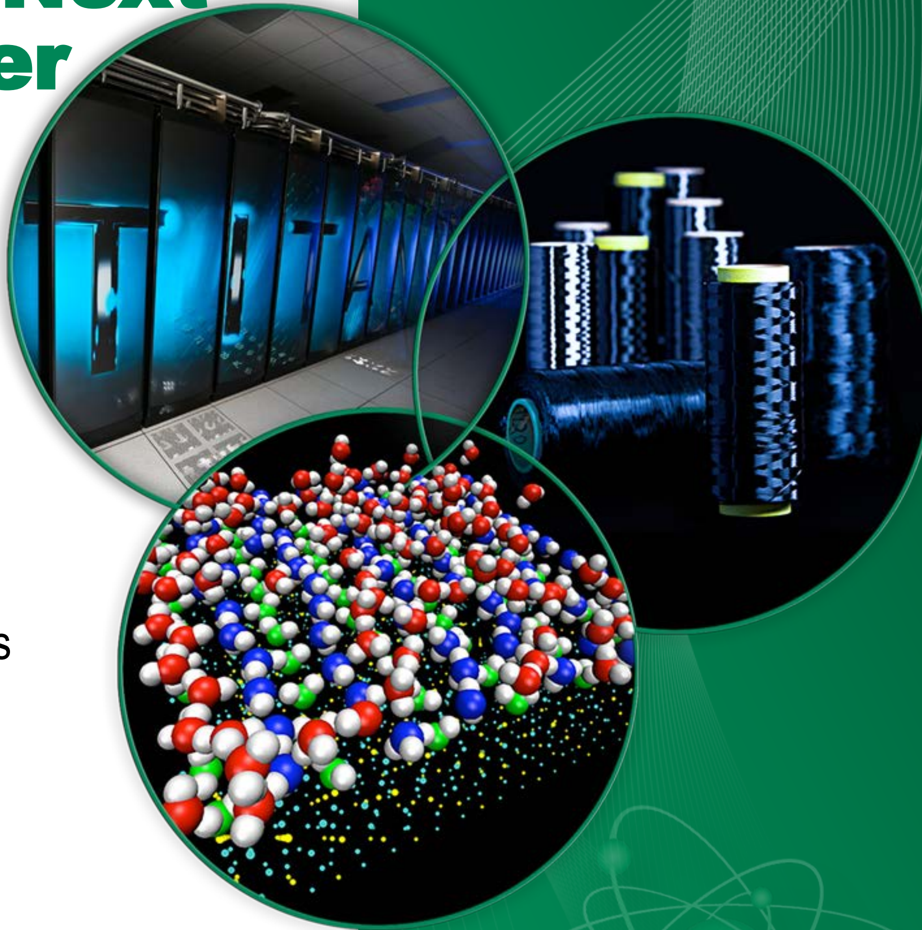
Project ID: PM062

High Performance Cast Aluminum Alloys for Next Generation Passenger Vehicle Engines

2012 FOA 648 Topic 3a



2014 DOE Vehicle Technologies Annual Merit Review and Peer Evaluation Meeting

June 19, 2014

Amit Shyam, Shibayan Roy, G. Muralidharan, Dongwon Shin, Adrian Sabau, Wally Porter, Thomas Watkins, Larry Allard and Allen Haynes: *ORNL*

Lin Zhang, Gregg Black: *Chrysler Group LLC*

Jose Talamantes, Andres Rodriguez: *Nemak S.A.*

Sponsored by
U.S. Department of Energy, Energy Efficiency and Renewable Energy, Vehicle Technologies Office

Overview

Timeline

- Start: November 2012
- *CRADA* Executed: Nov 2013
- End: November 2017
- 12% Complete.

Budget

- Total project funding.
  - DOE-$3500 K
  - Cost share ~$2000 K
- FY13 Funding - $875K
- FY14 Funding - $875K

Barriers

- Absence of ***economical*** lightweight materials with improved castability, high temperature strength and fatigue performance.
- A major barrier to the development of new alloys is the time-intensive trial and error approach applied to these complex systems. ***Integrated computational materials engineering*** (ICME) approach to accelerate the development and deployment of new cast aluminum alloys.

Partners

- CRADA Partners: Chrysler Group LLC, ORNL, Nemak Inc.
- Other Partners: Alcoa, Granta MI, ESI North America, Flow Science, Magma Foundry Technologies, Minco Inc.
- Project lead – *ORNL*

Relevance

- Opportunity to develop and commercialize the next generation of materials for light duty engines (with higher peak cylinder pressure and temperature) where Aluminum alloys use is limited due to these materials rapidly losing strength at temperatures > 200^{o}C.

- Objectives
  - Develop high performance cast aluminum alloys that have following characteristics
    - improved castability, high temperature strength and fatigue performance.
    - engine cylinder heads fabricated with new alloy will have > 25% strength improvement and will cost ~ 10% more than heads manufactured by 319 or 356.
    - will enable an increase in maximum component operating temperature by ~ 50^{o}C.
  - Evaluate the adequacy of existing ICME models and codes
    - Models and codes for the prediction of properties and development of cast aluminum alloys.
    - A gap analysis report for existing ICME codes for cast aluminum alloy development will be generated.

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Milestones

- Title: Selection of the cast aluminum alloy family for further development to refine alloy development path.

  Planned Date: 11/30/14 (on track)

- Title: Finish implementation of ICME models that could be iterated to accelerate the alloy development.

  Planned Date: 11/30/15

- Title: Finish identification of new alloy compositions with improved properties.

  Planned Date: 11/30/16

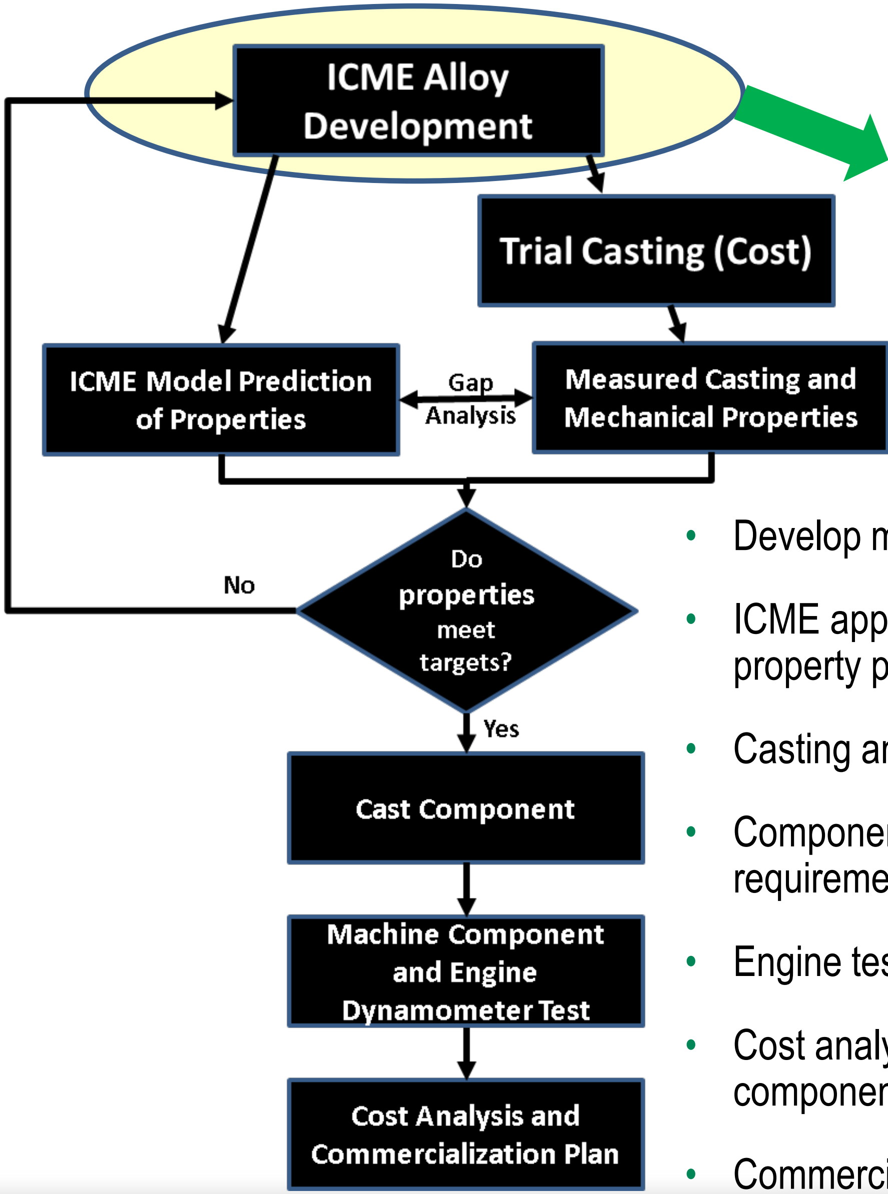
- Title: Complete cost model for component fabrication with new alloy.

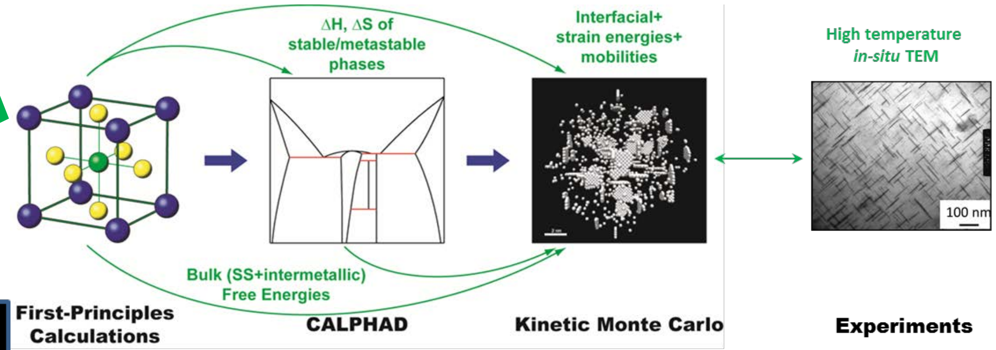
  Planned Date: 7/31/17

- Title: Finish commercialization plan for the new alloy.

  Planned Date: 11/30/17

Approach

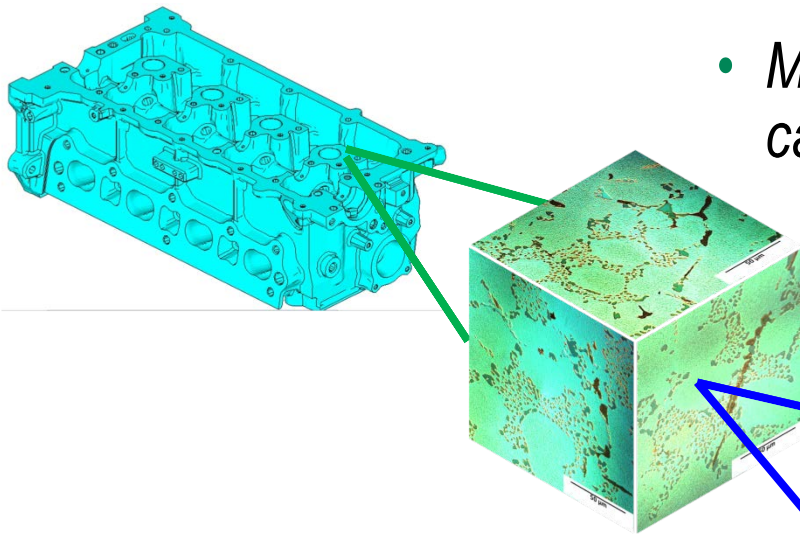


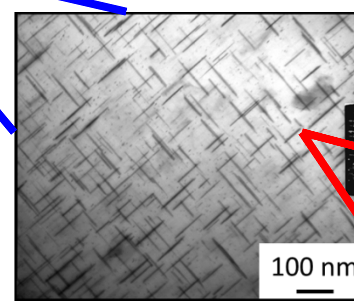


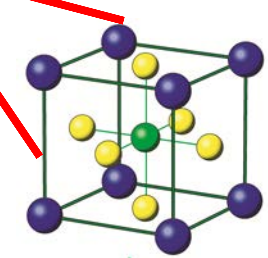
- Develop microstructure-property maps for baseline compositions
- ICME approach for alloy development and material and component property prediction
- Casting and mechanical property measurements for select compositions
- Components cast for materials that meet ***cost*** and property requirements
- Engine testing for components
- Cost analysis for production of large number (hundreds of thousands) of components
- Commercialization plan

ICME Approach and its evaluation

- *ICME evaluations*
- *Key microstructural scales defined for different properties*
- *Models and tools evaluated for predictive capabilities and ability to bridge scales*







<u>Model Type/Tool</u>

FEM → Phase Field/ProCast JMatPro/DICTRA → CALPHAD → DFT/Atomistic Modeling

Technical Accomplishments

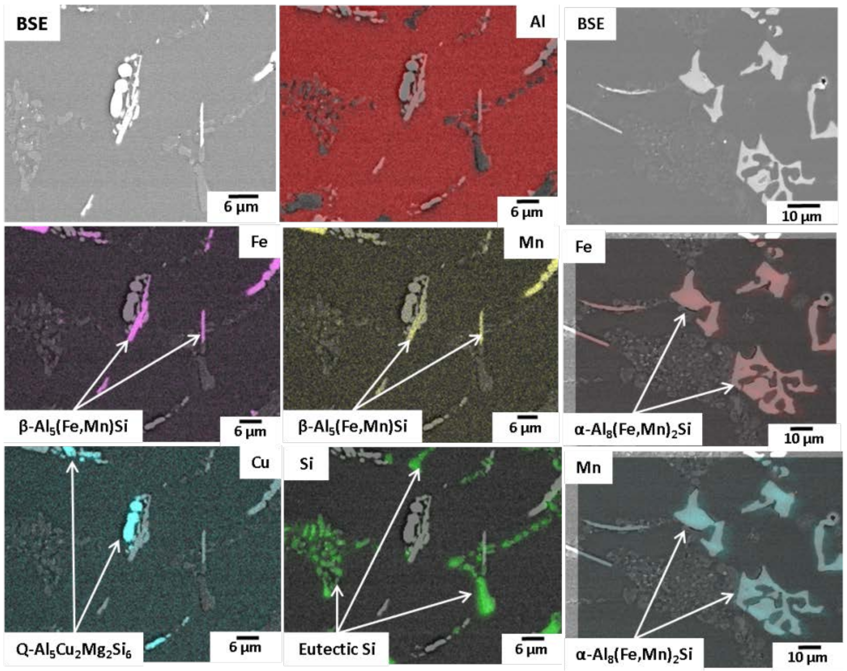
- Minimum target properties for new alloys (***to be developed***)

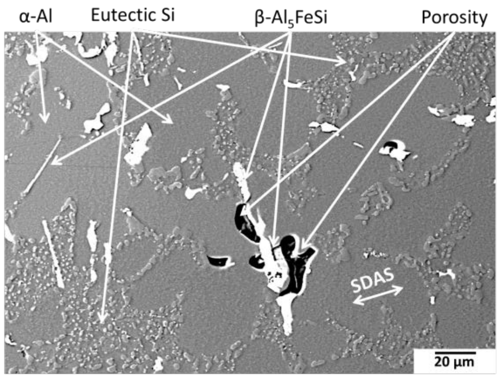
TABLE 6: Baseline and Targets for Cast Lightweight Alloy

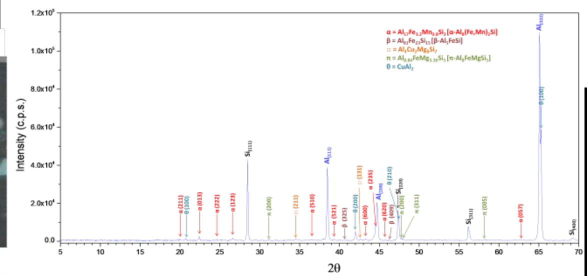
Property	Cast Aluminum Baseline	Cast Lightweight Alloy Targets	Key Properties (must meet)
Tensile Strength (Ksi)	33 KSI	40 KSI	Key
Yield Strength (Ksi)	24 KSI	30 KSI	Key
Density	2.7 g/cm^3	< 6.4 g/cm^3	Key
Elongation (%)	3.5 %	3.5 %	
Shear Strength	26 KSI	30 KSI	
Endurance Limit	8.5 KSI	11 KSI	
Fluidity (Die Filling Capacity/Spiral Test)	Excellent	Excellent	Key
Hot Tearing Resistance	Excellent	Excellent	Key
High Temperature Performance	@ 250C	@ 300 C	
Tensile Strength (KSI)	7.5KSI @ 250 C	9.5 KSI @ 300 C	Key
Yield Strength (KSI)	5 KSI @ 250 C	6.5 KSI @ 300 C	Key
Elongation in 2"	20% @ 250 C	< 20% @ 300 C	

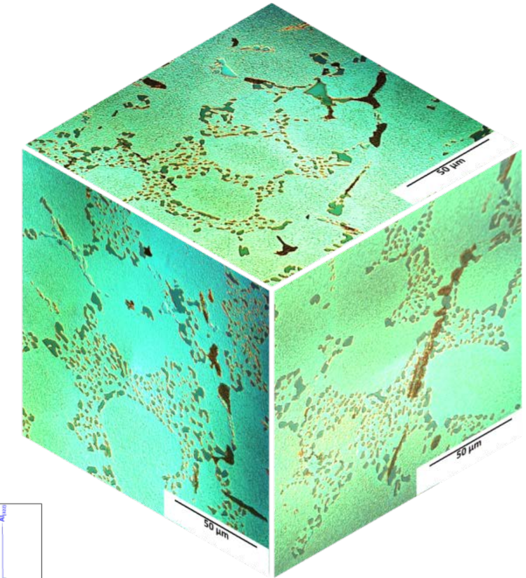
- Baseline materials supplied by Nemak
  - 319-T7; 356-T6; A356-T6; A356+0.5Cu-T6 alloy
  - All materials have secondary dendrite arm spacing (SDAS) of ~ 30 μm
- Characterization (for cylinder head application) of ***baseline materials***
  - Microstructure characterization
  - Mechanical properties; high temperature tests on preconditioned specimens
  - Thermal properties (thermal expansion, heat capacity, thermal expansion, thermal conductivity)

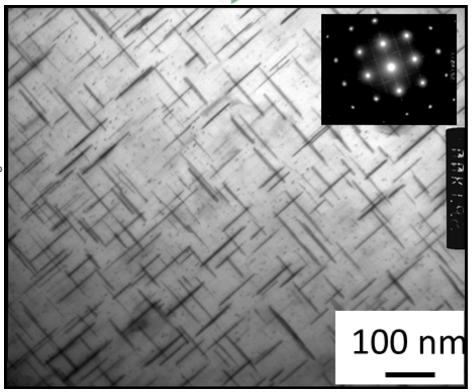
Microstructure characterization





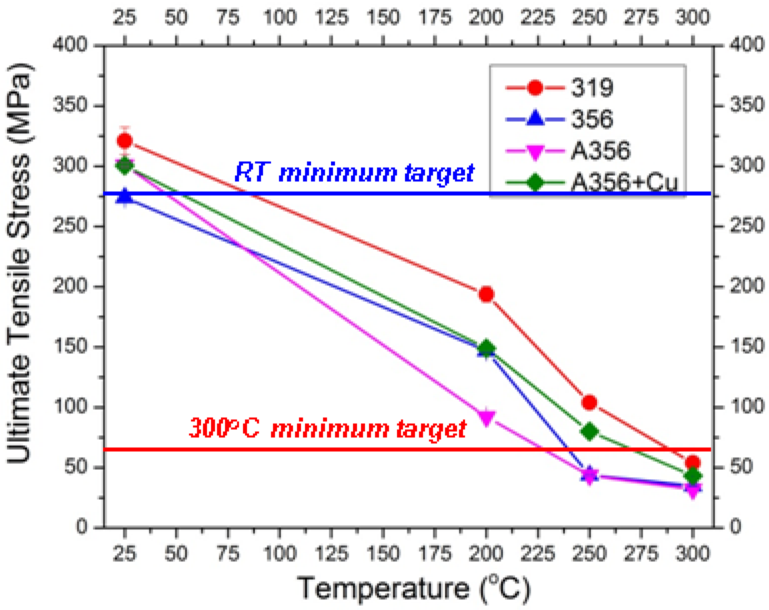


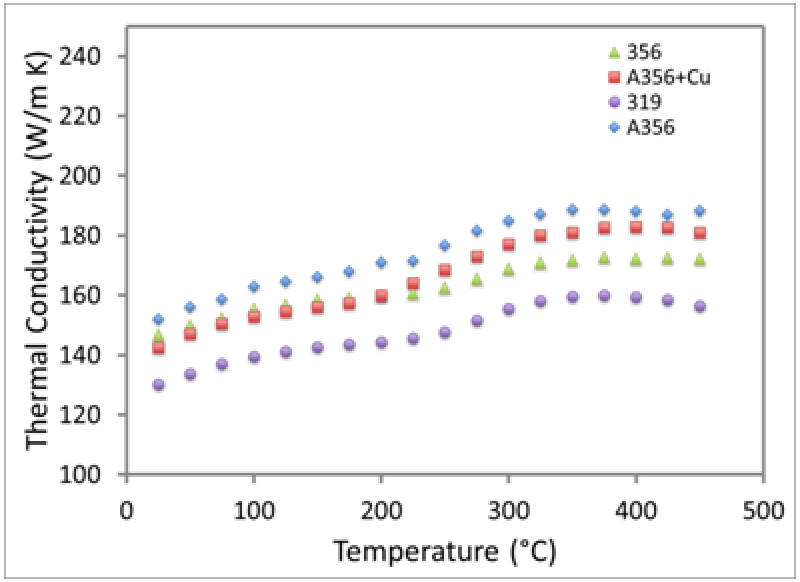


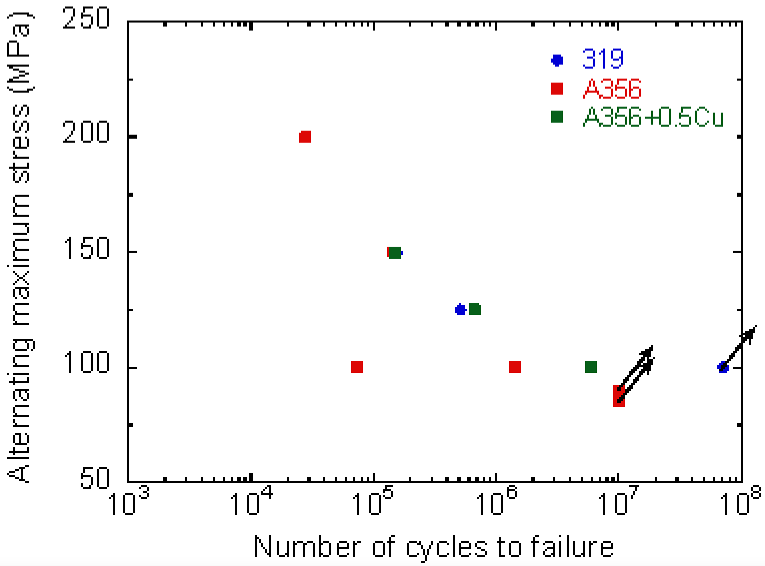


- Baseline material microstructure characterization (example for 319 alloy)
  - Optical, scanning and transmission electron microscopy.
  - Energy Dispersive spectroscopy, microprobe and X-ray diffraction.
  - Microstructure characterized to (i) relate to properties, (ii) develop new alloys with desirable microstructural constituents and (iii) ICME model development

Property Measurements







- *Processing ←→ Microstructure ←→ Properties mapping*
  - *Example 1 - Fatigue lifetime – pore size/large precipitate distribution relationship*
  - *Example 2 – Strength – precipitate distribution relationship*
- *ICME model evaluations and gap analyses on this knowledge base*

Responses to Previous Year Reviewers' Comments

- This is a new project with start date in November 2013 and was not reviewed last year.

Collaboration

- *CRADA* partners with significant cost share
  - Chrysler Group LLC - OEM automotive manufacturer
    - Advanced Powertrain
    - Powertrain Laboratories Engine, Transmission, & Component Testing
    - Engine Build, Powertrain Garage
    - Instrument Services, Tool Development and Support and Test Data Management
  - Nemak S. A. – Cylinder head supplier to Chrysler
    - Six world class product development centers
    - Product prototyping development at these centers utilizes the latest software and technologies to simulate processes and determine optimal product configurations
    - The Semi-Permanent Molding (SPM) technologies for cylinder heads include Gravity, Direct Pouring, Low Pressure, and Rotacast.
- Other cost share partners
  - Granta MI – Data management partner
  - ESI North America, Flow Science, Magma Foundry Technologies – casting simulation software
  - Minco Inc – casting supplies

Challenges and Barriers

- *Complexities of negotiating a multi-party CRADA (resolved)*
- *Complex and mature engineering alloys*
- *Predictive capabilities of several ICME tools are unknown*
- *Cost of ICME tools (casting simulation etc). Cost share mitigates the total cost. Cost of running an ICME type project is nonlinear.*
- *Cost share of partners can be nonlinear (heavy Nemak involvement in the beginning of the project and heavy Chrysler involvement in the later stages)*

Future Work

- Remaining in FY14
  - Finish baseline alloy characterization
  - Development of trial compositions
  - Screening of properties for trial compositions
  - Selection of alloy family for further development
  - Start ICME model development for properties
- FY15
  - Finish ICME implementation select baseline alloys
  - Model metal casting including flow modeling, defect (microporosity) and microstructure prediction (dendrite arm, eutectic fraction, etc.)
  - Identify gaps in existing ICME codes for cast aluminum
  - Identification of alloy compositions with improved properties in FY16

Summary

- **Relevance:** New alloys that can enable the development and implementation of higher efficiency passenger car engines
- **Approach/Strategy:** ICME approach to accelerate the development of cast aluminum alloys. Partner with major players in this area.
- **Accomplishments:** Characterized industry standard alloys that provide pathways for further alloy development.
- **Collaborations:** Chrysler, Nemak and smaller software cost-share partners
- **Proposed Future Work:**
  - Alloy chemistry prediction
  - Casting and screening of trial alloys
  - Characterization of new alloys
  - Casting of components and engine testing
  - Cost model for cylinder heads