UNIVERSITY OF
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Appendix C: Units, Equivalents and Energy Constants[1]

UNITS

The study of topics such as energy conservation involves the comparison of alternatives. The act of comparison is complicated if alternatives are expressed in incompatible units. It is not easy to tell at a glance whether a 100-watt light bulb or an electric motor producing 1/4 horsepower consumes more power. Adoption of a consistent system of units such as the SI system (Table 1) greatly simplifies the task of comparison.

In a consistent system of units, the 1/4 hp output is expressed as 186.5 watts (see Conversions in this appendix) so it is immediately apparent that the electric motor consumes more power than the light bulb. (This example has ignored some details. Light bulbs are rated by power consumption whereas motors are generally specified by their power output. A real electric motor does not convert all electric power to mechanical power, so more than 186.5 watts are actually consumed. Assuming a typical 85% conversion efficiency, the actual power consumption is closer to 186.5/.85 = 219 watts.)

Unfortunately, a consistent system of units is not sufficient to develop a full appreciation for energy matters, because a person must be able to comprehend the absolute magnitude of particular measurements as well as to merely compare the magnitudes of actions on the basis of greater or lesser. Most adults in this country have at least some appreciation for the absolute magnitude of a distance expressed as "1 mile" and for associated observations such as how long it would take to walk this distance. Individuals having some experience with electric motors are able to conjure up an image of the approximate size of a 1/4 hp motor and have a good feeling about its capabilities, but a 200-watt specification for a motor has little inherent meaning for many people.

Table 1. SI Units

Force:	**newton (N)**
Mass:	**kilogram (kg)** **metric tonne (t or mt)=1 kg**
Length:	**meter (m)**
Temperature:	**kelvin (°K)**
Work or Energy:	**joule (J) = 1 N-m**
Power:	**watt (w) = 1 J/sec**
Area:	**hectare (ha) = 104 m^2**
Volume:	**liter (l) = 0.001 m^3**
Pressure:	**pascal (Pa) = 1 N/m^2**

In this report, general measurements are given in the units commonly employed and supplemented by SI units where comparisons are in order.

This report uses units common to the subject being discussed. Fundamental SI units and conversions between systems of units are given in Table 8.

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Table 2. Energy Requirements for Phosphorus-Bearing Fertilizers (3)

P-Source	%P_2O_5	BTU/lb-P_2O_5	MJ/kg-P_2O_5
Basic Slag[a]	8-12	0.3 x 10^3	0.8
Monoammonium Phosphate[b]	48	3.6 x 10^3	8.3
Superphosphate[c]	20	3.7 x 10^3	8.5
Diammonium Phosphate[d]	46	6.5 x 10^3	15.1

Notes:

a Basic slag is byproduct of the steel industry composed of approximately 50% CaO and varying amounts of P_2O_5, MgO, and Mn.

b Often abbreviated as MAP. Also contains 11% N. The manufacturing energy is given per pound (or kg) of N plus P_2O_5.

c The manufacturing energy is given per pound (or kg) of P_2O_5.

d Often abbreviated as DAP. Also contains 20% N. The manufacturing energy is given per pound (or kg) of N plus P_2O_5.

Gallons-Diesel Fuel Equivalent (GDFE)

The use of common units (feet, acres, pounds) does not totally solve the problem of being able to comprehend absolute magnitudes of energy units. Units of horsepower-hour or joules do not carry an intrinsic meaning. For this reason, the artificial unit of "gallons-diesel fuel equivalent" (gdfe) has been adopted for this report. A gallon of diesel fuel has a certain amount of energy tied up in the chemical bonds of the fuel. The energy content of a gallon of diesel fuel used here is 147 x 106 J (1).

ENERGY CONSTANTS

Energy Value of Labor (1)

Fluck gives the energy equivalent for human labor as 594 MJ/day or 24.75 MJ/hour. This value is an estimate of the energy input required for the food, clothing, transportation, etc. of a worker. It specifically excludes energy used for leisure time activities.

Solar Radiation (2)

The solar intensity at the Earth's orbit is approximately 1353 watts/meter^2. The solar intensity on Earth's surface is dependent upon atmospheric conditions, time of day, etc. The solar intensity at the surface on a clear day with the sun directly overhead is about 900 watts/meter^2. At temperate latitudes, a rough average for solar intensity for all times and seasons is given as 100 watts/meter^2.

Table 3. Energy Requirements for Nitrogen-Bearing Fertilizers (3)

N-Source	%N	BTU/lb-N	MJ/kg-N
Ammonia	82	23.7 x 10^3	55
Ammonium Sulfate	21	25.0 x 10^3	58
Liquid UAN	32	28.0 x 10^3	65
Ammonium Nitrate	34	28.9 x 10^3	67
Urea	46	30.2 x 10^3	70

Energy Value of Fertilizers

Knowing the energy value of the various fertilizer materials is important given the preeminent position of fertilizers as an energy-consuming input in American agriculture. Manufacturing energy varies with the nutrient and manufacturing method. Tables 2, 3 and 4 give relevant data for the three most important fertilizer types.

Table 4. Energy Requirements for Potassium-Bearing Fertilizers (3)

		BTU	MJ
Potassium Source	%K_20	lb-K_20	kg-K_20
Muriate of Potash	50-60	2.15 x 10^3	5
Potassium Magnesium Sulfate	22	2.15 x 10^3	5
Potassium Sulfate	50	2.15 x 10^3	5

The data for the nutrients are given in terms of N, P_20_5, and K_20. This conforms with the usual practice of expressing fertilizer analysis in these units. If the analysis is known in the elemental form rather than the oxide form, use the following equivalencies.

1 lb P_20_5 = 0.4364 lb P
1 lb K_20 = 0.8301 lb K

The tables give data for fertilizer materials, i.e. those fertilizers generally containing a single nutrient.

Determining the energy embodied in mixed fertilizers, such as 10-10-10, requires assuming the energy content of the different ingredients in the mixture.

Use the following approximations when computing the energy content of mixed fertilizers.

N = 60.0 MJ/kg (26.0 x 10^3 BTU/lb)
P_20_5 = 8.5 MJ/kg (3.7 x 10^3 BTU/lb)
K_20 = 5.0 MJ/kg (2.1 x 10^3 BTU/lb)

Polyethylene for Plastic Mulch and Greenhouse Covering

Manufacturing energy: 150 MJ/kg (65 x 10^3 BTU/lb)
Density: 0.763 kg/m^3 (59.28 lb/ft^3)
4-mil "double poly": 29.2 MJ/m^2 (22.56 x 10^3 BTU/ft^2)
6-mil "double poly": 43.7 MJ/m^2

Energy Value of Pesticides

The process of determining the energy cost for pesticide use is similar to that for fertilizers. The total cost is the sum of the energy sequestered in the material itself and that required to apply it to the crops. The sequestered energy, in turn, is a combination of the indirect energy contained in feedstocks and packaging materials, direct processing energy, and energy required to deliver the material to the farmplace. In a similar manner, application energy is a combination of the energy in the fuels consumed in the power units and an amortization of the energy embodied in the machinery.

Table 5 shows the sum of indirect feedstock energy and direct processing energy for various pesticides.

After the active ingredient has been manufactured, it is combined with other materials into a formulation that is then packaged and shipped to the farm. Pimentel presented formulation, packaging, and transport energies for different formulation techniques (4) as shown in

Table 5.Pesticide Active Ingredient Production Energy (3)

Material	MJ per KG Active Ingredient
Herbicides	
MCPA	130
Diuron	269
Atrazine	189
Trifluralin	147
Paraquat	459
2,4-D	101
2,4,5-T	237
Chloramben	299
Dinoseb	80
Propanil	219
Propachlor	289
Dicamba	294
Glyphosphate	453
Diquat	399
Average	255
Insecticides	
DDT	101
Toxaphene	160
Methyl parathion	58
Carbofuran	453
Carbaryl	153
Average	185
Fumigants	
Methyl bromide	67
Fungicides	
Ferbam	64
Maneb	99
Captan	115
Sulfur	111
Average	97

Table 6. **Formulation, Packaging and Transportation Energy Inputs for Pesticides (4)**

	MJ/Kg Active Ingredient			
	Formulation	**Packaging**	**Transportation**	**Total**
Miscible oil	139	35.6	4.6	179
Wettable powder	10.5	10.9	[illegible]	[illegible]
Granules/dust	15.1	83.7	28.1	127

Table 7. **Energy Values of Common Fuels**

Input	Heat of Combustion or Enthalpy	Primary Energy
Direct Energy		
	BTU/gal	**BTU/gal**
Gasoline	125,000	152,800
Diesel Fuel	138,800	169,700
LP Gas	95,500	116,800
Fuel Oil	135,000	165,100
	BTU/ft^3	**BTU/ft^3**
Natural Gas	1,024	1,143
	BTU/kw-hr	**BTU/kw-hr**
Electric Power	3,413	13,900

Source: USDA & FEA

Table 6.

The energy cost to apply chemicals with a pull-type sprayer, as reported in the literature, ranges from 36.3 MJ/ha (0.1 gdfe/ac) (5) to 119.8 MJ/ha (0.33 gdfe/ac) (6). None of the literature reviewed specifically stated that the data included the sequestered energy in the machinery, so these data probably include direct fuel costs only.

Energy Required For Agricultural Fuels

The energy content of fuels can be considered in two ways. First, when it is necessary to determine how much of a particular fuel is required to supply a given amount of energy, one must use the heat of combustion or enthalpy of the fuel. Second, when it is desired to determine how much energy is consumed when a specific fuel is used, one must use the value for that fuel's primary energy content. This includes that energy necessary to extract and deliver the fuel to the point of use. Table 7 gives enthalpy and primary energy values for common agricultural fuels. Consider the case where 135,000 BTU/hr is required to maintain a greenhouse at some desired temperature as an example of the use of these constants. This would require burning 1 gallon of fuel oil per hour (assuming perfect combustion and heat transfer). Burning 1 gallon of fuel oil per hour represents an actual energy consumption of 165,100 BTU/hr.

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Table 8. List of Conversions,

If You Have	Multiply By	To Obtain
Acres	43560	Square feet
	0.004047	Square kilometers
	4047	Square meters
	0.0015625	Square miles
	4840	Square yards
Acre-feet	43560	Cubic feet
	1233.5	Cubic meters
	1613.3	Cubic yards
Barrels (petroleum, U.S.) (bbl.)	5.6146	Cubic feet
	35	Gallons (Imperial)
	42	Gallons (U.S.)
	158.98	Liters
British Thermal Unit (BTU)	251.99	Calories, gm
	777.649	Foot-pounds
	3.9275×10^{-4}	Horsepower-hours
	1054.35	Joules
	2.92875×10^{-4}	Kilowatt-hours
	1054.35	Watt-seconds
BTU/hour	4.2	Calories/minute
	777.65	Foot-pounds/hour
	3.927×10^{-4}	Horsepower
	2.92875×10^{-4}	Kilowatts
	0.292875	Watts (or Joule/second)
BTU/pound	7.25×10^{-4}	Calories/gram
BTU/square foot	0.271246	Calories/square centimeter (langleys)
	0.292875	Watt-hour/square foot
BTU/square foot/hour	3.15×10^{-7}	Kilowatts/square meter
	4.51×10^{-3}	Calories/square centimeter/minute
	3.15×10^{-8}	Watts/square centimeter
Bushel (bu.)	35.2	Liters
	.0352	Cu. meters
Calories (cal.)	0.003968	BTU

Table 8. List of Conversions,

If You Have	Multiply By	To Obtain
	3.08596	Foot-pounds
	1.55857×10^{-6}	Horsepower-hours
	4.184	Joules (or watt-seconds)
	1.1622×10^{-6}	Kilowatt-hours
Calories, food unit (calories)	1000	Calories, gram
Calories/minute	0.003968	BTU/minute
	0.06973	Watts
Calories/square centimeter	3.68669	BTU/square foot
	1.0797	Watt-hour/square foot
Calories/square centimeter/minute	796320	BTU/square foot/hour
	251.04	Watts/square em.
Candle power (spherical)	12.566	Lumens
Centimeters (cm.)	0.032808	Feet
	0.3937	Inches
	0.01	Meters
	10,000	Microns
Centimeters/second	0.032808	Feet/second
	0.022369	Miles/hr.
Cords	8	Cord-feet
	128 (or 4x4x8)	Cubic feet
Cubic centimeters	3.5314667×10^{-5}	Cubic feet
	0.06102	Cubic inches
	1×10^{-6}	Cubic meters
	0.001	Liters
	0.0338	Ounces (U.S., fluid)
Cubic feet (ft^3)	0.02831685	Cubic meters
	7.4805	Gallons (U.S., liquid)
	28.31685	Liters
	29.922	Quarts (U.S., liquid)
Cubic feet/minute	471.947	Cubic centimeters/second
Cubic inches ($in.^3$)	16.387	Cubic centimeters
	5.787×10^{-4}	Cubic feet
	0.004329	Gallons (U.S., liquid)
	0.5541	Ounces (U.S., fluid)

Table 8. List of Conversions,

If You Have	Multiply By	To Obtain
Cubic meters	1×10^{6}	Cubic centimeters
	35.314667	Cubic feet
	264.172	Gallons (U.S., liquid)
	1000	Liters
Cubic yard	0.76455	Cubic meters
	201.97	Gallons (U.S., liquid)
	27	Cubic feet
Feet (ft.)	30.48	Centimeters
	12	Inches
	1.8939×10^{-4}	Miles (statute)
Feet/minute	0.508	Centimeters/seconds
	0.018288	Kilometers/hour
	0.0113636	Miles/hour
Foot-candles	1	Psi
Foot of head (irrigation)	0.434	Psi
Foot-pounds	0.001285	BTU
	0.324048	Calories
	5.0505×10^{-7}	Horsepower-hours
	3.76616×10^{-7}	Kilowatt-hours
Gallons (U.S., dry)	1.163647	Gallons (U.S., liquid)
Gallons (U.S., liquid)	3785.4	Cubic centimeters
	0.13368	Cubic feet
	231	Cubic inches
	0.0037854	Cubic meters
	3.7854	Liters
	8	Pints (U.S., liquid)
	4	Quarts (U.S., liquid)
Gallons Diesel Fuel Equivalent (GDFE)	147×10^{6}	Joules
Gallons/minute	2.228×10^{-3}	Cubic feet/second
	0.06308	Liters/second
Grams	0.035274	Ounces
	0.002205	Pounds
Grams-centimeter	9.3011×10^{-8}	BTU/minute

Table 8. List of Conversions,

If You Have	Multiply By	To Obtain
Grams/meter^2	4.46 x 10^{-3}	Short ton/acre
	8.93	pounds/acre
Hectare	2.47	acre
Horsepower	42.4356	BTU
	550	Foot-pounds/second
	745.7	Watts
Horsepower-hours	2546.14	BTU
	641616	Calories
	1.98 x 10^6	Foot-pounds
	0.7457	Kilowatt-hours
Inches	2.54	Centimeters
	.083333	Feet
Joules	9.485 x 10^{-4}	BTU
	0.73756	Foot-pounds
	2.778 x 10^{-4}	Watt-hours
	1	Watt-seconds
Kilo calories (Kcal)	4.187 x 10^3	Joules
Kilo calories/gram	1799.5	BTU/pound
Kilograms	2.2046	Pounds-mass*
Kilometers	1000	Meters
	0.62137	Miles (statute)
Kilometer/hour	54.68	Feet/minute
Kilograms/hectare	.893	pounds/acre
	4.465 x 10^{-4}	Short ton/acre
Kilowatts	3414.43	BTU/hour
	737.56	Foot-pounds/second
	1.34102	Horsepower
Kilowatt-hours	3414.43	BTU
	1.34102	Horsepower-hours
Knots	51.44	Centimeter/second
	1	Mile (nautical)/hour
Langleys	1	Calories/square centimeter
	1.15078	Miles (statute)/hour

Table 8. List of Conversions,

If You Have	Multiply By	To Obtain
	1	Calories/square centimeter
Liters	1000	Cubic centimeters
	0.0353	Cubic feet
	0.2642	Gallons (U.S., liquid)
	1.0567	Quarts (U.S., liquid)
Lbs./acre	.0005	Short ton/acre
Liters/minute	0.0353	Cubic feet/minute
	0.2642	Gallons (U.S., liquid)/minute
Lumens	0.079577	Candle power (spherical)
Meters	3.2808	Feet
	39.37	Inches
	1.0936	Yards
Meters/second	2.24	Mile/hour
Metric ton	2205	Pounds-mass*
Metric ton/hectare	.446	Short ton/per acre
Miles (statute)	5280	Feet
	1.6093	Kilometers
	1760	Yards
Miles/hour	44.704	Centimeter/second
	88	Feet/minute
	1.6093	Kilometer/hour
	.447	Meters/second
Milliliter	1	Cubic centimeter
	0.1	Centimeter
Newton	.225	Pounds-force*
Ounces	0.0625	Pounds
Ounces (U.S., liquid)	29.57	Cubic centimeters
	1.8047	Cubic inches
	0.0625 (or 1/16)	Pint (U.S., liquid)
Pascal	1.45×10^{-4}	Psi
Pints (U.S., liquid)	473.18	Cubic centimeters
	28.857	Cubic inches
	0.5	Quarts (U.S., liquid)

Table 8. List of Conversions,

If You Have	Multiply By	To Obtain
Pounds	0.45359	Kilograms
	16	Ounces
Pounds of water	0.01602	Cubic feet of water
	0.1198	Gallons (U.S., liquid)
Pounds square/inch	0.06805	Atmospheres
	5.1715	Centimeters of mercury (O°C)
	27.6807	Inches of water (39.2°C)
Quad	10^{15}	BTU
Quarts (U.S., liquid)	0.25	Gallons (U.S., liquid)
	0.9463	Liters
	32	Ounces (U.S., liquid)
	2	Pints (U.S., liquid)
Square centimeters	0.0010764	Square feet
	0.1550	Square inches
Square feet	2.2957×10^{-5}	Acres
	0.09290	Square meters
Square inches	6.4516	Square centimeters
	0.006944	Square feet
Square kilometers	247.1	Acres
	1.0764×10^{7}	Square feet
	0.3861	Square miles
Square meters	10.7639	Square feet
	1.196	Square yards
Square miles	640	Acres
	2.7878×10^{7}	Square feet
	2.590	Square kilometers
Square yards	9 (or 3x3)	Square feet
	0.83613	Square meters
Therm	10^{5}	BTU
Tons, air conditioning	200	BTU/second
Tons, long	1016	Kilograms
	2240	Pounds
Tons, metric	1000	Kilograms

Table 8. List of Conversions,

If You Have	Multiply By	To Obtain
	2204.6	Pounds
Tons, short	907.2	Kilograms
	2000	Pounds
Watts	3.4144	BTU/hour
	0.05691	BTU/minute
	14.34	Calories/minute
	0.001341	Horsepower
	1	Joule/second
Watts/square centimeter	3172	BTU/square foot/hour
Watt-hours	3.4144	BTU
	860.4	Calories
	0.001341	Horsepower-hours
Yards	3	Feet
	0.9144	Meters

To convert between °C and °K: K = C + 273.15

To convert between °C and °F: 9(C + 40) = 5(F + 40)

*** 1 pound-mass exerts 1 pound-force at sea-level. The force exerted by a 1 pound-mass changes insignificantly over the surface of the earth; consequently, pound-mass and pound-force are often treated equivalently for terrestrial calculations.**