An Update on Alternative Fuels & the Renewable Fuel Standard (RFS2)

Center for BioEnergy Sustainability (CBES) Seminar

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

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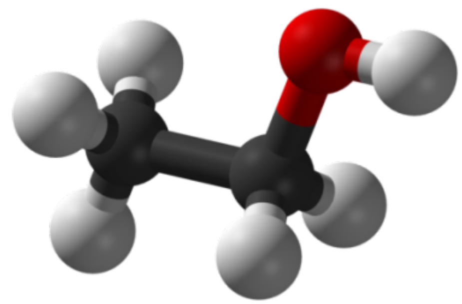
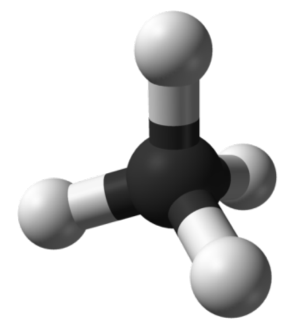
OUTLINE FOR TODAY'S PRESENTATION

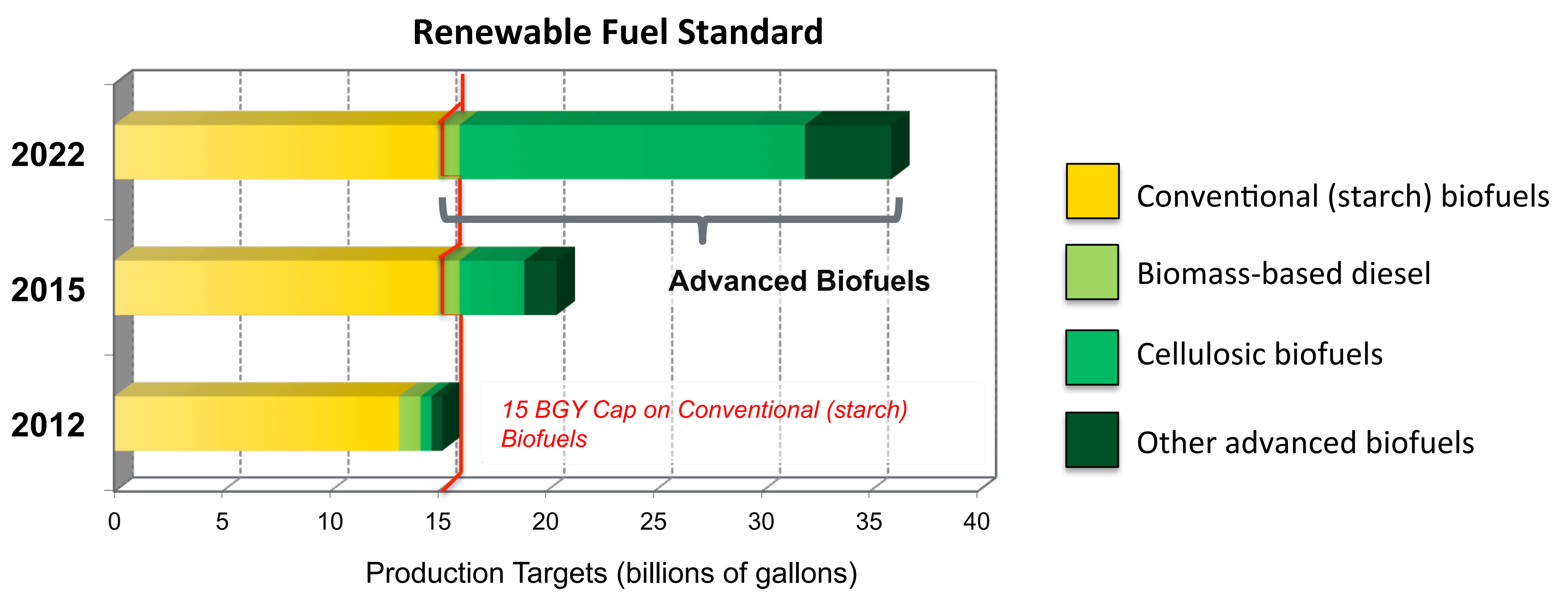
- **Background**
  - EISA (RFS2) & CAFE standards of 2011
  - Ethanol in context
- **EISA changes & RIN prices**
- **Various ethanol blends**
  - Background on octane
  - E15
  - E85
  - Renewable Super Premium (aka, E30)
- **Bio-based diesel**
- **Butanol**
- **Natural Gas**
- **Conclusions**





Key Policy Drivers – Renewable Fuel Standard

- The Renewable Fuel Standard (RFS) sets aggressive goals for the use of renewable fuels:
  - 36 billion gallons of renewable fuels by 2022; 21 billion gallons of advanced biofuels which reduce GHG emissions by 50 % relative to petroleum fuels
  - No more than 15 billion gallons of conventional corn-based ethanol
- Petroleum companies in the U.S. are required to meet minimum annual blending requirements or purchase credits for renewable fuels from other companies

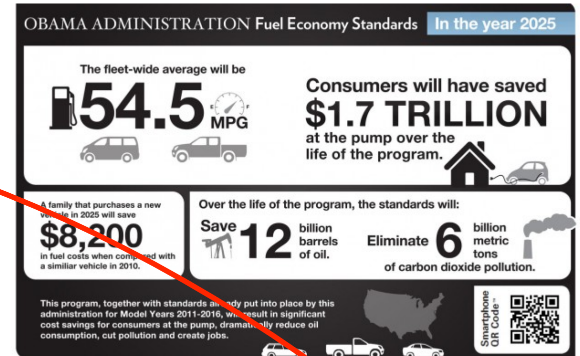


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Three Major Challenges Facing the Transportation Industry Over the Next Decade

54.5 mpg CAFE by 2025

-per U.S. EPA and U.S. DOT standards (2012 rule)



Fuel Economy Standards

Transportation Industry

Can smart use of biofuel enable CAFE and RFS simultaneously?

>70% less NOx

>85% less NMOG

EPA Tier 3 Emission Regulations

Further reductions in vehicle emissions

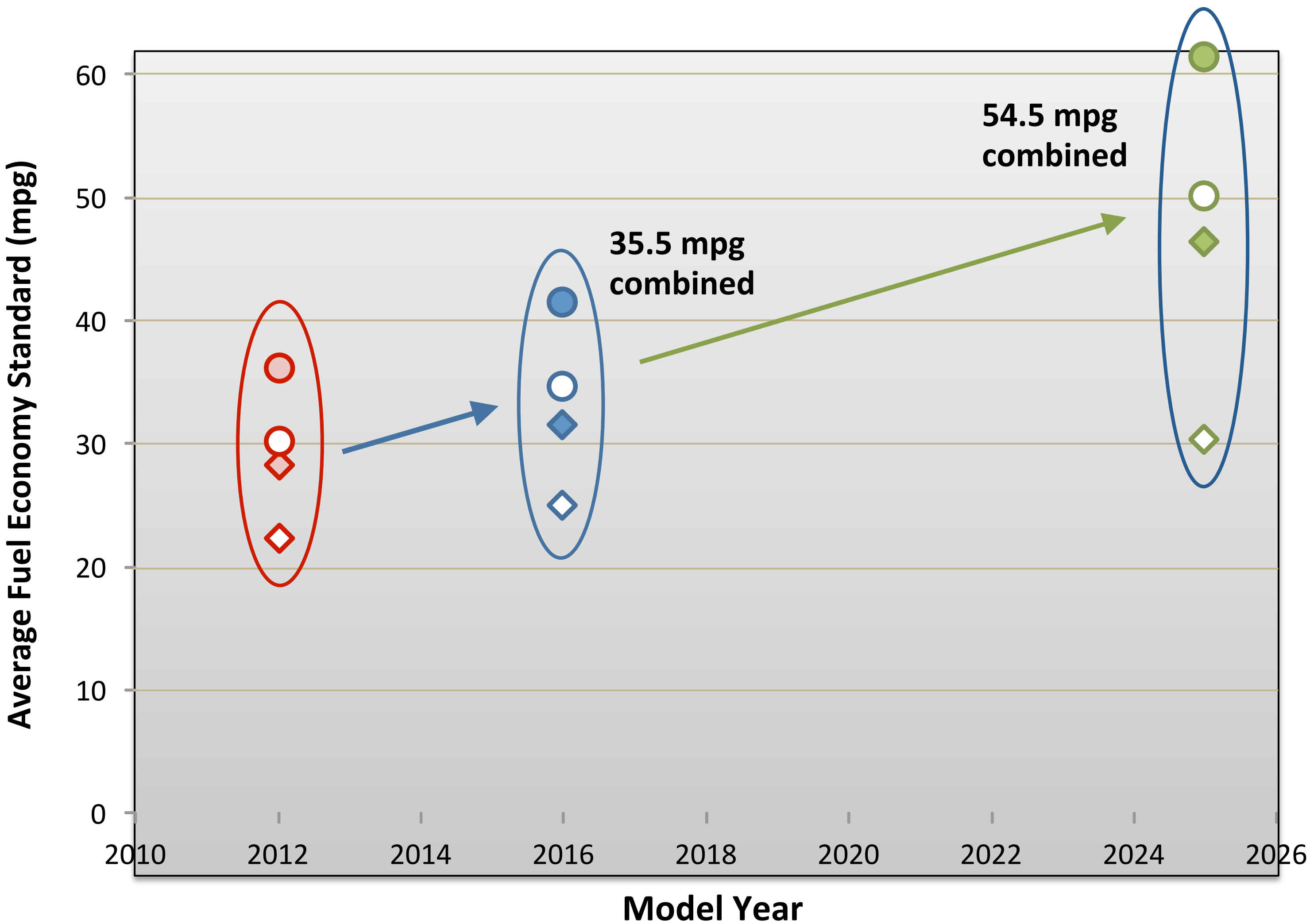
-per proposed EPA Tier 3 regulations (2013)

Renewable Fuel Standard

36 billion gallons /yr of renewable fuel by 2022

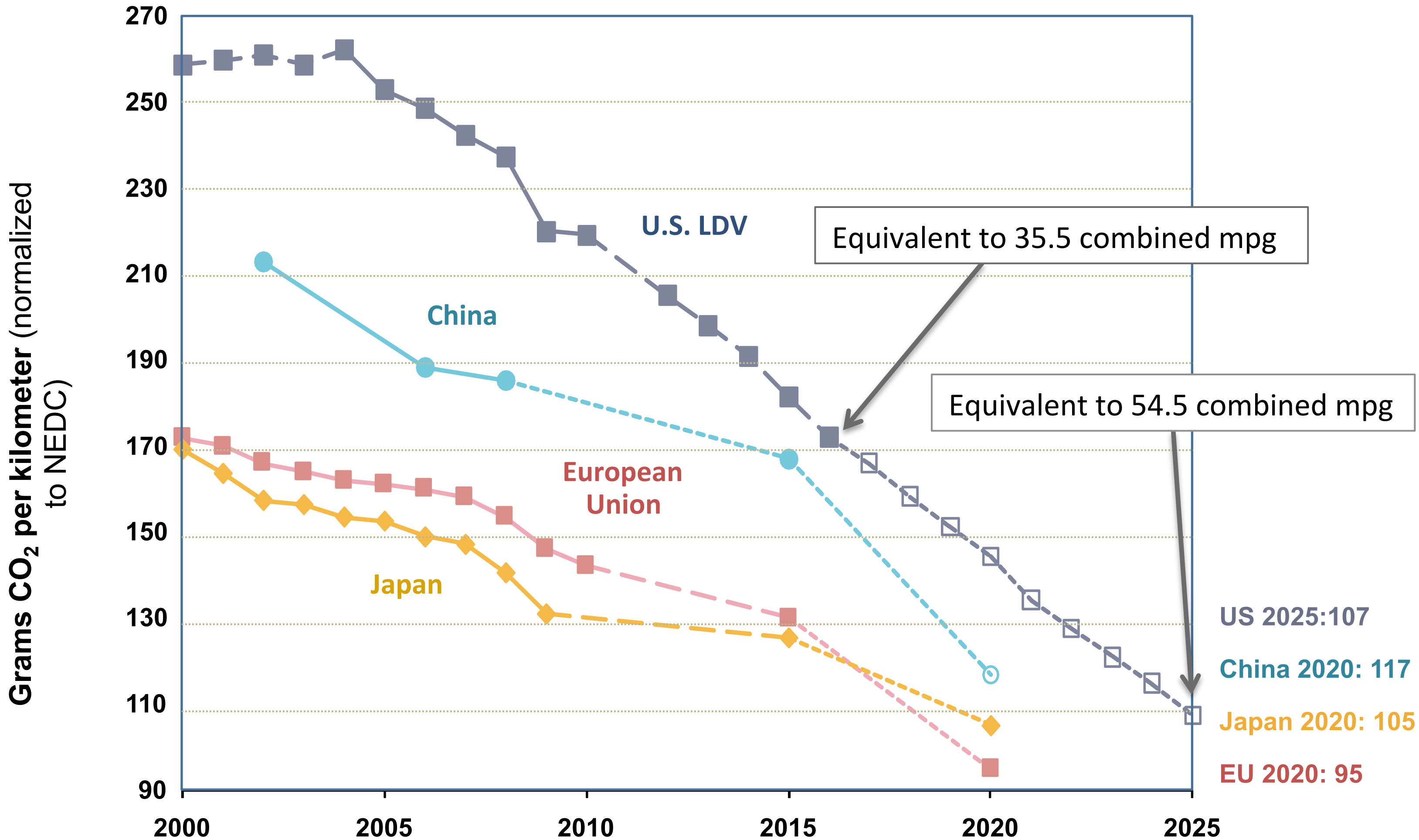
-per Energy Independence and Security Act of 2007

MEETING NEW U.S. FUEL ECONOMY STANDARDS AND CO_2 REGULATIONS WILL REQUIRE SIGNIFICANT ADVANCES IN *PRODUCTION VIABLE* ENGINE TECHNOLOGY



* Spread is due to range in standards for small/large passenger and light-duty truck

Meeting new fuel economy standards and criteria pollutant regulations will require significant advances in production viable vehicle technologies



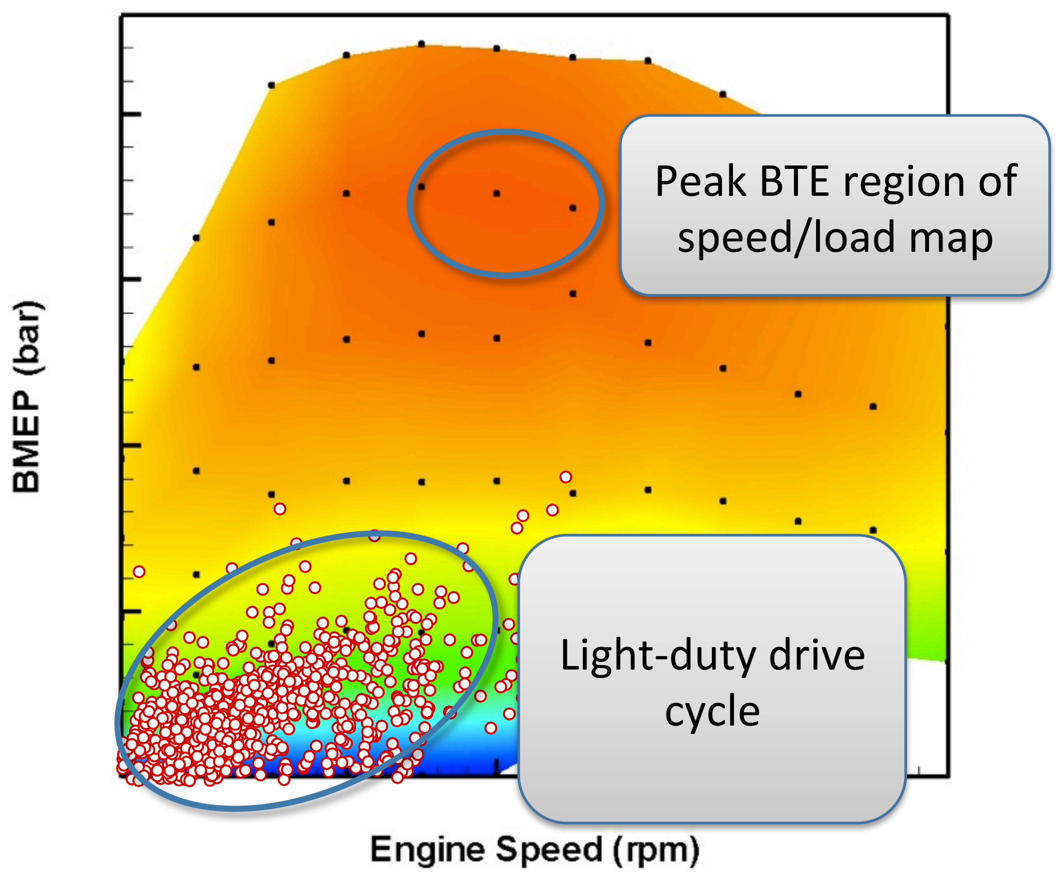
SIMPLIFIED PERSPECTIVE ON PATHWAY TO NEXT GENERATION OF HIGH EFFICIENCY ENGINES

Synergistic areas for game changing improvements in vehicle fuel efficiency:

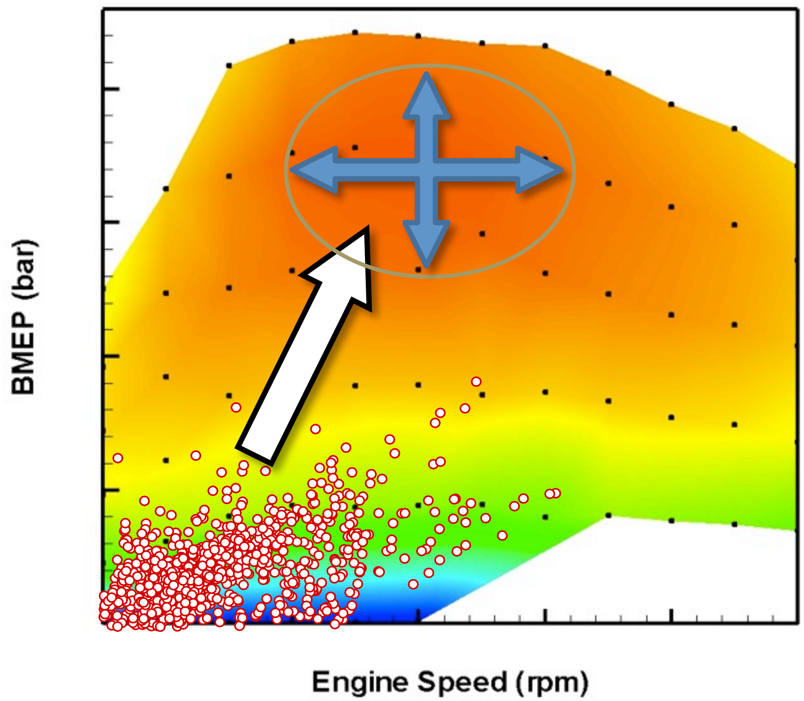
1. **Expansion of high engine-system efficiency plateau in speed/load domain.**
2. **Better matching of drive-cycle demands and high efficiency operation.**

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

Efficiency Contours for Light-Duty Engine



HIGH EFFICIENCY ENGINE-SYSTEMS AND ADVANCED HYBRID DRIVE SYSTEMS ARE KEY ENABLERS FOR SIGNIFICANT IMPROVEMENTS IN FUEL EFFICIENCY



Expanded high efficiency plateau and peak BTE.

LTC combustion

Adaptive controls

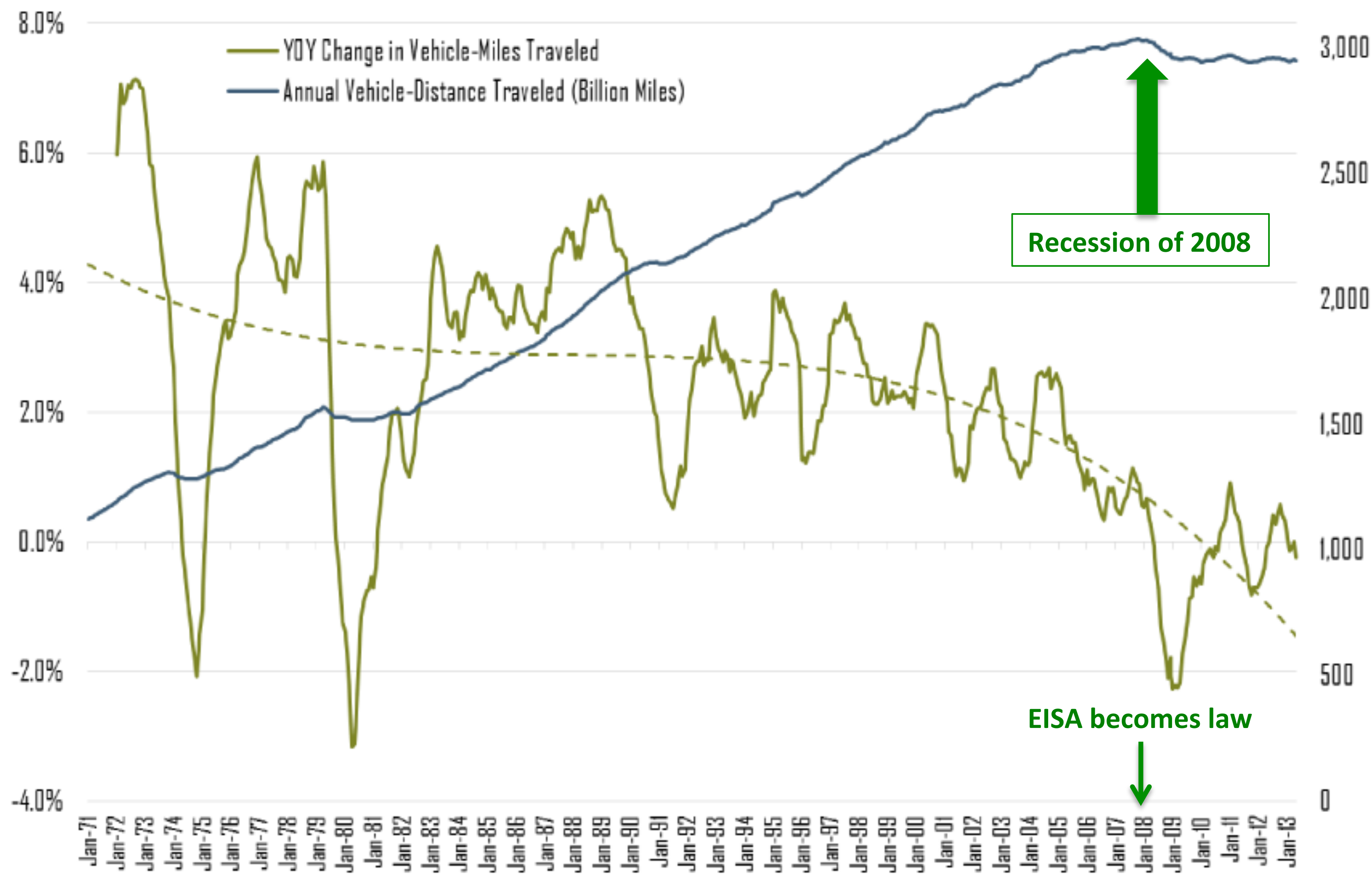
Energy recovery

Fuel properties

De-coupling of drive cycle speed/load demands through hybridization for better matching with engine-system high efficiency operation.

Reduced speed/load domain simplifies combustion and aftertreatment management and improves energy recovery opportunities.

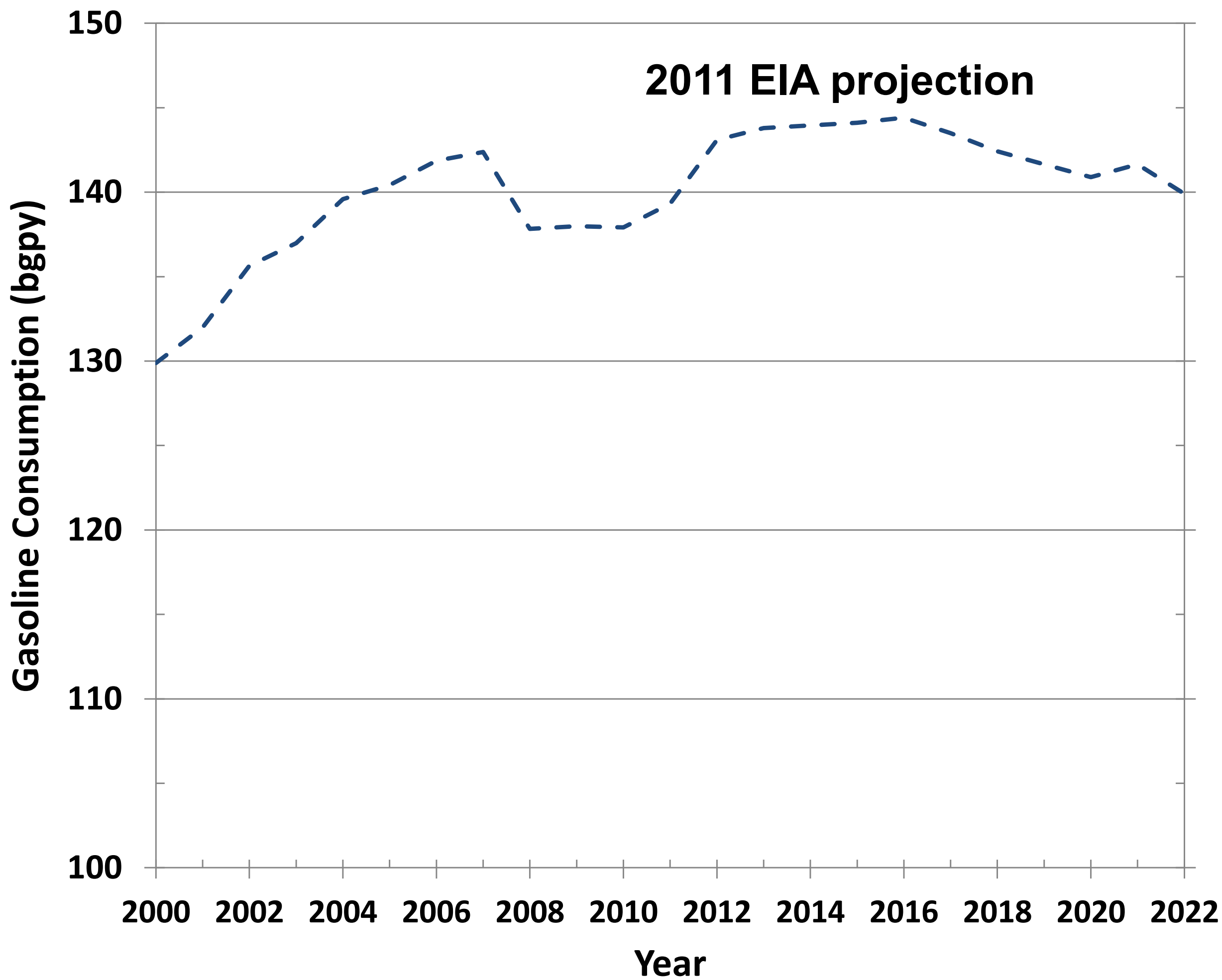
NEW PARADIGM: WE'RE DRIVING LESS … THIS CHANGES EVERYTHING!



Source: US Department of Transportation, Federal Highway Administration.
http://people.hofstra.edu/geotrans/eng/ch3en/conc3en/vehiclemilesusa.html

In 2011, EIA projected flat gasoline consumption for next decade

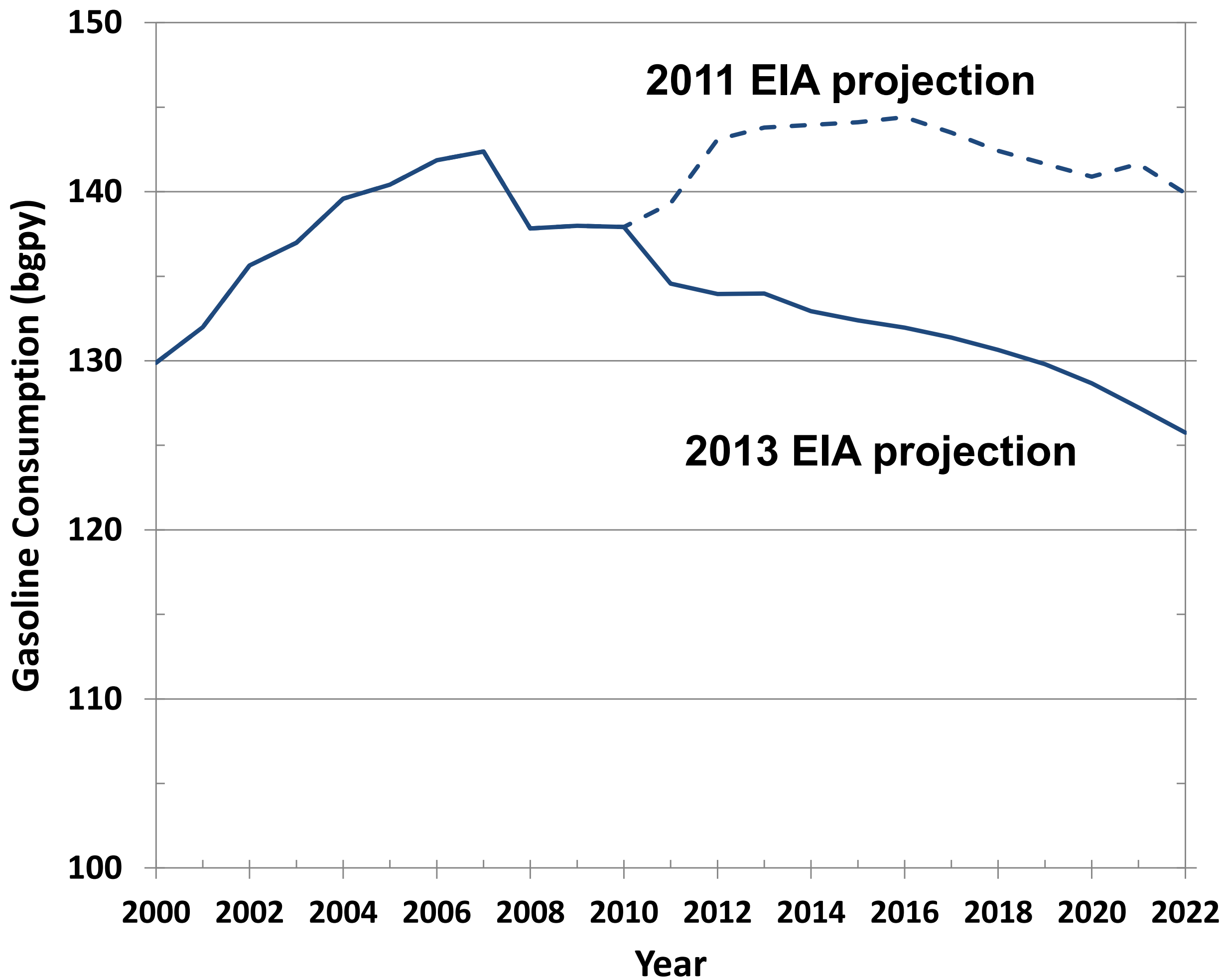
"Motor gasoline" includes E10. Flat demand at ~140bgpy led to projections of E15 allowing for *up to* 21bgpy ethanol. That was 2011….



http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2011&subject=0-AEO2011&table=11-AEO2011&region=0-0&cases=ref2011-d020911a

2013 EIA projection shows declining motor gasoline consumption.

Fuel economy rule finalized in 2012.

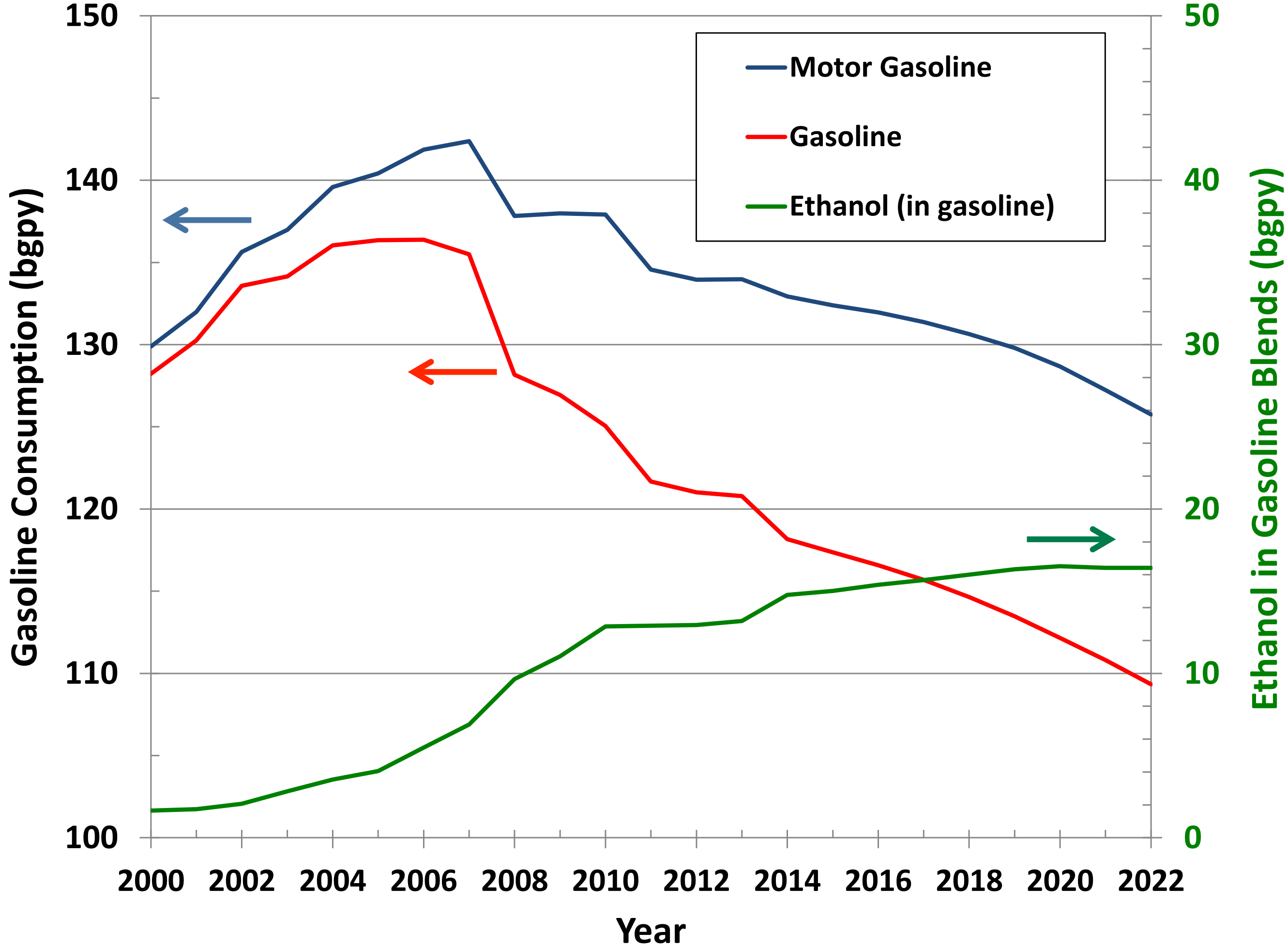


2013 EIA projection shows declining motor gasoline consumption.

Fuel economy rule finalized in 2012.

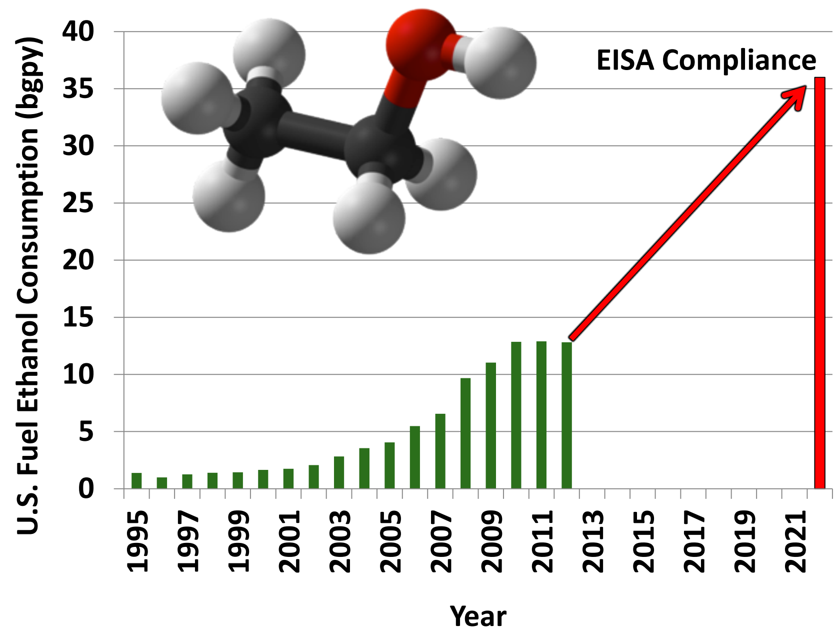
Note ethanol projection (assumes about half motor gasoline as E15 by 2022)

In 2007, the EIA projection for gasoline consumption in 2022 was 160 BGY … the difference far exceeds EISA volumes



BACKGROUND: U.S. ETHANOL PRODUCTION IS ENORMOUS

- **Currently consuming 13 billion gpy EtOH**
- **2022 EISA goal is 36 billion gpy of renewable fuels**
  - Gasoline consumption is ~130 billion gpy
- **Benchmarking and historical comparisons (thanks to Ron Graves)**
  - Current U.S. ethanol production is nearly double that of Brazil
  - Our RFS goal of 36 billion gpy renewables…
    - …falls short of crude oil imports from Canada (41 billion gpy)
    - …is greater than the oil imports from Saudi Arabi (19 billion gpy)
    - …is greater than oil imports from Venezuela (15 billion gpy)
    - …is an order of magnitude greater than South Africa's coal-to-diesel program (3 billion gpy)
    - …is an order of magnitude greater than WWII Germany's coal-to-liquids program (2 billion gpy)



- **Gasoline saved by 1 million electric vehicles: 0.5 billion gpy**
- **Gasoline saved by 10% weight reduction in cars: 5 billion gpy**

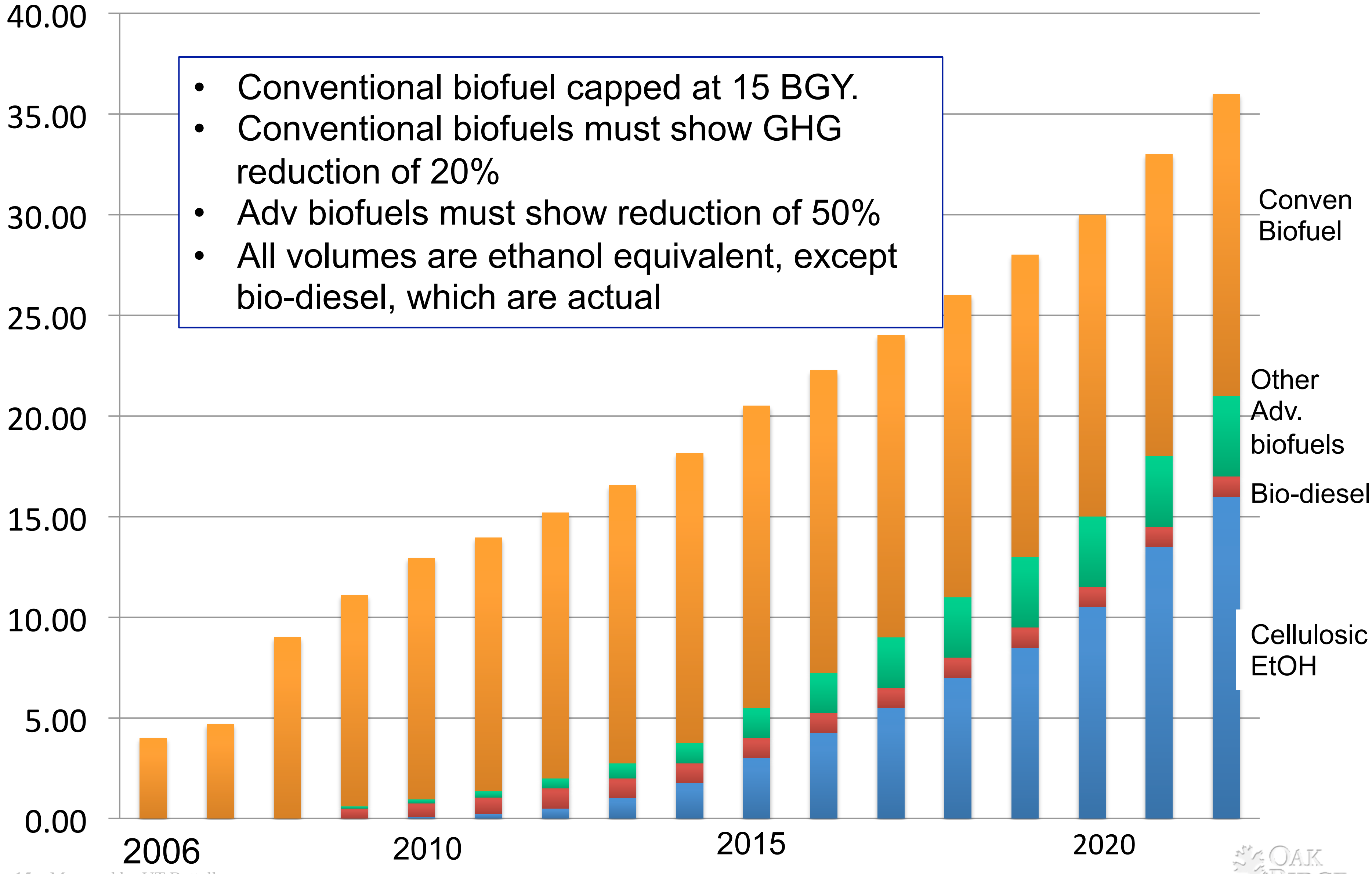
Motor Fuel Properties

Fuel	Energy density	Air-fuel ratio	Specific energy	Heat of vaporization	Viscosity	RON	MON
Gasoline	32 MJ/l	14.6	2.9 MJ/kg air	0.36 MJ/kg	0.4~0.8 cSt	91-99	81-89
Butanol	29.2 MJ/l	11.2	3.2 MJ/kg air	0.43 MJ/kg	3.6 cSt	96	78
Ethanol	19.6 MJ/l	9	3.0 MJ/kg air	0.92 MJ/kg	1.52 cSt	130	96
Methanol	16 MJ/l	6.5	3.1 MJ/kg air	1.2 MJ/kg	0.6 cSt	136	104

Biomass-based diesel is 35 MJ/l

- Ethanol has 2/3 energy density of gasoline
- Butanol has 85% energy density of gasoline
- Bio-diesel has 10% more energy density than gasoline

EISA Renewable Biofuel Volumes



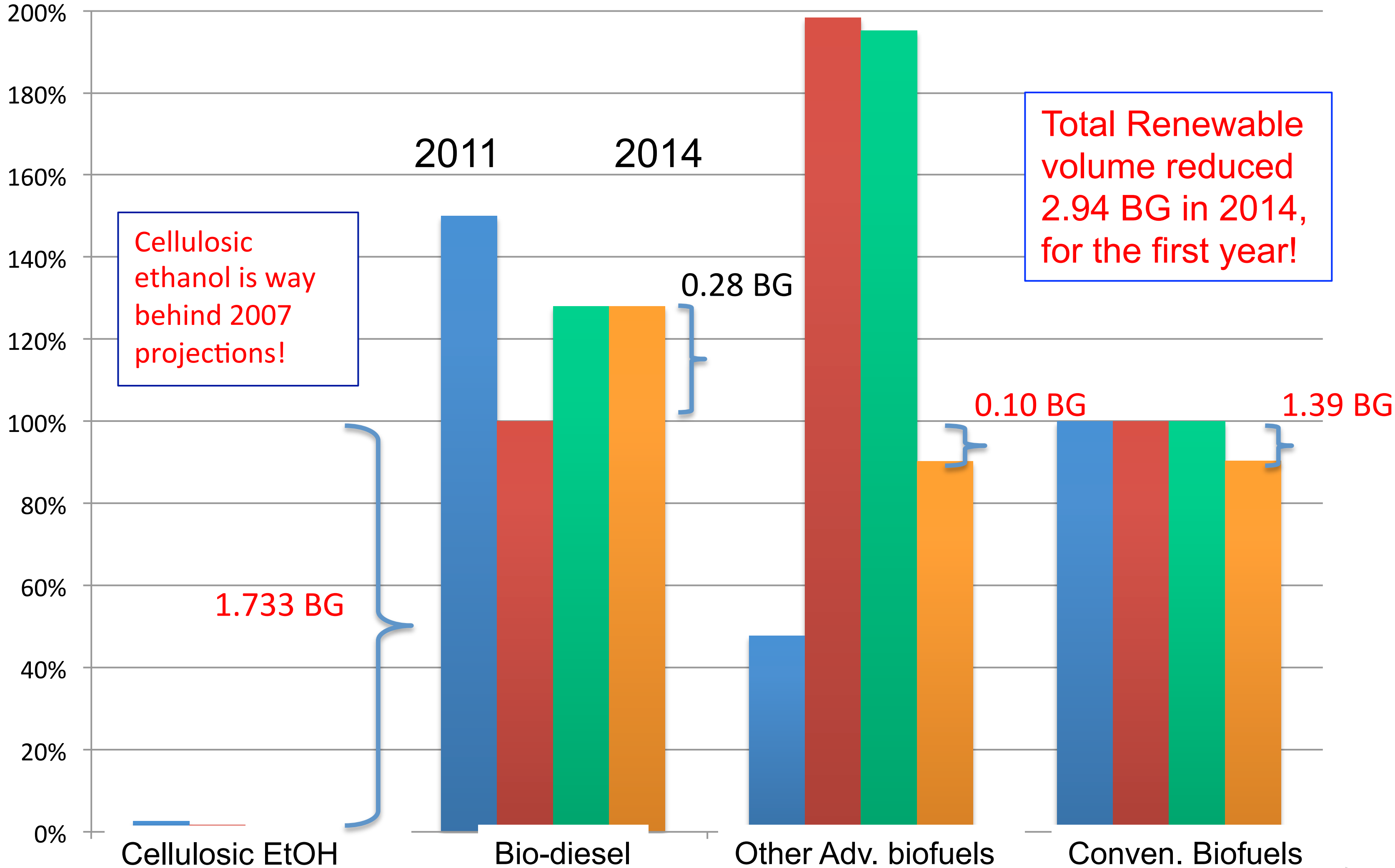
Source: http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm

EISA includes multiple "nested" categories

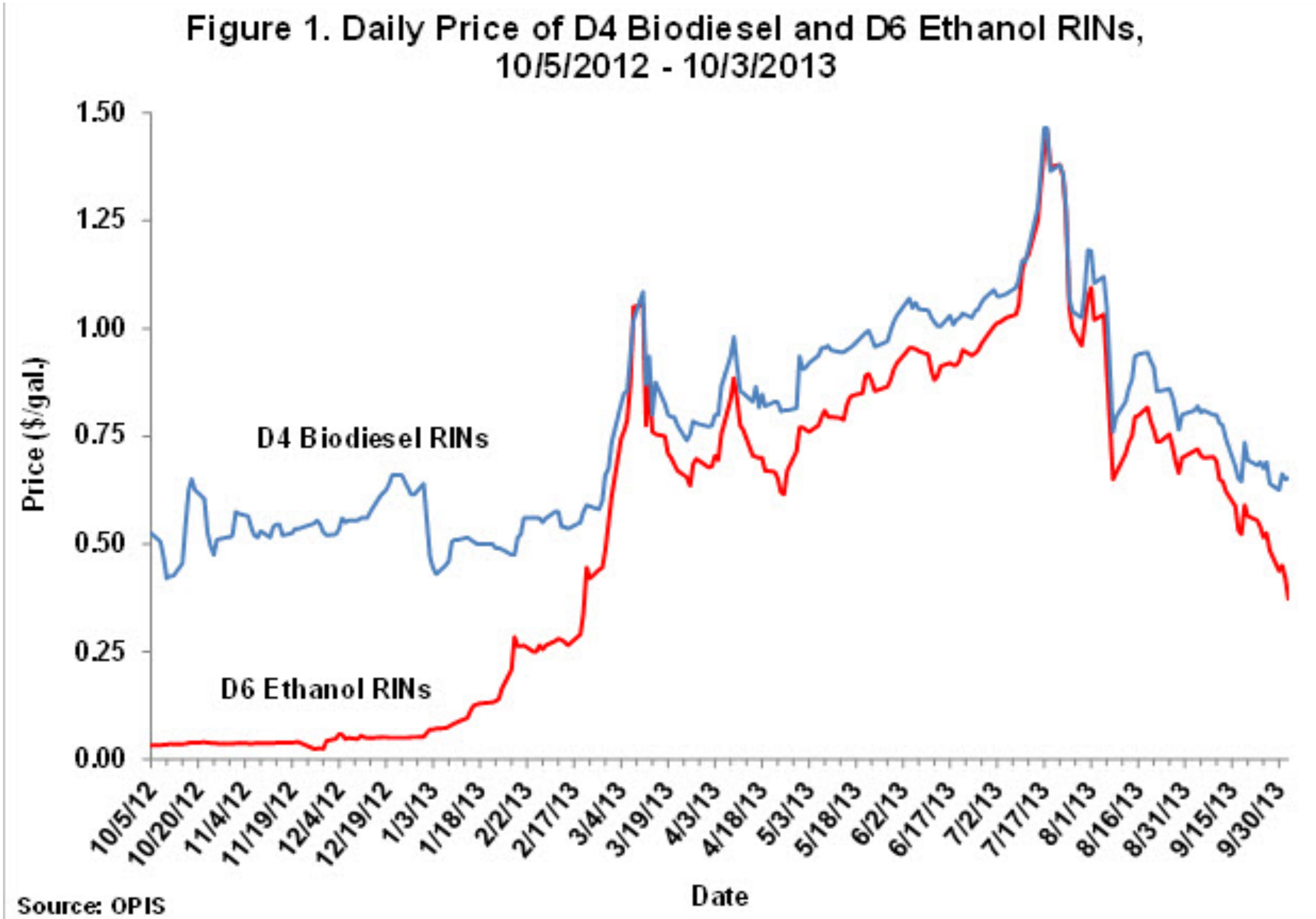
				Total Renewable Fuel (*)
Year	Total Advanced Biofuel (= not from corn)			(+ ethanol from corn) D6 RIN
	Biomass-Based Diesel D4/D7 RIN	Cellulosic Biofuel D3 RIN	D5 RIN	
2007				4.7
2008				9.0
2009	0.5		0.6	11.1
2010	0.65	0.1	0.95	12.95
2011	0.80	0.25	1.35	13.95
2012	1.0	0.5	2.0	15.2
2013	1.0	1.0	2.75	16.55
2014	1.0	1.75	3.75	18.15
2015	1.0	3.0	5.5	(+ 15) = 20.5
2016	1.0	4.25	7.25	(+ 15) = 22.25
2017	1.0	5.5	9.0	(+ 15) = 24.0
2018	1.0	7.0	11.0	(+ 15) = 26.0
2019	1.0	8.5	13.0	(+ 15) = 28.0
2020	1.0	10.5	15.0	(+ 15) = 30.0
2021	1.0	13.5	18.0	(+ 15) = 33.0
2022	1.0	16.0	21.0	(+ 15) = 36.0

* Volumes are ethanol equivalent except diesel, which is actual volume

Adjusted Volumes Compared to RFS2 Original Targets (2011-2014, proposed)



RIN market … 4 categories, and more recent data



http://farmdocdaily.illinois.edu/2013/10/whats-behind-the-plunge-in-rin.html

Octane 101 (who is RON and what does he have to do with this?)

- **Higher octane allows for more aggressive engine design, which can improve efficiency**
- **Higher octane fuels are better able to resist engine "knock"**
- **Knocking can destroy an engine so engines are designed & tuned to avoid it**
- **Higher octane yields only a modest improvement in the efficiency unless the engine is designed for it**
- **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**

ETHANOL FUEL BLENDING ("BUT WHAT ABOUT BOB"?)

- **Most finished fuel is hydrocarbon blendstock (BOB) and up to 10% denatured ethanol (E10)**
- **Gasoline fuel grades**
  - 87 AKI → 91-92 RON (86% of gas sold)
  - 89 AKI → 94 RON (6% of sales)
  - 91 AKI → 95 RON (8% of sales)
- **Splash blending – add ethanol to gasoline**
- **Match blending – tailor or change BOB to more precisely meet fuel specs**
- **Ethanol is 99 AKI or 109 RON** – least costly high-octane fuel stream
- **Vast majority of ethanol consumed in US is used in E10 (99%) … 130 BGY motor fuel → 13 BG ethanol**

How is the Octane Boost from Ethanol Best Utilized?

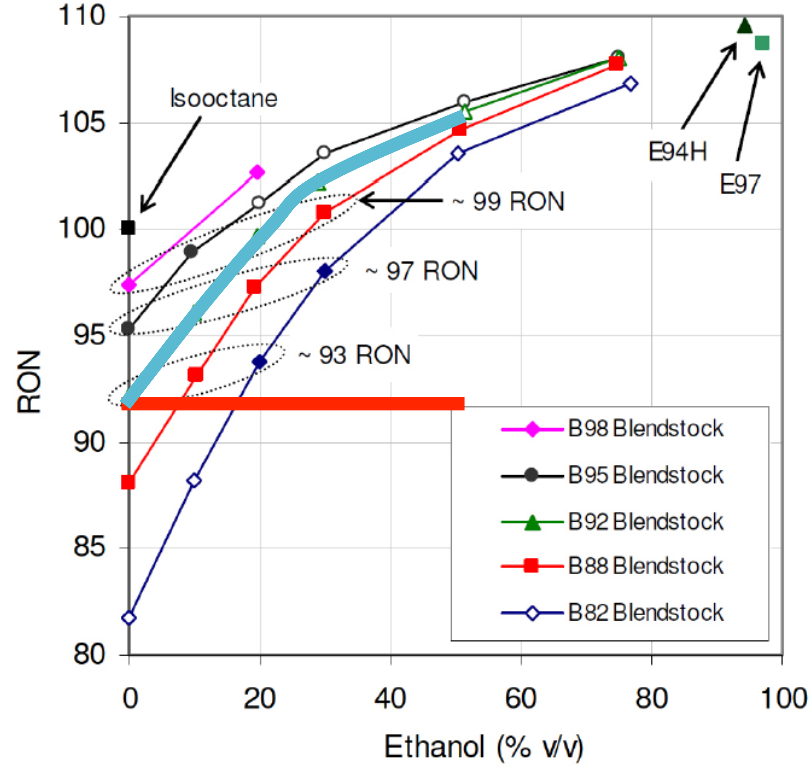
Option 1. Constant octane number for consumers

- Ethanol used to increase octane number of hydrocarbon blendstock (BOB)
- Lower GHG to produce BOB
- Lower cost BOB for refinery
- No octane number basis to increase efficiency

Option 2. Constant octane number for BOB

- Consumer realizes octane number boost with increasing ethanol content
- Potential to decrease vehicle GHG emissions on basis of octane number
- GHG emissions do not decrease at refinery (per unit volume BOB)

Stein et al/ SAE Int. J. Fuels Lubr./Volume 5, Issue 2 (May 2012), SAE 2012-01-1277



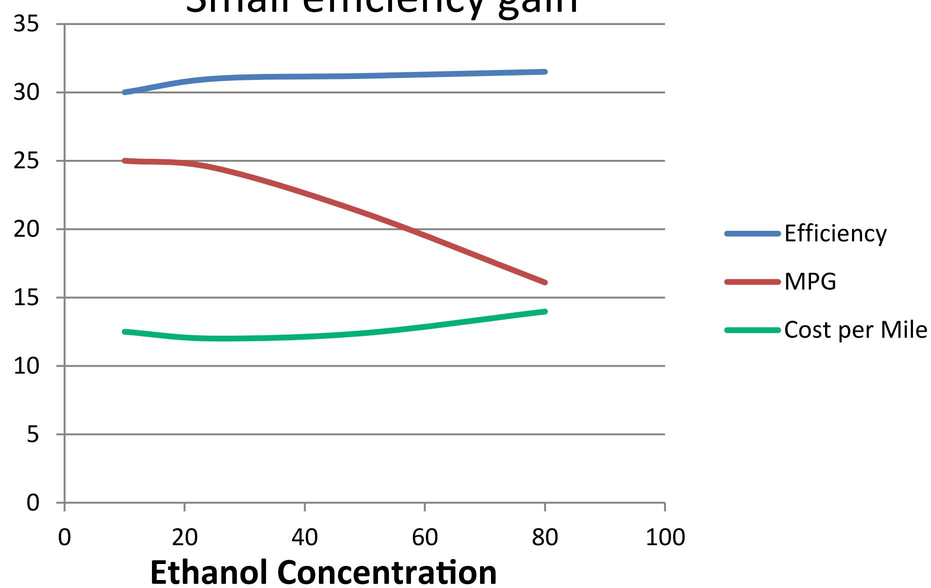
Which path reduces GHG emissions more on a lifecycle basis?

- Very little data exists on this question and more information is needed (all point to JCAP study)
- If refinery is best place to reduce GHG emissions, should this be reflected in GHG regulations?

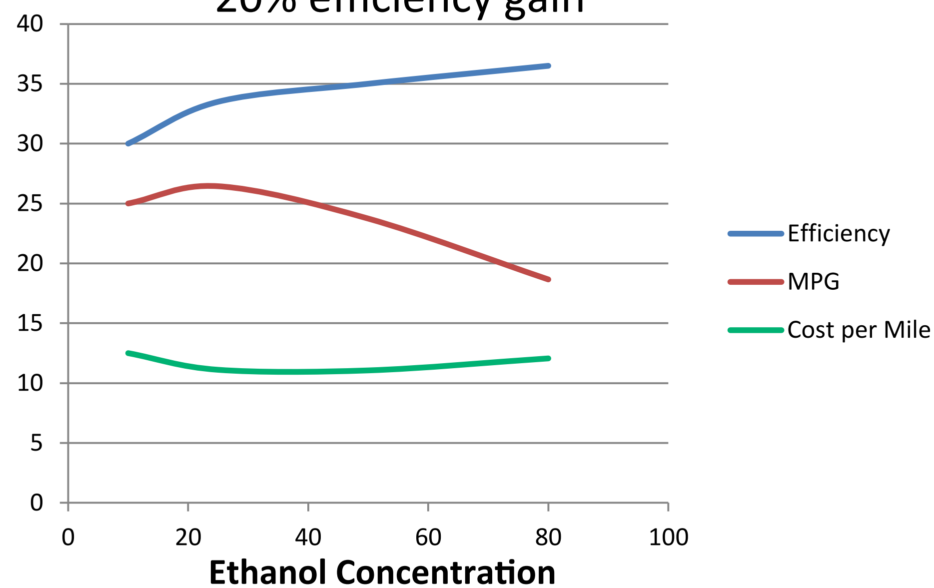
Is a "*Super Renewable Premium*" a Better Path for Ethanol?

- **Engine efficiency can improve with more ethanol**
  - Chemical octane number + latent heat of vaporization
  - Nonlinear relationship, E85 is beyond diminished returns
  - About 2/3 of octane number benefit is realized at 1/3 ethanol volume blending
  - Energy density penalty is linear with ethanol concentration
- **It is likely that optimum is E20-E50**
  - Less impact on range and tank mileage compared to E85
  - Enables downsized and boosted engines with additional system benefits

Non-optimized engine
Small efficiency gain



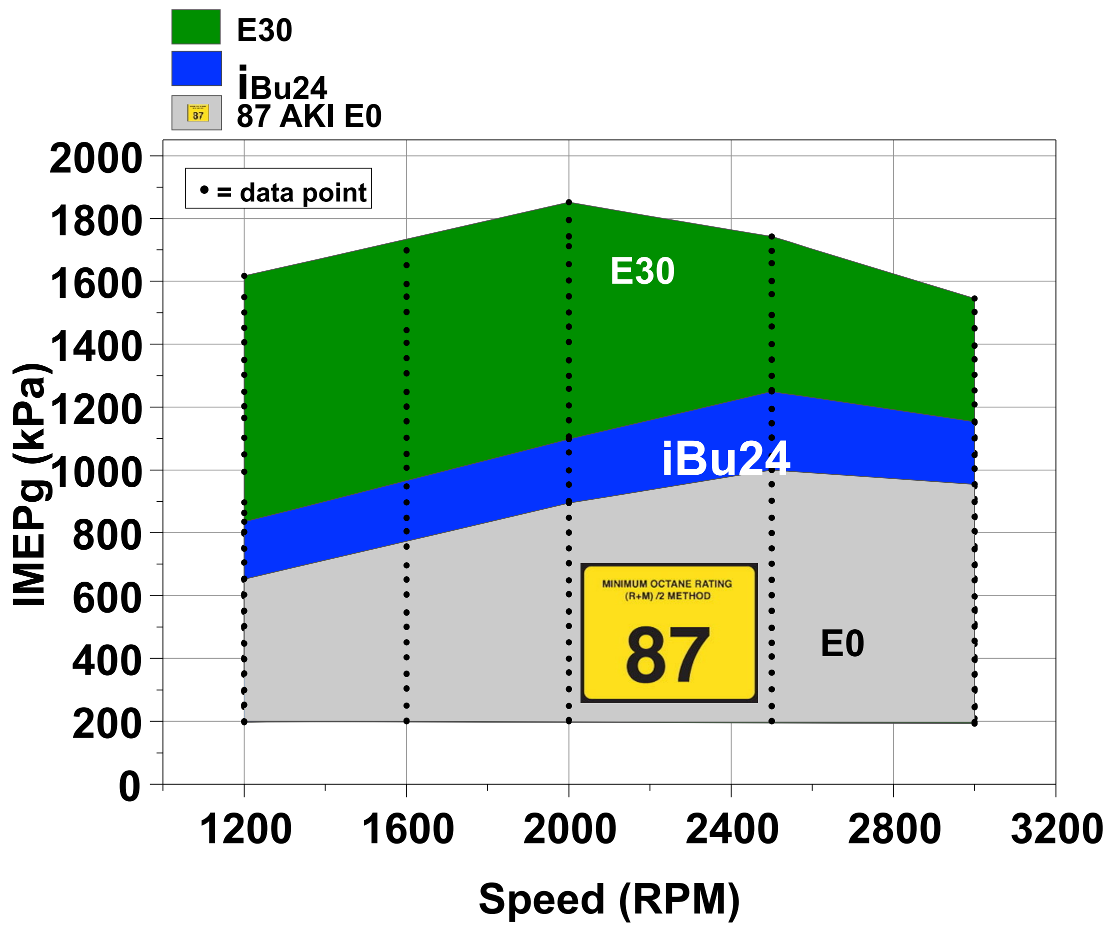
Optimized engine
20% efficiency gain



High Octane E30 Enables Doubling of Engine Torque over 87 AKI Gasoline in High CR, Boosted, DI Engine

(ORNL single-cylinder engine data)

- **Engine map shows available torque as function of speed for 3 fuels**
  - Isobutanol and ethanol added to same base gasoline
- **Isobutanol (24%) provides modest performance improvement over E0**
- **Ethanol (30%) *doubles* available torque**
- **Enables downspeeding and downsizing for improved fuel economy and lower GHG emissions**
  - Supports RFS and CAFE Compliance



Splitter and Szybist, submitted to *Energy and Fuels* 2013

QUESTIONS THAT NEED TO BE ADDRESSED … INITIAL SCOPING STUDY UNDERWAY

- **Confirm study that higher octane increases GHG (well to wheels) if using petroleum**
- **Does higher octane fuel increase GHG (well to wheels) if using super renewable premium (consider sustainability and not just GHG)?**
- **What is optimum level of ethanol for super renewable premium?**
  - From vehicle perspective → increased efficiency
  - From refiners perspective → lower quality BOB
  - From EPA perspective → considering GHG & criteria pollutants
  - From consumer perspective → economics of new vehicles & new fuel(s)
- **Can the infrastructure issues be addressed?**
  - Technical issues (but we know a lot more now)
  - Logistics of increased ethanol and less BOB
  - Legal & compliance issues (UL has unique role in this)
- **Do the benefits outweigh the costs?**
  - Does this offer a potential positive opportunity for all major stakeholders?

OEM Perspective on High Octane & E15 (Toyota)

Ethanol – Current perspective for US market

As current models were designed to tolerate up to E10, Toyota does not support E15 for legacy vehicles.

Toyota models now under development are to be E15 tolerant

Consolidated goal for mid-level ethanol blend is desired

Presented at 2013 Fuel Ethanol Workshop, Feb 2013, Las Vegas

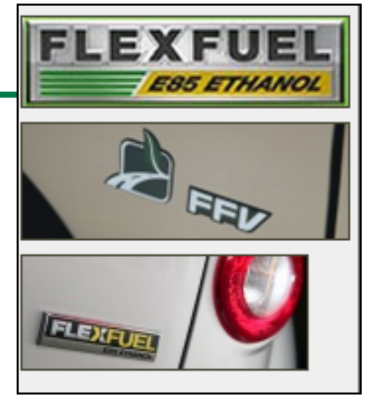
What's the Bottom Line on E15

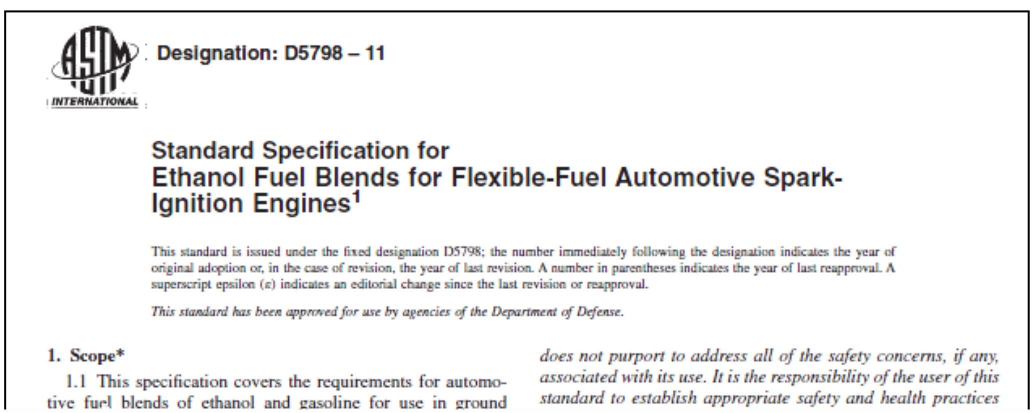
- E15 offers few advantages other than additional ethanol in fuel
- Infrastructure had significant inertia at E10 with little/no data beyond E10
- Significant animosity among stakeholders (top-down approach turned stakeholders off)
- Legacy fleet was not designed for E15 so OEMs only see additional liability with no added benefit
- E15 is now acceptable ~ 70% of new vehicles
- E15 is only available in very limited number of pumps
- At this point, E15 does not appear to be working, and doubtful that it will (Tim's opinion)

Consumers shy away from E85

- **Gasoline/E10 dispensers average ~2400 gal/day**
- **E85 dispensers average <70 gal/day**
  - 14M FFVs on road – **consume 4 gal E85 per vehicle per year**
- **Lower Energy Density and higher $/BTU (compared to gasoline or E10)**
  - Shortened range & Higher cost per mile
- **How much ethanol is in my "E85?"**
  - New ASTM spec for "Fuel for FFVs" allows 51% to 83% ethanol
    - Specification addresses quality and volatility of blends
    - Potential for improved range *some of the time* (when HC portion is higher)
    - Contributes to consumer confusion
- **Consumer acceptance is key to success of any new fuel**

➢ **High RIN price were beginning to promote E85 sales …**




ASTM INTERNATIONAL

Designation: D5798 – 11

Standard Specification for
Ethanol Fuel Blends for Flexible-Fuel Automotive Spark-Ignition Engines[1]

This standard is issued under the fixed designation D5798; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

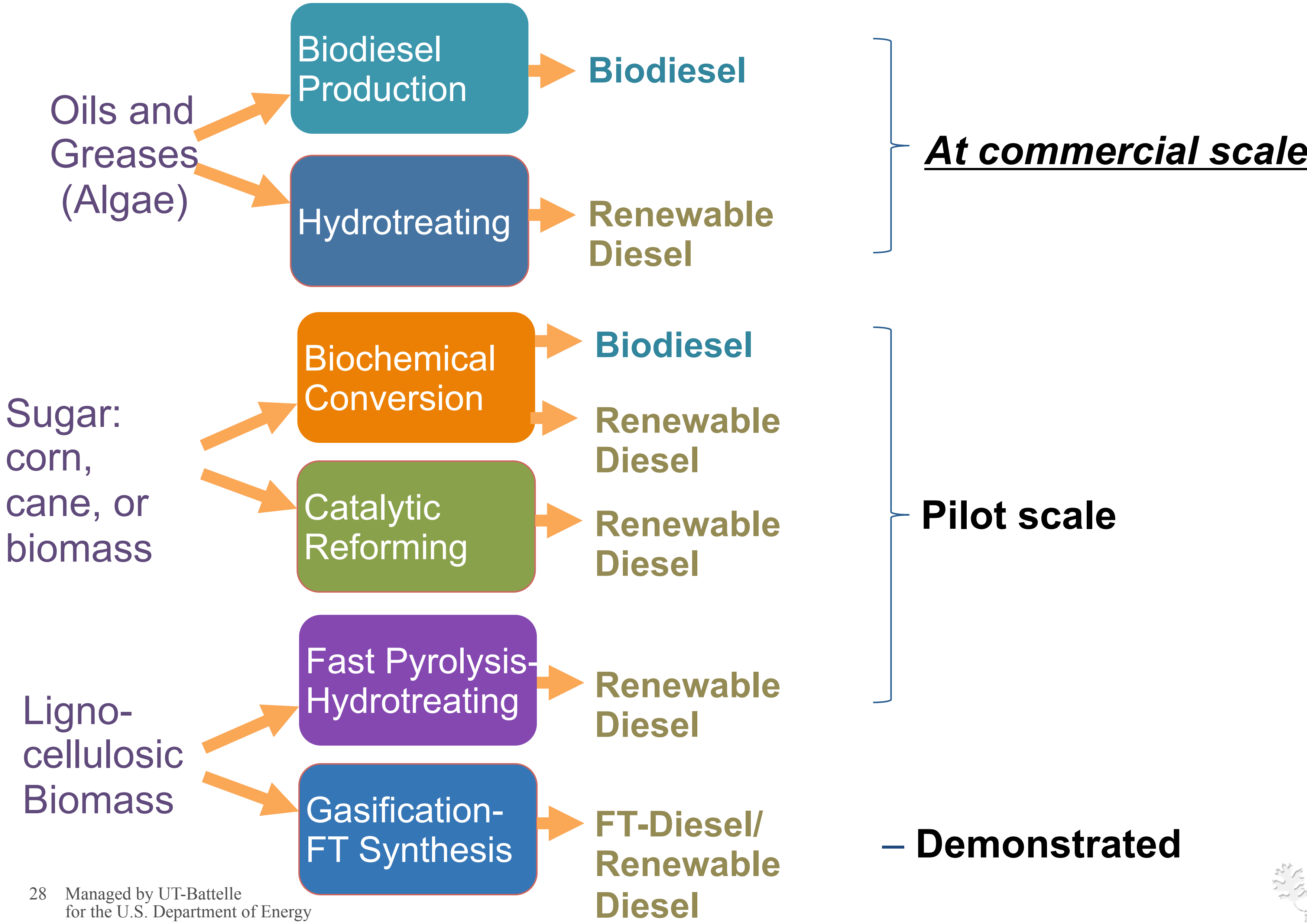
This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers the requirements for automotive fuel blends of ethanol and gasoline for use in ground

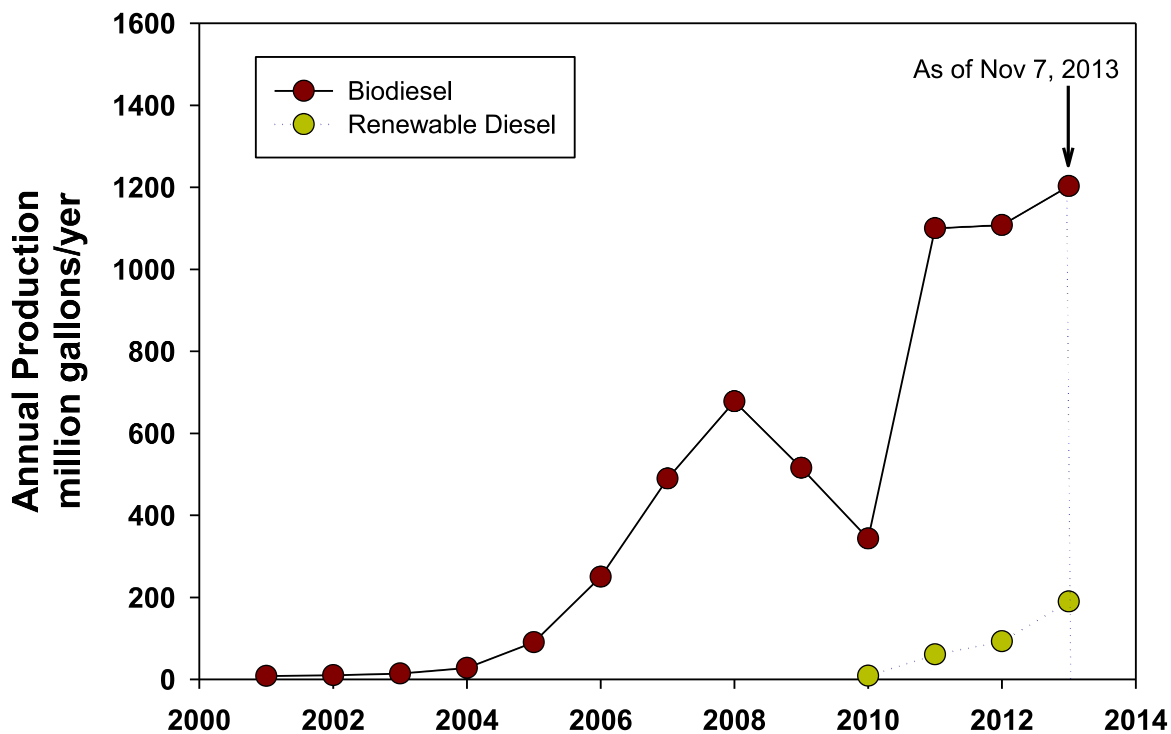
does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices

Biomass-Based Diesel Options



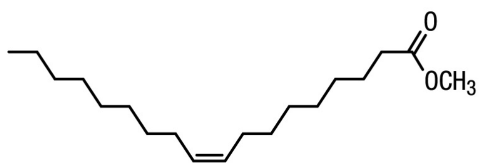
Market Status: Biodiesel Renewable Diesel

- **Both made from vegetable oil, animal fat, waste grease feedstocks**
- **Roughly 2.4 billion gallon per year current resource**
  - Market demand is leading to increased grease collection
  - Potential for new oil-seed crops or increased yield in conventional crops
  - Corn oil recovery from ethanol production
- **Renewable Fuel Standard mandates 1 billion gallon market … actually 1.28 BGY in 2014**
  - **Today, Congress urged EPA to increase mandate beyond 1.28 BGY**
  - **Industry projects to produce 1.7 BG in 2013**

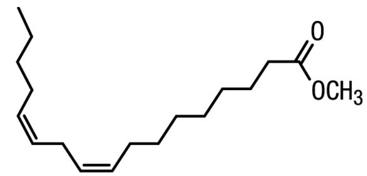


What are they?

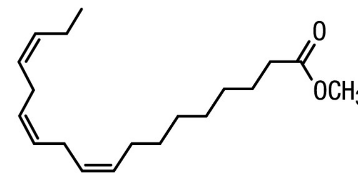
- **Biodiesel is an oxygenate made by reaction of fat or oil with methanol:**



Oleic acid methylester



Linoleic acid methylester



Linoleic acid methylester

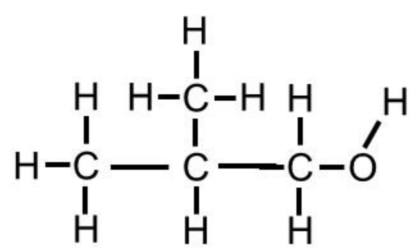
  - Energy content = 34 MJ/L (1.5X ethanol)
  - High cetane number, insoluble in water, biodegradable
  - Typically used as a blend B5 to B20
  - Potential issues with long-term storage unless handled properly

- **Renewable diesel is a hydrocarbon made by reaction of fat or oil with hydrogen at high pressure/temperature**
  - Energy content = 35 MJ/L (1.5X ethanol)
  - Very high cetane number, insoluble in water, less biodegradable
  - Typically used as a blend
  - Process economics not as favorable as biodiesel

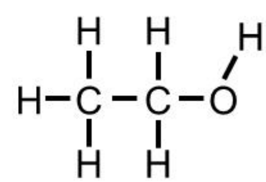
Isobutanol provides a pathway for meeting RFS requirement by allowing greater biofuel usage than can be achieved by ethanol

- Isobutanol can be produced from existing ethanol production plants via retrofit kits.
- Isobutanol has a much higher energy density than ethanol.
- Isobutanol has much lower water solubility relative to ethanol.
- Isobutanol has a slightly lower polarity index than ethanol suggesting reduced corrosion potential.
- Butanol receives 2X RINs than ethanol on a volume basis (1.6*1.3)

Property	Isobutanol	Ethanol	Gasoline
Oxygen (wt.%)	21.6	34.7	----
Blending ratio to achieve 3.7 wt.% oxygen, (%)	16	10	----
Heating Value relative to Gasoline (%)	84	66	100
Blending octane	105	122	87
Polarity Index	4	5.2	<2.4
Solubility in water (mL/100mL)	8.7	miscible	<0.01



Isobutanol



Ethanol

Butamax is hoping to commercialize butanol production

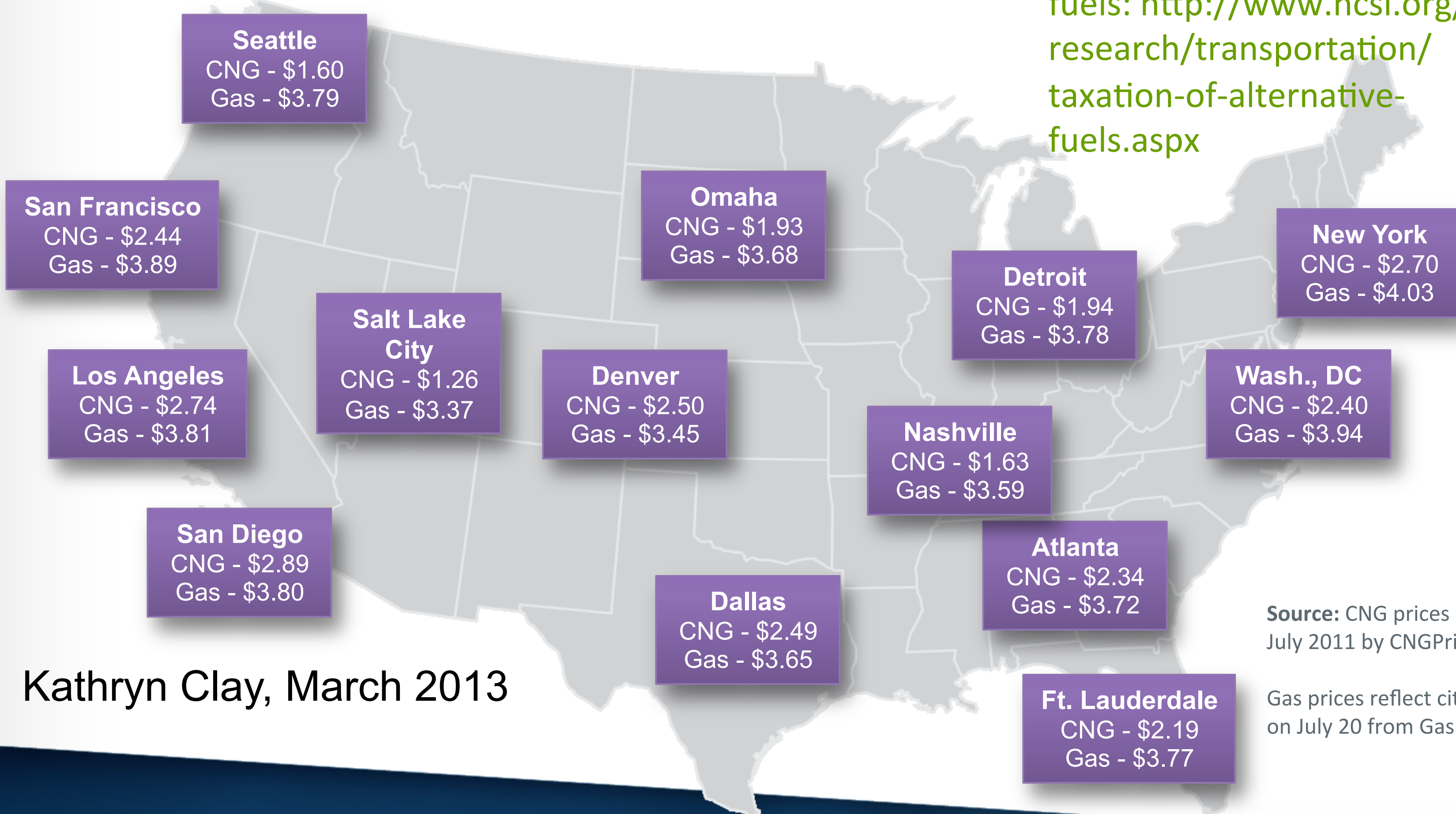
- Butamax Advanced Biofuels, LLC was formed as a joint venture between BP & DuPont
- Butamax process adds onto conventional ethanol plant --> uses conventional corn oil
  - Broke ground on construction on Highwater Ethanol plant in Oct 2013
  - 50 million gallon capacity ethanol

- ORNL is conducting materials compatibility study of infrastructure materials (16% & 24% butanol)
- Hoping to conduct vehicle studies for both butanol blends as well.

- Competitor: Gevo Biofuels

Natural Gas Price Advantage vs Gasoline ("Gas")

On average, CNG costs 47% less than gasoline on $/Btu basis. Summary of State taxes on alt fuels: http://www.ncsl.org/research/transportation/taxation-of-alternative-fuels.aspx



Kathryn Clay, March 2013

Source: CNG prices captured in July 2011 by CNGPrices.com

Gas prices reflect city average on July 20 from GasBuddy.com

Supply and Economics of Natural Gas

- New discoveries and technologies for shale gas recovery ensure long term price advantage over petroleum fuels (NRC studies)
- Well-head price is relatively small part of retail price, so world market price variations are filtered
- A substantial growth in vehicle use of natural gas is not enough to alter the economics and raise price (NRC 2013)
- What could upset this attractive pricing?
  - Larger uptake in electricity generation (30% now)
  - Export in large scale
  - Chemical industry migration to USA?
  - Unprecedented environmental push-back (studies of leakage and GHG impacts ongoing)
  - Other policy or regulation

Conclusion: NG expected to have price advantage over petroleum for some time.

Multiple sources and studies support this assessment. NRC, NPC, etc.

Where Natural Gas Based Fuels Stand Today

Fuel Path	Production Path	Current Output	Cost or Price	Vehicle Fueling Infrastructure	Vehicle Population
CNG	Extraction, compression	++++++	$	++	+
LNG	Liquefied CNG	+ (very large globally)	$$	+	HD only?
GTL Diesel or Gasoline	Syngas conversion Fischer Tropsch	++	$$$$	++++++	++++++
DME	To MeOH to DME	-	?	Conceptual	Test fleets
MeOH	Syngas conversion	++	$$$	-	-
Ethanol	Via MeOH or Syngas	+++ ? from NG.	$$$	+++	+++
Butanol		+	$$$	+++ (low level)	+++ (needs health impacts tests)
Electricity	combustion	+++++	$$		+

NG Based Fuels and Current Infrastructure

- CNG and LNG
  - Vast national distribution for residential, industry
  - Growing refueling infrastructure.
  - Growth in autos/pickups offered for CNG, HD vehicles for LNG, ~65,000 LDVs
- Gas-to-liquids:
  - Fits current vehicles and retail infrastructure
  - Costly process, capital intensive
  - Limited ongoing production
  - Indirect path…displace home heating oil with NG, release oil for motor fuel
- Methanol
  - No longer any vehicles or refueling
- Ethanol and similar alcohols
  - Feasible production path, reported to be lower cost than cellulosic, but no large scale production
  - Over 14 million FFVs on road for high-level blends
  - 2400-3000 refueling sites for "E85" (51-83%)
- DME:
  - Feasible for compression ignition engines
  - Requires new vehicles and refueling infrastructure
- Hydrogen
  - Beginnings of fuel infrastructure (~10 refueling sites)
  - Fuel Cell Vehicles feasible and improving
- Electricity
  - National supply distribution
  - Small but growing vehicle population

Conclusions …

- **The blend wall is real and limiting ethanol demand**
- **Gasoline consumption is actually decreasing and projected to drop significantly**
- **Cellulosic ethanol is coming to market slower than anticipated**
- **EPA's reduction in required volumes of renewable fuels could stifle the introduction of new fuels**
- **E15 & E85 still remain unpopular despite government support**
- **Renewable super premium is an attractive opportunity to reduce fuel economy & increase ethanol consumption**
- **There are additional renewable fuels and alternative fuels that will be considered, including cheap natural gas**

- **All of this will make the RFS2 more difficult to defend (my opinion) … need to do our part to verify its positive impact**
- **Modification of RFS2 is real possibility (again just my opinion)**

Acknowledgements … Thank you!

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- **DOE Vehicle Technologies Office**
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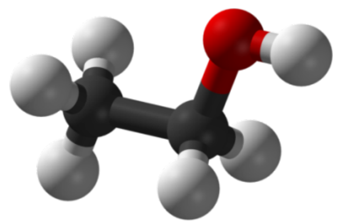
  - Ron Graves, Jim Szybist & Brian West
  - Paul Leiby
- **Bob McCormick, NREL**

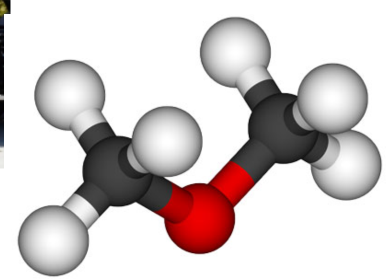
Backup Slides …

What fuels can we derive from NG?

These are the Natural Gas (derived) fuels listed in the Fuel Pathway Matrix provided to session participants.

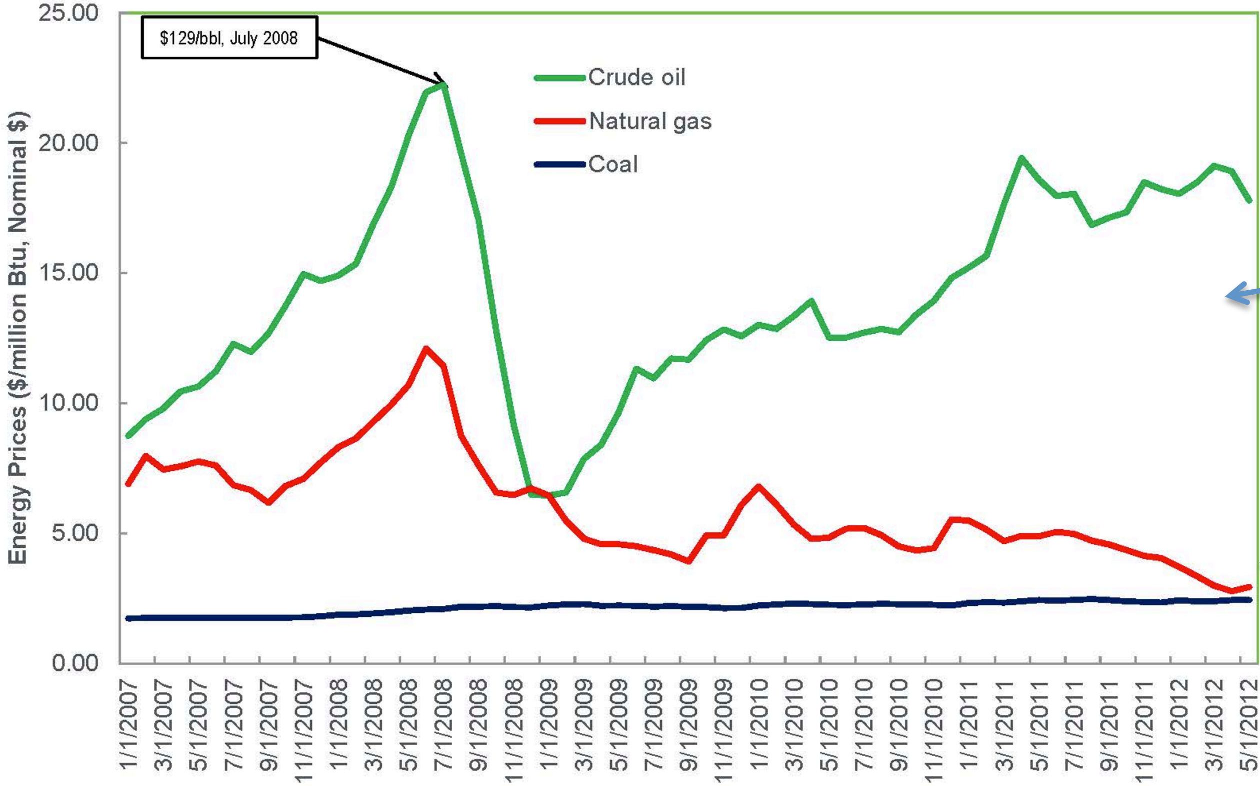
- LNG
- CNG
- NGLs (propane)
- Diesel
- Gasoline
- Mixed & Other Alcohols
- Butanol
- Ethanol
- DME
- Methanol
- Electricity
- Other





Energy Price Volatility

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

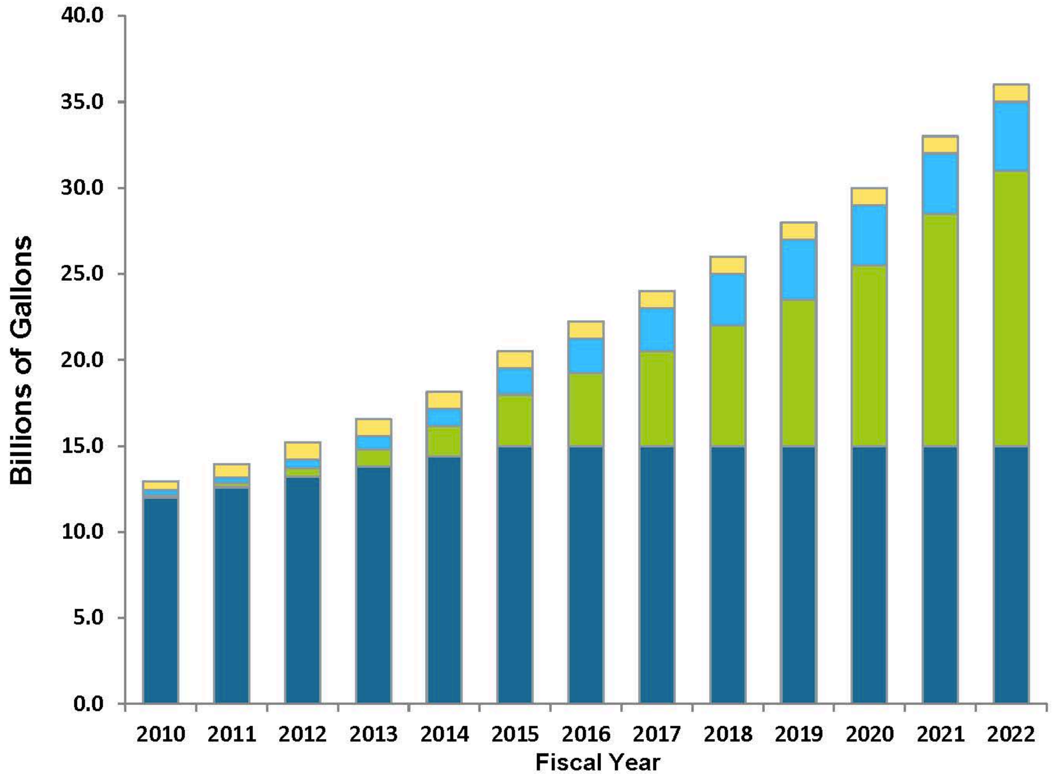


- Biomass at $70/dry metric tonne = $3.69/million Btu
- Corn at $7/bushel = $324/dry metric tonne = $14.50/million Btu

Source: Energy Information Administration, Monthly Energy Review, August 2012

Biomass Program Drivers
Energy Legislation: EISA

EISA RFS2 Renewable Biofuels Production Targets



Mandated Volumes in 2022

- **Advanced Biofuels**
  (50% or more GHG Reduction)
  Biobased Diesel = 1 BGY
  Other Advanced = 4 BGY
  Cellulosic = 16 BGY

- **Conventional Biofuels**
  (20% or more GHG Reduction)
  Starched Based = 15 BGY (Cap)

EISA defines ***Advanced Biofuel*** as "renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions…that are *at least 50 percent less* than baseline lifecycle greenhouse gas emissions." This includes biomass-based diesel, cellulosic biofuels, and other advanced fuels, including those derived from algae.