Appendix D: Supporting Documentation for the Economic Assessment of Measures in the Proposed Strategy

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

This Appendix presents technical information and calculations that support the economic analysis in Chapter VIII of the Proposed Strategy. Appendix D 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

As noted in Chapter V, emissions from dairy manure can be reduced by 75 percent by capturing or avoiding methane produced by about 1.05 million of the State's 1.4 million milking cows whose manure is managed anaerobically. This section identifies options for meeting these targets and describes the economic costs and potential revenues at both a project level and from a sector-wide perspective.

Several options exist to reduce methane emissions from manure management in California, but no single approach will be optimal for all dairies. Many factors—including dairy population and design as well as uncertainty related to technology, markets, financing, utility interconnection challenges, credit values under the Low Carbon Fuel Standard (LCFS), Renewable Fuel Standard (RFS), or offsets from the Cap-and-Trade Program, and potential future regulations—will affect the evolution of California's dairy industry and the build out of infrastructure to reduce methane emissions. Five strategies to reduce manure methane emissions are investigated in this analysis:

1. Scrape conversion and onsite manure digestion producing pipeline-injected renewable natural gas vehicle fuel
2. Scrape conversion and transport of manure offsite for centralized digestion producing pipeline injected renewable natural gas as a vehicle fuel
3. Scrape conversion, collection and open solar drying of manure onsite
4. Scrape conversion and onsite manure digestion for onsite production of renewable electricity
5. Conversion of dairy operations to pasture-based management

These represent example pathways that could be important for a sector-wide approach to reduce emissions, but they are not meant to rule out other solutions. The cost and efficacy of some options, such as solids separation, are not yet known with certainty and could not be included in this analysis. Solids separation and other potential mitigation methods deserve additional study of both their emission reduction potential and economic feasibility.

The strategies considered here aim to balance cost and feasibility while prioritizing economic and environmental benefits. Specifically, they aim to address water quality issues on dairies by including conversion to scrape systems, maximizing renewable natural gas production by utilizing above ground tank/plug flow digesters, avoiding increases in criteria pollutant emissions (most notably oxides of nitrogen, or NOx) and maximizing potential revenues by prioritizing pipeline injection of renewable natural gas.

Prioritizing these goals adds costs compared to a pathway that focuses on methane mitigation only. For example, covering lagoons and generating electricity in a reciprocating engine would theoretically reduce the same amount of methane at a lower cost but would result in other negative environmental effects. The strategies described in this analysis may appear more expensive but include important environmental and potential economic benefits that, while unquantified in this analysis, could potentially outweigh added costs.

These individual pathways are combined into three sector-wide scenarios for reducing methane emissions from manure management at California dairies by 20 percent in 2020, 50 percent in 2025 and 75 percent by 2030:

- Scenario A: All strategy 3 (scrape to manure collection and drying)
- Scenario B: Mixed approach (including all five strategies)
- Scenario C: All strategy 2 (centralized digestion and pipeline injection)

The first (Scenario A) represents a low cost case, but it also generates little economic value. The second (Scenario B) represents a reasonable mix of the pathways, informed by GIS analysis as described below, and it represents a diverse sector-wide approach to reducing emissions. The third (Scenario C) represents a high revenue case.

The analysis was informed by direct consultation with CDFA, academic researchers at UC Davis and elsewhere, project developers, and stakeholders. As part of developing this Proposed Strategy, ARB supported research at UC Davis to inform cost and performance estimates for dry scrape conversions, anaerobic digesters, and other pathways.[1] Additional research, including a separate report funded by Sustainable Conservation,[2] was also used to inform the cost and performance parameters assumed for this analysis. Many of the technologies and parameters included in this analysis are unproven and uncertain, and additional research and experience is necessary to further refine cost estimates associated with meeting the targets identified in this Proposed Strategy. These studies and consultations largely inform the assumptions listed in Table 11 at the end of this section.

Revenues were estimated using projected methane emission reductions from each pathway, where applicable, to determine the value of energy products and the number of saleable credits from the LCFS and the federal Renewable Fuel Standard Program or Cap-and-Trade offset credits. Credit and energy product values for the calculation of

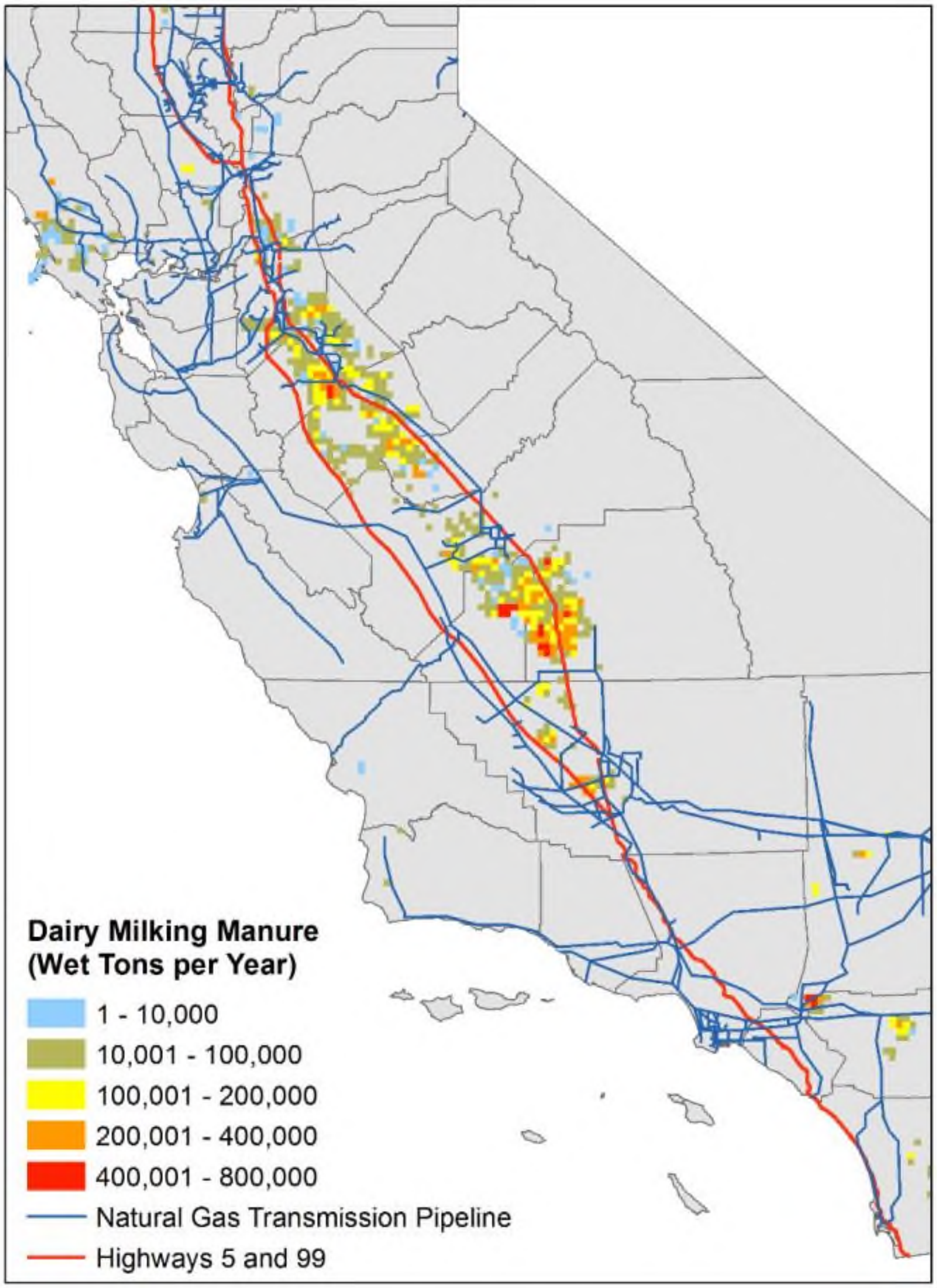
[1] Kaffka, S. et al (2016) Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California, Final Technical Report to the State of California Air Resources Board, February.
[2] Sustainable Conservation (2015) Combating Climate Change: Dairies Key in Reducing Methane, July. http://www.suscon.org/blog/2015/07/combating-climate-change-dairies-key-in-reducing-methane/.

revenues generally reflect current pricing. No revenue was assumed for soil amendment products or from compost associated with solid scrape operations. These products could also deliver significant revenues, at added cost, but their market potential is uncertain at this time.[3]

ARB conducted a Geographic Information System (GIS) analysis of dairies throughout the State to inform the scenario development. GIS informed estimates related to number of dairies that could feasibly inject renewable natural gas into the pipeline, the associated costs, the availability and costs associated with "clustering" dairies to centralize digestion and pipeline injection, opportunities for converting to pasture-based operations, and the mix of pathways included in Scenario B (mixed pathways). Figure 1 provides a spatial analysis of manure from milking cows in California.

[3] Soil amendment products from dairy digesters could provide greater potential revenues than energy sales from the digesters, potentially as much as $300 per cow per year in California. Informa Economics (2013) National Market Value of Anaerobic Digester Products, Prepared for Innovation Center for U.S. Dairy, February.

Figure 1: Location of Manure from Milking Cows in California



1. Costs and Revenues for Manure Management Projects

Five potential strategies to reduce manure methane emissions were explored. For clarity, the net present value of costs and revenues at the dairy level are estimated over a ten-year period and normalized to illustrate a representative dairy with 2,000 milking cows. The assumptions are subject to uncertainty and any actual project cost will vary from the estimate here.

a. Strategy 1 - Scrape Conversion and Onsite Manure Digestion Producing Pipeline-Injected Renewable Natural Gas as a Vehicle Fuel

This pathway utilizes solid scrape or vacuum manure management and above ground tank or plug-flow anaerobic digestion systems with biogas conditioning sufficient to produce renewable natural gas meeting utility pipeline injection or vehicle fueling standards. This pathway is prioritized for its environmental benefits and revenue potential. Based on ARB staff's GIS analysis, this pathway could provide approximately 7 MMT CO_2e (20-year GWP) in methane emission reductions from approximately 350,000 milking cows on about 150 dairies located within approximately two miles of a utility natural gas transmission pipeline or another connected dairy. The construction of as many as 200 miles of gas pipeline could be expected as part of this pathway in order to connect dairies to one another or directly to transmission pipelines. Pipeline injection of renewable natural gas avoids any new onsite NOx generation that would occur from on-site electricity generation.

Table 1: Estimated Costs and Revenues for Strategy 1: Scrape Conversion and Onsite Manure Digestion Producing Pipeline-Injected Renewable Natural Gas[4]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Scrape Conversion	$700,000	$21,000	
Digester	$2,917,000	$175,000	
Pipeline	$267,000	$13,000	
Interconnection	$1,000,000	$50,000	
Biogas Upgrading[5]		$192,000	
Fuel			$83,000
RINs			$537,000
LCFS Credits[6]			$845,000
Total	**$4,884,000**	**$451,000**	**$1,465,000**
Net Present Value (2016-2026)	**$2,500,000**		

Projected costs and revenues for this pathway are summarized in Table 1, normalized to a 2,000 cow dairy. Based on the assumptions used here, these projects show a positive return but revenues are highly dependent on the value of LCFS and RIN

[4] Summation may not be exact due to rounding. Capital costs amortized over 10 years with 7% interest. Discount rate is 5%. Costs normalized to representative 2,000 cow dairy.
[5] Biogas upgrading costs are assumed to be $8 per 1000 ft^3 in this pathway. (Pathway 2, described in Table 2, uses centralized facilities that are assumed to benefit from economies of scale that lower upgrading costs to $6 per 1000 ft^3.) This cost is assumed to include all costs, including amortized capital, but is represented here as an O&M cost for simplicity. Additional assumptions are outlined in Table 20.
[6] Once a regulation to control manure emissions is in place, LCFS credits for new dairy digester projects may no longer include credit for methane destruction, which is assumed here to increase the carbon intensity of biogas from dairy digesters from -276 to13 gCO_2e/MJ. This would reduce the number of credits generated by about 80 percent. Assuming a credit price of $100/MT, the average annual revenue from LCFS credits would be about $163,000, and the net present value for the project over ten years would fall by more than $5 million.

credits. Assuming average LCFS credit prices are $100/MT and cellulosic RIN credit prices are $1.85,[7] the net present value for this type of project is estimated to be about $2.5 million over ten years. However, as shown in Table 2, the net present value can fluctuate by several million dollars, depending on the value of these revenue streams.

Table 2: Net Present Value Over 10 Years for Strategy 1 - Onsite Digestion to Transportation Fuel as a Function of LCFS and RIN Credit Prices (Million Dollars)

		LCFS Credit Prices				
		$0	$50	$100	$150	$200
Cellulosic RIN Credit Prices	$0.00	-$8.2	-$5.0	-$1.7	$1.6	$4.8
	$0.50	-$7.1	-$3.8	-$0.6	$2.7	$6.0
	$1.00	-$6.0	-$2.7	$0.5	$3.8	$7.1
	$1.85	-$4.1	-$0.8	$2.5	$5.7	$9.0
	$2.50	-$2.6	$0.6	$3.9	$7.2	$10.4
	$3.00	-$1.5	$1.8	$5.0	$8.3	$11.6
	$3.50	-$0.4	$2.9	$6.1	$9.4	$12.7
	$4.00	$0.7	$4.0	$7.3	$10.5	$13.8

b. Strategy 2 - Scrape Conversion and Transport of Manure Offsite for Centralized Digestion Producing Pipeline-Injected Renewable Natural Gas as a Vehicle Fuel

This pathway is similar to the first, but rather than constructing digesters on each dairy, collected manure is transported to a centralized digester. (Under this strategy, the centralized digester could also potentially co-digest other feedstocks, such as food waste or municipal wastewater, to increase fuel production.) Centralized digestion, biogas upgrading, and pipeline interconnection can significantly cut costs for a cluster of dairies in close proximity to one another. Dairies that are not within two miles of a utility transmission line, are still of adequate size, and have appropriate milking cow population density to support pipeline injection of biogas may also choose to aggregate and construct centralized digestion facilities for processing manure. Some dairies face significant nutrient management challenges and may wish to pursue this as an option, as well.

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-

[7] The assumed cellulosic RIN credit value of $1.85 for dairy 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 LCFS and RIN credit prices are somewhat lower than current credit prices. The latest available information at the time of this writing (April 6, 2016), suggests that LCFS credits are trading for an average of $122/MT and cellulosic RINs could be worth about $2.10.

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. On average, each cluster is assumed to use 1-2 trucks to accommodate these trips. This analysis includes assumed costs for new low-NOx CNG trucks, a small fleet refueling station for each cluster, and hauling costs of $2/mile.[8]

Costs and revenues for the entire cluster are normalized to reflect the share for a representative 2,000 cow dairy, and are summarized in Table 3. Based on the assumptions and methods of this analysis, this pathway shows a positive return, but like Strategy 1, this result is highly dependent on the value of LCFS and RIN credits (see Table 4).

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[8] Hauling costs were roughly estimated based on California rates from (http://www.dat.com/resources/trendlines/van/west-regional-rates) and rounded up to be conservative.

Table 3: Estimated Costs and Revenue for Strategy 2 - Scrape Conversion and Transport of Manure Offsite for Centralized Digestion Producing Pipeline-Injected Renewable Natural Gas[9]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Scrape Conversion	$700,000	$21,000	
Digester	$1,874,000	$112,000	
Pipeline (Low Pressure)	$78,000	$4,000	
Pipeline (Transmission)	$105,000	$5,000	
Low NOx Trucks[10]	$44,000		
Manure Hauling		$20,000	
Interconnection	$209,000	$7,000	
Upgrading[11]		$144,000	
CNG Station (Small Fleet)[12]	$16,000	$2,000	
Fuel			$83,000
RINs			$537,000
LCFS Credits[13]			$845,000
Total	$3,026,000	$315,000	$1,465,000
Net Present Value (2016-2026)	**$5,544,000**		

[9] Summation may not be exact due to rounding. Capital costs amortized over 10 years with 7% interest. Discount rate is 5%. Costs normalized to representative 2,000 cow dairy.

[10] As for all costs/revenues in this table, costs for trucks represent a share of costs for the cluster, normalized to a 2,000 cow dairy. The portion of costs shown here is based on the assumption that a low-NOx truck costs $250,000.

[11] Biogas upgrading costs are assumed to be $6 per 1000 ft^3 in this pathway. This is lower than costs for upgrading in Pathway 1 because economies of scale are expected to drive lower costs. This cost is assumed to include all costs, including amortized capital, but is represented here as an O&M cost for simplicity. Additional assumptions are outlined in Table 20.

[12] Normalized share of a fueling station sufficient to supply a small fleet. Each cluster is assumed to have one station with a capital cost of $150,000. (Note that commercial stations are much more expensive.)

[13] Once a regulation to control manure emissions is in place, LCFS credits for new dairy digester projects may no longer include credit for methane destruction, which is assumed here to increase the carbon intensity of biogas from dairy digesters from -276 to 13 gCO_2e/MJ. This would reduce the number of credits generated by about 80 percent. Assuming a credit price of $100/MT, the average annual revenue from LCFS credits would be about $163,000, and the net present value for the project over ten years would fall by more than $5 million.

Table 4: Net Present Value Over 10 Years for Strategy 2: Centralized Digestion to Transportation Fuel as a Function of LCFS and RIN Credit Prices (Million Dollars)

		LCFS Credit Prices				
		$0	**$50**	**$100**	**$150**	**$200**
Cellulosic RIN Credit Prices	**$0.00**	-$5.1	-$1.9	$1.4	$4.7	$7.9
	$0.50	-$4.0	-$0.7	$2.5	$5.8	$9.0
	$1.00	-$2.9	$0.4	$3.6	$6.9	$10.2
	$1.85	-$1.0	$2.3	$5.5	$8.8	$12.1
	$2.50	$0.5	$3.7	$7.0	$10.3	$13.5
	$3.00	$1.6	$4.9	$8.1	$11.4	$14.6
	$3.50	$2.7	$6.0	$9.2	$12.5	$15.8
	$4.00	$3.8	$7.1	$10.4	$13.6	$16.9

c. Strategy 3 - Scrape Conversion, Collection and Open Solar Drying of Manure Onsite

Some dairy operations may not be suitable for digestion or may not be proximate to natural gas pipelines or transportation corridors to sell fuel. Other dairy farmers may wish to avoid the complexity of digester operation, power purchase agreements, and utility interconnections. In these cases, manure methane emissions may be avoided by converting from flush to solid scrape manure management systems. This method could reduce methane emissions by minimizing anaerobic manure processing and storage.

For example, solid scrape and vacuum manure collection can be used to collect manure this manure can then be dried onsite using concrete pads (pending available space and potential crop opportunity cost) before being used on the dairy or transported offsite. This process can potentially produce compost for sale, but costs and revenues associated with that operation are not included here. Conversion to solid manure management systems will affect how nutrients are provided to forage crops, and may add cost to forage production and dairy operations. NOx emissions are not expected to increase with this approach and co-benefits could include improvements in water quality and nutrient management

Projected costs for this pathway are summarized in Table 5. It represents the lowest cost option among the strategies considered in this analysis, but it is not assumed to generate any revenue, leading to a net present value loss of about $2.1 million over 10 years. Still, this pathway represents fairly low cost emission reductions ($4.9/MT using a 20-year GWP) and could break even with an upfront grant, or its equivalent, of about $1.9 million.

Table 5: Estimated Costs and Revenue for Strategy 3 - Scrape Conversion, Collection and Open Solar Drying[14]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Scrape Conversion	$700,000	$21,000	
Manure Drying Pad	$800,000	$36,000	
Total	**$1,500,000**	**$57,000**	**$0**
Net Present Value (2016-2026)	**–$2,089,000**		

d. Strategy 4 - Scrape Conversion and Onsite Manure Digestion for Onsite Production of Renewable Electricity

In situations where producing transportation fuel or pipeline injection are less practical, manure can be digested and converted to electricity onsite. This control pathway utilizes solid scrape manure management and above ground tank or plug-flow digesters to produce biogas for onsite electricity generation. Biogas conditioning to produce renewable natural gas that meets fuel quality requirements can improve the reliability and longevity of generation systems. While reciprocating internal combustion engines are often used for these applications, this analysis assumes that microturbines are used, to minimize air quality impacts. Fuel cells are another option but currently have higher costs and less demonstrated reliability.

Table 6 summarizes the projected costs and revenues for this pathway. Revenues come from the feed-in-tariff price for electricity, set pursuant to Senate Bill 1122 (Rubio, Statutes of 2012, Chapter 612) and offsets from the Cap-and-Trade program. (Cap-and-Trade offsets will not be available for projects built after a regulation is in place.) These revenue streams are more stable than for the transportation fuel pathways (Strategies 1 and 2), but are also significantly lower than for the transportation fuel strategies modeled here with project economics that are less favorable. The net present value of this project over ten years is -$5.7 million and an upfront grant of $5.3 million would be needed to break even. The associated costs of GHG reductions are \$13/MTCO_2e using a 20-year GWP (\$39/MTCO_2e using a 100-year GWP). Assumed operating costs associated with the digester and microturbine are strong drivers in this analysis, accounting for $3 million in costs over the 10-year analysis period.

[14] Summation may not be exact due to rounding. Capital costs amortized over 10 years with 7% interest. Discount rate is 5%. Costs normalized to representative 2,000 cow dairy.

Table 6: Estimated Costs and Revenue for Strategy 4 - Scrape Conversion and Onsite Manure Digestion for Onsite Production of Renewable Electricity[15]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Scrape Conversion	$700,000	$21,000	
Digester + Microturbine	$4,558,000	$387,000	
Upgrading[16]		$48,000	
Electricity			$272,000
C&T Offsets[17]			$192,000
Total	**$5,258,000**	**$456,000**	**$464,000**
Net Present Value (2016-2026)	**–$5,722,000**		
Added Revenue if Electricity is Used in Transportation Sector			
RIN Credits			**$537,000**
Net Present Value (2016-2026)	**–$1,579,000**		

Note that if electricity generated from biogas is used to charge electric vehicles, biogas used to generate electricity can be credited with cellulosic RIN credits which could add another valuable revenue stream. In this case, RIN credits would more than double revenue and add more than $4 million in net present value over 10 years. Based on the assumptions here, the project would still represent a net loss of $1.6 million over ten years but could break even with an upfront grant of $1.5 million. Costs of emission reductions over 10 years would fall to $4/MTCO_2e$ using a 20-year GWP ($11/MTCO_2e$ using a 100-year GWP).

e. Strategy 5 - Conversion of Dairy Operations to Pasture-Based Management

Some dairies could convert to a pasture-based model where manure decays aerobically in the field and emits a negligible amount of methane. Based on the current composition of the dairy industry in California, ARB staff estimates that 25 dairies, with about 50,000 milking cows, could convert to pasture-based operations without reducing herd size or procuring new land. This strategy would not increase NOx emissions, and could potentially improve water quality and nutrient management. Additional forage may need to be imported to meet animal nutrition needs and limit effects on milk production efficiency but those potential costs are not included here.

[15] Summation may not be exact due to rounding. Capital costs amortized over 10 years with 7% interest. Discount rate is 5%. Costs normalized to representative 2,000 cow dairy.

[16] Upgrading costs for electricity generation pathway assumed to be less than for pipeline injection pathways. This pathway assumes a cost of $2 per 1000 standard cubic feet, compared to costs of $6-8 for pipeline injection in Strategies 1 and 2.

[17] Offsets under the cap and trade program will be unavailable for projects built after a regulation to control manure emissions is in place. Eliminating revenue from cap and trade offsets would reduce the net present value shown here by about $1.5 million.

Projected costs for this strategy are summarized in Table 7. Converting to pasture-based systems has relatively high assumed costs and produces no revenue streams, leading to a pathway with a net present value of -$7.8 million over 10 years. Little information is available on the economics associated with converting to pasture. A detailed cost-benefit analysis on the impacts of dairy operations, either positive or negative, is beyond the scope of this analysis. Additional research is warranted to evaluate the viability of this pathway to reduce dairy methane emissions.

However, there are potential benefits associated with converting to pasture dairies and this approach deserves additional consideration and support for demonstration projects. 75 percent of the estimated capital cost and over 90 percent of the estimated operating costs come from pasture dairy irrigation. If dairies were to convert to pasture in areas where less irrigation are needed (for example, in northern parts of the State), they might be able to significantly cut costs associated with reducing methane from their operations.

Table 7: Estimated Costs for Conversion of Dairy Operations to Pasture-Based Management[18]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Fencing	$282,000	$7,000	
Irrigation	$3,333,000	$333,000	
Water Provision	$24,000	$1,000	
Shade Structures	$867,000	$22,000	
Total Costs	**$4,506,000**	**$363,000**	**$0**
Net Present Value (2016-2026)	**–$7,752,000**		

2. Costs and Revenues for Sector-Wide Scenarios to Meet Targets

Three scenarios were built, pulling from the strategies and assumptions described above, to provide a range of potential costs and revenues associated with meeting the methane manure emissions targets identified in this Proposed Strategy. Table 8 provides a schedule for the current number of milking cows that would have to be covered by projects that avoid methane emissions in order to meet these targets. In the mixed scenario (Scenario B), a consistent share of each project type is added over time (there is no prioritization in the rollout of one type of pathway compared to another).

[18] Summation may not be exact due to rounding. Capital costs amortized over 10 years with 7% interest. Discount rate is 5%. Costs normalized to representative 2,000 cow dairy.

Table 8: Modeled Build Out of Projects Over Time in Scenarios to Meet Manure Methane Reduction Targets

	Methane Reductions from 2013	Number of Cows (Cumulative)
2016	0	0
2017	5%	70,000
2018	10%	140,000
2019	15%	210,000
2020	20%	280,000
2021	26%	364,000
2022	32%	448,000
2023	38%	532,000
2024	44%	616,000
2025	50%	700,000
2026	55%	770,000
2027	60%	840,000
2028	65%	910,000
2029	70%	980,000
2030	75%	1,050,000

The scenarios include a mixed pathway (Scenario B) which represents ARB staff's best estimate of pathways that reasonably balances economic, operational, and environmental factors. It is described in further detail below. The other two scenarios are intended to provide higher and lower bounds on potential costs and revenues associated with meeting the targets. Scenario A represents a low cost case with no additional revenue and all emission reductions coming from dairies that convert to scrape collection and dry manure (Strategy 3). Scenario C represents a high value case where all emission reductions come from centralized digestion and pipeline interconnection as described for Strategy 2 (see Table 9).

These scenarios and the targets identified in this Proposed Strategy would reduce a cumulative 168 MMTCO_2e through 2030 using a 20-year GWP (58 MMTCO_2e using 100-year GWP) and 391 MMTCO_2e through 2040 (136 MMTCO_2e using 100-year GWP).

Table 9: Mix of Strategies in Scenarios (number of milking head covered by projects in 2030)

Strategy	A	B	C
(1) Scrape conversion and onsite manure digestion producing pipeline-injected renewable natural gas vehicle fuel		350,000	
(2) Scrape conversion transport of manure offsite for centralized digestion producing pipeline injected renewable natural gas as a vehicle fuel		300,000	1,050,000
(3) Scrape conversion, collection and open solar drying of manure onsite	1,050,000	200,000	
(4) Scrape conversion and onsite manure digestion for onsite production of renewable electricity		150,000	
(5) Conversion of dairy operations to pasture-based management		50,000	
Total	**1,050,000**	**1,050,000**	**1,050,000**

Results for the scenarios are summarized in Table 10. Scenario A represents a low cost, zero revenue case where a sufficient number of dairies transition to scrape operations to reduce methane emissions from manure management by 75 percent by 2030. This could have potential benefits, as described above, for nutrient management and water quality on the farm. Although this is not considered here, there could also be revenue gains (along with added costs) if manure were composted and sold. The sector-wide, net present value through 2030 for this scenario is -\$636 million, which represents emission reductions of about \$4/MTCO_2e using a 20-year GWP (\$11/MTCO_2e using 100-year GWP).

Table 10: Economic Analysis for Sector-Wide Scenarios Through 2030 (Million Dollars)[19]

	Scenario A	B	C
Capital	$493	$1,235	$995
O&M	$142	$837	$788
Revenue	$0	$2,157	$3,237
Net Present Value LCFS Credit $100 RIN Credit $1.85	–$636	$84	$1,454
$/MT CO2e (20-yr GWP)	$3.8	–$0.5	–$8.7
$/MT CO2e (100-yr GWP)	$10.9	–$1.5	–$24.9
Net Present Value LCFS Credit $40 RIN Credit $1.00	–$636	–$926	–$176

Scenario B includes a mix of all five strategies. Collectively, with LCFS credits assumed to be valued at $100/MT and RINs at $1.85, this scenario meets the targets in this Proposed Strategy with a positive net present value of $84 million through 2030. If the portion of milking cows in this scenario utilizing Strategy 4 were to use generated electricity for transportation fuel to capture RIN credits, it would increase revenues and net present value by about $200 million. Again, revenues are highly dependent on LCFS and RIN credit values. If LCFS credits were $40/MT and RINS were $1.00, the net present value of this scenario would fall by about a billion dollars, to -$926 million (-$823 million if the electricity is used as transportation fuel).

The value of LCFS and RIN credits is even more noticeable in Scenario C, where all emission reductions are achieved through centralized digestion that generates renewable natural gas for transportation fuel and LCFS credits. If instead of the assumptions used here, LCFS and RIN credits were valued at $40/MT and $1.00, respectively, the net present value would fall by $1.6 billion, and the scenario would have a net loss of $176 million through 2030.

Altogether, this analysis suggests that the dairy industry in California can significantly cut methane emissions and deliver low-cost GHG reductions. There are important uncertainties associated with project costs and potential revenues, however, which may limit project development without targeted support. And the State may wish to support

[19] Summation may not be exact due to rounding. Capital costs amortized over 10 years with 7% interest. Discount rate is 5%. In Scenarios B and C, beginning in 2025, regulation eliminates availability of C&T offsets for new electricity generating projects (Strategy 4) and for those that have been operating for 10 years. For projects producing transportation fuel (Strategy 1 and 2), beginning in 2025, the carbon intensity for LCFS credits for new projects and those that have been operating for 10 years increases from -276 to 13 gCO_2e/MJ. The impact of regulation on existing projects under the LCFS has not been determined, and this simply an assumption used for the sake of this analysis.

some higher cost strategies, including conversions to scrape or pasture-based systems, for other environmental reasons.

A mix of grants, especially for projects with lower revenues, and other mechanisms for pathways with higher revenues may be appropriate. This funding could come from federal sources, California's Greenhouse Gas Reduction Fund (GGRF), utility programs, the programs included in this analysis, or other sources. Limited federal grant funding is currently available, and more should be pursued. In his proposed 2016-17 Budget,[20] Governor Brown has proposed committing $55 million in GGRF funding for climate smart agriculture, including dairy digesters and healthy soils. And under a rulemaking by the CPUC pursuant to Assembly Bill 1900 (Gatto, Chapter 602, Statutes of 2012), California's natural gas utilities will offset half of renewable natural gas interconnection costs, up to $1.5 million per project and $40 million Statewide.

These programs provide a strong starting point for supporting the industry in reducing methane emissions and achieving the targets and benefits identified here. They should be built upon and bolstered. A financial working group may be helpful in recommending ways to leverage private sector investment and significantly scale efforts to rapidly cut methane emissions in California. Through careful investments and structured market-based incentives, project development may be accelerated to achieve emission reductions more quickly than the targets identified in this Proposed Strategy, and ahead of potential regulation of the industry.

Table 11: Assumptions for Manure Management Strategies at California Dairies

Costs	Capital	O&M	Reference
Rural, low pressure pipeline, $/mile	$ 200,000	5%	SusCon report cites costs of natural gas pipeline at 100,000-250,000 per mile. National Petroleum Council Transportation Fuels Study (RNG Topic Paper #22) cites pipeline costs as about $50/foot in agricultural areas, which is $260,000 per mile. Kern cluster project suggests $25-40/foot. We assume $200,000 per mile, or about $38/foot.
Natural gas transmission pipeline or urban low pressure pipeline, $/mile	$ 1,000,000	5%	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. Urban pipelines (e.g., connecting wastewater treatment plants to pipeline) and new utility pipelines for natural gas transmission are assumed to cost $1 million per mile, even in rural areas.
On-site Biogas Upgrading System, $/1000 scf		$8	SusCon report notes that biogas cleanup has significant economies of scale, and references clean-up costs of $8.12 per 1000 ft3 for a 1,500 cow dairy, and costs of between $5.45 and $8.56 for an 8,000 cow dairy. Onsite case assumes 2,200 cow dairy (average for the digester pathways) with cows producing 13.5 1000 ft3 per year at a cost of $8 per 1000 ft3. These cost are represented as O&M costs, and are assumed to include amortized capital costs.

[20] http://www.ebudget.ca.gov/2016-17/BudgetSummary/BSS/BSS.html

Centralized Biogas Upgrading System, $/1000 scf		$6	Pathway assumes 10 centralized upgrading facilities needed for 300,000 cows, or an average of 30,000 per facility. Assuming economies of scale for gas cleanup, low cost scenario assumes $6 per 1000 ft^3, mid cost assumes $8 per 1000 ft^3, and high cost assumes $10 per 1000 ft^3. Assume 30,000 cows per facility and 13.5 1000 ft^3 per year per cow. These costs are represented as annual (O&M) costs, and are assumed to include amortized capital costs.
On-site Utility Natural Gas Pipeline Interconnection, $	$ 1,000,000	5.0%	SusCon report cites interconnection costs of $1 million for a farm with more than 5,000 cows in Washington, which is assumed for costs here. SoCal Gas presentation suggests O&M of $48-66k per year on capital costs for interconnection of $1.3-1.9 million. Assuming $48k on capital of $1 million implies O&M of 4.8 percent. 5 percent used here. (http://americanbiogascouncil.org/webinars/22may14_pipelineBiogasCA.pdf)
Centralized Utility Natural Gas Pipeline Interconnection, $	$ 2,000,000	3.5%	SusCon report cites interconnection costs of $2 million for a farm with 40,000 cows. SoCal Gas presentation cites $1.3 million for delivery volumes of 1 MMscfd. 30,000 cows at 36.9 scfd/cow produce 1.1 MMscfd. Assume $2 million here. SoCal Gas presentation mentions O&M costs at $48-66k per year on capital costs for interconnection of $1.3-1.9 million. Implies O&M costs about 3.5 percent of capital costs. (http://americanbiogascouncil.org/webinars/22may14_pipelineBiogasCA.pdf)
Above Ground Tank/Plug-Flow Digester Installed Capital Cost, $ per head (2,000 cows)	$ 1,459	6.0%	Capital cost is a function of herd size. According to UC Davis report, the capital cost for plug-flow digesters with electricity generation equipment can be estimated as C(x) = 18431x^-0.275, where C(x) is capital cost per cow and x is number of cows. For 2000 cows, which is the average dairy size for plug-flow digester projects in mixed pathway, the capital cost is $2,279/cow. This cost is reduced by 36 percent, which SusCon report says is the amount added by electricity generation equipment to capital cost estimates for digesters. Thus removing the generator set reduces capital costs about 36 percent. SusCon report estimates O&M costs for digesters range between 1.5% and 11%, but recent projects in California are in the range of 6%-11%. Because no electricity generation equipment here, low end of that range (6%) used here.
Above Ground Tank/Plug-Flow Digester Installed Capital Cost, $ per head (10,000 cows)	$ 937	6%	Same rationale as above, but assuming 10,000 cows per centralized digester. Most centralized digesters in these scenarios pull from well over 10,000 cows, but economies of scale assumed to be flat after 10,000 cows.
Solid Scrape Conversion, $ per head	$ 350	3%	ARB estimated value. O&M based on estimated O&M fraction of capital costs for scrape systems from UC Davis study.
Concrete pad, $ per head	$ 400	4.5%	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, for dairy with 2,000 cows. O&M based on O&M as a function of total average cost in UC Davis pathway.

Nutrient separation, $/head	$ -	$0	Suscon report says limited literature suggests costs of $50-$600 per cow. SusCon report says limited literature suggests operating costs of $25-200 per cow. Higher cost systems offer higher rates of nutrient recovery. Assumed costs here are mid of the range provided, and assumed revenues (below) represent mid value, as well. Assume $300/head capital cost and $100/head operating costs. Mid case revenue assumed at $194/head implies net revenue per head of about $50/year on an annualized basis for a 10-year period with 7 percent interest.
Low NOx natural gas truck, $	$ 250,000		SusCon report
Manure Transport, $/mile		$2	Estimated 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
Small fleet natural gas fueling station, each	$ 150,000	10%	Suscon report says $100,000-200,000 for a small (slow-fast) fuel station serving 6 trucks, and $550,000-$850,000 for fueling station serving 25-40 trucks fueling 5,000-8,000 gge per night. With average number of trucks per cluster at 1.7, assume the lower end here, knowing that extra capacity could perhaps fuel other farm equipment.
Commercial natural gas fueling station, each	$ 3,500,000	10%	Midpoint of CalBio assumptions for cluster project. Note that if selling commercial fuel, can probably get the value of diesel fuel, instead of wholesale natural gas price.
Above Ground Tank/Plug-Flow Digester w/ Microturbine, Installed Capital Cost, $ per head (2,000 cows)	$ 2,279	8.5%	Same as above, without discounting by 36 percent to remove electricity generation equipment. Cost equals 18431*2000^-0.275. UC Davis report suggests cost of microturbine same as cost for engine. Assume operating costs are average of 6-11 percent suggested for California in SusCon report, or 8.5 percent.
Above Ground Tank/Plug-Flow Digester w/ Microturbine, Installed Capital Cost, $ per head (10,000 cows)	$ 1,464	8.5%	Same as above, but for 10,000 cows.
Fencing cost, $/ft	$ 1	3%	
Irrigation Cost, $ per acre	$ 5,000	10%	
Shade Structure Cost, $ per structure	$ 6,500	2.5%	
Water Provision, $	$ 180	1%	
Revenues			
Biogas Price, $ per 1,000 cubic feet		$ 3.46	
Diesel Equivalent Price, $ per gallon		$ 2.609	
Low Carbon Fuel Standard Credits, $ per ton		$ 100	
SB1122 Feet In Tariff Price, $ per kWh		$ 0.1263	
Carbon Credit Price, $ per		$ 13	

ton			
RINs, $/diesel gallon equivalent		$ 1.85	ARB estimate for average value through 2030, based on AEO and other assumptions
Soil amendment products from digesters, $ per cow		$ -	National Market Potential study shows per cow revenue from recovered nitrogen, phosphorus and nutrient enriched fiber as being $128/year, $194/year, and $297/year in low, mid and high cases, respectively. Assume mid case ($194/cow) here, which when coupled with costs described in nutrient separation cost reference box above, implies net revenues per cow per year of about $50.
Production Potentials			
Manure per cow, lbs per day	140		UC Davis: http://energy.ucdavis.edu/files/09-16-2014-08_Biomass_Resource-and-Facilities-Database-Update.pdf
Manure moisture content	87%		UC Davis: http://energy.ucdavis.edu/files/09-16-2014-08_Biomass_Resource-and-Facilities-Database-Update.pdf
Volume of manure, lbs wet per cubic foot	62		http://pss.uvm.edu/vtcrops/articles/ManureCalibration.pdf
Dump truck capacity (can couple 2), cubic yards	20		http://www.mastersonloam.com/trucks/ and http://www.calrecycle.ca.gov/SWFacilities/Directory/38-AA-0020/Document/298055
Manure hauled per trip (using 2 bins per truck)	33.2		-
Biomethane produced, cubic feet per cow, per year	12,019		
Biomethane produced, cubic feet per cow, per day	32.93		Based on estimate for CNG production, and LCFS conversion factors
Electrical Generation Capacity, kW per cow	0.123		33% efficiency, (0.24 DGE/cow-day) * (134.47 MJ/DGE) / (3.6 MJ/kWh) = 8.965 kWh, then / (24hr/day) = 0.373; 0.373* 0.33 = 0.123
CNG Fuel Production, gallons diesel equivalent per cow per day	0.24		ARB inventory and UC Davis report assuming 100% methane utilization
RIN credits, per cow per year	145		LCFS LHV for CA ULSD of 127,460 Btu and 77,500 Btu per RIN under RFS2
BTUs produced, per cow per hour	1,535		
Pasture Conversion			
Affected cows	50,000		
Affected dairies	25		
Cows per acre	3		
Parcel size, acres	5		
Parcels needed	3,333		
Fencing per parcel, ft	1,980		
Water troughs per parcel	1		
Shade structures per parcel	1		
Conversion Factors			
Pounds per ton	2,000		
Metric tons per Megaton	1,000,000		

MMBTU conversion factor	2.108		
BTU per MMBTU	1,000,000		
Hours per year	8,760		
Days per Year	365		
Cubic yards per cubic foot	0.03737		
Emissions and Reductions			
Methane Mitigated, metric tons CO2E per head per year (100-year GWP)	7.38		Average emissions reduction, based on ARB's greenhouse gas inventory, for milking cow in California with manure managed under anaerobic conditions.
Methane Mitigated, metric tons CO2E per head per year (20-year GWP)	21.26		
Microturbine NOx Emission Rate (ARB DG), pounds per Megawatt hour	0.07		http://www.arb.ca.gov/energy/dg/2006regulation.pdf
Offsets generation per cow, MT per year	7.38		From SusCon report. Note difference in assumption of methane mitigated per cow
Dairy LCFS credits per 1000 scf (post-reg, 13)	0.068		
Dairy LCFS credits per 1000 scf (pre-reg, -276)	0.35		
Financial parameters			
Interest rate	7%		
Loan period, years	10		
Discount rate	5%		

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 Proposed Strategy recommends reducing organics deposited to landfills by 90 percent by 2025, consistent with AB341. This ambitious target requires 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. As outlined in the dairy manure Proposed Strategy, some organic materials can possibly be co-digested with dairy manure in appropriate centralized locations.

This analysis attempts to bound the potential cost of achieving the organic diversion target outlined in the Proposed 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 organic waste streams through 2030 and feasible diversion paths. These waste projections and paths are then used to develop three scenarios by which California can achieve the targets in the Proposed Strategy. The estimated costs and potential revenue streams for each strategy are then discussed.

1. Organic Waste Projection Through 2030

For all three scenarios, the future organic waste in landfills (Table 12) is estimated using the composition of California's waste stream in 2014[21] and assuming organic waste streams grow proportionally to population.[22] 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.[23]

As not all paper is included in the AB 1826 definition of organic waste, Table 12 includes two paper subcategories to approximate food-soiled paper waste, compostable other miscellaneous paper and compostable remainder/composite paper.[24] 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 outlined in the Proposed Strategy, 90 percent of the waste in Table 12 must be diverted by 2025.

[21] 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/wastechar/PubExtracts/2014/SigTableFig.pdf.
[22] California population estimates obtained from California Department of Finance, P-2 State and County Population Projections, accessed February 8, 2016 and available at: http://www.dof.ca.gov/research/demographic/projections/.
[23] AB 1826 text available at: http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB1826&search_keywords.
[24] These subcategories are estimated from the 2014 Disposal-Facility-Based Characterization of Solid Waste in California by CalRecycle.

Table 12: Waste Characterization Projection[25]

Waste Type		Estimated Landfill Waste with No Additional Diversion		
	2014 (Wet Tons)	2020 (Wet Tons)	2025 (Wet Tons)	2030 (Wet Tons)
Compostable Paper[26]	2,093,000	2,206,000	2,301,000	2,394,000
Food	5,591,000	5,892,000	6,146,000	6,394,000
Leaves and Grasses	1,173,000	1,236,000	1,289,000	1,341,000
Prunings and Trimmings	962,000	1,014,000	1,058,000	1,100,000
Branches and Stumps	528,000	557,000	581,000	604,000
Lumber	3,677,000	3,874,000	4,042,000	4,205,000
Remainder/Composite Organic	1,323,000	1,395,000	1,455,000	1,514,000
Total	**15,347,000**	**16,174,000**	**16,872,000**	**17,552,000**

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 13 estimates the percentage of material diverted to each type of facility over time to achieve the organic diversion target. These diversion options are illustrative and do not represent all pathways that may be employed.

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.[27] Holding this tipping fee constant through 2030 and assuming the organic diversion targets are met, revenue to California landfills could decrease by $550 million in 2020 and $700 million in 2030. 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.

[25] The waste projections included in this table have been rounded.
[26] Includes two paper subcategories to estimate food-soiled paper waste: other miscellaneous paper-compostable and remainder/composite paper-compostable.
[27] 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.

Table 13: Possible Organic Waste Diversion Pathways

Waste Type	Year	Estimated Distribution of Organic Waste					
		Landfill	Reduction or Recycle	Food Recovery	Compost	AD and/or Compost	Chip & Grind
Compostable Paper[28]	2020-2030	15%	10%		75%		
Food	2020	20%		10%		70%	
	2025-2030			20%		80%	
Leaves and Grasses	2020	40%			60%		
	2025-2030				50%	50%	
Prunings and Trimmings	2020	50%			50%		
	2025-2030				100%		
Branches and Stumps	2020-2030	25%			50%		25%
Lumber	2020	35%	5%				60%
	2025-2030	20%	10%				70%
Remainder / Composite Organic	2020-2030				100%		

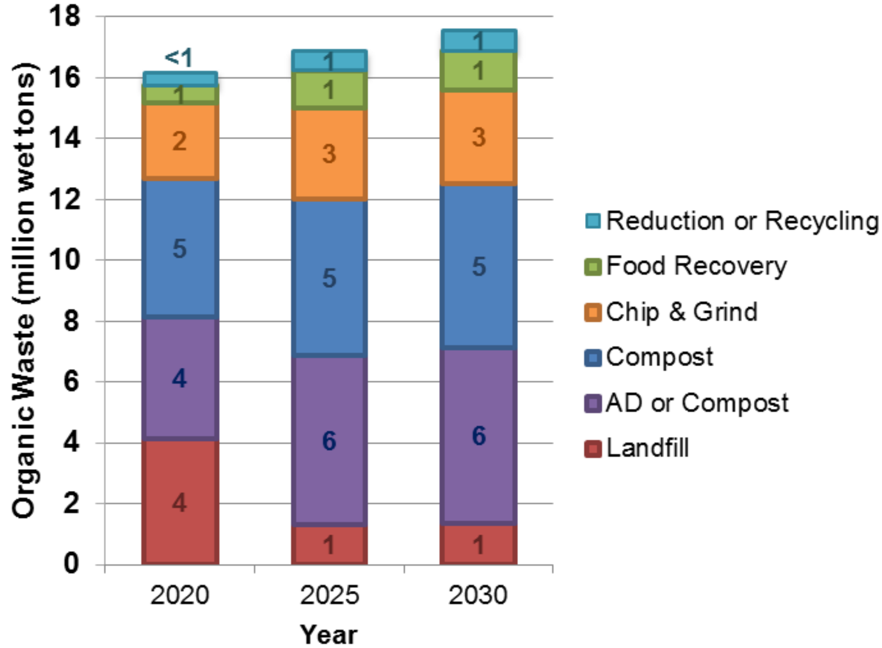
Conventional waste diversion options outlined in Figure 13 include composting, anaerobic digestion (AD), and chipping or grinding materials (Chip & Grind). In addition, reduction or recycling can be used to entirely avoid waste generation or reuse and recycle the waste before it reaches the landfill. 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.[29] In addition to generalized waste diversion goals, this Proposed Strategy recommends that California establish a food recovery goal of 10 percent by 2020 and 20 percent by 2025. In the Proposed Strategy, food recovery includes:

- Source Reduction - reducing the volume of surplus food generated in households and businesses
- Feeding the Hungry - donating extra food to food banks and shelters
- Feeding Animals - diverting food scraps to animal feed

[28] Includes two paper subcategories to estimate food-soiled paper waste: other miscellaneous paper - compostable and remainder/composite paper - compostable.
[29] 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.

Figure 2 outlines the portion of estimated organic waste diverted through the pathways in Table 13.

Figure 2: Proposed Organic Waste Utilization Pathways by Year



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 14 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 14, 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 2030.

Table 14: 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**

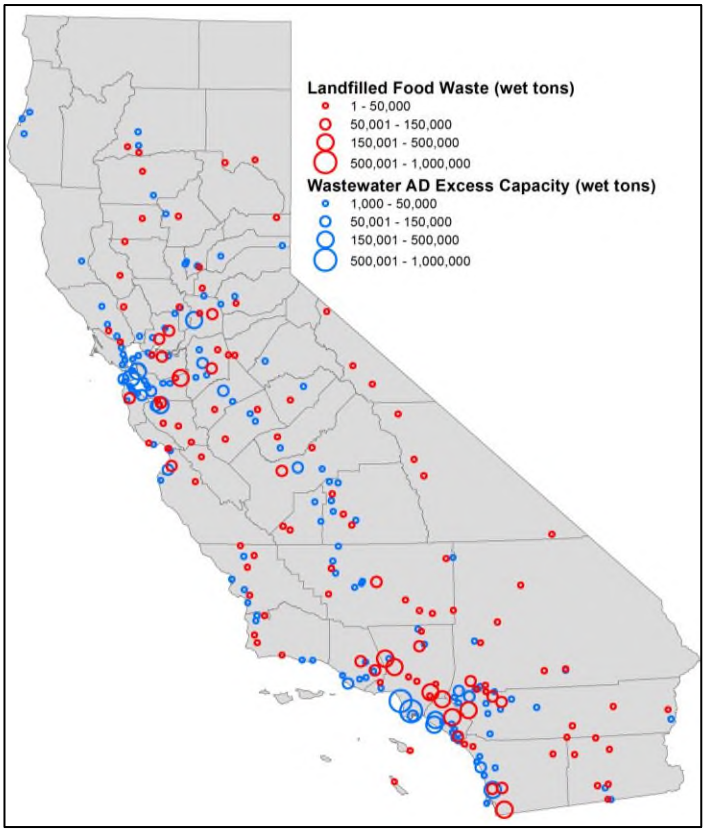
CalRecycle estimates the excess capacity at existing compost facilities based on the 2014 Disposal-Facility-Based Characterization of Solid Waste in California. California's compost needs in 2030 are estimated to range from 5 and 11 million wet tons per year.[30] Therefore, current excess composting 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.[31] The California Association of Sanitation Agencies (CASA) estimates existing excess capacity at wastewater treatment facilities for food waste and fats, oils, and grease is approximately 7 million wet tons per year (Table 16),[32] which could theoretically handle the 5 million wet tons of food waste that must be diverted in 2030 as well as the 650,000 wet tons of leaves and grasses that can be diverted to AD facilities.[33]

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 3. The analysis compared the match between landfilled food waste and wastewater treatment excess capacity to estimate the additional distance food waste would travel from landfill to wastewater treatment plant, finding that all food waste from landfills could 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. Utilizing landfills, rather than households, as the source of waste may result in economic and environmental trade-offs as waste transport and separation may be optimized on a local or regional, rather than state level.

[30] Figure 1, depends on the assumptions for how much waste is utilized by AD.
[31] US EPA (2016). https://www3.epa.gov/region9/waste/features/foodtoenergy/wastewater.html.
[32] 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.
[33] 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 3: Co-Location of Landfilled Food Waste and Wastewater Treatment Excess Capacity



2. Scenarios

The three scenarios are based on the projected waste data and potential diversion outlined in Table 13. All scenarios utilize 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 Table 13
- 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 Table 13
- 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 Table 13). The three scenarios evaluate the costs and revenues for utilizing food waste and grass and leaves in three pathways: all new anaerobic digestion facilities, all existing wastewater treatment anaerobic digestion facilities, and compost only. 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 Table 13 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 represent 36 percent of total waste digested at new AD facilities. 50 percent of AD digestate are utilized 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 Table 13 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 represent 36 percent of total waste digested at wastewater treatment facilities, 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 pay 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 2030, with some facilities accepting more or less depending on size.

Scenario 3 - New Compost Facilities

Scenario 3 assumes that all ‘Compost or AD’ materials in Table 13 are composted at new facilities, after filling existing excess capacity at compost facilities.

Waste Diversion By Scenario

Table 15 estimates the organic waste diverted by pathway for the various 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 15: Organic Waste Utilization by Scenario

Year	Waste Disposal 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
	Existing Compost Facilities	1.0	1.0	1.0
	New Compost Facilities	3.6	3.6	7.6
	New Compost Facilities for AD Biosolids	0.7	1.4	0.0
	New AD Facilities	4.0	0.0	0.0
	Existing WWTP AD	0.0	4.0	0.0
	Existing Chip and Grind	2.5	2.5	2.5
2025	Reduction, Recycle, Food Rescue	1.9	1.9	1.9
	Existing Compost Facilities	1.0	1.0	1.0
	New Compost Facilities	4.2	4.2	9.7
	New Compost Facilities for AD Biosolids	1.0	2.0	0.0
	New AD Facilities	5.6	0.0	0.0
	Existing WWTP AD	0.0	5.6	0.0
	Existing Chip and Grind	3.0	3.0	3.0
2030	Reduction, Recycle, Food Rescue	1.9	1.9	1.9
	Existing Compost Facilities	1.0	1.0	1.0
	New Compost Facilities	4.4	4.4	10.2
	New Compost Facilities for AD Biosolids	1.0	2.1	0.0
	New AD Facilities	5.8	0.0	0.0
	Existing WWTP AD	0.0	5.8	0.0
	Existing Chip and Grind	3.1	3.1	3.1

A principal difference in outcomes from these three scenarios is the number of new facilities needed to achieve the organic diversion targets. Table 16 shows the number of new compost or AD facilities needed for each scenario.

Table 16: Estimated Number of New Facilities

Scenario	Estimated Number of New Compost Facilities to Achieve Target			Estimated Number of New AD Facilities to Achieve Target		
	2020	2025	2030	2020	2025	2030
1. New AD	43	52	54	40	56	58
2. Existing WWTP	50	62	65	-	-	-
3. Compost Only	76	97	102	-	-	-

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 geographic region. Additional analysis on the relative economic and environmental impact of specific organic diversion strategies (including separating waste streams and centralized collection and processing) will be conducted as the organic diversion measures and programs are developed.

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 targets in the Proposed 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.[34] The report finds that the most cost-effective way to reduce food waste is through food waste prevention and recovery. 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.[35] 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 $55 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.[36] 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

[34] 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.

[35] 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.

[36] 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.

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 17.[37] Gore ASP compost facilities have demonstrated the ability to meet strict VOC emission 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 17: 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[38]
Total Cost	**$16,500,000**

Table 18 presents the estimated costs and revenue stream for a representative new compost facility. 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.[39] While co-location of landfills and compost facilities is ideal, this analysis assumes, on average, a 40-mile 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.

[37] Costs estimates based on information provided by CalRecycle.
[38] 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.
[39] https://archive.epa.gov/region9/organics/web/html/index-2.html

Table 18: Estimated Costs and Revenue per Compost Facility Through 2030[40]

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**
Net Present Value (2016-2030)	**-$2,100,000**		

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 - $2.1 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,[41] 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[42], while the sale of compost in San Francisco and Palo Alto has been recorded at $12 to $26 per ton.[43]

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

[40] Capital costs are amortized over 10 years with 7% interest. The discount rate is 5% and all values are rounded.

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

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

[43] 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

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 will upgrade to allow food waste generated biogas to be pipeline injected. Though more costly, this approach ensures minimal increase in co-pollutant emissions, especially NOx. Approximately 302 miles of new natural gas pipeline is required for the 118 facilities to inject biomethane into the natural gas system. Three miles of pipeline is apportioned to each facility in the cost calculation. The remaining 24 facilities are excluded from the analysis as they do not represent economically feasible organic diversion options for pipeline injection and their excess capacity is not necessary to meet the organic diversion goals.

The analysis only considers the incremental biogas produced from the addition of food waste to the wastewater treatment facility, and excludes potential biogas production from grass and leaves.[44] 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 28 represents an illustrative facility that processes 45,000 tons of food waste[45] and produces approximately 175 million standard cubic feet (scf) of biomethane each year for injection into the natural gas pipeline.[46] This generates revenues streams from sale of CNG fuel, LCFS credits, and RINs as outlined in Table 19.

[44] Grass and leaves may also be diverted to AD facilities that handle dairy manure either at a centralized location or on an individual farm as outlined in the dairy manure section of the Proposed Strategy.
[45] 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.
[46] 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 19: Estimated Cost and Revenue per Existing Wastewater Treatment Facility[47]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Organic Processing Facility and Facility Upgrades	$8,000,000	$800,000	
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	$1,000,000	$50,000	
Biogas Upgrading		$1,400,000	
Tipping Fee			$3,250,000
Fuel Sales			$600,000
LCFS Credits (CNG020)			$1,350,000
RINs			$4,300,000
Total	**$12,500,000**	**$4,300,000**	**$9,500,000**
Net Present Value (2016-2026)	**$26,800,000**		

The calculations outlined in Table 19 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,[48] assuming a LCFS credit price of $100 and a total RIN value of $1.85.[49] To further explore sensitivity to LCFS credit and RIN pricing, Table 20 presents the 10-year net present value of diverting organic waste to wastewater treatment facilities under a range of LCFS credit and RIN prices.

[47] Capital costs are amortized over 10 years with 7% interest. The discount rate is 5% and all values are rounded.
[48] 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.
[49] 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 (April 6, 2016), suggests that cellulosic RINs could be worth about $2.10.

Table 20: Net Present Value of Wastewater Treatment Facility Under Varying LCFS Credit and RIN Credit Prices (Million Dollars)

		Wastewater Treatment Facility				
		LCFS Credit Prices				
		$0	**$50**	**$100**	**$150**	**$200**
Cellulosic RIN Credit Prices	**$0.00**	-$17.0	-$12.1	-$7.2	-$2.2	$2.7
	$0.50	-$8.1	-$3.1	$1.8	$6.7	$11.7
	$1.00	$0.9	$5.8	$10.8	$15.7	$20.7
	$1.85	$16.3	$21.2	$26.1	$31.1	$30.0
	$2.50	$27.9	$32.9	$37.8	$42.8	$47.8
	$3.00	$36.9	$41.9	$46.9	$51.8	$56.8
	$3.50	$46.0	$50.9	$55.9	$60.8	$65.8
	$4.00	$55.0	$59.9	$64.9	$69.9	$74.8

For the facility outlined in Table 19, net present value is negative without the revenue generated from LCFS credits or RINs. 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 28 would break even over a 10-year financing period with an upfront grant of $16 million. Looking at LCFS credits and RINs in isolation, without revenue from LCFS credits, this illustrative facility would break even with a RIN price of $1 over the 10-year financing period. In the absence of revenue from RINs, the facility would breakeven at an LCFS credit price of $173. The US EPA's Renewable Fuel Standard (under which RINs are generated and sold) and California's LCFS program can offset large upfront capital costs that otherwise may prevent project development.

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.[50] 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 large 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.

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

g. New Anaerobic Digesters

Table 21 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.[51] 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.[52] 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

[51] 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 33. The calculation is based on EPA's CoEAT tool available at: https://archive.epa.gov/region9/organics/web/html/index-2.html.

[52] 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 21: Estimated Cost and Revenue per New Anaerobic Digester[53]

Component	Capital Cost	Average Annual O&M Cost	Average Annual Revenue
Anaerobic Digester	$20,000,000[54]	$2,000,000	
Organic Processing Facility	$8,000,000	$800,000	
CNG Vehicles (2)	$500,000	$50,000	
Organic Waste Transportation		$900,000	
Digestate Processing		$975,000	
Digestate Transportation		$420,000	
Pipeline	$3,000,000	$150,000	
Pipeline Interconnection	$1,000,000	$50,000	
Biogas Upgrading		$2,500,000	
Tipping Fee			$6,500,000
Fuel Sales			$1,300,000
LCFS Credits (CNG005)			$4,000,000
RINs			$9,500,000
Total	**$32,500,000**	**$7,845,000**	**$21,300,000**
Net Present Value (2016-2026)	**$70,200,000**		

The calculations outlined in Table 21 are highly sensitive to assumptions regarding the price of LCFS credits and RINs. To further explore sensitivity to LCFS credit and RIN pricing, Table 22 presents the 10-year net present value of diverting food waste to new AD facilities under a range of LCFS credit and RIN prices.

[53] Capital costs are amortized over 10 years with 7% interest. The discount rate is 5% and all values are rounded.
[54] Digester cost for facility with 100,000 tons per year throughput obtained at: https://fortress.wa.gov/ecy/publications/publications/1207036.pdf.

Table 22: 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 Prices				
		$0	$50	$100	$150	$200
Cellulosic RIN Credit Prices	$0.00	-$34.4	-$18.9	-$3.4	$11.9	$27.3
	$0.50	-$14.4	$0.9	$16.4	$31.8	$47.3
	$1.00	$5.4	$20.9	$36.3	$51.8	$67.2
	$1.85	$39.3	$54.8	$70.2	$85.6	$101.1
	$2.50	$65.2	$80.7	$96.1	$116.7	$133.9
	$3.00	$85.2	$100.6	$116.0	$131.5	$146.9
	$3.50	$105.1	$120.5	$136.0	$151.4	$166.9
	$4.00	$125.0	$140.5	$155.9	$171.4	$186.8

As outlined in Table 22, 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 21 viable. In the absence of revenue from the sale of LCFS credits, a RIN price of $0.87 is required for the facility to breakeven over a 10-year financing period. In the absence of RIN credit revenue, an LCFS credit price of $112 is required for the facility to breakeven over a 10-year financing period.

Without revenue from RINs or LCFS credits, an upfront grant of $32 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 $1 to $2 billion dollars and with potential cumulative revenue ranging from $2 to $5 billion through 2030. 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 23 presents the state wide cumulative capital costs, O&M costs, and revenue for each scenario, across all facilities needed to achieve the 2030 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 23 are estimated through 2030. Additional amortized capital payments continue through 2039 (as facilities are phased in over time) and annual O&M costs and revenues continue beyond 2030 for all three scenarios. O&M costs and revenues remain constant through 2030 this analysis. Scenario 1 and 2 show positive returns through 2030 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 23: Cumulative Estimated Costs and Revenues by Scenario Over 10-Year Accounting Period (Million Dollars)

Scenario 1: New AD	Component	Capital Cost	O&M	Revenue
New AD	54 Facilities	$1,200	$2,100	$5,800
New Compost	58 Facilities	$600	$650	$1,200
Total		**$1,800**	**$2,750**	**$7,000**
10-Year Net Present Value		**$2,500**		
Scenario 2: WWTP	**Component**	**Capital Cost**	**O&M**	**Revenue**
New Compost	65 Facilities	$720	$790	$1,500
Existing Wastewater Treatment	118 Facilities	$1,300	$3,700	$5,100
Total		**$2,020**	**$4,490**	**$6,600**
10-Year Net Present Value		**$162**		
Scenario 3: Compost	**Component**	**Capital Cost**	**O&M**	**Revenue**
New Compost	102 Facilities	$1,000	$1,100	$2,100
Total		**$1,000**	**$1,100**	**$2,100**
10-Year Net Present Value		**-$43**		

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.[55] 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 Proposed Strategy and deliver other environmental benefits.

5. Cost Assumptions Used for All Scenarios

Table 24 contains the assumptions used in each scenario, along with references.

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

Table 24: Assumptions

Costs	Capital	O&M	References
Natural gas transmission pipeline or urban low pressure pipeline ($/mile)	$ 1,000,000	5%	http://americanbiogascouncil.org/webinars/22may14_pipelineBiogasCA.pdf
On-site biogas upgrading system ($/1000 scf)		$ 8	http://www.suscon.org/news/pdfs/GHG_Mitigation_for_Dairies_Final_July2015.pdf
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 ($)	$ 1,000,000	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	$ 8,000,000	10%	Estimated cost of East Bay MUD and Central Marin processing stations. http://nepis.epa.gov/Adobe/PDF/P100LDEL.pdf.
Anaerobic digester (100,00 TPY capacity)	$20,000,000	10%	Estimated cost of San Jose ZNW Facility
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.
Biosolids ($/ton)		$ 12	http://www.cityofpaloalto.org/civicax/filebank/documents/15113
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

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. Still HFC emissions in California are expected to grow by more than 60 percent without additional action (as outlined in Figure 10 in Section VI).

The Proposed 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
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.[56]

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 beginning January 1, 2020 for non-residential refrigeration, and January 1, 2021 for residential refrigerator-freezers. The proposed measure also prohibits refrigerants with a 100-year GWP of 750 or greater for new air-conditioning equipment in the stationary air-conditioning beginning January 1, 2021, for both residential and non-residential.

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

Table 25 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).

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

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

Equipment Sector	General Description of Sector	Average Equipment Cost per Unit[57]	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
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

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

Equipment Sector	General Description of Sector	Average Equipment Cost per Unit[57]	Incremental Cost of Low-GWP Unit
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 26 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.

Table 26: 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[58]
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[59] 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[60], 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%	

[58] 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.

[59] 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.

[60] 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).[61] 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 27 shows the projected savings resulting from the use of low-GWP equipment

[61] 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 27: Estimated Low-GWP Equipment Savings[62]

Sector	Low-GWP Added Energy Efficiency	Annual Electricity Savings	Annual Refrigerant (lbs)	Annual Refrigerant Savings[63]	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

[62] Numbers may not add due to rounding.
[63] 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[63]	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 28 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 28: Estimated Net Cost of Low-GWP Equipment, Prohibition Measure[64]

Sector	Average Lifetime (yr)	Added Equipment Cost ($/yr)[65]	Annual Cost (Savings) ($/unit)	Estimated Units Replaced per Year[66]	Estimated Annual Net Cost (Savings)[67]
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

[64]Numbers may not add due to rounding.
[65] 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.
[66] 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.
[67] 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 ($/yr)[65]	Annual Cost (Savings) ($/unit)	Estimated Units Replaced per Year[66]	Estimated Annual Net Cost (Savings)[67]
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[68]					**$20,225,000**

[68] The annual cost would be applied for each year of the model year or cohort's lifetime. Table 28 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 34 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 methodology used to estimate the cost and savings of an HFC supply phasedown in 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 29.

Table 29: Estimated Net Cost of Low-GWP Equipment, HFC Phasedown Measure[69]

Sector	Average Lifetime (yrs)	Added Equipment Cost ($/yr)[70]	Annual Cost Savings ($/unit)	Estimated New Units[71] and Equipment	Estimated Annual Net Cost (Savings) ($/yr)[72]
Centralized System Large (2,000+ lbs)	15	$12,000	($15,000)	50	($189,000)

[69] Numbers may not add due to rounding.
[70] 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.
[71] 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.
[72] The annual cost would be applied for each year of the model year or cohort's lifetime. Table 29 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 34 of the Appendix.

Sector	Average Lifetime (yrs)	Added Equipment Cost ($/yr)[70]	Annual Cost Savings ($/unit)	Estimated New Units[71] and Equipment	Estimated Annual Net Cost (Savings) ($/yr)[72]
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
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[73]					**$14,115,000**

[73] The annual cost would be applied for each year of the model year or cohort's lifetime. Table 29 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 35 of the Appendix.

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 30 shows the estimated incremental equipment cost of an incentive program for new equipment and retrofits. The cost assumptions in Table 30 are the same as those used for high-GWP prohibitions outlined in Table 28. 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.

Table 30: Estimated Cost and Savings of Incentive Program for New Low-GWP Equipment (Per Piece of Equipment)

Sector	Average Lifetime (yrs)	Baseline Average Cost of Equipment	Incremental Cost for Low-GWP Equipment	Lifetime Cost	Annual Cost	Net Cost (Savings) ($/yr)
Centralized System Large[74] (2,000+ lbs)	15	$1,000,000	$200,000	($231,000)	($15,000)	($2,000)
Centralized System Medium[75] (200-2,000 lbs)	15	$250,000	$50,000	($55,000)	($4,000)	($500)
Refrigerated Condensing Units Small[76] (50-200 lbs)	15	$75,000	$15,000	($15,000)	($1,000)	$25
Refrigerated Condensing Units[77] (Less than 50 lbs)	20	$37,500	$7,500	($10,000)	($500)	($250)
Stand-Alone Refrigerated Display Cases[78]	20	$5,000	$1,000	($1,000)	($25)	$50

[74] The analysis assumes one per supermarket.
[75] The analysis assumes three to four per supermarket and one to two per grocery store.
[76] The analysis assumes one to three per grocery store.
[77] The analysis assumes up to several per small market.
[78] The analysis assumes several per small market and more for larger markets.

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 31 shows the cost of an incentive program to retrofit existing high-GWP equipment and Table 32 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 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 31: Estimated Cost and Savings of Incentive Program for Retrofit of Existing Low-GWP Equipment (Per Piece of Equipment)[79]

Sector	Post-Retrofit Remaining Life[80] (yrs)	One-Time Retrofit Cost ($/unit)	Lifetime Cost (Savings)	Added Annual Cost	Number of Equipment (unit/yr)	Net Cost (Savings) ($/yr)
Centralized System Large[81] (2,000+ lbs)	10	$80,000	($141,000)	$8,000	($14,000)	($6,000)
Centralized System Medium[82] (200-2,000 lbs)	10	$30,000	($31,000)	$3,000	($3,000)	($100)
Refrigerated Condensing Units Small[83] (50-200 lbs)	13	$6,000	($10,000)	$500	($1,000)	($300)
Refrigerated Condensing Units[84] (Less than 50 lbs)	13	$3,000	($7,000)	$250	($50)	($300)
Stand-Alone Refrigerated Display Cases[85]	13	$250	($500)	$50	($50)	($25)

[79] Numbers may not add due to rounding.
[80] Assumed to be 2/3 of total equipment lifetime.
[81] The analysis assumes one per supermarket.
[82] This analysis assumes three to four per supermarket and one to two per grocery store.
[83] This analysis assumes one to three per grocery store.
[84] This analysis assumes up to several per small market.
[85] This analysis assumes several per small market and more for larger markets.

Table 32: Estimated Annual Costs and Savings of Voluntary Incentive Program (Per Piece of Equipment) [86]

Sector	Incentive: New Equipment or Retrofit Existing	Added Annual Cost	Annual Cost (Savings)	Net Cost (Savings)	Pieces of Equipment (unit/yr)	Net Cost (Savings) ($/yr)
Centralized System Large (2,000+ lbs)[87]	New	$13,000	($15,000)	($2,000)	45	($91,000)
	Retrofit	$8,000	($14,000)	($6,000)	56	($340,000)
Centralized System Medium[88] (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[89] (50-200 lbs)	New	$1,000	($1,000)	$25	150	$3,000
	Retrofit	$500	($750)	($300)	3,800	($1,107,000)
Refrigerated Condensing Units[90] (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[91]	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 not use very-high GWP refrigerants and would not be affected by the sales ban. The

[86] Numbers may not add due to rounding. Estimated costs and savings are for participating businesses only.
[87] The analysis assumes one per supermarket.
[88] This analysis assumes three to four per supermarket and one to two per grocery store.
[89] This analysis assumes one to three per grocery store.
[90] This analysis assumes up to several per small market.
[91] This analysis assumes several per small market and more for larger markets.

retrofit cost shown in Table 33 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 33: Estimated Cost and Savings of Sales Ban of Very-High GWP Refrigerants (Per Piece of Equipment)[92]

Sector	Post-Retrofit Remaining Life[93] (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.

Table 34 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 33 shows the cost per year of a scenario where the retrofit rate is approximately 10 percent of existing very-high GWP equipment.

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

Table 34: Estimated Cost and Saving of a Very-High GWP Sales Ban (Per Year of Measure)[94]

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 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.

[94] Numbers may not add due to rounding.

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 could begin in 2019 and continue with a gradual phasedown in the supply until the new total allocation (as measured in CO_2e) would be 85 percent less than baseline. By 2025, the analysis finds that 63 percent of all new equipment will 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 35 shows the estimated cost, by year, and also aggregated cost and savings through 2030.

Table 35: 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	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**