Special Topics

Lighting Efficiency and Bulb Comparison

Electric Vehicles

Light Bulb Comparisons: Incandescents First

All have 100 W settings; 1540, 1350, 1490 lumens, respectively; 1.1, 1.8, 0.9 years at 3 hours per day

15 lumens per Watt typical of incandescent bulbs: basis for "equivalent power"

The CFLs: Oh How They've Fallen (in $$)

Have come way down in price; 900 lumen and 1600 lumen examples here, taking 13 and 23 W, respectively

Equivalent light output to 60 W & 100 W traditional incandescent ; 11 year lifetime (for good brands)

Note packaging error: both claim $1.57/yr elec. cost (at $0.11/kWh), but 23 W should be $2.77/yr

LED Bulbs

Expensive bulbs, but 18 & 23 year lifetimes; sipping energy

450, 650, and 800 lumens, taking 7.5 W, 12 W, and 14.5 W, respectively

Comparing Bulbs

Bulb	Power	Lumens	lm/W	equiv. "Power"	hours	cost/ bulb	bulb $/ 1000hr	elec $/ 1000 hr	total $/ 1000 hr
incandescent	100 W	1540	15.4	100	1200	$2.00	$1.67	$15	$16.67
long life incand.	100 W	1350	13.5	100	2000	$2.40	$1.20	$15	$16.20
"Eco" incand.	72 W	1490	21	100	1000	$1.55	$1.55	$10.80	$12.35
Philips big CFL	23 W	1600	69	100	12000	$2.90	$0.24	$3.45	$3.69
Philips med. CFL	13 W	900	69	60	12000	$2.00	$0.17	$1.95	$2.12
Philips LED bulb	7.5 W	450	60	40	20000	$11.00	$0.55	$1.13	$1.68
Philips LED flood	12 W	650	54	65	25000	$30	$1.20	$1.80	$3.00
Philips LED flood	14.5 W	800	55	75	25000	$35	$1.40	$2.18	$3.58

Costs for CFL/LED are substantially less than for incandescent: certainly in energy terms, but also bulb cost

Trusting the lifetime is key here. So **don't skimp** and get off-brand bulbs: go with the big, reputable names

Light Bulb Lessons

- Standing in the store, you can make well-informed quantitative decisions
  - lots of info in front of you
- For crying out loud, please start using lumens as a measure of brightness
  - because it actually *is* a measure of perceived brightness
  - we need to break the arcane connection to Watts
  - BTW, theoretical limit to "white" light efficacy is about 300 lm/W
- Incandescents burn out sooner, and cost more than CFL or LED lights, all things considered

Electric Propulsion

- Limited oil will squeeze transportation
- Meanwhile, lots of ways to make electricity
- Let's do electric cars!
  - issues:
    - how to measure MPG without gallons
    - energy density of batteries (far less than gasoline)
    - net efficiency, including power plant
    - CO_2 emission, including upstream electricity source
    - comparatively low propulsion cost
    - high cost of batteries
    - recharge time bottleneck

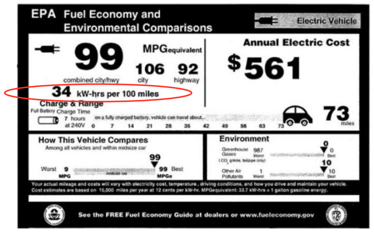
MPG for Electric Cars?

- No "Gallons," so how to rate efficiency?
  - energy per distance is useful
  - for that matter, gallons per mile is better than MPG
  - kWh per 100 miles is becoming standard in U.S.
    - and I approve: *mostly* a fundamental metric measure
- Window stickers show:

Model	type	kWh/100 mi	kWh to charge	range (mi)
Tesla Roadster	elec	30	75	245
Nissan Leaf	elec	34	25	73
Chevy Volt	PHEV	35	13	38
Ford C-Max Energi	PHEV	34	7	21
Prius Plug-In	PHEV	29	3.2	11

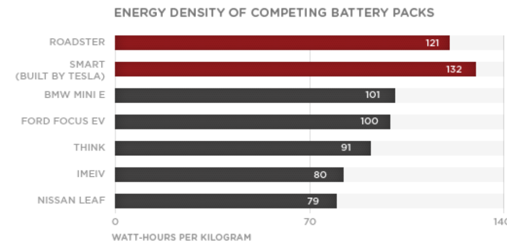
note how similar energy per mile is across wide range of models

Nissan Leaf Window Sticker



- Note 34 kWh per 100 miles
- 73 mile range: implies 25 kWh to charge
- 99 MPG equiv. based on 33.5 kWh/gal conversion
  - a little less than the *full* thermal content of 36 kWh/gal

Energy Density of Li-ion (the best, currently)



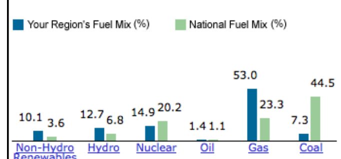
- Around 0.1 kWh/kg is typical for Li-ion
- Gasoline is 36 kWh/gal; 1 gal is 2.77 kg → 13 kWh/kg
  - gasoline is 130 times more energy dense than Li-ion
- 300 mile range requires 100 kWh; 1000 kg battery!

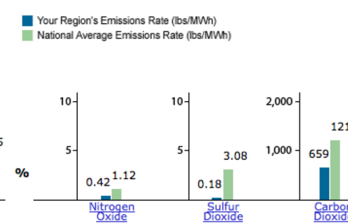
Efficiency Difference

- Gasoline (heat) engines typically turn in 15–25% efficiency at converting thermal energy into propulsion in a car
- Electric drive is probably about 85% efficient
  - so 130× gas/elec. energy density diff. turns into 30×
- But in terms of fossil fuel use, if getting electricity from 35% efficient power plant, and charging battery at 70% efficiency:
  - $0.35 \times 0.7 \times 0.85 = 21\%$
  - right back where we started: unclear if CO_2 advantage

Local Electricity Source Mix Matters

- Electricity source profile by zip code:
  - http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html
  - for 92093:





SoCal is 62% fossil fuel electricity (68.9% national average); CO_2 is among lowest in nation

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CO_2 Example: C-Max Energi (PHEV) in CA

- 34 kWh/100 mi in EV mode; 43 MPG in gas/hybrid mode
- EV mode CO_2 emissions
  - In CA, 659 lbs/MWh converts to 0.3 kg per kWh
  - so 100 EV miles → 0.3×34 = 10 kg of CO_2
  - but national average electricity mix → 19 kg CO_2
- Gas/hybrid mode CO_2 emissions
  - 100 miles takes 2.3 gal = 6.4 kg of gasoline
  - 3:1 rule makes this ~20 kg of CO_2
  - so 2× worse CO_2 to drive *same car* on gasoline in CA
  - closer to 3× worse when factoring refinery contrib. to gas
  - some parts of country: EV is *worse* on CO_2! (WY, KS, MO)
- Lesson: fix electricity sources before EV whole hog
  - or at least make sure local source makes sense

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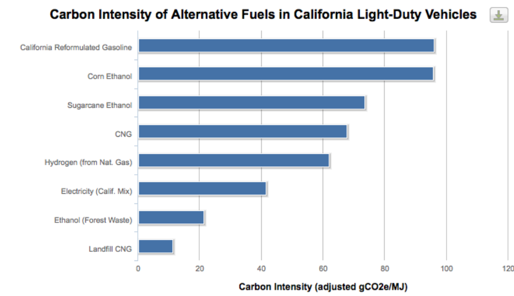

- Study in CA computed CO_2 intensity of various propulsion sources
  - http://www.afdc.energy.gov/data/tab/all/data_set/10329
  - shows EV as being 2.3× better; nat gas (CNG) between
  - waste products won't scale, so EV best scalable option

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Propulsion Cost: C-Max Energi as example

- To go 100 miles, the C-Max Energi takes 2.3 gal
  - based on window-sticker EPA rating of 43 MPG
  - will cost $9 when gas is $4/gal
- But 100 mi takes 34 kWh of charge in EV mode
  - at $0.15/kWh, this is $5 of electricity cost
- So about half as expensive to propel by electricity
  - function of gas and electricity price, though

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Battery Cost

- 300 mile range requires 100 kWh battery
  - at "EV-constant" of 33 kWh/100 mi
- Cost is in neighborhood of $500/kWh
- So 300 mile battery costs about $50,000
  - ever wonder why the Tesla is so expensive?
- My view: prices unlikely to fall enough to make electric cars a good mass solution anytime soon
  - where will the prosperity come from to afford these cars?

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Lifetime Savings?

- If you save $4 per 100 miles, and drive 125,000 miles, you save $5,000 in propulsion cost
- But if you have to replace battery after this time, and battery costs $500/kWh…
  - …you'd better hope your battery is less than 10 kWh
  - …which means 30 miles of maximum range
  - …which makes it harder to displace gasoline entirely in a PHEV (greater fraction of miles on gasoline)
  - and 30 miles is too short for EV-only vehicle
- So not clear that it's a dollars-and-cents win
  - yet fully advocate broader perspective/values than $$

Recharge times

- Adding gasoline to tank at 6 gallons per minute:
  - 3.6 kWh/sec = 13 MW of power!
  - two cars filling at a gas station = UCSD power!
- Charge efficiency 70−80%
  - other 20−30% generates heat
- Stick 100 kWh into battery in 10 minutes
  - 600 kW of power (current EVs accept 100−200× less)
  - 120 kW in heat/loss
  - distributed over 6 m^2 (cube 1 m on a side), 20 kW/m^2
  - naïvely hundreds of degrees C temperature rise

References and Announcements

- Additional Reading at Do the Math:
  - 48. Spectral Extravaganza: The Ultimate Light
  - 3. 100 MPG on Gasoline: Could We Really?
  - 8. MPG for Electric Cars?
  - 56. Battery Performance Deficit Disorder
- Last HW, last Quiz due Friday 6/7
- Do CAPEs
- Final Exam Wed., 6/12, 3:00−6:00 PM, York 2622
  - red half-sheet scan-tron form X-101864-PAR-L
  - #2 pencil
  - calculators OK