Hydraulic Hybrid Vehicle Technologies

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Project Engineer
Bosch Rexroth Corporation

Clean Technologies Forum, Sacramento, CA
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Introduction

Michael Conrad

Project Engineer – Intelligent Hydraulic Drive (IHD) Products

Birthplace & Date

- 1968, Findlay, OH

Education

- University of Toledo - Bachelor of Science Mechanical Engineering Technology
- University of Findlay – Masters of Business Administration

Career History

- **1989 – 1996:** The D.S. Brown Co., North Baltimore, OH – Project Engineer – High Load Bearings and Expansion Joints for Bridge Structures
- **1996 – 1999:** Cummins Filtration, Findlay, OH – Customer Engineer – Specialty Insert Molded Filtration
- **1999 – 2006:** DaimlerChrysler, Auburn Hills, MI – Product Engineer – Steering Column System Design
- **2006 – 2008:** John Deere, Dubuque, IA – C & F Quality Engineer – 4WD Loader Powertrain
- **2008 – Present**: Bosch Rexroth, Rochester Hills, MI – Project Engineer – Intelligent Hydraulic Drive (IHD) Products

Family

- Married, three children

Contents

- Company Introduction
- Trends & Drivers of Change
- What are Hybrids? Types of Hybrids
- Hydraulic Hybrids: Parallel and Series configurations & results
- Q&A

Contents

The Bosch Group

- Bosch achieved worldwide sales in 2007 of $63.4 billion
- Bosch employs approximately 271,000 people worldwide in more than 50 countries
- Bosch is a global leader in environmental stewardship
  - → Spending over 40% or +$2.0 billion of 2007 R&D budget on “green” technologies/products!

Bosch Group

Automotive Technology

Industrial Technology

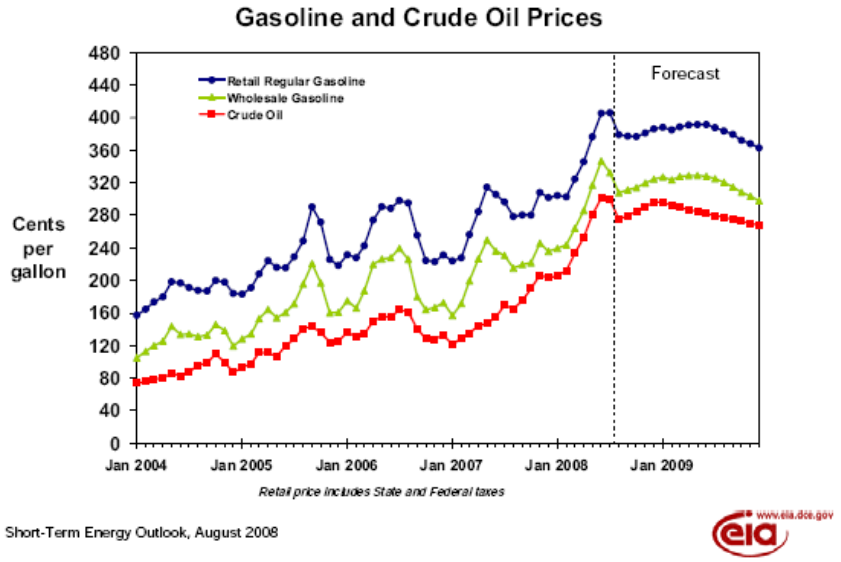
Bosch Rexroth AG

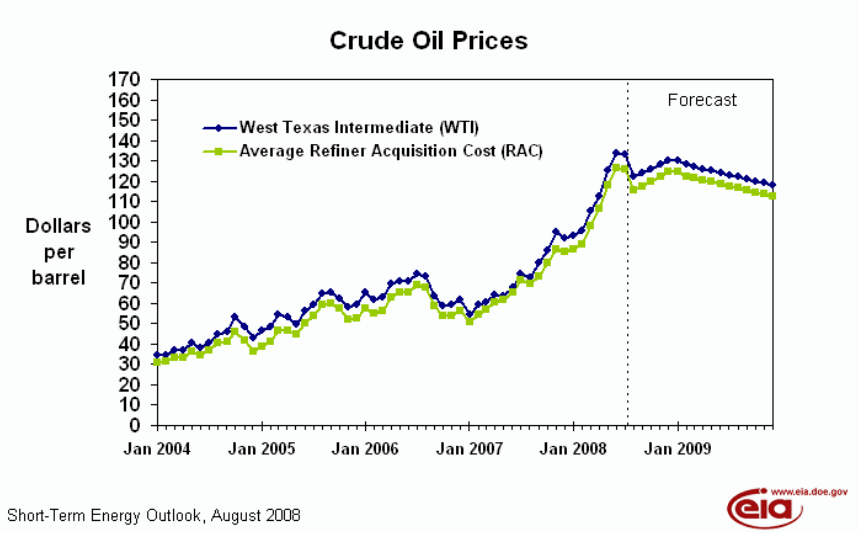
Consumer Goods and Building Technology

Contents

Trends & Drivers of Change

- **Rising Fuel Costs**
  - → $120 bbl reached → $5.00 gallon coming!
- **Major Engine Changes**
  - → Increased cost/complexity to comply with 2007, 2010 EPA
- **Green Footprint**
  - → Pressures to reduce carbon & overall environmental impacts
- **Trend towards integrated engine/drivelines**
  - → Especially in commercial vehicle fleets
- **Increasing electrical power needs**
  - → Especially in heavy vehicles and equipment





Market is evaluating many solutions: There is No Silver Bullet!

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Bosch Group

Alternative fuels

- → Ethanol
- → Biodiesel and renewable diesels
- → Natural gas (CNG, LNG)
- → Hydrogen
- → Coal-to-liquids
- → Advanced biomass (biobutane and E-Diesel)

Alternative powertrain

- → Advanced engine technologies (VVT, etc…)
- → Advanced transmission technologies (CVT, etc…)
- → Electric vehicles
- → Hybrid vehicles
  - Hybrid electric
  - Plug-in hybrid
  - Hybrid hydraulic

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What Are Hybrids?

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Hybrid comes from the Latin and means:

→ "mixed, having two origins"

- Hybrid vehicles use two types of energy to achieve optimal propulsion.

OEM's technology strategy

Hydraulic Hybrids:

- Use hydraulic pumps / motors
- Store energy in hydraulic accumulators

Electric Hybrids:

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

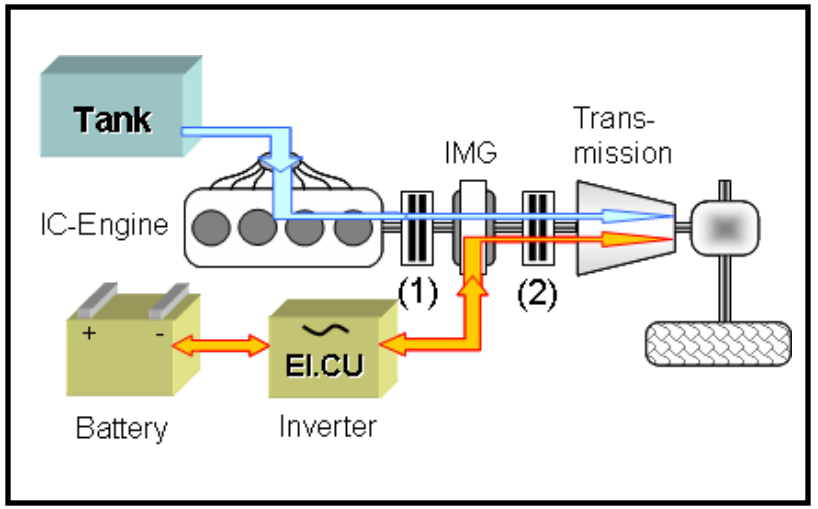
Hydraulic domain: Refuse Trucks, Construction Vehicles

Technology overlap

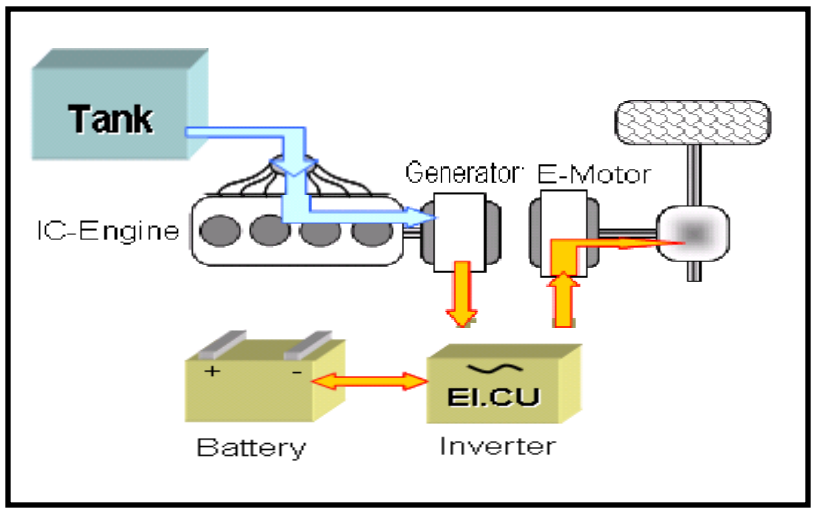
Electric domain: Pass. Cars, Light Comm. Veh.

Hybrid Electric Vehicles (HEV)

- Several different Hybrid Electric Vehicle architectures exist:
  - Types
    - Full Hybrid (electric driving)
    - Mild Hybrid (boost only, no e-drive)
  - Configurations
    - series, parallel, power split, dual mode
- Functions include:
  - Start-Stop
  - Boost to engine power
  - Electric Driving
  - Regenerative Braking
- Facilitates exportable power
- Fuel Economy improvements between 10% - 40% depending on system and driving cycle



Parallel Electric Hybrid Configuration



Series Electric Hybrid Configuration

Hybrid Hydraulic Vehicles (HHV)

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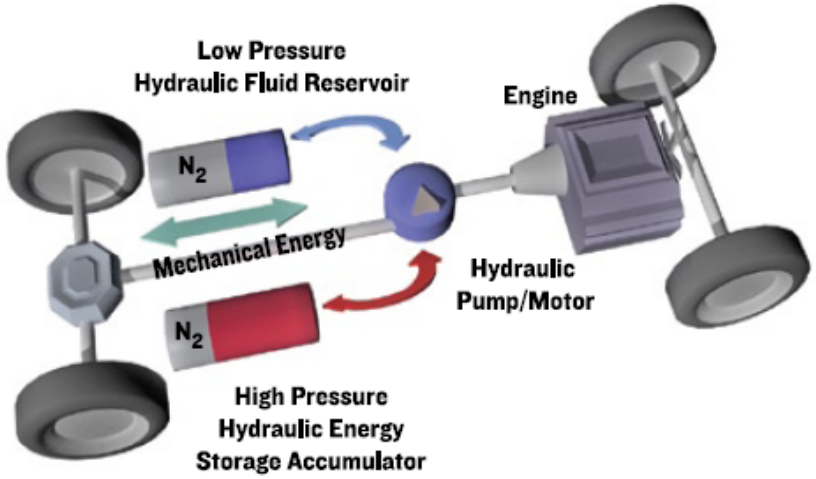
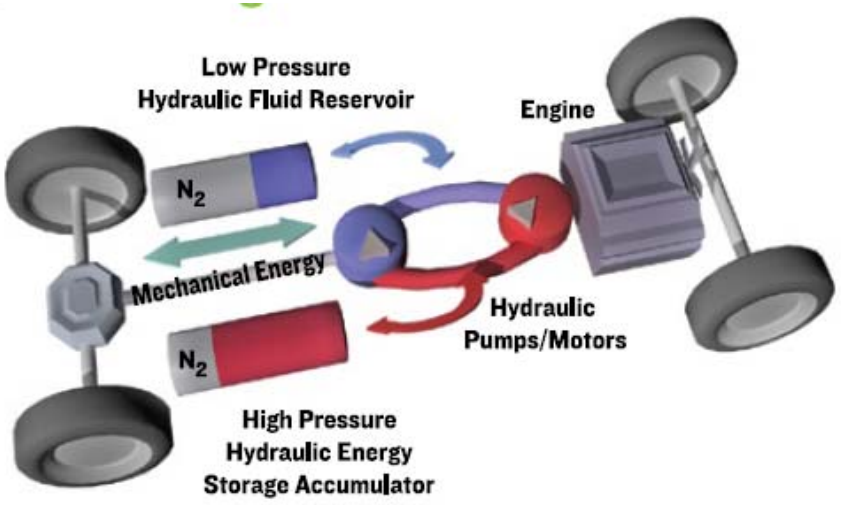
Parallel Hydraulic Hybrid



- 'Add-on' to existing drive train
- Stores the kinetic energy normally lost during braking in accumulators
- Utilizes conventional hydraulic products/technologies
- Improvements in fuel economy, emissions, brake life, acceleration

Series Hydraulic Hybrid

- Replaces conventional drive train
- Allows engine to operate at most efficient range
- Facilitates energy storage in accumulators
- Flexible configurations enable added functionality (active stability control, etc…)
- Improvements in fuel economy, emissions, vehicle performance



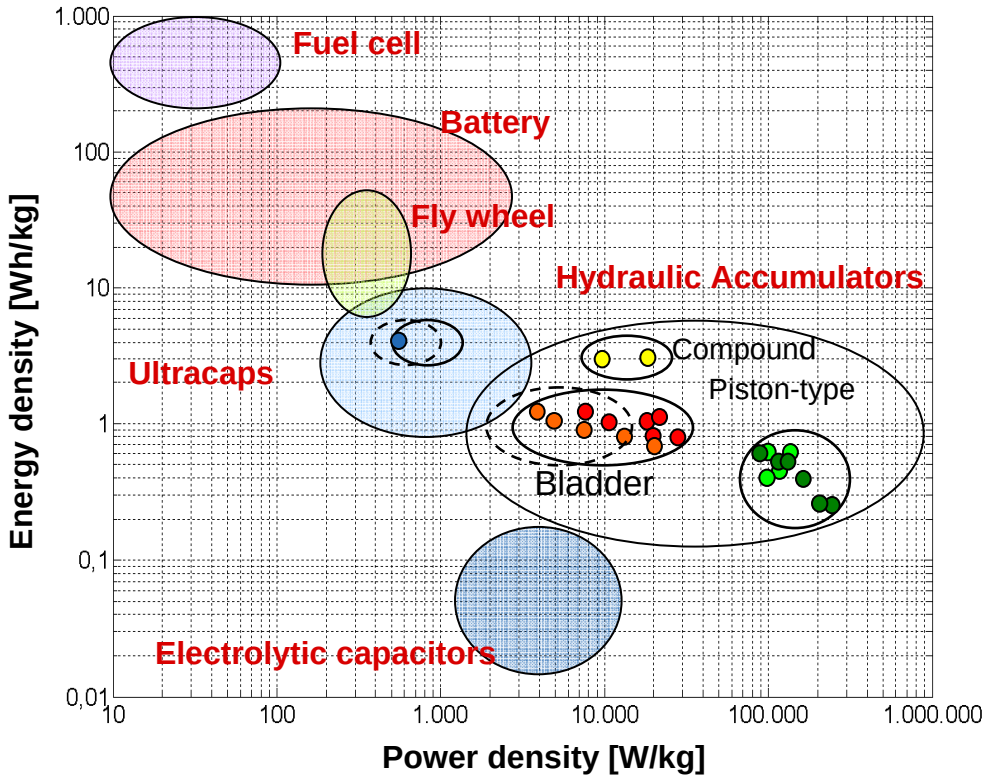
Energy Storage: Energy vs Power

Electrics

- High ***Energy*** Density
  - Extended run time
  - Extended peak load reduction
  - Auxiliary electric power available

Hydraulics

- High ***Power*** Density
  - Good recovery of kinetic energy (rate and efficiency)
  - Cycle benefits from fast energy release
  - High torque available
  - Lower cost potential



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Why Hydraulic Hybrid?

- High power hydraulic systems are robust
- Hydraulic systems are lighter than electric systems of similar power
- Hydraulic systems are cheaper than electric systems of similar power
- Conventional material and processes used
- With proper choice of oil, hydraulic systems will operate over full range of climatic conditions
- Reliable and quiet integrated systems available using fluid power industry components
- Hydraulic systems are fuel neutral can be applied to vehicles of all fuel types (CNG, LNG, Bio-based diesel, etc…)

Typical Applications for Hydraulic Hybrids

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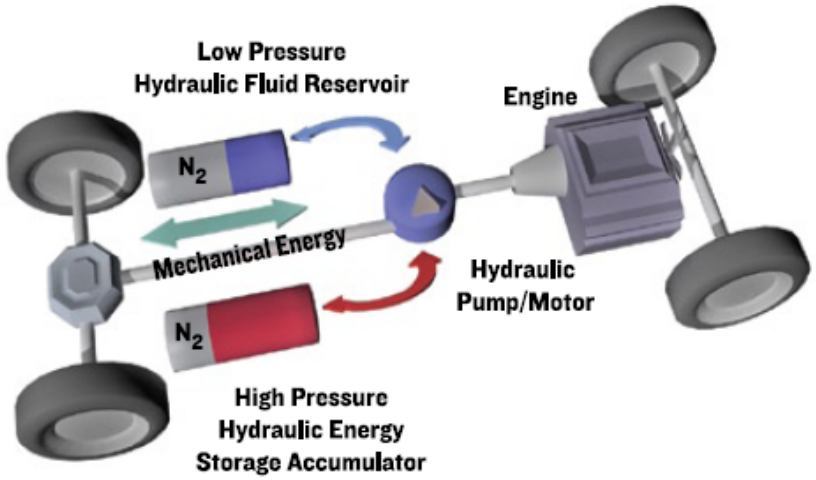
Parallel Hydraulic Hybrid



Medium/Heavy
Military

Refuse

Bus

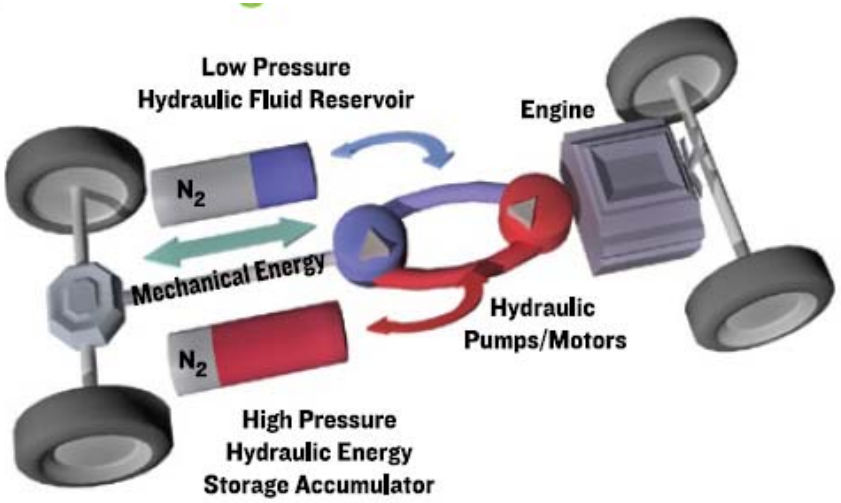
Series Hydraulic Hybrid

Light Military

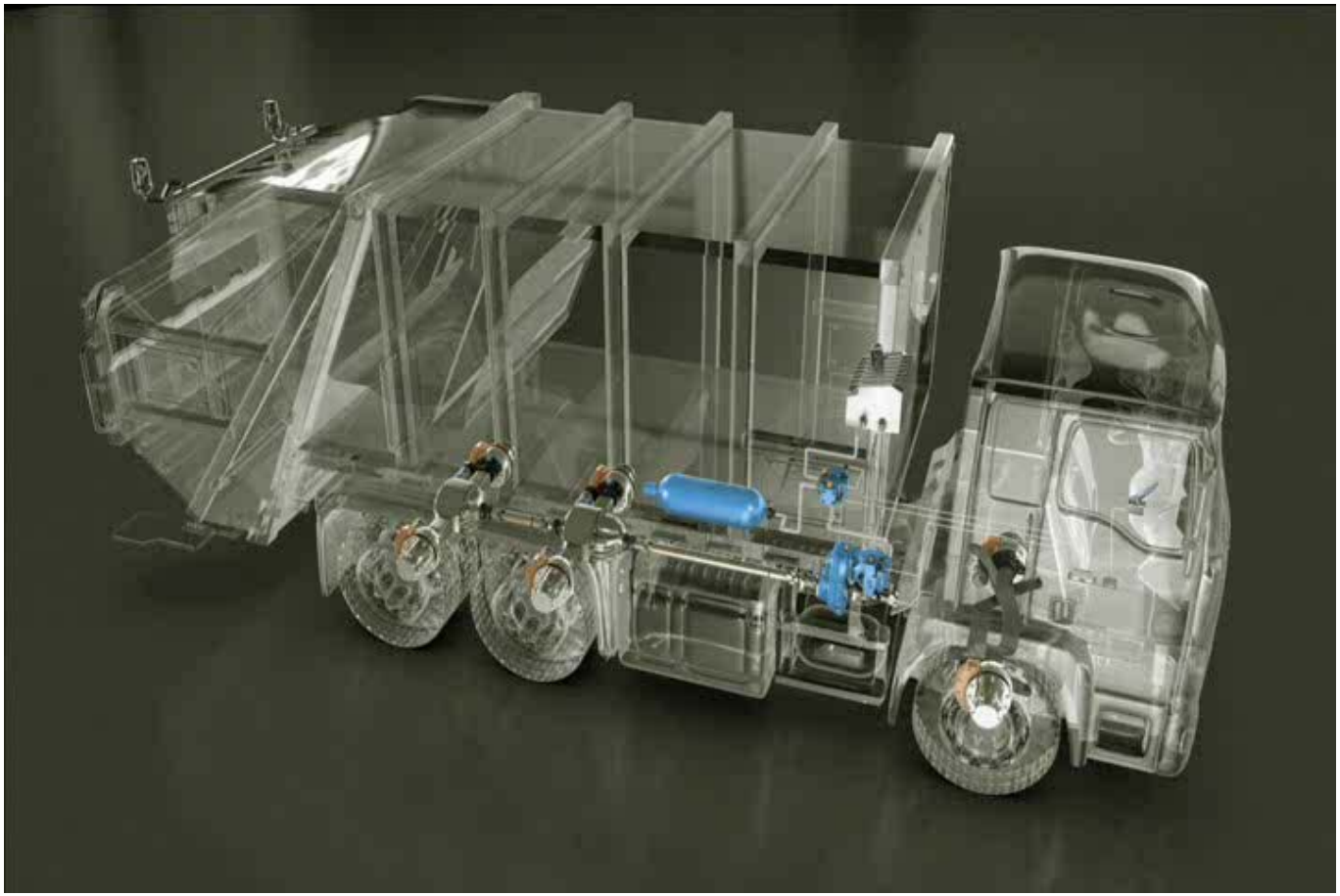
Delivery

Light Vehicles

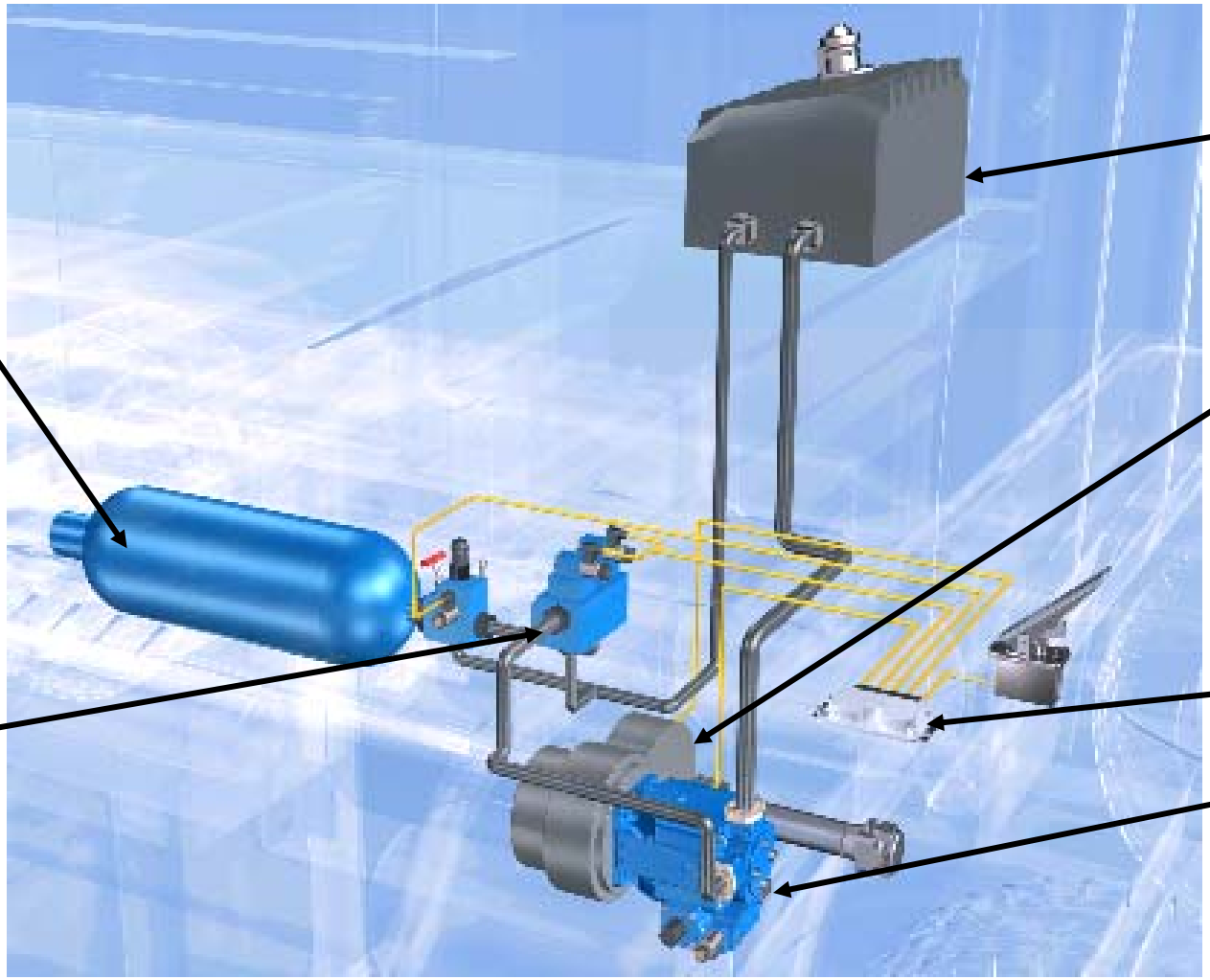
Bus



Parallel Hydraulic Hybrid System: Basic Operation



Parallel Hydraulic Hybrid System Configuration



Parallel Hydraulic Hybrid System: Refuse Example

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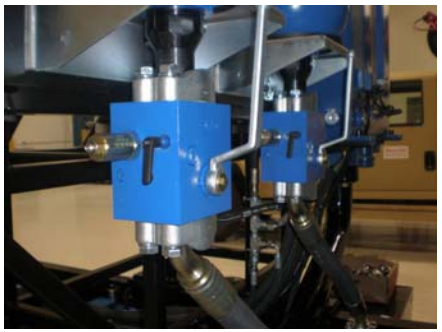

Pressure relief valves for accumulators

Manifold block

Pump/motor/gearbox

Pilot Oil Supply

Accumulators and integral reservoir

Bosch Controller

Parallel Hydraulic Hybrid System: Results

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Customer / Application	Technology / Configuration	RESULTS			
		Calculation	Simulation	Track / Dyno Test	Field Testing
		% FCR / % FEI	% FCR / % FEI	% FCR / % FEI	% FCR / % FEI
European Refuse Truck	Parallel HRB	--- ---	FCR = 16% FEI = 19%	FCR = 15% FEI = 17.6%	Expected 4Q2008
North American Refuse Truck	Parallel HRB	FCR = 11.5% FEI = 13%	--- ---	Expected 4Q2008	Expected 3Q2009
North American School Bus	Parallel HRB	FCR = 22.8% FEI =29.6%	TBD	TBD	TBD

FCR = **F**uel **C**onsumption **R**eduction

FEI = **F**uel **E**conomy **I**mprovement

Typical Applications for Hydraulic Hybrids

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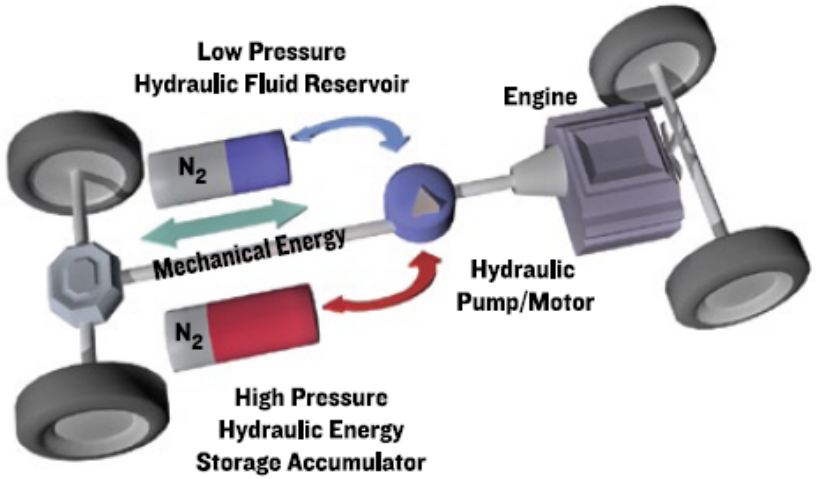
Parallel Hydraulic Hybrid



Medium/Heavy Military

Refuse

Bus

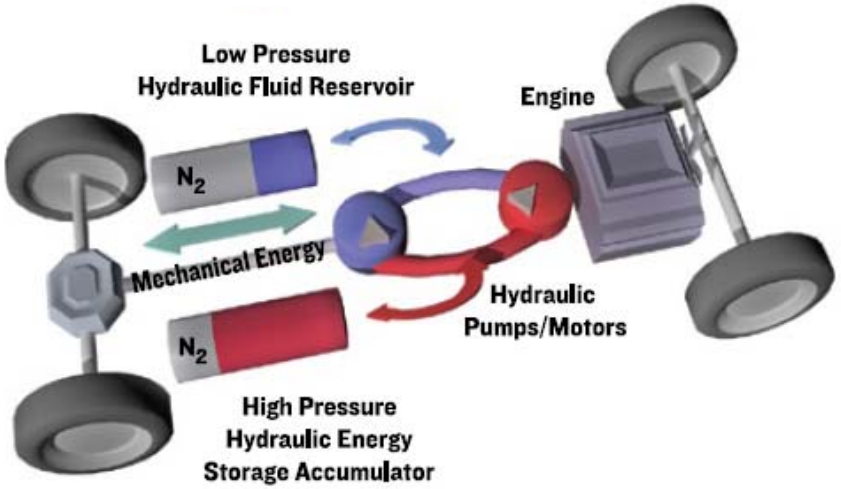
Series Hydraulic Hybrid

Light Military

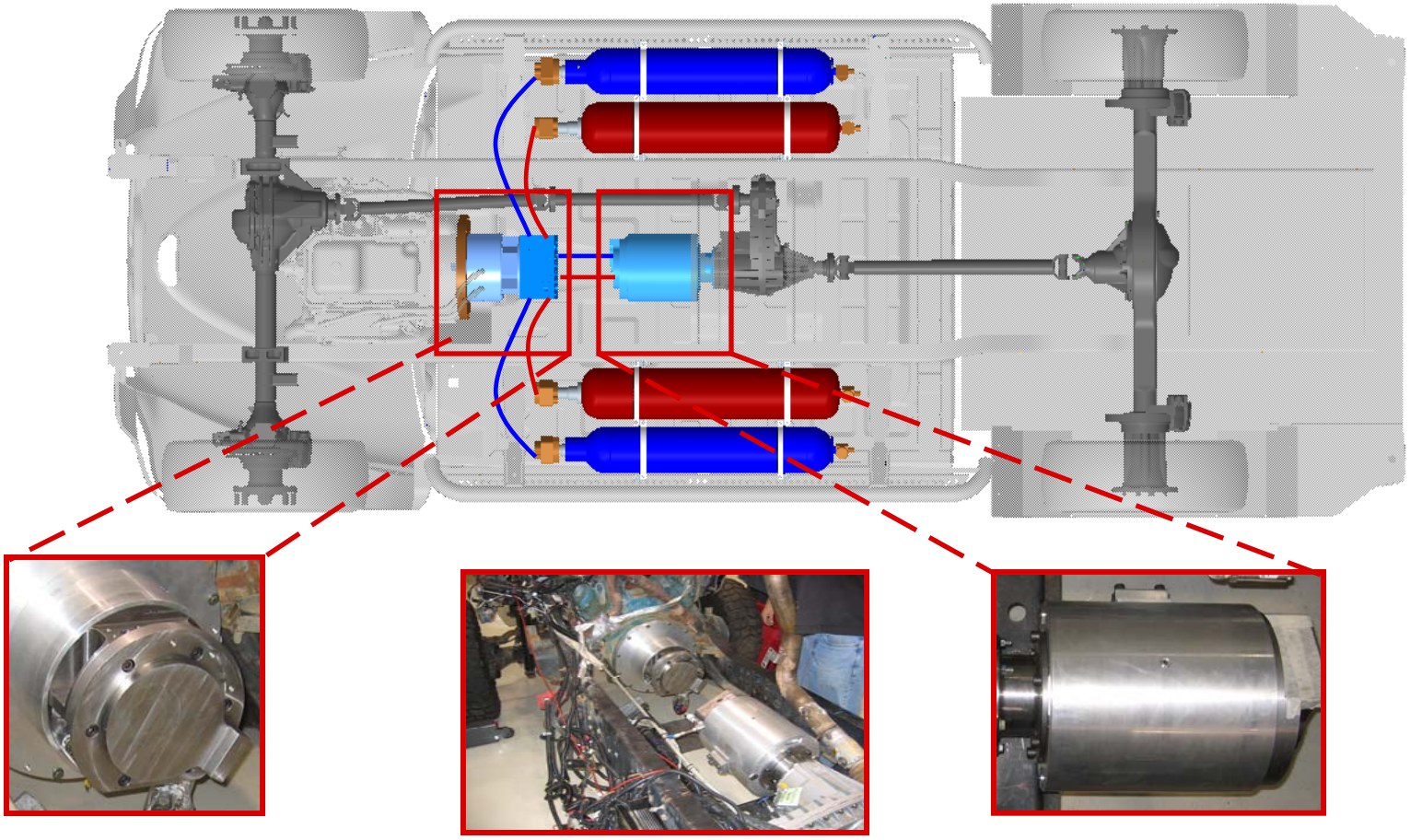
Delivery

Light Vehicles

Bus



Example Installation: Medium Duty Vehicle



Example Installation: Passenger Vehicle

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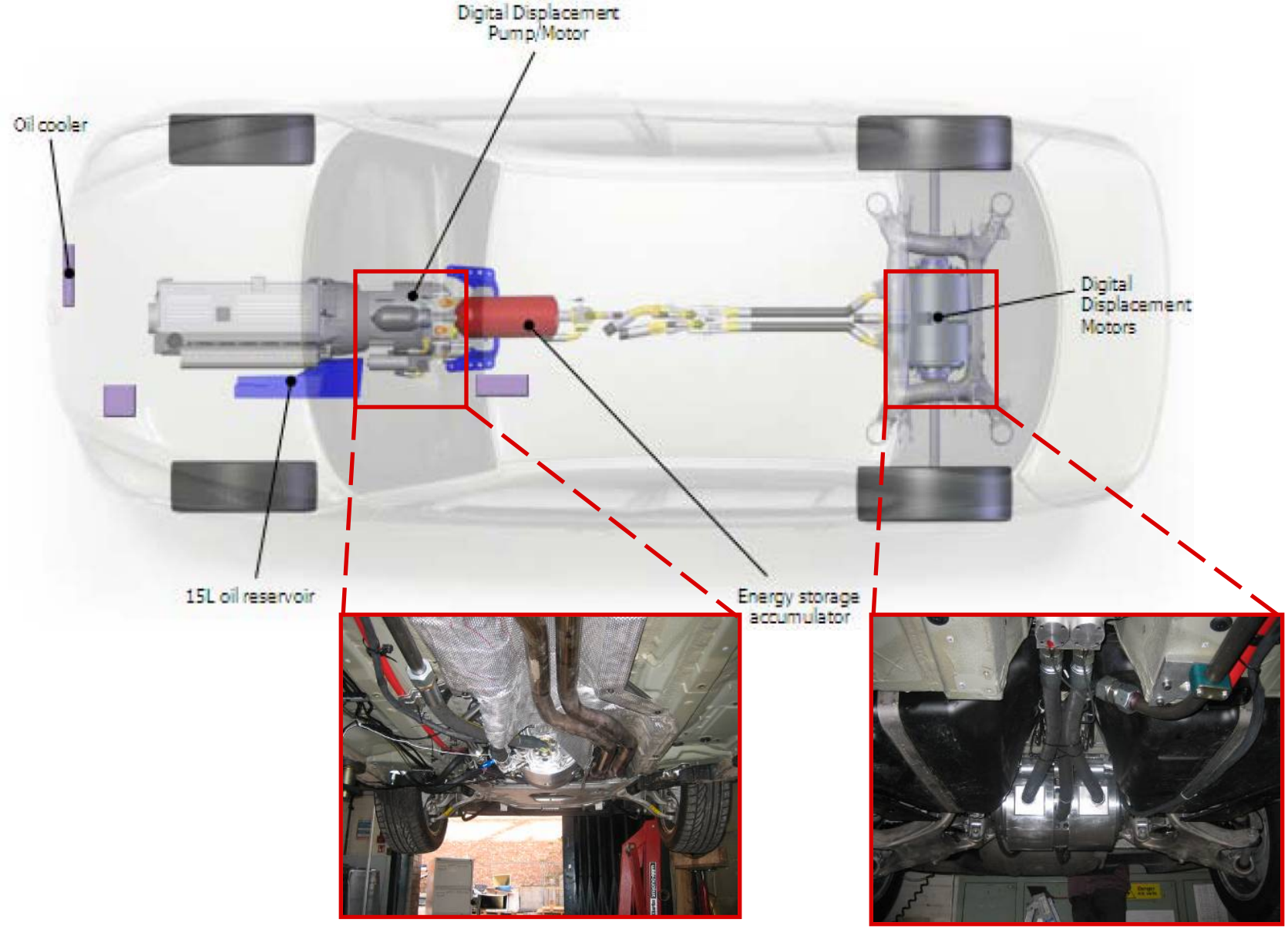

Series Hydraulic Hybrid System: Results

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Customer / Application	RESULTS			
	Calculation	Simulation	Track / Dyno Test	Field Testing
	% FCR / % FEI	% FCR / % FEI	% FCR / % FEI	% FCR / % FEI
Medium Duty Truck FTP 75	---	FCR = 47% FEI = 88.5%	TBD	TBD
Light Duty Passenger Vehicle NEDC	---	FCR = 41.7% FEI = 71.5	FCR = 34% FEI = 51%	TBD

FCR = **F**uel **C**onsumption **R**eduction

FEI = **F**uel **E**conomy **I**mprovement

Summary

- Hydraulic Hybrid Vehicle Technologies are here!
- Hydraulic Hybrid Vehicle Technologies can offer a significant value proposition
  - Reduced fuel consumption
  - Reduced emissions
  - Improved acceleration
  - Reduced brake wear
- Hydraulic Hybrid Vehicle Technologies are gaining momentum in the marketplace
- Hydraulics are known technology with history of quality, performance, and durability
- Bosch and Bosch Rexroth have combined leadership in advanced vehicle systems and hydraulic drive and control solutions

Please Come to the Midwest in October!

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