Mid-Level Ethanol Blends Test Program

DOE, ORNL, and NREL Team

Presented by

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This presentation does not contain any proprietary or classified information

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Overview

Timeline

- Start: Summer 2007
- End: Spring 2011
- % complete: ~75%

Budget

- **Total project funding**
  - **DOE >$45M through FY10**
    - **Contractors (DOE funds): ~$40M**
  - **Industry and EPA: $6M**
- **FY09: $ 20M**
- **FY10: $ 10M+**

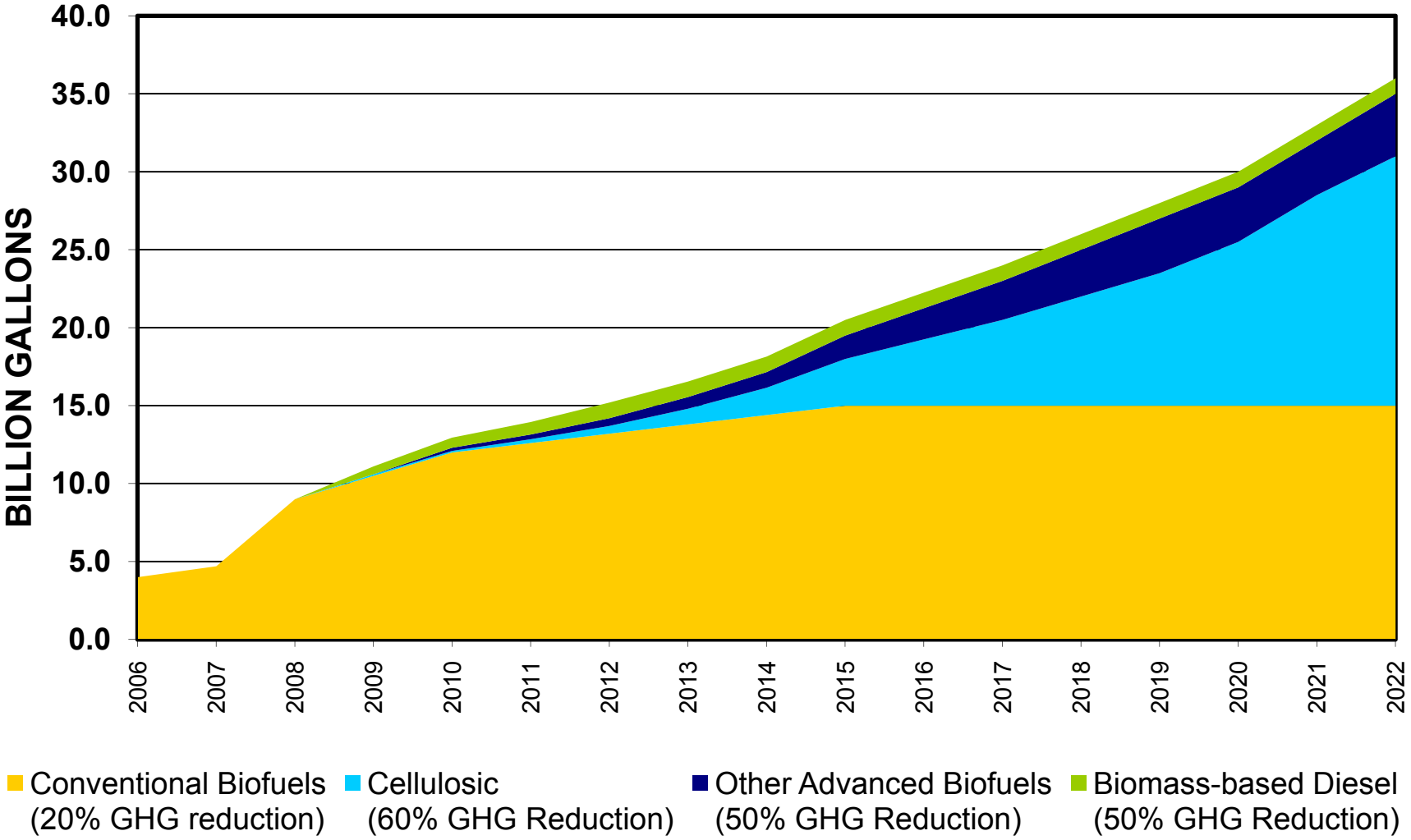
Barriers

- Non-petroleum based fuels infrastructure and end use
  - E15/E20 not legal fuels
  - Infrastructure to dispense into vehicles
  - Vehicle/engine safety and warranty issues (e.g., materials)
  - Vehicle/engine emissions

Major Partners

- EPA (government)
- CRC (autos and oils)
- Underwriters Laboratories
- OPEI (small nonroad engines)
- ISMA (snowmobiles)
- NMMA (marine)
- MIC (motorcycles and ATVs)

Renewable Fuels Standard (RFS) establishes specific annual volume requirements for biofuels



Relevance

Challenges Across Entire Biofuel Supply Chain

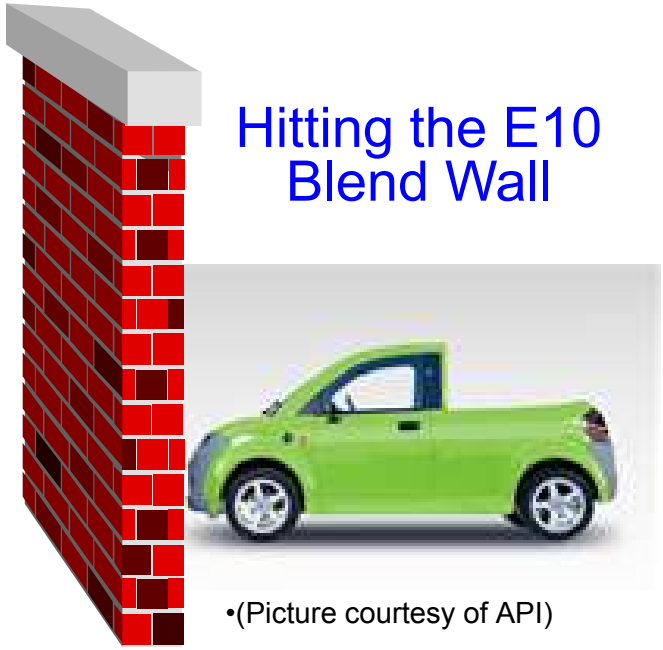
Feedstock Production → Feedstock Logistics → Biofuels Production → Biofuels Distribution → Biofuels End Use

Ethanol End Use Challenges:

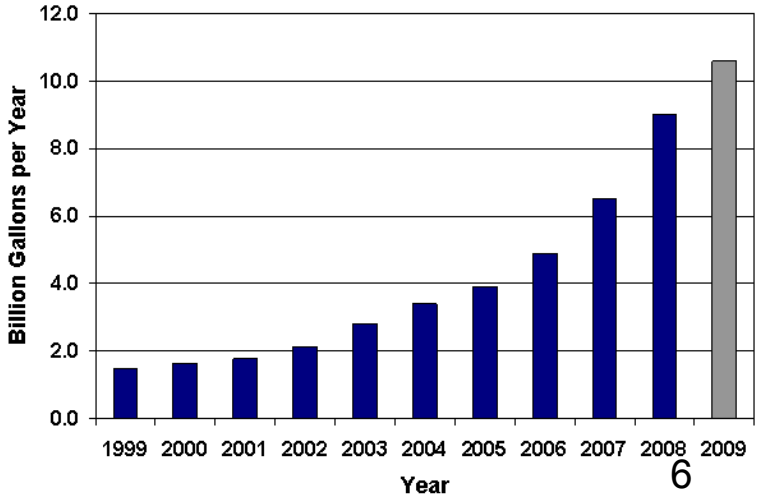
- *Ethanol as E85 can only be used in Flex Fuel Vehicles*
  - *~8M on road in U.S.*
  - *~2000 E85 pumps*
- *E10 is maximum allowable limit in "gasoline"*
  - *~240M gasoline vehicles in U.S.*
  - *>150,000 gasoline pumps*

Developing A Ready End-Use Market for Ethanol

- About 11 billion gallons of ethanol used in the U.S. in 2009
  - ~99% as E10
  - E10 market approaching saturation (blend wall).
- DOE strategy for expanding ethanol use
  - **Evaluate feasibility of using mid-level ethanol blends (e.g., E15, E20) in conventional vehicles (non-flex fuel vehicles)**
  - Expand E85 use by targeting specific regions/cities to establish high concentration of FFVs and infrastructure
- EPA has authority to approve waiver to allow >10% ethanol in gasoline
  - Evaluate effects on durability, driveability, materials, and emissions



•(Picture courtesy of API)



Goals and Objectives

- Determine Effects of Mid-Level Ethanol Blends on Legacy Vehicles, Engines, and Infrastructure
  - Short-term Effects
    - Emissions
    - Driveability
    - Equipment failure
  - Long-term (full life) Effects
    - Emissions
    - Driveability
    - Durability
    - Safety
- Enable informed decision-making

Selected Milestones

April 2009:

- **ORNL and NREL initiate additional V4 contracts to expand/accelerate vehicle aging**

October 2009:

- **ORNL initiates additional materials studies (stir tank experiments) with elastomers, metals, sealants, and plastics in ethanol blends**

November 2009:

- **NREL/ORNL publish SAE paper with additional statistical analysis of V1 data**
- **ORNL publishes results of stir tank work on materials coupons**

January 2010:

- **NREL/UL Dispensers entered conditioning chamber**

September 2010:

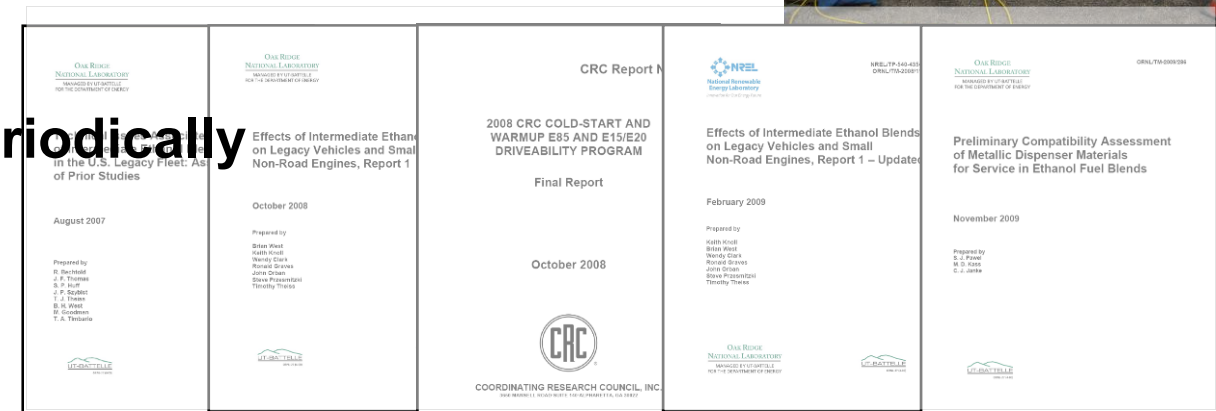
- **Complete full useful life emissions tests on 58 Tier 2 vehicles**

December 2010:

- **Complete full useful life emissions tests on 24 pre-Tier 2 vehicles**
- **Report on evap testing with CRC and EPA**

Approach

- Multiple parallel efforts
- Vehicle testing at national labs and subcontractors
  - ORNL, NREL, TRC, SwRI, ETC
- Small engine testing at National Labs and subcontractors
  - SNRE, other non-automotive engines
- Materials testing at national labs and contractors
- Industry/Stakeholder partnerships (e.g., CRC, EPA, UL, OPEI)
  - Share cost
  - Valuable guidance
- Report Progress Periodically



Task Summary
Team Developed List of 15 projects (Summer 2007)
Some complete, most underway

Highlighted tasks reviewed today

	Vehicle Tasks	Task Description	DOE Lead
✓	V1	Short-term "quick-look" emissions study of 16 vehicles (4 fuels)	ORNL/NREL
	V2	Detailed Exhaust emissions with EPA (22 vehicles, 31 fuels; E-89 with CRC, 2/31 fuels)	NREL
	V3	Vehicle Evaporative Emissions with CRC (E-77)	NREL
	V4	Full-life Vehicle Emissions Study (Catalyst Durability with CRC, E-87-2)	ORNL
	V5	Vehicle Driveability with CRC (CM-138)	NREL
	V6	Vehicle Fuel System Materials Compatibility with CRC (AVFL-15)	NREL
✓	V7	Vehicle Materials Review (University of MN/RFA Studies)	ORNL
	V8	Materials Compatibility with UL (E85 dispensers + materials studies)	ORNL
	V9	Vehicle On-board Diagnostics and Operations Issues	NA
	V10	Health Impacts	NA
	V11	Fleet Performance and Emissions with RIT	NREL
	Non-automotive Engines and small nonroad engines (SNREs)		
✓	SE1	SNRE emissions and temperature (quick-look, in-house ORNL and NREL, 6 engines, 4 fuels)	ORNL/NREL
✓	SE2	SNRE Full Useful Life Emissions and Durability (22 engines, 4 fuels, 17 engines to full life)	ORNL
	SE3	Chainsaw Safety Testing	ORNL
	SE4	Motorcycles, marine, ATVs, Snowmobiles	NREL

Technical Accomplishments -1

- **Completed and Published Legacy Vehicle Emissions Study (V1)**
  - **16 vehicles (1999 to 2007) tested at 3 sites for short-term emissions and fuel economy, catalyst temperature**
  - **First published October 2008, updated Report February 2009**
  - **SAE Paper published November 2009**
- **Detailed Vehicle Emissions Study with EPA and CRC continues (V2)**
  - **Phase 3 emissions testing completed: 15 vehicles tested with 30 match-blended fuels**
- **Initiated high-altitude, high-temperature driveability program for Summer 2010 (V5)**
  - **Follow on to cold weather study program with CRC, 2008**

Technical Accomplishments -2

- **Vehicle Evaporative Emissions Study with EPA and CRC nearly complete (V3)**
  - **16 vehicle study with 6 fuels to assess evaporative emissions impacts of ethanol blends**
- **Expanded and Accelerated Full Useful Life Vehicle Emissions Studies (V4)**
  - **82 vehicles (27 models) to be aged to full life to assess long term emissions impact of ethanol blends**
    - **3 subcontracts, 3 test sites**
    - **~29 vehicles complete, remainder under test (5/30/2010)**
- **Materials Compatibility Studies (V6, V8)**
  - **Reported on In-house materials studies**
  - **Initiated additional in-house and subcontracted efforts to examine wetted components or materials with ethanol blends**

Task V2: EPAct Program

V2 - Specific Objective/Overview of Tasks

- **Objective: Establish effects of RVP,T50,T90, aromatic content and EtOH levels on exhaust emissions from new Tier 2 and in-use vehicles**
- **Tasks include**
  - **Testing 15 new Tier 2 vehicles and 3 high mileage/emitter vehicles**
  - **Test fuel matrix of 31 fuels (including 1 E85 fuel)**
  - **Species measured: Regulated emissions, CO_2, NO_2, VOCs, ethanol, carbonyl compounds**
  - **VOCs include gaseous and semi-volatile organic (SVOC) compounds**
  - **N_2O, NH_3 and HCN by FTIR**
  - **Some PM, PM number and size, and SVOC speciation**

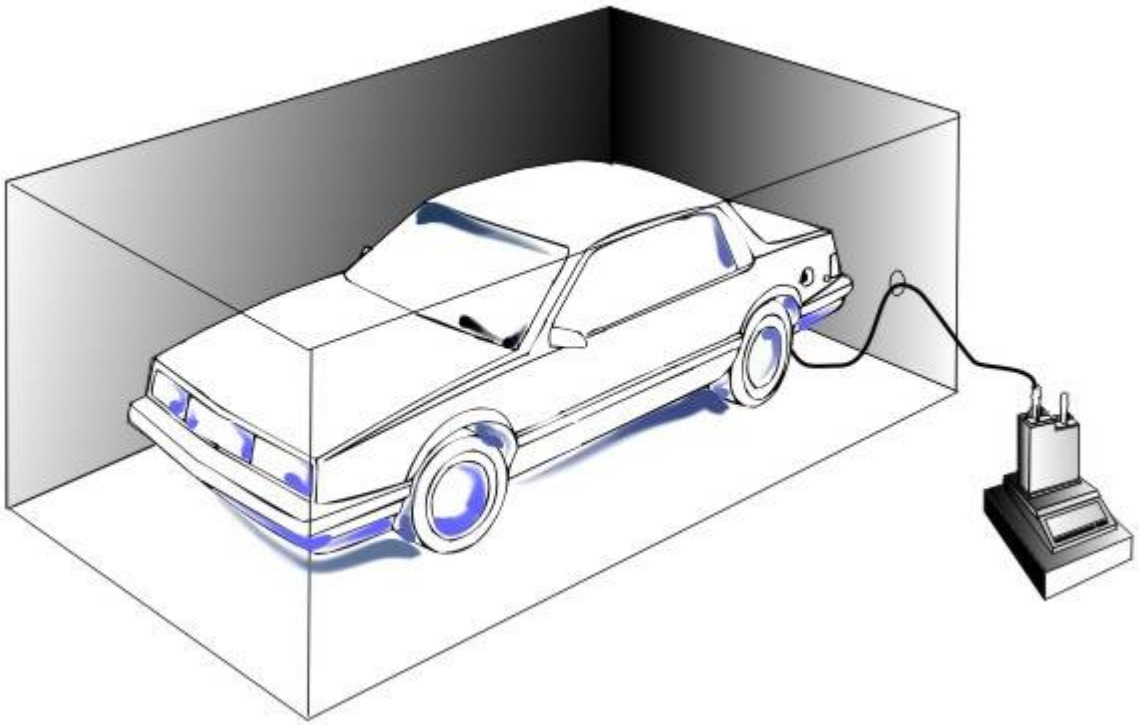
V2 Program Status

- Phase 3 emissions testing completed: 15 new Tier 2 vehicles at room temperature with 31 fuels.
- Statistical analyses of initial phase 3 testing data have begun.
- Beginning testing of new and high emitter vehicles at 20°F and 95°F with E0, E10, and E20.
- V2 (EPAct Program) to be completed by April 2011.

Vehicle Evaporative Emissions

V3: Evaporative Emissions (DOE, EPA, CRC)

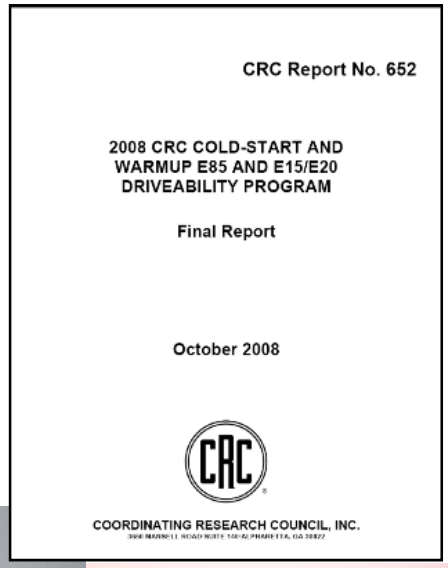
- 16 Vehicles / 6 Fuels (E0, E10, E20)
- Phase 1 (pilot) complete and published, June 2008.
- Phase 2 complete and published April 2010.
- Phase 3 testing complete, publication expected 4th Qtr 2010.
- Static Permeation, Running Loss Permeation



Vehicle Driveability / Operability

V5: Cold Start / Driveability (DOE and CRC)

- Class 1 & 2 fuels, 20 – 50 °F
  - CRC report issued Oct 2008
- Class 1 fuel, 95^{+}°F, 5000^{+} feet (alt.)
  - 20 vehicles, E0 / E10 / E20
  - Summer 2010 - Pueblo, CO.
  - Report expected 1st Qtr 2011


CRC Report No. 652

2008 CRC COLD-START AND WARMUP E85 AND E15/E20 DRIVEABILITY PROGRAM

Final Report

October 2008

CRC

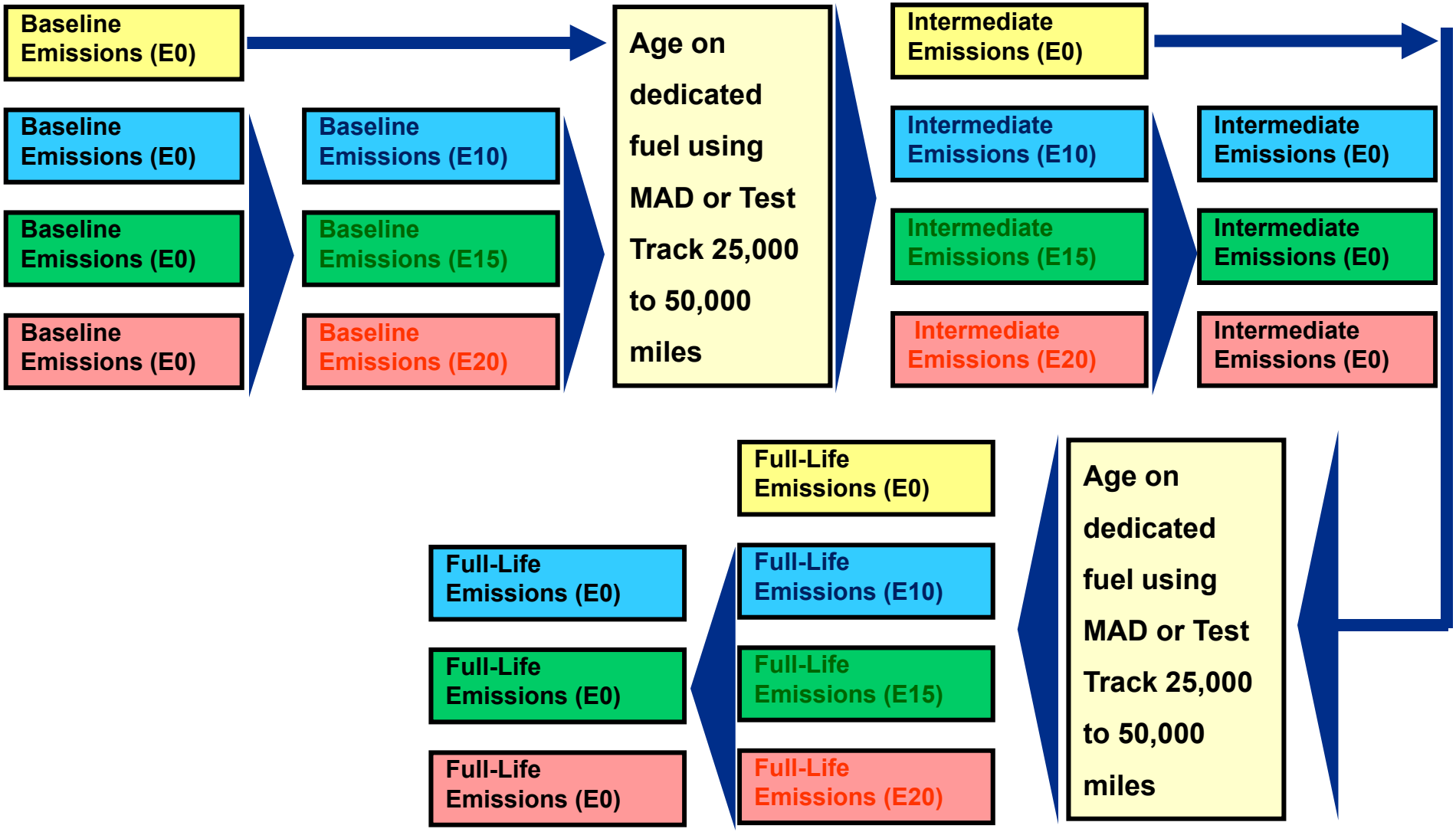
COORDINATING RESEARCH COUNCIL, INC.

V11: RIT Vehicle Fleet Study

- Detailed Emissions Study
  - 10 vehicles, splash blended E20
- Larger fleet study on-going with Monroe County.
  - 300 conventional vehicles
  - Highest miles: 36k miles on E20
  - No negative impacts observed

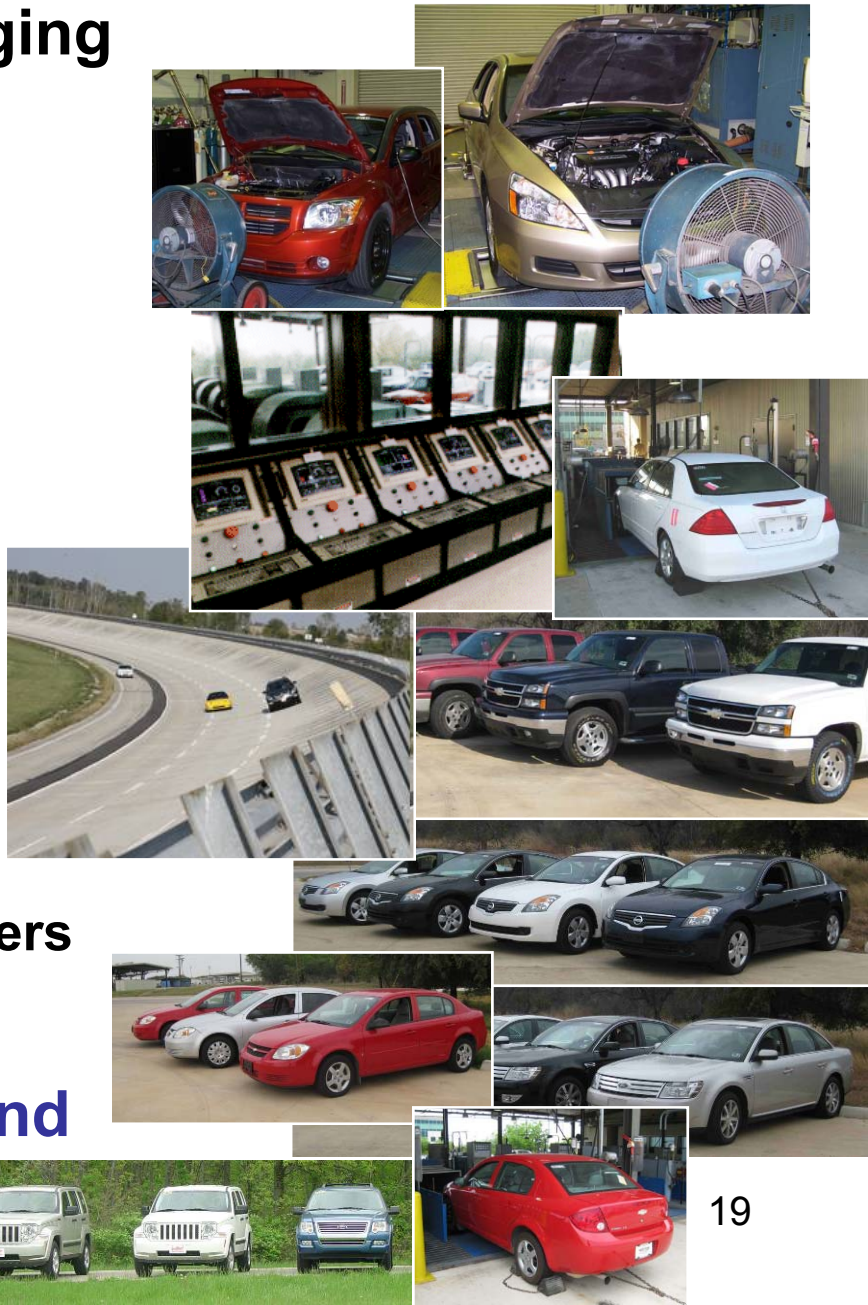
V4 - Vehicle Aging Program Overview

Acquire 2-4 "matched" vehicles for each model, dedicate each vehicle to 1 fuel (E0, E10, E15, or E20) for aging



V4 Project Status

- Vehicle emissions testing and aging underway at 3 sites
  - 19 Tier 2 models (58 vehicles)
  - 8 pre-Tier 2 models (24 vehicles)
- SwRI (E-87-2 with CRC)
  - Aging on mileage accumulation dynamometers
- TRC
  - Aging on test track
- ETC
  - Mileage accumulation dynamometers



Engine inspections planned at end

V4 – Vehicle Aging: 82 Vehicles Tested at 3 Sites

58 Tier 2 (19 models), 24 non-Tier 2 (8 models)

Year	Vehicle	number	Fuels			
2006	Chevrolet Silverado	4	E0	E10	E15	E20
2007	Honda Accord	4	E0	E10	E15	E20
2008	Nissan Altima	4	E0	E10	E15	E20
2008	Ford Taurus	4	E0	E10	E15	E20
2007	Chrysler Caravan	4	E0	E10	E15	E20
2006	Chevrolet Cobalt	3	E0		E15	E20
2007	Dodge Caliber	3	E0		E15	E20
2006	Nissan Quest	3	E0		E15	E20
2002	Nissan Frontier	3	E0		E15	E20
2002	Dodge Durango	3	E0		E15	E20
Transportation Research Center (Ohio), test track aging						
Year	**Vehicle**	**number**	**Fuels**			
2009	Jeep Liberty	3	E0		E15	E20
2009	Ford Explorer	3	E0		E15	E20
2009	Honda Civic	3	E0		E15	E20
2009	Toyota Corolla	3	E0		E15	E20
2005	Toyota Tundra	3	E0		E15	E20
2006	Chevrolet Impala	3	E0		E15	E20
2005	Ford F150	3	E0		E15	E20
2003	Toyota Camry	3	E0		E15	E20
2003	Ford Taurus	3	E0		E15	E20
2000	Chevrolet Silverado	3	E0		E15	E20
2003	Chevrolet Cavalier	3	E0		E15	E20
Environmental Testing Corp (Colorado), mileage accumulation dynamometers						
Year	**Vehicle**	**number**	**Fuels**			
2009	Saturn Outlook	2	E0		E15	
2009	Toyota Camry	2	E0		E15	
2009	Ford Focus	2	E0		E15	
2009	Honda Odyssey	2	E0		E15	
2000	Honda Accord	3	E0		E15	E20
2000	Ford Focus	3	E0		E15	E20

Non-Tier 2 Vehicles

Totals

35 Vehicles

33 Vehicles

14 Vehicles

V4 Test Schedule

Tier 2 Vehicle Testing to 120k odometer miles

Facility	# veh	Year and Model	2009 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2010 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SWRI	4	2007 Accord		35k		85k					120k	- - - -	10b*													
	4	2006 Silverado			27k					77k			120k													
	4	2008 Altima					20k				70k				120k											
	4	2008 Taurus									17k			67k				120k								
	4	2007 Caravan											45k		95k			120k								
	3	2006 Cobalt											50k			95k			120k							
	3	2007 Caliber																	50k		95k		120k			
	3	2006 Quest																	50k		95k		120k			
TRC	3	2009 Civic									4k					60k			120k							
	3	2009 Explorer									4k				60k				120k							
	3	2009 Corolla									4k					60k				120k						
	3	2009 Liberty										4k					60k			120k						
	3	2005 Tundra												50k				95k			120k					
	3	2006 Impala													35k				95k			120k				
	3	2005 F150															50k		95k			120k				
ETC (5000 ft El.)	2	2009 Odyssey								4k							60k		90k	120k						
	2	2009 Camry								4k							60k		90k	120k						
	2	2009 Focus								4k							60k		90k		120k					
	2	2009 Outlook								4k							60k		90k		120k					

non-Tier 2 Vehicle Testing (50k *test* miles, (up to or beyond full useful life miles)

Facility	# veh	Year and Model	2009 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2010 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SWRI	3	2002 Frontier																	95k		120k		145k			
	3	2002 Durango																		95k		120k		145k		
TRC	3	2003 Camry																	70K		95K		120K			
	3	2003 Cavalier																	70K		95K		120K			
	3	2003 Taurus																		70K		95K		120K		
	3	2000 Silverado																			95k		120k	145k		
ETC (5000 ft)	3	2000 Focus																			95k	120k	145k			
	3	2000 Accord																			95k		120k	145k		

Fuel System Materials Compatibility

V6: Fuel System Materials Compatibility (DOE and CRC)

- 3 Fuels: E0, E10, and E20-Aggressive
- Testing near completion. Report expected Summer 2010.
- Further testing being considered

Photos courtesy of CRC

V8: Fuel Dispenser Materials Compatibility

- Collaboration with UL – led to development of listing protocol for E85 pumps
- Additional materials studies in ORNL stir tanks - ongoing

Small Non-Road Engines (SNRE)
(Lawn and garden equipment, Generator Sets)

SE1: Emissions and Exhaust Temperature Pilot Study (6 engines)

- Published results in Mid-Level Blends Report 1 (October 2008)

SE2: Full Useful Life Emissions and Durability

- 17 engines aged to full life / 4 Fuels (E0, E10, E15, E20)
- Reported in Mid-Level Blends Report 1 (October 2008)

SE3-SE4: Additional non-automotive engines
Chainsaws, Motorcycles, Marine, Snowmobiles

Handhelds: Safety and Performance

- Residential and Commercial handhelds (chainsaws, hedgetrimmers)
- In contracting process

Marine: Outboard and Stern-Drive Engine Durability

- Outboard Engines: 3.5 HP 4-stk, 150-200 HP 2-stk, and 300 HP 4-stk
- Stern Drive / Inboard Engines: 4.3GL Volvo-Penta
- Contracting nearly complete – expect to begin testing in Summer 2010

Motorcycle: Engine Durability

- In contracting process
- Expect to begin testing 3rd Qtr 2010

Snowmobiles: Engine Durability

- In contracting process
- Expect to begin testing 3rd Qtr 2010

Collaborations

- EPA – Technical guidance, V2 cost share
- CRC – Technical guidance and technical support, cost share on multiple projects
- UL – Technical guidance, cost share, subcontract support
- ORNL/NREL – share technical project management, in-house testing
- SwRI, TRC, ETC – execution of subcontracts
- Battelle – Data analysis and warehousing

Future Work

- Complete Full Useful Life Vehicle Durability Study (V4) on 82 vehicles (Nov 2010)
- Complete EPAct Vehicle emissions study (V2) with EPA (Apr 2011)
- Complete high-temperature, high-altitude driveability study by September 2010 (V5)
- Complete Phase 3 of vehicle evaporative emissions study (V3) by Dec 2010
- Complete infrastructure materials studies with UL (Dec 2010)
- Continue to work with EPA, CRC, UL, and other government and industry stakeholders to plan and execute test programs

Summary

- **Relevance**
  - DOE, ORNL, and NREL Team working to establish feasibility of Mid-level Ethanol Blends.
  - Mid-level blends seen as key to compliance with EISA
- **Approach**
  - Multiple resources utilized in parallel to conduct massive test program
  - Collaborating with government and industry stakeholders
- **Technical Accomplishments**
  - Published results, frequent meetings with stakeholders, initiated multiple subcontracts, multiple parallel projects at several test sites
- **Collaboration**
  - Working closely with EPA, CRC, UL, industry stakeholders
- **Future Work**
  - Complete myriad of studies underway as quickly as possible

Backup Slides

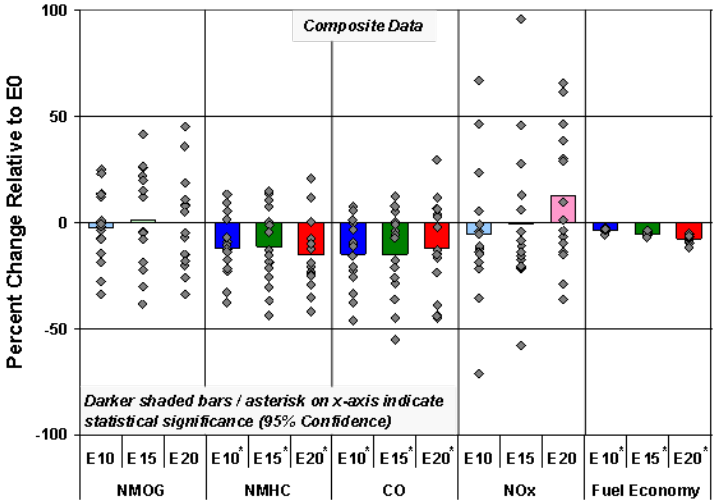
V1- Short Term Vehicle Emissions
Test Vehicles span 1999-2007

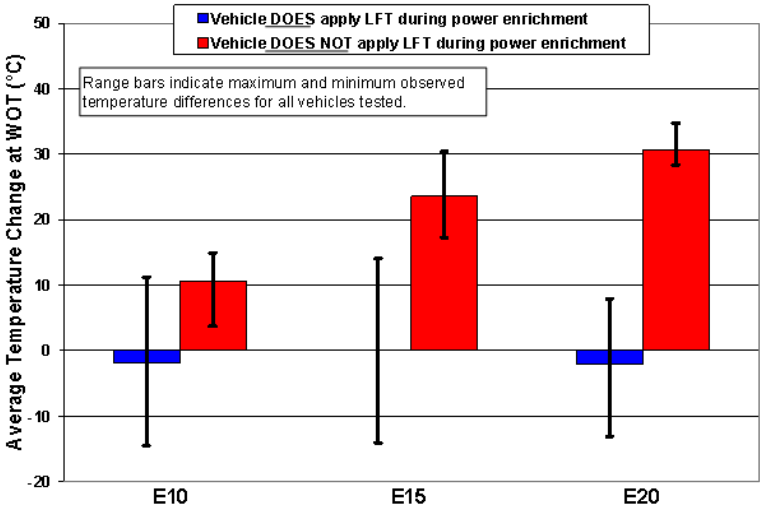
OEM (make)	Model	Year	Engine	Initial odometer reading (miles)	Emission standard	Test site	LFT at WOT?
Chrysler	Town & Country	2007	3.3 L V6	35,000	Tier 2, Bin 5	NREL/CDPHE	N
Ford	F150	2007	5.4 L V8	28,600	Tier 2, Bin 8	TRC	Y
Ford	F150	2003	5.4 L V8	57,000	Tier 1 LEV	TRC	Y
Ford	Taurus	2003	3.0 L V6	89,600	Tier 2, Bin 8	TRC	N
GM (Buick)	Lucerne	2007	3.8 L V6	10,000	Tier 2, Bin 5 (CA LEV II)	NREL/CDPHE and ORNL*	Y
GM (Buick)	LeSabre	2003	3.8 L V6	78,000	Tier 2, Bin 8	NREL/CDPHE	Y
GM	Silverado	2007	4.8 L V8	12,800	Tier 2, Bin 8	TRC	Y
Honda	Accord	2007	2.4 L I4	11,400	Tier 2, Bin 5 (CA LEV II)	TRC	N
Nissan	Altima	2003	3.5 L V6	53,300	LEV	TRC	N
Toyota	Camry	2007	2.4 L I4	26,440	Tier 2, Bin 5	ORNL and NREL/CDPHE*	Y
Toyota	Camry	2003	2.4 L I4	72,800	ULEV	ORNL	N
Chrysler	PT Cruiser	2001	2.4 L I4	93,400	NLEV	NREL/CDPHE	Y
Ford	Crown Victoria	1999	4.6 L V8	50,900	ULEV	NREL/CDPHE	Y
Honda	Civic	1999	1.6 L I4	79,680	Tier 1	ORNL	N
Toyota	Corolla	1999	1.8 L I4	96,400	Tier 1	NREL/CDPHE	Y
VW	Golf GTI	2004	1.8 L I4 Turbo	32,900	Tier 2, Bin 8	ORNL	Y

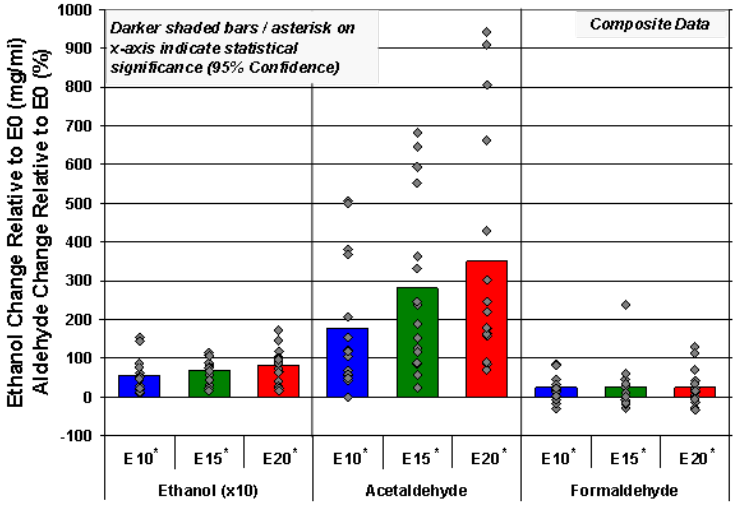
*Round-robin vehicle tested at two sites

V1- Vehicle Emissions Results:
(16 Vehicle Fleet – each point represents a vehicle)

- **Emissions / Temperature**
  - Regulated tailpipe emissions with E15 and E20 were similar to levels with E0 when averaged across multiple newer 'clean' vehicles.
  - Change in catalyst temperatures may affect durability.
- **Fuel Economy**
  - Fuel economy decreased for E10, E15, E20 closely tracked energy content







V2 - EPAct Program Vehicles

Vehicles in green text are FFVs

Make	Year	Brand	Model	Engine	Family	Bin
GM	2008	Chevrolet	Cobalt	2.2L I4	8GMXV02.4025	5
GM	2008	Chevrolet	Impala	3.5L V6-FFV	8GMXV03.9052	5
GM	2008	Saturn	Outlook	3.6L V6	8GMXT03.6151	5
GM	2008	Chevrolet	Silverado	5.3L V8-FFV	8GMXT05.3373	5
Toyota	2008	Toyota	Corolla	1.8L I4	8TYXV01.8BEA	5
Toyota	2008	Toyota	Camry	2.4L I4	8TYXV02.4BEA	5
Toyota	2008	Toyota	Sienna	3.5L V6	8TYXT03.5BEM	5
Toyota	2008	Toyota	Tundra	4.0L V6	8TYXT04.0AES	5
Ford	2008	Ford	Focus	2.0L I4	8FMXV02.0VD4	4
Ford	2008	Ford	Taurus	3.5L V6	8FMXV03.5VEP	5
Ford	2008	Ford/Mercury	Explorer/Mountaineer	4.0L V6	8FMXT04.03DB	4
Ford	2008	Ford	F150	5.4L V8-FFV	8FMXT05.44HF	8
Chrysler	2008	Dodge	Caliber	2.4L I4	8CRXB02.4ME0	5
Chrysler	2008	Dodge	Caravan	3.3L V6-FFV	8CRXT03.3NEP	5
Chrysler	2008	Jeep	Liberty	3.7L V6	8CRXT03.7NE0	5
Honda	2008	Honda	Civic	1.8L I4	8HNXV01.8LKR	5
Honda	2008	Honda	Accord	2.4L I4	8HNXV02.4TKC	5
Honda	2008	Honda	Odyssey	3.5L V6	8HNXT03.54KR	5
Nissan	2008	Nissan	Altima	2.5L I4	8NSXV02.5G5A	5