AQMD Hydraulic Hybrid Vehicle Forum and Technical Roundtable

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Hybrid Vehicle Technology to Date:

- Over 90% of commercialization effort has focused on electric hybrid vehicles (100% of all commercially available passenger cars and light truck hybrids are electric hybrids)
- Nearly all R&D funding has been allocated to electric hybrids (with the exception of EPA sponsored research that has begun to explore hydraulic hybrid technology)
- Hydrostatic drive components (pumps, motors, & hoses) have been proven for lawn/garden, agricultural, and construction equipment
- "Gap" between current hydrostatic systems and optimized hydraulic hybrids is:
  - Fluid storage in accumulators
  - Engine, pump and motor control strategy/optimization

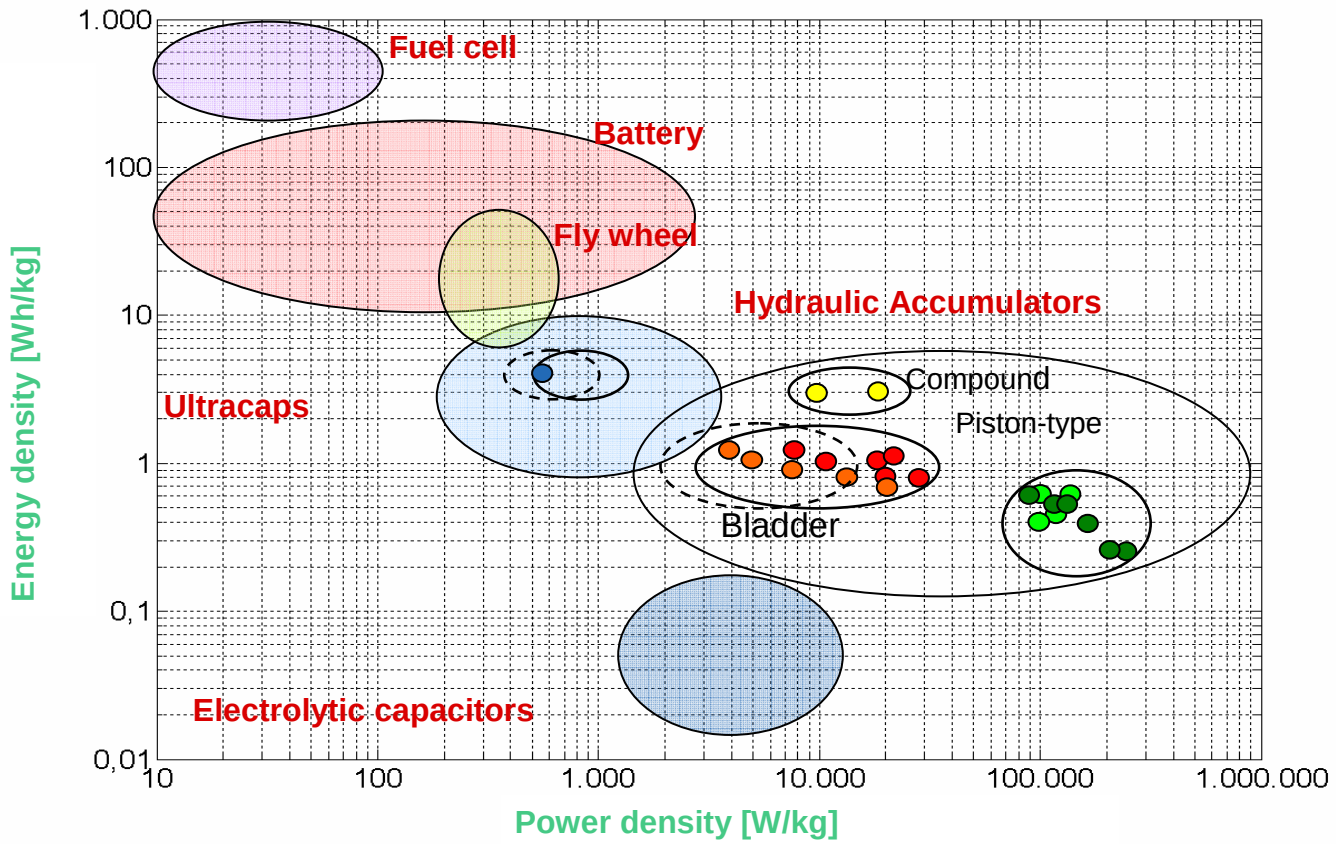
Why Hydraulic Hybrids?

- Hydraulic pump and motor efficiency is very high – better than motor/generator and battery
- Hydraulic pump/motors and accumulators are able to recapture a higher % of kinetic energy than electric motors/batteries during braking events, especially during rapid decelerations.

Room for both Hydraulic and Electric Hybrids -

- Electric hybrids may be better suited to applications that require exportable electric power and use a *parallel* hybrid drive system
  - Work trucks that operate power tools on job site
  - Food and beverage delivery trucks that operate an electric refrigeration compressor
  - Plug-in hybrid electric trucks that can use electricity from the grid during evening hours to smooth the utility demand curve
- Hydraulic hybrids may be better suited to applications that do an extreme amount of low speed stop/start driving and use a *series* hybrid drive system
  - Refuse
  - School bus, shuttle bus
  - Package delivery

Energy Storage Device Comparison – Power vs. Energy



Kinetic Energy = ½ mV^2 (m = mass; V = velocity)

Power = Work/time

Commercializing Hydraulic Hybrids
(How do we fill the gap?)

Needs:

- Regulatory
- Hydraulic System Suppliers
- Customers
- OEM/Engine Manufacturers

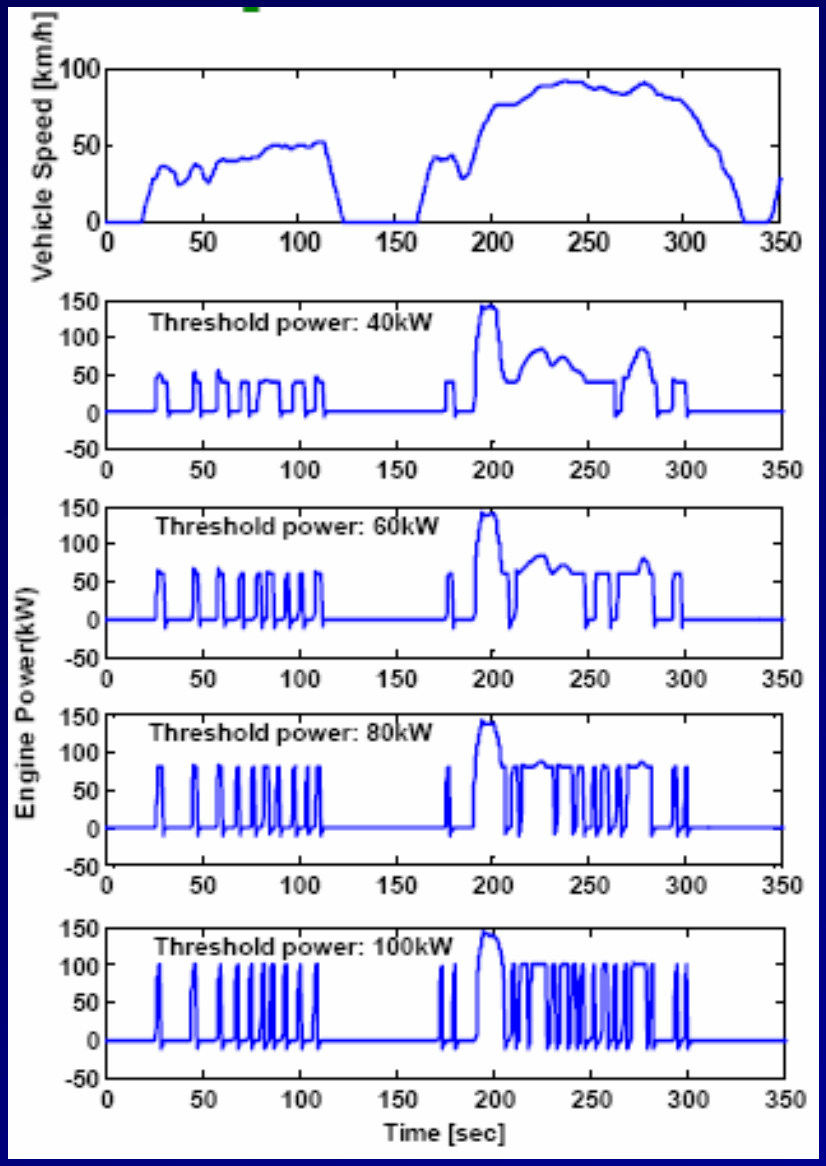
Regulatory

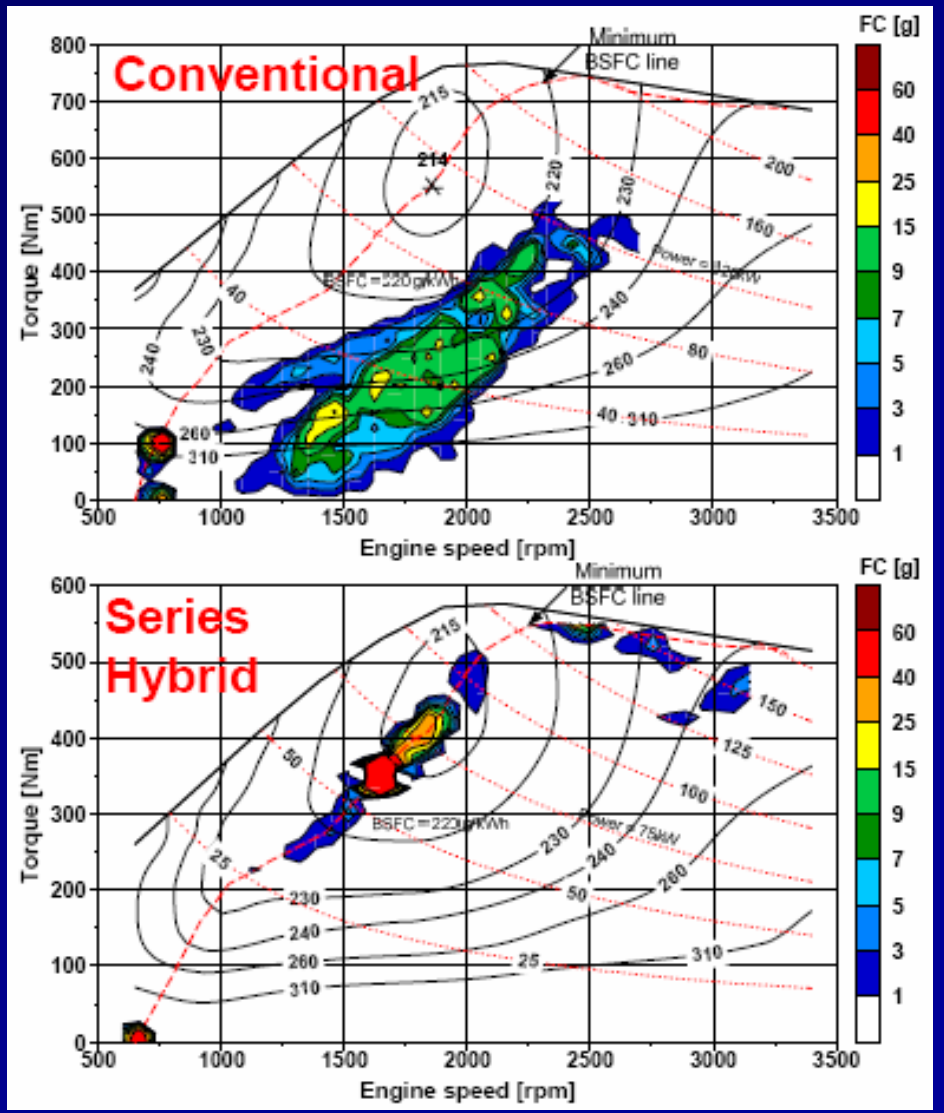
- Current Situation
  - Federal exhaust emission standards are expressed in grams per brake horsepower-hour
    - Testing is done on an engine dynamometer
    - Testing does not account for regenerative energy impact (reduced emissions and reduced fuel consumption)
- Future Needs
  - Emission test standards written for medium and heavy duty vehicles that give appropriate credit for reductions in exhaust emissions (similar to passenger car/light truck standards)

Hydraulic Supplier

- Optimization of pumps, motors, and accumulators – not a one size fits all answer across applications and GVW
- Accumulator technology advancements and cost effectiveness are probably the largest hydraulic supplier challenges
- System integration that achieves *advanced functionality* (will require close work with engine/vehicle OEM's)

Hydraulic & Engine Controller Challenges and Opportunities





Previous work – University of Michigan ARC – Filipi et al. (2007)

Customers

- Gain familiarity with and accept unique operation characteristics of series hydraulic hybrids
  - Some engine off operation will be normal
  - Disconnect between accelerator pedal position and engine response
    - (Vehicle may initially accelerate from stop when high pressure accumulator is sufficiently charged with the engine off)
- Gain experience with servicing and maintaining hydraulic hybrid vehicles
- Low volume field testing will facilitate this need

OEM/Engine Manufacturers

- System integration between engine, brake, vehicle, and hydraulic control systems that achieves *advanced functionality*
  - Engine off strategy/algorithm
  - Transient emissions
  - Engine lubrication
- Hydraulically driven AC compressor and power steering system with closed center steering gear
- Robust total vehicle that improves customer's bottom line

Conclusions

- Hydraulic hybrids can play a significant role in reducing fossil fuel consumption and in improving our air quality
- There are regulatory, hydraulic supplier, customer, and OEM/engine manufacturer needs that must all be addressed to successfully bring hydraulic hybrids to market
- The knowledge and ability to do this exist, *however*,
- Significant investment must be made to be successful
- Additional grant funding would be beneficial in bringing this technology to market with the advanced functionality necessary to reduce fuel consumption and improve air quality by the largest margin possible