National Renewable Energy Laboratory
Innovation for Our Energy Future

Partnerships for Advanced Biofuels

John Ashworth
Team Lead, Partnership Development

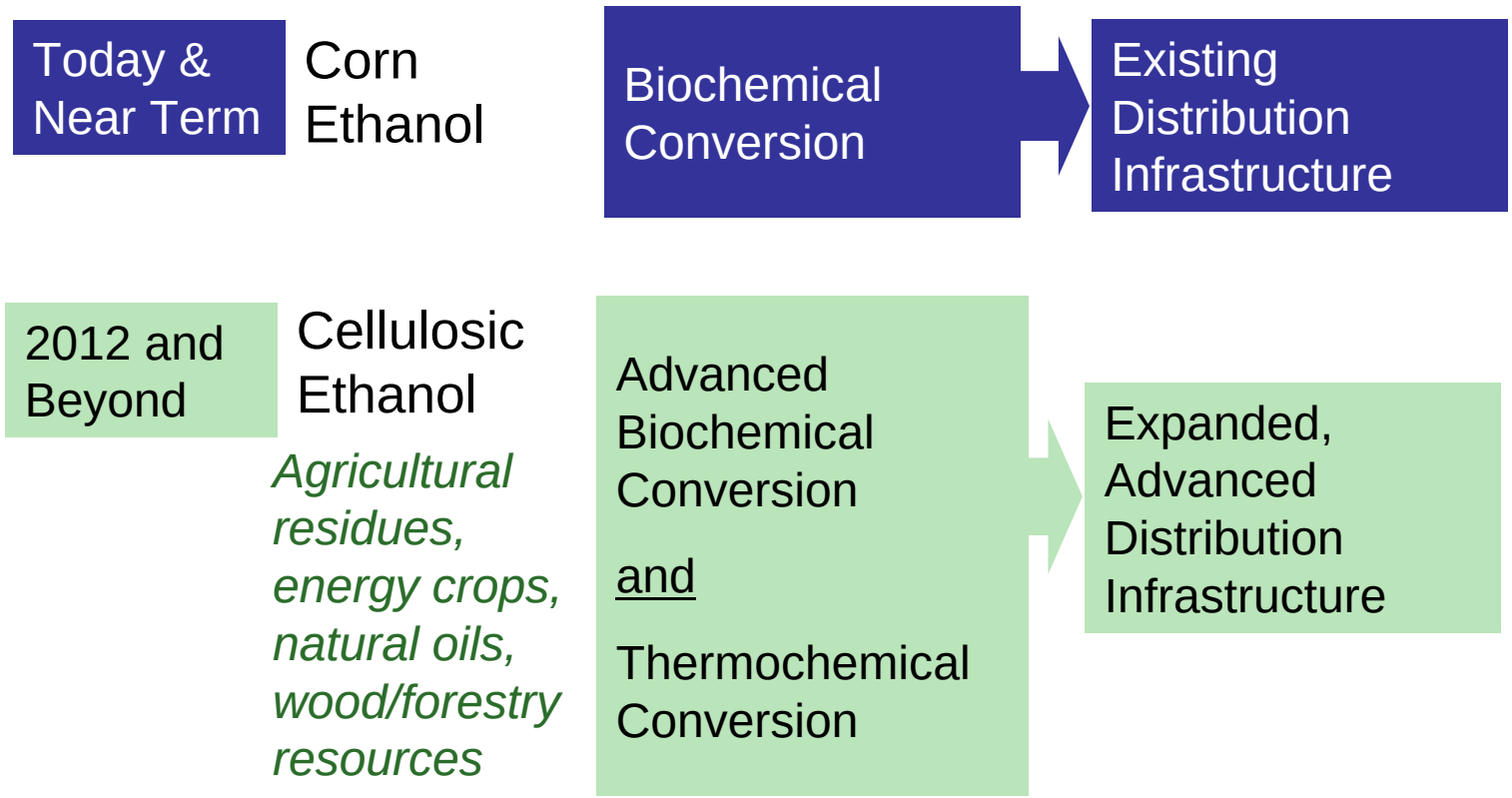
Prepared for the
Platts 2nd Annual Biofuels Conference

June 4, 2009

A Decade Ago, Biofuels Partnerships were Simple to Understand

- Farmers provided the grain feedstock to cooperatives or to integrated food processors (i.e., ADM or Cargill)
- Cooperative members provided equity investment
- Ag-oriented banks provided remainder of financing
- System integrators provided standard dry mill designs and construction expertise to cooperatives. ADM and Cargill did their own wet mill designs
- Equipment suppliers worked with the integrators, as did the yeast and enzyme suppliers
- Congress provided subsidies for fuel blending
- Integrated oil companies grudgingly providing blending market for ethanol

We Must Transition to Cellulosic Biomass and to Advanced Biofuels



Cellulosic ethanol will help meet future biofuels demand

U.S. National Commitment to Biofuels

Near-term – Cost Goal

"Cost-competitive cellulosic ethanol"

- Cost-competitive in the blend market by 2012

Longer-term – 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.

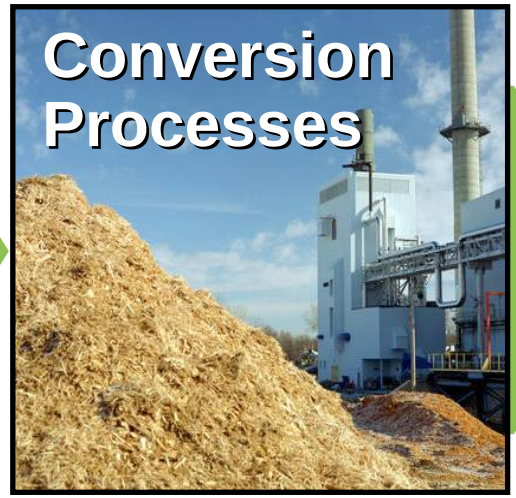
- Biomass-based diesel 50% reduction
- Advanced biofuels 50% reduction
- Corn grain-based ethanol 20% reduction
- Cellulosic Biofuels 60% reduction

Now We Transition to Biorefineries

- New feedstocks – from algae to ag. residues to switchgrass to softwoods
- New conversion systems – both biochemical and thermochemical or hybrid
- New end products – high density, infrastructure compatible fuels, as well as higher alcohols
- New risks
- New opportunities

The Biorefinery Concept

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



- Enzymatic fermentation
- Gas/liquid fermentation
- Direct microbial production of hydrocarbons
- Acid hydrolysis/ fermentation
- Gasification
- Combustion
- Co-firing
- Pyrolysis

Uses

Fuels
- Ethanol
- Butanol
- Higher alcohols
- Green gasoline
- Renewable diesel
- Jet Fuel

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

Biomass Feedstock Overview

- Feedstock cost and logistics research for DOE is carried out at Idaho and Oak Ridge National Labs
- Key research and partnership 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 grain

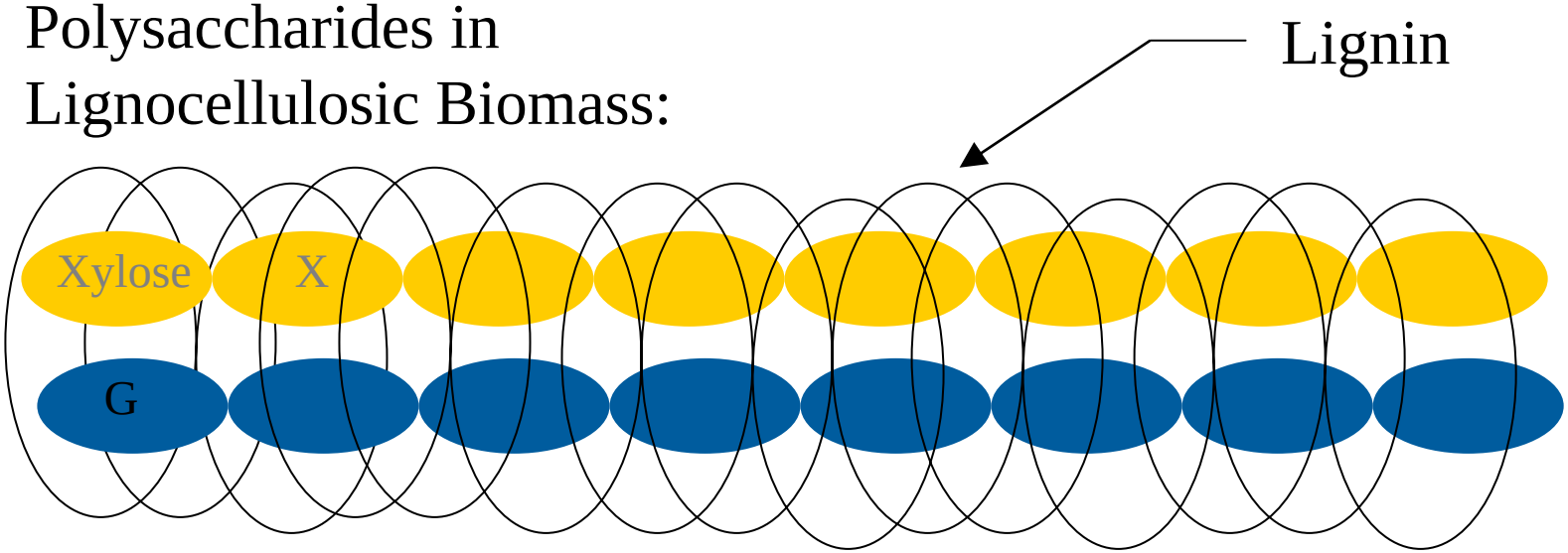
Short-rotation poplar
ZeaChem, Inc.

The Structures are Very Different

Sugars: Glucose

Starches: GlucoseGlucose

Polysaccharides in Lignocellulosic Biomass:



Historically, DOE research has focused on two Primary Conversion Routes to Ethanol

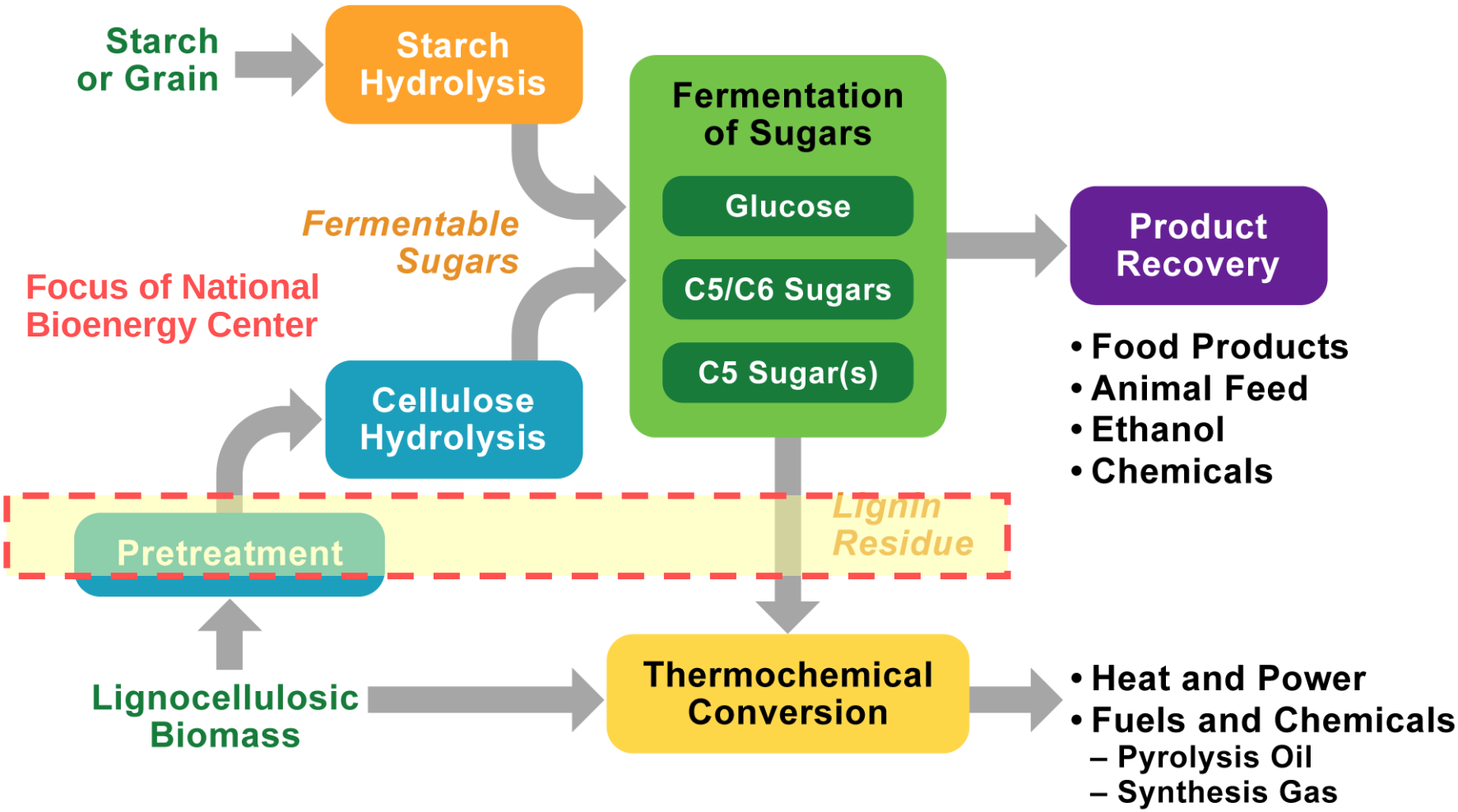
Transformation through Intermediates (sugars)

"Biochemical conversion"

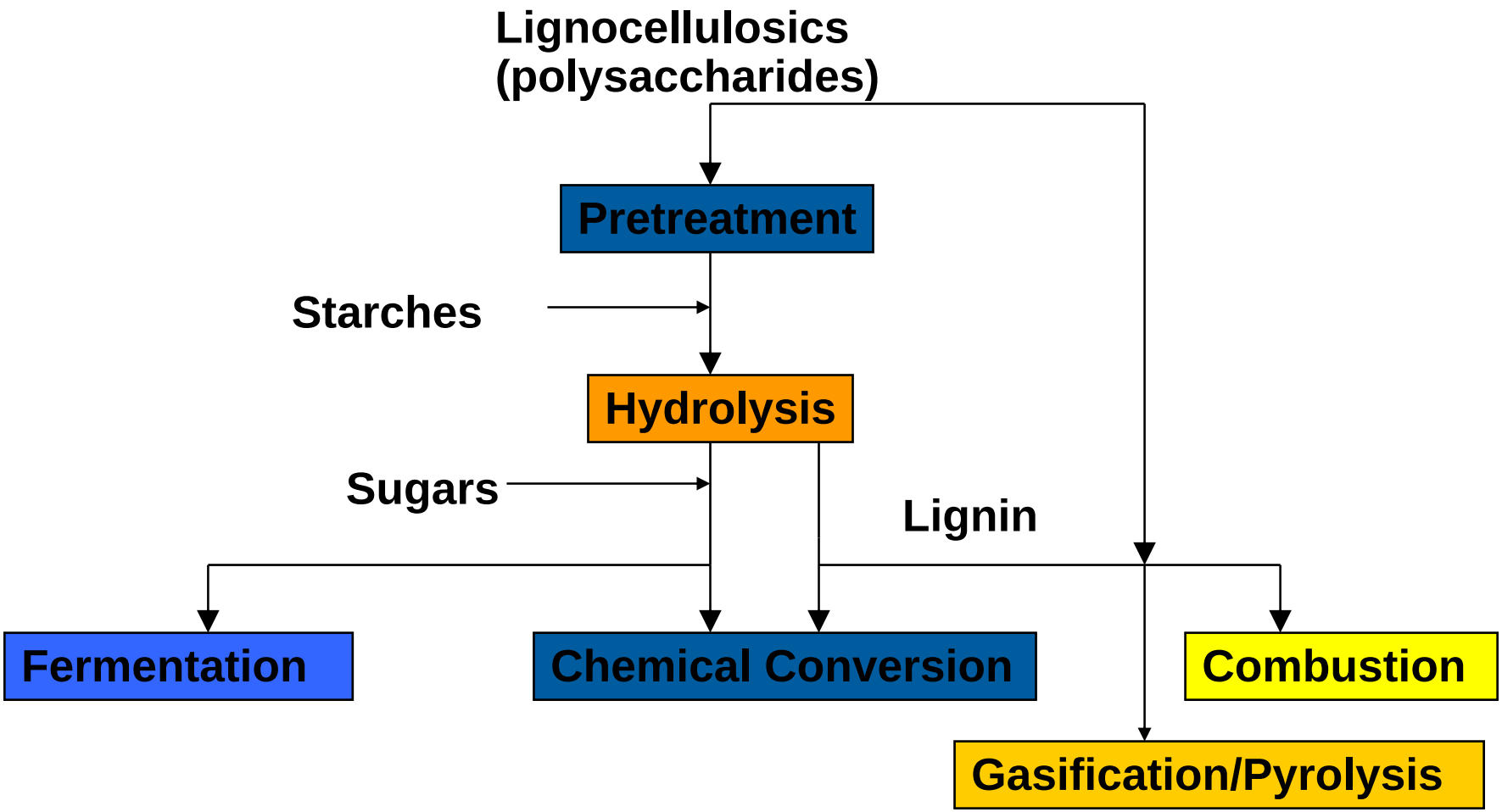
Reduction to building blocks: i.e. syngas (CO, H_2), Pyrolysis liquids

"Thermochemical conversion"

Integrated Cellulosic Ethanol Biorefinery

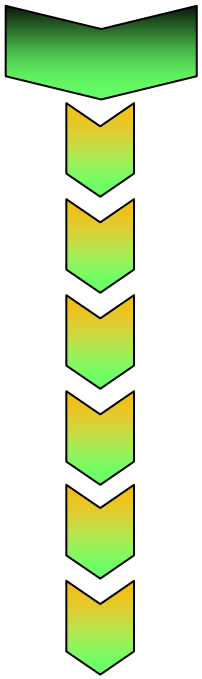


Historic Vision of the Primary Conversion Routes for “Biomass”



The National Policy Focus has been on Ethanol

Near Term



Long Term

Ethanol – as a blending agent from either grain or cellulosic material from Ag and/or Forestry industry

Biodiesel – Transesterified vegetable oils blended with diesel

Green Diesel/Gasoline – fats, waste oils, or virgin oils blended with crude oil as a feedstock for making low-sulfur diesel/gasoline in petroleum refinery

Pyrolysis Liquids – as a boiler fuel or an alternative feedstock to petroleum refinery or gasification facility, also a future source of aromatics and/or phenols

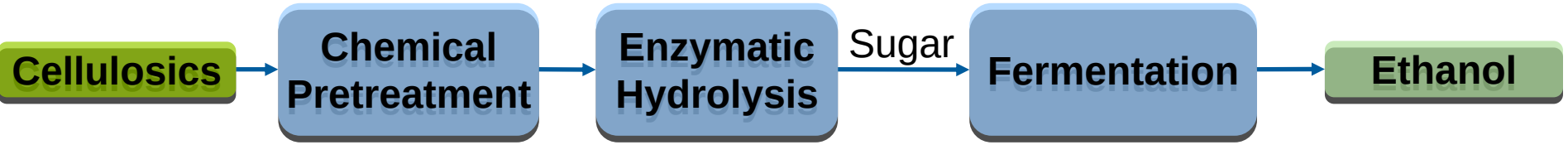
Synthesis Gas – for conversion to Fischer Tropsch liquids, MeOH/DME, or mixed alcohols

Algae – as alternative source of triglycerides for biodiesel or green diesel

Hydrocarbons – from hydrogenation of carbohydrates or lignin

Cellulosic Ethanol Research at NREL

Biochemical Ethanol

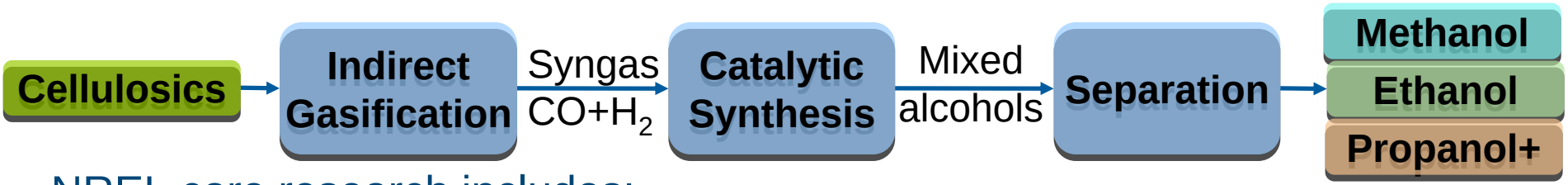


NREL core research includes:

- 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



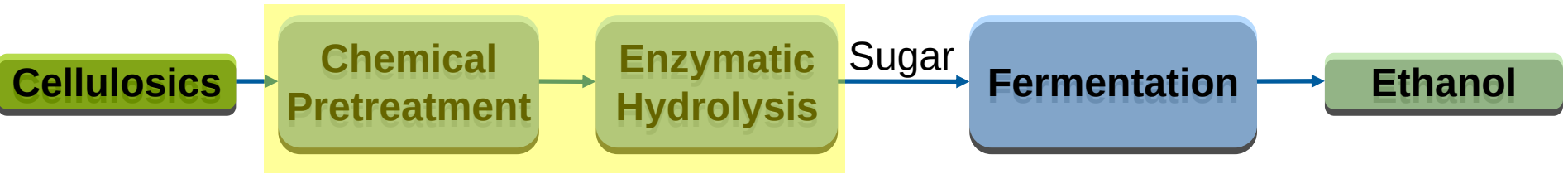
NREL core research includes:

- 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

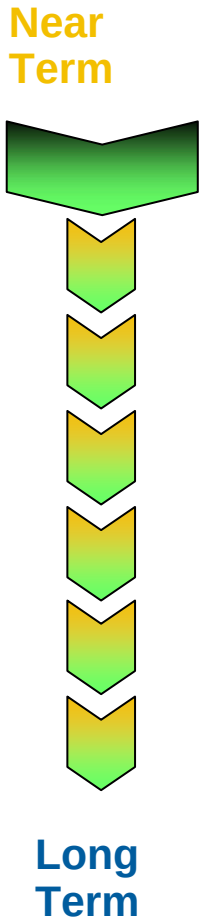


- Conversion of biomass to sugar is reasonably well understood
- Remaining challenges are not specific to ethanol as a product
- What else can sugar be used for?

Thermochemical Mixed Alcohols

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

Other Near-Term Biofuel Technologies



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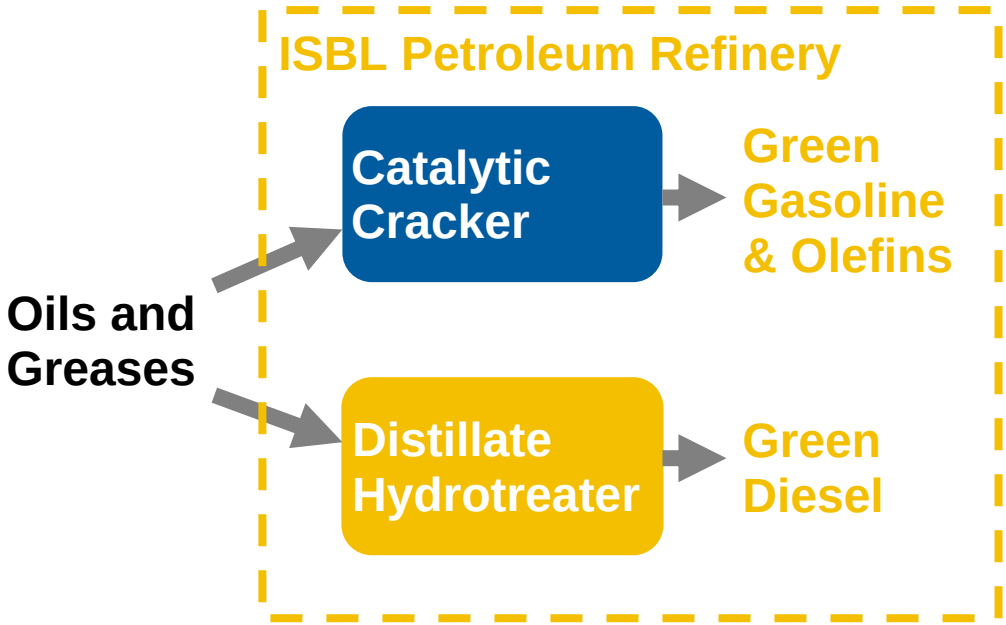
Green Diesel/Gasoline – fats, waste oils, or virgin oils blended with crude oil as a feedstock for making low-sulfur diesel/gasoline in petroleum refinery

Oils, Fats & Greases as Bio-renewable Petroleum Refinery Feedstocks



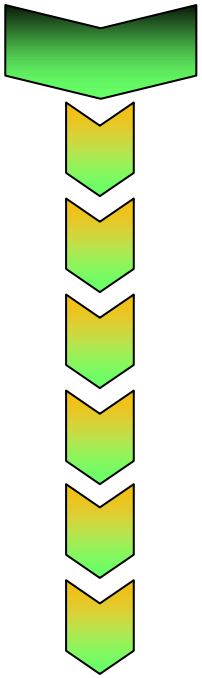
- Co-processing of oils and greases with petroleum fractions
- Utilize existing process capacity
- Potential for lower conversion costs (than FAME)
- Higher quality diesel blending component
- G/D flexibility

Based on Presentations at 1st International Biorefinery Workshop, Washington DC, July 20-21, 2005

- ***Future Energy for Mobility***, James Simnick, **BP**
- ***From Bioblending to Biorefining***, Veronique Hervouet, **Total**
- ***Opportunities for Biorenewables in Petroleum Refineries***, Jennifer Holmgren, **UOP**

Mid-Term Biofuel Technologies

Near Term



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Pyrolysis Liquids – as a boiler fuel or an alternative feedstock to petroleum refinery or gasification facility, also a future source of aromatics and/or phenols

Fast Pyrolysis and Bio-oil as a Feed to Power Plants or Petroleum Refineries

Bio-oil is comprised of many oxygenated organic chemicals, with water-miscible and oil-miscible fractions

Dark brown mobile liquid,

Combustible,

Not 100% miscible with hydrocarbons,

Modest heating value ~ 17 MJ/kg,

High density ~ 1.2 kg/l,

Acidic, pH ~ 2.5,

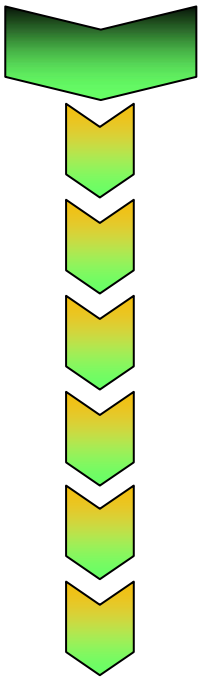
Pungent odour,

"Ages" - viscosity increases with time

Based on research at NREL (1990 - 2006)

Mid-Term Biofuel Technologies

Near Term



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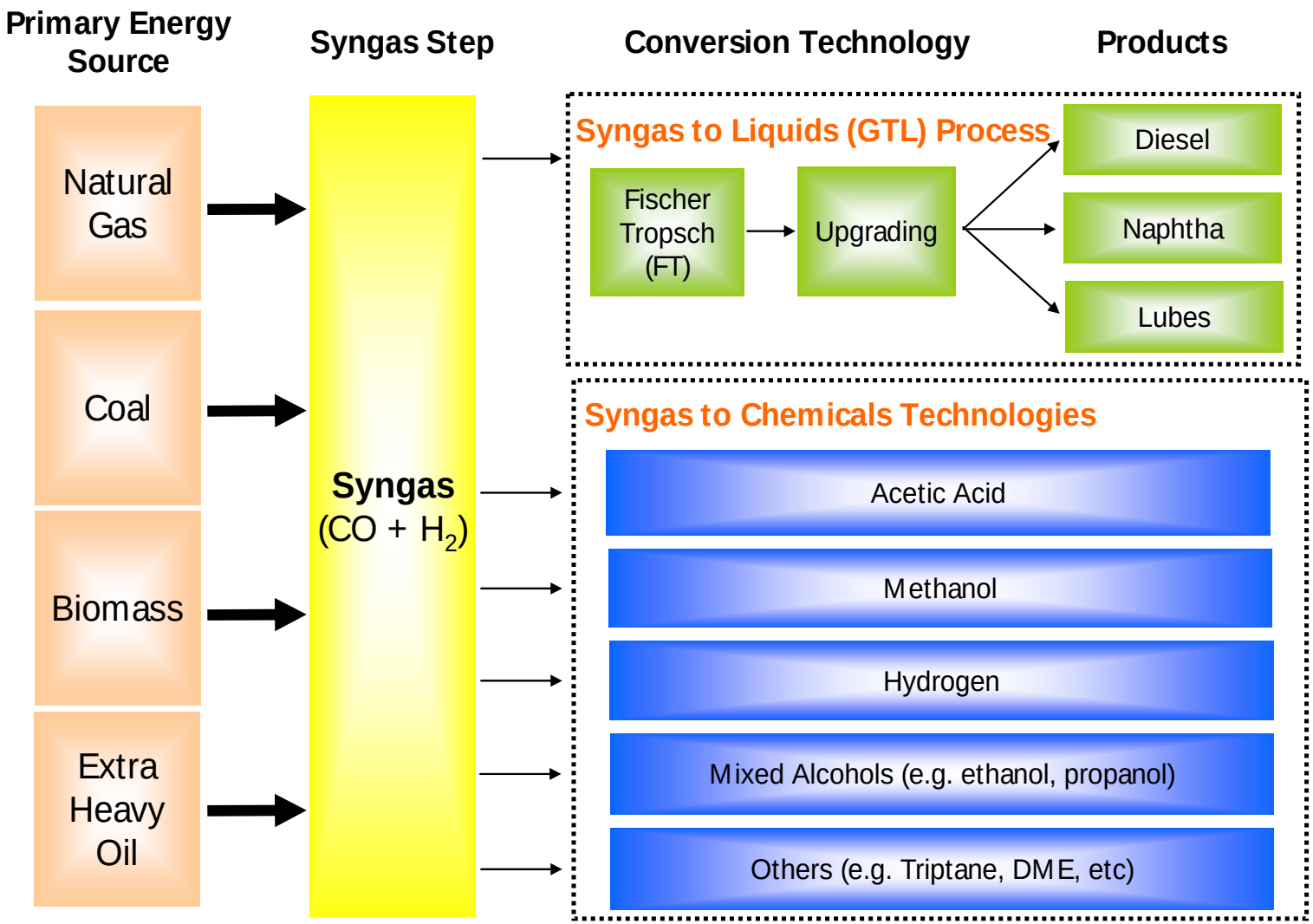
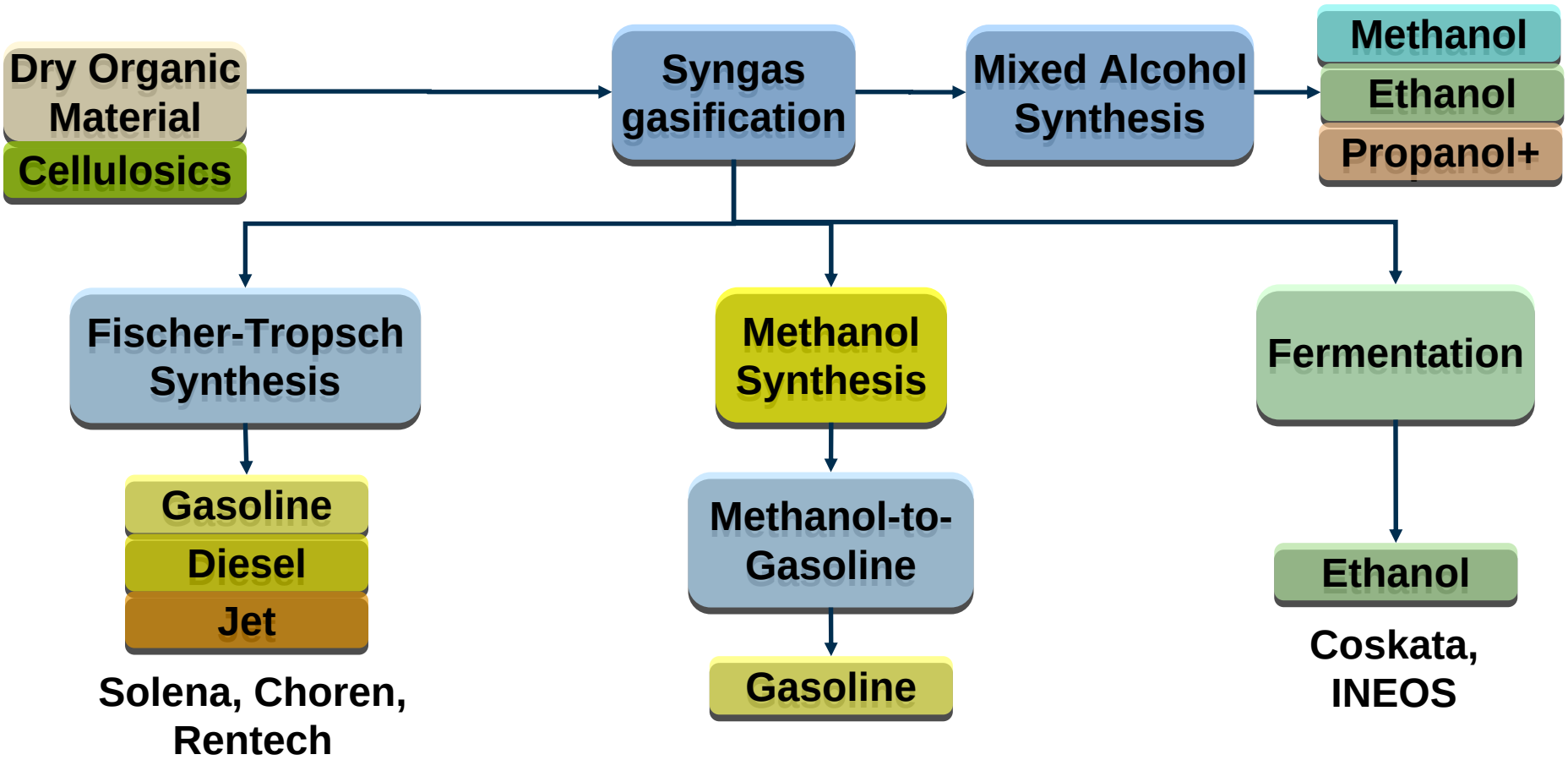
Gasification Offers Many Feed & Product Options



Slide courtesy of BP Corporation

Advanced Biofuels from Syngas



Benefits

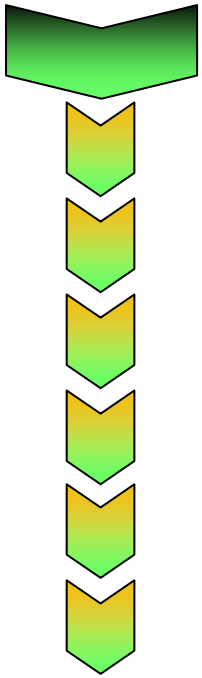
- Product versatility
- Proven technology

Challenges

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

Long-Term Biofuel Technologies

Near Term



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Synthesis Gas – for conversion to mixed alcohols, Fischer Tropsch liquids, methanol, or dimethyl ether

Algae to Fuels – either to biodiesel or as a lipid source for green diesel or synthetic gasoline

Hydrocarbons – from hydrogenation of carbohydrates or lignin

A Novel Approach -- Jet Fuel from Biomass

Combine two technologies: Algae & Green Diesel

Microalgae

CO2

Cultivation Ponds

60% Triglyceride

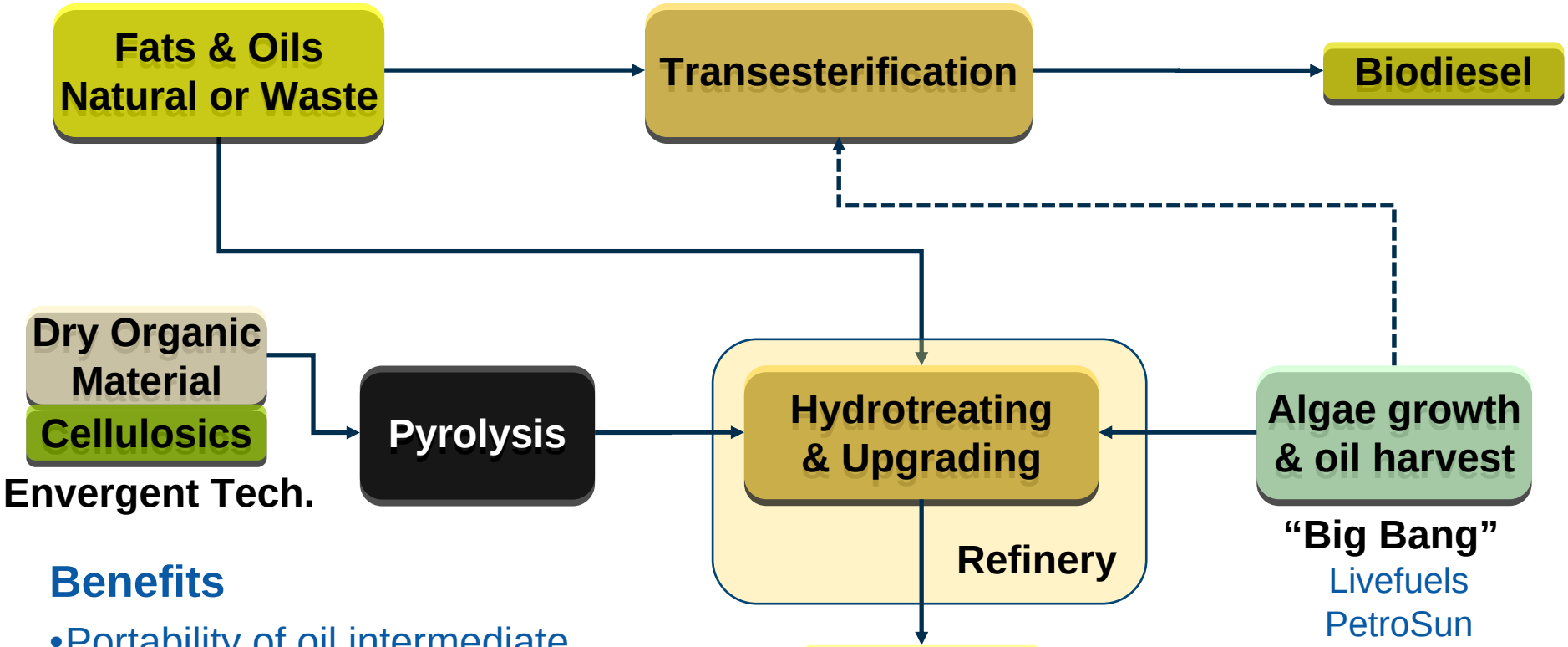
40% Carbohydrates and Protein

- Ethanol
- Power
- Food

Jet Fuel (JP-8)

Green Diesel

Advanced Biofuels from Fats and Oils



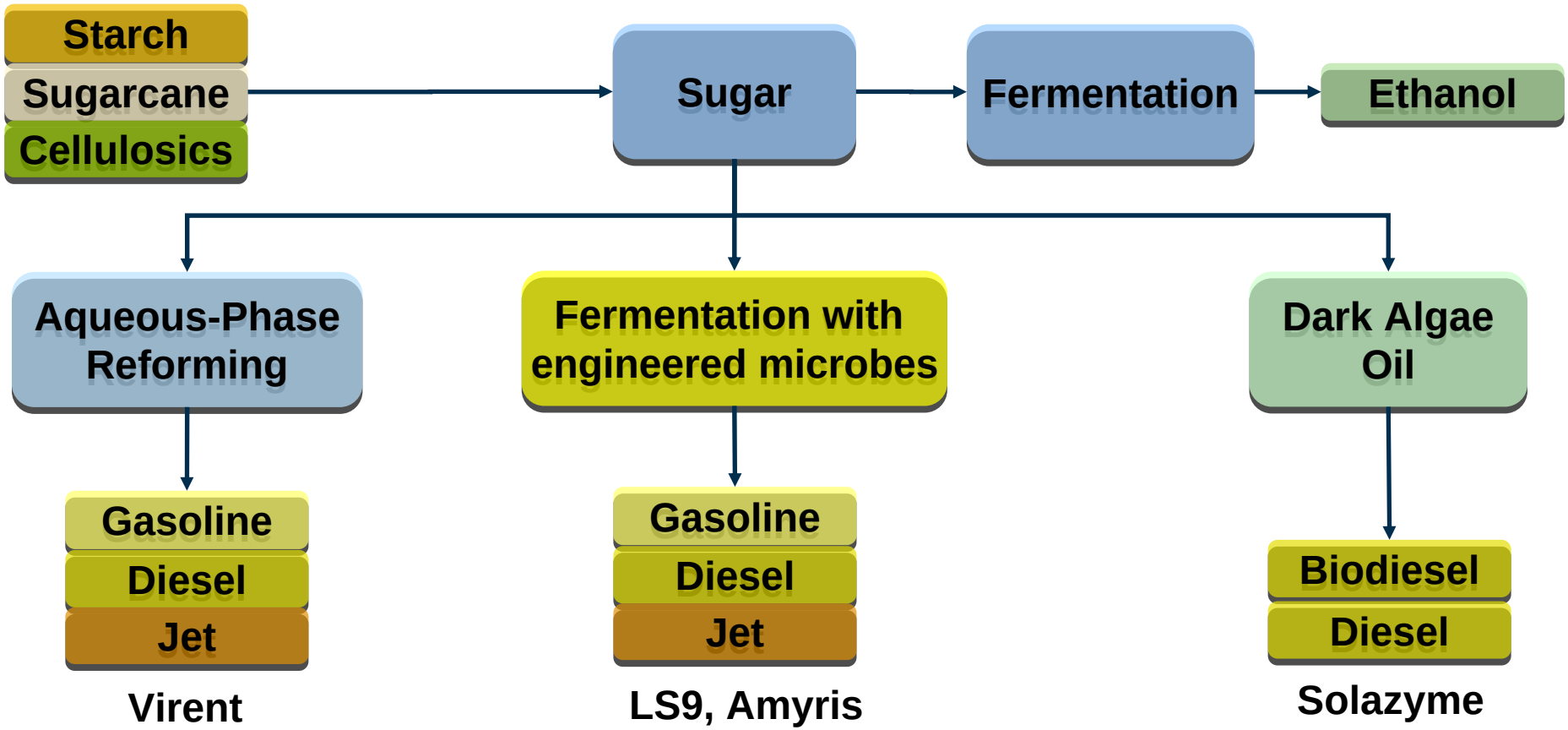
Benefits

- Portability of oil intermediate
- Infrastructure compatibility

Challenges

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

Advanced Biofuels from Sugars



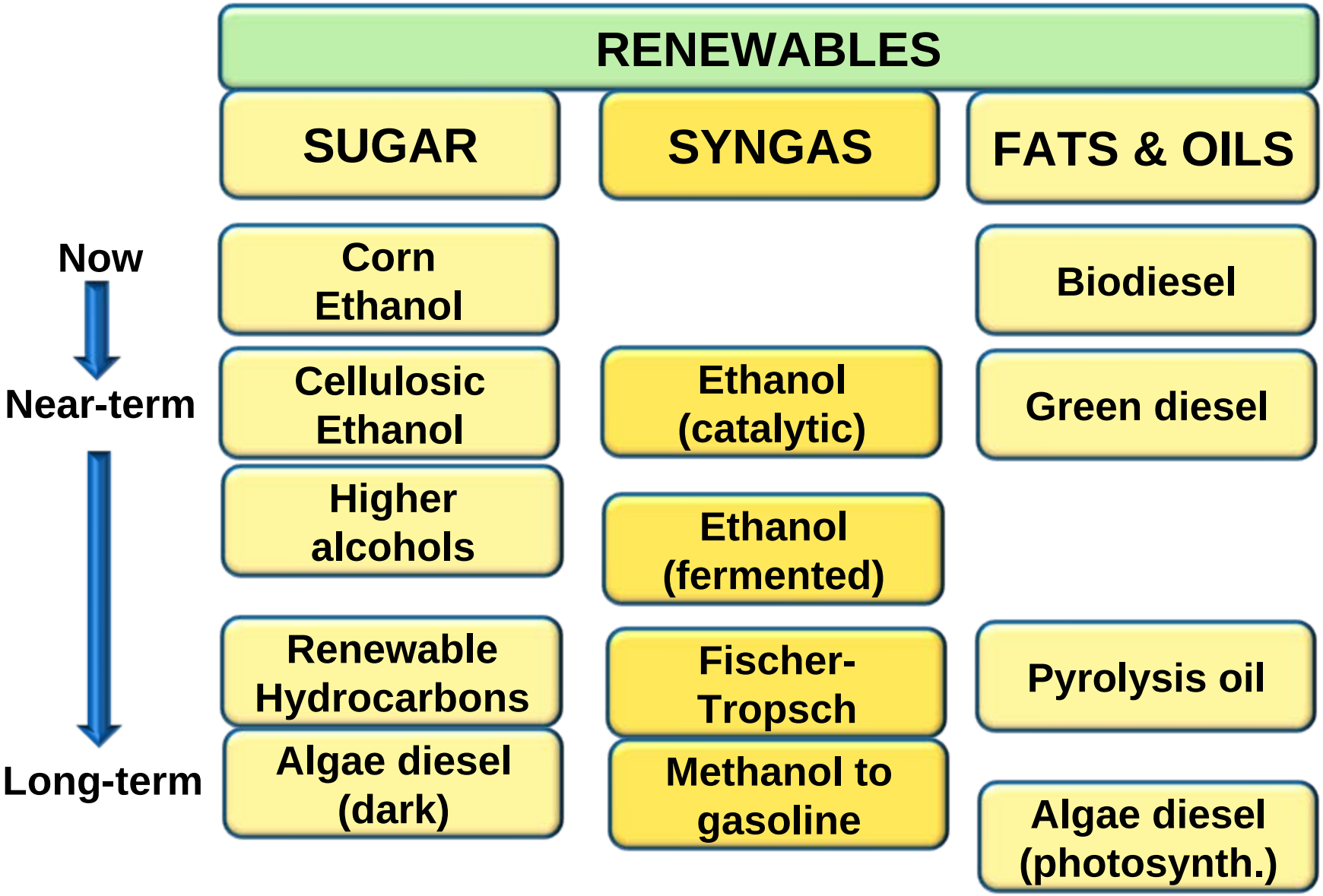
Benefits

- Infrastructure-compatible
- Highly controlled fuel properties

Challenges

- Feedstock availability
- Compatibility with cellulosic sugar

Future Options for Liquid Fuels



New Partnerships are Transforming the U.S. Biomass to Fuels Landscape

- University Scientists and Entrepreneurs
- Entrepreneurs and Venture Capitalists
- National Labs & Companies (small, medium, large)
- Integrated Fuel Companies and Universities
- Fortune 100 Companies and Start-ups
- Equipment Suppliers and the Emerging Biorefinery Industry
- The Department of Energy and USDA & private industry
  - Risk mitigation investments in research and in plants
  - Loan guarantees

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 and then advanced biofuels

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


Thank You for the Opportunity
Are there any Questions ?

Additional Slides