VEHICLE TECHNOLOGIES PROGRAM

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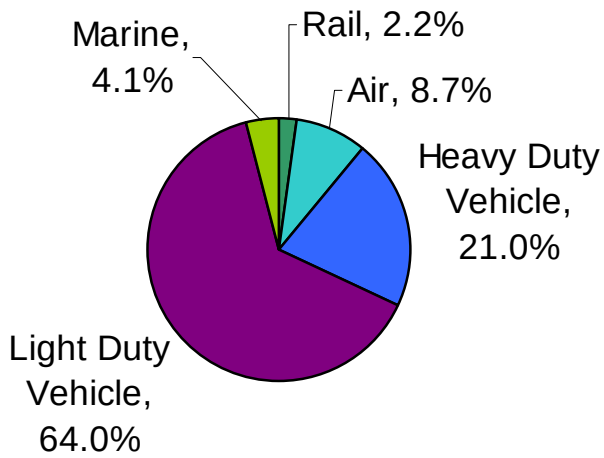
VENTURE CAPITAL TECHNOLOGY SHOWCASE
AUG 21 AND 22, 2007

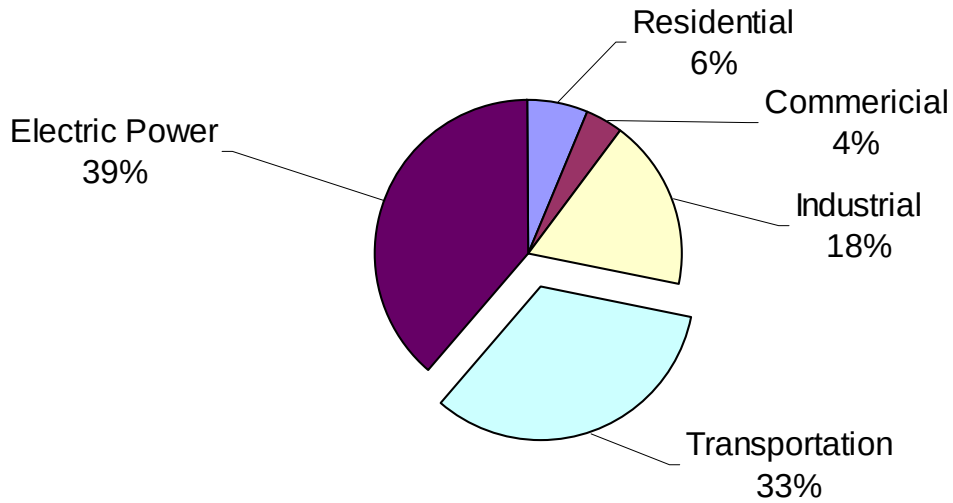
The Challenge

Transportation Petroleum Consumption by Sector



The transportation sector accounts for 2/3 of the oil use in the U.S. and is the fastest growing petroleum consuming sector.

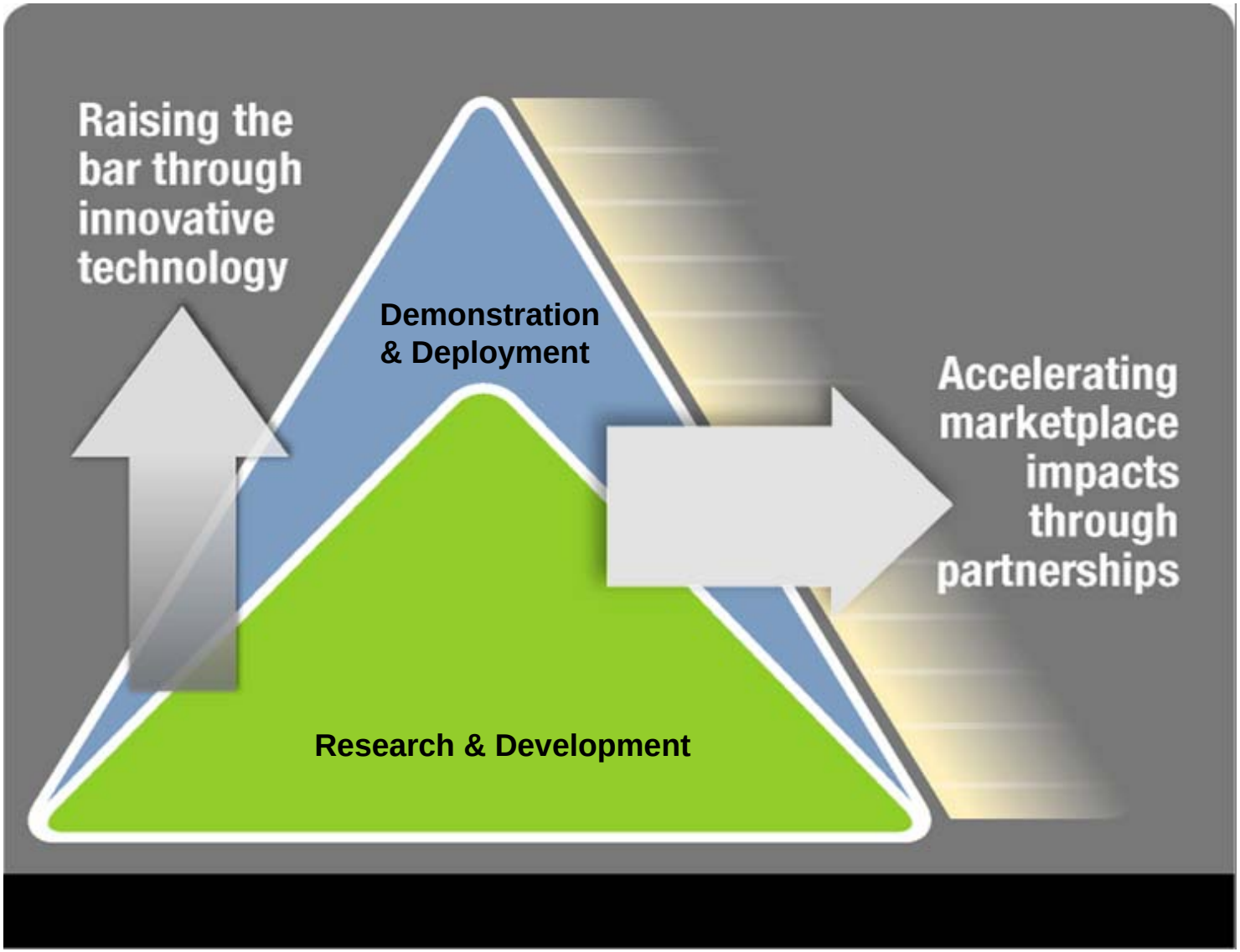
Carbon Dioxide Emissions by End Use Sector



The transportation sector accounts for 1/3 of the carbon dioxide released in the U.S. and is the fastest growing source.

Overcoming Our Addiction

Begins with Efficiency & Fuel Substitution R&D



Vehicle Technologies

Research Results that make a Difference

Advanced Technologies for High Efficiency Clean Vehicles

Vehicle Systems

- Aerodynamics
- Rolling Resistance
- Accessory Loads
- Systems Analysis and Target Setting

Tech Introduction

- EPAct
- Legislative & Rulemaking
- Clean Cities
- Validation
- Student Competitions
- GATE

Hybrid Propulsion

- Hybrid Electric Systems
- Power Electronics
- Advanced Batteries
  - –High Power
  - –High Energy
- Inverters/Controllers
- Motors

Advanced Combustion Engines

- Low Temp. Combustion R&D
- Emission Controls
- Light- & Heavy-Duty Engines
- Health Impacts
- Solid State Energy Conversion *(thermoelectrics)*

Fuels Technologies

- Bio-Based Fuels
- HCCI Fuel Characteristics
- Fischer-Tropsch Fuels & Blendstocks
- Advanced Lubricants

Materials Technology

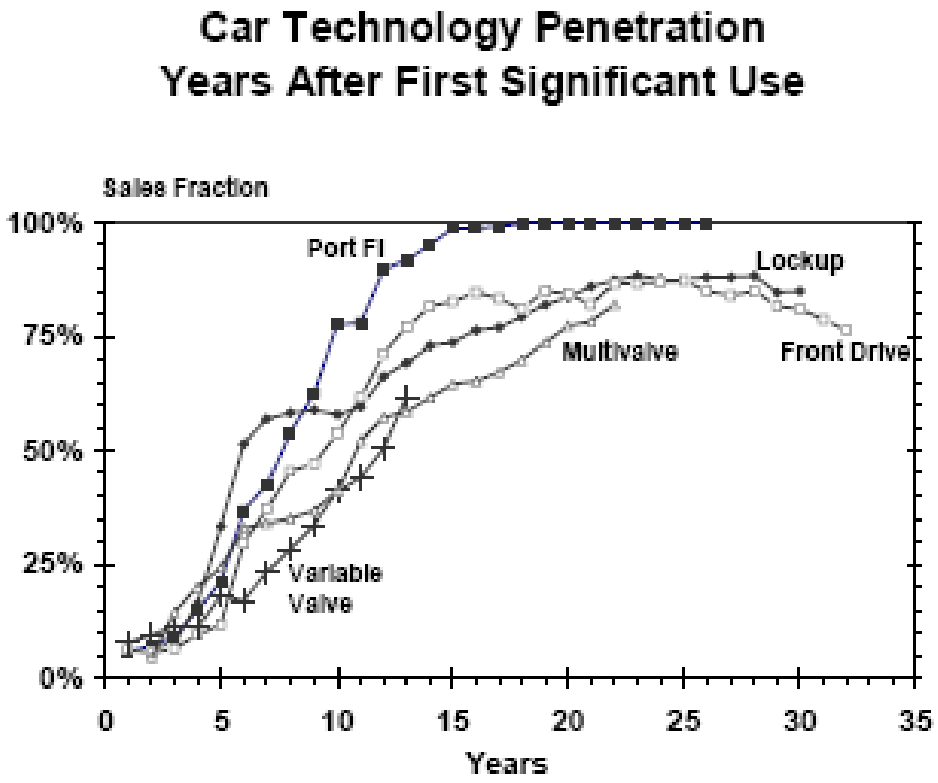
- Lightweight Structures
- Metal Processing
- Composite Development
- Processing and Manufacturing
- Design Data Test Methods
- Recycling Technology
- HTML

Technology Barriers

Research Seeks to Overcome These Hurdles

- **Components & Systems**
  - **Cost**
  - **Performance**
  - **Size and weight**
  - **Reliability**
- **High Volume Manufacturability**
- **Deployment & Infrastructure**

Market Trends



In the past, it has been observed that it takes about 12 years or more for a technology to reach maximum market penetration. How can this be accelerated?

Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2006, EPA420-R-011, July 2006, p. 62

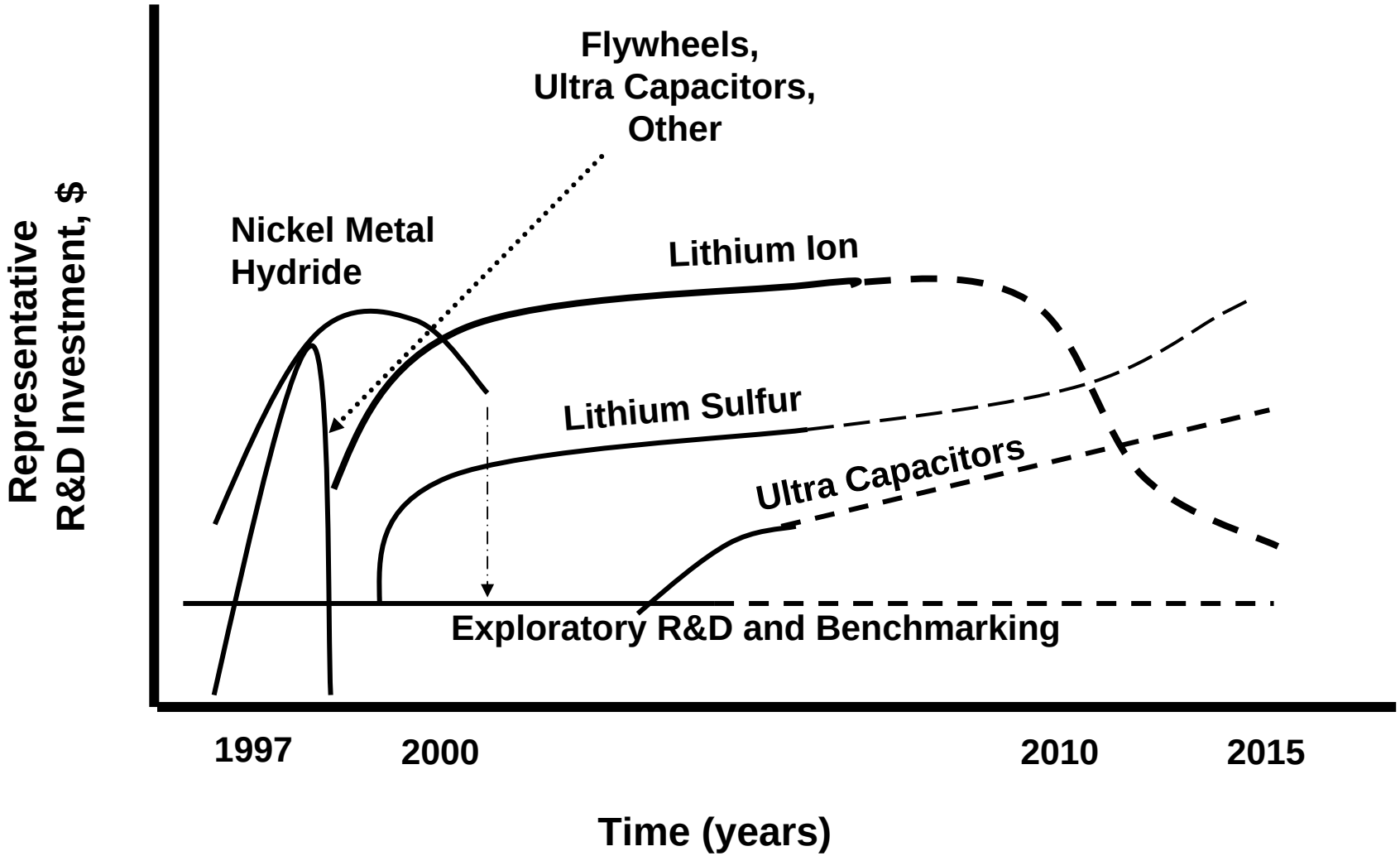
MARKET BARRIERS

- **Consumer**
  - Limited Market Drivers (consumer perception that fuel price increases are temporary)
  - Incremental Cost of Technology
- **Manufacturer**
  - High R&D Cost
  - Cost of Replacing Sunk Investments
  - Uncertain Market – Spurs Compromise Solutions
  - Globalization

Examples of Technology Success Stories

Deployed Technologies	Technology Partners	Policy Implications	Market Impact
Low Sulfur Diesel Fuel	ORNL NREL	Informed EPA of sulfur effects from fuel research	40B gallons of low sulfur diesel fuel used annually
Nickel Metal Hydride Batteries	Cobasys	Royalty payments to Treasury	Every US Hybrid Vehicle sold has IP from this battery research
Quick Plastic Forming of Aluminum	GM PNNL ORNL	Higher Energy Efficiency	Chevrolet Malibu MAXX 2004, Cadillac and other GM Vehicles
Light Duty Diesel Engine	Cummins ORNL SNL	Higher Energy Efficiency for Light Vehicles	Agreement with DaimlerChrysler for 2009 volume production

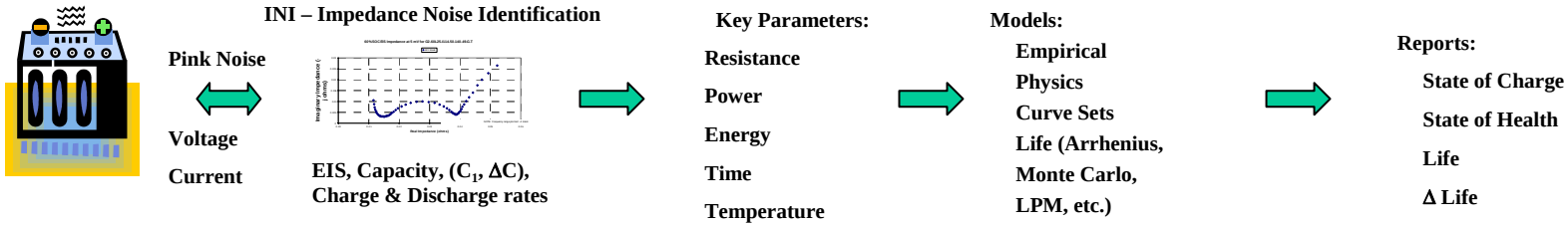
R&D Evolution



Smart Battery Status Monitor

- **Problem:** The required 15-year battery life and commensurate warranty issues for advanced batteries for hybrid and plug-in hybrid electric vehicles leads manufacturers to seek a rapid means to measure important battery parameters such as capacity, change in capacity, resistance, change in resistance, power, change in power, state of charge, state of health, and remaining life.

- **Description:** Idaho National Laboratories (INL), in partnership with Qualtech Systems Inc. (QSI), is developing a hardware device for U.S. Navy fighter aircraft that can measure battery impedance near real-time. This device when coupled with INL's diagnostic and prognostic models and testing and analysis methodologies will enable determination of the battery's state of health and remaining life in a flight maintenance environment.



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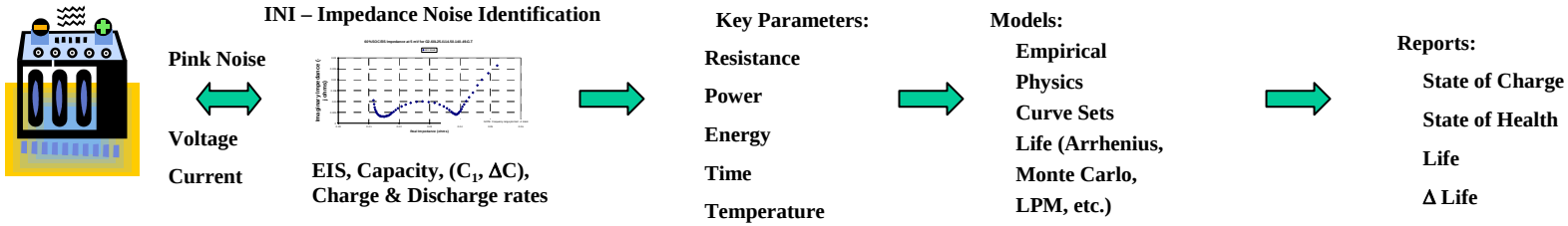
Smart Battery Status Monitor (cont.)

- **Impact:** The Smart Battery Status Monitor has utility for the domestic and international transportation vehicle market and to other users of advanced batteries e.g., the U.S. Department of Defense. A maintenance-environment diagnostic device for the US. Navy is estimated to cost about $10,000 each in small lots. No estimate has been developed yet for the cost of such devices in lots of 100,000.

- **IP:** INL and QSI have two patents pending and one Idea Disclosure Record (IDR)

- **Status:** Two separate but related near real-time in-situ impedance measurement devices have been demonstrated in the INL Energy Storage Laboratory, i.e., the Impedance Noise Identification System and the Compensated Synchronous Detection System.
  - The U.S Navy has announced an STTR Phase I award to QSI and INL to develop a Smart Battery Status Monitor (SBSM) for the Lockheed Martin F-35 Lightning II Joint Strike Fighter.
  - QSI's commercially available software environment consisting of TEAMS-RDS, TEAMS-KB, and TEAMATE for controlling the battery prognostic hardware, recording and analyzing the battery measurements and displaying the results is available for use in the SBSM.



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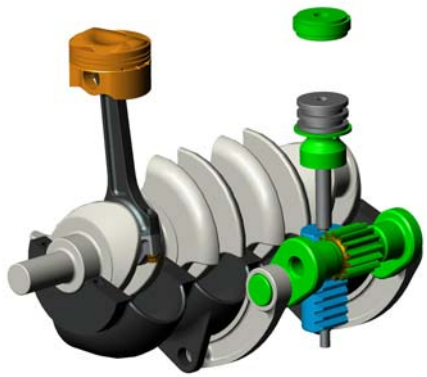
Variable Compression Ratio (VCR) Engine

- **Commercial benefits of VCR technology**
  - VCR enables up to 30% improvement in fuel economy.
  - Enables very efficient use of ethanol and other alterative fuels
  - Advantages: High power density; low emissions; low cost, fuel flexible



- **How variable compression ratio engine technology works**

  VCR enables over a 3X increase in power (horsepower per liter of engine displacement, hp/L) using the Prius engine as a baseline. Fuel economy gains are realized by using the VCR to increase engine efficiency, and VCR enables using a smaller engine to do the work of a larger conventional engine.

- **IP position**
  - US and European patents have been granted for the core technology.
  - Patents for refinements of the technology are being pursued.

- **Status**
  - DOE/Envera LLC currently assembling demonstrator car. Diesel engine design study completed in 2007 for one OEM.
  - A second OEM has decided to support R&D in FY 08 (gasoline engine).
  - Key decision making factors: Design simplicity; Design robustness; New power take-off design; OEMs increasingly interested in fuel economy.
  - Commercial sales (in the showroom) possible in 4 years.
  - Growth potential: VCR supports use of alternative fuels, reduction of diesel engine emissions, and advanced HCCI combustion. Can be combined with HEV technology.
  - Special needs: 1) Independent R&D development to ensure OEM moves forward with commercial sales. 2) Strengthen global IP position.

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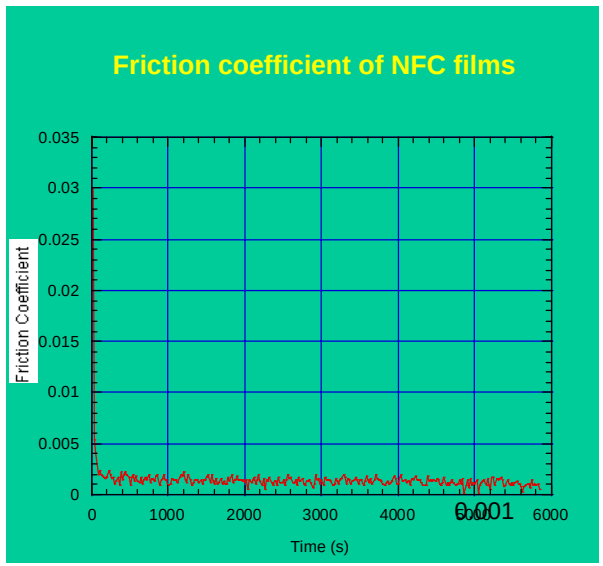
Near-frictionless Carbon Film

- **Problem:** Friction is a main source of lost energy in mechanical assemblies.
- **Description:** Argonne National Laboratory has developed a near-frictionless carbon (NFC) film that can reduce friction by up to 99% and prevent wear in a wide range of sliding contacts.
- **Impact:** Significant savings in energy, increased durability and performance in all kinds of moving mechanical assemblies, reduced emissions.
- **IP:** Argonne has a patent on this (NFC) technology and related superhard nano-technology.
- **Status:** NFC technology is being independently demonstrated at large volumes.
  - Available for commercial licensing.
  - The technology has a number of applications.
    - For magnetic data recording, capacity could increase up to 10-fold by allowing direct contact sliding
    - For next generation fuel injectors, improved durability under harsh engine conditions
    - Potential for tappets, bearings, valve lifters, and hydrogen engines
    - Bio-medical applications: hip and knees joint, stints, etc.
  - Large customer base and industrial interest
    - Over 5,000 inquires and numerous collaborations

Near-Frictionless Carbon Film Being Applied to Engine Parts



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Low-cost Carbon Fiber

- **Problem:** Carbon fiber can be used in production of strong, lightweight structures but at current price of $12–$30/lb is too expensive for many energy applications.
- **Description:** Technologies under development address cost reduction opportunities:
  - Feedstock - development of low-cost textiles and renewable lignin
  - Processing - development of thermo-chemical stabilization methods, rapid oxidation processes, and microwave-assisted plasma carbonization methods
- **Impact:** Achieving production cost of $5–$8/lb will make carbon fiber composites viable.
  - Energy applications that can make significant contributions to reducing oil consumption.
  - Carbon fiber composites could reduce vehicle mass by up to 40% and result in up to 25% increase in fuel economy
  - Carbon fiber's superior properties allow for more efficient wind turbine blades

Comparative Processing Speeds		
Stabilization Method	***Microwave Oxidation***	***Total (min)***
E-Beam	20-24 min	40-50
Ultraviolet	20-24 min	36-31
Thermo-chemical	20-24 min	25-34
Conventional processing		100-120

Melt spinner produces carbon fiber precursor from low-cost lignin

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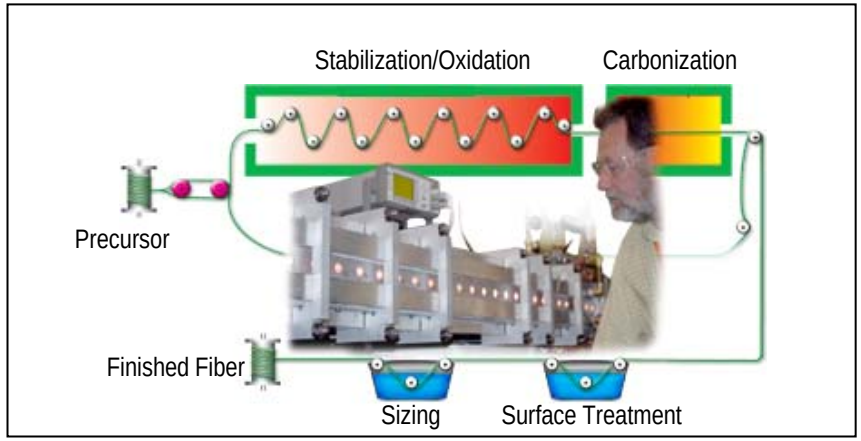
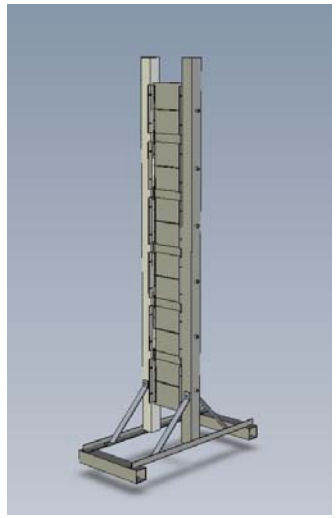
Low-cost Carbon Fiber *(continued)*

- **IP Position:** 3 patents issued, 5 patents filed, 7 disclosures
- **Technology Status:**
  - 11 Inventions developed to date that improve carbon fiber precursors, processing and fabrication
  - Reduced to Practice:
    - Microwave-assisted plasma carbonization
    - Textile-based precursors
    - Thermo-chemical stabilization
    - Plasma oxidation
  - **Time to availability:** 3-5 years
  - **Capital Needs:** Carbon fiber plant at $18M–$22M, 2M–4M pound capacity per year



Microwave-assisted plasma processing, shown in photograph, could replace conventional stabilization, oxidation, and carbonization processes represented in boxes at top of illustration

Artists' conception of next-generation carbon fiber production unit combining advanced oxidation and stabilization technologies



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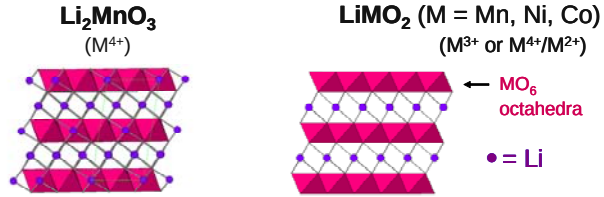
Structurally Integrated Cathodes for Li-Ion Batteries

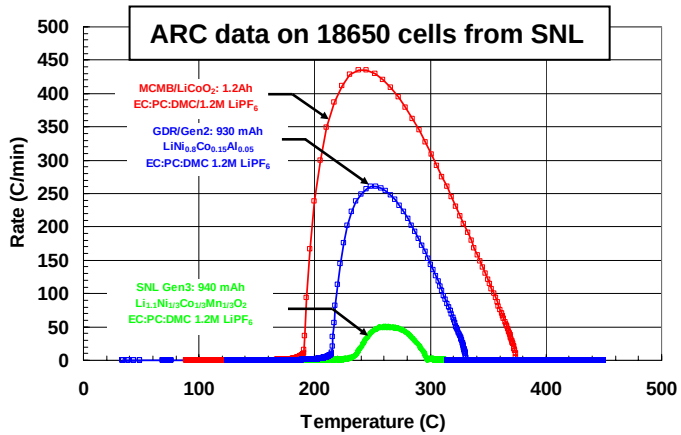
- **Problem:** More stable Li-Ion cell materials & chemistries are needed for hybrid and electric vehicle applications.
  - Fires & explosions with Li-Ion cells in consumer electronic devices illustrates the need for increased inherent safety. The significance of this issue increases as the battery size increases.

- **Description:** Layered metal oxide cathode materials are stabilized by structurally integrating exlectrochemically inactive material (Li_2MnO_3) with electrochemically active material ($LiMO_2$)

- **Impact:**
  - Greatly enhanced safety – less than 5% the heat generated by conventional Li-ion batteries
  - Structurally integrated cathode materials are much more stable than conventional layered metal oxide cathode materials
  - Significantly reduced heat from ARC tests illustrates its safety relative to conventional cathode materials.



- Li_2MnO_3 ($Li_2O•MnO_2$) is electrochemically ***inactive*** with respect to lithium insertion/extraction, whereas **$LiMO_2$** is ***active***
- **Strategy:** Embed inactive Li_2MnO_3 component within layered $LiMO_2$ structure to stabilize the electrode and to reduce the oxygen activity at the surface of charged (delithiated) electrode particles



Reduced oxygen activity, associated with new cathode materials, significantly reduces potential for thermal runaway.

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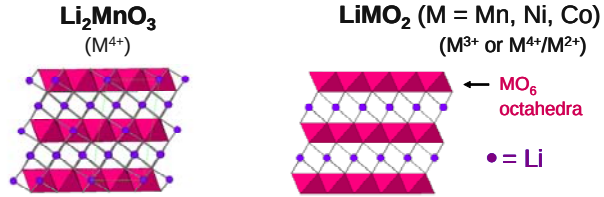
Structurally Integrated Cathodes for Li-Ion Batteries

- **IP:** Suite of inventions available on cathode materials of this type. 3 issued patents, 6 published patent applications, and several additional invention reports

- **Status:**
  - Initial patents have been licensed for use in power tools & the materials were proven superior to $LiCoO_2$ in licensee's product
  - This technology possesses adequate power and energy for: consumer electronics, power tools, toys, vehicles, etc.,
  - Direct substitution for conventional cathode
  - Need precursor processing equipment and calcining (high-temperature) furnaces for producing these new cathode materials



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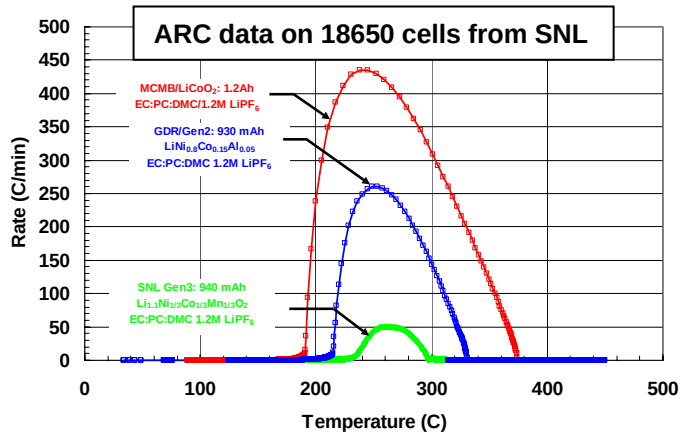

Reduced oxygen activity, associated with new cathode materials, significantly reduces potential for thermal runaway.

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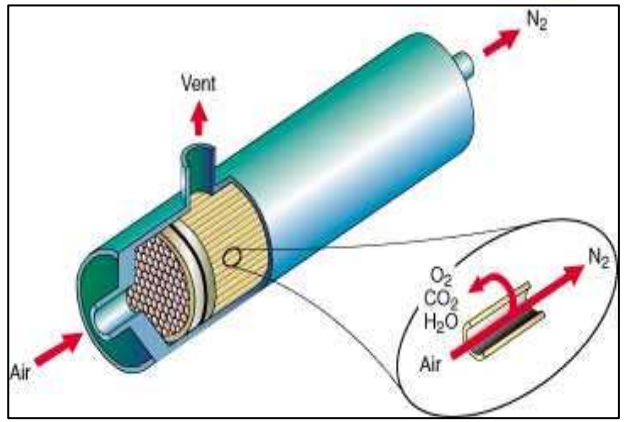
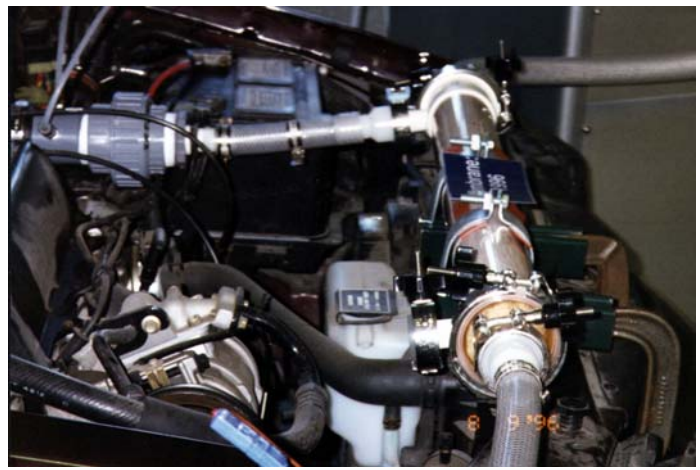
Air Separation Membrane System for Emissions Control

- **Problem**: Exhaust Emissions Control from transportation engines: NOx, Particulates, smoke, hydrocarbons, CO and air toxics. Problem affects all piston engines and therefore potential market opportunity is enormous.
- **Description:** This technology provides variable air composition (percentage of nitrogen and oxygen in the combustion air) on demand to provide the best available combination of fuel economy, power output and NOx emissions
- **Impact:** Can eliminate the need for corrosive exhaust gas recirculation for NOx reduction.
  - Benefits demonstrated in car, truck, locomotive and stationary engine applications
    - Up to 70% engine out NOx reduction,
    - Durable: 300,000 miles demonstrated
    - Reduce cost of aftertreatment.
- **IP:** A suite of 5 patents covering all engine applications
- **Status:**
  - Mature technology, with only control system still to be developed.
  - Small-scale production demonstrated; $20 M capital for membrane production plant for 400,000 units annually
  - High-volume production could be attained in 3 years
  - Many other applications possible.



Air separation membrane works by dividing the air into two streams: one is nitrogen rich, and the other is oxygen-rich.



Air Separation Membrane in a Car

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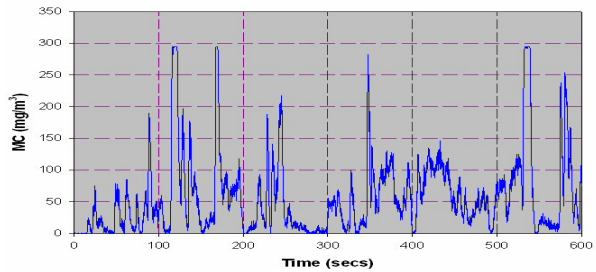
Real-time Portable Particulate Measurement System

- **Problem**: ~ 50% of the particulate emissions occur during transient operation of diesel engines. Currently there is no reliable instrument to measure particulate emissions on a real-time basis.
- **Description:** Laser Induced Incandescence (LII) technique offers a capability to measure particulate concentrations in real-time, in vehicles and in the laboratory
- **Impact:**
  - Helps identify highly polluting modes of engine operation
  - Helps develop strategies to mitigate overall particulate emissions
  - Can measure particulate size and volatile fraction
- **IP**: US patent 6,700,662 issued to ANL
- **Technology Status:**
  - Prototype developed
  - Remaining R&D before final production
    - Optimize power consumption to enable on-vehicle monitoring
    - Advances in lasers and optics will enable reducing size, reducing power consumption, and cost
    - Could become part of the on-board diagnostics
  - Tested by Cummins and Caterpillar
  - Instrument manufacturer needed to supply to engine manufacturers

TG-1: real-time particulate measurement system



On-vehicle measurement on a 1999 Mercedes C220

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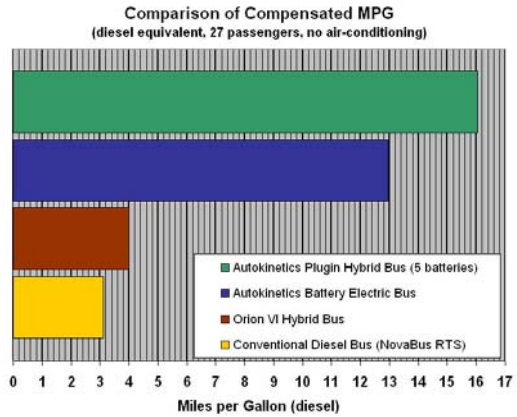
UltraLight Electric Transit Bus

- **Problem:** Conventional transit buses use too much fuel and are not environmentally friendly - 81,000 buses use 550 million gallons of fuel/year (2004), capital equipment is $3.7 billion
- **Description:** Autokinetics has developed a bus that is 50% lighter but more durable than a conventional bus and is powered by batteries and will achieve a 3X improvement in fuel economy with a 150 mile range
- **Impact:** Significantly reduce fuel consumption for transit agencies while improving reliability and life, and reducing emissions and operating costs.
- **IP:** Autokinetics holds US patent no. 6,685,254
- **Status:** Looking to build 5 buses for on-road testing with a transit agency and FTA Altoona Test certification. Will need full-scale structural test for certification. Eventually will develop and install small diesel engine for a hybrid system to extend range
  - Available for commercial licensing by manufacturer
  - Seeking partner to develop production ready bus

Design and fabricate lightweight frame, all electrical components, and use sodium nickel chloride batteries (high energy density, long cycle life, large % discharge) for power.



50% lighter, stronger, 3X fuel economy, no emissions

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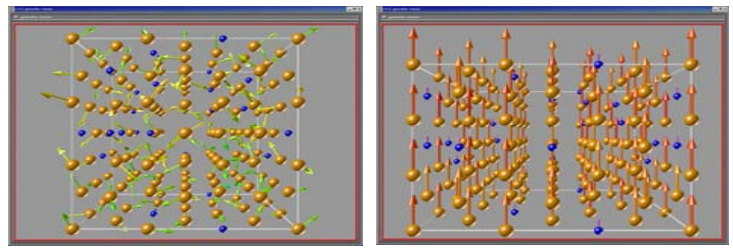
Magnetic Processing for Next-Generation Materials

- **Problem:** Traditional processing either cannot achieve the material microstructures required or they require costly, energy-intensive processing. Detrimental stresses or inferior microstructures resulting from conventional processes can require costly post-processing treatments
- **Description:** Technology uses strong magnetic fields (10-30 Tesla) to tailor and manipulate crystal structure and orientation to achieve microstructures
- **Impact:** This technology could facilitate development of the next generation of stronger, tougher structural and functional materials:
  - 20-50% lighter weight designs
  - Materials exhibiting about 80% lower residual stresses
  - 80% extension in component life
  - Possible elimination of the need for costly alloying chemistries
  - Many potential applications: stronger and tougher bearings, enhanced superconducting wires, smaller memory storage devices, improved magnets for transformers, and advances toward hydrogen storage.
- **IP Position:** 4 patents have been filed.
- **Status:** ORNL operates a demonstration facility at 9 Tesla
  - **Time to availability:** About 2 years
  - **Special needs to implement:** Sustained high strength magnetic field processing will rely upon stable superconducting magnets, at a larger scale, and faster material throughput.
  - **Capital Needs:** $500K for next-generation magnet

Magnetic Processing Laboratory Facility



High magnetic fields can tailor and enhance material performance at the nano scale, significantly improving bulk product performance

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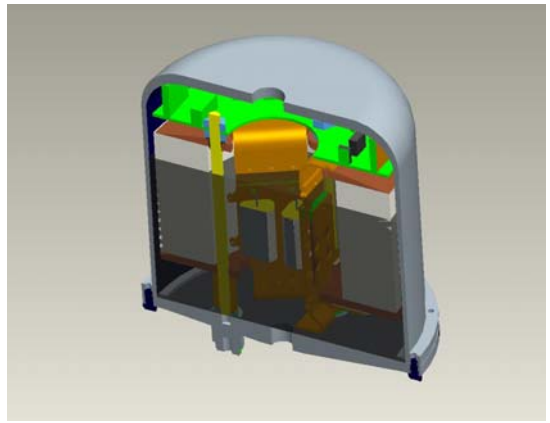
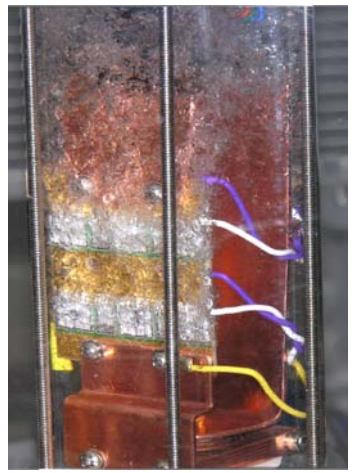
“Floating Loop” Direct Cooling for Power Inverters

- **Problem:** Conventional methods of cooling inverters in hybrid electric vehicles use large heat exchangers and dedicated cooling loops, resulting in increased vehicle weight and cost
- **Description:** The “floating loop” technology taps into the vehicle air conditioning system and refrigerant, instead of using a separate cooling system
- **Impact:**
  - Enables reduction of size (footprint), volume, and weight of the inverter by over 50% for easier packaging in the vehicle
  - Reduces required capacitor size, weight, and cost
  - Cooler operation dramatically increases inverter lifetime
- **IP Position:**
  - Multiple patents have been granted
  - The technology is available for licensing
- **Technology Status:**
  - The floating loop cooling method has been successfully demonstrated with an inverter design that has a volume less than half that of a commercial inverter
  - New connectors for the direct-cooled inverter have been developed to prevent leaks that occurred in early prototypes when the inverter was cooled with refrigerant under pressure
  - Time to Availability: Currently Available
  - Special Needs to Implement: None



Prototype of compact inverter used with the “floating loop” cooling technology



Silicon chip being directly cooled by liquid R134a coolant

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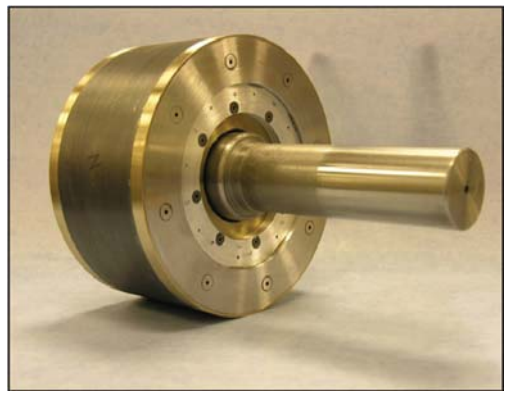
Novel Compact, High-Efficiency Motors for Hybrid Electric Vehicles

- **Problem:** Hybrid electric vehicle market penetration depends on high-performance, high-efficiency electric motors
  - Motor efficiency is limited by input voltage
- **Description:** A field excitation coil added to conventional motor designs has benefits in reduced motor size and cost, increased motor efficiency and increased power density*
- **Impact:**
  - Reduce the size of the motor by 20% with accompanying material cost reduction
  - Increase motor energy efficiency by reducing losses by up to 40%
  - Higher motor rotational speeds result in
    - Higher power density (because of reduced motor size)
    - Lower battery power requirement
  - Reduce the need for power converters to increase voltage between the battery and the motor
- **IP position:** Multiple patents have been granted, technology is available for licensing
- **Technology Status:**
  - Multiple motor designs have been implemented and tested via modeling/simulation and hardware prototyping
  - Available now
  - Special needs to implement: None



Prototype permanent magnet motor with brushless field excitation coil operates at 16,000 RPM

**Power density = horsepower/unit volume*

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