Materials-Enabled High-Efficiency Diesel Engines (CRADA with Caterpillar)

Project ID: PM020

Presented by **Mike Kass**

Brian Kaul, H. T. Lin, and Ray Johnson

Oak Ridge National Laboratory

Mark Veliz and Nate Phillips

Caterpillar®

Jerry Gibbs

Propulsion Materials

U.S. Department of Energy

2011 DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

May 10, 2011

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U.S. DEPARTMENT OF ENERGY

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Overview

Collaboration between ORNL and Caterpillar, Inc. to take advantage of advances in new materials & technologies and demonstrate significant improvements in engine efficiency for heavy-duty diesels

Timeline

- Project started on October-2009
- Valve & Head Installation –Feb 2011
- Valve Testing Completed – April 2011
- Exhaust Manifolds Delivery – Feb 2011
- Completion of Manifold Study – June 2011

Budget

- FY2009: $460K
- FY2010: $360K
- FY2011: $400K

Barriers addressed

- Changing internal combustion engine operational regimes
- Long lead times for materials commercialization
- Need to reduce weight
- Durability
- Cost

Partners

- ORNL Partnered with Caterpillar
- Caterpillar PI is Mark Veliz

Objective

Improve diesel engine performance, efficiency, and emissions through the application of materials enabling technologies. Increased power output and efficiency are leading to higher combustion and exhaust temperatures

Relevant to DOE goal of reaching 55% efficiency in a heavy-duty diesel engine

For FY10:

- **Experimental cell and engine fully commissioned.**
- **Evaluated novel turbine system (part of WFO agreement)**
- **Installed and commissioned power factor correction system**

For FY11:

- **Established transient dynamometer control**
- **Valve material project underway**
  - **Valves installed and currently being evaluated**
- **Materials for exhaust manifold study**
  - **Manifolds composed of novel stainless steel alloys received from Caterpillar for subsequent evaluation.**

Milestones

FY 2011 Milestone - *Complete*

- **Dynamometer controller upgrades to enable automated transient control (November 2010)**
- **Installation of nickel alloy valves for high temperature performance and durability study (February 2011)**

FY 2011 Milestones – *In Progress*

- **Evaluate performance of nickel alloy exhaust valves (April 2011)**
- **Evaluate the performance of stainless steel alloy exhaust manifolds (June 2011)**
- **Installation of Tier IV C9 diesel engine (July 2011)**
- **Performance study on C9 engine (September 2011)**

FY2011 Project Activities and Status

FY2011:

Currently evaluating high temperature performance of exhaust valves

- Valve alloy developed by materials scientist at ORNL
- Engine is operated using transient protocol
- Testing to be completed by April
- Valve lash measured approximately every 25 hours

Manifold alloy durability evaluation

- Manifolds received by Caterpillar
- To be evaluated under high stress transient cycle

Installation of Tier IV C9

- An advanced Tier IV C9 engine with emission control to be installed this summer.
- Aftertreatment and EGR-related projects are being scoped out for the remainder of FY2011.

Approach

This CRADA makes use of engine/combustion and materials expertise at Caterpillar and ORNL to provide new insight into the integration of novel materials technologies to better enable high temperature, high pressure engine operation.

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- Engine & tools
- Materials selection
- Technical support

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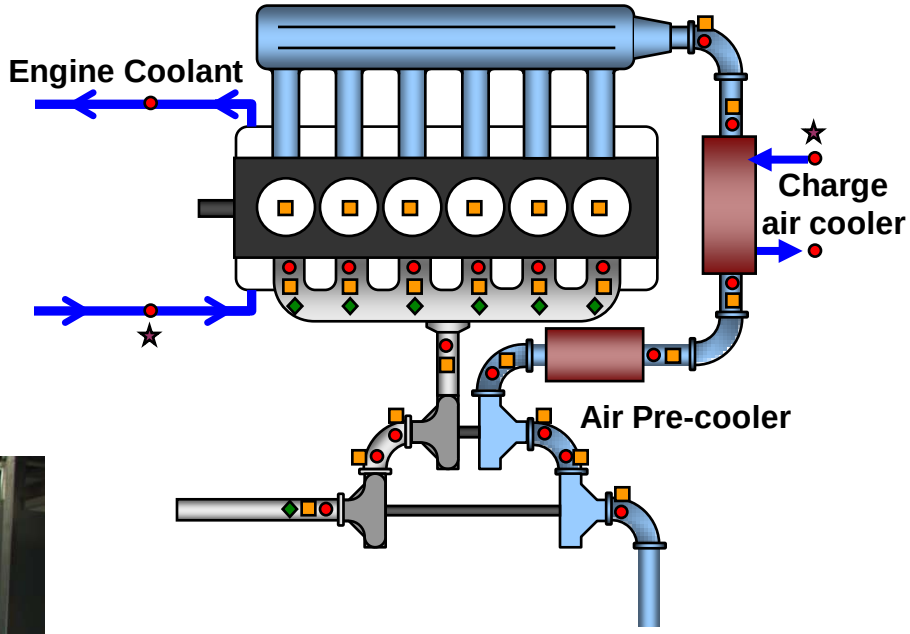
- Engine performance
- Diagnostics & analysis
- Materials characterization

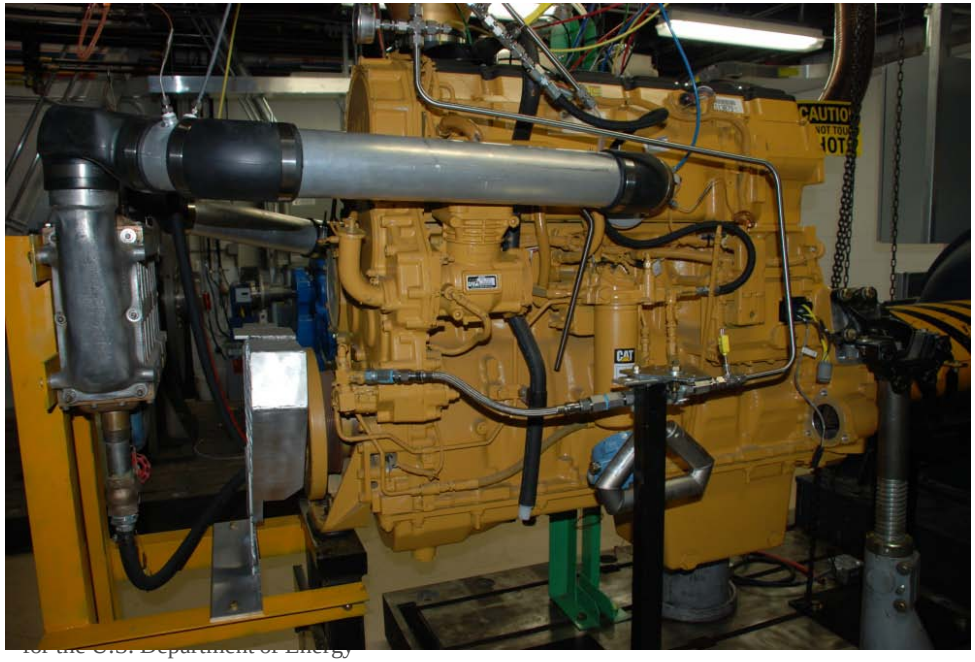
Materials & Engines approach provides a more complete understanding to better improve combustion, thermal management, emissions & cost reductions.

FY 2010 Technical Accomplishments
Completion of 2nd Law analysis and turbo performance studies

- **Completion of 2nd Law analysis on engine**
- **Results were used to consider energy recovery options**

Instrumentation Schematic





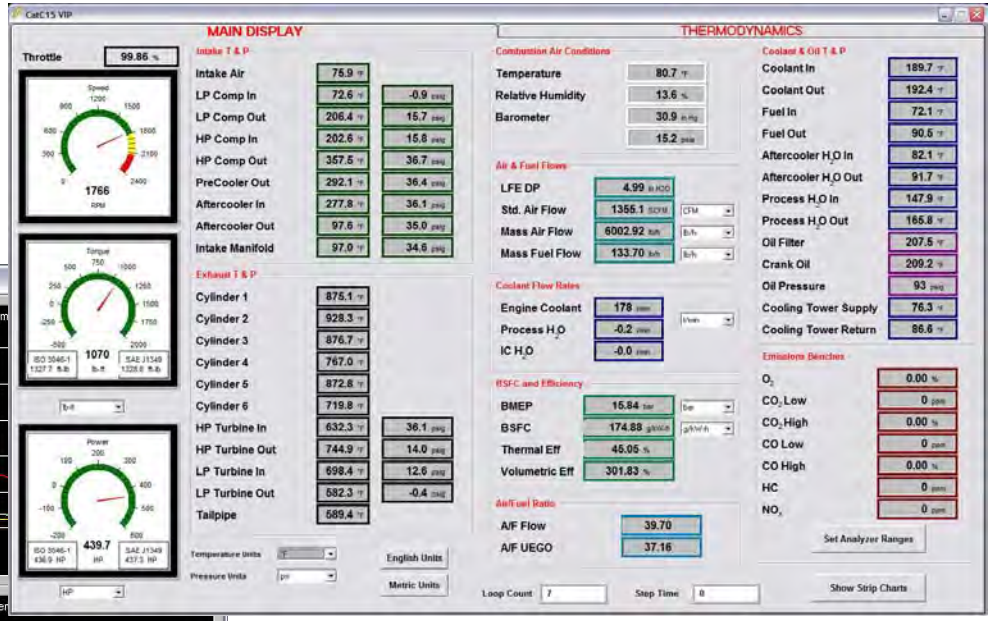
- **Successful demonstration of novel prototype turbocharger (WFO with Caterpillar)**
- **Tested turbo design to be considered on next gen engines**

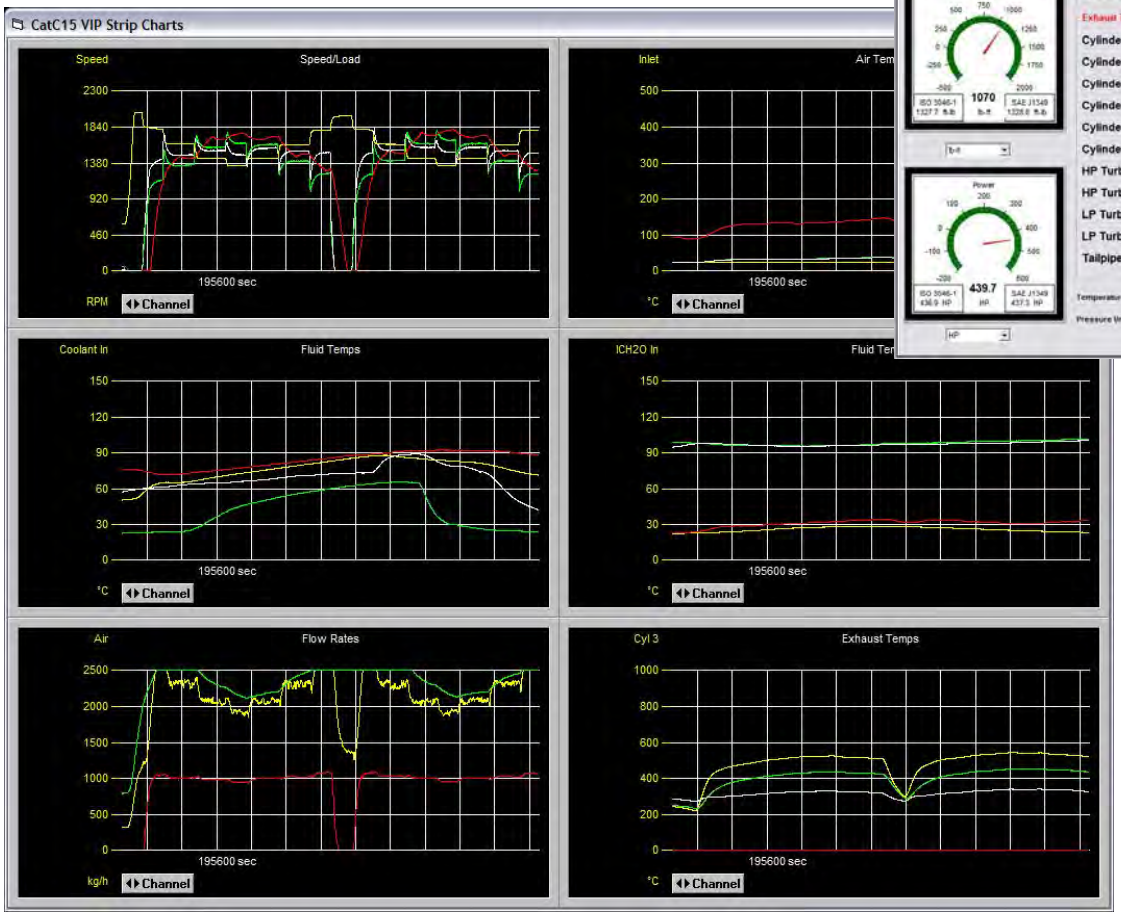
FY 2010 Technical Accomplishments
Power factor correction system commissioned

- **The electrical power produced by the dynamometer was not in phase with grid power**
- **A power factor correction system was procured and installed to properly manage the electrical signals from the dynamometer (prior to being returned to the power grid)**
- **This effort required approximately 1 month at a cost of ~$150K of internal funding**
- **Result Successful: Dyno power now in phase with electrical grid. No further issues noted.**

Technical Accomplishments
Automated transient dynamometer control established

- **Throttle card installed to enable transient control**
- **Automated program installed and commissioned**





- **This feature is currently being utilized on valve performance study**

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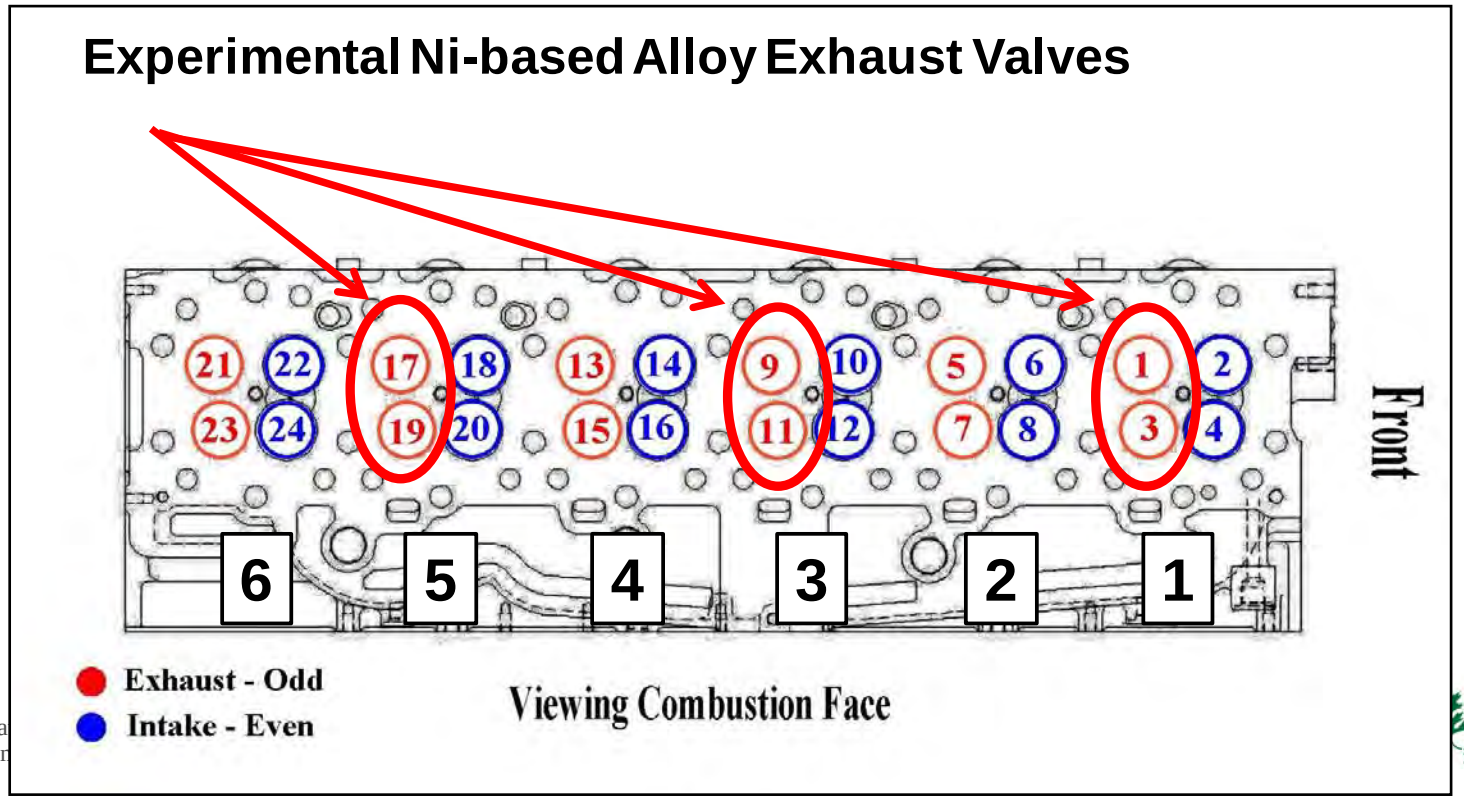
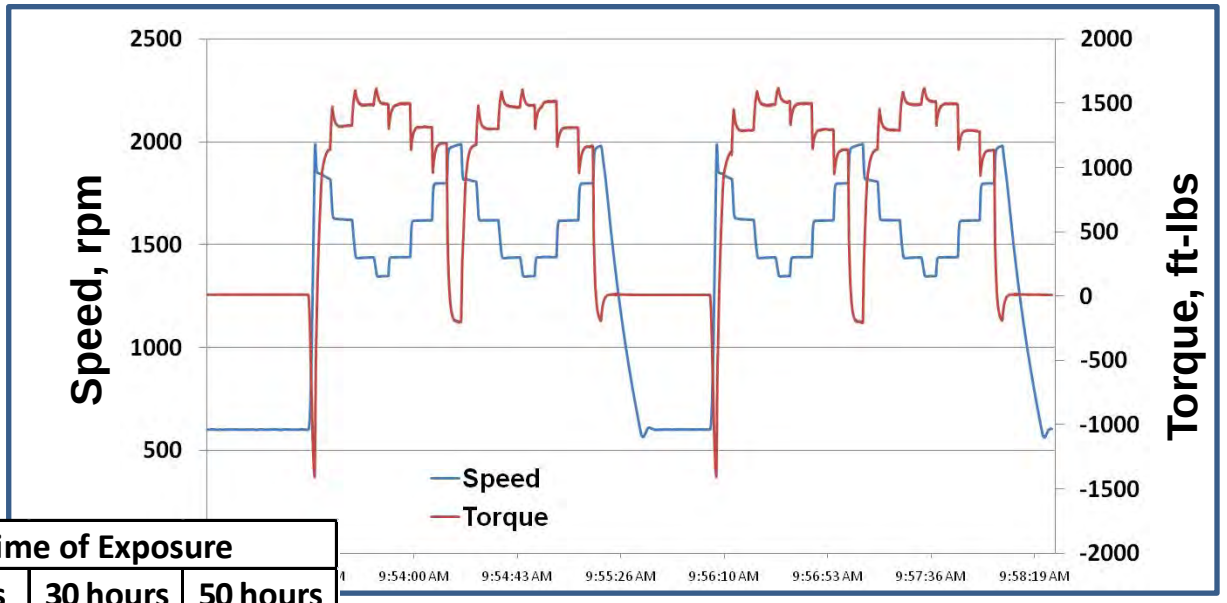
Technical Accomplishments
Nickel-based alloy exhaust valve study underway

- **Combustion temperatures & pressures are increasing for improved power and efficiency. New materials need to be developed to meet the challenges of higher combustion and exhaust temperatures.**
- **Metallurgists at ORNL have developed a nickel-based alloy for high temperature applications. Exhaust valves for the C15 ACERT were made and delivered to ORNL**
- **The valves were installed in cylinders 1, 3, and 5 and are compared to the standard steel valves currently used in cylinders 2, 4 & 6.**



Technical Accomplishments: Nickel-based alloy exhaust valve study (continued)

- Engine was operated for 200 hours according to the transient test cycle shown
- Valve lash was periodically measured to assess performance relative to baseline valve material



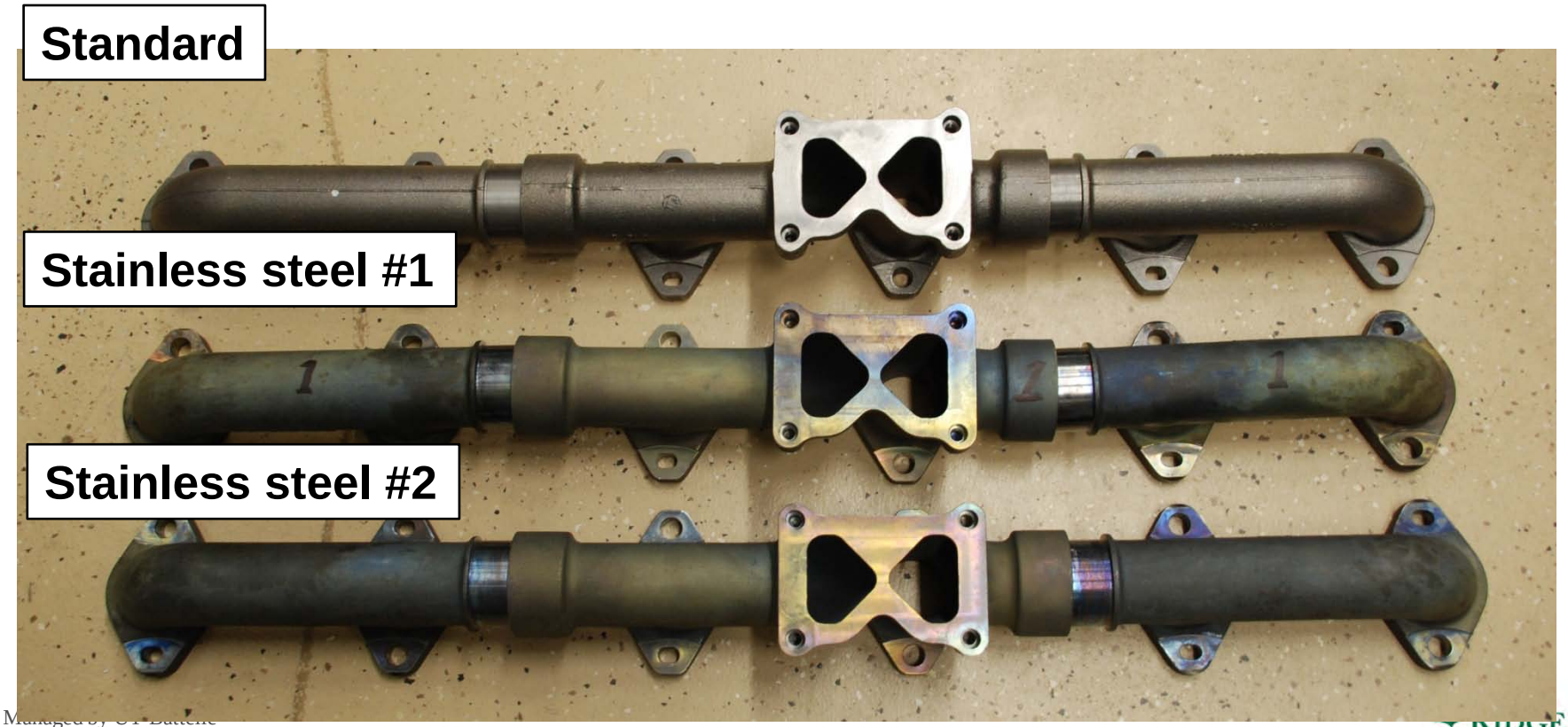
Cylinder Number	Valve Material	Valve Number	Time of Exposure 0 hours	30 hours	50 hours
1	Ni alloy	1	0.030	0.028	0.028
		3	0.030	0.028	0.028
2	Standard	5	0.030	0.028	0.028
		7	0.030	0.028	0.028
3	Ni alloy	9	0.030	0.028	0.028
		11	0.030	0.028	0.028
4	Standard	13	0.030	0.028	0.027
		15	0.030	0.028	0.027
5	Ni alloy	17	0.030	0.029	0.028
		19	0.030	0.028	0.028
6	Standard	21	0.030	0.028	0.027
		23	0.030	0.028	0.027

- Valve lash measurements showed very little recession of the valve
- Essentially no difference in the recession for either the standard and Ni-alloy valves

Technical Accomplishments

Two new exhaust manifolds composed on new alloys were developed for performance evaluation

- **Received 2 proprietary stainless steel exhaust manifolds for evaluation**
- **Manifolds represent a lower cost alternative to austenitic stainless steel for improved high temperature and thermal cycling performance**
- **Manifolds currently being instrumented to assess thermal performance**



Collaborations

- **Caterpillar is the industry partner on this CRADA**
- **Caterpillar has provided:**
  - Two 600hp motoring dynamometers
  - C15 ACERT engine & components
  - Technical support
- **Technology Transfer**
  - 2nd Law analysis was used to evaluate proprietary model
  - Improved turbo performance will be considered for future engine designs

Materials Evaluation Research Plan – Future Work

1. **Completion of stainless steel alloy exhaust manifold thermal performance study**
2. **Receive and install Tier 4 engine. Engine will be equipped with EGR and emissions control**
   - **Engine will be instrumented to assess 1st and 2nd Laws of Thermodynamic analyses**
3. **Evaluate emission control technologies**
4. **Analyze components for durability**
   - **Non-destructive evaluation**
   - **Micro-structural analyses**
5. **Temperature, flow rates, combustion data will be used to assess thermal management potential and identify locations for additional modifications**
6. **Expand research plan to additional components & materials**

Summary

- **We have established a unique CRADA with Caterpillar with the goal of evaluating new materials systems for improved engine efficiency**
  - » **Combines ORNL materials and engine/combustion R&D expertise with industry partner**
  - » **Similarly, materials and engine research staff at Caterpillar are also working together**
- **Performance assessment of nickel alloy exhaust valves is underway**
  - » Valve lash measurements indicated that the performance of the nickel alloy valves matches standard material
  - » Exhaust manifolds composed of stainless steel-based alloys have been received and will be instrumented for thermal performance
- **C9 engine has been identified for future emissions control and materials evaluation studies. Installation is anticipated later this FY**