Developments in Light Vehicle Life Cycle Analysis with Application to Electric Vehicles

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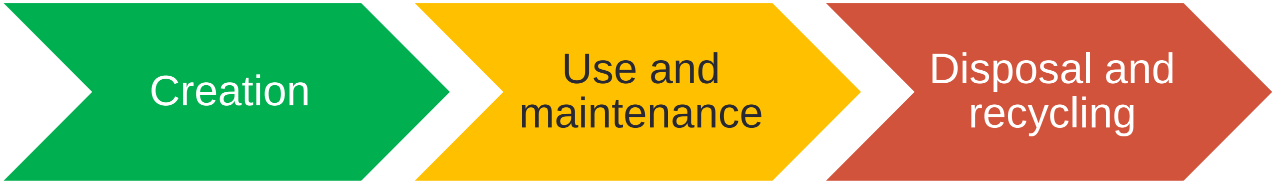
Background

- Life cycle analysis is a useful tool for comparing the environmental burdens of products
  - Analysis must take into account all materials and their production characteristics.
  - Should report both emissions and energy use from the full range of cradle to grave activities.



Life cycle analysis

- The range of activities includes several stages

  - **acquisition or harvesting** of raw materials,
  - **refining of the raw materials** into workable elements,
  - **combination and assembly** of these elements into the product,
  - actual **consumer use of the product**, including maintenance and repairs, and
  - **disposal and recycling** of the product at the end of its useful life

- Many consumers are unable to understand the nuances of each of these stages, and are not in a position to perform analyses on their own.

LCA Tool for vehicles

- We recognize that a true, full life cycling accounting can be quite data intensive.

- A simplified tool has been developed that allows rapid calculation of environmental impacts for one of the largest consumer purchases made on a regular basis:

The automobile

LCA Tool for vehicles

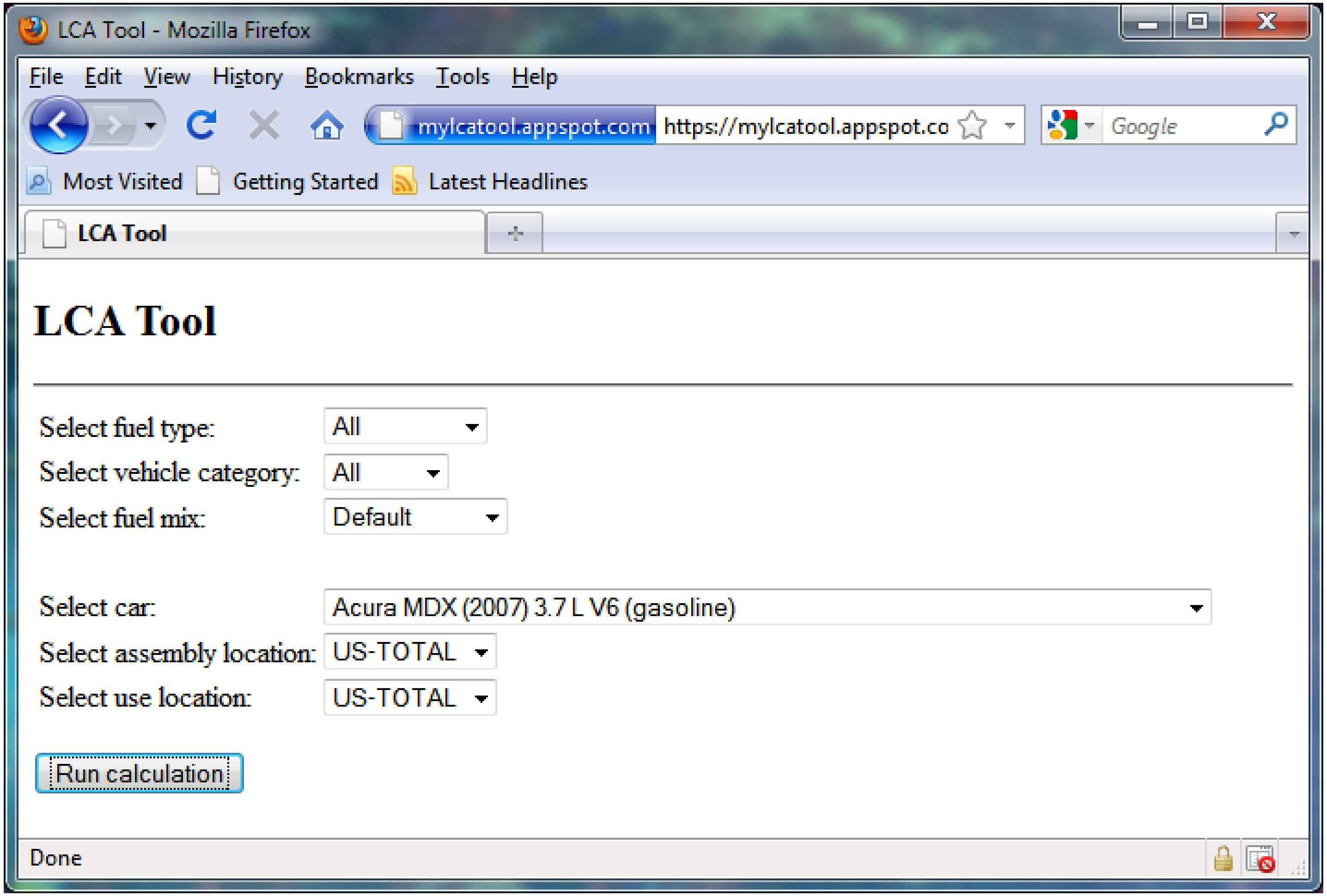
- Goal of current work: provide a tool to allow different vehicles to be evaluated on an equal footing.
  - Emphasis is not on an exact accounting but rather a rapid comparison tool
  - Algorithms developed to give estimates of the emissions and energy consumption of the vehicle over its lifetime

Implementation

- Tool based on a combination of Java code and GoogleApps databases
  - GoogleApps allows for easy update of databases and assumptions by those not fluent in web applications.
  - Databases are broken out by
    - Assumptions and constants,
    - Emission values,
    - Electricity mixes by state, and
    - Characteristics of over 400 automobiles
      - gasoline, diesel fuel, biodiesel, ethanol, natural gas, electric, and hybrid engines (stand-alone and plug-ins)

Example of LCA Tool

- Intro screen



Example of LCA Tool

- Results are shown in separate web page

LCA Tool Results

Vehicle:	Acura MDX (2007) 3.7 L V6	**Use location:**	US-TOTAL
Type:	gasoline SUV	**Assembly location:**	US-TOTAL
Mileage:	11 city, 23 highway	**Fuel mix:**	Default

	Lifetime emissions (lbs)				**Lifetime energy**	
	CO2eq	**SOx**	**NOx**	**Hg**	**MMBTU**	**% total**
Material production	18248	72	32	0.00034	114	6
Vehicle assembly	8831	35	16	0.00016	22	1
Fuel production / transport	73199	60	69	0.00024	234	13
Vehicle operation - fuel	244341	24	225	0.00075	1431	77
Vehicle maintenance	9624	39	17	0.00018	24	1
Vehicle disposal	11982	48	21	0.00022	30	2
Totals	370000	280	380	0.00189	1900	100

Example of LCA Tool

- Results are shown in separate web page

Example for electric vehicle showing electricity use values

LCA Tool Results

Vehicle:	Toyota Camry all-electric hypothetical (2007) hypothetical	**Use location:**	US-TOTAL
Type:	electricity Car	**Assembly location:**	US-TOTAL
Mileage:	19 city, 5 highway	**Fuel mix:**	Default

	Lifetime emissions (lbs)				**Lifetime energy**	
	CO2eq	**SOx**	**NOx**	**Hg**	**MMBTU**	**% total**
Material production	17265	68	31	0.00032	108	25
Vehicle assembly	7111	28	13	0.00013	18	4
Fuel production / transport	10264	41	18	0.00019	0	0
Vehicle operation - electricity	102636	406	182	0.00190	256	60
Vehicle maintenance	7566	30	14	0.00014	19	4
Vehicle disposal	10919	44	20	0.00020	28	6
Totals	160000	620	280	0.00288	430	100

Example of LCA Tool

- Results are shown in separate web page

Example for PHEV showing electricity and fuel use values

LCA Tool Results

Vehicle:	Theoretical PHEV-20 1.5 L 4 hybrid	**Use location:**	US-TOTAL
Type:	PHEV-20 gasoline Car	**Assembly location:**	US-TOTAL
Mileage:	35 city, 51 highway	**Fuel mix:**	Default

	Lifetime emissions (lbs)				**Lifetime energy**	
	CO2eq	**SOx**	**NOx**	**Hg**	**MMBTU**	**% total**
Material production	12321	49	22	0.00023	77	16
Vehicle assembly	5766	23	10	0.00011	14	3
Fuel production / transport	15621	25	18	0.00011	38	8
Vehicle operation - fuel	39202	4	36	0.00012	230	47
Vehicle operation - electricity	38766	153	69	0.00072	97	20
Vehicle maintenance	5504	22	10	0.00010	14	3
Vehicle disposal	8024	32	14	0.00015	20	4
Totals	130000	310	180	0.00153	490	100

Assumptions in model

- Vehicle lifetime miles reflect recent NHTSA work
  - 152,274 lifetime miles for cars and
  - 178,824 lifetime miles for pickups and SUVs

- Three fuel classes
  - Default
  - Low carbon burdens
  - High carbon burdens

Material acquisition energy

Material	MJ / kg
Aluminum (recycled)	52
Aluminum (virgin)	231
Copper (recycled)	50
Copper (virgin)	125
Fluids	50
Glass (float)	13
Glass (recycled)	7
Glass (textile)	13
Glass (virgin)	13
Iron (recycled)	37
Iron (virgin)	37
Lead (recycled)	13
Lead (virgin)	25

Material	MJ / kg
Magnesium (recycled)	19
Magnesium (virgin)	63
Nickel (recycled)	50
Nickel (virgin)	100
Other	50
Plastics (misc)	68
Plastics (recycled)	45
Plastics (virgin)	90
Rubber (recycled)	12
Rubber (synthetic)	26
Rubber (virgin)	40
Steel (recycled)	52
Steel (virgin)	65

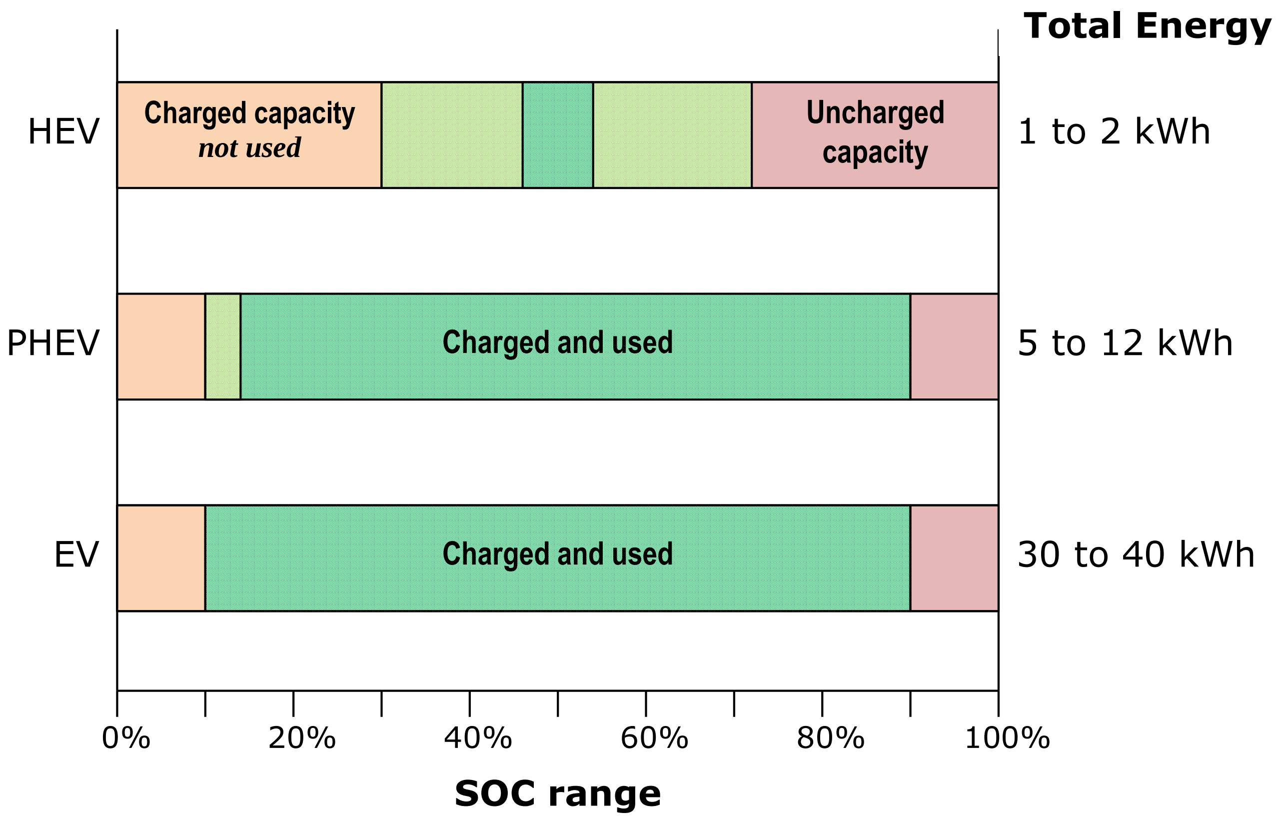
Assembly energy

End-Use	Share of electricity use	Estimated typical kWh/car	Value used in this study (kWh/car)
HVAC	11-20%	95-170	160
Paint systems (e.g. fans)	27-50%	230-320	260
Lighting	15-16%	130-140	130
Compressed air	9-14%	80-120	120
Materials handling/tools	7-8%	60-70	60
Metal forming	2-9%	20-80	30
Welding	9-11%	80-95	80
Miscellaneous	4-5%	35-45	20
Total	**100%**	**730-1040**	**860**

Treatment of hybrids and plug-ins

- Hybrid electric vehicles maintain at least 30 percent SoC at all times and rarely go above 70 percent SoC.
- Pure electric vehicles and plug-in hybrids use a wider range of the available battery capacity in normal use
- The treatment of electric and plug-in electric vehicles in the LCA tool is based on NiMH battery chemistry.
  - This is reflected in the material energy and material composition fraction allocation.

Battery use characteristics



adapted from draft version of "A Sensitivity Study of Different PHEV Battery Electric Ranges: Implications for Battery Cycling, Battery Life, and Petroleum Fuel Use over the Vehicle Lifetime" by R. Devault and D. Smith at ORNL

Example comparison

- Comparison between fuels using vehicles of similar sizes

	Effective mileage			Emissions / Energy				
Category	City	Hwy	Comb	CO2 eq.	SOx	NOx	Hg	MMBTU
IC Engine	17	36	26	250000	180	260	0.0012	1278
	23	39	30	210000	160	210	0.0011	1056
HEV	33	34	33	190000	180	200	0.0011	944
PHEV-20	35	51	42	130000	200	150	0.0011	611
EV-40	66	68	67	130000	330	170	0.0017	722
HEV with CNG	29	42	35	140000	150	140	0.0007	1000

Comments and conclusions

- Electric and plug in vehicles reduce carbon emissions but the use of grid electricity increases sulfur and mercury emissions.
  - Plug-in hybrid has the lowest energy footprint of all of these vehicles.

- Natural gas hybrids come close to the carbon emissions of the electrics but at much reduced sulfur and NOx emissions.

Future work

- Future version of tool will support advanced battery chemistries
  - Incorporate type and capacity, which specify minimum state-of-charge and corresponding weight and composition.
  - Changes to vehicle composition fraction tables and the algorithms that calculate raw material energy

- More accurate assessment of burdens of natural gas

Questions