The Role of Biofuels in the US Sustainable Transportation Challenge

Tim Theiss

Laboratory Relationship Manager (LRM)

EERE Bioenergy Technologies Office (BETO)

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Transportation Science Seminar Series

ORNL is managed by UT-Battelle
for the US Department of Energy

Oak Ridge National Laboratory

Presentation outline

- Background
  - Energy security
  - Vehicle driving changes
  - Environmental performance
- Federal Response
- ORNL Bioenergy Technologies Program
- Bioenergy Grand Challenges
- Final Thoughts

US petroleum consumption is huge

In 2013, US consumed 18.9 Million Barrels/day petroleum

2/3 used in transportation sector

40% of barrel of crude is gasoline

135 Billion gallons of gasoline a year

Visualizing our petroleum consumption

- Cowboys Stadium!
- 73 acres under roof
- 900 ft end-end
- 290 ft tall at max point
- 100 million ft^3

Total volume (end-end; floor-ceiling) would hold one day's worth of US oil

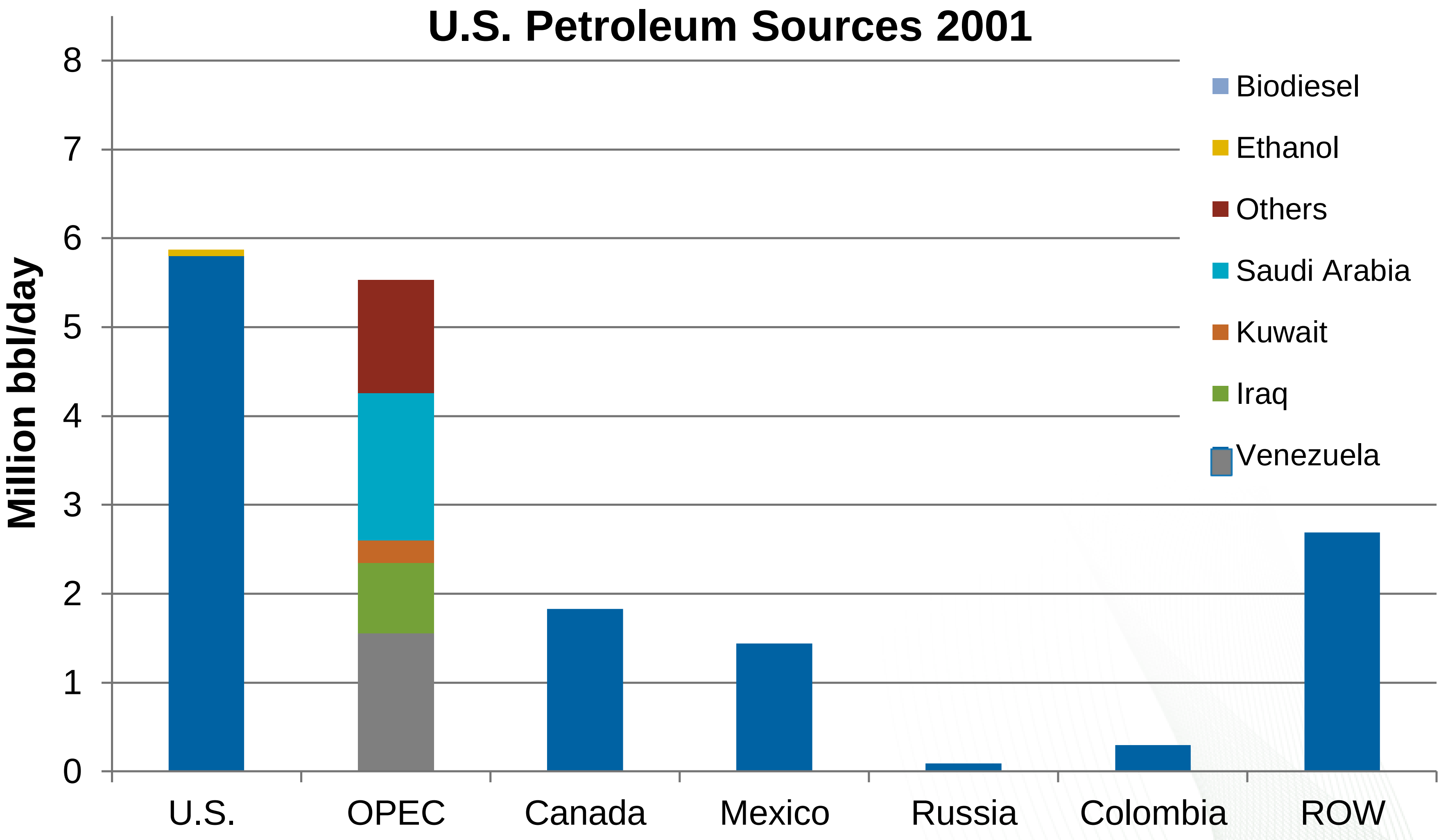
In 2013 US oil consumption – 18.9 million barrels a day

Line of barrels over 7400 miles long

~~ or ~~

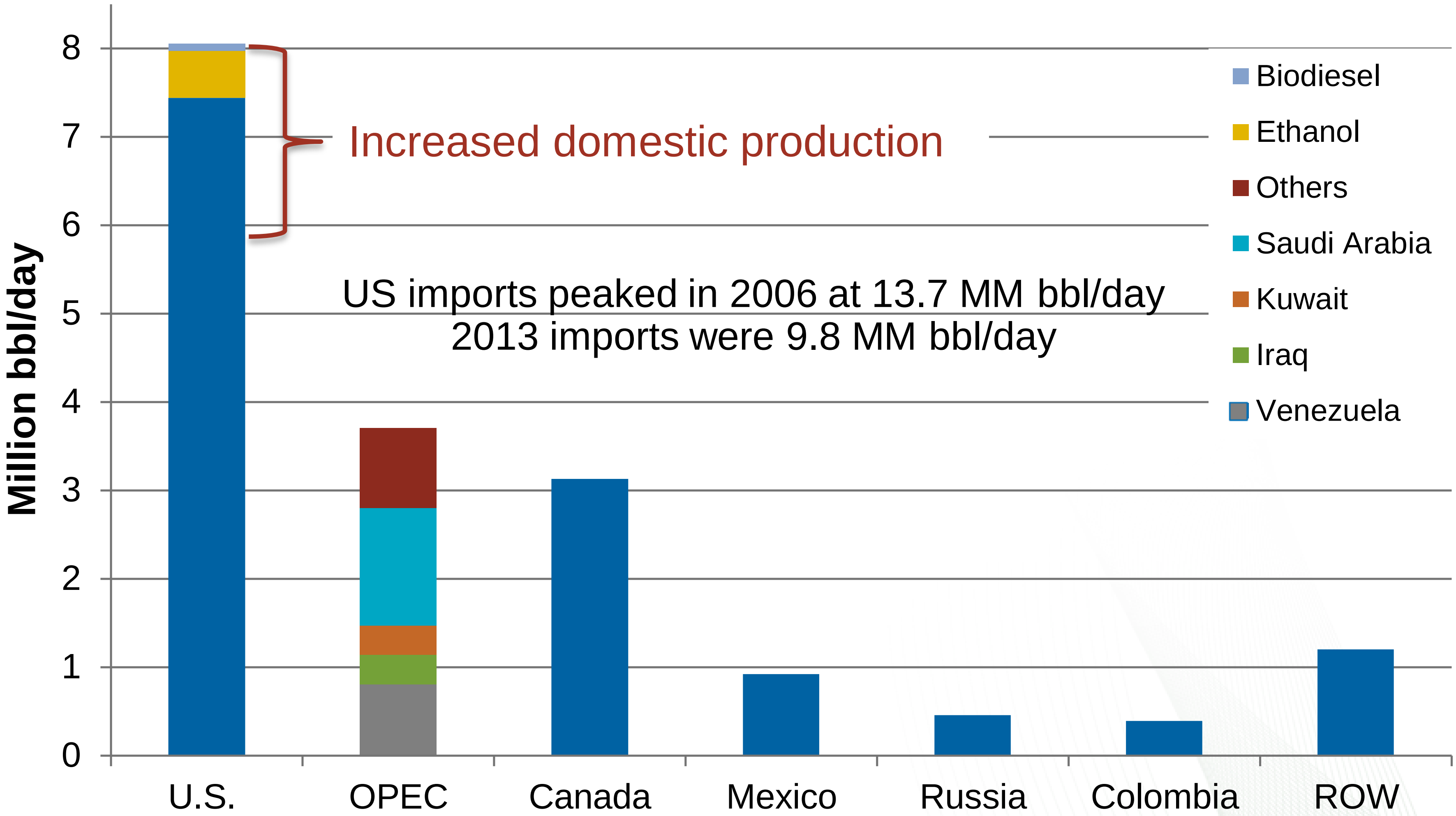
Knoxville – Boston – Seattle – San Diego – Kingston!

US obtains petroleum from multiple sources



Source: Energy Information Agency; http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbblpd_a.htm

Domestic petroleum production (2013) has increased significantly



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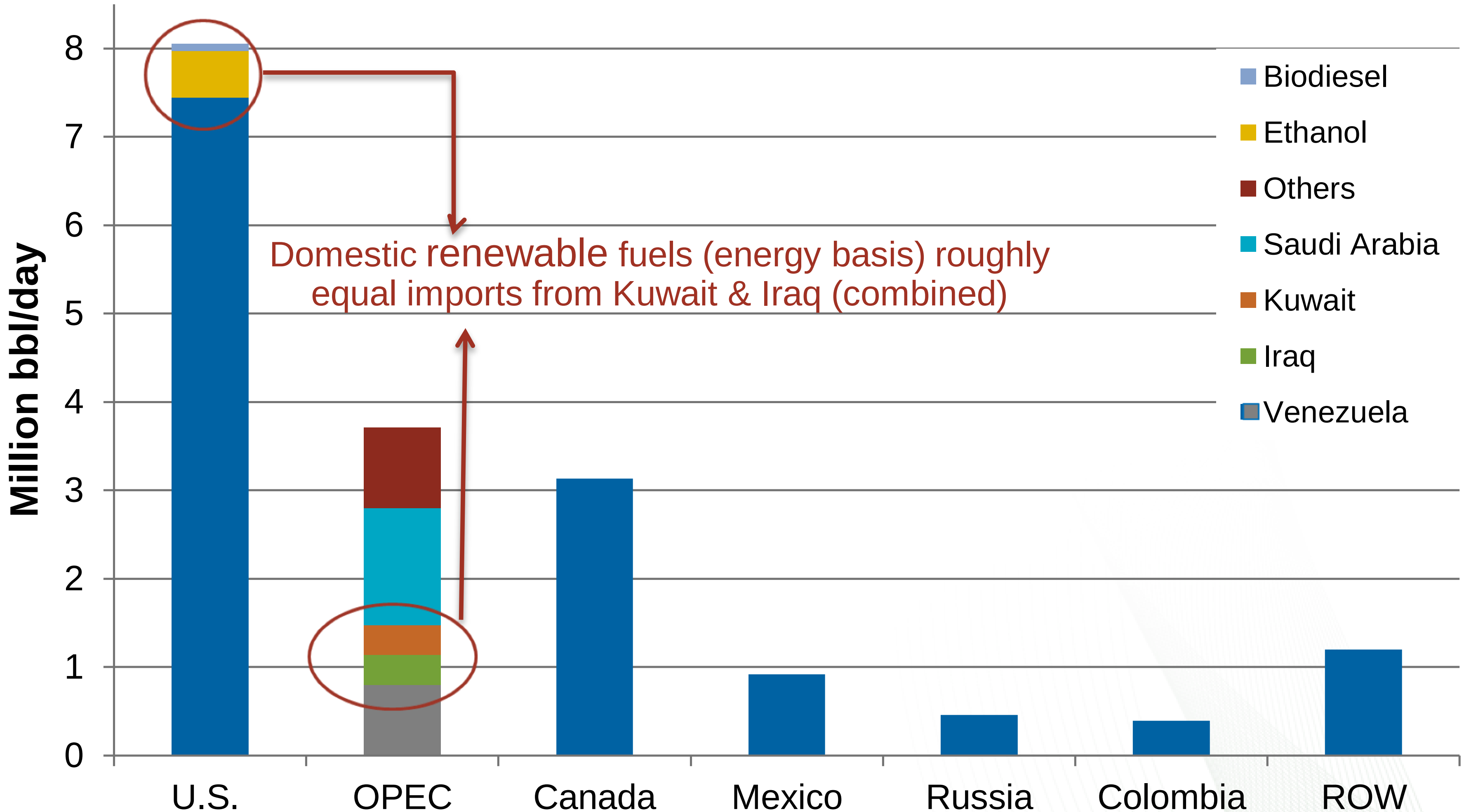
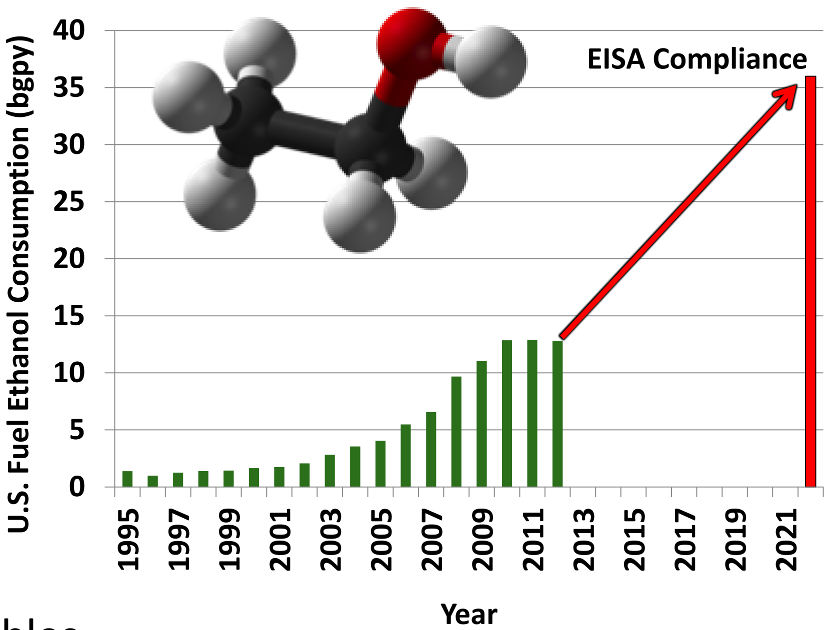


Source: Energy Information Agency; http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbblpd_a.htm

U. S. ethanol production is significant

- Currently consuming 13 billion gallons/year (BGY) ethanol
- US gasoline consumption – 135 BGY
- Most gasoline sold is E10 (10% ethanol) – at the blendwall
- Benchmarking and historical comparisons
  - Current U.S. ethanol production is nearly double that of Brazil
  - Our RFS goal of 36 billion gallons/year 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 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)

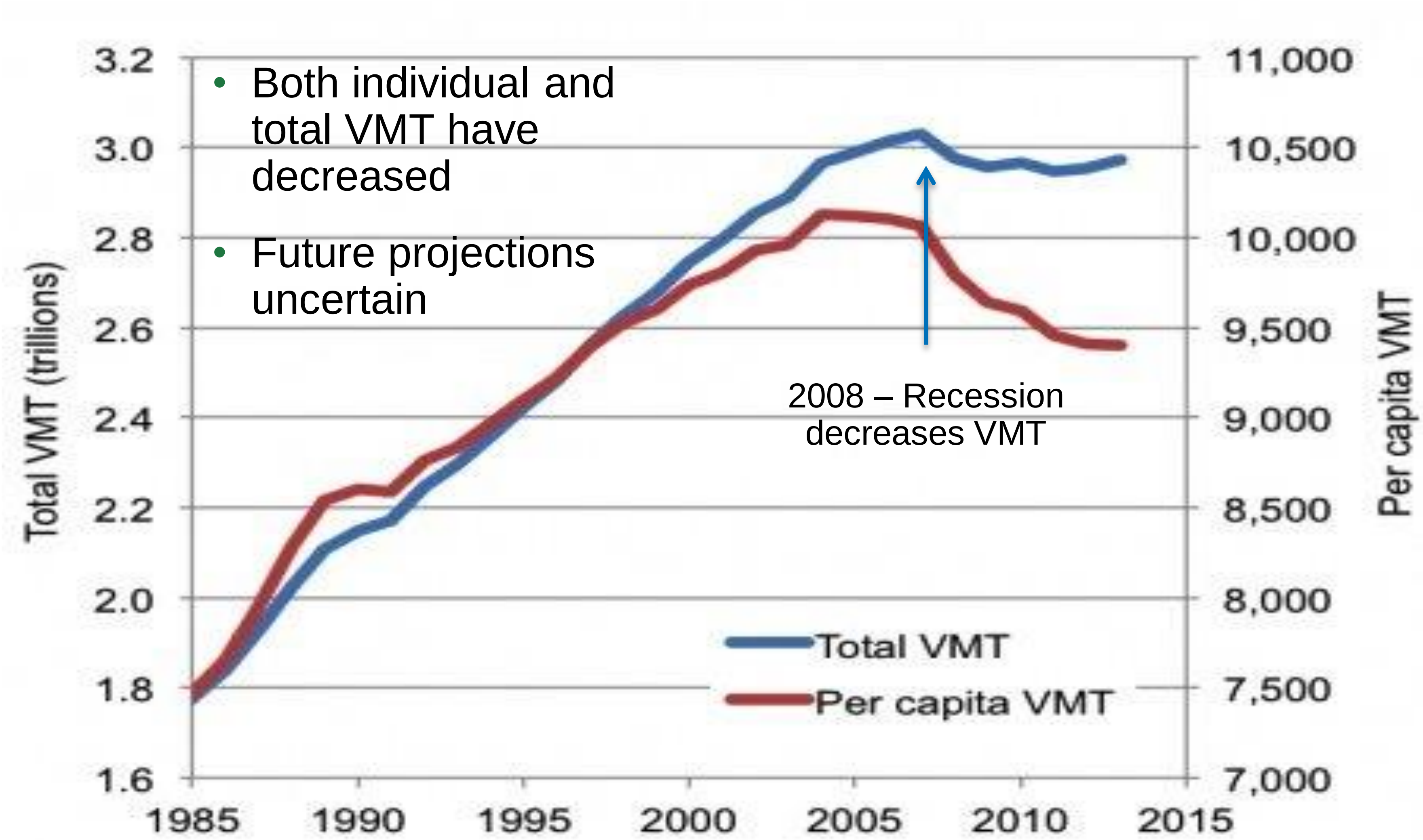


- **Gasoline saved by 1 million electric vehicles:** **0.5 Billion gal/yr**
- **Gasoline saved by 10% weight reduction in cars:** **5 Billion gal/yr**

Credit: Ron Graves

The trend in Vehicle Miles Traveled (VMT) has also changed recently

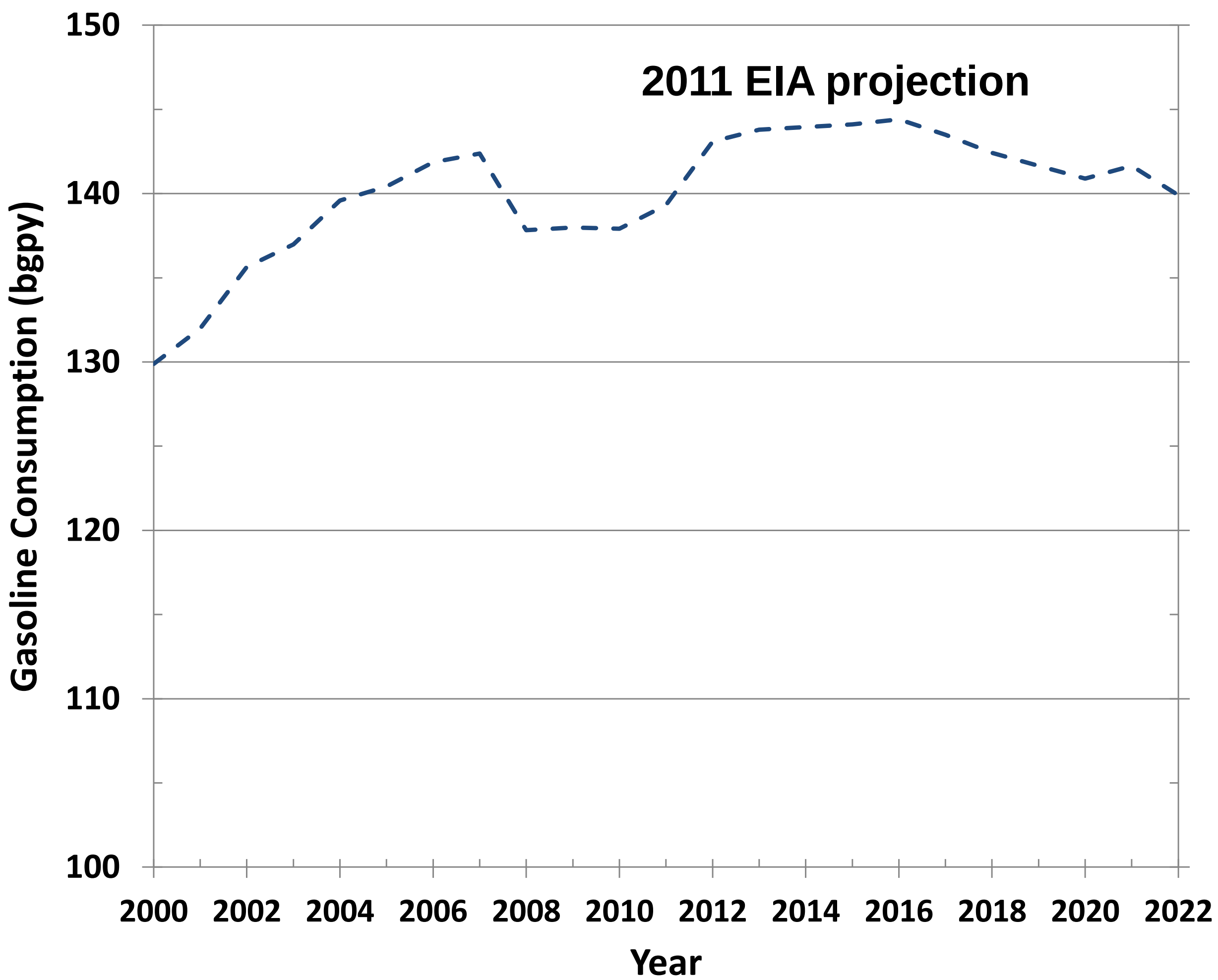
- Both individual and total VMT have decreased
- Future projections uncertain



Source: http://www.ssti.us/2014/02/vmt-drops-ninth-year-dots-taking-notice/

In 2011, EIA projected flat gasoline consumption for next decade

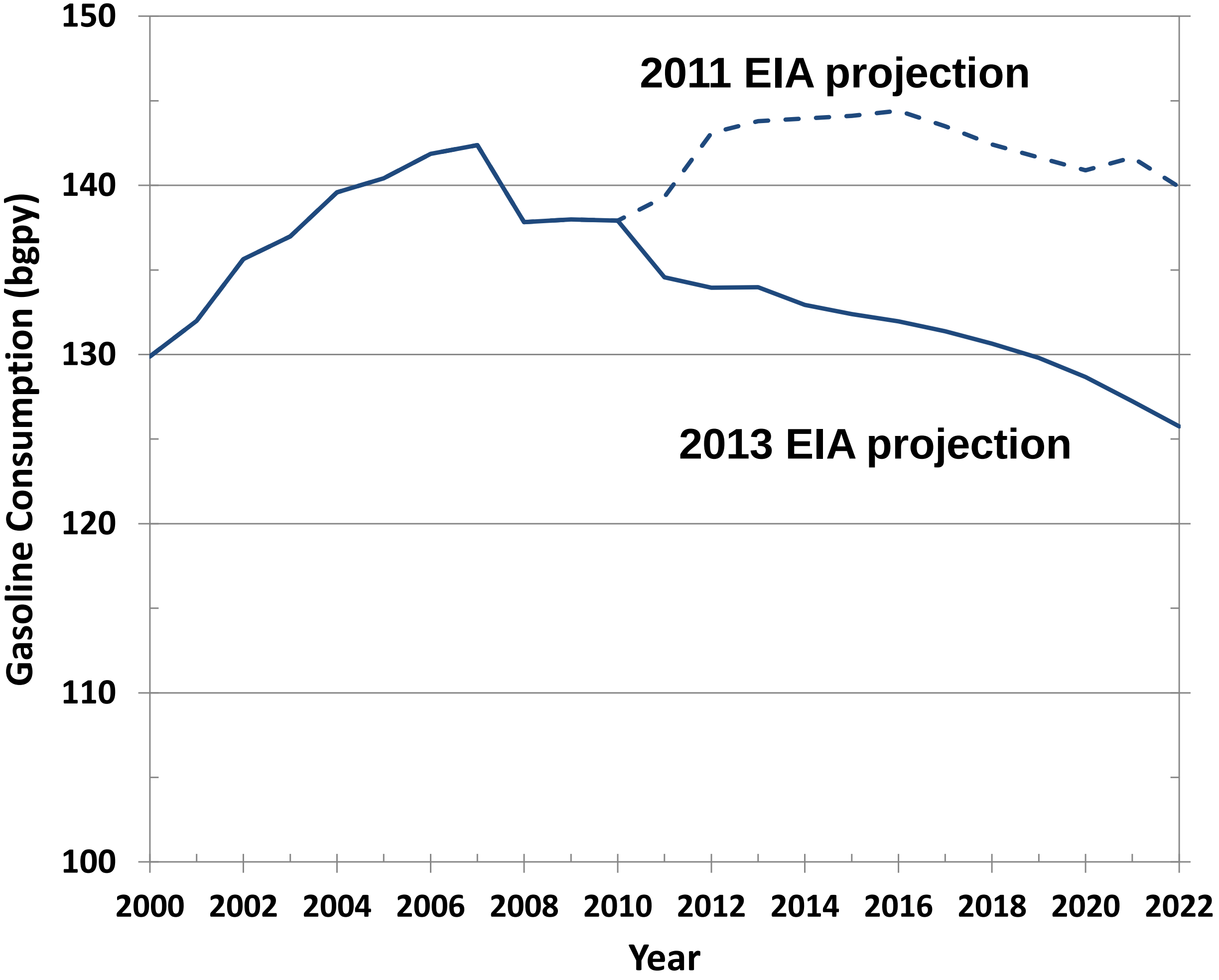
"Motor gasoline" includes E10. Flat demand at ~140bgpy led to projections of E15 allowing for *up to* 21bgpy ethanol. That was 2011….



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

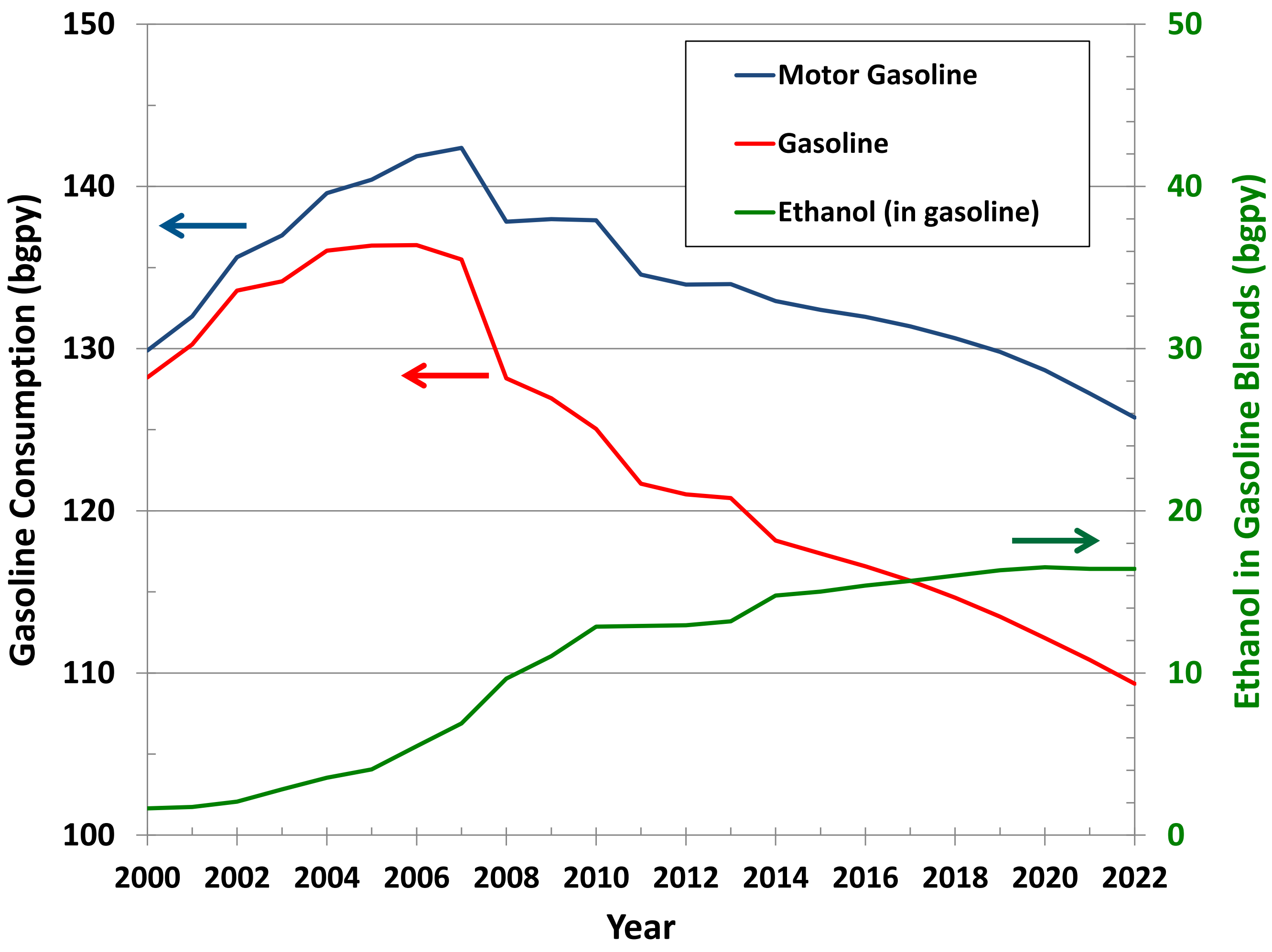
2013 EIA projection shows declining motor gasoline consumption.

Fuel economy rule finalized in 2012.



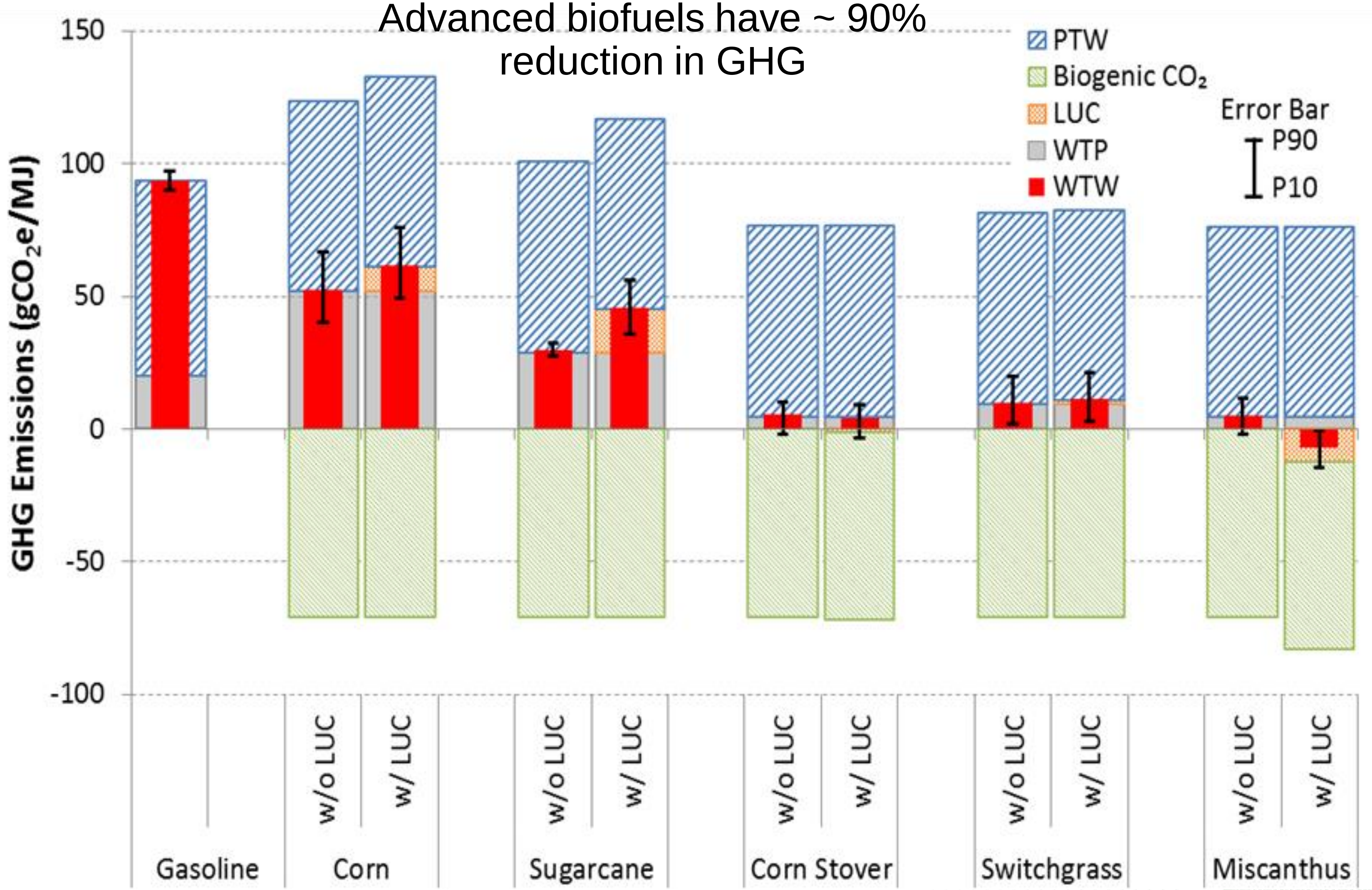
2013 EIA projection shows declining motor gasoline consumption. Fuel economy rule finalized in 2012.

In 2007, the EIA projection for gasoline consumption in 2022 was 160 BGY … a difference of 50 billion gallons a year in 2022



Biofuels provide significant lifecycle greenhouse gas (GHG) reductions

Advanced biofuels have ~ 90% reduction in GHG



From Wang M., et al., (2012), *Environ. Research Letters*

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  - Legislative action
  - EERE Bioenergy Technologies Office
- EERE Bioenergy Technologies Program
- ORNL Bioenergy Technologies Program
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Current regulation is driving unprecedented technology development

Fuel Economy Standards

2025 CAFE Standards

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

Emissions Regulations

↓ 70% NOx, 85% NMOG

< 10 ppm sulfur in gasoline

(U.S. EPA Tier 3 regulations)

Renewable Fuels Standard

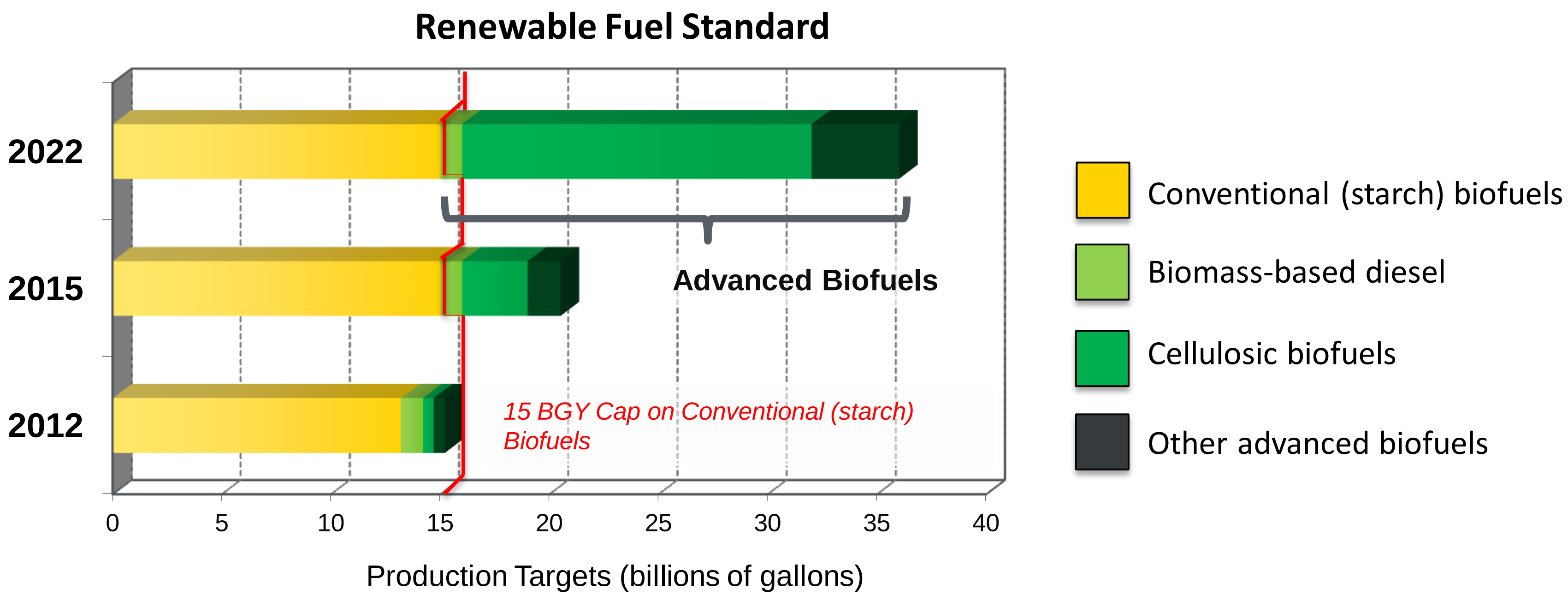
36 billion gallons by 2022

(EISA 2007)

First time transportation industry has faced "triple-threat" of this magnitude

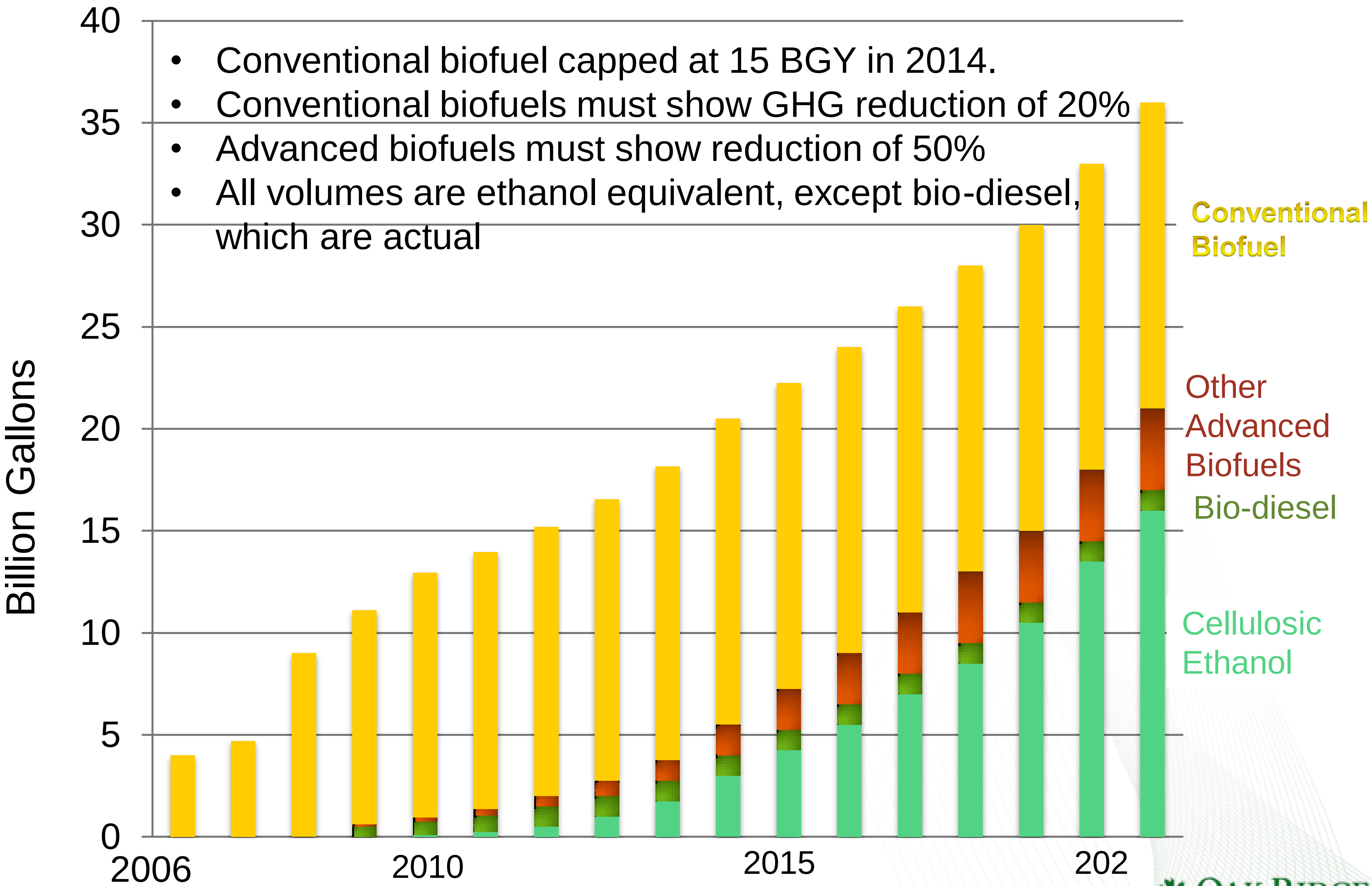
Key Policy Drivers – Renewable Fuel Standard

- 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



Renewable Fuel Standard mandates annual renewable fuel volumes

- Conventional biofuel capped at 15 BGY in 2014.
- Conventional biofuels must show GHG reduction of 20%
- Advanced biofuels must show reduction of 50%
- All volumes are ethanol equivalent, except bio-diesel, which are actual



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

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Structure of Bioenergy Technologies Office (BETO)

Program Portfolio Management

- Planning • Systems-Level Analysis • Performance Validation and Assessment
- MYPP • Peer Review • Merit Review • Quarterly Portfolio Review
- Competitive • Non-competitive • Lab Capabilities Matrix

Research, Development, Demonstration, & Market Transformation

Feedstock Supply & Logistics R&D
- Terrestrial
- Algae
- Product Logistics Preprocessing

Conversion R&D
- Biochemical
- Thermochemical
- Deconstruction
- Biointermediate
- Upgrading

Demonstration & Market Transformation
- Integrated Biorefineries
- Biofuels Distribution Infrastructure

Cross Cutting

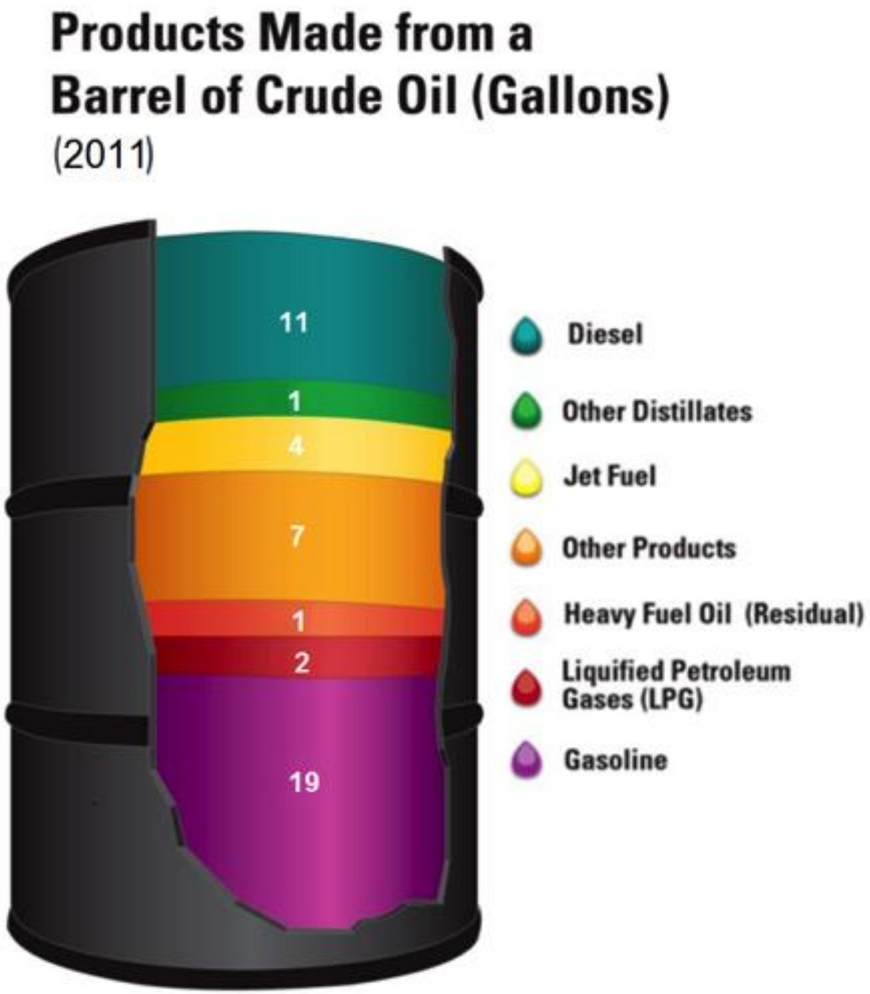
Sustainability
- Sustainability Analysis
- Sustainable System Design

Strategic Analysis
- Technology and Resource Assessment
- Market and Impact Analysis
- Model Development & Data compilation

Strategic Communications
- New Communications Vehicles & Outlets
- Awareness and Support of Office
- Benefits of Bioenergy/Bioproducts

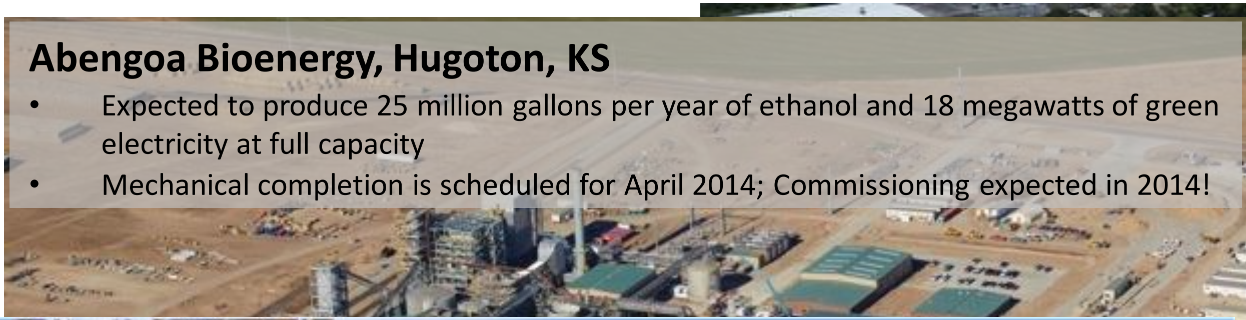
Credit: Jonathan Male, Director, Bioenergy Technologies Office

DOE interested in replacing the whole barrel



- Cellulosic ethanol only displaces gasoline fraction of a barrel of oil (about 40%).
- Reducing dependence on oil requires replacing diesel, jet, heavy distillates, and a range of other chemicals and products.
- Greater focus needed on RDD&D for a range of technologies to produce hydrocarbon fuels and displace the entire barrel of petroleum.
- 67% of barrel used in transportation at market value of $350B; 7% is used in chemicals/products at market value of $255B

Commercial advanced biofuels and bioproducts are reality



Abengoa Bioenergy, Hugoton, KS

- Expected to produce 25 million gallons per year of ethanol and 18 megawatts of green electricity at full capacity
- Mechanical completion is scheduled for April 2014; Commissioning expected in 2014!

POET-DSM Project LIBERTY, Emmetsburg, IA

- Expected to produce 20 million gallons per year of cellulosic ethanol at full capacity
- Major construction began November 2012, Ribbon cutting September 2014!

llons per year of cellulosic ethanol
nd vegetative waste
f cellulosic ethanol in July 2013
ellulosic ethanol in the U.S.

- ✓ Additional biorefineries are under construction – 88 MGY
- ✓ Close to EISA cellulosic ethanol 2010 mandated volume 5 years later

Credit: Jim Spaeth, Bioenergy Technologies Office

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Bioenergy spans from basic sciences to application

![BESC logo] BESC
BioEnergy Science Center

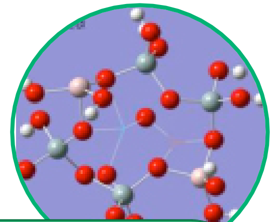
Molecular biology, chemical and structural analysis and characterization, modeling and simulation

Feedstock development

Biomass deconstruction

Center for BioEnergy Sustainability
Environmental Socio-economic indicators, Integrated land management, Management best practices

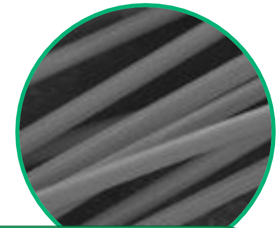
Feedstock Supply Analysis
Terrestrial & algal feedstocks, Advanced logistics, Supply & price projections



Conversion
Biochemical & thermochemical conversion, Catalytic upgrading, Materials of construction

- Bioproducts
- Biofuels
- Biopower

EERE Bioenergy Technologies Office



Carbon Fiber Technology Facility
Materials S&E

Lighter weight vehicles

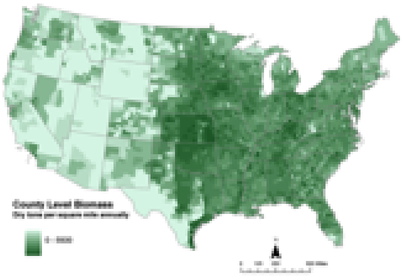
National Transportation Research Center
Engine evaluation
Fuel effects

Transportation biofuels

FLEX FUEL

ORNL supports Bioenergy Technologies Office (BETO) objectives in several platforms

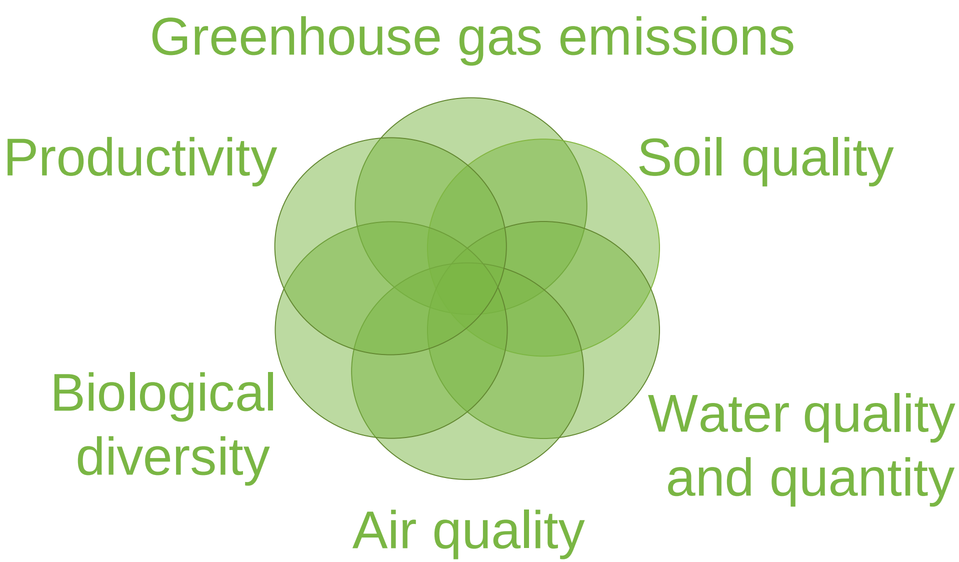
- Strategic Analysis & Environmental Sustainability
  - Defining bioenergy sustainability
  - Best Management Practices for energy crops

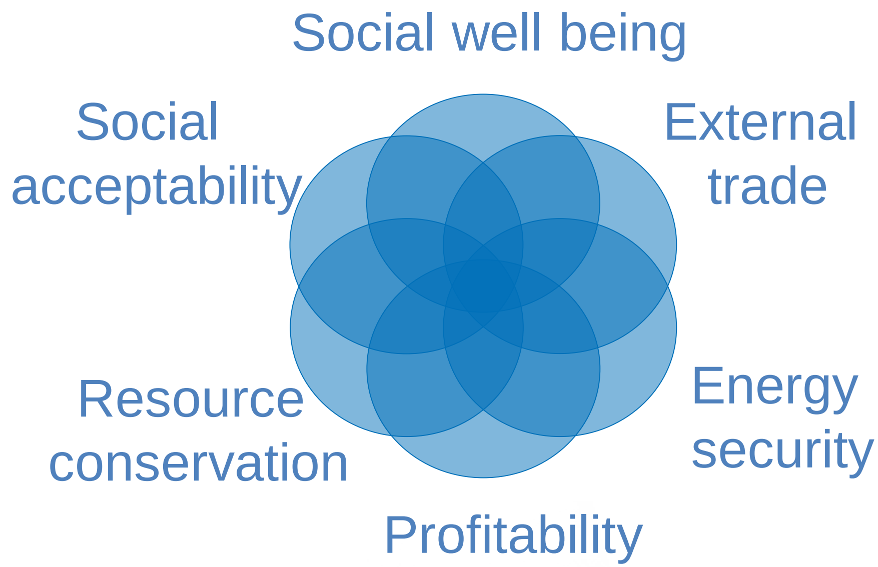


- Feedstock Supply & Logistics
  - Feedstock supply projections
  - Biomass engineering (logistics)

- Biomass Conversion (Biochemical & Thermochemical)
  - Catalytic upgrading of ethanol to HC
  - Novel catalyst for bio-oil upgrading
  - Materials compatibility of bio-oils
  - Advanced membranes for separation
- Demonstration & Market Transformation
  - High octane renewable super premium fuel

Use of science-based indicators to define bioenergy sustainability

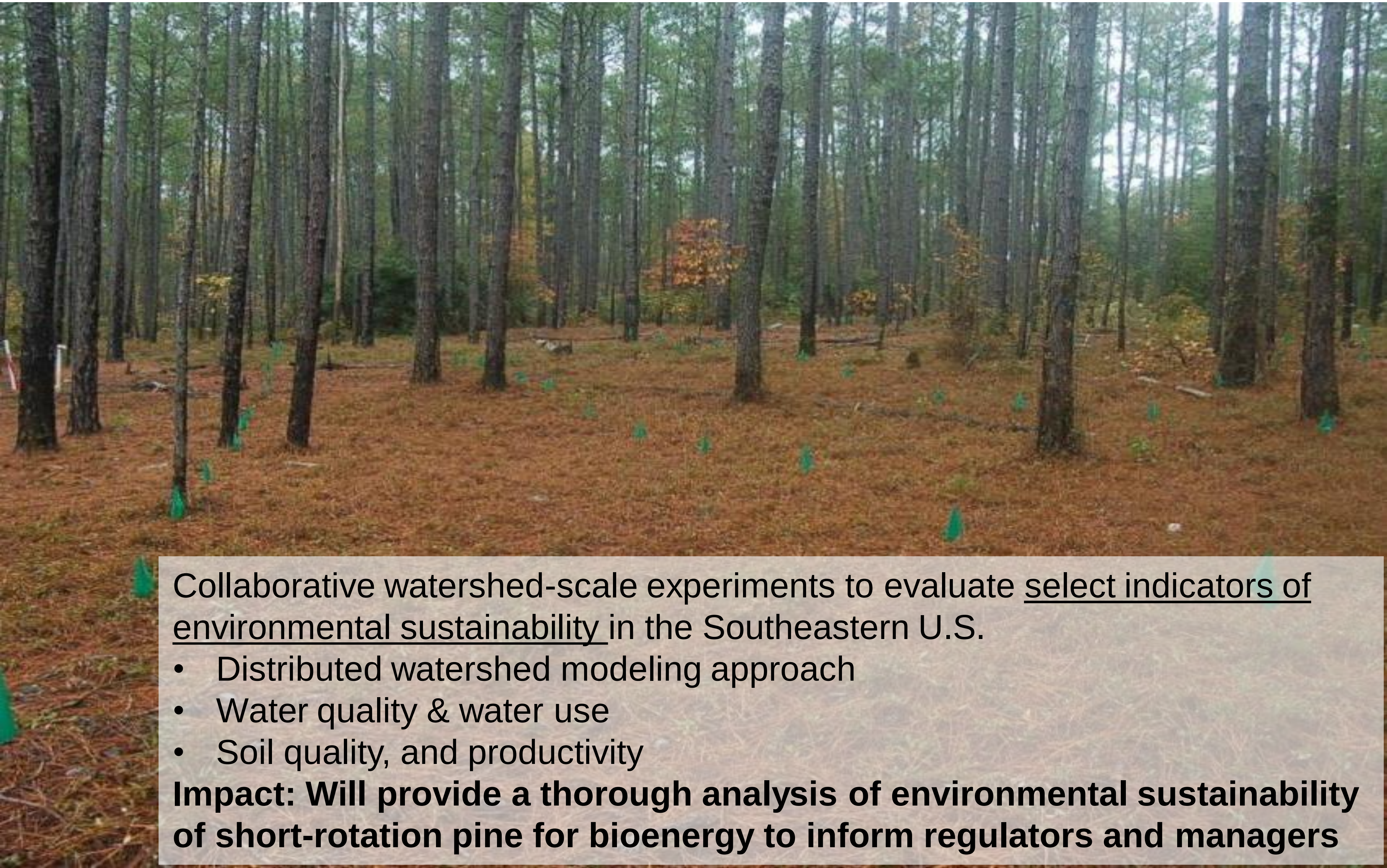




Ongoing work

- Advancing common definitions of environmental and socioeconomic costs and benefits of bioenergy systems
- Modifying sustainability indicators for algal biofuels
- Validating indicators through field studies

Best management practices for short-rotation woody crops being evaluated through long-term field study



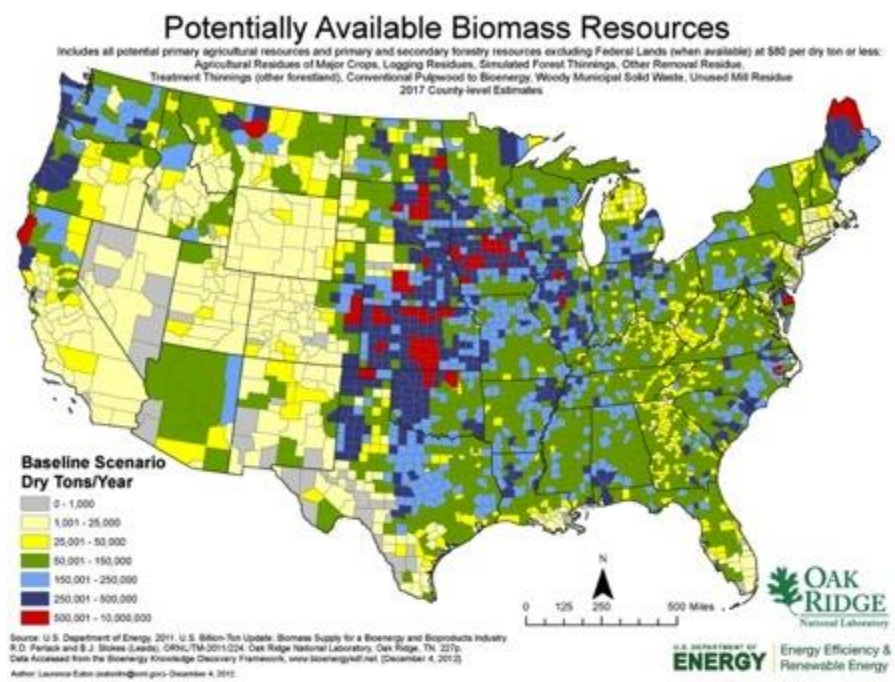
Collaborative watershed-scale experiments to evaluate select indicators of environmental sustainability in the Southeastern U.S.

- Distributed watershed modeling approach
- Water quality & water use
- Soil quality, and productivity

Impact: Will provide a thorough analysis of environmental sustainability of short-rotation pine for bioenergy to inform regulators and managers

Feedstock supply analysis considers cost, quantity and location

- Billion-Ton Study of 2005 helped support RFS volumes
- Billion Ton Update of 2011 included county-level cost & supply projections
- Conclusion: ample feedstock to replace up to 1/3 of petroleum with advanced biofuels
- Feedstock is roughly 1/3 cost of fuel
- Multi-institutional effort (DOE & USDA)
  - 20-year projections of economic availability of biomass at county level at any year
  - price, location, scenario
- Primary Resources
  - Forest resources (residues)
  - Ag resources (corn stover)
  - Energy crops (switchgrass)



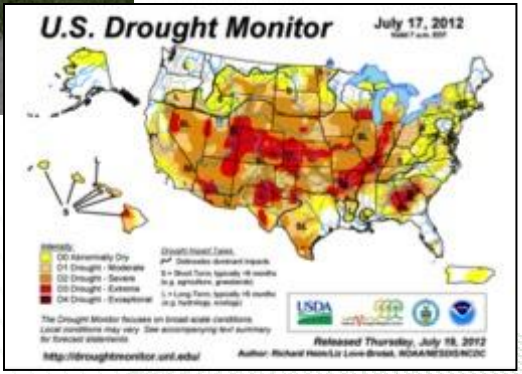
Challenges in scaling up a feedstock industry capable of meeting RFS targets*

- Supply system designs and management strategies to minimize feedstock costs
- Maintaining, even enhancing, feedstock quality or “convertibility”
- Managing risks of supply disruptions
  - Drought, flood, hurricanes
  - Inclement weather
  - Availability of appropriate equipment


Poor quality packages make biomass difficult to handle, store

2011

Year-to-year variability in growth and harvest conditions is challenging

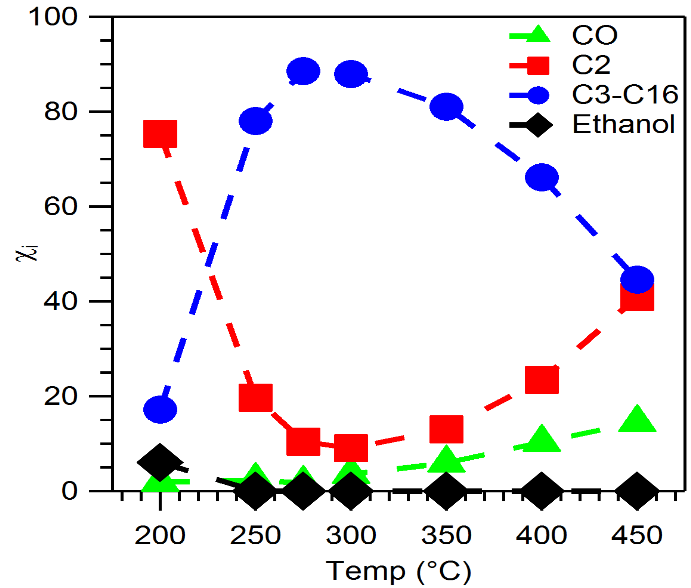


2012

*155 and 325 million DT/yr by 2017 and 2022, respectively (MYPP)

Direct catalytic conversion of ethanol is licensed

- Direct catalytic conversion of ethanol to hydrocarbon fuel blendstock demonstrated (can be blended with gasoline, diesel or jet fuel)
  - Complete conversion (100%) to hydrocarbon and water
  - Water concentration had no significant impact of ethanol conversion process so direct ethanol fermentation streams could be employed (7% - 100% ethanol)
  - Engine experiments at ORNL show combustion similar to gasoline
- Catalysis conditions are acceptable
  - Catalyst cost is reasonable
  - Catalyst conditions are not severe and long-term operation is promising
- Techno-economic analysis is encouraging
  - Cost comparable to petroleum-derived fuels
  - Use in retrofit of ethanol plant
- Licensed to Vertimass, LLC in March 2014
- Potentially addresses the “blend-wall” issue!



Constant LHSV of 2.93 h^{-1}

ORNL inventors (from left) Narula, Davison and Keller display the technology with Vertimass chairman William Shopoff.

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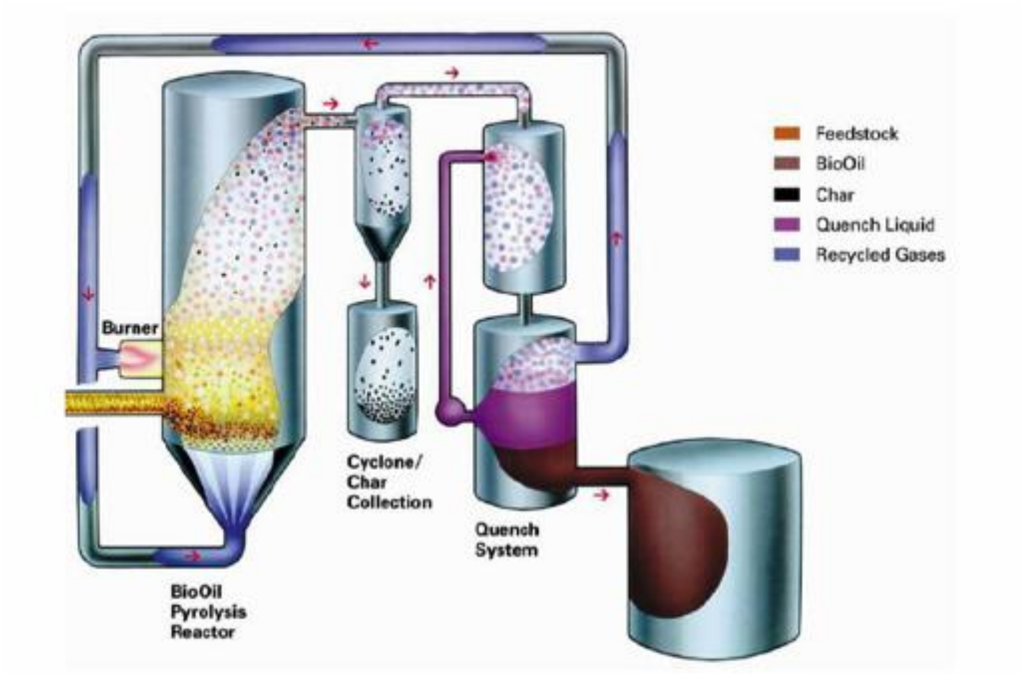
Fast pyrolysis is an efficient pathway to lignocellulosic liquid fuels

A Fast Pyrolysis Process (Dynamotive)



– Whole biomass
– Temperature: 450 °C
– Pressure: 1 atm
– Residence time: 1-2 s
– Atmosphere: inert
– High yield in liquids (bio-oils)
– Inexpensive
– Viable as small scale operation
– Bio-oils are highly acidic

Bio-oil composition	
C (wt%)	40.1
H (wt%)	7.6
O (wt%)	52.1
Moisture (wt%)	23.9

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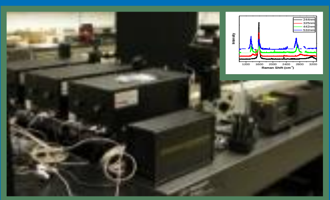
Approach for catalytic bio-oil upgrading

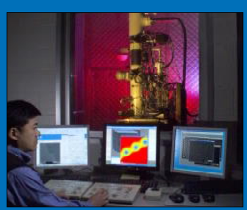
Micro-scale synthesis, characterization, detailed reactivity study

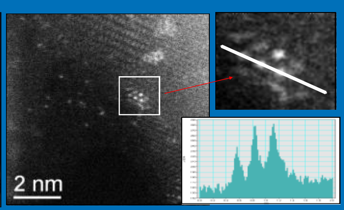
- Understand correlations between carbide synthesis conditions, structures & performance
- Leverage BES & university capabilities

Center for Nanophase Materials Sciences

UK University of Kentucky



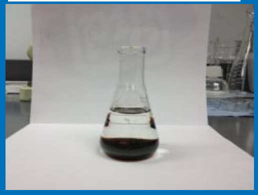




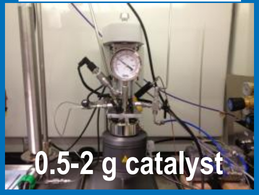
Tailor catalyst performance

Catalyst design, evaluation, scale-up

Model bio-oils



Lab reactors



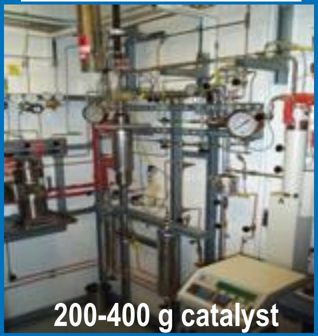
Reactor evaluation under relevant conditions

Pacific Northwest National Laboratory

- Activity
- Selectivity
- Stability
- Regenerability

Real bio-oils

Pilot flow reactor



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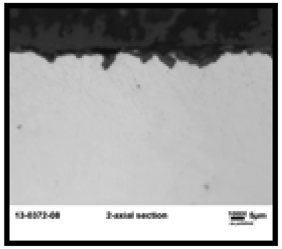
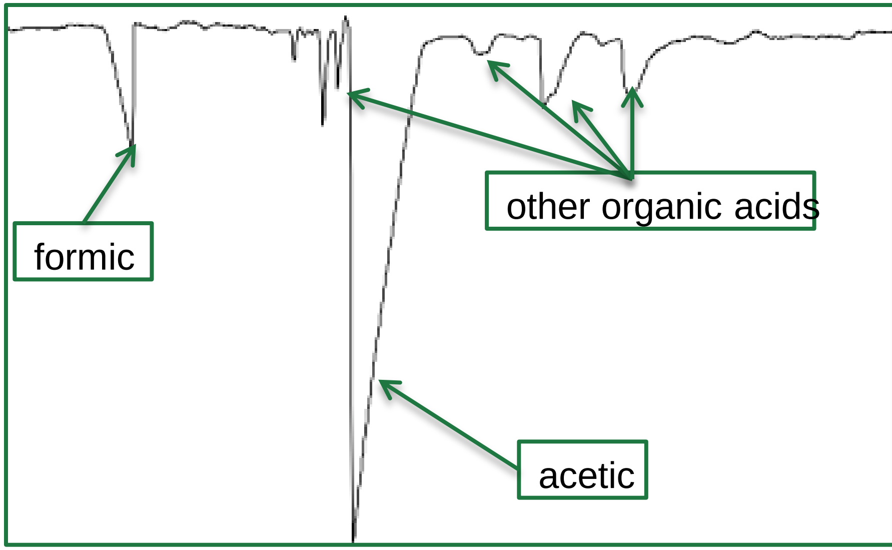
We are investigating bio-oil corrosion to develop and identify compatible materials

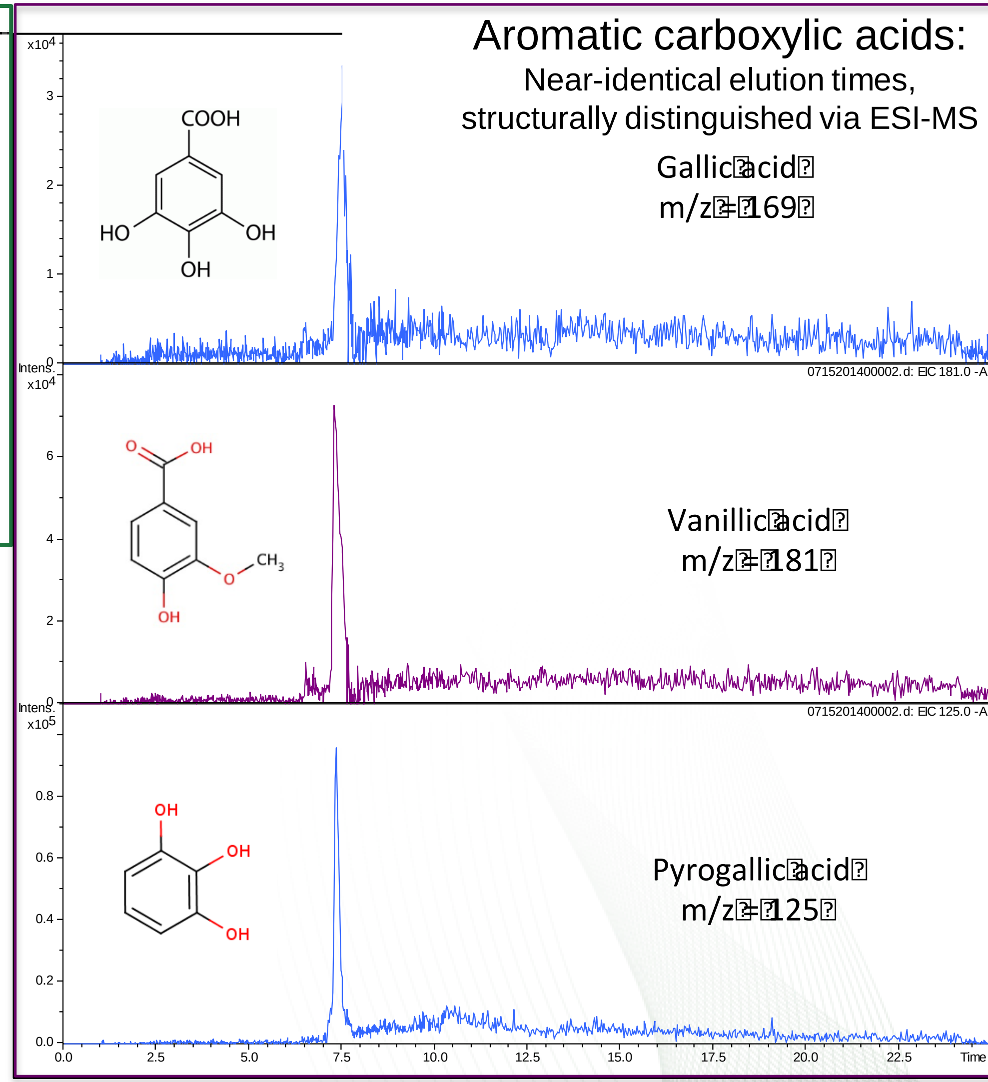
- Selected alloy samples are exposed in the laboratory to various bio-oils at selected temperatures
- Pipe sections made with different alloys are exposed in different biomass production systems
- Post-exposure metallurgical examination provides failure analysis
- Information is used to identify/develop lower-cost alloys
- Strong collaborations (12+ institutions)
- As produced bio-oils are very corrosive to common structural materials because of the significant carboxylic acid content
- Reduction of oxygen content to ≤ about 3.3% results in no corrosion of these materials even at elevated temperature

Atmospheric pressure test systems



Product identification in Bio-oils can help mitigate corrosion & assess material compatibility issues.





- Analytical chemistry applied to complex bio-oil matrices
- Polarity-matched treatment of samples = more accurate extractions, qualitative identification & quantification of oxygenates
- Also benchmarks catalytic upgrading, and valuable components in waste char

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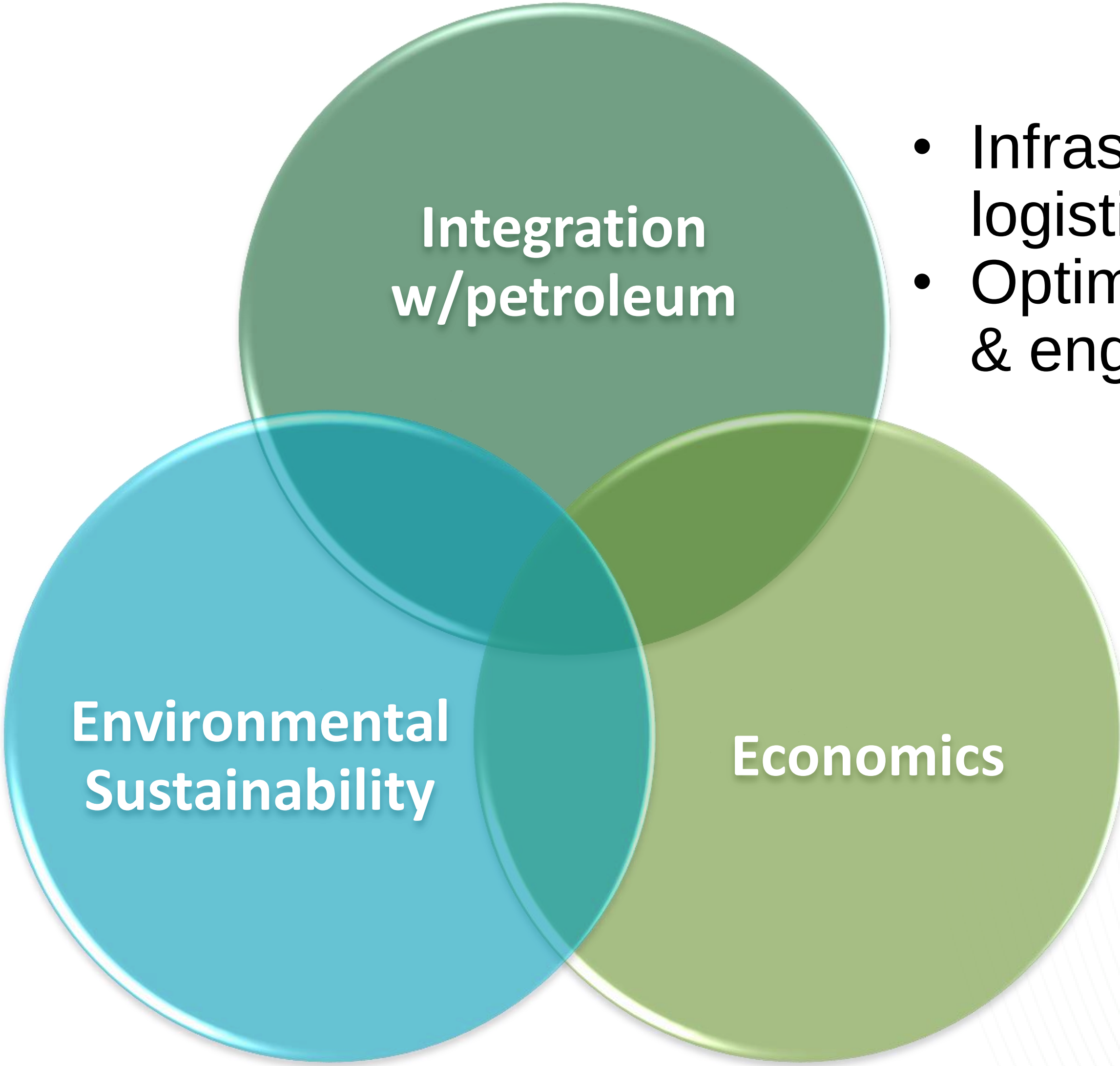
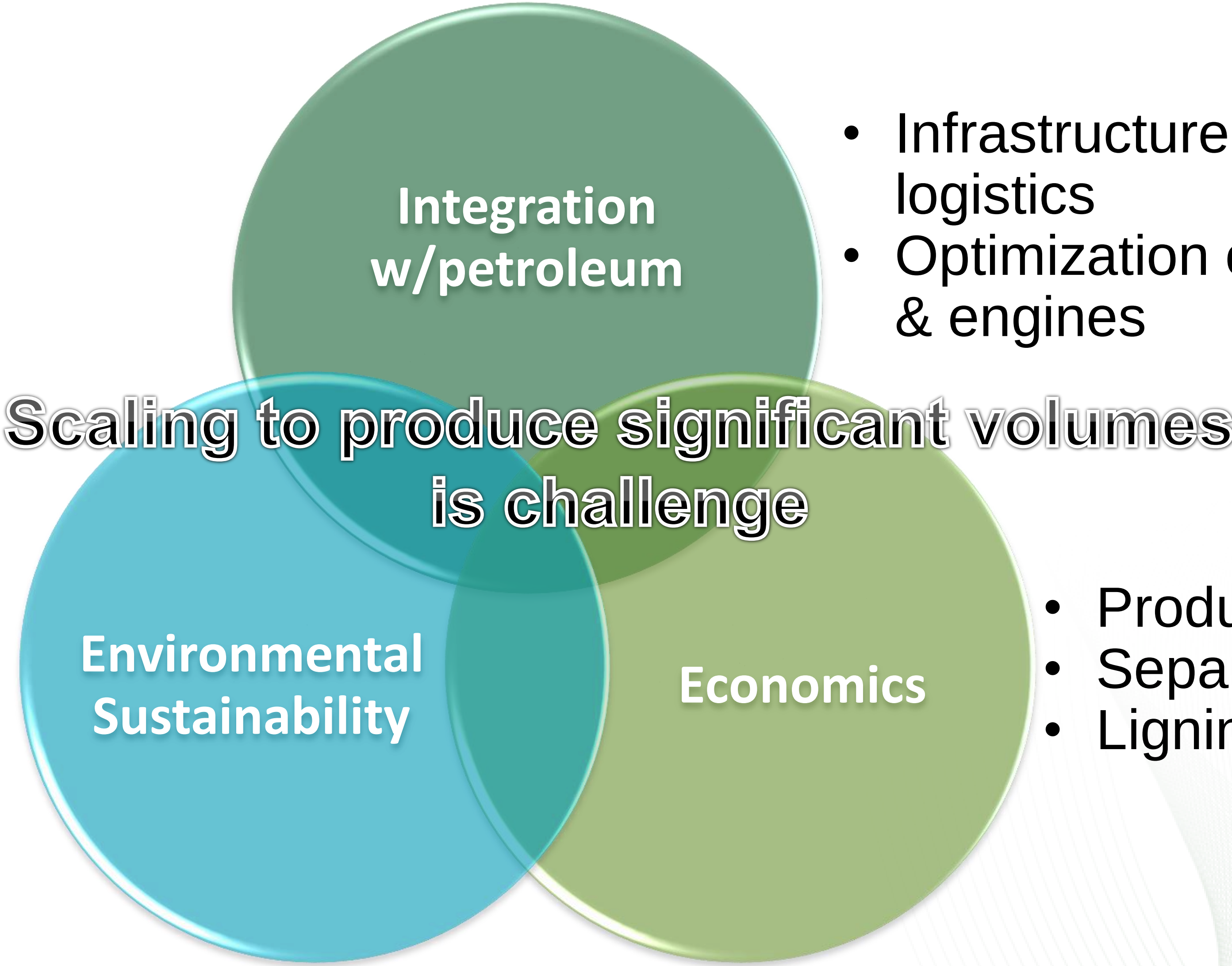
Grand Challenges in bioenergy technology …



- Infrastructure & logistics
- Optimization of fuels & engines

- Productivity
- Separations
- Lignin

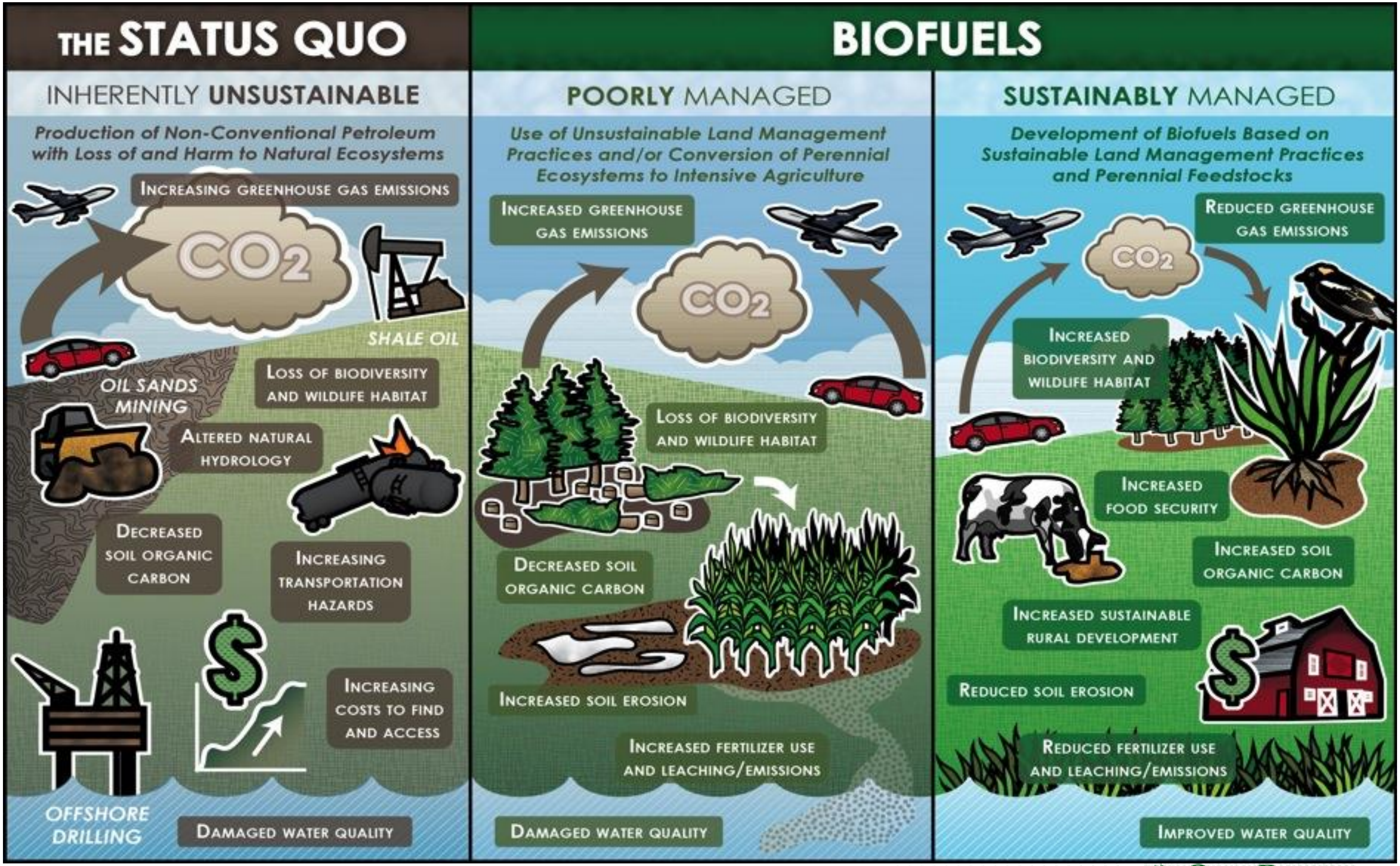
Grand Challenges in bioenergy technology …



- Infrastructure & logistics
- Optimization of fuels & engines

- Productivity
- Separations
- Lignin

Biofuels need to be sustainably managed

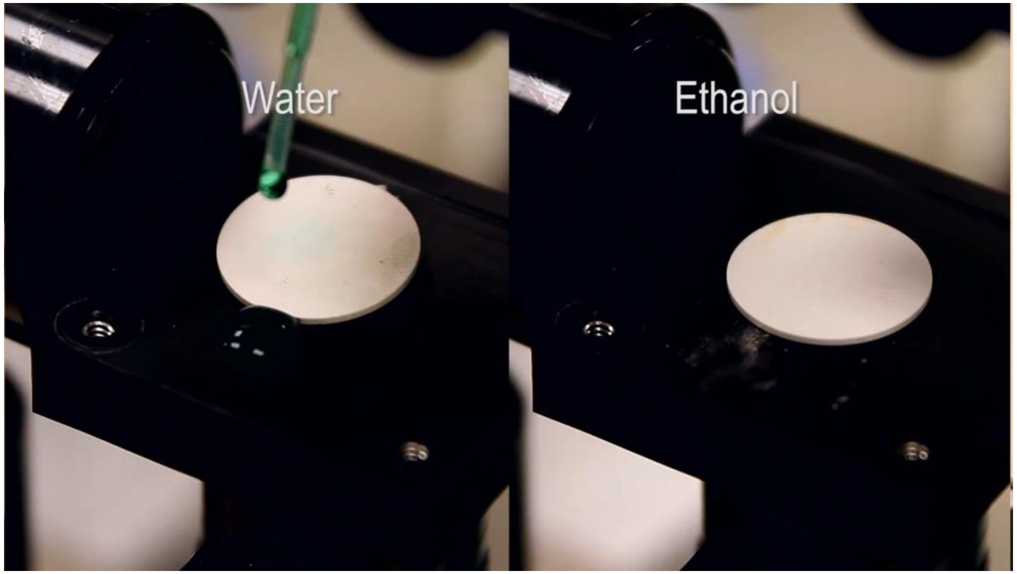


Dale B et al. (2014) Take a Closer Look: Biofuels Can Support Environmental, Economic and Social Goals. Environmental Science & Technology 48(13): 7200-7203.

ORNL develops membranes to speed the biomass conversion process

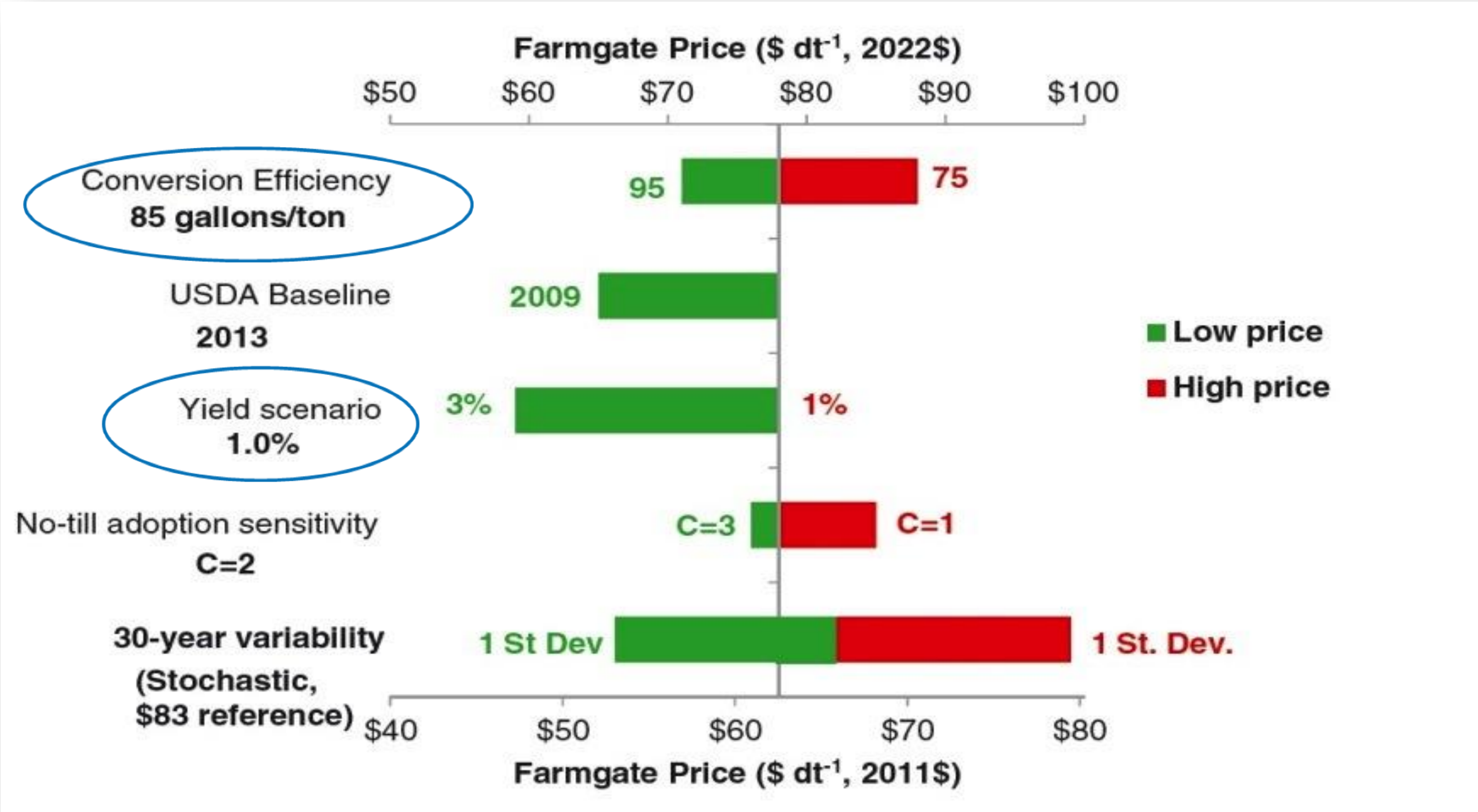
Tunable membranes win R&D 100 Award

- Separations are a common need in both biochemical & thermochemical conversion
  - Oil – water separations
  - Ethanol – water
  - Liquid – vapor phase
- ORNL researchers invented a new class of membranes that can selectively separate molecules in the vapor and liquid phases.
- HiPAS (High Performance Architectured Surface Selective) membranes can be engineered as superhydrophobic or superhydrophilic for use in various stages of the biomass-to-biofuel conversion process.
- These membranes offer an energy-efficient alternative to the distillation process for the biofuels industry.



The same HiPAS membrane can repel water while absorbing ethanol. The tunability of the membrane offers many opportunities for creating greater efficiency, increasing speed, and decreasing costs associated with the production of biofuels. This technology could also benefit the chemical, pharmaceutical, and gas separation industries.

Productivity is key to future advancements



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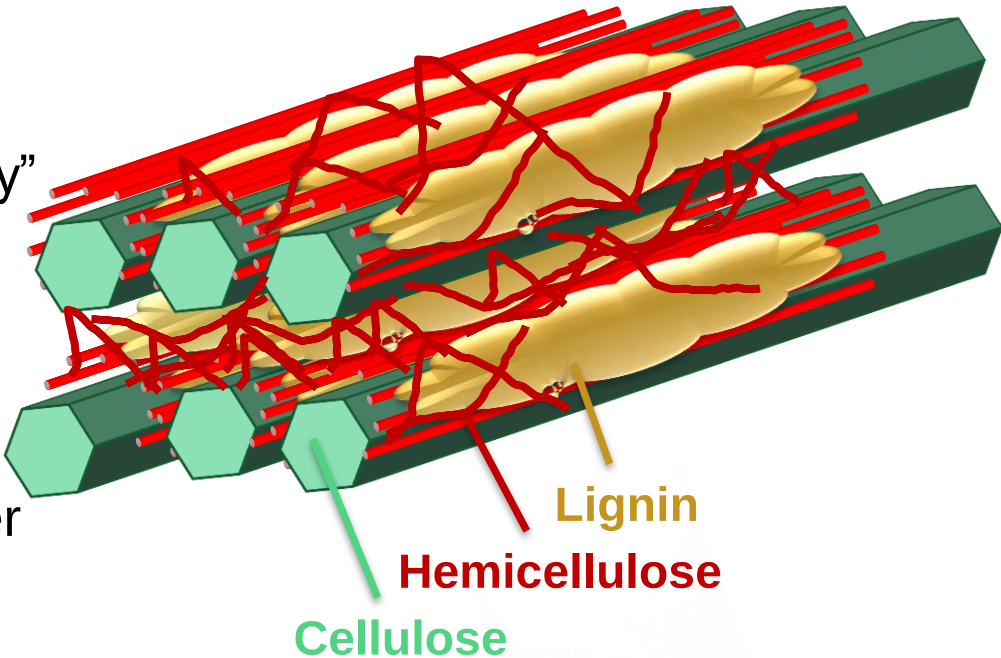
Something has to be done about lignin

- Lignin is significant fraction of plant material (200 MM ton/yr)
- “You can make anything in the world out of lignin … except money”
- Traditionally just burned
- Ability to characterize and manipulate lignin
- Possible use of lignin as pre-curser for carbon fiber
- Many other uses as bio-fuel or bio-product
- Represents significant opportunity for bioenergy (untapped potential)!



cellulose: 35-50%

hemicellulose: 20-35%

lignin: 10-25%

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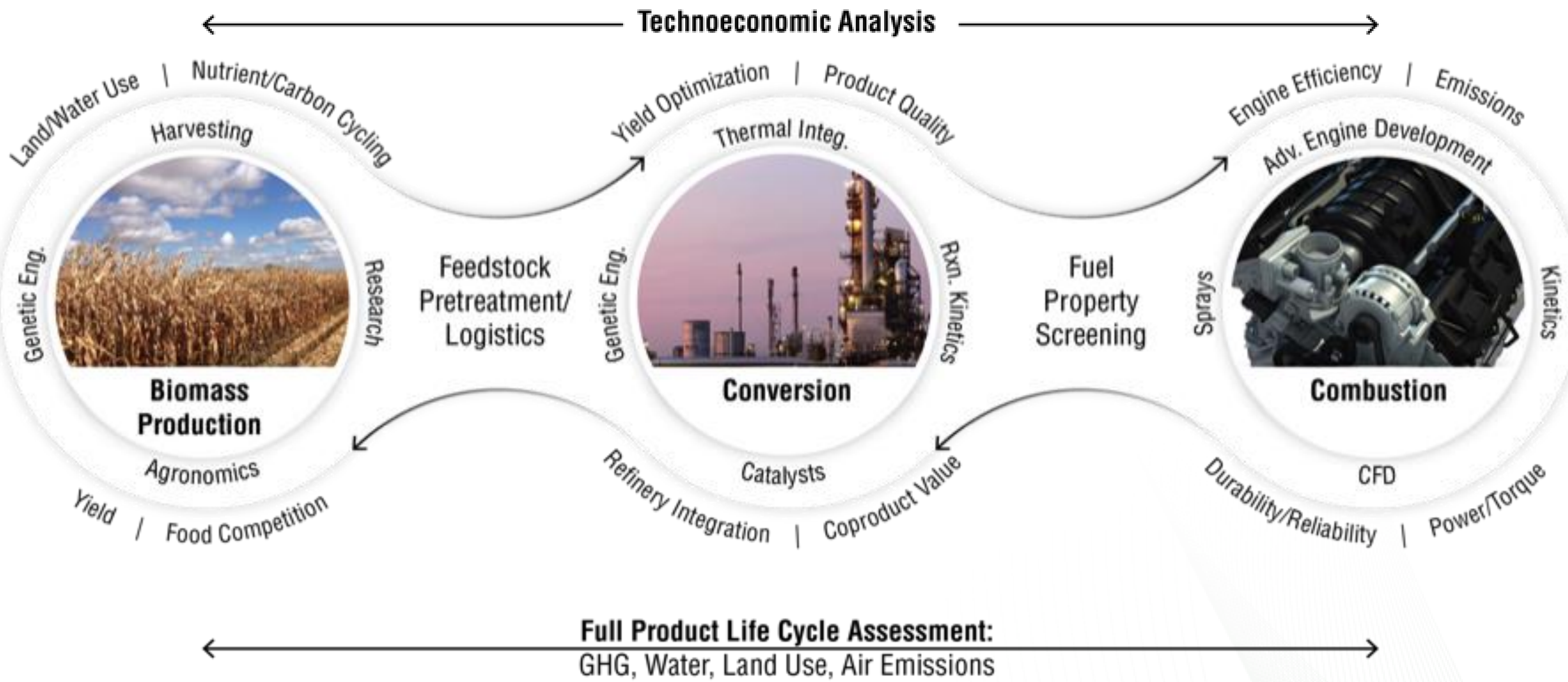
Infrastructure & logistics of biofuels and petro fuels are inherently different

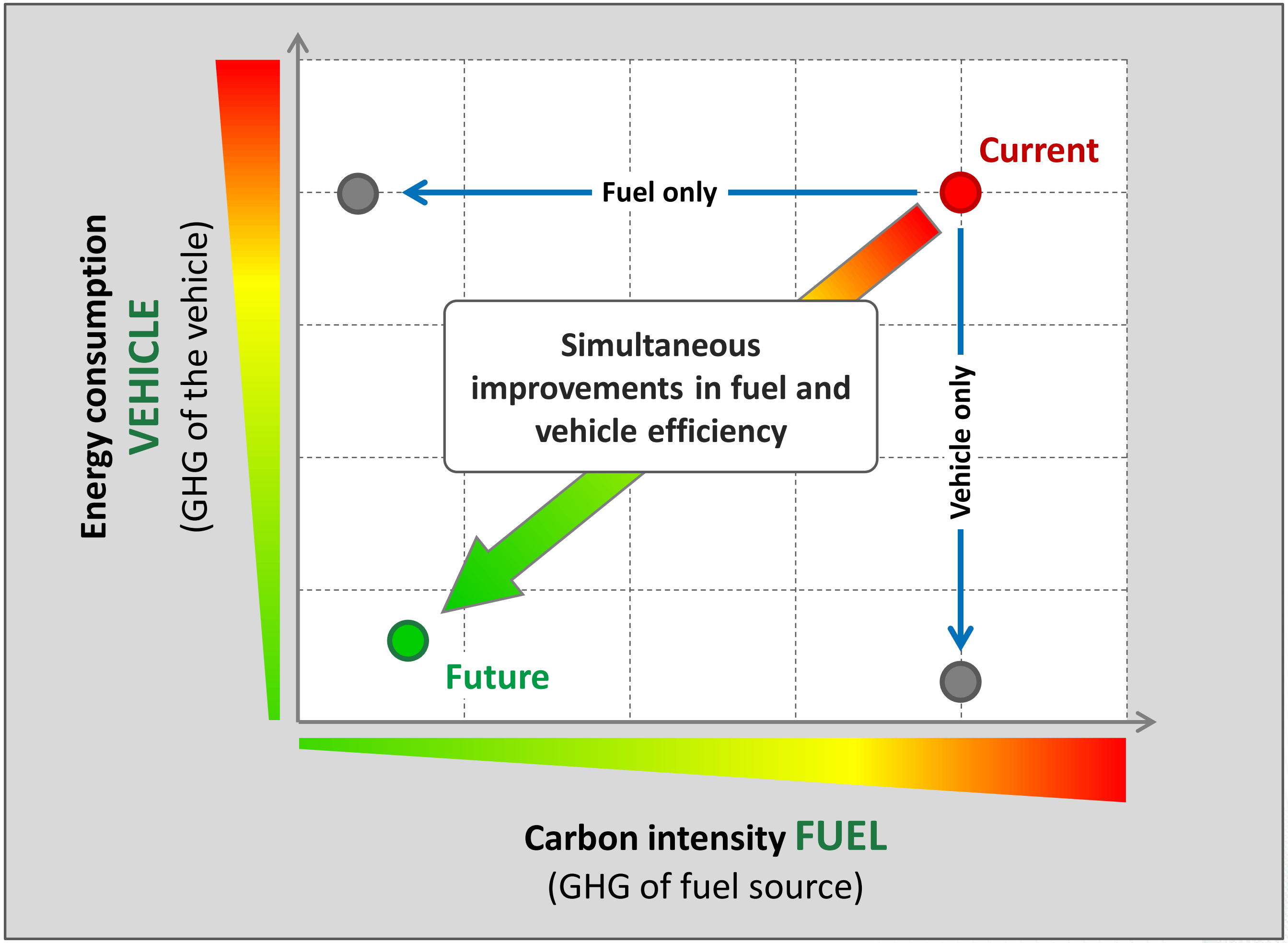
- Petroleum infrastructure consists of refineries, pipelines, terminals, transportation, fueling stations → massive investment
- Size disparity → typical petroleum refinery is 100X size of biorefinery
- Pipelines and transportation schemes differ for petroleum & 1st generation biofuels
- "Drop-in" biofuels will not alleviate the entire issue
- Biomass widely distributed; pipelines in wrong location
- Biomass harvested annually, must be stored (protected) then converted
- Insertion point of biomass into existing system not obvious …
- Need to re-think logistics and combined infrastructure

Effort to link and "optimize" biofuels to engines is underway



Credit: John Farrell, National Renewable Energy Laboratory

Advancements enabling potential for the <u>co-development</u> of fuel and engine technologies for reduced system GHG emissions



Credit: Robert Wagner

IS A "*RENEWABLE SUPER PREMIUM**" A BETTER PATH FOR ETHANOL?

- Engine efficiency can improve with increasing ethanol (in properly designed future engines/vehicles)
  - Chemical octane number + latent heat of vaporization permit higher compression ratio, optimized combustion phasing, increased power (downspeeding/downsizing)
- Likely that optimum blend is ~20-40% ethanol
  - Energy density penalty is *linear* with ethanol concentration, power and efficiency gains are *non-linear*
  - Tradeoff in efficiency, cost, and fuel economy
  - Ideal blend in <u>optimized</u> vehicles could improve fuel economy while using more ethanol
  - **Also legal to use in ~16M legacy Flex-Fuel Vehicles**

* "*Renewable Super Premium*,"
"New regular,"
"High Octane Base Fuel…"
Regardless of name, high octane blends have significant potential

Credit: Brian West

Presentation outline

- Background
- Federal Response
- ORNL Bioenergy Technologies Program
- Bioenergy Grand Challenges
- ➢ Final Thoughts

Conclusions

- Biofuels are already providing significant environmental and energy security benefits
- Additional benefits can be realized with advanced biofuels & bioproducts
- Advanced biofuels and bioproducts are a commercially available (on cusp of viability)
- ORNL is engaged in a comprehensive effort to support DOE for more advanced biofuels/products
- There are several “Grand Challenges” that will need to be solved to achieve optimum results
- But, there are new, real opportunities and realization that biofuels will be a part of any future sustainable transportation system

Acknowledgements

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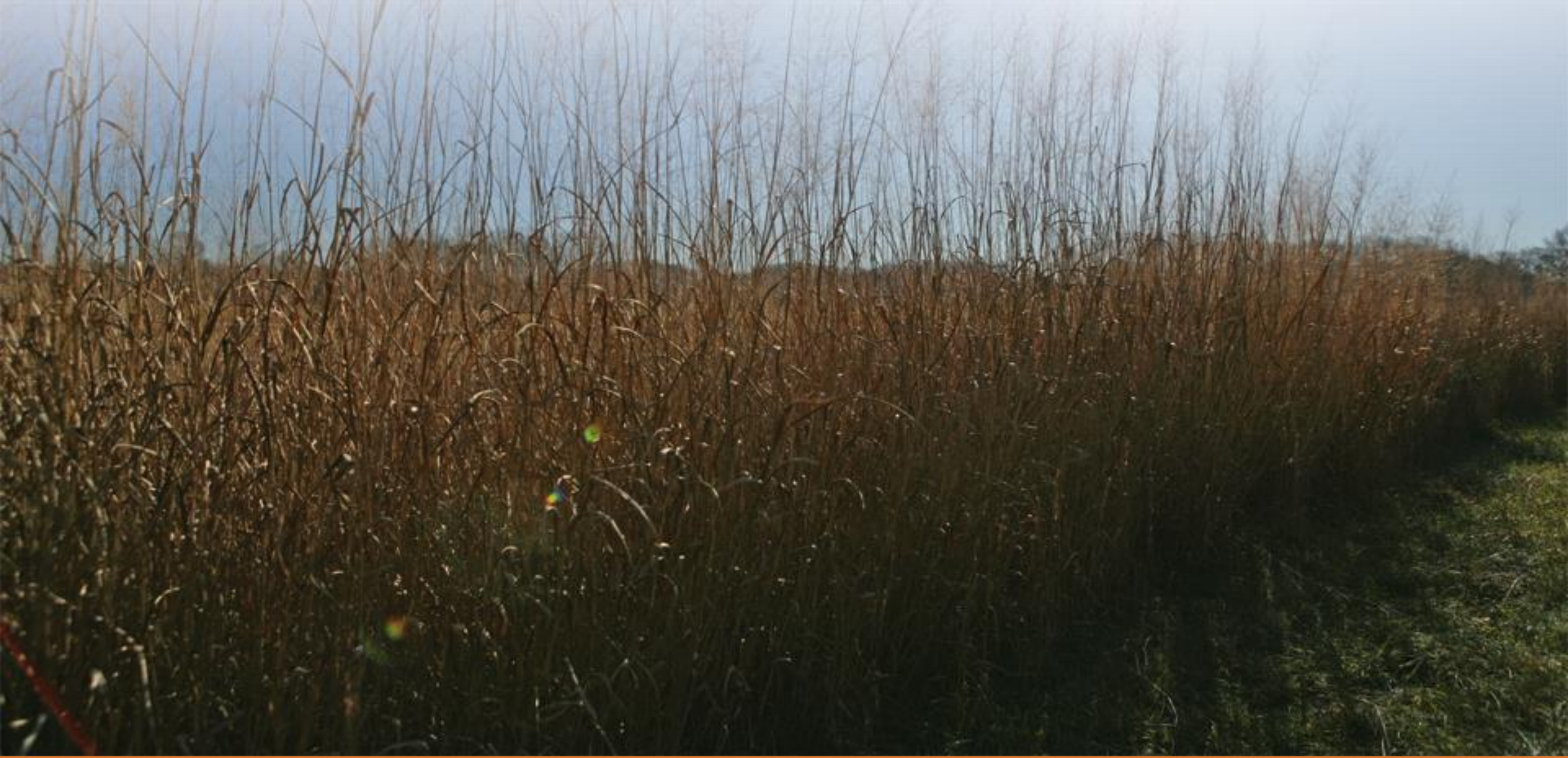
- Brian Davison – Biosciences Division
- John Farrell, National Renewable Energy Laboratory
- Michael Wang & Jennifer Dunn, Argonne National Lab
- Jonathan Male & Jim Spaeth, EERE Bioenergy Technologies Office

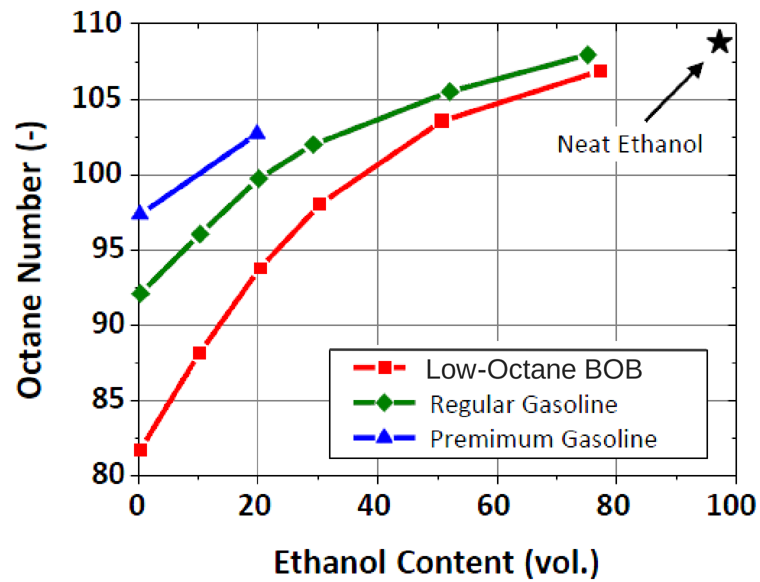
Thank you for your attention!

Tim Theiss
theisstj@ornl.gov
865/946-1348



Ethanol is a very effective octane booster

- ~2/3rd of octane benefit from first 1/3rd of ethanol volume percent
- EPA opened the door for a high octane ~E30 fuel in Tier 3 rule
  - "…we allow vehicle manufacturers to request approval for … fuel such as a high-octane 30 percent ethanol by volume blend (E30) for vehicles … optimized for such fuel"
- Road fuel infrastructure for a mid-level ethanol blend is not trivial (but significantly less complex than hydrogen or other alternatives)
  - Over 3000 E85 dispensers in service, over 16M FFVs on the road that could use RSP *today*



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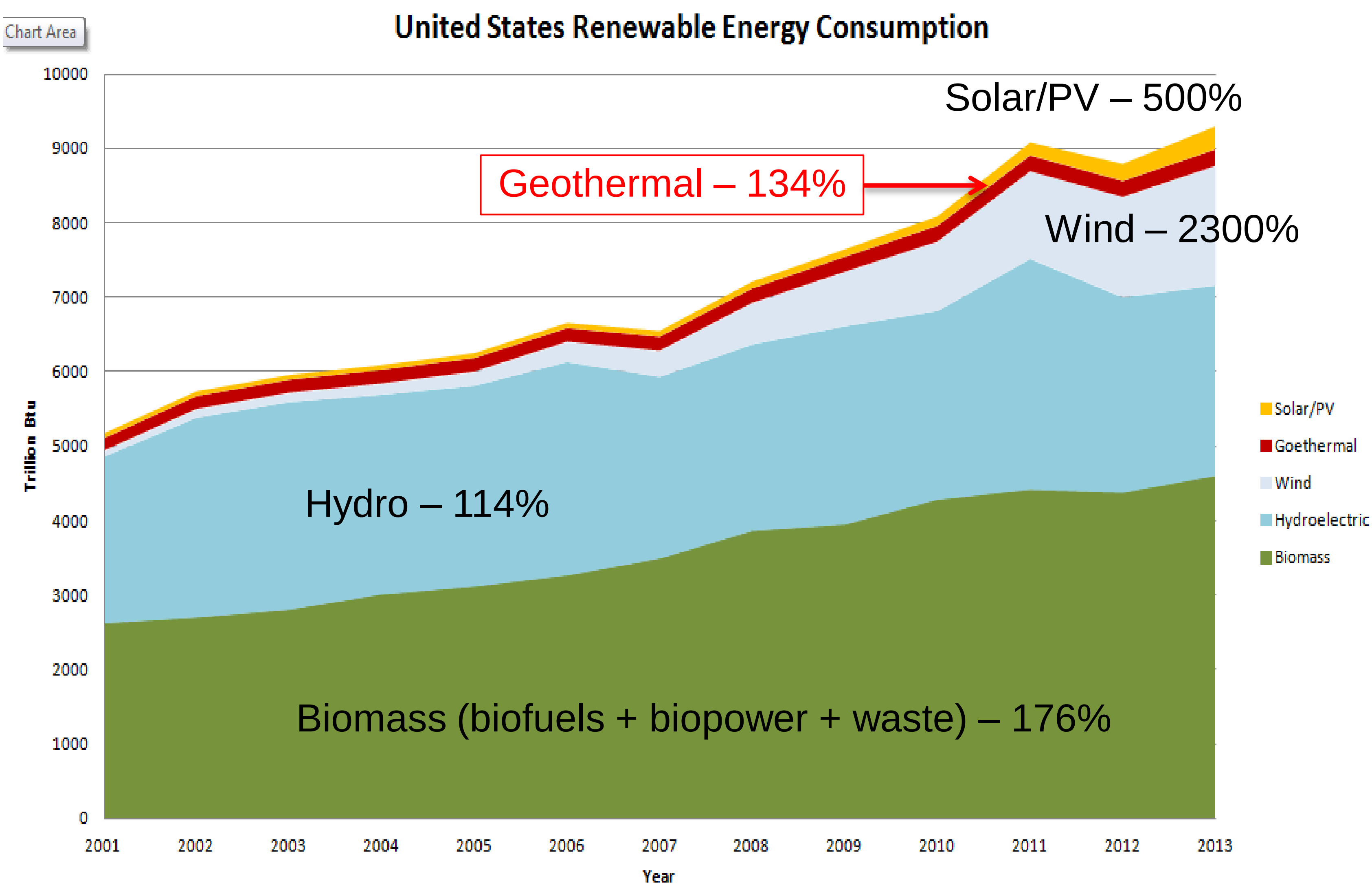
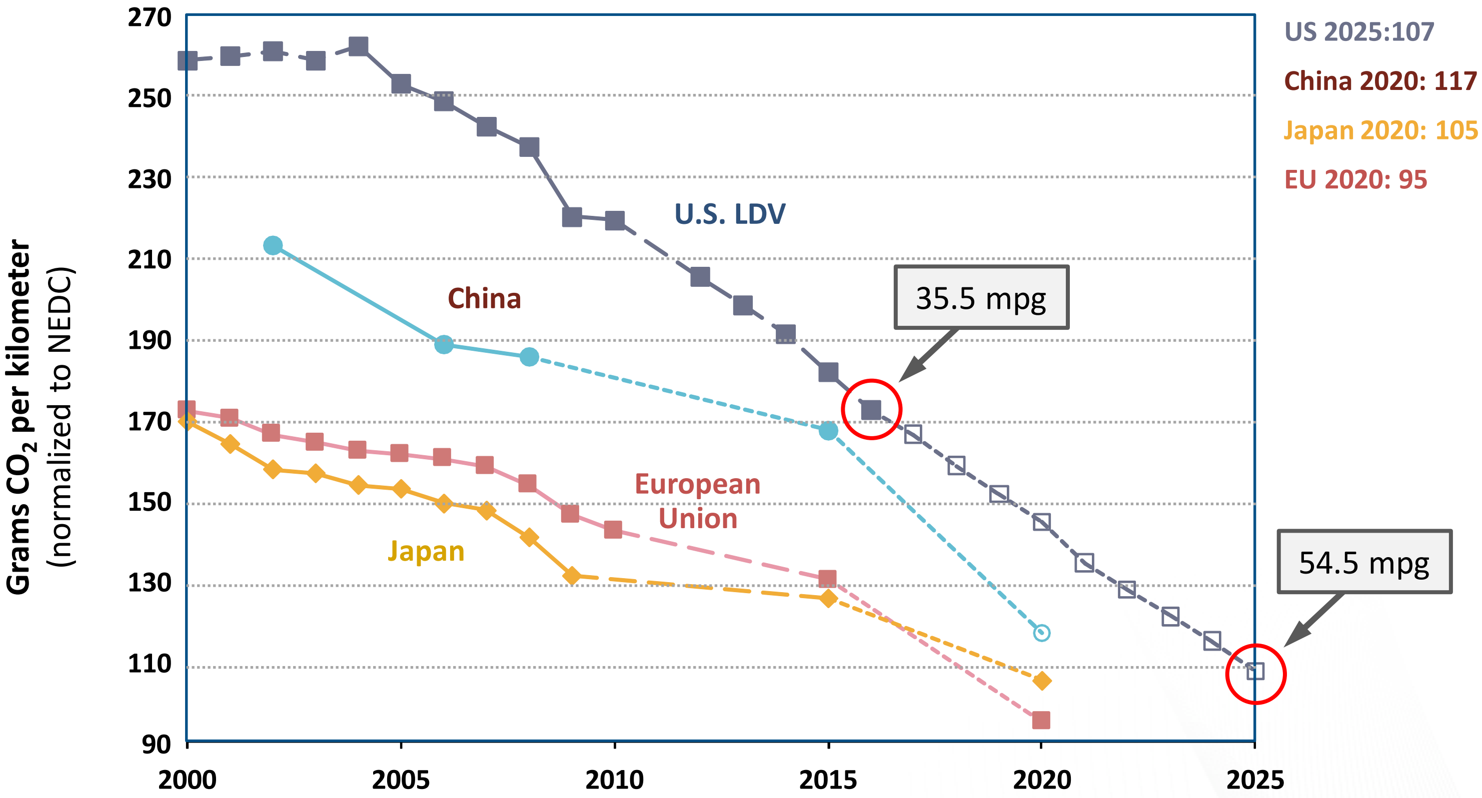
Renewable Energy Use Has Grown Significantly



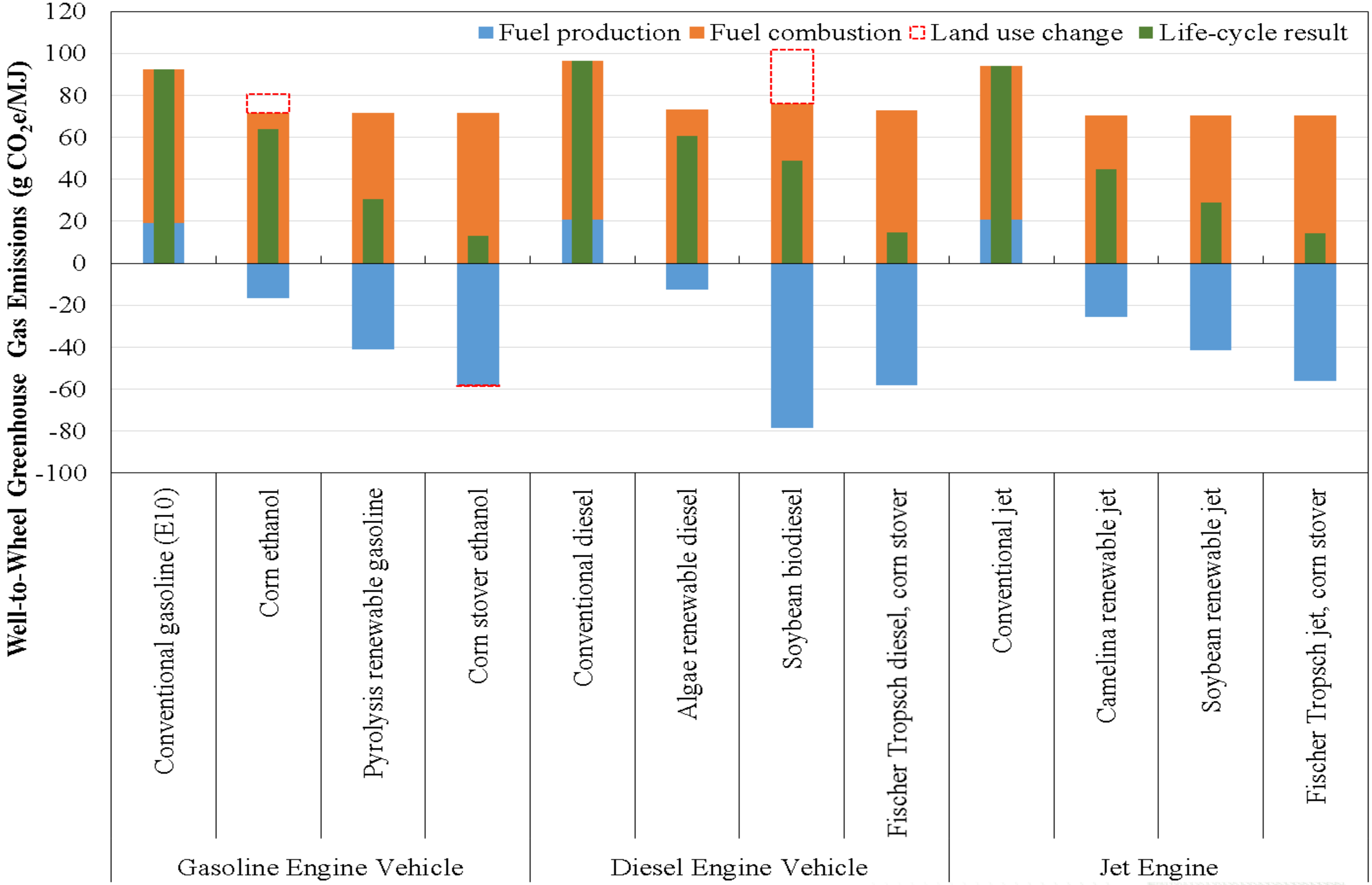
Source: Energy Information Administration, June 2014 Monthly Energy Review

Aggressive CO_2 emissions standards (i.e., fuel economy) are a global trend



[1] China target reflects gasoline fleet scenario. Inclusion of other fuels would lower this target.
[2] U.S. light-duty vehicles include light-commercial vehicles.

Environmental Performance (GHG) of biofuels compared with Petroleum



Biofuels achieve positive fossil energy balance

Biofuel energy balance = energy output - fossil energy input
Biofuel energy ratio = energy output/fossil energy input

	Corn	Sugar-cane	Corn Stover	Switch-grass	Miscanthus
Energy balance: MJ/liter[a]	10.1	16.4	20.4	21.0	21.4
Energy ratio	1.61	4.32	4.77	5.44	6.01

[a] A liter of ethanol contains 21.3 MJ of energy (lower heating value). Values close to or greater than 21.3 MJ are caused by co-produced electricity

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Three Major Challenges Facing the Transportation Industry Over the Next Decade

Can more sensible use of biofuels enable CAFE and RFS simultaneously?

54.5 mpg CAFE by 2025

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

Fuel Economy Standards

Transportation Industry

>70% less NOx

>85% less NMOG

EPA Tier 3 Emission Regulations

Further reductions in vehicle emissions

-per EPA Tier 3 regulations (2014)

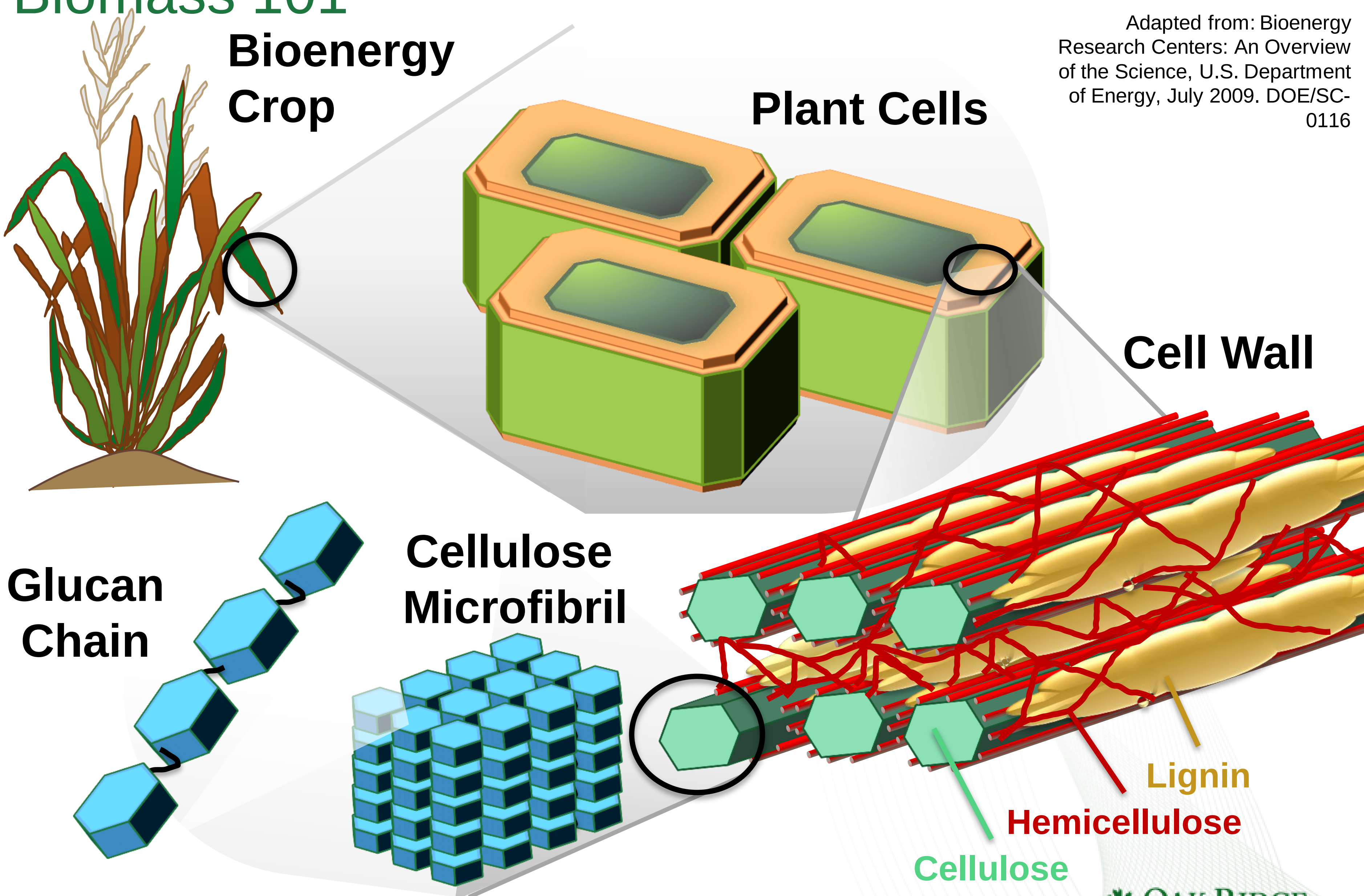
Renewable Fuel Standard

36 billion gallons /yr of renewable fuel by 2022

-per Energy Independence and Security Act of 2007

Biomass 101

Adapted from: Bioenergy Research Centers: An Overview of the Science, U.S. Department of Energy, July 2009. DOE/SC-0116



www.glbrc.org

INEOS New Planet Biorefinery

INEOS, Vero Beach, FL

- Expected to produce 8 million gallons per year of cellulosic ethanol and 6 MW of power from wood and vegetative waste
- initiated commercial production of cellulosic ethanol in July 2013
- First commercial production of cellulosic ethanol in the U.S.

Myriant's Bio-Succinic Acid Plant

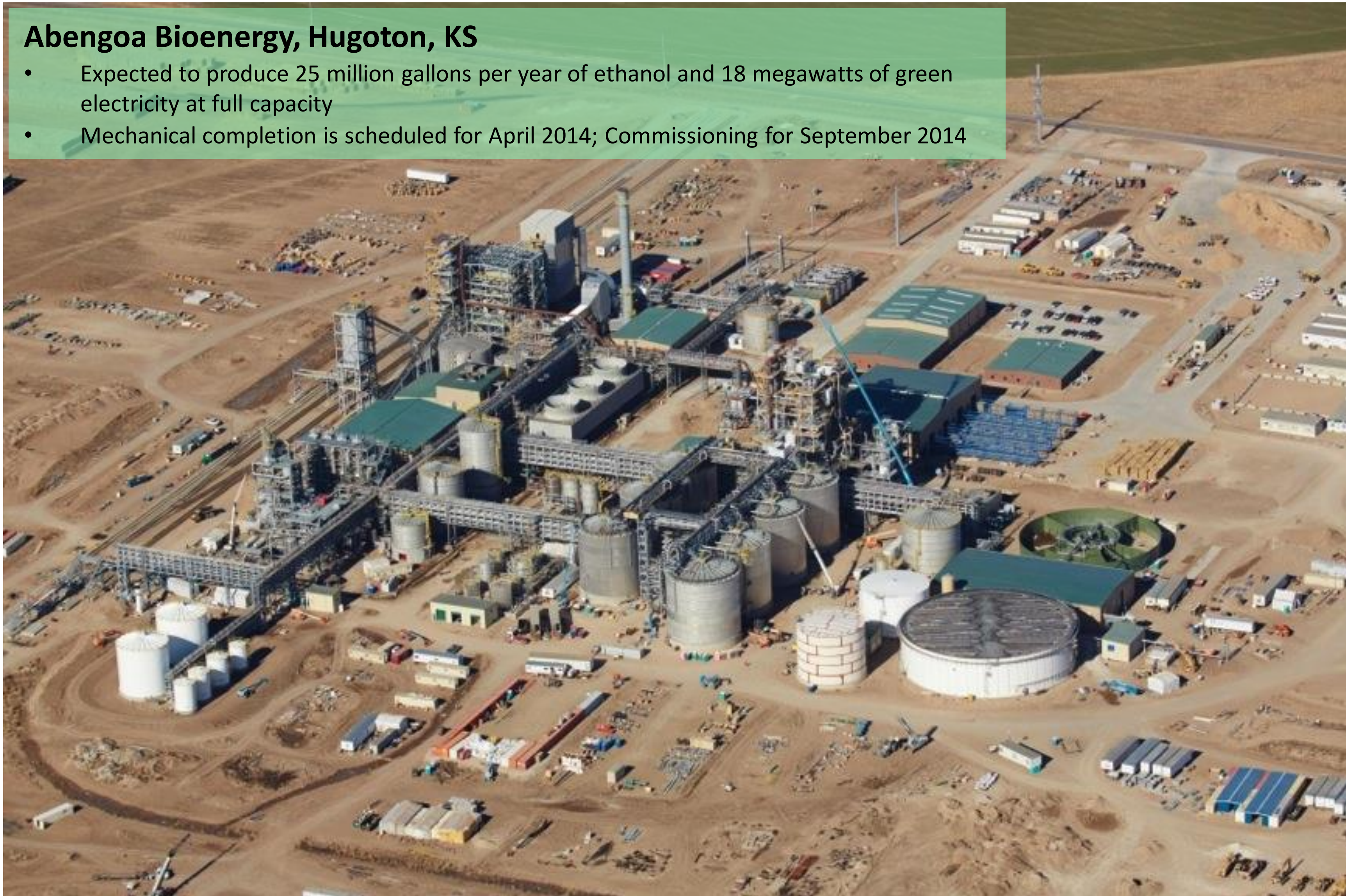
Myriant Succinic Acid Biorefinery , Lake Providence, LA

Biochemical conversion of sorghum grits to succinic acid.

Expected to process 50 dry tons/day to produce 30 Million Lbs/year of succinic acid and gypsum

Abengoa Bioenergy, Hugoton, KS

- Expected to produce 25 million gallons per year of ethanol and 18 megawatts of green electricity at full capacity
- Mechanical completion is scheduled for April 2014; Commissioning for September 2014



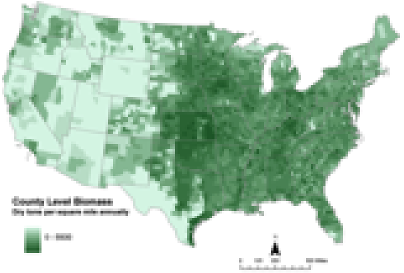
POET-DSM Project LIBERTY, Emmetsburg, IA

- Expected to produce 20 million gallons per year of cellulosic ethanol at full capacity
- Major construction began November 2012, Ribbon cutting September 2014!

ORNL Support for Bioenergy Technologies Office (BETO)

- Economic security with biofuels
- Defining bioenergy sustainability
- National & Global Sustainability metrics
- Water quality & biodiversity
- Best Management Practices for energy crops
- Bioenergy Knowledge Discovery Framework

- Strategic Analysis & Environmental Sustainability



- Feedstock supply projections
- Biomass engineering (logistics)

- Feedstock Supply & Logistics

- Catalytic upgrading of ethanol to HC
- Novel catalyst for bio-oil upgrading
- Computational Pyrolysis Consortium
- Materials compatibility of bio-oils
- Advanced membranes for separation

- Biomass Conversion (Biochemical & Thermochemical)

- Codes & Standards (fire codes harmonization)
- High octane renewable super premium fuel

- Demonstration & Market Transformation

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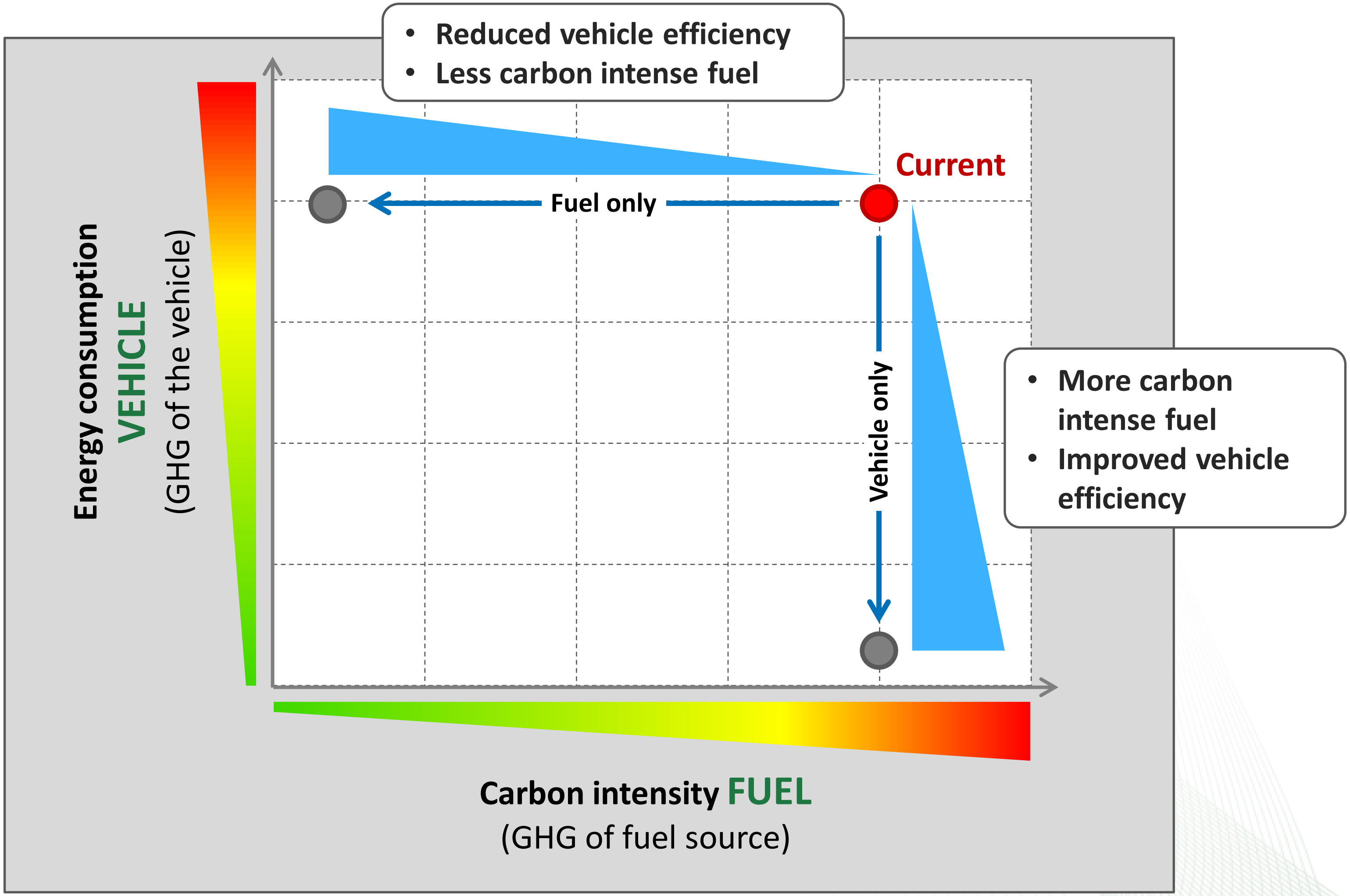
Another scenario is an increase in the GHG of the vehicle (fuel) to enable a significant decrease in the GHG of the fuel (vehicle)



Current trajectory on energy demand illustrates a mismatch between gasoline/diesel usage and refinery configurations

- Passenger vehicles will become more efficient and less miles driven
- Increase in diesel usage driven by developing countries and commercial sector
- Significant refinery investments will be required on current path
- End result is significant volume of excess low octane gasoline

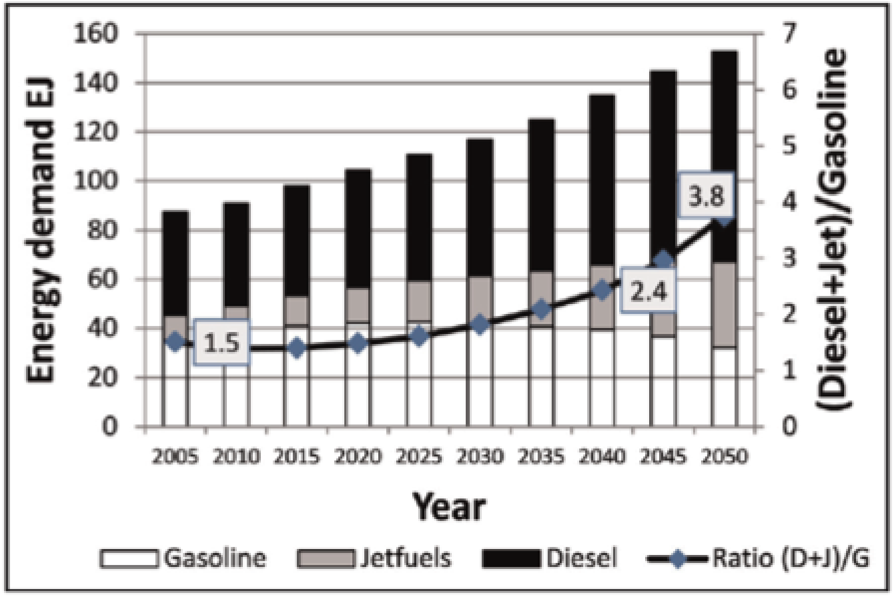
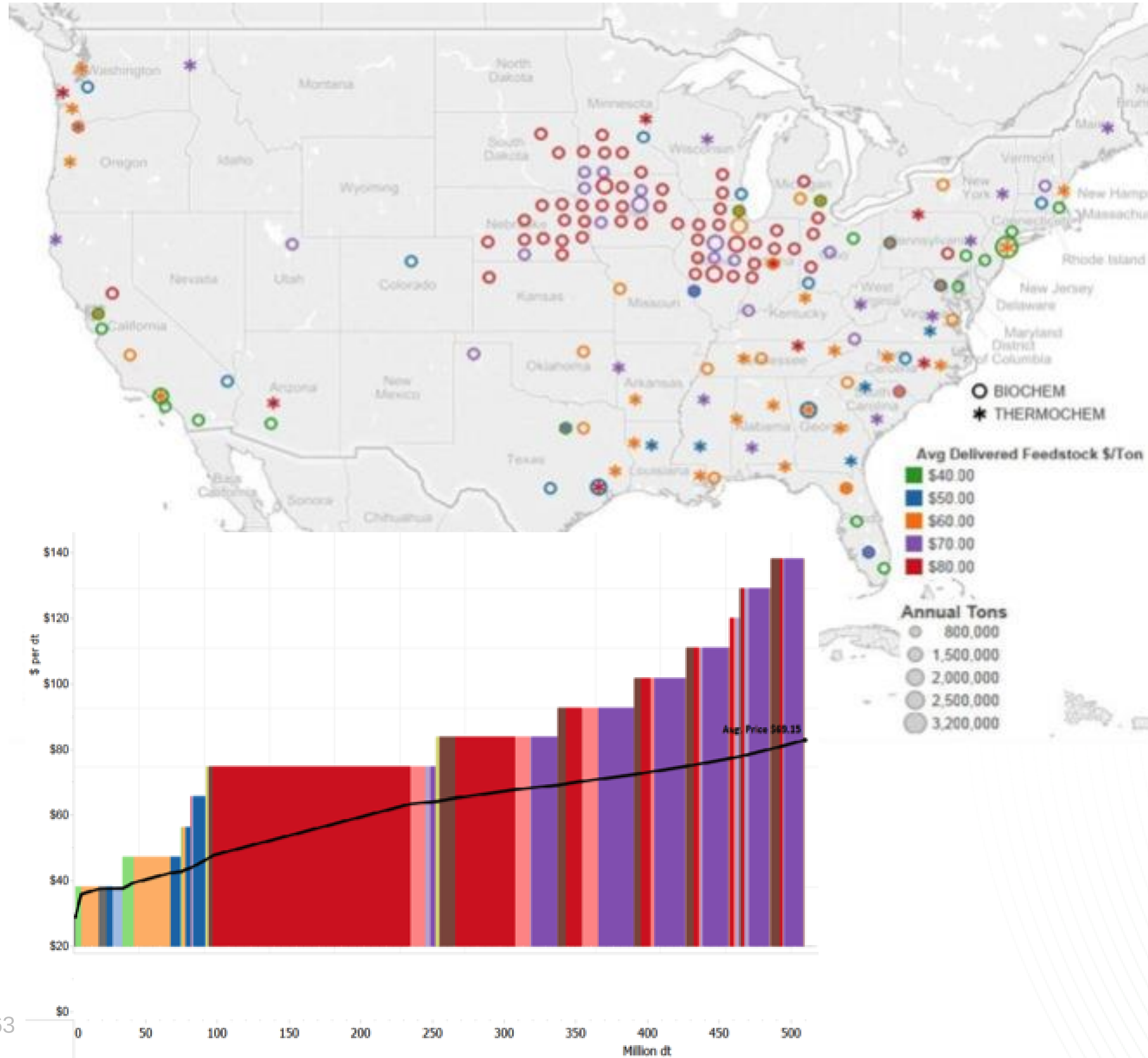


Figure 2. Projections for gasoline, jet fuel and diesel demand (Exa Joules, EJ) in the Freeway scenario of the World Energy Council.[8]

Potential opportunity for biofuels and technology to help offset mismatch between fuel usage and refinery configurations

<u>Reference:</u> Gautam T Kalghatgi, "The outlook for fuels for internal combustion engines", International Journal of Engine Research June 2014 vol. 15 no. 4 383-398.

Recent supply analyses develop supply curves and biorefinery location & cost maps



- Refinery map includes feedstock cost, haul costs and pre-processing costs
- Biochemical plants tend to use herbaceous feedstocks in Mid-West
- Thermochemical feedstocks tend toward woody crops in SE, NE, NW

Advanced biofuels and bioproducts are a commercial reality !

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✓ Additional biorefineries are under construction – 88 MGY

✓ Close to EISA cellulosic ethanol 2010 mandated volume 5 years later