



**Agriculture, Forestry, and Waste Management Technical Work Group
Summary List of Draft Priorities for Analysis**

	Policy Option	GHG Reductions (MMtCO ₂ e)			Net Present Value 2007–2020 (Million \$)	Cost-Effectiveness (\$/tCO ₂ e)	Level of Support
		2012	2020	Total 2007-2020			
	AGRICULTURE, FORESTRY, AND WASTE MANAGEMENT						
AFW-1	Agricultural Crop Management						TBD
AFW-2	Manure Management and Energy Utilization						TBD
AFW-3	Reductions in On-Farm Energy Use - Diesel - Electricity	0.02	0.06				TBD
AFW-4	Biodiesel Production						TBD
AFW-5	Ethanol Production	0.2	3.1	15	58	3	TBD
AFW-6	Preserve Lands with Carbon Storage Value						TBD
AFW-7	Biomass Feedstocks for Energy Production						TBD
AFW-8	Forestry Programs to Enhance GHG Benefits	0.2	-0.3	0.8			TBD
AFW-9	Source Reduction, Enhanced Recycling and Composting Programs						TBD
AFW-10	Landfill Methane Reduction Programs						TBD
	SECTOR TOTAL AFTER ADJUSTING FOR OVERLAPS						
	REDUCTIONS FROM RECENT ACTIONS (table to be added below)						
	SECTOR TOTAL PLUS RECENT ACTIONS						

AFW-1. Agricultural Crop Management

Mitigation Option Description

The amount of carbon stored in the soil can be increased by crop management practices that increase C inputs to soil and/or reduce soil organic matter decomposition rates. Adoption of conservation tillage, in particular no-till, can increase soil C stocks. Reducing mechanical soil disturbance reduces the oxidation of soil carbon compounds and allows more stable aggregates to form. Other benefits of conservation tillage include reduced wind and water erosion, improved soil structure and crop water use, reduced fuel consumption, and improved wildlife habitat. On non-irrigated cropland, increased cropping frequency to reduce or eliminate summer fallow goes hand in hand with adopting no-till practices. Improved nutrient management (i.e. better timing, application rates based on soil test, advanced fertilizer formulations, etc.) of both fertilizer and manure can increase nutrient use efficiency and reduce addition rates, thereby reducing nitrous oxide emissions and potentially fossil fuel use. For some production systems, organic farming practices result in lower net GHG emissions. Application of biochar (i.e. stable organic residues from biomass pyrolysis) to soils is a potential practice to capture and sequester atmospheric CO₂.

Mitigation Option Design

Goals:

- **No-Till Goal:** approximately 15% of total annual cropland is currently managed under no-till (most with reduced summer fallow). Achieve 50% no-till by 2020.
- **Nutrient Goal:** Increase nitrogen fertilizer efficiency by 20% through the use of best management practices by 2020.

Timing:

- **No-Till:** 30% no-till on annual croplands by 2012; achieve the full goal by 2020.
- **Nutrient Goal:** Increase fertilizer efficiency by 10% by 2012; achieve the full goal by 2020.
- **Parties involved:** To be determined (TBD).

Other: Current (2005) Colorado cropland: 1,923,000 ha dryland; 924,000 ha CRP; 1,000,000 ha irrigated cropland (~50% as hay).¹

Implementation Mechanisms

- **Increased extension/outreach (a good field-day program for dryland systems, through CSU researchers. has been developed over the past several years – could benefit from more resources). Extension related to nutrient management. ??**

¹ INSERT REFERENCE

- State incentives – e.g. favorable property tax rating for ‘high conservation management.’ ?
- R&D support for cropping systems research – e.g. selection/field studies on profitable oil seeds for inclusion in dryland rotation (cross reference to biodiesel incentives).
- Incentives for water conservation/more flexible water allocation could likely play in some way.

Related Policies/Programs in Place

Federal Conservation Compliance programs (but probably don’t specifically award for no-till and reduced summer fallow); possible upcoming provisions in Farm Bill (US or CO?).

Market-based incentives – e.g. CCX (Chicago Climate Exchange) project with the Rocky Mountain Farmer’s Union (RMFU).

Types(s) of GHG Reductions

- **CO₂:** Reducing tillage and soil disturbance slows the breakdown of plant material on the soil surface and in the root zone, accelerating the microbial processes that stabilize carbon and protecting carbon from oxidation, inhibiting the release of carbon back into the atmosphere. Additionally, reducing the amount of nitrogen fertilizer needed will reduce CO₂ emissions that result from the fertilizer manufacturing process.
- **N₂O:** Increasing the efficiency of nitrogen fertilizer application is expected to reduce N₂O emissions.
- Improved cultivation methods will reduce all GHG emissions that result from the combustion of distillates and other fossil fuels related to the use of farm equipment. However, this reduction is captured by AFW-3 and will not be quantified under this option.

Estimated GHG Savings and Costs per MtCO₂e

Note: The Metric unit “ha” is used in the analysis of this option, rather than the standard unit, acres. The GHG reductions above and costs below do not reflect the organic production incentives elements of this option. Because agricultural soils will only accumulate carbon up to a certain level before tapering off, the GHG benefit related to no-till soil carbon accumulation decreases in the post-2020 period before ceasing in 2025. The remaining benefit, which is permanent, is associated with lower fossil fuel consumption.

- **GHG reduction potential in 2012, 2020 (MMtCO₂e):**
 - No-till: 1.26, 0.71
 - Nitrogen Fertilizer Efficiency: TBD
- **Net Cost per MtCO₂e:**
 - No-till: -\$11.45
 - Nitrogen Fertilizer Efficiency: TBD

Data Sources:

Quantification of the no-till portion of this option is based upon 3,847,000 hectares of agricultural land in Colorado. This land is comprised of dryland, CRP, and irrigated land. Using standard unit conversions, the soil carbon accumulation rate of 1.37 MtCO₂/ha-yr was calculated from the midpoint of the range provided by Naderman *et al.*² The estimated cost savings (\$14.33 per hectare) related to the adoption of no-till farming was derived from an article by Tim McAlvay, of Texas A&M.³ The reduction in fossil diesel fuel use from the adoption of conservation tillage methods is 3.5 gallons/acre.⁴ From the CO Inventory & Forecast, the fossil diesel GHG emission factor is 8.37 MtCO₂e/1,000 gallons.

- Nitrogen management to reduce application rates while maintaining yields (i.e. increasing N use efficiency) – every one Mt of N in fertilizer savings yields as much as 50 MtCO₂ reduction (using Global Warming Potential for N₂O of 310 and assuming 1% N₂O-N emission per unit N added – IPCC default).
- Estimated rates 0.2 Mg C/ha-yr (0.75 MtCO₂/ha-yr) on dryland; 0.3-0.4 Mg C/ha-yr (1.1-1.5 MtCO₂/ha-yr) on irrigated cropland with no-till and reduced summer fallow (on dryland) adoption.
- Long-term dryland cropping systems research @ Sterling, Stratton, Walsh, Akron, Briggsdale – other relevant experiments in neighboring states (western KS, NE).
- Irrigation/tillage/fertilizer experiments at ARDEC, Ft. Collins.
- New reduced irrigation trials in northeast CO.
- Preliminary C and GHG emissions inventory.

Quantification Methods:

Based on the policy design parameters, the schedule for acres to be put into conservation tillage/no-till cultivation are shown in the table below. The mid-point of the estimated range for carbon sequestration (2.47 short tons/ha) in agricultural soils was used to estimate the total amount of carbon to be sequestered. Based on the Naderman et al study referenced above, it was further assumed that this additional carbon would be sequestered in the soil over a period of six years (after six years no further carbon is stored). The resulting annual carbon accumulation rate was converted into its CO₂ equivalent yielding 1.37 MtCO₂/ha-yr.

To estimate carbon stored each year, the annual accumulation rate was multiplied by the number of acres in the policy program each year. After six years, the crop acres that entered the program were assumed to not store additional carbon. Results are shown in the table below.

Additional GHG savings from reduced fossil fuel consumption were estimated by multiplying the fossil diesel emission factor and diesel fuel reduction per acre estimate provided above.

² Naderman, G., B.G. Brock, G.B. Reddy, C.W. Raczkowski, Long Term No-Tillage: Effects on Soil Carbon and Soil Density Within the Prime Crop Root Zone, Project Report, January 2006.

³ Tim McAlvay. AgNews News and Public Affairs: Texas A&M University System Agriculture Program. April 27, 2005. Accessed on July 11, 2007. Actual estimate is -\$5.80 per acre. Converted here to metric units.

⁴ Reduction associated with conservation tillage compared to conventional tillage, at <http://www.ctic.purdue.edu/Core4/CT/CRM/Benefits.html>, accessed August 2006.

Results are shown in the table below along with a total estimated benefit from both carbon sequestration and fossil fuel reductions.

Year	Hectares in Program	Hectares still accumulating carbon	MMtCO ₂ e Sequestered	Diesel Saved (1,000 gal)	MMtCO ₂ e from Diesel avoided	Total MMtCO ₂ e saved
2006	438,450	0	0.000	0	0.0000	0.0000
2007	511,525	511,525	0.700	4,422	0.0370	0.7375
2008	584,600	584,600	0.801	5,054	0.0423	0.8429
2009	657,675	657,675	0.901	5,686	0.0476	0.9482
2010	730,750	730,750	1.001	6,317	0.0529	1.0536
2011	803,825	803,825	1.101	6,949	0.0582	1.1589
2012	876,900	876,900	1.201	7,581	0.0635	1.2643
2013	949,975	438,450	0.600	8,213	0.0688	0.6692
2014	1,023,050	438,450	0.600	8,844	0.0741	0.6745
2015	1,096,125	438,450	0.600	9,476	0.0794	0.6798
2016	1,169,200	438,450	0.600	10,108	0.0847	0.6851
2017	1,242,275	438,450	0.600	10,739	0.0899	0.6903
2018	1,315,350	438,450	0.600	11,371	0.0952	0.6956
2019	1,388,425	438,450	0.600	12,003	0.1005	0.7009

Costs were estimated by multiplying the estimated savings per acre cited above (\$14.33) by the number of acres in the program each year. The effects of other existing incentive programs were not taken into account in these estimates. The resulting cost effectiveness of no-till cultivation is a cost savings of \$11.45/MtCO₂e.

- Project the “business as usual” (BAU) fertilizer use in order to determine the target schedule for the increase in fertilizer efficiency.
- Determine the life-cycle emission factor of fertilizer by adding the emissions that result from manufacturing to the emissions that result from manufacturing.
- Calculate the net cost of fertilizer efficiency improvement by subtracting the cost of implementing on-farm nutrient management from the averted cost of fertilizer.
- Process model-based inventory methods using Century and DayCent models, with uncertainty estimates based on Monte-Carlo and linear mixed-effect model approaches, at CSU

Key Assumptions: C maintenance (i.e. ‘permanence’ issue)

Key Uncertainties

Data on N₂O emissions is still sparse.

Need for low-intensity ‘in field’ soil C monitoring to decrease uncertainty (i.e. benchmark sites) in soil C sequestration estimates.

Additional Benefits and Costs

Rocky Mountain National Park N-Deposition MOU

Erosion reduction, air and water quality, wildlife habitat, increased net returns.

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD

AFW-2. Manure Management and Energy Programs

Mitigation Option Description

The methane emissions inherent from the anaerobic decomposition process of manure and other wastes may be captured and used as an energy source. Methane and nitrous oxide emissions can occur at several different places in the manure management process. Management techniques can also reduce GHG emissions and, with energy recovery, offset fossil-based energy. This option covers producer incentives to adopt programs to increase the number of methane capture and energy recovery projects or other manure management techniques that reduce methane and nitrous oxide emissions.

Mitigation Option Design

Goals: Implement manure management and energy programs (where feasible for adoption by the facility) on 80% of animal feeding operations (AFOs) by 2020.

- **Timing:** Implement programs on 10 AFOs by 2012; achieve the full goal by 2020.
- **Parties involved:** TBD
- **Other:** Currently, one housed commercial swine feeding operation utilizes a methane digester to produce power for facility use and one additional AFO is developing a manure energy recovery strategy.

Implementation Mechanisms

- Work with the Colorado Office of Energy to develop a pilot program to help fund manure energy recovery systems that are specific to the site and the operation. The pilot program would include a CAFO, a dairy and a swine operation.

Related Policies/Programs in Place

1) CDPHE, EPA and the NPS are participating in developing a Rocky Mountain National Park Nitrogen Deposition Reduction Plan. Part of the plan utilizes current Best Management Practices (BMPs), as well as on-going research into additional BMPs that can be used to reduce nitrogen emissions from livestock operations.

2) Recent state legislation that requires local cooperatives to purchase power generated from renewable resources could provide markets for energy generated from AFOs.

Types(s) of GHG Reductions

- **CH₄:** methane is captured and typically combusted in an energy recovery system or flare. Small amounts of N₂O and CH₄ are emitted from the combustion process.

- **CO₂**: carbon dioxide is reduced when the methane is converted to energy and that energy is used to offset fossil-based energy (e.g., electricity, natural gas, etc.). Small amounts of N₂O and CH₄ are also reduced from the fossil-based energy that is offset.

Estimated GHG Savings and Costs per MtCO₂e

- **GHG reduction potential in 2012, 2020 (MMtCO₂e):** TBD
- **Net Cost per MtCO₂e:** TBD

Data Sources: CO GHG Inventory & Forecast (I&F data), digester and engine generator set cost data from EPA and the literature, assume 75% of methane generated at AFO is collected, value of generated electricity (\$0.05/kW-hr),

Quantification Methods:

- Identify existing AFOs and populations with energy recovery in Colorado.
- Project populations to 2020 based on I&F assumptions.
- Determine incremental populations to achieve policy goals by 2020.
- Estimate methane reduced from these populations in 2012 and 2020 based on collection efficiency.
- Estimate GHGs reduced from electricity generated, which offsets grid-based power.
- Estimate capital and annual costs based on identified cost data. Annualize these costs per head of livestock for each livestock type (dairy, feedlot cattle, hogs).
- Determine cost effectiveness from emission reductions and annualized costs in each year.

Key Assumptions: TBD

Key Uncertainties

1) The minimum cost for developing a manure energy recovery system on an AFO facility is one million dollars. Without significant federal or state government assistance (50% - 100%) in developing the generation infrastructure, developing an energy recovery system for an AFO is not feasible for most operators.

2) The operator needs to have a buyer for the power generated or needs to receive a price per kilowatt for the power generated that provides an reasonable rate of return on the investment.

Additional Benefits and Costs

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD

AFW-3. Reductions in On-Farm Fossil Energy Use

Mitigation Option Description

This option seeks to develop and implement cost effective programs for renewable energy (biofuels, renewable electricity generation) and energy efficiency technologies for farmers and ranchers. Reductions in fossil fuel consumption reduce emissions of carbon dioxide, methane, nitrous oxide, and black carbon.

Mitigation Option Design

Goals:

- **Fossil fuel reduction goal:** 20% reduction in petro-diesel use by 2020.
- **Electricity reduction goal:** 40% includes reductions from electricity efficiency and on-site generation using renewable energy (solar, wind, hydro).

Timing:

- **Fossil fuel reduction goal:** Achieve 5% reduce consumption by 2012. Achieve the full policy goal by 2020.
- **Electricity reduction goal:** Achieve 10% reduce consumption by 2012. Achieve the full policy goal by 2020.

Parties involved: Colorado Rural Electric Associations, State Agriculture Organizations, Governors Office of Energy Management and Conservation, Colorado Department of Agriculture, Businesses providing energy efficiency and renewable energy equipment.

Other: As needed, identify incentives that encourage the growing and supply of feedstocks, and the utilization of ethanol in transportation markets across the state.

Implementation Mechanisms

- Colorado state government and others should work with rural electric associations in developing programs or businesses for services and products to increase energy efficiency and conservation. Develop group purchasing options and coordinate installation of products to lower costs.
- Develop state standards for ownership renewable energy credits (RECs) to be utilized by rural electric associations for upfront incentives in the form of a rebates (e.g. \$2 per watt of installed renewable energy generation on a farm or ranch). The REA's ownership of RECs would allow REAs to count the production over the life of the project toward the 10% renewable energy standard under HB 1281.
- Develop 3-4 case studies of energy efficiency measures taken on various agriculture operations (farm, ranch, feedlot, dairy, etc) to present around the state.

- Colorado state government should create incentives to upgrade REA distribution systems to “smart grid” technologies that can better take advantage of the benefits of distributed generation installed on farms and more sophisticated energy tracking devices on farms and businesses.
- REAs, Tri-State, and Colorado state government should consider and develop net metering standards above 25 kW in capacity that insures the economic viability of REAs.

Related Policies/Programs in Place

- Colorado Department of Agriculture’s Renewable Energy Grant Program under the Colorado Agriculture Development Authority. Provides grants to agriculture producers for on-farm renewable energy production. Includes grants for implementation up to \$100,000 and feasibility study grants up to \$25,000.
- USDA Farm Bill 9006 Renewable Energy/Energy Efficiency Grant and Guaranteed Loan Program. Provide grants up to 25% of the cost for renewable energy, biofuels production, and energy efficiency products.
- Chicago Climate Exchange Methane Offset allows producers with anaerobic digester generating power to receive income from sell of credits based on MTCO₂ Equivalent for Methane trapping and combustion. Metric ton of methane valued at 18 mtCO₂. At current price of a mtCO₂ on the exchange at \$3.30, a metric ton of methane would sell for more than \$59.
- Net metering up to 25 kW with REA service territories and new interconnection standards for all 22 REAs from HB07-1169.

Types(s) of GHG Reductions

TBD

Estimated GHG Savings and Costs per MtCO_{2e}

- **GHG reduction potential in 2012, 2020 (MMtCO_{2e}):**
 - Diesel Fuel: 0.018, 0.061
- **Net Cost per MtCO_{2e}:** TBD

Data Sources: Consumption of Distillate fuel by the agriculture sector in Colorado was projected from historical data found at www.eia.doe.gov. The petro-diesel emissions factor was calculated using the same method as AFW-1. Agricultural sector electricity consumption from in-state source (check with RCI TWG)?, CO grid electricity consumption emission factors for 2012 and 2020 (check with ES TWG); fuel reductions and capital costs for energy efficiency technologies from the literature.

Quantification Methods:

The business as usual (BAU) distillate fuel use for the CO agricultural sector was projected from historical (1984-2005) data retrieved from the EIA. Based upon the projected BAU distillate use, the target distillate reduction was calculated. Multiplying this reduction by the emissions factor

for distillate fuel yielded the incremental GHG benefit from a reduction in the use of distillate fuel. Results are displayed in the table below:

Year	BAU Distillate Use (1000 gal)	Target Distillate Reduction (1000 gal)	Incremental GHG Benefit from Distillate Reduction (MMtCO ₂ e)
2007	49,047	0	0.000
2008	48,135	445	0.004
2009	47,222	890	0.007
2010	46,310	1,335	0.011
2011	45,397	1,779	0.015
2012	44,485	2,224	0.018
2013	43,572	2,876	0.024
2014	42,660	3,527	0.029
2015	41,747	4,179	0.035
2016	40,835	4,831	0.040
2017	39,922	5,482	0.045
2018	39,010	6,134	0.051
2019	38,098	6,785	0.056
2020	37,185	7,437	0.061

- Estimate electricity reductions in each year based on agricultural sector consumption identified above and the policy goals;
- Estimate GHG reductions for the grid-based electricity that is offset in each year;
- Identify energy efficiency technologies to be applied to meet policy goals;
- Estimate annualized costs based on energy efficiency technologies applied (for both petro-diesel and electricity);
- Determine net costs based on annualized capital costs and savings from reduced energy consumption;
- Determine cost effectiveness from GHG reductions and annualized costs in each year.

Key Assumptions: TBD

Key Uncertainties

TBD

Additional Benefits and Costs

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD

AFW-4. Biodiesel Production

Mitigation Option Description

Provide incentives for the production of biodiesel from oilseed crops, waste vegetable oil, or other sources. Biodiesel use will offset diesel fuel derived from petroleum and will lead to decreased fossil fuel-based CO₂ emissions.

Mitigation Option Design

Goals: Produce enough biodiesel fuel to offset 20% of the state diesel fuel demand by 2020 using GHG-superior feedstocks.

Timing: Produce enough in-state biodiesel to offset 2% of Colorado's petro-diesel consumption by 2012 and 20% by 2020.

Parties involved: Governor's Office of Energy Management and Conservation, Colorado Dept. of Agriculture, Rocky Mountain Farmers Union, Colorado Farm Bureau, Colorado Livestock Association.

Other: Colorado's distillate fuel usage in 2002 was 0.73 billion gallons and is projected to be 1.25 billion gallons by 2020 (transportation diesel use was 0.57 billion gallons in 2002; 1.0 billion gallons by 2020).

Implementation Mechanisms

- Colorado agriculture producers and private industry should be encouraged to build and operate biodiesel facilities within Colorado using local resources and providing locally-available product.
- Colorado state government should actively evaluate the benefits and costs of incentive programs for new businesses entering the state for biodiesel production [For example, a particular plant may plan to use soybean oil not produced in the state and would likely need to be transported 1,000 miles or more to the site]. The costs should include the impacts to the environment as a whole as the fuel production cycles change, also the impacts to local and regional agricultural businesses (farming, feedlots, dairies) as the demand for feedstock crops increase and additional meal cake for livestock is available. In short, biodiesel production incentives should be established with consideration for the life-cycle of the fuel source in economic and environmental terms.
- Colorado state government should consider a Renewable Fuels Standard by volume of retail sales beginning at 2% and escalating to 5% in the short term. Increases in the RFS could be based upon local production levels.
- Colorado state government should consider a retail tax credit for sale of B20 fuel. The tax credit value could increase with great retail volume sold [similar to Iowa retail incentive]

- Implementation will likely require that oilseed crops be produced on land already in cultivation. Some conversion of idle land to new cropland could also occur which could decrease the overall carbon benefit to be gained from producing biodiesel [as soil organic carbon and soil nitrogen (as N₂O), both GHG sources, will be lost to the atmosphere when the land is converted to new cultivation].

Related Policies/Programs in Place

- Colorado Department of Agriculture's Renewable Energy Grant Program under the Colorado Agriculture Development Authority for grants up to \$100,000 for new biodiesel production facilities; \$25,000 for biodiesel feasibility studies; and \$50,000 for research. grants funded through 2009.
- The Colorado Clean Energy Fund under the Governor's Energy Office with [\$7 million in annual revenue?] for project development.
- The renewable fuels standard from the Energy Policy Act of 2005 requires 7.5 billion gallons of renewable fuel in the U.S. by 2012, including biodiesel.
- USDA Farm Bill grant and guaranteed loan program for biodiesel facilities and research.

Types(s) of GHG Reductions

- **CO₂:** Lifecycle emissions are reduced to the extent that biodiesel is produced with lower embedded fossil-based carbon than conventional (fossil) diesel fuel. Feedstocks used for producing biodiesel can be made from crops, which contain carbon sequestered during photosynthesis (e.g., biogenic or short-term carbon). The primary feedstocks are vegetable oils (soy, canola, sunflower, algal, etc.) and alcohols (either methanol or ethanol). From a recent report (Hill et al., 2006),⁵ biodiesel from soybeans contains 93% more useable energy than its petroleum equivalent and reduces lifecycle GHG emissions by as much as 41%. Higher oil production potential of different feedstocks (e.g., other oil crops, algae) will likely adjust the lifecycle GHG emissions further downward as they are developed as biodiesel sources. Local production of biodiesel also decreases the embedded CO_{2e} of biodiesel compared to importation of out of state vegetable oil supplies.

Estimated GHG Savings and Costs per MtCO_{2e}

TBD

Data Sources: *Information regarding current biodiesel feedstocks in CO, as well as current and historical production is necessary to complete quantification of this option.*

Data from the CO Draft Inventory & Forecast were the starting point for quantifying the benefits of offsetting fossil diesel consumption with biodiesel produced within the state (these do not incorporate future reductions in consumption due to TLU options). Fossil diesel consumption estimates are (under business as usual):

⁵ Hill et al, 2006, "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels," *Proceedings of the National Academy of Sciences*, volume 103, pp. 11206-11210, July 25, 2006.

Year	Diesel Consumption (MMgal/yr)
2012	828
2020	1,009

The policy design calls for 2% of the fossil diesel consumption to be offset by 2012 from in-state production and 20% offset by 2020. Therefore, incremental in-state biodiesel production targets are:

Year	Biodiesel Production Needed (MMgal/yr)
2012	0.02*828 – (BAU production)
2020	0.20*1009 – (BAU production)

The BAU biodiesel production in the state is unknown at this time. Once a baseline for biodiesel production in Colorado is established, it will be possible to project a BAU scenario.

The CO₂e emission factor for fossil diesel used in the inventory and forecast is 10.04 Mt/1,000 gallons. The lifecycle fossil diesel emission factor is 12.3 Mt/1,000 gallons.⁶

Quantification Methods:

GHG Reductions

A new study on lifecycle GHG benefits for biodiesel production and use was used to estimate the CO₂e reductions for this option.⁷ This study covered biodiesel production from soybean production, which is currently the predominant feedstock source for biodiesel production in the US and is assumed to remain that way for the purposes of this analysis (it is also the predominant feedstock of biodiesel production in CO). Lifecycle CO₂e reductions (via displacement of fossil diesel with soybean-derived biodiesel) were estimated by Hill et al to be 41%. This value is being used by the TLU TWG to estimate the benefit of the biodiesel component of the TLU biofuels option. Hence, this analysis focuses on incremental benefits of in-state feedstocks production with the focus on vegetable oils.

For this option, the incremental benefit of in-state production is derived from the lower embedded GHG content of biodiesel feedstocks (vegetable oil) avoided from having to transport the feedstocks from their likely source region. For this assessment, the likely source regions for soybean or canola oil are the U.S. mid-west or northern plains regions. Using South Dakota as a potential source region, rail transport would require shipments to central North Carolina of about 650 miles.⁸ Rail fuel consumption is about 400 ton-miles/gallon.⁹ The density of vegetable oil is

⁶ Hill et al, 2006, “Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels,” *Proceedings of the National Academy of Sciences*, volume 103, pp. 11206-11210, July 25, 2006.

⁷ *Ibid*

⁸ Mapquest directions, North Dakota to Colorado; www.mapquest.com.

⁹ U.S. National Atlas, at http://nationalatlas.gov/articles/transportation/a_freightrr.html.

about 3,700 tons/MMgal. From these inputs, a GHG emission rate of 130 MtCO₂/MMgal oil was calculated.

When combined with the other feedstocks needed to produce biodiesel (e.g., either methanol or ethanol),¹⁰ a gallon of vegetable oil will produce slightly more than one gallon of biodiesel. For the purposes of this estimate, each gallon is assumed to produce one gallon of biodiesel.

In addition to soybean oil, other oil feedstocks included in this analysis include animal oils (yellow grease, poultry fat, lard, and tallow), canola, and algal oils. It is assumed that technology advances will occur during the policy period that will allow for commercial scale production of algal oil to make up the shortfall (e.g., in the post-2015 period). With sufficient technology advancement, another option could be Fischer-Tropsch biodiesel from cellulose.

For oil sources other than soybean oil, the benefit for substituting in-state biodiesel for fossil diesel is estimated starting with the lifecycle soybean emission factor (7,261 MtCO₂e/MMgal from the Hill et al study). As mentioned previously, the benefits of the biodiesel component of the TLU biofuels option is based on displacement with soybean-based biodiesel. Hence, this analysis was designed to only account for the incremental benefit of in-state feedstock (oil) production using GHG preferential feedstocks. These include vegetable oils that produce greater volumes of oil per unit of energy input (e.g., canola), animal fats, and, in the future, algal oils.

Canola produces 127 gallons of oil per acre compared to soybeans at 48 gallons/acre. Assuming canola production energy inputs are not significantly greater than soy, the lifecycle emission rate for canola would be 7,261 x 48/127 or 2,744 MtCO₂e/MMgal. So the incremental benefit of canola over soy is 7,261 - 2,744 = 4,517 MtCO₂e/MMgal.

For animal fats and algal oils, CCS assumes that these have negligible embedded energy. So the incremental benefit over soy equals the lifecycle fossil diesel EF (12,306 MtCO₂e/MMgal) minus the soybean based EF (7,261 MtCO₂e/MMgal), which is 5,045 MtCO₂e/MMgal.

To meet the in-state production goals for 2012 and 2020, the table below provides the mix of oil feedstocks assumed in this analysis. The assumed mix relies heavily on new technologies (e.g., algal oil) to produce feedstocks in the post-2012 period.

Year	Oil Feedstock	Fraction of New Production	MMgal/yr Needed
2012	Soy	-	-
2012	Canola	-	-
2012	Animal	-	-
2012	Algal	-	-
2012 Total			-
2020	Soy	-	-
2020	Canola	-	-
2020	Animal	-	-

¹⁰ While the analysis here focuses on the primary feedstock for biodiesel, vegetable oil, the policy should also promote the production and use of alcohol feedstocks produced from renewable resources (e.g., starch or cellulosic ethanol, renewable methane to methanol).

2020	Algal	-	-
2020 Total		-	-
Excludes BAU production estimated to be XX MMgal/yr in 2012 and XX MMgal/yr in 2020.			

GHG reductions were estimated by multiplying the production of each oil feedstock by the applicable incremental benefit (e.g., by oil type). Total reductions in each year were estimated by summing the incremental benefit for each oil type.

Costs

Costs were estimated using information from an analysis of biodiesel production costs from the US DOE.¹¹ The value of incentives needed is assumed to be equivalent to the difference in the costs of producing fossil diesel and soy-based biodiesel (\$0.34/gallon). This value is very close to the incentive offered in a State of Missouri incentives program.¹² This program offers production incentives of \$0.30/gallon to producers up to 15 million gallons of production/yr. The incentive grants last for five years.

CCS assumed a similar incentive structure and that these would cover the costs of all grants or tax incentives associated with this policy (all other implementation mechanisms are assumed to be achieved within existing programs). The cost estimates are based on multiplying the amount of biodiesel produced in each year by the production incentive. This assumes that all production occurs at production facilities of less than 15 million gallons/yr. The production incentive runs out after five years of production.

Key Assumptions: Life-cycle GHG emission factors utilized/derived for this analysis are representative for each feedstock and for fossil diesel. Production incentives offered by this option are sufficient to drive production of GHG-superior feedstocks (e.g., superior to soybeans) and to increase the level of research and development needed for non-crop based feedstocks (e.g., algal biodiesel, Fischer-Tropsch biodiesel).

Key Uncertainties

TBD

Additional Benefits and Costs

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

¹¹ See www.eia.doe.gov/oiaf/analysispaper/biodiesel/index.html; accessed January 2007.

¹² Information on the Missouri Program: www.newrules.org/agri/mobiofuels.html#biodiesel, accessed January 2007.

Barriers to Consensus

TBD

AFW-5. Ethanol Production

Mitigation Option Description

Trees, crops and other plants convert atmospheric carbon to carbohydrate or fiber stocks that can be converted to liquid fuels, such ethanol. The use of these renewable, biological fuels can offset fossil fuel use and reduce associated net carbon dioxide emissions. Production incentives for the conversion of crops, forest sources, animal waste and other sources to ethanol through existing or new technologies can increase the level of ethanol use in future markets. In-state production of ethanol using GHG-superior feedstocks and processes (e.g. cellulosic technologies) offer the highest GHG benefits and complement policies to increase ethanol consumption (e.g. TLU-5).

Mitigation Option Design

Goals: Increase in-state ethanol production using GHG-superior feedstocks and production methods to 400 million gallons per year above BAU by 2020.

Timing: Add additional ethanol production capacity of 50 million gallons/yr by 2012 and achieve the full policy goal by 2020.

Parties Involved: Suppliers of feedstocks, ethanol producers and distributors.

Other: Colorado's gasoline consumption was 1.9 billion gallons in 2002 and is projected to be 2.2 billion gallons by 2020.

Implementation Mechanisms

TBD

Related Policies/Programs in Place

TBD

Types(s) of GHG Reductions

- **CO₂:** Lifecycle emissions are reduced to the extent that ethanol is produced with lower embedded fossil-based carbon than conventional (fossil) gasoline. Feedstocks used for producing ethanol can be made from crops or other biomass, which contain carbon sequestered during photosynthesis (i.e., biogenic or short-term carbon). There are two different methods for producing ethanol based on two different feedstocks. Starch-based ethanol is derived from corn or other starch/sugar crops. Cellulosic ethanol is made from the cellulose contained in a wide variety of biomass feedstocks, including agricultural residue (e.g., corn stover), forestry waste, purpose grown crops (e.g., switchgrass), and municipal solid waste. Local production of ethanol also decreases the embedded CO₂e of ethanol compared to importation from the current U.S. primary ethanol producing regions. Current research indicates cellulose-based ethanol production provides up to 72-

85% reduction in GHGs compared to gasoline, whereas an 18-29% reduction is measured from starch-based ethanol production compared to gasoline.¹³

Estimated GHG Savings and Costs per MtCO_{2e}

- **GHG reduction potential in 2010, 2020 (MMtCO_{2e}):** 0.2, 3.1
- **Net Cost per MtCO_{2e}:** \$3
- **Data Sources:** The target for ethanol production requires a fixed quantity of production above BAU, rather than a percentage increase. Therefore, it is not necessary to project the BAU ethanol production in Colorado to quantify the cost effectiveness and GHG reduction potential of AFW-5. The targets set forth in this option (50 MMgal/yr by 2012, 400 MMgal/yr by 2020) are reached by increasing the quantity of ethanol produced in CO by equal increments in the years leading up to the target years. The in-state production targets are shown in the table below.

Assumed Ethanol Production Schedule (MMgal/yr)	
2007	-
2008	10
2009	20
2010	30
2011	40
2012	50
2013	75
2014	100
2015	150
2016	200
2017	250
2018	300
2019	350
2020	400

Emission factors from gasoline, starch-based ethanol and cellulosic ethanol are based on the ANL Greet Model.¹⁴ The production cost differential for cellulosic versus starch-based ethanol is derived from analysis completed by the Energy Information Administration (EIA).¹⁵

Quantification Methods:

GHG Reductions

The benefits for this option are dependent on developing in-state production capacity that achieves benefits above the levels of existing and planned (BAU) starch-based

¹³ *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems—A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions*, General Motors, Argonne National Lab, and Air Improvement Resource, Inc., May 2005.

¹⁴ *Ibid.*

¹⁵ DOE EIA analysis can be found at www.eia.doe.gov/oiaf/analysispaper/biomass.html, accessed January 2007.

production in the U.S. (the benefits of using ethanol from starch-based production are already accounted for under TLU Option 5). Emission factors for reformulated gasoline, starch-based ethanol, and cellulosic ethanol were taken from a General Motors/Argonne National Lab study.¹⁶ These emission factors incorporate the GHG emissions during the entire life-cycle of fuel production (e.g., for gasoline: extraction, transport, refining, distribution, and consumption; for ethanol: crop production, feedstock transport, processing, distribution, and consumption). These life-cycle emission factors are referred to as “well-to-wheels” emission factors:

Fuel	Emission Factor (grams CO₂e/mi)
Reformulated gasoline	552
Starch-based ethanol	451
Cellulosic ethanol	154

In addition to cellulosic ethanol production, the other types of ethanol production processes targeted by this option include starch-based processes that achieve similar levels of life-cycle GHG reductions to cellulosic ethanol. These would be starch-based plants that use renewable fuels, such as biomass, biogas, landfill gas, or other renewable fuels. While CCS is not aware of any lifecycle emission factors for these types of plants (although several have been proposed in the U.S.), CCS assumes that reductions similar to cellulosic ethanol can be achieved.

Based on the emission factors shown above, the incremental benefit of the production targeted by this policy over conventional starch-based ethanol is 66% (reduction of CO₂e by offsetting gasoline consumption). This value was used along with the lifecycle emission factor for gasoline¹⁷ and the production in each year to estimate GHG reductions.

Costs

Costs for the incentives needed by this policy option are based on the difference in estimated production costs between conventional starch-based ethanol and cellulosic ethanol. The DOE EIA estimated that the cost to produce starch-based ethanol is \$1.10/gal compared to \$1.29/gal, or a difference of \$0.19/gal (in \$1998).¹⁸ In 2006 dollars, the difference is \$0.23/gal. These incentives are considered necessary in the near term (up to 2015) to help commercialize technologies that produce ethanol from cellulose or produce starch-based ethanol using renewable fuels. The incentives should also help to establish the infrastructure to deliver biomass to biorefineries, since producers will seek the local feedstocks or renewable fuels for their operations.

¹⁶ *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems—A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions*, General Motors, Argonne National Lab, and Air Improvement Resource, Inc., May 2005.

¹⁷ In the study mentioned above, the average fuel economy used was 21.3 miles/gallon or 100 miles/4.7 gallons. Multiplying this value by the emission factor of 552 grams/mile yields 11,745 grams/gallon.

¹⁸ DOE EIA analysis can be found at www.eia.doe.gov/oiaf/analysispaper/biomass.html, accessed January 2007.

By 2015, it is assumed that advances in cellulosic ethanol production (e.g., enzyme costs, production processes) will make cellulosic ethanol production cost competitive with starch-based production. Hence, the incentives are discontinued beginning in 2015. Note that there is currently federal legislative proposal to offer cellulose an incentive of \$0.765/gallon compared to the \$0.51/gallon currently offered for ethanol production.¹⁹ If enacted, this \$0.255/gallon premium could cover the additional incentives that are assumed to be needed by the State of Colorado. Obviously, the federal incentives do not assure that production facilities would locate in CO. These federal incentives have not been factored into the cost estimates for this option.

The costs for this option were estimated using the \$0.23/gal incentive multiplied by the production needed in each year. By 2015, it is assumed that these incentives will no longer be needed as cellulosic ethanol technologies become fully commercialized. Below is the assumed schedule for these incentives:

Year	New Capacity (MMgal)	Incentives Cost (MM 2006\$)	GHG Benefit (MMtCO ₂ e)
2007	-	\$0.00	0
2008	10	\$2.3	0.08
2009	20	\$4.6	0.15
2010	30	\$6.9	0.23
2011	40	\$9.2	0.31
2012	50	\$11.5	0.39
2013	75	\$17.3	0.58
2014	100	\$23.0	0.77
2015	150	\$0.0	1.16
2016	200	\$0.0	1.55
2017	250	\$0.0	1.93
2018	300	\$0.0	2.32
2019	350	\$0.0	2.71
2020	400	\$0.0	3.09

After discounting and leveling the costs from 2007-2020, the cost effectiveness is just under \$3.50/MtCO₂e and the net present value of the 2007-2020 costs are \$58 million.

- **Key Assumptions:** Starch-based ethanol production using renewable fuels achieves equivalent GHG lifecycle benefits as cellulosic ethanol; cellulosic production or starch-based production with renewable fuels can achieve the production levels in the near term (2014 production of 310 MMgal/yr) required by this policy option; Federal tax incentives do not preclude the need for the additional state incentives assumed for the cost estimate.

Key Uncertainties

TBD

Additional Benefits and Costs

¹⁹ D. Morris, *Making Cellulosic Ethanol Happen: Good and Not So Good Public Policy*, Institute for Local Self-Reliance, January 2007, at www.newrules.org/agri/cellulosicethanol.pdf, accessed January 2007.

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD

AFW-6. Preserve Lands with Carbon Storage Value

Mitigation Option Description

Reduce the rate at which existing crop/pasture and forested lands are converted to developed uses. The carbon stored in soils and aboveground biomass is typically higher in these lands than in developed land uses. Each year, developed areas also typically sequester less carbon dioxide than forested areas. Policies are needed to protect working farms and forests from unwise and unplanned development. Indirectly, this option also supports important policies in the transportation and land use sector by promoting more efficient development patterns (e.g. TLU-1).

Reduce the rate at which permanent grassland in the USDA Conservation Reserve Program is converted to cultivated cropland. Soil carbon stored in retired agricultural land that has been maintained as grassland is reversed when lands are put back to cultivation, resulting in net carbon emissions.

Mitigation Option Design

The rate of land conversion (from undeveloped to developed) in Colorado is estimated to be at least 100,000 acres per year. These lands include a mix of former cropland, untilled grassland, forests, and western slope shrublands. Land conservation strategies alone (absent significant growth management policy) are unlikely to alter the general rate of land conversion, but can play a role in determining which lands are protected from conversion. Further, land conservation is a generally expensive means of preventing carbon emissions, unless targeted toward highest return strategies. Colorado has an advanced program of land protection with a system of transferable tax credits for land-owners, dedicated public funding, and numerous local and statewide private land trusts. At present, the carbon storage value of lands protected is an uncompensated additional benefit that comes with the open space and wildlife habitat protection values of protecting lands. Additional incentives targeted toward the carbon storage value of land, over and above existing compensation for retiring development rights, would in theory drive more land protection toward high carbon value lands, and compensate landowners for the additional societal benefit of avoided carbon emissions. This policy would create a program to provide additional tax incentives for landowners donating development rights as part of an easement transaction for the carbon storage value of their land. In all likelihood this policy would focus on protecting forest lands from conversion, but some more mesic untilled grasslands might also qualify.

Colorado currently has 2,469,041 acres of land under CRP contract. 1,690,190 acres of those contracts are due to expire by 2011. Some percentage of these lands will be ineligible for a new contract (due to new rules and limits at the national level for CRP) or will have an economic incentive to re-convert to dry-land crops rather than re-enroll in CRP (particularly if dry-land biofuel crops become a feasible land use in Colorado). The cost of paying landowners to

maintain permanent grass cover, particularly if grazing is permitted as a land use providing some economic return, is likely to be low, with demonstrable carbon benefits. This policy would create a program to target either permanent or long-term contracts to maintain expired CRP acres in grass cover either with or without use as grazing lands.

Goals: Protect 3,500,000 acres of lands in natural cover that would have been converted by 2030.

Do these replace or refine the above?

- Increase the amount of high carbon value lands in land protection programs by 10% by 2020
- Maintain X acres of CRP land in permanent grassland cover by 2020

Timing: By 2015, protect 2,000,000 acres of lands that would have been converted (protect 1,500,000 by 2012); achieve the full goal by 2030.

Parties involved: TBD

Other: Data from the Natural Resources Conservation Service (NRCS) National Resources Inventory (NRI) show the following losses of lands between 1982 and 1997 to the “urban built-up” and “rural transportation” categories²⁰:

Land Cover/Use	10 ³ Acres Lost 1982-1997	Annual Average Loss (10 ³ acres)
Cultivated cropland	89.9	6.0
Non-cultivated cropland	36.1	2.4
Pastureland	46.9	3.1
Rangeland	176.9	11.8
Forest land	66.6	4.4
Totals	416	27.7

Implementation Mechanisms

Establish a fund to provide additional incentives (likely tax credits) above those currently granted for donated portions of easements, based on the avoided carbon emissions potential of the development rights being retired. Easement transactions include an appraisal of the value of the development rights forgone. Based on the amount of land disturbance associated with those rights, and the carbon storage value of the land in question (would need a simple method for evaluating carbon storage value based on existing land cover and condition), an avoided carbon emission value can be calculated. The fund would provide additional incentives based on the amount of avoided emissions associated with the transaction, thus rewarding landowners who

²⁰ See this table: <http://www.co.nrcs.usda.gov/technical/nri/tables/table5.pdf> for conversion rates between 1982 and 1997. The NRI annual acreage lost to development can be compared to an estimate from David Theobald of CSU of 33,700 acres/yr on average from 2000-2030.

protect the highest amount of carbon (or avoid highest potential carbon emissions) The value of the incentive can be set based on a portion of the value of a ton of avoided carbon emissions based on current markets for offsets (only a portion is appropriate since landowner has already been compensated for a portion of their donation of an easement from existing sources).

Establish a fund to pay for contracts with landowners who are not able to get expiring CRP acres back in to the system to maintain grass cover on their expired CRP acres. Least-cost policy mechanism would be for a bid-in process with contracts awarded in terms of CO2 equivalent cost-benefit (presuming some lands have higher carbon values associated with maintenance of grass cover). If there is not significant difference in carbon value, contracts would be evaluated solely on basis of cost and length of contract.

Ramping up the pace of land protection by increasing funding sources, combined with coordinated growth management strategies, could significantly reduce the pace of land conversion in the state. Land conservation organizations in Colorado have identified an additional 3 million acres of land as priorities for protection in the next ten years. Meeting this goal would require an additional XXX of dollars above existing sources. Targeting these acres in ways that maximized both the conservation values (open space, wildlife habitat, etc.) and growth management strategies (maintaining buffers between communities, protecting untilled landscapes on urban fringe, consolidating public lands holdings, etc.) would change baseline projections of land conversion associated with future population growth. In conjunction with growth management strategies developed as part of a climate strategy, identify priorities for land protection that would help implement those strategies. Direct a significant portion of new resources to those priorities, by making climate mitigation and growth management priorities of state funding sources (GOCO?). *[This seems like a complimentary implementation mechanism that supports protection of high carbon value lands by preventing their conversion to development, rather than a separate program with separate quantifiable GHG benefits. I placed the text here for now, for further consideration]*

Related Policies/Programs in Place

TBD

Types(s) of GHG Reductions

Avoided emissions from land use change

Maintenance of annual carbon sequestration potential

Estimated GHG Savings and Costs per MtCO₂e

TBD

Data Sources: Natural Resources Conservation Service data on Conservation Reserve Program acres expiring during the policy period, NRI data on agricultural/range/forest land lost to urban development, data on above and below ground soil carbon levels from CSU, USFS, and the scientific literature, costs for conservation easements on ag/range/forest land in CO.

Quantification Methods:

A. Maintaining CRP Land

CSU NREL has been conducting studies to evaluate differences in carbon storage value of alternative uses of CRP lands. If data are available, calculate average carbon storage value of formerly tilled lands with 15 years of grass cover (the length of a CRP contract) minus average carbon value of CRP lands returned to dry-land cropping. Assume cost to maintain land in that cover is average rental rate of dryland agriculture at a county level (that is what a CRP contract pays and this rate was sufficient to entice enrollment in the first place). Total amount of land likely to be available for this policy option would be the number of retiring CRP acres not likely to qualify under new CRP rules (Note: I am trying to obtain that number).

- Quantify CRP acreage potentially returned to active cultivation; quantify soil carbon stocks lost (express as annual CO₂ emissions). Note that these emissions are not currently included in the BAU projections of the I&F.
- Quantify annual average acres of ag/range/forest lost to development.
- Quantify carbon stocks lost for each land use (soil carbon in ag and range; above and below ground stocks for forestry) on an annual basis; convert to CO₂.
- Quantify acres protected in each year based on acres lost and the policy goals.
- Quantify costs to protect acres in each year from the cost of conservation easements/other implementation mechanisms.
- Quantify the cost effectiveness from annual GHG reductions and annualized costs.

The cost-benefit value of carbon with the evaluation method outlined above is likely at the high end for two reasons: 1) CRP lands 15 years after initial grass planting are likely continuing to accumulate carbon, but this approach would only value them for current carbon storage value; 2) some percentage (perhaps quite high) of farmers ineligible to re-enroll their lands in CRP are likely to be willing to continue to rent their lands for a much lower rate (since the costs of re-starting an ag operation are high and because most of these lands are very marginal compared to average dryland opportunities in a county). The costs estimated by using current rental rates would be on the low side only if there is some large increase in demand for dryland crops that would raise the bid-in rental price. The additional carbon benefits of this policy could be over-estimated if that the baseline scenario for many of these lands would be for them to remain as grass as it would be uneconomical to put them back into cropland.

B. Protecting high carbon value lands through land preservation

It will be difficult to calculate the costs and benefits of this particular strategy. Presumably, it would be cost-effective, since the value of the avoided emissions incentive can be set at a level gets the most value. The additional incentives presumably will both result in more easement transactions and will skew transactions towards more carbon valuable lands. For assessment purposes, we could calculate the carbon storage value of certain classes of land use; calculate the current rate of land protection in those high value types of land, assume some percentage

increase in that rate, and use a modest increase in the cost of those easements form new incentives (say 10%).

This type of approach should in theory avoid some of the problems of additionality and leakage that generally plague efforts to establish rigorous offset programs based on avoided emissions through land protection. Additionality is addressed through the fact that you aren't paying for the entire easement, but only a portion of the actual carbon storage value associated with it. So the program is creating an incentive for different transactions that might not otherwise have happened, based solely on carbon value. It is certainly likely that some landowners would have done the easement transaction without the added carbon incentive, and that causes some problems with additionality. Further, the calculation of the carbon incentive is based on the amount of development that could have occurred without the easement, there is again a chance that such development would not have occurred, absent the easement, but the appraised value is lower in cases of less likelihood of development. As with any land protection scheme, it is very difficult to assess the leakage issues; whether the protection of one piece of property just moved the development to another parcel. Since the program here is focused on the retirement of specific development rights, it is likely that there is an actual reduction in the amount and pace of such development, particularly in higher carbon value lands.

C? Analysis below originally provided to evaluate GHG benefits from reducing rates of forest conversion, overlaps with B above so may not longer be relevant?

Initial Information for Quantification of Goal

Goal levels translate into protecting:

- 300,000 acres of land per year from 2008-2012
- 111,111 acres of land per year from 2013-2030

Baseline land use conversion rates:

- Acres converted to development annually: ~33,703 acres per year (Dr. David Theobald of CSU projects that 1,011,090 acres will be converted to developed uses from 2000-2030)
- Approximately 22,286 acres of forest lost annually, based on historical forest losses calculated from NRI data (1982-2003) for CO. NRI does not include Federal land. See table below.
- Approx. 4,400 acres of forest converted to developed uses per year (1982-1997 NRI)
- Approximately 137,081 acres/yr of cultivated cropland enrolled in the CRP program

Land Use	Area 1982 (acres)	Area 2003 (acres)	Annual Change (acres/yr)	Annual Change (% of land use/yr)	Annual Change (% of total/yr)
Cropland	10,603,500	8,348,000	-107,405	-1.01%	-0.26%
CRP land	0	2,193,300	137,081	--	0.33%

Pastureland	1,164,700	1,001,800	-7,757	-0.67%	-0.02%
Rangeland	25,053,600	24,790,600	-12,524	-0.05%	-0.03%
Forest land	3,757,000	3,289,000	-22,286	-0.59%	-0.05%
Other rural land	876,000	1,006,000	6,190	0.71%	0.01%
Total	41,454,800	40,628,700	-39,338		-0.09%

Forest Carbon Stocks and Sequestration Potential (Source: USFS GTR NE-343, Methods for calculating forest carbon)

- What forest types will be protected and how much of each? Suggest assuming 50% Lodgepole and 50% Ponderosa because they are dominant types.

Lodgepole pine

Stand Age	Biomass Stock (tC/ac)	Soils Stock (tC/ac)
0	16.1	10.9
65	30.3	10.9
Annual flux (tC/ac/yr)	0.22	0.00

Ponderosa pine

Stand Age	Biomass Stock (tC/ac)	Soils Stock (tC/ac)
0	15.5	9.8
65	31.7	9.8
Annual flux (tC/ac/yr)	0.25	0.00

Assumptions for calculating avoided emissions from forest conversion:

- Approximately 35% of soil carbon stocks are lost when forests are converted to urban uses (Jenkins, pers com, awaiting reference)
- Approximately 53% of aboveground forest carbon stocks are removed under heavy harvest scenarios (Strong, 1997). Assume 53% of biomass carbon stocks are lost under a development scenario.

Illustrative Quantification for avoided forest conversion

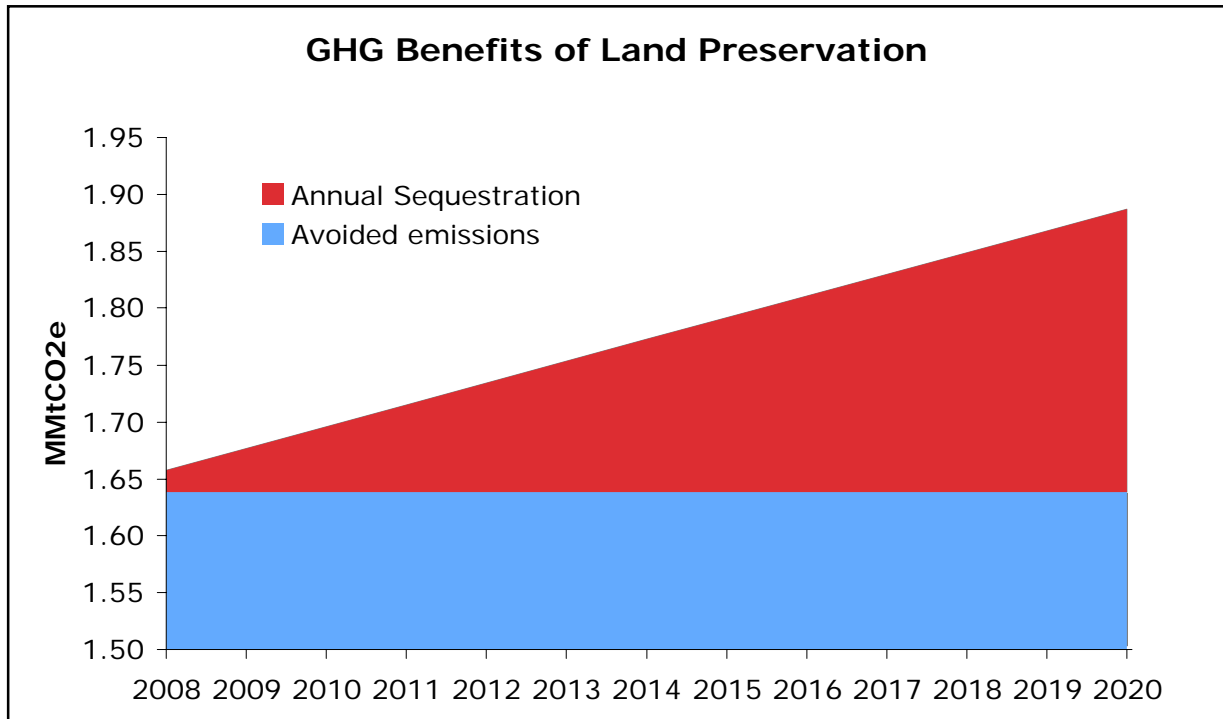
Assuming land protection reduces forest conversion by 100%, or 22,286 acres per year, avoided emission were calculated. [*This is for illustrative purposes only. The assumption is probably not realistic*]. Loss of forests to non-forest uses results in a large one-time surge of carbon emissions. In this case, it was assumed that 53% of carbon stocks in biomass and 35% of carbon stocks in soils would be lost in the event of forest conversion, with no appreciable carbon sequestration in

soils or biomass following development. The biomass loss assumption is based on research that shows heavy levels of individual tree removal results in the harvesting of 53% of carbon in aboveground biomass (Strong 1997). The soil carbon loss assumption was based on a study that shows about a 35% loss of soil carbon when woodlots are converted to developed uses (Jenkins, pers com). To estimate avoided emissions, the total number of acres protected in a year was divided into acres for Lodgepole pine and Ponderosa pine, assuming 50% of each are protected. Each area was multiplied by 53% of the biomass carbon stocks and 35% of the soil carbon stocks in 65-yr old stands. Results were converted to units of million metric tons CO₂ equivalent (MMtCO₂e). Avoided emissions are estimated at 1.64 MMtCO₂e/yr from 2008-2020, for a cumulative GHG benefit of 21.3 MMtCO₂e.

Forests preserved in one year continue to sequester carbon in subsequent years that otherwise would not occur if the forest was converted to another use. Thus, annual sequestration is accounted for on the number of acres preserved cumulatively under the program each year. Annual carbon sequestration was calculated each year by multiplying the cumulative acres protected by the average annual carbon flux for 65-yr old stands, separately for Lodgepole and Ponderosa pine. Annual rates of carbon sequestration (tons carbon sequestered per year) were calculated by subtracting total carbon stocks in forest biomass of 65 yr old stands from total carbon stocks in forest biomass of new stands and dividing by 65. Soil carbon density was assumed constant and is not included in the annual carbon flux calculations because default values for soil carbon density are constant over time in USFS GTR-343. Results are shown below.

	Acres protected	Annual C Sequestered (tons C)			Annual C Sequestered (MMtCO ₂ e)
		Lodgepole	Ponderosa	Total	
2008	22,286	2,434	2,777	5,211	0.02
2009	44,572	4,869	5,554	10,423	0.04
2010	66,858	7,303	8,332	15,634	0.06
2011	89,144	9,737	11,109	20,846	0.08
2012	111,430	12,172	13,886	26,057	0.10
2013	133,716	14,606	16,663	31,269	0.11
2014	156,002	17,040	19,440	36,480	0.13
2015	178,288	19,475	22,217	41,692	0.15
2016	200,574	21,909	24,995	46,903	0.17
2017	222,860	24,343	27,772	52,115	0.19
2018	245,146	26,777	30,549	57,326	0.21
2019	267,432	29,212	33,326	62,538	0.23
2020	289,718	31,646	36,103	67,749	0.25

Combined estimated carbon sequestration, assuming 22,286 acres of forests are protected annually that would otherwise be developed, are shown below.



Key Assumptions: TBD

Key Uncertainties

TBD

Additional Benefits and Costs

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD

AFW-7. Biomass Feedstocks for Energy Production

Mitigation Option Description

The goals of this option are to increase the use of low value wood material (including logging and mill residues), agricultural residues, and municipal solid waste fiber by appropriate processing centers for energy purposes (electricity, heating, liquid fuels). Offsetting fossil fuel use with biomass for energy, in applications such as distributed generation, combined heat and power and community energy systems will yield additional GHG emissions reduction benefits.

Mitigation Option Design

Goals: Increase production and use of biomass energy feedstocks by a factor of 10 by 2020 through sustainable harvesting and recovery practices.

Timing: Achieve an increase in consumption of biomass energy feedstocks of a factor of 3 by 2012; achieve the full goal by 2020.

Parties involved: TBD

Other: Not applicable

Implementation Mechanisms

TBD

Related Policies/Programs in Place

TBD

Types(s) of GHG Reductions

Displaces emissions from fossil fuel combustion

Others? E.g., could measures to increase supply of feedstocks lead to enhanced forest/ag carbon sequestration?

Estimated GHG Savings and Costs per MtCO_{2e}

It may be that the ES/RCI TWG will quantify GHG reductions associated with the consumption of renewable fuels in place of fossil fuels, which would take into account the GHG benefits of using biomass energy produced from feedstock envisioned under this option.

We may consider what additional GHG benefits are possible under this option.

We should plan to report on existing data for available biomass feedstocks and biomass feedstock potential in CO.

Data Sources: TBD

Quantification Methods: TBD

Key Assumptions: TBD

Key Uncertainties

TBD

Additional Benefits and Costs

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD

AFW-8. Forestry Programs to Enhance GHG Benefits

Mitigation Option Description

Carbon dioxide is captured and stored in trees, soil and other forest biomass. Any forest management activity that promotes forest productivity will increase carbon dioxide sequestration rates and enhance GHG benefits. Retaining forest management where it is being done and expanding the area covered by management plans would stimulate the rate of carbon sequestration. Use of biomass waste from forestry programs for energy purposes is covered under AFW-7. This option **focuses on** forest management methods to decrease the potential for catastrophic wildfires that result in large carbon losses and losses of near-term sequestration potential.

Mitigation Option Design

Goals: Treat 10% of Lower Montaine forests to reduce the risk of stand replacement fires and increase productivity by 2020.

Timing: Increase productivity by 2% by 2012 and achieve the full goal by 2020.

Parties involved: TBD

Other: Focus is on the lower elevation forest systems in the state.

Implementation Mechanisms

TBD

Related Policies/Programs in Place

TBD

Types(s) of GHG Reductions

Avoided non-CO₂ emissions from fire (CH₄, N₂O)

Avoided carbon losses from stand replacement fires

Estimated GHG Savings and Costs per MtCO₂e

Data Sources: Forest Inventory Analysis 2005, USFS GTR NE-343; Front Range Fuels Treatment Partnership Final Report 2006, Forest Biomass Removals for Fossil Fuel Offsets, Nelson, Kashian, and Ryan, unpublished report 2007.

Quantification Methods: The policy scenario is based on implementation of forest thinning to reduce the risk of catastrophic wildfires in the Lower Montaine Forests of Colorado. The net carbon sequestration of this policy scenario is compared to a baseline case where no thinning occurs and fires are more frequent. More details on the quantification will be added. Summary tables are provided below for initial discussion. Potential carbon sequestration in grasslands

established after forest burn is not accounted for, neither are trace gas emissions from fire (CH₄, and N₂O).

Carbon stocks/sequestration rates	Ton C/ac or ton C/ac/yr
Ponderosa Pine	
Biomass Carbon Stocks (65-yr old stand), tons C/ac	31.7
Annual sequestration in biomass, tons C/ac/yr	0.25
Douglas Fir	
Biomass Carbon Stocks (65-yr old stand), tons C/ac	56.3
Annual sequestration in biomass, tons C/ac/yr	0.50

Area of Lower Montaine Forest (LMF), elev range 5,00-8,000	Acres
Ponderosa Pine (PP), acres	801,457
Douglas Fir (DF), acres	311,859

Baseline: Ponderosa Pine, no thinning with fires

	Acres	Acres w/ Catastrophic Burn	Acres treated with thinning	Forest Carbon Stock at Start of Year (tC)	CO ₂ emissions from fire (tC)	CO ₂ removed from thinning (tC)	Carbon sequestered in biomass of un-burned forests (tC)*	Forest Carbon Stock at End of Year (tC)	Net Forest Carbon Flux
2008	801,457	20,036	0	25,406,192	-635,155	0	194,754	24,965,791	-440,401
2009	781,421	19,536	0	24,965,791	-619,276	0	189,885	24,536,401	-429,391
2010	761,885	19,047	0	24,536,401	-603,794	0	185,138	24,117,745	-418,656
2011	742,838	18,571	0	24,117,745	-588,699	0	180,510	23,709,555	-408,190
2012	724,267	18,107	0	23,709,555	-573,982	0	175,997	23,311,570	-397,985
2013	706,160	17,654	0	23,311,570	-559,632	0	171,597	22,923,535	-388,035
2014	688,506	17,213	0	22,923,535	-545,641	0	167,307	22,545,201	-378,334
2015	671,294	16,782	0	22,545,201	-532,000	0	163,124	22,176,325	-368,876
2016	654,511	16,363	0	22,176,325	-518,700	0	159,046	21,816,671	-359,654
2017	638,149	15,954	0	21,816,671	-505,733	0	155,070	21,466,008	-350,663
2018	622,195	15,555	0	21,466,008	-493,089	0	151,193	21,124,112	-341,896
2019	606,640	15,166	0	21,124,112	-480,762	0	147,414	20,790,763	-333,349
2020	591,474	14,787	0	20,790,763	-468,743	0	143,728	20,465,748	-325,015

Policy Scenario: Ponderosa Pine, thinning with no fire

	Acres	Acres w/ Catastrophic Burn	Acres treated with thinning	Forest Carbon Stock at Start of Year (tC)	CO2 emissions from fire (tC)	CO2 removed from thinning (tC)	Carbon sequestered in biomass of un- burned forests (tC)*
2008	801,457	0	40,073	25,406,192	0	-571,639	199,748
2009	801,457	0	40,073	25,034,300	0	-571,639	199,748
2010	801,457	0	40,073	24,662,409	0	-571,639	199,748
2011	801,457	0	40,073	24,290,517	0	-571,639	199,748
2012	801,457	0	40,073	23,918,626	0	-571,639	199,748
2013	801,457	0	40,073	23,546,734	0	-571,639	199,748
2014	801,457	0	40,073	23,174,843	0	-571,639	199,748
2015	801,457	0	40,073	22,802,951	0	-571,639	199,748
2016	801,457	0	40,073	22,431,060	0	-571,639	199,748
2017	801,457	0	40,073	22,059,168	0	-571,639	199,748
2018	801,457	0	40,073	21,687,277	0	-571,639	199,748
2019	801,457	0	40,073	21,315,385	0	-571,639	199,748
2020	801,457	0	40,073	20,943,494	0	-571,639	199,748

Net Benefits Ponderosa Pine: Difference in Policy and Baseline Scenario (policy minus baseline)

	Acres	Acres w/ Catastrophic Burn	Acres treated with thinning	Forest Carbon Stock at Start of Year (tC)	CO2 emissions from fire (tC)	CO2 removed from thinning (tC)	Carbon sequestered in biomass of un- burned forests (tC)*
2008	0	-20,036	40,073	0	635,155	-571,639	4,994
2009	20,036	-19,536	40,073	68,509	619,276	-571,639	9,863
2010	39,572	-19,047	40,073	126,008	603,794	-571,639	14,610
2011	58,619	-18,571	40,073	172,773	588,699	-571,639	19,238
2012	77,190	-18,107	40,073	209,071	573,982	-571,639	23,751
2013	95,297	-17,654	40,073	235,164	559,632	-571,639	28,151
2014	112,951	-17,213	40,073	251,308	545,641	-571,639	32,441
2015	130,163	-16,782	40,073	257,750	532,000	-571,639	36,623
2016	146,946	-16,363	40,073	254,735	518,700	-571,639	40,702
2017	163,309	-15,954	40,073	242,497	505,733	-571,639	44,678
2018	179,262	-15,555	40,073	221,268	493,089	-571,639	48,554
2019	194,817	-15,166	40,073	191,273	480,762	-571,639	52,334
2020	209,983	-14,787	40,073	152,730	468,743	-571,639	56,020

Net Benefits Douglas Fir: Difference in Policy and Baseline Scenario (policy minus baseline)

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	Acres	Acres w/ Catastrophic Burn	Acres treated with thinning	Forest Carbon Stock at Start of Year (tC)	CO2 emissions from fire (tC)	CO2 removed from thinning (tC)	Carbon sequestered in biomass of un- burned forests (tC)*	Forest Carbon Stock at End of Year (tC)	Net Forest Carbon Flux
2008	0	-7,796	15,593	0	438,942	-395,048	3,886	47,780	47,780
2009	7,796	-7,602	15,593	47,780	427,969	-395,048	7,675	88,376	40,596
2010	15,398	-7,412	15,593	88,376	417,269	-395,048	11,370	121,968	33,591
2011	22,810	-7,226	15,593	121,968	406,838	-395,048	14,972	148,729	26,761
2012	30,036	-7,046	15,593	148,729	396,667	-395,048	18,484	168,831	20,102
2013	37,081	-6,869	15,593	168,831	386,750	-395,048	21,908	182,441	13,610
2014	43,951	-6,698	15,593	182,441	377,081	-395,048	25,246	189,721	7,280
2015	50,649	-6,530	15,593	189,721	367,654	-395,048	28,501	190,829	1,108
2016	57,179	-6,367	15,593	190,829	358,463	-395,048	31,675	185,919	-4,910
2017	63,546	-6,208	15,593	185,919	349,501	-395,048	34,770	175,142	-10,777
2018	69,754	-6,053	15,593	175,142	340,764	-395,048	37,787	158,644	-16,498
2019	75,806	-5,901	15,593	158,644	332,245	-395,048	40,728	136,569	-22,075
2020	81,708	-5,754	15,593	136,569	323,939	-395,048	43,596	109,056	-27,513

Summary of Net Reductions from Policy Implementation

	Ponderosa Pine (tons C/yr)	Douglas Fir (tons C/yr)	Total (MMtCO2e)
2008	68,509	47,780	0.43
2009	57,499	40,596	0.36
2010	46,764	33,591	0.29
2011	36,298	26,761	0.23
2012	26,093	20,102	0.17
2013	16,144	13,610	0.11
2014	6,443	7,280	0.05
2015	-3,016	1,108	-0.01
2016	-12,238	-4,910	-0.06
2017	-21,229	-10,777	-0.12
2018	-29,995	-16,498	-0.17
2019	-38,543	-22,075	-0.22
2020	-46,877	-27,513	-0.27
Cumulative	105,854	109,056	0.79

Key Assumptions:

<i>Baseline assumptions:</i>	
Proportion burned annually	0.05
Proportion of burn that is catastrophic	0.5
Proportion of biomass emitted from burning and subsequent death/decay	1
Proportion of acres treated with thinning	0
Proportion of biomass removed during thinning	0.45
<i>Policy scenarios assumptions:</i>	

Proportion burned annually	0
Proportion of burn that is catastrophic	0.5
Proportion of biomass emitted from burning and subsequent death/decay	1
Proportion of acres treated with thinning	0.05
Proportion of biomass removed during thinning	0.45

Key Uncertainties

TBD

Additional Benefits and Costs

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD

AFW-9. Source Reduction, Enhanced Recycling and Composting Programs

Mitigation Option Description

Solid waste that is normally buried in landfills generates methane through decomposition processes. By preventing this source of methane, GHG emissions are reduced. Waste can be diverted through a variety of actions including composting, source reduction, recycling, and re-use. Alternatives to landfilling unprocessed organic material (food wastes, agricultural wastes, biosolids, lawn & garden wastes, or other organic materials) include composting and anaerobic digestion. Both alternatives reduce net GHG emissions and anaerobic digestion can also provide a source of renewable energy (methane). Source reduction and recycling also reduce product life cycle GHG emissions, including extraction and processing of raw materials, product manufacture, transport, and final disposal.

Mitigation Option Design

Goals: Divert 75% of wastes from landfilling by source reduction, recycling and composting.

Timing: Divert 25% by 2012; achieve the full goal by 2020.

Parties involved: TBD

Other: Not applicable.

Implementation Mechanisms

TBD

Related Policies/Programs in Place

TBD

Types(s) of GHG Reductions

TBD

Estimated GHG Savings and Costs per MtCO_{2e}

TBD

Data Sources: Need state-level data on current (BAU) recycling levels, preferably with estimates by waste category (as specified in EPA's WASTE Reduction Model or WARM); CO State or TWG estimates of waste reduction opportunities by WARM waste category (possibly from existing municipal programs like Fort Collins); current landfilling rates from CO I&F; data from CO municipalities or the literature on the capital and annual costs for source reduction, recycling, and composting programs.

Quantification Methods:

- Develop a schedule for landfill diversion in each year to be achieved via a combination of source reduction, recycling and composting;
- Apply WARM to the estimated source reductions in each waste category for both 2012 and 2020 based on the policy goals. WARM supplies lifecycle GHG reductions associated with the source reduction, recycling, and composting programs;
- Estimate annualized costs in each year based on the costs for waste diversion strategies and the volumes diverted in each year;
- Estimate the cost effectiveness of the option using the annualized costs and WARM GHG estimates in each year.

Key Assumptions: TBD

Key Uncertainties

TBD

Additional Benefits and Costs

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD

AFW-10. Landfill Methane Reduction Programs

Mitigation Option Description

Provide incentives that will result in an increase in the recovery of landfill methane for use as an energy source. Increasing the recovery of landfill methane will reduce emissions of this GHG and will offset the use of fossil fuels for commercial/industrial heat/steam generation or electricity production.

Mitigation Option Design

Goals: Implement controls or waste management options at municipal solid waste landfills such that 50% of the methane emissions that would be generated under business as usual conditions are avoided by 2020. This can be done through development of additional landfill gas to energy (LFGTE) projects, flaring, reducing the amount of biodegradable waste being landfilled, or possibly other methods.

Timing: By 2012, implement controls or management strategies at 12 sites not currently using these technologies; by 2020, achieve full implementation of the policy (50% coverage of generated methane).

Parties involved: TBD

Other: This policy is meant to cover sites that would not be expected to trigger the Federal New Source Performance Standards/Emission Guidelines (NSPS/EG) for landfills (and would be required to capture and control methane). Per the Colorado GHG Inventory & Forecast, the following landfills currently employ LFG controls:

Site Name	County	Control
County Line LF	Arapahoe	Flare
Fountain LF	El Paso	Flare
Foothills LF	Jefferson	Flare
Denver Regional North LF	Weld	Flare
Denver Regional South LF	Weld	Flare
Tower LF	Adams	Flare
Denver – Arapahoe	Arapahoe	LFGTE
Boulder LF	Boulder	LFGTE

Implementation Mechanisms

TBD

Related Policies/Programs in Place

TBD

Types(s) of GHG Reductions

TBD

Estimated GHG Savings and Costs per MtCO₂e

TBD

- **Data Sources:** Information from CDPHE on additional CO landfills that would be required to implement controls during the policy period due to Federal NSPS/EG; I&F information on methane emissions from each LF category; EPA model LFGcost-Web, which estimates the costs to implement different types of landfill gas controls (including LFG to energy); assumptions on the types of controls to be applied (flare, LFGTE plant type).
- **Quantification Methods:**
- The estimates would focus on the uncontrolled LF category; remove the sites from the I&F modeling that are expected to be controlled due to NSPS/EG; update the I&F estimates accordingly;
- Estimate methane emissions and emission reductions in each year based on the I&F and policy goals;
- Use LFGcost-Web model to estimate a range of costs for implementing LFG controls based on different technologies; this model handles large or small engine/gen sets, direct LFG use, turbines, combined heat and power turbines or engines, and leachate evaporators. TWG provides input on 2 or 3 of these technologies to be applied.
- From LFGcost-Web results of annualized costs, develop a statewide total based on methane controlled in each year
- From LFGcost-Web results of the electricity/methane produced, calculate emissions offset from fossil fuel consumption (assume natural gas lifecycle emissions for any direct use of natural gas) or electricity offset (use BAU CO grid emission factors for each year from the ES TWG). Add the emission reductions here to those calculated for methane reductions above (note that the ES or RCI TWG may claim overlapping reductions for the use of renewable fuels in their options; we'll need to adjust as needed).
- Estimate cost effectiveness from total annualized costs in each year and emissions reduced in each year.
- **Key Assumptions:** TBD

Key Uncertainties

TBD

Additional Benefits and Costs

TBD

Feasibility Issues

TBD

Status of Group Approval

TBD

Level of Group Support

TBD

Barriers to Consensus

TBD