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Increasing Biofuel Deployment through Use of High Octane Fuels

for the

Indiana Ethanol Forum

May 7, 2015

Tim Theiss*, Oak Ridge National Laboratory

(* on behalf of the 3-Lab team)

Outline of Presentation

- Background & motivation
- Project overview
- Technical highlights
  - E30 performance in existing FFVs
  - Dedicated High Octane Fuel Vehicle Demonstration
  - Infrastructure assessment for Mid-level ethanol blends
  - Market assessment of HOF
  - Well-to-wheel greenhouse gas (GHG) & energy analysis
- Summary
- Q & A

DOE work supported by:
Bioenergy Technologies Office &
Vehicle Technologies Office

Transportation Industry Faces Unprecedented Challenges

Renewable Fuel Standard

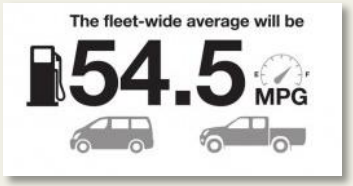
36 billion gallons by 2022

(EISA 2007)

Fuel Economy Standards

2025 CAFE Standards

(U.S. EPA and U.S. NHTSA standards)



Emissions Regulations

70% NO_x & PM, 85% NMOG

< 10 ppm sulfur in gasoline

(U.S. EPA Tier 3 regulations)

EPA

- High Octane Fuels (HOF) can create additional demand for large amounts of ethanol & enable improved fuel economy in **dedicated vehicles** (supports biofuels & automobile industries)

- Existing project is “scoping study” to address barriers, quantify benefits and determine if additional R&D is warranted

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The Team … a 3-Lab Collaboration


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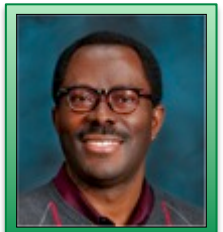
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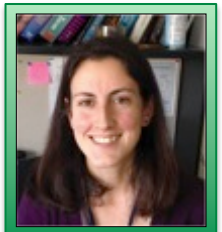
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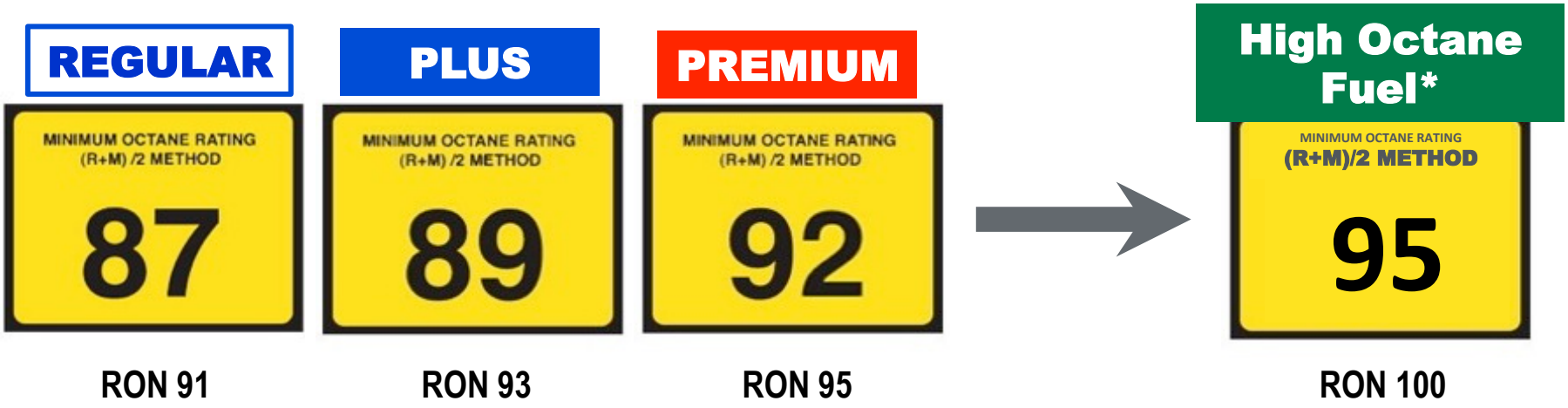
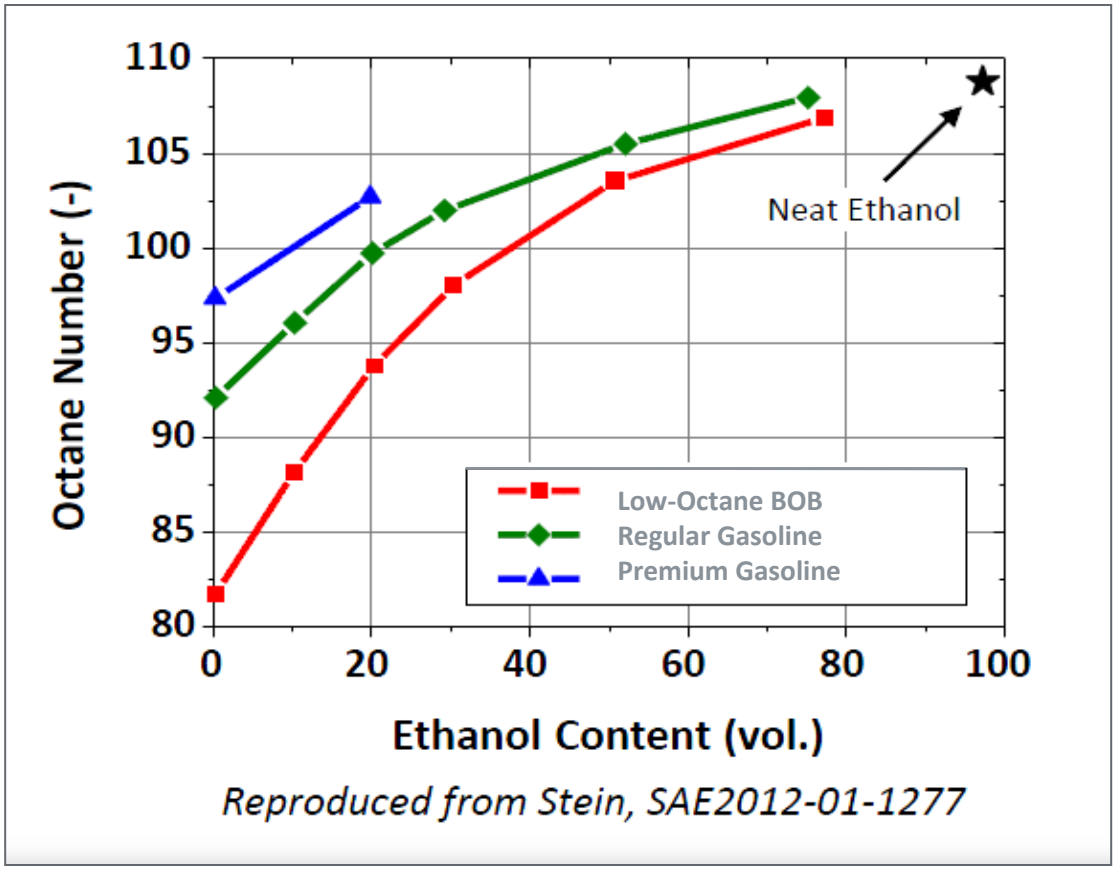
Background on Fuel Octane Number



- Octane is measured by RON (research octane number); MON (motor octane number) and AKI (anti-knock index) which is the average of RON + MON
  - Isooctane has an AKI, RON and MON of 100
- For modern technology engines, RON is the better measure of knock prevention
- Fuel octane number can be changed by using different octane petroleum or ethanol concentration
- Higher octane number allows for more aggressive engine design, which can improve efficiency

Motivation for High-Octane, Mid-Level Ethanol Blends

- Ethanol has 2/3 energy density of gasoline but high octane
- Non-linear influence of ethanol content → most benefit at lower levels
- Efficiency gains have been demonstrated in research studies at ORNL, Ford & others
- Optimum blend likely 20-40% ethanol → non-linear benefit of higher octane vs. linear decrease in energy density



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Investigate High Octane Fuel (HOF) at RON ~ 100 with 25-40% ethanol

Considering the Viability of High Octane Fuels

Stakeholder Engagement

Barriers & Opportunities

Information for Decision-Makers

Knock Resistance

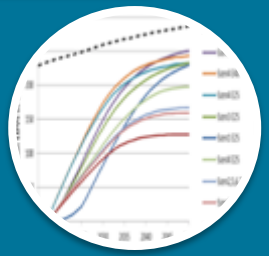
Existing Flex-Fuel Vehicles

Existing Infrastructure

Refinery Impact

Low-Cost Blendstocks

Dedicated HOF Vehicle Efficiency



Market Assessment

GREET

Well to Wheels Environmental Performance

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HOF in Legacy Flex-Fuel Vehicles

Background:

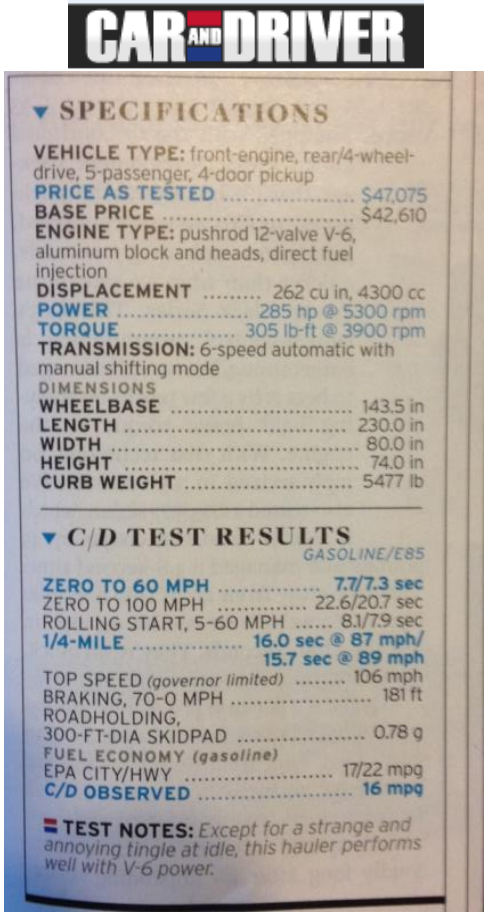
- 17M Flex-fuel vehicles have been sold
- FFVs capable of burning E0 (gasoline) to E85 can legally use mid-level ethanol blends today
- FFVs use very little E85 (~ 12 gal/year)
- Reduced range; higher costs/mile

Objective: Determine if today's FFVs offer any performance benefit (acceleration) with HOF

Motivation: Performance improvement in legacy FFVs could enable early adoption of high octane fuels

Difficult to introduce supply & demand for "alternative fuel" such as HOF (chicken & egg issue)

- ✓ **Car & Driver found Silverado FFV had 0.4 sec acceleration benefit with E85**
- ✓ **People pay for performance**



CAR AND DRIVER

▼ SPECIFICATIONS

VEHICLE TYPE: front-engine, rear/4-wheel-drive, 5-passenger, 4-door pickup
PRICE AS TESTED $47,075
BASE PRICE $42,610
ENGINE TYPE: pushrod 12-valve V-6, aluminum block and heads, direct fuel injection
DISPLACEMENT ..... 262 cu in, 4300 cc
POWER ..... 285 hp @ 5300 rpm
TORQUE ..... 305 lb-ft @ 3900 rpm
TRANSMISSION: 6-speed automatic with manual shifting mode
DIMENSIONS
WHEELBASE ..... 143.5 in
LENGTH ..... 230.0 in
WIDTH ..... 80.0 in
HEIGHT ..... 74.0 in
CURB WEIGHT ..... 5477 lb

▼ C/D TEST RESULTS

	GASOLINE/E85
ZERO TO 60 MPH	7.7/7.3 sec
ZERO TO 100 MPH	22.6/20.7 sec
ROLLING START, 5-60 MPH	8.1/7.9 sec
1/4-MILE	16.0 sec @ 87 mph/ 15.7 sec @ 89 mph
TOP SPEED (governor limited)	106 mph
BRAKING, 70-0 MPH	181 ft
ROADHOLDING, 300-FT-DIA SKIDPAD	0.78 g
FUEL ECONOMY (gasoline)	
EPA CITY/HWY	17/22 mpg
C/D OBSERVED	16 mpg

TEST NOTES: *Except for a strange and annoying tingle at idle, this hauler performs well with V-6 power.*

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Performance Improvement Demonstrated in Legacy FFVs With HOF

Approach:

- Evaluate 4 high-sales volume "ethanol tolerant" FFVs
- Prep and test with regular (E10 as baseline) & HOF (E30, 100 RON)

Status:

- Experiments complete (report in progress)
- Fuel economy tracks energy density (~10% less)
- Results (15-80 mph acceleration)
  - ✓ GMC Sierra (Silverado) – 0.45 sec
  - ▪ Chevy Impala – some benefit
  - ▪ Dodge Caravan – some benefit
  - – Ford F150 – no improvement

Majority of FFV Fleet

Long-term Questions:

- Is it possible to consume more ethanol in FFVs by reducing its concentration?
- Is this an opportunity to introduce HOF for "dedicated HOF" vehicles?

Test vehicle: GMC Sierra V6 FFV

If *half* FFVs on road today (~ 17M) filled up with E25 *half* the time, consume *half-billion* gallons more ethanol!

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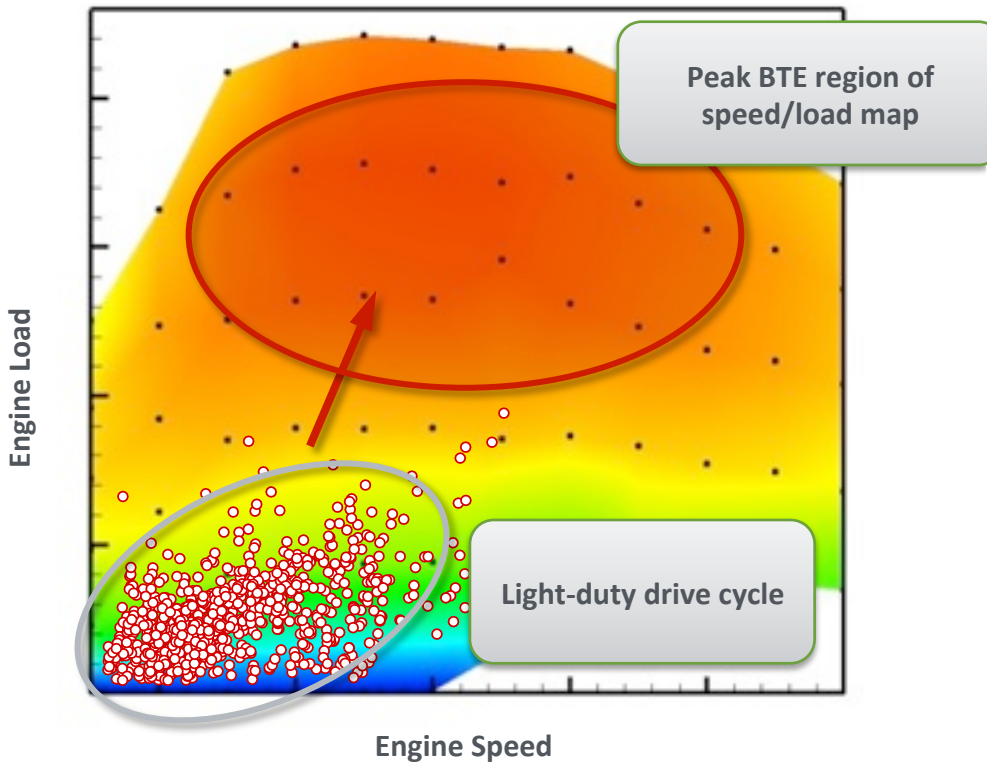
Higher Octane Fuel Enables Both Engine and Vehicle Efficiency Gains

- Many drive cycles do not coincide with engine's most efficient operating range
- Engine based technologies can improve the maximum efficiency
- Vehicle based technologies can shift engine drive-cycle demands to higher efficiency region
  - Down-speeding and down-sizing
- New technologies can help promote operation in the high efficiency plateau

Efficiency Contours for Light-Duty Engine



High fuel efficiency region of current passenger vehicle production engines is small and does not intersect light-duty drive cycle speed/load requirements.

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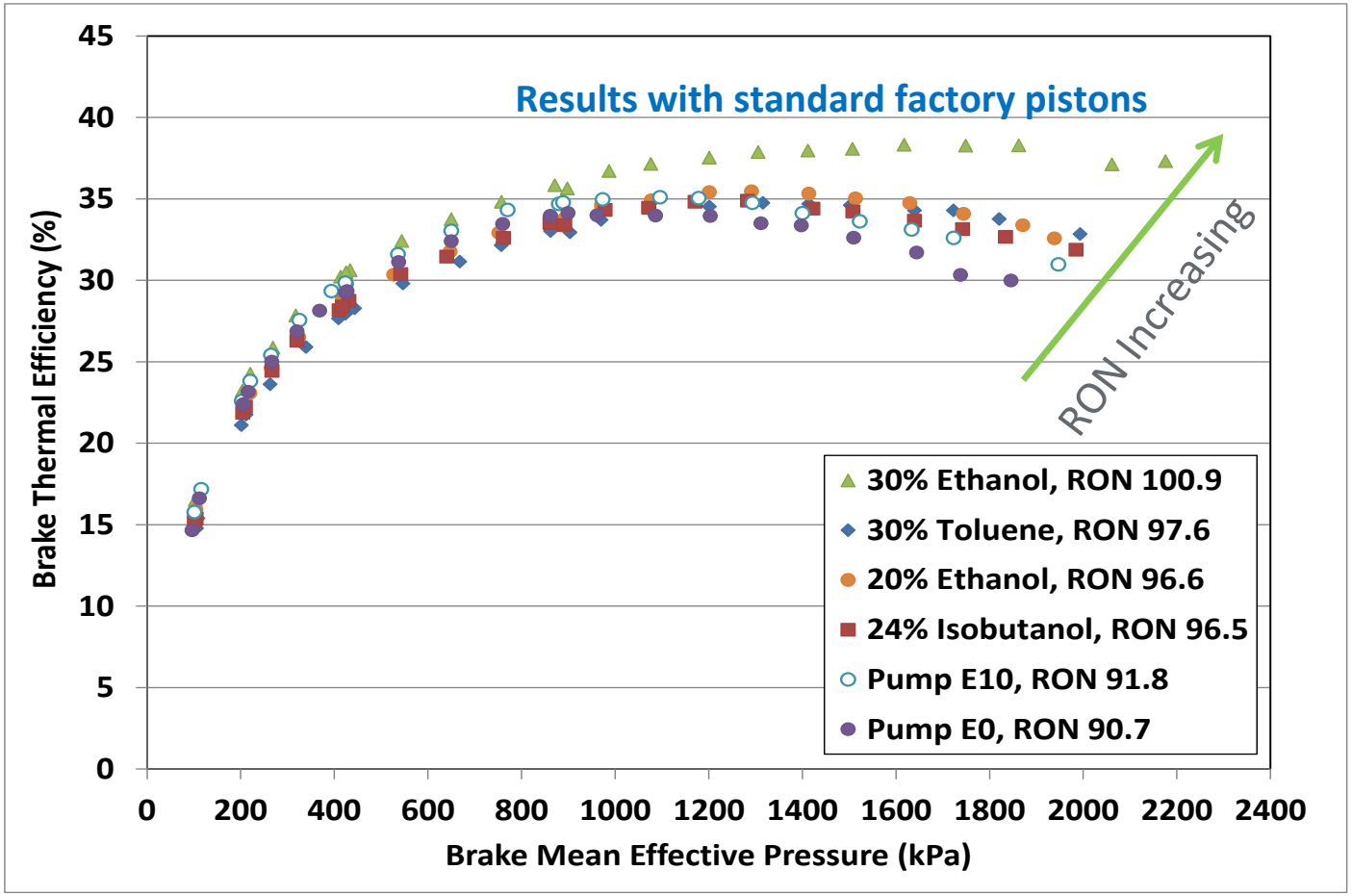
Increased Efficiency with High Octane Fuels Has Been Demonstrated



Industry Cost-Share, Funds-in, and Technical Support

- Ford
- General Motors
- Coordinating Research Council

Leveraging support from VTO & BETO

Higher octane increases maximum efficiency & high efficiency plateau of engines

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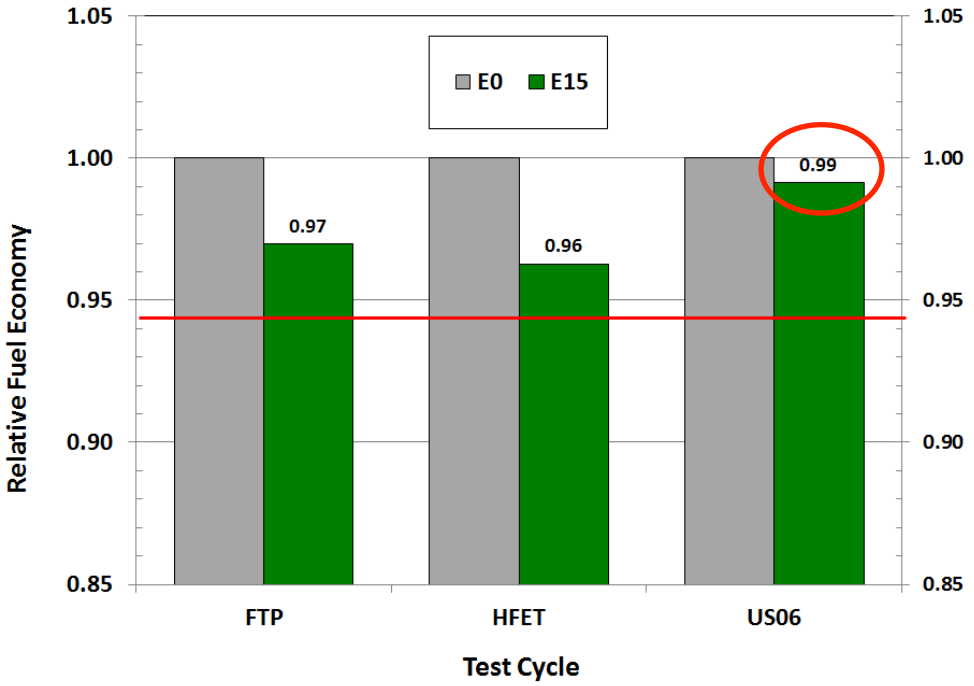
Benefits of Engine Downsizing with High Octane Ethanol Blend

- **E15-Compatible Ford EcoBoost Fiesta**
  - 1.0 liter, 3-cylinder turbo GDI engine
  - Premium fuel recommended for severe duty cycle (e.g., US06)
  - Smaller engine is more "knock limited"
- **Experiment:**
  - Blend regular E0 with 15% Ethanol (98 RON, E15 Premium RON)
  - FTP (City), HFET (Hwy), and US06 (high-load cycle)
  - *No Changes* to calibration or shift schedule
  - ➢ **Results within 1% of Volumetric Fuel Economy Parity on high-load driving cycle → almost 5% efficiency gain**
  - E15/E0 energy density ratio is comparable to E25/E10 ratio!

Addition of 15% ethanol boosts octane, improves engine performance & efficiency.



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High-Octane Efficiency Benefits Demonstrated at the Vehicle Level

- **Acquired vehicle suitable as "dedicated HOF vehicle"**
  - Currently conducting baseline tests on range of fuels with factory pistons/ calibration
  - Fuel blends will span various octane levels with different sources of octane number (e.g., Regular, Premium, E10-100 RON, E25-100 RON, E40-100 RON)

GM ATS Vehicle with 2.0 Turbo GDI Engine

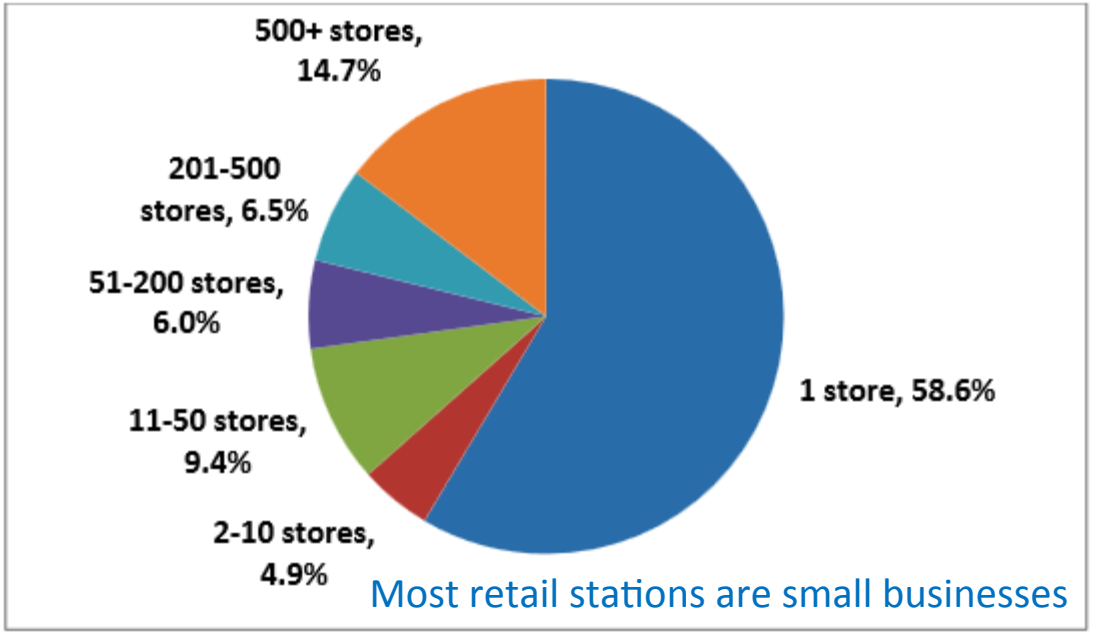
- **Implement engine and vehicle based tools to improve efficiency**
- **Will be able to demonstrate possible efficiency gains with "dedicated" HOF vehicle**
  - **Compare high octane from ethanol and gasoline**
  - **Will not universally apply to all vehicles or conditions!**

Key Assumption/Goal:
Volumetric Fuel Economy Parity

- **E25 – 5% efficiency gain**
- **E40 – 10% efficiency gain (stretch)**
- **Means same mpg – no mileage loss**
- **Work-in-Progress**

Is the Retail Infrastructure the "showstopper" to HOF?

- Determined costs to upgrade stations for E25 and E25+
- Identified compatible equipment by manufacturer and model
- Technically E25/E25+ is possible. Marketwise, E25 is less costly and more acceptable to retailers
- Most materials used are compatible
- Identified issue: refueling stations are not required to keep equipment records - a challenge for determining compatibility



Most retail stations are small businesses

- Estimate that ~ 20% of stations have to carry new fuel for it to be "widely available"
- Infrastructure barrier has been overstated!

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Market Assessment Study Examined Eight HOFV Adoption Scenarios

- Mandated deployment of HOF/HOFV (all vehicles starting in MY18 and largest 20% of stations)
- Replace mid-gr… convert premium fuel vehicles to …FV), then highest performance n… …s money
- Price-driven ad… …witch most efficient vehicl… …n subsidies (40% & 80% of incre… …grade to HOF)
- Eliminate high … …troduce ethanol-tolerant, premi… …icles, mandate all new refueling e…
- E85 becomes 5… …ntly a legal fuel), utilize FFV infra… …back-up fuel for HOFV u…
- Require al… …der pumps (capable of H… …ket-driven adoption
- Deploy HOF Regio… …vest, CA), build up from existing FFV infr… …cture
- Expensive - new UST and dispensers, $455 incremental cost for vehicles; 20% largest stations must sell HOF by 2023

Considered multiple policies to investigate impact of the assumptions – not predict "correct" scenario

Less Aggressive Policies

Rapid deployment bookend - mandate fuel, retail dispensing, and vehicles

Manufacturers proactively convert car models to HOFVs

Manufacturers proactively convert car models to HOFVs

Consumer choice/CAFE drivers - but mandate to optimize new vehicles to 98 RON and ethanol-tolerant

Consumer choice/CAFE drivers

Slow deployment bookend - E40, new UST and dispenser, high vehicle cost

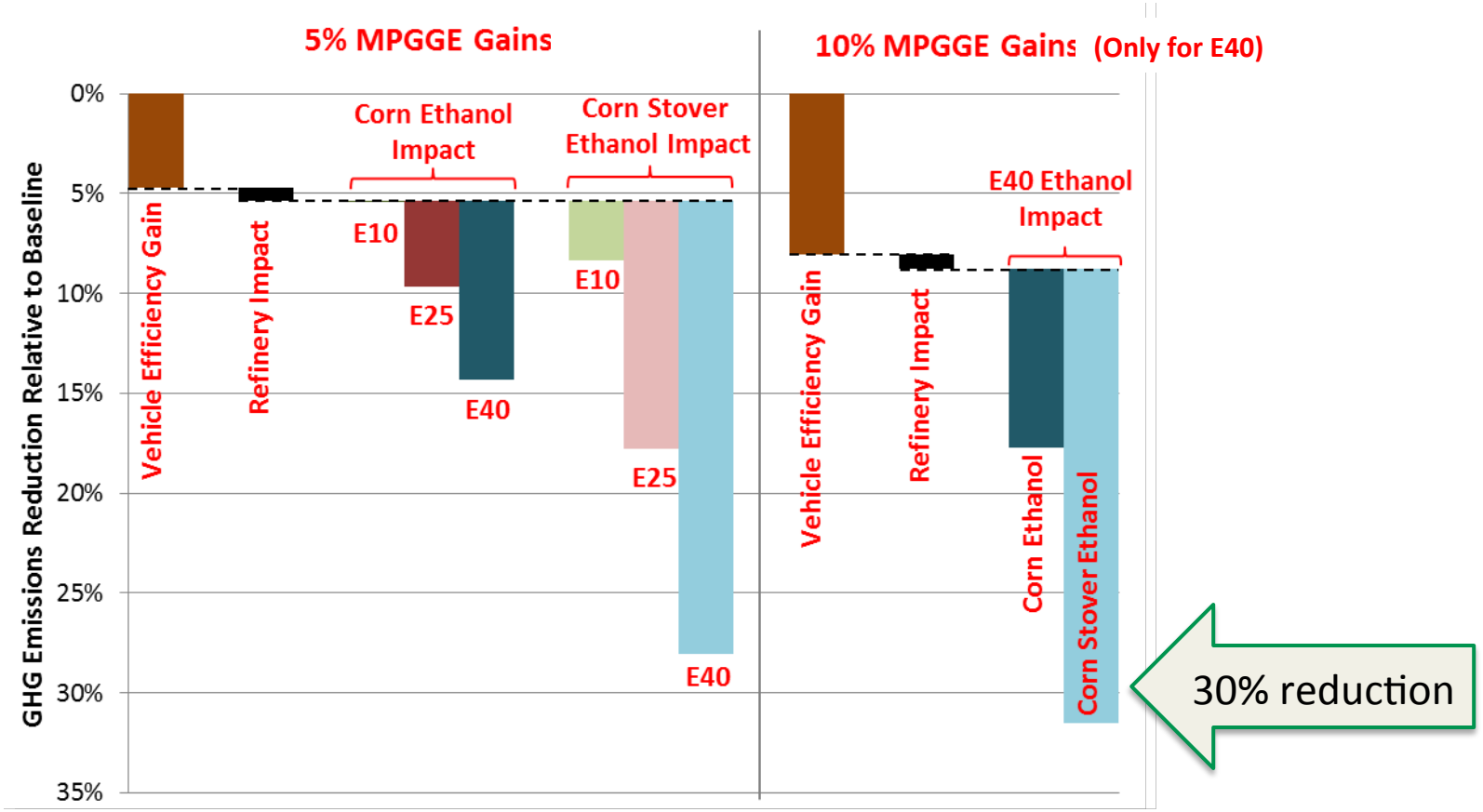
Ethanol Demand from Supply Chain Simulation- Preliminary

- Feedstock availability and cost do not limit deployment of HOF
- In all scenarios, dedicated HOFs make up more than a third of vehicle fleet by 2030
- Actual ethanol usage is limited by biorefinery construction rate for:
  - Rapid deployment scenario, E40 case throughout the simulation
  - Scenarios where only HOF refueling equipment is available drive a rapid increase in demand such that biorefinery construction is limiting in initial years (2020-2023)
- In scenarios with significant cost for HOF refueling equipment, HOF availability at retail limits actual demand
- Preliminary results show potential ethanol consumption in 2035 ranging from **28 to 58 billion gal/yr** for the E40 rapid deployment scenario and **18 to 32 billion gal/yr** for the E25 price driven scenario
- Range is based on different assumptions for vehicle fleet mix and vehicle fuel economy
- Both vehicle market penetration and ethanol demand sensitive to how HOF is treated for CAFE

Environmental Analysis of High Octane Fuel are Being Conducted

- Estimate well-to-wheels (WTW) energy and green house gas (GHG) emissions benefits of HOF with different ethanol blending levels
  - Conduct petroleum refinery modeling of producing HOF with different ethanol blending levels
  - Update upstream crude production and cellulosic and corn ethanol production
- Estimate WTW GHG emissions benefits of HOF
  - Assess vehicle efficiency gains by HOF
  - Analyze refinery challenges for meeting RON and RVP requirements with different ethanol blending levels without the 1 psi waiver for E10+
  - Estimate GHG benefits of corn and cellulosic ethanol blending for HOF production

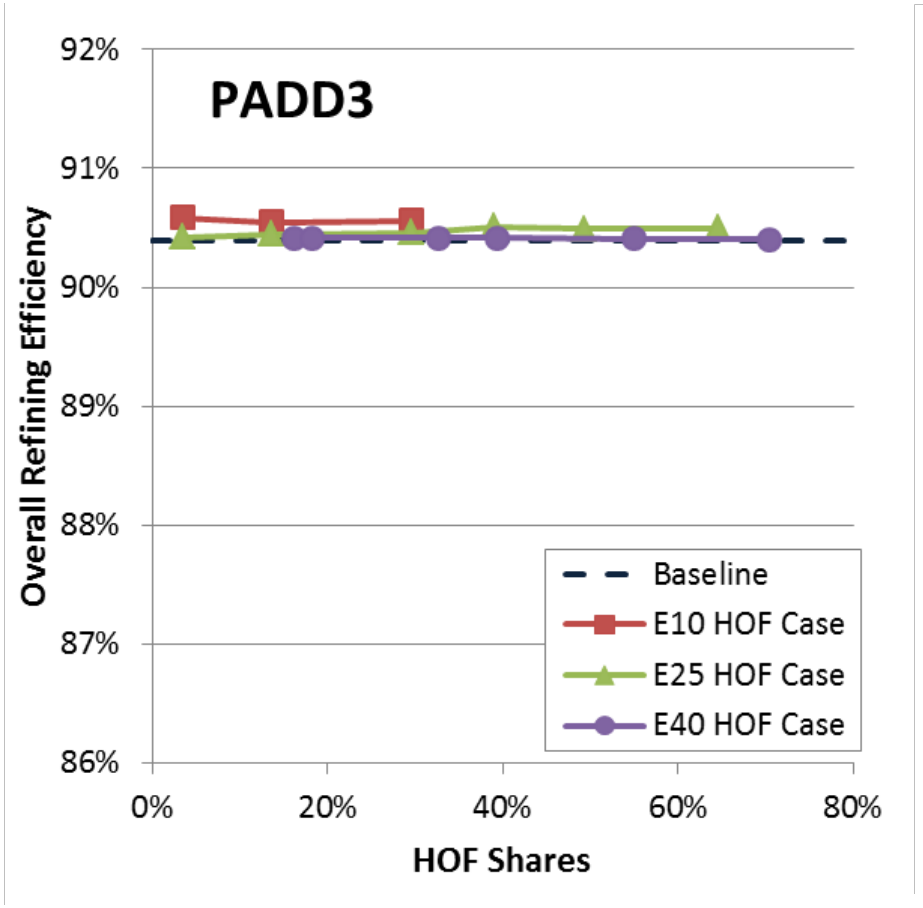
HOF with Mid-Level Ethanol Reduces WTW GHG Emissions

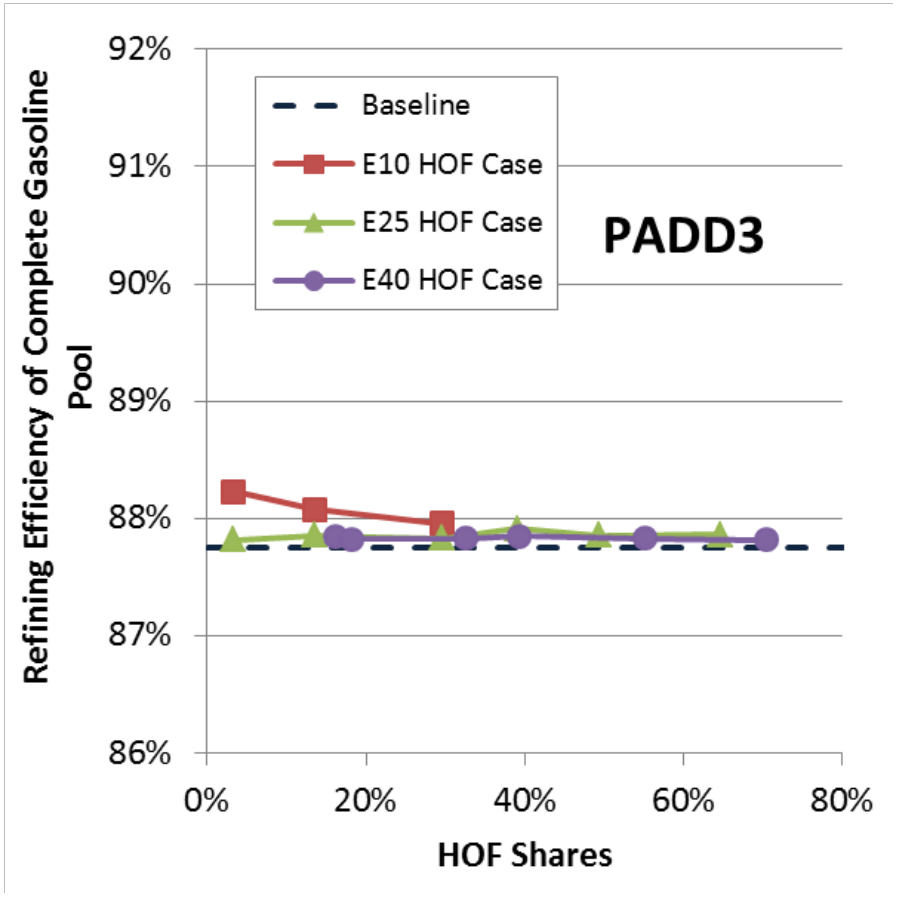


- GHG reductions due to efficiency gains: 5-9% respectively
- Minimal refinery Impact: <1%
- Additional GHG reductions for ethanol impact depends on ethanol source

✓ Efficiency-ethanol combined GHG reductions ~ 30% for cellulosic ethanol with E40!

Overall Refinery and Gasoline BOB Efficiencies Are Changed Little with Ethanol Blending Level and HOF Share





- BOB: Blendstock for Oxygenate Blending; BOB + Ethanol = Finished Gasoline
- E10 HOF is feasible only up to ~25% of gasoline market share
  - A result of **no new capital investment assumption**
- PADD2 shows similar trends

Provisional Results To Date Are Encouraging …

- ✓ Ethanol is a significant enabler for high octane fuels
- ✓ Potential vehicle efficiency gains significant (5-10% feasible)
  - ✓ Modest fuel savings
- ✓ Significant reductions in GHG (~30% with cellulosic ethanol)
- ✓ Little decrease in overall US refinery efficiency, even at very high demands
- ✓ Ethanol offers higher volume of high octane fuel and additional GHG benefits not achievable with E10
- ✓ Provides opportunities for refineries to export gasoline products
- ✓ Immediately usable in legacy FFVs (17M) – pathway to introduction
- ✓ Reasonable path forward in infrastructure
- ✓ Significant market share for dedicated HOF vehicles using different market scenarios
- ✓ Significant increase in ethanol demand (~XX BGY ethanol)
- ✓ With *equal* decreases in petroleum!

Thank you for this opportunity

Questions?