CATALYTIC CONVERSION OF SUGARS TO JET FUEL

NIST

4th International Conference on Biofuels Standards

November 14th 2012

VIRENT

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Overview

- General Background on Virent and Biofuel Industry
- BioForming® Technology
- Fuel Composition & Quality
- Aviation Fuel Program Activities

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Virent at a Glance

The global leader in catalytic biorefinery research, development, and commercialization.

Employees

120 Employees

Partners & Investors

Cargill

HONDA
The Power of Dreams

The Coca-Cola Company

> $77 MM in Equity Funding
> $76 MM in Gov & Industry

Technology

Converting plant-based feedstocks
to fuels and chemicals

Infrastructure

25x Development Pilot Plants
1x 10,000 gal/yr Demo Plant

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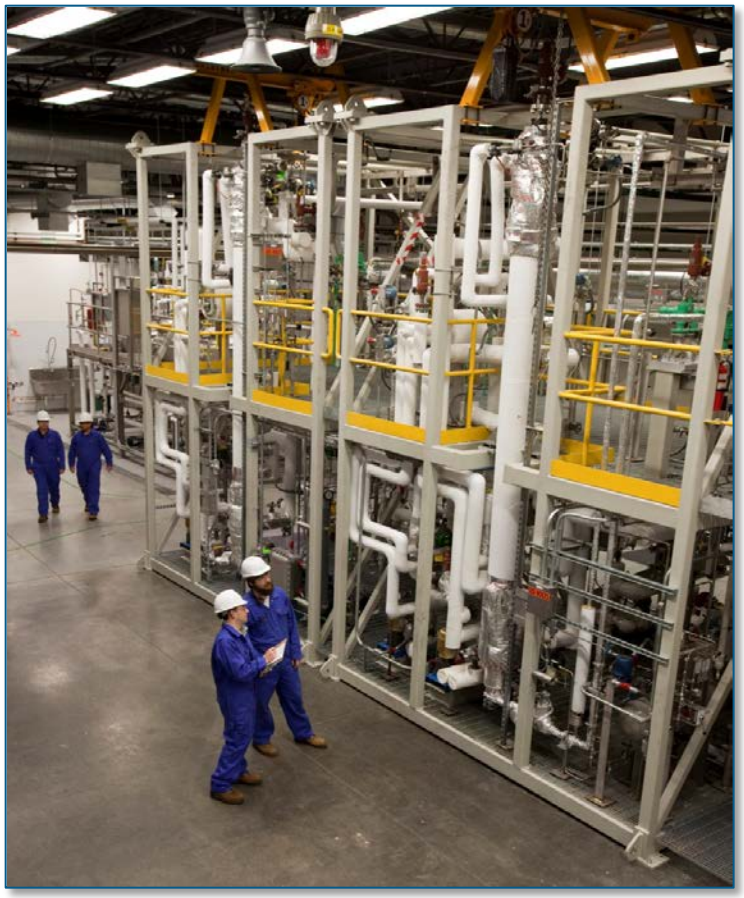
Virent's BioForming Technology

Leading catalytic route to renewable hydrocarbon fuels and chemicals.



"Eagle" Virent's Biogasoline Demonstration Plant- Madison, WI

Fast and Robust

- Inorganic Catalysts
- Moderate Conditions
- Industry Proven Scalability

Energy Efficient

- Exothermic
- Low Energy Separation
- Low Carbon Footprint

Premium Drop-in Products

- Tunable Platform
- Infrastructure Compatible
- Fuels and Chemicals

Feedstock Flexible

- Conventional Sugars
- Non-Food Sugars

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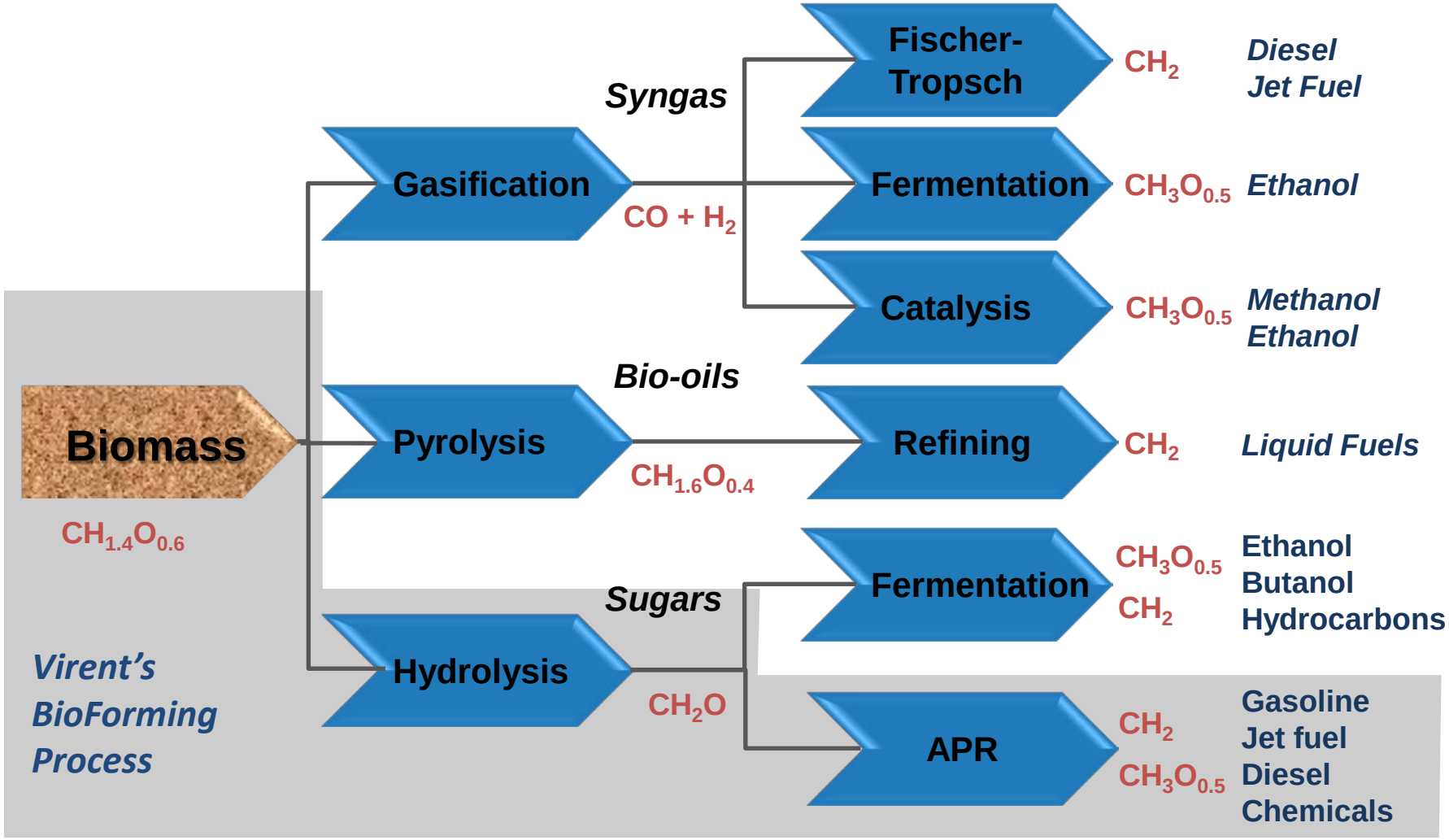
Fuels and Chemicals from Biomass



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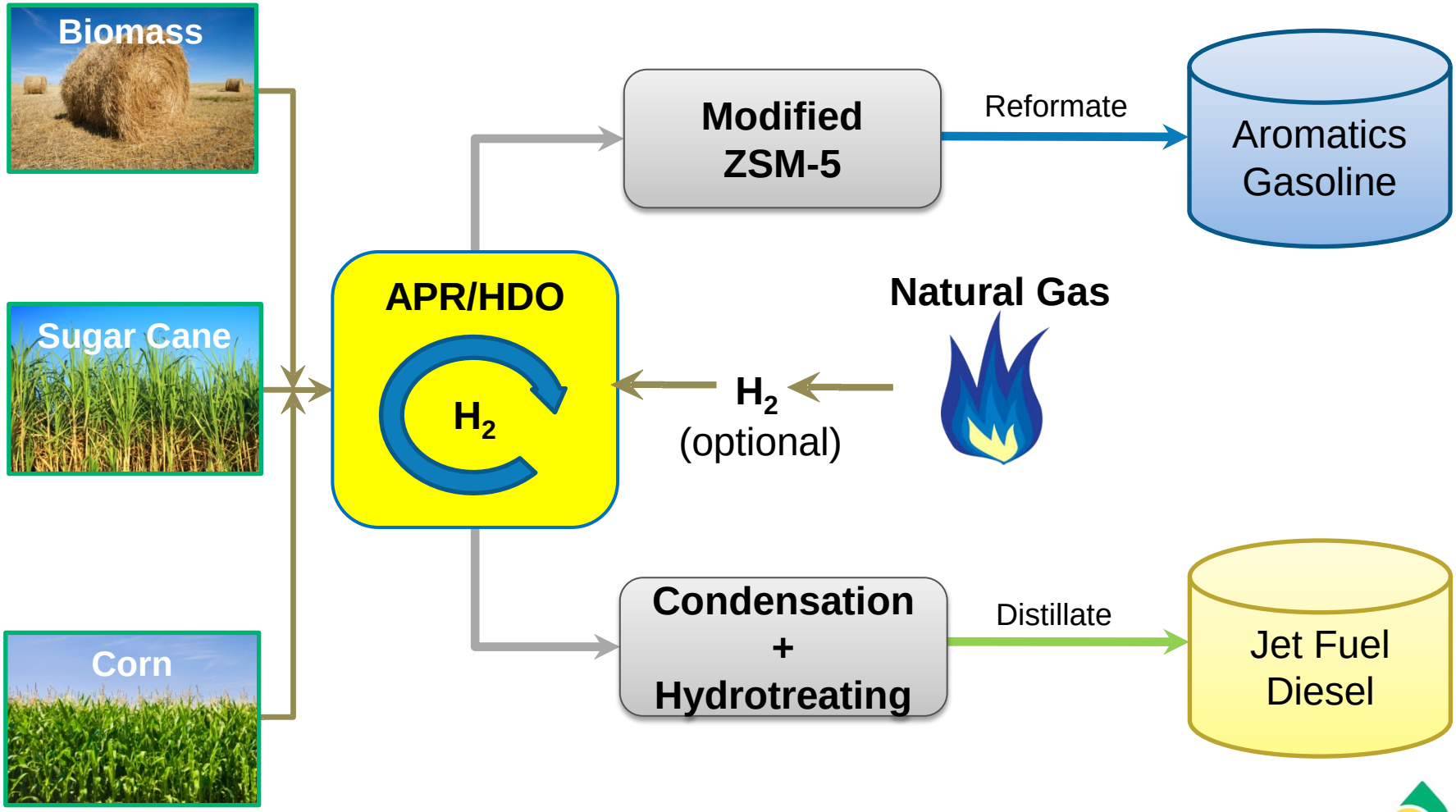
The BioForming Concept

Biobased feedstocks to direct replacement products.



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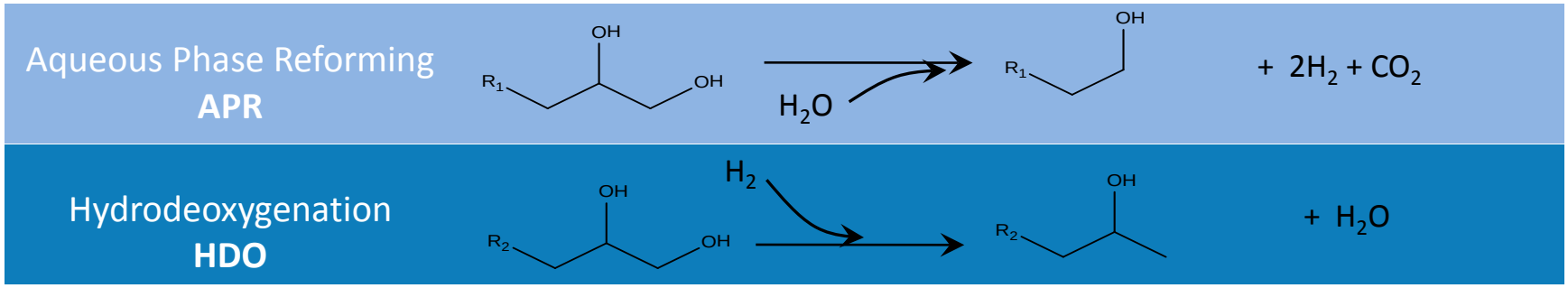
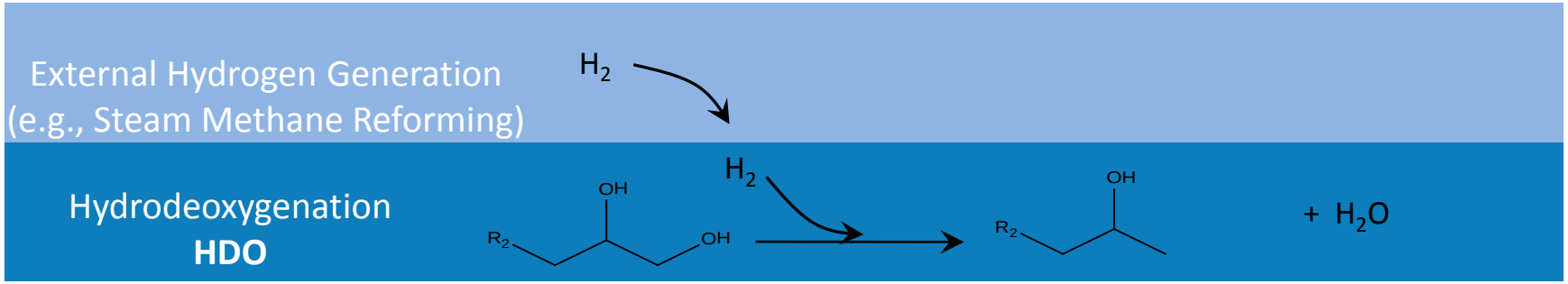
APR / HDO Reaction Pathways

Option 1 : In-Situ H_2 Production



Option 2 : Ex-Situ H_2 Production



- Decision is based the relative cost of carbohydrate feedstock vs. H_2 derived from Natural Gas
- Intermediate options exist using combinations of in-situ and ex-situ H_2 to varying degrees

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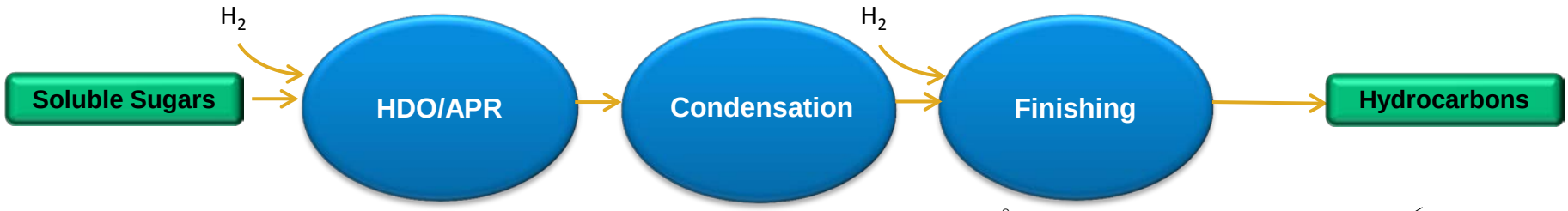
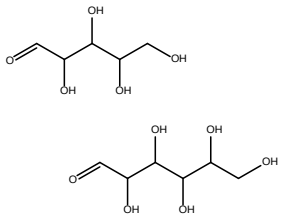
Process Chemistry



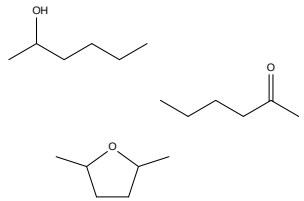


Reactive Oxygenates

Sugars, Oligosaccharides, Polyols, Furans

Carbon Chain Length ≤ 6

2-6 Oxygen/Carbon Chain

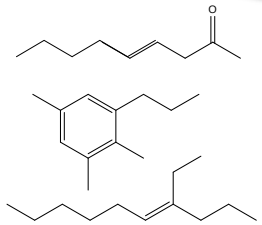


Moderate Functionality Controlled Reactivity Oxygenates

Alcohols, Ketones, Furans, Carboxylic Acids

Carbon Chain Length ≤ 6

1-3 Oxygen/Carbon Chain

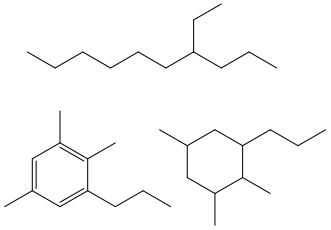


Low Functionality Hydrocarbons and Residual Oxygenates

Alkenes, Alkanes, Aromatics, Ketones, Esters

Carbon Chain Length 4-40

0-1 Oxygen/Carbon Chain



Hydrocarbons

Alkanes,Cycloalkanes, Aromatics

Carbon Chain Length 4-40

0 Oxygen/Carbon Chain

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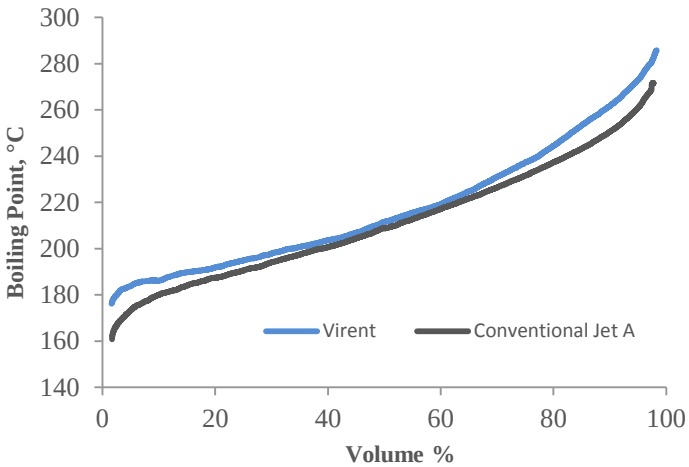
Virent Jet Fuel Properties

Similar Properties to Conventional Jet Fuel = Balanced Blending Component.

Specification Test	MIL-DTL-83133G Spec Requirement	JP-8	VIRENT
Physical and Chemical Properties			
Heat of Combustion (measured), MJ/Kg	≥42.8	43.3	43.3
Flash point, °C	≥38	51	40
Freeze Point, °C	≤-47	-50	<-60
Density @ 15°C, kg/L	0.775 - 0.840	0.804	0.805
Distillation			
10% recovered (T_{10}), °C	≤205	182	164
EP, °C	≤300	265	290
T_{90}-T_{10}, °C	≥22	62	86
Thermal Stability			
Temperature		260°C	325°C
Tube Deposit Rating	<3	1	1
Change in Pressure, mm Hg	≤25	2	0

Excellent freeze point and density due to unique Virent jet composition

Virent D-86 comparison to Jet-A



High thermal stability indicates low levels of impurities

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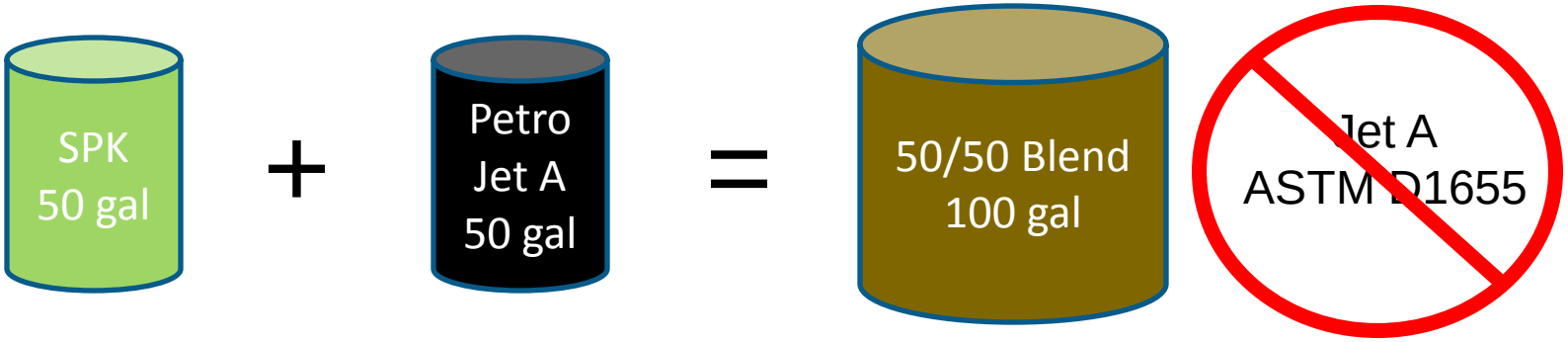
Balanced Blending Component

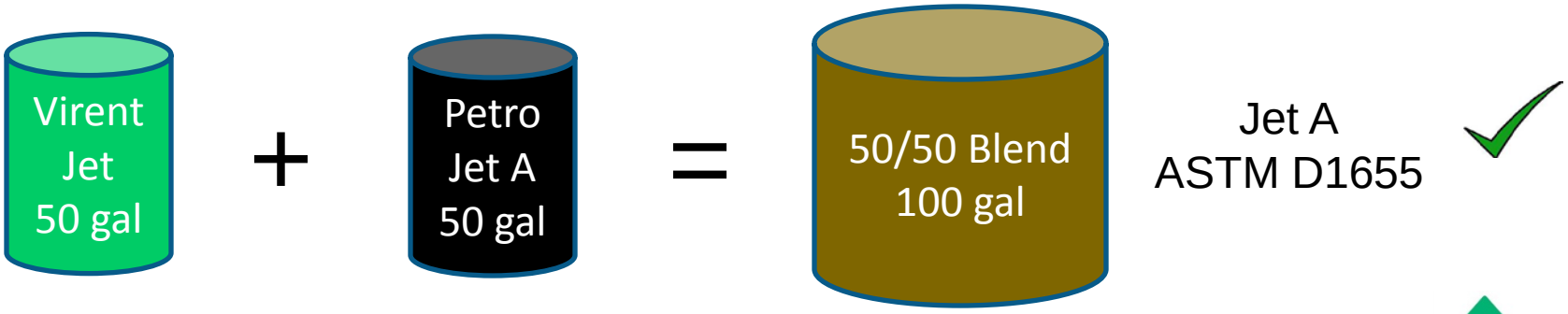
Benefits of a Balanced Blending Component Example:

Minimum density requirement of 775 kg/m^3
(correction required)

ρ = 750 kg/m^3 ρ = 790 kg/m^3 ρ = 770 kg/m^3



ρ = 805 kg/m^3 ρ = 790 kg/m^3 ρ = 797 kg/m^3



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Jet Fuel Activities - Summary

Certification Activities

Synthetic Aviation Fuels Specification
ASTM D 7566
(New Annex to be Approved)

Jet Product Development Activities

Rolls-Royce

BRITISH AIRWAYS

FAA Award
$1.5 MM Grant
Scale-up & Certification

Shell – Virent Collaboration
Technology Development

DOE Award
$13.4 MM Grant
Stover-to-Jet

DOE Jet Fuel Award

DOE Award

- Announced June 10, 2011
- Cellulosic sugars to jet fuel
- $13.4 MM Grant
- 3 year project

Project Partners

- VIRENT — Jet fuel production
- INL Idaho National Laboratory — Corn stover supply
- NREL NATIONAL RENEWABLE ENERGY LABORATORY — Corn stover processing
- NORTHWESTERN UNIVERSITY — Modeling

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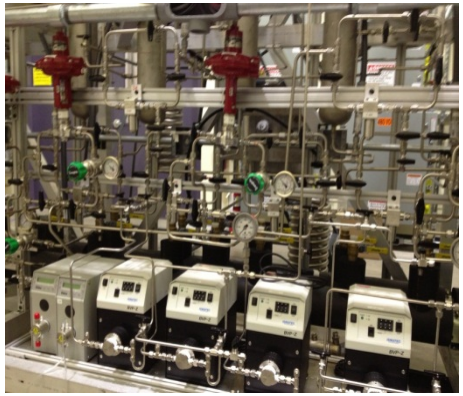
FAA Project

- Award to support production of jet fuel for ASTM certification
- Program will support the design, construction, and operation of 5 gallon/day distillate pilot plant
- Objective is to satisfy CAAFI's Fuel Readiness Level 6.1 requirements (fit-for-purpose properties evaluation)



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THANK YOU.

Virent converts plant-based sugars into 100% renewable chemicals and fuels. Our bio-based products are identical to those produced from petroleum—direct replacements that utilize today's processing, storage and transportation infrastructure. If you are interested in strategic partnering opportunities please contact:

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VIRENT

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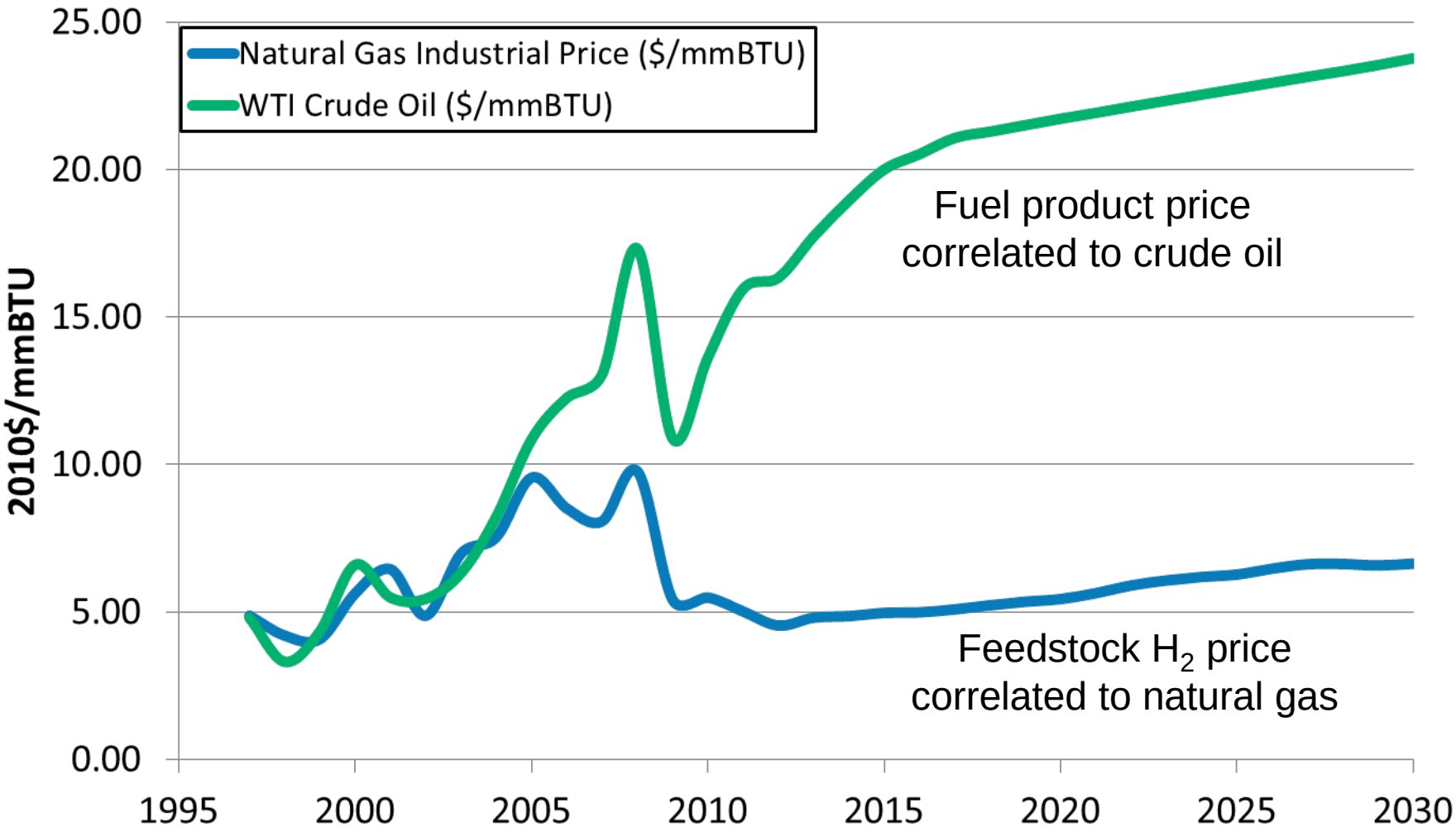
Henry Hub NG to WTI Crude Spread



Data: EIA historical and EIA AEO 2012 Reference Case Projections

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Theoretical Conversion Limits

APR/HDO of Sugar to Jet - No External Hydrogen

$3.58\ C_6H_{12}O_6 \rightarrow 1.0\ C_{14}H_{30} + 6.5\ H_2O + 7.5\ CO_2$

9.40 kg *$2.71*

1.0 gallon **$2.71**

APR/HDO of Sugar to Jet - Maximum External Hydrogen

$2.33\ C_6H_{12}O_6 + 15\ H_2 \rightarrow 1.0\ C_{14}H_{30} + 6.5\ H_2O$

6.11 kg *$1.77*

0.44 kg *$0.50*

1.0 gallon **$2.27**

Fermentation of Sugar to Ethanol Followed by Conversion to Jet

$3.50\ C_6H_{12}O_6 + 1.0\ H_2 \rightarrow 1.0\ C_{14}H_{30} + 7.0\ H_2O + 7.0\ CO_2$

9.18 kg *$2.65*

0.03 kg $0.04

1.0 gallon **$2.69**

Hydrodeoxygenation of Free Fatty Acid

$1.0\ C_{14}H_{22}O_2 + 3.0\ H_2 \rightarrow 1.0\ C_{14}H_{30} + 2.0\ H_2O$

3.32 kg $3.22

0.09 kg $0.10

1.0 gallon **$3.32**

Assumed Feedstock Costs:

Corn Starch @ $289/tonne; H_2 @ $1150/tonne; FFA @ $970/tonne

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Theoretical Conversion Limit Costs

Route To Jet Fuel	Sugar/Oil Cost ($/Gallon)	H_2 Cost ($/Gallon)	Fuel Cost ($/Gallon)
APR/HDO of Sugar to Jet Fuel – No External H_2	$2.71		$2.71
APR/HDO of Sugar to Jet Fuel – Max External H_2	$1.77	$0.50	$2.30
Fermentation of Sugar to Ethanol – Ethanol to Jet Fuel	$2.65	$0.04	$2.69
Free Fatty Acids (FFA) to Jet Fuel HEFA	$3.22	$0.10	$3.32

Assumed Feedstock Costs:

Corn Starch @ $289/tonne; H_2 @ $1150/tonne; FFA @ $970/tonne

Starch and FFA prices based on 5 year averages for US corn starch (Virent estimate) and US soybean oil.

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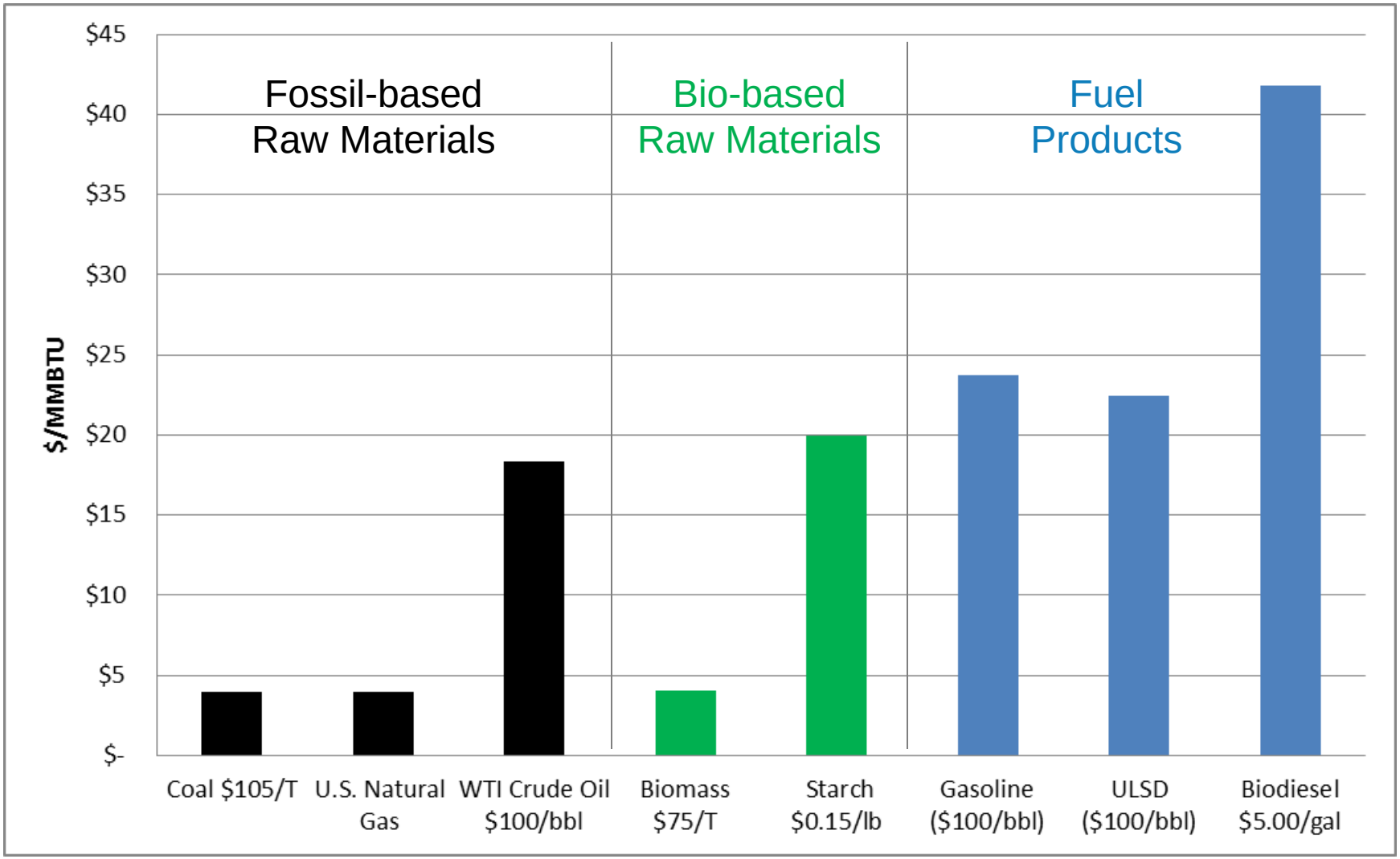
Energy Cost Comparison



Heating Value Data Sources: GREET and Aspen Plus

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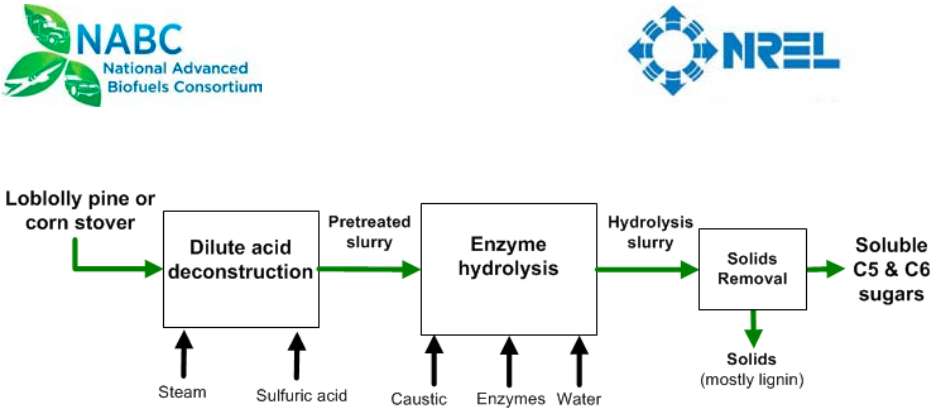
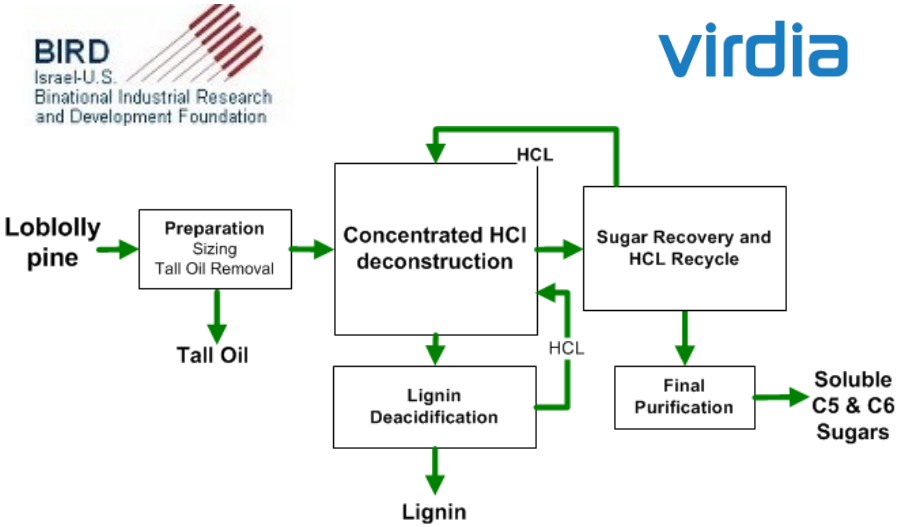
Cellulosics – Portfolio Approach

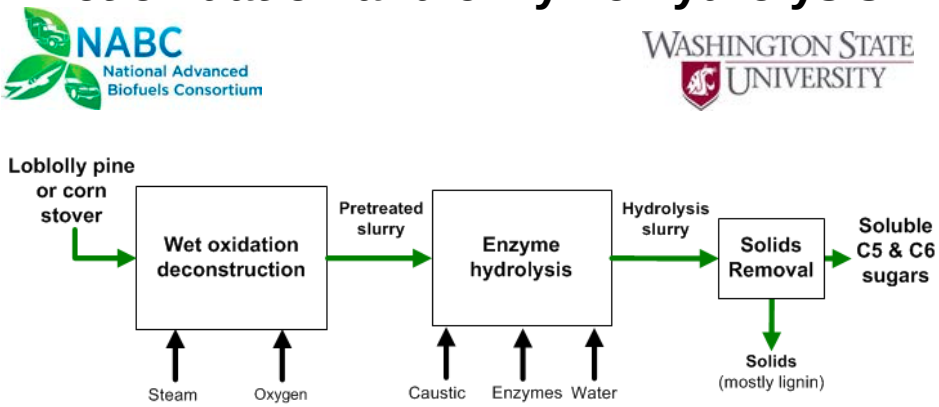
Dilute acid and enzyme hydrolysis



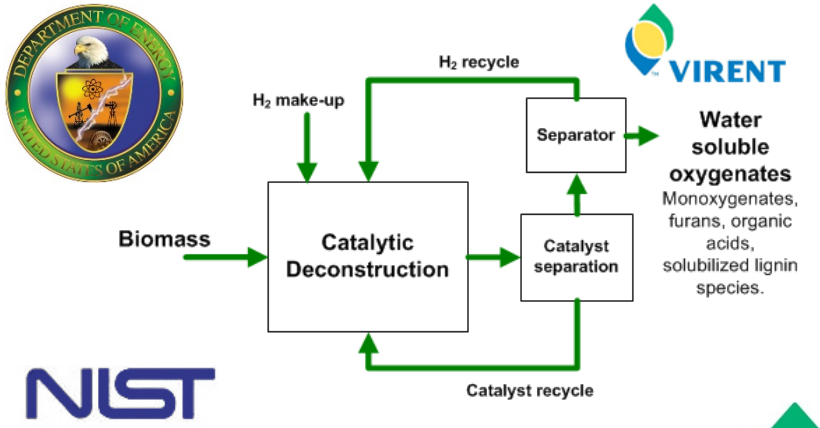
Cold Acid Solvent Extraction



Wet oxidation and enzyme hydrolysis



Catalytic Biomass Deconstruction



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Strategic Investors & Fuel Partners

Develop, deploy and commercialize at scale a renewable fuel platform that can utilize existing infrastructure.

Feedstock Logistics	Conversion Platform	Deployment Opportunity	Customer Acceptance
Cargill	VIRENT		HONDA
▪ Major shareholder ▪ Participating in feedstock development and commercial deployment	▪ Platform R&D ▪ Technology provider ▪ Feedstock R&D ▪ Catalyst development ▪ Operations	▪ Major shareholder ▪ Development partner ▪ Fuel qualification ▪ Scale-up partner ▪ Market channels	▪ Shareholder ▪ Support efforts to determine sustainability in current and next generation engines

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Feedstock Flexibility

Current Process

COMMODITY SUGARS
- Corn Starch
- Sugar Cane
- Sugar Beet

→

BIOFORMING

Virent's proprietary process to transform cost-effective sugars into fuels and chemicals

→

HYDROCARBON PRODUCTS
- Gasoline
- Diesel
- Jet Fuel
- Chemicals
- Plastics

In Development

NON-FOOD SUGARS
- Corn Stover
- Bagasse
- Switchgrass
- Miscanthus
- Wood

→

DECONSTRUCTION TECHNOLOGIES

Liberate sugars from cellulosic biomass cost-effectively

Development Portfolio
- National Advanced Biofuels Consortium
- Virdia Collaboration
- In-house Technology Development

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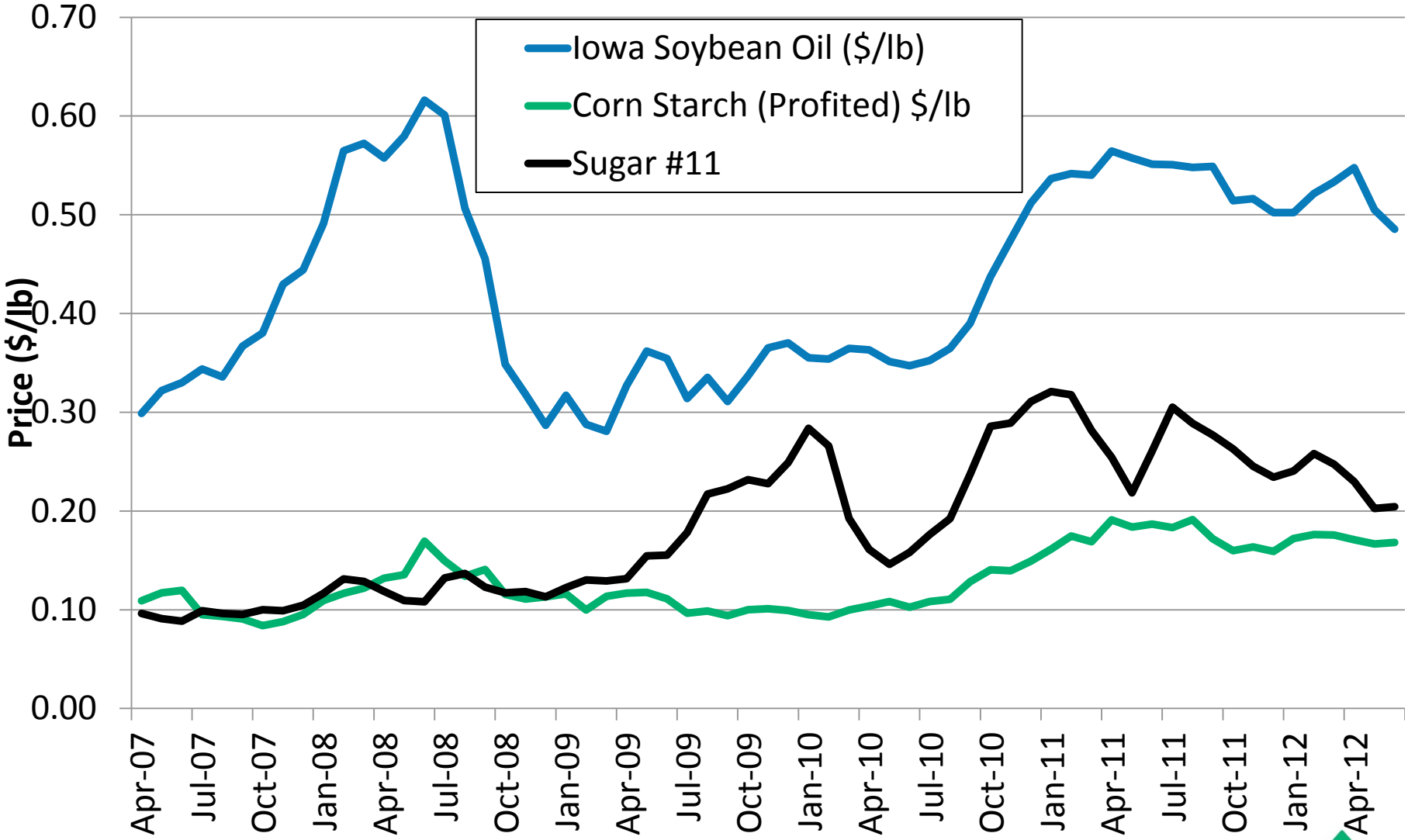
Historical Feedstock Pricing



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Military Fuel Testing

US Air Force
Wright Patterson AFB

- CRADA executed
- Samples tested

JP-8
Jet Fuel

US Navy
Patuxent River NAS

- CRADA executed
- Samples submitted

JP-5
Naval Jet Fuel

F-76
Naval Distillate Fuel

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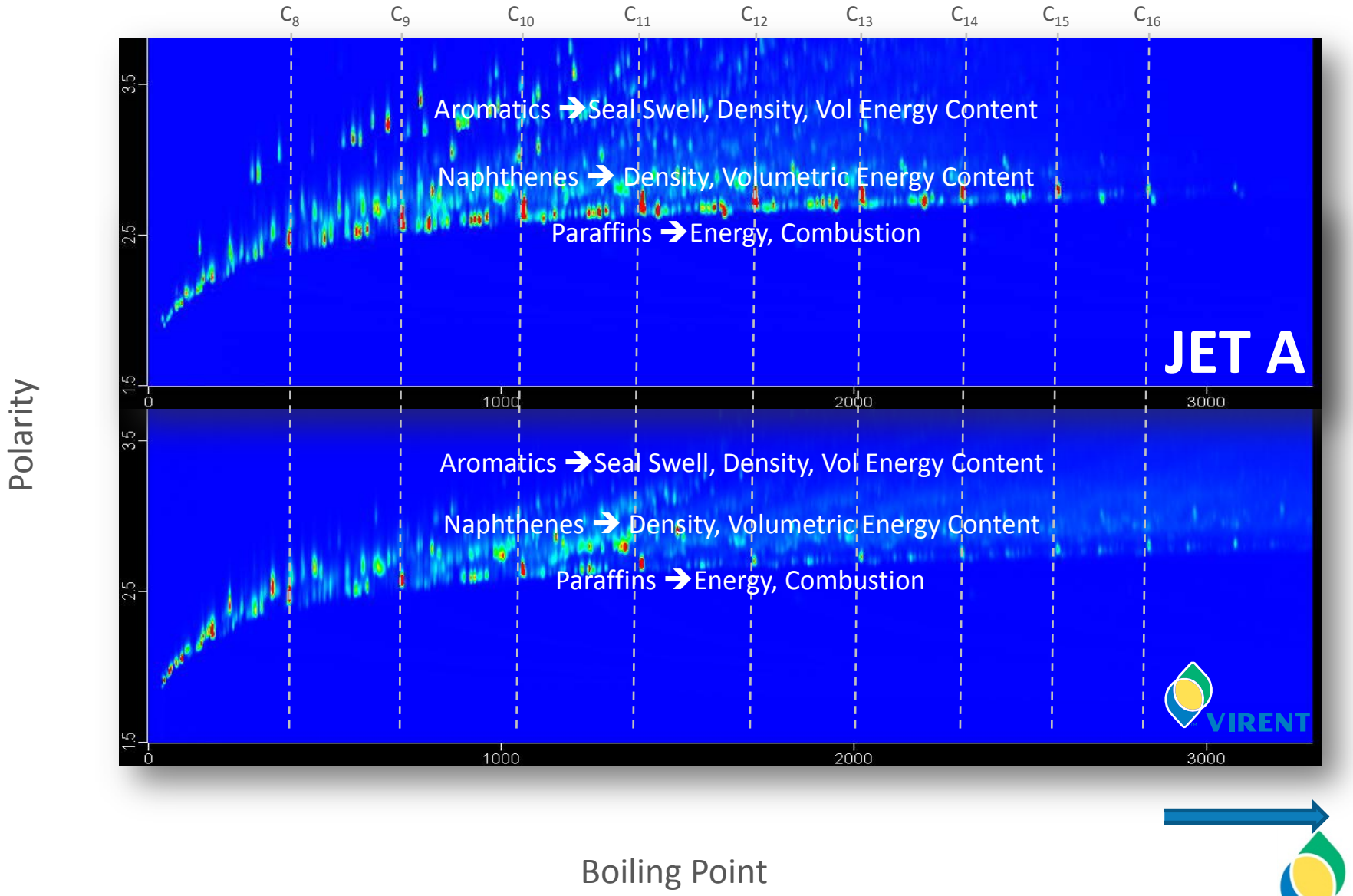
GC – GC Analysis



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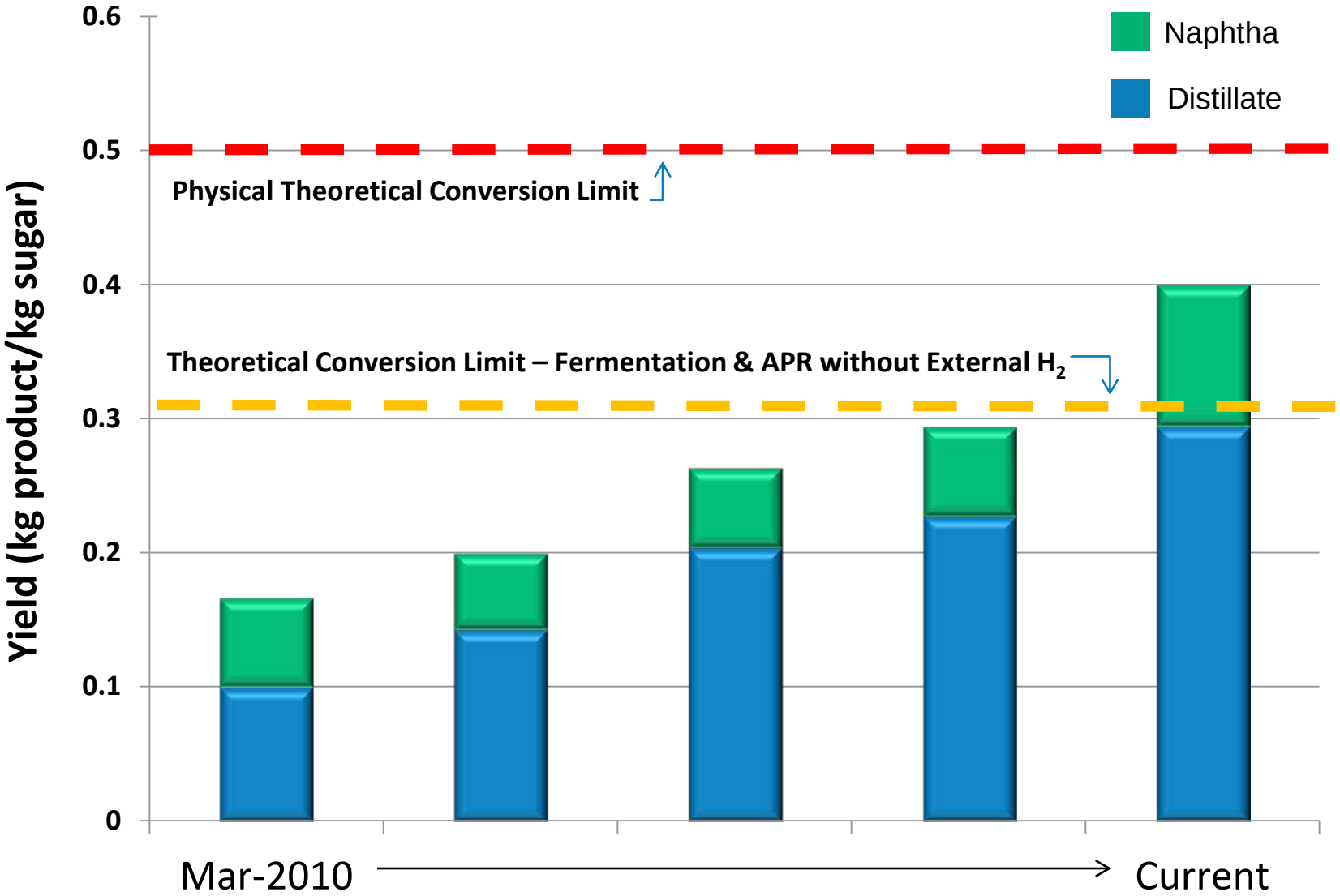
Virent Demonstrated Yields



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