Appendix B – Technical Notes and References

Energy
As described above, the SISC energy metrics includes direct energy use (fuel and electricity) and the embedded energy in pesticide and fertilizer products.

Electricity

- All electricity is included whether purchased or generated on-site.
- Electricity data at the farm or SISC Management Area level is allocated following the allocation method described below.
- Electricity data is collected in kilowatt hours (kWh), as this is how it is typically reported on utility bills. It will be converted to BtUs using the standard conversion of 3412.3 BtU/kWh.

Fuel

- Fuel for stationary equipment and off-road mobile farm equipment is included. On-road vehicle fuel is not included.
- Fuel data at the farm or SISC Management Area level is allocated following the allocation method described below.
- Fuel energy values are converted to BtUs using data from the EPA's Greenhouse Gas Inventory Protocol .[4]
- Fuel used by contractors to perform contracted services is included. Data is not required to be collected from contractors, but rather can be estimated using the allocation method described below.

Allocation Method
The method for allocating fuel and electricity uses management information to determine approximate *weighting factors which are then applied to the user's actual data for fuel and electricity totals* to estimate use by crop. Therefore, it is important to note the goal of the weighting exercise is to determine relative usage among crops, not to estimate actual usage. The exception to this is contracted services, for which these estimates are used in place of actual fuel use.

Fuel

$$Fuel_{Crop\ A} = (Weighting\ Factor_{Crop\ A} \times Actual\ Fuel\ Use_{Farm}) + Fuel_{Contracted\ Services}$$

Where:

$$Weighting\ Factor_{Crop\ A} = \frac{Fuel\ Estimate_{Crop\ A}}{\sum Fuel\ Estimate_{All\ Crops}}$$

Fuel Estimates

[4] US E.P.A. Office of Air and Radiation, "Direct Emissions from Mobile Combustion Sources", Climate Leaders Greenhouse Gas Inventory Protocol Core Modular Guidance, EPA 430-K-08-004, May 2008

Fuel estimates used in the weighting factor equation above are derived by summing the approximate fuel usage for several categories of activity. To minimize data requirements, this approach is only applied to diesel use. The weighting factors developed for diesel are then applied to any other fuels used. Users are given the option of manually adjusting the weighting factors for other fuels if they know the diesel factors are not representative of, for instance, their gasoline use.

The following equation illustrates how fuel estimates for each activity categories are derived and then summed:

$$Fuel\ Estimate_{Crop\ A} = \sum (HP_{tractor} \times SFC_{tractor} \times Time_{operation} \times Number_{operation}) + Fuel_{Irrigation}$$

Where:

$HP_{tractor}$ = Tractor Horsepower (entered by user)

$SFC_{tractor}$ = Specific Fuel Consumption = Fuel Efficiency (gal/hr)/ Horsepower
A default value of .0793 gal/hr-hp is used unless the user specifies another value for fuel efficiency, horsepower, or specific fuel consumption[5]

$Time_{operation}$ =Approximate time per acre for that category of activity. Values for this were derived by averaging values of activities for each category from the UC Davis Cost Return studies for tomatoes, potatoes, strawberries, and romaine lettuce hearts, as listed in Table 3.

Table 3. Average Operation times for Activity Categories

Operation	**Average Time (hrs/acre)**
Land preparation	0.27
Planting	0.44
Fertilizer application	0.28
Pest and weed control	0.39
Other cultivation practices	0.44
Harvesting	0.89

$Number_{operation}$ = Number of operations made by that tractor type for each activity category (entered by user)

$Fuel_{irrigation}$ = Fuel used by irrigation pumps. See *Irrigation Pumps* below.

Contracted Services

Fuel used by contractors to conduct contracted services is estimated using the same approach as above. Users are asked to estimate tractor type and horsepower for each activity. Fuel for aerial applications is included in contracted services.

Electricity Allocation

[5] This Specific Fuel Consumption value is the median of the values provided in: Grisso, et al. "Predicting Tractor Fuel Consumption." University of Nebraska – Lincoln. 2004. http://digitalcommons.unl.edu/biosysengfacpub/164

Similar to fuel, electricity is allocated by deriving weighting factors for each crop. As electric irrigation pumps consume a significant portion of the electricity used on most farms, weighting factors are derived by estimating electricity use by each electric pump, attributing it to crops watered by each pump according to the water quantities pumped.

Irrigation Estimates

The equation for calculating irrigation energy is:

$$Irrigation\ Energy_{BtU} = \frac{\frac{\left(Lift_{feet} + Pressure_{PSI} \times 2.311\right)}{3960}}{Efficiency_{pump} \times Efficiency_{power}} \times \frac{Water\ Quantity_{acreinc} \times 27{,}154}{60 \times gpm}$$

Where:

2.311 = the standard conversion factor from psi to feet of water (a measure of pressure)

3,960 = the standard conversion factor from feet of water to horse power: hp = gallons per minute/3960. We assume gpm is 1.

$\mathrm{Efficiency}_{\mathrm{pump}}$ = 0.58, an average taken from research published by the Texas Agricultural Extension Service (Table 3.6)

$\mathrm{Efficiency}_{\mathrm{power}}$ = Power efficiency values for the following energy sources are used:[7]

- Electricity = 85%
- Diesel = 30%
- Natural gas = 20%

27,154 = the standard conversion from acre inches to gallons

60 = minutes per hour

gpm = gallons per minute. A value of one is assumed.

Fertilizer Embedded Energy

Fertilizer data is collected as total amounts for each product applied during the harvest-to-harvest period for each crop. The energy used to produce each type of fertilizer is derived as follows.

Synthetic Fertilizers

- Energy to produce fertilizers is taken from a 2009 International Fertilizer Industry Association Report.[8] Values are taken from the "World Today" column of the Energy Consumption in Selected Fertilizer Processes and Products table.
- Embedded energy in blended products is calculated by multiplying the volume of each nutrient in the blend by a coefficient. Coefficients were derived by averaging the different forms of each nutrient weighted according to their total production. Therefore the following equation is used:

[6] New, L. Pumping Plant Efficiency and Irrigation Costs, Texas Agricultural Extension Service. See http://itc.tamu.edu/documents/extensionpubs/L-2218.pdf.

[2] ibid

[8] International Fertilizer Industry Association, "Fertilizers, Climate Change and Enhancing Agricultural Productivity Sustainably," First edition, IFA, Paris, France, July 2009. Annex 1. Energy consumption in selected fertilizer processes and products. http://www.fertilizer.org/ifa/HomePage/SUSTAINABILITY/Climate-change

$$E_{blend} = \left(\%N\left(48.9\frac{GJ}{MT}\right) + \%P2O5\left(1.7\frac{GJ}{MT}\right) + \%K2O\left(5.8\frac{GJ}{MT}\right)\right) * \frac{430\frac{Btu}{lb}}{1\frac{MJ}{MT}}$$

Compost

- The value for embedded energy from compost production includes the energy required to turn and process feedstock into compost. The feedstock itself was considered a byproduct, and thus no additional energy for feedstock production is included.
- Data is derived from the California Air Resources Board Composting Protocol (Aug 2010)[9]. A table in the report expresses overall fuel and non-irrigation electricity use per ton of compost feedstock for three separate windrows. Average values from these three windrows were used to estimate fuel and electricity use, as illustrated in the equation below.
- The process energy to produce compost is considered to be 148,996 BtU/ton compost. This value was arrived at using the following equation:

$$\frac{.36\text{ gal diesel}\left(\frac{138{,}7000\text{ BtU}}{\text{gal diesel}}\right) + 7.2\text{ kWh}\left(\frac{3412\text{ BtU}}{\text{kWh}}\right)}{\text{ton feedstock}} \times \frac{2\text{ tons feedstock}}{1\text{ ton compost}} = 148{,}996\frac{\text{BtU}}{\text{ton compost}}$$

Pesticide Embedded Energy

The embedded energy estimates produced by the SISC calculator are approximate and may not be accurate for specific pesticide ingredients. While the method may be a reasonable approximation for many pesticides, it may significantly under or over-estimate embedded energy for some products (particularly for minerals, biopesticides, and oils). The Stewardship Index will continue to assess this methodology.

Pesticide use data is collected by the calculator as total amounts for each product applied during the harvest-to-harvest period for each crop. The methodology for estimating embedded energy is based on a 2009 study by researchers at Cranfield University (Audsley et al 2009)[10], which finds that the energy used to produce pesticide active ingredients can be approximated based on the chemical's year of discovery (older chemicals are less energy intensive to manufacture per unit of weight than newer chemicals because of increasing complexity). The authors use previously published energy estimates for specific pesticide ingredients by Green (1987)[11] to arrive the following equation:

$$E = -399 + 10.8\,(Y - 1900)$$

Where:

E = MJ/kg active ingredient

Y = year of reported discovery

[9] California Air Resources Board, "Proposed Method for Estimating GHG Emissions Resuctions from Compost from Commercial Organic Waste." Aug 2010. Table 2, "Process Emissions from Compost Production" , p YY-11

[10] Audsley, E. et al., "Estimation of the greenhouse gas emissions from agricultural pesticide manufacturing", Cranfield University, August 2009.

[11] Green, M.B., "Energy in pesticide manufacture, distri ution and use". In Z.R. Helsel (ed) *Energy in Plant Nutrition and Pest Control*. Elsevier, Amsterdam, 1987. p. 165-177

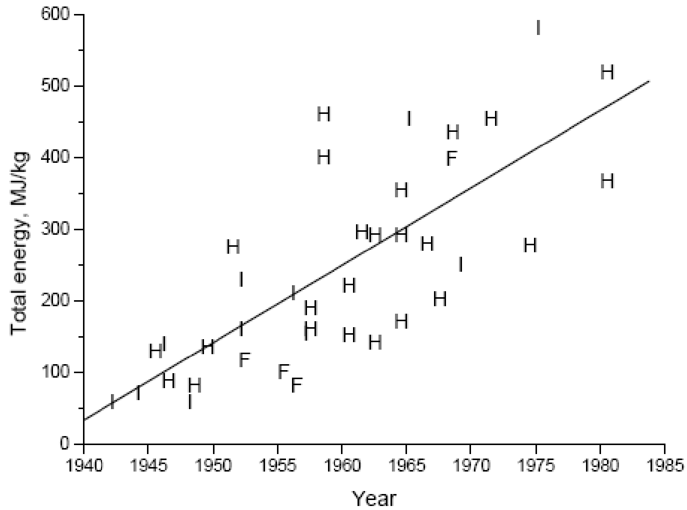

Figure 3. Total energy requirement for pesticide production (Green, 1987) versus date of first reporting. H: herbicide; F: fungicide; I: insecticide. Regression line: E = -399 + 10.8 (Y-1900), r^2 = 0.57.

Using this approach, embedded energy is calculated as follows:

- Active ingredients are categorized into 5-year bands by year of discovery, for which energy is calculated using the Cranfield University equation above. Following the authors method, ingredients introduced prior 1940 are estimated as being produced in 1940. The year of introduction for 914 active ingredients was provided to the Stewardship Index by Benbrook Consulting, drawing from the FootPrint Database.[12]
- Embedded energy is calculated for each active ingredient for nearly 17,000 pesticide products registered by EPA (including those cancelled after 2005). Pesticide product data was provided by Benbrook Consulting, drawing EPA's Pesticide Product Information System (PPIS).[13] For each product, the embedded energy for each pesticide active ingredient was calculated and summed.
- Embedded energy for active ingredients for which no year of discovery was provided is assumed to be 475 MJ/Kg (median value for embedded energy among the most used pesticides in the United Kingdom, as calculated in the Cranfield paper).
- Data characterizing the density of pesticide products was downloaded from the California Department of Pesticide Regulation to estimate weight per volume for liquid pesticide products (the EPA PPIS database does not include density or specific gravity). Density of the formulated product was obtained from CDPR for approximately 8,000 of the pesticide products in the PPIS data[14]; Benbrook Consulting also provided density data for approximately 4000 products. Density for all other wet products in the EPA database for which density was not provided by CDPR or Benbrook Consulting, are assumed to have a formulation density of 9.11 lbs per gallon (derived by averaging densities of the products in the data provided by Benbrook Consulting). Wet products are those characterized in the PPIS data as Emulsifiable Concentrate, Flowable Concentrate, Invert-Emulsifiable Conc, Oils (no added pesticide), Pressurized Liquid, Ready-to-

[12] Data provided by Benbrook Consulting on August 22, 2011. See http://sitem.herts.ac.uk/aeru/footprint.
[13] See http://www.epa.gov/pesticides/PPISdata/ , "Product Formulation"
[14] See http://www.cdpr.ca.gov/docs/label/prodtables.htm

Use Solution, Soluble Concentrate, and Formulation Unidentified. Using the specified or assumed product density, BtU per gallon of product is also calculated for all wet products.

The Cranfield method is intended for synthetic pesticides (ie organic compounds) and is not applicable to predict the energy embedded in inorganic compounds such as sulfur, copper sulfate, kaolin, etc. As a result, embedded energy estimates calculated by the SISC Calculator for inorganic pesticide active ingredients may not be reasonable. SISC is currently reviewing this issue.

In version 1.1 of the Calculator, compound-specific embedded energy values are included for two widely used inorganic pesticide ingredients: sulfur and lime:

Sulfur

EPA estimates that 90-95% of recovered sulfur is derived by the Claus process, which converts H2S to sulfur. [15] USGS estimates that agriculture uses at least 50% of the world's elemental sulfur production. Assuming then that most agricultural sulfur is derived by the Claus process, we assume that the energy requirements of the process may serve as a proxy for embedded energy of sulfur in pesticide products. The Landbank UK estimated in 1994 that the Claus process requires 2.0 MJ heat and 0.1 MJ of electricity to produce 1 kg of sulfur.[16] Thus, we use an embedded energy value for sulfur of 2.1 MJ/kg (903 Btu/lb).

Lime

SISC averaged embedded energy values published by the Ecoinvent Centre for two different lime manufacturing processes: Lime extracted from algae and lime produced as a byproduct of carbonation[17]. The un-weighted average of these values is 0.8 MJ/kg (344 Btus/lb).

Nutrients

The SISC calculator collects data in the form of the "N-P-K ratio" for both organic and synthetic fertilizers. Data is collected as total amounts for each product applied during the harvest-to-harvest period for each crop. Pounds of nitrogen and phosphorus applied are determined by summing all product applications for each crop's harvest-to-harvest period.

Synthetic fertilizers:

- Because the "P" in the N-P-K ratio listed on fertilizer labels actually signifies the percent content of P_2O_5, the following coefficient is used to convert pounds P_2O_5 to pounds P:

  1 lb P_2O_5 = .44 lbs. P[18]

[15] AP 42, Fifth Edition, Vol I, Section 8.13, "Sulfur Recovery," EPA (1994), http://www.epa.gov/ttnchie1/ap42/ch08/final/c08s13.pdf

[16] "The Phosphate Report Life Cycle Study: Lifecycle Assessment of Domestic Laundry Detergent Builders," Landbank UK (1994), p. 46. Accessed via Centre Europeen d'Etudes des Polyphosphates (CEEP), a sector group of the European Chemical Industry Council (CEFIC), http://www.ceep-phosphates.org/Files/Document/53/part02_p046-050.pdf

[17] Thomas Nemecek and Thomas Kagi, "Life Cycle Inventories of Agricultural Production Systems: Version 2.0 (2007)," Ecoinvent Centre, pp. 82-83 & 214.

- An average density of 11.11 lbs/gal is used to convert liquid fertilizers into dry weight. This value was derived by averaging the density of several common liquid fertilizers as published by the Fluid Fertilizer Foundation. [19]

Organic fertilizers

- Where a nutrient analysis has been conducted, the N-P-K value from this analysis should be used.
- Where growers do not know the nutrient value of the material, they may estimate values using a nutrient analysis table from the Western Fertilizer Handbook, which is referenced in the calculator.[20]
- While it is recognized that organic fertilizers often have slow release properties, at this time SISC does not attribute applications to multiple crops. Therefore, the entire nutrient value is attributed to the cultivated crop or subsequent crop if land is not cultivated at time of application. The benefits of the slow release should be visible when using the three-year average values, and SISC may revisit this component in the future.

Soil

SISC 's soil metric is the measured total organic carbon of the soil divided by that soil's potential to store organic carbon, as modeled using USDA's Soil Management Assessment Framework (SMAF). A score approaching 1 (or 100%) indicates that the soil has realized its full potential to hold soil organic matter.

While SMAF provides a suite of quantitative indicators for measuring different aspects of soil quality, the SISC metric and calculator use only the TOC indicator contained in SMAF.[21] SMAF adjusts a soil's TOC holding potential based on climate, soil series and soil texture. USDA has developed a national dataset for using SMAF, coding specific regions, soil types and textures into classes for use with SMAF. These data were also provided to SISC by USDA and are included in the SISC calculator.[22]

The SISC calculator requires the user to identify the soil series, soil texture and climactic region from drop down menus. Climactic regions are defined in the USDA data set for SMAF. The SISC calculator identifies the possible climactic regions for a given SISC Management Area depending on the county it resides in and includes them on a drop-down menu for selection by the user. The user is directed to USDA's Web Soil Survey to find the soil series and texture for the sampled soil if these are not already known.

Water

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[18] Mikkelsen, Robert, "Math Anxiety: Fertilizer Calculations". International Plant Nutrition Institute *Insights*. Jan 2011

[19] "Estimated Physical Characteristics of Fertilizer Material", Fluid Fertilizer Foundation, http://www.fluidfertilizer.com/pdf/Fluid%20Characteristics.pdf

[20] "Nutrient Analysis of Some Organic Materials", Western Fertilizer Handbook–Ninth Edition, 2002, Table 15, p. 319-320

[21] An Excel version of SMAF was provided to SISC by Doug Karlen at USDA's Agriculture Research Services on March 23, 2011. An online version of SMAF is also hosted at http://soilquality.org/tools/smaf_intro.html, although this site was not functioning at the time of publication. More information about SMAF can be found in: Andrews, S., Karlen, D., Cambardella, C., Soil Management Assessment Framework: A Quantitative Soil Quality Evaluation Method, Soil Sci. Soc. Am. J. 68:1945–1962 (2004) (see http://ddr.nal.usda.gov/bitstream/10113/9094/1/IND43661863.pdf).

[22] Data provided on April 5, 2011 by Susan Andrews, National Leader of the Soil Ecology Branch, National Soil Survey Center, Natural Resource Conservation Service, USDA.

[SISC is currently developing a methodology and calculator for estimating Simple Irrigation Efficiency, which requires calculation of crop evapo-transpiration. The methodology will be included here.]