California Low Carbon Fuel Standard
Rethinking Decarbonisation Incentives – Policy Case Studies
California Low Carbon Fuel Standard

This case study has been developed for the UK's Energy Systems Catapult under the Rethinking Decarbonisation Incentives project, aiming to draw lessons from international experience of policies to improve the framework of economic drivers for decarbonisation in the UK.

The Californian Low Carbon Fuel Standard (LCFS) is a market based mechanism with a strong economic incentive at its core. It combines an obligation to reduce the greenhouse gas (GHG) intensity of transport fuels with a credit / deficit trading mechanism for regulated parties. Lessons from the development and use of such a mechanism can be applied more broadly to other sectors.

This case study examines the key design factors that were implemented, the governance of the programme and how it is administered practically. The LCFS suffered from law suits filed against it and these are explored along with the revisions that were made as a result. Finally, the successes of the LCFS are reviewed.

Key findings

- Creating a stable price signal is key to stimulate investments in low carbon intensity (CI) fuels. Price volatility in the LCFS was reduced with the addition of a cost containment mechanism, which provided another compliance option should there be a shortfall in credits. Price volatility also occurred as a result of legal issues, which reduced confidence in the LCFS.

- The price signal needs to be high enough to pay back investment in advanced technologies. Low credit prices seen in the early phases of the LCFS were related to the legal issues that reduced confidence in the future value of banked credits. As the CI standards have become more stringent, the price of credits has increased in line with expectations about future compliance costs.

- The use of life cycle analysis (LCA) fully accounts for all GHG emissions of a fuel, nullifying emissions leakage. However, use of LCA is a contentious issue, especially regarding indirect land use change (ILUC) from biofuels. The LCA calculations for the LCFS have been amended taking into account stakeholder concerns, as well as advances in the science behind ILUC and other LCA issues. This highlights the importance of ensuring that any LCA measure is robust and that stakeholders are consulted in the process of implementation.

- Interactions with other political objectives, such as air quality, must be considered. Recent challenges to the LCFS have arisen due to the NOx emissions that would arise from increased bio-diesel and renewable diesel usage.

- The price signal is hidden from the consumer, which limits the extent to which the LCFS can directly act on the demand-side. Fiscal policy has therefore been used to complement the LCFS in order to drive consumer uptake of certain technologies.
Abbreviations

CAPA  California Administrative Procedure Act  
CARB  California Air Resources Board  
CEQA  California Environmental Quality Act  
CI  Carbon intensity  
ETS  Emissions trading scheme  
ILUC  Indirect Land Use Change  
GHG  Greenhouse gas  
GREET  The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation  
GTAP  Global Trade Analysis Project  
LCA  Life cycle analysis  
LCFS  Low carbon fuel standard  
LRT-CBTS  LCFS Reporting Tool and Credit Bank & Transfer System  
OPGEE  Oil Production and Greenhouse Gas Estimator  

Nomenclature

\( t\text{CO}_2e \)  Tonnes of carbon dioxide equivalent  
\( M\text{tCO}_2e \)  Million tonnes of carbon dioxide equivalent

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Policy overview

This case study has been developed for the UK’s Energy Systems Catapult under the Rethinking Decarbonisation Incentives project, aiming to draw lessons from international experience of policies to improve the framework of economic drivers for decarbonisation in the UK.

The Low Carbon Fuel Standard (LCFS) is a technology neutral market tool for the Californian transportation sector to reduce greenhouse gas (GHG) emissions by at least 10% by 2020. The LCFS obligates upstream fuel providers to lower the carbon intensity (CI) of fuels. The LCFS applies to any transportation fuel that is sold, supplied or offered for sale in California\(^1\). Transportation is a key sector in California accounting for 37% of GHG emissions (Figure 1).

![Figure 1 Greenhouse gas emissions by sector in California in 2015. (California Air Resources Board, 2017)\(^2\)](#)

This study examines the design and revisions of the LCFS especially through the institutional and mechanistic arrangements for administering the LCFS. It also covers the success of the LCFS in both providing the desired reductions in the CI of fuels and at delivering a strong and stable price signal to all stakeholders.

LCFS history, legal issues and design revisions

California’s LCFS was created by Executive Order in 2007. The programme was created to help meet state-wide reductions in GHG emissions as required by California’s Assembly Bill 32, The Global Warming Solutions Act of 2006\(^3\). The bill progressed through approval and began implementation April

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\(^1\) California Air Resources Board (2015). Low Carbon Fuel Standard Regulation.


The California Low Carbon Fuel Standard (LCFS) was implemented in 2010 with compliance starting at the beginning of 2011. A timeline of the key moments in the history of the LCFS have ‘been provided’ in Figure 2.

Figure 2. Timeline of key moments in the history of the LCFS.

The key mechanisms in place in the design of the LCFS are discussed in more detail later in the case study but a brief overview is provided here:

- Regulated entities are obligated to produce fuel that matches the CI standard (in tCO₂e) as set for that year by the California Air Resources Board (CARB).
- If a regulated entity fails to match the CI standard, the quantity of the credits or deficits are proportional to the difference between the fuel’s CI and the fuel standard CI.
  - LCFS credits are earned by providing a fuel that is below the CI standard
  - LCFS deficits are generated by providing fuel that is above the CI standard
- To maintain compliance, regulated entities must account for their deficits by purchasing or generating an equal number of credits during the compliance period.
- The CI standard is calculated through a “well to wheels” Life Cycle Analysis (LCA).
- Credits generated can be banked for compliance use in future years.

There were two main issues in the adoption of the LCFS: 1) opposition from the fuel industry; and 2) questioning of the science and uncertainty in the LCA. The fuel industry, especially the petroleum industry, is extremely influential in California. The petroleum industry has continually lobbied against the LCFS as it threatens its market share. The LCA was particularly contentious surrounding Indirect Land Use Change (ILUC), which is a scientific area that is particularly uncertain so presented technical challenges in quantifying emissions.

In 2009 two ethanol lobbying groups, the Renewable Fuels Association and Growth Energy, filed a lawsuit in the Federal District Court challenging the LCFS. They argued that the LCFS violates the Supremacy Clause and the Commerce Clause in the US Constitution. In 2011 a federal judge granted a preliminary injunction against the implementation of the LCFS, to which CARB appealed. The appeal

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was upheld in September 2013 and the LCFS was deemed legal as the intention of the LCFS was not to give the Californian businesses an advantage but to reduce GHG emissions by fully accounting for global warming potential of fuels. If the LCFS had been deemed unconstitutional it would not have been implemented.

CARB originally tried to make the policy relatively simple but as participants tried to generate credits in more varied and innovative ways the need to include more complex rules to the legislation became clear\(^9\). There were amendments in 2011 to help clarify, streamline and enhance certain provisions in the legislation. These improvements were made providing clarification on: the compliance schedule; the process for determining CIs; updating ILUC estimates; and allowing refineries to gain credits for innovative production technologies i.e. carbon capture.

There was another lawsuit in which the LCFS was challenged on the basis that the environmental factors had been insufficiently studied and therefore should be discontinued. The Court of Appeals in July 2013 found there to be deficiencies in CARB’s California Environmental Quality Act (CEQA) review process and required CARB to remedy legal defects in the initial LCFS\(^10\). These technical issues mainly related to the science on which the LCFS was based, particularly the ILUC which had been a contentious issue due to the unfavourable nature in which the LCFS valued corn ethanol. CARB were allowed to leave the LCFS in place during their review of the legislation, with CI levels frozen at their 2013 levels. CARB reviewed and revised the LCFS with stakeholder engagement, especially relating to ILUC and refinery process efficiencies. The LCFS was re-adopted in October 2015 for implementation in January 2016. A revised reduction schedule for CI standards was set which was more stringent due to the previous freezing of the CI standards, so as to still achieve the required reductions by 2020.

The new provisions in the re-adoption were designed to foster investments in the production of low-CI fuels, provided additional flexibility, updated critical information, simplified and streamlined operations and enhanced enforcement\(^11\). A key feature of the re-adoption is the addition of a cost containment feature called “Credit Clearance Market”. This Credit Clearance Market provides an additional route for compliance even in the event of a credit shortfall\(^12\). Those regulated entities that have additional credits to sell inform CARB who sell the credits on behalf of them to those regulated entities that require them at a fixed price for that year (inflation adjusted $200 per credit). The regulator sells the credits on a pro-rata share to those companies that are non-compliant. The remaining outstanding deficits are carried into future years but must be retired within 5 years and have a 5% interest rate on them.

In 2017, there was another lawsuit relating to the NOx emissions that would arise from increased biodiesel and renewable diesel usage. The court found that CARB’s assessment of the 2014 baseline rather than a 2010 baseline failed to define a properly identified baseline\(^13\). The court has allowed CARB to perform another analysis with a properly identified baseline, allowing the LCFS on diesel fuels to continue during the review.

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CARB has recently proposed changes to relax legislation so that the targets have to be met by 2022 rather than 2020. To counter this relaxation of legislation CARB are extending the timeline of the LCFS to 2030 in line with state-wide reductions of GHG to 40% below 1990 levels by 2030.

**Key design aspects and governance**

The California LCFS was initially designed with several principles in mind, such that market forces would act to ensure the efficiency of the scheme:

- Firstly, it is technology neutral, which allows the regulated entities more flexibility in choosing how to comply, as noted below, and to encourage innovation.
- Secondly, allowing for voluntary trading of LCFS credits allows the market to determine the price, based on supply and demand of those credits. The cost of compliance is directly related to the price and availability of renewable fuels relative to conventional fuels, and therefore the key driver is the difference between the marginal costs of renewable and conventional fuels. In efficient conditions, the LCFS credit price will adjust to the point at which the marginal cost of the conventional fuel less the cost of the LCFS deficits are equal to the marginal cost of the renewable fuel plus the value of the credits created.
- Additional flexibilities were afforded to participants in the form of allowing credits to be banked, as well as allowing firms to incur a deficit in some years. These mechanisms were introduced to ensure that firms do not face price shocks.

Traditional fossil fuels i.e. petrol and diesel, typically have high CI and therefore earn deficits, whereas renewable energy sources have low CI and therefore earn credits. To maintain long-term compliance, regulated entities have five options:

1. Purchasing LCFS credits from other suppliers in the market,
2. Producing or blending low CI fuels,
3. Changing production methods of traditional fuels to reduce CI in the supply chain, e.g. carbon capture or sequestration,
4. Banking LCFS credits for use in future years,
5. Reducing production (although this is the most unlikely of compliance pathways).

The availability of different compliance mechanisms allows flexibility for individual entities and for the market as a whole in determining their favoured compliance strategy.

The fundamental mechanism of the LCFS is the ability to calculate the CI of different fuels. Calculating the fuel intensities of conventional fuels is carried out using the open source Oil Production and Greenhouse Gas Estimator (OPGEE) tool developed by Stanford University. OPGEE calculates annual average carbon intensity. For renewable fuels, the CI is calculated through a combination of direct and indirect emissions. For the direct emissions The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) developed by Argonne National Laboratory is used. For indirect emissions (through land use change) the general equilibrium model Global Trade Analysis Project.
(GTAP) is used\textsuperscript{20}. There is significant complexity associated with calculating the CIs and the scientific consensus in the LCA literature is constantly evolving\textsuperscript{21}. CI derived from change in land use are particularly contentious and can change depending on calculation methodology\textsuperscript{22}. The LCFS makes regulated parties use the same tools so that the credits are calculated the same across the regulated area.

To calculate whether credits or deficits have been generated the first equation (below) is used. Each regulated party is required to obtain a fuel pathway certificate to determine the CI of each fuel produced. The CI of each fuel is then multiplied by the energy efficiency adjustment factor of that fuel. The energy efficiency adjustment factor of a fuel is to account for differences in the ability of a fuel to be converted to drive. The quantity of the credits or deficits created are calculated by multiplying the quantity of the fuel (in MJ) by the efficiency adjusted CI. The compliance obligation of a regulated party is the sum of the deficits generated and deficits carried over (the second equation (below)). If a regulated party has no compliance obligation then it has generated credit over that period. Deficits can be carried over for a maximum of five year and incur a 5% interest rate on them.

\[
\text{Credits or deficits (MT)} = ((\text{CI Standard} – \text{CI of Fuel Pathway Certificate}) \times \text{Energy Efficiency Adjustment Factor}) \times \text{Conversion Constant}
\]

\[
\text{Compliance Obligation} = \text{Deficits Generated} + \text{Deficits Carried Over}
\]

CARB set the long-term reductions for the transportation sector in line with the state-wide GHG reductions. CARB acts as a quasi-judicial authority acting with the jurisdiction of the Superior Courts of the State of California\textsuperscript{23}. A key decision for policy makers however, relates to the setting of the CI on a year-by-year basis. The setting of standards is a balance between scientific and political processes\textsuperscript{24}. The stringency of the CI is fixed across the programme length, but the interim prices could be set in a variety of ways to influence the credit price. CARB set the overall reductions and also set the interim CI standard at the beginning of the LCFS so that the CI standard became more stringent towards the end of the policy rather than at the beginning\textsuperscript{25}. The more gradual approach would avoid disruption and allow industry time to adapt, making it more politically palatable\textsuperscript{26}. However, status quo production allowed industry to maintain compliance through to 2013\textsuperscript{27}.

\textsuperscript{23} California Air Resources Board (2015). Low Carbon Fuel Standard Regulation
To prove compliance, regulated parties are required to report progress quarterly and account balancing annually. Reporting is carried out on the CARB website using the online LCFS Reporting Tool and Credit Bank & Transfer System (LRT-CBTS). Responsibility for reporting is solely on the regulated parties. CARB publishes transactions to improve the transparency of the programme and therefore increasing the efficiency of the programme\textsuperscript{28}. If a regulated party fails to report, CARB will consider all relevant circumstances and seek penalties and injunctive relief as permitted by State law. CARB will also seek legal action in the event of reported non-compliance. On the CARB website\textsuperscript{29} there are two out of court settlements and one notice of violation. In communication with CARB, they confirmed that the preferred method is out-of-court settlements as it avoids the expense and distraction of litigation. However, when an out of court settlement cannot be achieved they will litigate against the violating party\textsuperscript{30}. The result of the notice of violation was that the Attorney General filed a lawsuit that imposed a $300,000 penalty. The result of the two out of court settlements were $90,000 and $393,000. Any penalties are deposited in the air pollution control fund, the use of which is limited and needs to be appropriated by legislation before it can be spent.

The LCFS allows indefinite banking of credits across years, in the LRT-CBTS, with the intention of improving efficiency and reducing costs by increasing flexibility. If there are insufficient credits in the market to meet compliance, this can lead to price increases. Conversely, if the credits were not bankable then the surplus credits become valueless, creating price drops\textsuperscript{31}.

One solution to reduce price volatility is the inclusion of a cost containment mechanism, the mechanism has been discussed above. The legislation added the Credit Clearance Market which has given LCFS credit pricing more stability and improving the investment signal to investors. This can lead to increased innovation as investments would be deemed less risky as it places a hard cap on the cost of compliance.


\textsuperscript{29} California Air Resources Board (2018). LCFS Enforcement. Retrieved on 28/03/2018 from \url{https://www.arb.ca.gov/fuels/lcfs/enforcement/enforcement.htm}.


and acts by eliminating the small probability high compliance cost events due to insufficient credits being available to the market\textsuperscript{32}. Cost containment however could reduce the highest pay outs for investors due to the credit price being capped\textsuperscript{33}.

A problem for LCFS are that the emissions in a regulated market can be moved to an unregulated market. This is called emissions leakage\textsuperscript{34}. The California LCFS accounts for this by using LCA therefore accounting for all the emissions relating to the fuel and not just the emissions relating to the fuel that are in-state or during combustion alone. The LCA for the LCFS includes ILUC\textsuperscript{35} i.e. from expansion of land used to grow biofuels. Accounting for this is very important to fairly reflect the impacts of biofuel cultivation; however, this factor is very difficult to calculate with certainty, and has resulted in some controversy.

Although the LCFS targets the fuel suppliers in the transportation sector there are exemptions. Suppliers of fuels that are deemed to have CI below the standard CI as set by CARB through to 2020 are not obligated to be regulated by this scheme but are incentivised to opt in. By opting in they create the opportunity to gain LCFS credits and then sell them, generating revenue. Other exemptions include: military vehicles, fuel suppliers of a particular fuel whose combined fuel production is below 420 Million MJ per year, locomotives, ocean-going vessels (not applicable to recreational or commercial harbour craft) and aircraft. Exemptions on non-road transport are due to the inter-state and international nature of the other modes of transport and therefore fall outside the jurisdiction of CARB.

**LCFS CI reductions**

There has been significant overcompliance in CO\textsubscript{2e} saved in the early years of the scheme\textsuperscript{36}. Between 2011 and 2015 the LCFS has saved 16.8 Mt CO\textsubscript{2e}, which is an overcompliance of 7.4 Mt CO\textsubscript{2e}. If overcompliance continues, then the policy will be more successful in terms of reducing emissions than had originally been planned for. However, overcompliance in a system that allows indefinite banking of credits could be a misleading statistic as the overcompliance has generated credits which will just be retired in future years to meet ever tightening CI standards.

Therefore, despite the level of overcompliance in the early years of the scheme, it is still not certain whether the LCFS will be successful in reaching the carbon reduction targets for 2020. Indeed, it is projected that the CI of fuel in California will miss the target of 10% reduction in CI by 2020 - with the LCFS expected to generate 7-8% reductions in the CI of fuels (with the percentage reduction missed to be met by banked credits)\textsuperscript{37}.

The reductions in CI intensity of the Californian transportation sector have come through increases in alternative fuel use, primarily: biodiesel, renewable diesel, biogas and electricity. Alternative fuels in the transportation sector, by energy content, have increased from 6.2% to 8.1% from 2011-2015\textsuperscript{38} (Table 1). There has also been a 21% reduction in the average CI of alternative fuels from 2011-2015 down from 86 gCO\textsubscript{2e}/MJ to 68 gCO\textsubscript{2e}/MJ\textsuperscript{39}. Table 1 demonstrates that ethanol usage has been relatively stagnant through 2011-2015. The diesel substitutes, biodiesel and renewable diesel, have both had increase greater than a factor of 10 (which is far higher than the national average over the same time period).

Table 1. Total transportation energy use reported in California’s LCFS programme (million gallons of gasoline equivalent).

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>12,948</td>
<td>13,089</td>
<td>12,788</td>
<td>13,093</td>
<td>13,323</td>
</tr>
<tr>
<td>Diesel</td>
<td>3,905</td>
<td>4,026</td>
<td>3,831</td>
<td>3,875</td>
<td>3,884</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1,015</td>
<td>1,005</td>
<td>1,008</td>
<td>1,012</td>
<td>1,038</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>13</td>
<td>21</td>
<td>63</td>
<td>71</td>
<td>133</td>
</tr>
<tr>
<td>Renewable diesel</td>
<td>2</td>
<td>10</td>
<td>127</td>
<td>122</td>
<td>179</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>82</td>
<td>94</td>
<td>100</td>
<td>109</td>
<td>76</td>
</tr>
<tr>
<td>Biogas</td>
<td>1.8</td>
<td>1.8</td>
<td>12</td>
<td>30</td>
<td>77</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.4</td>
<td>1.3</td>
<td>3.6</td>
<td>8.5</td>
<td>13</td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
<td></td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Total alt fuel</td>
<td>1,115</td>
<td>1,134</td>
<td>1,314</td>
<td>1,354</td>
<td>1,515</td>
</tr>
<tr>
<td>Total alt fuel (% of total energy)</td>
<td>6.2%</td>
<td>6.2%</td>
<td>7.3%</td>
<td>7.4%</td>
<td>8.1%</td>
</tr>
<tr>
<td>Non-biofuel portion of alt fuel</td>
<td>7.6%</td>
<td>8.6%</td>
<td>8.8%</td>
<td>10.9%</td>
<td>10.9%</td>
</tr>
</tbody>
</table>


**LCFS price signals**

Given the current state of advanced fuel technologies, large reductions in the average CI of fuels are not possible without significant investment from upstream firms and downstream consumers. For upstream firms, there is a significant requirement for large scale investment in infrastructure, and to further scientific and engineering knowledge. For downstream consumers, there is a requirement for significant personal investment in alternative fuel vehicles.

LCFS credit prices have shown considerable variation since the LCFS credit price is linked to both the current demand and the future expected LCFS credit price. Figure 4 shows that the price signal has been strongly impacted by court procedures. In times of doubt, LCFS credit prices have dropped; in times of confidence the LCFS credit prices have risen. The markets responsiveness to these perceived or actual changes, in both the present and in the future, can lead to price volatility. High price volatility can undermine the underlying policy providing weak economic incentives to all stakeholders. This uncertainty impacted the potential effectiveness of this policy. The key factors that lead to uncertainty in the LCFS are:

- Supply:
  - Production constraints: production can be limited by insufficient investment in the commercialisation of renewable technologies.
  - Insufficient infrastructure to support low CI fuels: infrastructure is typically expensive i.e. sufficient charging point density for electric vehicles, and therefore requires significant investment.
  - Innovation / technological developments: to reach the carbon reduction targets of the LCFS there was need for innovation to drive technological advances.

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advances of this nature are uncertain in relation to successful developments and regarding which technology will achieve these technological advances.

- **Demand:**
  - Consumer preference: consumer preference can dictate the market from "bottom-up" rather than the "top-down" factors relating to supply.

The assumptions about how the market would adapt that were made in the modelling before the LCFS was implemented are significantly different from the assumptions made in current modelling, due to the uncertainty of how the market would adapt\(^{45}\).

![Graph showing daily LCFS credit prices and credit transactions](image)

**Figure 4. Daily LCFS credit prices and credit transactions\(^{46}\)**

Since the re-adoption of the LCFS in late 2015, the consistency of the economic signal has improved. The re-adoption included a cost containment mechanism which has provided more certainty in the long-term LCFS credit value. The LCFS credit price is now more reliable acting as a reliable economic signal to encourage investment.

The LCFS creates an implicit tax on conventional fuel generation that decreases profitability, which in turn acts to discourage their production. It simultaneously provides an implicit subsidy to renewables (through the market price for credits), which acts to encourage their production\(^{47}\). Since companies are profit driven, it is unlikely that these companies will accept a reduction in the profit margins and therefore the cost will be passed onto the consumer\(^{48}\). The LCFS therefore provides an economic signal to both

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the supplier and the consumer, which should drive change in technologies and behaviours and hence lead to substitution of technology from conventional fuels to renewable fuels\textsuperscript{49}.

The explicit signal to the market is the price of LCFS credits. The market price of credits is related to supply and demand, and the cost of compliance. The stringency of the CI standards will greatly impact the quantity and price of LCFS credits. As the CI standard becomes more stringent the price is expected to increase as the marginal cost between the conventional fuels and renewable fuels increases, further strengthening the explicit price signal to upstream investors. Promotum’s analysis shows that a $100 credit value provides sufficient incentive to achieve the desired GHG reductions\textsuperscript{50}. In addition, the ability for firms to bank credits introduces a time dependency, so that the price of LCFS credits today are impacted by the expected price of LCFS credits in the future (i.e. they are affected by anticipated cost increases, technological constraints, and policy changes). If the LCFS is expected to be easier to comply with in early years than in future years, then the high price in future years is realised in the early years’ price due to anticipation\textsuperscript{51}. High credit value generates investor confidence that there will be adequate price for their credits to provide a valuable return on investment within their required payback period.

As the price of LCFS credits become more expensive, the price at the pump will become more expensive, which can act as an economic signal. However, the cost of the LCFS is somewhat hidden from the consumer, which masks the economic signal. For years the price has been estimated at 3 or 4 cents per gallon\textsuperscript{52} which may not been a strong enough economic incentive to influence the consumer into buying a new alternative fuel car. The effect at the pump has been growing and the Oil Price Information Service estimate that in 2017 this has been raised to 8.5 cents per gallon\textsuperscript{53}. It is difficult to estimate the impact on retail fuel prices, as the LCFS has internal pricing. Two other estimates are 5 cents per gallon on the online price calculator on the CARB website and UC Berkley economist Severin Borenstein estimated 7 cents per gallon in January 2018. The exact price is hidden from consumers by other factors including a gas-tax hike of 12 cents per gallon in April 2018 and the cap-and-trade system is estimated to add another 12 cents per gallon\textsuperscript{54}. As the LCFS becomes more stringent the economic signal against conventional fuels will strengthen, despite the direct cost of the LCFS being hidden from the consumer. This might encourage consumer investment in alternative fuel vehicles.

A key objective of the LCFS is to stimulate innovation. It is hoped that the market will invest in innovative technologies to help meet ever more stringent compliance targets in the future. For these investments to occur the investors need long term stability due to the lengthy timescale in which they will make returns\textsuperscript{55}. Due to initially weak investment signals as a result of the legal battles, the expected innovation has not occurred and development in commercial scale low CI fuel production has been slow\textsuperscript{56}. Due to weak investment signals there has been insufficient investment in bringing ultra-low carbon fuel (<30gCO\textsubscript{2}/MJ) capacity online at the volumes needed to meet the more stringent future target. As an LCFS incrementally becomes more difficult to comply with reductions in CI of fuels are typically also


incremental and therefore larger scientific “break-throughs” do not occur. With the inclusion of a cost containment system in the LCFS the price volatility will decrease due to increased certainty in compliance the investment signal for breakthrough technologies should improve.

The main alternative fuel in use in California is ethanol, which is blended into the gasoline. Currently 10% by volume ethanol is blended into the gasoline which is the maximum allowed without alternative infrastructure being required. This is termed the “blend wall”. Currently California has not overcome the “blend wall” which is indicative that the economic signal has not been strong enough to encourage large infrastructure investments. For example, E85, a high ethanol blend (85%), use has not greatly increased. Another low CI fuel would be cellulosic ethanol, created from crop residue. These fuels have successfully reached commercial scale but no cellulosic ethanol was consumed in California in 2015. As this technology matures the capital costs and operating costs will reduce.

A key question in determining the success of a policy is determining the efficiency of the policy. It is argued that the LCFS cannot attain the “first best” efficient system and has much higher abatement cost to the transportation sector than an efficient policy. The implicit subsidy on low CI fuels from the LCFS does not discourage consumption. Another clue that the market is working inefficiently is if there are low trade volumes, although this maybe an artefact of the relative ease of compliance early in the LCFS. As can be seen in Figure 4, as the CI standard has become more stringent in time the trade volumes have increased, potentially showing that the market is now working more efficiently.

There has been a significant increase in the number of electric vehicles in California from 60,000 in 2014 to 197,000 in 2016. Electric vehicles were estimated to account for 1.3 billion miles (or 13 million gasoline gallon equivalents). The state of California however has strong fiscal incentives specifically targeting electric vehicles and the uptake of electric vehicles including a $7,500 federal tax cut and a $2,500 state rebate. If an electricity provider gains credits in California as a transportation fuel provider they are obligated to pass on those savings to the customers, for example, Pacific Gas and Electric (a utility company) are awarding their customers who buy or lease an electric car an additional rebate of $500. These direct cash incentives to the customer help them overcome the capital investment required to make the move to electric and are more obvious to the final consumer. These incentives are more likely to change influence behaviour than a slight increase in conventional fuel prices at the pumps. The LCFS however works in conjunction with these other more direct incentives providing a clear signal towards electric vehicles away from conventional fuels. Half of the electric vehicles sold in the USA are sold in California.

Key findings

Creating a stable price signal is key to stimulate investments in low Carbon Intensity (CI) fuels. Price volatility was reduced with the addition of a cost containment mechanism, in order to provide another compliance mechanism should there be a shortfall in credits. Price volatility also occurred as a result of legal issues that reduced confidence in the LCFS.

To incentivise investment both upstream and downstream stakeholders the LCFS required **sufficiently high price levels**. Initially the stringency of the CI standards in early years meant that compliance was relatively easy. As the CI standards become more stringent, compliance will require the use of more advanced fuel technologies, and the cost of LCFS credits will increase in line with expectations about the higher compliance costs.

Due to a low LCFS credit price prior to the re-adoption of the LCFS in 2015, there had been **insufficient investment signals to support dramatic changes in fuel technologies**. There have however been gradual increases in low CI fuels.

The **use of life cycle analysis (LCA)** fully accounts for all GHG emissions of a fuel, nullifying **emissions leakage**. However, LCA are a contentious issue, especially regarding indirect land use change (ILUC) from biofuels. The LCA calculations for the LCFS have been amended taking into account stakeholder concerns, as well as advances in the science behind ILUC and other LCA issues. This highlights the importance of ensuring that any LCA measure is robust and that stakeholders are consulted in the process of implementation.

It is also necessary to **consider interactions with other political objectives, such as air quality**. Recent challenges to the LCFS have arisen due to the NOx emissions that would arise from increased bio-diesel and renewable diesel usage.

**The price signal is hidden from the consumer, which limits the extent to which the LCFS can directly act on the demand-side.** Fiscal policy has therefore been used to complement the LCFS in order to drive consumer uptake of certain technologies.
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