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Innovative technology solutions for sustainability

MSTRS Meeting - May 5, 2015:

Raising Gasoline Octane – The Considerations

Chris Standlee – Executive Vice President
Abengoa Bioenergy

ABENGOA at a Glance

Abengoa is an international company that applies innovative technology solutions for sustainability in the energy and environment at sectors

2
Attractive growth sectors
Energy & Environment

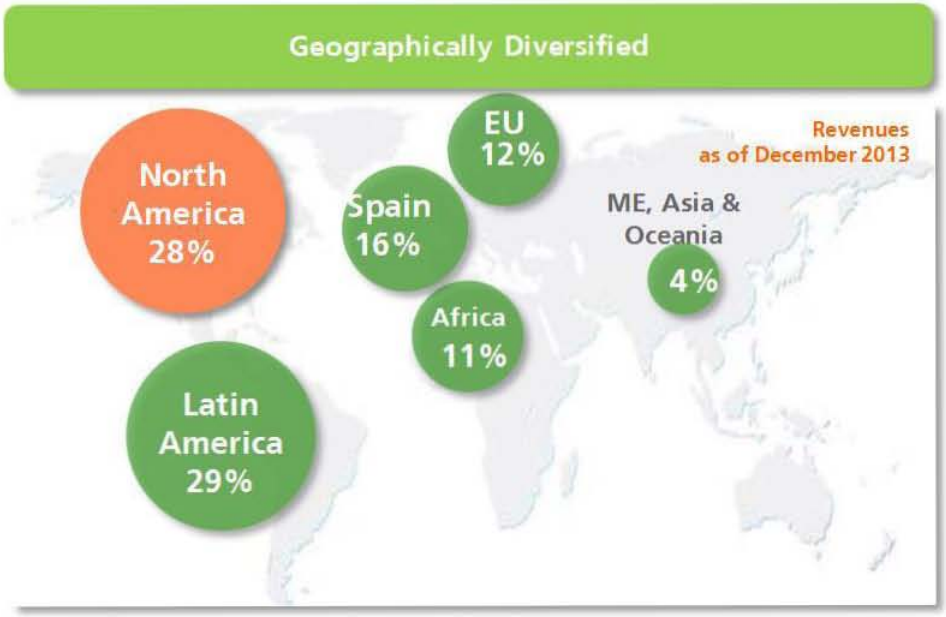
$10.1B revenues in 2013
$1.9B EBITDA in 2013
$3.1B capex in 2013

+70
Countries with local presence & operations

+26,800
Employees worldwide

Significant R&D investment

ISO/SOX$_{404}$
Compliance
since 2007



Proven track record

We focus our growth on the development of new technological solutions that contribute to sustainability in...

...providing Complete Solutions based on our:

- Cutting Edge Technology
- Green Field Project Development Capabilities
- Engineering & Construction Expertise
- Ad-hoc Project Financing Facilities
- Outstanding Operation & Maintenance Experience

Established 1G presence…

	1G Commercial Plants	1G Biofuel Capacity (mgal)
USA	6	380
Europe	6	395
Brazil	2	65
Total	14	840

2014 Global Production

Ethanol (ML):	2,580
Sugar (KTPY):	453
Feed (KTPY):	1,640
Electricity (MWh):	1,209,000
Biodiesel (ML):	106

- Biofuel plant
- 2nd Generation plant constructed
- Offices

The only company with a truly global footprint and a wide array of products

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Leader in Cellulosic Ethanol Technology (fuels from biomass, including organics)

Hugoton (USA)
2G bio-refinery; 25 M gal.
Demonstrates the viability of the 2G technology developed by **Abengoa**

Patents: 86

Thanks to our technological development, we can offer **pioneering solutions** in the **Biomass, Biofuels and Bioproducts Markets**

A proven solution for Waste to Biofuel

A sustainable technology to recycle/reduce solid waste to landfill.

A disruptive **solution** for densely populated areas, to address **waste management problems** and support **GHG reduction**

W2B demonstration plant **operational**; Grand Opening was **June 2013**

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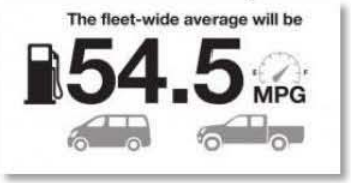
Ethanol for Octane
The Compliance challenges…

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

- Renewable Super Premium created with higher ethanol blends (E25-E40) utilized in **dedicated vehicles** can help achieve all three (and supports both biofuels & automobile industries)

- Ongoing collaboration project between Argonne and Oak Ridge National Laboratories, and NREL is a "scoping study" to address barriers, quantify benefits and determine if additional R&D is warranted

Source: DOE

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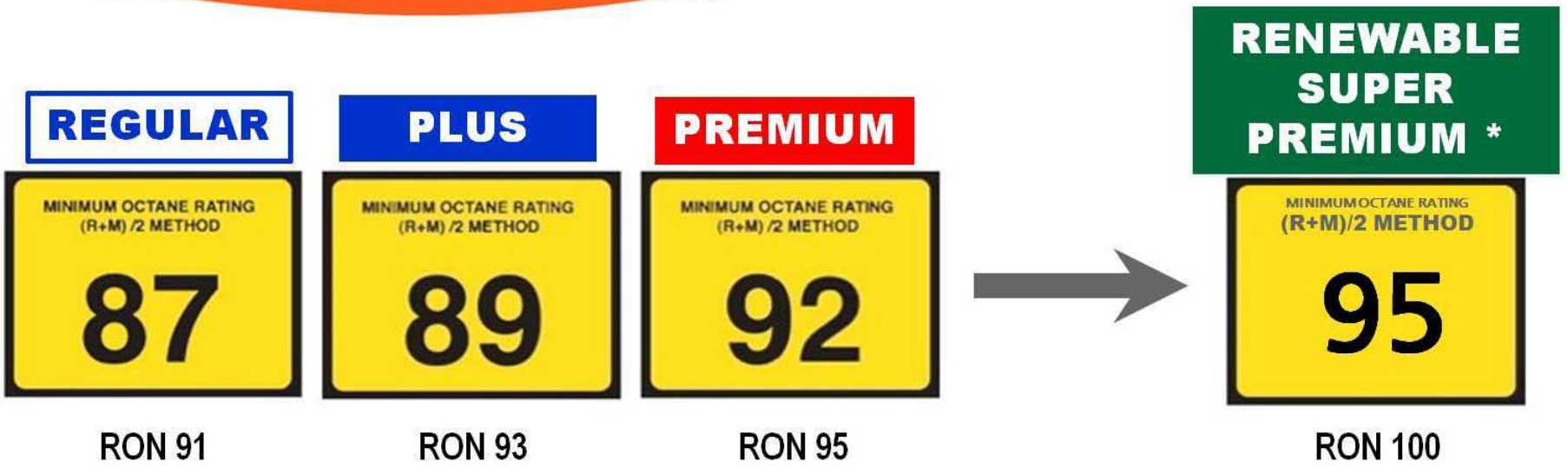
Fuel Octane



- 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 performance and efficiency

Source: DOE

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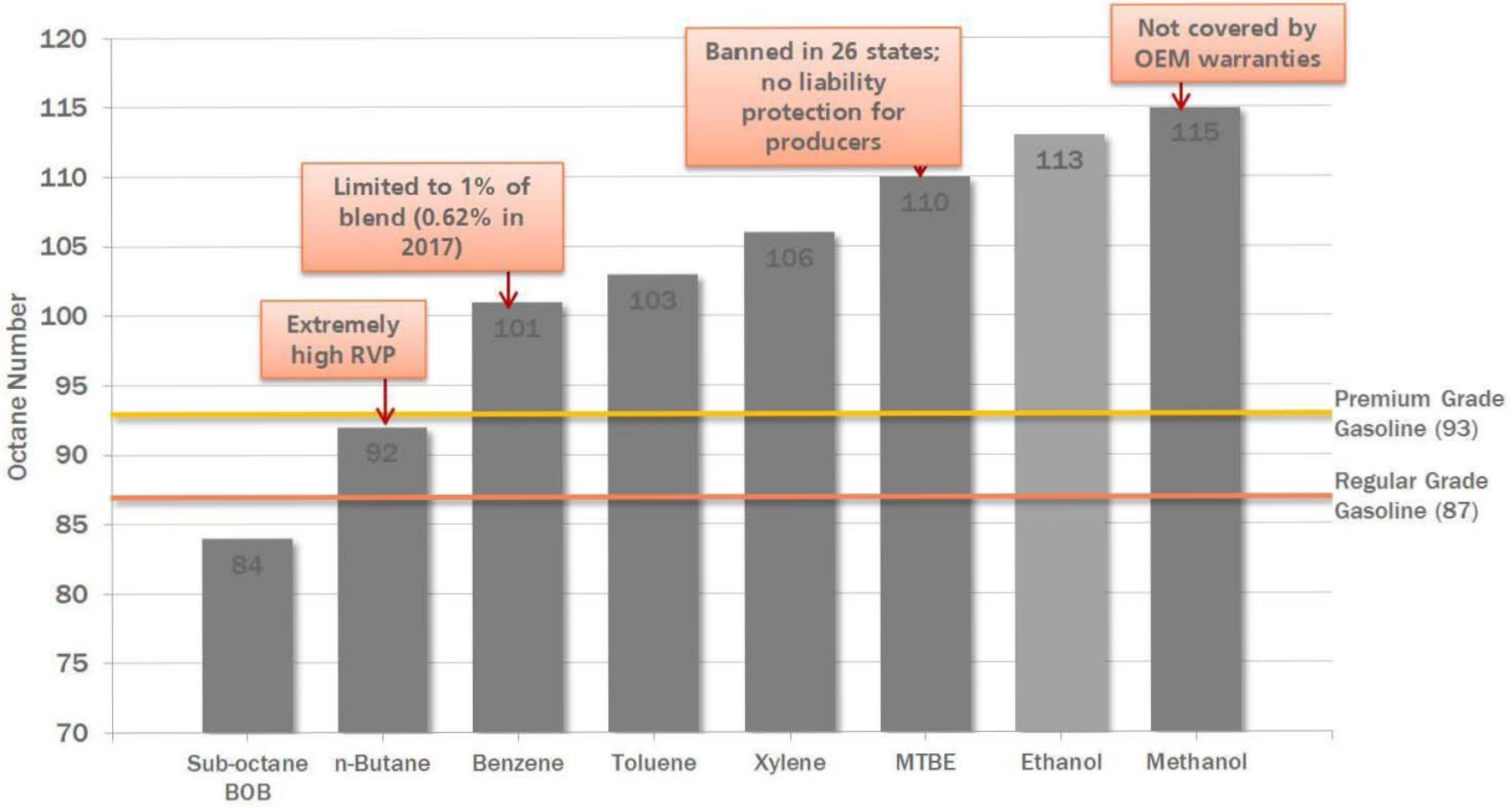
Ethanol's Octane Advantage

"Blending Octane" Values for Various Gasoline Components



Source: U.S. Dept. of Energy, National Renewable Energy Laboratory

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Ethanol as a source of octane in "Renewable Super Premium" (RSP)

- Ethanol has unique characteristics that make it highly attractive as the source of octane in a high-octane future fuel (20-40% ethanol by volume)
  - Significantly increases RON (95-102)
  - High heat of vaporization/charge cooling effects
  - Lowers CO2 emissions at part-load
  - Reduces/dilutes toxics emissions (sulfur, benzene & butadiene)
  - Reduces PM emissions
  - Reduces RVP (vs. E10)
  - Lower price than RBOB and CBOB gasoline
  - Oxygen content for RFG areas

See:

1. *Stein et al/SAE Int. J. Engines/Volume 6, Issue 1 (May 2013);*
2. *J.E. Anderson et al. "High Octane Number Ethanol-Gasoline Blends: Quantifying the Potential Benefits in the United States," Fuel 97:585-594, 2012*

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Thoughts on RSP

RSP "...could help manufacturers who wish to raise compression ratios to improve vehicle efficiency as a step toward complying with the 2017 and later GHG and CAFE standards."

"...a mid-level ethanol-gasoline blend (greater than E20 and less than E40) appears to be attractive as a long-term future fuel for automotive engines in the U.S."

Ford

AVL

OAK RIDGE National Laboratory

"A new high octane fuel could make better use of ethanol's properties, moving the nation toward multiple goals."

RSP offers "ridiculous power and good fuel economy."

Mercedes-Benz

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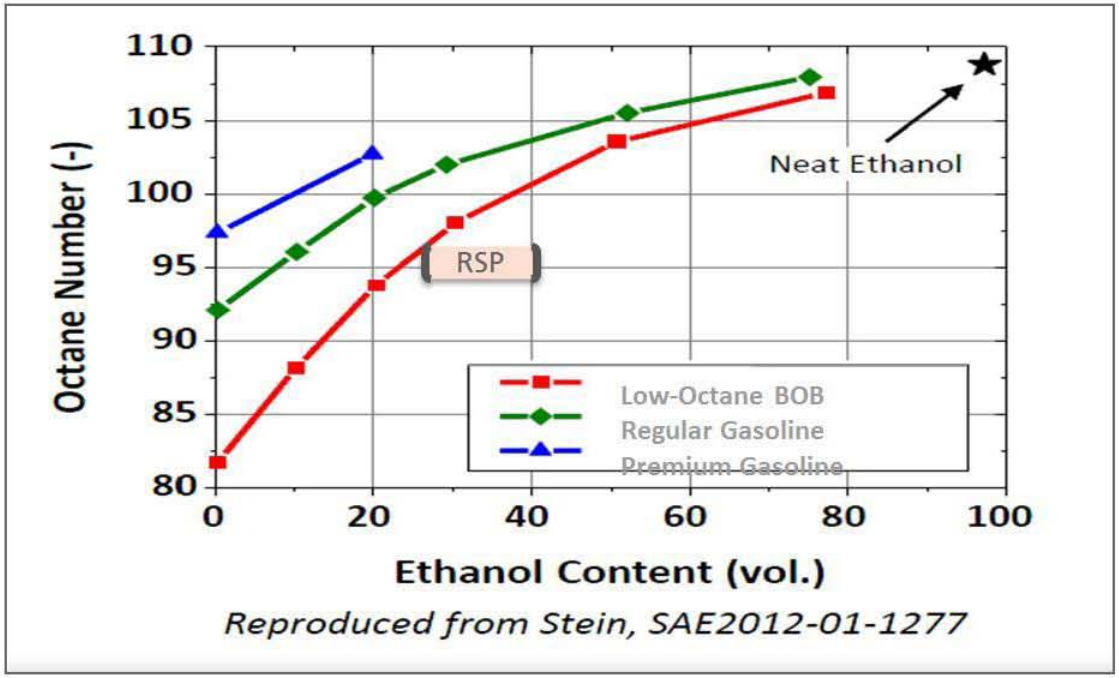
Benefits of High-Octane, Mid-Level Ethanol Blends

- Ethanol has 2/3 energy density of gasoline but high octane
- Non-linear influence of ethanol content → most benefit at lower levels
- 2/3 of octane benefit from first 1/3 of ethanol volume percent
- 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



Reproduced from Stein, SAE2012-01-1277

Study Assumption/Goal:
Volumetric Fuel Economy Parity
- **E25 – 5% efficiency gain**
- **E40 – 10% efficiency gain (stretch)**

Defines "Renewable Super Premium" as RON ~ 100 with 25-40% ethanol

Source: DOE and ORNL

Chicken or egg? Which comes first: the ethanol supply or the engine/vehicle?

Issues:

- Ethanol Supply certainty
- Feedstock Availability
- Fuel distribution / infrastructure limitations
- Impact on legacy vehicles during transition

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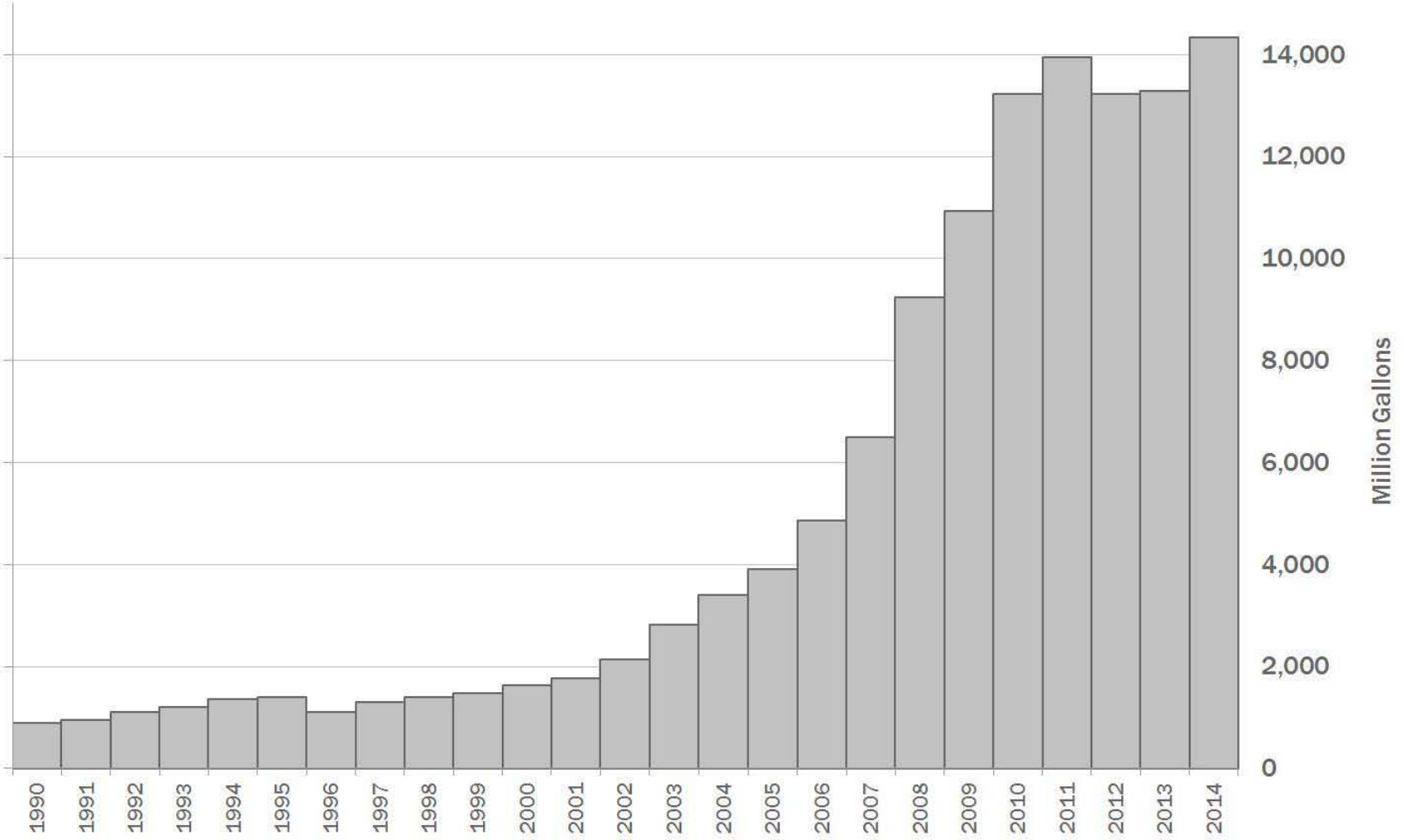
Ethanol Supply
Total Capacity near 15 mgpy

U.S. Ethanol Production



Availability of Land for starch based Biofuels Production

- Study by Steffan Mueller, University of Illinois at Chicago, using USDA Cropland Data Analysis shows US has ample land for biofuel expansion before accessing high carbon ecosystems
- Analysis identifies 100 million hectares in crops and 90 million hectares of available lands.
- 28 million hectares higher than the baseline set by the EPA of 162 million hectares for agricultural land that qualifies for biofuels production

Source: Steffan Mueller et al., "An assessment of available lands for biofuels production in the US using USD cropland data layers:, Journal of Agricultural Extension and Rural Development, October 2012

Ample Cellulosic Feedstock sources

- Potential biomass feedstocks are numerous and widespread throughout the United States.
- In 2010, the Environmental Protection Agency estimated that the 16 billion gallons of cellulosic biofuels mandated by the RFS for 2022 would be derived from dedicated energy crops (49.4%), agricultural residues (35.6%), urban waste (14.4%), and forest residue (0.6%).
- Several studies based on agronomically viable U.S. biomass production suggest that the biofuels potential is significantly larger than 16 billion gallons.

Source: Congressional Research Service: "Cellulosic Ethanol: Feedstocks, Conversion Technologies, Economics, and Policy Options" (October 22, 2010)

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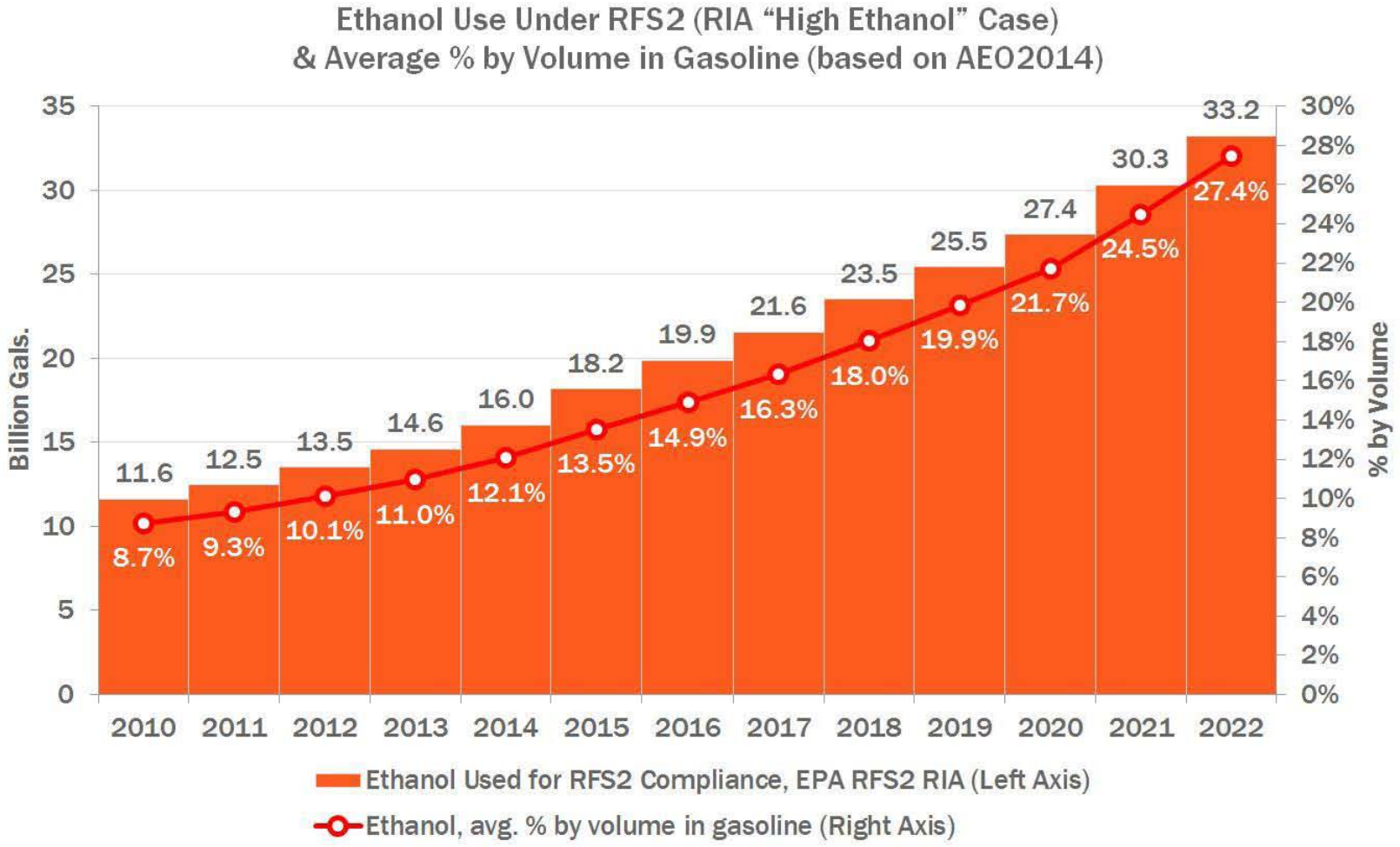
Ethanol consumption envisioned under RFS2



Note: Includes domestic corn ethanol, cellulosic ethanol, and imported ethanol

Source: RFA

DOE : The infrastructure barrier has been overstated:

- **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**

Oak Ridge National Lab:

Road fuel infrastructure for a mid-level ethanol blend is not trivial (but significantly less complex than many other alternatives)

- **Over 3000 E85 dispensers in service, over 17M FFVs on the road that could use an E25-E40 fuel *today***
- **Thousands of dispensers replaced annually. *Invest in upgraded dispensers now***

"Blend Wall", or Blend Bump?

- More than enough E10+ compatible vehicles to break through "blend wall"
  - 19 million FFVs (8% of fleet)
  - 83% of autos approved by EPA for E15; 17% explicitly warranted by OEMs
  - Current fleet approved by EPA to consume ~30 bg of ethanol

- E15/E85 infrastructure is the limiting factor
  - 2.5% of stations offer E85; <1% offer E15
  - But RFS RIN mechanism would drive rapid investment/upgrades if statute was enforced
  - Ethanol/Ag industries are investing tens of millions in retail E15/E85 infrastructure projects

Source: RFA

What about cost?

- Stillwater Associates estimated the cost of infrastructure to allow E30 blending to be between $.0024 and $.0056/gallon on a fifteen year amortized basis.
  - The gasoline distribution system can be modified to accommodate the rollout of E30 …with the installation of E30 compatible equipment while making routine equipment upgrades, holding down costs.
  - Gasoline marketers should be willing to invest in E30 because it allows them to participate in the ethanol market directly

- Mathpro, Inc. and representatives from Ford, GM and Chrysler all recommend "further consideration of higher-octane gasoline in the US"
  - "Increasing the octane rating…would enable higher engine efficiency…, facilitating compliance with federal fuel economy and greenhouse gas (GHG) emissions standards"
  - "The refining sector could produce BOBs yielding finished E20 and E30 gasolines with higher octane ratings at modest additional refining cost"
  - "Producing E20 and E30 gasoline pools would incur somewhat lower refining costs, petroleum use, and CO2 emissions than using the corresponding volumes of ethanol in combinations of E10 and E85."

See:

1. *Stillwater Associates LLC "The Cost of Introducing an Intermediate Glend Ethanol Fuel for 2017 and later vehicles", October 17, 2012*
2. *J.E. Anderson et al. "Refining Economics of US Gasoline: Octane Ratings and Ethanol Content," Environ. Sci. Technol. 2014, 48, 11064-11071*

RSP and Advanced ICEs

- Per DOE, Feedstock availability and cost do not limit deployment of RSP
- Both vehicle market penetration and ethanol demand sensitive to how RSP is treated for CAFE
- Oak Ridge NL data suggest that E25-E40 blend in future vehicles can return equivalent "tank mileage" as E10 in conventional vehicles
  - Energy density penalty is *linear* with increasing ethanol concentration
  - But power and efficiency gains are *non-linear*
  - In testing on multiple legacy FFVs, splash blended E30 (100.7 RON) increased performance1.7%-3% over E10, with 1%-2% fuel economy change and "no notable emissions changes"
- "Volumetric Fuel Economy Parity" means *every gallon* of ethanol displaces a *gallon* of gasoline
  - CAFE benefit to OEM is significant (same miles with less BTUs)
  - GHG Benefit is also significant (same miles with less GHG)
- Can simultaneously help achieve RFS compliance

Source: Oak Ridge National Lab

Just for fun

World's Fastest Car is a Flex Fuel Vehicle

- **Koenigsegg One:1**
  - "one-to-one"
- **5.0 liter turbo V8**
- **1341 hp with E85**
  - 1161 hp with pump gasoline

Koenigsegg

Zero to 60 mph: 2.5 sec
Zero to 100 mph: 4.5 sec
Standing ¼-mile: 9.0 sec
Top speed: 273 mph

http://www.koenigsegg.com/wp-content/uploads/Koenigsegg_2014_One1.pdf
http://www.caranddriver.com/reviews/2015-koenigsegg-one1-first-drive-review

Source: Oak Ridge National Laboratory

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Questions