A New Comparison of Greenhouse Gas Emissions from California Agricultural and Urban Land Uses

Steve Shaffer and Edward Thompson, Jr.

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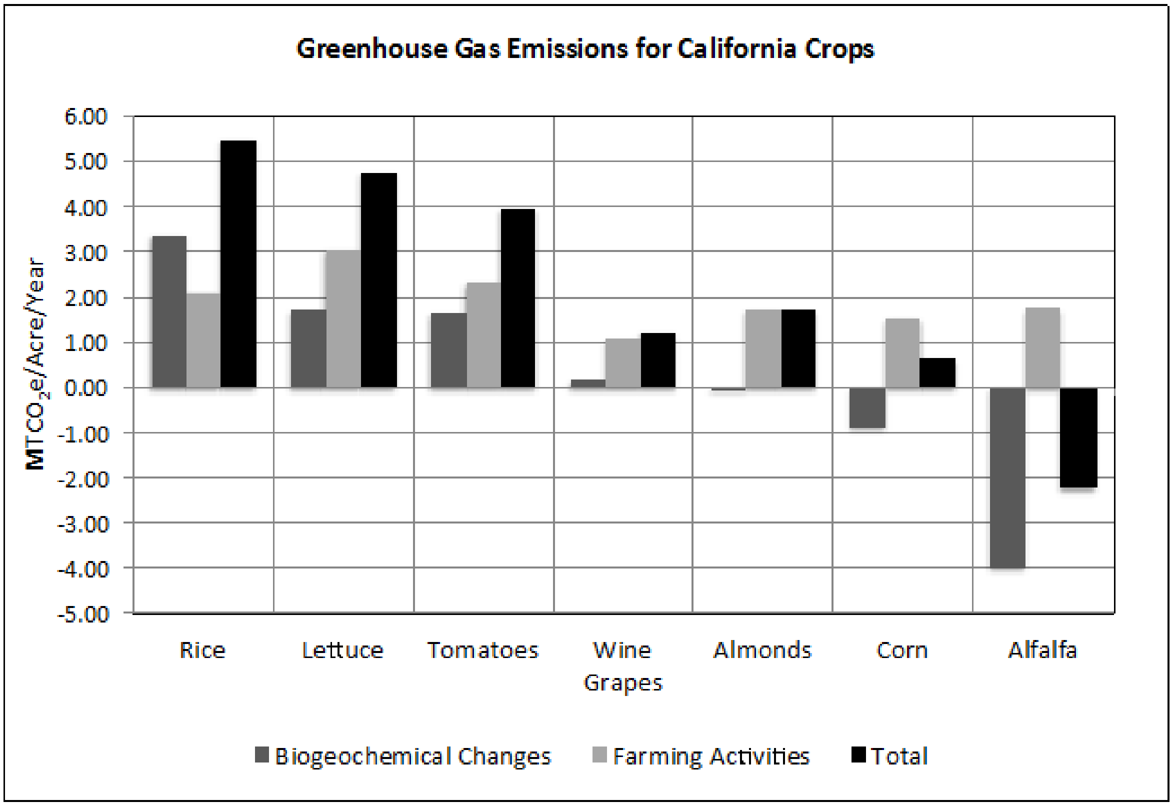
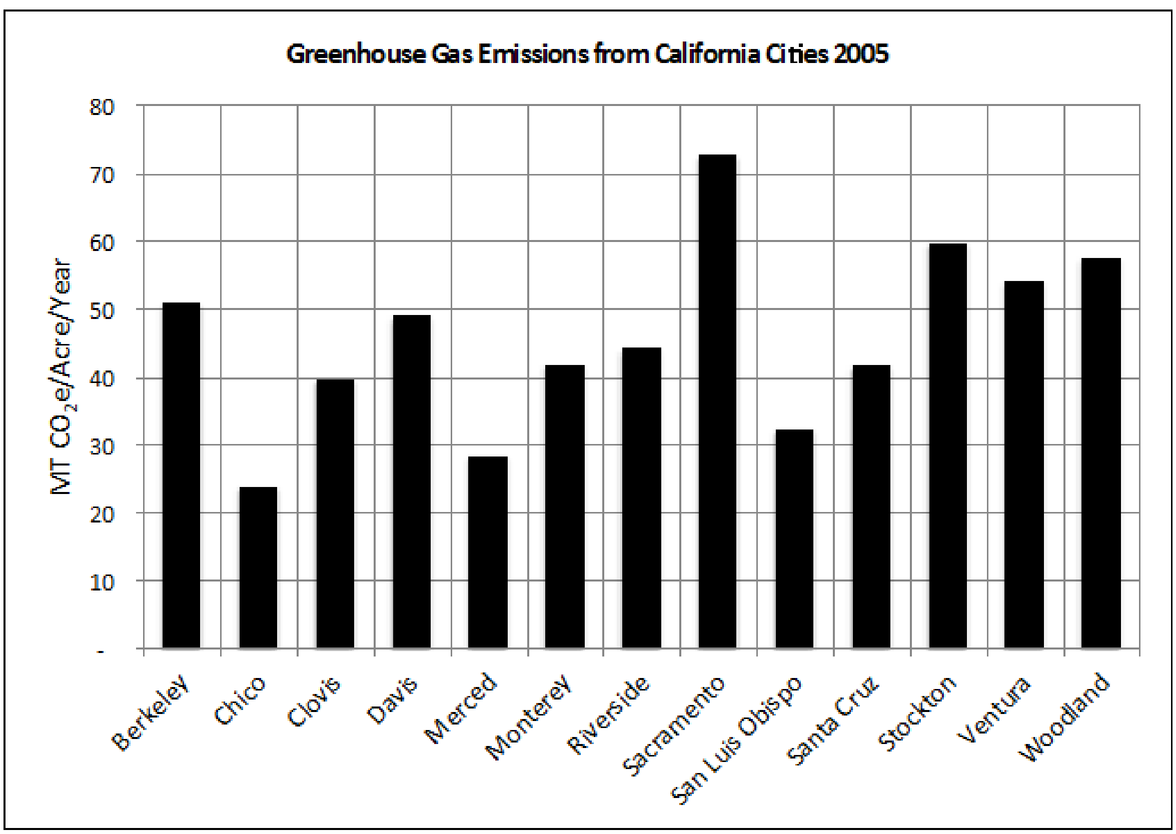

Greenhouse Gas Emissions for California Crops
MT CO_2e/Acre/Year
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
Rice
Lettuce
Tomatoes
Wine Grapes
Almonds
Corn
Alfalfa
Biogeochemical Changes
Farming Activities
Total


Greenhouse Gas Emissions from California Cities 2005
MT CO_2e/Acre/Year
80
70
60
50
40
30
20
10
-
Berkeley
Chico
Clovis
Davis
Merced
Monterey
Riverside
Sacramento
San Luis Obispo
Santa Cruz
Stockton
Ventura
Woodland

A New Comparison of Greenhouse Gas Emissions from California Agricultural and Urban Land Uses

Steve Shaffer and Edward Thompson, Jr.[1]

"*Recent research has shown that greenhouse gas emissions from urban areas are much greater than those from agricultural lands on a per-acre basis. As California's population increases, pressures to convert agricultural croplands and rangelands to urban and suburban development also increase. Conservation of these lands will be important in meeting our long-term climate goals*."

California Air Resource Board
Climate Change Scoping Plan, May 2014 Update[2]

Summary

The groundbreaking research done by Professor Louise Jackson and colleagues at U.C. Davis[3], cited by the California Air Resources Board (CARB) in its most recent Climate Change Scoping Plan update (quoted above), introduced the concept that the conversion of farmland to urban uses has significant negative consequences for climate change. This report corroborates their work by collecting and analyzing subsequent research done on greenhouse gas emissions from agricultural and urban land uses throughout California. It focuses on crop production because most of the land immediately surrounding California cities – and at risk of conversion to urban uses – is highly productive irrigated cropland.

Our analysis finds that per acre greenhouse gas emissions from urban land uses average 58 times greater than those from crop production. This compares favorably with the multiple of 70 found by Jackson, et al.

We calculate that the weighted statewide average of emissions from the seven of California's leading crops is 0.89 metric tons CO_2 equivalent per acre per year, compared with 0.81 $MTCO_2e$ reported by Jackson, et al., for Yolo County. The statewide weighted average of emissions from the 13 cities we studied is around 51 metric tons CO_2 equivalent per acre per year, compared with 61.5 for Jackson, et al.

The difference between the average emissions of crops and urban areas is approximately 50.4 $MTCO_2e$ per acre. Based on this differential, if California farmland conversion could be reduced by half (from 39,500 to 19,750 acres per year), within a decade it would avoid the emission of a cumulative total of 55 million metric tons of greenhouse gases, equivalent to avoiding emissions from more than 129 billion vehicle miles travelled (VMT).

These findings reinforce CARB's conclusion that "farmland and open space conservation can play a key role in helping communities achieve the objectives of the Sustainable Communities Strategies." And they support the Board's recommended strategy of "conserving these lands … by using incentives for conservation easements, supporting urban growth boundaries, and maintaining agricultural zoning."[4]

Financial Support has been provided by the David and Lucile Packard Foundation and members of American Farmland Trust

Agricultural Greenhouse Gas Emissions

In California, agriculture contributes only eight percent of total man-made greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)[5]. Of the 38 million metric tons of CO_2 equivalent California agriculture produces annually, roughly 63 percent is from livestock operations, 27 percent is from crop production and the remaining 10 percent is from the use of fossil fuel to run equipment, irrigation pumps, etc.[6] (Table 1).

Within the crop sector, the two main sources of greenhouse gases are changes in the biogeochemistry of soil, water and air caused by crop production; and direct emissions from farming activities such as plowing, planting, fertilizing and harvesting. This report encompasses both of these sources, relying on modeling tools developed and tested by leading research institutions.

Table 1 – Sources of Agricultural Greenhouse Gas Emissions in California

California Agriculture Total 2012 - MMT CO_2e	38.0
Livestock	24.0
Enteric Fermentation (Digestive Process)	11.8
Manure Management	12.2
Crop Growing & Harvesting	10.3
Soil Preparation and Disturbances	8.8
Rice Cultivation & Crop Residue Burning	1.4
General Fuel Use	3.8
Diesel	2.8
Natural Gas	0.7
Gasoline	0.3

Methodology Used to Calculate Greenhouse Gas Emissions from Crop Production

Crop production causes changes in the biogeochemistry of soil, water and air that are one source of greenhouse gases from agriculture. For example, cultivating the soil exposes it to air, causing some of the organic carbon contained in it to oxidize into carbon dioxide (CO_2) that is released into the atmosphere. On the other hand, incorporating organic matter such as crop residue (stalks, leaves, etc.) into the soil increases soil carbon (sequestration). The measure of the increase or decrease in soil organic carbon is referred to as "dSOC."

Changing the water content of soil through irrigation increases the amount of biological activity in soil, primarily of microbes that convert inorganic and organic forms of nitrogen present in soil into compounds needed by plants for growth. But the process also produces nitrous oxide (N_2O), a potent greenhouse gas with 300 times the global warming potential of a comparable amount of CO_2. Fertilization adds reactive nitrogen, some of which is also oxidized to produce N_2O. When microbes break down organic matter in the absence of oxygen as they do to crop residue in flooded rice fields (and in the guts of cattle and other ruminant animals), the process of anaerobic decomposition produces methane (CH_4), another greenhouse gas that is 25 times as potent as carbon dioxide.

For purposes of this report, the greenhouse gas emissions from these biogeochemical changes from the production of California crops were calculated using the DeNitrification-DeComposition Model (DNDC) developed at the University of New Hampshire[7]. The results reported here came from previous analyses of specific crops sponsored by the California Almond Board (almonds), California Vintners Association (wine grapes), a collaboration between the California Rice

Commission, Environmental Defense Fund and others (rice) and CARB (alfalfa, tomatoes, lettuce and corn).[8] These crops collectively represent 4 million acres or roughly half of all the irrigated cropland in California (Table 2). The calculations in each of these reports were done by Bill Salas and Pete Ingraham at Applied GeoSolutions (AGS), who aggregated the findings for AFT.

Table 2 – California Crops Studied by Acreage

Crop	Acres (2012)
Alfalfa	1,550,000
Almonds	780,000
Rice	556,000
Wine Grapes	506,000
Tomatoes (Processing)	258,000
Lettuce	199,700
Corn (Grain)	180,000
Total	4,029,700

The DNDC model does not attempt to estimate emissions from farming activities conducted above ground. To calculate these emissions, we relied on the Cool Farm Tool (CFT) developed by Unilever Corporation and researchers at the University of Aberdeen (Scotland) in collaboration with the Sustainable Food Lab[9]. CFT is a farm-level greenhouse gas emissions calculator that provides scenario modeling and emissions evaluation of practices that farmers employ in the field, including operation of machinery, irrigation, application of fertilizers and pesticides and management of crop residue. It also takes into account life cycle emissions from the upstream production of agricultural inputs such as fertilizer. For purposes of our analysis, data on energy, water, fertilizer and other inputs were obtained from the University of California Cooperative Extension Service's Crop Production Cost and Return studies, which are considered the definitive source of this kind of information.[10] Daniella Malin of the Sustainable Food Lab, a project of Ag Innovations Network, ran the CFT model for the crops in this report.

Results of Agricultural Greenhouse Gas Emissions Analysis

The DNDC model calculates emissions of methane (CH_4) and nitrous oxide (N_2O), changes in soil organic carbon (dSOC) as a measure of CO_2 emissions or carbon sequestration, as well as their sum total, expressed as Global Warming Potential (GWPnet). The reported results of the analyses of total greenhouse gas emissions from biogeochemical changes for specific California crops are shown in Table 3.

Table 3 – Greenhouse Gas Emissions from Biogeochemical Changes for California Crops

	Emissions Per Acre Per Year – $MTCO_2e$			
Crop	N_2O	CH_4	dSOC	GWP_{net}
Rice	0.57	3.33	-0.52	3.37
Lettuce	2.49	-0.16	-0.64	1.70
Tomatoes	1.37	-0.18	0.44	1.64
Wine Grapes	0.45	-0.01	-0.29	0.15
Almonds	0.52	0.00	-0.54	-0.02
Corn	2.12	-0.11	-2.88	-0.87
Alfalfa	0.20	-0.11	-4.06	-3.97

As Table 3 illustrates, greenhouse gas emissions from biogeochemical changes associated with crop production differ significantly, though most crops tend toward the mid-range. At one extreme, rice has exceptionally high emissions primarily because methane (CH_4) is released by anaerobic decomposition when the fields are flooded.[11] At the low end, the negative emissions from alfalfa production are due largely to the significant amount of carbon sequestered (removed from the atmosphere and stored) in the soil by its expansive root system.

In the mid-range, crops like lettuce[12] and processing tomatoes tend to have higher emissions than grapes and almonds because of greater applications of nitrogen fertilizers. Corn emissions are marginally negative because its high consumption of nitrogen fertilizer is offset by the incorporation of crop residue, i.e., the corn stalks, back into the soil after harvest.[13] These differences among crops are reflected in a breakdown of the specific types of greenhouse gases shown in Table 3.

The other major source of greenhouse gas emissions from crop production is farming activities like plowing, planting, fertilizing and harvesting. Results of the CFT analysis of these emissions for the selected crops are shown in Table 4.

Table 4 – Sources of Greenhouse Gas Emissions from Farming Activities for California Crops

	Emissions Per Acre Per Year – $MTCO_2e$					
Crop	Fertilizer	Pesticides	Residue Management	On-Farm Energy Use	Irrigation	Total
Rice	0.50	0.04	0.04	1.19	0.33	2.10
Lettuce	1.23	0.12	0.21	0.43	1.04	3.04
Tomatoes	0.28	0.09	0.14	1.09	0.71	2.31
Wine Grapes	0.09	0.08	0.03	0.22	0.65	1.08
Almonds	0.23	0.09	0.18	0.22	1.00	1.72
Corn	0.34	0.02	0.14	0.30	0.71	1.52
Alfalfa	0.02	0.03	0.13	0.62	0.92	1.73

As in the case of emissions from biogeochemical changes, those from farming activities will vary depending on the specific practices employed and site-specific characteristics of the soil, weather, etc. In particular, emissions from irrigation pumps, which are a significant percentage of total emissions for all California crops, vary significantly with the amount of water applied, which itself depends on location, weather and irrigation method used. The CFT used horizontal and vertical distance, water quantity, power source and irrigation method to determine energy used for irrigation. Statewide energy mix averages are used in converting electricity to greenhouse gasses.

To calculate the total greenhouse gas emissions from crop production, emissions from biogeochemical changes in the soil were added to those from farming activities. These results are shown in Table 5.

Table 5 – Total Per Acre Greenhouse Gas Emissions for California Crops

	Emissions Per Acre Per Year – $MTCO_2e$		
Crop	Biogeochemical Changes	Farming Activities	Total
Rice	3.37	2.10	5.47
Lettuce	1.70	3.04	4.74
Tomatoes	1.64	2.31	3.95
Wine Grapes	0.15	1.08	1.23
Almonds	-0.02	1.72	1.70
Corn	-0.87	1.52	0.65
Alfalfa	-3.97	1.73	-2.24

While total greenhouse gas emissions from California's leading crops vary significantly, most are within the range of 1 to 5 $MTCO_2e$ per acre per year. As shown in Table 6, the weighted average of the emissions from the selected crops, based on the acreage planted, is 0.89 $MTCO_2e$ per acre per year. This is very close to the 0.85 $MTCO_2e$ per acre per year average determined by Jackson, et al., for Yolo County.

Table 6 – Annual Per Acre Greenhouse Gas Emissions for Leading California Crops

Crop	Emissions/Acre/ Year $MTCO_2e$	Acres Planted	Total Annual Emissions	Weighted Average
Rice	5.47	556,000	3,041,525	
Lettuce	4.74	199,700	945,922	
Tomatoes	3.95	258,000	1,018,471	
Wine Grapes	1.23	506,000	621,735	
Almonds	1.70	780,000	1,328,478	
Corn	0.65	180,000	116,532	
Alfalfa	(2.24)	1,550,000	(3,476,380)	
Total		4,029,700	3,596,282	0.89

Greenhouse Gas Emissions from Urban Land Uses

On a *per acre* basis, urban land uses tend to generate significantly more greenhouse gases than crop production and other agricultural uses. The primary source of urban emissions is the combustion of fossil fuels to generate energy for homes, commercial buildings, industry and transportation. Emissions from landfills and sewage treatment plants are another significant source, as is the use of energy for pumping water.

Methodology Used to Calculate Greenhouse Gas Emissions from Urban Land Uses

To meet greenhouse gas reduction goals established under the Global Warming Solutions Act (AB 32), many California cities conducted inventories of their greenhouse gas emissions as baseline information in the development of Climate Action Plans.[14] To do so, they used a standardized methodology developed by the California Statewide Energy Efficiency Collaborative. We used these figures, as reported by the cities for which we could find data, to calculate *per acre* urban emissions by dividing the total emissions by the land area of the respective cities reported by the U.S. Census Bureau.

Results of Urban Land Use Greenhouse Gas Emissions Analysis

The greenhouse gas emissions reported by the selected cities are shown in Table 7. Most inventories are for the year 2005. The categorical breakdown was specified by the Air Resource Board methodology. In some cases, where the inventories conducted for the cities do not appear to have strictly followed the categorization protocol, there are gaps in some categories, although all emissions appear to be accounted for.

Citywide greenhouse gas emissions from urban land uses vary widely. There is a twenty-fold difference between the highest and lowest total emissions among the cities we studied. Not surprisingly, larger cities tend to have higher greenhouse gas emissions, with notably higher emissions from industry and transportation. The average of the cities we studied is 1.06 million metric tons per year and the median is 563 thousand metric tons per year.

Table 7 – Sources of Greenhouse Gas Emissions from Selected California Cities

City	Residential	Commercial Industrial	Transport	Solid Waste	Other	Total
Berkeley	152,599	157,746	265,544	NA		575,889
Chico	161,743	NA	322,602	19,987		504,332
Clovis	81,758	92,100	370,517	22,910	23,649	590,934
Davis	95,106	44,123	164,195	5,943		309,367
Merced	104,457	147,974	145,563	7,754	17,262	423,010
Monterey	48,057	87,577	75,635	15,763		227,032
Riverside	462,985	588,753	1,078,130	159,677		2,289,535
Sacramento	748,985	1,008,433	2,135,180	401,910	258,736	4,553,051
San Luis Obispo	55,377	57,950	132,142	18,768		264,237
Santa Cruz	74,769	82,812	157,599	12,455	12,017	339,652
Stockton	776,186	277,362	1,132,265	165,497	8,694	2,360,932
Ventura	NA	NA	401,259	NA	349,046	750,305
Woodland	85,131	106,955	359,648	3,349	7,904	562,987

Per acre greenhouse gas emissions also vary significantly from city to city, but the range is much narrower than for total emissions, as shown in Table 8. The weighted average greenhouse gas emissions among the cities is 51 $MTCO_2e$ per acre per year. In general, the per acre greenhouse gas emissions from the cities we studied tend to be somewhat lower than the 61.5 tons per acre that Jackson, et al., determined to be the average for Yolo County urban areas

Table 8 – Per Acre Greenhouse Gas Emissions for California Cities

City	Total Annual Emissions	Land Area (Acres)	Annual Emissions Per Acre ($MTCO_2e$)
Berkeley	575,889	11,328	51
Chico	504,332	21,120	24
Clovis	590,934	14,899	40
Davis	309,367	6,330	49
Merced	423,010	14,925	28
Monterey	227,032	5,421	42
Riverside	2,289,535	51,930	44
Sacramento	4,553,051	62,669	73
San Luis Obispo	264,237	8,179	32
Santa Cruz	339,652	8,154	42
Stockton	2,360,932	39,469	60
Ventura	750,305	13,469	54
Woodland	562,987	9,792	57

Comparison of Greenhouse Gas Emissions from Crop Production and Urban Areas

Because of the significant variations in greenhouse gas emissions from both crops and urban areas, the difference between the two sources will also vary widely with the specific crops being displaced by urban development – and, over the longer term, by whatever crops may be grown on the land in the future. Indeed, both the particular farming practices used on the land (for example, the application of more or less fertilizer or water) and the type of urban development (high or low density, conventional versus LEED-certified buildings, etc.) that replaces agriculture will further influence the change in greenhouse gases on any given acre of land when its use changes.

Because of these variations, attempting to determine the change in emissions when any given parcel of farmland is converted to urban use with this kind of exactitude would appear to be counterproductive and unnecessary for purposes of justifying a general policy of encouraging farmland conservation and protection as a strategy for reducing greenhouse gas emissions. It should be sufficient for purposes of establishing such a policy to demonstrate that there is a reliably significant increase in emissions, within a given range, whenever cropland is converted to urban use. That is what our research shows.

On average, our calculations show that the annual per acre greenhouse gas emissions from the production of California's leading crops average 50.4 tons per acre lower than the emissions from urban areas around the state (Table 9). This is somewhat lower, but still comparable to the 60.7 MT per acre per year difference found by Jackson, et al., in their study of Yolo County emissions. This translates into a multiple of 58 times higher greenhouse gas emissions from urban areas than from irrigated cropland, again within the same order of magnitude as the 70-fold difference calculated by Jackson.

Table 9 – Comparison of Greenhouse Gas Emissions from California Crops and Urban Areas

	Annual Per Acre Emissions ($MTCO_2e$)		
	Maximum	Weighted Average	Minimum
Crop Production	5.47	0.89	(2.24)
Urban Areas	73	51	24
Difference	67.2	50.4	26.1
Multiple (Urban: Crops)		58	

Potential Climate Benefits of Reducing Greenhouse Gas Emissions Through Farmland Conservation and Protection

Based on the average differential (50.4 $MTCO_2e$/acre/year) between emissions from crop production and urban land uses, for each 10,000 acres of California farmland not converted to urban use, the annual greenhouse gas savings would be equivalent to taking 98,800 cars off the road and reducing vehicle miles travelled by almost 1.2 billion miles[15] (Table 10). If farmland conservation and protection programs could halve the average annual conversion of 39,500 acres of California agricultural land to urban uses, [16] within a decade a total of about 55 million $MTCO_2e$ of greenhouses gases could be avoided, with a climate benefit equivalent to reducing VMT by more than 129 billion miles.

Table 10 – Equivalent Reduction in Greenhouse Gases and VMT from Auto Travel

	Crop Production	Urban Land Uses	Difference
Emissions ($MTCO_2e$/Acre/Year)	0.89	51.0	50.4
Emissions Per 10,000 Acres	8,924	512,972	504,048
Equivalent Number of Autos	1,750	100,583	98,833
Equivalent Annual VMT (Millions)	21	1,207	1,186

Conclusions and Observations

This compilation of data and its analysis corroborates the groundbreaking research done by Jackson, et al., demonstrating that when cropland is converted to urban uses, greenhouse gas emissions increase by an order of magnitude, regardless of the crop being grown on the land or the type of urban development that replaces agriculture. American Farmland Trust believes that this finding supports a policy of investing cap-and-trade revenue from AB 32 in programs that effectively conserve and protect agricultural land.

Though the terms "conservation" and "protection" of farmland are often used interchangeably, they not the same thing. And both are instrumental in maintaining the agricultural land base and its public benefits, whether related to food production, climate change or other needs such as watersheds or habitat.

Conservation of farmland, properly understood,[17] entails minimizing its conversion to nonagricultural uses by preventing its unnecessary or premature development, generally through conscientious planning and appropriate land use policies. This is critical to establishing a favorable environment for long-term investment in agriculture – including investment in agricultural easements. Farmland conservation plans and policies also complement and reinforce the strategy of promoting urban infill and more efficient (higher density) suburban development – which has the reciprocal benefit of reducing farmland conversion and greenhouse gas emissions associated with it.

Because land use policies are subject to change, however, longer-term protection of farmland from development is also needed through mechanisms such as Williamson Act contracts and, ideally, perpetual conservation easements. The donation and sale of such easements are more attractive to owners of farmland in a context that assures them that urban development will not encroach on their farming operations. And as easement acquisitions multiply within a given agricultural area – particularly if concentrated along urban growth boundaries – they tend to reinforce conservation-oriented land use policies by making it less likely that those policies will be abandoned or weakened. Thus, farmland conservation and protection buttress each other, creating synergy that makes each more effective than they tend to be when pursued independently.[18]

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[1] Steve Shaffer is the principal of Environmental Consulting for Agriculture and former chief of the environmental stewardship division of the California Department of Food and Agriculture. Edward Thompson, Jr., is California Director and Senior Associate of American Farmland Trust. AFT is a national nonprofit organization that advocates for conserving and protecting farmland, promoting environmentally beneficial farming practices and maintaining agriculture as an economically viable use of the land. The authors wish to acknowledge the substantial contributions of those who actually conducted the research reported in this paper: William Salas, President and Chief Scientist, and Pete Ingraham, Research Scientist, Applied GeoSolutions; and Daniella Malin, Senior Program Manager, Agriculture and Climate, Sustainable Food Lab.

[2] First Update to the Climate Change Scoping Plan: Building on the Framework Pursuant to AB 32, The California Global Warming Solutions Act of 2006, http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf

[3] Jackson, et al., University of California, Davis, Adaptation Strategies for Agricultural Sustainability in Yolo County, California: A White Paper from the California Energy Commission's Climate Change Center, July 2012 (CEC-500-2012-032).

[4] *Supra, fn. 2.*

[5] Methane and nitrous oxide both have greater global warming potential than the same mass of carbon dioxide. To allow comparisons and to calculate their cumulative effect, the emissions of all three are typically reported in metric tons of their CO_2 equivalents ($MTCO_2e$).

[6] California Air Resources Board, California Greenhouse Gas Emission Inventory 2000-2012 (May 2014), http://www.arb.ca.gov/cc/inventory/inventory_current.htm

[7] DNDC is a mathematical computer model that performs process-based simulations of nitrogen and carbon dynamics in agro-ecosystems. Based on environmental drivers like soil characteristics, temperature and precipitation data, crop characteristics, and crop management, the model predicts crop growth and yield, greenhouse gas emissions and other environmental effects like nitrogen leaching and runoff. The results it produces have been validated by comparison to actual field measurements over several decades of

application. To calculate the greenhouse gas emissions of leading California crops, the DNDC model was used to run thousands of simulations based on hundreds of soil types throughout state, accounting for weather variability over more than 20 years. The results of these simulations were used to determine the range (5th and 95th percentiles) and average emissions. See, *Users Guide for the DNDC Model (Version 9.5)*, Institute for the Study of Earth, Oceans and Space, University of New Hampshire, August 2012

[8] D. Hunter, et al, Carbon Dynamics of Orchard Floor Applied, Chipped Almond Prunings as Influences to Cover Crop Management and Farm Practices, Final Report to the California Department of Food and Agriculture Specialty Crop Block Grant Program, 2013; A. Jordan, Field Testing a Carbon Offset and Greenhouse Gas Emissions Model for California Winegrape Growers. Final Report to the California Department of Food and Agriculture Specialty Crop Block Grant Program, 2013; California Air Resources Board, Compliance Offset Protocol, Rice Cultivation Projects; C. Li, et al, Calibrating, Validating, and Implementing Process Models for California Agriculture Greenhouse Gas Emissions, Final Report for CARB Contract Number 10—309, 2013.

[9] The Cool Farm Tool (http://www.coolfarmtool.org) is a farm-level calculator that has been tested and adopted by a range of multinational companies that are using it to work with agricultural suppliers to measure, manage, and reduce greenhouse gas emissions in the effort to mitigate global climate change. It uses multifunctional models built through empirical research from a broad range of published data sets, International Panel on Climate Change (IPCC) methodology and advanced algorithms to calculate estimates from the following emissions sources:

- On-farm fuel and electricity use from tractors, irrigation, etc., utilizing standard conversion factors;
- Fertilizer production emissions based on full life cycle analysis principles, including all relevant activities and emissions from raw material supply up to the final finished product at factory gate including all energy use and non-CO_2 emissions;
- Soil carbon sequestration based on an empirical model built from over 100 global datasets; and
- Soil nitrous oxide emissions based on an empirical model built from an analysis of over 800 global datasets.
- Agricultural methane emissions using IPCC estimates
- Pesticide production emissions
- Crop residue emissions and background N_2O emissions using IPCC methodology

[10] Published on the U.C. Davis, Agricultural & Natural Resources Division Web site, http://coststudies.ucdavis.edu/ Data for tomato production had to be constructed anew because Extension data were based on furrow irrigation that is now largely an obsolete practice in the era of drip irrigation.

[11] It should be noted that flooding of rice fields after harvest also provides tens of thousands of acres of winter habitat for migratory waterfowl and other birds on the Pacific Flyway.

[12] Lettuce data are based on the assumption that two crops are produced in a single year, thus doubling its annual emissions.

[13] The incorporation of residue is typically much lower when corn is used for silage (livestock feed) rather than harvested for grain.

[14] Statewide Energy Efficiency Collaborative, Climate Action Planning for Community-Wide GHG Emissions, http://californiaseec.org/tools-guidance/climate-action-planning-for-community-wide-ghg-emissions

[15] Based on EPA estimates of annual average travel of 12,000 miles and 5.1 $MTCO_2e$ per car. Source: http://www.epa.gov/otaq/climate/documents/420f11041.pdf

[16] Department of Conservation, Farmland Mapping and Monitoring Program, *Net Important Farmland Conversion 1984-2010*. A 19,750-acre annual reduction in farmland conversion could be achieved by increasing the average density of new urban development from the current statewide average of 9 people per acre to 18 people per acre.

[17] Conservation: “The careful use of natural resources to prevent them from being lost or wasted.” Merriam-Webster Dictionary.

[18] This has important implications for preventing “leakage,” which is to say the potential for the protection of some farmland to shift development toward other farmland. For further elaboration on this phenomenon, see, E. Thompson, Hybrid Farmland Protection Programs: A New Paradigm for Growth Management? 23 William & Mary Environmental Law & Policy Review 830 (Fall 1999).

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