National Renewable Energy Laboratory
Innovation for Our Energy Future

Cellulosic Ethanol and Advanced Biofuels Overview

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NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC

The Biorefinery Concept

- Trees
- Grasses
- Agricultural crops
- Residues
- Animal wastes
- Municipal solid waste

- Enzymatic fermentation
- Gas/liquid fermentation
- Acid hydrolysis/ fermentation
- Gasification
- Combustion
- Co-firing
- Pyrolysis

Uses

Fuels
- Ethanol
- Renewable diesel

Power
- Electricity
- Heat

Chemicals
- Plastics
- Solvents
- Chemical intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty acids
- Acetic acid
- Carbon black
- Paints
- Dyes, pigments, and ink
- Detergents

Food and Feed

U.S. National Commitment to Biofuels

<u>Near-term</u> – Cost Goal

"Cost-competitive cellulosic ethanol"

- Cost-competitive in the blend market by 2012

<u>Longer-term</u> – Volumetric Goal

EISA (Energy Independence & Security Act)

- **36 billion** gallons renewable fuel by 2022
  - **21 billion** gallons cellulosic + advanced biofuels

Renewable Fuel Standard (RFS) goals for biofuels penetration are based on specific GHG reductions from the fossil fuel it replaces.

• Biomass-based diesel	50% reduction
• Advanced biofuels	50% reduction
• Corn grain-based ethanol	20% reduction
• Cellulosic Biofuels	60% reduction

NREL Research Overview

NREL’s National Bioenergy Center Facilities

Thermochemical Conversion

- Micro-reactors to pilot plants

Biochemical Conversion

- Bench scale to ton/day

Genomics Laboratory

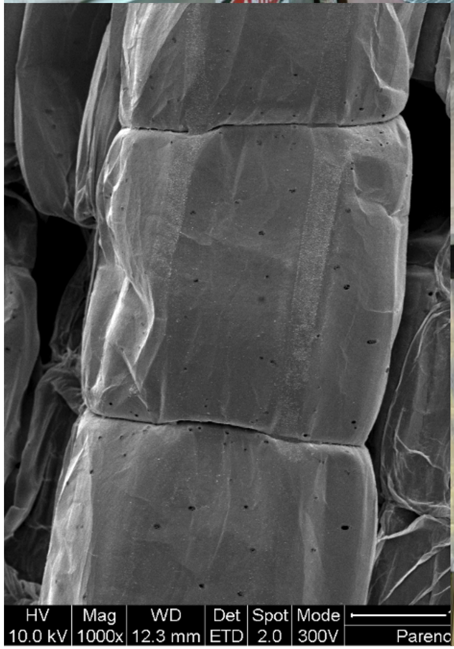
- Tools for strain development

Biomass Characterization

- Wet chemical and NIR

Spectroscopy Facilities

- nmr, IR, LIBS, MBMS



Biomass Feedstock Overview

- Feedstock cost and logistics research for DOE is carried out at Idaho and Oak Ridge National Labs
- Key challenges:
  - Collection, processing and storage logistics
  - Consistent supply and quality
  - Quantity sufficient to justify large biofuels plants
- Biomass ultimately needs an industrial-class distribution system similar to corn

Short rotation poplar
ZeaChem, Inc.

Cellulosic ethanol research at NREL

Biochemical Ethanol

Cellulosics → Chemical Pretreatment → Enzymatic Hydrolysis $\xrightarrow{\text{Sugar}}$ Fermentation → Ethanol

NREL core research includes:

- Increase pretreatment conversion
- Reduce enzyme cost
- Reduce commodity chemical usage

2008 State of Technology predicts $2.61/gal ($3.92/gal gas equiv.)

Thermochemical Mixed Alcohols

Cellulosics → Indirect Gasification $\xrightarrow[\text{CO+H}_2]{\text{Syngas}}$ Catalytic Synthesis $\xrightarrow[\text{alcohols}]{\text{Mixed}}$ Separation → Methanol / Ethanol / Propanol+

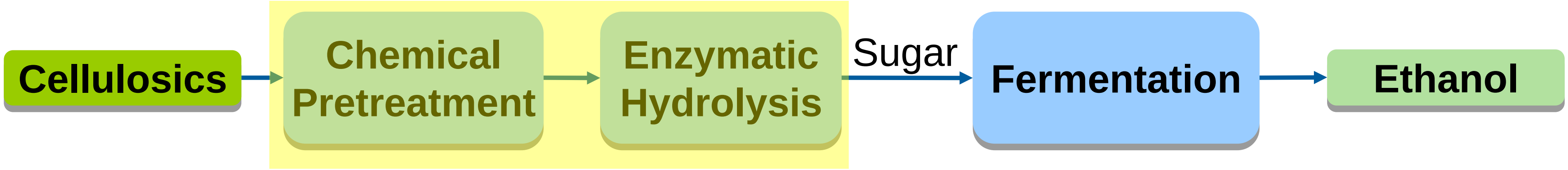
NREL core research includes:

- Increase tar reformer conversion
- Identify sulfur mitigation solution
- Improve alcohol synthesis catalyst performance

2008 State of Technology predicts $2.40/gal ($3.60/gal gas equiv.)

Cellulosic ethanol research at NREL

Biochemical Ethanol



- Conversion of biomass to sugar is reasonably well understood
- Remaining challenges are not specific to ethanol as a product
- What else can sugar be used for?

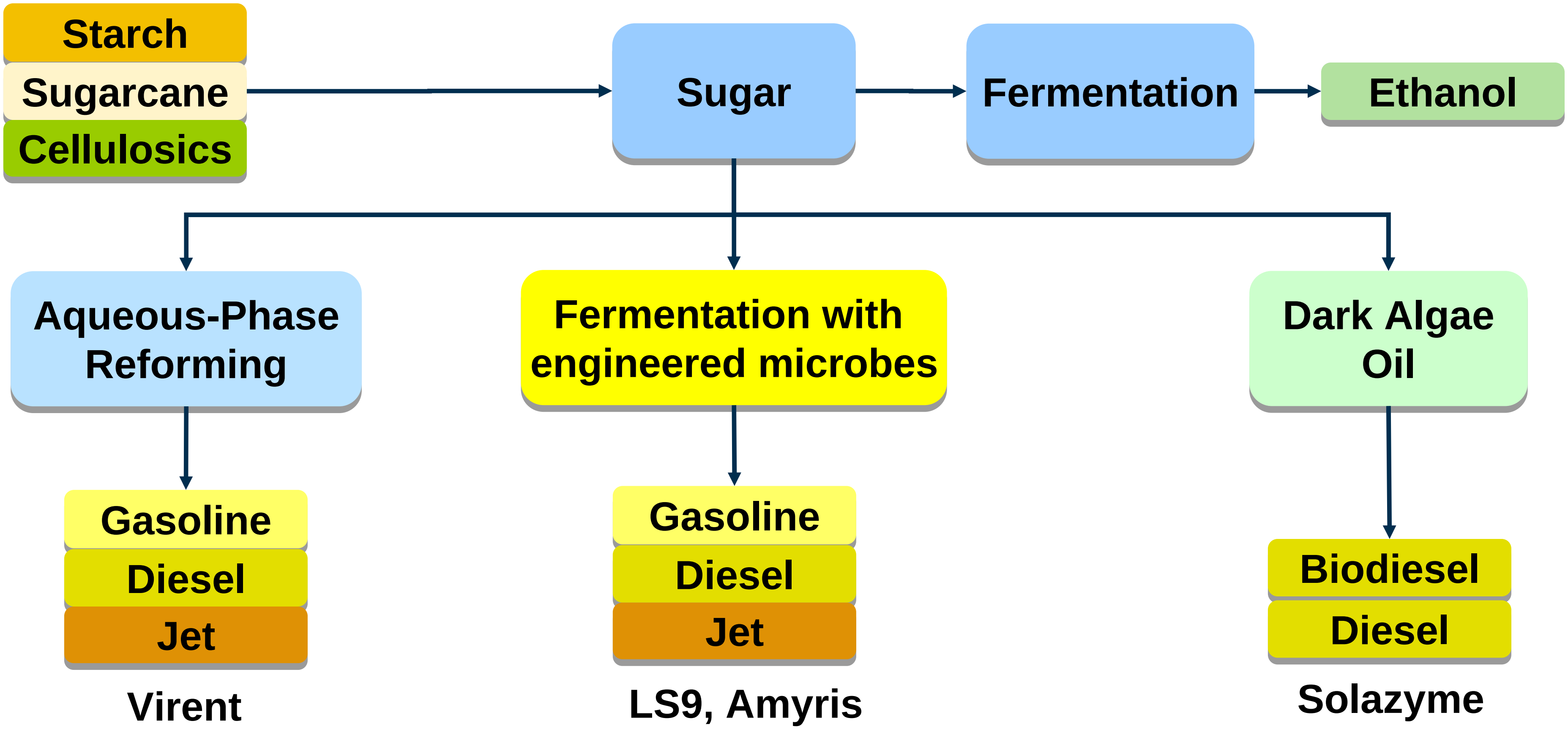
Thermochemical Mixed Alcohols

- Current catalyst selectivity is marginally acceptable
- Mixed alcohol separation adds cost and complexity
- What else can syngas be used for?

Future options for liquid fuel

	RENEWABLES		
	SUGAR	**SYNGAS**	**FATS & OILS**
Now	Corn Ethanol		Biodiesel
Near-term	Cellulosic Ethanol	Ethanol (catalytic)	Green diesel
	Higher alcohols	Ethanol (fermented)	
	Renewable Hydrocarbons	Fischer-Tropsch	Pyrolysis oil
Long-term	Algae diesel (dark)	Methanol to gasoline	Algae diesel (photosynth.)

Advanced biofuels from sugar



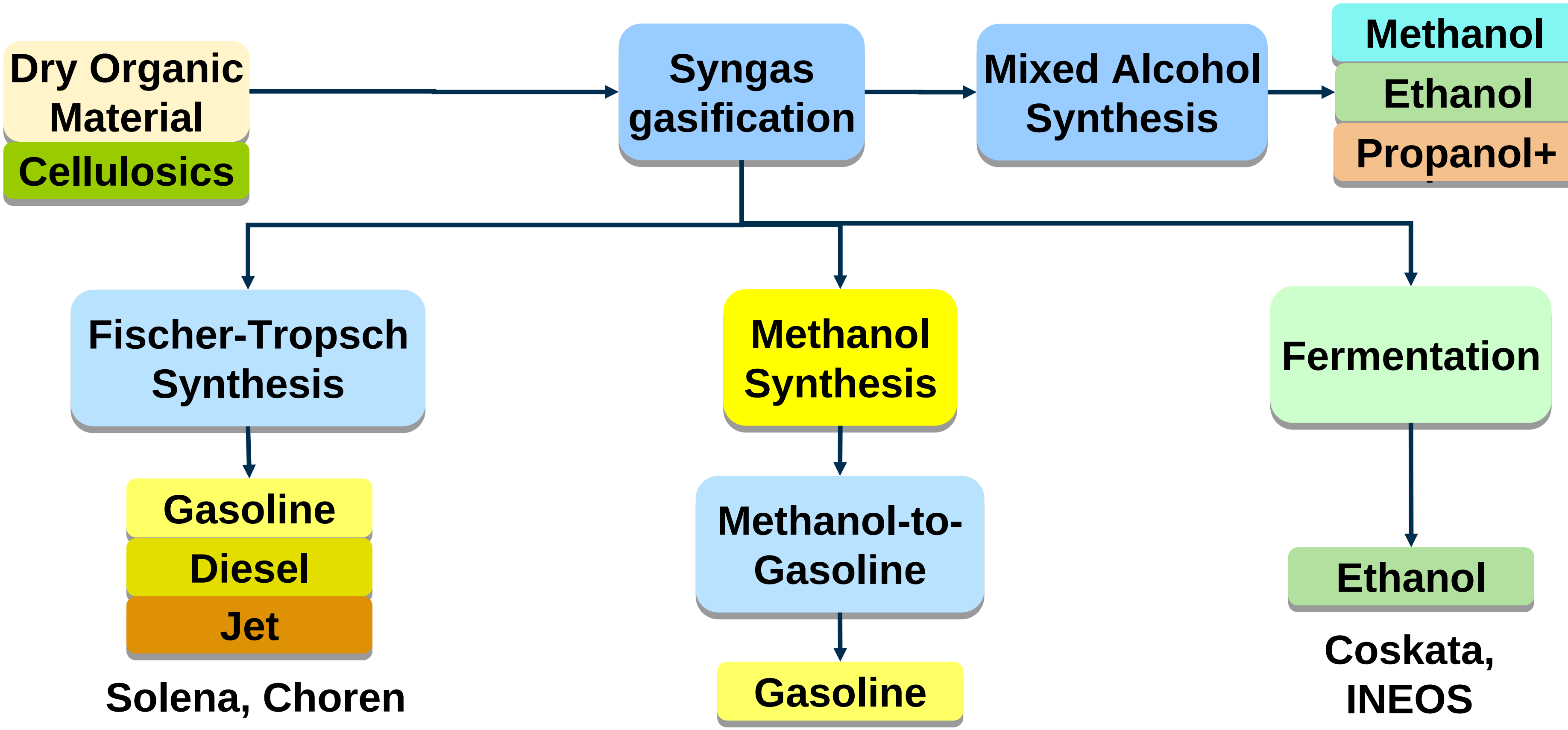
Benefits

- Infrastructure-compatible
- Highly controlled fuel properties

Challenges

- Feedstock availability
- Compatibility with cellulosic sugar

Advanced biofuels from synthesis gas



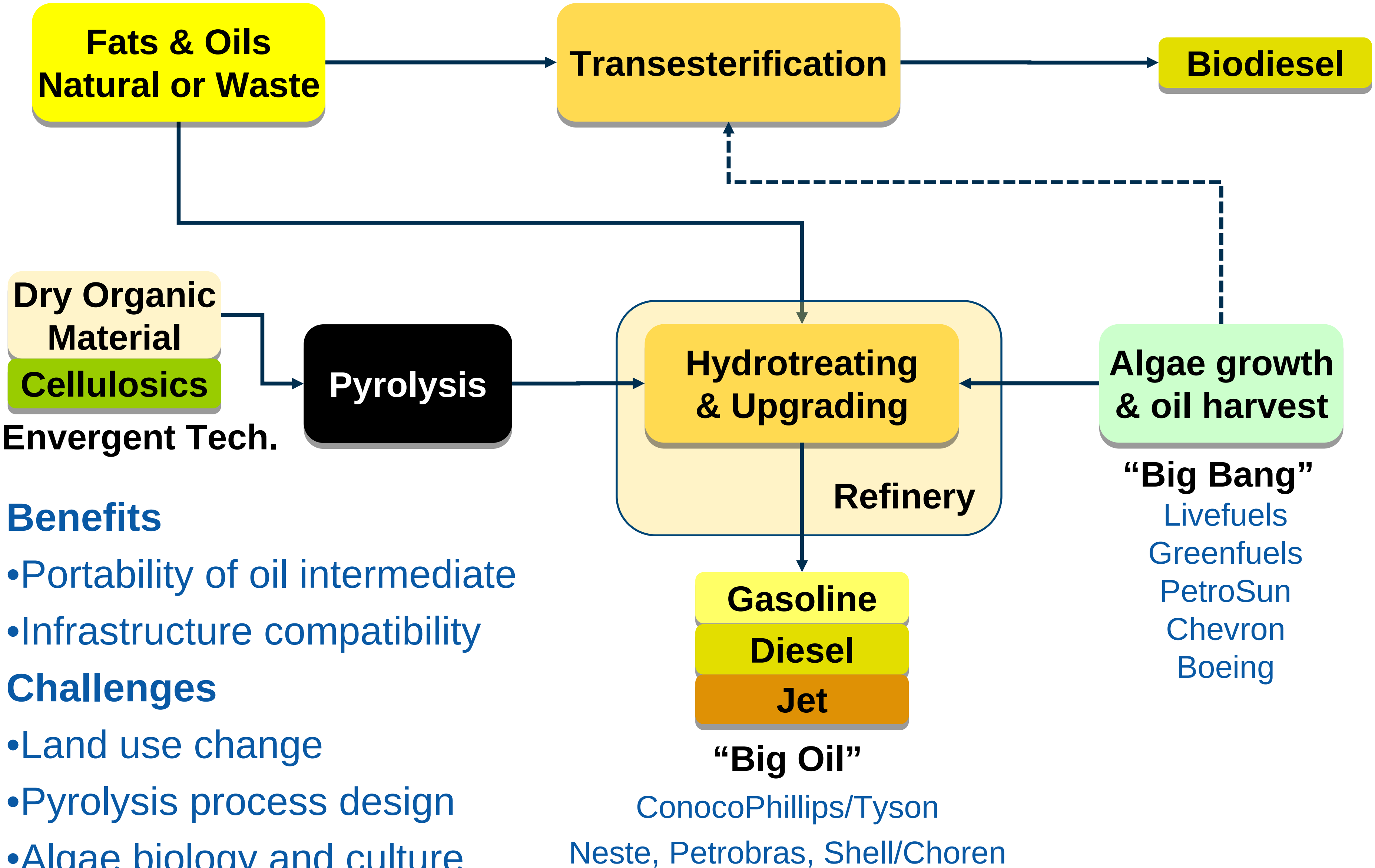
Benefits

- Product versatility
- Proven technology

Challenges

- Biomass collection radius dictates smallish plant size
- Limited economy of scale

Advanced biofuels from fats and oils



Benefits

- Portability of oil intermediate
- Infrastructure compatibility

Challenges

- Land use change
- Pyrolysis process design
- Algae biology and culture

Fuel Summary Table

Near Term

	Technology Status	Production Barriers	Market Barriers	Top Inhibitor
Biochemical Ethanol	Pilot/Demo	Low	Medium	Feedstock availability
Thermo Mixed Alcohols	Pilot/Demo	Low	Medium	Feedstock availability
Green Diesel	Demo	Low	Low	Feedstock cost vs. oil
Fischer-Tropsch Diesel	Demo	Medium	High	Capital Investment
Methanol-to-Gasoline	Demo	Medium	High	Capital Investment
Renewable Hydrocarbons	Lab/Pilot	Medium	Medium	Feedstock availability
Pyrolysis oil	Lab	High	Low	Process Technology
Algal Diesel	Lab	Very High	Low	Process Technology

Long Term

Summary and Conclusions

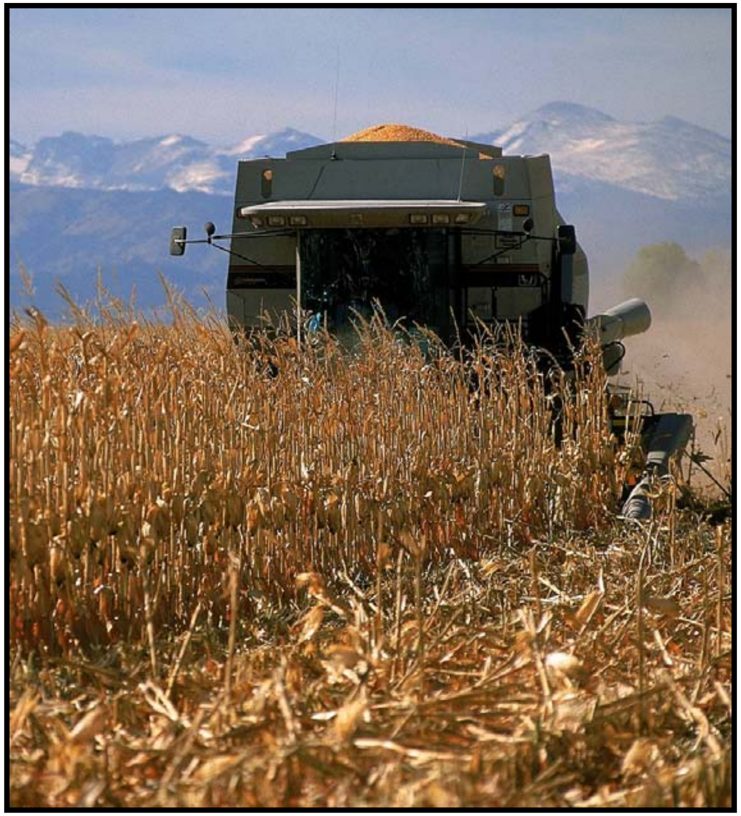
Biofuels are the only renewable option for liquid transportation fuels

Ethanol and biodiesel are the best near-term options for deployment, but we must transition to cellulosic biomass

NREL researchers are working to reduce ethanol conversion costs and provide public information on biofuel production economics

Cellulosic ethanol is in the pilot stage with several demo plants planned

Several options for advanced biofuels with better infrastructure compatibility are on the horizon



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http://www.eere.energy.gov/biomass

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- **Andy Aden, Abhijit Dutta, David Hsu**
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