Field to Market Energy Use Metric: Updates for Fieldprint Platform 3.0

Contributors: Allison Thomson (Field to Market), Wil Mannes (Field to Market and Colorado State University) and Stewart Ramsey (IHS Markit)

Initial peer-review and member review: August 17, 2017
Revised: November 3, 2017
Approved by Metrics Committee: November 14, 2017

Introduction

The Field to Market Energy Use Metric was first developed in 2009 for estimation of individual field-scale energy use in commodity crop production systems. While some revisions and additions have been made over time, documentation has not been kept up to date, and in many cases more recent data are now available. In anticipation of the complete redevelopment of the Fieldprint Platform, we conducted a review of available documentation and metric performance. We are recommending updates to the metric to both incorporate updated data and more carefully document assumptions. These include updates both to default data files, as well as structural updates to the calculation of the metric. This document provides a brief overview of the full metric review and details on the sections it was deemed necessary to update. The documentation has been reviewed and approved by two independent peer-reviewers and the Field to Market Metrics Committee.

The Energy Use Metric accounts for all energy used in the production of one crop in one year, from any pre-planting activities through to the first point of sale. It includes all energy used in field operations, including tillage, planting, harvest, fertilizer and crop protectant applications; irrigation energy; crop drying and/or storage; transportation to the first point of sale; and energy embodied in the amount of fertilizer, crop protectants and seed used for production of the crop. The overall scope of the metric is not changed at this time, and not all components are revised with this effort or described in detail below. On review, some updates were determined to be necessary to keep the calculations in line with the most recent information from government agencies and literature sources.

This document describes the updates in detail and will be used to adjust the data sources and documentation of the Energy Use Metric. Like all Field to Market Metrics, the Energy Use Metric will be evaluated at least once every three years for user feedback and necessary updates based on advances in relevant science or available data products. In the following sections we note particular areas where we recognize that updated or additional information would be valuable to the metric; we welcome collaboration to address these areas and will revise the metric accordingly as new information becomes available.

Updated Components of the Energy Use Metric

Each section below describes an update to a data resource or assumption within the Energy Use Metric. Literature resources and other material cited is organized at the end of the document, by section. The objective of this documentation is to highlight the data sources and process that are changing from the existing calculations currently implemented in the Fieldprint Platform.

1. Crop Protectant Energy Update

The Energy Use Metric accounts for the energy embodied in crop chemicals (energy required to produce the chemical) and the energy required to apply crop protectants to the field. This update only addressed the first component – embodied energy. The amount of energy embodied in crop chemicals was updated to account for more recent survey information from USDA's Chemical Use Survey, including the type of product used and the amount used. The overall calculation elements remain the same as in the current version – the number of application trips and the number of products used are accounted for based on average application rates and typical product types applied derived from USDA data; we continue to use the same source of data from the literature (Audsley et al, 2009) to estimate the amount of energy required to produce crop chemicals. The objective was to update the estimated embodied energy value for a single application of each type of product (herbicide, insecticide, fungicide) for each crop (alfalfa, barley, corn, cotton, peanut, potato, rice, sorghum, soybean, sugar beet, wheat) in the Field to Market program.

The first step was accessing the most recent pesticide survey year(s) available through USDA-NASS' Agricultural Chemical Use Program for each crop and extracting three key data points: the "Domain Category" column, the "applications measured in pounds" value column, and the "Applications measured in lb./acre/application, avg." value column. The chemical category of interest (fungicide, insecticide, herbicide) is then extracted for the "multi-state" data categorization from USDA. As many different forms of the same active ingredient (AI) are included, the data were sorted and processed to account for the most commonly applied AI's and restricted to 80% of the mass (reported in pounds of AI) of chemical applied by crop and category. The total mass of chemical applied is then used to calculate the fraction of total mass from each of the active ingredients (AIs) identified. This provides a foundation from which to make BTU/acre/application estimates.[1]

The amount of each product applied by category is extracted from the USDA NASS Chemical Use Survey data in lb./acre/application[2]. Next, the total energy requirement to produce the AI are pulled from Audsley et al (2009; Table 8) When specific AI information is not available, the average energy by product category (herbicide, insecticide, fungicide) from Audsley et al (2009; Table 10) is used. Data are then converted from MJ/kg to BTU/lb. using standard conversion factors of 948 BTU per MJ and 2.2 pounds per kg [((MJ/kg * 948)/2.2)=BTU/lb].

Given this information, the energy embodied in each individual application (BTU/acre/application) can be calculated by multiplying the energy per unit of product (BTU/lb.) by the application rate from USDA (lb./acre/application). To obtain the weighted average per application, the resulting energy per application (BTU/acre/application) is multiplied by the fraction of the total mass of all chemical in that category applied. These chemical- specific weighted averages are subsequently added together and averaged, providing a weighted average per application in BTU/acre/application for each category of crop protectant.

This process is repeated utilizing the second most recently available year of USDA data for the same crop and chemical category. The weighted averages per application for the two survey years under consideration are then averaged to account for possible variation in application rates and a changing subset AI group.

The Fieldprint Platform will use this average energy per application value (crop and protectant category specific) and multiply it by the number of crop protectants (number of products and number of times applied during the growing season) applied by the grower (user input) to provide an embodied energy value associated with crop protectant application. This update accounts for recent changes in active ingredient applications (types and amounts) and enables full documentation of the process for determining appropriate values for new crops. The update provides estimates by crop type and by chemical category (herbicide, insecticide, fungicide).

2. **Energy Index Update**

---

[1] : Where multiple forms of the same AI such as Glyphosate, Glyphosate Iso. Salt, and Glyphosate Dim. Salt are present, they are summed together to form 1 A.I. entity, referred to as “Total Glyphosate” in this scenario. Each of these AI's portion of the "total Glyphosate" value is accounted for by dividing the subset AI/total Glyphosate before they are summed into one entity by the total.

[2] Determining “Total Glyphosate” lbs./acre/application is accomplished by multiplying the lbs./acre/application for each individual A.I. entity making up “Total Glyphosate” by its fraction of the "Total Glyphosate". These individual A.I. entity fraction-totals are added together and averaged, thus offering a weighted lbs./acre/application "Total Glyphosate" value.

The energy index is a standard reference table for the Fieldprint Platform that contains information on fuel types, the energy content of each fuel type (in British Thermal Units (BTUs)) and the subsequent greenhouse gas (GHG) emissions associated with the combustion of the fuel. In addition to the updates to data described here, the new version of the Fieldprint Platform will provide an option for users to directly enter their fuel energy usage. With advances in technology, many tractors will track the total fuel usage over a season and the information on energy use from field operations is readily accessible by the grower. This will be considered a more accurate reflection of energy usage – users will be able to enter the fuel amount and type. However, in cases where this is not known, and in order to convert energy usage appropriately to greenhouse gas emissions values, the following data updates are proposed. Here we accessed standard government databases to update the energy index table.

2.1 **Energy Content**

The energy content of 11 common fuel types[3] (in BTU's per unit of fuel) were updated by employing the higher heating values from the Department of Energy's 2014 "Alternative Fuels Data Center – Fuel Properties Comparison" chart or "AFDC".

Where the higher heating values of specific fuels were not available (B100 & B20 Biodiesel, E10 & E85 gasoline) fuel specific calculations were made based on reference information provided by AFDC; the calculations are described in Table 1.

Table 1 – Fuel specific energy content calculations for fuels not available in AFDC.

Fuel Type	**AFDC Information (per 1 gallon)**	**Reference data (AFDC)**	**Calculated Energy (BTU) in fuel**
B100	Contains 93% of the energy found in 1 gallon of diesel fuel	Diesel fuel- 138,490 BTU/gallon	0.93*138,490 = 128, 796
B20	Contains 99% of the energy found in 1 gallon of diesel fuel	Diesel fuel- 138,490 BTU/gallon	0.99*138,490 = 137,105
E10	Contains 97% of the energy found in 1 gallon of regular unleaded gasoline	Reg. Unleaded gasoline- 124,340 BTU/gallon	0.97*124,340 = 120,237
E85	Contains 73-83% of the energy found in 1 gallon of gasoline (78% used in calculations)	Reg. Unleaded gasoline- 124,340 BTU/gallon	0.78*124,340 = 96,985

---

[3] Diesel, B5 Biodiesel, B20 Biodiesel, B100 Biodiesel, Gasoline (regular unleaded), E10 gasoline, E85 gasoline, LP Butane, Propane (LPG), Natural Gas, Compressed Natural Gas, Methanol, and Electricity

LP Butane and Natural Gas energy content numbers also were not available through the AFDC and were instead offered by the EPA's 2014 "Emission Factors for Greenhouse Gas Inventories" document (EPA, 2014).

2.2 **Greenhouse Gas Emissions**

EPA (2014) provides greenhouse gas emission factors for many fuels in kilograms of carbon dioxide per gallon of fuel (kg CO_2/gallon), grams of methane per gallon (g CH_4/gallon), and grams of nitrous oxide per gallon (g N_2O/gallon) produced via combustion, with CH_4 and N_2O values subsequently converted to kg CH_4/gallon and kg N_2O/gallon using a standard conversion factor[4]. These CH_4 and N_2O kg/gallon factors were transformed into CO_2e values by multiplying the CH_4 value by a global warming potential (GWP) value of 25 (EPA 2014 via IPCC) and the N_2O value by a GWP of 298 (EPA 2014 via IPCC). Once all values were in common units (kg CO_2e), they were summed and multiplied by 2.205 to convert the value from kilograms to pounds (kg CO_2e /gallon to lb CO_2e/gallon).

Blended fuels (B5, B20, E10, & E85), compressed natural gas, and electricity emission factors were not provided in EPA (2014) and were calculated using fuel specific methodologies (Figure 1). Blended fuel emissions were estimated by linearly interpolating a given blended biofuel percentage between the emission factor of the petroleum based fuel emission (0% biofuel) and the published emission factor of 100% biofuel as illustrated below.

- Blended fuels

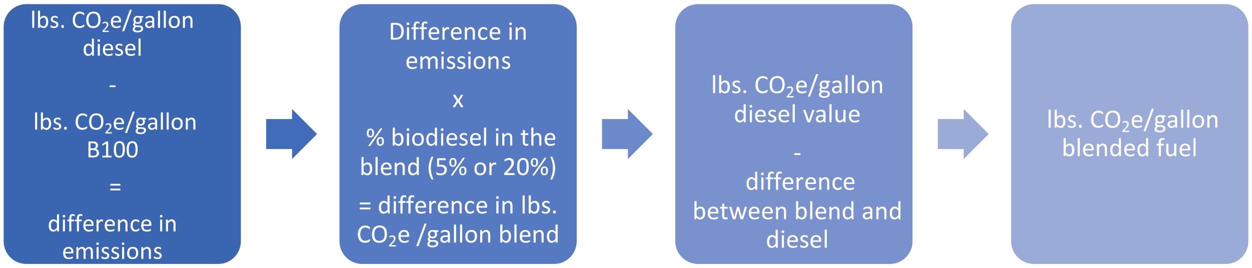


Figure 1. Biofuel blend example. An ethanol blend calculation is constructed the same way, with the regular gasoline emissions per gallon value replacing the diesel emissions value and E100 CO_2e emissions substituting for B100 CO_2e emissions.

- Compressed natural gas (CNG)

---

[4] Methanol's CO_2 emission factor was provided, however CH_4 and N_2O emission factors were not. Therefore, only CO_2 emissions were calculated.

Compressed natural gas, as the name implies, is simply natural gas compressed into liquid form. To find pounds (lbs) CO_2e produced per gallon of CNG combusted, energy content (BTU) and calculated CO_2e natural gas values were used along with the BTU energy content from AFDC. Dividing the CO_2e value of natural gas by its BTU energy content results in emissions per BTU of natural gas. The BTU energy content value in one gallon of CNG was then multiplied by the emissions per BTU of natural gas value to provide CO_2e emissions per gallon of CNG.

- Electricity

The average emission rate when generating one kilowatt hour (KWh) of electricity has been updated to account for shifts in generation technologies and energy fuel sources. Energy Information Agency (EIA) data providing electricity emissions (in million metric ton (MMT) CO_2) and consumption values (in Megawatt hours (MWh)) by state in 2014 was used to determine emission rates in CO_2/KWh electricity consumed. This was accomplished through dividing total electric emission values by consumption values for all states (data for Vermont were not available), resulting in MMT CO_2/MWh. These values were multiplied by a standard conversion factor of 2205 lbs./metric ton to obtain a value in lbs. CO_2/MWh, which can subsequently be divided by 1000 to get the desired lbs. CO_2/KWh electricity generated per state. Summing these state values and dividing by 49 provides a national CO_2 emissions average in lbs. CO_2/KWh electricity consumed of 1.18 lbs CO2e per kWh. The individual state values will be used in the Fieldprint Platform, with this national value used for Vermont.

We recognize that this is an imperfect estimate of the emissions associated with electricity consumption as it does not account for interstate trade; we will revisit these assumptions as additional data sources become available. In addition, we are adding in the option for a user to indicate if renewable electricity is either purchased or generated (and used) on farm, in order to provide credit for specific action taken for renewable electricity sources.

- Diesel fuel equivalents

Calculating the final energy use metric across the range of activities on farm requires conversion to a common unit. As the most common fuel our users select, we use diesel fuel as the equivalent when conversions are necessary. Thus, the final update to the energy index table involved the conversion of emissions per fuel unit (gallon, KWh, etc.) into emissions per gallon of diesel fuel equivalent. This was carried out by dividing an individual fuel's lbs. CO_2e/fuel unit value by its fuel/diesel ratio (calculated by dividing the BTU value in 1 gallon of the individual fuel by the BTU value of 1 gallon of diesel).

3. **Grain Transportation**

The energy required for grain transportation from the field to the first point of sale has been updated to account for the most common mode of crop transportation, via semi-truck and trailer. Semi-truck and trailer combinations carry a gross weight between 20,000-26,000 lbs. when empty and upwards of 80,000 lbs. when full (Energy.gov, 2010), leading to a "Class 7-8 Combination truck" qualification in Davis et al (2015). Vehicles with this classification are estimated to attain a fuel usage of 5.8 miles per gallon of diesel fuel when transporting a full load (Table 5.2, Davis et al, 2015). These new values will be used to calculate fuel usage based on the total volume of grain transported and distance to the point of sale (user inputs).

An additional update to the calculator will include a new question to users to indicate whether or not they have a "back haul" – that is, after transporting the crop, does the truck return to the farm empty, or with some product returned (e.g. fertilizer). If they indicate there is a backhaul use, then only the one-way distance for a full truck will count as their transportation energy. If they do not, the truck will be assumed to return empty (fuel usage estimate of 7.3 mpg) and the return energy will be counted as part of the transportation energy use for that crop.

4. **Fertilizer Energy Update**

Over time the process of manufacturing fertilizer products has undergone technological and efficiency changes. To account for these changes, updated embodied energy values were updated to the most recent information used in the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model - 2016 (version 1.3.0.13130, Database version #13098) (https://greet.es.anl.gov/) developed for use in life cycle analysis of transportation fuels in the United States. As this includes life cycle analysis of a range of biofuels, one important resource for which the energy and greenhouse gas contribution is included is fertilizers used in production of crops for biofuels. We use this as the main data source, with adjustments to account for fertilizer blends not provided directly in the GREET databases. Previous versions of the energy use metric used earlier versions of GREET from prior to 2010.

When a nutrient value is not specifically stated as per pound of nutrient (N, P_2O_5, or K), GREET (2016) provides the value in BTU/lb. product[5]. To convert these BTU/lb. product values to BTU/lb. nutrient, the BTU/lb. product value is divided by the percentage of nutrient in the fertilizer product, exemplified below.

Ammonium Nitrate (34-0-0):

$$\frac{8{,}810\ BTU\ per\ lb.product}{34\%\ N} = 26{,}539\ BTU\ per\ lb.N$$

---

[5] Product refers to a nutrient blend amount (I.e. Per pound of 10-10-10 fertilizer)

Blended fertilizer energy value calculations began with consulting Cornell University literature[6] to determine which fertilizer products are commonly used in dry and liquid blended fertilizers, with the results represented in Table 2.

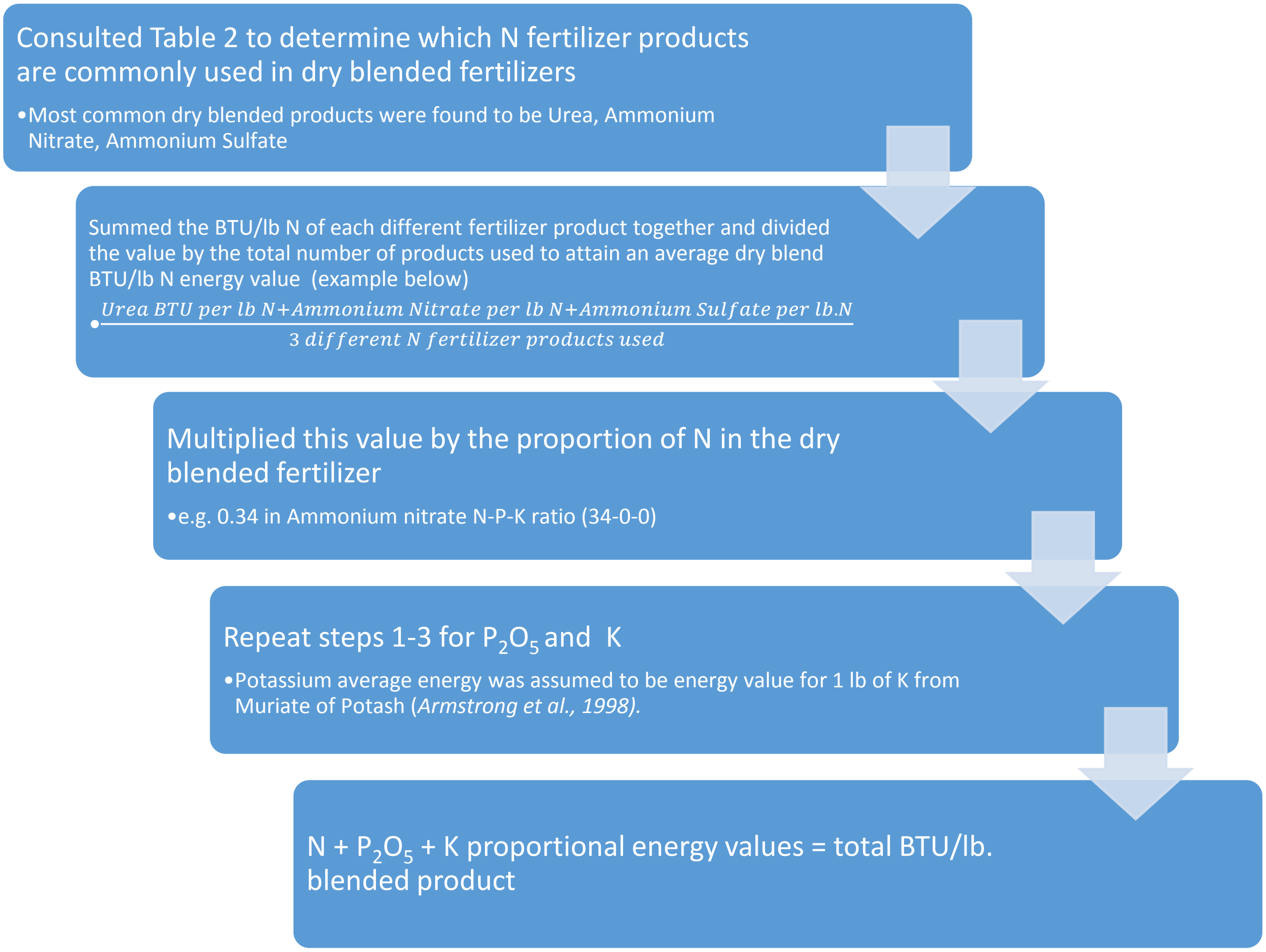
Table 2. Fertilizer products commonly used in different blend forms

	Dry	**Liquid**
Nitrogen	Ammonium Sulfate, Ammonium Nitrate, Urea	UAN 28%, 30%, 32%
P_2O_5	Triple Superphosphate	Superphosphate
Potassium (K)	Muriate of Potash	Muriate of Potash

Common dry blended fertilizers are by nature a mixture of nutrients, creating a custom nutrient blend for growers with specific needs. The energy associated with creating these custom blends is calculated differently than the fertilizer products previously discussed. Figure 2 below describes this process, using nitrogen as an example of how blended fertilizer embodied energy is calculated.

---

[6] https://nrcca.cals.cornell.edu/nutrient/CA4/CA4_SoftChalk/CA4_print.html



Consulted Table 2 to determine which N fertilizer products are commonly used in dry blended fertilizers

- Most common dry blended products were found to be Urea, Ammonium Nitrate, Ammonium Sulfate

Summed the BTU/lb N of each different fertilizer product together and divided the value by the total number of products used to attain an average dry blend BTU/lb N energy value (example below)

- $\frac{Urea\ BTU\ per\ lb\ N + Ammonium\ Nitrate\ per\ lb\ N + Ammonium\ Sulfate\ per\ lb.N}{3\ different\ N\ fertilizer\ products\ used}$

Multiplied this value by the proportion of N in the dry blended fertilizer

- e.g. 0.34 in Ammonium nitrate N-P-K ratio (34-0-0)

Repeat steps 1-3 for P_2O_5 and K

- Potassium average energy was assumed to be energy value for 1 lb of K from Muriate of Potash (*Armstrong et al., 1998).*

N + P_2O_5 + K proportional energy values = total BTU/lb. blended product

Figure 2. Common Dry blend fertilizer calculations (Nitrogen example)

To compute liquid fertilizer blends the process previously described was repeated, using information on N and P products commonly found in liquid blends (Table 2). As previously mentioned, muriate of Potash, used 95% of the time potassium fertilizer is applied, is used to represent the K energy value. After the BTU/lb. of blended product is obtained, the liquid fertilizer blends are converted to BTU/gallon of product by using the specific pounds per gallon of each liquid blend fertilizer product via the Mid-Atlantic Regional Water Program's 2006 "Mid-Atlantic Nutrient Handbook".

Furthermore, liquid blends 7-21-7 and 10-34-0 are calculated using different nitrogen sources, as neither uses the nitrogen products commonly found in a liquid blend. 10-34-0 uses Anhydrous Ammonia (AA) as an N source (Liquid Products LLC, 2006) while 7-21-7 uses 6.18% Anhydrous Ammonia, .41% Nitrate, & .41% Urea (Mears, 2014). Fertilizer 10-34-0's N energy value is determined by simply multiplying AA's total energy per lb. N by the 10% N that makes up 10-34-0. Fertilizer 7-21-7 energy values from N are calculated by taking each N fertilizer products percentage in forming 7-21-7 (e.g. AA's 6.18%) multiplied by the energy value per lb. N of product. These values are then summed together, providing 7-21-7's N energy value. After accounting for the change in nitrogen source, these products follow the same calculation process described above for P_2O_5 and K energy value calculations and subsequent total energy values.

Lime was calculated on a per ton applied basis. GREET (2016) values for lime as fertilizer products include mining, transportation to the mixer and transportation to the farm. Both "Other Limestone" and "Dolomite Lime" were assigned this value.

5. Seed

Seed energy values for each of the 10 crops assessed in Field to Market (2016)[7] were calculated by using 2013-2015 crop energy use rates on a per unit of crop yield basis[8]. Each year's crop energy use was multiplied by 1.5 to account for the high energy demand of producing crops for seed (150% of the energy used to grow the crop for grain production). This is the same multiplier factor that is used in the current version of the Energy Use Metric. This update is intended to reflect the update in the data source and not the assumption (150%).

There is limited information available in the literature on energy used in seed production. The most comprehensive study on cropland energy use, West and Marland (2002), refers to a method documented in an engineering handbook from 1980 (Heichel, 1980) that recommends using the retail cost of seed to determine the embodied GHG emissions. Using the Field to Market National (2016) values has the advantage of the seed energy values being consistent with the Energy Use metric, and provides a value based on physical rather than economic considerations.

The 150% factor was determined based on input from seed industry members of Field to Market, who indicated the additional level of management, fertilizer, irrigation, and crop protectants, used in seed production compared to commercial production. The new seed energy values for 2013-2015 were then summed and divided by three to offer an average seed energy value in BTU/bushel[9]. We recognize that seed crop management may differ by crop considered and will include this topic in discussions with relevant grower groups and other stakeholders as we add additional crops to the system, to ensure the multiplying factor accurately reflects level of effort. This is another topic where we would welcome additional resources and information to be incorporated in future updates.

6. Irrigation

The current energy use metric implicitly assumes a perfect transfer of energy for the operation of pumps for irrigation. Based on a review of available information from USDA (2016) and Kranz (2012) we have elected to update this assumption to account for energy lost in operation of the systems. These sources have determined that a pump efficiency rating of 75% is

---

[7] Barley, Corn Grain, Corn Silage, Cotton, Peanuts, Potatoes, Rice, Soybeans, Sugar Beets, Wheat

[8] Potatoes and Rice measured in BTU/cwt (hundred weight), while Sugar Beets (BTU/ton) and Cotton (BTU/lb. Lint) have crop specific measurements.

standard; therefore the energy use metric will be adjusted to accurately represent the average pump efficiency rating. In practice, this decrease in pump efficiency leads to an overall increase in energy consumption per gallon of water applied.

In the calculation of the metric, this new pump efficiency factor of 0.75 used as a multiplier only in the instances where a user does not directly enter energy use. This calculation combines the pump pressure with pumping depth, and with total amount of water applied, to calculate the energy required to move that amount of water the required distance.

Note that, if known, users can directly enter the amount of energy (in amount of fuel or electricity used to run their pump) in which case the pump efficiency is not necessary.

We are also undertaking additional research on irrigation efficiency to inform users around the relative efficiency of equipment and water use decision making available to them. We anticipate this information will be available in about one year, and will be incorporated into the metric as appropriate.

7. Post-harvest Handling

This is composed of energy estimates for crop drying and/or storage, and is based on crop specific estimates of energy requirement for removal of a point of moisture from a University of Wisconsin publication (Sanford, 2005). Several grain drying experts from Field to Market member organizations were consulted and did not identify any updated information from this resource.

An update of the specific estimates for cotton lint drying were provided by Cotton, Inc. Estimates provided previously have been recently revised based on new analysis from USDA and in the literature. Based on fuel use measured from drying systems from 2007-2010, assuming initial cotton seed moisture of 11%, Baker and Hughs (2012) found an average drying energy requirement of 480 BTU per pound, with a median of 338 BTU per pound, leading to the conclusion that the current energy requirements are overestimated. Based on these findings, we are correcting the cotton drying energy to correspond to the median value for “Normal” moisture content. The new values are indicated in Table 3 for the four moisture categories of cotton that users select from in the Fieldprint Platform.

Table 3: Replacement values for cotton lint drying energy.

Cotton Moisture Content at Ginning	**Thermal Energy – Old BTU/lb lint**	**Thermal Energy – New BTU/lb lint**
Very Dry	315	100
Normal	739	300
Wetter than Normal	1087	500
Very Wet	1436	700

8. Field Operation Energy Use

Energy used in field operations is derived directly from the RUSLE2 model, which is run for all users of the Fieldprint Platform. We have obtained the underlying table of energy values associated with each individual operation. We have filtered and indexed the database for use as a reference to assist in interpretation of energy use scores, and provide the option for off-line calculation as an evaluation and additional resource for users.

9. Co-Products

Following review of the Fieldprint Calculator code, we are removing the option to default to or user-specify co-products. This is currently an automatic calculation for cotton, based on an industry assumption of 83% of economic value comes from lint, and 17% from seed. Other crops have the option to indicate if some proportion of the crop economic value comes from other than the primary Field to Market product (grain, lint). For example, a wheat grower who harvests the straw and sells it can indicate some proportion of economic value from the co-product. This fraction has been used to adjust all metrics accordingly.

On review, this was determined to be an unnecessary complication, and misleading for other metrics. The co-product approach based on economic value can have importance if the results of the energy, GHG, land use or irrigation metrics are used further in a Life Cycle Assessment. However, co-product calculations are not compatible with the environmental models that represent other metrics, such as RUSLE2 for soil erosion. As the environmental outcomes are the foundation of the metrics, we are using this update to remove the co-product calculation.

Users who are still interested in understanding the economic allocation of their “Fieldprint” scores to different co-products can apply a co-product fraction calculation to their Fieldprint results. Field to Market will provide guidelines for users who wish to make this adjustment to specific metrics.

Summary

The modifications described here will provide more accurate and traceable calculations of energy use on farm for the Fieldprint Platform. This document describes the updates relevant to the implementation of the metric in the new version of the Platform, currently under development. These changes will also carry over to the Greenhouse Gas Emissions metric, which includes conversion of energy use to carbon dioxide equivalent values, as well as non-energy sources of greenhouse gas emissions.

Overall, we were able to identify appropriate data sources to generate this information. We do note, however, that one category with insufficient data is the energy required to produce crop chemicals; while we are able to combine USDA usage statistics with literature values, there are many chemical products and even product categories for which values are not available in the literature. Additional information would help improve accuracy of energy estimates from crop production.

In addition, we have noted where advances in understanding and/or data resources would improve on the assumptions and databases used in our metric, including see energy and greenhouse gas emissions from electricity generation in different regions. We are committed to collaborating with the research community to help advance the collective resources for accurate assessment of on-farm energy use.

References

Field to Market, 2009. Environmental and Socioeconomic Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States (First Report). January 2009. Available from: www.fieldtomarket.org.

Crop protectant update

USDA, 2017. USDA Agricultural Chemical Use Program. *USDA - National Agricultural Statistics Service - Surveys - Chemical Use*. United States Department of Agricultural, n.d. Web. May-June 2017.https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/index.php

Audsley, E., K. Stacey, D.J. Parsons, and A.G. Williams. 2009. *Estimation of the Greenhouse Gas Emissions from Agricultural Pesticide Manufacture and Use*. Rep. Cranfield: Cranfield U, 2009. Available from:
https://dspace.lib.cranfield.ac.uk/bitstream/1826/3913/1/Estimation_of_the_greenhouse_gas_emissions_from_agricultural_pesticide_manufacture_and_use-2009.pdf

Energy Index update

USDOE, 2014. United States. Department of Energy. *Alternative Fuels Data Center – Fuel Properties Comparison*. N.p.: U.S. Department of Energy, 2014. Web.
https://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf

US EPA, 2014. United States. Environmental Protection Agency. *Emission Factors for Greenhouse Gas Inventories*. U.S. Environmental Protection Agency, 4 Apr. 2014. Web. June-July 2017.https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

EIA, 2017. "State Electric Profiles." *Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government*. N.p., n.d. Web. 17 July 2017.https://www.eia.gov/electricity/state/archive/2014/

EIA, 2017. “State Carbon Dioxide Emissions” *Energy Information Administration - EIA - Official Energy Statistics from the U.S. Government*. N.p., n.d. Web. 17 July 2017 https://www.eia.gov/environment/emissions/state/

Grain transportation update

USDOE, 2010. "Fact #621: May 3, 2010 Gross Vehicle Weight vs. Empty Vehicle Weight." *Department of Energy*. Energy.gov, May-June 2010. Web. 17 July 2017.
https://energy.gov/eere/vehicles/fact-621-may-3-2010-gross-vehicle-weight-vs-empty-vehicle-weight

Davis, S.C., S.W. Diegel and R.G. Boundy. 2015. *Transportation Energy Data Book: Edition 35*, ORNL-6992, Oak Ridge National Laboratory, September 2015. Web.
http://cta.ornl.gov/data/tedb34/Edition34_Full_Doc.pdf

Fertilizer Updates

Elgowainy, A., D.Dieffenthaler, V. Sokolov, R. Sabbisetti, C. Cooney, and A. Anjum. 2013. GREET Life-cycle Model. Vers. V.1.30.13130. Argonne, Illinois: Argonne National Laboratory, 2013. Computer software.

The Mosaic Company, 2016. Urea Ammonium Nitrate. *Cropnutrition.com*. Web. June-July 2017. (http://www.cropnutrition.com/urea-ammonium-nitrate)

Cornell University, 2010. Nutrient Management- Competency Area 4: Nutrient Sources, Analyses, Application Methods. *Nrcca.cals.cornell.edu*. Web. June-July 2017. https://nrcca.cals.cornell.edu/nutrient/CA4/CA4_SoftChalk/CA4_print.html

Mears Fertilizer, Inc., Jan.-Feb. 2014. Product Specifications - NPK Solution Fertilizer 7-21-7. *Mearsinc.com*. Web. June-July 2017. http://www.mearsinc.com/site_files/wp-content/uploads/2014/02/SPEC-LB0721071.pdf

Liquid Products LLC, 2006. 10-34-0 AMMONIUM POLYPHOSPHATE SOLUTION." Liquidproducts.net. Web. June-July 2017. http://www.liquidproducts.net/SpecSheets/10-34-0_spec_shet.pdf

Armstrong, D. L., and K. P. Griffin., eds. "Production and Use of Potassium." Better Crops With Plant Foods 82.3 (1998): 6. International Plant Nutrition Institute - (IPNI). June-July 2017. https://www.ipni.net/ppiweb/bcrops.nsf/$webindex/02FB2A65B5DE395D852568F000674947/$file/98-3p06.pdf

Haering, K. C., G. K. Evanylo, and A. O. Abaye. 2006. Commercial Fertilizers. *The Mid-Atlantic Nutrient Management Handbook*. Greenbelt, MD: Mid-Atlantic Regional Water Program, 2006. 189-91. *Extension.psu.edu*. Penn State University Extension. Web. July-Aug. 2017.

GREET. 2016. GREET model - 2016 (version 1.3.0.13130, Database version 13098). https://greet.es.anl.gov/.

Seed Update

Field to Market, 2016. Environmental and Socioeconomic Indicators for Measuring Outcomes of On Farm Agricultural Production in the United States (Third Edition). ISBN: 978-0-692-81902-9.

Heichel, G., 1980. Energy attributable to seed. In: Pimentel, D. (Ed.), Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, FL, pp. 27–3

West, T.O., and G. Marland. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agriculture, Ecosystems and Environment 91:217–232.

Irrigation Update

USDA, 2016. Chapter 8: Irrigation Pumping Plants *Part 623 Irrigation National Engineering Handbook* https://policy.nrcs.usda.gov/OpenNonWebContent.aspx?content=39789.wba page 164.

Kranz, William, 2012. "Updating the Nebraska Pumping Plant Criteria" http://extension.missouri.edu/sare/documents/UpdatingPumpingPlantPerformanceCriteria2012.pdf via Nebraska Pumping Plant Performance Criteria

Crop Drying

Baker, K. and E. Hughs. 2012. A survey of seed cotton dryers in cotton gins in the southwestern United States. Applied Engineering in Agriculture 28(1): 87-97.

Sanford, 2005. Reduce Grain Drying Costs this Fall. University of Wisconsin, Biological Systems Engineering publication. September 2005.