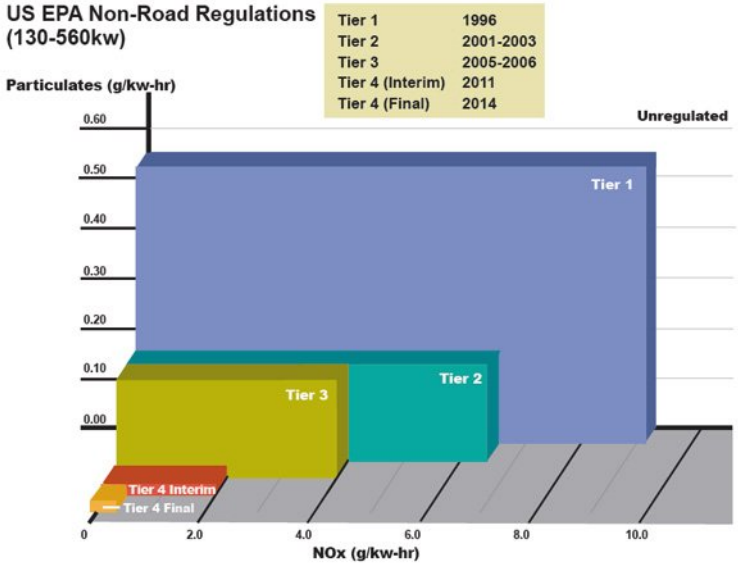
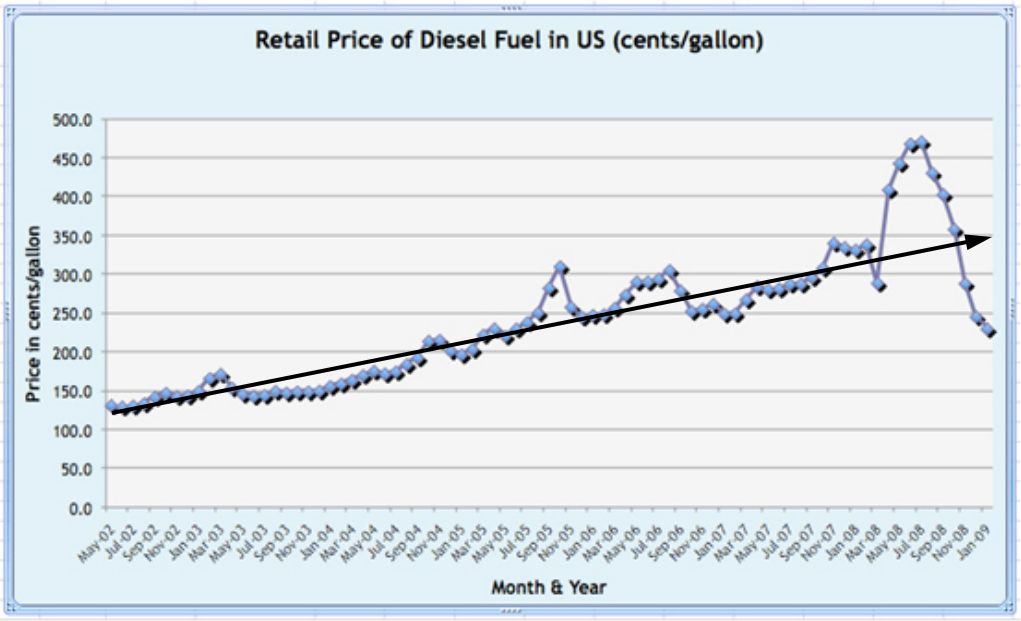
Hybrid Machines

Why the interest in hybrid technology?

- Emissions! Tier IV emission regulations are very tight. Less fuel burned per operation is less exhaust output to clean up.
- Operating costs! Diesel fuel is only getting more expensive (as are machines) – it is THE single biggest cost of ownership (production machines). Owners want to maximize productivity of the machine. Better fuel efficiency means less money spent and more money made. Owners are willing to pay for it if the payback is short (less than 2 years) and so long as durability/reliability are equal to or better than existing machinery.





Hybrid Machines

What's out there today?

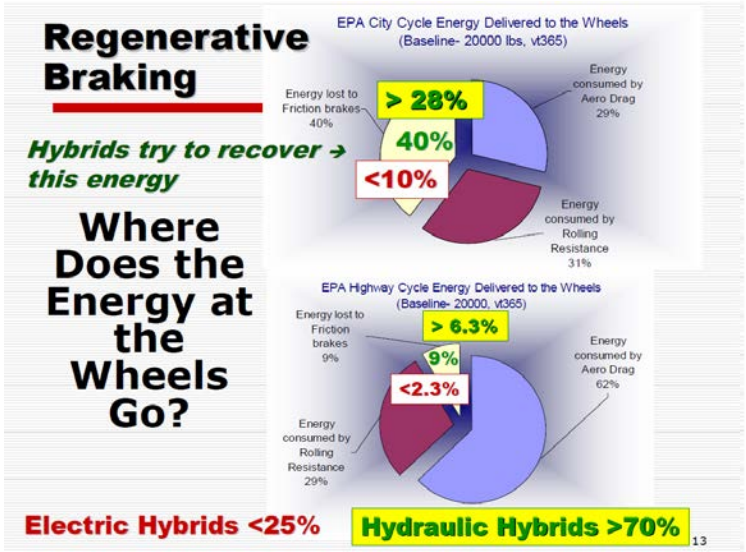
- You've probably heard of the Toyota Prius, and most likely the Honda and Ford hybrids.
- Electric hybrids very prevalent in the automotive world.
- Most of the world thinks hybrid = electric. Marketing of the electric hybrids has been very good, far superior to that of hydraulic.
- Komatsu has developed an electric hybrid excavator.

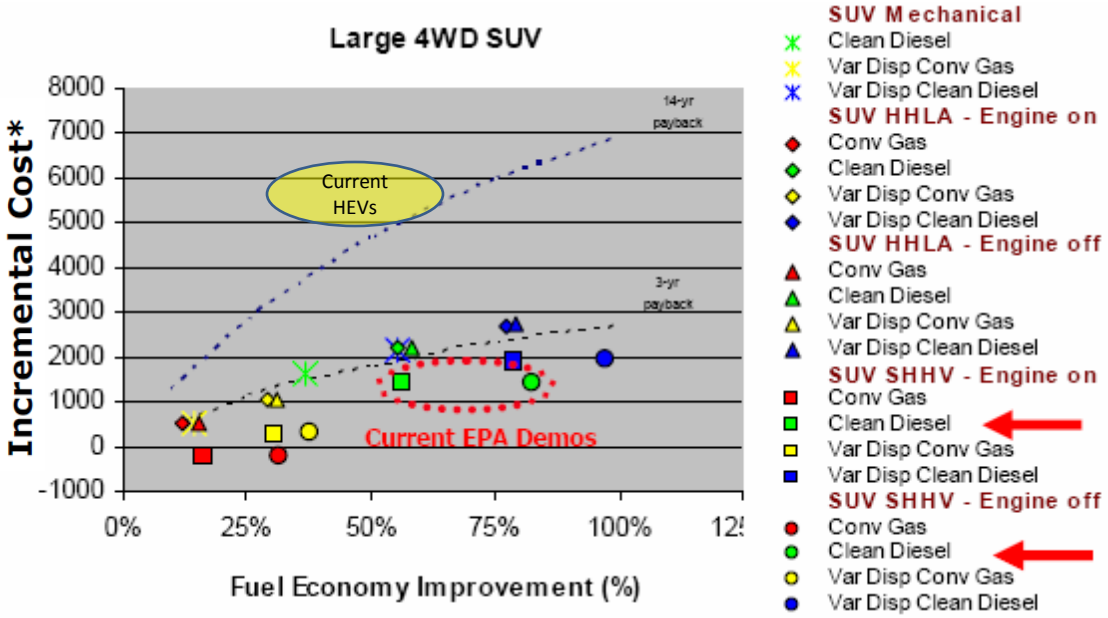
If everyone is using electric hybrids it must be the best way to go, right?

Hybrid Machines

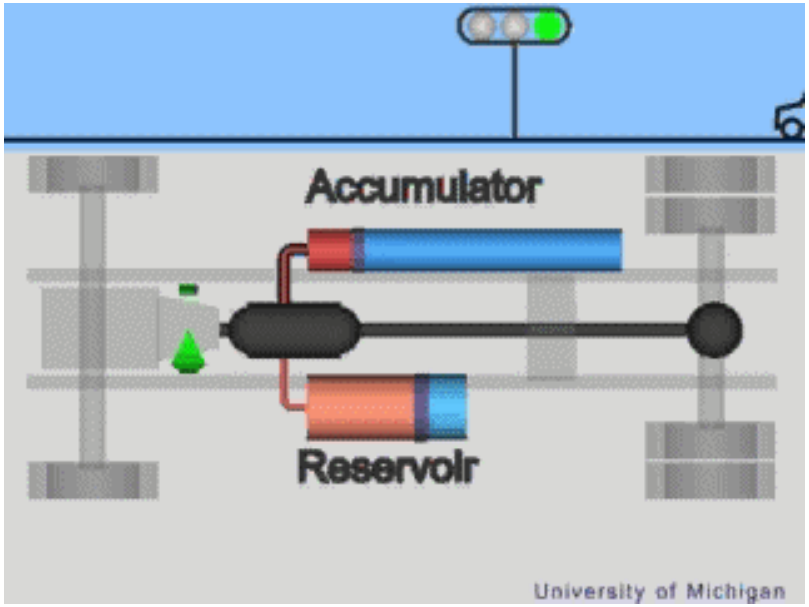
What you may or may not know is that . . . . .

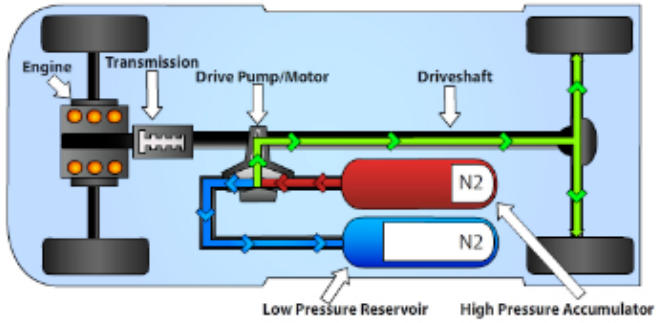
- Work was started by the EPA in the 1980s to study hydraulic hybrids.
- The EPA has concluded (2006) that for on-highway vehicles a hydraulic hybrid is more energy efficient and lower cost than competitive electric hybrids.
- Parker and Eaton have developed hydraulic hybrid systems that are now commercially available . UPS has installed the Eaton system on delivery trucks; they have reported substantial fuel savings – up to **70% improvement** in city driving.





Hydraulic Hybrid – How Does It Work

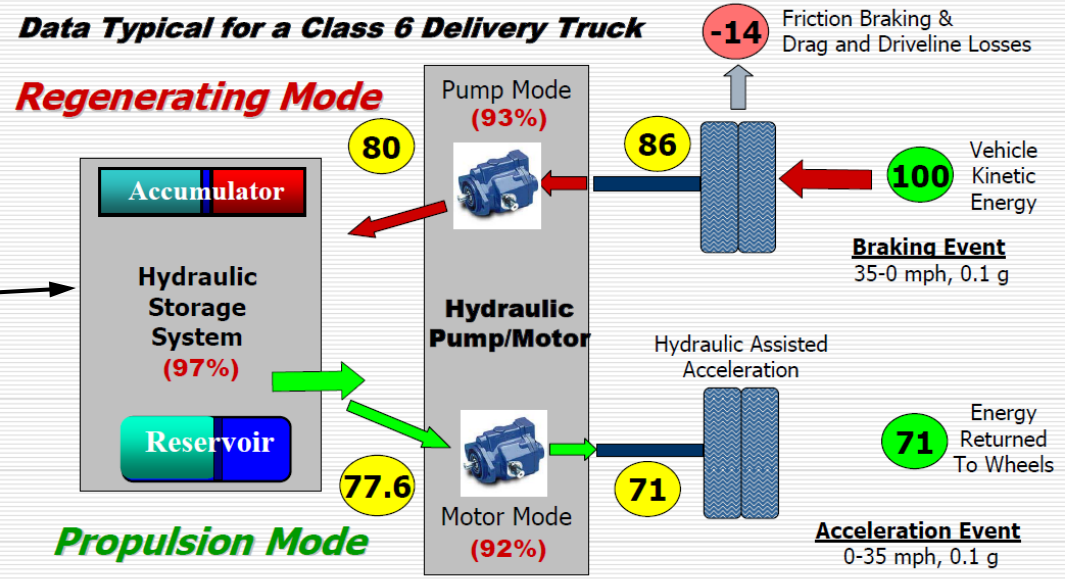




Assumes gas is hot. If allowed to cool efficiency suffers.

Efficiencies While Braking/Accelerating **Hydraulically**

Data Typical for a Class 6 Delivery Truck



*Analysis courtesy of **Automotive Research Center** – University of Michigan*

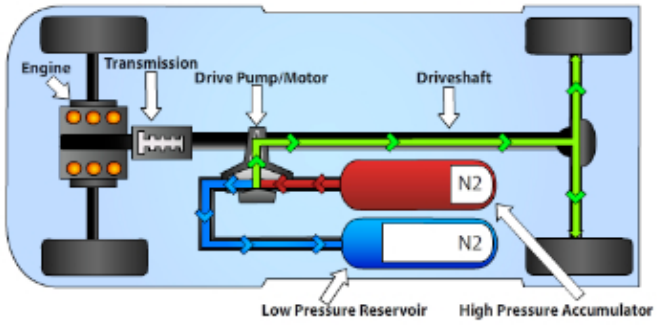
Hydraulic vs Electric Hybrid

Hydraulic Hybrid

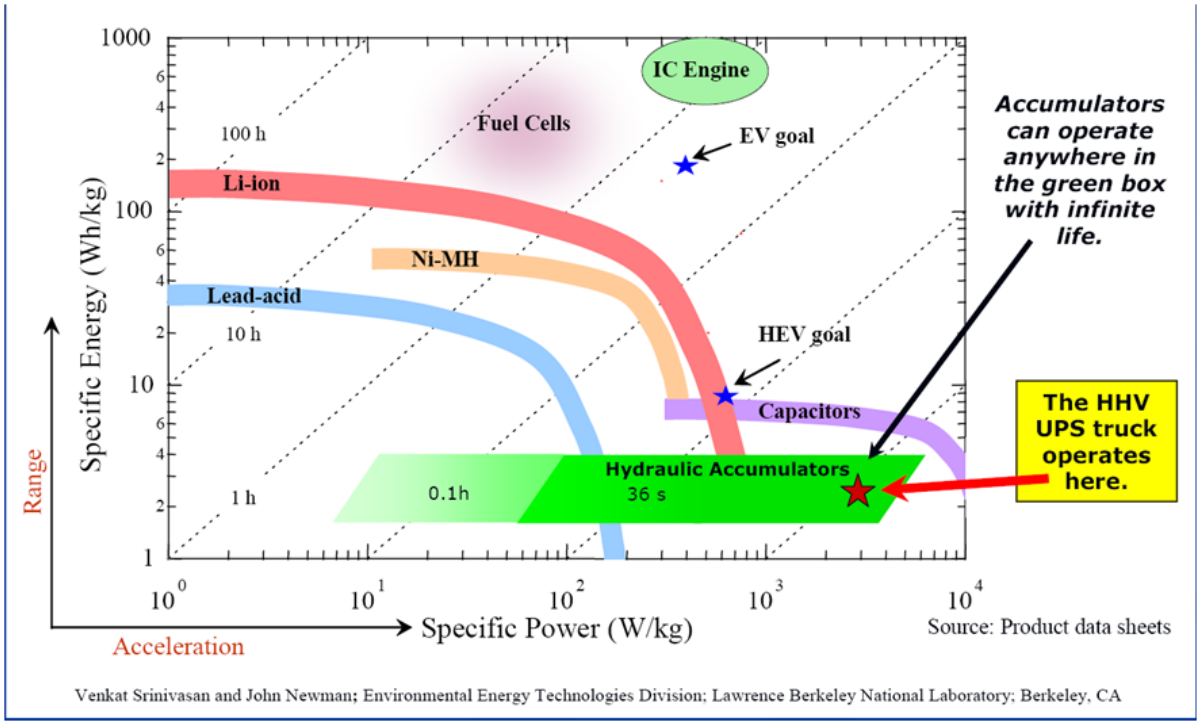
- Higher power density than electric
- Less expensive than electric
- Greater reliability (no batteries)
- Uses existing technologies
- More efficient than electric

Electric Hybrid

- Higher energy density than hydraulic
- Quieter operation
- Easier integration with electric vehicles



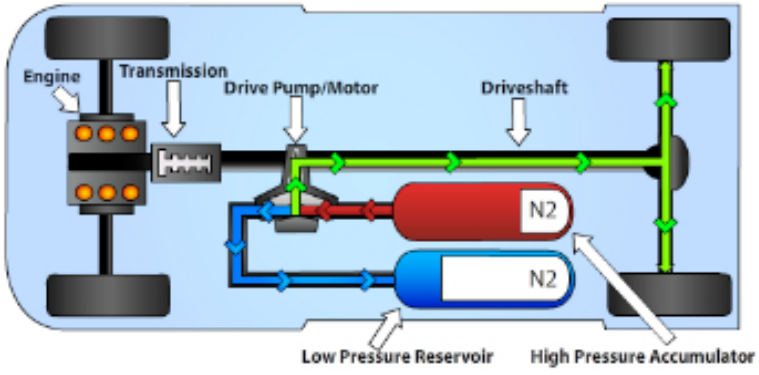
Electric hybrid architecture very similar to hydraulic.



Parallel vs Series Hybrid

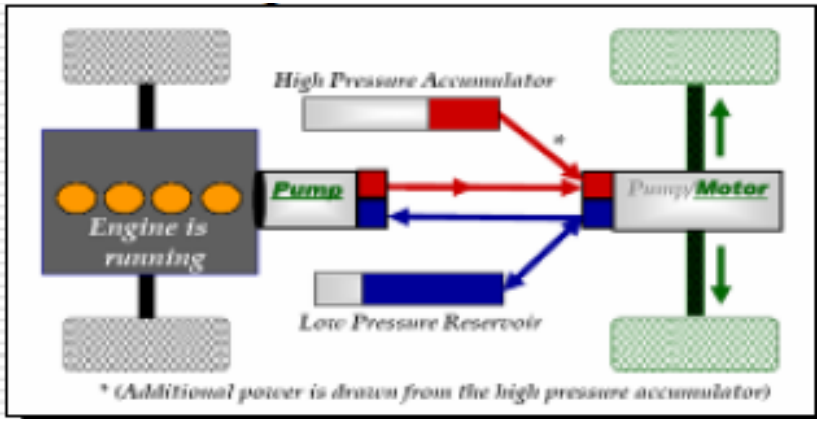
Parallel System

- Uses existing machine transmission
- Hydraulic power is passed through existing driveline
- Once energy is depleted or charged the hydraulic system shuts off
- Engine may be on or off during discharging or charging
- Easier to implement on existing machine (the system is an add-on)
- Fuel savings is good (20-40% per EPA)



Series System

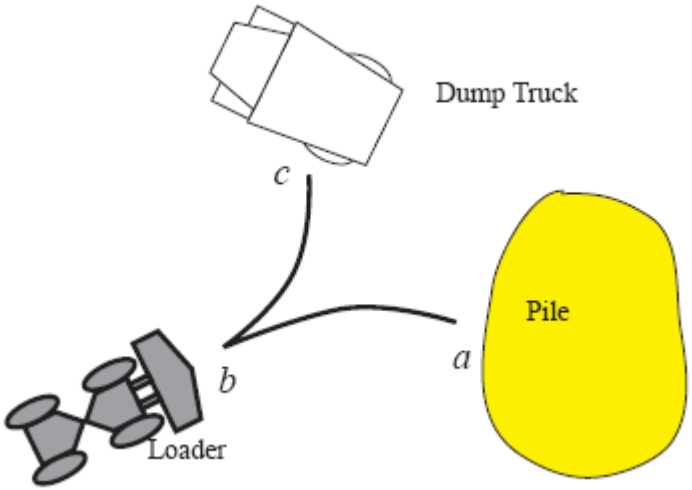
- Replaces machine transmission with hydraulic pump and pump/motor (similar to a hystat trans)
- Once system depleted or charged engine driven pump takes over
- Engine may be on or off during discharging or charging
- More difficult to implement machine (machine powertrain redesign)
- **Fuel savings is much better than parallel (60-80% per EPA)**

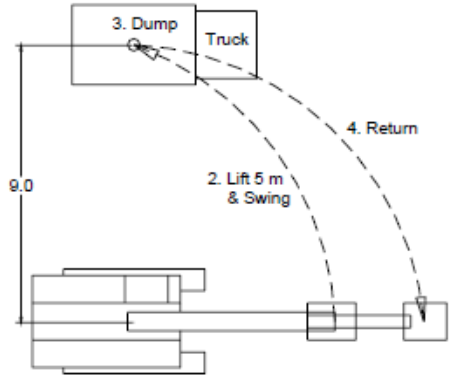


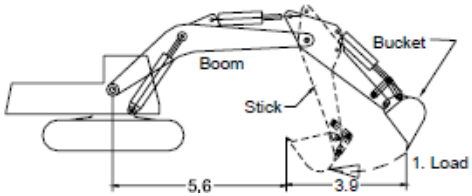
Hydraulic Hybrid System Considerations

Two major items to consider before designing/installing a hydraulic hybrid:

- **Does the machine lend itself to energy recovery?** A typical hydraulic excavator has multiple opportunities to recover energy during truck loading – swing, boom down, stick in, and bucket out (dump).
  A wheel loader looks like a good candidate on the surface, but a detailed analysis of the machine energy usage shows that most of the free energy available is used to power the hydraulics (TL cycle, backing out of pile, machine directional change energy is used to lift the bucket on approach to truck or drop bucket on approach to pile). A detailed energy audit of the machine and cycle should be performed before laying out a hybrid design.







Hydraulic Hybrid System Considerations

Two major items to consider before designing/installing a hydraulic hybrid:

- **Is the amount of energy storable and/or usable?** A large mining truck (LMT) weighing several hundred kips has tremendous potential when starting down a grade into the pit. To store that energy hydraulically would require an accumulator as large as the truck. LMT = impractical for hydraulic hybrid from machine kinetic energy. However after dumping the load there is some energy to recover in hoist down.

  Another example is boom down energy on a HEX. The energy analysis shows there is energy available, however it is typically in the form of high flow low pressure. This can be dealt with but is not ideal from an energy density perspective.

Hydraulic Hybrid System Considerations

Design considerations of a hydraulic hybrid system:

- Where can the energy be redirected (drive location between pump/motor and powertrain)? Engine mount, drop box, integration with transmission, etc. Drive location dictates pump/motor speed, which determines the necessary displacement.
- Where will the accumulators fit?
- How is the energy used (when to capture and when to redirect)?
- What is accumulator charge pressure and system operating pressure? This affects performance as well as accumulator volume. Larger accumulators cost more money, weigh more, and don't package well.
- How will the system trigger itself to charge/discharge? Will it be automatic or require operator intervention?

- The round trip cycle time must be completed quickly.
- Keep line lengths short to minimize pressure losses.
- Higher pressures, low flows = smaller, lighter, (generally) lower cost.
- Keep serviceability in mind – don't get the mechanics angry.

Hydraulic Hybrid System Considerations

Emerging technologies that can support hydraulic hybridization:

- Digital displacement controlled pump (DDC) – Claimed low mechanical losses at low displacements.
- Composite accumulators (carbon fiber) – Doesn't address size but substantial decrease in weight. Less machine weight = more productivity.
- Hydraulic transformer – Device to transform pressure from one level to another. For full hydraulic machines can move hydraulic energy between systems with little (theoretical) loss.

Conclusions

- The hydraulic hybrid has demonstrated superior performance (in terms of cost, efficiency, and reliability) when compared to electric hybrids
- Off the shelf components and technology are the building blocks of typical hydraulic hybrid systems
- Hybrid systems operate in two primary modes – economy and performance
- Understanding the application is key for achieving best fuel economy and/or productivity