Fundamental Advancements in Pre-Chamber Spark Ignition and Emissions Control for Natural Gas Engines

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Argonne National Laboratory, USA
PI: Doug Longman
Munidhar Biruduganti
Ashish Shah
Riccardo Scarcelli
Joohan Kim
Sibendu Som
Prasanna Chinnathambi

Oak Ridge National Laboratory, USA
PI: Scott Curran
Josh Pihl
Jim Szybist
Melanie Moses-DeBusk
Chloé Lerin
Sreshtha Sinha Majumdar

US Department of Energy, USA
Kevin Stork
Gurpreet Singh
Michael Weismiller

National Renewable Energy Laboratory, USA
PI: Brad Zigler
Matthew Ratcliff
Shashank Yellapantula
Mohammad Rahimi
Ray Grout
Jon Luecke
Whitney Collins

Sandia National Laboratories, USA
PI: Mark Musculus
Zheming Li
Rajavasanth Rajasegar
Dalton Carpenter (U South Carolina, USA)
Yoichi Niki (Nat. Inst. Maritime Port Aviation Tech, Japan)
Jose Maria Garcia Oliver (U Poly. Valencia / CMT, Spain)
Christine Rousselle (U Orleans, France)

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*For more details, see Zigler et al, "Fundamental Advancements in Pre-Chamber Ignition and Emissions Control for Natural Gas Engines," 2019 DOE Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting: https://www.energy.gov/sites/prod/files/2019/06/f64/ft080_%20zigler_2019_o_4.30_4.02pm_jl.pdf

Motivation: R&D is needed to achieve diesel-like efficiency in ultra-lean MD/HD NG engines

- DOE Vehicle Technologies Office (VTO) has **specific input regarding natural gas (NG) engine research needs** for efficiency and emissions
  - Annual Natural Gas Vehicle Technology Forum
  - Natural Gas Vehicle Research Workshop (July 2017), which fed VTO's funding opportunity announcement (FOA) and the Lab Call that resulted in this multi-lab project

- **Key high-level NG engine research needs:**
  - Research needed to address ***barriers for achieving diesel like efficiency*** for NG engines
  - Ignition technology to enable ultra-lean operation (***pre-chamber***, volumetric ignition)
  - Fundamentals for improving NG combustion efficiency (***physics, thermodynamics and chemistry***)
  - ***Low temperature combustion*** (LTC) concepts conceivable for NG engines, ensure real-world mode switching and emissions control compatibility
  - Advances in computational fluid dynamics ***(CFD) and modeling for NG engines***
  - Avoiding knock and ***abnormal combustion*** (i.e. low speed pre-ignition)
  - Fundamental catalysis research for methane conversion is needed due to ***challenge of methane activation***
  - Research needed for both stoichiometric and ***lean engine (LTC and conventional) emission control***

Objectives: overcome barriers in simulation/ modeling, dilution limits, pre-ignition, and emissions control

This project focuses on early stage research focusing on pre-chamber spark-ignition (PCSI) to achieve diesel-like efficiency in medium duty (MD) and heavy duty (HD) NG gas engines by extending the lean dilution limit and/or exhaust gas recirculation (EGR) dilution limit, as well as shortening burn duration, with integrated aftertreatment

Impact:

This project integrates experimental and simulation based tasks to address four key barriers to market penetration of PCSI for MD/HD NG engines:

Barrier 1 – ***Inadequate science base and simulation tools to describe/predict the fluid-mechanical and chemical-kinetic processes governing PCSI*** to enable engineers in industry to optimize designs for efficiency, noise, reliability, pollutant formation, emissions control integration, and drivability

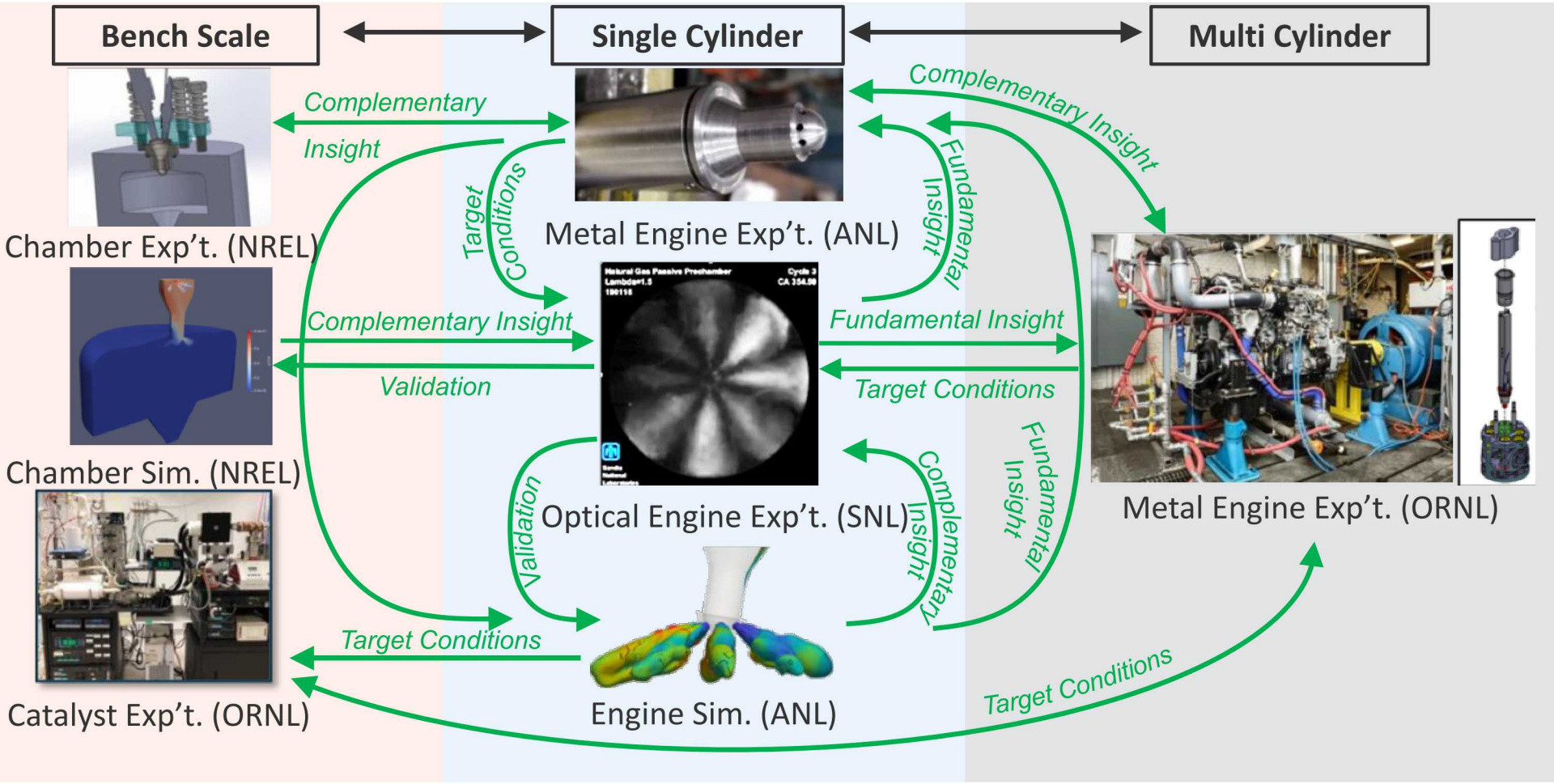
Barrier 2 – Limited ability to ***extend EGR and/or lean dilution limits*** at higher loads

Barrier 3 – Increased propensity for PCSI ***hot-spot pre-ignition*** at high loads relative to spark ignition

Barrier 4 – ***Ineffective methane catalysts*** for the high engine-out unburned fuel concentrations coupled with low exhaust temperatures (<<400 °C) of high efficiency engines

Approach: Integrate technical specialties through collaboration across four US DOE national labs.

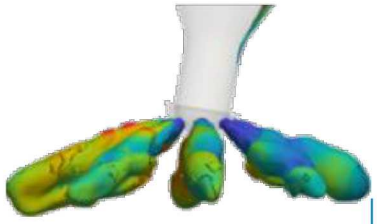
Collaboration and integration across four national labs connect fundamental experiments and modeling to practical hardware

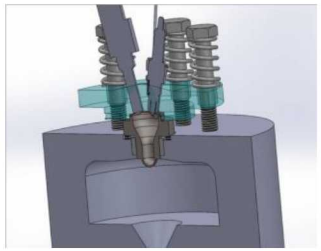


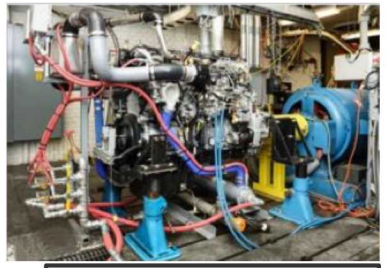
DOE laboratory expertise and capabilities focus on early-stage research to address key barriers for NATURAL GAS engines

Approach: Integrate technical specialties through collaboration across four US DOE national labs.

Modular PCSI designs with as much commonality as possible are used across all platforms







Simulation

Engine Sim. (ANL)
High fidelity CFD focusing on PCSI output mixing, with ignition and flame propagation models.

Chamber Sim. (NREL)
Zero dimensional (0D) and CFD map PCSI composition output to explore main chamber ignition sensitivity.

Bench Scale

Chamber Exp't. (NREL)
PCSI added to constant volume chamber to study pre-chamber variable effects on main chamber ignition over lean / dilute conditions.

Catalyst Exp't. (ORNL)
Synthesize novel methane oxidation catalysts (MOCs) and evaluate performance with PCSI NG engine exhaust conditions.

Single Cylinder

Metal Engine Exp't. (ANL)
Single cylinder engine experiments with borescope access to study PCSI effects on lean / dilute operation and efficiency / engine-out emissions tradeoffs.

Optical Engine Exp't. (SNL)
Single cylinder engine experiments to study PCSI output penetration to main chamber and characterize flame propagation vs. sequential autoignition.

Multi Cylinder

Metal Engine Exp't. (ORNL)
Modified HD engine with PCSI in all cylinders to study dilution tolerance, conduct thermodynamic analysis of efficiency potential tradeoffs related to lean / dilute combustion with PCSI, and provide exhaust information for MOC studies.