Emerging Hybrid and Electric Vehicles and Their Impact on Energy and Emissions

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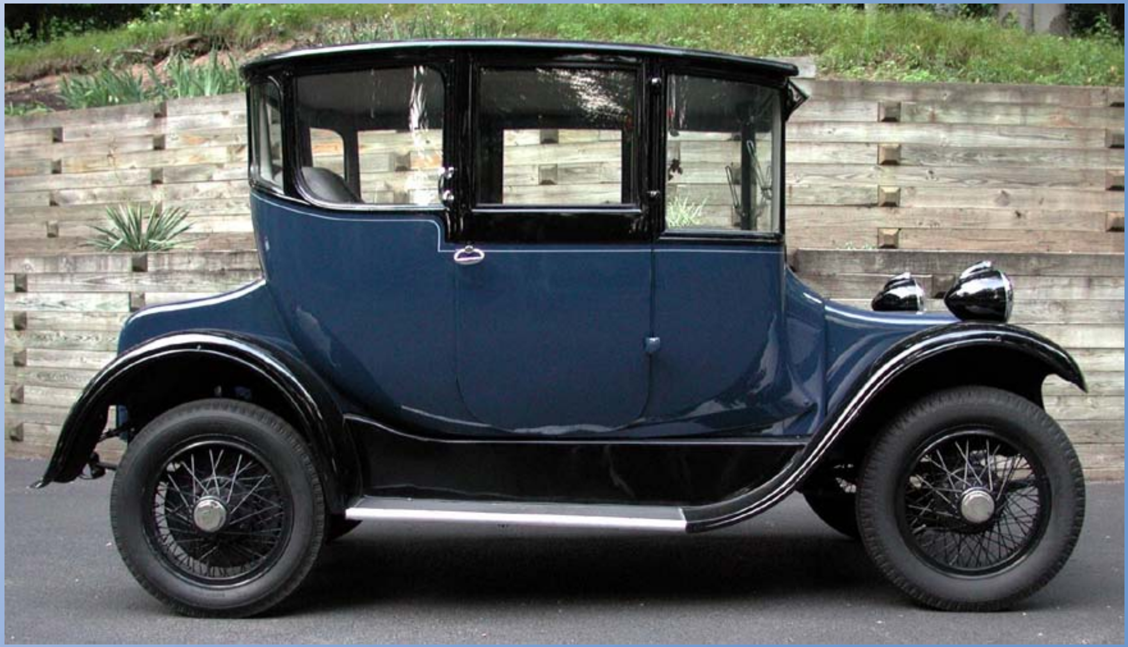
Overview

- Early electric cars and advantages
- Energy and power issues
- The modern hybrid
- Energy and environment motives for hybrids and electrics
- Near-term; myths and trends

Early Electric Cars

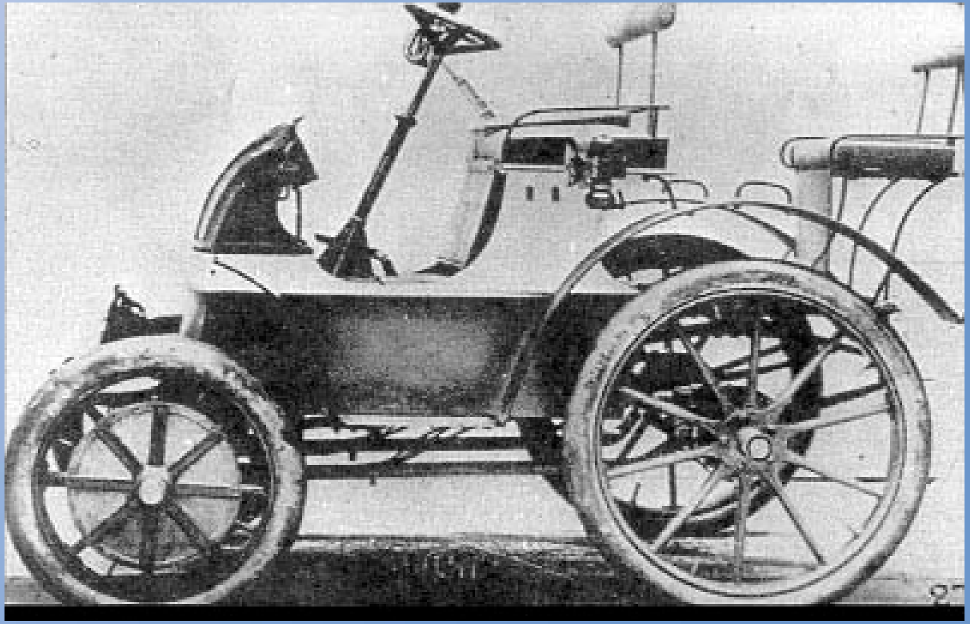
- Electric vehicles are clean and easy to use.
- Low maintenance, available infrastructure.
- Electric motors were easy to control.
- Motors have high power-to-weight ratio.
- 1914 Detroit Electric car.
- Limited range.

Source: I. Pitel.



Early Hybrid Cars

- The advantages of electric drives are substantial, but range is a challenge.
- Hybrids can deliver energy for long intervals.
- Retain the reliability and ease-of-use advantages of electric cars.
- The 1900 Porsche hybrid.



Gasoline Car Culture

- The Ford Model T in 1909 made cars affordable. Original list price: US$290.
- Gasoline was a waste product of oil refining.
- Low-cost mass production, low fuel costs, and performance limits helped fuel-driven cars overtake electric cars by 1920.
- Reliability has been improving continuously for fuel vehicles.
- There was little change in *electric* car technology until the 1960s.

www.xtec.es

Revival

- Revival of hybrid cars about 1970.
- New electronics attempted in the 1980s (GM Sunraycer).

eands.caltech.edu

- Mature power electronics since early 1990s.
- NiMH batteries matured enough in the late 90s.
- Li-ion almost there now.

www.treehugger.com

Revival

- Maturing power electronics overcame major performance barriers in the 1990s.
- 2000 General Motors EV1 high-performance electric car prototype.
- Limited range. Storage problems unresolved.

Source: www.gmev.com

Hybrid Designs Continue

- The advantages of hybrids (no mechanical drive train) have long dominated for the heaviest vehicles.
- At the largest sizes – ships and locomotives – the diesel-electric hybrid has been important since the 1920s.

Energy and Power Needs

- Electric motors have high power density and good control.
- A car needs to store energy for range.
- Alternatives:
  - Capacitors or inductors
  - Flywheels or springs
  - Compressed air tanks
  - Batteries
  - Liquid fuel
- Figures of merit:
  - Useful storage per unit mass
  - Useful energy rate (power) per unit mass

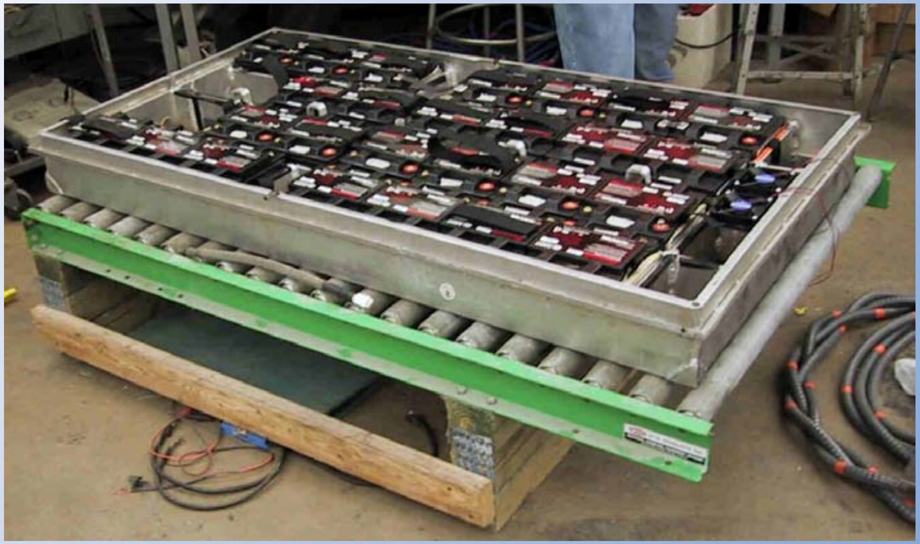
A 90 HP electric motor based on automotive duty.

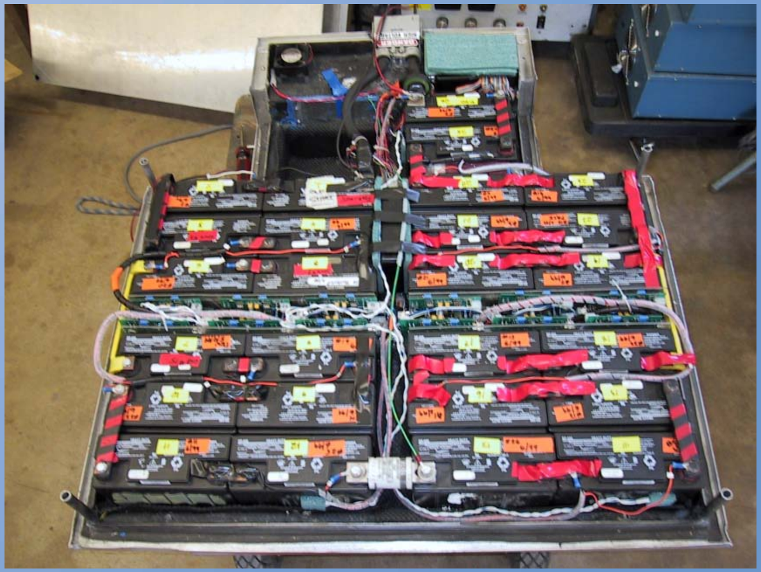
Energy and Power Needs

Storage technology	Energy density
Lead-acid batteries	100 kJ/kg (30 W-h/kg)
Lithium-ion batteries	600 kJ/kg
Compressed air, 10 MPa	80 kJ/kg (not including tank)
Conventional capacitors	0.2 kJ/kg
Ultracapacitors	20 kJ/kg
Flywheels	100 kJ/kg
Gasoline	43000 kJ/kg

Energy and Power Needs

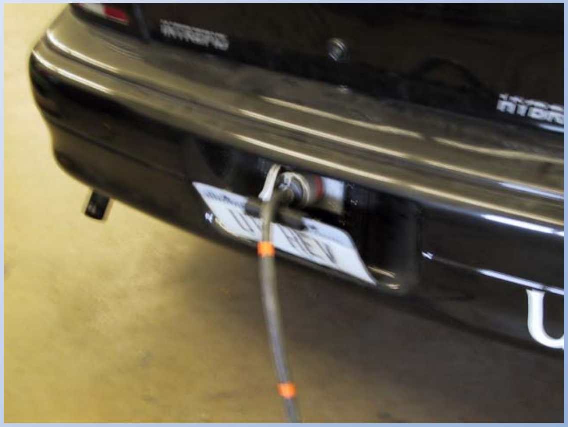
- Lead-acid battery energy density is only about 1% of the usable energy in gasoline.
- Sample test car: 275 kg battery pack → equivalent to 4 L of gas!

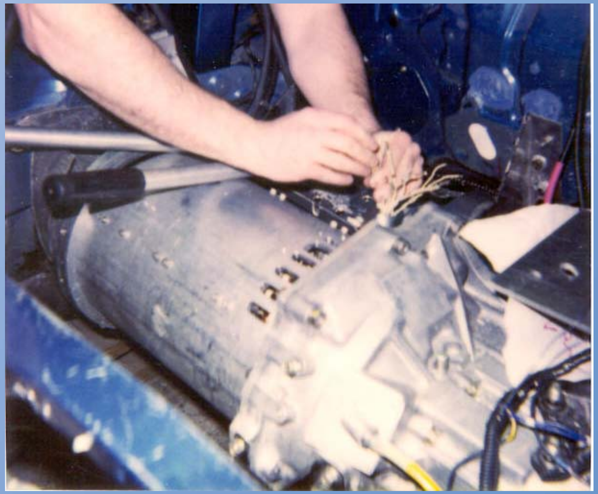




Energy and Power Needs

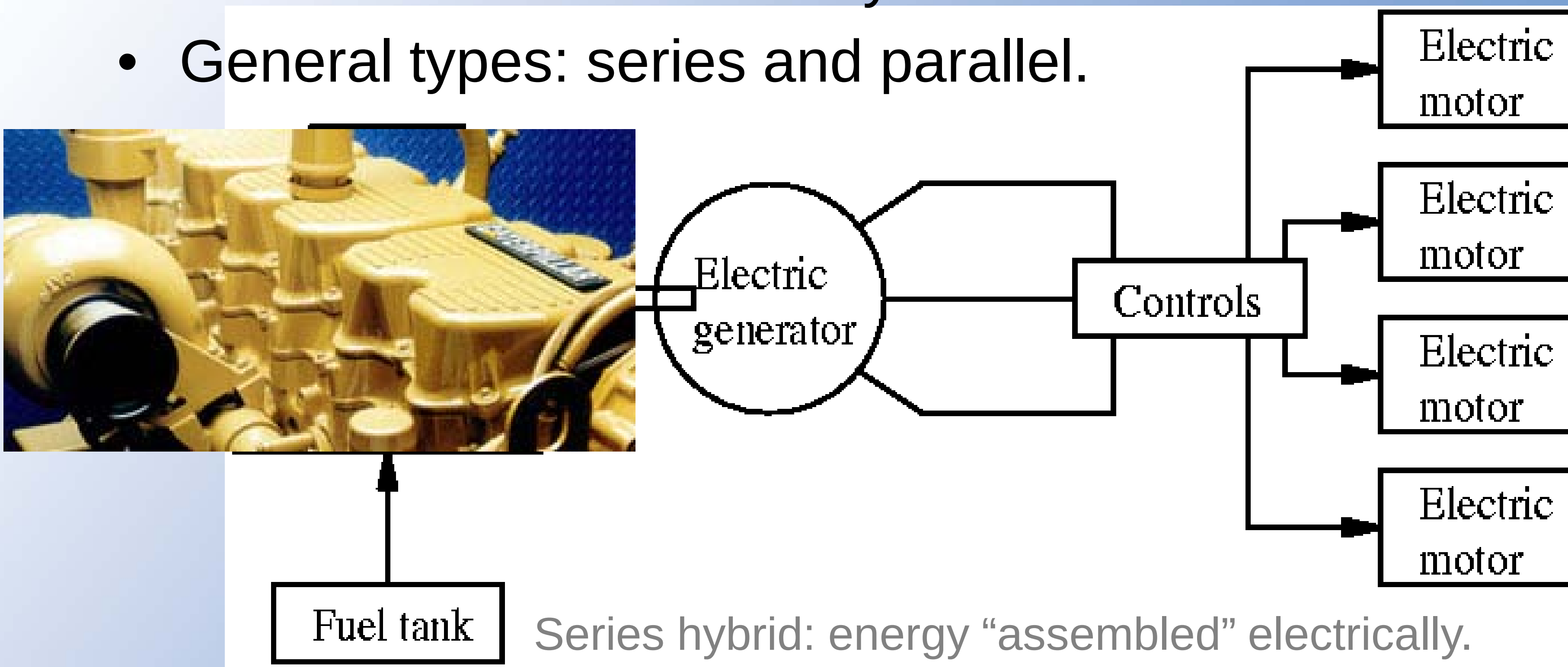
- Rate is a problem.
- Example: refill a gas tank with 15 gal in 5 min.
- The energy rate is roughly that of 20 major campus buildings!
- It is costly and problematic to fill batteries quickly.





The Modern Hybrid

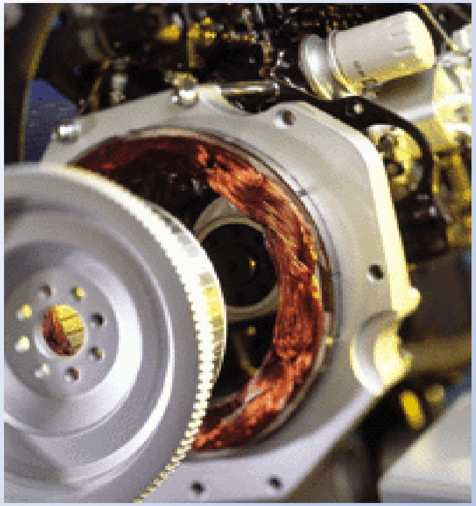
- Efficiency and emissions improvements motivate modern hybrid designs.
- Power electronics is nearly routine.
- General types: series and parallel.



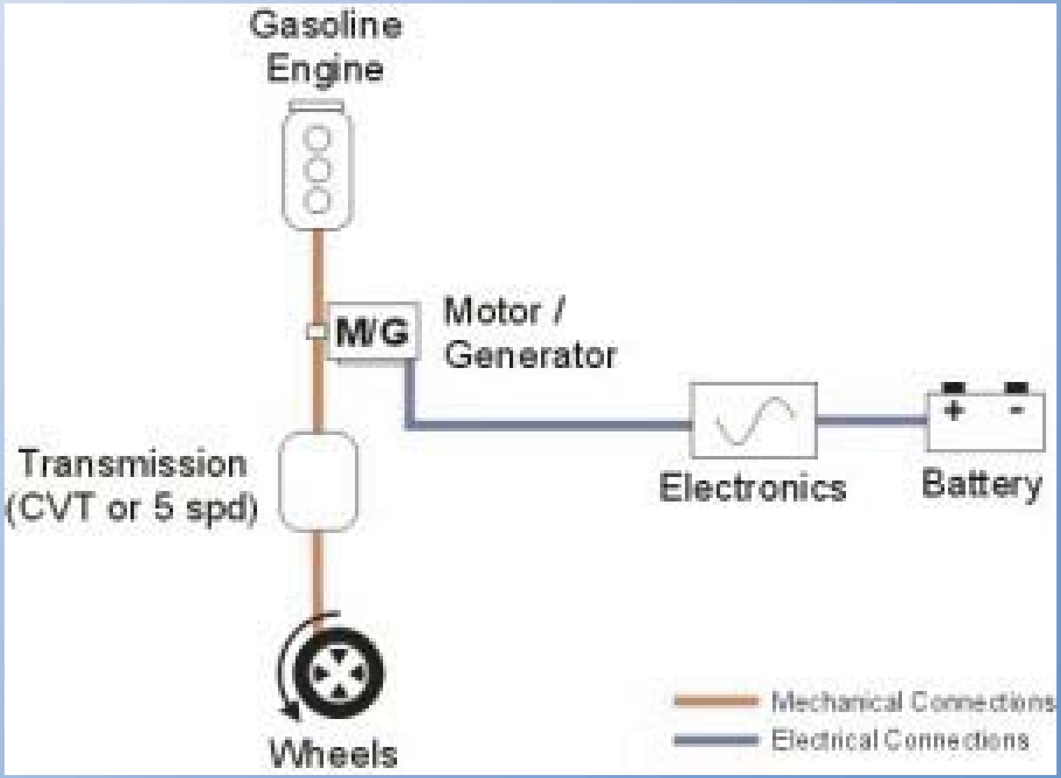
Series hybrid: energy “assembled” electrically.

The Modern Hybrid

- Parallel hybrid:



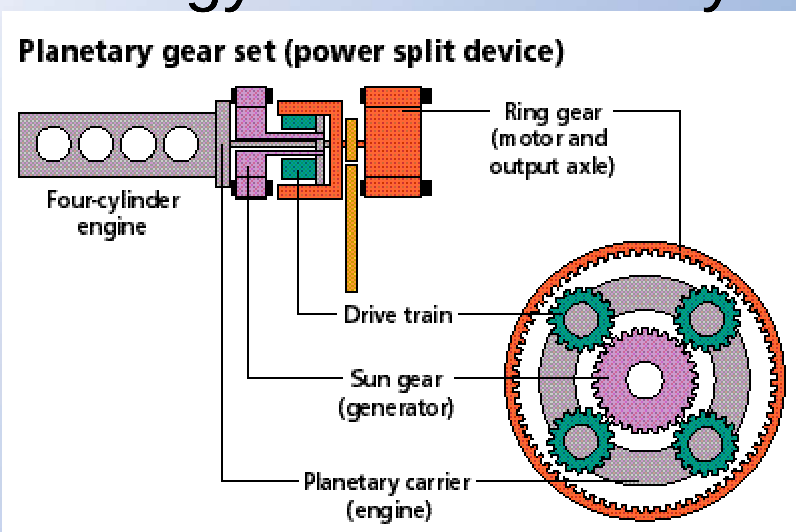
Source: Mechanical Engineering Magazine online, April 2002.

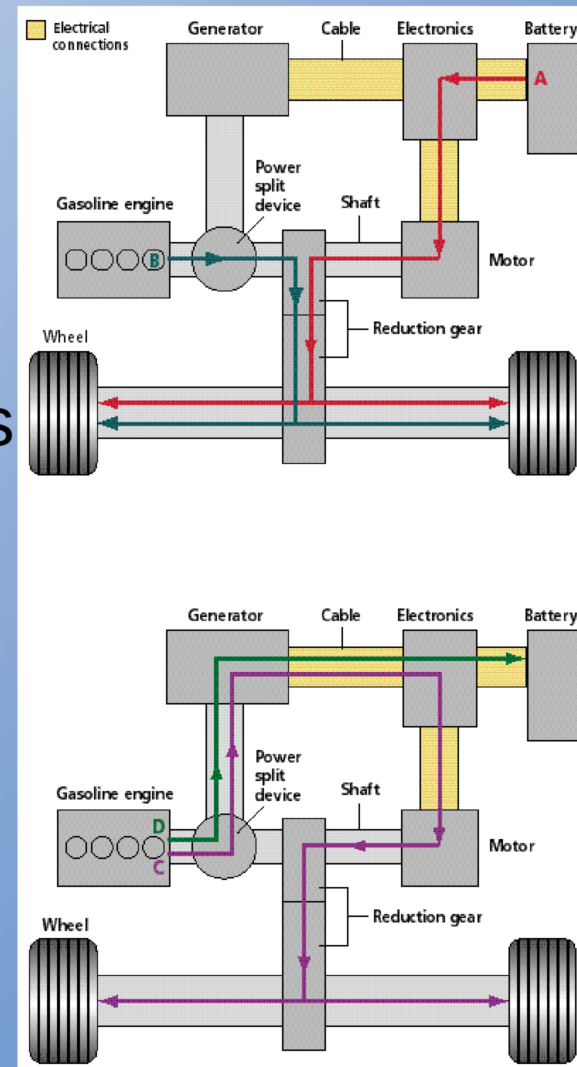


Credit: Honda

The Modern Hybrid

- The Toyota and Ford “dual” hybrids are parallel designs with some series modes.
- The Honda “mild” parallel hybrid uses electric machine to recover braking energy and allow easy engine start and stop.





Source: Toyota

Hybrid Electric Cars -- Production

- Honda Insight

Source: www.familycar.com

Hybrid Electric Cars -- Production

- Honda Civic

Source: www.auto-sfondi-desktop.com

- Toyota Prius (2^{nd} generation)

Source: www.theautochannel.com

Hybrid Electric Cars -- Production

- Ford Escape

Source: www.edmunds.com

- Lexus Hybrid SUV

Source: msnbcmedia.msn.com

Motives for Electric Vehicles

www.valvoline.com

- Energy flexibility.
- Energy efficiency.
- Reduced emissions.
- Cleaner, quieter cars without performance changes.
- For electric cars, the ultimate fuel source is hydro, wind, nuclear, or any electricity source.
- Emissions are eliminated, or moved to a central plant where large-scale control is possible.

Motives for Hybrid Vehicles

- Overcome energy storage (range) and power (fuel rate) problems.
- Good designs yield double the fuel economy.
- In principle, it might be possible to triple the fuel economy.
- The overall efficiency is similar to thermal electric power plants.
- Exhaust emission management is simplified.

Emission Improvements

An HEV has at least five characteristics that reduce emissions:

1. The engine is smaller since the electric motor does some of the work, especially during peaks.
2. The engine can shut off when the car stops.
3. We can choose to operate the engine only at its highest efficiency.
4. The electrical system can be used to prepare emission controls for cold starts.
5. Braking energy can be recovered and stored in the batteries.

Efficiency and Emission Improvements

- Efficient engines not good for direct use can be installed.
  - Atkinson cycle
  - Brayton cycle (turbines)
- The Prius achieves about 90% reduction in exhaust emissions, with no sacrifice in performance.

Volvo turbine hybrid prototype

- Large improvements in hydrocarbons and carbon monoxide.
- Possibility of zero-emission electric operation.

Electric Vehicle Emissions Aspects

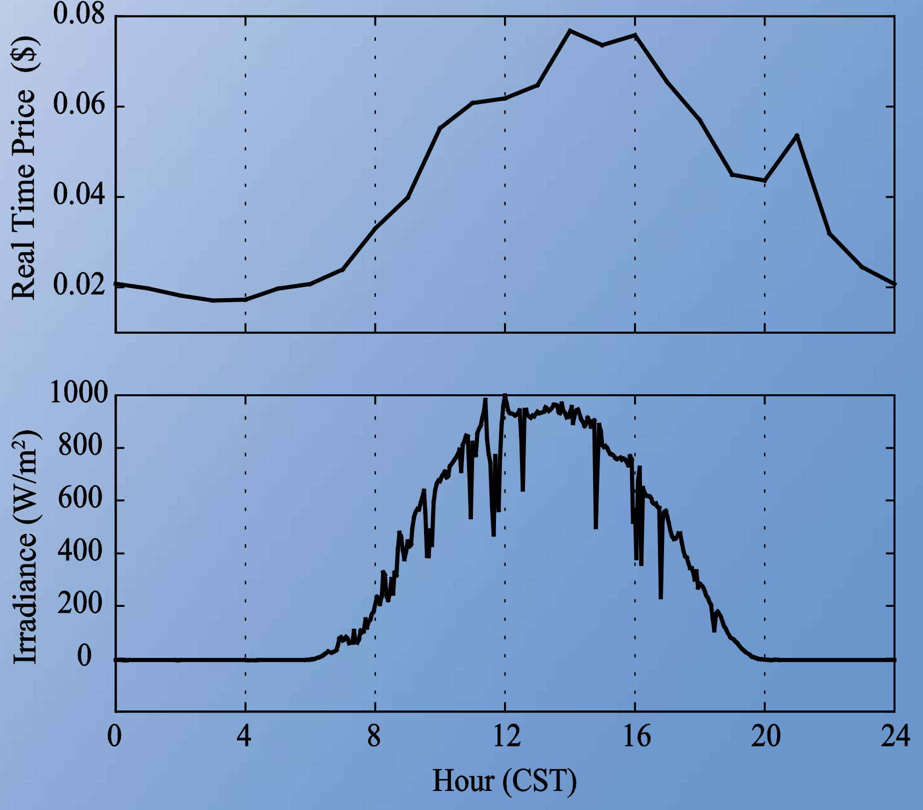
- “Just” moves emissions to a power plant.
- But:
  - Opportunity for large emission control infrastructure
  - Resource flexibility
- Higher overall system efficiency.

Emission Improvements: Electric

- Emission impacts depend on generation resource mix.
- Basis from average U.S. mix given here.
- Large-scale reductions (>90%) in
  - Hydrocarbon emissions
  - Carbon monoxide
  - Oxides of nitrogen
- Substantial reductions in carbon dioxide.
- Small reductions in oxides of sulfur.

Energy Issues: Electric and Plug-In

- Energy flexibility: an electric or plug-in hybrid can run on nuclear, solar, wind, or other carbon-free resources.
- Key attribute:
  time shifting of load.



Energy Issues: Electric and Plug-In

- Wind and solar resources are highly variable and have considerable randomness.
- Hard in a power grid:

  Energy delivered must match energy used, second by second.
- Integration of random resources requires extra conventional capacity to achieve the match.

Energy Issues: Electric and Plug-In

- Electric and plug-in hybrid cars provide a new type of large-scale flexible load.
- Battery charging can be adjusted dynamically to help with the system match.
- Possible storage resource with major benefits.
- Shift load into night hours.

Night Energy Shifting

- Typical electricity price ratio day-to-night is about 6:1.
- Sometimes electricity is *free* at night.
- There is substantial night capacity available to charge vehicle batteries.

Power Requirements

- Typical car, 4000 lb loaded, axle needs:
  - 20 HP on level road at 65 mph.
  - 55 HP to maintain 65 mph up a 5% grade.
  - 55 HP to maintain 95 mph on level road.
  - Peak power of about 150 HP to provide 0-60 mph acceleration in 10 s or less.
- Plus losses and accessories.

Power Requirements

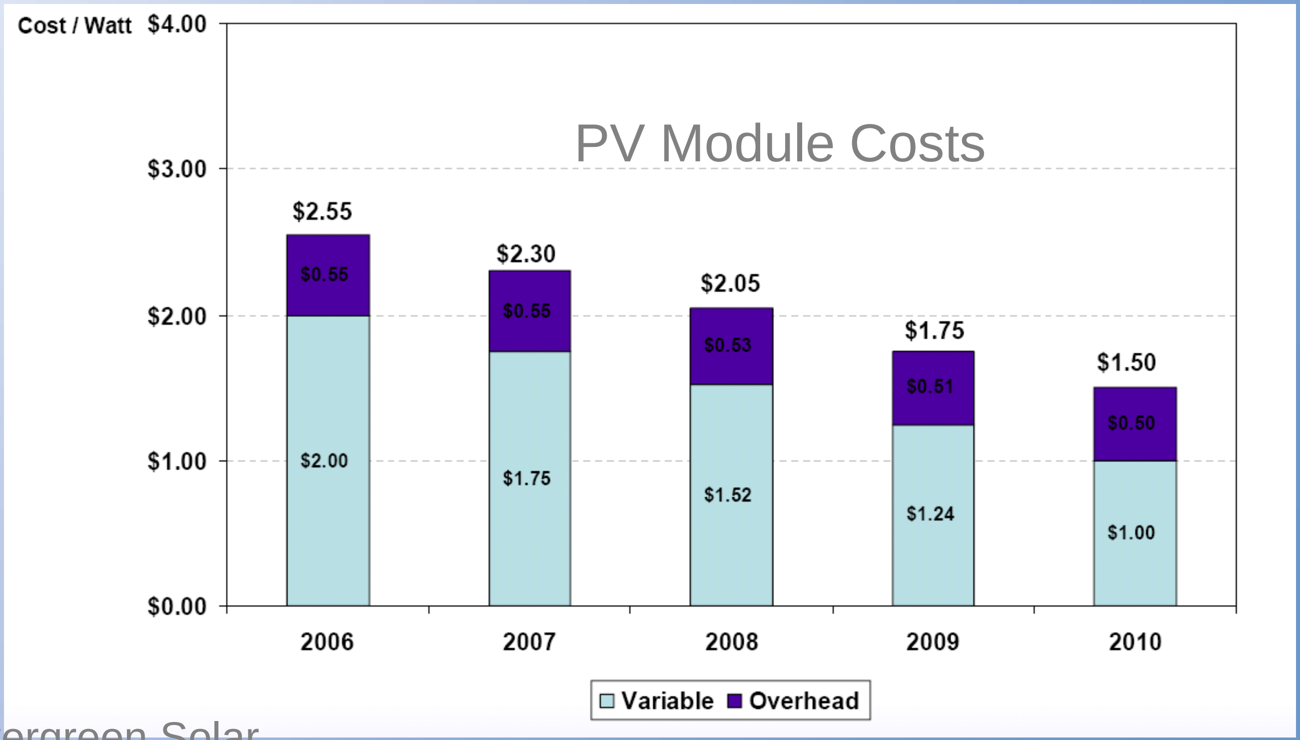
- Easy to meet performance requirements with electric drive train – except range and refuel.
- Better tradeoffs: not as much oversizing is required.
- Hybrid design: engine delivers average needs, electric motor can manage peaks.

Energy Costs

- Take gasoline at $2.40/gallon, and a car that achieves 30 miles/gallon.
- Energy cost is $0.08/mile.
- Now take electricity at $0.12/kW-h, and a car that consumes 200 W-h/mile.
- Energy cost is $0.024/mile.
- But, much cheaper with night charging.

Energy Costs

- Example: if solar electricity costs $0.30/kW-h, costs to operate a car are still well below those of hydrocarbon fuel.



Source: Evergreen Solar

Solar Power

- Solar-to-vehicle is interesting:
  - Photovoltaic module captures roughly 20% of sunlight energy.
  - If a residential system is used to charge a car, this solar energy becomes primary – minimal intermediate processing.
  - 10x or more better energy use than biofuel.

Charging Requirements

- For plug-in charging, rates are limited by resource availability.
- Residential:
  - 20 A, 120 V outlet, about 2 kW maximum.
  - 50 A, 240 V outlet, up to 10 kW.
- Commercial:
  - 50 A, 208 V, up to 12 kW.
- All are well below traction drive ratings.

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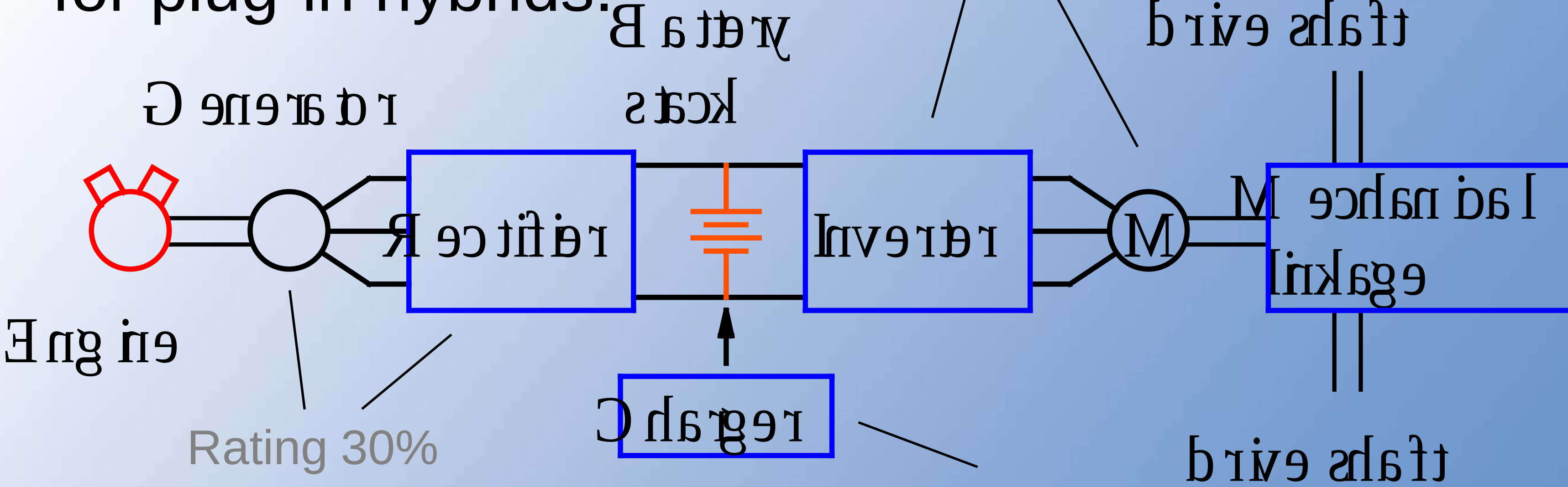
Architectures -- Series

- Probably favored for plug-in hybrids.



Implications

- Battery charging: equipment is small compared to car systems – integrate into vehicle.
- Even a modest charger, 2 kW, can recharge a modest plug-in hybrid in a few hours.
- Minimal infrastructure implications.

Myth: Limited market

"No one wants to buy a second car suitable just for commuting."

Fact: Most driving needs can be met with a car that has just 40 miles of range.

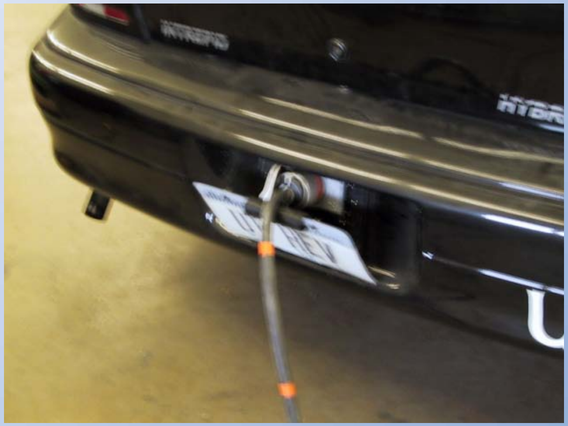
Fact: Most of my neighbors own multiple cars, with at least one used almost exclusively for commuting.

Source: www.edmunds.com

Myth: Inadequate infrastructure

"Houses and businesses will need much more electrical infrastructure to support plug-in hybrids and electrics."

Fact: The best designs use about 150 W-h/mile. A 6 h charge from a 120 V outlet is more than enough for a 40 mile battery.



Myth: Stepping stones

- {**Hybrid, electric, fuel cell**} vehicle designs are a stepping stone toward longer term {**hybrid, electric, fuel cell**} vehicles.

- *Fact: ALL vehicle designs are increments toward people's aspirations for personal transportation.*

www.xtec.es

Source: msnbcmedia.msn.com

Myth: Industry as a group is converging toward the best solutions

- "Existing design are proven and capable, and should be emulated."
- *Fact: Hybrids on the road have not achieved the performance levels and efficiencies of known electric car designs.*

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Near-Term Trends

- The plug-in hybrid will enter the market soon.
- A series design like the Chevrolet Volt has very significant promise.
- Electric vehicle designs have a definite place.
- Expect viable cars from Nissan and others in about two years.

Near-Term Trends

- Emissions impacts are large and will be more substantial as resources shift toward renewables.
- Renewables and plug-in vehicles complement each other well.
- Efficiency is very high compared to biofuels, and compares favorably with petroleum.