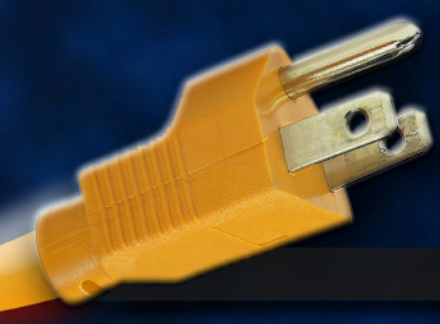
Sorting Through the Many Total-Energy-Cycle Pathways Possible with Early Plug-In Hybrids



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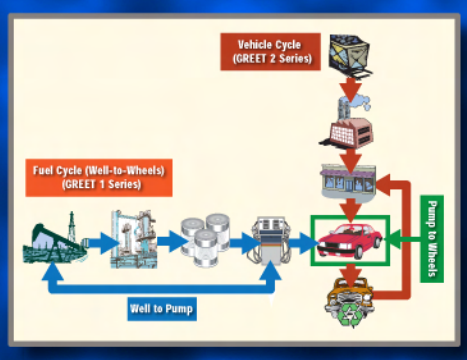
Introduction

Considerable effort has been spent to develop alternatives to gasoline, such as alcohol fuels, electric vehicles (EVs), hybrids (HEVs), plug-in hybrids (PHEVs), and fuel cell vehicles (FCVs), for personal transport, in order to improve air quality, reduce oil consumption, and reduce greenhouse gases. Proponents of each extol its virtues, but which options should be pursued? Two questions are asked: How can the most vehicle-kilometers be supplied with a given feedstock? Which vehicle types produce the lowest impacts in terms of petroleum use and greenhouse gas (GHG) emissions?

Methodology

A lifecycle inventory (or total energy cycle) analysis was performed for primary fuels and vehicle materials in the ground through vehicle use and recycling. The total energy cycle includes the fuel cycle (well-to-wheels, WTW), comprised of two parts, the well-to-pump (or plug) (WTP), and (plug or) pump-to-wheel (PTW) steps, and the vehicle cycle (vehicle material production, fabrication, assembly, disassembly, and recycling), which contributes significantly to total energy use and emissions.

The Powertrain System Analysis Toolkit (PSAT) was used to characterize the PTW stage. Simulation results are interfaced with GREET.



This graph illustrates how the different components contribute to the total energy cycle. It compares total energy use per kilometer of travel for a conventional spark-ignition engine vehicle (CV) running on gasoline to that for a plug-in hybrid running on electricity produced by combustion of oil in a boiler (for cases with one and zero battery replacement). Although the WTP energy for the CV is considerably smaller than that for the PHEV, because of the losses in conversion to electricity, the more efficient utilization of electric energy within the vehicle (PTW) more than makes up for that disadvantage. The vehicle cycle energy for the PHEV is larger than that for the CV, but the difference is small, so the total energy use for the PHEV is lower than that for the CV. Battery replacement does not significantly impact the total energy, but concerns about possible material scarcity and impacts of disposal make recycling imperative.

Vehicles and Pathways

This table shows the types of vehicles studied, the fuels considered, and the processes by which they were supplied. These were chosen for their likely availability in the year 2015. The vehicles included conventional SI (including flex fuel), diesel, hybrid, PHEV, and FCV. Plug-in hybrids were examined in two modes: charge-depleting (CD), in which energy from the grid is supplied via a battery, and charge-sustaining (CS), in which energy is supplied by a fuel as a normal hybrid.

Refined Oil	Natural Gas	Coal	Farmed Trees	Wind/Solar
Industry-average petrol, for SI ICE or Li-ion PHEV (CS)	CNG, for SI ICE	CTL (FTD), for CIDI	Ethanol (E85), for SI ICE FFV	Electricity; Li-ion PHEV (CD)
Oil sands produced in situ, (upgraded with H_2 from NG), for SI ICE	FTD, for CIDI	Electricity from current average coal boiler; Li-ion PHEV (CD)	Ethanol (E85); Li-ion PHEV FFV (CS)	H_2 via electrolysis; FCV
Oil sands via surface mining, (upgraded with H_2 from NG), for SI ICE	Electricity via existing simple-cycle turbines; Li-ion PHEV (CD)	Electricity from new coal boiler; Li-ion PHEV (CD)	Electricity from boiler; Li-ion PHEV (CD)	
Industry average petrol, for Ni-MH SI ICE hybrid (HEV)	Electricity via existing combined-cycle plants; Li-ion PHEV (CD)	Electricity from IGCC; Li-ion PHEV (CD)	Electricity from combined cycle via synthesis gas; Li-ion PHEV (CD)	
Industry-average diesel, for CIDI	H_2 from SMR; PHEV FCV (CS)			
Electricity from existing oil-fired boiler, for Li-ion PHEV (CD)				

Acronyms

Fuels and processes

- RFG reformulated gasoline/petrol (refined petroleum product)
- CG conventional gasoline/petrol (refined petroleum product)
- (C)NG (compressed) natural gas
- (G)H2 (gaseous) hydrogen
- CTL coal-to-liquids (product is low-sulfur diesel fuel)
- FTD Fischer-Tropsch process for producing diesel fuel from gas or solid feedstock
- IGCC integrated gasification combined-cycle (produces electricity from coal)
- SMR steam methane reforming (produces H_2 from natural gas)

Vehicle and powertrain types

- EV electric vehicle
- HEV hybrid electric vehicle
- PHEV plug-in hybrid electric vehicle
- FCV fuel cell vehicle
- CV conventional vehicle
- SI ICE spark-ignition, internal-combustion engine
- CIDI compression-ignition direct-injection (diesel)
- FFV flexible-fueled vehicle

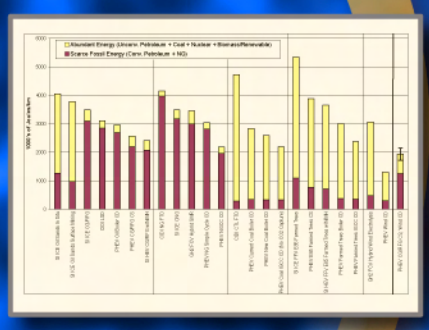
Battery types

- Ni MH nickel metal hydride (battery chemistry used in existing HEVs)
- Li-ion lithium-ion (family of battery chemistries candidates for future HEVs and PHEVs)

Other

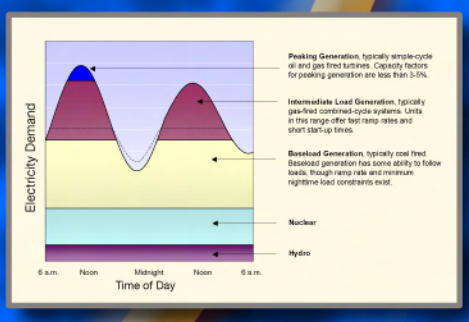
- CD charge-depleting mode (all-electric)
- CS charge-sustaining mode (hybrid)
- GHG greenhouse gases
- WTW well-to-wheels
- WTP well-to-pump (or plug)
- PTW pump (or plug)-to-wheels
- GREET **G**reenhouse **G**ases **R**egulated **E**missions and **E**nergy Use in **T**ransportation Model
- PSAT **P**owertrain **S**ystem **A**nalysis **T**oolkit

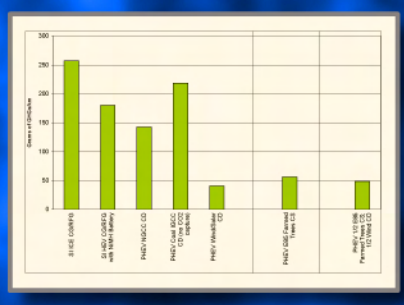
Results



This figure compares total energy use for all of the pathways considered in this analysis, split into scarce fossil fuels (petroleum and natural gas) and fuels with less stringent supply constraints. Pathways are grouped by primary energy source.

- For each feedstock, electricity use is the lowest energy path
- Combined-cycle electricity use beats older technologies
- Options that require conversion of a fuel to a liquid are energy intensive
- Options that rely on abundant fuels minimize use of scarce ones





Biofuels do not look significantly better than coal-based options on a total energy basis, but do for greenhouse gas emissions. This graph compares lifecycle GHG emissions for conventional vehicles to those from the lowest GHG pathways for each primary energy source examined. Renewable options reduce GHG emissions by a factor of three or more, compared to the fossil-based options.

In reality PHEVs will use electricity from the mix of utility fuels, which depends on the time of day and the season, as well as the plants available. This figure shows schematically how electrical load during the summer might be supplied. The usual assumption is that plug-in hybrids would be charged during the overnight minimum, to help the utility flatten its load curve. In the near term, charging PHEVs overnight would imply higher utilization of the coal plants, tending to raise GHG emissions. Charging in early evening would imply use of combined-cycle natural gas plants, with lower GHG emissions but higher fuel costs. Charging on-peak could imply use of less efficient simple-cycle gas-fired plants, with higher GHG emissions and fuel prices. In the mid-term, utilities could change their dispatch order to favor the gas combined-cycle plants, but this would require financial or regulatory incentives. In the long term, additional low-carbon baseload capacity could be brought online to serve the now flatter-load curve, caused by large numbers of PHEVs charging overnight.

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