

South Coast AQMD Hydraulic Hybrid Forum

Hydraulic Hybrid Vehicles 101

Delivering Efficiency to Commercial Vehicles

November 15, 2007

John J. Kargul

Director of Technology Transfer

Office of Transportation and Air Quality

U.S. Environmental Protection Agency

(734) 214-4386



Clean Automotive Technology

www.epa.gov/otaq/technology

What is a Hydraulic Hybrid?

A hybrid vehicle, in addition to its main engine, has a drivetrain that can recover and reuse energy.

(it has two on-board energy storage systems)

Hydraulic Hybrids

- Store energy in hydraulic accumulators
- Use hydraulic pump-motors

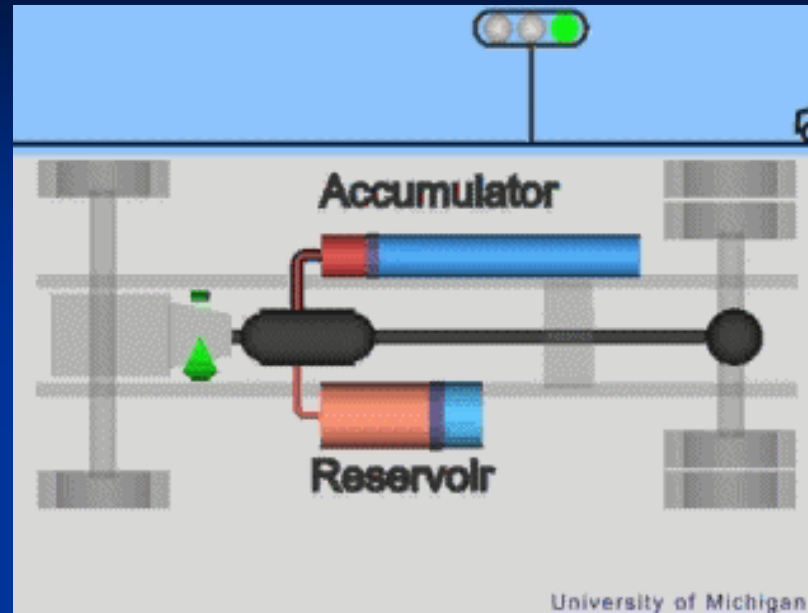
Electric Hybrids

- Store energy in batteries and/or ultra-capacitors
- Use electric generator-motors

HHV Drivetrain Configurations

Parallel HHVs

- ✓ Engine
- ✓ Transmission
- ✓ Drive Pump/Motor
- ✓ Drive Shaft
- ✓ Rear Axle

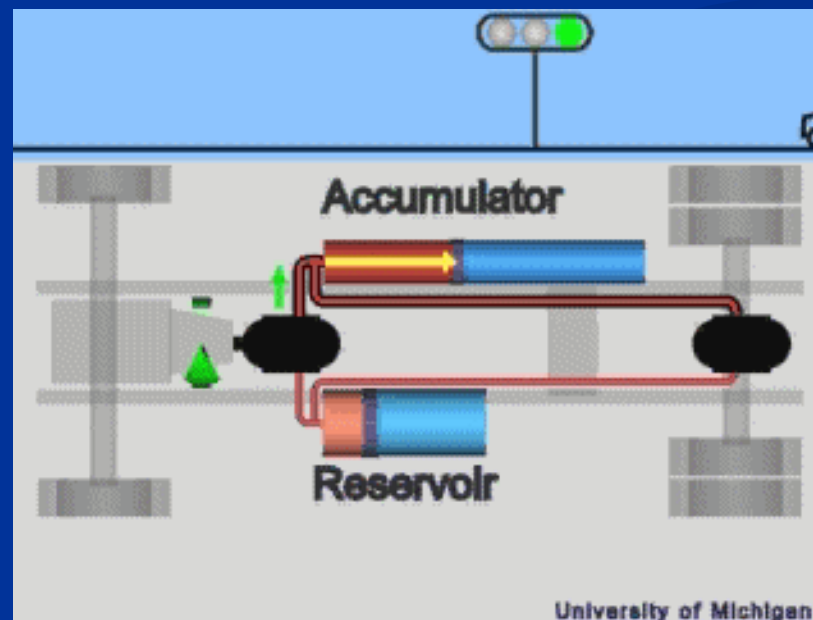


Benefits

- ✓ Fuel savings
- ✓ Reduced emissions
- ✓ Reduced brake and engine wear

Series HHVs

- ✓ Engine
- ✓ Engine Pump/Motor
- ✓ Drive Pump/Motor
- ✓ Drive Shaft (some designs)
- ✓ Rear Axle



Benefits

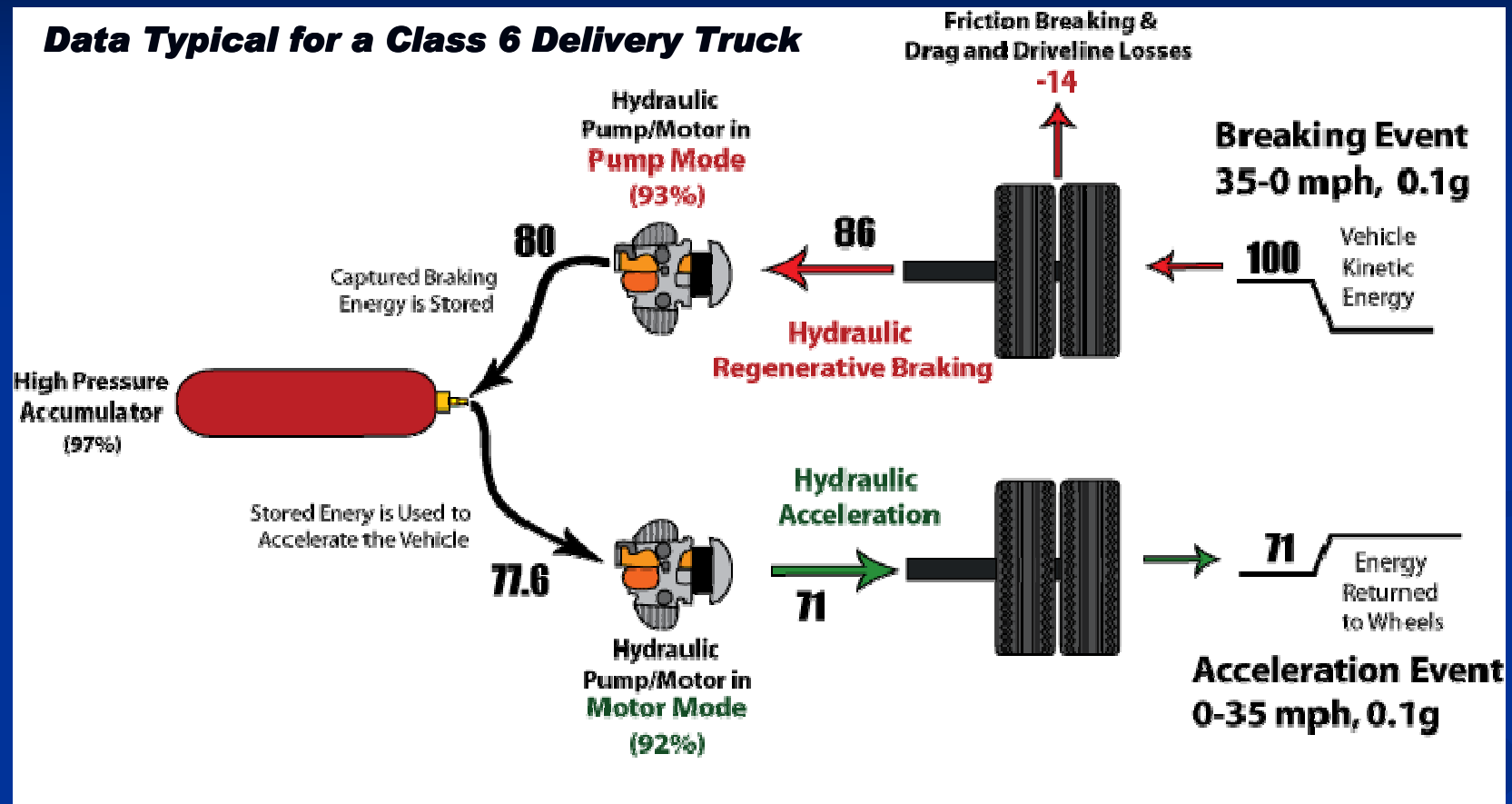
- ✓ Greatest fuel savings
- ✓ Reduced emissions
- ✓ Reduced engine on-time (no idling)
- ✓ Reduced brake and engine wear
- ✓ Lowest Cost

Strategies Which Increase Average Vehicle Efficiency

- 1. Capture and re-use energy normally lost to friction braking**
 - ✓ Regenerative braking
- 2. Improve average efficiency of engine / drivetrain**
 - ✓ Shutoff engine at stops (no idling)
 - ✓ Shutoff engine at all times when not needed (series only)
 - ✓ Operate engine at best efficiency (series only)

How It Works...

Efficiencies While Braking/Accelerating

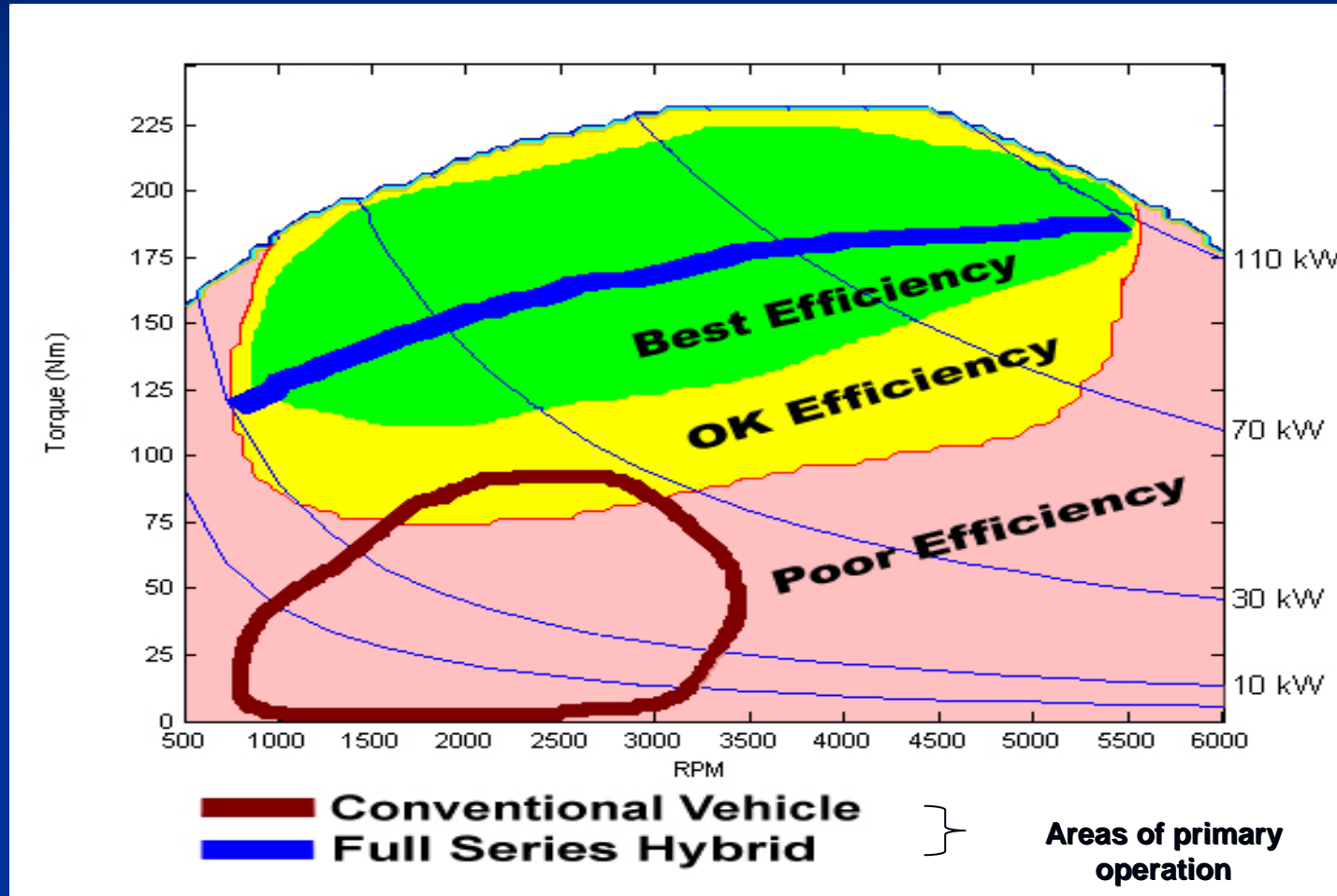


Analysis courtesy of **Automotive Research Center** – University of Michigan

Hydraulic Hybrids >70%

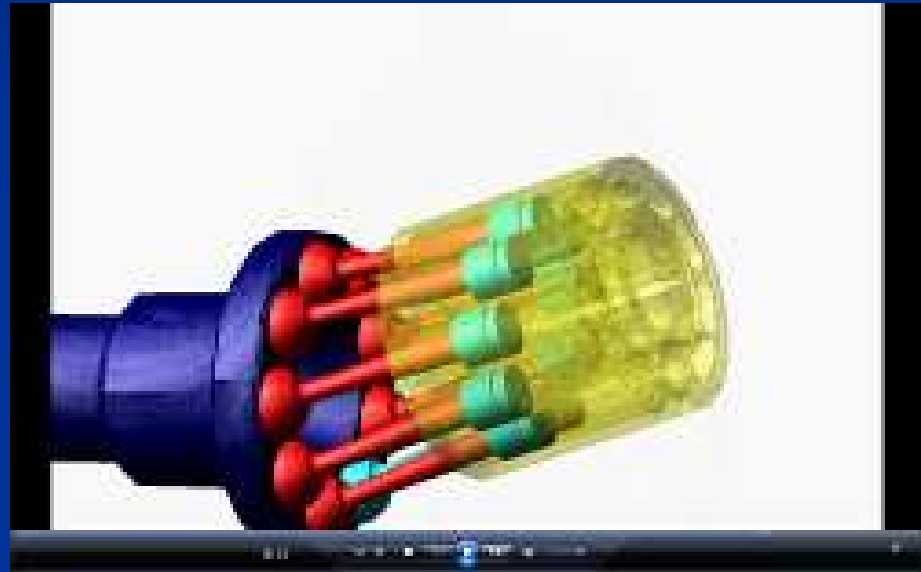
Electric Hybrids <25%

Power Map for a Typical Engine for Series Hybrids



How It Works...

Power from the Pistons/Barrel

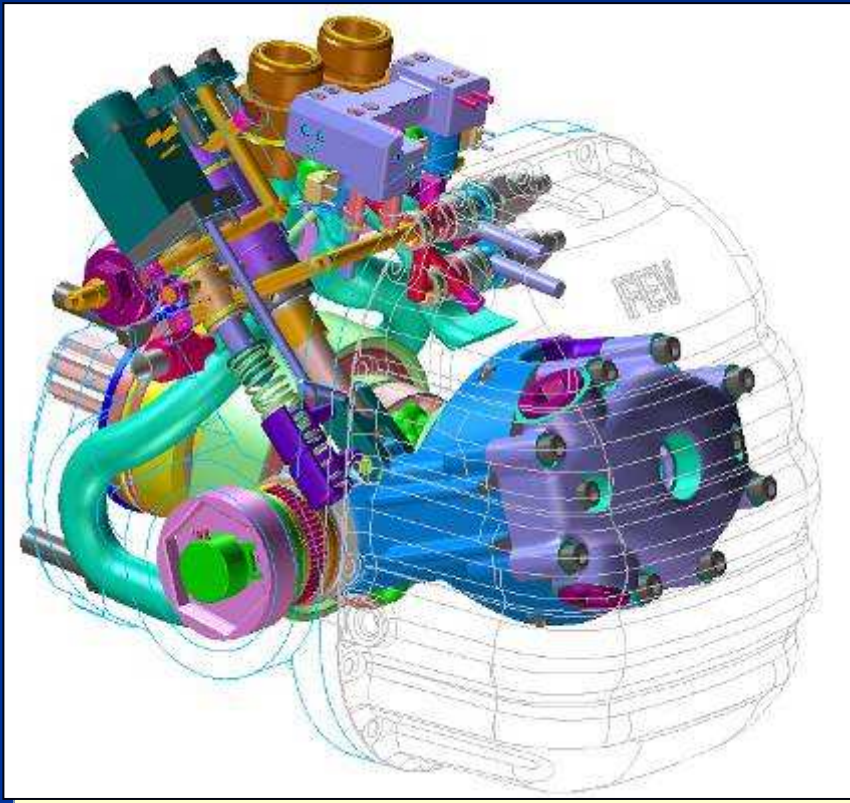


High power density capable of producing:

- ☑ 330 HP at 5000 psi at 45 deg.
- ☑ 510 HP at 7000 psi at 45 deg.

How It Works...

Bent-Axis Pump-Motors



110cc pump-motor assembly



How It Works...

Adding Accumulators for Energy Storage

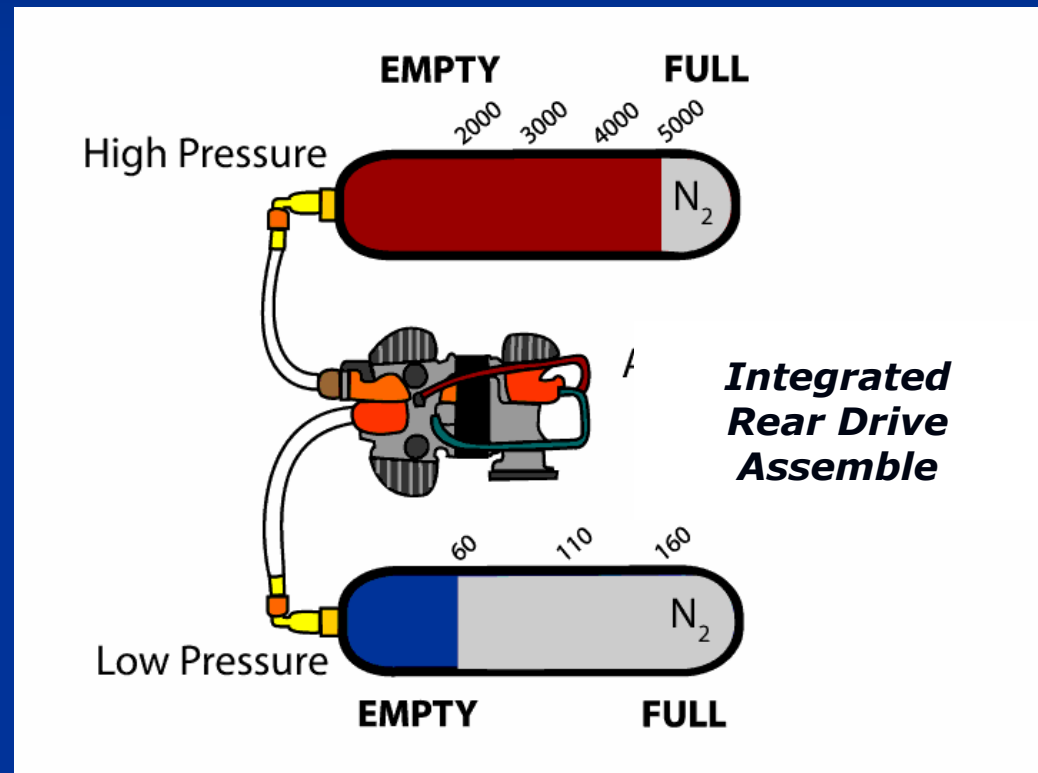
As hydraulic fluid enters either accumulator, the nitrogen (N_2) in that accumulator compresses and its pressure rises.

High Pressure

2000 to 5000 psi

Low Pressure

60 to 160 psi



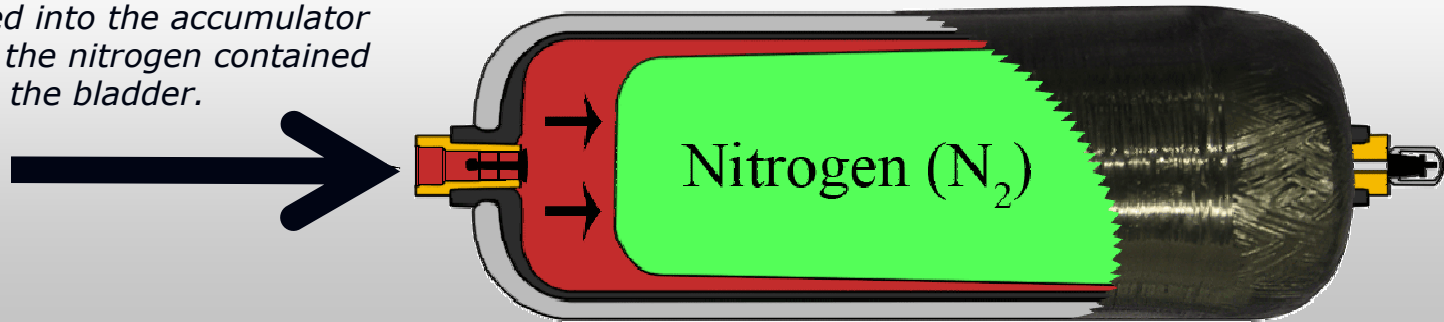
Future systems will utilize 7,000 psi

How It Works...

Types of Accumulators

"Bladder" Style

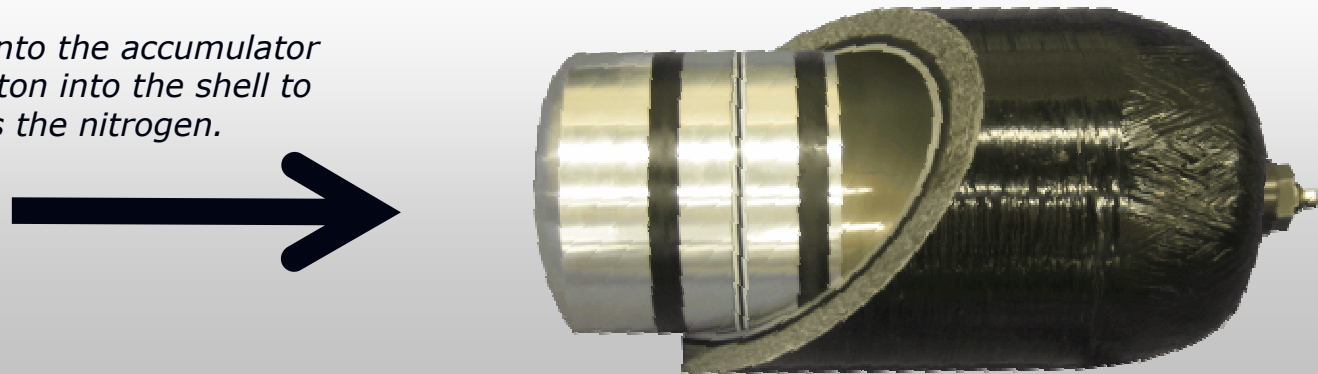
Fluid pumped into the accumulator compresses the nitrogen contained in the bladder.



A low pressure accumulator is pre-charged with fluid and nitrogen to about 60 psi.

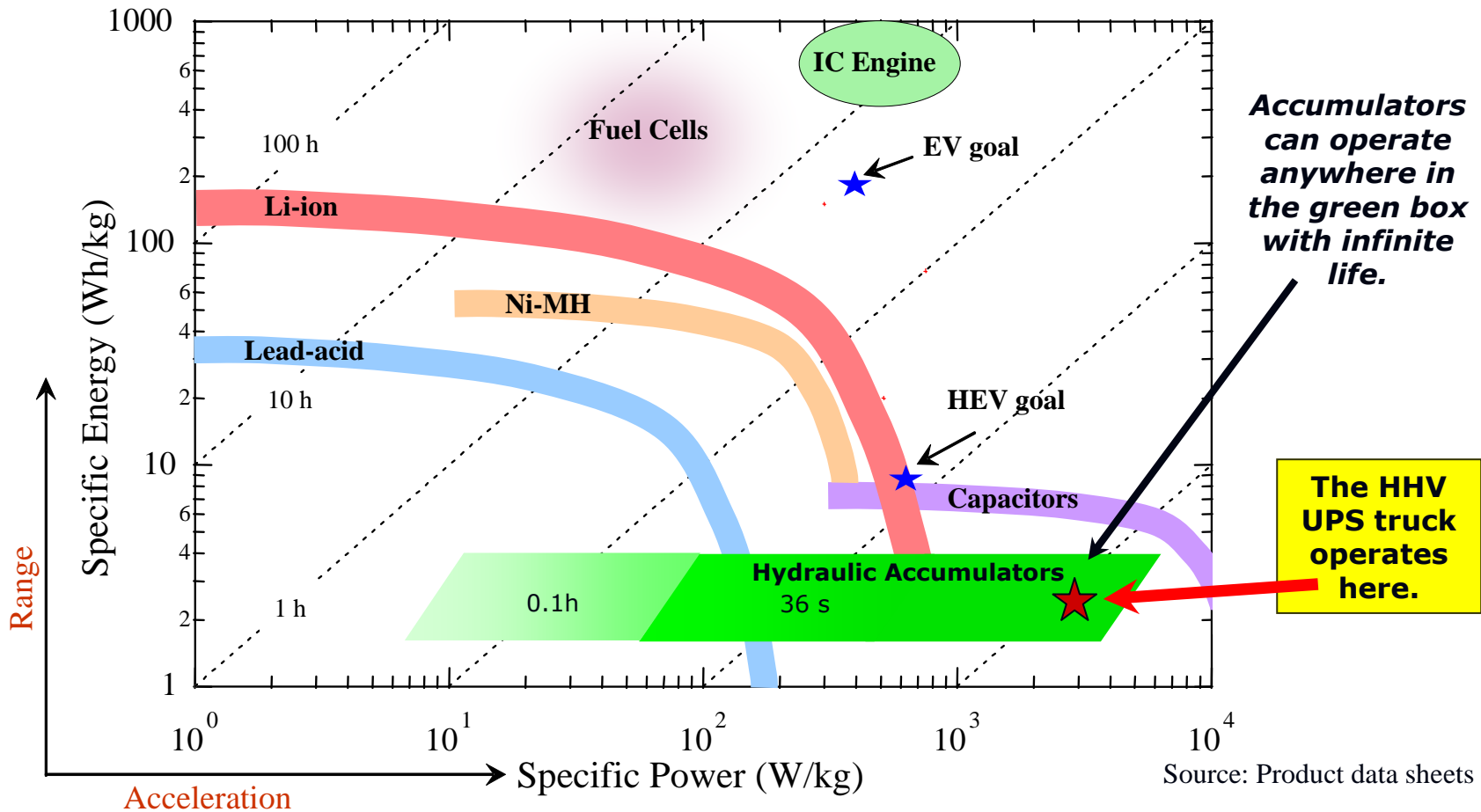
"Piston-Shell" Style

Fluid pumped into the accumulator pushes the piston into the shell to compress the nitrogen.



A high pressure accumulator is pre-charged with fluid and nitrogen to about 2000 psi.

Relative Performance of Various Energy-Storage Devices



Venkat Srinivasan and John Newman; Environmental Energy Technologies Division; Lawrence Berkeley National Laboratory; Berkeley, CA

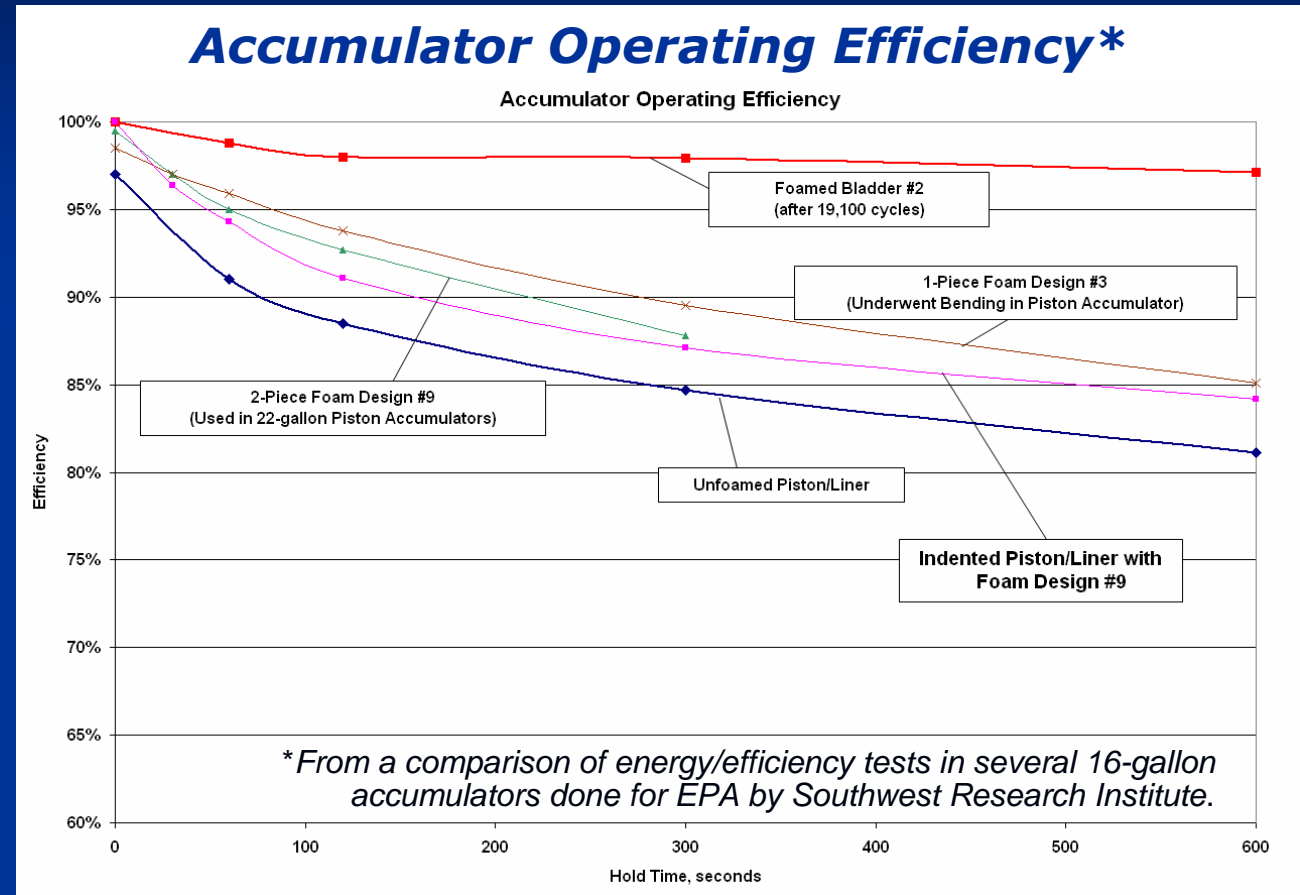
Charge/Discharge Efficiency...

✓ 60-second Hold

After a 60 sec hold, typical foamed accumulators were able to retain **94% to 98%** of the energy.

✓ 10-minute Hold

The best accumulator tested was able to retain **97%** of the energy.



Enabling Engine-Off Power Brake System

Brake Booster Unit

1. EPA designed hydraulic brake booster
2. Direct replacement for stock hydro booster
3. Uses onboard hydraulic pressure supply
4. Enables engine off operation
5. Performs and feels the same as stock brake booster
6. Very low energy consumption



Enabling Engine-Off Power Steering System

Closed Center Steering Gear

1. EPA designed closed center power steering
2. Direct replacement for stock open center steering
3. Eliminates the engine driven power steering pump
4. Uses on board hydraulic pressure supply
5. Enable engine-off operation
6. Performs and feels the same as stock power steering
7. Very low leakage in neutral position



Overview of EPA Demonstration Vehicles



Goals

- To demonstrate *Best Possible Business Case* for hybrids to both manufacturers, suppliers and fleets
- To show that series Hydraulic Hybrids Vehicles (HHV) have *highest efficiency* at the *lowest cost* potential
- To definitively show that there are *no technical barriers* for series HHVs to be commercially viable

EPA Hydraulic Hybrid Timeline

Chassis 6 – Taurus size

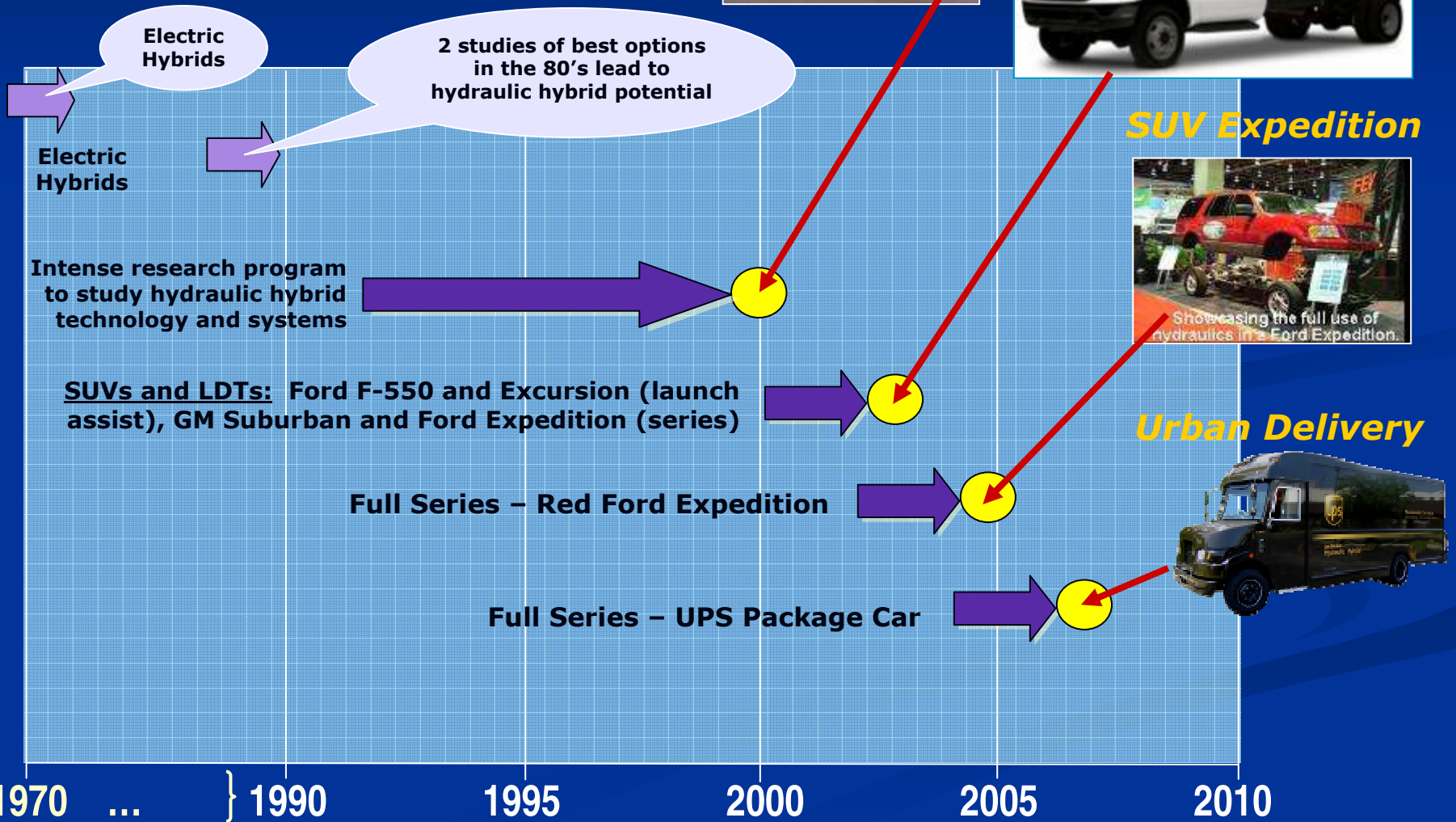
F-550 Work Truck



SUV Expedition



Urban Delivery



Why Series Hydraulic Hybrids?

- ✓ **Highest possible fuel economy**
- ✓ **Lowest incremental cost**
 - Shortest payback to owner
 - Highest lifetime-savings
- ✓ **Enables unique high-efficiency engines**

- ✓ **Ultra-low emissions**
- ✓ **Greater reductions in greenhouse gases**
- ✓ **Greater reductions in oil use**

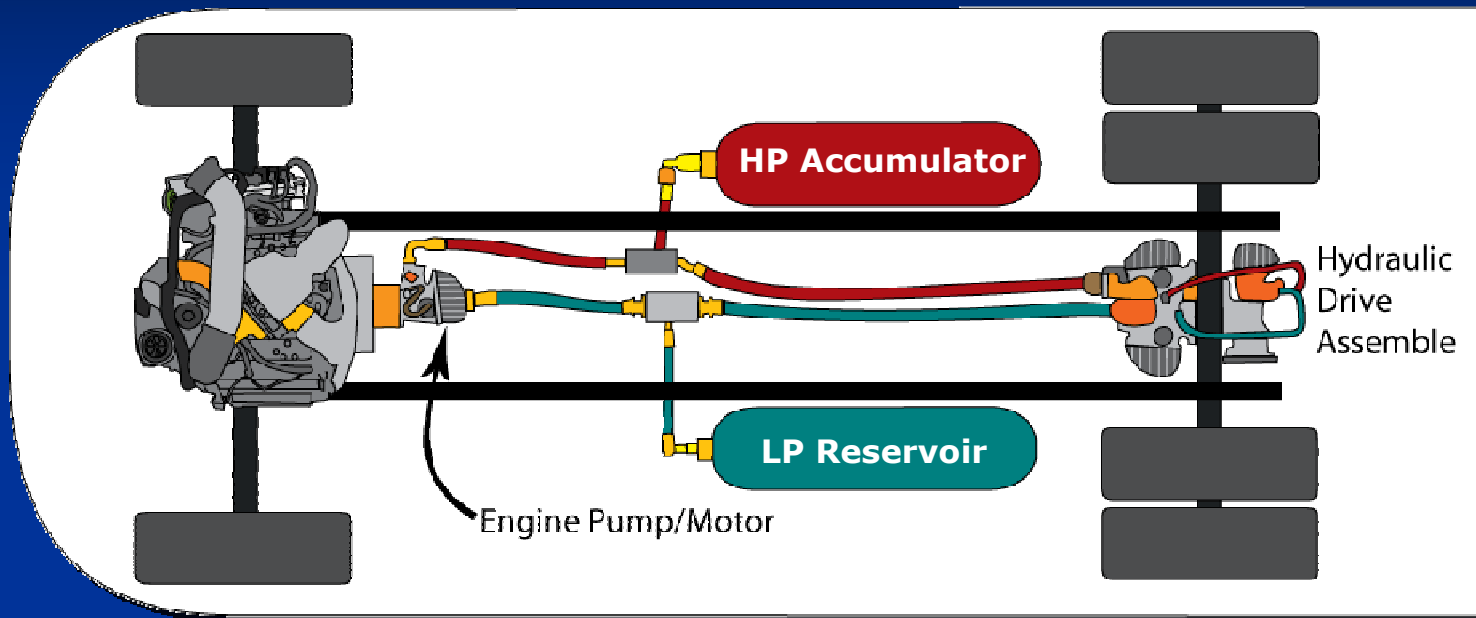
EPA's Full Series Hydraulic Hybrid Urban Delivery Vehicle

Hydraulic Hybrid UPS Package Car Demonstration Creates "Real World" Experience



- 60-70% mpg improvement in city driving
- 2-3 year payback has attracted attention from fleets
- Potential for net Lifetime savings over \$50,000 with \$2.75/gal fuel costs
- Demonstration to accelerate technology transfer to industry & familiarity with technology
- Partners (UPS, Eaton, International Truck, US Army)

Full Series Hydraulic Hybrid Truck Configuration



Benefits

- ✓ Reduced fuel consumption
- ✓ Reduced emissions
- ✓ Reduced engine on-time (no idling)
- ✓ Reduced brake and engine wear



Fuel Economy Improvement



Summary of Initial Lab Results using EPA City Cycle

	MPG	Increase
Baseline Vehicle	10.4	---
Hydraulic Hybrid engine always running	14.4	39%
	15.0	44%
Hydraulic Hybrid engine-off when truck not moving	15.8	52%
	16.5	59%
Hydraulic Hybrid engine-off when truck decelerating or not moving	17.8	70%
	18.1	74%

On-Road Field Testing



- **Field Tests** – On-road field testing during normal on-route package delivery began last fall in the Detroit area.
- **UPS Very Pleased with Results** – With how the vehicle performed, and with the fuel economy gains demonstrated in these early tests.
- **More Testing** – Additional field testing is focusing on evaluating the performance characteristics of options for potential “pre-production” trucks.
- **Durability Testing** – Mileage accumulation durability testing will begin in early 2008.

45-50% Initial In-Service MPG Improvement using Prototype Hardware



More MPG is Coming Through...

- **Improving Engine-off Accessories** – Installing 2nd generation engine-off power brakes and power steering (less energy consuming)
- **Replacing Engine Pump** – More efficient EPA hardware
- **Shutting Engine Off More** – Advanced control strategy
- **Lowering Weight** – Eliminating prototype hardware and mounting structures which enabled testing with the body off added about 2500 pounds of incremental vehicle weight (target weight increase is about 900-1200 pounds)

Series Hydraulic Hybrid Yard Hostler

Projected Benefits

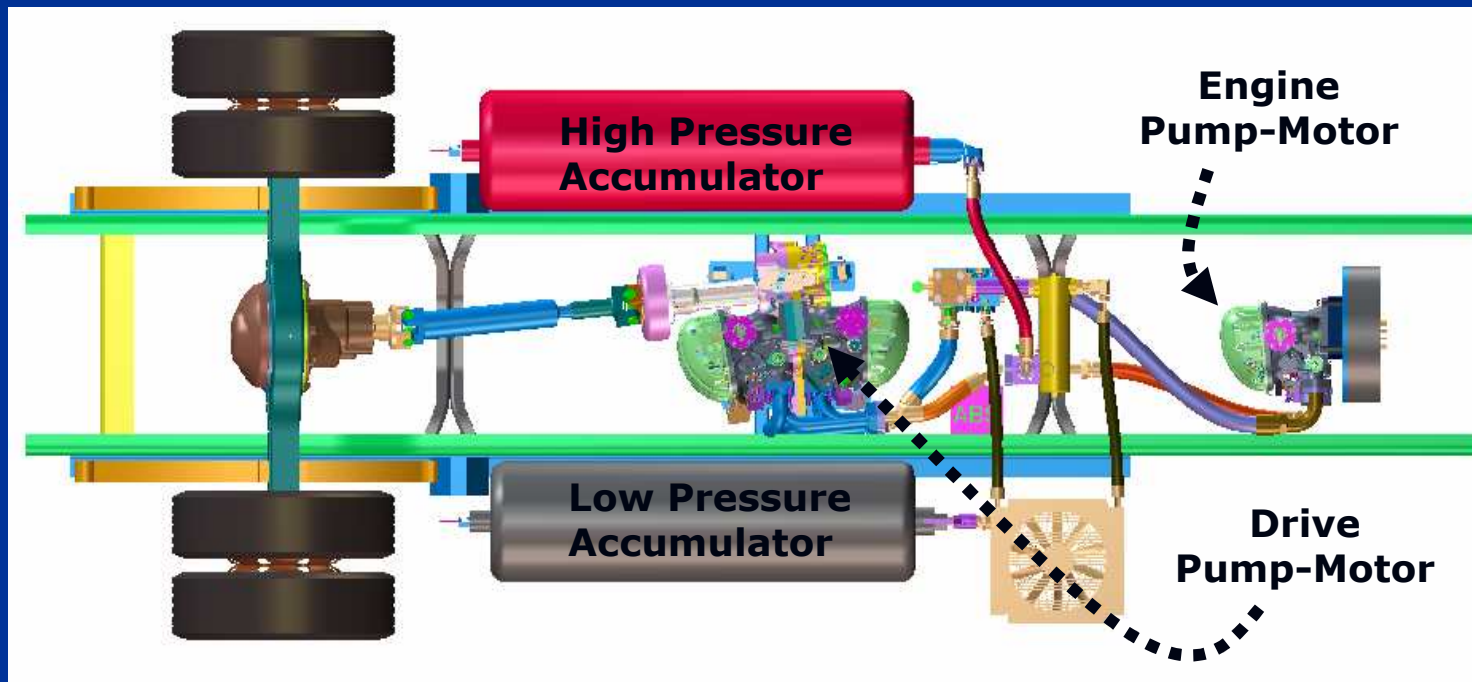


- 50-60% projected efficiency improvement in port operation (preliminary)
- Fuel savings \$23,000 with \$2.75/gal fuel costs (7 years for first owner)
- Demonstration to accelerate technology transfer to industry & familiarity with technology

Partners

- ✓ *EPA (Region 2, OIA, and OTAQ-NVFEL)*
- ✓ *Port Authority of New York and New Jersey*
- ✓ *APM Terminals North America*
- ✓ *Parker-Hannifin Corporation and Kalmar Industries*

Series Hydraulic Hybrid Yard Hostler Concept for Chassis Layout



This is Just the Beginning

Full Series Hydraulic Hybrids Create the Opportunity to use New High Efficiency Engines

Clean Diesel Combustion (CDC)

- No NOx Aftertreatment – EPA is working with International and Ford
- Effective use of DME

E85 (or M85) Fueled Engine

- Diesel efficiency levels (40%) from Ethanol or Methanol
- Engine costs similar to gasoline engines
- Supports US renewable fuel initiatives

High Efficiency Gasoline (HCCI)

- Homogenous Charge Compression Ignition
- Diesel efficiency levels (40%) from gasoline (Tier2 bin 2 emissions)
- Engine costs similar to gasoline engines

Direct Hydraulic Power (Free Piston Engine)

- High efficiency (40%) hydraulic power directly from a free piston – no crank

HyTEC –Hybrid Thermal Energy Converter

- Recovers energy from engine exhaust heat,
- Yields fuel cell efficiency levels at 1/5th the cost