Intermediate Ethanol Blends

Plans and Status

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NREL (Wendy Clark, Keith Knoll, Doug Lawson)

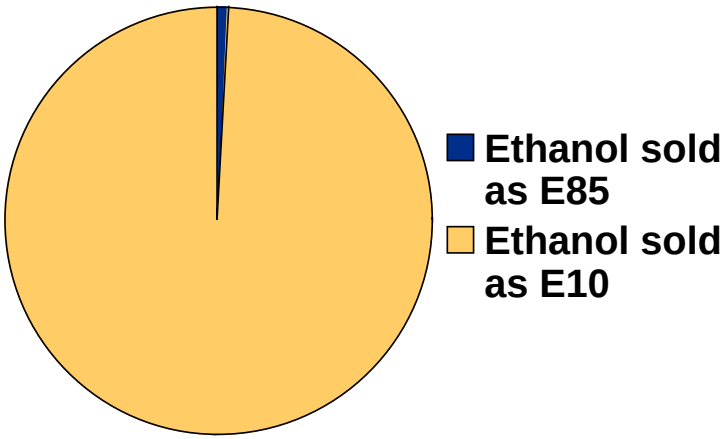
ORNL (Ron Graves, Brian West, Tim Theiss, John Thomas, Sean Huff)

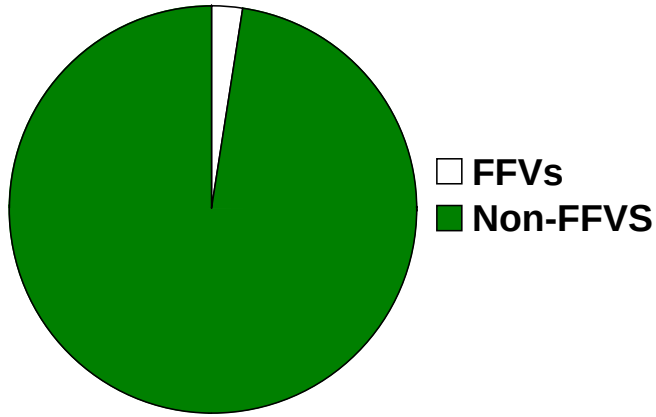
and many others …

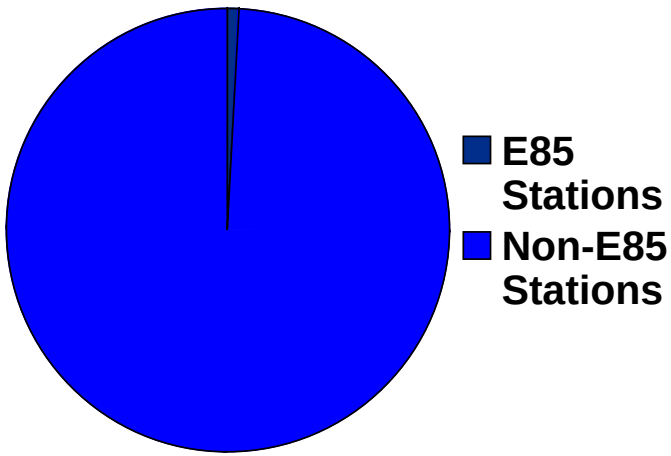
20 in 10/EISA Goals Cannot be Met Solely Through Expansion of E10 Gasoline

- **Ethanol markets cannot absorb the ethanol volume specified by the Energy Independence & Security Act (36B gallons)**
  - **Today, blended gasoline used in standard vehicles (non-FFVs) is limited to 10 percent ethanol (E10).**
  - **More than 99 percent of the fuel ethanol produced today is used in E10 blends; a tiny fraction is used to produce E85 for FFVs.**
  - **E10 markets are likely to saturate by ~ 2012, as production capacity approaches 14B gallons (~10% of all gasoline sold).**
- **There are two paths to increase ethanol markets >14B gallons:**
  - **Path A: Saturate E10 markets, and significantly expand E85 markets at an accelerated pace**
  - **Path B: Certify "intermediate blends" of gasoline to use up to 15 or 20% ethanol (E15, E20) and let market forces drive ethanol supply distribution**
- **DOE is investigating ALL paths, but this project is designed to determine the impact of Path B on the existing "legacy" fleet of vehicles and non-road equipment**

Nation has limited E85 Infrastructure







E85 Route to Solution:

For example, in order for E85 market to absorb 25 billion gallons of ethanol per year by 2017 we estimate that the US would need :

- 10 billion gallons per year of E85, **250X** more than today.
- **100 million** FFVs **vs 6** million FFVs today.
- **60,000** E85 stations **vs 1,200** today.

Background

- **DOE intermediate ethanol blend test plan development began March 2007**
  - **DOE funding: $14.6M (2007 & 2008)**
  - **Organizational meetings – DOE, National Labs, EPA, USDA, State of MN – March & June 2007**
  - **Literature search April-July 2007**
  - **Small, non-road engines (SNRE) given priority in summer 2007 at EPA request**
  - **Established leveraging with CRC**
  - **Vehicle evaluations underway late CY 2007**
  - **Plans for other non-road in progress: ATVs, marine, motorcycles, snowmobiles**

Industry Interactions on Intermediate Ethanol Blends

- **Received input on vehicle testing from USCAR & incorporated into DOE plan (October 2007)**
- **Presented DOE test plans for vehicles and small engines to USCAR (January 2008)**
  - **Ongoing interactions between USCAR, Oil Cos. (CRC, ASTM) and National Labs on technical details**
- **Honda and the Automobile Importers of America to be briefed soon**
- **RFA being briefed today**
- **Ongoing discussions with representatives of the small / non-road engine manufacturers (December 2007– February 2008)**
  - **Planning a workshop for Spring 2008**
- **Industry interactions proving highly valuable**
  - **Provide input on test plans & vehicle/engine selections**
  - **All DOE tests at neutral sites**
  - **Coordinating Research Council (CRC) is main venue of collaboration and cost-share**

Overview of Intermediate Ethanol Blend Vehicle Studies

- **Seven active vehicle tasks underway (11 total)**
- **Addressing key questions on E15/20 impacts on legacy fleet**
  - **Emissions**
  - **Catalyst durability**
  - **Driveability**
  - **Materials compatibility**
  - **Four fuels in most tests—E0, E10, E15, E20**
- **Vehicle Test Fleet**
  - **46 vehicles today**
  - **100 by March**
  - **155 by May**
- **5 of 7 vehicle tasks complete by end of CY 2008**
- **Other 2 tasks are longer term, significant data available in CY 2008**
  - **Full-useful life catalyst durability testing (with CRC)**
  - **E0 to E20 speciated exhaust emissions study (with EPA)**

Task V1: Vehicle Pilot Study

- **Plan developed in collaboration with EPA**
- **11 late-model vehicles**
  - **Instrumentation: TCs, UEGO, ALDL/DLC/CAN**
- **E0, E10, E15, and E20 fuels**
- **Triplicate LA92 drive cycles on each fuel**
  - **NMOG, NO_X, CO, CO_2, ethanol, aldehydes, mpg**
- **CRC E-60 Wide Open Throttle protocol to assess open-loop fuel trim/catalyst protection**
- **Daily log to note driveability issues, MILs, etc.**
- **Testing is underway**

Task V1: Vehicle Pilot Study

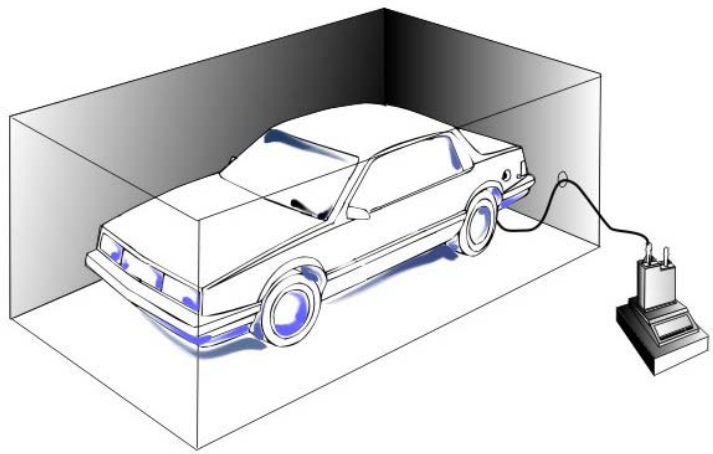
MY2003 & 2007
Most popular
Cars & trucks
6 OEMs

Task V2: Emissions/EPAct Program with EPA

- **EPA/DOE Cooperation**
- **Objective: Establish effects of RVP,T50,T90, aromatic content and EtOH on exhaust emissions from Tier 2 vehicles**
- **Fuel matrix (computer-generated/optimal) includes 29 fuels**
  - **Fuel variables: T50 (4 levels); T90 (2 levels); EtOH (4 levels); RVP (2 levels); Aromatics (2 levels)**
- **22 test vehicles in Phases 1 & 2; 19 vehicles in Phase 3**
- **Program Design (LA92) will be used throughout)**
  - **Phase 1: RFS2 Pilot at 75°F (3 fuels tested in 22 vehicles, results => RFS2 NPRM)**
  - **Phase 2: RFS2 Pilot at 50°F (3 fuels tested in 22 vehicles)**
  - **Phase 3: Main Program (25 fuels tested in 19 Tier 2 vehicles, E85 tested in 4 FFVs)**
- **Species measured (continuous and bag): Regulated emissions, CO_2, NO_2, VOCs, ethanol, carbonyl compounds**
- **Fuel blending began in February; Phase I testing to begin on April 1**

Task V3: CRC E-77 Evaporative Emissions Projects

- **Led by EPA**
- **E-77 Pilot, Draft Report under review by committee (10 older cars, all E0 fuels)**
- **E-77-2 Current test program at ATL (4 Tier 2 vehicles, 4 Tier 1, all "enhanced" evaporative systems; E0, E10, E20)**
- **E-77-2b EPA testing at SwRI (8 vehicles – E0, E10, possibly E20)**
- **E-77-3 EPA field testing study with ERG – looking for leakers**



Task V4: Catalyst Durability and Aging

- **Planned in collaboration with CRC and USCAR**
- **80 vehicles (10 vehicle types x 8 each)**
  - **Vehicle selection based on CRC E-87**
- **E0, E10, E15, and E20 fuels**
- **CRC E-60 Wide Open Throttle protocol to assess open-loop fuel trim / catalyst protection**
- **Status: RFP to be issued in Q1 2008**

Task V4: Catalyst Durability and Aging Protocol

- **Acquire vehicles, run single FTP and CRC E-60 WOT**
  - **Confirm open-loop characteristics observed in CRC E-87**
- **10 vehicle types**
  - **Baseline FTP emissions on E0 (all vehicles)**
  - **Baseline on E10, E15, E20 (2 vehicles per fuel)**
- **Age vehicle 25,000 miles using EPA Standard Road Cycle**
  - **Splash blended retail gasoline (RE0, RE10, RE15, RE20)**
- **Duplicate FTPs on E0 and Exx (4 tests per vehicle)**
- **Repeat until 50,000 miles driven or vehicle reaches full useful life**

Task V4 Catalyst Aging

Baseline	Aging	Emissions	Aging	Emissions
E0	RE0	E0	RE0	E0
E0	RE0	E0	RE0	E0
E0 + E10	RE10	E0 + E10	RE10	E0 + E10
E0 + E10	RE10	E0 + E10	RE10	E0 + E10
E0 + E15	RE15	E0 + E15	RE15	E0 + E15
E0 + E15	RE15	E0 + E15	RE15	E0 + E15
E0 + E20	RE20	E0 + E20	RE20	E0 + E20
E0 + E20	RE20	E0 + E20	RE20	E0 + E20

Task V5: CRC Cold-Start & Driveability (CM-133)

- **Initiated as FFV E85 Cold-Start / Driveability program to update ASTM volatility class vapor pressure (RvP) requirements for Flexible-Fuel Vehicles (FFVs)**
- **Targets volatility classes 1 and 2**
- **Uses industry accepted CRC protocols/raters**
- **Intermediate blends added to address Exx-fueled vehicle performance in same volatility classes**

Task V5: CRC Cold-Start & Driveability Program Summary

- **Exx Fuel Matrix:**
  - **E0 at 5.7 & 7.9 psi RVP**
  - **E15 at 6.7 & 10.0 psi RVP**
  - **E20 at 6.7 psi RVP**
- **Exx Temperature Matrix**
  - **Class 1: 30°F to 40°F**
  - **Class 2: 20°F to 30°F**
- **Exx Program Schedule**
  - **Testing completed February 2008**
  - **Full data analysis complete November 2009**
  - **Interim results should be available earlier**

Task V6: CRC AVFL-15, E20 (Vehicle Fuel System) Durability

- **Evaluate durability impacts of wetted fuel system components when exposed to E20**
  - **Fuel system designs selected with the most E20 susceptibility for testing using new fuel system components**
  - **Targeting suspected vulnerable parts and test processes**
  - **Complete fuel system test rigs to be constructed instead of complete vehicle testing to reduce cost**
  - **Accelerate aging via raised temperatures, 'aggressive' alcohol**
  - **Functional part testing to aid in wear determination**
  - **Material compatibility to be evaluated based on wear analyses**
- **Fuels: E0, E10 (base fuel), and aggressive E20**
- **Project start 1st Quarter 2008, 15 months in length**
- **Working with Transportation Research Center, Inc.**

Task V6: Program Approach

- **Fuel Pump**
  - **Initial Phase: Soak fuel pump components in E20**
  - **Testing on E20; affected designs retested using E10**
    - **Endurance Test (SAE J1537)**
    - **Extended fuel soak with periodic operation**
  - **Soak E20 components in E0 and retest**
- **Fuel Injector**
  - **Durability Test (SAE J1832)**
  - **Test on E20, then select designs on E10**
- **Complete Fuel System Fuel Exposure**
  - **11 month soak at elevated temperature using fuel circulation with fuel refreshed periodically and analyzed for material degradation**
  - **E20 and E10 are tested in parallel for each selected system**

Tasks V7-V11

- **Tasks V7 & V8: Materials Compatibility (MN/RFA and UL)**
  - **Monitor ongoing activities**
  - **Assess need for parallel or follow-on efforts**
- **Task V9: OBD and operations issues**
  - **Plans contingent on issues observed during V1-V5**
- **Task V10: Health Impacts – TBD**
- **Task V11: Monitor and Assist Rochester Institute of Technology in E20 Test and Evaluation Program**

Task V11: Monroe County Pickup in the Delphi emissions test facility

Intermediate blends impacts on small non-road engines

- **Small, non-road engines study well underway (accelerated schedule requested by EPA)**
  - **Emissions and durability**
- **Small-engine industry advising on test plans, procedures, test devices**
  - **Workshop in March 2008**
- **Additional engine studies will follow, pending resource availability**
  - **Marine engines**
  - **ATVs, snowmobiles, motorcycles**
  - **Heavy-duty gasoline engines**

Small Non-Road Engine Study Includes In-House and Subcontracted Efforts

- **Open Loop, non-road SI engines expected to be very sensitive to increased ethanol content**
- **Wide range of displacement and full useful life. DOE study examining engine classes I (lawnmower), II (small tractor), and IV (string trimmers, chainsaws, etc.)**
- **SE1: In-house evaluations at ORNL and NREL**
  - **Temperature and emissions on 4 fuels. (Full useful life testing on 50 hour leafblower at NREL)**
  - **Class I (5-10 hp) and Class II (10-25 hp) generators (ORNL)**
  - **Class IV line trimmer and leaf blower (NREL)**
- **SE2: Full useful life evaluations at TRC on all four fuels**
  - **Residential and Commercial - Class I & Class IV engines**
  - **Emissions and temperatures at break-in, half life, and full useful life**
  - **E0 baseline on all engines at beginning and end. Exx emissions at each testing interval**
- **SE3: Class II: Larger equipment (e.g. tractors) - deferred at this time; hope to leverage EPA program in FY08**
- **SE4: Motorcycles, ATVs, marine - planning stages, no funding yet**

Task SE2: Class I and IV Full Useful Life Testing

Baseline	Aging	Emissions	Aging	Emissions
 **E0**	**E0**	**E0**	**E0**	**E0**
 **E0 + E10**	**E10**	**E10**	**E10**	**E0 + E10**
 **E0 + E15**	**E15**	**E15**	**E15**	**E0 + E15**
 **E0 + E20**	**E20**	**E20**	**E20**	**E0 + E20**

Preliminary Findings

- **Very limited observations from ongoing tests with new vehicles confirm prior studies that drivers may not notice any immediate impact of E20 on vehicle driveability.**
- **Cannot extrapolate this result to older vehicles, so new data are required.**
- **Longer-term performance effects on new vehicles are not known.**
- **Preliminary data is insufficient to assess intermediate-blend impacts on key concerns of vehicle catalyst durability, emissions.**
- **For small, non-road engines, NO_x and operating temperatures increase with increasing ethanol content, and CO and HC decrease.**
  - **Regulated emissions standard (NO_x + HC) still met; EPA and states may be more concerned about NO_x increases, regardless.**

Supplemental Slides

Task V8: Materials Compatibility (Placeholder Task)

- **Dispenser component tests underway**

- **Second apparatus constructed for elastomer and metal-based coupon studies**
  - **More fundamental material study**
  - **Dynamic test (stir tank)**
  - **Temperature control (60°C)**
  - **Coupons periodically removed for analysis**
  - **Apparatus potentially available for evaluation of automotive materials**

Task V11: Monitor and Assist Rochester Institute of Technology in E20 Test and Evaluation Program

- **Goal: To determine the impact of E20 on existing, conventional vehicles (Non-FFV)**
- **Monroe County, NY has dedicated 10 older vehicles (1998-2004 models, wide range of mileages)**
- **E20 from dedicated tank at Monroe County Fleet Center : fueling beginning week of 28 Jan 08; test duration 1yr.**
- **Emissions testing baseline on unleaded complete (Delphi-Henrietta facility, FTP 75 protocol, three reps/vehicle)**

MC Pickup in the Delphi emissions test facility

Task V11: Rochester Institute of Technology E20 Test and Evaluation Program

- **Follow up testing will be done after E20 implementation (late spring-summer '08)**
- **All ten vehicles have Networkcar vehicle monitoring system w/GPS**
- **Driver comment cards for subjective driveability evaluations**
- **Fuel and oil will be sampled periodically (some to NREL)**
- **Will track maintenance data, mileage, OBD/MILs, failures (due to fuel), performance/driveability**
- **Life cycle analysis using GREET model to determine predicted emissions deltas for these vehicles for comparison with test data**

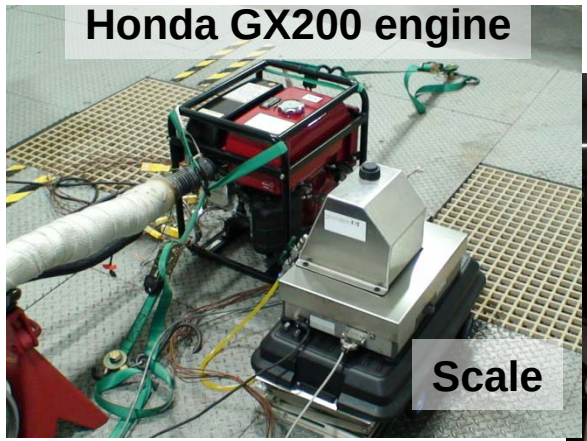
		Monroe County E20 Vehicle Testing List			
Fleet Number	Model Year	Manufacturer	Model Type	Date of Test - gasoline	Mileage at test
3562	1998	Ford	F150 Pickup	3-6 Dec 2007	73860
3675	2000	Chevy	Impala Sedan	6-8 Nov 2007	83030
4029	2001	Ford	F250 Pickup 4x4	11-14 Nov 2007	54499
4030	2001	Ford	F250 Pickup 4x4	6-8 Nov 2007	107611
4066	2001	Chevy	Silverado 1500 Pickup 4x4	27-30 Nov 2007	119776
4075	2001	Chevy	Suburban/Blazer 4x4	27-30 Nov 2007	48787
4126	2002	Chevy	G3500 Van	11-14 Nov 2007	82794
4137	2002	Ford	F250 Pickup 4x4	11-13 Dec 2007	120818
4140	2002	GMC	Sierra 1500 Pickup 4x4	27-30 Nov 2007	51123
4230	2004	Ford	F250 Pickup 4x2	1-3 Nov 2007	29738

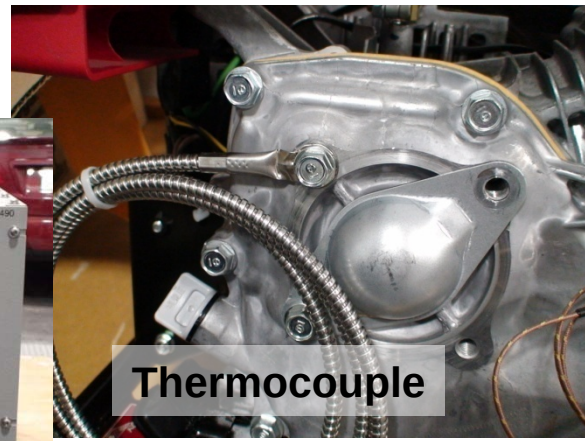
SNRE Program Summary to date

- **ORNL generator set testing complete**
  - Honda GX200 engine - Class I commercial
  - 1999 Honda generator –Class I (used)
  - Briggs and Stratton engine - Class II residential
  - Kohler V-twin- Class II commercial
- **NREL Class IV tests complete**
  - Stihl line trimmer - Class IV commercial
  - Poulan leaf blower - Class IV residential
- **TRC underway - full useful life data planned**
  - Briggs & Stratton pressure washer - Class I residential
  - Poulan leaf blower - Class IV residential
  - Honda generator - Class I commercial
  - Stihl line trimmer - Class IV commercial

ORNL evaluated 4 small engines at Fuels, Engines, Emissions Research Center

- **Engines Instrumented for**
  - **Temperatures**
    - **Exhaust Manifold**
    - **Cylinder Jug**
    - **Engine Oil**
    - **Cylinder Head**
  - **Emissions**
  - **Air:fuel ratio**
  - **Gravimetric fuel consumption**
- **Resistive Load Bank used to simulate 6-mode emissions test**
- **Engine-Driven Generators:**
  - **200 cc Honda (new, Class I, commercial)**
  - **249 cc Briggs and Stratton (new, Class II residential)**
  - **163 cc Honda (used 1999 model)**
  - **725 cc Kohler V-twin (new, Class II commercial)**
- **Test Fuels (E0, E10, E15, E20)**





NREL Evaluated Two Class IV Small Engines at its ReFUEL Engine Test Facility

- **Engines Instrumented for**
  - Temperatures (Exhaust Manifold, Cylinder Jug, Engine Oil, Cylinder Head)
  - Emissions
  - Air:fuel ratio
- **Automated throttle actuator used to follow CFR-specified 2-mode cycle.**
  - 4.25 minutes at 100% Load
  - 0.75 minutes at idle
  - Emissions and Durability Cycles
- **Two Engines Evaluated:**
  - 25 cc Poulan Leaf Blower (2-stroke Class IV residential)
  - 28.4 cc Stihl Line Trimmer (4-stroke Class IV commercial – uses fuel/oil mix)
- **Test Fuels (E0, E10, E15, E20)**

Poulan Leaf Blower
25 cc 2-Cycle Residential

Stihl Line Trimmer
28 cc 4-Cycle Commercial

Engine Temperature Instrumentation

Raw Exhaust Sampling Via PEMS System