POTENTIAL ENERGY EFFICIENCY SAVINGS IN THE AGRICULTURE SECTOR

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ABSTRACT

This report outlines the methodology and results for a study of the potential cost and energy savings available from energy efficiency in the agriculture sector nationally and in several states. The methodology described leads to a conservative estimate of 1 billion dollars per year. The largest savings are available in the motor system (especially irrigation pumping), onsite transportation, and lighting energy end-uses. We also discuss the extreme conservative nature of the potential savings and how the estimates could be improved with the collection of more detailed data in specific areas, primarily increased understanding of energy use on the farm and measured impacts of energy-efficient technology and practice upgrades. Nevertheless, the savings potential amounts to 10 percent of total energy expenses for the sector nationwide and 35 percent savings based on only characterized energy end-uses and deserve a closer look and better data collection.

INTRODUCTION

This is the third American Council for an Energy-Efficient Economy (ACEEE) report in a series focusing on the nature of energy use in agriculture in the United States, model programs to promote efficiency on the farm, and overall potential cost and energy savings for the sector through the implementation of increased energy efficiency. The first report (Brown and Elliott 2005) was a review of end-use energy on farms, including the challenges in determining those due to lack of data, and large sector and regional diversity. In the second (Brown, Elliott, and Nadel 2005), we sought to understand and improve the extant programs for increasing energy efficiency in the agriculture sector. In that report we found that local (or apparently local) programs, where implementers understand the needs of particular farm-types and farmers, have the most impact on cost and electricity savings for the farmers. This finding is a reflection of the diversity of the sector and the need for focused data (in the case of programs, evaluation data) collection regarding energy use in the agriculture sector.

This third and final report in the series is an exercise in determining the potential cost and energy savings to the farmer upon implementation of energy efficiency measures. Using available farm-type-specific data from the agriculture energy use characterization nationally and for select states, we then apply measures with known energy efficiency improvement impacts and are able to estimate the total potential cost and energy savings in the agricultural sector. Like its companions, this report's results show that an improved understanding of energy use on the farm, as well as of the potentially implementable energy efficiency measures on the farm, is required to achieve a robust understanding of potential energy and cost savings to the farmer and, in turn, to greater society. Indeed, the results of this initial analysis indicate that a significant opportunity exists, which makes a compelling case for better understanding the energy and cost savings available from increased efficiency in the agriculture industry.

DETERMINING THE POTENTIAL ENERGY SAVINGS IN THE AGRICULTURE SECTOR

The potential for energy efficiency is determined by both how energy is used and what technologies and practices are available to change practice from existing norms. The approach we used for determining the energy efficiency potential is based on a methodology developed by ACEEE over many years of analyses (e.g., SWEEP 2002, Ecotope 2003, and Optimal 2003). The methodology has been used for the residential, commercial, and industrial sectors in the past and required refinements to fit the needs of and data available for the agriculture sector. This section provides an overview of the methodology, reviews the modifications, and outlines the decision-making process for including certain farm-types and technologies while excluding others.

Energy Efficiency Potential Methodology

The methodology for determining the energy efficiency potential is straightforward: the current energy consumption for an end-use is multiplied by the product of the savings potential of the combined measures affecting that end-use and the remaining portion of the market to be saturated (see Equation 1). This methodology was refined for the agriculture sector for two primary reasons: fuel diversity and farm-type diversity.

Equation 1. Basic Energy Saving Potential

Total End-Use Energy Use	X	(Remaining Available Market x Potential Saved Energy per Measure)	=	Total Potential Saved Energy

Up to this point the methodology had been limited to single- or two-fuel energy efficiency potential. In the agriculture sector, however, there is a greater diversity of fuels used, even for the same end-use in different regions or farm-types. For this reason, the methodology was expanded to cover five different sources: diesel, electricity, gasoline, natural gas, and all other fuels (including propane). We used the *1997 Census of Agriculture* (USDA 1999), which covered the full diversity of fuel expenses for each farm-type in each state. Energy use was broken down by end-use, as described in our characterization report, *On-Farm Energy Use Characterizations (*Brown and Elliott 2005). The measure savings were determined by primary fuel type. We converted all fuels into British thermal units (Btu). This normalization of units gave us the ability to measure the energy efficiency potential across fuels, while still identifying the large savings opportunities within each fuel. It also allowed us to identify differences among fuel uses for each farm-type or technology.

Farm-type diversity was the other impetus for modification of the methodology, allowing us to better estimate the potential for the agriculture sector. The agriculture sector is not monolithic, and different farm-types have very different energy needs. For instance, the energy needs of a dairy farm (milking motors, milk coolers) are very different from those of a hog and pig farm (ventilation and lighting) and cattle feedlots (onsite transportation and water pumping). In addition, there are significant differences within a farm-type by region. This diversity represents a challenge, however, because of the limited availability of disaggregated data on energy end-uses (as discussed in Brown and Elliott 2005).

Further, there are other attributes that can affect farm energy use. For example, the needs of an irrigated farm are very different from those of a non-irrigated farm, even if they are of the same farm-type. For this reason, we also parsed states from the national picture. Although resources did not allow for a full review of states, we chose states that we felt would present a broad overview for their regions. Farms were disaggregated in the same fashion as they are in USDA (1999) for data consistency reasons. The farm-types with the largest value of shipments were chosen, followed by those with the largest energy expenditures (these often coincided). All farm-types qualifying at the state level were included in the national estimates. Table 1 shows the farm-types reviewed for the nation and each of the sample states.

As with the characterization study (Brown and Elliott 2005), we used *1997 Census of Agriculture* data (USDA 1999), supplemented with data from the Economic Research Service (ERS 2004) at the U.S. Department of Agriculture. The ERS data is the broad source of the *Census of Agriculture* and is much more flexible for analysis and presentation than the *Census*. When actual energy used was unavailable, energy expenditures were used as a proxy. The expenditures were divided by the price for the narrowest region available to calculate energy used. Commercial fuel cost rates from the *State Energy Data Report* (SEDR) (DOE 1999) were used for all states. The commercial rate was used because the SEDR documentation indicates that agricultural use is included in the commercial category. Anecdotal evidence indicates that depending on the size of a farm, the rate structure for fuel will vary, so use of the commercial rate is an estimate, and resulting energy consumption estimates should be treated as an approximation.

Table 1. Farm Types Reviewed for Characterization and Energy Efficiency Potential

Geographical Area	Farm-Types Reviewed for Energy/Cost Savings Potential							
	All Types	Poultry	Dairy	Greenhouse/ Nursery	Cattle Feedlots	Oilseed and Grain	Fruit and Tree	Hogs and Pigs
USA	X	X	X	X	X	X	X	X
California	X		X	X	X	X	X	
Florida	X			X			X	
Kansas	X				X	X		
New York	X		X					
Vermont	X		X					
Wisconsin	X		X		X			

To measure potential from energy efficiency improvements, we took data from the state and farm-type characterizations, and identified the high energy use measures, as these are likely to have large savings potentials. Note that the efficiency measures do not reference specific brands or products, but refer to general categories of technologies and practices. Not all measures were expected, nor were found to have a large savings potential for all farm-types. A full list of these measures considered can be found in Table 2.

Data regarding the potential energy saved for the wide array of fuels and end-uses in the agriculture sector is also presented in Table 2. This information is presented in the form of a savings potential co-efficient, defined here as the percentage reduction that a measure can have on the baseline measurement of energy use for that measure. These measures include both technology improvements (e.g., the retrofitting of compact fluorescent light bulbs in place of incandescent light bulbs) and practice improvements (e.g., a transition to no-till agriculture serves). Comprehensive information about the energy efficiency potential for all measures specific to the agriculture sector is not available and indeed there is a major need for further research (see discussion section). To function as a proxy for such data, we present initial estimates here developed by ACEEE based on a wide variety of data sources. These sources include energy efficiency program evaluations, research on specific efficiency improvements on technologies (not specific to the agriculture sector), and interviews with experts in the field that have been installing or using the new equipment.

In the agriculture sector, many of the individual states in our sample provided usable, state-specific data for measure savings. California, for example, has collected a large amount of measure-specific data as a result of the rigorous evaluation standards required for programs and projects that use Public Benefit Funds money. Some of this data can be translated to other states, especially within the same climate regions and within the same or similar farm-types. In cases where empirical evidence from other states, such as in Florida, supported the use of the state-specific savings estimates we also used the data. Other states have robust information regarding a few farm types. For example, New York, Wisconsin, and Vermont have a wealth of information on dairy farm energy efficiency improvements. At the state level, wherever possible, we based our estimates for potential savings on information gathered within the state as indicated in Table 2.

Table 2. Categories and Sub-Categories for Energy-Efficient Measures

Category	Sub-Categories	Data Source for Savings Potential	Savings Potential Co-Efficient*
Motors	Pumps	Nadel et al. 2002	0.34
	Fans and Blowers	Nadel et al. 2002	0.41
	Compressors	Nadel et al. 2002	0.25
	Material Handlers	Elliott 2001	0.15
	Material Processors	Nadel et al. 2002	0.10
	Refrigeration	Nadel et al. 2002	0.20
	Other Motors	Nadel et al. 2002	0.05
Drying and Curing		Unpublished research	0.15
Water Heating		Optimal Energy et al. 2003	0.2
Heating Ventilation and Air Conditioning (HVAC)		Optimal Energy et al. 2003	0.3
Lighting	Farm Buildings	Nadel et al. 1998	0.40
	Residential	Nadel et al. 1998	0.70
	Area	Martin et al. 2000	0.70
	Other Lighting	Martin et al. 2000	0.40
On-Site Transportation		DeCicco 1997, Program Implementers	0.37
Machinery	Tractors	Program Implementers, Distributors	0.70
	Grain and Bean Combines	Program Implementers, Distributors	0.05
	Cotton Pickers	PCCA 2003	0.05
	Forage Harvesters and Planters (Self-Propelled)	Program Implementers, Distributors	0.05
	Hay Balers	No Meaningful References Found	—
	Other Machinery	Program Implementers, Distributors	0.05
Other On-Farm Energy Use		No Meaningful References Found	—

*Potentials used for national level for all farm types, and where no local or farm type data available, at the regional level. Saturation co-efficient not included. Primary fuel savings potential only.

Finally, this study bases total potential energy savings on best efficiency options available within an end-use. That is, we do not consider fuel switching as a measure option.

Because the majority of available data are approximations, we were conservative in their application. For instance, if several data sources reported different savings, we chose the lower range. Further, measures where savings data was not available were not included in the analysis. For example, we were unable to acquire data on savings for hay baler energy efficiency improvements, so they are omitted. This produces an even more conservative estimate because, although we use a full energy use baseline from the sector, where we do not have the information so no savings is projected. Moreover, a significant data gap exists in regard to other on-farm energy use, as noted at the bottom of Table 2. A large portion of energy consumption cannot be attributed to the sectors already outlined, but it is felt that the savings potential would be a very large number if quantified. Though we believe this significantly underestimates the savings within the agriculture sector, without data to prove otherwise, we prefer to be conservative in the estimates of potential savings and identify areas where empirical evidence indicates that large savings may be available as priorities for further research. These areas are discussed later in this report.

Specific Measures Identified

This section outlines the chosen measures and their savings potentials as defined in Table 2 in more detail. While some measures are specific to the needs of a farm-type or region, others are general energy efficiency improvements. These general improvements and the data used to define their potential energy savings are discussed in this section.

- *Motor systems.* Motor measures included a variety of general and application-specific measures. For all motors, especially pumps for irrigation, motor optimization programs and motor audit programs, specifically those in California, indicate a potential savings of about 30 percent. All other motor measures are based on process, technology, and motor replacement program evaluations (Nadel et al. 2002).
- *Drying and curing.* The savings potential for the drying and curing end-use stemmed from unpublished data from research done in North Carolina by the authors. No other useable data was found for that end-use, although a number of program implementers mentioned it to be a potentially large savings area.
- *Water heating.* Water heating in agriculture also presented a challenge in terms of defining the extent of water heating as an end-use. For the purposes of this study, we chose to use estimates for water heating savings found in the residential and commercial sectors. Very little data is available for characterizing the water heating applications in the agriculture sector, so identifying and focusing on the residential and commercial components gave us a very approximate estimate of potential savings. Available data indicate a similar cost-effective savings potential, approximately 20 percent, in the residential and commercial sectors (Optimal Energy et al. 2003).
- *Lighting.* Lighting measures included, but were not limited to, compact fluorescent lights, reduced wattage incandescent lamps, high intensity discharge retrofits, occupancy sensors, day lighting controls, and timer controls. Because of the differing cost of electricity in the agriculture sector (both residential rates and commercial rates are used, very few states use a special agriculture rate), it is not possible to make a division between measures based on a specific cost of conserved energy. We estimate that in the agriculture sector, including the combined measures would produce a savings estimate of

between 40 and 70 percent, based on the individual lighting applications (Nadel, Atkinson, and McMahon 1992; Martin et al. 2000, Nadel et al. 1998).

- *On-site transportation and machinery.* The potential savings from on-site transportation and machinery were estimated on the basis of commercially available technologies and practices. The onsite transportation savings potential includes both commercially available technology upgrades (combustion engines only) and changes in practices from which we got reported savings from program implementers in several states. Machinery upgrades involved a great deal more process upgrades, as many farmers and program implementers reported that technology upgrades in the market quickly become so ubiquitous that a farm's survival depends on their uptake. These practice change measures are the average of small changes in behavior such as crop planning and larger-scale changes such as converting to no-till agriculture (where applicable).
- *Heating, cooling, and ventilation (HVAC) and water heating.* These measures were also included in the analysis because although agriculture-specific data could not be found regarding their energy savings, they are well known in other sectors to be areas of large potential savings. Because of the lack of data on energy use on the farm, however, we have little knowledge (except in certain regions and farm-types) of the amount of energy used for these end-uses. As an approximation, we base available HVAC savings on studies from the residential and commercial sectors, which document roughly a similar savings estimates rate (Optimal Energy et al. 2003).
- *Other on-farm energy use measures.* This category refers to measures applying to on-farm energy use that is not yet quantified. While we have some understanding of what those measures may be, without solid data regarding the amount of energy used on the farm for those end-uses, it is impossible to quantify or estimate the potential energy and cost savings. Because the non-quantified end-use energy is a large portion of the energy use for most states (Brown and Elliott 2005), and certainly nationally, this may make up a large percentage of the total savings, indicating that our estimations here are very conservative. To bound the savings potential on the upper end, we include in the results the percentages of known savings only including the known energy end-uses. While this does not provide a reasonable estimate of cost and money savings for the entire sector based on energy efficiency improvements, it does reflect the potential for savings based on the known and quantified end-uses and known and quantified measure savings.

Market Saturation of Measures

To gain a more realistic view of energy efficiency, we included saturation coefficients, defined as the portion of the market that has already adopted the technology or practice. The purpose of these is to adjust the savings potential to reflect existing adoption of each measure. Actual market data was rather limited (again, except in the case of California), and as a result a default estimate of 20% saturation was applied to all the savings potential results where more specific data were not available. Although saturation is highly variable, we based this assumption on evidence from other sectors (Optimal Energy et al. 2003). As more evaluation and research is completed in the agriculture sector, we hope that these numbers can be updated, more accurately pinpointing areas of largest remaining potential.

Clearly, this analysis makes use of a patchwork of data sources. We believe, however, that in order to justify the cost of collecting more robust data, we must first confirm that there is a significant opportunity for savings in the sector. Our analysis provides a conservative estimate of potential energy savings in the agriculture sector, allowing for these estimates to be refined as better data become available. Our analysis also provides a shell for adding more data as they become available.

Measuring Savings

A large fraction of the energy used on farms could not be included in this analysis of savings potential because either the on-farm end-use has not yet been identified or because the savings resulting from measures installed has not been quantified. Because of the uncertainty resulting from these unknown factors, we chose to make a conservative assumption that the savings potential for this energy use was zero, even though the authors are confident that similar savings exist for the fraction of the energy use not considered in the overall savings estimate. This leads to what appears to be a very small savings potential for the overall sector.

Perhaps a more useful measure identifies the savings available from *known* energy end-uses. If we compare the known savings potential available to the known energy end-uses only, we get a much larger percentage savings potential. While this does not reflect the savings potential for the entire sector, it does provide a more accurate percentage of savings available based on known information. This number provides a known energy savings based on the current available data within the sector and is a useful measure when considering program target and design in the sector in the absence of better data collection. In the results tables below, this percentage of savings based on the portion of the energy use in the sector that has been defined is listed in the "Percentage Fuel Saved, Known End-Uses" column.

ENERGY EFFICIENCY SAVINGS POTENTIAL IN THE AGRICULTURE SECTOR

The potential for energy and cost savings in the agriculture sector, according to our conservative analysis, is over 34 trillion Btus and over one billion dollars per year. For a sector roughly the size of the residential home appliance market in terms of energy use, this is a significant savings number and deserves further consideration on the part of policy-makers and program implementers. Further, these estimates do not include non-energy benefits, such as delay of last mile infrastructure,[1] increased financial stability due to reduced energy cost exposure, and decreased use of other resources such as water.

This section reviews the impacts of the energy efficiency measures with the largest savings potential in the agriculture sector. It bears reiterating that the analysis described above dictates that these numbers are preliminary estimates based on limited data and should be taken as orders of magnitude unless otherwise noted. We first present overall savings at the national level and for selected states. Next, savings available by fuel (excluding fuel switching as noted earlier) and savings by measure are presented. The fuel and measure

[1] The last mile refers to rural electric distribution upgrades that can be avoided through reductions in demand from efficiency and conservation.

result also indicate within each measure which farm-types and states would be best served by focusing on this measure. Also included is a measure of available savings based not on the entirety of the agriculture sector, but instead on the information available on energy end-uses. The section is followed by an outline of specific data needs to increase understanding of energy use and potential for energy savings in the agriculture sector, in order to gain a more accurate estimate of savings potential.

In the tables that follow, the "total" column estimates include the end-uses and savings for measures that we have information on, but are percentages over the entirety of fuel use for the sector. Thus, savings from measures not considered would increase the total. The column labeled "Percentage Fuel Saved, Known End-Uses" represents the known energy potential savings for the known energy end-uses, illustrating the savings available in the sector. The final column of the table shows the total cost savings by fuel type and total energy for the measures considered. Many other end-uses have vast potential for savings in the agriculture sector. These "other not categorized" end-uses are not included in the subsequent national and state tables as the information is not presently quantifiable. Again, this further reinforces the very conservative nature of this energy savings potential estimate for the agriculture sector.

The tables that follow contain estimates of potential energy and monetary savings at the national and state level. The columns are broken down into three parts. The first section represents savings potential in energy (in British therm units) regarding most significant end-uses (motors, lighting, machinery, and a total for all). The second section illustrates potential fuel savings as a percentage for the total sector and with known end-uses. The final column reveals our projected total energy savings in dollar terms. Various rows describe the fuel used or farm-type, dependent on the state in question. Dairy farms are highlighted in Wisconsin and Vermont, for example, along with potentially high savings with diesel fuel, the agent used in product transport.

The columns that appear in the following tables are defined as:

- *Total motors:* This column represents energy use for all types of motors including pumps, fan, compressors (both air and refrigeration), conveyers, and any other application that uses either an electric motor or a stationary gas or diesel engine.
- *Total lighting*: This column represents all on-farm lighting including residential lighting as well as larger-scale lighting in barns, such as hog and pig farms, and area lighting.
- *Total transport:* This column includes on-farm vehicles including trucks and fork-lifts.
- *Machinery:* This column represents farm-specific equipment such as tractors, combines, harvesters, and hay bailers.
- *Percentage fuel saved for total sector:* This column is the total savings estimate divided by the total energy use in the sector.
- *Percentage fuel saved for known end-uses:* This column is the total savings estimate divided by the fraction of the total energy use in the sector that could be categorized.
- *Total monetary savings:* This column represents the change in energy expenditures that result from the estimated energy savings. Note that we used 2003 energy prices and did not project any future changes in energy prices.

Agriculture Sector Potential Energy Savings: National

Potential energy savings nationwide are presented by end-use in Table 3. It is clear from this analysis that the largest savings potential exists for diesel and gasoline fuels in the "transport" category. Other large energy savings result from electricity savings in the motors and lighting end-uses, resulting in large monetary savings because of the relatively high price of electricity nationwide, as compared to diesel and gasoline. A final note about nationwide potential savings is that the fuels comprising the "other" category (propane, kerosene, fuel oils, and lubricants) represent a substantial savings in the motors sector, a reflection of the diversity of fuel use for similar end-uses in the agriculture sector.

Table 3. Total Savings Potential by Fuel Type at the National Level

	Savings Potential (Trillion Btu)					Percentage Fuel Saved		
USA	**Total Motors**	**Total Lighting**	**Onsite Transport**	**Machinery**	**Total**	**Total Sector**	**Known End-Uses**	**Total Monetary Savings (Million $)**
Gasoline	33.7	0.0	0.6	0.0	34.3	24.1%	25.1%	383
Diesel	2.0	0.0	8.2	42.9	53.1	14.7%	47.6%	499
Natural Gas	0.3	0.0	0.0	0.0	0.3	0.6%	29.5%	3
Other	4.1	0.0	0.0	0.0	4.1	2.8%	27.5%	40
Electricity	1.6	1.6	0.0	0.0	3.2	2.6%	30.9%	88
Total Energy	42.1	2.5	8.9	44.5	98.0	9.7%	34.4%	1,014

The large savings available for gasoline and diesel fuel are a reflection of three factors. The first is that the motors, transportation, and machinery end-uses on the farm are among the largest energy end-uses in the sector, and further, that the fuel choice for these end-uses is largely gasoline and diesel. Second, it is a reflection of the available energy use and measure savings information in the agriculture sector. Third, the savings as a fraction of the specific fuel use is significant. This factor is illustrated by comparing the percentage of potential savings over the entire sector for gasoline (24 percent) to the percentage of potential savings over the known and characterized energy end-uses (25 percent), which shows that the known information for this fuel in the sector is large. Indeed, only four percent of the gasoline use in the agriculture sector nationwide is uncharacterized, owing to a large amount of data collection on machinery, motors, and transportation end-uses in the field.

Nationwide analysis by farm-type by fuel is shown in Table 4. Because of the high degree of uncertainty in the data (with the exception of particular farm-types and end-uses, such as irrigation, discussed later in this report), potential savings estimates are given by total energy savings for the farm-types. Nationwide, the farm-types with the largest value of shipments were identified and chosen for this analysis under the assumption that they were the potentially largest source of savings from increased energy efficiency. The summarized savings from these farm types make up 92 of the 98 trillion Btus of potential savings for the entire sector, indicating that within the sector, these farm-types should be the primary target for increasing energy efficiency in the sector at the national level.

Table 4 indicates that the oilseed and grain farming sub-sector, with a potential savings of 17 trillion Btus and 167 million dollars, has the largest potential for energy savings of the farm-types identified. This could be partially reflective of our lack of knowledge of subsector energy use and potential savings per measure, and partially reflective of the sheer size of the subsector and the relatively large energy use of oilseed and grain farming, especially in the motors and transportation end-uses.

Table 4. Total Savings Potential by Farm Type at the National Level

	Savings Potential (Trillion Btu)					Percentage Fuel Saved		
USA	Total Motors	Total Lighting	Onsite Transport	Machinery	Total	Total Sector	Known End-Uses	Total Monetary Savings (Million $)
Poultry—Total Energy	3.0	0.6	0.1	0.3	4.5	10%	47%	67.6
Dairy—Total Energy	3.4	0.1	0.0	0.6	4.6	5%	16%	54.4
Greenhouse/ Nursery—Total Energy	2.1	0.2	0.0	0.3	2.6	6%	24%	29.4
Cattle Feedlots—Total Energy	10.1	1.2	0.1	1.6	13.0	8%	19%	145.3
Oilseed and Grain Farming—Total Energy	13.2	0.2	2.3	1.3	17.1	12%	27%	167.7
Fruit and Tree—Total Energy	2.2	0.1	0.4	1.8	4.7	10%	26%	48.4
Hog and Pig—Total Energy	1.5	0.7	0.1	0.5	2.8	13%	42%	45.9

Agriculture Sector Potential Energy Savings: States

The diversity of energy use in the agriculture sector, due to the diversity of farm types and the fuel use choices for necessary energy end-uses, as well as the overwhelming majority of current agriculture programs addressing the needs of the sector from the state level (Brown, Elliott, and Nadel 2005), indicates the importance of determining the energy and cost savings available from increasing energy efficiency at the state level. For this analysis, six states were chosen for analysis in an effort to gain a better understanding of the diversity and commonality in energy savings at the state level. These six states, California, Florida, Kansas, New York, Vermont, and Wisconsin, have different primary farm-types within the state, differing importance of agriculture to the state economy, and different climatic regions, all reflecting different energy needs and economic priorities. Our companion report characterizing energy use in agriculture examined the on-farm energy use and detailed our understanding of the agriculture structure within the states (Brown and Elliott 2005). We use these characterizations as the foundation for our savings estimates.

California.

Table 5 shows the potential energy efficiency savings for the state of California by fuel use for the entire agriculture sector and for total energy use for the largest subsectors (by value of shipments). The total potential energy savings for the state is 5.4 trillion Btus or 94 million dollars. The average energy savings available is based on overall sector energy use ranges between 4 and 17 percent and based on characterized energy end-uses between 24 to 28 percent. These figures account for the available state-specific data on savings and saturation levels in the state. These numbers show a large amount of savings in the energy efficiency savings still available.

Table 5. Potential Energy and Monetary Savings in California

	Savings Potential (Trillion Btu)					Percentage Fuel Saved		
California	**Total Motors**	**Total Lighting**	**Onsite Transport**	**Machinery**	**Total**	**Total Sector**	**Known End-Uses**	**Total Monetary Savings (Million $)**
Gasoline	0.09	0.00	0.28	0.00	0.37	4%	24%	4.4
Diesel	1.01	0.00	0.85	1.71	3.57	17%	48%	36.5
Natural Gas	0.07	0.00	0.00	0.00	0.07	1%	35%	0.4
Other	0.00	0.00	0.00	0.00	0.00	0%	1%	0.0
Electricity	0.84	0.74	0.00	0.00	1.58	13%	41%	52.7
Total Energy	1.56	0.74	1.13	1.71	5.14	11%	43%	94.1
Dairy—Total Energy	0.68	0.03	0.01	0.04	0.77	10%	32%	9.8
Greenhouse/Nursery–Total Energy	1.39	0.09	0.03	0.05	1.56	14%	39%	16.9
Cattle Feedlots—Total Energy	0.44	0.05	0.01	0.01	0.51	17%	39%	4.5
Oilseed and Grain Farming—Total Energy	0.27	0.02	0.10	0.01	0.39	11%	33%	3.3
Fruit and Tree—Total Energy	2.60	0.18	0.46	1.71	4.96	12%	49%	44.1

Florida.

This analysis indicates that the state of Florida could save about a trillion Btus and over 13 million dollars in energy, as indicated in Table 6. Florida has two primary agriculture farm-types—greenhouse/nursery farms and fruit and tree farming. The table also shows that Florida farmers, more so than the other sample states, prefer the use of gasoline, diesel, and electricity over other fuels to satisfy their end-uses and as a result, the savings lie almost entirely in these fuels. In comparison to other states, the two primary farm types in Florida make up over 85 percent of the potential savings from all potential energy savings predicted in the sector, indicating that programs targeted at the two farm-types have the potential to achieve the bulk of the agriculture sector savings available in the state. It should also be noted that the potential fuel savings available in Florida based on overall sector energy use is 15 percent and based on characterized energy end-uses is 41 percent.

Table 6. Potential Energy and Monetary Savings in Florida

Florida	Savings Potential (Trillion Btu) Total Motors	Total Lighting	Onsite Transport	Machinery	Total	Percentage Fuel Saved Total Sector	Known End-Uses	Total Monetary Savings (Million $)
Gasoline	0.130	0	0.186	0.000	0.316	50%	50%	3.37
Diesel	0.077	0	0.062	0.316	0.454	2%	9%	4.45
Natural Gas	0.000	0	0	0	0.000	0%	0%	0
Other	0.001	0	0	0	0.001	4%	37%	0.01
Electricity	0.176	0.143	0	0	0.319	14%	57%	6.01
Total Energy	0.383	0.143	0.248	0.316	1.090	15%	41%	13.83
Greenhouse/ Nursery—Total Energy	0.397	0.023	0.037	0.018	0.475	15%	41%	6.1
Fruit and Tree Farming	0.287	0.028	0.044	0.115	0.475	12%	47%	5

Kansas.

In Kansas, the analysis reflects a savings from energy efficiency improvements of 3 trillion Btus and over 29 million dollars. The largest fuel savings are derived from diesel fuel use, stemming from motor uses (diesel is the primary motor fuel in Kansas) and onsite transportation. Of the known diesel energy end-uses, the analysis reflects that savings amount to over half of the energy expenditures in Kansas. Table 7 also shows that in Kansas the potential energy savings available based on overall sector energy use is 11 percent and based on known energy end-uses is 47 percent. As the table indicates, almost a fifth of the known savings are in feedlot operations, with motors being the most important category.

Table 7. Potential Energy and Monetary Savings in Kansas

Kansas	Savings Potential (Trillion Btu) Total Motors	Total Lighting	Onsite Transport	Machinery	Total	Percentage Fuel Saved Total Sector	Known End-Uses	Total Monetary Savings (Million $)
Gasoline	0.022	0	0.019	0	0.041	1%	17%	0.4
Diesel	0.844	0	0.419	1.465	2.728	21%	50%	25.4
Natural Gas	0.332	0	0	0	0.332	5%	42%	1.7
Other	0.000	0	0	0	0.000	0%	0%	0
Electricity	0.013	0.061	0	0	0.074	4%	39%	2
Total Energy	1.211	0.061	0.437	1.465	3.175	11%	47%	29.5
Cattle Feedlots—Total Energy	0.449	0.040	0.031	0.060	0.580	12%	30%	6.4

New York.

New York State had the most in-depth and usable data among the sample states, for both the characterization of on-farm energy end-use as well as data on efficiency measures installed in an agricultural setting. Table 8 indicates that diesel fuel energy efficiency offers the greatest savings in agriculture in New York, including motors, onsite transportation, and machinery. Among the known energy end-uses, savings from diesel fuel could amount to 50 percent of expenses on that fuel. The potential energy savings available in New York based on total sector energy use is 10 percent and based on characterized energy end-uses is 44 percent. Altogether, we project that more than 1 million Btus and 14 million dollars could be saved in New York State.

In New York, dairy farms produce over half the agricultural output of the state. As a result, the state has completed a great deal of research on energy use on dairy farms and runs multiple programs aimed at improving energy efficiency in the dairy sector. Although savings in this farm-type are still large, the numbers are adjusted for program evaluation saturation results, but still indicate that the remaining savings in the sector is at least 343 billion Btus and 5.4 million dollars.

Table 8. Potential Energy and Monetary Savings in New York

	Savings Potential (Trillion Btu)					Percentage Fuel Saved		
New York	**Total Motors**	**Total Lighting**	**Onsite Transport**	**Machinery**	**Total**	**Total Sector**	**Known End-Uses**	**Total Monetary Savings (Million $)**
Gasoline	0.018	0	0.053	0	0.071	4%	25%	0.8
Diesel	0.276	0	0.131	0.434	0.840	19%	50%	8.3
Natural Gas	0.0006	0	0	0	0.0006	0%	22%	0.0
Other	0.012	0	0	0	0.012	1%	15%	0.1
Electricity	0.092	0.088	0	0	0.180	9%	41%	5.3
Total Energy	0.399	0.088	0.184	0.434	1.105	10%	44%	14.5
Dairy—Total Energy	0.277	0.011	0.011	0.044	0.344	NA	22%	5.4

Vermont.

Vermont's savings potential is located primarily in diesel fuel, again in the area of motors and transport. Vermont is the only state within the sample states in which one type of farming, in this case dairy farms, represents the overwhelming majority of economic output from the agriculture sector. In Vermont, the dairy farming industry is very important economically and culturally, and increasing energy efficiency on the farms is recognized as a viable option for stabilizing farm production costs. As a result, Vermont has a statewide program for increasing energy efficiency on dairy farms. From data provided by Efficiency Vermont, we were able to estimate saturation rates in Vermont for dairy farms and found that the remaining savings for the farm-type is about 38 billion Btus and $800,000. Notably, the potential fuel savings available based on overall sector energy use in Vermont is 9 percent and based on characterized energy end-uses is 36 percent. 14 percent of fuel saved by known end-uses is attributable to dairy farms, as illustrated in Table 9 below. Other savings in the state result from the remaining agriculture sector, but data was not found regarding other farm-types in the state, so much of the energy savings data is extrapolated from the national farm-type mix, leading to an estimate of potential savings of about 250 billion Btus.

Table 9. Potential Energy and Monetary Savings in Vermont

	Savings Potential (Million Btu)					Percentage Fuel Saved		
Vermont	**Total Motors**	**Total Lighting**	**Onsite Transport**	**Machinery**	**Total**	**Total Sector**	**Known End-Uses**	**Total Monetary Savings (1,000$)**
Gasoline	65	—	980	—	1,045	1%	17%	12
Diesel	90,642	—	48,870	92,456	231,968	16%	37%	2,382
Natural Gas	—	—	—	—	—	0%	0%	—
Other	1,339	—	—	—	1,339	1%	18%	21
Electricity	6,655	13,716	—	—	20,371	5%	29%	592
Total Energy	98,702	13,716	49,850	92,456	254,723	9%	36%	3,008
Dairy—Total Energy	24,450	2,465	459	—	37,039*		14%	784

* This number does not equal the total of the indicated end-uses because there was data available for water heating savings in the state of Vermont, so it was used. This is the only state in which there was data indicating end-use for water heating.

Wisconsin.

Wisconsin has had strong programs in agriculture energy efficiency, especially for the dairy farm-type. The available information from program evaluation was used to determine saturation and limited actual measure savings, leaving a remaining potential for 10 million dollars in savings in the sector. For the state overall, potential savings are located in the diesel and electricity fuels, and could lead to 2 trillion Btus and 24.7 million dollars in savings. Table 10 below shows that the average energy savings available based on overall sector energy use is 11 percent and based on characterized energy end-uses is 42 percent. Within Wisconsin diary farms, there is a potential fuel savings of 27 percent for known end-uses with a total monetary savings of 11 million dollars.

Table 10. Potential Energy and Monetary Savings in Wisconsin

	Savings Potential (Trillion Btu)					Percentage Fuel Saved		
Wisconsin	**Total Motors**	**Total Lighting**	**Onsite Transport**	**Machinery**	**Total**	**Total Sector**	**Known End-Uses**	**Total Monetary Savings (Million $)**
Gasoline	0.018	0	0.063	0	0.081	3%	23%	0.9
Diesel	0.540	0	0.368	0.533	1.442	19%	47%	14.9
Natural Gas	0.003	0	0	0	0.003	0%	26%	0.0
Other	0.001	0	0	0	.001	0%	2%	0.0
Electricity	0.224	0.199	0	0	0.422	11%	41%	8.9
Total Energy	0.786	0.199	0.431	0.533	1.949	11%	42%	24.7
Dairy—Total Energy	0.612	0.027	0.026	0.087	0.751	10%	27%	10.6
Cattle Feedlots—Total Energy	0.116	0.030	0.008	0.010	0.163	14%	35%	1.3

Crosscutting End-Use: Irrigation and Motors

Irrigation is often the largest part of the motors end-use, and therefore merits further discussion here. Irrigation represents a large energy load for the agriculture sector in many states and is a critical part of the agriculture industry in the United States. A great deal of research has been completed on irrigation measures and saturations, and as a result, we expect these estimates to be among the most accurate in this research. Because of the plethora of available information on energy use for irrigation, as well as the large use of energy in irrigation in the sector and the large resulting potential for savings, the following is an in-depth look at the results of our analysis regarding irrigation specifically and the benefits of increasing efficiency for this motors-based energy end-use.

Increasing energy efficiency in irrigation has a large potential to save energy and money in the agriculture sector. We estimate that across all fuel types, there is the potential to save $436 million annually. The largest impact of energy efficiency measures in irrigation is in the oilseed and grain farming farm-type, with an estimated 321 million dollars annual savings potential for the sub-sector if the market were fully saturated with currently commercial energy-efficient technologies. Other farm-types that stand to have substantial efficiency gains from irrigation energy efficiency improvements are cattle feedlots and hog and pig farms.

It is important to note that the benefits of increasing energy efficiency in irrigation are not solely (or even primarily) energy related. Extensive research has been conducted on the water-saving benefits of improving irrigation efficiency (CEC 2003). This effect is especially important at the state level, especially in states with water resource and distribution problems, like California. Our analysis does not quantify all the energy and non-energy benefits of irrigation efficiency measures. Energy savings are substantial enough in most water-restricted states, however, that they present a compelling argument to improve efficiency. In California, for instance, the estimated energy savings from full market saturation is 3 trillion Btu, translating into $37 million per year. In less water-restricted states, the estimated savings are still substantial, especially in relation to the overall state savings potential (see Table 11).

Table 11. Irrigation Savings Potential

State	Energy Savings (Btu)			Cost Savings		
	Irrigation	Total State	%	Irrigation	Total State	%
USA	40 trillion	156 trillion	25	$436 million	$1.6 billion	27
California	3 trillion	12 trillion	25	$37 million	$180 million	20
Florida	1 trillion	3 trillion	33	$12 million	$37 million	32
Kansas	1.4 trillion	6 trillion	23	$15 million	$65 million	23
New York	676,000 million	2 trillion	34	$7.3 million	$31 million	24
Vermont	95,610 million	354 billion	27	$578,000	$6 million	10
Wisconsin	958,000 million	4 trillion	24	$10 million	$51 million	20
Note: Please note assumptions from the text before citing this table.						

In farm-types and in regions with relatively little irrigation, other motor uses are generally among the largest energy uses on the farm followed by on-site transportation and lighting. Table 12 shows that motor energy is a relatively large savings opportunity independent of the amount of irrigation pumping in the state. The table shows that irrigation is about 29 percent of the total potential motor savings.

The importance of motors can be seen especially in the state of Vermont, where dairy farms are the primary farm type. Even though the dairy irrigation needs for the state of Vermont are only three percent of the savings, the overall savings potential reflects a similar overall motor savings percentage as irrigation-heavy states. This presents a great opportunity for states with a large amount of dairy to upgrade motors and increase the energy efficiency on the farm, leading to all the benefits of energy efficiency discussed above. In prior research we found that this measure is already being implemented in many of the dairy farm-dominated areas, and that programs designed to target the dairy industry have quantified benefits (Brown, Elliott, and Nadel 2005).

Table 12. Potential Irrigation and Total Motor Energy Savings ($) Nationwide and in Selected States

State	Irrigation Motor Savings (million $)	% of Total Savings Potential	Other Motor Savings (million $)	% of Total Savings Potential	Total Motors as % of Total Savings Potential
USA	436	29	27	2	31
California	25	19	15	11	30
Florida	4	20	2	8	28
Kansas	10	24	11	1	25
New York	1.5	20	6	8	28
Vermont	1	3	1.1	32	35
Wisconsin	8	23	2.5	7	30

CONCLUSIONS

This study shows savings of over 98 trillion Btus and 1 billion in dollars from increasing energy efficiency in the agriculture sector. This is a savings of over 10 percent of total energy use on the farm. The analysis is very conservative because of the relatively limited data indicating how energy on the farm is used and further lack of data on savings potentials for particular energy end-uses. Where we had no data indicating savings, we assumed that the no savings was available in that end-use. This leads to a very conservative estimate because it reflects savings from *known* energy efficiency measures, but then calculates percentage savings over energy use for the *entire* sector. This percentage is useful for getting a very conservative estimate of overall savings available. It is perhaps more helpful on a practical level to measure the potential savings as compared to our defined characterization of energy end-use, leaving out the end-uses that have not yet been quantified. Including only the energy use characterized in this analysis, the savings are equal to 34 percent of the energy expenditures.

This analysis shows significant energy and cost savings on the portion of the energy end-use that we have been able to adequately characterize. In order to gain further understanding of energy efficiency potential in the agriculture sector, two data needs must be satisfied. The first is a better understanding of how energy is used on the farm. The second is a more detailed understanding of energy savings for conservation measures on the farm. A detailed description of the first set of data needs is listed in our companion report, *On-Farm Energy Use Characterizations* (Brown and Elliott 2005), and so this discussion focuses on recommendations for improving data availability on energy savings measures in the sector.

Specific data needs include extensive data collection and research to determine how energy is used on the farm in all its fuel-forms. Better data in this area will lead to a more accurate characterization of the farm sector and therefore a better estimate of potential savings. The largest need for savings data is on the actual savings of installed energy efficiency measures. Estimates in this survey were sometimes found from small-scale studies of measures for specific farm-types, but were more often drawn from expert opinion or experience in other sectors. More accurate measure savings data is the highest priority for research in this area. The following recommendations reflect hints provided by this analysis as to how the priorities should be set for acquiring the data.

1. *Machinery and on-site transportation.* Diesel energy use is clearly dominant on the farm for machinery and is the largest opportunity for savings in many of the sample states and nationwide. According to empirical evidence, energy efficiency improvements stemming from improvements in machinery are often completed for economic reasons and do not require program intervention for encouragement. Changes in farming techniques implemented in programs such as the Georgia programs (Brown, Elliott, and Nadel 2005) have been shown to reduce diesel fuel use and decrease the energy production costs to the farmer. Whether or not farming technique changes (no-till farming, for example) have widespread applicability or can be economically justified remains unknown. The highest priority need, which could likely lead to the largest amount of potential savings, is in this area.
2. *Motors.* Energy use from motors is a large portion of energy use in all sectors of the U.S. economy, and much work has been done on end-use and potential improvements. For this agriculture sector analysis, we used a combination of measure saving results from similar end-uses in other sectors and limited data from agriculture programs across the country. A more accurate analysis would involve studying the impacts of energy efficiency measures in an agriculture setting. In other words, if we knew the energy savings based on the specific end-use that the technology is used for and how these savings vary within and between applications, we would have a more accurate ability to judge energy efficiency potential for motor improvements in the agriculture sector.
3. *Estimating savings for uncategorized energy uses.* One of the greatest challenges of determining energy efficiency potential is the lack of a complete characterization of energy use on the farm. There are many opportunities to improve the characterization, but in the interim, a useful measure would be to determine an average savings potential rate for the entirety of the uncharacterized agriculture sector. This could be based on estimated savings from other sectors combined with the agriculture-specific saturation rate or on other estimations.

Clearly, there are large cost savings available to the agriculture sector from energy efficiency. This report gives a very conservative estimate, and we hope that it will encourage further, more detailed data collection and study. Regardless, it identifies primary areas for savings—motors (including irrigation), lighting, and onsite transportation.

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