Supply Chain Emissions: Conventional "Industrial" Milk

In which CMS estimates emissions of carbon dioxide and methane from the farm to the consumer, accounting for energy inputs on the farm, in transportation to the processing plant, refrigeration, and distribution to grocery stores. This is a generalized and simple back-of-the-envelope study, and does not compare organic to conventional milk supply chains. Some supply chain segments are noted, but *not* estimated.

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Carbon Dioxide, Methane, & Nitrous sources

	Energy input	Conversion	Conversion		
	per cwt (100 lb milk	per lb milk	per gallon milk	kg CO2/gallon	g CO2/gallon
Land	not estimated				
(conversion from forest to ag)					
Farm building construction	not estimated				
Farmer's household	not estimated				

Dairy cows' feed	An approximation	Feed	Table 1	
g CO2 per kg soybean crop	182.87	g CO2 per kg soy		
Feed per dairy cow per day	28.50	kg		
ag emissions per cow per day	5,212	g CO2 per cow per day		
ag emissions per cow per year	1,902,305	g CO2 per cow per yr		
ag emissions per gallon of milk	2,660	gallons per cow per year		lb CO2 per gallon
Total approx feed emissions	715.2	g CO2 per gallon of milk		1.58

Table 2	Annual milk prod'n per Holstein	
Measured Holstein herd of 118 cows		
	lb milk/cow/yr	gallons milk/cow/yr
Average prod'n	22,930	2,660

Methane: Lactating cows	original data	Table 3		Methane emissions per gallon of milk produced		
	liters CH4/cow/day	liters CH4/cow/yr	g CH4/cow/yr	g CH4/gallon milk	g CO2-e/gallon milk	lb CO2 per gallon
Eructation	552	201,480	131,740	49.5	1,040	2.29
Cow manure	35	12,775	8,353	3.1	66	0.15
Eructation plus manure	587	214,255	140,093	52.7	1,106	2.438

Seems very high relative to energy emissions. But it checks out.

Table 4	Comparing above results to other sources	
Crutzen et al:	55.00	kg CH4 per animal per year
EPA, enteric fermer	98.70	kg CH4 per animal per year
EPA, manure	55.30	kg CH4 per animal per year
Kinsman, eructatioı	131.74	kg CH4 per animal per year
Kinsman, manure	8.35	kg CH4 per animal per year

GWP coefficients	
CO2	1
CH4	21
N2O	310

Table 5	Nitrous oxide emission from manure management			
	g per head/yr	g per gallon milk	CO2-e per gallon m	lb CO2 per gallon
	970.00	0.36	113.05	0.249

Dairy Farm	original data		Table 5	Emissions on the farm		
	Energy input	Conversion	Conversion			
	per cwt (100 lb milk	fuel per lb milk	fuel per gallon milk	kg CO2/gallon	g CO2/gallon	lb CO2 per gallon
Propane	0.11	0.001	0.0001	0.001	0.73	0.0016
	gallons/cwt	gallons/lb	gallons/gallon milk			
Electricity	4.00	0.040	0.0046	0.003	3.45	0.0076
	kWh/cwt	kWh/lb milk	kWh/gallon milk			
Diesel	0.13	0.001	0.0002	0.002	1.53	0.0034
	gallons/cwt	gallons/lb	gallons/gallon milk			
Gasoline	0.02	0.000	0.0000	0.000	0.21	0.0005
	gallons/cwt	gallons/lb	gallons/gallon milk			
Total dairy farm				0.01	5.92	0.0131

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Transportation to processing plant	original data		Table 6			
Dairy to Processing Plant	Energy input	Conversion	Conversion	Transportation emissions per gallon of milk		
Ryan & Tiffany	per cwt (100 lb milk	fuel per lb milk	fuel per gallon milk	kg CO2/gallon	g CO2/gallon	lb CO2 per gallon
Diesel fuel	0.10	0.001	0.00012	0.001	1.18	0.003
	gallons/cwt	gallons/lb	gallons/gallon milk			
Total transportation				0.001	1.18	0.003

Processing	original data		Table 7			
	Energy input	Conversion	Conversion			
	per cwt (100 lb milk	fuel per lb milk	fuel per gallon milk	Milk processing emissions per gallon of milk		
	Cubic ft/cwt	cf/lb milk	cf/gallon milk	kg CO2/gallon	g CO2/gallon	lb CO2 per gallon
Natural Gas	7.90	0.079	0.0092	0.0005	0.50	0.0011
Electricity	0.37	0.0037	0.00043	0.0003	0.32	0.0007
	kWh/cwt milk	kWh/lb milk	kWh/gallon milk			
Total Plant				0.0008	0.82	0.0018

Refrigerated Trucking	original data		Table 8			
	Energy input	Conversion	Conversion	Trucking emissions		
	ton-miles per gallon	al fuel /400 ton-mile	fuel per gallon milk	kg CO2/gallon milk	g CO2/gallon	lb CO2 per gallon
Assume 200 miles each way (400 rt)	75.60	5.291	0.0014	0.01	13.74	0.030

Energy use, emissions at groceries	not estimated	Energy use, emissions at warehouses	not estimated

Driving to pick up milk			Table 9			
	Fuel economy	Fuel per trip	Fuel / gallon milk	Emissions of CO2 per gallon of milk		
	Miles per gallon	gallons gas per trip	per 1 gallon milk	kg CO2/gallon	g CO2/gallon	lb CO2 per gallon
Assume a 1-mile drive (2 miles rt)	18.62	0.11	0.11	0.95	955	2.10
miles round trip	2.00					

Conversion factors	Table 11	
Methane factors, 1 liter CH4	0.654	g CH4
1 gram CH4	1.529	liter CH4
Electricity	1.640	lb CO2 per kWh
		(US average)
Gasoline	19.59	lb CO2 per gallon
Diesel	22.38	lb CO2 per gallon
Propane	12.67	lb CO2 per gallon
Pipeline natural gas CO2	12.06	lb CO2 per ccf
Pipeline natural gas (CH4 fugitive)	0.07	lb CH4 per ccf
Density of milk = ~1.033	1.033	cf water at 20C
1 gallon of water =	8.35	lb
1 gallon of milk	8.62	lb
1 gallon of milk	3.91	kg
1 kg	2.2046	lb

One tonne CH_4 occupies 1,529.38 m^3 of volume.

1 m^3 CH_4 = 0.00065386 tonne = 0.65386 kg, 1 liter = 0.65386 g CH_4; 1 g CH_4 = 1.52938 liter.

1 ft^3 CH_4 = 0.65386 kg m^{-3}/ 35.31 m^3 ft^{-3} = 0.018518 kg = 0.040824 lbs CH_4.

1 lb	453.59	g
1 gram	0.002204634	lb

Table 10	Summary of GHG emissions from milk supply chain		
Source	g CO2-e/gallon	lb CO2-e per gallon	Percent
Land	not estimated		
Farm building construction	not estimated		
Farmer’s household	not estimated		
Feed	715	1.577	24.57%
Methane (eructation)	1,040	2.293	35.74%
Methane (manure)	66	0.145	2.27%
Nitrous (manure)	113	0.249	3.88%
On the farm	6	0.013	0.20%
Transportation to processing	1	0.003	0.04%
Processing	1	0.002	0.03%
Trucking	14	0.030	0.47%
At the Grocery Story	not estimated		
Driving 2 miles RT to pick up milk	955	2.105	32.80%
Total milk supply chain	2,911	6.417	100.0%

One gallon of milk weighs (lb):	8.62
CO2-e per gallon of milk: percent of its weight:	74.4%
Carbon-e per gallon of milk: percent of its weight:	20.3%

All except driving	4.312	50.0%

Cell: B25
Comment: Rick Heede:
NREL 1998, p.

Cell: C26
Comment: Rick Heede:
NREL (1998) Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, 314 pp. www.nrel.gov/docs/legosti/fy98/24089.pdf

NREL (1998)
Table 62: LCI Results for Soybean Agriculture (for 1 kg of soybeans)
Carbon Dioxide (grams CO_2, fossil) emissions
Energy Input:

Diesel Tractor	84.6843 g CO_2 per kg soybeans
Gasoline Tractor	20.7032
Gasoline Truck	21.328
Natural Gas Use	0.00497
Propane Use	2.61254
Electricity Use	4.40514
Nitrogen Fertilizer Production	17.9255
Phosphate Fertilizer Production	11.9934
Potash Fertilizer Production	7.5756
Agrochemicals Production	11.6376

Total Soybean Agriculture: 182.87 g CO_2 per kg soybeans (= 0.183 kg CO_2 per kg)

Cell: H28
Comment: Rick Heede:
Kinsman et al, 1995: 118 lactating Holstein cows in the herd, average of 602 kg body mass, average feed of 17.5 kg per cow per day (feed composition shown in Table 1), and average milk production of 28.5 kg per cow per day. Milk production thus averaged 10,403 kg per year (assuming the average over the 112-day measurement period can be annualized). This quanity of milk, which equals 22,930 lb, is 46 percent higher than the Minnesota data (Ryan & Tiffany, below) of 15,708 lb of milk per average dairy cow per year.

Cell: B34
Comment: Rick Heede:
Data on methane emissions from dairy eructation and flatulence from Kinsman, R., F. D. Sauer, H. A. Jackson, & M. S. Wolynetz (1995) "Methane and Carbon Dioxide Emissions from Dairy Cows in Full Lactation Monitored over a Six-Month Period," Journal of Dairy Science, vol. 78:2760-2766. This paper describes the estimation methodology (which did not alter the customary habits of the cows so as to not induce stress), were made in the feed and milking barn, and separately estimated methane from eructation and manure. They also estimated CO_2 from respiration (6,136 liters CO_2 per cow per day), which CMS ignored, since this is converted from carbon in the feed. Nitrous emissions from manure was not measured.

Cell: C44
Comment: Rick Heede:
Kinsman et al 1998, p. 2760: "Crutzen et al calculated that cattle in developed countries emitted 55 kg of CH_4/yr per animal in contrast to cattle in developing countries, where CH_4 emission is 35 kg/yr per animal.

Crutzen, P. J., I. Asselmann, and W. Seiler. 1986. Methane production by domesticated animals, wild ruminants, other herbivorous fauna and humans. Tel- lus Ser. B Chem. Phys. Meteorol. 38:271.

Cell: I44
Comment: Rick Heede:
IPCC Second Assessment Report. IPCC's Third Assessment lists GWP for methane as 23xCO_2, and for nitrous as 296xCO_2, but these latter values have not yet been certified for national inventories, and CMS complies with the convention of using certified values.

Cell: C45
Comment: Rick Heede:
Clean Air - Cool Planet Beta version campus emissions calculator. www.cleanair-coolplanet.org/toolkit/content/view/43/124/

CACP cites EPA data from the annual US inventory, protocol appendix. Also cites EPA estimates of emissions from "manure management" totals 55.3 kg CH_4 per head per year. Thus, EPA's total (153 kg CH_4 per year) exceeds Kinsman et al's total (140 kg CH_4 per year).

Cell: D53
Comment: Rick Heede:
EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001 (April 2003) EPA 430-R-03-004; Annex L & M.

CMS converts 0.97 kg per head per year (from "manure management") to g per gallon of milk (at 2,660 gallons per head per year), then multiplies by the N_2O GWP factor of 310 x CO_2, per IPCC SAR.

Cell: B56
Comment: Rick Heede:
Ryan and Tiffany (1998), pp. 14:
Table 9:

Farm Level-- per cwt	Diesel	Gasoline	LP	Electric

Energy Consumption (gallons or kwh)	0.13 gallons	0.02 gallons	0.11 gallons	4.00 kWh

Cell: B80
Comment: Rick Heede:
Ryan & Tiffany (1998), p. 14: Total diesel fuel requirements to transport raw milk to a bottling
plant are estimated at 9,410,000 gallons per year statewide. Since Minnesota produced 9.41 billion lb of milk in 1995, the authors assumed 0.001 gallon per lb of milk transported, or 0.10 gallon per cwt.

Cell: B85
Comment: Rick Heede:
Ryan and Tiffany (1998), pp. 14-15: "Processing Energy: Eighty-six percent of milk from Minnesota farms is processed into products such as cheese, butter, and yogurt, while 14 percent goes into the fluid milk channel. We assume 51 percent of Minnesota milk is made into cheese and 35 percent is dried. Both cheese-making and drying activities concentrate the constituents of milk and change it to more stable forms. One hundred pounds of raw milk can produce 10 pounds of cheese and 5.6 pounds of whey powder. Processing plants use energy for pumping, pasteurizing, drying, heating to stimulate fermentation, heating to change product form, packaging and for sanitation. These activities and the time requirements to make cheese or dry whey makes the more-intensive application of energy at cheese and whey-drying facilities, intuitively obvious. Data from three large Midwestern plants indicates that 0.03951 Mcf of natural gas and 1.4957 kWh of electricity are needed for each hundred pounds of raw milk used to make cheese. Milk drying activities required four times as much natural gas, and nearly twice the electricity, as cheese-making. Milk drying requires 0.161205 Mcf of natural gas, and 2.57268 kWh, per hundred pounds of raw milk. Fluid milk plants use energy for pumping, pasteurizing homogenizing, packaging, and for sanitation. Published data shows that compared to cheese production, energy expended in fluid bottling requires 20 percent of the natural gas and 25 percent of the electricity as that applied per hundredweight of raw milk used for cheese-making. Thus, 0.007902 Mcf of natural gas and 0.37393 kWh of electricity are required to process each cwt. of raw milk for fluid consumption."

Note: CMS uses the last data cited to estimate processing energy and emissions per gallon of fluid milk.

Cell: B99
Comment: Rick Heede:
CMS does not have a realistic estimate of typical distance between the nation's milk processing plants and the grocery store. We assume 200 miles for this calculation (400 miles roundtrip).

Cell: C99
Comment: Rick Heede:
Ryan & Tiffany (1998). Further research may improve this datum, especially for refrigerated trucks from processing plant to grocery distribution warehouse (which we have ignored) to typical trucking store-to-store routes. And back to warehouse, presumably deadhead run.

Cell: B116
Comment: Rick Heede:
2003 estimate using 2001 data from EIA's AER. Update to 2006.

Cell: B124
Comment: Rick Heede:
Fugitive methane factor developed for Aspen emissions inventory (Natural gas) -- 0.00567 kg CH_4 per kg CO_2 from gas combustion.

Cell: B126
Comment: Rick Heede:
The density of milk (g/L) changes with temperature. For example, the denisty of milk = 1.003073 - 0.000179t - 0.000368F + 0.00374N, where t = temperature in degrees C; F = percent fat; and N = percent nonfat solids

Specific gravity of whole cow milk (ratio of density of milk to density of water) varies among breeds and among cows within breed. For example, mean specific gravity of Holstein milk at 20 C/20 C is 1.0330 (range 1.0268 to 1.0385) and for Ayrshire milk is 1.0317 (range 1.0231 to 1.0357), while Jersey milk also has a mean of 1.0330 (range 1.0240 to 1.0369). [see Sherbon JW, Physical Properties of Milk, Chapter 8 in Wong et al, 1988]