Enhanced Ethanol Engine And Vehicle Efficiency

(Agreement 13425)

Presented by **Brian West**

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Goals and Objectives (Purpose)

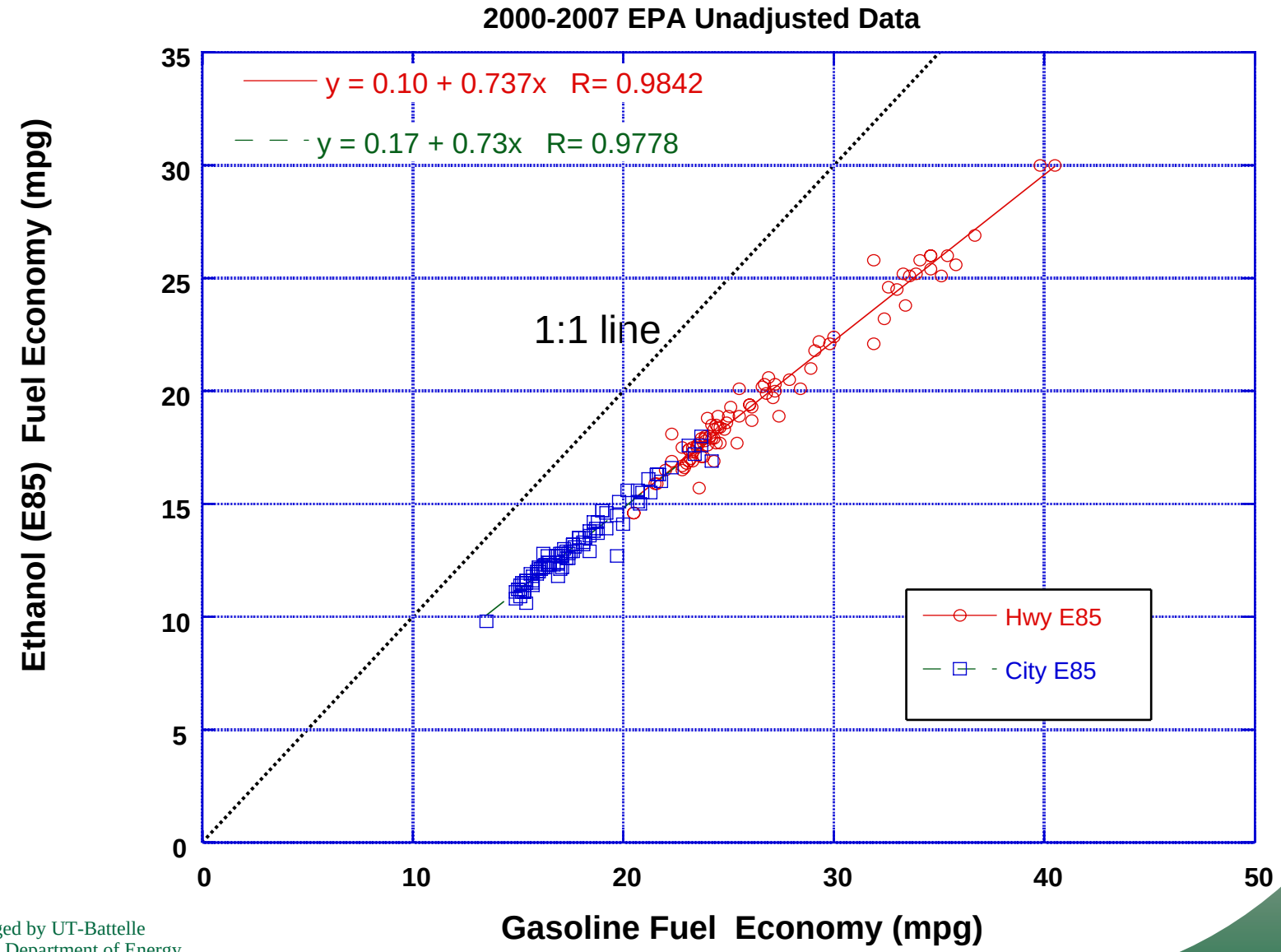
- **Presidential 20-in-10 initiative and EISA (Energy Independence and Security Act) aim to reduce gasoline consumption**
  - **Ethanol a key component to strategy**
- **Enable reduction of petroleum imports through more efficient use of ethanol**

Market Barrier: Tank mileage of ethanol vehicles needs improvement

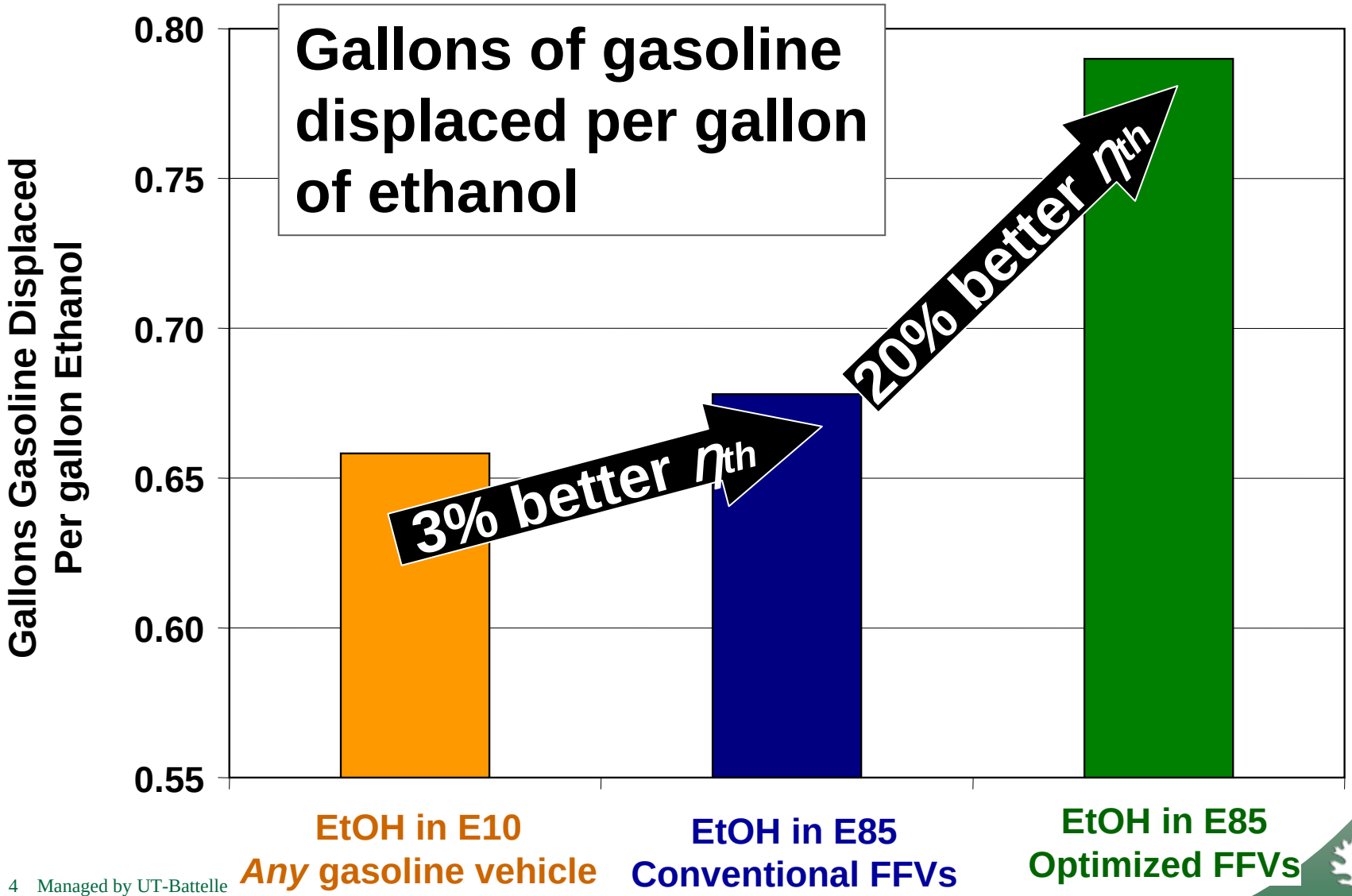
Barrier: E85 has 30% lower energy density than gasoline

Ethanol Fuel Economy Shows Expected Decrease for US FFV Fleet

25-30% drop in tank mileage is common consumer complaint about E85



Optimized FFVs using E85 can displace more gasoline than E10 or conventional FFVs



Approach: Exploit ethanol properties to enhance efficiency

Favorable Properties

- High octane number
- High latent heat of vaporization
- Extended lean combustion limit
- Ideal reductant for certain HC SCR lean NOx control technology

Engine Technologies

- Turbo or supercharging
- Increased compression ratio
- Direct injection
- Variable valve timing
- Cylinder deactivation
- Lean burn with advanced lean NOx catalysts

Technologies listed can be combined to close fuel economy gap, provide consumer incentive to use E85, lower petroleum use

Reviewing two projects today with common purpose

- **CRADA with Delphi: "Enabling High Efficiency Ethanol Engines"**
  - **ORNL/Delphi CRADA focused on modeling and more fundamental engine experiments**
    - **Stoichiometric combustion**
    - **ORNL's variable C/R engine**
    - **Delphi SIDI engine**
- **"Open" (non-CRADA) DOE project on improving Flex-Fuel Vehicle efficiency**
  - **Initial focus on lean combustion**
  - **Current platform is Saab BioPower FFV**

Ethanol R&D activities underway in multiple labs at ORNL/FEERC NTRC building

Analytical Lab: Exhaust speciation support

New engine cell under development for Delphi Ethanol CRADA. Scheduled completion summer 2008.

Variable Compression Ratio Engine Supporting first phase of Delphi CRADA

Lean-Burn FFV activity in Vehicle Research Lab

DELPHI/ORNL CRADA: Enabling High Efficiency Ethanol Engines

Project Start – FY 2008

Support – 2/3rd Non-Petroleum Based Fuels R&D, 1/3rd Vehicle Systems R&D

Specifics include:

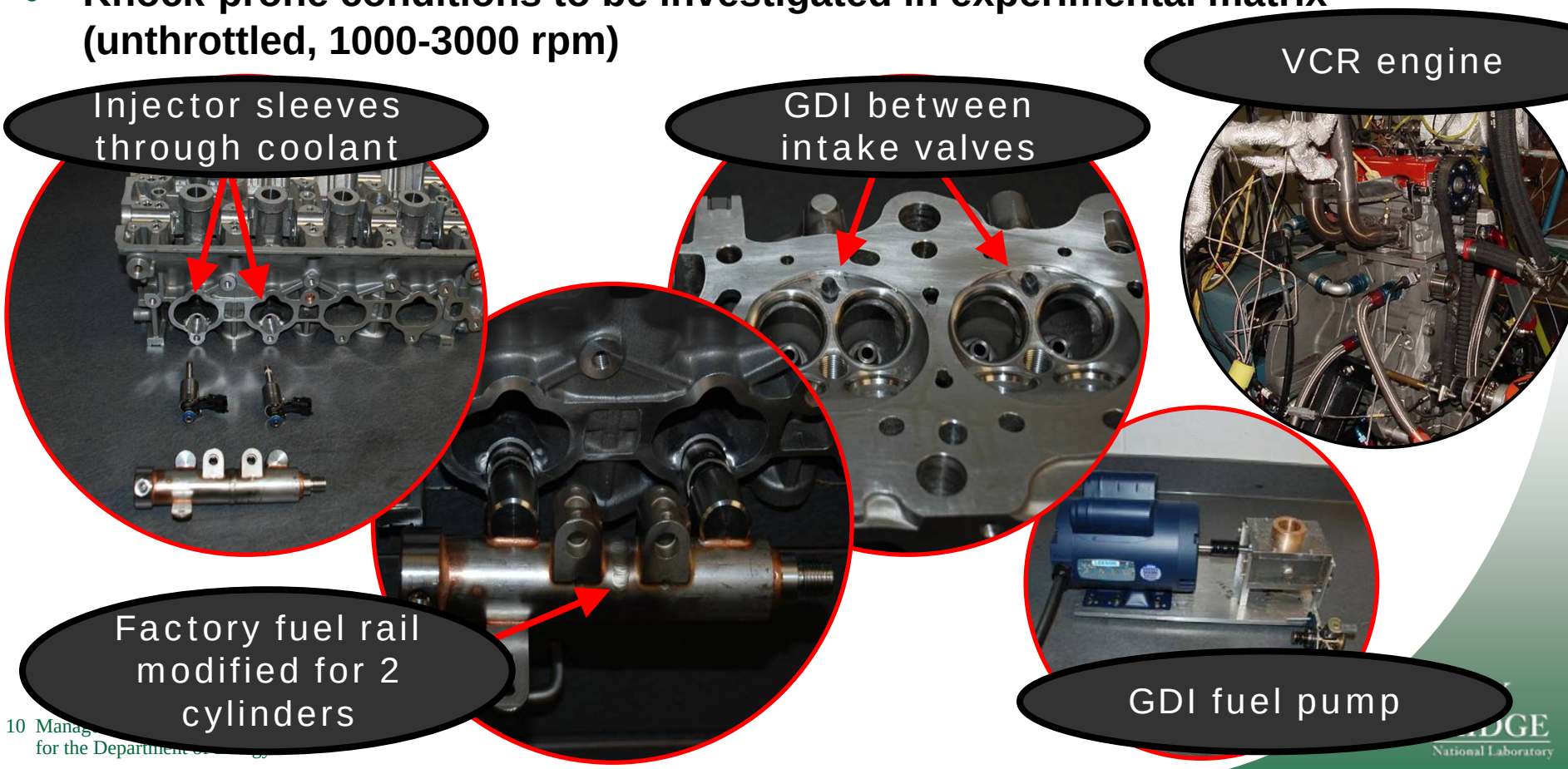
- **Stoichiometric combustion**
- **Variable C/R engine experiments and simulations to explore opportunities of ethanol and blends**
- **Develop multi-cylinder engine platform**
  - **Direct injection, cam-phasing with variable valve lift, Cylinder Pressure Development Controller (CDPC)**
  - **Explore efficiency opportunities identified in earlier simulations and VCR experiments**
- **Drive-cycle estimations of efficiency and emissions for conventional and hybrid ethanol-fueled vehicles using Powertrain Systems Analysis Toolkit (PSAT)**

Technical Status & Accomplishments (Delphi CRADA)

- **Engine Cell under construction at ORNL to support Delphi CRADA**
- **Engine build (at Delphi) in progress with expected delivery to ORNL of June 2008**
- **GT Power and AVL FIRE models developed and in-use to support engine design and operating strategies**
- **Variable C/R engine at ORNL undergoing conversion to DI. Experiments expected to begin in Spring 2008.**
- **Baseline ethanol PSAT vehicle model under development**

ORNL 2-cylinder VC/R engine to investigate compression ratio and efficiency limits with ethanol blends (Delphi CRADA)

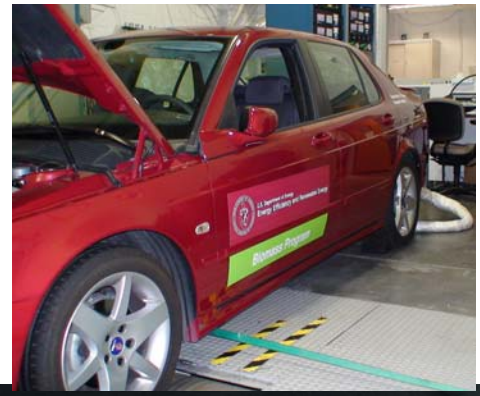
- **Acura Integra head being modified with GDI capability to investigate ethanol charge cooling, anti-knock properties**
- **8.5 to 17.5 compression ratio range in PFI configuration, estimated maximum compression ratio of 16.0 in GDI configuration**
- **Knock-prone conditions to be investigated in experimental matrix (unthrottled, 1000-3000 rpm)**



Lean-Burn opportunities being studied in non-CRADA vehicle project

Approach

- **Improve efficiency through lean combustion**
  - **Baseline target FFV on E85 and gasoline**
  - **Develop means for closed-loop lean operation**
- **Assess and address NOx emissions**
  - **Acquire Ag/Al_2O_3 catalysts and develop in-pipe fuel spray system**



Using ASTM grade ethanol and Federal Certification Fuel. Outside scope to consider effects of contaminants or other quality issues

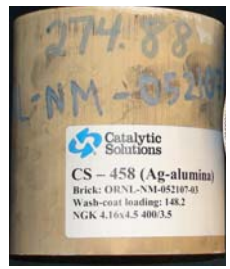
Not within scope of this project, but 20 in 10 and EISA are promoting ethanol availability.

Have interest from Saab to try and help with engine controls

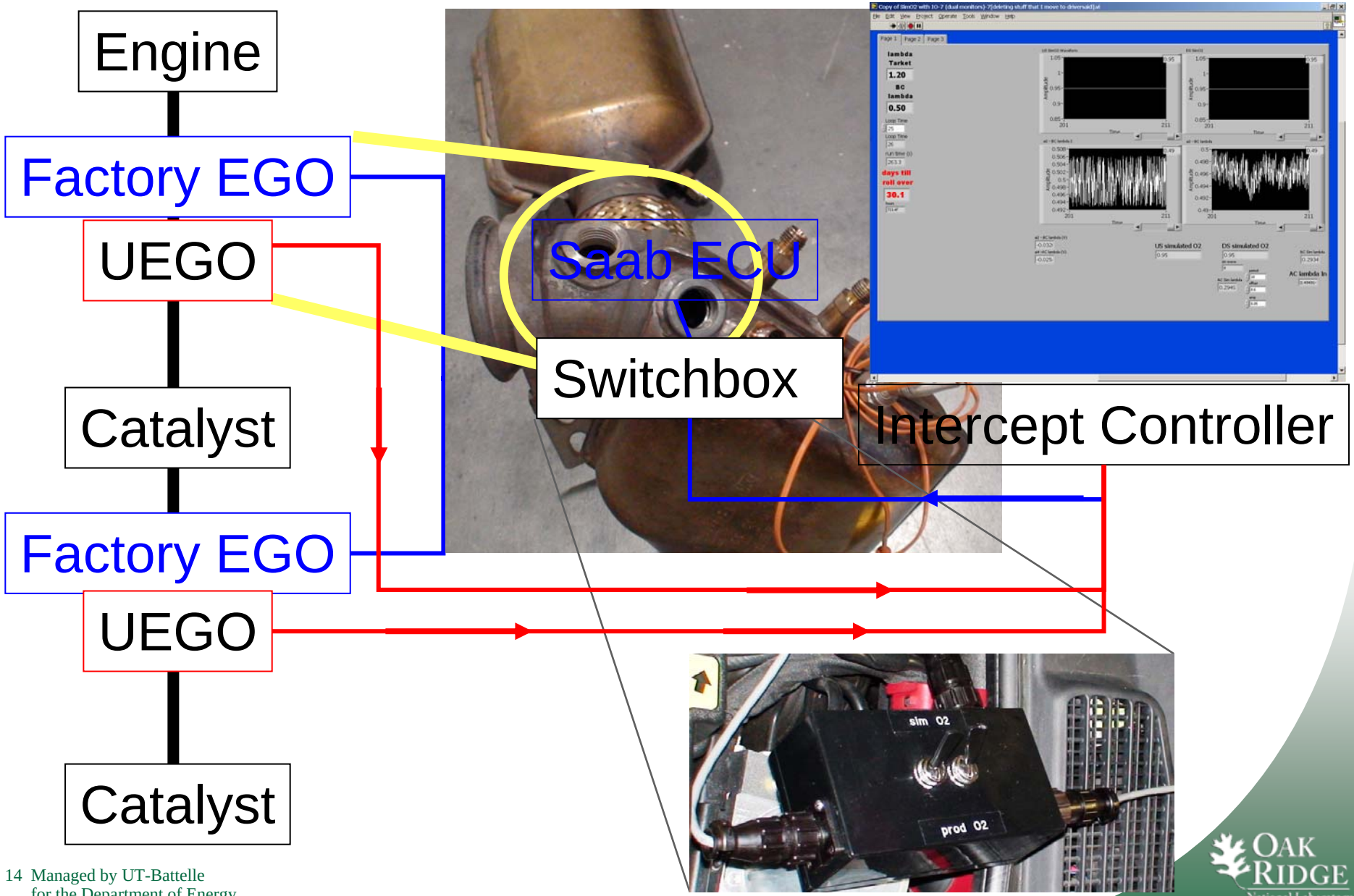
- **Wea[illegible]nesses:**
  - **No mention of [illegible] considered?**
  - **Efforts are nee[illegible] with this sort of vehi[illegible]arch. If E85 is not made available then there is no need to optimize vehicles for use with E85.**
  - **Try to partner with automotive industry (GM/Saab) to get ECM calibration codes and algorithms where possible.**
- **Recommendations:**
  - **Continue …E85 FFV studies to demonstrate other powertrain performance areas….gain enhanced performance, particularly fuel economy**

Technical Accomplishments Summary

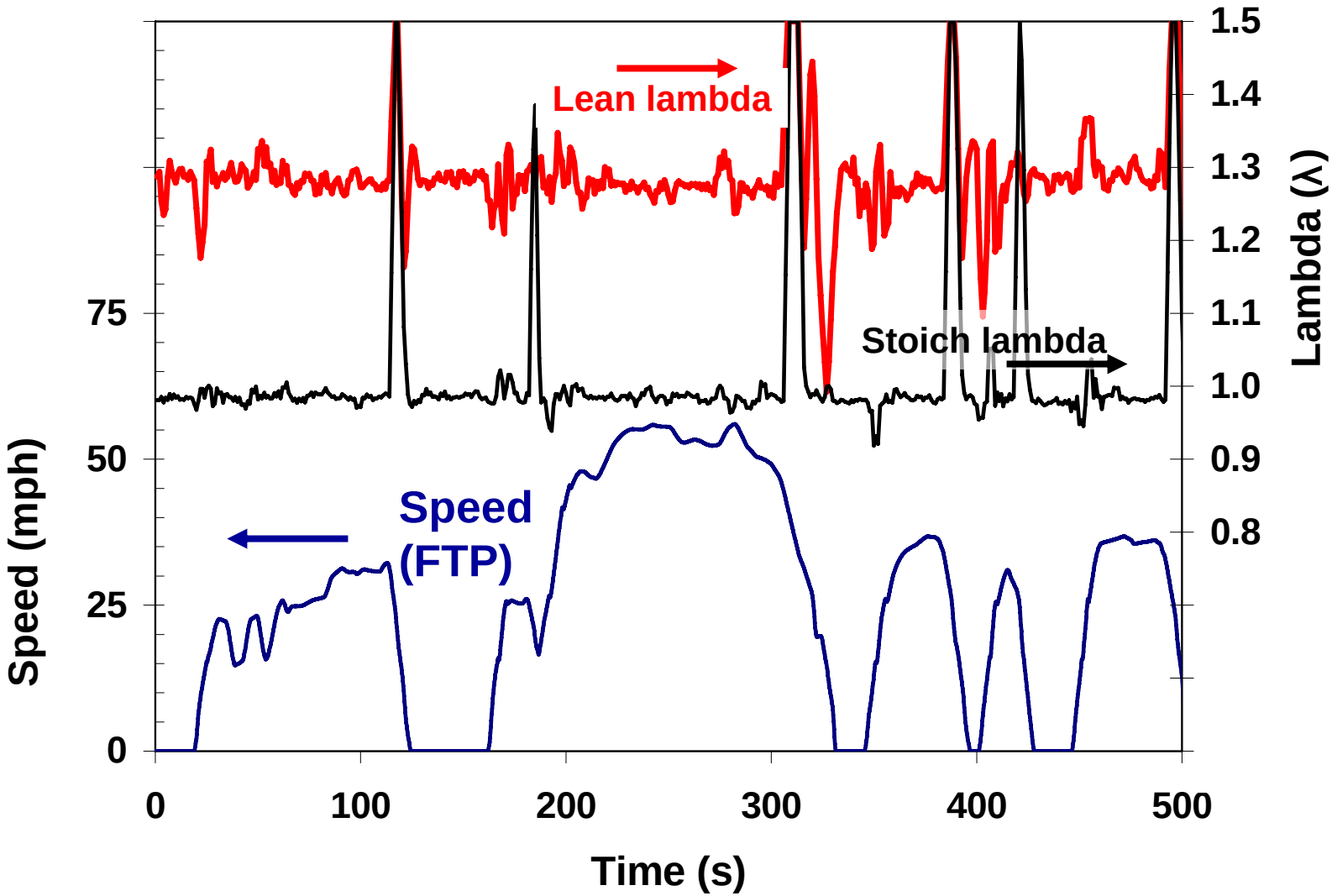
- **Demonstrated 3-6% fuel economy improvement in preliminary lean-burn experiments on 2 FFVs**
- **Acquired and baselined 2007 Saab 9-5 BioPower FFV (leveraged with OBP)**
  - **Fuel economy, emissions, HC speciation**
  - **Presentation at SAE Government/Industry Meeting**
  - ***Transactions* paper presented at Fall Powertrain Fluids Meeting (2007-01-3994)**
- **Developed intercept control to operate Saab in closed-loop lean mode**
- **Initial evaluation of Ag/Al_2O_3 catalysts for lean-burn NOx control**



Intercept control developed for closed-loop lean operation

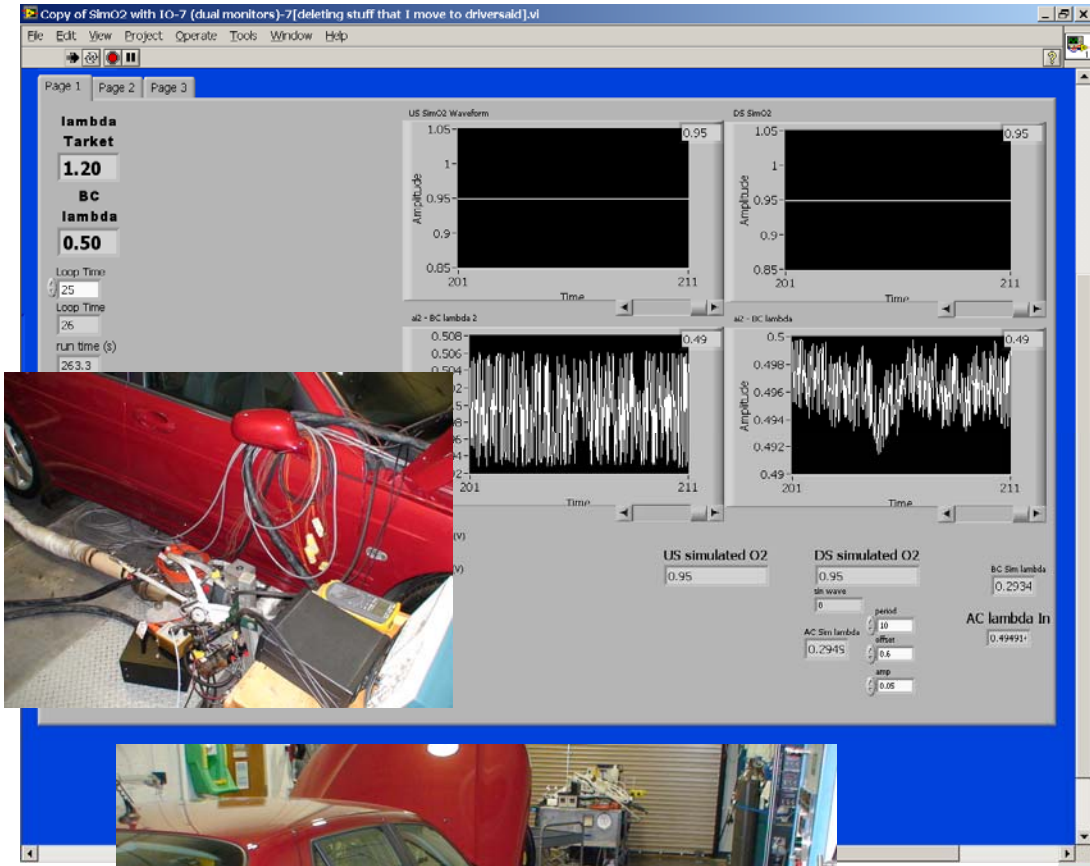


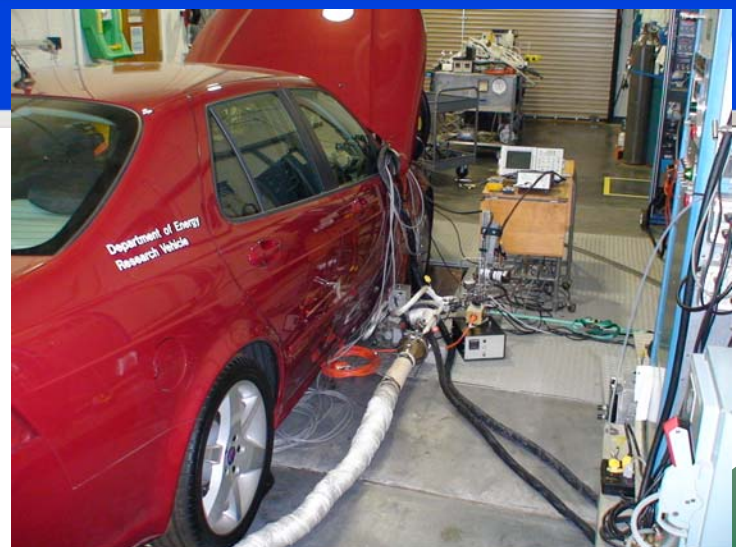
Intercept control used to accomplish closed-loop lean operation in Saab vehicle



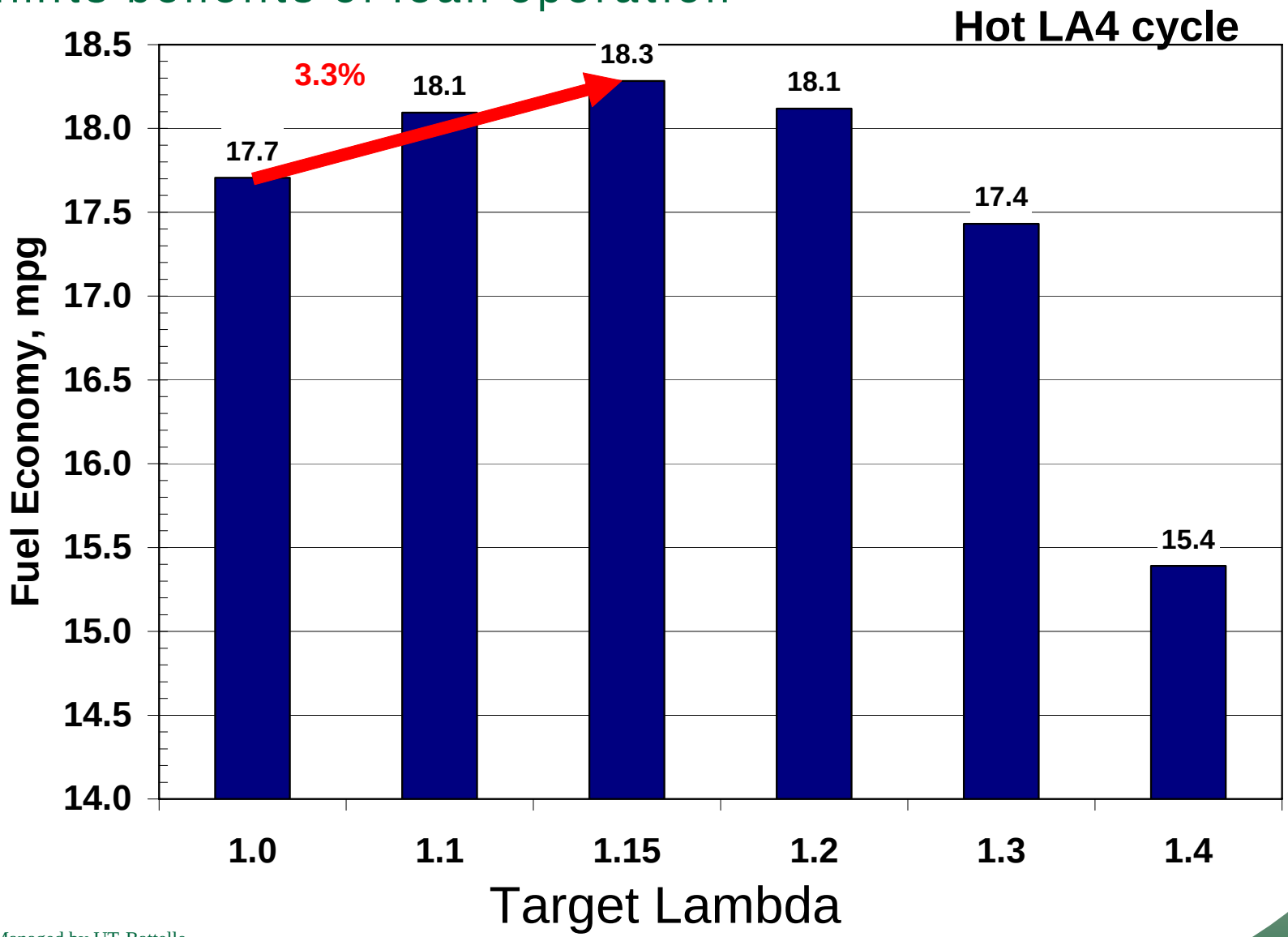
Benefits of Lean-burn to be assessed on Saab BioPower FFV

- **Wide-range UEGOs adjacent to factory EGO sensors**
  - **Factory EGO signals intercepted by LabVIEW, biased signals returned to ECU**
- **Steady cruise and FTP cycle experiments conducted with and without Lean NOx catalysts**
- **Need to acquire spark control**



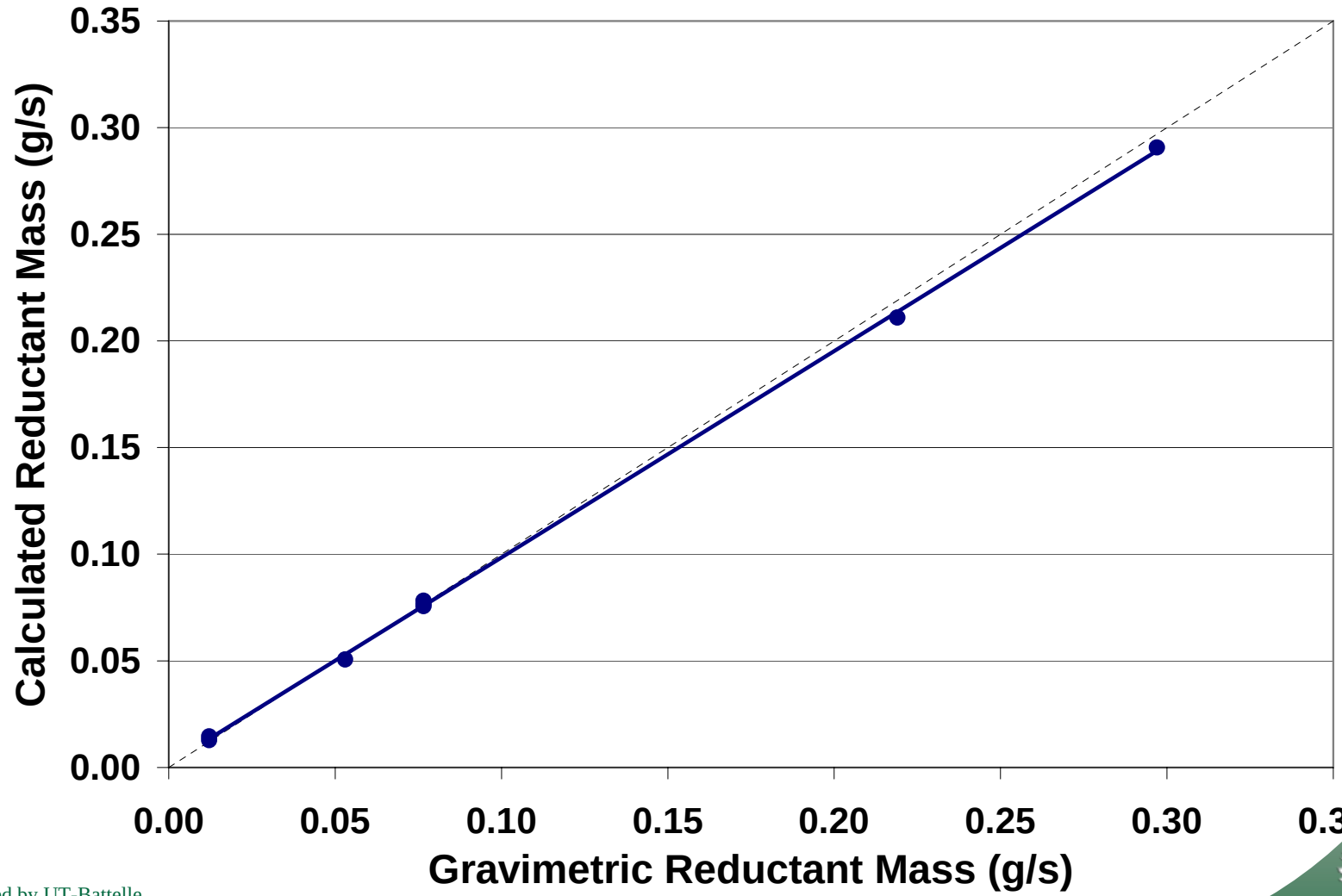


Closed-loop lean burn experiments net improved fuel economy. Lack of spark control limits benefits of lean operation



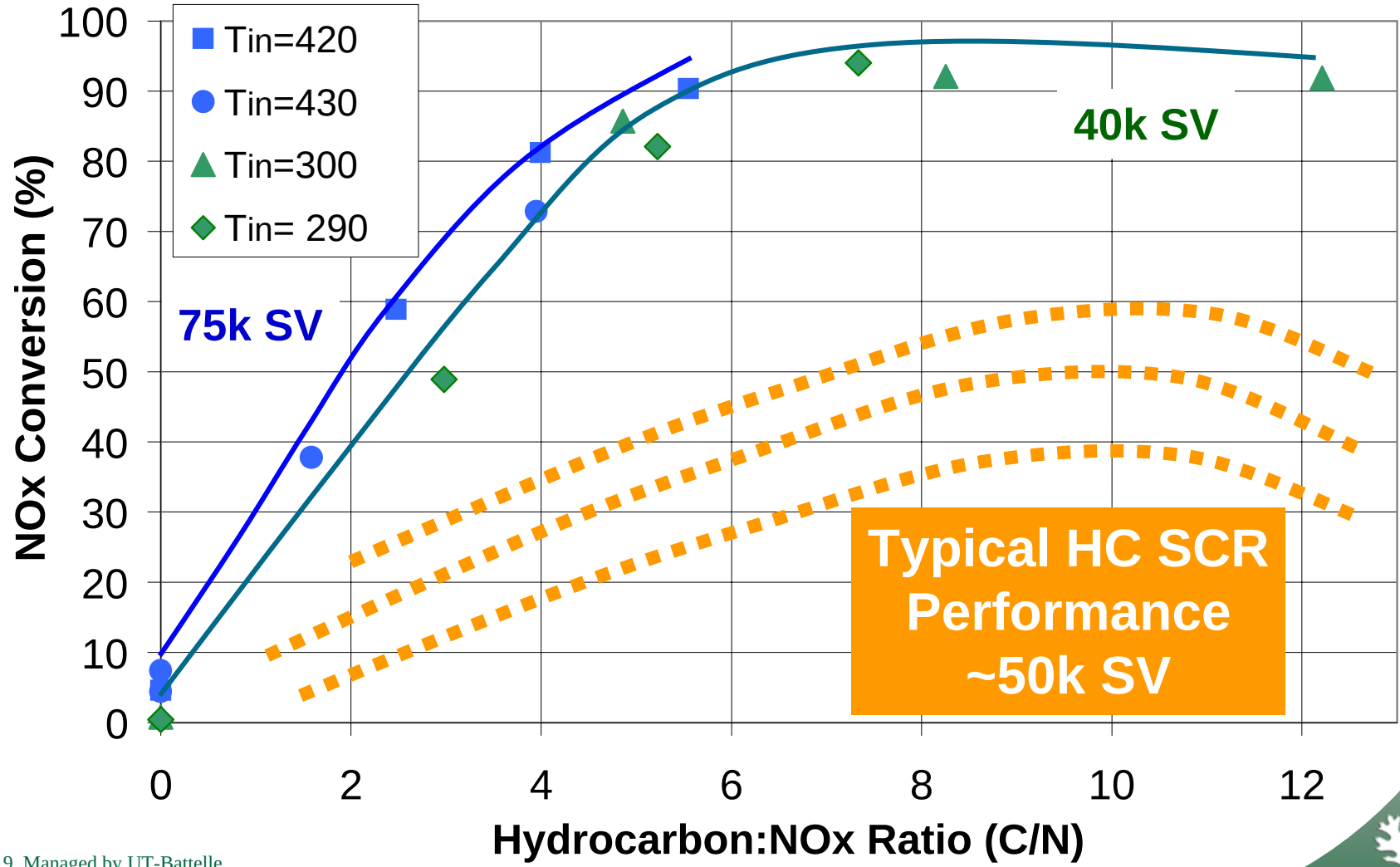
Measuring reductant spray rate and exhaust ethanol concentrations critical to understanding catalyst performance and reductant fuel penalty

Excellent agreement between gravimetric ethanol spray rate and gas-phase ethanol measurements (Innova ethanol analyzer)



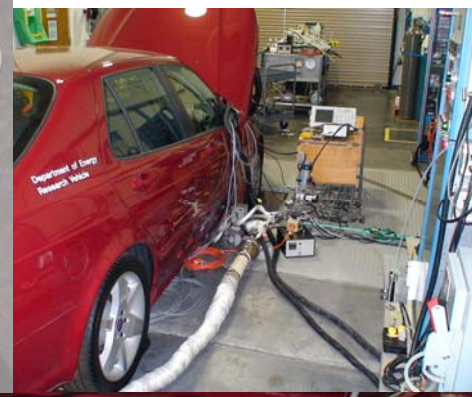
Preliminary Ag/Al_2O_3 catalyst evaluations show good NOx conversion with low fuel penalty

Catalyst Provided by Catalytic Solutions
Exhaust generator: Saab BioPower vehicle
Lambda: 1.2-1.3; Reductant: E85; SV=40-75k



Summary of Lean-burn experiments using Saab vehicle

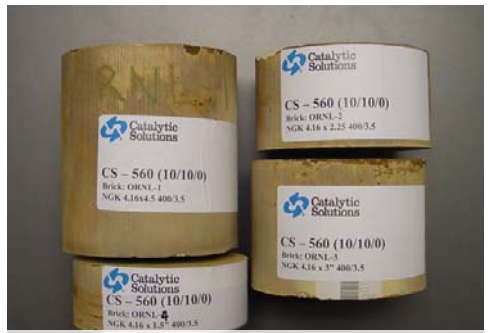
- **Silver-alumina (Ag/Al2O3) catalysts obtained from Catalytic Solutions in May 2007, canned in June.**
- **Vehicle exhaust modified to accept silver catalyst(s) downstream of factory TWCs**
- **Ethanol spray system developed for reductant delivery**
  - **Gravimetric measurement of reductant spray for accurate fuel penalty assessment**
- **Initial experiments with E85 reductant resulted in high NOx conversion with HC slip. Catalytic Solutions provided oxidation "clean up" catalysts for follow-on experiments**
  - **Plan to evaluate E85, E95 and E100 reductants**
  - **May consider on-board approaches to remove ethanol from gasoline**
- **Vehicle fueled from offboard tank to enable gravimetric fuel consumption**



Plans for 2008 and beyond

- **Parallel paths to demonstrate lean-burn with advanced catalysts**
  - **Intercept control of lambda with aftermarket spark control**
  - **Complete control with aftermarket controller**
  - **Collaboration with Saab**
- **Oxidation catalysts for tailpipe "clean up"**
  - **Examine E85, denatured ethanol, neat ethanol, and stripped ethanol**

Hardware acquired for custom aftermarket control



Oxidation catalysts

Tech Transfer, Publications, Collaborations and Industry Interactions

- **Collaboration/communication with GM and Saab on 9-5 BioPower vehicle baseline experiments**
  - **Saab exploring means to support spark control**
- **Presentation at SAE Government/Industry Meeting, May 2007**
- **SAE paper 2007-01-3994 at Fall Powertrain Fluids Meeting, Oct 2007**
  - **Accepted for *SAE Transactions***
- **Lean NOx and oxidation catalysts provided by Catalytic Solutions**
- **CRADA with Delphi**

Enhanced Ethanol Engine and Vehicle Efficiency (Closing Summary)

- **Relevance**

  Increased ethanol vehicle efficiency extends benefit of displacing petroleum with ethanol, while also mitigating market barrier related to tank mileage

  Directly related to President's 20 in 10 initiative and EISA

- **Approach**

  Vehicle and engine-based experiments to develop and demonstrate relevant advanced technologies that exploit properties of ethanol

- **Accomplishments**

  Demonstrated improved fuel economy with lean-burn in closed-loop operation. Developed Lean NOx system and demonstrated >90% conversion efficiency.

  Established CRADA with Delphi

- **Tech Transfer/Collaboration**

  Working closely with industry (GM and Saab), Catalytic Solutions; frequent publication, new CRADA with Delphi.

- **Future Research**

  Complete drive-cycle lean-burn demonstration with advanced lean-NOx catalyst, conduct advanced combustion research with Delphi in CRADA

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