal rate of return of a project is more than 10% higher than a reference level [44] – but regardless of the specific definition taken it is clear that policy is inefficient when it results in large windfall profits to producers.

Allowing the market to determine the value of support may reduce the risk of overcompensation, but it does not eliminate it. A review of renewable energy support schemes notes that, “A possible weakness of an obligation system is the overcompensation of low-cost producers. Practical experience to date shows that in Sweden, existing capacity may indeed have received more support than needed from the system” [45]. In the longer term the market should respond to this situation by expanding supply of lower cost fuels bringing the value of support down, and forcing the higher cost producers to become more efficient or close.

While avoiding overcompensation is a reasonable policy objective, the social cost of overcompensation is relatively modest for a small (but growing) industry as compared to an established industry. In the context of commercialising new processes with the intention of delivering very aggressive long-term supply growth it may be that it is better to have a degree of tolerance for overcompensation in the short term and thereby allow excess funds to be recycled into new investments, rather than to focus too much on avoiding overcompensation and thereby create support mechanisms that do not generate enough value to spur investment at all.

- Policy hypothesis 11: The desire to avoid overcompensation should not be allowed to stand in the way of adopting effective policies.

4.4 Target setting

Within an alternative fuel mandate, or comparable systems such as low carbon fuel standards (equivalent to GHG reduction mandates), setting the level of ambition for targets is crucial to determining the overall benefits delivered and costs incurred by a program, and its impact on investment decisions. Setting very ambitious targets makes compliance harder, and may make the average cost of compliance higher by moving the marginal fuel production opportunities up the cost curve. On the other hand, delivering meaningful GHG reductions to meet international goals requires largescale supply and aggressive growth. It is argued that setting firm and ambitious AAF targets well in advance is crucial because, “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” [23].

Part of the interest in setting specific volume targets well in advance comes from the desire to provide market certainty, but it is also informed by the need at the jurisdictional level to develop a portfolio of policies that delivers on overall climate change targets. The European Union, for instance, relies on transport renewable fuels to contribute to overall renewable energy targets, and for renewable energy supply to contribute to overall climate targets [46]. Stating a precise level of volume supply requirement for 2030 has the prima facie appeal of precisely defining what those contributions will be.

For AAF programmes in particular, the task of target setting is made difficult because of the inherent unpredictability of fuel supply growth. As noted above, existing targets have failed to be matched by supply growth. For an embryonic industry, slightly different assumptions on growth rate can lead to very different supply outcomes a decade or two decades hence [47].

The U.S. EPA has struggled to set achievable cellulosic volume targets one year at a time under the RFS (6), so it should, perhaps, not be surprising when regulators have difficulty pre-empting long term production volumes. The upshot of this is that while there is a strong desire to set firm targets a long way in advance and assume they will be met, experience teaches us that where AAFs are concerned the world is more complicated than that.

It is one of the central contentions of this paper that when attempting to develop a new AAF industry more or less from scratch, it is more important to provide fuel producers with confidence about the value of support available than about the size of the future market (7). The value of a large target to a potential AAF producer is that it increases confidence that there will be a future market available for their product at the necessary price. It is argued that such confidence can be better developed by using policy tools that retain a degree of flexibility about AAF supply a decade out.

In the case that AAF can be produced sustainably and at a reasonable price, there is a clear case to deliver very large volumes to assist in meeting 2050 climate targets. It would therefore seem to be irrational to purposefully constrain the rate of development should the market start to grow faster and at lower cost than expected. Equally, in the case that the production cost of AAF is higher than expected and fails to reduce in line with predictions, it would seem entirely reasonable to allow the volume of production to expand more slowly (and indeed to reassess the role of AAF technology in meeting climate targets). The novel AAF support mechanism described below is therefore based on the idea of predictable support value and delivering market growth, rather than meeting exactly long-term targets.

- Policy hypothesis 12: Setting exact long-term supply targets for fuels that are not yet commercialised creates the conditions for policy failure.

4.5 Credit markets and flexibility mechanisms

It is not necessary that a biofuel mandate should be accompanied by a market in tradable credits. In several EU countries, it is incumbent on fuel suppliers to comply with mandates only through supplying fuels, without access to the flexibility provided by credit markets.

Nevertheless, in jurisdictions including the U.S. (federal), California and the UK, as well as under the aviation sector’s CORSIA [48] compliance with alternative fuel requirements is to be demonstrated through the redemption of tradable credits, effectively allowing obligated parties to pay other operators to supply alternative fuels for them.

The goal of a credit trading option is to provide additional flexibility for the market to determine the most efficient way to meet policy goals. For instance, if the market decides that a large amount of AAF should be supplied in the south of a country and none in the north, then better to allow the inconsistency (subject to fuel quality legislation) than to force suppliers to even out the supply with no net environmental benefit. Similarly, if one obligated fuel supplier is also a market leader in AAF production, it may be more efficient to allow that supplier to generate excess credits and sell them into a credit market, than to try to force all suppliers to make comparable investments. A credit market can also add transparency to the value of AAFs. Within a credit market, the value of a unit volume of AAF can be approximated as the sum of its value as an energy carrier plus the value of one unit of compliance credits. In the absence of a credit trading market, AAF producers may find it more difficult to establish the true market value of their fuels. A credit market can also be combined with a degree of temporal flexibility with a view to reducing overall compliance costs. Under the California Low Carbon Fuel Standard (LCFS), for instance, producers are allowed to bank excess credits earned in years with a higher alternative fuel supply relative to targets, and spend these banked credits to comply in years with a lower alternative fuel supply relative to targets. A similar allowance is made under the UK Renewable Transport Fuel Obligation (RTFO). Adding flexibility to the compliance market reduces the risk of cost spikes in the event of production bottlenecks, and allows fuel suppliers to seek the most cost effective compliance strategies over the lifetime of a program, rather than only year-on-year [49]. Introducing a credit market may also give AAF producers flexibility to prioritise near-term cashflow over total value. If credits are awarded at the point of fuel supply, fuel producers have the option to either sell them immediately for cash or to bank them in the hope of better returns at a later date.

- Policy hypothesis 14**:** tradable credit markets add flexibility to AAF support systems that can be valuable to AAF producers.

4.6 Price floors and caps

Several existing biofuel mandates include some form of cost-containment mechanism so that obligated fuel-suppliers are not subject to prosecution or excessive penalties in the event that the market is unable to supply the required alternative fuel at acceptable prices. An analysis showing the benefit of effective cost containment notes that, “Because most renewable energy mandates rely on advances in new technologies, a binding mandate may lead to situations with exceedingly high short-run compliance costs. As a result, cost containment provisions can play an important role in preventing short-run increases in compliance costs…[and] can substantially increase the efficiency of renewable fuel mandates” [50].

Existing cost-containment mechanisms include the RTFO buy-out price in the UK, the credit clearance market under the LCFS in California, and the cellulosic waiver credit for the cellulosic mandate under the U.S. federal RFS. The RTFO buy-out is a simple mechanism whereby obligated parties can pay to comply as an alternative to supplying renewable fuels [51]. It becomes economically rational for obligated suppliers to pay the buy-out price if the cost of alternative fuels ever rises higher than the cost of fossil fuels plus the buy-out (or if there were structural barriers such as a blend wall preventing available alternative fuels being supplied to the target volumes).

The credit clearance market under the LCFS is a slightly more complicated system. Within this system, obligated parties unable to meet their obligations at year end from their own banked credits are required to purchase any available credits from other parties, at or below a prescribed clearance price (8). This provides a guarantee to credit generators that their credits will be bought in the event of a short market. Any compliance obligation that cannot be met after the clearance market is then banked on the obligated supplier’s account as a deficit (subject to interest) and carried into the following year [52], [53].

The cellulosic waiver credit system under the RFS is somewhat different in that it effectively allows an obligated supplier to ‘convert’ their cellulosic obligation into an advanced (9) biofuel obligation [34], by purchasing one cellulosic waiver credit from EPA to allow an advanced RIN to substitute for a required cellulosic RIN. The price of the waiver is defined in the statute as whichever is higher between 25 ¢ and $3 minus the price of gasoline. The combination of the waiver provision and the annual shortfalls in cellulosic fuel supply make the price of a cellulosic waiver credit, and therefore marginal value of a gallon of cellulosic fuel over a gallon of advanced fuel, relatively predictable. Some commentators have argued that the waiver provision is a primary reason for the failure of the RFS to drive target levels of AAF investment, “The low waiver price is largely responsible for the failure of the current biofuel policy to stimulate cellulosic ethanol market development” [54]. When the value of the waiver is added to the price of an advanced RIN and added to other incentives for AAF supply, however, it can be demonstrated that given the value from RFS an ethanol equivalent gallon of cellulosic fuel should be worth at least $3 [11]. Add in the value from other U.S. incentives such as the LCFS and the second generation tax credit, and arguably the potential value of a gallon of cellulosic fuel has been over $5 for much of the decade, even with the application of cost containment. If investors had confidence that that price was achievable over the lifetime of an investment, one would have expected to see more capacity come online, so it seems reasonable to conclude that investors haven’t had confidence in the support on offer.

One approach that has been mooted in some jurisdictions to provide additional investor certainty is the introduction of a floor price for credits within biofuel mandates. The imposition of a price floor would, in principle, provide investors with an indication of the minimum value that would be provided by a support mechanism, thus significantly reducing downside risk for AAF production. Implementing such a floor, however, is difficult within a biofuel mandate that is designed to allow the market to set credit prices [55]. One option to set a price floor that would be relatively simple would be for the authority implementing a biofuel policy to guarantee to buy credits at a certain price. These could then be retired by the authority, or else banked and offered for later resale to obligated parties at a higher guaranteed price. The former approach would add more tension to the market, but the latter would allow for the system to be potentially self-financing. While such a system is possible, there is generally political resistance to regulators taking on such a role, especially if there is the possibility of significant expenditure commitments. It is difficult, however, to impose a minimum price on transactions between private operators, not least because the price of credits may often be bundled with the value of fuel in private transactions. The situation for biofuel policy is different to the situation for cap and trade policies, where it government can easily set a minimum price on allowances [55]. To date, the author is not aware of a biofuel mandate under which a price floor has been implemented.

While price floors are challenging politically and practically, it is clear that there is the potential to improve the value certainty offered in biofuel policy by reducing the risk of very low support value. The novel framework presented in this paper approaches this problem by suggesting a system of defined charges levied on obligated parties with the money raised being recycled to credit holders.

- Policy hypothesis 15**:** Investment in AAF can be accelerated by reducing downside risk.

5 CONFIDENCE, UNCERTAINTY AND DISCOUNTING

Existing incentives for AAF production have not delivered the progress desired, but this has not been for want of trying. For instance, a 2013 study noted that the value of U.S. AAF incentives in place at the time, "greatly increases the theoretical market value of an alternative fuel relative to its baseline sale price. In the case of cellulosic ethanol, for example, the combined value of the LCFS credits, RINs, and production tax credits increases the value of a given gallon of cellulosic ethanol to as much as $5 per gallon" [28]. The fact that these incentives failed to deliver a level of investment consistent with their prima facie value was put down to the associated uncertainty regarding the future value of these incentives: "investors discount the nominal value of incentives, and so the de facto value of cellulosic ethanol is much lower for the purposes of investment calculations."

The author is not aware of any published analysis detailing an analytical framework used by investors for valuing future alternative fuel policy, but anecdotal evidence suggests that investors apply aggressive discounting when assessing the value of incentives when assessing net present value of AAF projects. In some cases, such as the second generation biofuel producer tax credit, it is believed that the potential value from AAF support policy is effectively discounted to zero in business case assessment. Mobilising investment is therefore arguably in large part a question of reducing the discount rates explicitly or implicitly applied to the value of biofuel support policy. There is a significant risk of a cognitive dissonance between regulators and investors if policy decisions are based on an assessment of the value of support that does not take into account likely discounting in real investment decision making.

This process of discounting of future policy value when taking investment decisions plays a central role in undermining the achievement of true technology neutrality in alternative fuel support policy. Take the U.S. example detailed above, under which the value of cellulosic biofuel production may be as high as $5 per gallon of ethanol. Any facility already operational (such as the biogas facilities that currently generate most cellulosic RINs) has a clear incentive to maximise production, provided this can be done at an operational cost of less than $5 per ethanol gallon equivalent. The production decision can be made based on current value – when the fuel value is above production costs, the plant can run, whereas should the fuel value fall below production costs, production can be reduced. In contrast, an investment in a new high capital expenditure facility will only be made if there is confidence that the value of the output AAF will consistently be higher than production costs, even after discounting the value of policy. A policy framework that provides a $5 per gallon price signal to existing plants may therefore effectively provide only a $2.50 per gallon price signal to investments in new AAF technologies. Because of this discounting, AAF technologies that are potentially cheaper than first generation technologies over the lifetime of an investment may still not be pursued – hardly a technology neutral outcome. To the extent that policy uncertainty drives up required rates of return sought by investors and therefore increases the cost of capital to AAF projects, it also undermines the contribution of AAF deployment to rural development goals. A higher capital cost means that more income from a successful AAF project will be siphoned off to repay investors, leaving less to be returned into the rural economy.

6 PRINCIPLES FOR SUCCESSFUL COMMERCIALISATION POLICY DESIGN

Based on a consideration of the issues introduced above, and of policy design principles identified in previous literature, the following is suggested as a list of key principles for designing effective advanced alternative fuel policy.

1) Provide a clear value signal [15], [28]
2) Provide some form of tradable credits [35]
3) Provide long-term support [23], [26]–[28]
4) Avoid direct competition with low capex alternative fuel pathways [15], [23]
5) Be robust against underachievement of targets [31], [35]
6) Be robust against overachievement of targets [35]
7) Deal with sustainability issues upfront [23], [27], [35]
8) Provide complementary support for technology commercialization [26], [35], [56], [57]

7 DEFINING THE ADVANCED ALTERNATIVE FUEL SUPPORT OBLIGATION

In the introductory sections of this paper, a range of issues facing AAF development, and afflicting the effectiveness of existing AAF support policies, were discussed. In this section, a novel support framework is proposed, which it is claimed could provide significantly enhanced value confidence to AAF investors and thereby deliver better policy outcomes than simple mandates for the same nominal level of regulatory commitment. This framework is referred to as an Advanced Alternative Fuel Support Obligation, or AAFSO. The precise delineation of which fuels should be counted as AAFs and made eligible for support under an AAFSO is (in part) a political question to be determined by the appropriate authorities in any jurisdiction seeking to introduce an AAFSO. It is intended that an AAFSO would be used specifically to support the deployment of high capital expenditure new technologies in need of commercialisation, and it is hoped that such support would be predicated on appropriate assessment and demonstration of net climate benefit and sustainability.

7.1 Credit award

Under the AAFSO, as under existing biofuel mandates, Advanced Alternative Fuel Credits (AAFCs) would be awarded for either the supply or production of eligible AAF fuels. The choice of production or supply as the point of credit generation will depend on administrative considerations. Crediting at the point of fuel supply to market has the advantage of running in parallel with existing excise duty reporting requirements.

Crediting at the point of production has the advantage that it awards credit directly to the fuel producer, rather than relying on value pass through from a third party fuel supplier to the AAF producer. The unit of production is similarly an administrative choice – for instance whether to award credits by volume of fuel or by energy content. Fuels such as electricity and hydrogen could readily be included within the AAFSO framework, subject only to setting an appropriate relative credit rate (based for instance on energy content, or potentially energy content modified by drivetrain efficiency).

7.2 The support obligation

The value proposition under the AAFSO would derive from an annual obligation on fuel suppliers (10) to support the supply of AAF by purchasing a share of the AAFCs produced in that year proportionate to the amount of obligated fuel they had supplied.

$$\mathit{Obligation\ to\ buy\ credits} = \mathit{Total\ credit\ supply}\ x\ \frac{\mathit{Fuel\ supplied\ by\ supplier}}{\mathit{Total\ fuel\ supplied}}$$

For instance, if one single fuel supplier supplied half of all the transport fuel in a jurisdiction, that supplier would incur an obligation to support the production of AAF by purchasing half of the credits available on the market. This provides a slightly different framing to the legal obligation on fuel suppliers in traditional biofuel mandates. Under the AAFSO, the formal obligation is not to deliver a certain amount of AAF, but to provide financial support through credit purchase to producers of AAFs (11).

Notice that the obligation to purchase credits is defined not in absolute terms (a volume target for each operator, as in existing biofuel mandates) but as a fraction of credits produced. Under the AAFSO, therefore, all credits must be purchased, regardless of the total number generated. Clearly, such a potentially unlimited credit purchase obligation would be controversial without taking measures to limit the cost burden placed upon fuel suppliers. The obligation on fuel suppliers to buy credits must therefore be associated with an overall annual supply target and an annual target price for credits, both of which should be set by the relevant regulator, ideally well in advance. The combination of this supply target and price target would set a defined cap on the cost of the support obligation to fuel suppliers.

7.3 Targets for supply and value

The overall annual supply target should reflect the amount of AAF that the regulator intends to be supplied in each year of the obligation. The target price should reflect the cost of support that the regulator considers it appropriate to impose on fuel suppliers, and ideally should be set at a level consistent with making the first generation of cellulosic fuel production financially attractive. In the case that the actual production of AAF was less than or equal to the annual supply target, then fuel suppliers would be obliged to buy all available credits at the target price, on a pro rata basis. However, should the supply of AAF exceed the supply target, the credit purchase price would be scaled down in proportion to the actual level of supply in that year.

$$\mathit{Purchase\ price} = \mathit{Target\ price}\ \times \min\left(1, \frac{\mathit{Annual\ supply\ target}}{\mathit{Actual\ credit\ supply}}\right)$$

The total cost to the fuel suppliers (and hence fuel consumers) of the AAFSO would thus be firmly capped.

$$\mathit{Cost} \leq \mathit{Target\ price}\ \times\ \mathit{Annual\ supply\ target}$$

Should the number of credits generated be double the supply target, then the required purchase price would be halved. Regardless of the amount of AAF supplied in the year, the overall program cost could thus not rise above the maximum limit. The market, however, is still given a role – given confidence in the incentive, the supply of AAF can be expected to increase until the credit purchase price reduces to the marginal cost of fuel supply (12). The AAFSO thus prioritizes continuing to expand the AAF supply over the possibility to deliver target supply volumes for a marginally reduced cost. The AAFSO is designed so that the value of credits cannot start to fall until the market has developed to such a degree that total available AAF supply exceeds annual targets, i.e. so that there must already be several facilities operating successfully before there could be even a marginal reduction in support value from the policy.

7.4 Enhanced certainty

By clearly defining the AAF support payments required from obligated companies, the AAFSO provides a clear value signal to AAF producers. By relating the required purchase price to the total amount of AAF supplied, the AAFSO ensures that the value of the incentive would not collapse in the case that supply grows more quickly than anticipated (an outcome that should be considered a success, but that could be very challenging for AAF producers under a simple mandate structure). By obliging fuel suppliers to support all the AAF produced, rather than making them directly responsible for meeting a target, the AAFSO avoids imposing politically unsustainable penalties on fuel suppliers in the case that industrial deployment is slower than anticipated. By making the total cost of AAF support relatively predictable, the AAFSO allows policy makers to gain a clearer understanding of expected cost vs. benefit for the policy.

7.5 The in-year and end-of-year markets

The support obligation would need to be resolved at the end of the compliance year. At that point, some parties would hold credits, and some would have purchase obligations. In some cases, an obligated party may already hold credits as well as having generated a purchase obligation. The simplest way to manage the system would be to have a central automated broker allowing obligated parties to purchase additional credits up to their obligations, and transferring those funds automatically to the parties surrendering credits. Credits already held by obligated parties would be cancelled against their pro-rata obligations. Penalties would be appropriate for late payment of support obligations

In addition to the end of year market, it is suggested that credit trading should be permitted through the year to add additional flexibility to the system. This would primarily serve the purpose of allowing fuel producers to achieve positive cashflow up to 12 months earlier than through the end of year market, presumably by selling at a discount. It would also allow obligated parties to negotiate favourable terms for credits with fuel producers, for instance in exchange for offtake agreements. Parties trading during the year would shoulder the risk associated with the possibility of credit values being reduced (or increased) due to a stronger-than or weaker-than expected market – but this risk is still much less than that shouldered in more volatile existing credit markets.

8 COMPARISON OF CHARACTERISTICS OF AAF SUPPORT POLICIES

Table II: Review of characteristics of types of alternative fuel support policy

	Volume mandate	Volume mandate with credits and cost containment	Tax incentive	AAFSO
How value of fuel is determined	Fuel value + value to obligated party of compliance	Fuel value + credit value (up to cap)	Government sets value of incentive	Government sets target price for credits
How compliance/ credit value is determined	Obligated parties balance risk of non-compliance versus desire to minimise costs. Theoretically, ‘compliance premium’ reflects marginal compliance option.	If supply is adequate with credits below price cap, same as volume mandate. If supply is limited or marginal cost of compliance high, credit price floats to the cap price.	Government sets price at value considered to balance cost against benefit	Government sets price at value considered to balance cost against benefit
Volume supplied	Should match mandate	Will match mandate unless cost exceeds cap price, in which case obligated parties will ‘buy-out’ instead	Unlimited – as much as can be delivered at support value	Unlimited – as much as can be delivered under adjusted credit price
Cost (borne by consumers/ obligated parties)	Unlimited – Whatever is necessary to achieve volume	Capped – Up to target volume x credit price cap	Unlimited – Volume of fuel produced x value of support	Capped – up to annual supply target x target credit price
Implication of under-supply	Targets are missed. Obligated parties cut off fuel supply or face fines/legal action.	Transfer of funds to buy-out. Can be presented as an extra tax on fuel consumers.	Reduces both cost and benefits of scheme	Reduces both cost and benefits of scheme
Implication of over-supply	Compliance premium falls towards zero. Fuel must be sold close to or even below value of embedded energy. Producers face losses.	Excess credits cannot be sold. Price of credits drops very low. Producers likely face losses.	Scheme becomes very expensive. Producers well supported.	Scheme delivers added benefits at no increased cost. Producers receive reduced but still significant rate of support.

9 DIFFERENTIATING SUPPORT IN AN AAFSO

The details of the AAFSO laid out above assume that every unit of eligible fuel is equally rewarded under the scheme, one credit per unit of supply. In this case of an AAFSO with no internal differentiation, all policy judgement about the value of specific production pathways for alternative fuels must be included in the eligibility criteria to identify which fuels are to be counted as AAFs. It may also be desirable to consider a type of AAFSO in which further differentiation between fuels were to be permitted. This might include providing more generous incentives for fuels that are considered to deliver larger GHG emissions, more generous incentives for fuel pathways that involve land rehabilitation, or more generous support for fuel pathways that demonstrably avoid interfering with existing supply chains (i.e. avoid indirect emissions). The precise details of which policy goals could or should be supported through enhanced support are beyond the scope of this paper, but it is possible to suggest mechanisms through which such support could be provided, and two such possibilities are detailed below.

9.1 Differentiated incentives through multiple counting

One approach that could be adopted to provide enhanced support for AAF pathways considered more beneficial would be to offer the possibility of generating more than a single credit for such fuels. This approach would be analogous to existing incentives for AAF supply in the European Union under the RED, where fuels produced from cellulosic materials are eligible to be counted twice towards renewable energy targets. Multiple crediting provides considerable flexibility, as the rate of multiple crediting could in principle be readily varied to any level of precision to allow either a very coarse or very granular differentiation of levels of support to different AAF pathways. Multiple counting does not add significant additional complexity to the AAFSO system, as once credits are awarded the in-year market and end-of-year processes continue as detailed above. Multiple crediting would not affect total cost of the system to fuel suppliers and consumers. The disadvantage of multiple crediting is that a larger level of production of the 'best' AAFs would result in reductions in the value of each AAFC in the case that the number of AAFCs generated exceeds the annual supply target. In an extreme case, if the full supply target were met using a double counted AAF pathway, it could halve the required purchase price per credit. The value of multiple counting under the existing RED has been questioned by stakeholders [58], although this criticism may in part reflect the considerable uncertainty associated with future RED compliance, and the idea that multiple counting multiplies value uncertainty.

9.2. Differentiated incentives through variable target price

An alternative approach to differentiating support under an AAFSO would be to award different types of credit for different AAFs, each with a separate target credit price, but under a single combined annual supply target. In this approach, during the end-of-year reconciliation process each obligated fuel supplier would acquire a support obligation on a pro rata share of the credits generated in each of the different price categories. This approach has the advantage over the multiple counting approach detailed above that increased supply of the AAF pathways considered best performing would never reduce the purchase price for credits. The flip-side of this advantage is that the use of a split market of this sort would introduce a degree of uncertainty into the overall cost of the program. The maximum cost to fuel suppliers/consumers would now become:

$$Cost \leq Highest\ category\ target\ price \times Annual\ supply\ target$$

To again consider an extreme case, if all AAF was supplied in a category with twice the 'standard' target price, the cost of the program would be double what it would be if al AAF was supplied in the standard category. While this additional cost ought by hypothesis to be associated with an additional benefit, cost increases compared to expectations could potentially undermine political support for the programme. Introducing multiple credit categories could also be seen as introducing additional complexity for obligated parties.

Whichever approach to value differentiation were to be implemented, creating only a modest differentiation in value would likely be less disruptive to the programme than implementing large differences in target price or crediting rate.

10 THE ELEPHANT GRASS IN THE ROOM – A NOTE ON FEEDSTOCK SUPPLY

Many AAF technologies require a large supply of cellulosic or ligno-cellulosic material. It is often assumed that use of such materials for bioenergy is intrinsically more sustainable than the use of higher value materials (sugars, starches, oils) from food crops, but this may not always be the case. Growing energy crops has land use implications just as growing food crops does, although it might be expected that associated ILUC emissions may be lower for cellulosic crops [59]. Similarly, removing residues that would otherwise remain in place or that have existing uses can raise sustainability issues [20], [60]. An AAFSO could be implemented without associated sustainability governance rules, but it is strongly recommended, both for minimising negative impacts and for reducing political instability, that any AAFSO should include robust controls on sustainability of feedstock acquisition [61].

11 CONCLUSIONS

Despite high hopes, the development of advanced alternative fuels (AAF) technologies, notably cellulosic biofuels, has lagged dramatically behind policy aspirations from a decade ago. This deployment failure reflects a number of external factors, and technology challenges in commercialising new processes, but also reflects policy frameworks that have been ill suited to purpose. Existing mandates and tax incentives have singularly failed to deliver the level of future value certainty that is necessary to allow investment in high capital expenditure facilities that are perceived to be associated with high technology risk, with the result that the expected future value of incentives is significantly discounted when making investment decisions.

This paper outlines a novel policy framework for AAF commercialisation support, the Advanced Alternative Fuel Support Obligation, or AAFSO. By setting a defined target price for credits awarded to AAF producers, the value uncertainty of market-based mandate programmes is avoided. Under the AAFSO, there is no possibility of excessive compliance price spikes due to undersupply of AAFs. By allowing the set value of support to be reduced proportionately if more AAF is supplied than the target for a given year, the total cost of the programme to fuel suppliers and consumers is capped, removing a source of political instability in existing tax incentive programmes. By allowing the market to increase the AAF supply past the set annual target without risking a collapse in the value of the incentive, the AAFSO avoids placing arbitrary limitations on the expansion of an industry that government intends to grow dramatically in the longer term. The value proposition to AAF producers is thus made much more predictable than in existing mandate schemes, whether supply targets are under-achieved or over-achieved. It is claimed that such a system has the potential to deliver significantly more rapid commercialisation of AAF supply, at an expected cost to consumers no higher than that of existing programmes.

12 NOTES

(1) The usage of terms such as 'first generation', 'second generation' and 'advanced' to describe parts of the biofuel industry is perennially complicated by the lack of any universal convention. Within this paper, 'first generation' refers to biofuels produced by conversion of higher-value molecules such as oils, starches and sugars that have alternative uses as food or feed, while the term 'advanced alternative fuels' is used to refer to alternative fuels (not necessarily limited to biofuels) that are produced using less established technologies from lower value molecules, such as lignocellulose. The main first generation technologies within this terminology are fermentation, transesterification and lipid hydrotreating. Advanced alternative fuel technologies could include (but are not limited to) cellulose hydrolysis for fermentation, pyrolysis with upgrading, gasification with Fischer-Tropsch synthesis, algal biofuel production, carbon monoxide synthesis, power-to-liquids and hydrothermal liquefaction.

(2) The question of the GHG emissions benefits delivered by different biofuels, and how AAFs compare to the better performing first generation fuels, is a vexed one that cannot be resolved in this paper, and the GHG intensity of AAF production will be sensitive to production processes and feedstock choices. The central contention is that when feedstock harvesting and processing are dealt with appropriately, it is possible to deliver AAFs with very low GHG intensities, even when considering CO2 emissions associated with carbon stock changes in biomass and soils [62], [63].

(3) By 'first-to-nth of a kind' plants, we mean the first set of AAF production facilities using a given technology, the successful operation of which will enable operational learning an deficiency improvements for future facilities, and convince future investors that the AAF technology in question has a lower risk profile than previously perceived. 'nth of a kind' plants can then be built with lower capital and operational expenditures, and lower cost of capital.

(4) To focus solely on a concept such as net present value is a simplification, but hopefully a useful one. Real world investment decisions are affected not solely by balance sheet calculations at the project level, but also informed by consideration of broader prospects for the industry and other subjective factors brought to the table by the individual investor or institution. Still, showing a positive prospective balance sheet can be thought of as a *sine qua non* for mobilising AAF investments.

(5) Overcompensation refers to the case that the value of public support for supplying an alternative fuel is disproportionate to the actual marginal cost of supplying that fuel. For example, if a $1 per gallon tax credit is offered for a fuel that has a production cost only $0.50 above the wholesale fossil fuel price, producers of that fuel would arguably be being overcompensated by $0.50. Overcompensation increases the cost of policies to society, and can become a barrier to good policy-making by creating a strong and well financed vested interest in favour of preserving excessive incentives to incumbents.

(6) It should be noted that while there are obvious advantages to predicting supply one year hence rather than ten years hence, it can also be argued that the very process of annual revisions to the cellulosic standard under RFS has inhibited investment, putting EPA in the unenviable position that setting targets low may prevent the investment needed to meet even a low target, whereas setting targets high will lead to accusations of over-optimism and putting excessive costs onto industry.

(7) Recognising that these are not independent variables – higher support value will generally contribute to meeting higher targets, while a higher target will generally contribute to a higher value of support.

(8) A sale below the clearance price might occur in the case that the obligated supplier was willing to enter into some complementary agreement, for instance for offtake or investment.

(9) In the RFS, the term 'advanced' biofuel refers to any fuel other than corn-ethanol assessed by EPA as delivering a 50% or better carbon saving, and thus in practice covers almost all biofuels supplied in the U.S. except corn ethanol.

(10) The term, 'fuel suppliers' is used to refer to the companies putting fossil fuels, and often renewable fuels, into the transport fuel market. The precise mode of definition of a fuel supplier may differ by jurisdiction, for instance under the UK RTFO the party owning transport fuel as it crosses the duty point incurs an obligation. The obligation of each fuel supplier could be made proportional to fossil fuel supply only, or to total supply of all liquid fuels.

(11) This might in some jurisdictions introduce complications related to whether the AAFSO has the legal character of a tax. Such administrative issues are of great importance to the effective implementation of a scheme, but are not considered in this paper.

With the caveat that given the relatively long turnaround to bring a new facility into operation, there is a limit to how quickly a growing AAF market can react to market signals.

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15 LOGO SPACE

Cerulogy