Sustainable TRANSPORTATION Working Group

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

Virtual Vehicle Initiative

Accelerating Vehicle Innovation through a Full 3D High Fidelity Simulation Environment

Summary of Stakeholders Meeting—March 13, 2015

National Laboratory Team
Oak Ridge National Laboratory
Argonne National Laboratory
Sandia National Laboratories
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
National Renewable Energy Laboratory

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

Executive Summary

An industry stakeholder meeting was held at the headquarters of the US Council for Automotive Research (USCAR) to assess interest and priorities in the development and use of a "Full 3D High Fidelity Simulation Environment" (3DHiSE) for accelerating vehicle innovation using high-performance computing (HPC) architectures. As part of a process of reviewing "Big Ideas" in the DOE system, the meeting was organized by a DOE national laboratory team at the encouragement of the DOE Sustainable Transportation Leadership. In the DOE system, the 3DHiSE concept has been known as "Virtual Vehicle." The meeting format was structured to hear and document challenges *exclusively faced by the industry* and opportunities for which 3D simulation via emerging affordable petascale computing might be a powerful resource. The 24 industry participants included auto OEMs, truck and engine OEMs, off-highway equipment makers, major suppliers, and USCAR leadership.

The meeting achieved the objective of obtaining stakeholder feedback and setting research priorities for the next generation of affordable computational power. Many examples of research areas were described in which 3DHiSE-type computational tools are needed to achieve accelerated development and commercialization of fuel-efficient vehicles and powertrains, including exploration of higher-risk paths and opportunities to capture real-world fuel economy that are missed because of shortcomings in time-intensive processes like calibration. Generally, the greatest needs arise where it is essential to computationally link multiple processes and components (e.g., aero-crash-thermal-lightweighting, and combustion-thermal-fluid dynamics-structure) without losing the fidelity of any of the components. There was broad support for a computational environment having an adaptive fidelity feature. It was noted that today's vehicle design and calibration optimization are being compromised as a result of the length of the process, and discoveries of undesirable attributes are being made in vehicle prototypes instead of during the design and simulation steps. Off-cycle (i.e., outside certification test cycles, real-world) benefits of technologies are being missed. The participants were asked to comment on potential greenhouse gas emission and fuel use benefits of new HPC methods. There was universal affirmation that the benefits are substantial, although specific *quantification* would require some follow-up with the participants. Since fuel-efficient technologies do not save fuel unless they are purchased and used, affordability was reinforced as an objective, along with new system innovations. The benefits go well beyond Corporate and Fuel Economy (CAFE) standards, especially considering the freight and off-highway sectors.

The industry endorsement of, passion for, and expectation of moving forward with this idea/initiative appear very strong.

Recommended next steps are

- Clarify estimates of quantified benefits in GHG and petroleum use.
- Proceed with a technical planning workshop.

Introduction and Objectives

The purpose of this meeting was to assess industry interest in the development of an open-source Full 3-Dimensional High Fidelity Simulation Environment (3DHiSE) for accelerating vehicle innovation using high-performance computing (HPC) architectures. This report contains a summary of feedback gathered at the meeting during the presentation and interactive sessions.

The stakeholder meeting was attended by representatives from the following organizations:

- US Department of Energy (DOE)
- Fiat Chrysler Automobiles (FCA)
- General Motors (GM)
- Deere & Company
- Cummins, Inc.
- Caterpillar, Inc.
- Delphi Automotive PLC
- Ford Motor Company
- Sandia National Laboratories
- Lawrence Livermore National Laboratory
- Oak Ridge National Laboratory (ORNL)
- National Renewable Energy Laboratory (NREL)
- Argonne National Laboratory
- Lawrence Berkley National Laboratory (LBL)
- DCYI Engineering Consulting
- U.S. Council for Automotive Research (USCAR)

A full list of attendees is included in Appendix A. Note that since this was a stakeholder-oriented meeting, the perspectives of software vendors, universities, regulators, and the like were not captured in this meeting. They may be included in a future workshop. Before the meeting, the organizers presented the purpose and scope to the USDRIVE Vehicle Systems Tech Team and received concurrence to proceed.

Background

The foundation of the 3DHiSE concept was created within DOE in 2009 by Dr. Steven Koonin, former Under Secretary for Science at DOE. At that time, a full vehicle simulation was deemed too complicated. So the scope was reduced to internal combustion engines only. As summarized in Figure 1, the idea continued to evolve, and the "Virtual Vehicle" was presented at the National Laboratories Big Ideas Summit in 2013 with the support of four national labs. Gaining traction, the concept was included in discussions regarding DOE transportation ideas and at the initial Transportation Working Group (TWG) meeting in 2014. Later that year, DOE approved the national laboratories to convene an industry stakeholders meeting. The national laboratory team then prepared read-ahead materials and made a presentation at the December TWG meeting. The directive from the TWG meeting was to proceed with the stakeholder meeting with input from the U.S. DRIVE Vehicle Systems Analysis Technical Team (VSATT), which was collected in January 2015. Consensus was sufficient to warrant the recent stakeholder meeting covered in this report.

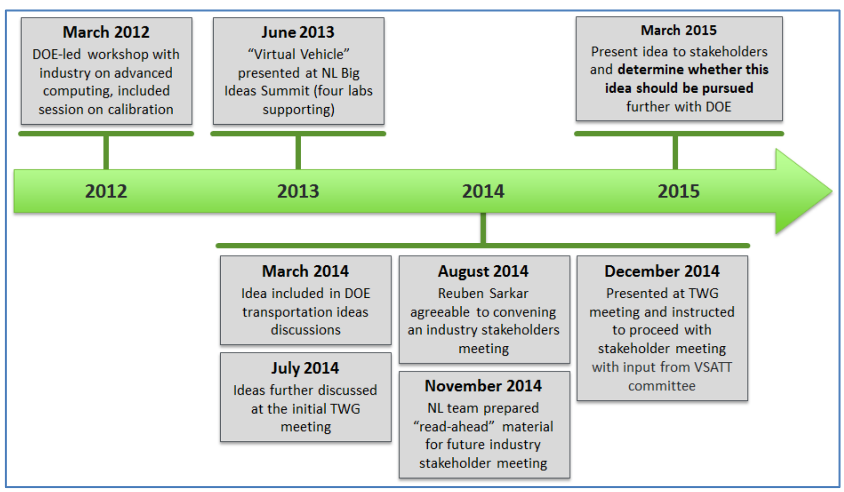


Figure 1: Maturation of 3DHiSE concept.

Approach to Stakeholder Meeting

To assess the industry need for and overall benefits of a 3DHiSE project, several questions were posed for the participants. Examples of the questions are

- What challenges and approaches in vehicle design and simulation would benefit from leveraging the oncoming affordable petascale computing, if developed in a 3DHiSE initiative?
- What are the potential benefits in reducing greenhouse gas emissions and petroleum usage?
- Are there new technologies and systems to be discovered as well as accelerating the development process?

To address these questions, the stakeholder meeting was broken into two general parts designed both to fully inform participants of the task at hand and to solicit their valuable feedback:

1. **Part One:** The purpose of this segment was to set the stage by engaging stakeholders with presentations on industry perspective, the state of the art in vehicle modeling, and advanced computing opportunities and recent successes.
2. **Part Two:** This segment focused on interactive sessions, open discussion of industry challenges and opportunities, prioritization of those challenges and opportunities, and finally an open discussion of the path forward. Participation in activities "a" and "b" (described below) was limited to industry participants. Non-industry participants were allowed to ask clarifying questions but not to participate in the prioritization.
    a. During the open discussion of industry challenges and opportunities, stakeholders were asked to write down their ideas, or questions, on note cards. These cards were then organized into categories on display boards.
    b. During the prioritization session each stakeholder was given five adhesive dots with instructions to place them on the ideas that they think are most important, with only one marker dot per person allowed per card.

The full agenda is provided in Appendix B, and a listing of the top stakeholder ideas from activity "b" is included in Appendix C.

Figure 2: Step "a" of the interactive session, stakeholders sharing ideas and challenges.

Figure 3: Industry stakeholders voting on ideas during step "b" of the interactive session.

Discussion

Opportunities that are unique to 3DHiSE were summarized in an industry perspective presentation. For example, Figure 4 provides a list of identified gaps in analysis capability, such as the need for 3D vehicle dynamics to predict vehicle function in real-world environments (e.g., cold, wet, and hot) and to evaluate new power sources and fuels.

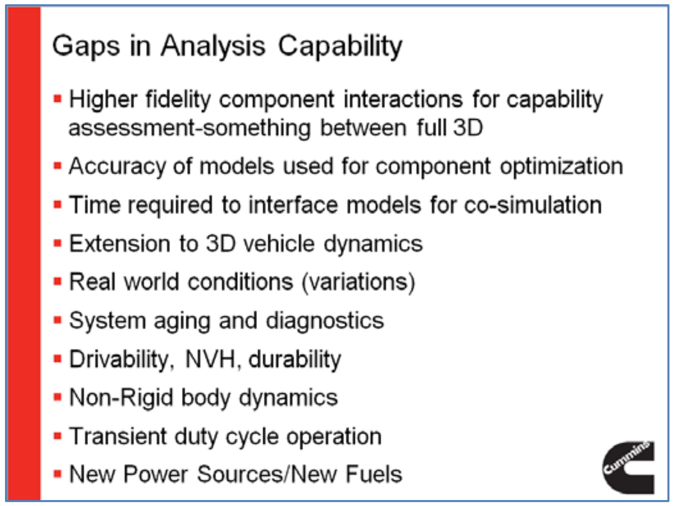


Figure 4: Gaps in analysis capability.

A general consensus was reached among the stakeholders that similar opportunities exist in the vehicle calibration space, as noted in the discussion period and evidenced by a related idea card that received many votes (see Appendix C). The idea is that 3DHiSE could be used for calibration development for engines and transmissions, creating the ability to handle the rapidly growing number of calibration variables. An exponential increase in vehicle component and subsystem complexity has resulted in a similar increase in complexity in the design and calibration parameter space, which has become so large that reaching a fully optimized design is cost-and time-prohibitive. An illustration of this idea was provided by an industry stakeholder during the interactive session:

> *"Even if an optimal design solution is reached for a component or subsystem, the solution becomes sub-optimal through calibration of the subsystems as a whole." — original equipment supplier*

3DHiSE's potential impact on design optimization, vehicle calibration, and vehicle operation in a data-rich environment creates a unique opportunity to reach a fully optimized design and thereby minimize cost, reduce greenhouse gas (GHG) emissions, and improve fuel economy. This opportunity was also reflected in another industry stakeholder comment regarding the significant amount of "discovery" currently taking place at the vehicle prototype stage. Discovery of compatibility or compliance issues at the prototype stage of vehicle development is costly, and it is difficult to correct findings at that point. With high-fidelity simulation, discovery at the vehicle prototype stage can be minimized and therefore the time to market for technological advancement reduced.

The participants also widely supported and recognized the potential for a 3DHiSE modeling framework to offer the ability to assess noise factors, enable virtual product validation, and serve as an on-board diagnostics plant model. Virtual product validation also offers the potential to design and model mixed materials and multi-materials, which would take advantage of the unique capabilities that HPC offers. These unique potential benefits were echoed in comments from a heavy equipment original equipment manufacturer (OEM) during the interactive session. Currently, whole-vehicle simulation is done piecewise and therefore relies on people to interact and convey information. 3DHiSE has the potential to change this process by integrating the piecewise functions into a larger simulation. As a result, simulation time can be reduced; and the resulting design can be optimized by evaluating transients, cold start, and so on, which will ultimately allow the design to achieve a higher state of efficiency.

An idea from the interactive session that received significant votes during the prioritization activity was to use the 3DHiSE framework to create a complete virtual-engine 3D simulation. This simulation should include combustion, structure and materials, airflow, cooling, and dynamics. In support of this utilization, the following comment was made by an industry stakeholder during the interactive session:

> *"There is a significant opportunity for fuel consumption reduction by coupling the simulation of combustion and cooling system."* — heavy equipment OEM

3DHiSE also has the potential to reduce the cost of fuel saving technologies, enabling these technologies to have a greater market penetration, as captured by a stakeholder in an industry perspective presentation:

> *"Affordability is crucial, not just for emerging markets, but for North America as well. You can add a lot of technology to the vehicle, but people aren't willing to pay anything for it."* — passenger vehicle OEM

If the cost of new technologies can be offset through innovation and by optimizing current systems, greater improvements in fuel efficiency can be realized over a larger number of vehicles in the future. Passenger car OEMs noted the challenge of modeling and calibrating for cold-start emissions. This requires very detailed models of combustion, computational fluid dynamics (CFD), component heat transfer, and aftertreatment, all working together. Experiments to validate performance at a range of cold conditions require temperature-controlled engine or vehicle cells, which are not widely available. New technologies must meet emissions requirements for a variety of conditions before they make it to production. 3DHiSE has the potential to provide an integrating framework to link existing tools that model several of these subsystems and simulate at the system or vehicle level any number of environmental conditions. Another industry comment on this topic was

> *"Nearly every new product development project has a goal that relates to improving fuel economy. Companies are only willing to accept a certain level of risk."* — heavy equipment OEM

Innovative technologies that can improve fuel economy are often not included in new product offerings because of the risk of compromising other product attributes. For instance, including costly waste heat recovery technology would have a positive impact on fuel efficiency but might negatively impact the exhaust, emissions, or other related systems. The use of high-fidelity modeling would allow for optimization and integration of new technologies and enable a better understanding of the effects on other vehicle systems, and thus reduce risk. Therefore, it is possible with this capability to realize greater incremental improvements in fuel economy.

Figure 5: Participants provide and review ideas during the interactive session.

Finally, an example of how 3DHiSE can potentially improve fuel economy from an aerodynamics perspective was discussed during a walk-up presentation by a passenger vehicle OEM. Currently, external aerodynamics of the entire vehicle is modeled using the Reynolds-Averaged Navier–Stokes equations (RANS), which provide a time-averaged mean value for a velocity field. The limitation of this computationally straightforward approach can be illustrated by the following example. Consider taking successive pictures of a velocity vector at a specific point of turbulent flow over a period of time. Because of the nature of turbulent airflow, this velocity vector will change over time, but RANS will return a constant velocity vector, essentially an average of the pictures taken. Where greater fidelity is required, a method known as large eddy simulation (LES) is used. LES resolves large scales of the flow field solution numerically and models the smaller scales of the solution. Consider taking successive pictures again; with LES, the variations in the velocity vector are clearly visible at each specific point.

Since LES requires higher-resolution meshing, applying it to the entire vehicle is cost-prohibitive currently because of the significantly increased computational resources it requires. If LES could be applied to the entire vehicle, in a cost- and time-effective manner, the design could be optimized to minimize the drag coefficient and reduce noise. Optimization of vehicle aerodynamics, either using LES or achieving even greater fidelity using direct numerical simulation, would require a 3DHiSE that leverages petascale and beyond HPC infrastructures. The use of this high-fidelity simulation environment in combination with crash and thermal management to optimize the design would create improvements in fuel economy and a corresponding reduction in GHG emissions.

Another idea from the interactive session that was supported by the prioritization activity was in regard to "off-cycle" credits, specifically how to use the 3DHiSE tool set to promote the development of new fuel saving technologies. Off-cycle technologies achieve real-world CO_2 reductions in the field that are not reflected in current vehicle certification test procedures. The US Environmental Protection Agency (EPA) requires manufacturers to apply for CO_2 reduction credits, including demonstration and supporting data, to receive the credits.

The question of how 3DHiSE would contribute to meeting Corporate Average Fuel Economy (CAFE) requirements and beyond was addressed in comments made by an engineering consulting firm during the interactive session. It was suggested that one approach to meeting the CAFE requirement for new cars and trucks of 54.5 miles per gallon is to incorporate off-cycle credits for fuel-saving technologies. 3DHiSE would have the unique ability to determine which technologies have a greater effect on fuel economy over real-world cycles. As a result, stakeholders would benefit from having to spend less time developing, validating, and implementing new fuel-saving technologies. 3DHiSE could also provide manufacturers with a standard by which to validate these technologies with EPA to realize off-cycle credits.

Another perspective on how to go beyond CAFE, brought up during the interactive session:

> *"Consider looking beyond the vehicle to modeling a well-to-wheel analysis of alternative and biofuels."* – original equipment supplier

Modeling the utilization of a potential new fuel would also create the opportunity to understand the impact on GHG emissions from an overall well-to-wheel perspective. The ability to understand the potential impact without actually implementing the new fuel, or fuels, on a large scale affords the industry the opportunity to consider many alternate paths to reduced GHG emissions and improved fuel economy with a relatively small investment of time and resources.

The medium- and heavy-duty vehicle sector is the fastest growing GHG contributor in transportation. These vehicle makers are responding to their first-ever GHG regulations that were recently implemented. A perspective from that stakeholder area:

> *"It would be better to be preemptive rather than reactive. 3DHiSE could allow testing to be completed in the lab through multiple iterations, rather than having to test in the full vehicle. Due to the high level of complexity of our offerings, 3DHiSE would reduce the amount of testing required for validation, and ultimately result in better solutions to improve fuel economy and reduce greenhouse gas emissions."* – heavy-duty vehicle OEM

Summary of Findings and Recommendations

Overall Encouragement to Proceed, with Guidance

Based on the industry stakeholder perspectives and examples discussed, a general consensus was obtained at this meeting in favor of moving forward with 3DHiSE. To consider this concept in greater detail, we must revisit the questions posed in conveying the objectives of the stakeholder meeting.

A consensus was reached among industry stakeholders that there are valuable opportunities unique to this high-fidelity modeling framework. Several of these unique opportunities also provide support and consensus with regard to reducing petroleum consumption and GHG emissions and meeting and exceeding CAFE standards. A focused technical roadmap workshop is needed to ensure that critical gaps are filled. Software vendors need to join the discussion. 3DHiSE has the potential to deliver shorter development cycles, virtual component validation, and conjugate and transient modeling, which in turn would equate to lower-cost and more innovative fuel saving technologies. Consequently, 3DHiSE has the potential in the near and long term to contribute to the DOE mission of reducing petroleum use and GHG emissions, and the national laboratories have unique resources and expertise to address this opportunity and ultimately transition their findings to industry. Further discussions are needed to properly scope short- and long-term efforts and to confirm vehicle modeling applications that can most benefit from 3DHiSE. Industry stakeholder involvement is crucial. Industry must ensure that DOE and the national laboratories have enough awareness of industry capabilities not to duplicate industry efforts.

Recommendations for Computational Structure

- **Adaptive model fidelity** — Flexibility in the computational environment is needed to link to a hierarchy of models that can be invoked based on the available computational resources and the degree of accuracy needed to address specific questions, as well as error quantification. This capability was also referred to as "auto-scaling."
- **Modularized architect design space** — This enables the segmentation of physics and model fidelity to optimize the co-simulation space. One example discussed was full simulation of cold-start emissions with integrated models of combustion, catalysis, thermal, and other factors. A second example was full-engine process modeling with integrated structure, materials, combustion, and so on.
- **Helping users find what they are not looking for: mining and managing big data sets.** — The large amounts of data output from such a high-fidelity model would require the development of tools to allow users to identify findings they are not looking for (e.g., unexpected component failure, issues that may be obvious in a given situation but not in simulations).
- See the idea cards in Appendix C for other recommendations.

Example Problems for 3DHiSE

The examples here are representative, but not inclusive, of all the suggestions from the meeting.

- **Accelerating and improving the design/calibration process (cold-start problem).** With a higher-fidelity design simulation, we expect to be closer to a final calibration before the hardware and test cell phase. This would also address an exponentially increasing number of calibration parameters and lead to more optimal calibrations to avoid losing the fuel economy and emissions benefits as a result of a sub-optimal calibration. A specific challenge discussed during the meeting is cold-start emissions for emerging gasoline direct-injection engines and Tier 3 emissions requirements. This requires co-simulation of combustion, CFD, thermal/heat transfer, and catalysis.

- **Aerodynamic analysis at greater fidelity, combined with weight reduction and thermal management.** This challenge was described in an industry presentation. The recommendation is to move aerodynamic models to LES methods for entire vehicles and simultaneously assess vehicle weight and thermal management strategies. Management of noise is critical for consumer acceptance. Reduction of aerodynamic drag is a large GHG reduction opportunity for both cars and trucks.

- **Engine combustion, CFD, fuels, materials/structure co-optimization**. Engine design could be taken to the next level by co-processing the combustion side with materials/structural response. The computational environment would need to be developed so that doing so becomes an affordable, time-effective process. This would include processing thermal management, structural integrity, and noise with combustion parameters.

Other examples of how 3DHiSE could help meet and improve upon today's fuel economy standards are provided in the discussion section of this report, directly addressing opportunities for GHG emissions reduction, such as the potentially significant impact of the realization of off-cycle CAFE credits. Furthermore, 3DHiSE could provide the framework for industry to build the tools necessary to be proactive and more predictive, rather than merely reacting to CAFE goals.

Benefits related to reduced petroleum usage and reduced GHG emissions

- **Discovery and innovation enabled with 3DHiSE.** Among the stakeholder examples of new technologies and approaches that could be realized through HPC are
  - Improved aerodynamics, within constraints of weight, safety, noise, consumer acceptance
  - Capturing full powertrain efficiency potential via optimal calibration
  - 3D engine combustion, structure, cooling, aftertreatment emissions improvements
  - Capturing real-world, off cycle benefits with more robust integrated models to identify effective technologies
  - Biofuel + engine co-development

  The advantage of most of these technologies is that they relate to most (~97%) of the cars consumers are choosing, as well as the freight sector. Any one of them could achieve an ~10% fuel economy improvement, and success on several would offer greater benefits. A 10% improvement widely applicable to vehicles sold in a given year could reduce fuel use by 250 million gallons in the first year (similar to the impact of 500,000 new electric vehicles on the road).

- **Benefit of faster introduction of efficient and affordable technologies.**
  - Shorter design cycle
  - Reduced time needed for calibration
  - Affordability and value for consumer acceptance.

  For each year taken off the development cycle for a 10% more efficient vehicle, the fuel saved in just the first year is approximately 250 million gallons if the improvements are widely implemented. Early introduction of efficient technologies is crucial, because that efficiency advantage persists through the 10–12 year life of the vehicle. Once the typical 15 million new cars are sold in a given year, there is no way to improve their efficiency while they are in use. Accelerated development and deployment saves billions of gallons over a model-year lifetime of fuel usage. Affordability is crucial for consumer acceptance. Fuel economy regulations are effective only if consumers accept the efficient vehicles. More complete analysis of the benefits is an objective of the Initiative team.

The Path Forward

Moving forward, information generated at this stakeholder meeting pertaining to requirements for 3DHiSE—including short-, mid-, and long-term goals—should be compiled into a technical roadmap with input from an additional workshop.

Based on the strong endorsement from the stakeholders at this meeting, the next steps for the 3DHiSE idea are to add clarity to the fuel efficiency and GHG benefits and to engage additional industry stakeholders, national laboratory researchers, software vendors, and appropriate DOE personnel in a multi-day workshop to prepare a technical roadmap. The information obtained from the workshop in concert with the information and ideas collected during this stakeholder meeting will be used to develop an actionable plan for the complete development of 3DHiSE in close collaboration with stakeholders. The participants may want to consider proposing a modest effort as a test case for 3DHISE benefits.

Appendix

A. Meeting Agenda

STAKEHOLDER MEETING

Accelerating Vehicle Innovation through a Full 3D High Fidelity Simulation Environment

USCAR Facilities, Southfield MI

March 13, 2015

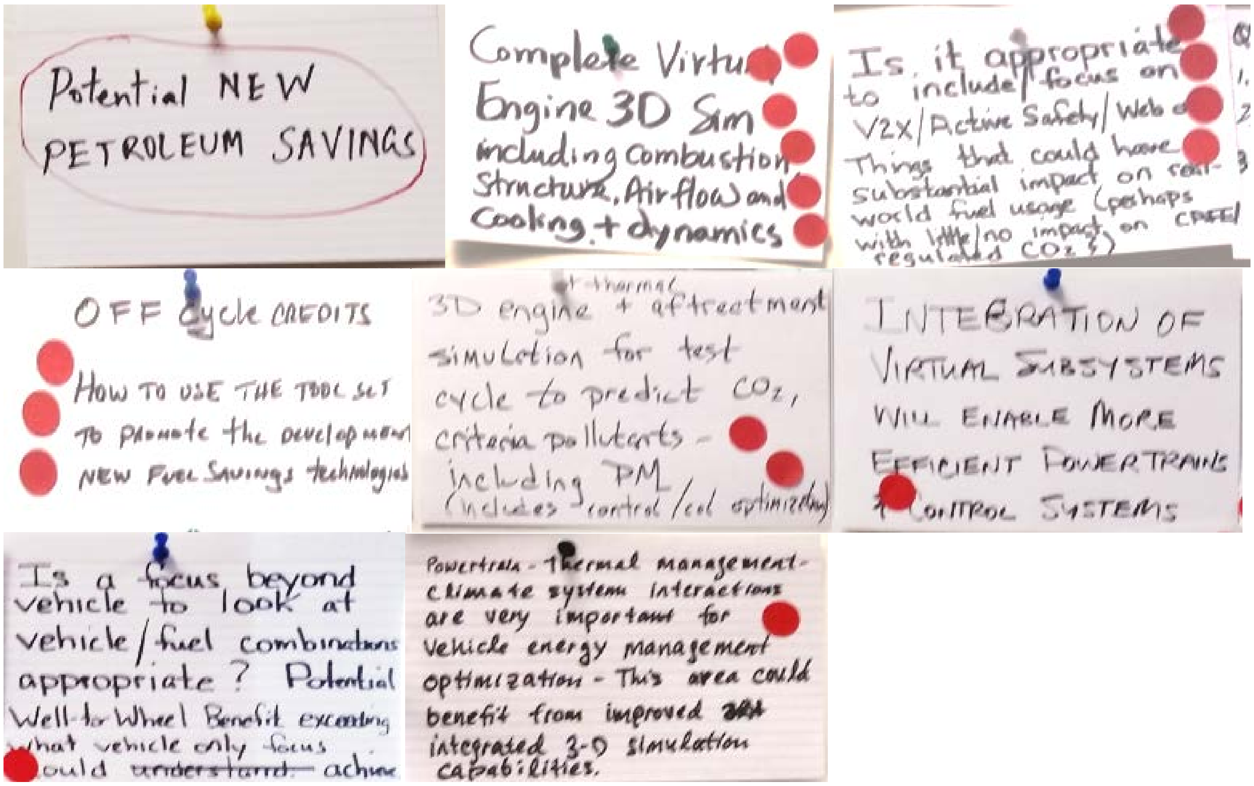
Pre-meeting			
7:30 am (30 min)	**Continental Breakfast**	Networking	All
Setting the Stage			
8:00 am (30 min)	**Presentation** – Welcome and meeting background	Dr. Robert Wagner, Director of the Fuels Engines and Emissions Research Center, Oak Ridge National Laboratory	Wagner
8:30 am (30 min)	**Presentation** – Industry perspective	Dr. Gary Smyth, Executive Director of Global R&D Laboratories, General Motors	Smyth
9:00 am (30 min)	**Presentation** – Industry perspective	Dr. Wayne Eckerle, Vice President of Corporate Research and Technology, Cummins	Eckerle
9:30 am (30 min)	**Presentation** – Industry perspective	Mr. Jeff Zyburt, President of DCYI Engineering Consulting & Process Development	Zyburt
10:00 am (15 min)	**Break**		
10:15 am (30 min)	**Presentation** – State-of-the-Art in vehicle systems modeling	Mr. Aymeric Rousseau, Manager of the Vehicle Modeling and Simulation Section, Argonne National Laboratory	Rousseau
10:45 am (30 min)	**Presentation** – Advanced computing opportunities and recent successes	Dr. Sreekanth Pannala, Distinguished Research Staff, Computing and Computational Sciences Directorate, Oak Ridge National Laboratory	Pannala
Interactive Sessions and Information Gathering			
11:15 am (45 min)	**Interactive session** – Open discussion of industry challenges and opportunities	Everyone will be asked to discuss and write down (on provided index cards) thoughts on the highest priority needs. Ideas and thoughts will be captured and grouped on flip charts.	All
12:00 pm (60 min)	**Lunch** ($3.00) **and additional walk-up perspectives**	Opportunity for walk-up presentations on stakeholder perspectives. Participants will also have an opportunity to "mark" ideas that are of the most importance to them.	All
1:00 pm (30 min)	**Interactive session** – Open discussion of industry prioritization exercise	Results of the prioritization exercise will be discussed and summarized to capture stakeholder perspectives.	All
1:30 pm (30 min)	**Interactive session** – Open discussion of path forward	Open discussion of potential paths forward including possibly those different than the intention of this meeting.	All
2:00 pm (30 min)	**Break**	Opportunity for scribes to work on quick summary of the meeting.	All
Wrap-up			
2:30 pm (60 min)	**Report out** –Summary of the meeting	Summarize and confirm meeting outcome with key takeaways for DOE on stakeholder interest and value of this idea to move forward.	Wagner/Pannala
3:30 pm	**Adjourn**		All

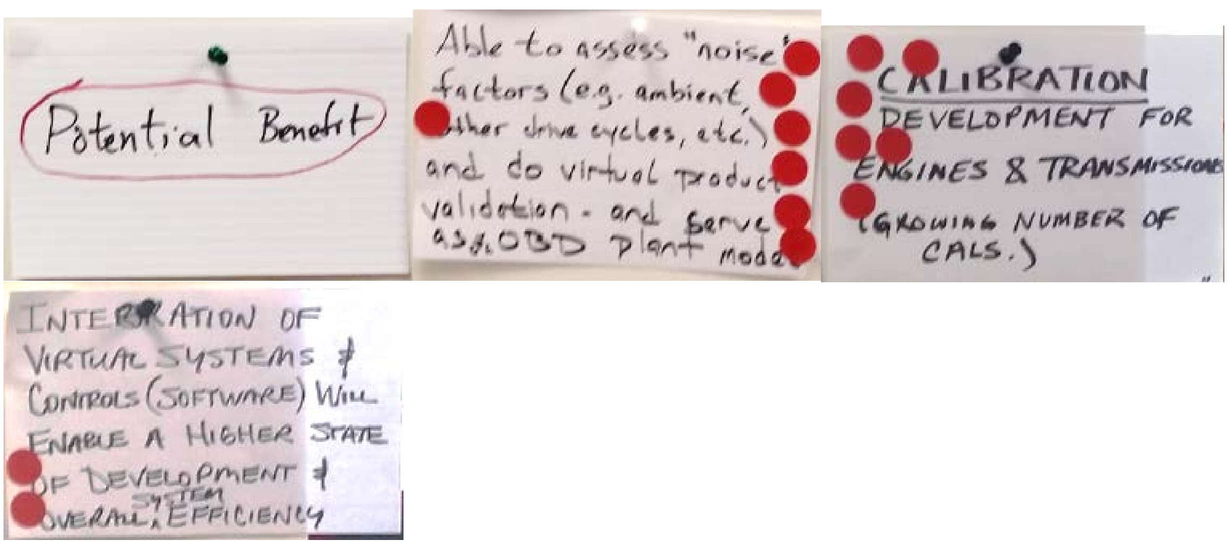
B. List of Attendees

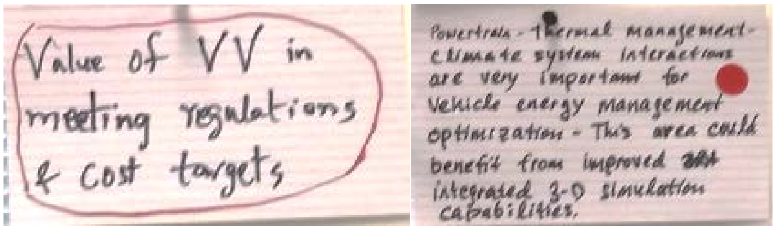
National Laboratories (10)		
LBL	Samveg Saxena	Research Scientist
Argonne	Aymeric Rousseau	Manager, System Modeling and Control
Argonne	Ann Schlenker	Section leader, Center for Transportation Research
Sandia	Guilhem Lacaze	Researcher Scientist
NREL	Ahmad Pesaran	Group Manager, Energy Storage
LLNL	Matt McNenly	Computational Scientist
ORNL	Sreekanth Pannala	Distinguished Research Staff
ORNL	Ron Graves	Director, Sustainable Transportation Program
ORNL	Robert Wagner	Director, Fuels Engines and Emissions Research Center
ORNL	Johney Green	Director, Energy and Transportation Science Division
SRA International	Russ Campbell	Engineer
Industry (24)		
DCYI	Jeff Zyburt	President, DCYI Engineering Consulting
Ricardo	Aaron Van Natter	Chief Engineer III
Caterpillar	Keven Hofstetter	Engineering Technical Steward, L6 Machine Performance Simulation
Cummins	Tara Hemami	Director, System Performance Analysis group
Cummins	Vivek Sujan	Modeling Lead, Power Systems Optimization group
Cummins	Wayne Eckerle	Vice President–Corporate Research and Technology
Navistar	Laura Ricart-Ugaz	Chief Engineer Development
FCA	Bill Resh	Senior Manager, Powertrain Virtual Analysis
FCA	Ken DeGroot	Advanced Emissions PZEV and AT-PZEV, Fuel Economy and GHG Regulation Engineer
FCA	Pradeep Attibele	VSATT representative
FCA	Ron Reese	Manager, Advanced Combustion Systems
FCA	Steve Barnhart	
Ford	James Yi	Technical Leader and Manager, Combustion System R&D
Ford	Mark Jennings	VSATT representative
GM	Bahram Khalishi	
GM	Gary Smyth	Executive Director of Global R&D
GM	Mike Kropinski	
GM	Norm Bucknor	VSATT representative
GM	Ron Grover	Staff Researcher, Advanced combustion engine concepts, spray modeling in CFD
USCAR	Steve Zimmer	Executive Director, USCAR
John Deere	Duane Eaton	Global Director of Product Engineering Service
John Deere	Gui Xinqun	Manager, John Deere Power Systems
Delphi	Harry Husted	Chief Engineer, Product Integration and Controls at Delphi
Delphi	John Kirwan	Chief Scientist, Delphi Powertrain Systems
Department of Energy (4)		
DOE	David Anderson	DOE Vehicle Systems Lead
DOE	Gurpreet Singh	DOE Advanced Combustion Engine (ACE) Lead
DOE	Ken Howden	DOE ACE emissions lead
DOE	Reuben Sarkar (phone)	Deputy Assistant Secretary of Transportation

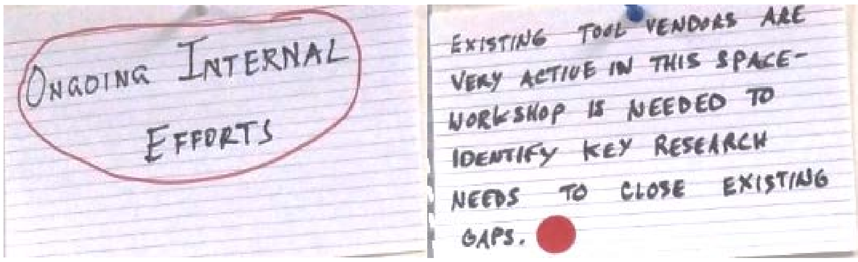
C. Top Prioritized Stakeholder Ideas

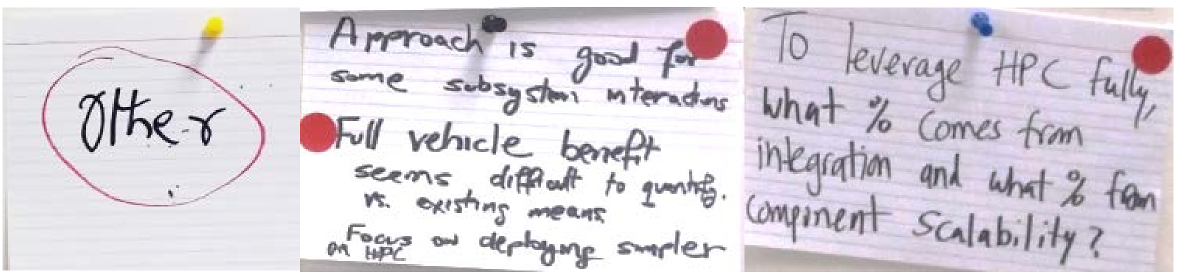
Ideas were captured with note cards and then grouped. All cards receiving at least one vote are included below, by group.

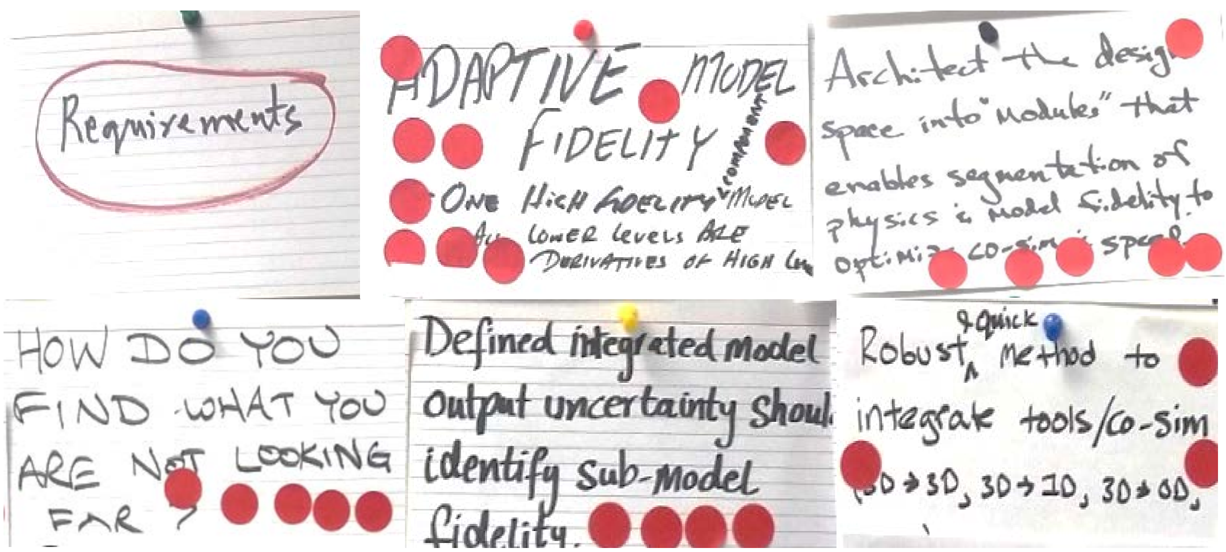


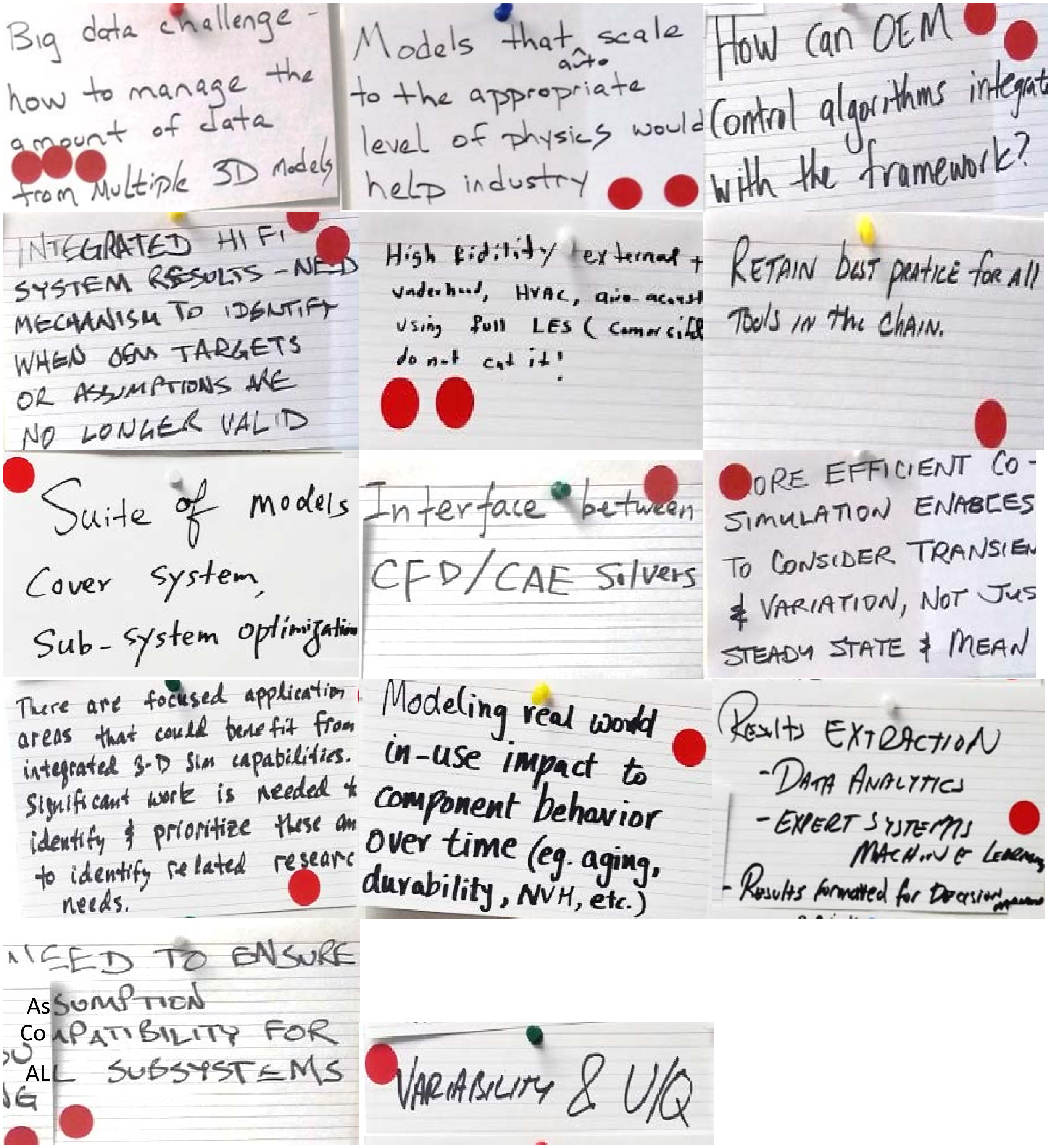



Value of VV in meeting regulations & cost targets
Powertrain - thermal management - climate system interactions are very important for vehicle energy management optimization - This area could benefit from improved integrated 3-D simulation capabilities.


ONGOING INTERNAL EFFORTS
EXISTING TOOL VENDORS ARE VERY ACTIVE IN THIS SPACE - WORKSHOP IS NEEDED TO IDENTIFY KEY RESEARCH NEEDS TO CLOSE EXISTING GAPS.


Other
Approach is good for some subsystem interactions
Full vehicle benefit seems difficult to quantify vs. existing means
Focus on HPC on deploying simpler
To leverage HPC fully, what % comes from integration and what % from component scalability?


Requirements
ADAPTIVE MODEL FIDELITY
ONE HIGH FIDELITY MODEL
ALL LOWER LEVELS ARE DERIVATIVES OF HIGH
Architect the design space into "modules" that enables segmentation of physics & model fidelity to optimize co-sim & speed
HOW DO YOU FIND WHAT YOU ARE NOT LOOKING FOR?
Defined integrated model output uncertainty should identify sub-model fidelity.
Robust & quick method to integrate tools/co-sim
3D→3D, 3D→1D, 3D→0D,


Big data challenge - how to manage the amount of data from Multiple 3D models
Models that auto scale to the appropriate level of physics would help industry
How can OEM Control algorithms integrate with the framework?
INTEGRATED HI FI SYSTEM RESULTS - NEED MECHANISM TO IDENTIFY WHEN OEM TARGETS OR ASSUMPTIONS ARE NO LONGER VALID
High fidelity external + underhood, HVAC, aero-acoust using full LES (commercial do not cut it!
RETAIN best pratice for all Tools in the Chain.
Suite of models Cover system, Sub-system optimization
Interface between CFD/CAE Solvers
MORE EFFICIENT CO-SIMULATION ENABLES TO CONSIDER TRANSIENT & VARIATION, NOT JUST STEADY STATE & MEAN
There are focused application areas that could benefit from integrated 3-D Sim capabilities. Significant work is needed to identify & prioritize these areas to identify related research needs.
Modeling real world in-use impact to component behavior over time (eg. aging, durability, NVH, etc.)
Results EXTRACTION
-DATA ANALYTICS
-EXPERT SYSTEMS MACHINE LEARNING
-Results formatted for Decision
NEED TO ENSURE ASSUMPTION COMPATIBILITY FOR ALL SUBSYSTEMS
VARIABILITY & U/Q