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ANAEROBIC DIGESTION OF SOLID ORGANIC WASTE: OBSTACLES AND OPPORTUNITIES IN CALIFORNIA

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Abstract

California has an ambitious target of diverting 75% of organic resources from landfill by 2025. For this target to be met, a substantial investment in developing end market capacity is required. Solid organic waste anaerobic digestion (SOW AD) is a potential solution to meet this goal. Diversion policies, as well as supportive financial mechanisms, are typically precursors to market adoption of this technology. However, widespread adoption in California has not taken place. This thesis explores obstacles and opportunities derived from stakeholder interests and uses a case study of an early-stage SOW AD development company to emphasise methods of overcoming these obstacles and taking advantage of opportunities. Although government and private sector environmental concerns and policies provide basis for SOW AD opportunities, with higher energy product pricing and improved project economics from landfill bans for organic resources, it is not always enough. The thesis explores the conditions under which stakeholders can better align their interests in order to provide a stable market for SOW AD. This could be based on improving diversion policy implementation as well as greater energy product support. To conclude it is argued that the adoption of SOW AD technology supports the state and federal government targets, by providing organic resources processing and clean energy products as the US seeks to reclaim environmental leadership.

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Glossary of Terms

BioMAT: The BioMAT is a fixed price feed-in tariff provided to bioenergy power sources by the three Californian investor-owned utilities.

Californian Public Utilities Commission (CPUC): The regulatory agency that regulates private owned public utilities in California.

Carbon Intensity (CI): The measure of carbon dioxide produced by fuel types.

Environmental, social, and governance (ESG) Goals: Criteria used by financial evaluators of private sector entities that are beyond traditional measures of profitability to include ESG considerations.

Low Carbon Fuel Standard (LCFS): The Californian Low Carbon Fuel Standard is a mechanism to reduce transportation fuel carbon intensity by supporting alternative fuels.

Municipal solid waste (MSW): Refers to general comingled waste.

Organic resources: Refers to the collective term of organic waste, including food and green waste, defined as materials with value, rather than as a waste stream.

Renewable gas standard (RGS): A requirement for natural gas utilities to have a specific quantity of renewable gases in the pipeline.

Renewable identification number (RIN): The number provided to biofuel to track usage in the federal Renewable Fuel Standard.

Renewable natural gas (RNG): A gas with the same properties as conventional natural gas but produced from the capture of the methane generated by the decomposition of organic material and upgraded to pipeline quality.

SB 1122: Californian Senate Bill that introduced the BioMAT feed-in tariff. The BioMAT tariff provides a fixed price for electricity from bioenergy sources.

SB 1440: Californian Senate Bill that initially pushed to introduce a Renewable Gas Standard (RGS) but was revised to raise a suggestion to the Californian Public Utilities Commission to consider such a standard.

SB 1383: Californian Senate Bill that set target of 50% organic resources from 2014 levels diverted from landfill by 2020 and 75% by 2025.

SB 619: Californian Senate Bill that postponed the enforcement of penalties for jurisdictions not meeting SB 1383 targets until 2023.

Short Lived Climate Pollutant (SLCP) Strategy: The Californian strategy to lower SLCP's. For this thesis, the methane abatement target of 40% by 2020 based on 2010, is relevant.

SoCalGas: The largest natural gas utility in the US. Based in California.

Solid organic waste anaerobic digestion (SOW AD): The decomposition of organic materials in the absence of oxygen (anaerobic digestion) to produce biogas. Solid organic waste refers to food and green waste.

The United States Environmental Protection Agency (EPA): An executive agency of the federal government which deals with environmental matters.

Introduction

Overview of Anaerobic Digestion

Organic solid waste management is a mechanism to reduce harmful greenhouse gas (GHG) emissions such as methane. Anaerobic digestion (AD) is a solution for organic waste that cannot be reduced at source and cannot be fed to people nor animals.[1] This can include, but is not limited to, food processing by-products, yard waste, kitchen scraps, and brown grease waste from restaurant grease interceptors. When these waste streams decompose in landfills, they release methane, a GHG that has a 20-year global warming potential 80 times that of carbon dioxide.[2] This is why over the past 20 years, policy makers have sought technology capable to transform the waste into energy while addressing climate concerns.

AD 'is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which is combusted to generate electricity and heat, or can be processed into renewable natural gas and transportation fuels.'[3] The remaining by-product, digestate, can be used directly or composted with green waste to produce a carbon-rich compost product. AD can play a role in the current energy transition by providing renewable natural gas to pipeline. Biomethane brings all the energy system benefits of natural gas without the associated net emissions and can make existing gas infrastructure compatible with a low-emissions future.[4] This energy source does not have the same inherent conflicts that other bioenergy sources have, such as biofuels using crops, since the resource cannot be used elsewhere. Despite the potential and positive contribution of AD to achieving climate targets, the deployment is facing difficulties that are going to be explored in this thesis.

The question of organic waste anaerobic digestion opportunities and obstacles is being examined in the US due to its slow adoption. In 2019, there were 68 stand-alone food waste digesters in the

[1] EPA, "Industrial Uses for Food Waste," accessed October 11, 2020, https://www.epa.gov/sustainable-management-food/industrial-uses-wasted-food.
[2] UNECE, "The Challenge," accessed October 11, 2020, https://www.unece.org/energywelcome/areas-of-work/methane-management/the-challenge.html.
[3] American Biogas Council, "What is Anaerobic Digestion?" accessed October 11, 2020, https://americanbiogascouncil.org/resources/what-is-anaerobic-digestion/.
[4] IEA "Outlook for biogas and biomethane: Prospects for organic growth," accessed October 11, 2020, https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth#

US.[5] In Germany, there were 95 comparable digesters operating in 2014.[6] The quantity of organic waste generated in the two countries is vastly different, with 40 million tons and 12 million tons generated annually in the US and Germany, respectively.[7] The magnitude of the organic waste problem is greater in the US, yet Germany is further ahead in developing recycling markets.

Despite the slow uptake of solid organic waste AD technology (SOW AD) in the US, the thesis examines the enabling framework at government and market level leading to create opportunities for greater adoption. For this thesis, solid organic waste refers to food waste and green waste that is typically comingled with municipal solid waste (MSW). This material is referred to as *organic resources*, as a means of showing its potential value in creating clean energy products. The capture of this material in AD is an opportunity to lower the emissions of fuels within the North American energy mix that have historically been produced by fossil fuels. AD can also contribute to the decarbonisation of the waste management sector, through the diversion of organic resources from decomposition in landfills. Landfills are the third-largest source of human-related methane emissions in the US, accounting for 110.6 million metric tons of carbon dioxide equivalent of methane.[8] It is therefore important to consider the diversion policies that move methane producing material from landfills to markets that capture harmful GHGs.

There are currently eight state-wide landfill diversion policies related to organic waste.[9] The choice to enact policy, and deciding targets, enforcement, and regulated parties, is a multi-faceted subject.[10] These states, mostly on the east coast, were able to enact organic waste policy based on their individual situations relating to political considerations, funding, infrastructure, and

[5] IEA, "Outlook for biogas and biomethane: Prospects for organic growth".
[6] Joel Edwards, Othman Maazuza, and S. Burn, "A review of policy drivers and barriers for the use of anaerobic digestion in Europe, the United States and Australia," *Renewable and Sustainable Energy Reviews* 52 (3), http://DOI:10.1016/j.rser.2015.07.112.
[7] RTS, "Food Waste in America in 2021," accessed January 15, 2021, https://www.rts.com/resources/guides/food-waste-america/ and Germany Federal Ministry of Food and Agriculture, "National Strategy for Food Waste Reduction," accessed January 15, 2021, https://www.bmel.de/EN/topics/food-and-nutrition/food-waste/national-strategy-for-food-waste-reduction.html.
[8] EPA, "Basic Information on Landfill Gas, Landfill Methane Outreach Programme," accessed October 11, 2020, https://www.epa.gov/lmop/basic-information-about-landfill-gas.
[9] Correct at the time of writing. California, Massachusetts, Vermont, Rhode Island, Maryland, and Connecticut. New York and New Jersey have passed state-wide policies that will come into effect in 2022.
[10] Harvard Law School: Food Law and Policy Clinic, "Bans and Beyond: Designing and Implementing Organic Waste Bans and Mandatory Organics Recycling Laws,"accessed January 15, 2021, https://www.chlpi.org/wp-content/uploads/2013/12/Organic-Waste-Bans_FINAL-compressed.pdf

enforcement logistics.[11] Some of these states, such as Massachusetts and Connecticut, have seen commercial AD development in response to diversion targets. These diversion policies help to unlock organic resources from the traditional method of disposal, landfill. Diversion policy is intended to provide market signals to the development and lending community of the long-term viability of AD facilities. These policies are considered an important first step for AD market development in North America, and, more generally, for fighting climate change and transforming waste into something more valuable. California is the most populous state, has a strong food production industry and has experienced significant climatic events which may explain why it has one of the most ambitious diversion policy goals.

Widespread adoption of SOW AD technology has not been the case in California despite an ambitious landfill diversion policy, supportive energy product financial mechanisms and abundant organic resources. Understanding why this is the case will be at the centre of this thesis. The cornerstone diversion policy is SB 1383, which set a target of 50% organic resources from 2014 levels diverted from landfill by 2020 and 75% by 2025. To meet this, it is estimated that 150-200 new facilities, approximately $2-$3 billion in investment, will be needed.[12] On the other side of the AD process, end market financial support mechanisms exist in California, such as the Low Carbon Fuel Standard, the BioMAT electricity tariff and the federal Renewable Fuel Standard. These tools give AD energy products higher than typical energy market pricing. California is also abundant in suitable AD organic resources. According to the American Biogas Council, California generates 12.3 million tons of food waste alone per year, which has a biogas potential of 67.2 billion cubic feet per year.[13] Despite these supportive measures SOW AD technology has not become the dominant end market for organic resources in California. The reasons for this will be explored in the obstacles chapter.

[11] Ibid.
[12]Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California,* (Stanford: Tom Kat Center for Sustainable Energy, 2018).
[13] "California: Biogas State Profile," American Biogas Council, accessed October 11, 2020, https://americanbiogascouncil.org/wp-content/uploads/2020/06/ABC-2020-State-Profiles-5.pdf

Thesis purpose

This thesis is tasked with exploring the opportunities and obstacles of SOW AD development in California. The supportive components of diversion policy suggest that California should be a thriving market for widespread adoption. However, the lack thereof must be assessed to understand where the shortcomings exist and how this can be changed.

To explore the opportunities and obstacles of SOW AD development in California, this thesis will be divided into 3 chapters. The obstacles and opportunities of SOW AD development will be shown to be products of stakeholder interests which can be conflicting or converging with those of the SOW AD sector, respectively. Chapter 1 will show that various stakeholder conflicts with the SOW AD sector are impeding diversion policy implementation. It is hypothesised that the same pattern of conflicts explains why decisions on the energy market and financial incentives continue to present obstacles to SOW AD development. There are additional obstacles facing SOW AD adoption in California. However, due to the limits of the thesis format, only those mentioned will be assessed.

Chapter 2 will explore opportunities for Californian SOW AD development. Environmental concerns at all levels of government have translated into policies and targets that provide opportunities to develop SOW AD. Emerging coalitions of industry leaders seeking GHG emissions reduction targets are potentially a powerful ally for SOW AD developers in California. Landfill bans improve the economics of SOW AD projects by providing longer term organic resource availability and pricing, regardless of existing markets conflicting interests. The Low Carbon Fuel Standard (LCFS) provides a lucrative offtake policy for Renewable Natural Gas (RNG) as can be seen through existing plants converting from electricity generation to gas upgrading. The use of compost in agriculture provides an additional end market for the by-product of the AD process, digestate. The vast size of the Californian agricultural markets and the growing trend to sustainable farming practises, helps displace traditional petrochemical fertilizer in favour of compost products for nutrient provision.

Chapter 3 will use a case study analysis of an early-stage development company based in California whose principal purpose is to build organic resources recycling capacity to meet

California's diversion policy targets. The case study explores how the obstacles, such as conflicting stakeholder interests, impact the development process. Furthermore, the innovative strategies used to mitigate these obstacles and manage SOW AD project development will be examined. Additionally, the methods that are used to take advantage of opportunities will be considered. From these factors, recommendations will be drawn upon which may enable greater adoption of SOW AD technology in California. The conclusion will bring together the salient points of the prior chapters to demonstrate the current state of the SOW AD sector in California and potential future research topics.

Chapter 1: Obstacles

Introduction

In the Californian context, previous actions, policies, and energy market conditions have created obstacles that have prevented widespread adoption of SOW AD technology. Stakeholders involved in the implementation of diversion policy, from government levels to energy market players, all may have potentially conflicting interests with SOW AD developers, which have consequences for Californian law's, SB 1383, successful implementation. The abundance and market penetration of other renewable energy resources prevents SOW AD projects from competing on a levelized cost basis. Existing financial support mechanisms favour small-scale and farm-based AD, rather than the SOW AD sector. This, combined with a lack of coordination between energy and organic resources diversion policy, has led to slow in-state SOW AD adoption whilst out-of-state capacity has grown to feed into the Californian RNG market. Local acceptance can also be an obstacle to SOW AD development.

This chapter will explore the obstacles to adoption of large-scale SOW AD facilities in California. Obstacles that will be discussed are competing stakeholder interest and diversion policy implementation, which impact all other obstacles, unfavourable energy markets dynamics and limited financial incentives, uncoordinated diversion and energy policies, and local acceptance. Solutions to these obstacles will be discussed in the recommendations chapter, drawing on the case study. To provide context of the obstacles facing SOW AD adoption to meet SB 1383 targets, major stakeholders, their interests, and the impact on diversion policy implementation will be analysed. The hypothesis is that all the obstacles explored result from conflicting interests between main actors and SOW AD development, as explored in the full stakeholder interest mapping in Appendix A.

Stakeholder Interest and Barriers to Diversion Policy Implementation

Landfill diversion policies differ from state to state. The introduction of source separating organic resources and mandatory landfill diversion policies are vital for the development of SOW AD. The diversion thresholds and limitations of these policies vary considerably from state to state, and

successful implementation requires enforcement, penalties, and transition strategies.[14] However, stakeholders' vested interests can impact the implementation of diversion policy. The interests and potential conflicts of main actors with the SOW AD sector will be demonstrated to impact the implementation of SB 1383.[15] Refer to Appendix A for the full stakeholder interest mapping.

Conflicting Interests at Levels of Government

Each level of government may have an impact on the implementation of diversion policy. Decisions made at the federal and state level influence the organic resources solutions implemented at the municipal level. Local municipal government in California may seek solutions to SB 1383 targets which have shorter development timelines. For example, composting is a lower cost solution and currently the most prominent organic resources recycling market. However, as will be further explored in later sections, this is a lower value end use for organic resources.[16]

State government impacts development of SB 1383 organic resources end markets through the lack of a Renewable Gas Standard and stringent natural gas quality standards that apply to gas fed into the system within California, but not for out of state sources.[17] This increases the barriers for RNG offtake options from SOW AD facilities.

State bureaucracy in California can impede the development of markets through an onerous and uncomprehensive permitting process for higher value recycling markets. The current system favours composting, which as an end-market type suffers from several limitations, such as emissions capture, contamination removal, scope of material types that can be accepted and marketability for compost products.[18] In order for California to meet the SB 1383 targets of 75% organic resources diverted from landfill by 2025, approximately 150 – 200 new facilities will be

[14] Commission for Environmental Cooperation, *Characterization and Management of Organic resources in North America—Foundational Report.* (Commission for Environmental Cooperation, 2017).
[15] Main assumption: SOW AD is a vital solution to diverted MSW organic resources. This is due to the ability of these facilities to accept large volumes of organic resources, with contamination removal capability, and its position in the EPA Food Recovery Hierarchy.
[16] See the EPA Food Waste Recovery Hierarchy.
[17] The rationale behind this decision will be explored in the *unfavourable market dynamics* section.
[18] Source: Author's previous professional experience.

needed.[19] However, at the current pace this will not occur. There is a conflict in the facility permitting process due to the difference in permitting processes in different parts of the state, as well as the multiple bureaucracies involved such as CalRecycle and the Californian Air Resources Board (CARB).[20] CalRecycle manages oversight for Californian non-hazardous waste handling facilities and program and CARB monitors air pollution and air quality standards. Currently, technologies that have been approved in one region must be approved again for use in another region.[21] This creates a major obstacle through increased cost and delays to development. Without changes to the process, SB 1383's aggressive timeline will not be met due to a lack of new market entrants.

There is a potential conflict of diversion policy and federal government, with regards to energy pathway policies that provide support to AD. Current federal financial support mechanisms favour other biogas types (farm-based and landfill gas). Without adapting current, or creating additional, support mechanisms it is unlikely that sufficient capacity will be invested in to meet the diversion policy goals.

All potential conflicts between levels of government and SOW AD development have the same impact on the implementation of diversion policy; limiting the development of end-markets that can accept organic resources diverted through SB 1383 enforcement. If there is an insufficient market capacity to accept the diverted waste, then the onus to separate will be hard to enforce. Government interests' impact on policy implementation is evident across *all* obstacles considered in this thesis.

Organic Resources Service Recipients

Within the context of Covid-19 and the disruptive impact of it, haulers, businesses, and citizens actors may be less inclined to push for the aggressive timelines of SB 1383 and rather spend financial capacities and political capital on economic recovery, rather than on greater organic resource separation and collection. In April 2021, SB 619 was introduced to delay the enforcement

[19] Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California,* 5.
[20] Ibid.
[21] Ibid.

of SB 1383 until 2023. SB 619 demonstrates the conflicting interests of service recipients and the development of SOW AD.

Non-Governmental Organizations

There are several prominent NGOs that are opposed to the development of supportive RNG policy, such as Earth Justice and the Sierra Club. They have been part of coalitions, alongside other renewable energy industries, to block the introduction of a Renewable Gas Standard being introduced.[22] This is largely due to the perception that RNG is used to justify continued expansion of natural gas infrastructure. These NGOs often support the full electrification movement and consider an underdeveloped biogas industry as undesirable in comparison with more developed renewable energy sources. This push impacts the implementation of diversion policy due to the prevention of greater organic resources recycling capacity being constructed due to unstable markets for energy products. These groups oppose decisions taken at the state level to support the SOW AD sector and exert a strong lobby on the Californian Public Utilities Commission (CPUC). The conflict between NGOs and the broader AD sector is prevalent in several obstacles, such as *the lack of coordination between diversion and energy policy* and *local acceptance.*

Existing Organic Resource Market Players

The existing organic resource market players, landfills and compost facilities, may be supportive of diversion policy but will want to see it implemented in ways that cement their incumbent position, and share, in the market. Compost facilities are the current incumbent market for already separated organic resources that cannot be fed to animals. They are supportive of diversion policy, but are often vertically integrated with haulers of waste, who also own landfills.[23] This market may push to limit new entrants who compete with them and influence policy to benefit them most.

Landfill players are hesitant to let income-generating organic resources go to other markets.[24] Installation of landfill gas capture infrastructure, which are supported by existing financial incentive mechanisms by providing high value to the gas, are intended to justify the allowance of

[22] Interview with Mr. R., a senior leader in an industrial association which desires anonymity.
[23] Ibid.
[24] Author's previous professional experience.

organic resources to continue going to landfill. Landfills use this as a demonstration that they are capturing the emissions of organic resources decomposition through this technology.

Existing organic resources market players have interests in limiting the development of SOW AD facilities to retain their dominant position. Moreover, the lack of coordination of diversion and energy policies and the limited financial mechanisms for SOW AD contribute to this dominating position and reduce uptake of alternative organic resources solutions.

Energy Market Players

Existing energy market players, such as shale gas, solar and wind power, impact the implementation of diversion policy by making organic resources end-market development (SOW AD) difficult. Existing renewable energy industries oppose off-take policy that would help AD market develop through creating opposition coalitions in the decision-making process of CPUC.[25] The abundance of shale gas in the US has lowered the price of natural gas. Opposition groups have argued that RNG will only increase the cost of rate payers and continue the use of natural gas rather than transition to full electrification.[26] Without these supportive policies for pathways it is difficult for SOW AD facilities to be developed and financed. This will be further explored in the *uncoordinated diversion and energy policies* and *unfavourable energy market dynamics* obstacles.

Unfavourable Energy Market Dynamics

After exposing the competing interests of different stakeholders in the diversion policy and their 'blocking' capacity, this subsection will explore the different categories of obstacles resulting from such divergent interests.

The first category of obstacles concerns the difficulty of AD competitively selling energy products to two offtake markets: biomethane for pipeline injection and electricity production. Each market is addressed individually, then the availability of cheaper alternative renewable energy resources is assessed and to conclude, the limited financial incentives available are considered.

[25] Interview with Mr. R.
[26] Ibid.

The SOW AD sector is positioned in conflict with the existing Californian energy market as exposed in the stakeholder interest section previously. Both biogas upgrading to biomethane for pipeline injection and electricity from biogas compete against incumbent sources. The competitiveness of biomethane against natural gas is low in the absence of preferential pricing support such as California's Low Carbon Fuel Standard. Without this credit mechanism the higher cost of biomethane production makes this offtake pathway uneconomical. Pipeline injection comes with additional costs and barriers, such as high interconnection costs and gas quality standards.

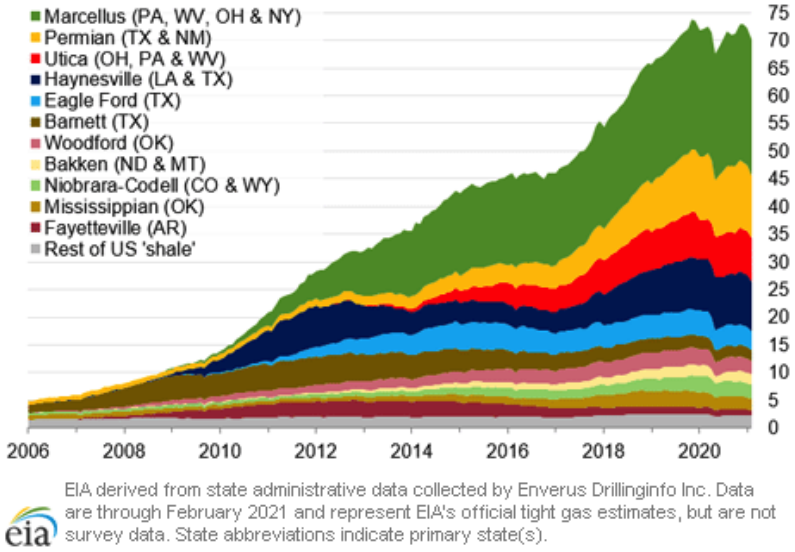
In the use of biogas for power generation, the incumbent power mix will be considered. Biogas production costs from the literature will be discussed with regards to the availability of and levelized cost of electricity generation (LCOE) from other renewable sources. This demonstrates that a financial support mechanism, such as a Feed-in-Tariff, is required to make biogas electricity competitive. However, such policies are becoming less favourable due to the increase in cheap power from other renewable technologies, such as solar and wind. This will be explored further with the BioMAT tariff in the *limited financial incentives* section.

Lack of Biomethane Cost Competitiveness

There is a severe deficit in cost competitiveness of biomethane. It is not, and unlikely to become, price competitive with conventional natural gas.[27] The cost difference is due to the well-established streamlined production, distribution, and marketing of conventional natural gas. Natural gas supply has grown through the advent of hydraulic fracturing, also known as 'fracking'. Although President Biden placed a moratorium of fracking permits on public lands, most drilling companies have stockpiles of unused permits which are not affected by this, and private land can still be used for exploration and production.[28] It does not cancel existing field development plans. The production of shale gas has risen since the late 2000s with the development of the Marcellus field (**Figure 1**).

[27] RBC ESG Stratify, *Renewable Natural Gas: Where is the Gas is Green and the Grids are Pretty*, (RBC Capital Markets, 2020), 24.
[28] Matt Egan, "No, Joe Biden did not just ban fracking," *CNN*, January 21, 2021, https://edition.cnn.com/2021/01/27/business/fracking-ban-biden-federal-leasing/index.html

Figure 1: U.S. dry shale gas production (billion cubic feet per day)



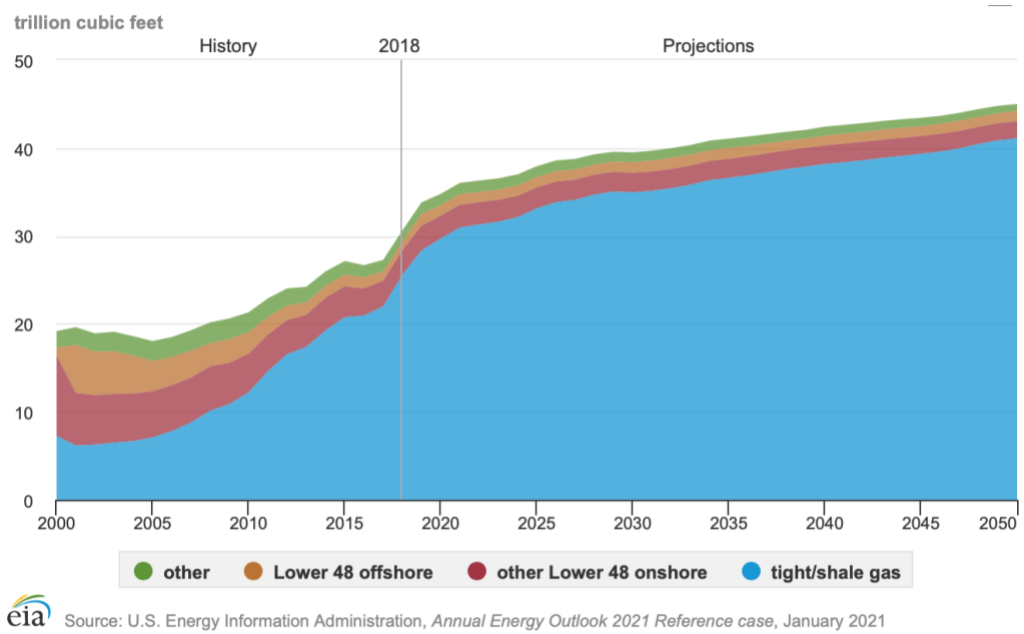
Source: EIA, May 20, 2021, Natural gas explained: Where our gas comes from

Biomethane not only competes on price but also against the immense production capacity of shale gas. The shale gas revolution and abundance of cheap natural gas has driven many RNG companies out of business.[29]

The practise of producing lower cost natural gas is unlikely to stop under the current administration due to vested interests from producing regions and the unique political capital involved.[30] The US Energy Information Agency (EIA) projects shale gas production to increase through to 2050 (**Figure 2**).

[29] Thomas N. Russo, "Regulatory Challenges Facing Renewable Natural Gas," *Natural Gas and Electricity 36,* no. 10 (May 2020): 30.
[30] Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California,* 25.

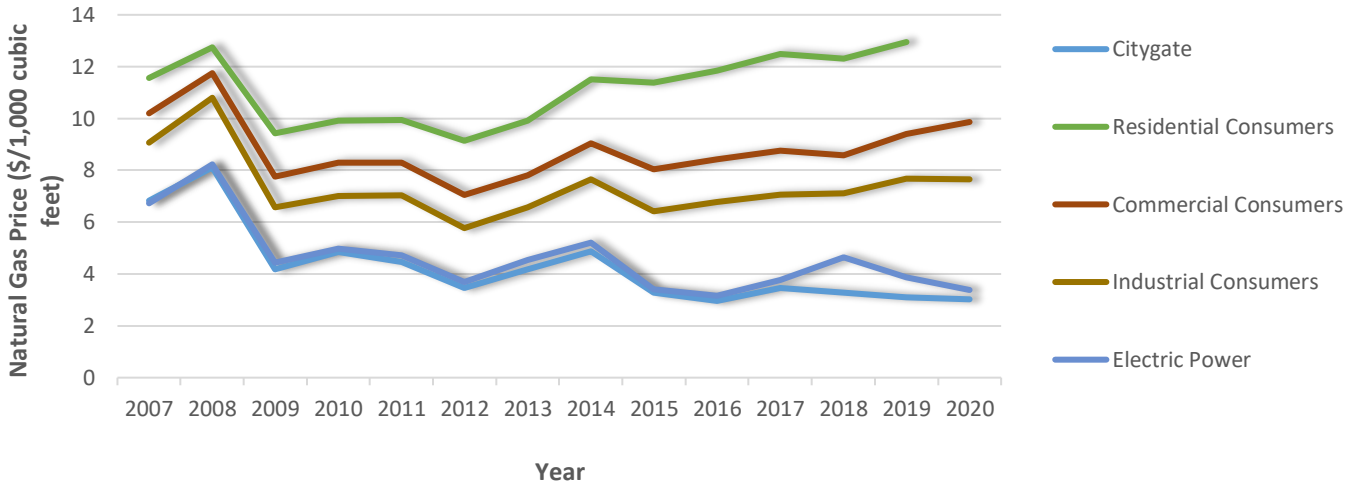
Figure 2: U.S. dry natural gas production by type, 2000-2050



Source: EIA, May 20, 2021, Natural gas explained: Where our gas comes from

This domestic availability since 2009 has helped lower the price of natural gas for all consumer types in California (**Figure 3**). It is politically difficult to impose barriers upon Californians to access this low-cost energy product.

Figure 3: Historical natural gas pricing in California

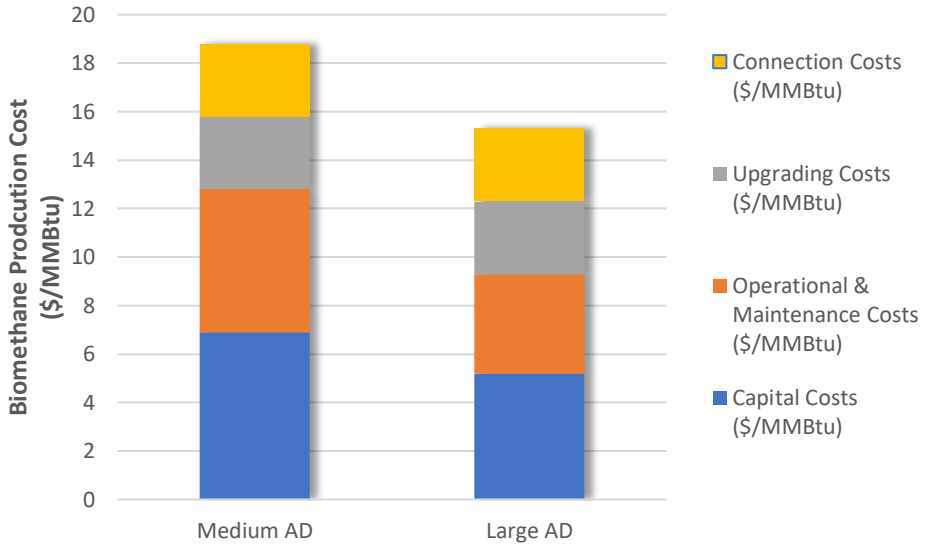


Source: EIA, March 20, 2021, Natural Gas Prices

High Biomethane Production Costs

According to the IEA, the average cost of producing biomethane is between $15.30/MMBtu and $18.80/MMBtu for SOW AD facilities (**Figure 4**).[31] For a large AD to be competitive, it would need approximately a financial support mechanism of between $8/MMBtu and $12/MMBtu depending on customer type. Existing support mechanisms will be explored in the next subsection.

Figure 4: Biomethane production cost by component[32]

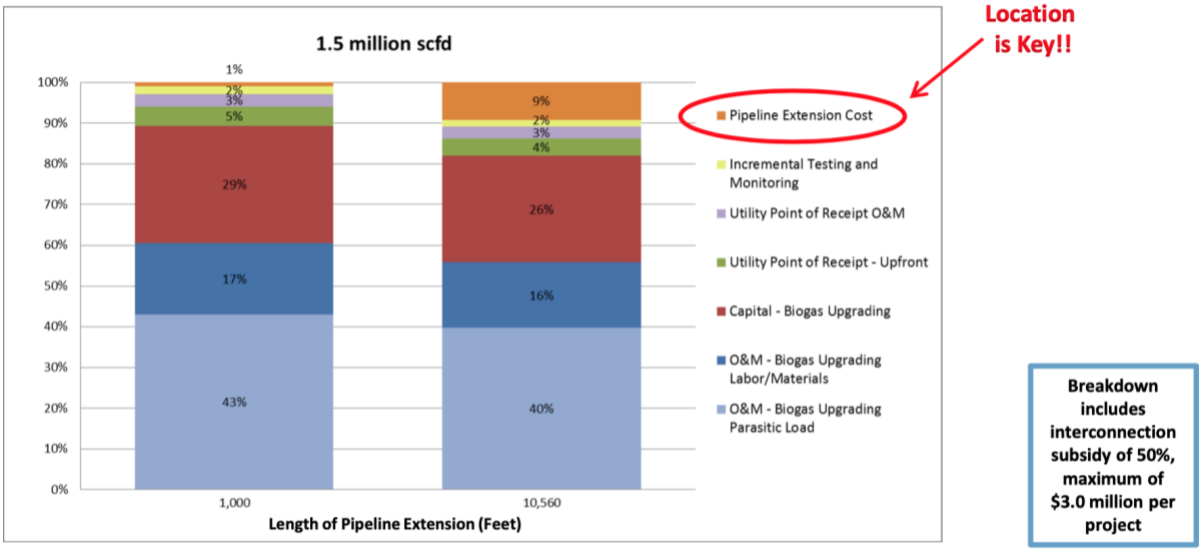


Source: IEA, 11 October 2020, Outlook for biogas and biomethane: Prospects for organic growth

Biomethane's uncompetitive costs are due to the infrastructure investments that are required. The cost of connecting AD to the pipeline infrastructure can be very costly for a relatively small quantity of biomethane produced, often accounting for between 1% and 9% of total capital costs (**Figure 5**).[33]

[31] *Medium AD* refers to an output flow rate of 250 m^3/hour of biogas and *Large AD* refers to an output flow rate of 750 m^3/hour of biogas. IEA, "Outlook for biogas and biomethane: Prospects for organic growth".
[32] IEA, "Outlook for biogas and biomethane: Prospects for organic growth".
[33] In California, connecting to a transmission pipeline costs $1 million per mile. Jaffe, Amy Myers, *Final Draft Report on The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute*, (UC Davis, 2016).

Figure 5: Estimated breakdown of lifecycle costs to produce and inject RNG into the pipeline[34]



Source: Haines, Deanna. "Getting the Facts on Renewable Natural Gas: Making California's future renewable." Presentation, Fort Worth, Texas, October 23, 2018.

There are four factors that increase the cost of injection: location of plant, nearby pipeline capacity, gas pressure at the site of injection and customer demand near site of injection (**Table 1**).[35] Conventional natural gas producing fields must also undergo injection costs. However, AD produces significantly lower quantities of gas than conventional fields, so the costs are amortized across a smaller production and thus makes the process more expensive.

Table 1: Factors that increase cost of pipeline injection[36]

Factor	Notes
Location of plant	Further distances from pipeline network may increase interconnection costs and make permitting process arduous
Nearby pipeline capacity	If closest pipeline is already near or at capacity, it will not be able to accept more RNG
Gas pressure at the injection site	Injected RNG needs to match the pressure of the gas currently in the pipeline

[34] Based on 1.5 million SCFD of biogas for 15 years.
[35] Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California*.
[36] Ibid.

Customer demand near site of injection	According to the PG&E requirements, there must be "adequate and stable" demand on the gas pipeline for it to accept any RNG supply

Incongruent Regional Gas Quality Standards and Regulations

RNG quality deeply affects the cost competitiveness of SOW AD facility energy products. California has the strictest pipeline injection gas standards in the US.[37] However, there is a conflict that arises between in-state and out-of-state RNG producers. There is a lack of standardization across states on pipeline gas regulation, as well as supporting public policies. This is due to a history of different politics within the natural gas industry and the differing experience of states with regards to climate change events and pipeline accidents.[38] These factors have created incongruency in gas quality policy. The largest natural gas provider in California, SoCalGas, has the strictest regulations in the US for injecting within their system boundary.[39] High gas quality standards have created a delay in the Southern Californian SOW AD sector injecting.[40] Out-of-state RNG injection is not subjected to the same stringent quality requirements as in-state producers. Furthermore, in 2015, the CPUC decided that the full cost of complying to quality standards would be the responsibility of the producer. This creates an additional cost for RNG produced in-state, making it less competitive than RNG originating from other states.

Competitive Alternative Renewable Energy Sources

There is a lack of a narrow levelized cost of electricity (LCOE) from biogas range in the existing literature. Most sources discuss a price range of $60-$190/MWh.[41] The growing trend of existing AD converting to RNG production suggests that electricity pricing is less favourable than financial incentives for RNG production.[42] Taking the median LCOE, $125/MWh, AD is marginally profitable in the Californian industrial and commercial electricity markets (**Table 2**).

[37] Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California*.
[38] Ibid.
[39] Ibid. SoCalGas has a minimum heating value of 990 Btu/scf but allows for lower heat value waivers to be given by the CPUC. This adds further time and costs to projects. This may be due to pipeline safety and integrity measures after high profile and fatal pipeline explosions.
[40] CR&R, a franchised waste management company with an operational AD outside of Los Angeles, were only able to connect in 2018 despite the first phase of the plant being operational in 2015.
[41] IEA, "Outlook for biogas and biomethane: Prospects for organic growth".
[42] Financial mechanisms and their favourability are explored in the next subsection.

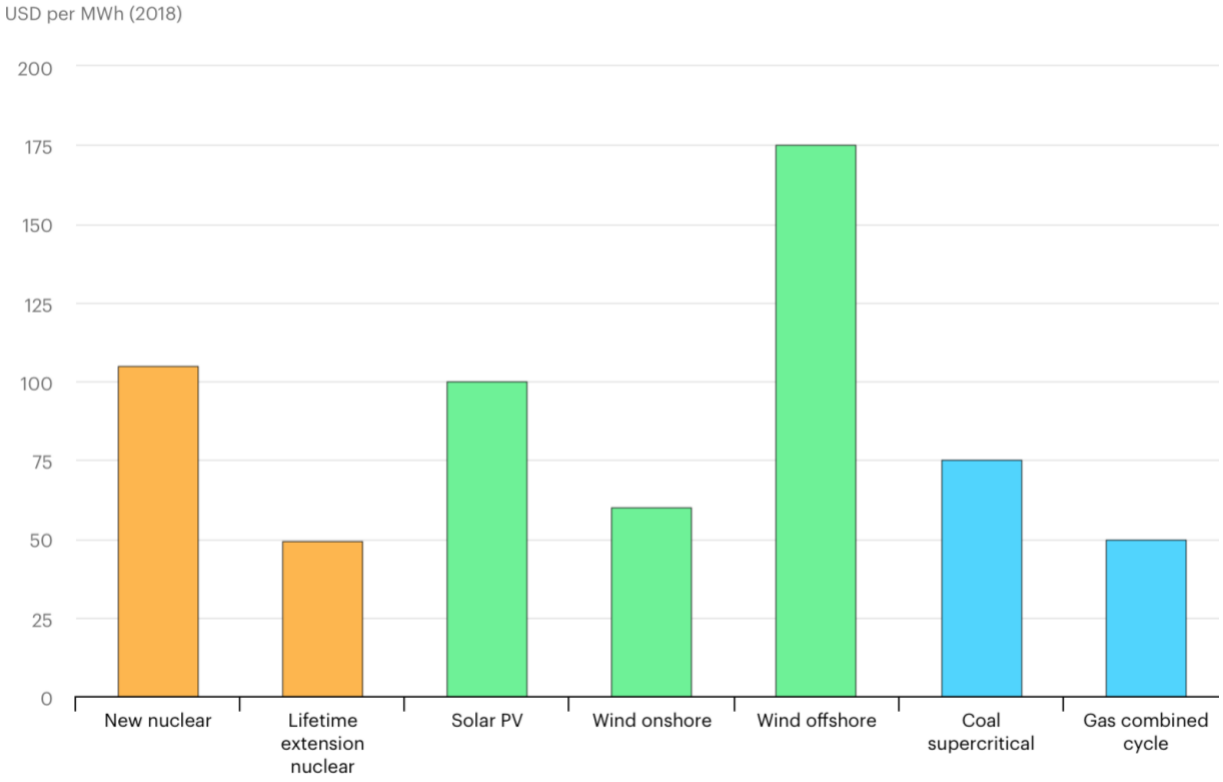
Table 2: 2019 California electricity commodity prices

State	Industrial Electricity Price ($/MWh)	Commercial Electricity Price ($/MWh)
California	$134	$166.7

Source: EIA, California State Energy Profile, December 20, 2020.

Furthermore, it has higher generation costs than all other electricity sources, apart from offshore wind, which makes other renewable sources more attractive on a cost basis (**Figure 6**).

Figure 6: Levelized cost of electricity generation by technology



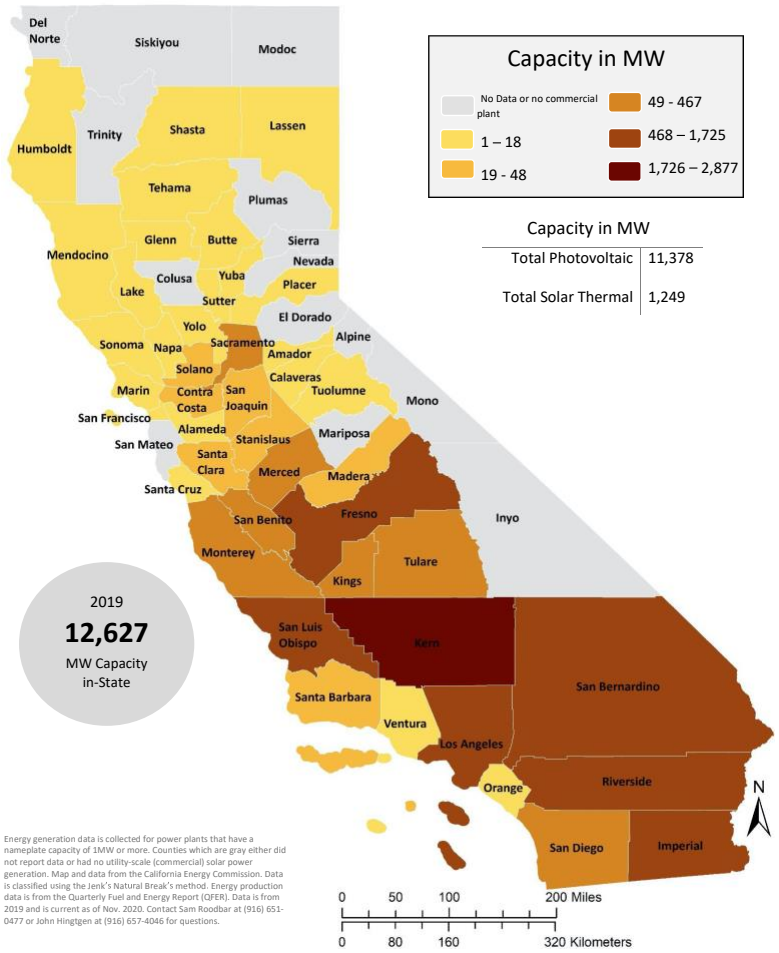
Source: IEA, Projected Costs of Generating Electricity, December 20, 2020.

California is ranked first in the US for electricity production from solar.[43] In 2019, there was 12,627 MW utility-scale installed capacity (**Map 1**). The incumbent solar industry creates a barrier for the SOW AD sector competing in electricity production as it seeks to maintain its market

[43] EIA, "California State Energy Profile", Accessed December 20, 2020, https://www.eia.gov/state/?sid=CA.

share.[44] Furthermore, California's efforts to increase energy efficiency and implement new technologies has also slowed growth in the demand for energy, making the electricity market more competitive.[45]

Map 1: 2019 California utility-scale solar capacity by county



Source: California Energy Commission, Utility Scale Solar Capacity by County, December 20, 2020.

To assist the broader AD industry in participating in the Californian energy markets, there are several financial incentives. However, they will be shown to be in favour of agricultural AD and landfill gas projects, rather than the SOW AD sector.

[44] Interview with RNG Coalition.
[45] EIA, "California State Energy Profile".

Limited Financial Incentives

This section will cover three financial incentives; the Californian low carbon fuel standard (LCFS), Renewable Fuel Standards administered through renewable identifiable numbers (RIN), and the BioMAT programme. The two RNG supportive mechanisms, the RFS and LCFS, have had a major impact on the end markets for biogas projects across the US. There is a growing trend in the US of biogas plants installing upgrading equipment and connecting to pipelines for RNG injection. The RFS, administered through RINs, give higher value to animal waste and agricultural organic resources.[46] The LCFS favours small-scale and farm-based AD. The BIOMAT programme supports bioenergy projects with a higher electricity price. However, preferential pricing is given to other categories than organic resources AD and the overall capacity for this category is limited to 110 MW for the whole state and is currently undersubscribed.[47]

These existing incentives do not currently support large-scale AD infrastructure investment. Rather, they provide greater incentives to farm-based AD facilities, instead of SOW AD facilities that could help California meet SB1383 mandated targets. This is due to the historical market development of biogas projects across the US being predominantly farm-based or landfill gas. Additionally, the current mechanisms create investment risk for the SOW AD sector as other sources are prioritized, which may create investor scepticism of the longevity of sector support.

Renewable Fuel Standard

The RFS is an example of existing supportive financial mechanisms lacking on giving parity to the SOW AD sector. There are two programs available in California for the exchange and purchase of renewable energy credits that influence the value of RNG on the market.[48] The national RFS aims to encourage low-carbon energy sources to replace gasoline in transportation. Companies must use a certain minimum amount of energy from renewable sources such as compressed biomethane. Companies can earn credits called Renewable Identification Numbers (RINs) to

[46] The US EPA sets volume obligations for renewable fuels. To do this, ethanol gallon equivalents of renewable fuel give a renewable identification number (RIN). A RIN is an environmental credit used by obligated parties to demonstrate volume requirements are met, either by producing the fuel or by purchasing on the market.
[47] Category 3 is likely given a higher pricing due to the increased cost of organic resources collection from sustainable forest management, such as wood clearing in forest fire warning areas.
[48] Biogas World, "How to finance your anaerobic digestion project in North America?", Accessed December 20, 2020, https://www.biogasworld.com/news/funding-anaerobic-digestion-project-north-america/.

offset its renewable energy requirement.[49] RINs are determined by the process used in production as well as the organic resource(s) used (**Table 3**). RIN categories have different prices (**Figure 7**).

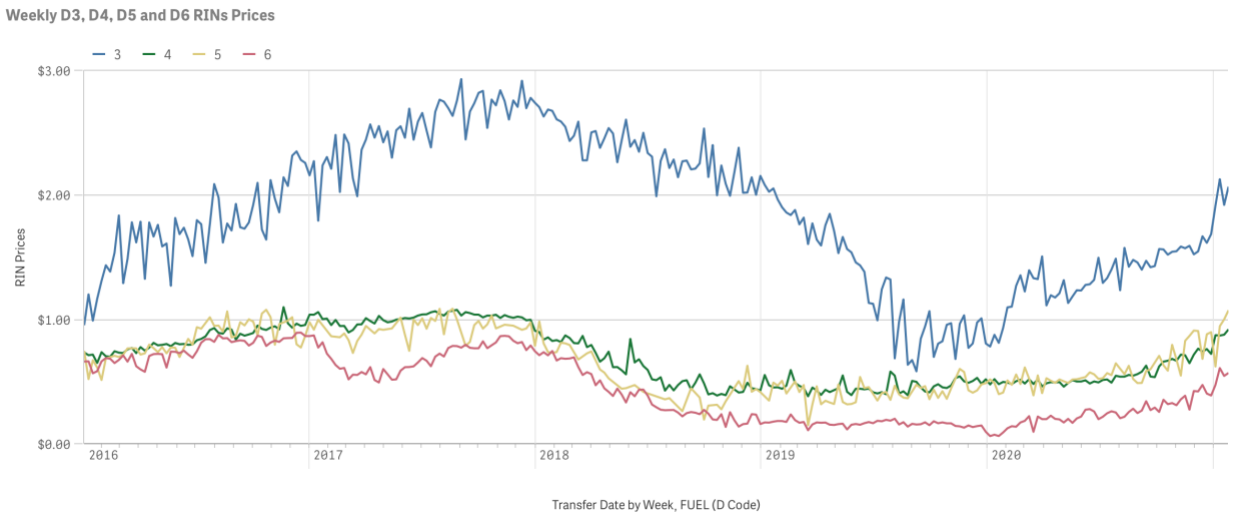
Table 3: RIN categories[50]

Category	Criteria
D5 Advanced Biofuel (SOW AD's Category)	Can be made from any type of renewable biomass except corn starch ethanol Must reduce lifecycle GHG emissions by at least 50%, compared to the petroleum baseline
D4 Biomass-Based Diesel	Examples include biodiesel and renewable diesel Must reduce lifecycle GHG emissions by at least 50%, compared to the petroleum baseline
D3 or D7 Cellulosic Biofuel	Renewable fuel produced from cellulose, hemicellulose, or lignin To be eligible for D7 RINs the fuel must be cellulosic diesel Must reduce lifecycle GHG emissions by at least 60%, compared to the petroleum baseline
D6 Renewable Fuel	Includes ethanol derived from corn starch, or any other qualifying renewable fuel Fuel produced in new facilities or new capacity expansions must reduce lifecycle GHG emissions by at least 20%, compared to the average 2005 petroleum baseline

In 2014, the US Environmental Protection Agency (EPA) made RNG eligible for D3 RINs, under the cellulosic category. This increased RNG production six-fold between 2014 and 2016. Now RNG production accounts for almost all D3 compliance.[51] However, non-cellulosic organic resources, such as food waste, generate D5 RINs which are typically priced at half the value.

[49] Biogas World, "How to finance your anaerobic digestion project in North America?"
[50] EPA. "What is a fuel pathway?", Accessed December 20, 2020, https://www.epa.gov/renewable-fuel-standard-program/what-fuel-pathway.
[51] RBC ESG Stratify, *Renewable Natural Gas: Where is the Gas is Green and the Grids are Pretty*.

Figure 7: Weekly RIN pricing from 2016-2021



Source: EPA, RIN Trades and Price Information, January 20, 2021.

Farm-based AD and landfill gas are given higher values than organic resources AD (**Table 4**). This current valuation conflicts with Californian organic resources diversion as landfill operators generate valuable D3 RINs through the capture of landfill gas. Having lower RIN values for organic resources like green waste and food waste is a disincentive for any potential organic resources recycler to invest in or accept this organic resource if they currently qualify for D3 RINs. The favouring of agricultural AD and discouraging of co-digesting organic resources, creates additional obstacles for AD adoption and SB1383 implementation.

Table 4: Organic resource type and RIN category and value[52]

Feedstock Type	RIN Category and Value
Organic resources AD (food waste, food waste and green waste)	D5 (Low)
MSW wastewater treatment	D3 (High)
Agricultural AD	D3 (High)
Cellulosic (green waste)	D3 (High)
Landfill gas	D3 (High)
Co-digestion	D3/5 (Medium)

[52] Biogas World, "How to finance your anaerobic digestion project in North America?"

Creating stability through a RIN price guarantee would be difficult to implement, as this would entail altering the underlying federal legislation. Vested interests from existing producers of higher value RIN renewable fuels would try to block attempts to change the current pricing system. RIN price fluctuation, and low price for SOW AD RNG, creates a barrier to investment. The volatility involved in the market may create investor hesitation, and even give SOW AD project valuations a steep discount to the credit value when calculating potential project revenue.[53]

California's Low Carbon Fuel Standard

The second credit mechanism, the Low Carbon Fuel Standard (LCFS), aims to stimulate the production and use of fuels from renewable energy sources to reduce GHGs. The LCFS is administered by CARB with the goal of reducing the carbon intensity of transportation fuel in-state by 10% by 2020 as compared to 2010.[54] Similar to the RFS, fuels with lower emissions create credits, whilst fuels that generate greater emissions incur deficits. A producer of deficit emission fuels purchases credits to create balance.

The program's standards are based on the intensity of GHGs emitted by fuel, called Carbon Intensity (CI). This is evaluated according to the complete life cycle of the energy used as fuel and takes the form of credits. The number of credits generated by each fuel type is proportionate to the CI. The value of biogas depends on its CI. Again, farm-based AD development is favoured by this incentive (**Table 5**).

Table 5: Organic resources type and LCFS value (carbon intensity score)[55]

Organic Resource Type	LCFS Value
SOW AD	Medium-High (CI~ -10)
MSW wastewater treatment	Low-Medium (CI~ 40)
Agricultural AD	Extremely High (CI~ -250)
Landfill gas	Low (CI~ 50)
Co-digestion	Medium-High (CI~ -10)

[53] Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California*.
[54] EPA, "What is a fuel pathway?".
[55] Biogas World, "How to finance your anaerobic digestion project in North America?"

The LCFS provides a 'fall back' price that can help reduce investor hesitation caused by RIN market instability.[56] RNG producers can benefit from both the RIN and LCFS carbon pricing by sending gas by pipeline to transportation obligated parties in California. Since 2019, the credit pricing has been above $150/ton of CO2 (**Figure 8**).

Figure 8: Historical LCFS prices ($/CO2 ton)

Despite the LCFS being developed in California, qualifying RNG has not been sourced from in-state. In 2017, more than 95% of qualifying RNG was sourced from out-of-state facilities.[57] This is due to a combination of previously identified obstacles, such as lower gas quality standards in other regions, and obstacles yet to be addressed, such as a lack of coordination between energy and diversion policy. If additional measures are not introduced to support the inclusion of Californian RNG, this trend of out-of-state facilities generating the majority of RNG LCFS credits is likely to continue and organic resources diversion goals are unlikely to be met.

California's BioMAT

California SB 1122 introduced the BioMAT tariff for electricity generated by bioenergy projects. This tariff sets the price of power, dependent on generator type, for a 20-year period (**Table 6**). Category 1, which SOW AD facilities qualify for, provides a power price of $127.72/MWh. Considering the above-mentioned LCOE range of $60-$190/MWh, this tariff may not be attractive

[56] Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California*.
[57] Ibid.

to many AD power generators. The length of the tariff period (20 years) may be the only positive side to this support mechanism, as it allows for a degree of income predictability.[58]

Table 6: CPUC's BioMAT Categories Criteria

Category	Description	Capacity	Price ($/MWh)
1	Biogas from wastewater treatment, municipal organic resources diversion, food processing, and co-digestion	110 MW	$127.72
2	Dairy and other agricultural bioenergy	90 MW	$183.72 - $187.32
3	Bioenergy using by-products of sustainable forest management (including fuels from high hazard zones)	50 MW	$199.72

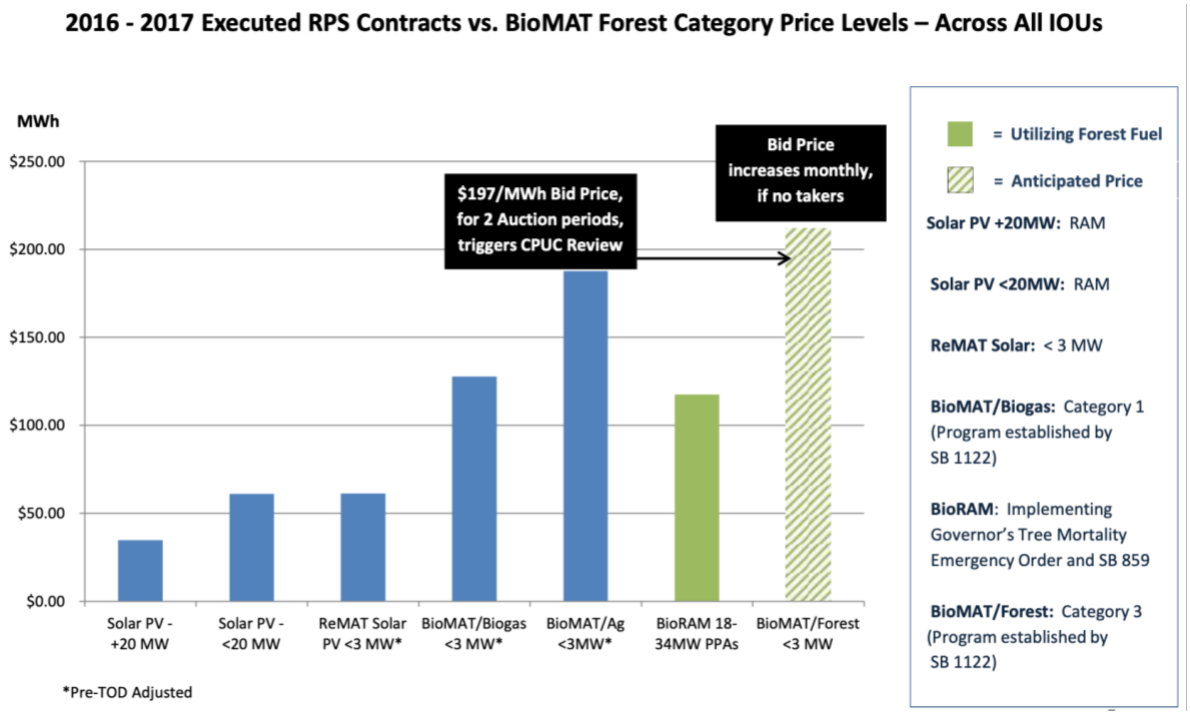
Source: CPUC, Bioenergy Feed-in Tariff Program, January 20, 2020

The tariff limits participants to facilities that have less than 5MW capacity. The preference is for smaller scale, decentralized producers. This is a barrier for SOW AD developers, as typically greater economies of scale, meaning higher power production and consumption of organic resources, are needed to attract investors. This limit adds further credence to preferential treatment of other AD types through existing financial incentives. Additionally, as of 2017 only 7.4MW of the 110MW for category 1 were allocated after two years of this incentive being in place, further demonstrating unattractiveness to investment.

The program cost is high compared to other renewable procurement options (**Figure 9**). The BioMAT has a price change mechanism where if there is a lack of participants the price given increases, and if there is an abundance of participants the price lowers. Given that there is low subscription, and no indication of a competitive market developing, it may be difficult to justify adding new sources to program in the future. Solar PV options are considerably cheaper than the category 1 (SOW AD) tariff, due in large part to a competitive market that has developed over the past 20 years.

[58] Interview with an SOW AD developer familiar with California AD market.

Figure 9: Comparison of average levelized price by renewable technology



Source: CPUC, Status of Bioenergy Market Adjusting Tariff (Biomat), October 11, 2017.

Uncoordinated Diversion and Energy Policies

Challenges, such as environmental protection, energy, and waste diversion, are often considered by policy instruments at different levels (municipality, state, federal) and for different sectors, like agriculture and transportation.[59] This can create a preference for end uses other than AD, such as compost, as these facilities require support mechanisms other than energy product off take. Energy policies, such as full electrification and the lack of a renewable gas procurement strategy disincentivises SOW AD development. The adoption of these policies, instead of SOW AD sector supportive policy, may prevent long-term visibility on future profitability to investors interested in supporting clean energy infrastructure.

It is hypothesised that energy and diversion policies are not naturally aligned, and a greater coordination would initiate wider adoption of SOW AD. Biogas producers often describe a lack

[59] Nevzorova, Tatiana, & Kutcherov, Vladimir, "Barriers to the wider implementation of biogas as a source of energy: a state-of-the-art review," *Energy Strategy Reviews* 26: 1-12, https://doi.org/10.1016/j.esr.2019.100414

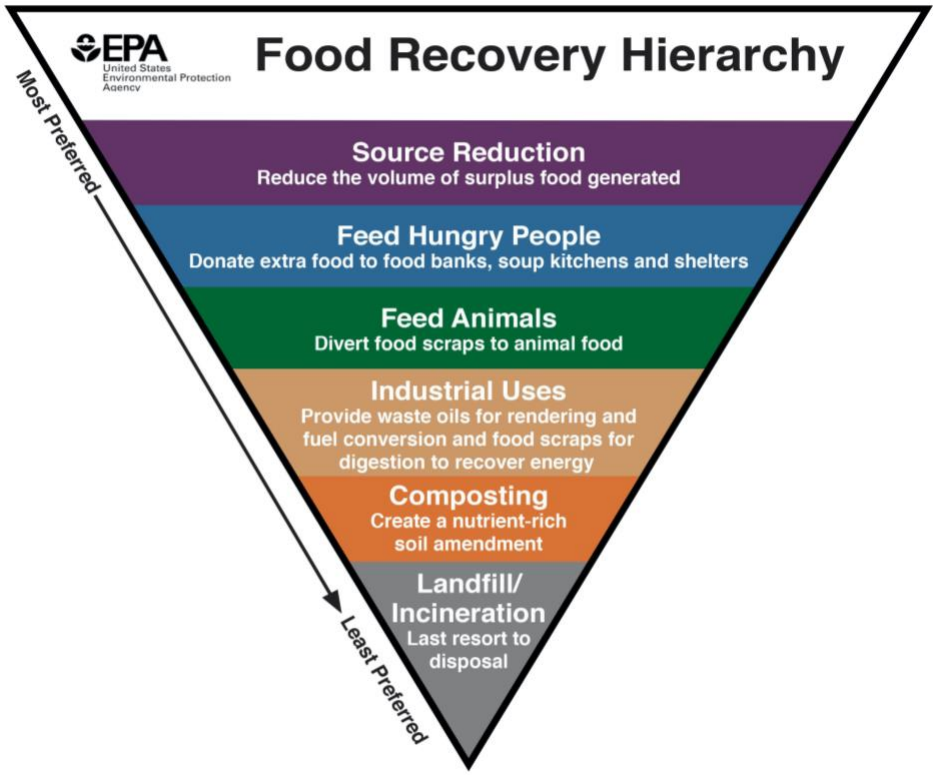
of political support and a desire for clear policy.[60] The examples of SB 1383, the Californian cornerstone waste diversion policy, and SB 1440, a bill that attempted to create a renewable gas procurement requirement but was altered to be just a consideration, will be assessed to demonstrate how incumbent organic resource markets may be given preferential treatment and existing renewable energy industries are hindering end-market development for SOW AD. The result of this lack of coordination between the two policies will be the hindering of Californian diversion and broader decarbonisation goals.[61] The movement for full electrification will also be shown to create an obstacle for the offtake pathway of RNG.

SB 1383

SB 1383 set the state-wide target of reducing organic resources disposal by 50% from 2014 levels by 2020, and a 75% reduction by 2025. This will require the organic resources recycling markets to handle an additional 27 million tons of waste by 2025.[62] In order to meet these targets, approximately 150-200 new "landfill equivalent" facilities will be required at an investment of between $2-$3 billion.[63] Furthermore, cooperation between different government entities is needed to meet the goals of SB 1383.[64] However, SB 1383 does not mandate for where the diverted waste goes, who is responsible for the diversion, and who pays for the cost.[65] Rather, the bill broadly aims to move organic resources further up the EPA Food Recovery Hierarchy (**Figure 10**). With a lack of coordination between state energy policies and diversion policies, organic resources will be kept towards the least preferred end, such as compost and landfill.

[60]Nevzorova, Tatiana, & Kutcherov, Vladimir, "Barriers to the wider implementation of biogas as a source of energy: a state-of-the-art review."
[61] It is currently easier to flare biogas than it is to inject into the pipeline or generate electricity.
[62] Source: Heather Jones, "SB 1383: a revolution for organic waste," *BioCyle*, March 17, 2020, https://www.biocycle.net/sb-1383-revolution-organic-waste/
[63] Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California*
[64] Ibid.
[65] Interview with Mr. R.

Figure 10: US EPA food recovery hierarchy



Source: EPA, Food Recovery Hierarchy, January 20, 2020

Attempts at a Renewable Gas Standard

A Renewable Gas Standard (RGS) in California would provide support to SOW AD development by providing a requirement for utilities to procure a certain amount of RNG from certain organic resources by certain dates, with a prescribed price ceiling. Emphasis has been placed upon California meeting its goals for reducing fugitive methane emissions, climate change and renewable energy goals through a feasible RNG market development alternative to the RFS.[66] Having a long-term procurement requirement for Californian gas companies would create market assurance and increase confidence from the investment community. Such an idea is like the long-term Power Purchase Agreements (PPA) that were crucial in large scale solar development, which provided a price schedule that allowed market development and protected ratepayers and limited costs. The current RNG market is often compared to electricity market of the early 2000s, with a

[66] Maritza Correa et al., *Renewable Natural Gas: Insights and Recommendations for California*

need for greater market transparency, an RNG credit market and standardization.[67] However, SB 1440 was an attempt to do this this but was blocked by the industries it sought to emulate.

The evolution of SB 1440 highlights the lack of coordination between energy and diversion policy, as well as the conflict with the SOW AD sector and existing energy market players. It was originally intended to create an RGS in California. However, due to significant opposition from the solar industry, pipeline owners and consumer protection groups, the bill was amended in its final stages to require the CPUC to merely consider setting such targets.[68] This demonstrates how incumbent energy players are furthering the lack of, and preventing better, coordination of energy and diversion policies due to the competing interests explained in the stakeholder mapping.

Despite the setback, SoCalGas announced it would replace 20% of its throughput with RNG by 2030.[69] This is not insignificant; however, it does not address the disconnect between the diversion policy requirements and renewable energy goals. This is due to RNG procurement not necessarily having to be from in-state facilities. This may continue the trend of out-of-state RNG production capacity increasing.

Full Electrification

In California, and across the US, there is a movement to tackle GHG emissions by full electrification.[70] SB 1440 opposition highlights the political and decision-making power that members of this movement have. The existing power sector, specifically solar and wind, view RNG policy development as an encroachment on their market share. These industries prefer to advance policies that favour electrification instead. This movement has found support from well-established non-governmental organizations (NGOs) such as the Sierra Club and Earth Justice as exposed in the stakeholder mapping.[71] These NGOs doubt the environmental claims of RNG and

[67] Thomas N. Russo, "Regulatory Challenges Facing Renewable Natural Gas."
[68] Interview with Mr. R.
[69] SoCalGas, "California's Clean Energy Future: Imagine the Possibilities," accessed January 20, 2021, https://www.socalgas.com/1443742344191/scg-vision-paper-04032019.pdf
[70] Justin Gerdes, "California nears tipping point on all-electric regulations for new buildings," *GreenTech Media*, July 29, 2020, https://www.greentechmedia.com/articles/read/california-nears-tipping-point-on-all-electric-building-regulations.
[71] The Sierra Club and Earth Justice published a report in 2020 referring to the promise of RNG as a 'myth'.

consider the lack of market development as proof of its undesirability when compared to other renewable energy sources, such as wind and solar.

Impact of Lack of Coordination

The lack of coordination between energy and diversion policies has several impacts upon the adoption of SOW AD. The lack of an RGS creates the obstacle of increased difficulty in securing long-term off-take contracts of RNG. For large-scale SOW AD projects to be financed, investors typically need to see long-term income sources identified and under contract or letter of intent. Developers typically seek 10-year contracts with natural gas companies to assuage investor concern.[72] In the absence of an RNG procurement requirement for natural gas companies, developers will need to be innovative to get these critical contracts.

This lack of coordination also creates an economical and environmental challenge for the SOW AD sector, and all sources of biogas. If the disconnect is not resolved then biogas from SB 1383 organic resources will be flared or, even worse, allowed to escape fugitively into the atmosphere, due to no RNG requirements.

Local Acceptance

Local community consultation is important for project acceptance. Perception of AD is not always positive and can persist throughout all stages of development.[73] With a large-scale facility, traffic increase and odour issues can arise if organic resources are stored improperly.[74] The use of land for energy projects is often controversial, regardless of the renewable technology. For example, the largest county in the US, San Bernardino County, banned utility-scale renewable energy projects in many unincorporated areas.[75] In regions where community concerns have not been voiced at an early stage in the development process, it has created a vocal opposition group to

[72] Thomas N. Russo, "Regulatory Challenges Facing Renewable Natural Gas."
[73] BioEnergy DevCo's planned facility near Seaford, Maryland is facing local opposition in the final planning and permission stage. Over 130 residents and advocates are opposing the project. https://www.foodandwaterwatch.org/2021/02/12/bioenergys-biogas-proposal-overwhelmed-by-local-opposition/
[74] There are several examples of ADs facing local pressure due to odour. For example, the Heartland Biogas Project in Colorado received over 600 odour complaints from residents. https://www.cpr.org/2016/12/16/fed-up-with-the-smell-neighbors-want-the-weld-county-biogas-project-shut-down/
[75] Samantha Gross, "Renewables, land use, and local opposition in the United States", *Brookings Institute*, January 2020.

development which can lead to political figures becoming unsupportive. Policies like San Bernardino's can have lasting effects on facility development.

The principal opposition to RNG development in California is political opposition from environmental justice advocates.[76] These groups often do not understand or otherwise misrepresent the value associated with biogas-upgrading to RNG. There is a concern that promoting RNG, or any biogas development, is a method for sustaining the natural gas industry.[77] This view has been furthered by the controversy around the supposed grassroots organization *Californians for Balanced Energy Solutions*. This organization was funded by SoCalGas to discredit the full electrification movement. When the organization filed to be an official party of the decision-making process on rulemaking to reduce home and building emissions with the CPUC, it failed to disclose it was created by SoCalGas, who would lose a considerable amount of business from full electrification policies.[78] Furthermore, the lack of information presented to the public and policymakers about RNG and its capability in converting waste into an energy source that furthers both state clean energy and climate change goals has not helped make the case either.[79]

[76] Interview with Mr. R.
[77] Ibid.
[78] LA Times Editorial Board, "SoCal Gas' sleazy 'Astroturf' effort to keep fossil fuels flowing in California", *Los Angeles Times*, August 10, 2019, https://www.latimes.com/opinion/story/2019-08-10/socalgas-astroturf-cpuc-aliso-canyon.
[79] Thomas N. Russo, "Regulatory Challenges Facing Renewable Natural Gas."

Chapter 2: Opportunities

Despite the previously mentioned obstacles, California presents several substantial opportunities for SOW AD development. This chapter will explore the opportunities for development of large-scale SOW AD facilities in California.[80]

There are several lucrative economic opportunities for SOW AD development that derive from supportive policies at the state government level. The landfill diversion bill SB 1383 provides opportunities for SOW AD developers by increasing the availability of organic resources, of which access to can be a major source of project risk. The LCFS provides a greater price commanded by RNG and obligated parties for purchasing credits to offset their own emissions.

The value of the SOW AD sector goes beyond sheer economic concerns. SOW AD supports environmental measures and goals of stakeholders, from government to civil society. This can be seen through the ambitious local governments in Californian opting for zero waste goals. Traditionally polluting industries, such as agriculture and fossil fuel infrastructure, are seeking to decarbonise using SOW AD products like compost and RNG. Coalitions of private sector businesses, across many industries, demonstrate environmental, social, and governance (ESG) targets of meeting climate goals, in which organic resource diversion from landfill and the use of clean energy products that lower fossil fuel dependence are key elements.

Various levels of government are advancing climate change concerns and goals. The federal government set the goal of reducing GHG emissions by 50-52% from 2005 levels, by 2030, and reducing methane emissions 90% by 2030.[81] The Californian state government 2017 Short Lived Climate Pollutant (SLCP) strategy aims to reduce methane emissions by 40% by 2030, through the advancement of SB 1383, the LCFS and other bills.[82] Some local governments have set more

[80] Large-scale are considered due to the sizeable financial investment required for these projects. Having a larger processing capacity for organic resources and a greater quantity of energy products generated can make it easier to access investment. Small-scale typically do not have these economies of scale.
[81] U.S. Federal Government, *Nationally Determined Contribution*, (2021), https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20States%20of%20America%20First/United%20States%20NDC%20April%2021%202021%20Final.pdf
[82] Other bills aim to tackle black carbon (soot) and hydrofluorocarbons (HFCs) which are outside of the scope of this thesis.

ambitious targets to advance climate goals, such as zero waste commitments in San Francisco, prior to state and federal government pledges.[83] These multi-level policies largely reflect civil society's climate change concerns and the need for policy change to promote behaviours and processes that prevent further environmental degradation. The willingness and need for action require all energy sources available to be mobilised, including the SOW AD sector, which can contribute clean energy products and methane capture.

With government and civil society prioritizing environmental protection and climate change, the private sector has largely embraced these ideals. The growing importance of, and valuation based upon, ESG factors demonstrates this trend. Industries responsible for a large proportion of GHG emissions are changing processes, and even core business activities. Manufacturers are seeking power and resources from renewable sources, whilst investing in recycling capability for waste materials. The agricultural sector, responsible for 38% of methane emissions, is engaging in new farming methods and land management practises.[84] Some incumbent Californian energy market players are aligning with Paris Agreement recommendations with a strong focus on RNG, creating additional demand for SOW AD energy offtake products.

Opportunities for SOW AD from Converging Stakeholder Interests

All opportunities for SOW AD development stem from the government policies and private sector values. To understand fully, the interests of stakeholders are shown to have much in common with SOW AD developers. The growing concern of environmental degradation at all levels of governance, and private sector advancement of measures to avoid furthering climate change present areas of common interest with SOW AD developers. Here these potentially converging interests of stakeholders with SOW AD developers are explored, with the consequential opportunities addressed. Refer to Appendix B for full stakeholder interest mapping.

[83] San Francisco's zero waste policy dates to 2003, whereas the SLCP was finalized in 2017.
[84] Matt Tomich, "Getting the most out of methane reduction," *The Hill*, May 6, 2021, https://thehill.com/opinion/energy-environment/552167-getting-the-most-out-of-methane-reduction

Cooperative Interests at Levels of Government

There are opportunities for cooperation between SOW AD developers and all levels of government. Californian local government wish to be compliant with SB 1383. Compliance requires sufficient processing capacity for organic resources, of which SOW AD technology is ideally suited to bring organic resources higher up the EPA end-use hierarchy. As SB 619 demonstrated, there is a fear amongst jurisdictions and stakeholder groups that adequate organic resource recycling capacity does not exist currently and do not want to be penalised for this. Some local governments are mandated for more ambitious targets. San Francisco, for example, implemented mandatory diversion in 2009. SOW AD can provide solutions to both SB 1383 compliance and more ambitious targets set by local government. Greater SOW AD deployment would remedy the concerns of SB 619's delayed SB 1383 penalty enforcement. This opportunity also ties into the goals of the state government.

The Californian state government seeks to meet not only SB 1383 requirements but also GHG emissions reductions. There's a potential cooperation with SOW AD developers through the diversion of organic resources from landfill and through the energy products produced. RNG from SOW AD facilities displace natural gas, lowers the carbon intensity of fuel sources, and helps solve organic resources recycling problems. This convergence of interests between state government and SOW AD developers needs to be supported by state bureaucratic apparatus.

State bureaucracies seek to enforce diversion policy and provide business development tools and resources for end-markets that will provide capacity. This cooperation is an opportunity for SOW AD developers as it increases the availability of organic resources, as seen in the opportunity of improved economics from landfill ban. Furthermore, wider deployment of SOW AD would provide greater processing capacity which would lessen the need for additional delays to SB 1383 enforcement.

The federal government has vested interests in reaching the goals of the Paris Agreement and the Nationally Determined Contribution. Abating methane emissions through supporting SOW AD, and the wider biogas sector, provides an opportunity for the US to meet the target of reducing GHG emission by 50-52% from 2005 levels by 2030. The CLEAN Future Act has set the target

of methane emissions reduction of 90% by 2030.[85] These GHG emission reduction goals give a strong potential for cooperation with the SOW AD sector to advance these targets. The Coalition for RNG provides advocacy for the RNG industry and actively lobbies for greater consideration of its role in the energy transition. Success of these efforts can be seen in the federal tax credit of 30% for the construction of new AD facilities.[86]

Organic Resource Generators/Haulers

The interests of haulers are often converging with SOW AD developers and provide substantial opportunities. Californian haulers have vested interests in holding lucrative waste collection agreements for municipalities. As these municipalities seek to comply with SB 1383 targets, separate collection of organic resources and diversion from landfill are becoming more common as a requirement for these contracts. Often these haulers will seek a third party to develop, build, own and operate diversion assets. This opens areas of cooperation with SOW AD developers as it can guarantee a beneficial reuse end market for municipal organic resources collected. Long term organic resources contracts with franchised haulers helps SOW AD developers secure financing.

Private sector businesses are taking a greater interest in increasing the importance of ESG goals. This provides an opportunity for cooperation with SOW AD developers to recycle organic resources, as well as provide clean energy products which lower dependence on fossil fuels.

Civil Society

NGOs can have interests that are supportive of greater SOW AD adoption in California, such as Californians Against Waste.[87] Organic resources can be a difficult to recycle material with the current lack of processing capacity in California. SOW AD facilities can provide this service and advance a broader acknowledgment of circular economy.

Citizens share some common interests which provide opportunity for SOW AD. Residents are increasingly looking to lower their impact upon the environment in terms of producing waste that

[85] Matt Tomich, "Getting the most out of methane reduction."
[86] Matt Tomich, "Getting the most out of methane reduction."
[87] Californians Against Waste, "Issues," accessed on May 20, 2021, https://www.cawrecycles.org/issues.

goes to landfill. Residential activism in environmentalism provides an opportunity to support SOW AD development, for topics such as improving air quality. Furthermore, resistance of citizens to new landfills represents an opportunity for SOW AD development.

Existing Organic Resource Market Players

Landfill owners, who are often part of vertically integrated franchise haulers, will need to comply with SB 1383 when it becomes enforced. However, landfills are not only motivated by the need to avoid fines. Diverting organic resources to SOW AD facilities and other beneficial reuse markets will increase the lifespan and likely decrease the quantity of odour complaints from residents, helping increase the local acceptance of these assets. The interests of existing end markets for organic resources may be converging with the development of SOW AD.

Compost facilities have vested interests that provide potential cooperation with the SOW AD sector. Composts are typically lower cost infrastructure investments, with simple processes and a lower tolerance for organic resources with contamination (plastics and packaging etc.). SOW AD facilities require greater financing and usually have capability for removing contamination in organic resources. This presents a potential opportunity for market cooperation.

Energy Market Players

The various energy market players, such as pipeline owners, have interests that may present opportunities for SOW AD development. Pipeline owners have vested interests in natural gas infrastructure having a role in the energy transition. RNG is a supportive product that may help prevent these assets from becoming stranded. Utilities are interested in providing customers with clean energy products whilst being cost competitive. Full electrification will require customers to replace not only appliances but building infrastructure. Using RNG will allow for a decarbonised product offering with a lower cost than full electrification.[88] Even under the most ambitious full electrification scenario analysis, gas demand remains substantial which would be better met with

[88] Navigant Consulting, *Analysis of the Role of Gas for a Low-Carbon California Future*, (Boulder: Navigant Consulting, 2018).

RNG.[89] These are evident in the opportunities of reducing GHG emissions and supportive off take policy for RNG.

Agricultural Sector

The Californian agricultural sector presents an opportunity as a potential large market for SOW AD digestate compost products. California's agricultural sector is the largest grower of vegetables and fruits in the US.[90] However, it is threatened by the effects of climate change. An increasing number of growers are seeking to participate in carbon farming and more sustainable methods, such as reducing dependence on petrochemical fertilizers. Compost products can be an important part of this by contributing to increased soil health and water retention.

Opportunities from GHG emissions reduction targets

At a national level the US has developed policies to support and set targets for GHG emissions reduction. Beneficially reusing organic resources, capturing fugitive emissions, and providing clean energy products are some ways in which the SOW AD sector can participate in, and facilitate the goals of, this movement.

National Methane Emissions Reductions

The goal to reduce GHG emissions by 50-52% below 2005 levels by 2030 is ambitious. Methane, the primary component of allowing organic resources to decompose in landfills, is the second most prevalent GHG in the atmosphere and has a far greater warming capability than carbon dioxide. It accounts for 20% of methane generated in California.[91]

The introduction of the CLEAN Future Act in March 2021 set a methane emission reduction target of 90% by 2030. It included a $35 billion plan for the Department of Energy to explore new technologies for addressing leakage from fossil fuel sources.[92] Exploring other methane abatement

[89] Interview with Mr. R.
[90] California Department of Food and Agriculture, "California Agriculture Production Statistics", accessed May 15, 2021, https://www.cdfa.ca.gov/Statistics/.
[91] CalRecycle, "California's Short-Lived Climate Pollutant Reduction Strategy", accessed May 20, 2021, https://www.calrecycle.ca.gov/organics/slcp.
[92] Matt Tomich, "Getting the most out of methane reduction."

methods than capturing organic resources, such as capping abandoned oil and gas wells, are typically more expensive (**Table 7**).

Table 7: Sources of methane and cost to capture[93]

Sources of Methane	Cost of Capturing ($ per metric ton of CO2 equivalent)
Abandoned oil and gas wells	$67
Organic resources	$16

Tackling methane emissions from abandoned oil and gas wells (AOG), and the wider fossil fuel industry, is important. However, when the cost and quantity of emissions reduced is compared, supporting organic waste AD provides a comparable result but with a substantially lower cost: $50-$100 billion for AOG versus $5.5 billion to support development of AD for all organic resource types, including SOW AD.[94] Combining this federal support with other sectors of society will be important for SOW AD development in California.

Ambitious Local Government

Misalignment between federal, state, and municipal levels of governance can be an opportunity for SOW AD development. Local municipalities can set more ambitious goals, with regards to emissions reduction or organic waste diversion, than the state government. Net zero goals in cities such as San Francisco and San Jose have spurred greater development of organic resources recycling infrastructure. California cities are typically first movers in the US for ambitious local policy, and when successful, are often implemented in other states.[95] This presents opportunity for SOW AD development which goes beyond California. These policies, albeit ambitious, require support from the private sector to succeed.

Private Sector Partnerships for Organic Resources and Energy Products

The We Mean Business Coalition, which includes over 1,700 industry-leading companies with a $24 trillion market cap, addressed a letter to the federal government in support of President Biden's

[93] Ibid.
[94] Ibid.
[95] Interview with Mr. R.

climate target to reduce GHG emissions by at least 50% by 2030, based on 2005 levels.[96] This is evident of the increasing importance of environmental, social and governance (ESG) goals in the private sector. North America is the global leader in sustainability reporting, with the number of companies producing sustainability reports increasing from 88% in 2017 to 95% in 2020.[97]

The rise of ESG importance in the private sector has already benefited farm-based AD. Vanguard Renewables, a developer and owner of several farm-based AD, launched the Farm Powered Strategic Alliance (FPSA) with Starbucks, Unilever, and Dairy Farmers of America. It aims to provide a circular solution to food waste and GHG emissions. The alliance works by partners committing their organic resources to Vanguard and receive RNG, thereby lowering their reliance on fossil fuels. This alliance helps Vanguard develop facilities across the US in two ways; access to organic resources and RNG purchasers in areas where FPSA partners have facilities.

There may be an opportunity for SOW AD developers to create similar coalitions with industries in California, for organic resources provisions and clean energy products. As previously discussed in Chapter 1, SB 619 pushed back the enforcement of penalties for SB 1383 to 2023 due to concern from generators of organic resources and jurisdictions due to the lack of recycling infrastructure. This presents an opportunity for SOW AD developers to partner with concerned stakeholder groups, municipalities, and industry groups, who supported this bill. It can provide processing capacity for organic resources and advance broader ESG goals of these groups. Alongside the growing private sector desire for sustainable climate change solutions, the carbon consciousness of the agricultural sector is also increasing.

Compost Use in Agriculture

Compost use in the Californian agricultural sector is growing. International programs like the "*4 per 1000"* initiative is illustrating the role that soil can play in atmospheric carbon sequestering.[98] Remediating land in California should be at the top of environmental agencies and activists

[96]We Mean Business Coalition, "408 Businesses and Investors Support U.S. Federal Climate Target in Open Letter to President Biden", accessed April 13, 2021, https://www.wemeanbusinesscoalition.org/press-release/businesses-investors-support-u-s-federal-climate-target-open-letter-president-biden/
[97] KPMG IMPACT, *The time has come: the KPMG survey of sustainability reporting 2020,* December 2020.
[98] 4 per 1000 Initiative, "Welcome to the 4 per 1000 initiative", accessed May 20, 2021, https://www.4p1000.org.

concerns. Innovative ongoing testing on applying compost to agricultural and range land is showing promising results in its ability to improve soil health and contribute to carbon sink effect.

In Californian agricultural agencies there is a growing drive to use compost products to improve soil health.[99] California's Healthy Soil Initiative is a collaborative effort between state agencies and departments to improve soil health.[100] This initiative demonstrates state bureaucracy potential support not only for the diversion of organic resources to SOW AD facilities, but also for digestate compost products use in agricultural markets.

Compost can be produced from SOW AD facilities by using digestate and additional organic resources. Digestate is the substance that is present after the anaerobic digestion of biodegradable material. The volume of digestate can be approximately 90% of the organic resources that are digested.[101] This can be a large quantity of product rich in nitrogen, phosphorous and potassium.[102] Green waste can be composted with digestate to give the compost greater marketability due to the carbon added.[103] The Californian SOW AD sector has an increased trend of composting and AD co-locating.[104]

Existing stand-alone compost facilities in California have saturated the retail market for compost products.[105] However, there are concerted efforts to break into the agricultural sector for compost use in soil amendment and fertilizer products. Agriculture in California demonstrates a promising market for compost products. Compost can assist agriculture in addressing issues arising from climate change: drought and nutrient management. Climate change threatens this industry in several ways. A drier climate will reduce crop yields, decline water resources, and reduce overall soil health.

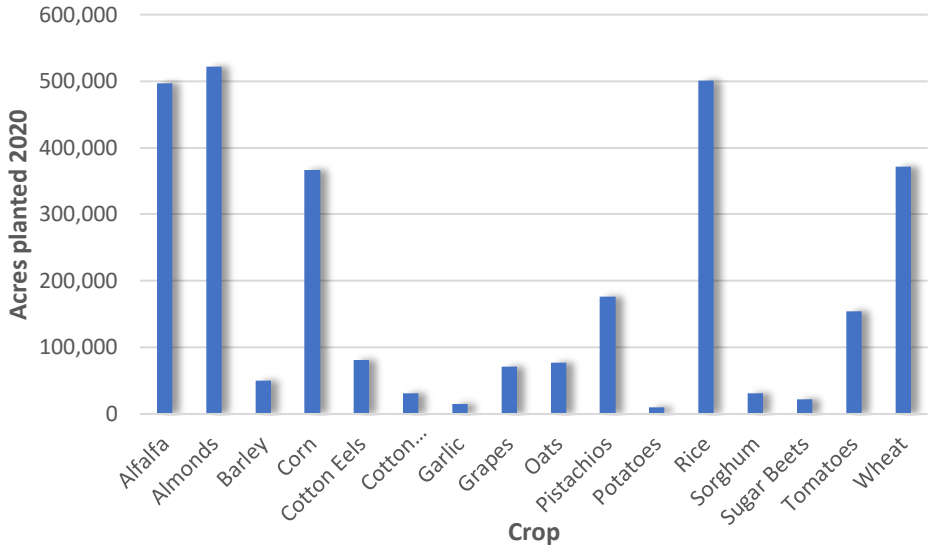
[99] Ibid.
[100] California Department of Food and Agriculture, "California's Healthy Soils Initiative", accessed April 20, 2021, https://www.cdfa.ca.gov/healthysoils/
[101] Biogas Info, "Digestate", accessed on April 20, 2021, https://www.biogas-info.co.uk/about/digestate/
[102] Ibid.
[103] Digestate nutrient values cannot be changed unless the organic resources fed to the AD change. Digestate markets in California are currently underdeveloped.
[104] Author's previous professional experience.
[105] Ibid.

With a shift in farming techniques and a growing push for the decarbonisation of agriculture, compost is becoming a valuable product. Analysis will focus on how changing farming practises and goals could increase the demand for compost products.

The State of Californian Agriculture

California grows over a third of vegetables and two thirds of fruits in the US.[106] Californian climate makes it a major grower of alfalfa, nuts, and rice amongst other crops (**Figure 11**). Ensuring the sustainability of these products is essential to future farming.

Figure 11: Select crops planted acreage in California (2020)

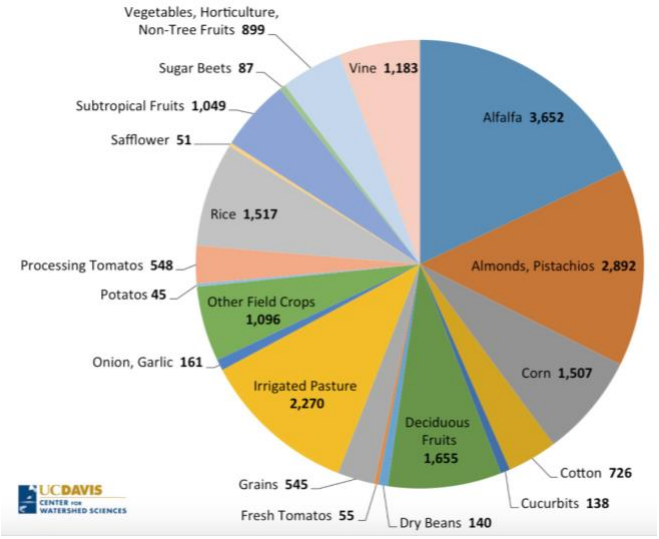


Source: California Department of Food and Agriculture, "California Agriculture Production Statistics", May 15, 2021.

Crops grown in California are substantial consumers of water resources (**Figure 12**). Water security of agriculture is a crucial concern for the sector and is anticipated to be greatly affected by climate change.

[106] California Department of Food and Agriculture, "California Agriculture Production Statistics", accessed May 15, 2021, https://www.cdfa.ca.gov/Statistics/.

Figure 12: Water consumption by crop type (1,000 acre-feet)



Source: Congressional Research Service, California Agricultural Production and Irrigated Water Use, June 30, 2015

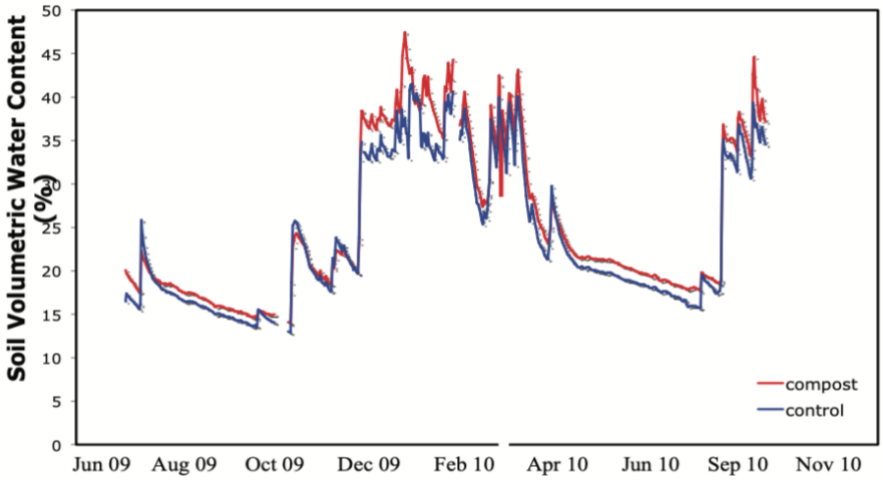
Applying compost to soil can increase water retention, lowering the demand for water resources. There are ongoing projects that explore this concept and the broader idea of *carbon farming*.[107]

Carbon Farming and Compost

Carbon farming is the broad term used for a variety of agricultural methods aiming at sequestering atmospheric carbon into soil, crop roots and leaves.[108] Long term carbon farming projects, such as the Marin Carbon Project, demonstrate the benefits of applying compost to remediate land (**Figure 13**).[109] The project is restoring rangeland with improved forage, with early results suggesting substantial soil carbon sequestering.

[107] Carbon Cycle Institute, "Carbon Farming," accessed May 20, 2021, https://www.carboncycle.org/carbon-farming/
[108] Nath, Arun Jyoti, Lal, Rattan, Das, Ashesh Kumar, "Managing woody bamboos for carbon farming and carbon trading," *Global Ecology and Conservation*, 3: 654–663. doi:10.1016/j.gecco.2015.03.002
[109] Marin Carbon Project, "Marin Carbon Project," accessed May 20, 2021, https://www.marincarbonproject.org/about.

Figure 13: Moisture content in soil when compost is and is not applied



Direct application of digestate, or further composting with green waste, can provide a product that assists with enhancing soil 'water-holding capacity, provides stable, slow-release nutrients, enhances soil carbon sequestration and increases forage production without harming native plant communities.

According to the Marin Carbon Project, there is a 27-33 million metric tons potential for compost in California.[110] This could be applied to a quarter of rangelands in California, which would sequester approximately 337 million MT of CO2e per year. Mitigating GHG emissions through soil carbon sequestering is concurrent with California's, and the US', climate change goals. Such an aim gives the deployment of SOW AD greater value.

Current Compost Usage

Beyond the demonstration carbon farming projects, there are commercial growers using compost products. The California Compost Coalition estimates that approximately 7.5 million tons of bulk compost products are used in croplands each year.[111] Large growers are moving from fertilizers to compost use. For example, Earthbound Farm, a large grower of salad greens, has around 30,000

[110] Marin Carbon Project, "Marin Carbon Project."
[111] California Compost Coalition, "The SB 1383 Progress Report," *Sustainable Organic Management,* 7 (7), July 2020.

acres and applies between 3 and 10 tons of compost per acre.[112] This provides an opportunity for SOW AD development, as it can contribute to a greater supply of compost products to meet an increasing demand from agriculture. By combining processes of AD and compost, the SOW AD sector can produce valuable clean energy and compost products, whilst keeping organic resources higher in the EPA recovery hierarchy.

Advancing GHG Emissions Reductions

Using SOW AD technology as a preferred method for recycling organic resources provides GHG emissions reduction possibilities across multiple facets. Capturing the methane from organic resources avoids atmospheric emissions and displaces conventional natural gas. The compost produced from organic resources and digestate can be used to displace petrochemical fertilizers, a source of GHG emissions, and help soil sequester carbon and improve water retention to mitigate scarcity.

Improved Economics from Landfill Bans

Organic waste landfill bans provide strong basis for SOW AD development. They provide long-term increased organic resources availability due to the separate collection requirements in hauling agreements and ban of traditional end markets. Landfill bans or the implementation of landfill taxes improve the tipping fee that SOW AD facilities can charge for organic resources, which lowers the dependence on energy product pricing.

Increased Organic Resources Availability

Access to organic resources is typically a great source of risk for any AD project.[113] Having long term contracts in place with reputable clients, such as franchised haulers, is a prerequisite for access to project financing.

California's diversion policy regulations requirement for jurisdictions to implement mandatory organic resources collection programs for all producers was devised to inspire greater processing

[112] CalRecycle, "Case Studies on Compost Use in Agriculture," accessed May 20, 2021, https://www.calrecycle.ca.gov/organics/farming/casestudies
[113] Brean Capital presentation at RNG Project Financing conference, May 20th, 2021.

infrastructure investment.[114] The collection of separated organic resources and contracted agreements between haulers and processing facilities will help finance these SOW AD facilities.[115] Jurisdictions with franchised hauling agreements are frequently including the ability to divert organic resources as a crucial condition to contract awarding.[116] As haulers desire to win these lucrative deals for collection they must find and partner with diversion markets such as SOW AD facilities.

Partnering with franchised haulers can decrease the risk of SOW AD projects. The largest franchised haulers are national carriers with substantial portfolios of waste collection and disposal assets. The risk of these haulers going bankrupt is low which helps SOW AD developers approach financing due to decreased organic resource availability risk.

The quantity of organic resources that are projected to require processing capability by 2025 provide a substantial opportunity for SOW AD development (**Table 8**). There will be a predicted shortfall in processing capacity of around 8 million tons per year. Assuming SOW AD facilities are co-located with composting capability, 6 million tons per year of suitable organic resources could be available by 2025 for new developments.

Table 8: Estimated processing capacity in 2025 (million tons)[117]

Technology	Estimated Anticipated Capacity by 2025	Estimated Needed Capacity by 2025	Difference
Anaerobic Digestion	1.0	2.7	(1.7)
Compost	5.3	9.6	(4.3)
Co-Digestion	0.21	2.4	(2.2)
Chip & Grind	3.5	3.3	0.2
Total	10	18	(8.0)

[114] CalRecycle, *Analysis of the progress towards SB 1383 waste reduction goals* (Sacramento CA 2020) https://www2.calrecycle.ca.gov/Publications/Details/1693.
[115] Ibid.
[116] A franchised hauler is a hauler which holds the exclusive right to collect waste for a particular city, county, or region.
[117] CalRecycle, *Analysis of the progress towards SB 1383 waste reduction goals.*

The implementation of organic waste diversion bans, the signals made to private and state investors, can make it difficult for a state to reverse these policies. State bureaucracies, such as CalRecycle, provide grant financing to SOW AD developers to facilitate landfill diversion of organic resources. In the last grant cycle, 2018-2019, $18.5 million was awarded to 6 projects.[118] From an economic and political perspective, if there is an electoral change it would still not be in the interest of state government and bureaucracies to repeal SB 1383 as large sums of public spending would become sunk costs. Furthermore, once investment has been placed in separating and processing organic resources and residents become accustomed to diversion, civil society and private business would be unlikely to support repealing the policy.

Organic Waste Bans Raise Tipping Fees

Organic waste bans typically present an economic opportunity for SOW AD facilities with the ability to command greater tipping fees. A tipping fee is the price that landfills charge waste generators for disposal and is set by the landfill. Landfill tipping fees are a useful, albeit somewhat imprecise, marker for prices that other end-markets can charge for organic resources.

Diversion policy often provides AD facilities with favourable tipping fees. SOW AD facilities decide tip fees based on several factors, for example gas yield, contamination level, quantity, and term of contract. SOW AD facilities generate income from receiving a tip fee from organic resources and from the products produced (biomethane, electricity, compost products). According to the Environmental Research & Education Foundation (EREF) California has higher than average tip fees for North America.[119] Tipping fees in states with organic waste diversion mandates are typically higher (Appendix C). Regional tip fees have increased since 2016 (**Table 9**).

[118] CalRecycle, "Organics Grant Program," accessed May 20, 2021, https://www.calrecycle.ca.gov/climate/grantsloans/organics

[119] Environmental Research and Education Foundation, "Analysis of MSW Landfill Fees: 2020," accessed May 15, 2021, https://erefdn.org/product/analysis-msw-landfill-tipping-fees-2/.

Table 9: Historical regional tip fees[120]

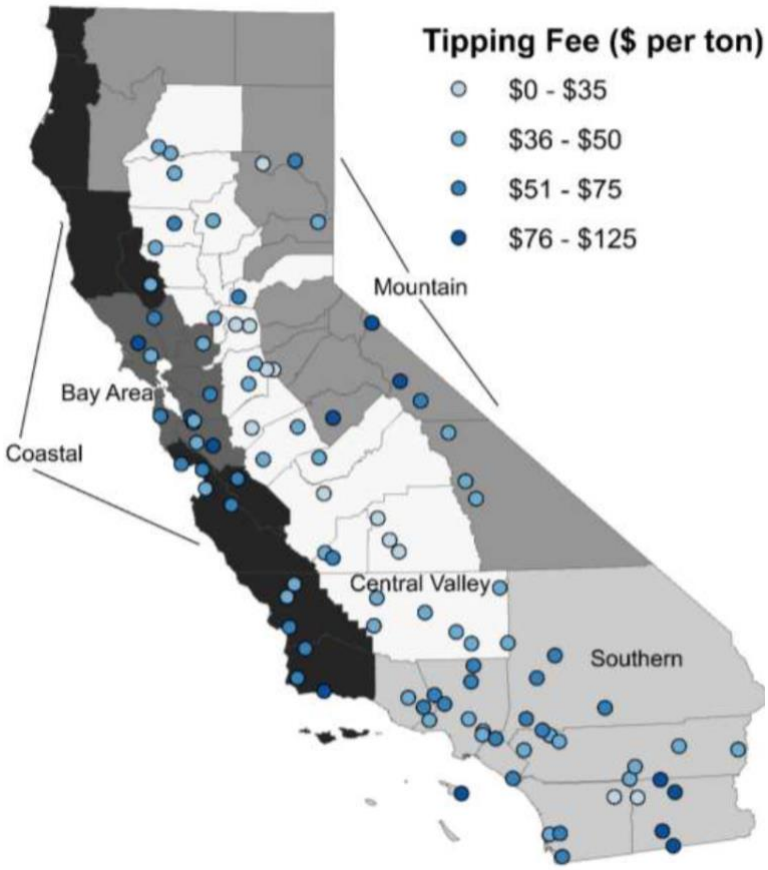
Region	Average tipping fee ($/ton)					Average year-over-year change
	2016	2017	2018	2019	2020	
Pacific (AK, AZ, CA, HI, ID OR, WA)	$61.20	$60.20	$68.54	$73.03	$72.03	+4.4%

Rising regional tip fees, combined with the evident lack of sufficient organic resources processing capacity in California, presents SOW AD developers with a potentially lucrative opportunity. Having the ability to charge a greater tip fee can help subsidize a SOW AD facility's overall economic situation if energy pricing is unfavourable or volatile. This can assuage the investor scepticisms of financial support mechanism and reduce investment risk identified in Chapter 1. A greater contracted tip fee for organic resources can improve the investment profile of SOW AD projects.

Within California, landfill tipping fees are typically higher near population centres (**Map 2**). A larger population typically corresponds to a greater quantity of organic resources generated.

[120] Ibid.

Map 2: 2013 Regional tipping fees in California



Source: CalRecycle, Landfill Tipping Fees, February 2015.

If SOW AD facilities can be sited close to these centres a higher tip fee can be charged. Even if plants need to be sited outside of the centre, then a slightly cheaper tip fee could be charged to compensate the greater transportation cost.

Supportive Offtake Policy for RNG

Supportive offtake policy for RNG provides a substantial opportunity for SOW AD development in California. As previously discussed, supply contracts for organic resources are usually a requirement for access to finance. On the other end of the SOW AD process, energy product offtake agreements are also heavily sought after. The supportive offtake financial mechanisms, such as LCFS, provide support for SOW AD development in two ways: the LCFS provides a value to RNG beyond commodity pricing, and creates obligated parties to purchase credits. Additionally,

the optional RNG procurement targets by SoCalGas demonstrates an opportunity for the SOW AD sector to grow.

LCFS Demonstrates the Value of RNG

The LCFS provides a substantially higher value to biomethane than natural gas. As mentioned in Chapter 1, the LCFS can provide greater price stability for SOW AD RNG. The price commanded by SOW AD RNG is far greater than the natural gas commodity price. With both LCFS and RIN values subscribed, the price can be more 12 times greater than conventional natural gas (**Table 10**).

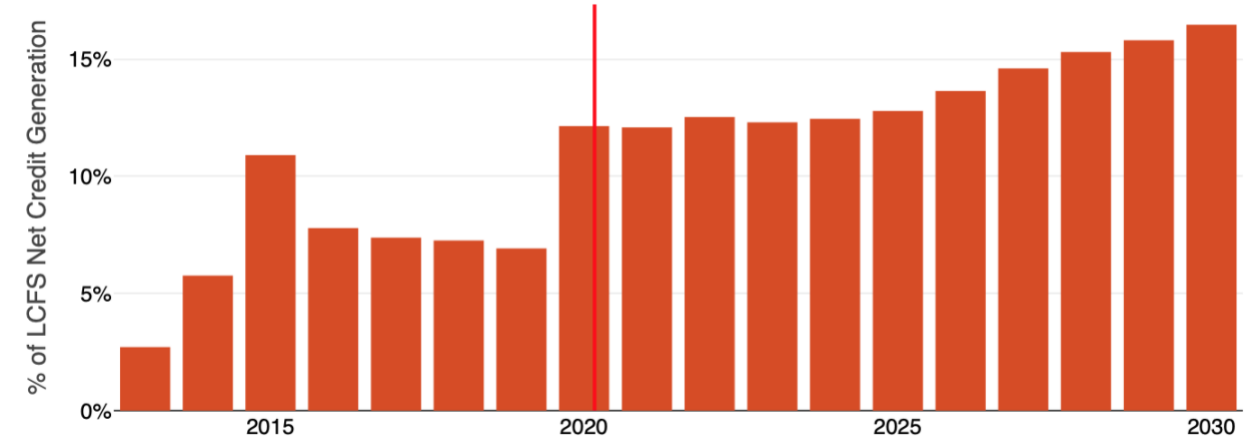
Table 10: Example price of SOW AD RNG[121]

RNG Price component	Price ($/MMBtu)
LCFS	~$19.70[122]
D5 RIN Value	~$15.32[123]
Commodity Price	~$2.97[124]
Total SOW AD RNG Price	**~$37.99**

The outlook for the SOW AD sector's contribution to the LCFS credit generation is positive. RNG's contribution to LCFS credits is expected to grow (**Figure 14**).

[121] Calculated by author. Individual components are sourced below.
[122] Assuming carbon price of $187/ton CO2 and a carbon intensity score of -10 grams CO2. Sources: CARB, "Weekly LCFS Credit Transfer Activity Reports," accessed May 16, 2021, https://www.arb.ca.gov/fuels/lcfs/credit/lrtweeklycreditreports.htm.
Biogas World, "How can you get funding for your anaerobic digestion project in North America and assess value of biogas?", accessed May 16, 2021, https://www.biogasworld.com/news/funding-anaerobic-digestion-project-north-america/.
[123] Assuming 1 RIN/77,000 Btu and average 2021 D5 RIN price of $1.18. Sources: American Biogas Council, "RIN Calculator," accessed May 16, 2021, https://americanbiogascouncil.org/resources/rin-calculator/. EPA, "RIN Trades and Price Information," accessed May 16, 2021, https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information.
[124] Henry Hub Natural Gas price from Business Insider, daily price from May 16th, 2021.

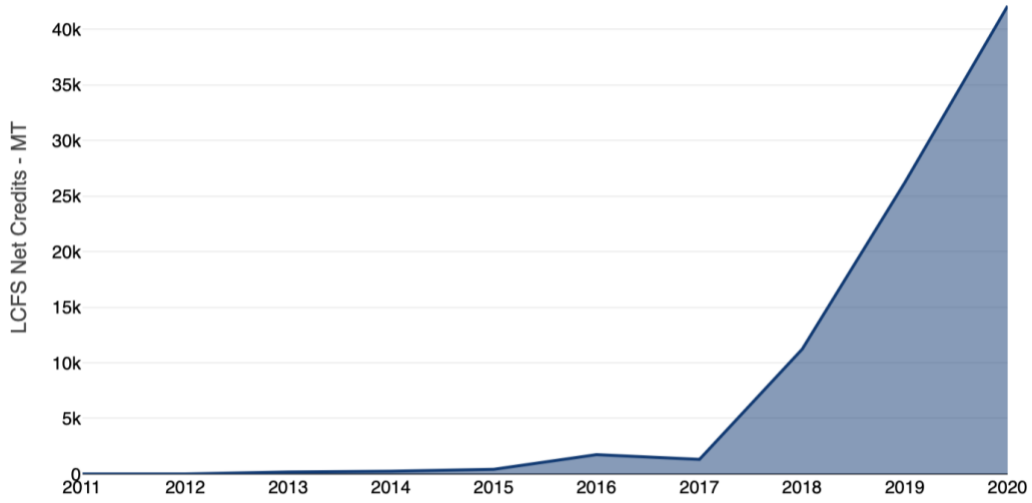
Figure 14: Projection of RNG proportion in LCFS credit generation



Source: Stratas Advisors, LCFS Forecast: EV and Biogas Growth Likely to Decrease LCFS Credit Prices, Changing HVO Economics, accessed May 16, 2021.

SOW AD facilities are increasingly taking advantage of the LCFS credit mechanism (**Figure 15**).

Figure 15: Historical SOW AD RNG LCFS net credits



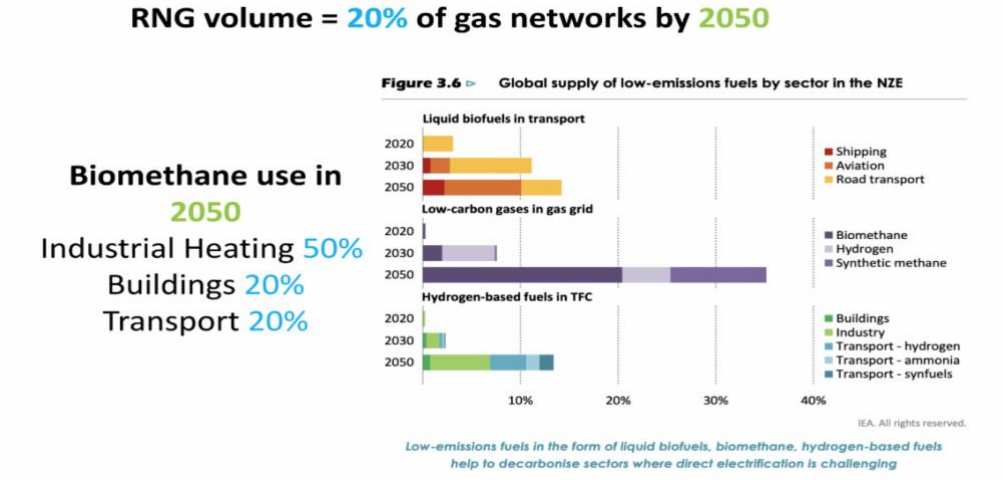
Source: Ibid.

Across North America, biogas plants are converting from electricity to biomethane pipeline injection due to the improved attractiveness of this offtake pathway.[125] This trend of converting to biomethane production highlights the opportunity stemming from this credit mechanism.

Optional RNG Procurement Targets by Utilities

Californian natural gas utilities' decarbonisation goals and targets provide opportunity for greater adoption of SOW AD technology. SoCalGas, the largest natural gas utility in the US, committed to 20% of gas in its pipeline to be RNG by 2030.[126] The announcement is part of the utility's alignment with the Paris Agreement target recommendations. Procurement targets have been further supported by the CPUC, through the approval of SoCalGas and San Diego Gas & Electric's requests to offer a voluntary RNG tariff to customers.[127] This demonstrates growing consensus and support for RNG from existing energy infrastructure providers, market players, and regulators, in large part due to growing pressure to decarbonise existing fossil fuel assets. The IEA predicts the role of RNG to grow in the pursuit of getting to net zero (**Figure 16**).[128] The quantity of RNG in gas networks is forecasted to be 20%.

Figure 16: Global supply of low-emissions fuels by sector in the net zero emissions



[125] Brad Pleima, "Biogas to RNG Projects: What, Why and How?" *BioCycle*, March 11, 2019. https://www.biocycle.net/biogas-rng-projects/
[126] SoCalGas, "Aspire 2045: Sustainability and Climate Commitment to Net Zero."
[127] Bioenergy Insight, "SoCalGas, SDG&E's voluntary RNG tariff request approved," *Bioenergy Insight*, December 18, 2020, https://www.bioenergy-news.com/news/socalgas-sdges-voluntary-rng-tariff-request-approved/
[128] IEA, *Net Zero by 2050: A Roadmap for the Global Energy Sector*, (Paris: IEA), May 2021. https://www.iea.org/reports/net-zero-by-2050

By supporting renewable gases, such as RNG, SoCalGas can be part of the broader energy transition without stranding assets.

Chapter 3: Case Study and Recommendations

This chapter will explore a case study of a SOW AD development company and its perspective on the obstacles and opportunities explored in this thesis. This chapter will be organized with a methodology section, demonstrating the rationale, selection criteria and desired outcomes of the case study. Then it will be followed by feedback from the developer on the obstacles and opportunities discussed in Chapters 1 and 2. To conclude this chapter recommendations will be presented based upon the feedback as well as those which are evident from the obstacles and opportunities.

The case study intends to provide useful, practical, and innovative examples of how SOW AD developers are working to overcome the obstacles identified. On the same hand, it intends to illustrate how the developer takes full advantage of opportunities for SOW AD in California. Using developer feedback, recommendations are suggested for each stakeholder on how to better support adoption of SOW AD for achieving SB 1383's ambitious goals.

A case study of a large-scale SOW AD facility developer will be used to highlight opportunities and methods to overcome obstacles. This company is in the early stages to develop, build, own and operate large-scale SOW AD facilities across North America. An early-stage developer was chosen as it is the stage in which project motivation and assumptions of business plans are under the greatest scrutiny.[129] Additional criterion is the aim to penetrate agricultural sectors with compost products. This is due to the importance of finding markets for digestate products. I have chosen AD Company X (Company X) for the case study based upon my previous professional experience, their vast experience in both the US and Europe, my personal relationship, and their willingness to give feedback on the obstacles and opportunities explored in this thesis.[130]

Company X has been chosen for its extensive history in the US and European biogas industries. Company X is a development company that develops, builds, owns, and operates AD facilities which not only provide solutions to organic waste recycling but redefines the interconnection

[129] The Economic Intelligence Unit, "Managing the Risk in Renewable Energy," *The Economist*, 2011.
[130] The name of the company has been anonymized to avoid assigning sensitive information to a particular developer.

between the energy, waste, and agricultural sectors, creating an alternative future for the industrial ecosystem and closes the organic waste loop. Their principal aim is to develop recycling capacity that will further SB 1383's targets.

The case study has been conducted through several interviews and presentations of obstacles from November 2020 to May 2021 with Mr. C., a Vice President at Company X. Feedback on obstacles have been received both verbally and in written form. This feedback has been transcribed into prose and verified with Company X to ensure accuracy and completeness of responses from interviews.

Taking Advantage of Opportunities

Company X is motivated to develop organic resource processing solutions to help California meet SB 1383's targets. Overall, Company X sees the greatest development opportunity coming from the lack of organic resources processing capacity. Company X uses various strategies to take advantage of opportunities stemming from the topics discussed in Chapter 2 (**Table 11**).

Table 11: Company X's strategies to take advantage of SOW AD opportunities[131]

Topic	Opportunity	Company X's Strategy to Maximise Opportunity
Converging Stakeholder Interests with SOW AD	Jurisdictions and haulers meeting SB 1383 targets.	Develop and execute projects in sequence to achieve mutual commitments for early compliance with SB1383 and securing organics material resources. Involve them in the development process to gain mutual trust in projects.
	Decarbonising natural gas infrastructure	Early outreach to potential off-takers in different sectors such as utilities and voluntary market, to achieve early commitments of in-state produced RNG.
Private Sector Coalitions	Organic resource recycling services.	Approach industrial and commercial clients through dedicated sourcing platforms by bundling organic resources volumes and

[131] Source: interviews with Mr. C.

		providing capacity commitments based on delivery commitments.
	Clean energy offtake.	Approach organizations, such as RE100, to provide renewable energy offtake volumes with mutual commitments.[132]
Ambitious Local Government	Local government net zero goals.	Identify dedicated local governments in California, and US, that strive for net zero goals to explore opportunities in Joint Development Agreements (JDAs) in achieving these goals.
Increased Compost Use in Agriculture	Compost products in agricultural sectors.	Early engagement with compost producers that require bulk material to produce final organic compost product blends in different qualities and identifying the potential nutritional values of SOW AD compost.
Improved Economics from Diversion Policy	Increased organic resource availability.	Strongly advocating to state legislators that complying with today's organic collection and diversion only will not support the SLCP reduction goals anticipated by the implementation of SB1383. Advocating for strong enforcements including implementation of landfill taxes to accelerate implementation and enforcement.
	Higher tipping fees.	Provide pricing model that is related to actual and future organics resource mix to attract organic resources in early stage whilst guaranteeing long-term project economics.
Supportive Offtake Policy	LCFS pricing	Explore LCFS market in California, and across US to mitigate uncertainty of future price. Identify interested and willing markets to commit early to long-term contracts.
	Voluntary RNG market.	Early engagement with interested parties in the voluntary offtake market that are interested in long-term offtake such as utilities in their desire to decarbonize their pipelines.

[132] RE100, "The RE100", accessed June 10, 2021, https://www.there100.org/about-us.

Converging Stakeholder Interests with SOW AD

Opportunities stemming from converging stakeholder interests are pursued by Company X using several strategies. Company X partners with jurisdictions and haulers which desire to meet SB 1383 targets by developing and executing projects within a timeline that meets policy compliance, with mutual commitments from each side (organic resources and processing capacity from haulers and jurisdictions, and Company X, respectively). Company X develops these relationships with stakeholders and aligns interests by having them involved throughout the development process. This helps build mutual trust and confidence in projects. Having haulers and jurisdictions provide organic resources to projects greatly improves Company X's likelihood of securing financing.

Company X realizes the development opportunity from natural gas infrastructure players seeking to decarbonise by conducting early outreach and engagement with potential RNG buyers, across different sectors such as utilities and the voluntary market. This strategy helps Company X achieve early commitments for the off-take of in-state produced RNG, which are crucial for accessing investment.

Private Sector Coalitions

Company X incorporates the potential opportunities of private sector coalitions, organic resources availability and clean energy offtake. Company X approaches industrial and commercial clients for organic resource diversion, by offering bundling services and reserving processing capacity.[133] Company X engages with businesses that are looking to transition from fossil fuels to renewables, such as RE100 companies.[134] Company X pursues mutual commitments to provide clean energy and for these businesses to purchase clean energy products. This strategy diversifies the organic resource client portfolio and offtake markets for Company X, thereby lowering project risk.

Ambitious Local Government

Company X works with local governments that have ambitious net zero goals. Company X identifies local governments that strive for net zero goals throughout California, and the US, and

[133] Bundling services refers to the ability to collect different types of organic resources at the same time, rather than several collection services. This typically lowers the cost to service recipients.
[134] RE100, "The RE100".

use Joint Development Agreements (JDA) to advance these projects.[135] These agreements allow Company X to explore project with local governments in greater depth.

Increased Compost Use in Agriculture

Company X accesses agricultural sector compost product demand by conducting early engagement with existing compost producers. Compost producers often require additional bulk material to produce compost product blends of different qualities. Company X works with these producers to incorporate SOW AD compost products into their agricultural blends. Existing compost marketers have access to agricultural buyers. By supplying compost products to bulk producers, Company X is not competing but complementing the work of the incumbent market. Accessing this market provides an additional source of revenue to Company X's SOW AD projects.

Improved Economics from Diversion Policy

Diversion policy improves the economics of Company X's projects. Company X advocates each level of government to go beyond current enforcement and policy compliance, by introducing landfill taxes to accelerate the diversion policy implementation. This strategy may increase organic resource availability in potential areas of development.

Company X benefits from higher tipping fees by providing a long-term pricing model that is relative to the organic resource components provided by clients. For example, higher levels of contamination command a higher tipping fee. This approach allows Company X to attract organic resources at an early stage whilst guaranteeing favourable long-term economics by providing visibility on future project income.

Supportive Offtake Policy

Company X benefits from the supportive offtake policy of LCFS programs. Company X explores the LCFS market in California by identifying interested market players who are willing to commit early to long-term RNG contracts. These may be voluntary parties, such as utilities looking to

[135] JDAs are agreements that set terms between two parties working on a project.

decarbonise natural gas infrastructure. Furthermore, Company X considers additional LCFS markets to mitigate any future price uncertainty risk in the Californian LCFS market.

Overcoming Obstacles

Mitigating Conflicting Stakeholder Interests

Company X is developing SOW AD in California but is faced with several obstacles stemming from conflicting stakeholder interests (**Table 12**). Company X's greatest threats to development stem from conflicts at the government level and competing energy market players. Conflicting interests from social actors (businesses, citizens, and NGOs) and from certain energy infrastructure players (utilities and transmission system operators) do not have a significant impact on Company X's development process because their interests do not easily manifest into meaningful barriers. On the other hand, the greatest threats mentioned, alongside with hauler interests, are far more pressing for Company X's development process.

Table 12: Stakeholders potential conflict with Company X, the impact on Company X's development process and Company X's mitigation strategies[136]

Stakeholder Type	Stakeholder	Potential Conflict with SOW AD	Impact on Company X's Development Process	Company X's Mitigation Strategies
Government	Jurisdiction/ Municipality	May seek an organic resources recycling option which is lower on the EPA hierarchy but typically shorter development timeframe than AD (compost). May not want to burden citizens with greater disposal costs during economically hard times.	Delay of process. Reason to build infrastructure questioned.	Create a simpler AD solution that can cope with the simpler approach. Influence jurisdiction to fully embrace the implementation of commingled collection of organic green and food waste to justify SOW AD infrastructure. Advocate jurisdictions to unbundle waste hauling franchise with waste processing duty in public procurement process.

[136] Source: interviews with Mr. C.

	State Government and Institutions (CalRecycle, Air Resources Board)	Stringent gas quality levels. Land use restrictions. No Renewable Gas Standard. Lack of coordination between energy and diversion policy. Favouring existing RE markets. Lack of comprehensive, universal state-wide permitting processes. Extremely stringent permitting process (CEQA).[137]	Delay of process.	Develop projects in rural areas of California or out of state at border. Advocate CalReycle to implement and enforce SB 1383 as planned, not allowing any delay.
	Federal Government	Lack of a coherent national natural gas quality standard. Limited financial support for SOW AD. Economic downturn, limited capital deployment.	Can lead to situation that offtake agreements cannot be closed before financial close.	Approach voluntary RNG market for offtake agreements.
Organic Resources Service Recipients	Hauler	New diversion targets threaten prominent income generating assets (landfills) and require additional investments in organic resources separation. Cost pass through to customers.	Insufficient organic resources can be secured.	Offer simpler AD solution that is capable to compete with composting if food waste content is low.
Existing Organic Resource Market Players	Landfill Owners	Earn valuable credits if have landfill gas infrastructure installed. Organic resources provide gas production and decomposes thus limiting its physical usage of landfill capacity. Do not want to lose income from organic resources.	Delay of development.	Build facility at or adjacent to landfill and cooperate with landfill owner, which is typically a waste hauler.
	Compost Facility Operator	Low-cost organic disposal option. Incumbent and do not want competitors taking organic resources.	Potential delay.	Cooperate with compost operators and form joint ventures (JV). Develop and propose simple AD solution that can compete with composting.

[137] California Environmental Quality Act (1970). CEQA is criticized as being frequently used as a tool to block development on grounds that are unrelated to environmental protection.

Energy Market Players (infrastructure, marketers)	Pipeline Owner	High RNG quality required, expensive and timely process for connection. No RGS.	Delay of development.	Develop projects in rural areas of California or out of state at border.
	Existing Renewable Energy Industry (Solar, wind, shale gas)	Opposition to policy that supports biogas development. Lower cost competitiveness of RNG.	Development in danger.	Lobby on all levels in Sacramento (State, CalRecycle etc.) to influence and show the consequences.

Government Conflicts and Mitigation

Company X faces divergent interests from local government's opting for simpler, and often quicker to develop, organic resource recycling solutions like composting. Alongside this, they may also not want to increase citizen's disposal costs under the current Covid-19 financial setting. These conflicts call into question Company X's rationale for building infrastructure. However, Company X uses several mitigation strategies to overcome this conflict with jurisdictions. First, Company X is technologically agile, meaning that they are not bound to a particular AD technology provider or solution. This allows Company X to scale up or down the complexity of the solution for processing organic resources, which impacts project development time, hence overcoming the first conflict of jurisdictions choosing composting over SOW AD. Secondly, Company X actively lobbies local government to comingle food waste and green waste collection together. This lowers the overall cost of collection for citizens, as it requires less infrastructure. Furthermore, it justifies the building of additional SOW AD infrastructure as it can process comingled organic resources. Finally, Company X seeks to influence jurisdictions to separate the waste hauling franchise with waste processing duty in the public procurement process. If successfully lobbied, this gives greater freedom of action to the jurisdiction to decide where the organic resources go, rather than the haulers, who have vested interests in landfills remaining the end market.

Lack of coordination at the state government and institutions, and federal government level can delay Company X's development process. The lack of an RGS, stringent gas quality standards, lack of comprehensive permitting process and restrictions on land use all provide obstacles to Company X's operations. However, Company X mitigates the effects of these barriers through

facility siting choice. Company X develops projects that are in rural California, which are typically not subject to same land use restrictions. Company X also explores sites that are outside of California but are close to the state border, which helps to avoid the issues stemming from Californian gas quality standards and the permitting process.

The limited financial support for SOW AD at the federal and state government level can impact Company X's ability to secure off take agreements. This can lead to a situation where off take agreements may not be secured before financial close. Company X mitigates this obstacle by approaching voluntary RNG markets, such as utilities undergoing decarbonisation.

Existing Energy Market Player Conflicts and Mitigation

One of the greatest threats to Company X's development goals comes from blocking of supportive policy by existing energy market players. The blocking of a mandated RGS demonstrates the severity of this risk. Company X advocates its interests in policy making through direct lobbying and industry interest groups, such as the Coalition for Renewable Natural Gas.

Company X faces potential delays to development due to the high costs of interconnecting to pipelines and from stringent gas quality standards. Again, Company X mitigates this by exploring site locations in rural areas or out of state on the Californian state border. Rural areas typically have lower costs for land. By siting out of state but on the border removes the need to apply to the stringent Californian gas quality standards.

The overall risk from these conflicting interests is the uncertainty of Company X obtaining project financing due to the lack of interest in the incumbents striving for a swift diversion of organic resources from the existing disposal solutions (landfill). This is further exacerbated by the limited financial incentives available to Company X and the blocking of greater supportive measures by existing energy players.

Impacts of Obstacles and Mitigation Strategies

The obstacles explored in this thesis can produce impacts upon Company X's plans for developing SOW AD facilities, but Company X use several mitigation strategies to overcome these (**Table 13**). The obstacles are market, financial, policy and social in nature.

Table 13: Impacts of obstacles and mitigation strategies[138]

Obstacle	Obstacle Type(s)	Impact	Company X Mitigation Strategies
Unfavourable Energy Market Dynamics	Market Financial Policy	Uncertainty of RNG offtake in California.	Exploit other US RNG markets. Exploit voluntary markets for RNG offtake. Pivot to electricity production and BioMAT.
Limited Financial Incentives	Financial	Uncertainty on part of project income (20-30%).	Find purchasers of RNG in voluntary market and/or out of state.
Uncoordinated Diversion and Energy Policy	Policy Market	Not matching the targets creates uncertainty in the development and might cause delay.	Continue advocating, influencing, communicating, and lobbying for better coordination.
Local Acceptance	Social Financial	Resistance leads to lengthy development procedures and additional costs.	Early community outreach, hire local workforce, include local engineering companies in the development and permitting process to facilitate the process.

Unfavourable Energy Market Dynamics

The unfavourable energy market dynamics creates uncertainty in the Californian RNG market. However, Company X mitigates risks from this by exploring voluntary markets, as previously discussed. Company X is also exploring additional RNG markets, with Oregon having an LCFS program and other states likely to adopt this mechanism soon.[139] Company X is considering the ability to switch to electricity production and participating in the BioMAT tariff if alternative RNG markets are not accessible.

[138] Source: interviews with Mr. C.
[139] RBC ESG Stratify, *Renewable Natural Gas: Where is the Gas is Green and the Grids are Pretty*.

Limited Financial Incentives

The limited financial incentives available to SOW AD development creates an impact on part of Company X's project income, on the off-take side which typically accounts for between 20 and 30% of a project's total income. SOW AD facilities usually generate 65-75% of its income from the tipping fees for organics resource processing services. Company X mitigates this project income risk by finding RNG demand in the voluntary market or out of state. Additionally, this risk can be mitigated by charging higher tipping fees, as was explored in Chapter 2. Company X offers guaranteed processing capacity for jurisdictions for when SB 1383 penalties are enforced. The reservation and guarantee of capacity can be charged with a premium tip fee for this service.

Uncoordinated diversion and energy policy

The uncoordinated diversion and energy policy impacts Company X development due to targets and deadlines for diversion implementation not being met. As previously noted, project income depends largely on tipping fees from diverted organic resources. The lack of coordination causes uncertainty and potential delay to Company X's development timeline. Company X mitigates this risk by pursuing advocacy, influence in decision making, communicating benefits of SOW AD technology, and lobbying for better coordination through interest groups and industry associations at all levels of governance. They do this through membership of advocacy groups, such as the Coalition for RNG. Success of this lobbying can be seen through the alteration of SB 619. The bill originally postponed the enforcement of SB 1383 indefinitely. Had the bill been passed with such language, Company X, and the broader SOW AD industry, would have faced grave development risk which would make financing almost impossible to secure. However, the bill was passed with conditions that only postponed the enforcement from 2022 to 2023.

Local Acceptance

The lack of local acceptance can produce barriers to Company X's development. Resistance can create lengthy development procedures with additional costs. Local acceptance is more likely in instances in which developers engage with the community in the early stages. Company X conducts community outreach to internalise local concerns into the business plan. Company X plans to hire local workforces, including local engineering companies to facilitate the permitting process. Local acceptance is typically not a problem if citizens are engaged in an early stage.

Recommendations

Each stakeholder has a part to play in enabling greater adoption and development of SOW AD for organic resources recycling. Actions are recommended for all major stakeholders considered in this thesis' analysis (**Table 14**).

Table 14: Recommended actions for stakeholders to enable greater SOW AD adoption

Stakeholder	Recommended Action(s)
SOW AD Developers	Clearly communicate the benefits of SOW AD solution to all stakeholders. Flexibility in energy product off-take options and markets. Pursue partnerships with organic resources clients, such as haulers and jurisdictions.
Jurisdiction/Municipality	Introduce a clause in franchised hauler agreements that requires haulers to demonstrate processing capacity for organic resources. Alternatively, waste processing duties could be separated from waste hauling franchise contracts.
State Government and Bureaucracies (CalRecycle, Air Resources Board)	Place pressure on jurisdictions for compliance with SB 1383, to introduce the franchise agreements clause. Fund studies of compost derived from food waste and green waste, and its effects on cropland. Current studies focus on manure compost. Introduce Renewable Gas Standard. Create a comprehensive permitting process. Remove conditions of proving technology already in place in different state regions. Stipulate same pipeline quality standards for out of state RNG producers or provide financial support for in-state upgrading.
Federal Government	Introduce a federal LCFS with stipulations for local RNG production and consumption or stimulate development of state or regional LCFS programs with similar principles. Introduce price floors for D5 RIN and LCFS credit pricing. Introduce a federal Renewable Gas Standard.
Haulers	Partner with SOW AD developers to comply with organic diversion goals and hence secure processing capacity.

Businesses[140]	Pressure local jurisdictions and state government to enforce SB 1383 and meet targets. Create coalitions with SOW AD developers to provide organic resources and markets for clean energy products that displace conventional natural gas.
NGOs[141]	Provide future perspective of energy sector that includes both electrification and gas demand met by RNG.
Citizens	Pressure local jurisdictions and state government to enforce SB 1383 and meet targets. Educate younger generations who are more sensitive and receptive to changing behaviour of segregating organics from municipal waste. Participate in the RNG tariffs from natural gas utilities.
Pipeline Owners	Support in-state SOW AD RNG production through interconnection assistance in feasibility and planning.
Existing Energy Industry Players (Solar, wind, shale gas)	Support RNG to decarbonise existing energy infrastructure and the deployment of RNG in transportation sector that cannot be electrified.
Agricultural Growers	Incorporate compost use for soil revitalisation, keeping nutrients in the loop and soil carbon sequestration, replacing petrochemical fertiliser, into net zero goals.

SOW AD Developers

As the stakeholder with the most vested interest in seeing a greater adoption of SOW AD in California, developers must clearly communicate the benefits of SOW AD technology for processing organic resources. Furthermore, the common interests that the SOW AD sector has with other stakeholders should be a key component of this education.

Partnerships with key organic resources clients, such as haulers and jurisdictions, should be a priority. There is clear alignment of interests between these stakeholders. However, this may not be a straightforward task due to previously mentioned vested interests. Developers should pursue greater communication and information sharing efforts with these stakeholders to better align

[140] *Business* refers to large actors in sectors that can be a source of organic resources, like grocery stores and food processors, as well as industries that consume natural gas in processes.
[141] The Sierra Club and Earth Justice are two examples of NGOs opposed to RNG development.

interests and potential partnerships. Without these partnerships, SOW AD projects are unlikely to be financed.

Additionally, developers need to explore all potential energy pathways and markets. The availability and feasibility of different energy markets depends on several factors, including the obstacles previously mentioned. Developers must consider offtake flexibility in business models to ensure market access for energy products.

Jurisdictions/Municipalities

Jurisdictions should play an important role in advancing SB 1383 and the adoption of SOW AD technology. They can do this by including a clause in lucrative franchised hauler agreements which require haulers to demonstrate signed agreements to take organic resources to SOW AD facilities for processing. This would inspire collaboration between haulers and developers, as organic resource supply agreements are vital to project financing.

State Government

The Californian state government could implement additional supportive schemes for the SOW AD sector. Embracing a Renewable Gas Standard that focuses on RNG from organic resources with timelines that are in line with SB 1383 enforcement. Greater pressure from state government upon local jurisdictions to meet SB 1383 should be applied, in particularly with an organic resources processing capacity clause in franchised hauling agreements.

State government should fund studies for compost use on major crops. To date there are very few, if any, studies on compost derived from AD digestate and green waste and its effects on soil water retention and crop yields. Current studies focus on the use of manure compost.

State bureaucracies should create a streamlined, comprehensive permitting process. This should also remove the need to prove feasibility of technology that is used in other regions in the state. Additionally, financial support should be offered to in state RNG producers to meet the stringent pipeline quality standards that do not apply to out of state producers.

Federal Government

A federal LCFS should be introduced with stipulations for local RNG production and consumption. An alternative to this would be to stimulate the development of state or regional LCFS programs with a similar focus on local production and consumption. Such a policy could be supported through the introduction of a federal Renewable Gas Standard. This would inspire development of RNG markets beyond California.

The SOW AD sector could be further supported through greater economic guarantees of financial support credits, through price floors of D5 RINS and LCFS credits. The Californian LCFS could be adapted to reserve credits for RNG by source (farm-based, SOW AD, landfill gas etc.).

Haulers

Haulers should partner with SOW AD developers to meet its diversion goals and its organic resources processing capacity. This helps haulers retain and win additional contracts with municipalities. SOW AD developers with organic resources agreements have greater access to financing.

Businesses

Businesses should pressure local jurisdictions and state government to enforce SB 1383 and meet targets. They can do this through creating coalitions with SOW AD developers to provide organic resources and markets for clean energy products that displace conventional natural gas.

NGOs

NGOs should present a realistic view of future energy markets and sources. The most ambitious electrify everything scenarios still require a strong gas supply. These ideas should be united and push for greater quantities of RNG to be injected to displace conventional natural gas as is possible.

Citizens

Like businesses, citizens should apply pressure to local jurisdictions and state government to enforce SB 1383 and meet targets. Especially educate younger generations who are more sensitive and receptive to changing behaviour of segregating organics from municipal waste. Additionally,

citizens can participate in the RNG tariffs from natural gas utilities. Utilities can support this by advertising this option. This won't inspire greater adoption of SOW AD technology, but it sends strong market signals to utilities and pipeline owners that customer preference is changing.

Pipeline Owners

Pipeline owners should facilitate easier interconnection of SOW AD facilities to pipelines. RNG volumes flowing through pipelines makes a case for the continued use of these assets as the US undergoes a clean energy transition.

Existing Energy Market Players

Natural gas companies, along with pipeline owners, should support and facilitate greater RNG quantities in the existing infrastructure. Furthermore, support for RNG in transportation that cannot, and is unlikely to be, electrified should be pursued.

Agricultural Growers

The agriculture sector should, along with state government, conduct studies on the use of SOW AD digestate and green waste compost products. Major growers can incorporate compost use for soil revitalization, keeping nutrients in the loop, and soil carbon sequestering into plans to reach net zero emissions.

The role of the federal, state, and municipal governments is important in developing a stable and lucrative market for SOW AD development. The enforcement of diversion policy and greater financial incentives for off take options are the highest priorities for next steps. Additionally, haulers need to be better inclined and incentivised to work with SOW AD developers to secure organic resources to facilitate greater financing availability for development.

Conclusions

Based on the exploration of Californian experience, this thesis shows that SOW AD is a sector that is expected to contribute to the climate mitigation and energy transition strategy. California has the potential to see greater adoption of SOW AD technology to meet SB 1383's ambitious targets. The targets set for diverting 75% of organic resources from landfill by 2025 are backed by legislative efforts to enforce these goals. This provides substantial opportunities for the development of SOW AD facilities. However, obstacles persist in the market due to conflicting interests of stakeholders, such as existing energy market players and levels of government, which prevent a wider adoption of SOW AD technology as an enabler of these ambitions.

The experience of Company X is evident of developers exploring innovative ways to pursue the opportunities provided by Californian diversion policy. On the other hand, Company X's case demonstrates the barriers which must be mitigated when developing solutions. Overall, the case study shows that greater alignment of stakeholder interests is needed to implement the diversion policy, facilitate predictable energy pricing for off take products, and create a stable market for SOW AD development.

President Biden's administration's climate targets, specifically methane abatement, could serve SOW AD developers well. The analysis provides recommendations for further action at all levels of government and key sources of organic resources to foster a stronger market for SOW AD development. Financial incentives for SOW AD energy product off take must be strengthened to provide income security and forecasting. Local government must pursue the enforcement of diversion policy on timelines that are mandated. Part of this can be achieved through insisting on collaboration between haulers and SOW AD developers.

Future research should consider the experience of the European Union and the diversion of organic resources and SOW AD development. The different political system, a supra national organization with member states free to implement rather than the US federal system, should be explored to understand if the same conflicts emerge from interests of stakeholders at different levels. This thesis did not explore vehicle fuel demand for compressed RNG. Research could be conducted on

the growing markets for compressed natural gas fleets and the switching of diesel fuelled long haul trucks to natural gas vehicles.

Appendix A: Stakeholder interests and the negative impact(s) on diversion policy implementation

Stakeholder Type	Stakeholder	Interests	Potential Conflict with SOW AD	Impact on Diversion Policy
Government	Jurisdiction/ Municipality	Simple solution to organic resource diversion requirements, represent citizens	May seek a processing option which is lower on the EPA hierarchy but typically shorter development timeframe than AD (compost). May not want to burden citizens with greater disposal costs during economically hard times.	May support solutions to organic resources diversion that are lower on the EPA hierarchy (composting). Pushback on policy timeline due to financial difficulties from Covid-19.
	State Government	Reaching ambitious climate goals by reducing GHG emissions, state energy independence	Stringent gas quality levels. Land use restrictions. No Renewable Gas Standard.	Out-of-state AD capacity increases due to lower gas quality. In-state capacity does not develop, resulting in insufficient recycling for organic resources.
	Federal Government	Energy independence and security	Lack of a coherent national natural gas quality standard. Limited financial support for SOW AD. Economic downturn, limited capital deployment.	Lack of new facility developed to handle SB 1383 quantities due to drawdown of end market pathways. Scarcity of capital and low appetite for project financing due to recession.
	State Institutions (CalRecycle, Air Resources Board)	Effective policy that is compliant with laws.	Lack of coordination between energy ad diversion policy. Favouring existing RE markets. Lack of comprehensive, universal state-wide permitting processes.	Lack of new facilities built to handle SB 1383 quantities, due to timely permitting process.

			Extremely stringent permitting process (CEQA).[142]	
Organic Resources Service Recipients	Hauler	Control most, if not all, aspects of the waste industry through vertical integration. Use market position to secure favourable terms. Keep existing disposal solutions to maximise profits.	New diversion targets threaten prominent income generating assets (landfills) and require additional investments in organic resources separation. Cost pass through to customers.	Slow implementation until there is enforcement (2023) that makes it uneconomical to continue status quo. Awaiting third parties to develop solutions. Low effort in separating organics from MSW or commingling collection of green and food waste.
	Business	Lowest cost disposal, reliability of service, improve local environment for commerce.	Increased cost and effort in separating waste.	Perceived opinion of increased disposal costs due to SOW AD may create local opposition.
	Citizen	Lowest cost disposal, reliability of service, improve local environment	Increased cost due to organics diversion, learning and norms changing	Perceived opinion of increased disposal costs due to SOW AD may create local opposition.
Civil Society	NGOs	Promoting particular interests.	Opposition to RNG policy, favouring full electrification. Preference for other RE types.	Lack of Renewable Gas Standard prevents wider adoption of SOW AD/organic resources recycling capacity.
Existing Organic Resource Market Players	Landfill Owners	Maintain capacity and daily tonnage. Process waste responsibly.	Earn valuable credits if have landfill gas infrastructure installed. Organic resources provide gas production and decomposes thus limiting its physical usage of landfill capacity. Do not want to lose income from organic resources.	Unlikely to support moving organics from landfills to other facilities as it would reduce income. Installation of infrastructure to capture landfill gas, which current financial support mechanisms encourage. Low effort in separating organics from MSW.

[142] California Environmental Quality Act (1970). CEQA is criticized as being frequently used as a tool to block development on grounds that are unrelated to environmental protection.

				Opposition to new entrants that take market share.
	Compost Facility Operator	Secure long-term organic resources contracts. Provide organic resources recycling.	Low-cost organic disposal option. Incumbent and do not want competitors taking organic resources.	Opposition to new entrants that take market share. Keep organic resources lower down the EPA hierarchy of end-markets.
Energy Market Players (infrastructure, marketers)	Pipeline Owner	Keep infrastructure in good condition. Provide natural gas to customers. Balance supply and demand. Add RNG to justify business model.	High RNG quality required, expensive and timely process for connection. No RGS.	Cost of connecting to pipeline decreases number of facilities developed to recycle organic resources.
	Utility	To provide energy products that match customer preferences and regulatory requirements	Cheaper renewable sources. Lobbying by existing RE.	Limited end-market development for SOW AD (both RNG and electricity). This prevents sufficient organic resources recycling capacity being built.
	Transmission System Operators	Maintain grid stability, provide reliable power services	High infrastructure investment. Limited of biogas electricity support.	Limited end-market development for biogas to electricity. This prevents sufficient organic resources recycling capacity being built.
	Existing Renewable Energy Industry (Solar, wind, shale gas)	Full electrification. Oppose any natural gas infrastructure expansion. Limit other RE sources penetration of electricity market.	Opposition to policy that supports biogas development. Lower cost competitiveness of RNG.	Opposition to biogas end-market development: preventing the building of sufficient organic resources recycling capacity.

		Maintain natural gas competitiveness and infrastructure (shale).		

Appendix B: Stakeholder interests and potential cooperation with, and opportunities for, SOW AD[143]

Stakeholder Type	Stakeholder	Interests	Potential Common Interests with SOW AD	Potential Opportunity for SOW AD
Government	Jurisdiction/ Municipality	Solution to organic waste diversion requirements, represent citizens.	SB 1383 compliance. Improving air quality for citizens.	Meeting state GHG emissions reduction goals.
	State Government	Reaching ambitious climate goals by reducing GHG emissions, state energy independence.	SB1383 target success. Air quality improvement. Investment in state. Meeting state GHG reduction goals.	Meeting state GHG reduction goals. Provide renewable baseload energy for decarbonization of energy grid (electricity/gas).
	Federal Government	Energy independence and security.	Reaching Paris Agreement climate goals.[144] Decoupling economic growth from pollution.	Meeting national GHG emissions reduction goals.
	State Departments (CalRecycle, Air Resources Board)	Effective policy that is compliant with laws.	Tools for business development.[145] Enforcement of diversion policy.	Improved economics from landfill bans. Implement landfill tax to drive diversion.
Organic Resource Service Recipients	Hauler	Control most, if not all, aspects of the waste industry through vertical integration and favourable terms. Keep existing disposal solutions to maximise profits.	Diversion policy compliance. Single organic resource stream to collect (food and green waste together).	Improved economics from landfill bans. Implement landfill tax to drive diversion.
	Business	Lowest cost disposal, reliability of service, improve local environment for commerce. Meeting ESG goals.	The provision of an environmentally sound end market for organic resources, increased	Private sector partnerships for organic resources and energy products.

[143] Sourced by author. Particular ideas are referenced as needed.
[144] As seen in the US' recommitment to the Paris Agreements in January 2021.
[145] Such as grants and calculators for LCFS credits.

			importance of ESG goals.	
Civil Society	NGOs	Promoting particular interests. Full electrification.	Improving air quality for citizens near landfills. SOW AD provides circular economy development.	Meeting state GHG reduction goals and decarbonization of energy grid (electricity/gas).
	Citizen	Lowest cost disposal, reliability of service, improve local environment.	The provision of an environmentally sound end market for organic waste.	Meeting GHG emissions reduction goals.
Existing Organic Resource Market Players	Landfill Owners	Maintain capacity and daily tonnage. Process waste responsibly. Compliance with SB 1383.	Increase lifespan of landfill by lowering capacity consumed by organic resources.	Improved economics from landfill bans.
	Compost Facility Operator	Secure long-term organic resources contracts. Provide organic resources recycling.	Low contamination tolerance – market cooperation.	Improved economics from landfill bans.
Energy Market Players (infrastructure, marketers)	Pipeline Owner	Keep infrastructure in good condition, connect customers with producers of gas. Provide natural gas to customers. Balance supply and demand. Add RNG to justify business model.	In-state source of natural gas. Decarbonising natural gas infrastructure.	Supportive offtake policy for RNG.
	Utility	To provide energy products that match customer preferences and regulatory requirements	Lower cost of transition by maintaining natural gas infrastructure instead of full electrification.	Supportive offtake policy for RNG.
	Transmission System Operators	Maintain grid stability, provide reliable power services.	Diversification and decarbonisation of energy mix.	Supportive offtake policy for biogas.
	Existing Energy Industry (Solar, wind, shale gas)	Full electrification. Oppose any natural gas infrastructure expansion.	Decarbonising the natural gas infrastructure.[146]	Supportive offtake policy for RNG.

[146] SoCalGas, "Aspire 2045: Sustainability and Climate Commitment to Net Zero," accessed May 20, 2021, https://www.socalgas.com/clean-energy/sustainability

		Limit other RE sources penetration of electricity market. Maintain natural gas competitiveness and infrastructure (shale).	Prevents stranding of natural gas assets. Provides clean gas supply for hard-to-electrify industry.	Meeting state GHG reduction goals.
Agriculture	Growers	Predictable yield per acreage. Increase soil health. Lower water usage. Lower use of petrochemical fertilizers. Prevent desertification/drought concerns.	Switching from fertilizer to organic compost products (from digestate) for soil nutrients. Use of compost to increase water retention in soil.	Compost use in agriculture to increase the organic matter in the soil, water holding capacity, improve soil heath, and sequestering carbon.

Appendix C: Average tipping fees at a state level

State	Average Tipping Fee ($/ton	Organics Ban?
Alaska	$142.33	N
Rhode Island	$115	Y
Hawaii	$114.33	N
Vermont	$101.95	Y
Washington	$95.99	N
Delaware	$85	N
New Jersey	$78.80	Y
Maine	$75.21	N
New Hampshire	$74.34	N
Pennsylvania	$73.45	N
New York	$71.71	Y
Oregon	$71.53	N
Missouri	$67.91	N
Maryland	$66.73	Y
Wisconsin	$61	N
Idaho	$59.02	N
Colorado	$58.42	N
Minnesota	$57.78	N
Wyoming	$57.64	N
Florida	$56.51	N
California	$55.48	Y
West Virginia	$54.66	N
Virginia	$53.43	N
Illinois	$51.71	N
Tennessee	$51.53	N
South Dakota	$51.22	N
North Dakota	$48	N
Georgia	$47.88	N
Iowa	$47.07	N
North Carolina	$45.97	N
South Carolina	$45.91	N
Ohio	$45.39	N
Arizona	$44.89	N

Oklahoma	$44.76	N
Kansas	$42.79	N
Michigan	$42.77	N
Texas	$42.22	N
Nebraska	$41.47	N
Nevada	$39.90	N
New Mexico	$38.20	N
Louisiana	$37.53	N
Kentucky	$36.32	N
Indiana	$36.27	N
Utah	$33.80	N
Alabama	$32.93	N
Montana	$32.06	N
Arkansas	$30.53	N
Mississippi	$30.36	N
National Average	**$53.72**	

Source: EREF, Analysis of MSW Landfill Fees: 2020, January 2021.

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