Appendix F: Supporting Documentation for the Economic Assessment of Measures in the SLCP Strategy

Supporting Documentation for the Economic Assessment of Measures in the SLCP Strategy

This Appendix presents technical information and calculations that support the economic analysis in Chapter VIII of the SLCP Strategy. Appendix F contains information for three measures for which there is great potential for low-cost emission reductions. Reducing methane from dairy manure, diversion of landfilled organic waste, and hydrofluorocarbon (HFC) emission reductions all have large economic and environmental potential as outlined in the subsequent sections.

A. Methane Emission Reductions from Dairy Manure

The dairy economic analysis presented in Section VIII of the SLCP Strategy, examined six mitigation pathways and two sector wide cost bounding scenarios to achieve a 22 MMTCO2e (20-yr GWP) reduction in dairy manure methane in 2030. This appendix provides more detail about the assumptions and calculation methodologies used for these analyses. First, each pathway is described along with a summary of the assumptions used to calculate capital costs, annual operations and maintenance (O&M), and annual revenue (Table 1 through Table 10). Next, a more detailed breakout of the total capital costs, annual O&M, and annual revenue for an example 2,000 cow dairy are provided for each pathway (Table 11 through Table 20). Finally, additional detail is provided for the two sector-wide economic analyses that we used to bound the estimate for total costs to reduce dairy manure methane by 22 MMTCO2e (20-yr GWP) in 2030 (Table 21 through Table 23).

1. Cost Analysis Methodology

Six potential pathways to reduce manure methane emissions were analyzed. Not every pathway may be feasible for every dairy, and a variety of pathways will be employed to reach the targets. These pathways do not represent an exhaustive list of mitigation options and variations may be used by some dairies. The assumptions used to analyze these pathways are subject to uncertainty and any actual project cost will vary from the estimate here. The six pathways include:

1) Scrape conversion and onsite manure digestion producing:
   a) electricity or
   b) pipeline-injected renewable natural gas vehicle fuel
2) Scrape conversion and transport of manure offsite for centralized digestion (cluster) producing:
   a) electricity or
   b) pipeline injected renewable natural gas as a vehicle fuel
3) Retain existing manure lagoon management with onsite covered lagoon digestion producing:
   a) electricity or
   b) pipeline-injected renewable natural gas vehicle fuel

4) Retain existing manure lagoon management with onsite covered lagoon digestion, and convey biogas to a central location (cluster) via low-pressure collector pipeline for biogas clean-up to produce:
   a) electricity or
   b) pipeline-injected renewable natural gas vehicle fuel
5) Conversion of dairy operations to pasture-based management
6) Scrape conversion, collection and open solar drying of manure onsite

Pathway 1 assumes solid manure management, which includes solid scrape and vacuum systems. There is a cost for dairies that use anaerobic lagoons to convert to solid systems. Each dairy uses an above ground tank or plug-flow digester to produce biogas. The biogas use was analyzed for two sub-pathways: 1a assumed electricity production, and 1b assumed biogas was converted to transportation fuel. In pathway 1a, electricity was produced by a microturbine with the intention to emit less local NOx emissions compared to an internal combustion reciprocating engine generator. In pathway 1b biogas is injected into the transmission pipeline. Table 1 contains a summary of costs and revenues for Pathway 1a and Table 2 contains a summary of costs and revenue for Pathway 1b.

Table 1: Summary of Assumptions for Dairy Pathway 1a - Scrape Conversion and Onsite Manure Digestion Producing Electricity

Costs			
Item	**Capital**	**O&M**	**Reference**
Scrape Conversion[1]	$350 per milking head	3%	ARB Estimated Value
Digester and Microturbine with Electricity Equipment	Cost per head = 18,431*[# milking head]^-0.275	8.5%	UC Davis Report
Interconnection	$1,000,000	5%	Suscon Report
Biogas Upgrading	Included in O&M	$6 per 1,000 SCF biogas[2]	

Revenue		
Item	**Value**	**Reference**
Electricity Generation	0.123 kW per milking cow	UC Davis Report and ARB Inventory assuming 100% methane utilization
SB1122 Electricity Tariff Price	$ 0.1263 per kWh	SB1122 Feed in Tariff Price[3]
Mitigatable methane (lagoon management)	7.38 metric tons CO_2e per milking head per year (100-yr GWP)	ARB GHG Inventory
Mitigatable methane (other management)	2.13 metric tons CO_2e per milking head per year (100-yr GWP)	ARB GHG Inventory
Cap-and-Trade Offset	$13 per ton CO_2e mitigated (100-yr GWP)	Estimate
Soil Amendment	$0[4]	

[1] Scrape conversion costs were only assumed for lagoon manure management. Other manure management types were assumed to require no capital to convert to solid manure management.
[2] These costs are represented as annual O&M costs, and are assumed to include amortized capital costs.
[3] https://www.pge.com/en_US/for-our-business-partners/floating-pages/biomat/biomat.page
[4] Soil amendments were assumed to have zero value due to uncertainty in future markets, but could provide additional revenue.

Table 2: Summary of Assumptions for Dairy Pathway 1b - Scrape Conversion and Onsite Manure Digestion Producing Pipeline-Injected Renewable Natural Gas

Costs			
Item	**Capital**	**O&M**	**Reference**
Scrape Conversion[5]	$350 per milking head	3%	ARB Estimated Value
Digester without Electricity Equipment	Cost per head = 64% * 18,431*[# milking head]^-0.275	6%	UC Davis Report and Suscon Report[6]
Interconnection	$2,000,000	5%	Suscon Report
Pipeline	$200,000 per mile	5%	Suscon Report[7]
Biogas Upgrading	Included in O&M	$8 per 1,000 SCF biogas[8]	Suscon Report

Revenue		
Item	**Value**	**Reference**
Biomethane production	21,601 standard cubic feet per milking cow per year	UC Davis Report[9]
Biogas price	$ 3.46 per 1,000 cubic feet	
RIN Credits (above ground or plug-flow digester)	288 RINS per cow per year	Biomethane production *1028 scf per btu / 77,000 btu per RIN
RIN Credit Price	$1.85 per RIN credit	Estimate
LCFS Credit Price	$100	Estimate
Soil Amendment	$0[10]	

Pathway 2 is similar to Pathway 1, except centralized digesters are used instead of individual digesters on each dairy, and only dairies using anaerobic lagoon manure management are included in the analysis. ARB staff selected 55 centralized locations that would pull from 1.05 million dairy cows to digest manure and inject it into the pipeline. The number and location of centralized facilities was estimated, but not optimized, and there may be configurations that could reduce collective costs among clustered dairy farmers more than shown here. As modeled, the statewide scenario required building approximately 200 miles of low-pressure pipeline and 55 miles of new natural gas transmission pipeline. The average centralized digester was fed by approximately 40 truckloads of manure per day, with the trucks traveling an average round-trip distance of approximately 7 miles per load. This analysis includes assumed costs for new low-NOx CNG trucks, a small fleet refueling station for each cluster, and hauling costs. The number of trucks needed was estimated assuming 1 roundtrip per hour running 7.5 hours per day hauling 33.2 tons of manure per trip. The central digesters are assumed to be plug-flow or above ground tank digester types. The biogas use was analyzed for two sub-pathways: 2a assumed electricity production, and 2b assumed biogas was converted to transportation fuel. In pathway 2a, electricity was

[5] Scrape conversion costs were only assumed for lagoon manure management. Other manure management types were assumed to require no capital to convert to solid manure management.
[6] O&M assumed to be lower than electricity generating pathways because there is no electricity generating equipment
[7] Low pressure rural pipeline
[8] These costs are represented as annual O&M costs, and are assumed to include amortized capital costs.
[9] Above ground tank or plug flow with uncovered effluent pond, adjusted to assume 100% of manure volatile solids reached the digester.
[10] Soil amendments were assumed to have zero value due to uncertainty in future markets but could provide additional revenue.

produced by a microturbine with the intention to emit less local NOx emissions compared to an internal combustion reciprocating engine generator. In pathway 2b, a portion of the transportation fuel was used in a small local station to fuel manure hauling trucks and a portion was injected into the transmission pipeline. Costs and revenue are distributed among the dairies in a cluster according to milking population. Table 3 contains a summary of costs and revenues for Pathway 2a and Table 4 contains a summary of costs and revenue for Pathway 2b.

Table 3: Summary of Assumptions for Dairy Pathway 2a - Scrape Conversion and Transport of Manure Offsite for Centralized Digestion Producing Electricity

Costs			
Item	**Capital**	**O&M**	**Reference**
Scrape Conversion	$350 per milking head	3%	ARB Estimated Value
Digester and Microturbine with Electricity Equipment	Cost per head = 18,431*[# milking head]^-0.275	8.5%	UC Davis Report
Interconnection	$5,500,000 per cluster	3.5%	Suscon Report
Biogas Upgrading	Included in O&M	$2 per 1,000 SCF biogas[11]	
Low NOx Natural Gas Truck Purchase	$250,000 each	Assumed to be included in trucking costs below	Suscon Report
Manure transport cost		$2 per mile plus $15 per trip	Compilation[12]
Constants			
Manure trips	1 truckload per hour 7.5 hours per day	Estimate based on average trip distance from GIS analysis	
Manure per cow	140 lbs per day (wet)	UC Davis[13]	
Manure hauling capacity	33.2 tons (wet) per trip	Calculation[14]	

Revenue		
Item	**Value**	**Reference**
Electricity Generation	0.123 kW per milking cow	UC Davis Report and ARB Inventory assuming 100% methane utilization
SB1122 Electricity Tariff Price	$ 0.1263 per kWh	SB1122 Feed in Tariff Price[15]
Mitigatable methane (lagoon management)	7.38 metric tons CO_2e per milking head per year (100-yr GWP)	ARB GHG Inventory
Cap-and-Trade Offset	$13 per ton CO_2e mitigated (100-yr GWP)	Estimate
Soil Amendment	$0[16]	

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[11] These costs are represented as annual O&M costs, and are assumed to include amortized capital costs.
[12] $2 per mile is based on California rates from http://www.dat.com/resources/trendlines/van/west-regional-rates and rounded up to assume it includes added incremental cost of ultra-low NOx natural gas truck. $15 per trip covers future minimum wage, assuming 1 trip per hour. Trip costs were calculated using the amount of manure produced, the number of truckloads needed and the round trip distance to the central digester.
[13] http://energy.ucdavis.edu/files/09-16-2014-08_Biomass_Resource-and-Facilities-Database-Update.pdf
[14] Assuming a truck can haul 40 cubic yards and manure is 62 pounds per cubic foot (wet) from http://pss.uvm.edu/vtcrops/articles/ManureCalibration.pdf, http://www.mastersonloam.com/trucks/ and http://www.calrecycle.ca.gov/SWFacilities/Directory/38-AA-0020/Document/298055
[15] https://www.pge.com/en_US/for-our-business-partners/floating-pages/biomat/biomat.page
[16] Soil amendments were assumed to have zero value due to uncertainty in future markets but could provide additional revenue.

Table 4: Summary of Assumptions for Dairy Pathway 2b
- Scrape Conversion and Transport of Manure Offsite for Centralized Digestion Producing Pipeline-Injected Renewable Natural Gas

Costs			
Item	**Capital**	**O&M**	**Reference**
Scrape Conversion	$350 per milking head	3%	ARB Estimated Value
Digester with No Electricity Equipment	Cost per head = 64% * 18,431*[# milking head]^-0.275	6%	UC Davis Report and Suscon Report[17]
Interconnection	$5,500,000 per cluster	3.5%	Suscon Report
Biogas Upgrading	Included in O&M	$6 per 1,000 SCF biogas[18]	
Low NOx Natural Gas Truck Purchase	$250,000 each	Assumed to be included in trucking costs below	Suscon Report
Manure transport cost		$2 per mile plus $15 per trip	Compilation[19]
Pipeline	$200,000 per mile	5%	Suscon Report[20]
Transmission Pipeline	$1,000,000 per mile	5%	SoCal Gas[21]
Small CNG Station	$150,000 each, 1 per cluster	10%	Suscon Report
Constants			
Manure trips	1 truckload per hour 7.5 hours per day	Estimate based on average trip distance from GIS analysis	
Manure per cow	140 lbs per day (wet)	UC Davis[22]	
Manure hauling capacity	33.2 tons (wet) per trip	Calculation[23]	

Revenue		
Item	**Value**	**Reference**
Biomethane production	21,601 cubic feet per milking cow per year	UC Davis Report[24]
Biogas price	$ 3.46 per 1,000 cubic feet	
RIN Credits (above ground or plug-flow digester)	288 RINS per cow per year	Biomethane production *1028 scf per btu / 77,000 btu per RIN
RIN Credit Price	$1.85 per RIN credit	Estimate
LCFS Credit Price	$100	Estimate
Soil Amendment	$0[25]	

[17] O&M assumed to be lower than electricity generating pathways because there is no electricity generating equipment

[18] These costs are represented as annual O&M costs, and are assumed to include amortized capital costs.

[19] $2 per mile is based on California rates from http://www.dat.com/resources/trendlines/van/west-regional-rates and rounded up to assume it includes added incremental cost of ultra-low NOx natural gas truck. $15 per trip covers future minimum wage, assuming 1 trip per hour. Trip costs were calculated using the amount of manure produced the number of truckloads needed and the round trip distance to the central digester.

[20] Low pressure rural pipeline connecting central digester to the transmission pipeline.

[21] SoCal Gas suggests pipelines might cost $200-300 per foot near roadways (http://americanbiogascouncil.org/webinars/22may14_pipelineBiogasCA.pdf), which would translate to about $1-$1.5 million per mile. 55 miles of transmission pipeline extensions are assumed to be needed, and costs are divided among all clusters by milking population.

[22] http://energy.ucdavis.edu/files/09-16-2014-08_Biomass_Resource-and-Facilities-Database-Update.pdf

[23] Assuming a truck can haul 40 cubic yards and manure is 62 pounds per cubic foot (wet) from http://pss.uvm.edu/vtcrops/articles/ManureCalibration.pdf, http://www.mastersonloam.com/trucks/ and http://www.calrecycle.ca.gov/SWFacilities/Directory/38-AA-0020/Document/298055

[24] Above ground tank or plug flow with uncovered effluent pond, adjusted to assume 100% of manure volatile solids reached the digester.

[25] Soil amendments were assumed to have zero value due to uncertainty in future markets but could provide additional revenue.

Pathway 3 assumes individual dairies retain existing anaerobic lagoon manure management and collect biogas from the covered lagoons. Only dairies already using anaerobic lagoon manure management are included in this scenario. Biogas use was analyzed for two sub-pathways: 3a assumed electricity production, and 3b assumed biogas was converted to transportation fuel. In pathway 3a, electricity was produced by a micro turbine to reduce local NOx emissions. In pathway 3b, transportation fuel was injected into the transmission pipeline. Pipeline injection of renewable natural gas avoids new onsite NOx generation that would occur from on-site electricity generation. Table 5 contains a summary of costs and revenues for Pathway 3a and Table 6 contains a summary of costs and revenue for Pathway 3b.

Table 5: Summary of Assumptions for Dairy Pathway 3a – Covered Lagoon Manure Management with Collected Methane Producing Electricity

Costs			
Item	**Capital**	**O&M**	**Reference**
Covered Lagoon Digester	Cost per head = 12,146*[# milking head]^-0.25	6%	UC Davis Report
Interconnection	$1,000,000	5%	Suscon Report
Biogas Upgrading	Included in O&M	$6 per 1,000 SCF biogas[26]	

Revenue		
Item	**Value**	**Reference**
Electricity Generation	0.066 kW per milking cow	UC Davis Report[27]
SB1122 Electricity Tariff Price	$ 0.1263 per kWh	SB1122 Feed in Tariff Price[28]
Mitigatable methane (lagoon management)	7.38 metric tons CO_2e per milking head per year (100-yr GWP)	ARB GHG Inventory
Cap-and-Trade Offset	$13 per ton CO_2e mitigated (100-yr GWP)	Estimate
Soil Amendment	$0[29]	

[26] These costs are represented as annual O&M costs, and are assumed to include amortized capital costs.
[27] Adjusted to match biogas production assumptions. Covered lagoon digesters are approximately 11 percent less efficient at biogas production per pound of manure based on the UC Davis Report, and 40% of manure volatile solids are assumed to be lost during solids separation.
[28] https://www.pge.com/en_US/for-our-business-partners/floating-pages/biomat/biomat.page
[29] Soil amendments were assumed to have zero value due to uncertainty in future markets, but could provide additional revenue.

Table 6: Summary of Assumptions for Dairy Pathway 3b – Covered Lagoon Manure Management with Collected Methane Producing Pipeline-Injected Renewable Natural Gas

Costs			
Item	**Capital**	**O&M**	**Reference**
Covered Lagoon Digester	Cost per head = 12,146*[# milking head]^-0.25	6%	UC Davis Report
Interconnection	$2,000,000	5%	Suscon Report
Pipeline	$200,000 per mile	5%	Suscon Report[30]
Biogas Upgrading	Included in O&M	$8 per 1,000 SCF biogas[31]	Suscon Report

Revenue		
Item	**Value**	**Reference**
Biomethane production	11,520 cubic feet per milking cow per year	UC Davis Report[32]
Biogas price	$ 3.46 per 1,000 cubic feet	
RIN Credits (covered lagoon)	153.8 RINS per cow per year	Calculation[33]
RIN Credit Price	$1.85 per RIN credit	Estimate
LCFS Credit Price	$100	Estimate
Soil Amendment	$0[34]	

Pathway 4 is a second cluster scenario, where dairies retain existing anaerobic lagoon manure management, collect biogas from the covered lagoons, and pipe the biogas to a central location for clean-up. No additional trucking is needed in this scenario, as biogas is transported via low-pressure pipeline. Only dairies already using anaerobic lagoon manure management are included in this scenario. Pathway 4 uses the same 55 dairy clusters described in Pathway 2. As before the number and location of centralized facilities was estimated, but not optimized, and there may be configurations that could reduce collective costs among clustered dairy farmers more than shown here.

Biogas use was analyzed for two sub-pathways: 4a assumed electricity production, and 4b assumed biogas was converted to transportation fuel. In pathway 4a, electricity was produced by a micro turbine to reduce local NOx emissions. In pathway 4b, transportation fuel was injected into the transmission pipeline. Pipeline injection of renewable natural gas avoids new onsite NOx generation that would occur from on-site electricity generation. As modeled, pathway 4b required building approximately 2,200 miles of low-pressure pipeline and 55 miles of new natural gas transmission pipeline. Of the 2,200 miles of low-pressure pipeline needed, 2000 miles are used to connect individual dairies to the central location, and 200 miles are used to connect the central location to the transmission pipeline.

[30] Low pressure rural pipeline
[31] These costs are represented as annual O&M costs, and are assumed to include amortized capital costs.
[32] Lagoon digester, assumes 60% of manure volatile solids reaches digester because 40% are lost in solids separation.
[33] Biomethane production (scf) * 1028 scf per btu / 77,000 btu per RIN
[34] Soil amendments were assumed to have zero value due to uncertainty in future markets but could provide additional revenue.

Table 7 contains a summary of costs and revenues for Pathway 4a and Table 8 contains a summary of costs and revenue for Pathway 4b.

Table 7: Summary of Assumptions for Dairy Pathway 4a – Covered Lagoon Manure Management with Centralized Biogas Clean-up Producing Electricity

Costs			
Item	**Capital**	**O&M**	**Reference**
Covered Lagoon Digester	Cost per head = 12,146*[# milking head]^-0.25	6%	UC Davis Report
Interconnection	$5,500,000 per cluster	3.5%	Suscon Report
Biogas Upgrading	Included in O&M	$2 per 1,000 SCF biogas[35]	

Revenue		
Item	**Value**	**Reference**
Electricity Generation	0.066 kW per milking cow	UC Davis Report[36]
SB1122 Electricity Tariff Price	$ 0.1263 per kWh	SB1122 Feed in Tariff Price[37]
Mitigatable methane (lagoon management)	7.38 metric tons CO_2e per milking head per year (100-yr GWP)	ARB GHG Inventory
Cap-and-Trade Offset	$13 per ton CO_2e mitigated (100-yr GWP)	Estimate
Soil Amendment	$0[38]	

[35] These costs are represented as annual O&M costs, and are assumed to include amortized capital costs.
[36] Adjusted to match biogas production assumptions. Covered lagoon digesters are approximately 11 percent less efficient at biogas production per pound of manure based on the UC Davis Report, and 40% of manure volatile solids are assumed to be lost during solids separation.
[37] https://www.pge.com/en_US/for-our-business-partners/floating-pages/biomat/biomat.page
[38] Soil amendments were assumed to have zero value due to uncertainty in future markets, but could provide additional revenue.

Table 8: Summary of Assumptions for Dairy Pathway 4b – Covered Lagoon Manure Management with Centralized Biogas Clean-up Producing Pipeline-Injected Renewable Natural Gas

Costs			
Item	**Capital**	**O&M**	**Reference**
Covered Lagoon Digester	Cost per head = 12,146*[# milking head]^-0.25	6%	UC Davis Report
Interconnection	$5,500,000 per cluster	3.5%	Suscon Report
Pipeline	$200,000 per mile	5%	Suscon Report[39]
Biogas Upgrading	Included in O&M	$6 per 1,000 SCF biogas[40]	

Revenue		
Item	**Value**	**Reference**
Biomethane production	11,520 cubic feet per milking cow per year	UC Davis Report[41]
Biogas price	$ 3.46 per 1,000 cubic feet	
RIN Credits (covered lagoon)	153.8 RINS per cow per year	Calculation[42]
RIN Credit Price	$1.85 per RIN credit	Estimate
LCFS Credit Price	$100	Estimate
Soil Amendment	$0[43]	

Pathway 5 assumed some dairies could convert to a pasture-based model where manure decays aerobically in the field and emits a negligible amount of methane. GIS analysis was used to analyze existing land area associated with dairies and to estimate the remaining amount of land purchase needed to meet the target cow density. Resulting diet changes are assumed to increase enteric emissions and reduce milk production. The impact of these effects on cost effectiveness was assessed by assuming manure methane reductions were partially offset by a 35 percent increase in enteric emissions. Revenue loss from decreased milk production was not directly accounted for due to a lack of information on this effect. Little information is available on the economics associated with converting to pasture, and most of the capital and operations and maintenance costs are assumptions based on ARB staff best estimates, review of limited studies, or direct calls to manufacturers. Table 9 contains a summary of assumptions used to calculate costs for Pathway 5; the pathway does not produce any new revenue.

[39] Low pressure rural pipeline
[40] These costs are represented as annual O&M costs, and are assumed to include amortized capital costs.
[41] Lagoon digester, assumes 60% of manure volatile solids reaches digester because 40% are lost in solids separation.
[42] Biomethane production (scf) * 1028 scf per btu / 77,000 btu per RIN
[43] Soil amendments were assumed to have zero value due to uncertainty in future markets but could provide additional revenue.

Table 9: Summary of Assumptions for Dairy Pathway 5 – Conversion to Pasture

Costs			
Item	**Capital**	**O&M**	**Reference**
Land Purchase	$7,700 per acre	n/a	USDA[44]
Fencing	$1.07 per foot	2.5%	ARB Analysis[45]
Irrigation	$5,000 per acre	10%	ARB Analysis
Shade Structures	$6,500 per structure	2.5%	ARB Analysis
Water Troughs	$180 per parcel	1%	ARB Analysis

Constants		
Item	**Value**	**Reference**
Milking Cow Density	3 cows per acre	
Parcel Size	5 acres	
Additional Acres to Purchase	200,000 acres	ARB GIS Analysis
Fencing per Parcel	1,980 feet	
Water Troughs per Parcel	1	
Shade Structures per Parcel	1	

Pathway 6 assumes all dairies use open solar drying of manure for 8 months of the year. This pathway may be an option for dairy operations not suitable for digestion or not near natural gas pipelines or transportation corridors to sell fuel, or for dairy farmers that wish to avoid the complexity of digester operation, power purchase agreements, and utility interconnections. This method could reduce methane emissions by minimizing anaerobic manure processing and storage. Dairies that used anaerobic lagoons require conversion to solid scrape or vacuum manure management. This process can potentially produce compost for sale, but costs and revenues associated with that operation are not included here. Table 10 contains a summary of assumptions used to calculate costs for Pathway 6.

Table 10: Summary of Assumptions for Dairy Pathway 6 – Scrape Conversion and Solar Drying

Costs			
Item	**Capital**	**O&M**	**Reference**
Scrape Conversion[46]	$350 per milking head	3%	ARB Estimated Value
Land and concrete drying pads	$400 per milking head	4.5%	UC Davis Report[47]

[44] USDA Land Values 2015 Summary http://usda.mannlib.cornell.edu/usda/nass/AgriLandVa//2010s/2015/AgriLandVa-08-05-2015.pdf

[45] ARB staff determined typical costs from studies and calls to manufacturers for estimates. Operations and maintenance was estimated based on the complexity of the system.

[46] Scrape conversion costs were only assumed for lagoon manure management. Other manure management types were assumed to require no capital to convert to solid manure management.

[47] Capital cost per cow represents interpolated value between 1,500 and 3,000 cow values for scrape to open solar drying (8 months) pathway in UC Davis study. O&M based on O&M as a function of total average cost in UC Davis pathway.

2. Costs and Revenues for an Example 2,000 Milking Cow Dairy

An economic analysis was performed for each pathway on a dairy-by-dairy basis to account for cost differences between dairies of different sizes. However, to provide an overview comparison by pathway, the costs and revenues for an example 2,000 cow dairy that manages manure using anaerobic lagoons were analyzed. The effect of regulation on this theoretical project was also analyzed. The pre regulation scenario assumes the project is operating before regulation that would affect revenue, and all revenue is available for the full 10 year analysis timeframe. The post regulation scenario assumes the project begins operating after regulation, which affects some revenue streams. Once a regulation to control manure emissions is in place, LCFS credits for new dairy digester projects no longer include credit for capturing and utilizing methane that would have otherwise been emitted into the atmosphere, which reduces the LCFS revenue by approximately 90 percent. The negative carbon intensity, or "negative CI" LCFS credit prices are more valuable, as they include additional credit for capturing and utilizing methane that would have otherwise been emitted into the atmosphere.[48] Additionally, cap and trade offset credits would no longer be available after regulation.

Tables 11 through Table 20 provide a detailed breakdown of costs and revenues for the example 2,000 cow dairy for each pathway. Total capital costs, annual operations and maintenance (O&M) costs, and annual revenues are provided for each pathway, considering the two regulation scenarios. Two values are listed for revenues affected by regulation; one if the project began operating before regulation ("Pre reg") and one if the project began operating after regulation ("Post reg").

The net present value (NPV) is calculated assuming capital costs are amortized over 10 years with 7% interest, and includes 10 years of annual O&M and revenue. All costs and revenues used for NPV calculations are discounted at 5% per year. If applicable, NPV is calculated for two scenarios: a project that begins operating before regulation, and a project that begins operating after regulation. If a project begins operating before regulation is in place, revenue is assumed to be at the "Pre reg" value for all 10-years of the analysis. If the project begins operating after regulation is in place, revenue is assumed to be at the "Post reg" value for all 10-years.

Assumptions used to calculate these costs are summarized by pathway in Table 1 through Table 10. Note that the values in Table 11 through Table 20 may not add precisely due to rounding.

[48] The negative carbon intensity, or "negative CI" LCFS credits are available for projects that begin operating before regulation and are more valuable because they include additional revenue for capturing and utilizing methane that would have otherwise been emitted into the atmosphere. The positive carbon intensity or "positive CI" LCFS credits are available for projects that begin operating after regulation and are less valuable because the capture and destruction of methane. Any sources with a regulatory requirement to reduce emissions cannot receive credits for those reductions.

Table 11: Estimated Costs and Revenues for a 2,000 Cow Dairy: Pathway 1a - Scrape Conversion and Onsite Manure Digestion Producing Electricity

Component	Total Capital	Annual O&M	Annual Revenue
Scrape Conversion	$696,000	$21,000	
Digester with Microturbine	$4,538,000	$386,000	
Interconnection	$1,000,000	$50,000	
Biogas Upgrading		$258,000	
Electricity Generation			$271,000
Cap-and-Trade Offset			Pre reg: $191,000 Post reg: $0
Total	**$6,234,000**	**$714,000**	**Pre reg: $461,000** **Post reg: $271,000**
NPV Pre-Regulation (10yrs)	**-$8,808,000**		
NPV Post-Regulation (10yrs)	**-$10,280,000**		

Table 12: Estimated Costs and Revenues for a 2,000 Cow Dairy: Pathway 1b - Scrape Conversion and Onsite Manure Digestion Producing Pipeline-Injected Renewable Natural Gas

Component	Total Capital	Annual O&M	Annual Revenue
Scrape Conversion	$696,000	$21,000	
Digester	$2,905,000	$174,000	
Pipeline	$914,000	$46,000	
Interconnection	$2,000,000	$100,000	
Biogas Upgrading		$344,000	
Fuel			$149,000
RINs			$1,061,000
LCFS Credits			Pre reg: $865,000 Post reg: $110,000
Total	**$6,514,000**	**$684,000**	**Pre reg:$2,074,000** **Post reg: $1,319,000**
NPV Pre-Regulation (10yrs)	**$3,268,000**		
NPV Post-Regulation (10yrs)	**-$2,262,000**		

Table 13: Estimated Costs and Revenues for a 2,000 Cow Dairy: Pathway 2a - Scrape Conversion and Transport of Manure Offsite for Centralized Digestion Producing Electricity

Component	Total Capital	Annual O&M	Annual Revenue
Scrape Conversion	$696,000	$21,000	
Digester with Microturbine*	$4,538,000	$386,000	
Low NOx Truck Purchase*	$140,000		
Manure Hauling		$95,000	
Interconnection*	$849,000	$30,000	
Biogas Upgrading*		$86,000	
Electricity			$271,000
Cap-and-Trade Offsets			Pre reg: $191,000 Post reg: $0
Total	**$6,223,000**	**$617,000**	**Pre reg: $461,000 Post reg: $271,000**
NPV Pre-Regulation (10yrs)	**-$8,042,000**		
NPV Post-Regulation (10yrs)	**-$9,515,000**		

*Costs are shared among dairies in the cluster, these costs represent a share of the total

Table 14: Estimated Costs and Revenues for a 2,000 Cow Dairy: Pathway 2b - Scrape Conversion and Transport of Manure Offsite for Centralized Digestion Producing Pipeline-Injected Renewable Natural Gas

Component	Total Capital	Annual O&M	Annual Revenue
Scrape Conversion	$696,000	$21,000	
Digester without Microturbine*	$2,905,000	$174,000	
Low NOx Truck Purchase*	$140,000		
Manure Hauling		$95,000	
Interconnection*	$849,000	$30,000	
Pipeline (rural low pressure)*	$75,000	$4,000	
Pipeline (transmission)*	$104,000	$5,000	
Biogas Upgrading*		$258,000	
CNG Station (small)*	$23,000	$2,000	
Fuel			$149,000
RIN Credits			$1,060,000
LCFS Credits			Pre reg: $865,000 Post reg: $ 110,000
Total	**$4,792,000**	**$588,000**	**Pre reg: $2,074,000 Post reg: $1,319,000**
NPV Pre-Regulation (10yrs)	**$6,203,000**		
NPV Post-Regulation (10yrs)	**$373,000**		

*Costs are shared among dairies in the cluster, these costs represent a share of the total

Table 15: Estimated Costs and Revenues for a 2,000 Cow Dairy: Pathway 3a – Covered Lagoon Manure Management with Collected Methane Producing Electricity

Component	Total Capital	Annual O&M	Annual Revenue
Covered Lagoon Digester	$3,616,000	$217,000	
Interconnection	$1,000,000	$50,000	
Biogas Upgrading		$137,000	
Electricity			$144,000
Cap-and-Trade Offsets			Pre reg: $191,000 Post reg: $0
Total	**$4,616,000**	**$404,000**	**Pre reg: $335,000 Post reg: $144,000**
NPV Pre-Regulation (10yrs)	**-$5,609,000**		
NPV Post-Regulation (10yrs)	**-$7,082,000**		

Table 16: Estimated Costs and Revenues for a 2,000 Cow Dairy: Pathway 3b – Covered Lagoon Manure Management with Collected Methane Producing Pipeline-Injected Renewable Natural Gas

Component	Total Capital	Annual O&M	Annual Revenue
Covered Lagoon Digester	$3,616,000	$217,000	
Interconnection	$2,000,000	$100,000	
Rural Low Pressure Pipeline	$914,000	$46,000	
Biogas Upgrading		$183,000	
Fuel			$79,000
RIN Credits			$566,000
LCFS Credits			Pre reg: $831,000 Post reg: $ 59,000
Total	**$6,530,000**	**$546,000**	**Pre reg: $1,476,000 Post reg: $703,000**
NPV Pre-Regulation (10yrs)	**$3,000**		
NPV Post-Regulation (10yrs)	**$5,962,000**		

Table 17: Estimated Costs and Revenues for a 2,000 Cow Dairy: Pathway 4a – Covered Lagoon Manure Management with Centralized Biogas Clean-up Producing Electricity

Component	Total Capital	Annual O&M	Annual Revenue
Covered Lagoon Digester	$3,616,000	$217,000	
Pipeline to Central Location	$740,000	$37,000	
Interconnection	$849,000	$30,000	
Biogas Upgrading		$46,000	
Electricity			$144,000
Cap-and-Trade Offsets			Pre reg: $191,000 Post reg: $0
Total	**$5,205,000**	**$330,000**	**Pre reg: $335,000 Post reg: $144,000**
NPV Pre-Regulation (10yrs)	**-$5,678,000**		
NPV Post-Regulation (10yrs)	**-$7,151,000**		

Table 18: Estimated Costs and Revenues for a 2,000 Cow Dairy: Pathway 4b – Covered Lagoon Manure Management with Centralized Biogas Clean-up Producing Pipeline-Injected Renewable Natural Gas

Component	Total Capital	Annual O&M	Annual Revenue
Covered Lagoon Digester	$3,616,000	$217,000	
Interconnection*	$849,000	$30,000	
Pipeline to connect dairy to central location	$740,000	$37,000	
Pipeline to connect central location to interconnect*	$76,000	$4,000	
Transmission Pipeline*	$104,000	$5,000	
CNG Station*	$23,000	$2,000	
Biogas Upgrading*		$258,000	
Fuel			$80,000
RIN Credits			$566,000
LCFS Credits			Pre reg: $831,000 Post reg: $58,000
Total	**$5,408,000**	**$552,000**	**Pre reg: $1,476,000** **Post reg: $703,000**
NPV Pre-Regulation (10yrs)	**$1,184,000**		
NPV Post-Regulation (10yrs)	**-$4,781,000**		

*Costs are shared among dairies in the cluster, these costs represent a share of the total

Table 19: Estimated Costs for a 2,000 Cow Dairy: Pathway 5 – Conversion to Pasture

Component	Total Capital	Annual O&M	Annual Revenue
Land Purchase	$2,041,000		
Fencing	$281,000	$7,000	
Irrigation	$3,313,000	$331,000	
Water Troughs	$24,000	$200	
Shade	$861,000	$22,000	
Total	**$6,520,000**	**$360,000**	**$0**
NPV* (10yrs)	**-$9,949,000**		

*NVP is the same regardless of regulation

Table 20: Estimated Costs for a 2,000 Cow Dairy: Pathway 6 – Scrape Conversion and Solar Drying

Component	Total Capital	Annual O&M	Annual Revenue
Scrape Conversion	$696,000	$21,000	
Concrete Drying Pads and Land	$795,000	$36,000	
Total	**$1,491,000**	**$57,000**	**$0**
NPV* (10yrs)	**-$2,077,000**		

*NVP is the same regardless of regulation

3. Costs and Revenues for Sector-Wide Scenarios

Two pathways were selected to bound potential sector-wide cost and revenue from mitigation of dairy manure. Dairy operations were assumed to choose the pathway with the highest net present value if LCFS and RIN credits were available (2b – central digestion producing transportation fuels), or the lowest cost option in the absence of revenue (6 – scrape conversion). This provides a likely cost bounding considering scenarios with and without LCFS and RIN credits. It is important to note that these scenarios were selected as an economic bounding exercise, and they are not intended to suggest a preferred or expected path forward. Actual implementation of any regulatory requirements will likely include a suite of potential mitigation options.

The sector-wide scenarios use the same assumptions as the individual pathways, but aggregate cumulative costs and revenues from 2017 through 2030, based on individual dairy economics assuming a model build out timeline. There are additional costs and benefits after 2030, but these are not included in the analysis. The effect of regulation timing on revenue was also analyzed. Regulation affects the value of LCFS credits and cap-and-trade offsets, thus has an impact on the overall economics of pathway 2b, but not pathway 6, which has no revenue. Specific assumptions used for each sector-wide scenario can be found in Table 21 and Table 23.

A summary of cluster implementation schedule, costs, and revenues for sector-wide scenario 2b can be found in Table 21. All costs and revenues through 2030 were included in the calculation, though there would be additional costs, revenue and methane mitigation after 2030. Upfront capital represents the amount of capital needed to finance the new projects in a given year. This upfront capital is paid back as annual loan amortized over 10 years at 7 percent interest and a 5 percent discount rate. The annual capital spent by all dairies represents the total loan payment in a given year across all dairies. Annual O&M and revenue were assessed for each dairy and each year through 2030, with 5% discounting.

Table 21: Annual Build Out Schedule, Costs, and Revenue for Sector-Wide Scenario 2b - Scrape Conversion and Transport of Manure Offsite for Centralized Digestion Producing Pipeline-Injected Renewable Natural Gas [49]

Year	New Clusters	Dairies in New Clusters	Milking Head in New Clusters	Upfront Capital for New Clusters	Annual Capital Spent, All Dairies	Annual O&M Spent, All Dairies	Annual LCFS Revenue, All Dairies			RIN Credit Revenue	Other Revenue
							No Reg	2026 Reg	2024 Reg		
2017	1	7	32,070	$58	$8	$8	$14	$14	$14	$17	$2
2018	3	21	79,018	$143	$28	$25	$46	$46	$46	$56	$8
2019	4	31	89,109	$164	$50	$44	$79	$79	$79	$97	$14
2020	3	36	75,430	$138	$67	$59	$104	$104	$104	$127	$18
2021	4	42	96,136	$166	$88	$76	$133	$133	$133	$163	$23
2022	4	32	59,584	$108	$99	$85	$147	$147	$147	$180	$25
2023	4	37	88,521	$140	$114	$98	$169	$169	$169	$207	$29
2024	5	38	86,974	$136	$128	$110	$188	$188	$164	$230	$32
2025	4	50	94,631	$140	$142	$121	$207	$207	$160	$253	$35
2026	4	45	71,722	$108	$151	$128	$217	$199	$155	$266	$37
2027	4	52	73,207	$107	$154	$134	$217	$184	$141	$277	$39
2028	4	34	53,875	$77	$145	$136	$201	$157	$116	$281	$39
2029	6	52	75,503	$105	$139	$141	$188	$130	$91	$290	$41
2030	5	66	76,712	$104	$135	$146	$179	$109	$72	$298	$42
Total	**55**	**543**	**1,052,492**	**$1,694**	**$1,448**	**$1,312**	**$2,087**	**$1,863**	**$1,591**	**$2,743**	**$384**

LCFS revenue was assessed for three regulation scenarios: 1) no regulation, 2) 2026 regulation, and 3) 2024 regulation. Regulation effective dates were assumed to be January 1st of the regulation year. A summary of LCFS calculation for each regulation scenario can be found in Table 22. Any project started before the effective date of the regulation receives LCFS credits at the “negative CI” including methane destruction for 10 years. After 10 years the dairy no longer receives credit for methane destruction which reduces LCFS revenue for any remaining year through 2030. Some dairies could potentially reapply for LCFS methane destruction credits for an additional 10 years. This option was excluded for simplicity, and due to uncertainty in the number of projects that would reapply. Projects established after regulation receive the positive CI LCFS price for all years through 2030. In the no regulation case, all projects receive LCFS credits including methane destruction for up to10 years then drop down to the lower LCFS revenue for any remaining years through 2030.

[49] All costs and revenue in millions of dollars, and discounted at 5% per year.

Table 22: LCFS Revenue Assumptions for Three Regulation Scenarios[50]

	No Regulation	Regulation 2026	Regulation 20204
Cluster Established Before Regulation	Up to 10-years of LCFS credit at negative CI, remaining years through 2030 at positive CI	Up to 10-years of LCFS credit at negative CI, remaining years through 2030 at positive CI	Up to 10-years of LCFS credit at negative CI, remaining years through 2030 at positive CI
Cluster Established After Regulation	n/a	LCFS credit for all years at positive CI	LCFS credit for all years at positive CI

A summary of dairy implementation schedule, costs, and revenues for sector-wide scenario 6 can be found in Table 23. As in Table 21, upfront capital represents the amount of capital needed to finance the new projects in a given year. This upfront capital is paid back as annual loan amortized over 10 years at 7 percent interest and a 5 percent discount rate. The annual capital spent by all dairies represents the total loan payment in a given year across all dairies. Annual O&M and revenue were assessed for each dairy and each year through 2030, with 5% discounting.

[50] The negative carbon intensity, or "negative CI" LCFS credits are available for projects that begin operating before regulation and are more valuable because they include additional revenue for capturing and utilizing methane that would have otherwise been emitted into the atmosphere. The positive carbon intensity or "positive CI" LCFS credits are available for projects that begin operating after regulation and are less valuable because the capture and destruction of methane. Any sources with a regulatory requirement to reduce emissions cannot receive credits for those reductions.

Table 23: Annual Build Out Schedule, Costs, and Revenue for Sector-Wide Scenario 6 - Scrape Conversion and Solar Drying

Year	New Scrape Conversion Projects	Milking Head in New Projects	Upfront Capital for New Projects	Annual Capital Spent, All Dairies	Annual O&M Spent, All Dairies
2017	4	34,363	$26	$4	$1
2018	14	78,714	$56	$11	$3
2019	18	85,430	$58	$19	$5
2020	20	81,038	$53	$26	$7
2021	26	90,865	$56	$33	$9
2022	19	59,383	$35	$36	$10
2023	33	91,977	$51	$42	$11
2024	35	86,682	$46	$46	$12
2025	44	94,306	$48	$51	$14
2026	40	73,957	$36	$53	$14
2027	45	71,123	$33	$53	$15
2028	40	53,114	$23	$49	$15
2029	65	73,293	$31	$46	$15
2030	90	78,488	$31	$44	$16
Total	**493**	**1,052,733**	**$583**	**$513**	**$147**

B. Methane Emission Reductions from Landfill Organic Waste Diversion

Achieving California's methane reduction targets requires optimizing the use and disposal of methane generating organic materials. To that end, the SLCP Strategy recommends reducing organics deposited to landfills 50 percent from 2014 levels by 2020 and 75 percent from 2014 levels by 2025, consistent with SB 1383. These ambitious targets require putting organic materials to the highest feasible use and developing infrastructure and markets to optimize the economic and environmental value of California's waste streams across sources.

When considering waste diversion options it is essential to balance environmental and economic benefits with any potential impacts on criteria pollutant emissions and ecosystem and human health, especially in disadvantaged communities. Avoiding organic waste generation entirely is the best option to reduce emissions, protect health, and minimize costs. However, once generated, there are many options for creating environmental and economic benefit through the appropriate utilization organic waste. Organics can be diverted to waste facilities with existing excess capacity, including composting facilities, stand-alone anaerobic digesters, and wastewater treatment anaerobic digesters. New facilities can also be built in optimized locations.

This analysis attempts to bound the potential cost of achieving the organic diversion targets outlined in this SLCP Strategy by exploring the use of three types of facilities for the handling of diverted materials. The scenarios are illustrative and do not represent a preferred strategy or technology or the realized mixture of voluntary and regulatory actions that may achieve the organic diversion targets. The final mix of strategies used to meet the organic diversion target cannot be predicted, but will likely involve a variety of facility types analyzed in the three illustrative scenarios.

The analysis begins with the methodology used to estimate the organic waste targets through 2025 and feasible diversion paths. These waste diversion targets and diversion options are then used to develop three scenarios by which California can achieve the targets in SB 1383. The estimated costs and potential revenue streams for each strategy are then discussed.

1. Organic Waste Diversion Targets

SB 1383 requires a 50 percent reduction in the level of statewide disposal of organic waste from the 2014 level by 2020, and a 75 percent reduction from the 2014 level by 2025. The organic diversion targets presented in this economic analysis were calculated using the composition of California's waste stream in 2014,[51] as outlined in Table 24. Organic waste, as defined by AB 1826, includes food waste, green waste, landscape and pruning waste, nonhazardous wood waste, and food-soiled paper waste that is mixed in with food waste.[52] This economic analysis relies upon existing definitions of what types of materials are considered organics. CalRecycle, in consultation with ARB and stakeholders, will be establishing a definition of organics that is specific to addressing the novel requirements of SB 1383. As such, the targets in this Appendix are for illustrative purposes and are subject to change.

Not all paper is included in the AB 1826 definition of organic waste. Compostable paper in Table 24 includes two subcategories that approximate food-soiled paper waste: compostable other miscellaneous paper and compostable remainder/composite paper.[53] The remaining paper in California landfills, while not included in this analysis, is a critical component in achieving the goals of AB 341 and must also be diverted to the highest value usage, including source reduction, reuse, and recycling. To meet the targets required by SB 1383, 50 percent of 2014 organic waste must be diverted by 2020 and 75 percent by 2025. While this economic analysis relies on existing definitions of organic material, the emission reductions associated with the diversion targets (presented in Table 8 of the SLCP Strategy) are calculated with a broad definition that includes all biodegradable waste, including items such as all paper, all wood, and some textiles and carpet. Therefore, achieving the targets in this analysis and the estimated emission reductions may require the diversion of additional materials from landfills beyond those outlined in Table 24.

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[51] The 2014 Disposal-Facility-Based Characterization of Solid Waste in California was produced under contract by Cascadia Consulting Group and released by CalRecycle on October 6, 2015. For the waste characterization utilized in this analysis, see Table 7 in the Significant Tables and Figures document available at: http://www.calrecycle.ca.gov/Publications/Detail.aspx?PublicationID=1546.

[52] AB 1826 text available at: http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB1826&search_keywords.

[53] These subcategories are estimated from the 2014 Disposal-Facility-Based Characterization of Solid Waste in California by CalRecycle.

Table 24: 2014 Organic Waste Characterizations

Waste Type	2014 (wet tons)
Compostable Paper*	2,093,462
Food	5,591,179
Leaves and Grasses	1,172,925
Prunings and Trimmings	962,262
Branches and Stumps	528,493
Lumber	3,676,710
Remainder/Composite Organic	1,323,465
Alternative Daily Cover	1,294,515
TOTAL	**16,643,011**
2020 Organic Waste Diversion Target	***8,086,575***
2025 Organic Waste Diversion Target	***12,653,633***

a. Waste Diversion or Recovery Pathways

Organic waste in landfills is not homogeneous, and represents different sources, composition, methane generating potential, and challenges for recycling and diversion. As such, not all organic waste can, or should, be handled through the same processes. ARB and CalRecycle collaborated to outline potential diversion strategies by organic waste subcategory to meet the waste diversion targets. For each organic waste subcategory, Table 25 and Table 26 estimate the percentage of material diverted to each type of facility over time to achieve the 2020 or 2025 organic diversion targets, respectively. These diversion options are illustrative and do not represent all pathways that may be employed.

Table 25: Possible Organic Waste Diversion Pathway to Meet 2020 Target

Waste Type	2014 Waste (Wet Tons)	Estimated Distribution of Organic Waste (Wet Tons)					
		Landfill	Reduction or Recycle	Food Recovery	Compost	AD or Compost	Chip & Grind
Compostable Paper	2,093,462	628,039	209,346		1,256,077		
Food	5,591,179	1,146,192		559,118		3,885,869	
Leaves and Grasses	1,172,925	879,694			293,231		
Prunings and Trimmings	962,262	721,697			240,566		
Branches and Stumps	528,493	396,370					132,123
Lumber	3,676,710	2,573,697	183,836				919,178
Remainder/Composite Organic	1,323,465	1,323,465					
Alternative Daily Cover	1,294,515	647,258			647,258		
2014 TOTAL	**16,643,011**	**8,316,410**	**393,182**	**559,118**	**2,437,141**	**3,885,869**	**1,051,301**
Percent of 2014 Waste		**50%**	**50%**				

Table 26: Possible Organic Waste Diversion Pathway to Meet 2025 Target

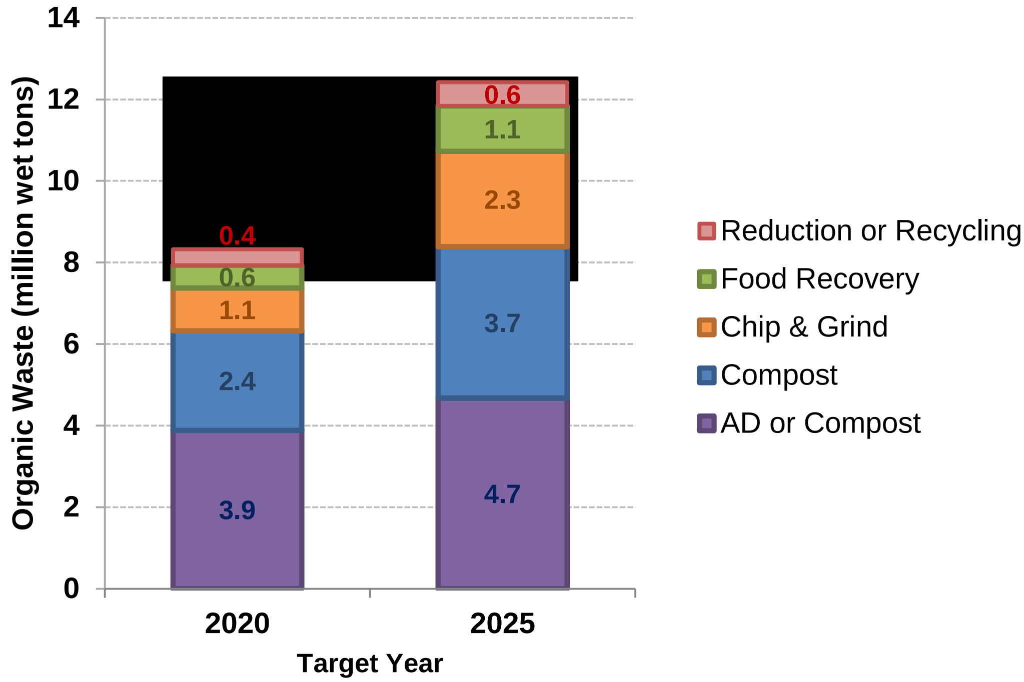
Waste Type	2014 Waste (Wet Tons)	Estimated Distribution of Organic Waste (Wet Tons)					
		Landfill	Reduction or Recycle	Food Recovery	Compost	AD or Compost	Chip & Grind
Compostable Paper	2,093,462	628,039	209,346		1,256,077		
Food	5,591,179	385,791		1,118,236		4,087,152	
Leaves and Grasses	1,172,925				586,463	586,463	
Prunings and Trimmings	962,262				962,262		
Branches and Stumps	528,493	396,370					132,123
Lumber	3,676,710	1,103,013	367,671				2,206,026
Remainder/Composite Organic	1,323,465	1,323,465					
Alternative Daily Cover	1,294,515	388,355			906,161		
2014 TOTAL	**16,643,011**	**4,225,032**	**577,017**	**1,118,236**	**3,710,962**	**4,673,614**	**2,338,149**
Percent of 2014 Waste		**25%**	**75%**				

Conventional waste diversion options outlined in Tables 25 and 26 include composting, anaerobic digestion (AD), and chipping or grinding materials (Chip & Grind). In addition, reduction or recycling can be used to avoid waste generation or reuse and recycle the waste before it reaches the landfill. Food recovery is another important strategy that can remove potent methane-generating waste from landfills while minimizing nutritional loss in the food system. The US Department of Food and Agriculture estimates that approximately one-third of all food produced in the United States is not consumed, representing 1,249 calories per person per day.[54] In addition to generalized waste diversion goals, under SB 1383 20 percent of the edible food waste must be recovered for human consumption by 2025. In this SLCP Strategy, food recovery includes:

- Source Reduction - reducing the volume of surplus food generated in households and businesses
- Feeding the Hungry - donating appropriately safe extra food to food banks and shelters

Figure 1 outlines the organic waste diversion by pathway from Tables 25 and 26.

Figure 1: Proposed Organic Waste Utilization Pathways by Year



[54] USDA (2014). The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States. Available at: http://www.ers.usda.gov/media/1282296/eib121.pdf.

Diverting a significant fraction of organic waste from landfills will cause a sharp decline in tipping fee revenue for landfills, which includes governmental fee revenue for both local governments and the State. In 2015, CalRecycle estimated the median tipping fee at California landfills as $45 per ton.[55] Holding this tipping fee constant through 2025 and assuming the organic diversion targets are met, revenue to California landfills could decrease by $365 million in 2020 and $570 million in 2025. This loss in revenue could impact the State's ability to meet existing statutory obligations and thus as California optimizes reduction, diversion, and disposal of waste, additional funding options should be explored that are not solely reliant on landfill fees.

b. Existing Excess Capacity at Waste Treatment Facilities

Leveraging existing excess capacity at California's waste treatment facilities can dramatically reduce the number of new facilities that may be required to handle diverted organic waste and help maximize the environmental and economic potential of organic waste diversion. Existing facilities that may accept organics from landfill include compost facilities, wastewater treatment facilities with anaerobic digestion, and Chip & Grind facilities. Table 27 presents the estimated excess capacity currently available at California wastewater treatment plants with anaerobic digesters and compost facilities. Though Chip & Grind excess capacity is not included in Table 27, CalRecycle estimates that existing Chip & Grind facilities will have sufficient capacity (and there will be sufficient product demand) to handle all diverted organic materials in this analysis through 2025.

Table 27: Estimated Current Excess Capacity

Facility Type	Estimated Annual Excess Capacity (Wet Tons)
Compost	1,000,000
Wastewater Treatment	7,000,000
Total	**8,000,000**

CalRecycle estimates the excess capacity at existing compost facilities based on the 2014 Disposal-Facility-Based Characterization of Solid Waste in California. To meet the 2025 diversion target, California's compost needs are estimated to range from 3 and 8 million wet tons per year.[56] Therefore, current excess composting capacity of 1 million wet tons per year is insufficient to handle future diversion needs.

US EPA estimates that the nearly 140 wastewater treatment facilities with anaerobic digesters in California have an estimated excess capacity of 15 – 30 percent.[57] The California Association of Sanitation Agencies (CASA) estimates existing excess

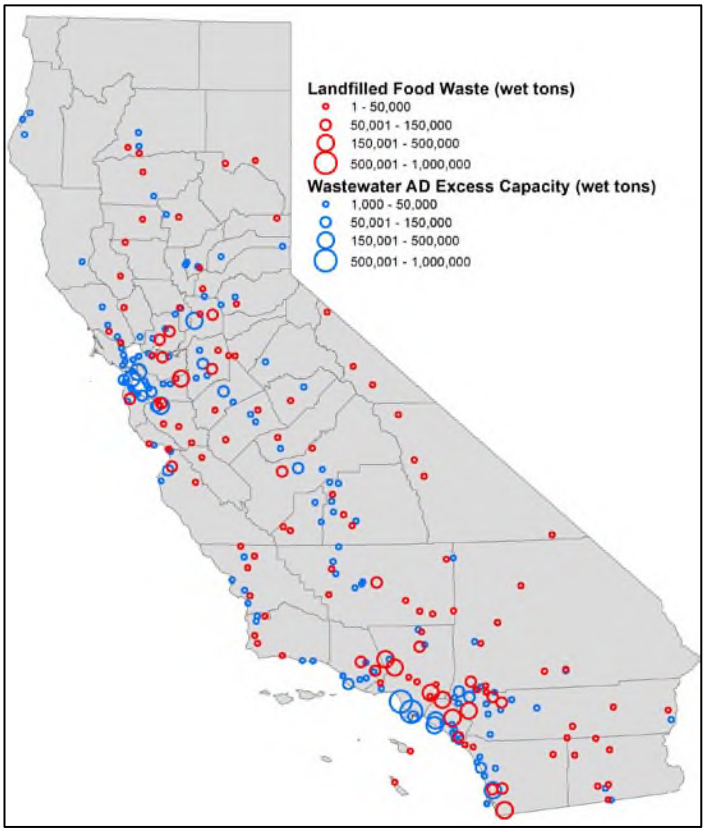
[55] Tipping fees vary by geographic region, type of waste, operational factors and consumer type. The median tipping fee is utilized to reflect the state mass balance of the waste characterization, www.calrecycle.ca.gov/publications/Documents/1520%5C20151520.pdf.
[56] Figure 2, depends on the assumptions for how much waste is utilized by AD.
[57] US EPA (2016). https://www3.epa.gov/region9/waste/features/foodtoenergy/wastewater.html.

capacity at wastewater treatment facilities for food waste and fats, oils, and grease is approximately 7 million wet tons per year (Table 27),[58] which could theoretically handle the 4 million wet tons of food waste diverted to AD in 2025 (Table 26) as well as the 600,000 wet tons of leaves and grasses that can be diverted to AD facilities.[59]

Additionally, a geospatial analysis carried out by ARB indicates that food waste and wastewater treatment excess capacity are spatially correlated throughout California, as highlighted in Figure 2. The analysis compared the location of landfilled food waste and wastewater treatment excess capacity to estimate the additional distance food waste would travel from landfill to wastewater treatment plant. The analysis found that all food waste from landfills could theoretically be consumed by wastewater treatment plants within 30 miles. In this analysis, the landfill is treated as the source of waste (including food waste); therefore waste is transported to the nearest landfill where organics are separated, processed, and transported to their final destination including centralized digester, wastewater treatment plant, or compost facility. Alternatively, though this option was not analyzed, food waste could be separated by households, and travel directly to pre-processing locations, then to wastewater treatment plants with excess capacity. Each of these options results in economic and environmental trade-offs that should be analyzed at the regional level to identify the best course of action. It is likely that a combination of these methods will be utilized, depending on the region.

[58] Assuming a MCRT of 15 days, CASA estimates that 17 facilities have an existing excess capacity of 5,805,000 gallons per day. The total estimate, when expanded across all facilities in California handling at least a million gallons a day, is estimated as 8,000,000 gallons per day. Applying mass loading for food waste and fats, oils, and grease results in an excess capacity for food waste of 6,035 dry tons per day or 7,342,500 wet tons per year. This information was provided by CASA on November 9, 2015.
[59] Does not include additional facilities needed to handle the potential increase in residual biosolids and assumes that co-digestion at wastewater treatment plans is both technologically and economically feasible for food waste as well as grasses and leaves. This analysis assumes that 100 percent of food waste can feasibly be diverted from landfills.

Figure 2: Co-Location of Landfilled Food Waste and Wastewater Treatment Excess Capacity



2. Scenarios

The three scenarios are based on the potential organic waste diversion options outlined in Tables 25 and 26. All scenarios include the following assumptions:

- Existing excess compost capacity is fully utilized
- New compost facilities are constructed to handle all materials listed under the 'compost' heading in Tables 25 and 26
- Each new compost facility has a throughput of 100,000 wet tons per year
- Existing Chip & Grind facilities have capacity to handle all materials projected to be diverted to 'Chip & Grind' in Tables 25 and 26
- Food recovery targets are reached (10 percent in 2020 and 20 percent in 2025)

Therefore, the only difference between the scenarios is the waste utilization of food waste and grass and leaves ('Compost or AD' in Tables 25 and 26). The three scenarios are described below. The actual future utilization of food waste and grass and leaves will most likely be some mix of these options. Since it is not possible to predict the exact mix of utilization pathways, these three scenarios were developed to bound potential costs and revenues.

Scenario 1 - New Centralized AD Facilities

All ‘Compost or AD’ food waste, grass and leaves in Tables 25 and 26 are handled by new centralized AD treatment facilities, and the methane is injected to pipelines. It is assumed that there is a modest market for AD digestate, which represents 36 percent of the digested waste. 50 percent of AD digestate are assumed to be disposed of at no cost; i.e., the cost to process and ship the digestate is offset by any potential revenue. The other 50 percent of AD digestate is processed and shipped to compost facilities, and AD facilities pay the cost for transportation and compost tipping fees. This composted digestate requires construction of additional compost facilities. New centralized AD facilities are assumed to accept 100,000 tons of organic material, including both food waste and grass and leaves, per year on average.

Scenario 2 - Existing Wastewater Treatment Plant AD

Scenario 2 assumes that all ‘Compost or AD’ materials in Tables 25 and 26 are diverted to existing wastewater treatment facilities with AD, utilizing a majority of the estimated existing excess capacity. Upgrading and permitting costs are included for each facility, which could include digester expansion to allow for additional capacity. The scenario assumes there is no market for AD biosolids, which represents 36 percent of total digested waste, and new compost facilities are constructed to handle the residual biosolids. There is a cost to process the biosolids at wastewater treatment plants, and the materials are trucked to new compost facilities. The wastewater treatment plants pay for the cost to transport biosolids to compost facilities and pays tipping fees. It is assumed that, with modification, existing wastewater treatment facilities can accept 50,000 tons of organic material per year on average by 2025, with some facilities accepting more or less depending on size. The 50,000 capacity includes 45,000 wet tons of food waste and up to 5,000 wet tons of grasses and leaves.

Scenario 3 - New Compost Facilities

Scenario 3 assumes that all ‘Compost or AD’ materials in Tables 25 and 26 are composted at new facilities, after filling existing excess capacity at compost facilities.

Waste Diversion By Scenario

Table 28 estimates the organic waste diverted by pathway for the two target years. The overall waste diverted from landfills is the same in each scenario, but the pathway for diversion differs. Scenarios 1 and 2 require processing of more total organic material, because some portion of AD material is processed twice: once for the AD process and once to compost the biosolids or digestate. This double counting is necessary to accurately predict the number of new composting facilities needed, however, no additional organic material is diverted from the landfill in these scenarios.

Table 28: Organic Waste Utilization by Scenario

Diversion Target Year	Waste Diversion Pathway		Scenario		
			1. New AD	2. Existing WWTP	3. Compost Only
			(Million Wet Tons of Waste)		
2020	Reduction, Recycle, Food Rescue		1.0	1.0	1.0
	Compost	Existing Excess Capacity	1.0	1.0	1.0
		New Facilities	1.4	1.4	5.3
		New Facilities for Biosolids	0.7	1.4	--
	Anaerobic Digestion		3.9	3.9	--
	Chip and Grind		1.1	1.1	1.1
2025	Reduction, Recycle, Food Rescue		1.7	1.7	1.7
	Compost	Existing Excess Capacity	1.0	1.0	1.0
		New Facilities	2.7	2.7	7.4
		New Facilities for Biosolids	0.8	1.7	--
	Anaerobic Digestion		4.7	4.7	--
	Chip and Grind		2.3	2.3	2.3

A principal difference in outcomes from these three scenarios is the number of new facilities needed to achieve the organic diversion targets. Table 29 shows the number of new compost or AD facilities needed for each scenario.

Table 29: Estimated Number of New Facilities

Scenario	Estimated Number of New Compost Facilities		Estimated Number of New AD Facilities	
	2020	2025	2020	2025
1. New AD	21	36	39	47
2. Existing WWTP	28	44	--	--
3. Compost Only	53	74	--	--

3. Facility-Level Cost and Revenue Calculations

This section outlines the facility-specific costs and revenues that underlie the three statewide scenarios for organic diversion. Cost estimates rely on information obtained from California agencies, academic researchers, and industry estimates. This analysis estimates the incremental impact of the scenarios, therefore, only the impact associated with the diverted material is considered. Net present value calculations are used to determine the profitability of the three potential scenarios. By calculating the present value of future cost and organic diversion over a 10-year financing period, the net present value calculation provides insight into the feasibility of projects at the facility level.

There is uncertainty regarding the costs, savings, and potential revenue streams associated with organic waste diversion. Social welfare impacts, including those related to health, noise, odor, ecosystem benefit, and water impacts, are not included in this analysis but require additional consideration and analysis prior to the implantation of any organic diversion measure. Additional uncertainty related to existing infrastructure and technology development may also create economic impacts not analyzed in this analysis, which relies on available data to estimate the direct economic impact, including costs, fuel and energy savings, and potential revenue streams, of achieving California's organic waste diversion target.

This analysis assumes that organic waste is handled through existing collection routes for households, businesses, and industrial entities and no additional costs are incurred from curbside to arrival at the landfill. This assumption, while simplifying, may ignore both costs and efficiencies that result from optimized organic waste disposal within a eographic region.

The costs of diverting organic materials to existing facilities are assumed to be equal across all three scenarios. This analysis assumes that there is no net economic impact from reducing organic waste or diverting organics to existing facilities as detailed in the sections below. Scenario costs vary based on the relative cost of new AD and compost facilities as well as costs associated with retrofitting existing wastewater treatment plants to accept food waste.

a. Education and Outreach

Education and outreach is helpful to support any major change to public systems. While not quantified in this analysis, State and federal funds could contribute to awareness of California's organic waste diversion goals and provide support for organic waste reduction, recycling, and food recovery. Given the uncertainty surrounding measure implementation, these costs are not included in the analysis but represent the potential use of State and federal funding to achieve the organic diversion targets.

b. Food Recovery

The food recovery target in this SLCP Strategy can be achieved through source reduction, diverting food to feed the hungry, and utilizing food scraps as animal feed. A 2016 report estimates that achieving a national 20 percent reduction in food waste by 2025 will require an investment of $18 billion, but results in a societal benefit of $100 billion and the creation of 15,000 jobs per year.[60] The report finds that the most cost-effective way to reduce food waste is through food waste prevention and recovery.

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[60] A Roadmap to Reduce U.S. Food Waste by 20 percent is available for download at: http://www.refed.com/download. The 20 percent reduction in food waste includes 27 strategies to reduce food waste including prevention, recovery, and recycling.

Scaling the investments to California (assuming the State comprises 12 percent of the US population in 2025) achieving a 20 percent food recovery target could require investments of $1.8 billion, or $200 million a year from 2016 through 2025.[61] These investment requirements are mitigated by an estimated annual business profit potential of $228 million in food waste savings. These figures do not include benefits that arise from household savings and food donations, which could result in an estimated annual economic value of $1.2 billion for California. Food recovery will also generate cost savings in avoided tipping fees, estimated at $25 million in 2020 and increasing to $50 million in 2025 (assuming a tipping fee of $45).

Given the variability in methods that can be used to achieve California's food recovery targets and the uncertainty surrounding costs and scalability, the analysis assumes that food recovery will have no net impact on the California economy. Because potential revenues and avoided tipping fees outweigh costs of achieving a 20 percent food recovery target (as estimated at a national level), this is a conservative approach.

c. Chip & Grind

The location of Chip & Grind facilities may require additional transportation of materials, resulting in increased fuel and vehicle costs. However, Chip & Grind facilities also produce salable products including mulch, and woodchips, and compost.[62] In the analysis, revenue from the increased sale of materials is assumed to offset any costs from transportation and processing of lumber and branches and stumps, resulting in no net economic impact.

d. Existing Compost Facilities

The analysis assumes that existing compost facilities are permitted and able to operable at full capacity and that no there are no additional operating and maintenance costs associated with filling excess capacity. It is assumed there is no cost for the transportation of organic materials, as material is already traveling to the existing compost facility from the landfill and the material represents a small fraction of the total compost amount.

e. New Compost Facilities

New compost facilities are required in all three scenarios. To comply with federal, State, and local air quality requirements, the analysis assumes that all facilities are Gore positive aerated static pile (ASP) compost facilities with costs outlined in Table 30.[63] Gore ASP compost facilities have demonstrated the ability to meet strict VOC emission

[61] See the marginal food waste abatement cost curve on page 23 of A Roadmap to Reduce U.S. Food Waste by 20 percent for additional information. The required investment of $14.9 billion includes food waste prevention and recovery only. The additional investments outlined by ReFED are captured through the AD or compost pathway.
[62] An example of the products produced at one Chip & Grind facility in San Diego is available at: http://www.sandiego.gov/environmental-services/miramar/greenery/cmw.shtml.
[63] Costs estimates based on information provided by CalRecycle.

controls set by the San Joaquin Valley Air Pollution Control District and the South Coast Air Quality Management District and significantly reduce odor, making them a feasible option across California.

Table 30: Estimated Cost of a Representative New Compost Facilities

Gore Positive Aerated Static Pile (ASP) Compost Facility	
Facility Component	**Capital Investment**
Permitting	$900,000
Infrastructure	$11,500,000
Equipment	$3,900,000
Land	$200,000[64]
Total Cost	**$16,500,000**

Table 31 presents the estimated costs and revenue stream for a representative new compost facility over a 10-year period. Transportation of organic materials from the centralized processing point (either landfill or materials recovery facilities) to the compost facility are included in the analysis, although these costs may not be explicitly born by the compost facility. In the Co-Digestion Economic Analysis Tool (CoEAT), US EPA estimates a waste hauling cost of $0.18 per ton-mile.[65] This analysis assumes that waste is transported 40-miles round trip between landfills and new compost facilities. This allows for location flexibility in geographic regions where permitting of new compost facilities may be difficult. In this analysis, each new facility purchases one low NOx compressed natural gas (CNG) truck to transport organic materials.

Table 31: Estimated Costs and Revenue per Compost Facility Through 2030[66]

Component	**Capital Cost**	**Average Annual O&M Cost**	**Average Annual Revenue**
Gore ASP Compost Facility	$16,500,000	$1,650,000	
CNG Vehicles	$250,000	$25,000	
Transportation		$720,000	
Tipping Fee			$4,500,000
Total	**$16,750,000**	**$2,395,000**	**$4,500,000**
10-Year Net Present Value	**-$2,200,000**		

[64] Assumes 25 acre facility with a cost of $7,700 per acre, the average value of an acre of farm land in California, http://www.usda.gov/nass/PUBS/TODAYRPT/land0815.pdf.
[65] https://archive.epa.gov/region9/organics/web/html/index-2.html
[66] Capital costs are amortized over 10 years with 7% interest. The discount rate is 5% and all values are rounded. Cost references are presented in Table 33.

The net present value assumes a 10-year finance period with 7 percent interest and a discount rate of 5 percent. This representative compost facility has a net present value of - $2.2 million over the 10-year period, therefore is not economically viable without additional funding sources. An upfront grant of $2 million would allow this project to break even, highlighting the need for incentives and State action to achieve the organic diversion goals.

This analysis does not include the sale of compost products,[67] because there is large variation and uncertainty in the processing costs and demand for compost products. In the analysis any revenue generated from compost materials is assumed to mitigate costs associated with processing and transporting the final products, resulting in no net economic impact. However, this may underestimate future revenue at compost facilities. A 2014 analysis of the economic impact of composting found that over 30 percent of compost revenues were related to the sale of soil, compost, and mulch,[68] while the sale of compost in San Francisco and Palo Alto has been recorded at $12 to $26 per ton.[69]

f. Upgrading Existing Wastewater Treatment Facilities with Anaerobic Digesters

Costs for diverting organic waste to existing wastewater treatment facilities is estimated as the incremental costs and benefits that result from the addition of organic waste to the wastewater facility anaerobic digester. While wastewater treatment facilities have significant revenue potential, difficulty in securing financing, potential restrictions in permitting and land use, and aging facilities may restrict the ability of facilities to receive new organic waste streams. For facilities that are able to secure financing and accept organic waste, costs include facility improvements, construction of pre-processing facilities, transportation costs, costs associated with biosolid processing transportation and disposal, and costs associated with biogas generation, cleaning, and injection into pipelines.

The analysis assumes that all biogas generated through organic waste diversion will be used as transportation fuel, as this represents the highest value use of biomethane. There are 118 wastewater treatment facilities located less than 8 miles from a natural gas pipeline. These facilities represent 95 percent of the existing excess capacity and it is assumed in this analysis that these facilities can upgrade to allow food waste generated biogas to be pipeline injected. Assuming each wastewater treatment facility can accept 45,000 wet tons of food waste a year, meeting the SB 1383 targets will require diversion of organic food waste to 86 facilities in 2020 and 104 facilities in 2025. Three miles of pipeline is apportioned to each facility in the cost calculation, assuming that facilities greater than 3 miles from a pipeline are not economically feasible options for pipeline injection.

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[67] http://www.calrecycle.ca.gov/publications/Documents/1520%5C20151520.pdf

[68] http://www.mncompostingcouncil.org/uploads/1/5/6/0/15602762/economic_impact_study_final-2-2-15.pdf

[69] http://www.sfgate.com/bayarea/article/S-F-s-scraps-bring-joy-to-area-farmers-3246412.php and http://www.cityofpaloalto.org/civicax/filebank/documents/15113

The analysis only considers the incremental biogas produced from the addition of food waste to the wastewater treatment facility, and excludes any potential biogas production from anaerobic digestion of grass and leaves. While capital costs include upgrades to the entire wastewater treatment facility, the analysis assumes that any biogas produced by the facilities prior to the addition of food waste continues to be used in the same capacity to satisfy existing contractual obligations. However, it is possible that some or all facilities would inject all biogas into the pipeline, resulting in additional revenue.

The costs associated with processing food waste at wastewater treatment facilities can vary greatly by facility and are subject to a great degree of technological and regulatory uncertainty. While costs and potential revenue will vary by facility, Table 32 represents an illustrative facility that processes 45,000 tons of food waste[70] and produces approximately 175 million standard cubic feet (scf) of biomethane each year for injection into the natural gas pipeline.[71] This generates revenues streams from sale of CNG fuel, LCFS credits, and RINs as outlined in Table 32.

[70] This limit is subject to permitting but is within the range of East Bay MUD's limit of 250 tons of food waste per day (91,250 tons per year) and Central Marin Sanitation Agency's limit of 5,474 tons per year. http://nepis.epa.gov/Adobe/PDF/P100LDEL.pdf.

[71] Biomethane calculation assumes 45,000 tons per year of food waste or 291,655,440 ft^3 of biogas per facility per year, converted to biomethane assuming the conversions outlined in Table 33. The calculation is based on EPA's CoEAT tool available at: https://archive.epa.gov/region9/organics/web/html/index-2.html.

Table 32: Estimated Cost and Revenue per Existing Wastewater Treatment Facility[72]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Organic Processing Facility and Facility Upgrades[73]	$12,000,000	$1,200,000	
CNG Vehicles (2)	$500,000	$50,000	
Organic Waste Transportation		$450,000	
Biosolid Processing		$975,000	
Biosolid Transportation		$425,000	
Pipeline	$3,000,000	$150,000	
Pipeline Interconnection	$3,000,000	$150,000	
Biogas Upgrading		$1,400,000	
Tipping Fee			$3,300,000
Fuel Sales			$600,000
LCFS Credits (CNG020)			$1,300,000
RINs			$4,300,000
Total	**$18,500,000**	**$4,800,000**	**$9,500,000**
10-Year Net Present Value	**$17,000,000**		

The calculations outlined in Table 32 are highly sensitive to assumptions regarding the price of LCFS credits and RINs. It is assumed that wastewater treatment facilities generate LCFS credits through the CNG020 pathway with a proposed biomethane carbon intensity of 7.75,[74] assuming a LCFS credit price of $100 and a total RIN value of $1.85.[75] To further explore sensitivity to LCFS credit and RIN pricing, Table 33 presents the 10-year net present value of diverting organic waste to wastewater treatment facilities under a range of LCFS credit and RIN prices.

[72] Capital costs are amortized over 10 years with 7% interest. The discount rate is 5% and all values are rounded. Cost references are presented in Table 37.

[73] Food waste pre-processing to remove contamination can be a significant barrier and could significantly increase the cost of projects depending on the source and quality of the feedstock.

[74] This analysis assumes wastewater treatment facilities are medium to large as outlined in Alternative Case 2 in under the CNG020 pathway as outlined in Table 6 of the LCFS Regulation available at: www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.

[75] The assumed cellulosic RIN credit value of $1.85 for biomethane includes a D5 RIN ($0.85), cellulosic waiver credit ($0.90) and value from the Blenders Tax Credit ($0.10 per D5 RIN). These assumptions for RIN credit prices are somewhat lower than current credit prices. The latest available information at the time of this writing (November 20, 2016), suggests that cellulosic RINs could be worth about $2.10.

Table 33: Net Present Value of Wastewater Treatment Facility Under Varying LCFS Credit and RIN Credit Prices (Million Dollars)

		Wastewater Treatment Facility				
		LCFS credit price				
		$0	$50	$100	$150	$200
Cellulosic RIN credit prices	$0.00	-$26.3	-$21.3	-$16.3	-$11.4	-$6.4
	$0.50	-$17.2	-$12.3	-$7.3	-$2.3	$2.6
	$1.00	-$8.2	-$3.2	$1.7	$6.7	$11.6
	$1.85	$7.1	$12.1	$17.1	$22.0	$27.0
	$2.50	$18.9	$23.8	$28.8	$33.7	$28.7
	$3.00	$27.9	$32.8	$37.8	$42.8	$47.7
	$3.50	$36.9	$41.9	$46.8	$51.8	$56.7
	$4.00	$45.9	$50.9	$55.8	$60.8	$65.8

For the facility outlined in Table 32, the 10-year net present value is positive across a wide combination of RIN and LCFS credit prices. However, in the absence of revenue generated from LCFS credits or RINs, the 10-year net present value is negative. If LCFS and RIN credit revenues do not materialize, State resources could be deployed to shore up financing of biomethane projects through mechanisms such as upfront grants, loan assistance programs, and tax incentives. For example, the illustrative facility in Table 32 would break even over a 10-year financing period with an upfront grant of $24 million. State agencies are collaborating to find solutions to the economic challenges associated with upfront capital costs and financing for wastewater treatment projects.

Wastewater treatment facilities are not limited to generating transportation fuels from diverted organic material. In 2013, 85 percent of wastewater treatment facilities with anaerobic digesters used biogas on site and 22 percent generated electricity.[76] Generating electricity for on-site use and selling excess electricity to the grid is an option for many facilities and can provide stable yet less lucrative potential revenue streams. However, these options generally emit criteria pollutants, including NOx, which might make operations unviable, especially in nonattainment areas. Additional revenue potential can be realized through the development of sustainable markets for residual products including heat dried residual pellets, fertilizer, mulch, and soil amendments. While concerns related to the transportation and application of residual and related products have limited their use, creating markets for these products could result in additional revenue streams for compost, wastewater treatment, and new AD facilities and should be considered a priority for State and local incentives related to market research and incentives. The size of the additional revenue stream depends on the specific products and market development, but could be on par with revenues generated from LCFS credits.

[76] http://nepis.epa.gov/Adobe/PDF/P100LDEL.pdf.

g. New Anaerobic Digesters

Table 34 outlines the estimated costs and revenue potential for an illustrative new anaerobic digester that has a throughput capacity of 100,000 tons per year and produces approximately 385 million scf of biomethane per year.[77] In this scenario, the biomethane is injected into the natural gas pipeline for use as transportation fuel and receives RINs and LCFS credits for the CNG005 pathway with a carbon intensity of -22.93.[78] For this illustrative scenario it is assumed that 50 percent of AD digestate is utilized at no cost and 50 percent is processed and shipped to compost facilities. While concerns related to the transportation and application of residual and related products have limited their use, creating markets for digestate could result in large additional revenue streams for new AD facilities and should be considered a priority for State and local incentives related to market research and incentives.

The realized costs of an anaerobic digester may vary greatly based on geographic location and concerns related to odor, permitting difficulty, and existing infrastructure. This illustrative facility outlines the revenue potential as well as the significant capital costs that are required to construct a new anaerobic digester.

[77] Biomethane calculation assumes 100,000 tons per year of food waste or 644,464,440 ft^3 of biogas per facility per year, converted to biomethane assuming the conversions outline in Table 37. The calculation is based on EPA's CoEAT tool available at: https://archive.epa.gov/region9/organics/web/html/index-2.html.

[78] The CI for CNG005 is outlined in Table 6 of the LCFS Regulation available at: www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.

Table 34: Estimated Cost and Revenue per New Anaerobic Digester[79]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Anaerobic Digester	$35,000,000	$3,500,000	
Organic Processing Facility[80]	$12,000,000	$1,200,000	
CNG Vehicles (2)	$500,000	$50,000	
Organic Waste Transportation		$900,000	
Digestate Processing		$975,000	
Digestate Transportation		$425,000	
Pipeline	$3,000,000	$150,000	
Pipeline Interconnection	$3,000,000	$150,000	
Biogas Upgrading		$2,500,000	
Tipping Fee			$6,500,000
Fuel Sales			$1,300,000
LCFS Credits (CNG005)			$4,500,000
RINs			$9,500,000
Total	**$53,500,000**	**$9,850,000**	**$21,00,000**
10-Year Net Present Value	**$35,000,000**		

The calculations outlined in Table 34 are highly sensitive to assumptions regarding the price of LCFS credits and RINs. To further explore sensitivity to LCFS credit and RIN pricing, Table 35 presents the 10-year net present value of diverting food waste to new AD facilities under a range of LCFS credit and RIN prices.

[79] Capital costs are amortized over 10 years with 7% interest. The discount rate is 5% and all values are rounded. Cost references are presented in Table 37.

[80] Food waste pre-processing to remove contamination can be a significant barrier and could significantly increase the cost of projects depending on the source and quality of the feedstock.

Table 35: Net Present Value of Anaerobic Digester Facility Organic Diversion under Varying LCFS Credit Prices and RIN Credit Prices (Million Dollars)

		New AD Facility				
		LCFS credit price				
		$0	$50	$100	$150	$200
Cellulosic RIN credit prices	$0.00	-$72.9	-$55.7	-$38.6	-$30.0	-$4.2
	$0.50	-$53.0	-$35.8	-$18.7	-$10.0	$15.7
	$1.00	-$33.1	-$15.9	$1.3	$9.9	$35.6
	$1.85	$0.8	$18.0	$35.2	$43.8	$69.5
	$2.50	$26.7	$43.9	$61.1	$69.7	$95.4
	$3.00	$46.7	$63.8	$81.0	$89.6	$115.3
	$3.50	$66.6	$83.8	$100.9	$109.5	$135.3
	$4.00	$86.5	$103.7	$120.9	$129.5	$155.2

As outlined in Table 35, there is the potential for very large revenue streams from the sale of LCFS credits and RINs. However, these revenue streams are necessary to make the illustrative facility in Table 31 viable. Without revenue from RINs or LCFS credits, an upfront grant of $67 million would be required in order for this illustrative facility to breakeven over a 10-year financing period. While the revenue potential from RINs and LCFS credits is high, it is also uncertain which may present difficulty in obtaining financing. Alternatively, facilities can generate electricity for use on-site as well as sale to the grid, which has lower, but potentially more stable, potential revenue. On-site transportation fuel use is another feasible revenue option for facilities located large distances from the pipeline. On site criteria co-pollutant emissions are generally higher for electricity generation then for pipeline injection.

4. Estimated Cost and Revenue by Scenario

There are many potential ways to divert and utilize organic waste in California, and high uncertainty surrounding future compliance responses, costs, and markets. This analysis outlines three scenarios that achieve the organic diversion target by focusing on one type of facility for the handling of food waste and some grasses and leaves. While the pathway to compliance is unknown, the scenarios outline the potential range of capital costs, potential revenue, and uncertainty that exists in the treatment and diversion of organic waste. Regulatory, technological, political, financial, and market uncertainty must be considered in additional to the direct costs and potential revenue outlined in this analysis.

The three scenarios in this analysis indicate that achieving the organic diversion target could require an estimated capital investment of $900 million to $2.8 billion dollars and with potential cumulative revenue ranging from $1.7 to $7.1 billion over a 10-year period. The wide range in revenues highlight the value in existing, yet uncertain, revenue streams when biomethane is used for transportation fuel. High capital costs, as well as significant O&M also may discourage investment in facilities that could result in positive economic gains and highlights the need for State incentives, funding, and regulations to achieve the organic waste diversion targets.

Table 36 presents the state wide cumulative capital costs, O&M costs, and revenue for each scenario, across all facilities needed to achieve the 2020 and 2025 organic diversion target. In this analysis, the organic diversion and food recovery targets are met linearly over time, with new facilities coming on-line as additional capacity is needed. Projects are financed over 10 years assuming a 7 percent cost of capital and a 5 percent discount rate.

The scenario costs in Table 36 are estimated through 2025. Additional amortized capital payments continue through 2034 (as facilities are phased in over time) and annual O&M costs and revenues continue beyond 2025 for all three scenarios. O&M costs and revenues remain constant through 2025 this analysis. Scenario 1 and 2 show positive returns through 2025 due to biomethane generation, LCFS credit, and RIN credit generation. Despite the potential value of organic waste diversion, there are significant upfront capital costs that may prevent long-term revenue streams.

Variable revenue streams, such as RIN and LCFS credits, while lucrative, do not facilitate easy access to capital. The State must work with both public and private lenders to eliminate barriers to obtain capital for these projects through grants, reducing lender risk and lowering interest rates, or making regulatory changes.

Table 36: Cumulative Estimated Costs and Revenues by Scenario Over 10-Year Accounting Period (Million Dollars)[81]

Scenario 1: New AD	Component	Capital Cost	O&M	Revenue
New AD New Compost	47 Facilities 36 Facilities	$2,400 $400	$3,100 $400	$7,000 $700
Total		**$2,800**	**$3,500**	**$7,700**
10-Year Net Present Value		**$1,400**		
Scenario 2: WWTP	**Component**	**Capital Cost**	**O&M**	**Revenue**
New Compost	44 Facilities	$500	$500	$900
Existing Wastewater Treatment	104 Facilities	$1,600	$2,800	$5,700
Total		**$2,100**	**$3,300**	**$6,600**
10-Year Net Present Value		**$1,300**		
Scenario 3: Compost	**Component**	**Capital Cost**	**O&M**	**Revenue**
New Compost	74 Facilities	$900	$900	$1,700
Total		**$900**	**$900**	**$1,700**
10-Year Net Present Value		**-$110**		

Despite the uncertainty, existing facilities are able to obtain financing to handle diverted organic materials through public and private partnerships with encouraging results. US EPA analyzed six wastewater treatment facilities, two located in California that upgraded to accept food waste and had estimated pay back periods ranging from zero to 12 years.[82] These facilities received funding assistance from $250,000 to $35 million and produce energy and fuel for revenue.

Altogether, this analysis suggests that the diversion of organic waste can result in environmental and economic value to California. There are important uncertainties associated with facility costs and potential revenues, however, which may limit project development without additional support. In the absence of revenue from LCFS credits and RINs, significant financial support may be required to achieve the targets identified in this SLCP Strategy and deliver other environmental benefits.

5. Cost Assumptions Used for All Scenarios

Table 37 contains the assumptions used in each scenario, along with references.

[81] All values are rounded.
[82] http://nepis.epa.gov/Adobe/PDF/P100LDEL.pdf

Table 37: Organic Diversion Scenario Assumptions

Organic Diversion Scenario Assumptions			
Costs	**Capital**	**O&M**	**References**
Natural gas transmission pipeline or urban low pressure pipeline ($/mile)	$1,000,000	5%	http://www.suscon.org/news/pdfs/GHG_Mitigation_for_Dairies_Final_July2015.pdf
On-site biogas upgrading system ($/1000 scf)		$7	Upper bound of range provided by CASA in public comment
Centralized biogas upgrading system ($/1000 scf)		$6	http://www.suscon.org/news/pdfs/GHG_Mitigation_for_Dairies_Final_July2015.pdf
On-site utility natural gas pipeline interconnection ($)	$3,000,000	5%	
Cost per acre of California farm land for compost facility ($/acre)	$7,700		http://www.usda.gov/nass/PUBS/TODAYRPT/land0815.pdf
Gore Positive Aerated Static Pile (ASP) compost facility	$16,500,000	10%	Cost estimates from CalRecycle assumes 25 acre facility processing 100,000 tpy
Organic processing station including pre-processing and facility upgrades	$12,000,000	10%	Mid-range of estimated costs based on information from East Bay MUD, CMSA, and LACSD. Information provided by CASA in public comment. References available at: http://nepis.epa.gov/Adobe/PDF/P100LDEL.pdf.
Anaerobic digester	$35,000,000	10%	Estimated capital investment for the East Bay MUD digester (22 million gallon per day capacity) https://nepis.epa.gov/Adobe/PDF/P100LDEL.pdf
Low NOx CNG truck	$250,000	10%	Estimate from ARB Staff, Vision 2.0 assumes CNG heavy duty vehicle costs $250k in 2016 and costs reduce to $144 by 2030
Waste transport ($/ton-mile)		$0.18	https://archive.epa.gov/region9/organics/web/html/index-2.html
Average mileage for transportation of organics to WWTF (miles)		50	Assumption informed by geo-spatial analysis
Average mileage for transportation of organics to AD (miles)		50	Assumption informed by geo-spatial analysis of waste location
Average mileage for transportation of biosolids (miles)		130	http://scap1.org/Biosolids%20Reference%20Library/2014%20SCAP%20Biosolids%20Trends%20Update.pdf

Cost of biosolid disposal ($/ton)		54	http://scap1.org/Biosolids%20Reference%20Library/2014%20SCAP%20Biosolids%20Trends%20Update.pdf
Average mileage for transportation of organics to compost (miles)		40	Assumption informed by geo-spatial analysis of waste location
Revenues			
Biogas price ($/ 1000 cubic feet)		$3.46	
Tipping fee at compost facilities ($/ton)		$45	http://www.calrecycle.ca.gov/publications/Documents/1520%5C20151520.pdf.
Tipping fee at AD facilities ($/ton)		$65	-
Tipping fee at wastewater treatment facilities ($/ton)		$65	
Low Carbon Fuel Standard credits ($/ton)		$100	
RINs, $/77,000 BTU		$1.85	Internal ARB calculation based on public RIN values.
Conversion Factors			
Biogas per wet ton food waste	6,444		https://archive.epa.gov/region9/organics/web/html/index-2.html
Biogas to biomethane conversion	0.6		https://archive.epa.gov/region9/organics/web/html/index-2.html
scf to BTU	1,028		http://www.arb.ca.gov/cc/inventory/doc/docs1/1a3b_onroad_fuelcombustion_naturalgas_ch4_2013.htm
Food total solids (fraction)	0.3		https://archive.epa.gov/region9/organics/web/pdf/ebmudfinalreport.pdf
Biosolids from food waste digestion (fraction)	0.36		https://archive.epa.gov/region9/organics/web/pdf/ebmudfinalreport.pdf
Financial parameters			
Interest rate	7%		
Loan period, years	10		-
Discount rate	5%		

C. Hydrofluorocarbon (HFC) Emission Reductions

Note: The following HFC section was written before the global phasedown of HFCs was agreed to on October 15, 2016 (the “Kigali Amendment”). ARB is currently evaluating the Kigali Amendment’s impact upon HFC emissions in California; this section will be further updated to reflect changes in BAU emissions, additional needed reductions, and the cost and benefit of HFC reductions measures.

As described in Section VI, HFCs are the fastest-growing source of GHG emissions globally and in California. California is among the world's leaders in reducing HFC emissions, with existing actions leading to significant reductions in HFC emissions in California through 2030, compared to where they would be otherwise.

The SLCP Strategy describes a set of four potential measures that can reduce HFC emissions by 40 percent in California by 2030. The proposed measures are anticipated to reduce cumulative HFC emissions by 260 $MMTCO_2E$ (20-year global warming potential (GWP)) by 2030 to meet the SLCP emission reduction target. This section estimates the potential costs and savings of the four proposed HFC emission reduction measures which are:

1. Prohibition on New Equipment with High-GWP Refrigerants
2. HFC Supply Phasedown (now covered by the global HFC phasedown)
3. Financial Incentive Program for Low-GWP Refrigeration Early Adoption
4. Sales Ban of Very-High GWP Refrigerants

The potential costs and cost savings of the four proposed HFC emission reduction measures are based on the three main variables: the incremental equipment cost of low-GWP units, gains or losses in energy efficiency and resulting change in energy consumption, and the projected price of HFCs relative to the price of replacement of natural refrigerants and the new generation of synthetic refrigerants, hydrofluoro-olefins (HFOs).

The proposed HFC measures would require new stationary refrigeration and AC equipment to use refrigerants with a lower-GWP than the current high-GWP HFC refrigerants. In many cases, there is an incremental cost to lower-GWP equipment relative to the cost of high-GWP equipment. The higher capital cost is often offset by energy efficiency gains and subsequent decreased energy costs over the equipment lifetime. Although it is anticipated that the incremental cost of low-GWP equipment will decline over time, this learning effect is not accounted for in this analysis with all costs and savings assumed to remain constant through 2030. In all tables, annual and cumulative costs are presented in 2016 dollars.

This analysis assumes that the growth in refrigeration and AC equipment is correlated with projected population growth in California through 2050, projected at 0.746% annually, according to California Department of Finance.[83]

1. Prohibition on New Equipment with High-GWP Refrigerants

This proposed measure prohibits the use of high-GWP refrigerants in new stationary refrigeration and air-conditioning equipment. For the stationary refrigeration sector, refrigerants with a 100-year GWP of 150 or greater would be prohibited for new equipment for non-residential refrigeration, and also for residential refrigerator-freezers. The proposed measure also prohibits refrigerants with a 100-year GWP of 750 or

[83] http://www.dof.ca.gov/research/demographic/projections/

greater for new air-conditioning equipment in the stationary air-conditioning, for both residential and non-residential. (Start dates for measures have not yet been determined, pending the completion of the impact evaluation of the Kigali Amendment.)

a. Initial Added Cost of Low-GWP Refrigeration and AC Equipment

Table 38 shows the incremental cost of low-GWP refrigeration and air-conditioning equipment. Due to the lack of low-GWP equipment currently in operation, cost estimates were obtained through a survey of industry stakeholders for the average cost of baseline business-as-usual equipment using high-GWP HFCs, and new low-GWP equipment using natural refrigerants or new low-GWP (synthetic refrigerants HFOs). The incremental capital cost of low-GWP equipment varied greatly across respondents, ranging from slightly less to more than double the cost of high-GWP equipment. For air-conditioning, less data is available relative to refrigeration as low-GWP air-conditioning is still in development and is not widely used. In this analysis, it is assumed that the incremental cost of lower-GWP air-conditioning ranges from 5 to 15 percent higher than the business-as-usual, or BAU, high-GWP refrigerant equipment.

Table 38: Estimated Initial Added Cost of Low-GWP Refrigeration and Air-Conditioning Equipment

Equipment Sector	General Description of Sector	Average Equipment Cost per Unit[84]	Incremental Cost of Low-GWP Unit
Stationary Refrigeration Sectors			
Large Commercial Large Centralized System (2,000+ lbs)	Centralized system with 2000 or more lbs of refrigerant charge (average charge 2,485 lbs). Generally, one system can be used per large retail facility such as a supermarket.	$1,000,000	$200,000
Medium Commercial Medium Centralized System (200 – 2,000 lbs)	Distributed type equipment with more than one unit. Average charge size 700 lbs, three or four units may be used in a supermarket.	$250,000	$50,000
Large Cold Storage	Charge size is 2000 lbs or more per facility.	$3,500,000	$500,000
Medium Cold Storage	Average charge size of 565 lbs per facility	$1,750,000	$250,000
Industrial Process Cooling	Average charge size of 4,440 lbs per facility for Industrial processing such as manufacturing or food processing.	$2,500,000	$250,000
Refrigerated Condensing Units (50-200 lbs)	Used in retail food and other cooling, average charge 122 lbs per system.	$75,000	$15,000

[84] Assumes the BAU baseline is high-GWP.

Equipment Sector	General Description of Sector	Average Equipment Cost per Unit[84]	Incremental Cost of Low-GWP Unit
Refrigerated Condensing Units (Under 50 lbs)	Used in convenience stores, other smaller refrigeration needs. Average charge 31 lbs per system.	$37,500	$7,500
Standalone (Self-Contained) Refrigeration Units	Smaller self-contained equipment average charge 7 lbs or less. Does not include refrigerated vending machines already covered by U.S. EPA requirements.	$5,000	$1,000
Residential-Type Refrigerator Freezer	Average charge of 0.34 lbs per normal domestic appliance.	$1,165	$150
Stationary Air-Conditioning Sectors			
Centrifugal Large Chiller (2000+ lbs)	Chiller with 2000 lbs refrigerant or more. Typically used for large building AC. Average charge size of 3,978 lbs	$300,000	$30,000
Medium Centrifugal Chiller (200-2000 lbs)	Chiller containing 200 to 2000 lbs refrigerant. Average charge of 1,007 lbs	$200,000	$20,000
Medium Packaged Chiller (200-2000 lbs)	Chiller containing 200 to 2000 lbs refrigerant, generally smaller than centrifugal type. Average charge size of 526 lbs	$200,000	$20,000
Commercial Unitary AC (50-200 lbs)	AC system contains on average 100 lbs of refrigerant.	$13,000	$1,300
Commercial Unitary AC (Less Than 50 lbs Charge)	Smaller AC systems contain on average 15 lbs of refrigerant.	$4,000	$400
Commercial Window AC Units	Window units contain an average of 1.5 lbs refrigerant.	$900	$90
Residential Unitary AC	Residential AC systems contain on average 7.5 lbs refrigerant.	$4,000	$400
Residential Window AC Units	Window units contain an average of 1.5 lbs refrigerant.	$800	$80

b. Savings from Energy Efficiency

The added cost of low-GWP equipment is generally offset by reduced energy usage from using low-GWP refrigerants. Table 39 shows the energy efficiency savings used in this cost analysis. The change in energy efficiency is relative to HFC equipment currently being manufactured. In this analysis, the ozone-depleting substance (ODS) refrigerant HCFC-22 has the same or better energy efficiency relative to most low-GWP refrigerants. However, new HCFC-22 equipment has been prohibited since January 1, 2010, and therefore cannot be considered as baseline for new equipment.

Refrigerant systems using only CO_2 as the refrigerant are known as transcritical CO_2 systems. Compared to baseline HFC refrigeration, transcritical CO_2 systems have shown energy efficiency gains of 10 to 18 percent in climates where the ambient temperature is less than 87 °F. In higher ambient temperatures, energy penalties can be incurred compared to baseline refrigerant systems, although significant research and development is occurring to manufacture transcritical systems that work efficiently in higher ambient temperatures.[85, 86] For example, transcritical CO2 systems have been installed in warm weather climates in Louisiana, Alabama, Georgia, and Florida; and also in Brazil; Indonesia, Australia, and Spain, showing energy efficiencies equivalent or better than HFC refrigeration systems. In California, more than 20 transcritical systems have been installed, several of them in high-temperature ambient climates.[87]   Cooling a CO_2 secondary cooling loop or cascade system with an HFC refrigerant or ammonia as the primary refrigerant appear to operate at the same energy efficiency or better than all-HFC systems, including in very hot ambient temperatures.[88]

Ammonia refrigeration has long-established energy efficiency benefits compared to fluorinated refrigerants including HFCs. Typical energy efficiency gains of using ammonia refrigerant range from 3 to 10 percent or greater, depending upon the specific type of equipment.[89, 90, 91]

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[85] ASHRAE, 2015. "System Efficiency for Natural Refrigerants" Anatolii Mikhailov and Hans Ole Matthiesen, Technical Feature in ASHRAE Journal, August 2015. Available at: https://www.ashrae.org/File%20Library/docLib/eNewsletters/Mikhailov-082013--05142015feature.pdf (accessed 9 April 2016).

[86] UNEP, 20115. "Montreal Protocol on Substances that Deplete the Ozone Layer UNEP 2014 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee 2014 Assessment". February 2015. United Nations Environment Programme (UNEP). Available at: http://ozone.unep.org/en/assessment-panels/technology-and-economic-assessment-panel (accessed 11 July 2016).

[87] Shecco, 2015. Guide to Natural Refrigerants in North America - State of the Industry 2015. Shecco publications, 17 September 2015. Available at: http://publication.shecco.com/publications/lists (accessed 6 July 2016).

[88] Mycom-Mayekawa, 2015. "Low Refrigerant Charge Ammonia/CO_2 Chiller in a Supermarket Application" case study. Available at: http://www.ammonia21.com/web/assets/link/4091_GUIDE_NA_Case%20Study_MYCOM_1.pdf (accessed 11 July 2016).

[89] ASHRAE, 2010. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). ASHRAE Position Document on Ammonia as a Refrigerant. June 30, 2010. Available at: https://www.ashrae.org/File%20Library/docLib/About%20Us/PositionDocuments/Ammonia-as-a-Refrigerant-PD-2014.pdf (accessed 16 June 2016).

[90] AMIC, 2014. Australian Meat Industry Council (AMIC) Fact Sheet 3 "Out with the Old & In with the New: Freon vs. Ammonia & Glycol Refrigeration Systems". Available at: http://www.amic.org.au/SiteMedia/W3SVC116/Uploads/Documents/Freon%20vs%20Ammonia%20&%20Glycol%20Refrigeration.docx (accessed 13 July 2016).

[91] Industrial Refrigeration Handbook, Wilbert F. Stoecker. McGraw-Hill, 1998. ISBN 0-07-061623-X

Hydrocarbon refrigerants are more energy efficient than HFC refrigerants in all end-use sectors for which they have been approved for use by the U.S. EPA. Energy efficiency gains of more than 30 percent have been shown for some smaller refrigeration equipment, with efficiency gains of 2 to 5 percent for residential refrigerator-freezers, and 5 to 10 percent for air-conditioning.[92, 93, 94, 95, 96]

Hydrofluoro-olefin (HFO) refrigerant blends are new and energy efficiency data is limited, although several studies indicate that they are equivalent to slightly more energy-efficient than HFCs used in refrigeration and air-conditioning, ranging from the same efficiency as HFC-134a or R-410A (an HFC blend), to nine percent greater energy efficiency than R-404A, a relatively energy-inefficient HFC blend used widely in retail food.[97, 98, 99, 100]

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[92] EIA, 2014. "Putting the Freeze on HFCs: A Global Digest of Available Climate-Friendly Refrigeration and Air-Conditioning Technologies", May 2014. Environmental Investigation Agency (2014). Available at: http://eia-global.org/images/uploads/Putting_the_Freeze_on_HFCs_Final.pdf. (Accessed 17 March 2016).

[93] DOE, 2011. Department of Energy, Technical Support Document of Final Rule for Residential Refrigeration Products, September 3, 2011. Available at: https://www1.eere.energy.gov *(accessed 12 February 2016).*

[94] "Comparative Performance of Hydrocarbon Refrigerants", I.L Maclaine-cross and E.Leonardi, School of Mechanical and Manufacturing Engineering, The University of New South Wales. Available at: http://www.academia.edu/9496884/Comparative_Performance_of_Hydrocarbon_Refrigerants (accessed 28 January, 2016).

[95] Sattar, et. al, 2007. "Performance Investigation of Domestic Refrigerator Using Pure Hydrocarbons and Blends of Hydrocarbons as Refrigerants", M. A. Sattar, R. Saidur, and H. H. Masjuki. World Academy of Science, Engineering and Technology, Number 29, 2007. Available at: http://citeseerx.ist.psu.edu (accessed 12 February 2016).

[96] DOE, 2015. "Alternative Refrigerant Evaluation for High-Ambient-Temperature Environments: R-22 and R-410A Alternatives for Mini-Split Air Conditioners", Report ORNL/TM-2015/536, October 2015. Oak Ridge National Laboratory managed by UT-Batelle for Department of Energy. Available at: http://energy.gov/sites/prod/files/2015/10/f27/bto_pub59157_101515.pdf (accessed 11 January 2016).

[97] Ibid.

[98] Dupont (Chemours), 2015. "Opteon Product Information Bulletin Low GWP Replacement for R-134a", and "Opteon Product Information Bulletin for Stationary Refrigeration", technical data literature available at: https://www.chemours.com/businesses-and-products/fluoroproducts/opteon-refrigerant/ (accessed 13 July 2016).

[99] Honeywell, 2015. "R410A and R22 low GWP alternatives for A/C - Focus on high ambient performances" by Dr. Jean de Bernardi and Dr. Abdenacer Achaichia; and Solstice refrigerants technical data literature. Available at: http://www.honeywell-refrigerants.com/ (accessed 13 July 2016).

[100] UNEP 2016. "Promoting Low-GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries (PRAHA)", United Nations Environment Program (UNEP), document number UNEP/OzL.Pro/ExCom/76/10 April 16, 2016. Available at: http://www.multilateralfund.org/76/pages/English.aspx (accessed 12 March 2016).

Table 39: Estimated Added Energy Efficiency of Low-GWP Refrigerants

Equipment Sector	Added Energy Efficiency of Low-GWP Refrigerants	Mix of Low-GWP Refrigerants Used in Analysis[101]
Centralized System Large (2,000+ lbs)	7.5%	50% carbon dioxide (CO_2), 45% HFO blends, 5% ammonia (NH_3)
Centralized System Medium (200-2,000 lbs)	7.5%	
Cold Storage Large (2,000+ lbs)	8.0%	80% NH_3, 20% CO_2
Cold Storage Medium (200-2,000 lbs)	8.0%	
Process Cooling Large (2,000+ lbs)	7.5%	50% CO_2, 50% NH_3
Refrigerated Condensing Units Small (50-200 lbs)	7.5%	33% CO_2, 33% NH_3, 33% HFOs[102] or HFO blends
Refrigerated Condensing Units (less than 50 lbs)	7.5%	
Stand-Alone Refrigerator Display Cases	6.1%	50% CO_2, 50% hydrocarbons
Residential Refrigerator-Freezer	3.0%	100% hydrocarbons
Centrifugal Chiller Large (2,000+ lbs)	1.0%	50% HFC-32[103], 50% HFOs
Centrifugal Chiller Medium (200-2,000 lbs)	1.0%	
Chiller - Packaged Medium (200-2,000 lbs)	1.0%	
Unitary A/C Small (50-200 lbs)	2.0%	HFC-32
Unitary A/C Central (less than 50 lbs)	2.0%	
Window AC units commercial	2.0%	
Residential AC Central	2.0%	
Window AC Units Residential	2.0%	

101 Improved energy efficiency of CO_2 refrigeration systems is dependent upon the ambient air temperature, with energy efficiency decreasing as the temperature increases. Below the critical temperature of CO_2 at 87 °F, energy efficiency of 2-6 percent has been measured (ASHRAE, 2009 www.ashrae.org), (Australian GCC, 2008) http://www.r744.com/files/news/green-cooling-council_montreal_apr08.pdf., and (Emerson, 2015) http://www.emersonclimate.com/en-us/Market_Solutions/By_Solutions/CO2_solutions/Documents/Commercial-CO2-Refrigeration-Systems-Guide-to-Subcritical-and-Transcritical-CO2-Applications.pdf.

102 Energy efficiency of HFOs is generally the same as the HFC refrigerants they replace, although manufacturers have tested HFO equipment and concluded that it is three percent more energy efficient than HFC equipment (Danfoss, 2014) available at: http://turbocor.danfoss.com. Hydrocarbons, with GWPs less than 20 have demonstrated energy efficiency in refrigeration and AC equipment, with average efficiency improvements between 6 and 15 percent compared to HFCs (A.D. Little, 2001) Energy Consumption Characteristics of Commercial Building HVAC Systems. Volume I: Chillers, Refrigerant Compressors, and Heating Systems Prepared by Detlef Westphalen and Scott Koszalinski of Arthur D. Little, Inc. for Office of Building Equipment, Office of Building Technology State and Community Programs, U.S. Department of Energy. April 2001., (Wang, et al., 2009) https://www.energystar.gov/ia/partners/manuf_res/downloads/Appliance_and_Recycling_Quick_Start_Guide.pdf.

103 HFC-32 has a 100-year GWP of 675, and a 20-year GWP of 2330 and would be used instead of the standard HFC refrigerant R-410A. DOE research indicates that HFC-32 is 2 percent to 13 percent more energy efficient than baseline R-410A in AC equipment (DOE, 2015) http://www.osti.gov/scitech/.

In this analysis, an ARB uses an electricity cost of 14 cents per kWh for commercial customers, and a cost of 17 cents per kWh for residential customers, based on recent California electricity prices posted by the Energy Information Administration (EIA, 2016).[104] The analysis assumes no relative increase or decrease in future electricity prices.

c. Savings or Added Cost from low and lower-GWP Refrigerants

High-GWP HFC refrigerants cost more per pound than the low-GWP refrigerants CO_2 and ammonia, but less per pound than hydrocarbon refrigerants and the new HFO refrigerants. The costs used in this analysis are based on a survey of average refrigerant prices and are as follows:

- HFCs (average of the six most commonly used HFCs): $6.90/lb.
- CO_2: $2.00/lb.
- Ammonia: $3.00/lb.
- Hydrocarbons: $9.00/lb.
- HFOs and HFO blends: $15.00/lb.

Due to the non-patented status of the natural refrigerants CO_2, ammonia, and hydrocarbons, it is assumed that their prices remain constant through 2030. HFOs are currently made in small quantities, and prices could be reduced in the future as HFO production increases. However, as some HFOs may be more cost-intensive to manufacture than HFCs, it is assumed that the cost will remain constant through 2030. This analysis assumes that the cost of high-GWP HFC refrigerants will double by 2030 due to an HFC phasedown or other regulatory pressures that will decrease the supply of high-GWP HFCs. The doubling of high-GWP HFC costs by 2030 is conservative, as previous phasedowns of ozone-depleting refrigerants have resulting in a five to six-fold increase in prices. The cost of lower-GWP HFCs such as HFC-32 is expected to remain constant, as they are not affected by HFC phasedowns. Table 40 shows the projected savings resulting from the use of low-GWP equipment

[104] EIA, 2016. U.S. Energy Information Administration. Electric Power Monthly, Table 5.6.A. “Average Price of Electricity to Ultimate Customers by End-Use Sector”. By State, January 2015 and January 2016. Cents per Kilowatthour. https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a.

Table 40: Estimated Low-GWP Equipment Savings[105]

Sector	Low-GWP Added Energy Efficiency	Annual Electricity Savings	Annual Refrigerant (lbs)	Annual Refrigerant Savings[106]	Annual Total Savings
Centralized System Large (2,000+ lbs)	7.5%	$ 12,000	600	$ 3,000	$ 15,000
Centralized System Medium (200-2,000 lbs)	7.5%	$ 3,000	200	$ 1,000	$ 4,000
Cold Storage Large (2,000+ lbs)	8.0%	$ 15,0000	1,200	$ 10,000	$ 25,000
Cold Storage Medium (200-2,000 lbs)	8.0%	$ 8,000	150	$ 1,000	$ 9,000
Process Cooling Large (2,000+ lbs)	7.5%	$ 11,000	350	$ 3,000	$ 13,665
Refrigerated Condensing Small (50-200 lbs)	7.5%	$ 1,000	25	$ 100	$ 1,000
Refrigerated Condensing Units (Less than 50 lbs)	7.5%	$ 500	5	$ 25	$ 500
Stand-Alone Refrigerated Display Cases	6.1%	$ 50	0.5	$ 2	$ 50
Centrifugal Chiller Large (2,000+ lbs)	1.0%	$ 500	150	($ 250)	$ 200
Centrifugal Chiller Medium (200-2,000 lbs)	1.0%	$ 532	24	($ 45)	$ 487
Chiller Packaged Medium (200-2,000 lbs)	1.0%	$ 319	42	($ 77)	$ 242
Unitary A/C Small (50-200 lbs)	2.0%	$ 174	13	$ 0	$ 174
Unitary A/C Central (Less than 50 lbs)	2.0%	$ 27	2	$ 0	$ 27

[105] Numbers may not add due to rounding.
[106] Refrigerant cost increases for chillers used in air-conditioning, therefore, savings are shown as negative.

Sector	Low-GWP Added Energy Efficiency	Annual Electricity Savings	Annual Refrigerant (lbs)	Annual Refrigerant Savings[106]	Annual Total Savings
Window AC Units Commercial	2.0%	$ 1	0.2	$ 0	$ 1
Residential AC Central	2.0%	$ 6	1.2	$ 0	$ 6
Window AC Units Residential	2.0%	$ 2	0.2	$ 0	$ 2
Residential Refrig Freezer	3.0%	$ 3	0.02	$ 0.05	$ 3

d. Added Cost and Savings: Net Cost of Low-GWP Equipment

Table 41 presents the added cost and savings are added together to show a net cost per year of equipment life. We then multiply the net cost per year of equipment life by the total number of new equipment each year, to show a theoretical annual cost if all new equipment is manufactured as low-GWP to meet the high-GWP refrigerant prohibitions.

Table 41: Estimated Net Cost of Low-GWP Equipment, Prohibition Measure[107]

Sector	Average Lifetime (yr)	Added Equipment Cost ($/yr)[108]	Annual Cost (Savings) ($/unit)	Estimated Units Replaced per Year[109]	Estimated Annual Net Cost (Savings)[110]
Centralized System Large (2,000+ lbs)	15	$13,000	$15,000	50	($114,000)
Centralized System Medium (200-2,000 lbs)	15	$3,000	$4,000	1,600	($549,000)
Cold Storage Large (2,000+ lbs)	20	$25,000	$25,000	10	($2,000)
Cold Storage Medium (200-2,000 lbs)	20	$12,500	$9,000	20	$81,000

[107] Numbers may not add due to rounding.
[108] The added equipment cost per year is calculated by taking the total added initial cost of the equipment, and dividing by the average years of equipment lifetime. The annual savings has been calculated by determining all annual savings and dividing by the average years of equipment cost. All costs and savings are shown in today's dollars; no discounted cost has been used.
[109] The estimated number of new units is derived from research and analysis conducted for the ARB Refrigerant Management Program regulation, equipment data registered through the Refrigerant Management Program data, and additional analysis used in the ARB Greenhouse Gas Emissions Inventory as developed by Gallagher, et al. 2014.
[110] Net Cost or savings is equal to the cost per unit multiplied by the number of units produced, by model year or cohort.

Sector	Average Lifetime (yr)	Added Equipment Cost ($/yr)[108]	Annual Cost (Savings) ($/unit)	Estimated Units Replaced per Year[109]	Estimated Annual Net Cost (Savings)[110]
Process Cooling Large (2,000+ lbs)	20	$12,500	$14,000	5	($6,000)
Refrigerated Condensing Units Small (50-200 lbs)	15	$1,000	$1,000	4,000	$78,000
Refrigerated Condensing Units (Less than 50 lbs)	20	$400	$500	15,700	($2,200,000)
Stand-Alone Refrigerant Display Cases	20	$50	$50	34,000	$618,000
Centrifugal Chiller Large (2,000+ lbs)	20	$1,500	$800	300	$176,000
Centrifugal Chiller Medium (200-2,000 lbs)	20	$1,000	$500	100	$42,000
Chiller – Packaged Medium (200-2,000 lbs)	20	$1,000	$200	500	$387,000
Unitary A/C Small (50-200 lbs)	15	$100	$200	5,000	($426,000)
Unitary A/C Central (Less than 50 lbs)	15	$50	$50	169,000	$0
Window AC Units Commercial	12	$10	$0	54,000	$325,000
Residential AC Central	15	$50	$10	482,000	$10,123,000
Window AC Units Residential	12	$10	$5	310,000	$1,552,000
Residential Refrigerator Freezer	15	$10	$5	1,266,000	$10,125,000
Total Annual Cost of Equipment Model Year[111]					**$20,225,000**

[111] The annual cost would be applied for each year of the model year or cohort's lifetime. Table 41 shows the cost if the prohibition were the only proposed HFC measure implemented. The cumulative costs of the four proposed HFC measures are shown in Table 48 of the Appendix.

Due to the very high number of new residential appliances per year, and their net added cost, residential AC and refrigerator-freezers account for virtually all of the added net cost of low-GWP equipment. The current best estimate for added cost per unit ($400 for central AC, and $150 for refrigerator-freezers) may decrease in the future as production of lower-GWP equipment increases and economies of scale are realized. The added cost of low-GWP residential refrigerator-freezers could also be reduced due to a March 29, 2016 Federal proposal by the U.S. EPA that will prohibit high-GWP refrigerants in new units as of January 1, 2021. Presumably, a national requirement would result in greater production of low-GWP appliances than a California-only requirement, with greater cost savings due to a nation-wide transition resulting in mass production or import of low-GWP equipment. The U.S. EPA proposed regulation had not been adopted as of April 2016.

2. HFC Supply Phasedown

The HFC supply phasedown measure is no longer specific to California, but is international in scope and all developed countries, including the U.S., will follow the same phasedown schedule. Although the phasedown measure is no longer attributed to ARB, the cost and benefit analysis summarized below is still an accurate representation of the impact on businesses and residents in California.

The methodology used to estimate the cost and savings of a global HFC supply phasedown as it affects California is the same as that used for high-GWP refrigerant prohibitions, with one exception; the incremental equipment is estimated to be ten percent less than the cost used for the prohibitions measure. Analysis conducted for the European Union F-gas regulation concluded that non-prescriptive measures in which HFCs can be used in conjunction with a gradually decreasing HFC supply are approximately ten percent less costly than sector specific high-GWP prohibitions (Oko Recherche, 2011). Additionally, trade organizations such as the Alliance for Responsible Atmospheric Policy (ARAP), representing more than 100 equipment manufacturers and refrigerant manufacturers, state that an HFC phasedown could be met with a much lower added cost than specific high-GWP prohibitions. The costs of the high-GWP phasedown are shown in Table 42.

Table 42: Estimated Net Cost of Low-GWP Equipment, HFC Phasedown Measure[112]

Sector	Average Lifetime (yrs)	Added Equipment Cost ($/yr)[113]	Annual Cost Savings ($/unit)	Estimated New Units[114] and Equipment	Estimated Annual Net Cost (Savings) ($/yr)[115]
Centralized System Large (2,000+ lbs)	15	$12,000	($15,000)	50	($189,000)
Centralized System Medium (200-2,000 lbs)	15	$3,000	($4,000)	1,600	($1,076,000)
Cold Storage Large (2,000+ lbs)	20	$22,000	($25,000)	10	($22,000)
Cold Storage Medium (200-2,000 lbs)	20	$11,000	($9,000)	25	$55,000
Process Cooling Large (2,000+ lbs)	20	$11,000	($14,000)	10	($12,000)
Refrigerated Condensing Units Small (50-200 lbs)	15	$1,000	($1,000)	3,900	($311,000)
Refrigerated Condensing Units (Less than 50 lbs)	20	$500	($500)	15,700	($2,772,000)
Stand-Alone Refrig Display Cases	20	$10	($50)	34,300	$420,000
Centrifugal Chiller Large (2,000+ lbs)	20	$1,000	($800)	200	$137,000
Centrifugal Chiller Medium (200-2,000 lbs)	20	$1,000	($500)	100	$34,000
Chiller Packaged Medium (200-2,000 lbs)	20	$1,000	($200)	500	$336,000

[112] Numbers may not add due to rounding.
[113] The added equipment cost per year is calculated by taking the total added initial cost of the equipment, and dividing by the average years of equipment lifetime. The annual savings has been calculated by determining all annual savings and dividing by the average years of equipment cost. All costs and savings are shown in today's dollars; no discounted cost has been used.
[114] The estimated number of new units is derived from research and analysis conducted for the ARB Refrigerant Management Program regulation, equipment data registered through the Refrigerant Management Program data, and additional analysis used in the ARB Greenhouse Gas Emissions Inventory as developed by Gallagher, et al. 2014.
[115] The annual cost would be applied for each year of the model year or cohort's lifetime. Table 42 shows the cost if the HFC phasedown were the only proposed HFC measure implemented. The cumulative costs of the four proposed HFC measures are shown in Table 48 of the Appendix.

Sector	Average Lifetime (yrs)	Added Equipment Cost ($/yr)[113]	Annual Cost Savings ($/unit)	Estimated New Units[114] and Equipment	Estimated Annual Net Cost (Savings) ($/yr)[115]
Unitary A/C Small (50-200 lbs)	15	$100	($200)	4,900	($469,000)
Unitary A/C Central (Less than 50 lbs)	15	$50	($25)	169,000	($586,000)
Window AC Units Commercial	10	$25	($10)	54,000	$289,000
Residential AC Central	15	$25	($10)	482,000	$8,709,000
Window AC Units Residential	10	$25	($10)	310,000	$1,345,000
Residential Refrigerator-Freezer	15	$10	($10)	1,266,000	$8,227,000
Total Annual Cost of Equipment Model Year[116]					**$14,115,000**

3. Financial Incentive Program for Low-GWP Refrigeration Early Adoption

In order to incentivize low-GWP refrigeration prior to any mandatory regulatory measures, ARB has requested funding from the Greenhouse Gas Reduction Fund (GGRF) to use as a financial incentive, as a grant, loan, or other payment to be determined, to encourage new retail food facilities to use low-GWP refrigeration. Additionally, current stores using high-GWP equipment with remaining useful life could use funding to replace the high-GWP refrigerant in existing equipment, with low-GWP refrigerant, in a process known as a retrofit.

Table 43 shows the estimated incremental equipment cost of an incentive program for new equipment and retrofits. The cost assumptions in Table 43 are the same as those used for high-GWP prohibitions outlined in Table 41. This analysis assumes that the entire incremental cost of low-GWP equipment is covered by the incentive. However, the cost-effectiveness of this proposed measure could be improved if the necessary incentive is less than the incremental cost of low-GWP equipment.

[116] The annual cost would be applied for each year of the model year or cohort's lifetime. Table 42 shows the cost if the prohibition were the only proposed HFC measure implemented. The cumulative costs of the four proposed HFC measures are shown in Table 48 of the Appendix.

Table 43: Estimated Cost and Savings of Incentive Program for New Low-GWP Equipment (Per Piece of Equipment)

Centralized System Large[117] (2,000+ lbs)	15	$1,000,000	$200,000	($231,000)	($15,000)	($2,000)
Centralized System Medium[118] (200-2,000 lbs)	15	$250,000	$50,000	($55,000)	($4,000)	($500)
Refrigerated Condensing Units Small[119] (50-200 lbs)	15	$75,000	$15,000	($15,000)	($1,000)	$25
Refrigerated Condensing Units[120] (Less than 50 lbs)	20	$37,500	$7,500	($10,000)	($500)	($250)
Stand-Alone Refrigerated Display Cases[121]	20	$5,000	$1,000	($1,000)	($25)	$50

In addition to incentivizing new low-GWP equipment, existing high-GWP equipment could be converted to using lower-GWP refrigerants in a process known as a retrofit, where the high-GWP refrigerant is removed, and new lower-GWP refrigerant is added, along with minor modifications such as replacing seals and the refrigerant oil. Table 44 shows the cost of an incentive program to retrofit existing high-GWP equipment and Table 45 presents the cost of a voluntary retrofit program.

The relative high cost savings of are due to the inherent inefficiency of the refrigerant being replaced, which is R-404A, a high-GWP blend of HFCs. Almost any refrigerant replacement will result in significant energy efficiencies compared to R-404A. In this analysis, we assume that the replacement refrigerant is an HFO-HFC blend, either R-448A, or R-449A, each with a 10 percent greater efficiency than R-404A. The same kWh and electricity cost from the Prohibition analysis is used here. The total cost of an incentive program is limited by available funds, and is not known. The following shows a theoretical net cost of an incentive program for one year for new equipment, if 80% of new large and medium centralized systems are incentivized, four percent of smaller units (50 to 200 lbs charge size), two percent of refrigeration units with less than 50 lbs

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[117] The analysis assumes one per supermarket.
[118] The analysis assumes three to four per supermarket and one to two per grocery store.
[119] The analysis assumes one to three per grocery store.
[120] The analysis assumes up to several per small market.
[121] The analysis assumes several per small market and more for larger markets.

charge size, and one percent of stand-alone (self-contained equipment). For existing equipment, we assume that a number equal to one-year's turnover rate could be retrofitted. For equipment with a 20-year lifetime, the retrofit rate would be 5% of all equipment, and for equipment with a 15-year lifetime, the retrofit rate would be 6.7%. The cost of the following analysis assumes that approximately $240 million dollars in incentive funds could be available. Although the funding would be one-time and at the time of the new low-GWP equipment installation, or retrofit activity, the cost is shown on an annualized basis over the lifetime of the equipment to be consistent with cost analysis by year of equipment life.

Table 44: Estimated Cost and Savings of Incentive Program for Retrofit of Existing Low-GWP Equipment (Per Piece of Equipment)[122]

Sector	Post-Retrofit Remaining Life[123] (yrs)	One-Time Retrofit Cost ($/unit)	Lifetime Cost (Savings)	Added Annual Cost	Number of Equipment (unit/yr)	Net Cost (Savings) ($/yr)
Centralized System Large[124] (2,000+ lbs)	10	$80,000	($141,000)	$8,000	($14,000)	($6,000)
Centralized System Medium[125] (200-2,000 lbs)	10	$30,000	($31,000)	$3,000	($3,000)	($100)
Refrigerated Condensing Units Small[126] (50-200 lbs)	13	$6,000	($10,000)	$500	($1,000)	($300)
Refrigerated Condensing Units[127] (Less than 50 lbs)	13	$3,000	($7,000)	$250	($50)	($300)
Stand-Alone Refrigerated Display Cases [128]	13	$250	($500)	$50	($50)	($25)

122 Numbers may not add due to rounding.
123 Assumed to be 2/3 of total equipment lifetime.
124 The analysis assumes one per supermarket.
125 This analysis assumes three to four per supermarket and one to two per grocery store.
126 This analysis assumes one to three per grocery store.
127 This analysis assumes up to several per small market.
128 This analysis assumes several per small market and more for larger markets.

Table 45: Estimated Annual Costs and Savings of Voluntary Incentive Program (Per Piece of Equipment) [129]

Centralized System Large (2,000+ lbs)[130]	New	$13,000	($15,000)	($2,000)	45	($91,000)
	Retrofit	$8,000	($14,000)	($6,000)	56	($340,000)
Centralized System Medium[131] **(200-2,000 lbs)**	New	$3,000	($4,000)	($500)	1,300	($439,000)
	Retrofit	$3,000	($3,000)	($100)	1,600	($202,000)
Refrigerated Condensing Units Small[132] **(50-200 lbs)**	New	$1,000	($1,000)	$25	150	$3,000
	Retrofit	$500	($750)	($300)	3,800	($1,107,000)
Refrigerated Condensing Units[133] **(Less than 50 lbs)**	New	$500	($500)	($100)	300	($44,000)
	Retrofit	$250	($500)	($300)	16,000	($4,545,000)
Stand-Alone Refrigerated Display Cases[134]	New	$50	($25)	$25	300	$6,000
	Retrofit	$25	($25)	($25)	34,000	($480,000)
Total Estimated Annual Net Cost (Saving)						**($7,239,000)**

4. Sales Ban of Very-High GWP Refrigerants

To determine the incremental cost of complying with a sales ban of very high-GWP refrigerant (100-year GWP > 2500), this analysis assumes that a sales ban of refrigerant with a GWP > 2500 can be met by replacing the old refrigerant (if necessary) with new refrigerant, in a process called a retrofit. It is not anticipated that a sales ban of very-high GWP refrigerants will require purchasing new equipment sooner than the normal expected lifetime of the existing equipment, although some equipment owners may choose to purchase new low-GWP equipment rather than replace the existing refrigerant. Air-conditioning equipment, residential refrigeration, and residential AC do

[129] Numbers may not add due to rounding. Estimated costs and savings are for participating businesses only.
[130] The analysis assumes one per supermarket.
[131] This analysis assumes three to four per supermarket and one to two per grocery store.
[132] This analysis assumes one to three per grocery store.
[133] This analysis assumes up to several per small market.
[134] This analysis assumes several per small market and more for larger markets.

not use very-high GWP refrigerants and would not be affected by the sales ban. The retrofit cost shown in Table 46 is an average of quotes from technicians who conduct refrigeration retrofits. There are estimated significant savings over equipment lifetime resulting from the reduced energy usage of lower-GWP refrigerants, similar to the retrofit cost outlined in the proposed incentive program measure.

Table 46: Estimated Cost and Savings of Sales Ban of Very-High GWP Refrigerants (Per Piece of Equipment)[135]

Sector	Post-Retrofit Remaining Life[136] (yrs)	One-Time Retrofit Cost ($/unit)	Lifetime Cost (Savings)	Added Annual Cost	Cost (Savings) ($/yr)	Cost (Savings) ($/yr)
Centralized System Large (2,000+ lbs)	10	$80,000	($141,000)	$8,000	($14,000)	($6,000)
Centralized System Medium (200-2,000 lbs)	10	$20,000	($31,000)	$3,000	($3,000)	($100)
Cold Storage Large (2,000+ lbs)	13	$200,000	($230,000)	$15,000	($17,000)	($2,000)
Cold Storage Medium (200-2,000 lbs)	13	$100,000	($115,000)	$7,500	($9,000)	($1,000)
Process Cooling Large (2,000+ lbs)	13	$100,000	($182,000)	$7,500	($14,000)	($6,000)
Refrigerated Condensing Units Small (50-200 lbs)	10	$6,000	($10,000)	$1,000	($1,000)	($500)
Refrigerated Condensing Units (Less than 50 lbs)	13	$3,000	($7,000)	$250	($500)	($500)
Stand-Alone Refrigerated Display Cases	13	$250	($500)	$25	($50)	($25)

The total equipment cost of a sales ban is dependent upon the numbers of equipment undergoing a retrofit, which would not necessarily be required if the equipment did not require new refrigerant, as is common in many self-contained equipment. Also, stockpiled or recycled refrigerant would still be available during a sales ban on new production.

[135] Numbers may not add due to rounding.
[136] Assumed to be 2/3 of total equipment lifetime.

Table 47 is a continuation of the cost for a sales ban measure. In addition to showing the cost per unit, the number of units affected by the measure is estimated. Table 45 shows the cost per year of a scenario where the retrofit rate is approximately 10 percent of existing very-high GWP equipment.

Table 47: Estimated Cost and Saving of a Very-High GWP Sales Ban (Per Year of Measure)[137]

Sector	Added Unit Cost	Cost or (Savings)	Net Costs per Unit	Number of Equipment (unit/yr)	Net Cost (Savings)
Centralized System Large (2,000+ lbs)	$8,000	(-$14,000)	(-$6,000)	10	(-$523,000)
Centralized System Medium (200-2,000 lbs)	$3,000	(-$3,000)	(-$250)	2,500	(-$310,400)
Cold Storage Large (2,000+ lbs)	$15,000	(-$17,000)	(-$2,000)	25	(-$34,000)
Cold Storage Medium (200-2,000 lbs)	$7,500	(-$9,000)	(-$1000)	50	(-$48,000)
Process Cooling Large (2,000+ lbs)	$7,500	(-$14,000)	(-$6,000)	10	(-$68,000)
Refrigerated Condensing Units Small (50-200 lbs)	$600	(-$1,000)	(-$500)	8,000	(-$3,019,000)
Refrigerated Condensing Units (Less than 50 lbs)	$250	(-$500)	(-$500)	32,000	(-$9,294,000)
Stand-Alone Refrigerated Display Cases	$25	(-$50)	(-$25)	70,000	(-$982,000)
Estimated Annual Cost (Savings)					**(-$14,278,000)**

5. Cumulative Cost of All Measures

This analysis estimates a net cost as a result of the proposed prohibition and phasedown measures and net savings from the proposed incentive and sales ban measures. This analysis also finds that all four measures are estimated to contribute to HFC emission reductions. As new equipment can only be built as low-GWP once, new equipment can be assigned to only one of the four reduction measures. Existing equipment can also be retrofitted to lower-GWP refrigerants, which will increase HFC emission reductions faster than waiting for natural equipment turn over. As existing equipment can be retrofitted, the estimated annual percentage of new low-GWP

[137] Numbers may not add due to rounding.

equipment (new and retrofit) can equal more than 100 percent of estimated unit turn over per year.

The following section outlines the assumptions that were used to determine the combination of measures contributing to both cost and savings as well as HFC emission reductions and are presented by proposed measure.

Incentive Program

From 2017 through 2020, an incentive program could incentive a switch to low-GWP refrigeration for up to 80 new large and medium refrigeration systems. The analysis also assumes an additional four percent of new refrigerated condensing units (50 to 200 lbs of refrigerant), two percent of new refrigerated condensing units less than 50 lbs, and one percent of new stand-alone (self-contained) refrigerated display cases could be incentivized to switch to low-GWP refrigerant.

Sales Ban

For existing units, the analysis estimates that approximately five to seven percent of refrigeration units could be retrofit to lower-GWP refrigerants each year, from 2019 through 2025. The analysis assumes that the sales ban could also be responsible for five to six percent of all new low-GWP refrigeration equipment. The sales ban would not apply to refrigerants used in air-conditioning.

HFC Phasedown

A phasedown in the supply of new HFC refrigerant will begin in 2019 and continue with a gradual phasedown in the supply through 2036 until the new total allocation (as measured in CO_2e) will be 85 percent less than baseline. By 2025, we estimate that up to half of all new equipment could be low-GWP due to an HFC phasedown.

High-GWP Refrigerant Prohibitions in New Equipment

Prohibition measures would take place immediately after measures implementation and would result in an estimated 80 to 90 percent turnover to low-GWP equipment until implementation of HFC phasedowns. The percent of equipment becoming low-GWP as a result of the prohibitions would gradually decrease, and by 2025, the analysis estimates 37 percent of all new equipment will be low-GWP due to the prohibitions.

Given the transition towards low-GWP refrigeration and AC equipment as modeled in this analysis, Table 48 shows the estimated cost, by year, and also aggregated cost and savings through 2030.

Table 48: Cumulative Cost of all Measures (Million Dollars)

Measure		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Incentive Program	Added Cost	$5	$11	$17	$18	$18	$18	$18	$18	$18	$19	$19	$19	$19	$19
	Savings	($6)	($12)	($19)	($20)	($20)	($20)	($20)	($20)	($20)	($21)	($21)	($21)	($21)	($21)
	Net Cost or (Savings)	($1)	($1)	($2)	($2)	($2)	($2)	($2)	($2)	($2)	($2)	($2)	($2)	($2)	($2)
Sales Ban	Added Cost	$0	$0	$16	$40	$64	$89	$115	$136	$150	$151	$152	$147	$141	$148
	Savings	$0	$0	($26)	($65)	($105)	($146)	($187)	($224)	($246)	($248)	($249)	($237)	($232)	($240)
	Net Cost or (Savings)	$0	$0	($11)	($26)	($41)	($57)	($73)	($88)	($96)	($97)	($97)	($90)	($90)	($92)
HFC Phasedown (through global Kigali Amendment)	Added Cost	$0	$0	$0	$2	$4	$11	$28	$56	$91	$124	$160	$198	$237	$276
	Savings	$0	$0	($0)	($1)	($3)	($7)	($19)	($39)	($63)	($87)	($113)	($140)	($168)	($196)
	Net Cost or (Savings)	$0	$0	$0	$0	$1	$4	$9	$18	$28	$37	$47	$58	$69	$80
High-GWP HFC Prohibitions	Added Cost	$0	$0	$0	$19	$73	$123	$164	$194	$218	$246	$273	$299	$325	$352
	Savings	$0	$0	$0	($21)	($55)	($87)	($113)	($132)	($147)	($165)	($181)	($198)	($215)	($233)
	Net Cost or (Savings)	$0	$0	$0	($2)	$18	$36	$51	$62	$71	$82	$91	$101	$110	$120

All Measures Combined	**Cumulative Cost**	$5	$16	$50	$128	$287	$528	$852	$1,257	$1,734	$2,274	$2,877	$3,540	$4,262	$5,058
	Cumulative Savings	($6)	($18)	($64)	($171)	($354)	($613)	($952)	($1366)	($1843)	($2363)	($2927)	($3524)	($4159)	($4849)
	Cumulative Net Cost or (Savings)	**($1)**	**($2)**	**($14)**	**($43)**	**($67)**	**($85)**	**($100)**	**($110)**	**($109)**	**($89)**	**($50)**	**$16**	**$103**	**$209**