The LCA Inventory of Light-Duty Vehicles
Version II

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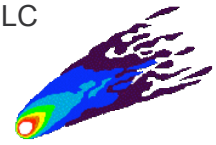


Objectives of work

- Verify prior work using independently derived method vis-à-vis methods used previously
- Create a single tool that contains all data, calculations, and references in a single location that can be applied to any light vehicle, regardless of type

Supported vehicle and fuel types

- We wanted a single tool that could be used to analyze a wide variety of vehicles and fuels

	Gasoline	B80	Diesel fuel	E85	Natural gas	Electric
Car	✓	✓	✓	✓	✓	✓
Pickup	✓	✓	✓	✓	✓	✓
SUV	✓	✓	✓	✓	✓	✓
Hybrid car	✓	✓	✓	✓	-	-
Hybrid pickup	✓	✓	✓	✓	-	-
Hybrid SUV	✓	✓	✓	✓	-	-
PHEV-20 car	✓	✓	✓	✓	✓	-
PHEV-30 car	✓	✓	✓	✓	✓	-
PHEV-60 car	✓	✓	✓	✓	✓	-

New analysis tool

- A new analysis tool was developed in Excel™
- It consists of several worksheets
  - Assumptions
  - Vehicle database
  - Materials database
  - Vehicle composition
  - Electricity mixes
  - Emissions data
  - Calculations

Assumptions

- Some examples:
  - assembly energy (not including embedded material energy) is 4800 BTU per pound of final vehicle
  - recycling energy, not including the energy to dismantle the vehicle and dispose of materials, is 1630 BTU per pound
  - The vehicle lifetime miles for cars, pickups, and SUVs is 126,000
  - Vehicle lifetime repair coefficients (the replacement fraction of the original vehicle mass) is taken as 10 percent for cars, pickups and SUVs.
  - The city/highway driving fraction for each vehicle type is 55 / 45 percent.

Vehicle database

- Lists weight and mileage for each vehicle

Column heading	Example value	Range of values
Category	Car	Can be car, pickup, SUV
Fuel Type	Gasoline	Can be gasoline, diesel fuel, E85, B80, natural gas
Hybrid	no	can be yes or no
Plug-in	no	can be yes or no
Plug-in capacity	0	rated PHEV range in miles
Weight in lbs	*3,285*	*Reported curb weight, not used in calculations*
City mileage (EPA)	*24*	*EPA city mileage*
Highway mileage (EPA)	*34*	*EPA highway mileage*
City mileage (CU)	*16*	*Consumer Reports city mileage*
Highway mileage (CU)	*34*	*Consumer Reports highway mileage*
Calculation weight	3,285	Corrected vehicle weight used in calculations
Actual city mileage	17	City mileage used in calculations
Actual highway mileage	37	Highway mileage used in calculations

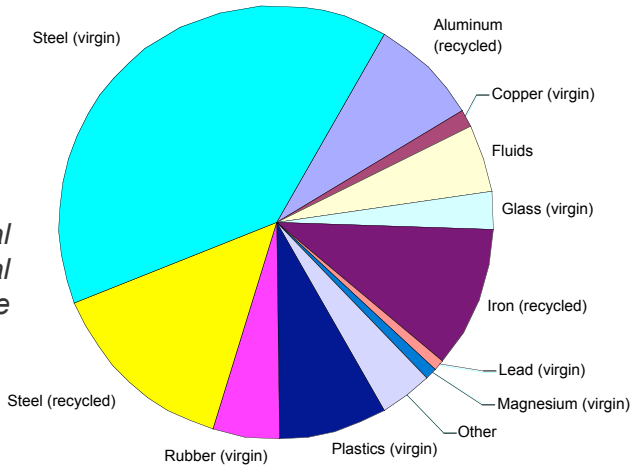
Materials database worksheet

- Lists the energy requirements for the extraction and refinement of all raw materials

Material	MJ / kg
Aluminum (recycled)	52
Aluminum (virgin)	231
Copper (recycled)	50
Copper (virgin)	125
Glass (recycled)	7
Glass (virgin)	13
Iron (recycled)	37
Lead (recycled)	13
Lead (virgin)	25
Nickel (recycled)	50
Nickel (virgin)	100
Plastics (recycled)	45
Plastics (virgin)	90
Rubber (recycled)	12
Rubber (synthetic)	26
Rubber (virgin)	40
Steel (recycled)	52
Steel (virgin)	65

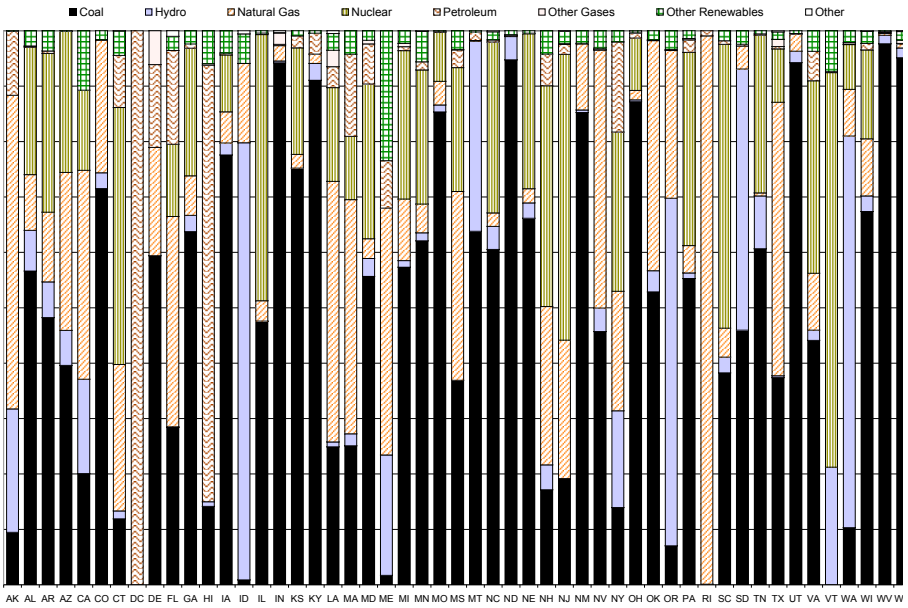
Vehicle composition

Example material composition of typical passenger vehicle



Electricity mixes

EIA State-by-state data used to determine effects of manufacturing, battery charging, etc.



Electricity mixes

- Data for California show a large difference between the EIA and CEC numbers
- The discrepancy is explained by the CEC assumption that the Intermountain and Mohave coal plants are considered in-state, since they are in California control areas.
  - In other words, the California Energy Commission does not treat state boundaries as limits when compiling their numbers.

Fuel type	EIA energy mix	CEC energy mix
Coal	1.1%	20.1%
Hydro	19.8%	17.0%
Natural Gas	46.7%	37.7%
Nuclear	18.1%	14.5%
Other	0.1%	-
Other Gases	1.0%	-
Other Renewables	11.9%	10.7%
Petroleum	1.3%	-

Emissions data

Pounds of emissions per gallon of fuel consumed by vehicle

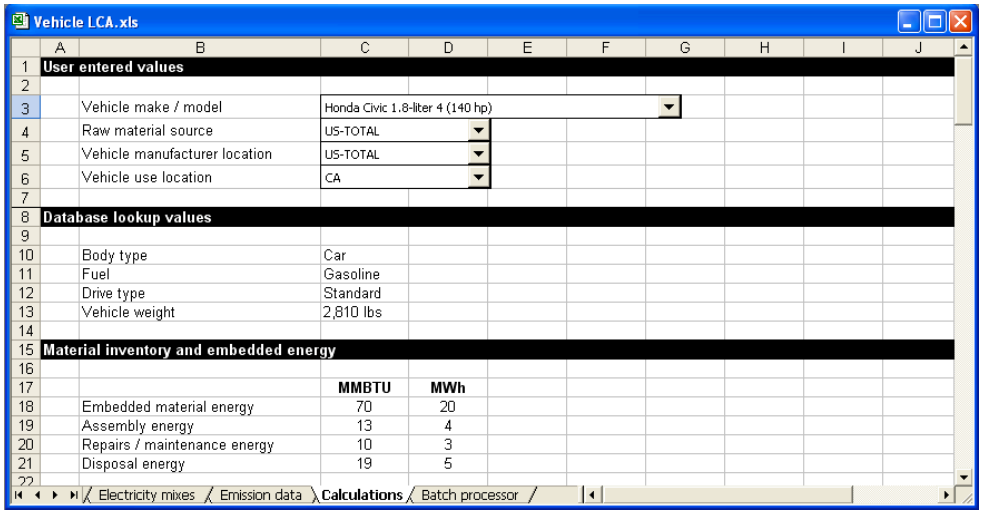
	CO2	SOx	NOx	CH4
gasoline	19.6	0.0019	0.0181	0.0037
diesel fuel	22.4	0.0035	0.0416	0.0008
E85	2.9	0.0003	0.0107	0.0038
B20	22.6	0.0035	0.0416	0.0008
natural gas	22.0	0.0001	0.0200	0.0470

Pounds of emissions per gallon of fuel for upstream activities

	CO2	SOx	NOx	CH4
gasoline	4.8	0.0048	0.0048	0.0321
diesel fuel	4.1	0.0095	0.0095	0.0287
E85	7.7	0.0001	0.0030	0.0157
B20	4.6	0.0010	0.0116	0.0229
natural gas	5.0	0.0000	0.0056	0.0800

Calculations worksheet

User selects vehicle type and locations…



Calculations worksheet

Spreadsheet calculates site emissions from electricity use…

Vehicle LCA.xls

	A	B	C	D	E	F	G	H	I	J
23	**Material source location emissions - lbs per MWh**									
24										
25			***Energy mix***		**CO2**	**SO2**	**NOx**	**CH4**	**Hg**	
26		Natural gas	19%		216	0.05	0.19	0.67	0.00000	
27		Coal	50%		1,081	5.08	2.13	0.02	0.00003	
28		Oil	3%		53	0.28	0.09	0.19	0.00000	
29		**Totals**			**1,350**	**5.41**	**2.42**	**0.88**	**0.00003**	
30										
31	**Manufacture location emissions - lbs per MWh**									
32										
33			***Energy mix***		**CO2**	**SO2**	**NOx**	**CH4**	**Hg**	
34		Natural gas	19%		216	0.05	0.19	0.67	0.00000	
35		Coal	50%		1,081	5.08	2.13	0.02	0.00003	
36		Oil	3%		53	0.28	0.09	0.19	0.00000	
37		**Totals**			**1,350**	**5.41**	**2.42**	**0.88**	**0.00003**	
38										
39	**Vehicle use location emissions - lbs per MWh**									
40										
41			***Energy mix***		**CO2**	**SO2**	**NOx**	**CH4**	**Hg**	
42		Natural gas	38%		450	0.00	0.15	0.67	0.00000	
43		Coal	20%		437	2.05	0.86	0.02	0.00001	
44		Oil	0%		0	0.00	0.00	0.19	0.00000	
45		**Totals**			**888**	**2.06**	**1.02**	**0.88**	**0.00001**	
46										

Electricity mixes | Emission data | **Calculations** | Batch processor

Calculations worksheet

Total lifetime miles, fuel use, and emissions are then calculated…

Vehicle LCA.xls

	A	B	C	D	E	F	G	H	I	J
46										
47	**Lifetime mileage and emissions**									
48										
49		***Fuel use***								
50					gasoline	diesel	E85	B80	electricity	LNG
51			Total miles	Mileage	*gallons*	*gallons*	*gallons*	*gallons*	*MWh*	*gallons*
52		Lifetime city driving	69,300	22	3186	0	0	0	0	0
53		Lifetime highway driving	56,700	44	1289	0	0	0	0	0
54		**Total / average**	**126,000**	**32**	**4475**	**0**	**0**	**0**	**0**	**0**
55										
56		***Total energy***								
57										
58		Total lifetime MMBTU			**515**	**0**	**0**	**0**	**0**	**0**
59										
60		***Emissions per vehicle in pounds***								
61										
62					**CO2**	**SO2**	**NOx**	**CH4**	**Hg**	
63		Fuel production			21,479	21	21	144	0.00000	
64		Fuel transportation			1,834	0.3	3.4	0.1	0	
65		Fuel use			87,546	9	81	17	0.00000	
66										

Electricity mixes | Emission data | **Calculations** | Batch processor

Calculations worksheet

Results are shown in a summary table…

Vehicle LCA.xls

Printable report

Emissions estimates for Honda Civic

Vehicle data

Type	Standard Gasoline Car
Fuel economy	22 city, 44 highway

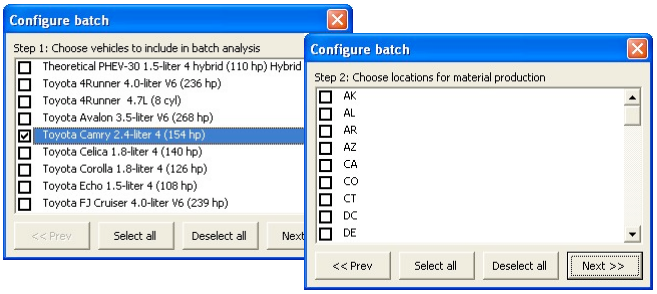
Lifetime emissions and energy use

	Lifetime emissions				Lifetime energy use	
	CO2 equiv	SOx	NOx	Hg		
	lb	*lb*	*lb*	*lb*	*MMBTU*	*% of total*
Material production	11,181	44	20	0.00021	70	10%
Vehicle assembly	5,338	21	10	0.00003	13	2%
Fuel production / transport	26,331	22	25	0.00000	84	12%
Vehicle operation	87,894	9	81	0.00000	515	72%
Vehicle maintenance	4,147	17	7	0.00008	10	1%
Vehicle disposal	4,816	11	6	0.00006	19	3%
Total	**140,000**	**120**	**150**	**0.00036**	**711**	**100%**

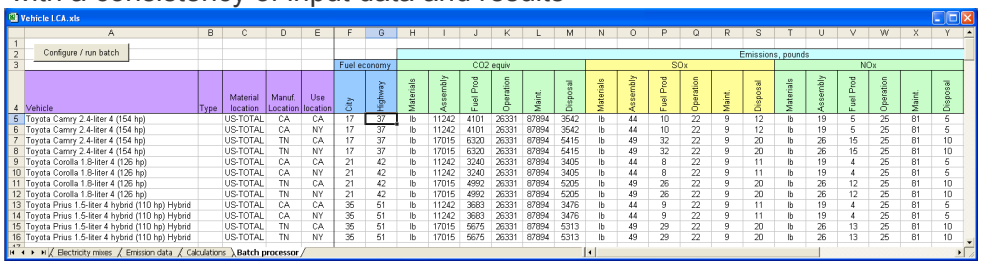
Electricity mixes | Emission data | Calculations | Batch processor

Batch processor

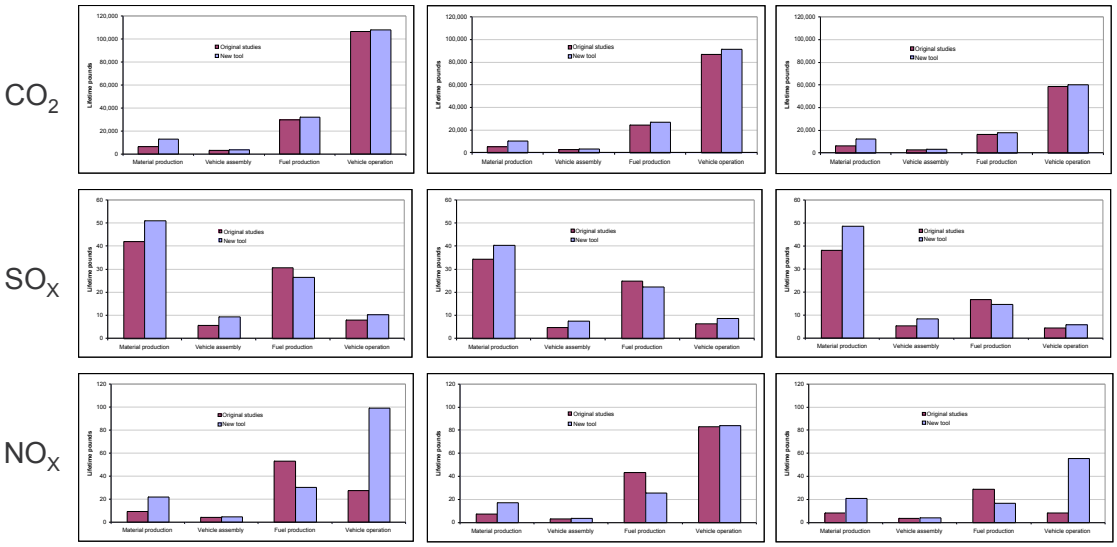
- A batch processing sheet allows the user to specify a variety of analyses to perform in unattended mode



- Large numbers of analyses can be performed with a consistency of input data and results

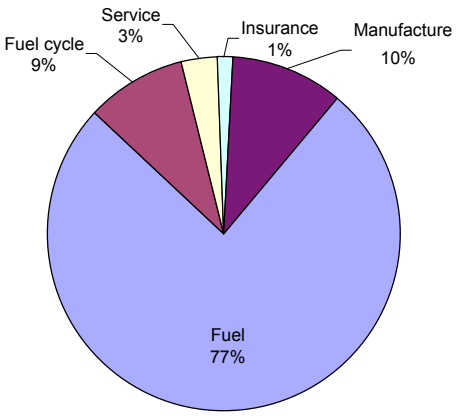


Comparison with original studies



Comparison with other studies

- New LCA tool results give these energy inputs across the range of “average” light vehicles:
  - materials & manufacture: 10%
  - fuel production / transport: 12%
  - vehicle operation: 75%



- These numbers correspond well with those identified in the 1998 study by MacLean and Lave of Carnegie Mellon University

Example results

Corolla

	Lifetime emissions				Lifetime energy use	
	CO2 equiv	SOx	NOx	Hg		
	lb	*lb*	*lb*	*lb*	*MMBTU*	*% of total*
Material production	10,325	41	18	0.00019	64	9%
Vehicle assembly	4,929	20	9	0.00003	12	2%
Fuel production / transport	27,376	22	26	0.00000	88	12%
Vehicle operation	91,384	9	84	0.00000	535	74%
Vehicle maintenance	3,830	15	7	0.00007	10	1%
Vehicle disposal	4,447	10	5	0.00005	17	2%
Total	**140,000**	**120**	**150**	**0.00034**	**726**	**100%**

Prius

	Lifetime emissions				Lifetime energy use	
	CO2 equiv	SOx	NOx	Hg		
	lb	*lb*	*lb*	*lb*	*MMBTU*	*% of total*
Material production	12,470	49	22	0.00023	78	15%
Vehicle assembly	5,604	22	10	0.00003	14	3%
Fuel production / transport	18,061	15	17	0.00000	58	11%
Vehicle operation	60,288	6	56	0.00000	353	66%
Vehicle maintenance	4,581	18	8	0.00009	12	2%
Vehicle disposal	5,293	12	6	0.00006	20	4%
Total	**110,000**	**120**	**120**	**0.00040**	**535**	**100%**

Example results

PHEV-20

	Lifetime emissions				Lifetime energy use	
	CO2 equiv	SOx	NOx	Hg		
	lb	*lb*	*lb*	*lb*	*MMBTU*	*% of total*
Material production	12,344	49	22	0.00023	77	18%
Vehicle assembly	5,699	23	10	0.00003	14	3%
Fuel production / transport	9,647	8	9	0.00000	42	10%
Vehicle operation	53,476	51	54	0.00024	269	62%
Vehicle maintenance	4,554	18	8	0.00009	12	3%
Vehicle disposal	5,274	12	6	0.00006	20	5%
Total	**91,000**	**160**	**110**	**0.00064**	**434**	**100%**

PHEV-30

	Lifetime emissions				Lifetime energy use	
	CO2 equiv	SOx	NOx	Hg		
	lb	*lb*	*lb*	*lb*	*MMBTU*	*% of total*
Material production	12,799	51	23	0.00024	80	21%
Vehicle assembly	5,888	24	11	0.00003	15	4%
Fuel production / transport	4,038	3	4	0.00000	33	9%
Vehicle operation	50,117	84	53	0.00041	217	58%
Vehicle maintenance	4,719	19	8	0.00009	12	3%
Vehicle disposal	5,463	13	6	0.00006	21	6%
Total	**83,000**	**190**	**110**	**0.00082**	**377**	**100%**

Example results

Average Standard midsize car

	Lifetime emissions				Lifetime energy use	
	CO2 equiv	SOx	NOx	Hg		
	lb	*lb*	*lb*	*lb*	*MMBTU*	*% of total*
Material production	13,654	54	24	0.00025	85	9%
Vehicle assembly	6,519	26	12	0.00003	16	2%
Fuel production / transport	37,106	30	35	0.00000	119	12%
Vehicle operation	123,862	12	114	0.00000	725	74%
Vehicle maintenance	5,064	20	9	0.00009	13	1%
Vehicle disposal	5,881	14	7	0.00007	23	2%
Total	**190,000**	**160**	**200**	**0.00044**	**981**	**100%**

Average Midsize luxury car

	Lifetime emissions				Lifetime energy use	
	CO2 equiv	SOx	NOx	Hg		
	lb	*lb*	*lb*	*lb*	*MMBTU*	*% of total*
Material production	15,418	61	27	0.00028	96	9%
Vehicle assembly	7,360	29	13	0.00003	19	2%
Fuel production / transport	42,746	35	40	0.00000	137	12%
Vehicle operation	142,688	14	131	0.00000	835	74%
Vehicle maintenance	5,718	23	10	0.00011	14	1%
Vehicle disposal	6,641	15	8	0.00008	26	2%
Total	**220,000**	**180**	**230**	**0.00049**	**1127**	**100%**

Comments on CNW report

CNW shows the energy needed for the raw materials and assembly of a Honda Civic to be 18 percent of the total energy use of the vehicle, while for the Civic Hybrid the fraction jumps to 25 percent.

	Civic	Civic Hybrid
Suppliers	8.6%	11.6%
Main Plant	9.4%	13.7%
Transport	1.1%	1.2%
Distribution	2.1%	2.4%
Fuel Efficiency	28.9%	13.5%
Replacement	11.5%	16.9%
Disassembly	8.9%	14.5%
Recycle	10.5%	15.2%
Non-Recycle	19.1%	10.9%

Using specifications for the non-hybrid 2006 Honda Civic (2810 pounds and 22 / 44 MPG city / highway), the new LCA tool gives the following results:

	Lifetime emissions				Lifetime energy use	
	CO2 equiv	SOx	NOx	Hg		
	lb	*lb*	*lb*	*lb*	*MMBTU*	*% of total*
Material production	11,181	44	20	0.00021	70	10%
Vehicle assembly	5,338	21	10	0.00003	13	2%
Fuel production / transport	26,331	22	25	0.00000	84	12%
Vehicle operation	87,894	9	81	0.00000	515	72%
Vehicle maintenance	4,147	17	7	0.00008	10	1%
Vehicle disposal	4,816	11	6	0.00006	19	3%
Total	**140,000**	**120**	**150**	**0.00036**	**711**	**100%**

Comments on CNW report

- Assuming the fuel consumption values are similar between the two studies (based on rated mileage)
  - The implication is that the maintenance and disposal energy values in the new LCA tool would have to be ***at least 25 times larger*** to match the CNW values.
  - With such multipliers in place, the energy required to put a car through the waste and recycling streams rivals or exceeds the total lifetime fuel energy use of the vehicle

Comments on CNW report

- CNW cites the energy cost of a Yukon at $2.94 per mile.
  - A lifetime of 200,000 miles gives an ownership energy cost of $600,000
- The “cheapest” vehicle to operate, the Toyota Scion, is assigned an energy cost of $0.48 per mile
  - A 120,000 mile life gives an energy cost of $60,000.

- There are 240 million passenger vehicles in the U.S.
  - ***If we assume an average CNW-based impact of $300,000 per vehicle, the overall cost of the fleet is $72 trillion, or over five times the Gross Domestic Product for 2006.***
  - We must ask ourselves: is the entire U.S. economy is operating solely for the purpose of funding the automotive industry?

Comments on CNW report

- The CNW report has a number of fatal flaws:
  - It has not – and could not – pass a peer review in any respectable forum. Peer review is required for any technical study to be taken seriously.
  - CNW makes damaging claims with no substance or reliable calculations to back up the conclusions.
  - CNW data sources are not public nor fully documented.
  - CNW methodology is not documented.
  - CNW assigns costs that are clearly risible yet are gaining traction due to volatility of the issues.
- In short, the CNW Dust-to-Dust report is succinctly described as a sensationalistic piece of garbage.