VEHICLE TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Overview of the DOE VTO Propulsion Materials Program

June 9, 2016

Jerry Gibbs

Materials Technologies

- **Materials Technologies $27. M**
  - **Lightweight Materials $21.6 M**
    - Properties and Manufacturing
    - Multi-material Enabling
    - Modeling & Computational Materials Science
  - **Propulsion Materials $5.3 M**
    - Engines. Cast Al, Fe, & steel, & High Temperature Alloys
    - Exhaust System. Low Temperature Catalysts
    - Integrated Computational Materials Engineering

	Lightweight	Propulsion	HTML
FY12 Enacted	$28.3 M	$13.0 M	$1.0 M
FY13 Enacted	$28.3 M	$12.3 M	$0.9 M
FY14 Enacted	$28.0 M	$9.2 M	$0
FY15 Enacted	$28.5 M	$7.1 M	$0
FY16 Enacted	$21.6 M	$5.3 M	$0

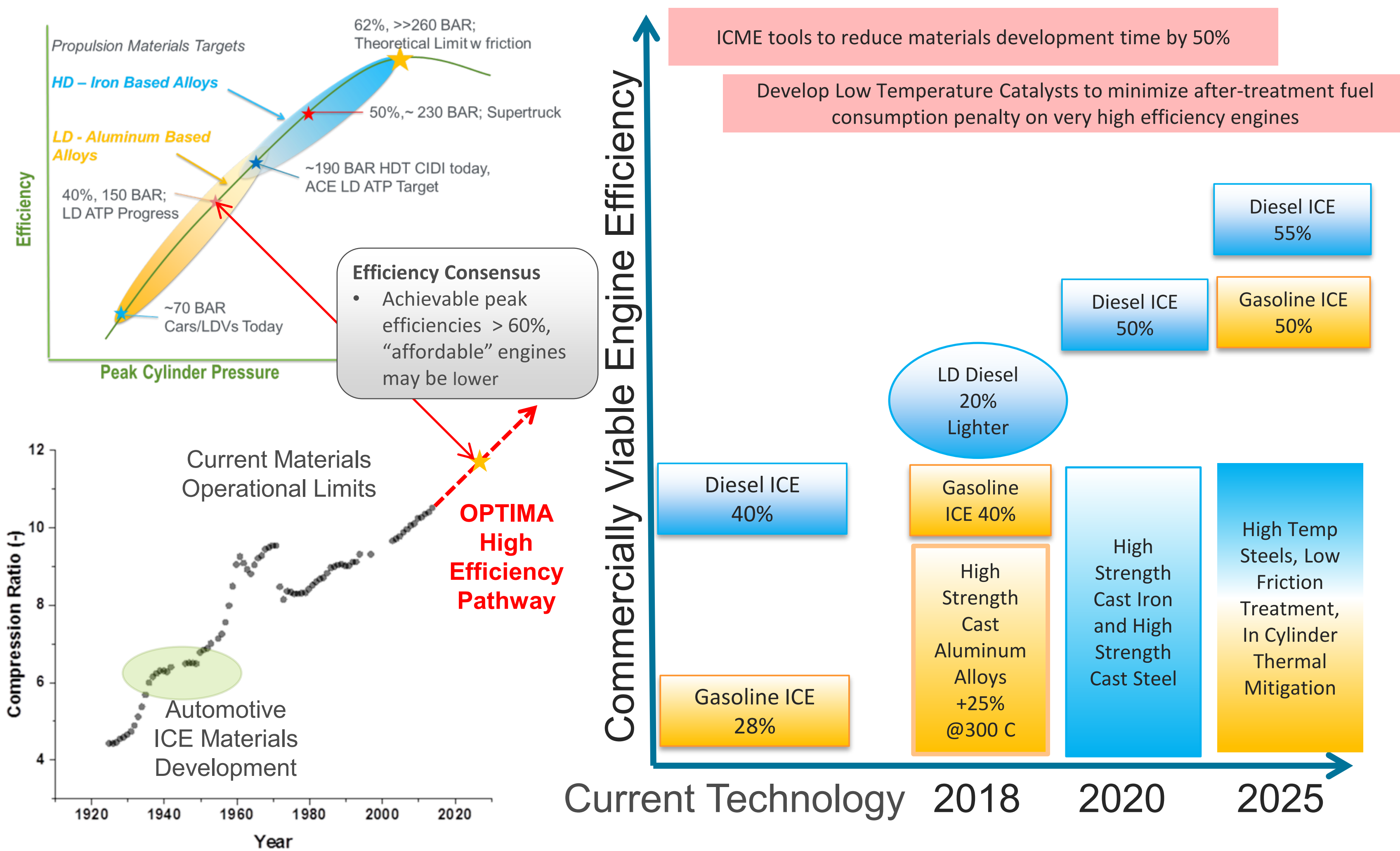
Propulsion Materials

- Targets **powertrain materials** requirements for future automotive and heavy-duty applications: engine, transmission, exhaust components, and targeted materials for electric powertrains. As the weight of the vehicle structure is reduced the percentage of the total vehicle weight in the powertrain is increasing.
- Address materials for high efficiency Internal Combustion Engines, powertrain materials interactions with new fuel compositions.
- Address new materials requirements for new exhaust After-treatment systems essential to the commercialization of next generation internal combustion engines
- Most (85%)Propulsion Materials projects utilize Integrated Computational Materials Engineering (ICME) to set performance targets and accelerate results in materials discovery, materials formulation, and materials processing techniques.
- Identifies gaps in existing ICME tools and develops new topics to expand the use of computational methods in materials development and materials engineering
- *Address Materials and Materials Processing issues that impact the performance of Power Electronics and Electric Drive Technology (EDT), Currently transitioning to EDT R&D team*

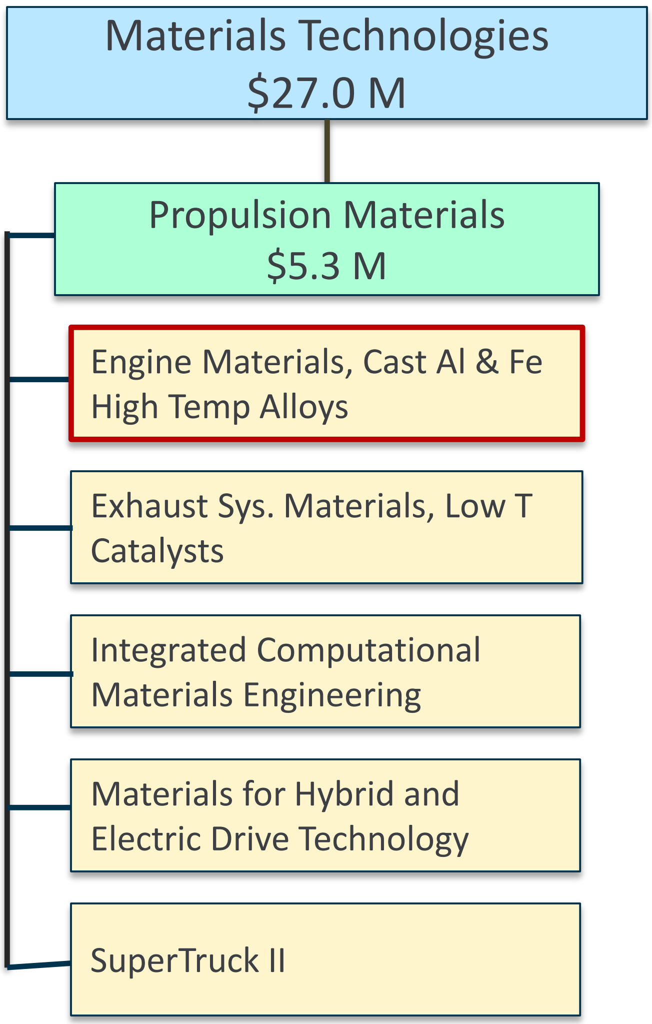
Workshop Propulsion Materials R&D Gaps and Targets

Metric	2013	2050	Material Gaps
Powertrain Weight Reduction (ICE/HEV)	Baseline - LDV Baseline – HDV	40% lighter- LDV 20% lighter- HDV	Structure and Volumetric Efficiency (block, head, transmission; AL ,CF)
Power density	LDVs -2.7L 196 HP (73.4 HP/L) HD15L 475HP (32 HP/L)	LD 1.3L 196 HP (150 HP/L) LW-LD 0.7L 98 HP HD 9L 475HP (53 HP/L)	Structure and rotating components (crankshaft, pistons, connecting rods, gears; Steels +)
Energy Recovery	LDV <5% Turbocharged HD ~99% Turbocharged	LDV ~50% Turbo/ TEs/ Turbo-compounding HD~ 99%Turbo/Waste Heat Recovery	Turbo-machinery Superchargers, Rankine Cycle components, seals, fluid interactions
Exhaust Temperatures (Exhaust Valve to Turbo Inlet)	LDV - 800 °C HDV - 700 °C	1000 °C - LDV 900 °C - HDV	Valves (super alloys & Ceramics) E Manifolds, Turbochargers
Cylinder Peak Pressures	LDV ~ 50 bar HDV 190 bar	>103 bar - LDV gasoline >150 bar ATP-DI gasoline >260 bar – HDV	Structure and rotating components , gaskets, valves, friction
Engine Thermal Efficiency	LDV 30% e HDV 42% e	LDV 45% e, Stretch 55+% e HDV 55% e, Stretch 60% e	Thermal Management, Structure, Friction
Exhaust Temperature / After-treatment	LDV 3 Way, >350C HDV Nox/HC/PM, >350C	LDV 150C +>350C HDV 150C +>350C	Catalyst Performance

Materials Pathway and Efficiency



Propulsion Materials–Engine/ Powertrain Materials



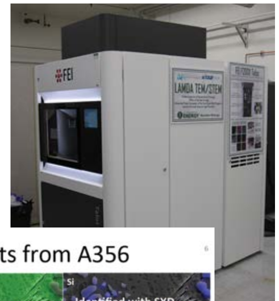
- Targets the Advanced Combustion Engine team stretch goals, 50%+ efficiency for heavy-duty and automotive engines
  - **Lightweight Cast alloys for automotive engines and transmissions: GM; Ford; ORNL/Chrysler**: Lightweight high strength aluminum alloy development to replace A356 or A319 and enable higher operating temperatures and higher efficiency combustion regimes.
  - **High performance Cast Ferrous Alloys for Heavy-duty Applications: Caterpillar**: High strength, low cost cast alloy development to provide performance superior to Compacted Graphite Iron, easily cast and machined, and at a cost similar to cast iron, enabling engines with higher peak cylinder pressures and increased efficiency.
  - **High performance Cast Steels for Crankshafts: Caterpillar/GM**: High performance low cost cast steel providing performance similar to high cost forged steel units, enabling a low cost pathway to increased engine efficiency in automotive and heavy duty applications.

Engine Materials Example: ORNL Provides Unique Capabilities to Industry

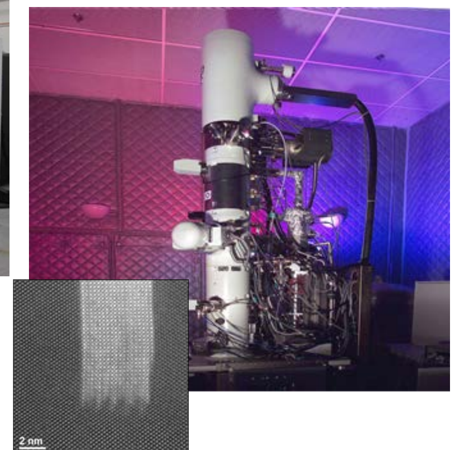
BROOKHAVEN NATIONAL LABORATORY

NSLS/NSLS II

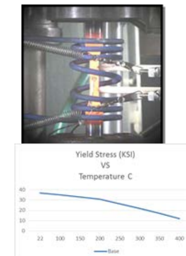
TALOS STEM



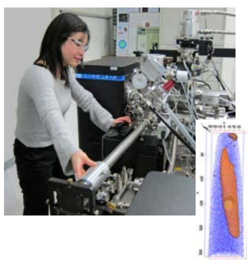
JOEL ACEM

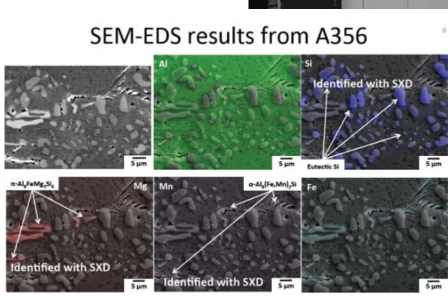


High Temperature Materials Characterization (HTML)



LEAP Atom Probe





FCA

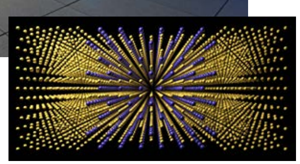
FIAT CHRYSLER AUTOMOBILES

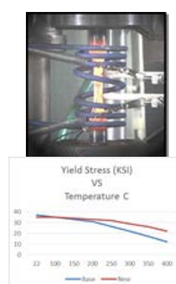
OAK RIDGE National Laboratory

html High Temperature Materials Laboratory

nemak

TITAN Supercomputer





HTML

Spallation Neutron Source

Propulsion Materials– Exhaust System Materials, Low T Catalysts

Materials Technologies
$27.0 M

Propulsion Materials
$5.3 M

- Engine Materials, Cast Al & Fe, High Temp Alloys
- Exhaust System Materials and Low T Catalysts
- Integrated Computational Materials Engineering
- Materials for Hybrid and Electric Drive Technology
- SuperTruck II

– Fundamental Catalyst Materials
  - **ORNL:** Evaluation of catalyst microstructures and

– Exhaust Aftertreatment Components
  - **ORNL/Ford**: Impacts of biofuels on component life and development of mitigation strategies
  - **ORNL**: Durability of diesel particulate filters

– Low Temperature Catalysts
  - **Ford/ORNL** - Automotive
  - **Chrysler (FCA)/PNNL** - Automotive
  - **Cummins/PNNL** – Heavy-Duty Trucks

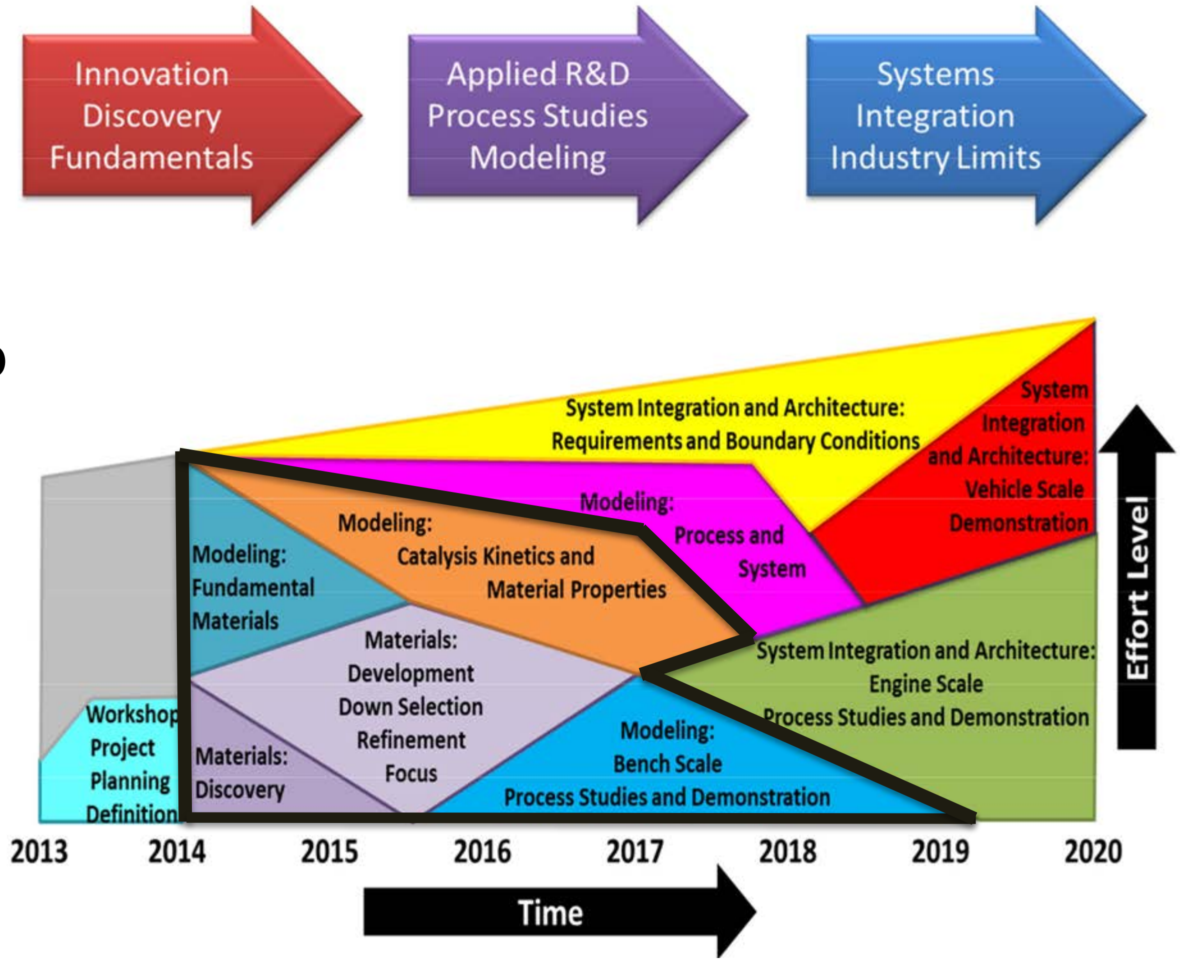
The Propulsion Materials'

Low Temperature

Catalyst development effort is guided by the **US CAR** advanced aftertreatment workshop report and all materials development and validation activities reside in the areas outlined in **Black**

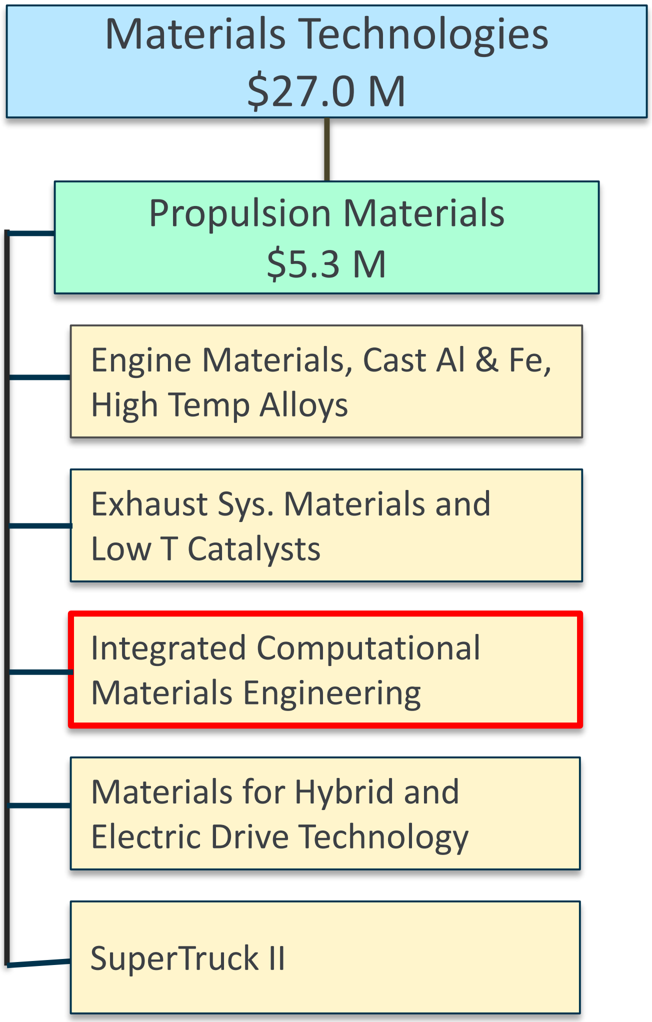
bridging materials fundamentals and applied R&D

Future Automotive Aftertreatment Solutions: The 150° C Challenge Workshop Report



http://www.pnnl.gov/main/publications/external/technical_Reports/PNNL-22815.pdf

Propulsion Materials– Integrated Computational Materials Engineering



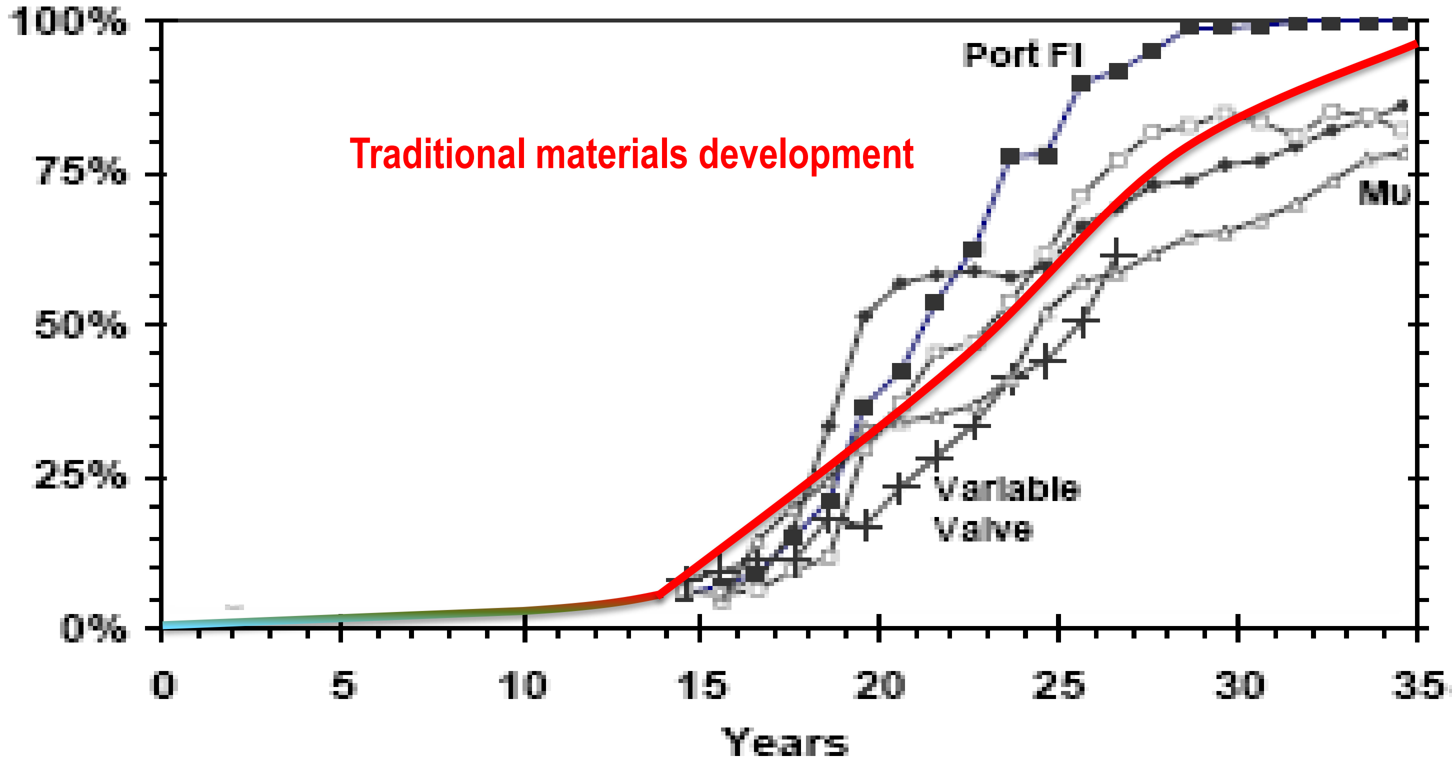
– Integrated Computational Materials Engineering

- Each Propulsion Materials FOA project includes a multi-scale ICME application, validation, and gap analysis component (two were included in the President's Materials Genome announcement).
- **ORNL**: Utilize ICME/FEA linked to conjugate heat transfer and advanced combustion models to identify material property requirements, critical components, and to quantify potential engine efficiency improvements.
- **ORNL:** Team has gained access to the TITAN Supercomputer to do large field computational modeling of Aluminum (ORNL internal award).
- **ORNL:** Team has been awarded an ORNL internal grant to evaluate a "Large Data" approach to rapid alloy formulation and optimization.

Materials Development and Implementation Timelines

Vehicle Technology Development And Penetration Curves

Technology Implementation Timeline

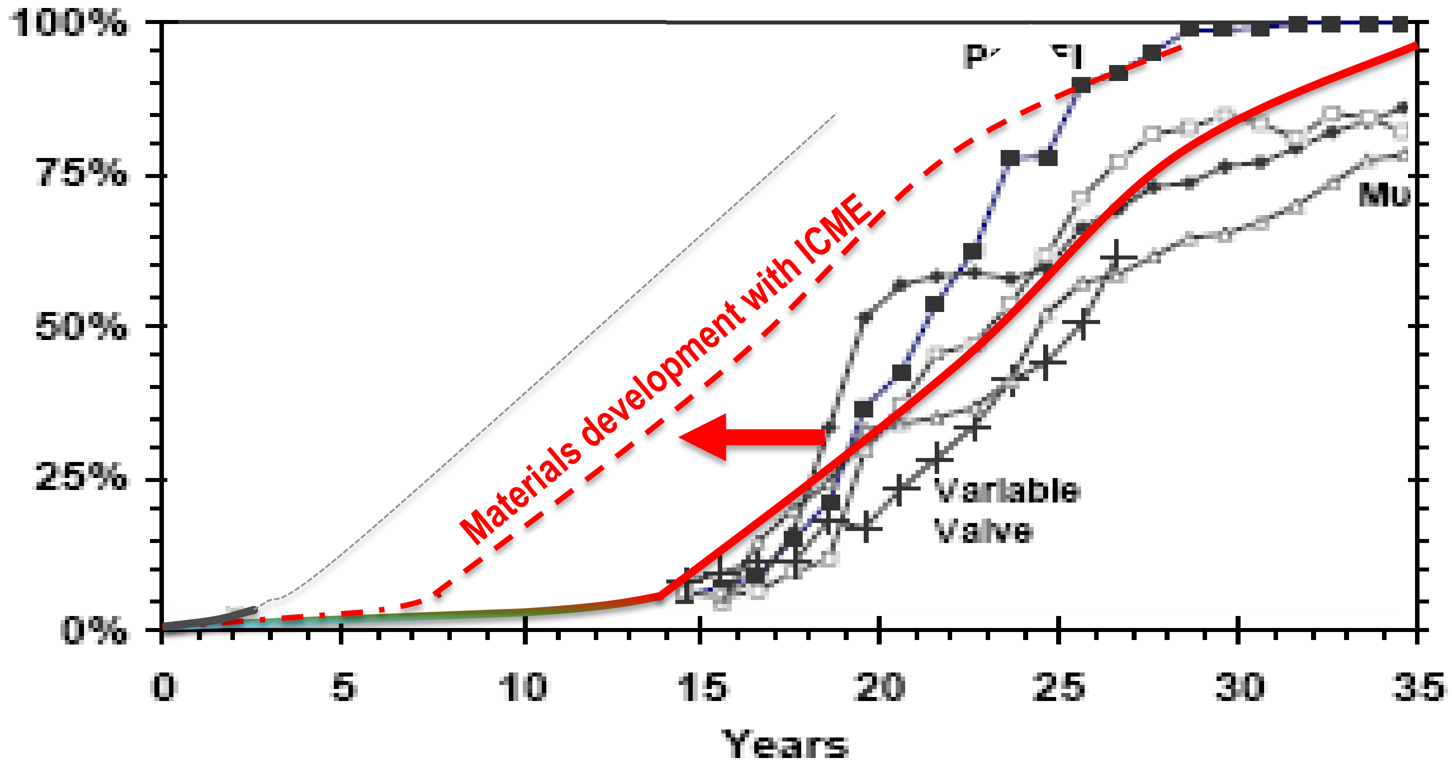


Technology Research Effort

Basic Science Applied R&D Industry Technology Transfer

Materials Development and Implementation Timelines

Technology Implementation Timeline

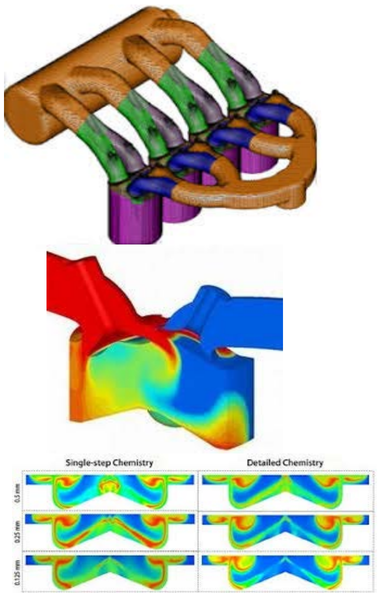


Technology Research Effort

Basic Science Applied R&D Industry Technology Transfer

Target Setting by Linking Combustion Modeling to Materials Models

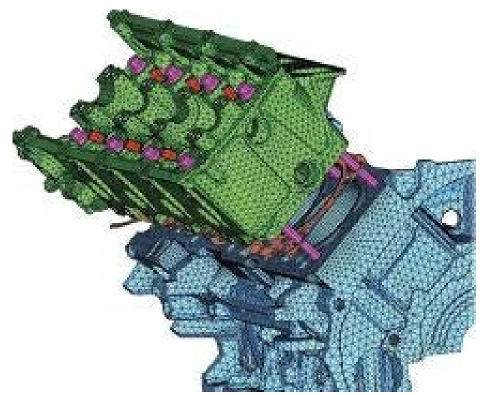
Advanced Combustion Models



Temperature and pressure Boundary conditions

Efficiency improvement potential

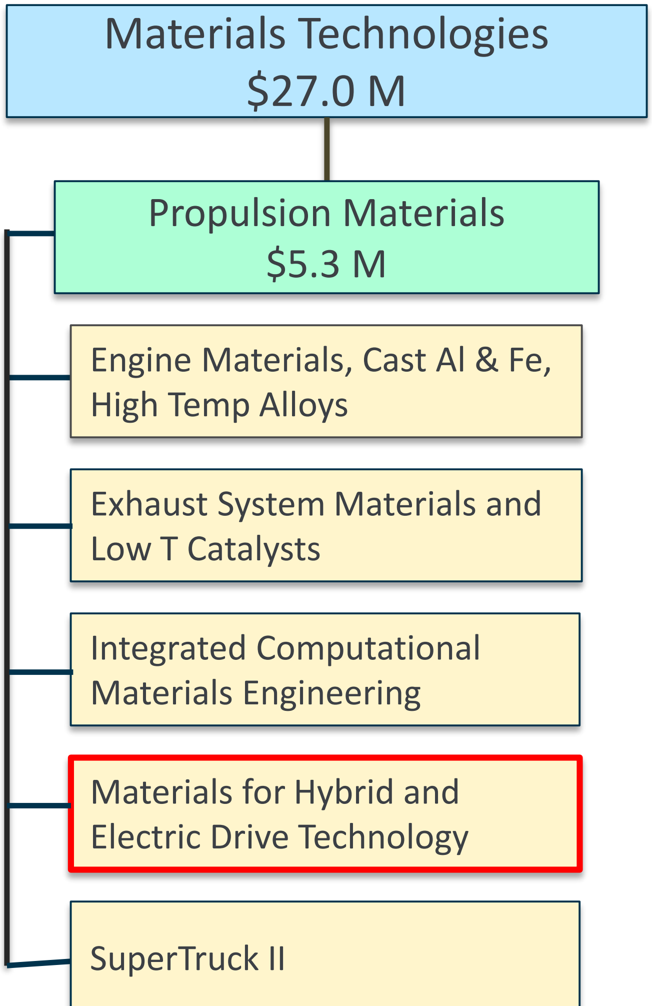
Finite Element Baseline Design Constraints



Prioritized Components and Material Property Targets

Identify and prioritize the material improvements needed to enable high efficiency combustion systems, and <u>quantify the benefits</u>.

Propulsion Materials– Materials for Hybrid and Electric Drive Systems

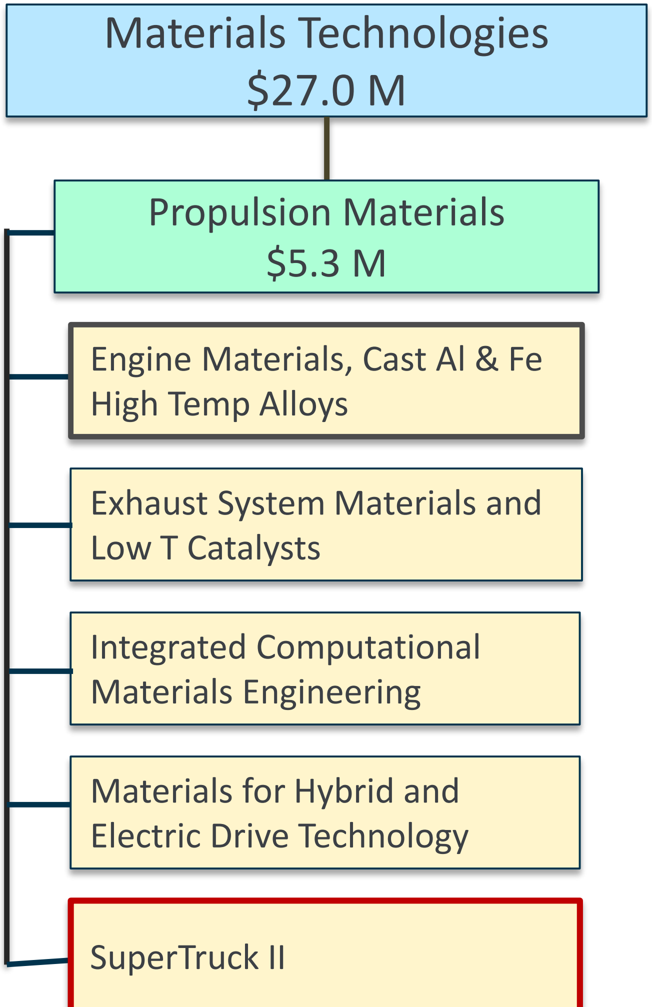


– Materials for Hybrid and Electric Drive Systems

- **PNNL**: Friction Stir Processing of Induction Motor Rotors, Higher performance, potential for reduced cost.
- **PNNL:** Potential Follow-ons -Friction Stir Processing for Induction Motor Components- High performance CF infused Copper Shorting Bars, High Silicone Steel for motor Laminates.
- **ORNL**: High temperature power electronics, materials, structure, joining, and thermal fatigue. Being presented in the PEEM session.
- **ORNL:** High Silicon Steel for induction motor Laminates

Note: All these projects are either ending or transitioning to the Electric Drive Technology (EDT) R&D team

Propulsion Materials– Supertruck II



– **SuperTruck II**

- **In FY16 Propulsion Materials is committing $2.5M to the SuperTruck II Funding Opportunity Announcement (FOA)**
- The FOA process is still ongoing, we cannot discuss until after the process is completed.

Contact Information

Thank You

Jerry Gibbs
jerry.gibbs@ee.doe.gov