VIRENT IS A WORLD LEADER IN CREATING SUSTAINABLE FUELS AND CHEMICALS.

Our patented BioForming® process transforms sugars from renewable feedstocks into everyday products such as gasoline, diesel, jet fuel and chemicals.

Catalytic Conversion of Lignocellulosic Biomass to Conventional Liquid Fuels and Chemicals

Randy D. Cortright

CTO/Founder

Catalysis and Alternative Feedstocks for the Biofuels Industry

Council for Chemical Research's New Industrial Chemistry and Engineering Workshop

9/31/2011

Virent at a glance

VIRENT

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

Employees

Partners & Investors

Cargill

HONDA
The Power of Dreams

Financial

Infrastructure

Strategic Investors & Partners

VIRENT

NABC National Advanced Biofuels Consortium

Pacific Northwest NATIONAL LABORATORY

HCL CleanTech Enabling Bio-Fuels

NREL NATIONAL RENEWABLE ENERGY LABORATORY

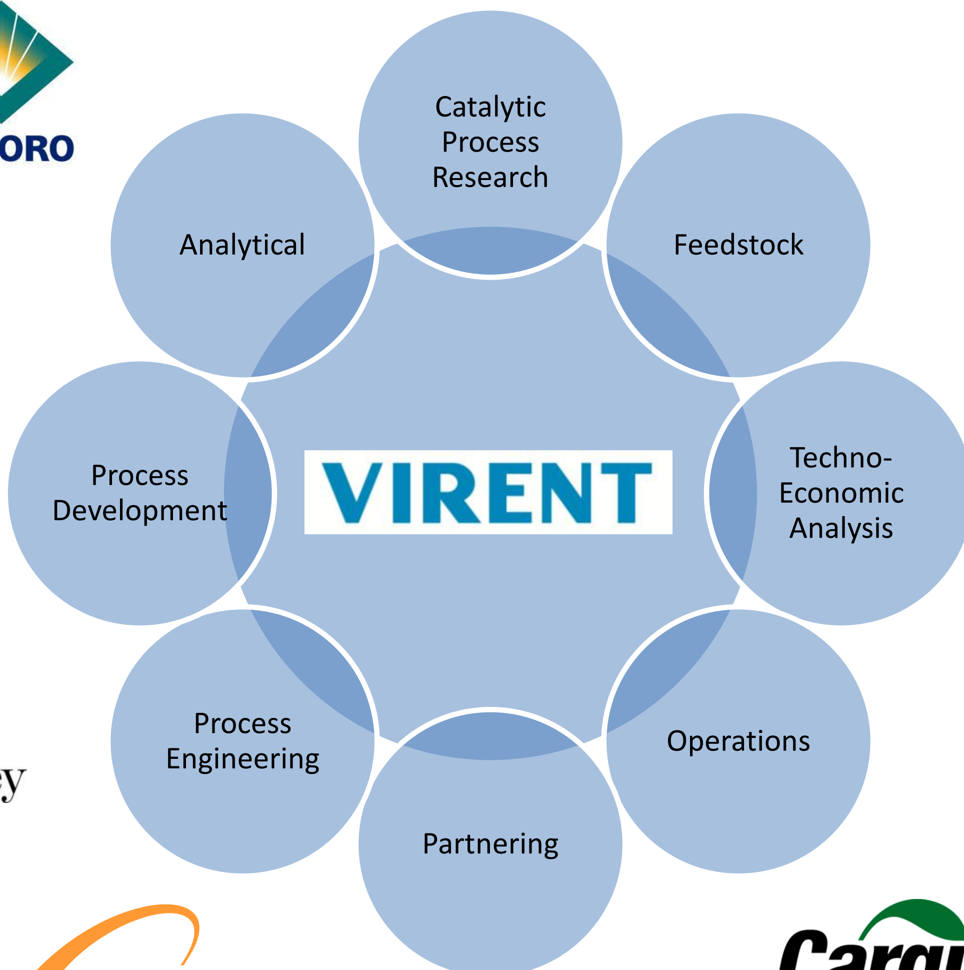
DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

DEPARTMENT OF THE NAVY UNITED STATES OF AMERICA

ATP ADVANCED TECHNOLOGY PROGRAM NIST

Feedstock Logistics	Conversion Platform	Deployment Opportunity	Customer Acceptance
Cargill	VIRENT	Shell	HONDA
• Major Shareholder • Participating in feedstock development and commercial deployment	• Platform Research & Development • Technology Provider • Feedstock R&D • Catalyst Development • Operations	• Major Shareholder • Development Partner • Fuel Qualification • Scale-Up Partner • Market Channels	• Shareholder • Support Efforts to Determine BioGasoline's Suitability in Current & Next Generation Engines

Organization Capabilities



Employees from leading energy, agribusiness and chemical companies; start-ups; and research institutes

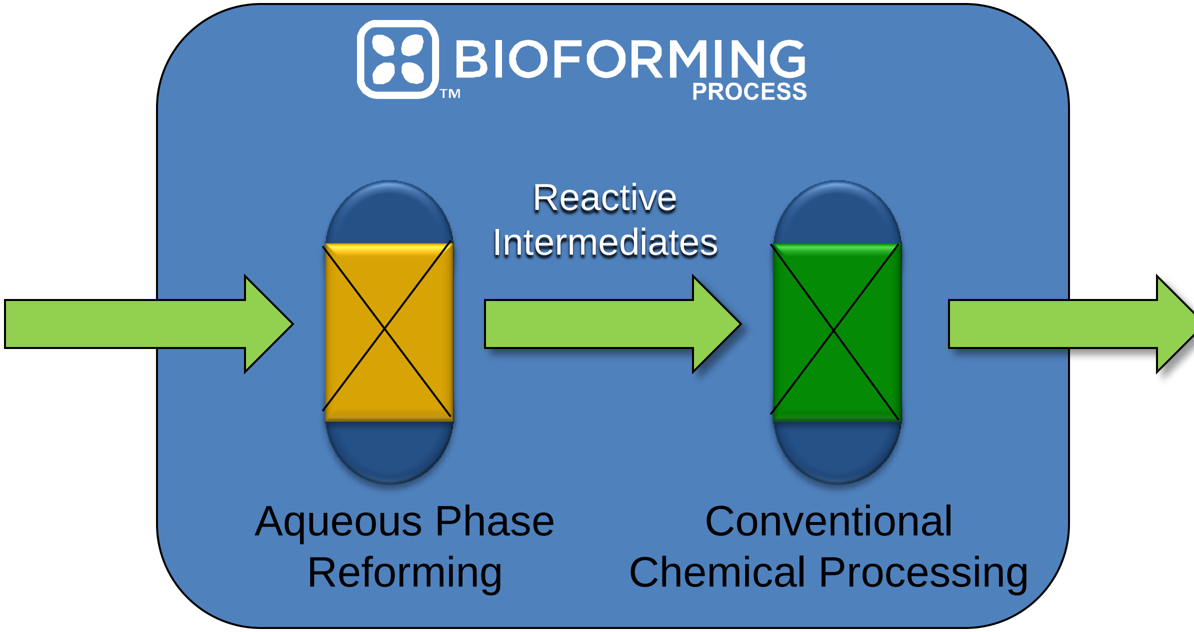
The BioForming® Process

Converting Multiple Feedstocks to High Value Hydrocarbons

Cellulosic

Sugars

Starches



Chemicals

Fuel Gas

Hydrogen

Reformate

Gasoline

Jet

Diesel

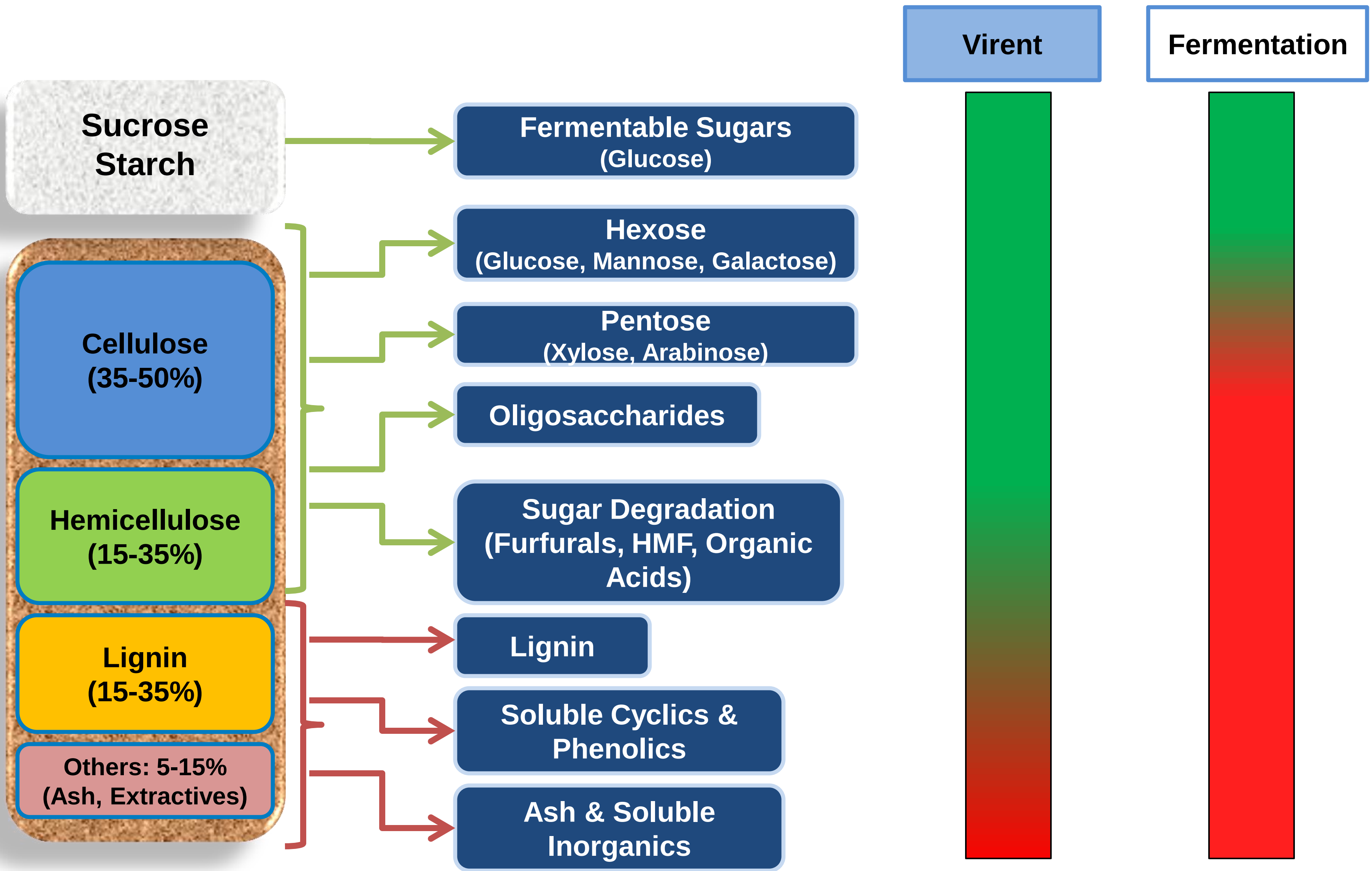
Familiar to Petrochemical Industry

- Similar Reactor Processing Practices
- Proven Catalytic Scale-Up Engineering
- Industry Experience Operating at Scale

High Quality Drop-in Products

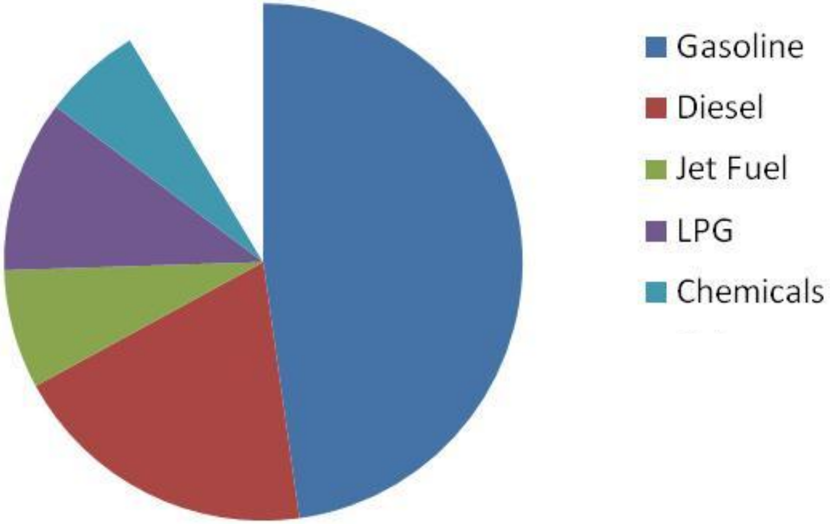
- Premium Hydrocarbon Mixtures
- Tunable to Produce Desired Blends
- Adaptable to Provide Chemicals
- Compatible with Logistics Infrastructure
- High Energy Content

BioForming Feedstock Advantage



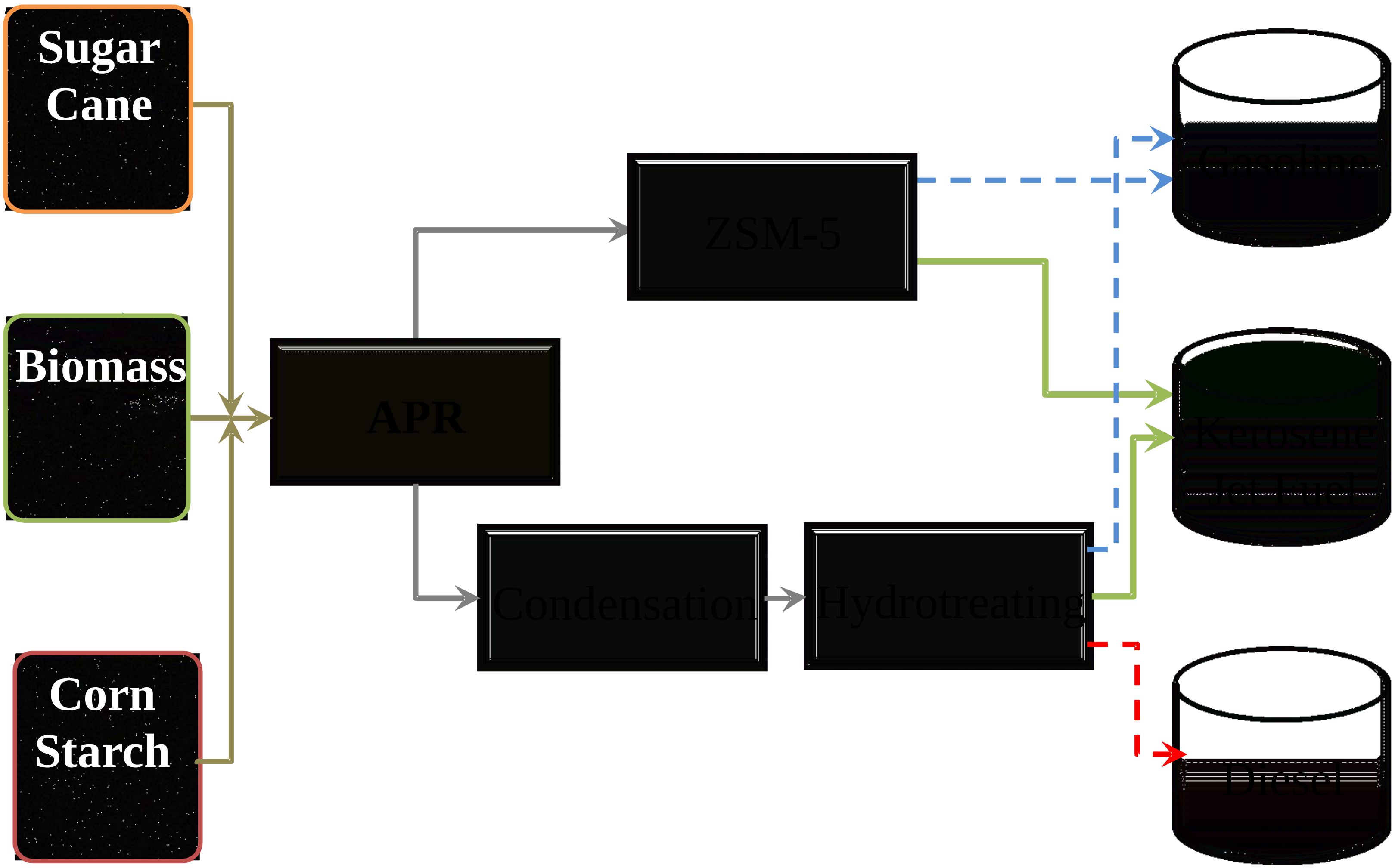
Sustainable Energy Security

Virent Technology can Replace > 90% of the Barrel

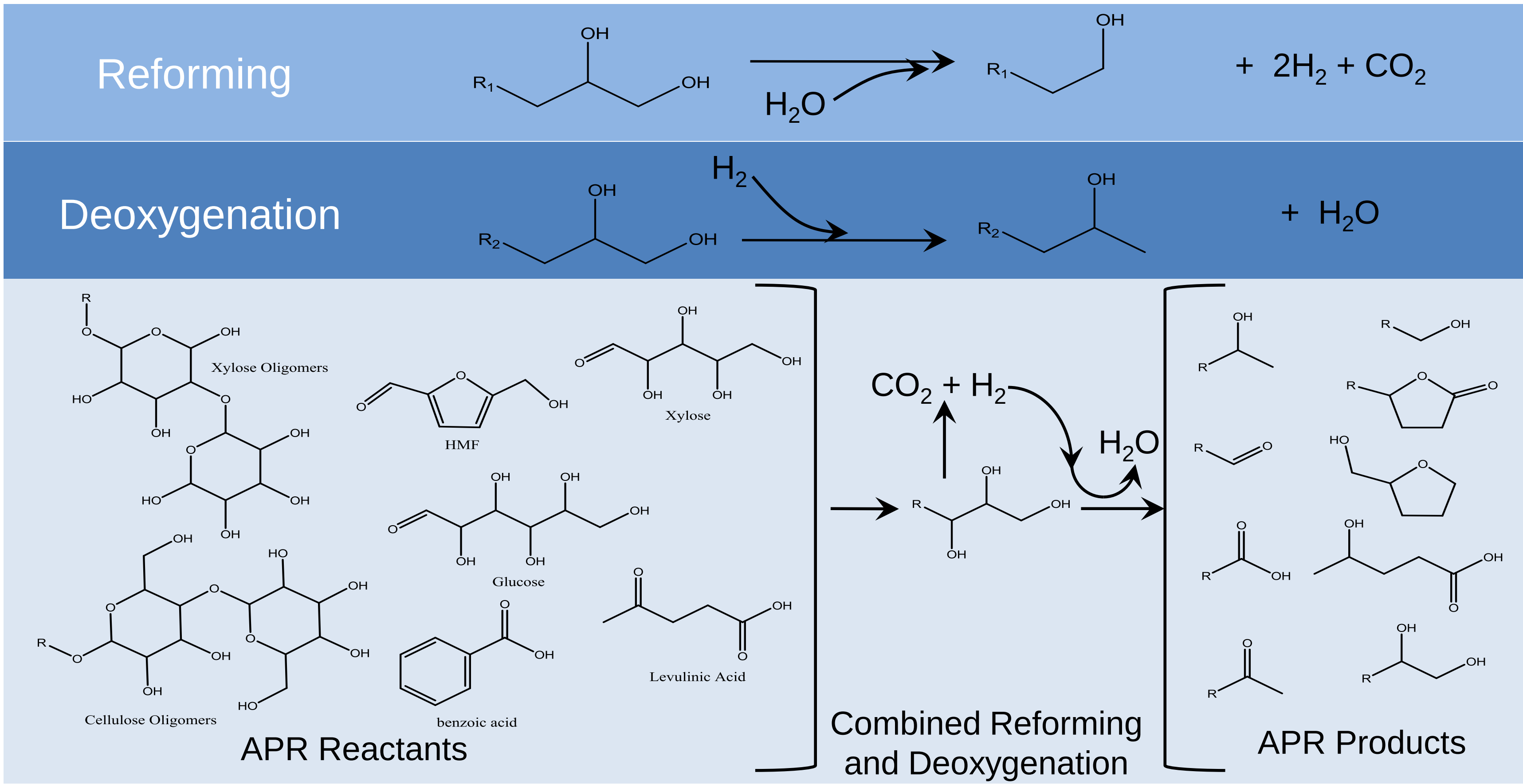


The US consumes over 18 million barrels of oil per day. 49% is imported from foreign countries.

BioForming® Concept

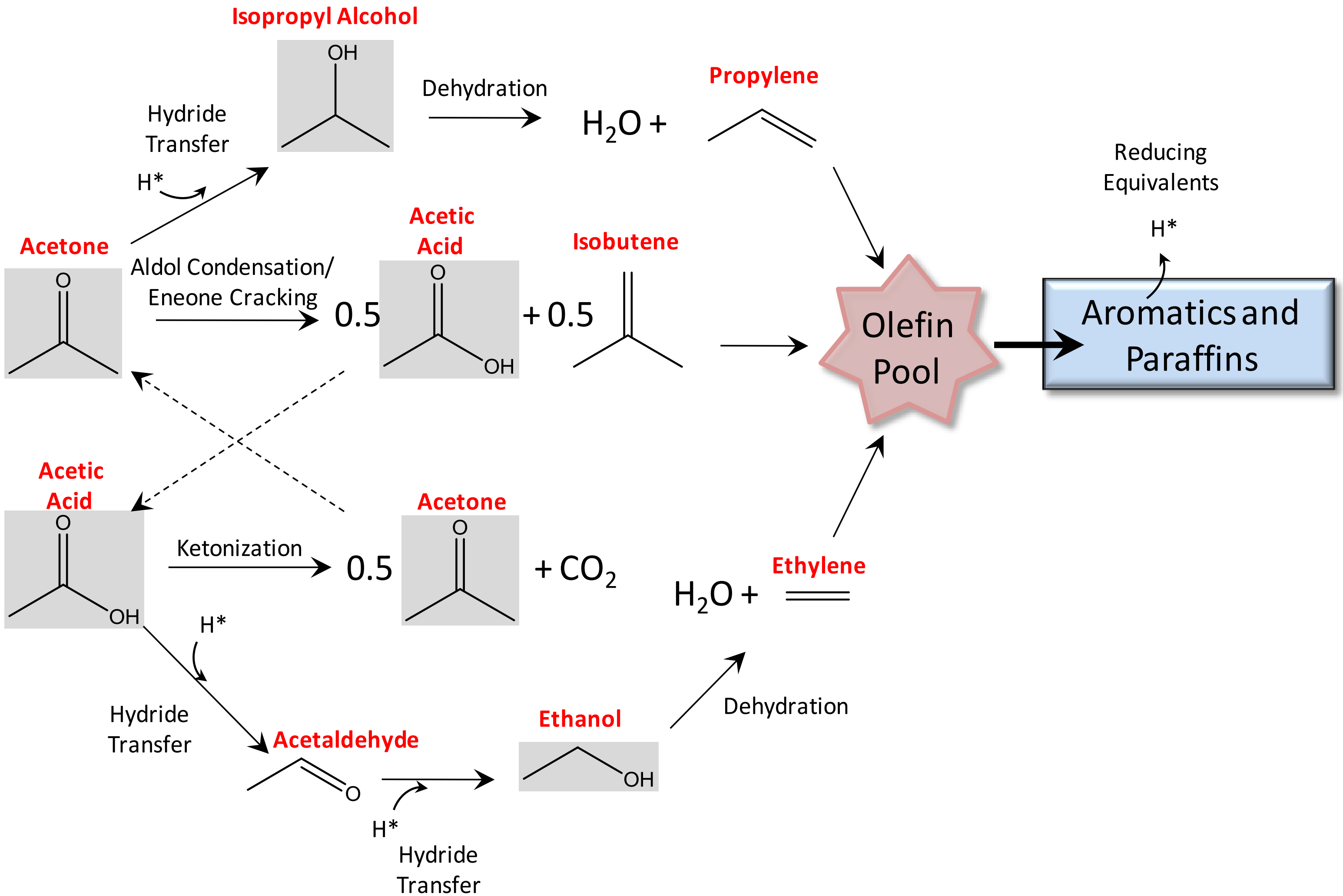


APR Reaction Pathways to Reactive Intermediates

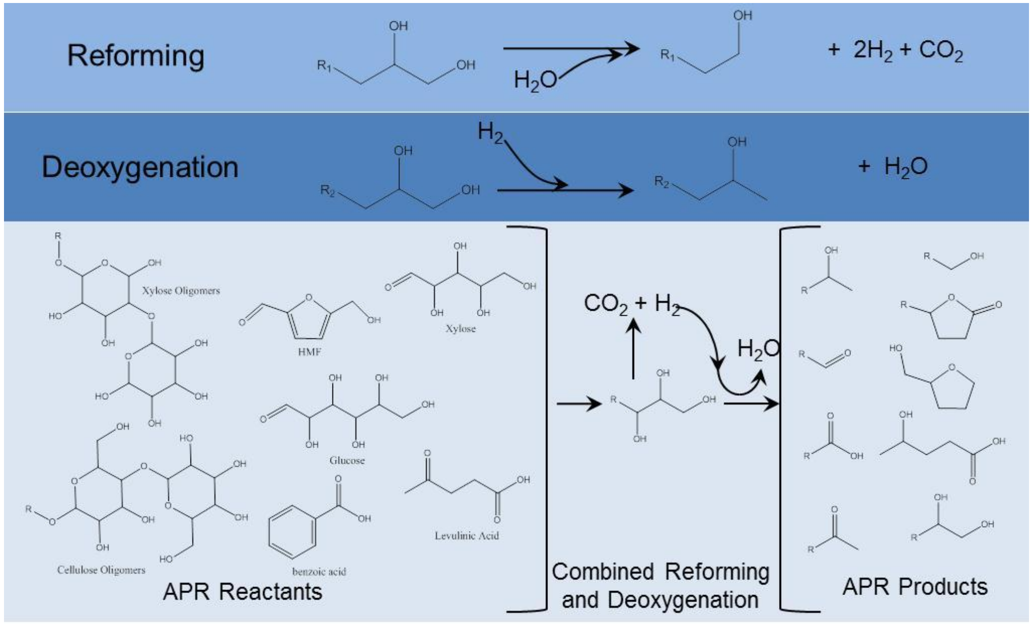


- Intermediate oxygenate composition impacts downstream processing
- Intermediates can be tuned to achieve different final product goals

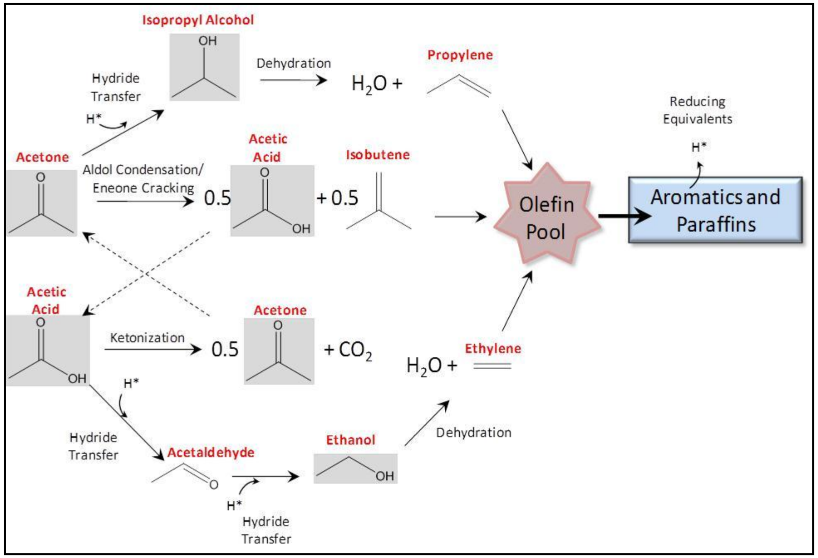
Reaction of Oxygenates over ZSM-5

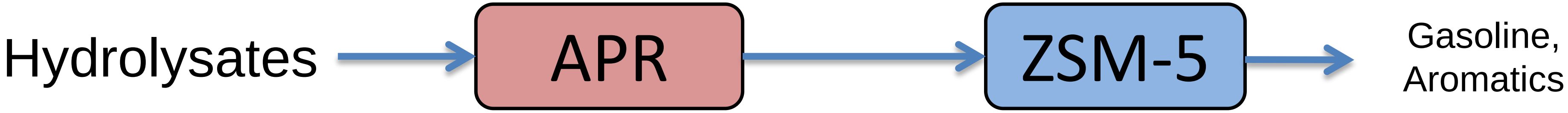


APR Chemistry



ZSM-5 Chemistry





Product Development Progress

Date	Jan-2008	July-2008	Sep-2008	Dec-2008	Apr-2009	Eagle
Dienes and Cyclic olefins						
Acidity						
Benzene						
Ketones						
Distillation End Point						

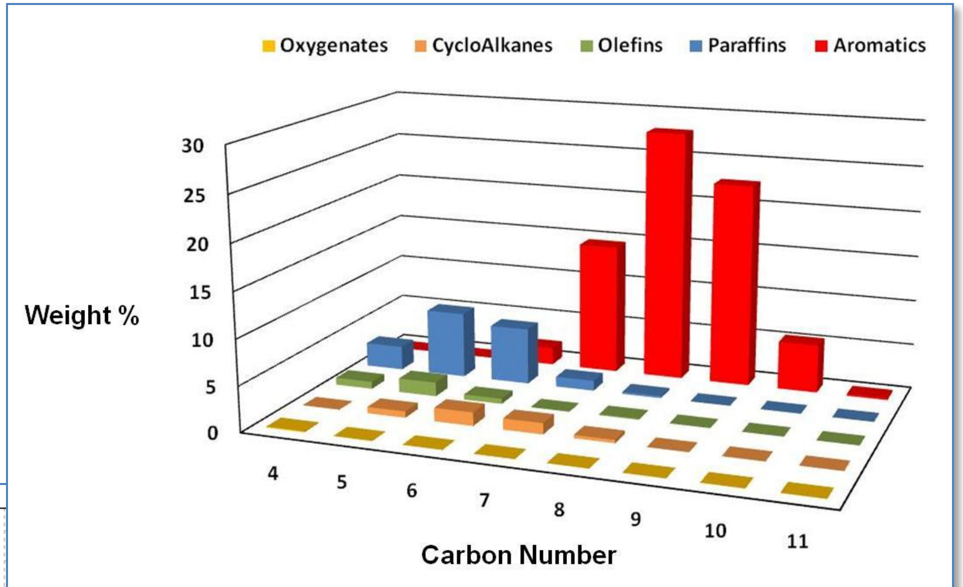
Increasing Quality and Volume

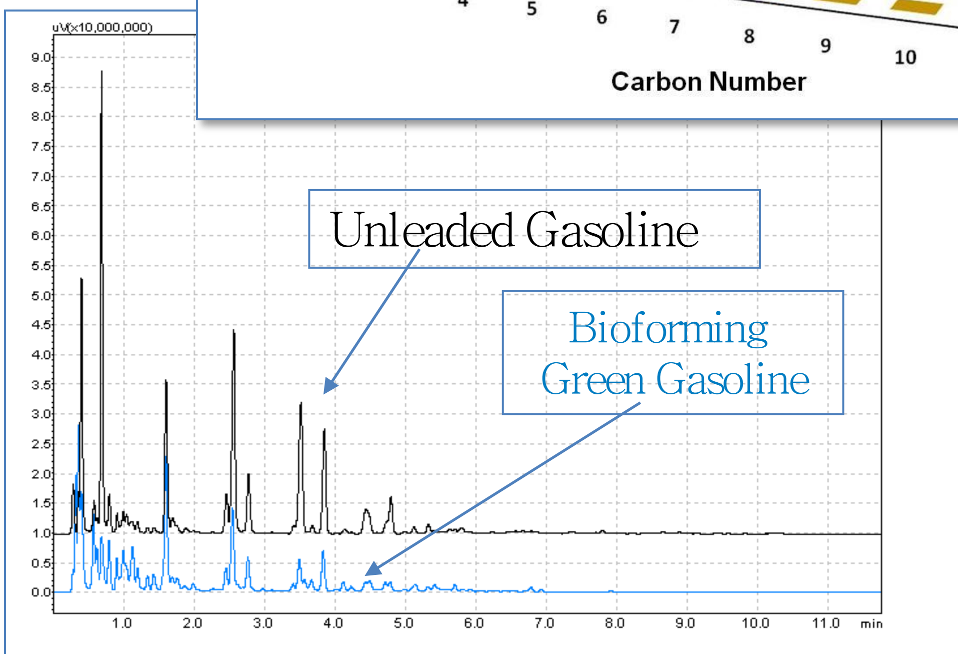




Virent's BioGasoline Product

Premium product with the same components as petroleum derived gasoline





Unleaded Gasoline
115,000 BTUs/Gal

Bioforming BioGasoline
+120,000 BTUs/Gal

Ethanol
76,000 BTUs/Gal

~ 20 liters of sugar derived gasoline from Virent's Bioforming process.

Reactor Configurations

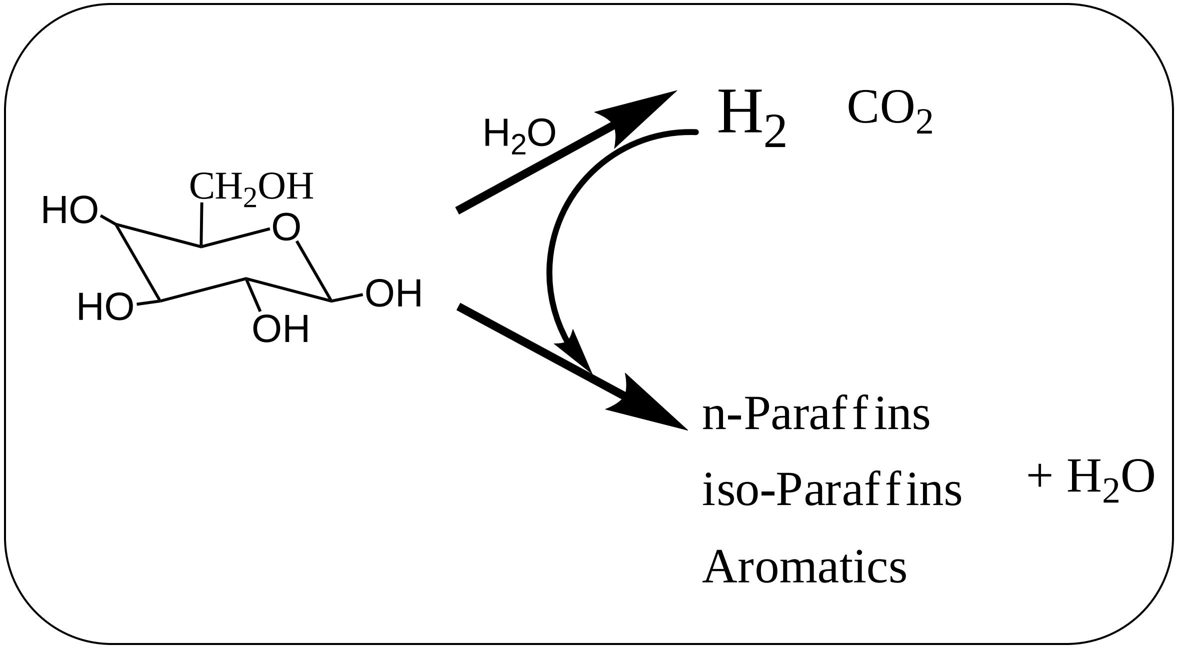
- Virent has 20+ continuous and integrated pilot plants
- Contains feed carboy, pumps, heaters, jacketed reactors, cooler, separators
- Automated control allows for 24/7 operation
- Multiple temperature, pressure, & flow measurement points with data collection
- Feed rates range from 0.1 to 40 mL /min
- Plants easily modified to a myriad of process steps and configurations

- Scale-up of 100X
- Full length reactors and commercial scale catalyst
- 10,000 gal/yr sugar to gasoline integrated continuous process plant
- Feedstock handling and purification system flexibility
- Fully automated and controlled by DCS (Delta V)
- Product volumes for registration, fleet testing, and Ferrari Scuderia race team

Virent BioGasoline Product Validation

"No Harms" Fleet Trials

Generation of Hydrocarbons from Sugar with In-situ Hydrogen Generation



- Recovery of bio-based carbon can be increased by suppressing reforming reactions and using externally supplied hydrogen.

Overall Theoretical Stoichiometry

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

Hydrocarbon contains 65 % of Sugar Carbon
Hydrocarbon contains 94% of LHV of Sugar

Instead, bring in H_2 from external source

$$2.33\ C_6H_{12}O_6 \rightarrow C_{14}H_{30} + 14H_2O$$

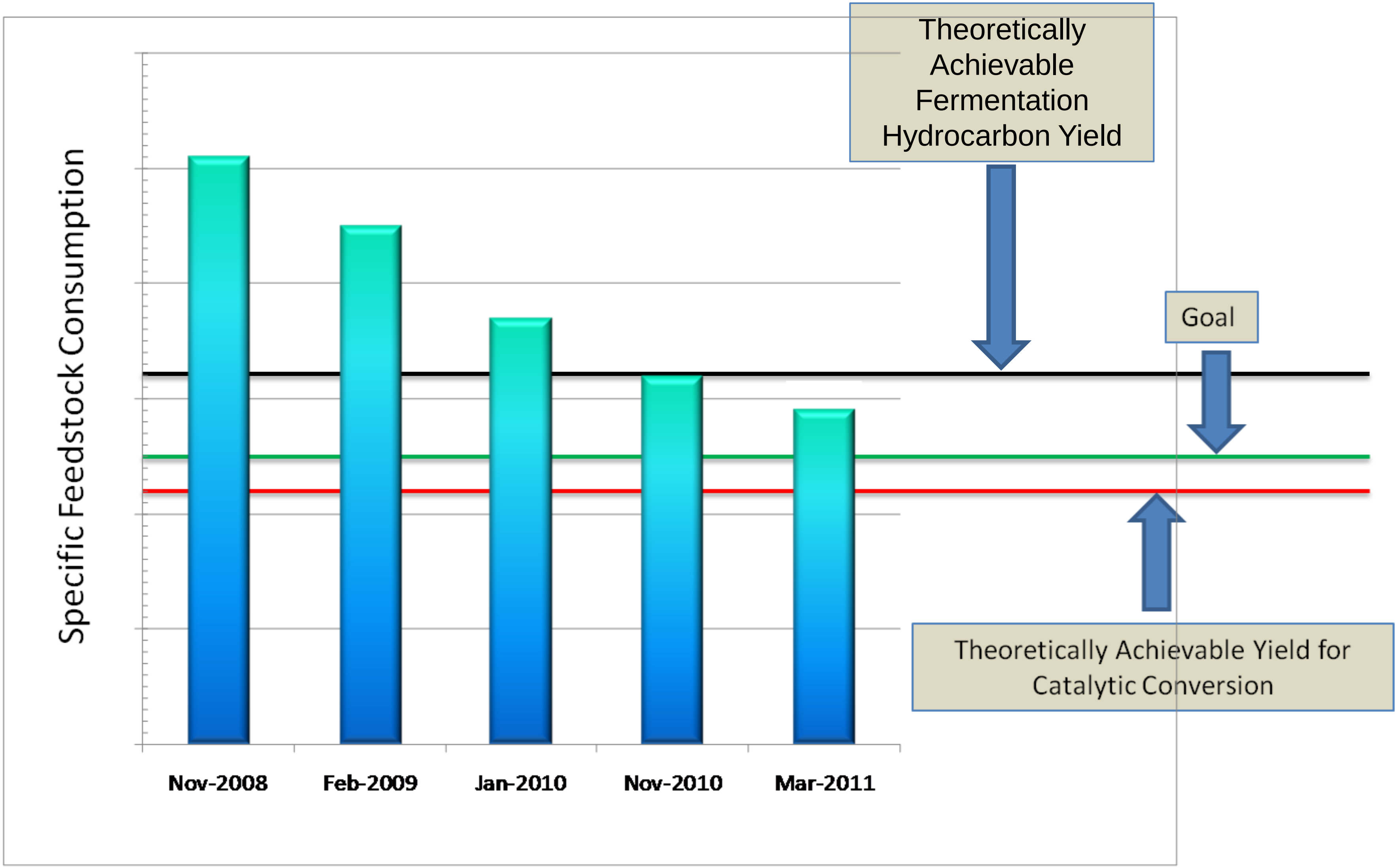
Hydrocarbon contains 100 % of Sugar Carbon
Hydrocarbon contains 140% of LHV of Sugar

Feedstock Optimization

- Natural gas as a supplemental feed can improve economics as a low cost source of hydrogen.
- Internal H_2 Production or External Supply
  - Stoichiometry Example
  - $2.08\ C_6H_{12}O_6 = C_8H_{18} + 4.5\ CO_2 + 3.5\ H_2O$
  - $4\ C_6H_{12}O_6 + 27\ H_2 = 3\ C_8H_{18} + 24\ H_2O$

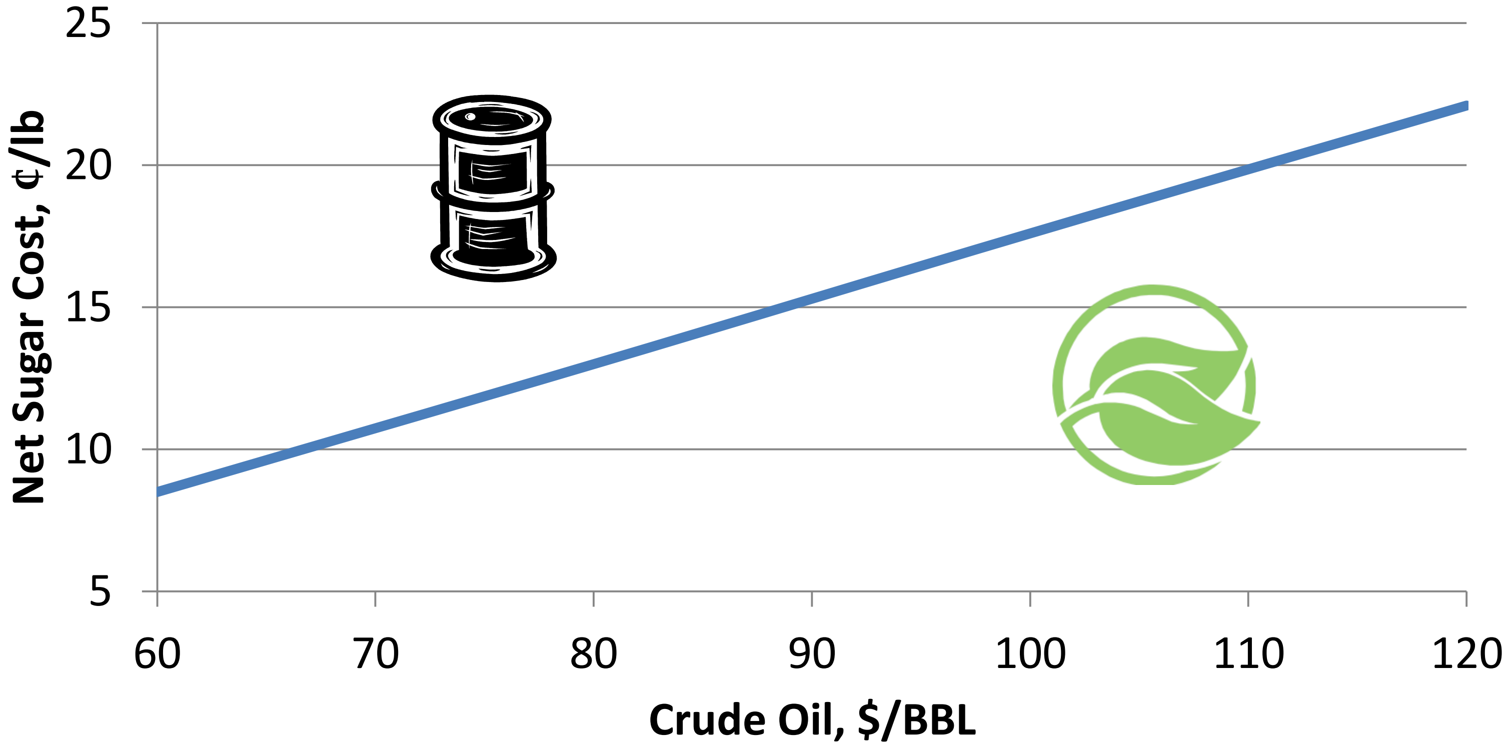
	Internal H2 (lbs glucose / gal) {lbs glucose/lb HC}	**External H2 (lbs glucose / gal) {lbs glucose/lb HC}**	**Theoretical H2 Requirement (kg H2 /gal)**
Octane	19.3 {3.3}	12.3 {2.1}	0.42
Xylene	21.3 {2.9}	16.2 {2.3}	0.31

Process Yield Advantage



BioForming Refinery Break Even

Cash cost break even for a Virent Bioforming refinery producing aromatic chemicals and biogasoline.



<u>*Notes:*</u>
**Product Values utilize historic Crude to Product Value Ratios from Mid 2007 to Mid 2010*
**Major Utilities Cost Assumptions of $6/mmbtu NG and $0.07/kw-hr*
**Includes Variable and Fixed costs*

Sugars to Cellulosic Migration Plan

VIRENT

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

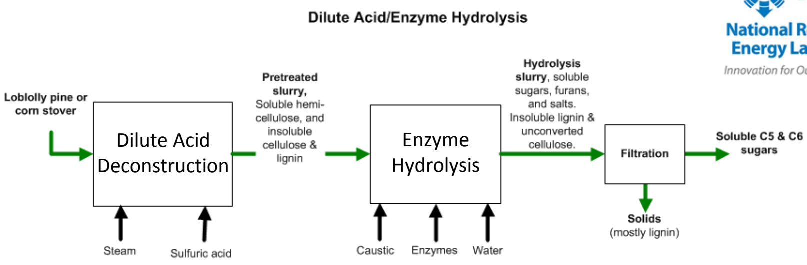
Liberate sugars from cellulosic biomass cost-effectively

<u>Development Portfolio</u>

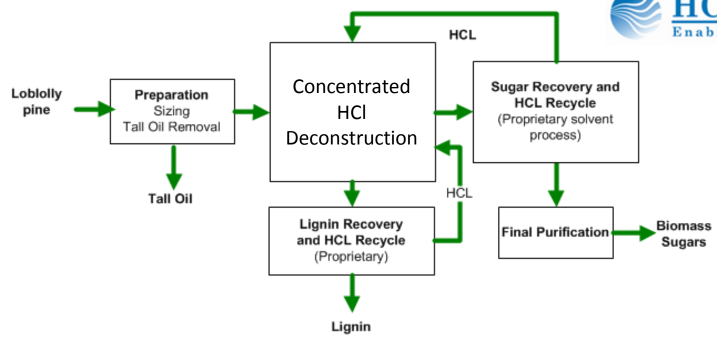
National Advanced Biofuel Consortia
HCL Cleantech Collaboration
NREL Collaboration
In-house Technology Development

Virent Deconstruction Partners

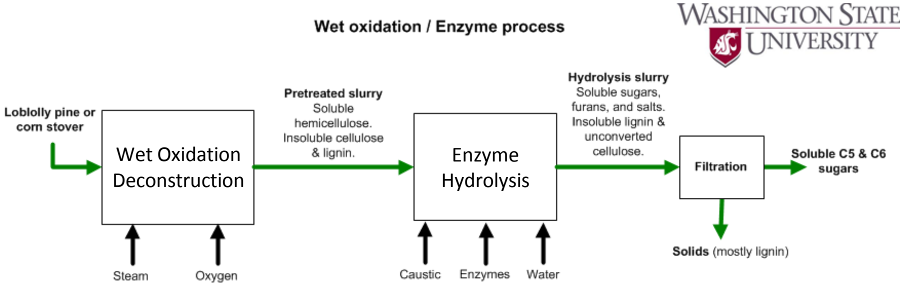
- Dilute acid pretreatment and enzyme hydrolysis



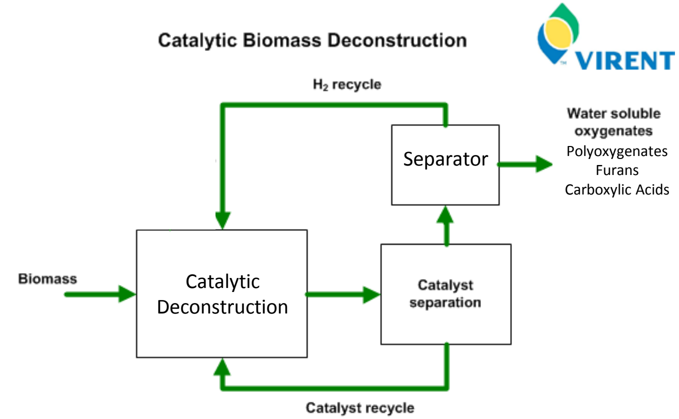
- Strong acid pretreatment



- Wet oxidation and enzyme hydrolysis



- Virent catalytic deconstruction



VIRENT

Cellulosic biomass to gasoline, 6/2/2011

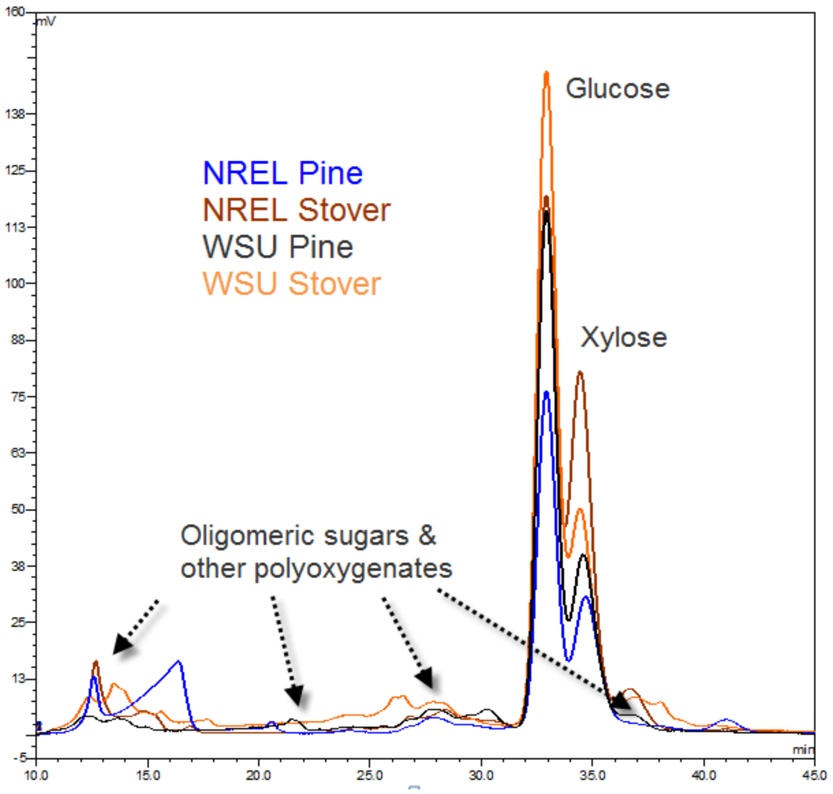
NABC
National Advanced Biofuels Consortium

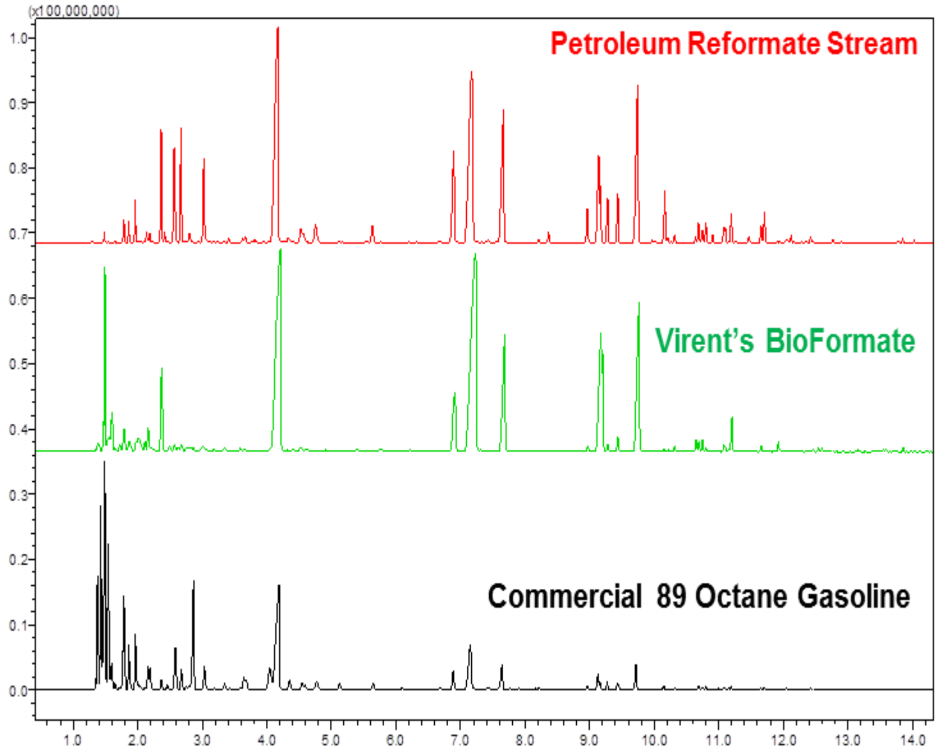
Iowa State University
Catchlight Energy
A Chevron | Weyerhaeuser Joint Venture
NREL
National Renewable Energy Laboratory
Washington State University
World Class. Face to Face.
Pall Corporation
Pacific Northwest National Laboratory
Proudly Operated by Battelle Since 1965
bp
TESORO
Argonne National Laboratory

Recent Progress - Biogasoline

NABC Work

- Stover from ISU, pine residues from Catchlight
- NREL, WSU, and Virent making Hydrolysates
- Virent converted hydrolysates into BioFormate™ gasoline product





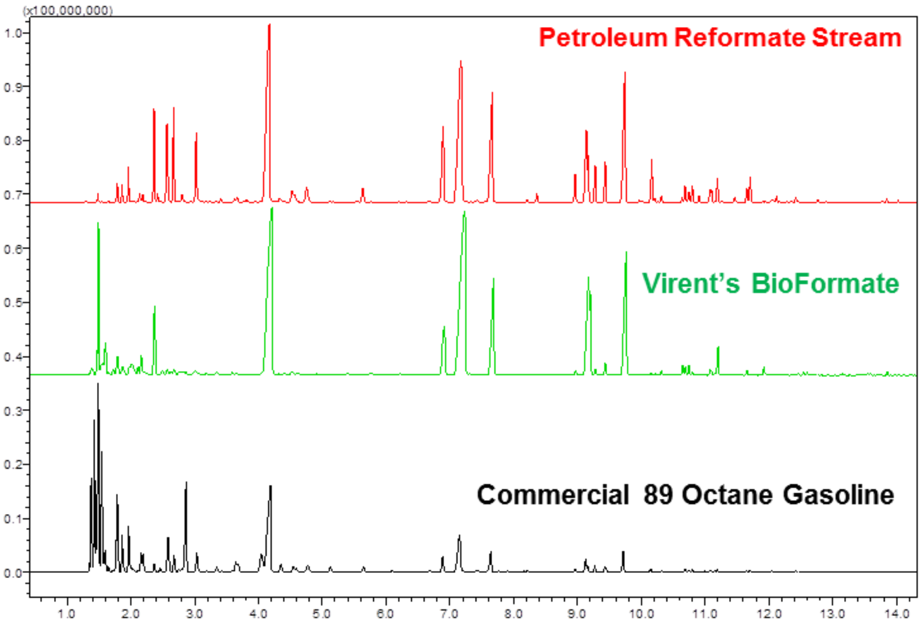
Biobased Reformate: Fuels and Chemicals

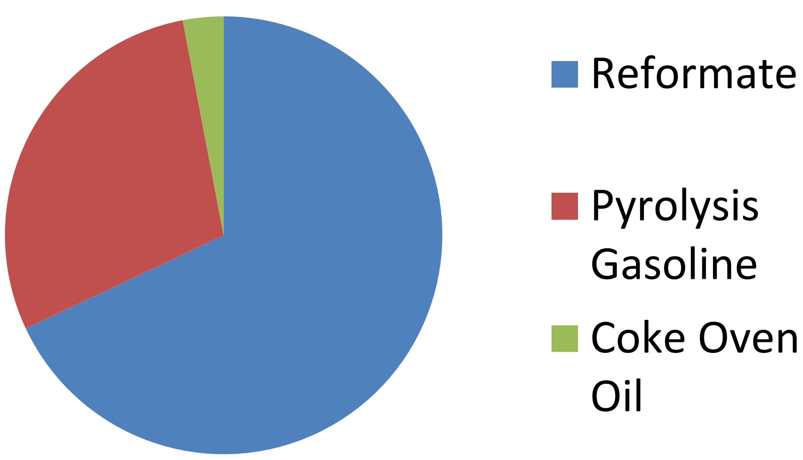
VIRENT

Virent produces a biobased reformate that is identical to petroleum reformate in an oil refinery.

Reformate is used as a high octane blend component in gasoline

Reformate is a significant source of benzene, toluene, and xylenes used in the chemical industry.





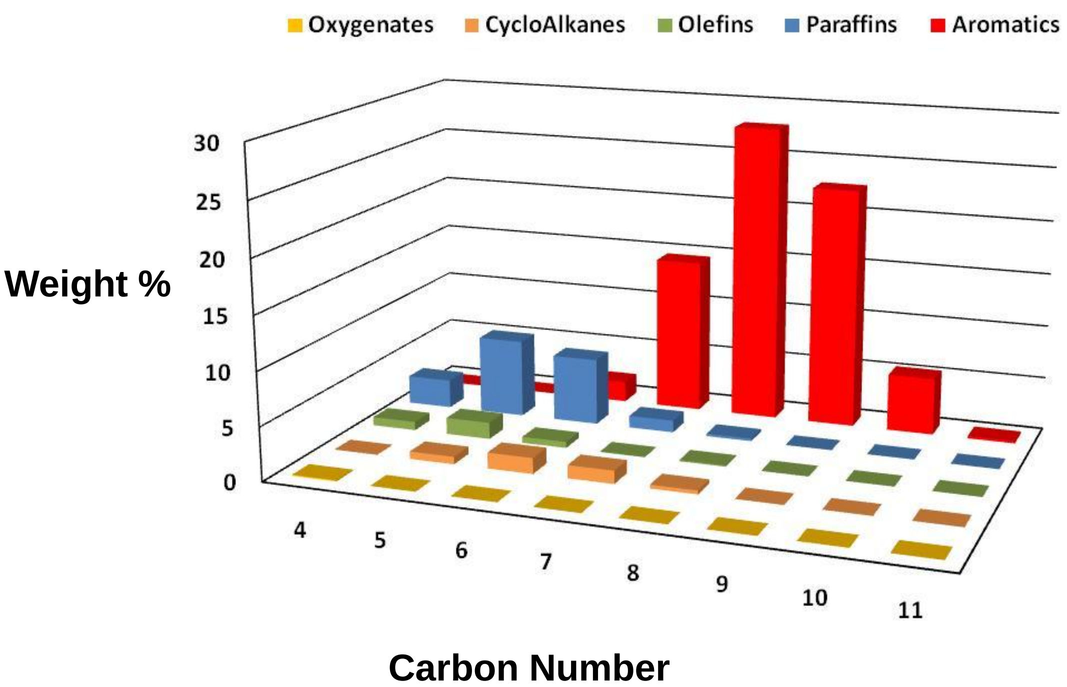
Nearly 70% of the world's aromatics are derived from reformate.

Shale gas and gasoline market dynamics are reducing the production of reformate from refineries.

Continued upward pricing pressure on aromatics is expected.

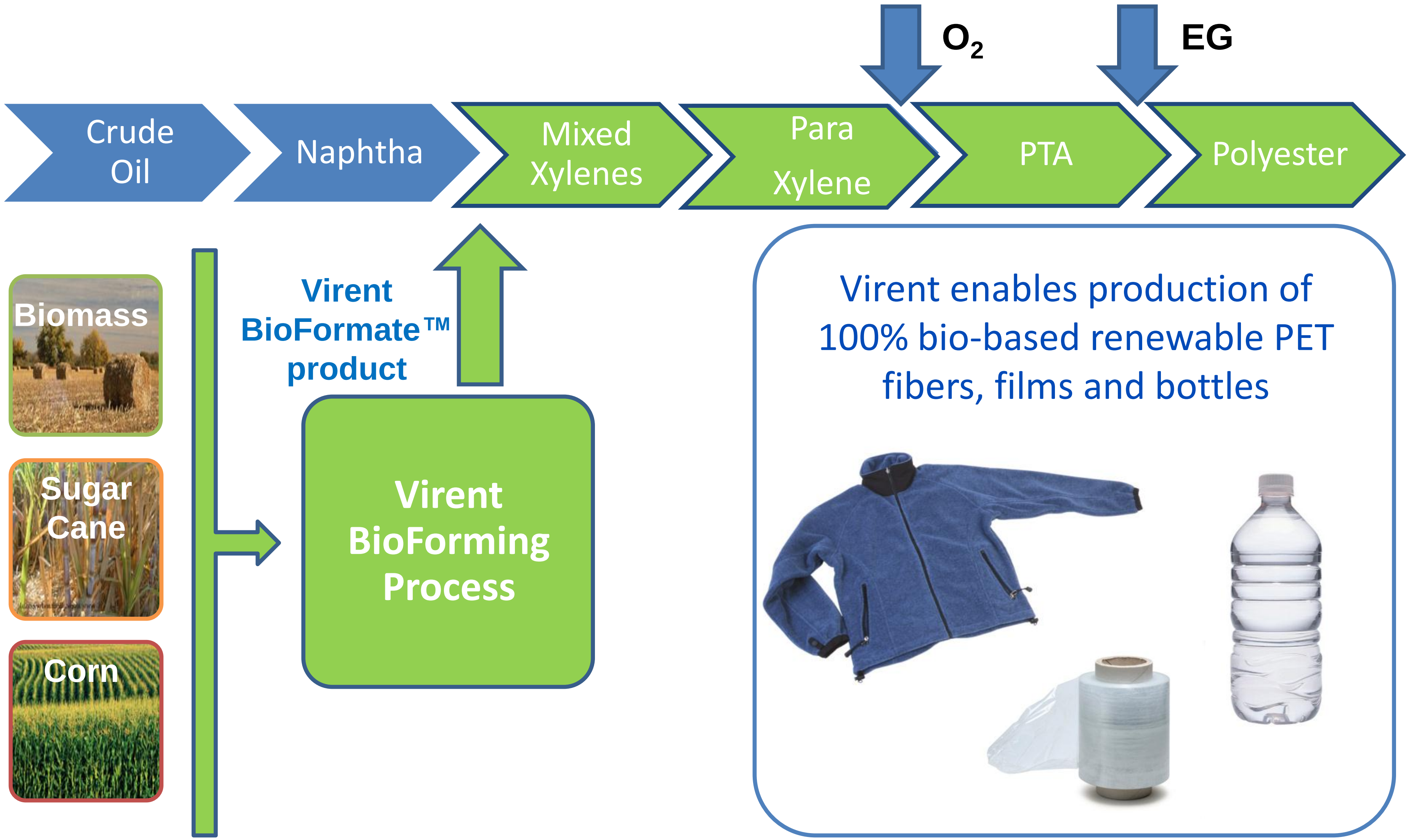
Virent's BioGasoline Composition

Virent's BioGasoline product resembles a typical refinery reformate stream which is the dominant feedstock source for many chemicals and plastics in use today.



	Typical Catalytic Reformate (Vol%)	Virent BioGasoline Product (Vol%)
Paraffins	22.5	20.6
Napthenes	0.7	3.9
Aromatics	60.8	64.4
Overall Totals	84.0	88.9
Typical RON	~95 - 105	105

Virent Enables 100% Renewable PET



High Quality, Drop-in Chemicals

chemicalweek

Virent Unveils Biobased P-Xylene Process

2:52 PM MDT | June 6, 2011 | Rebecca Coons

Coca-Cola is working to increase the renewable content of its packaging.

Virent (Madison, WI), a catalytic chemistry firm, says it has successfully produced *para*-xylene (*p*-xylene) from plant-based sugars. The *p*-xylene, which Virent has tradenamed BioFormPX,is identical to *p*-xylene produced via petroleum-based processes and can be used as a drop-in replacement in the value chain, says Kieran Furlong, Virent's commercial manager/chemicals.

The breakthrough will allow polyethylene terepthalate (PET) manufacturers to produce the commodity resin entirely from renewable resources.

Virent's plant-based para-xylene

Aromatic Product Tree

AROMATICS

- **Ortho-Xylene**
  - **Plasticizers**
  - **Polyethylene Naphthalate (PEN)**

- **Meta Xylene**
  - **Purified Isophthalic Acid (PIA)**
  - **Polyethylene Terephthalate (PET)**

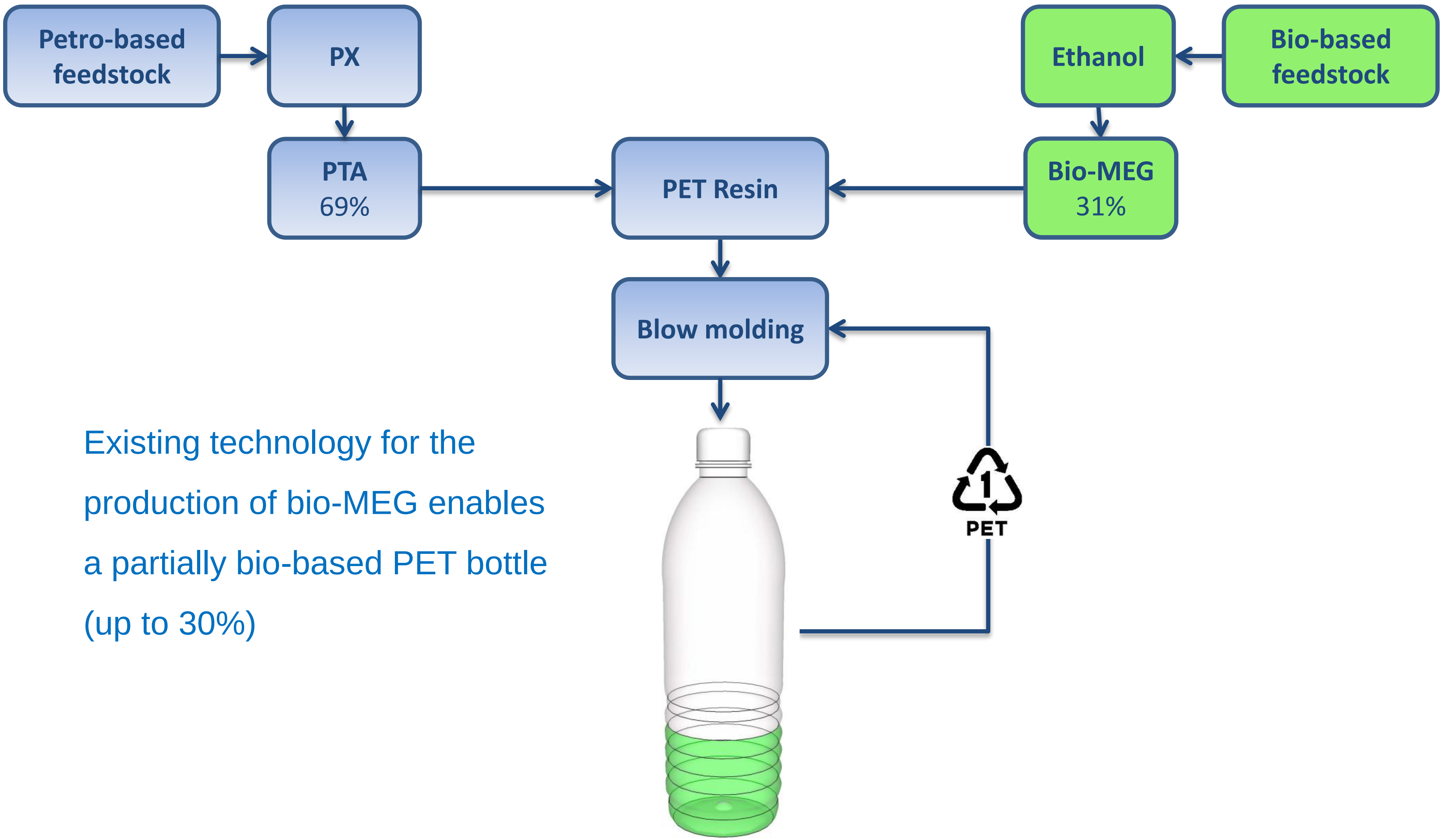
- **Para-Xylene**
  - **Purified Terephthalic Acid (PTA)**
  - **Polyethylene Terephthalate (PET)**

- **Toluene**
  - **Toluene Diisocyanate (TDI)**
  - **Polyurethane Foams**

- **Benzene**
  - **Polycarbonates**
  - **Phenolic Resins**
  - **Nylon 6**
  - **Polystyrenes**

Benzene, Toluene and Xylenes have a wide range of everyday end use products and are heavily dependent on fossil fuel sources for production.

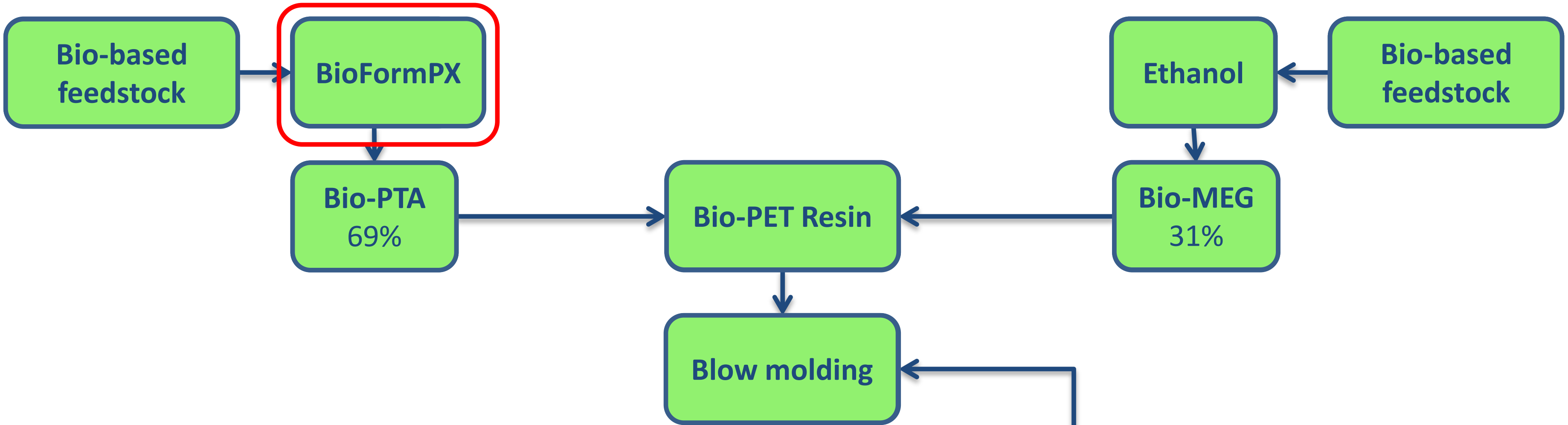
Current State-of-the-Art PET

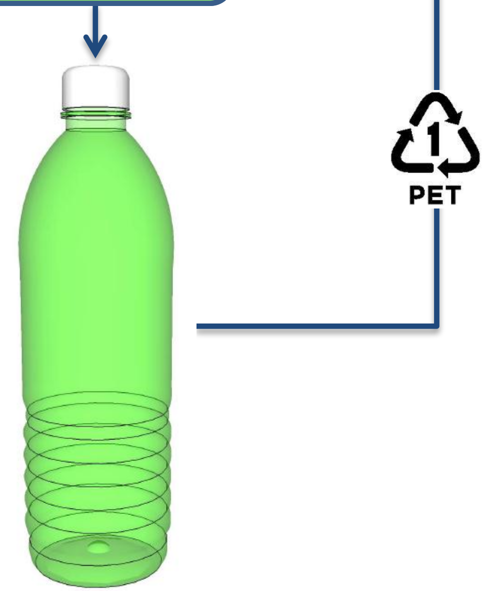


Existing technology for the production of bio-MEG enables a partially bio-based PET bottle (up to 30%)

Adapted from Coca-Cola website graphic
http://www.thecoca-colacompany.com/citizenship/plantbottle_basics.html

Virent Enables 100% RR-PET



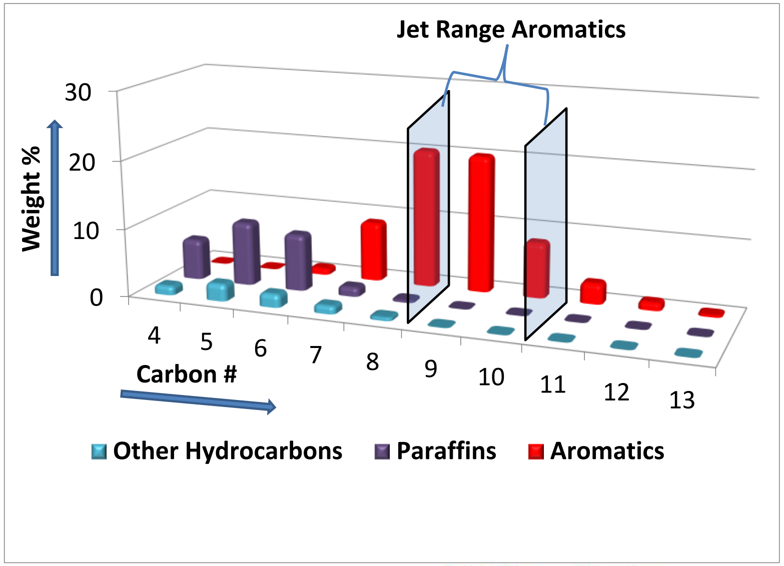


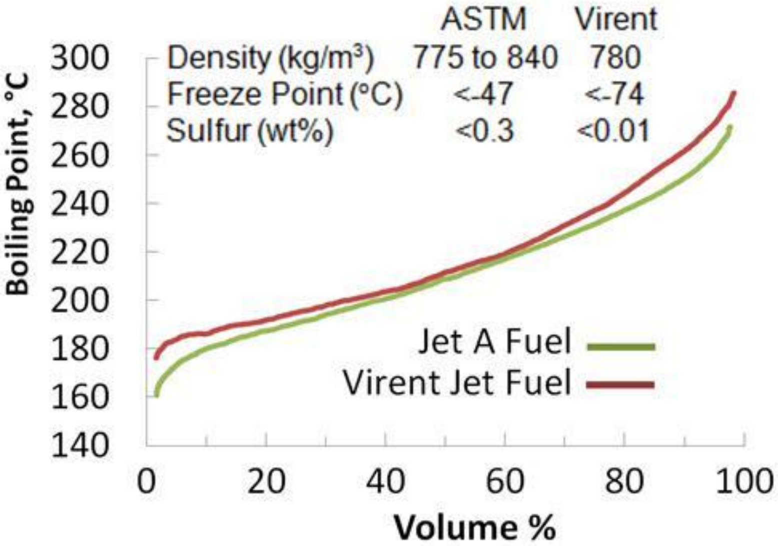
Virent technology for bio-based PX enables a 100% bio-based PET bottle that is:

- 100% Recyclable
- 100% Renewable

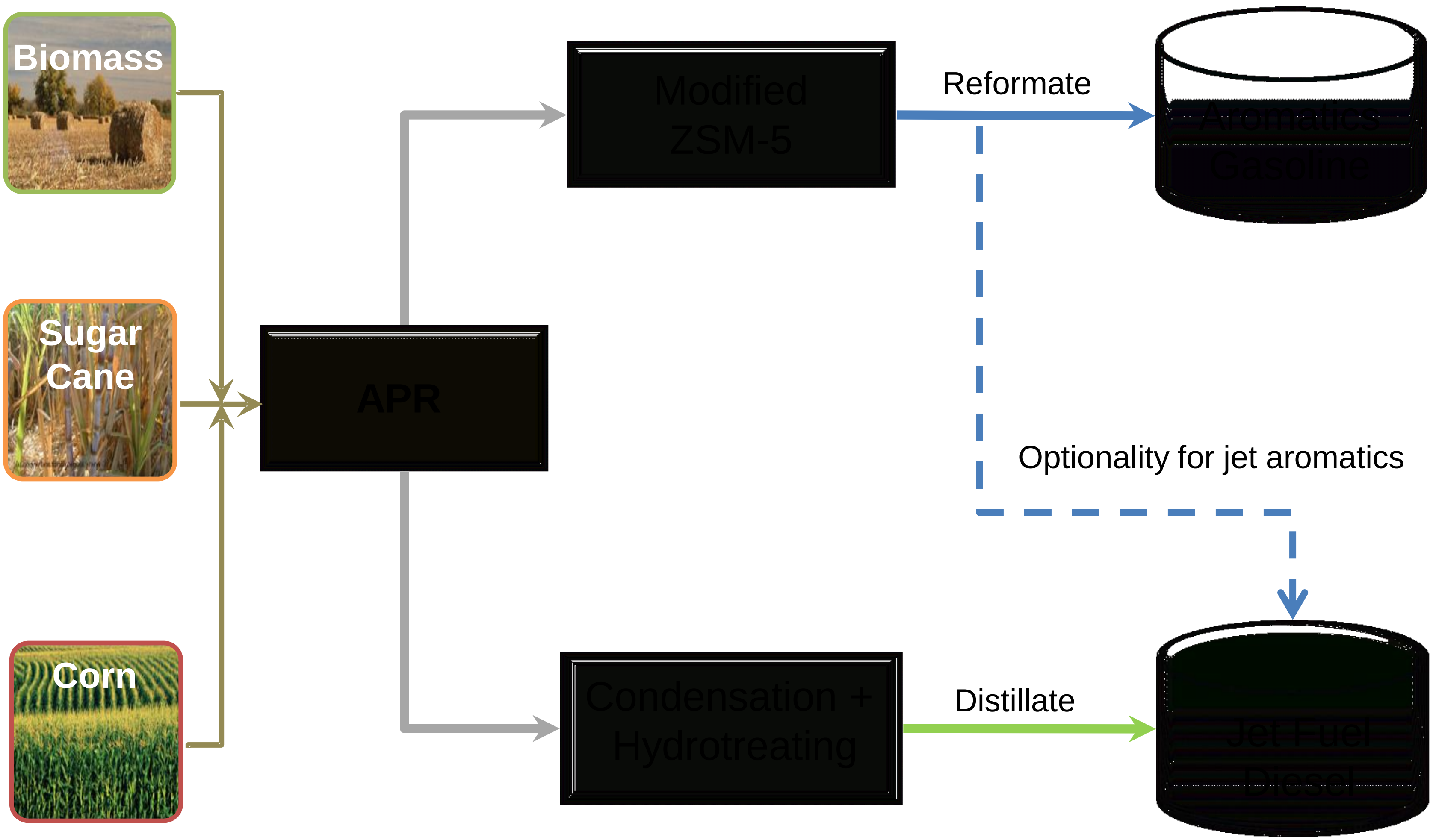
Adapted from Coca-Cola website graphic
http://www.thecoca-colacompany.com/citizenship/plantbottle_basics.html

Renewable Jet Fuel

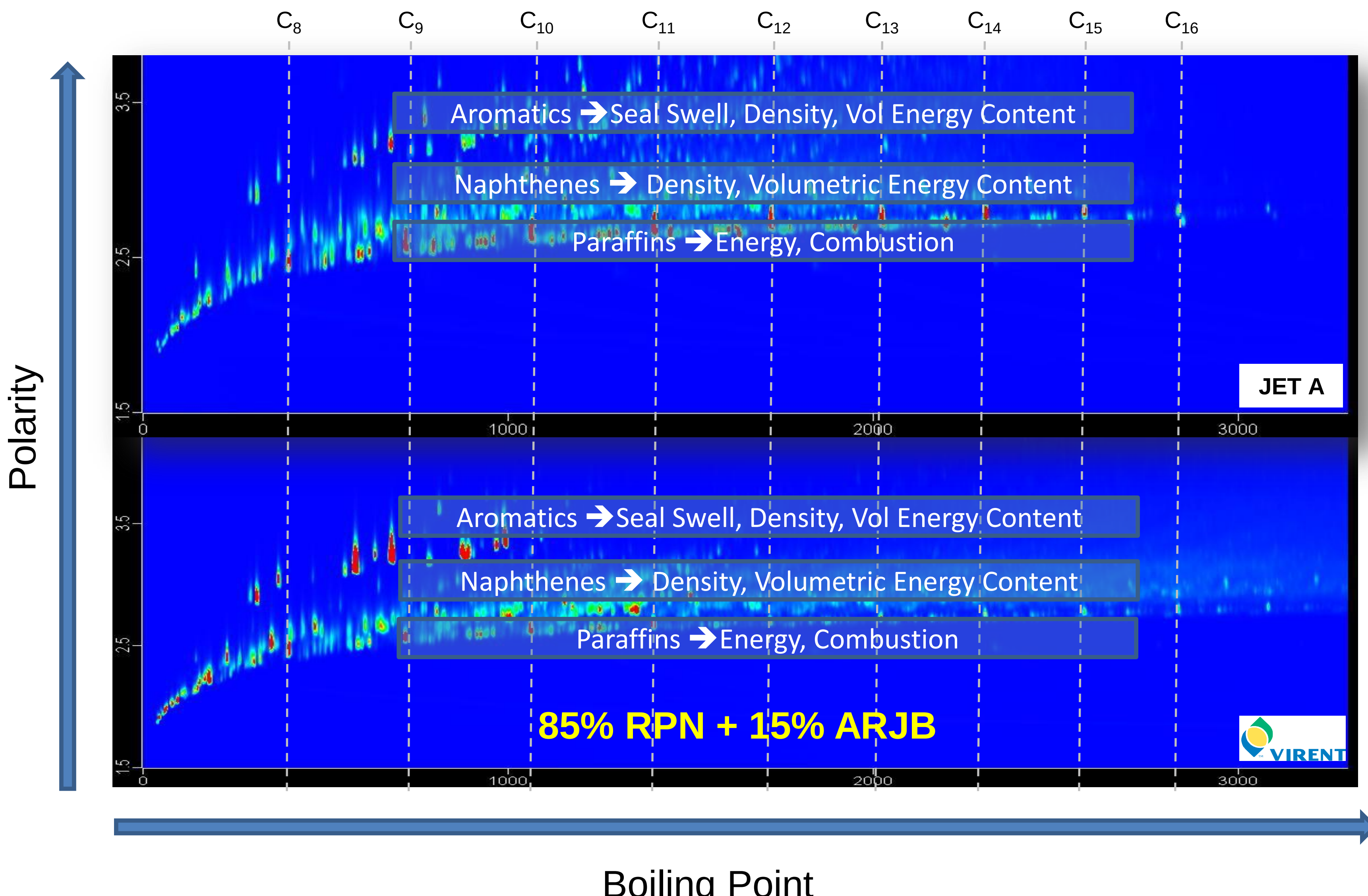




BioForming® Concept



Fully Renewable Synthetic Jet

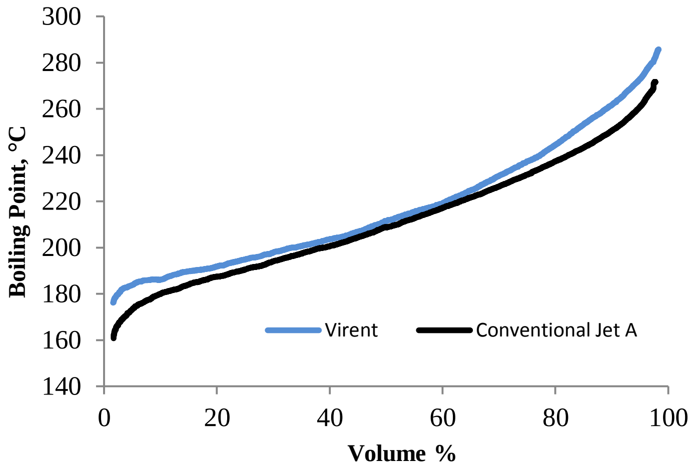


Jet Specification Evaluation - RPN Wright Patterson AFB

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

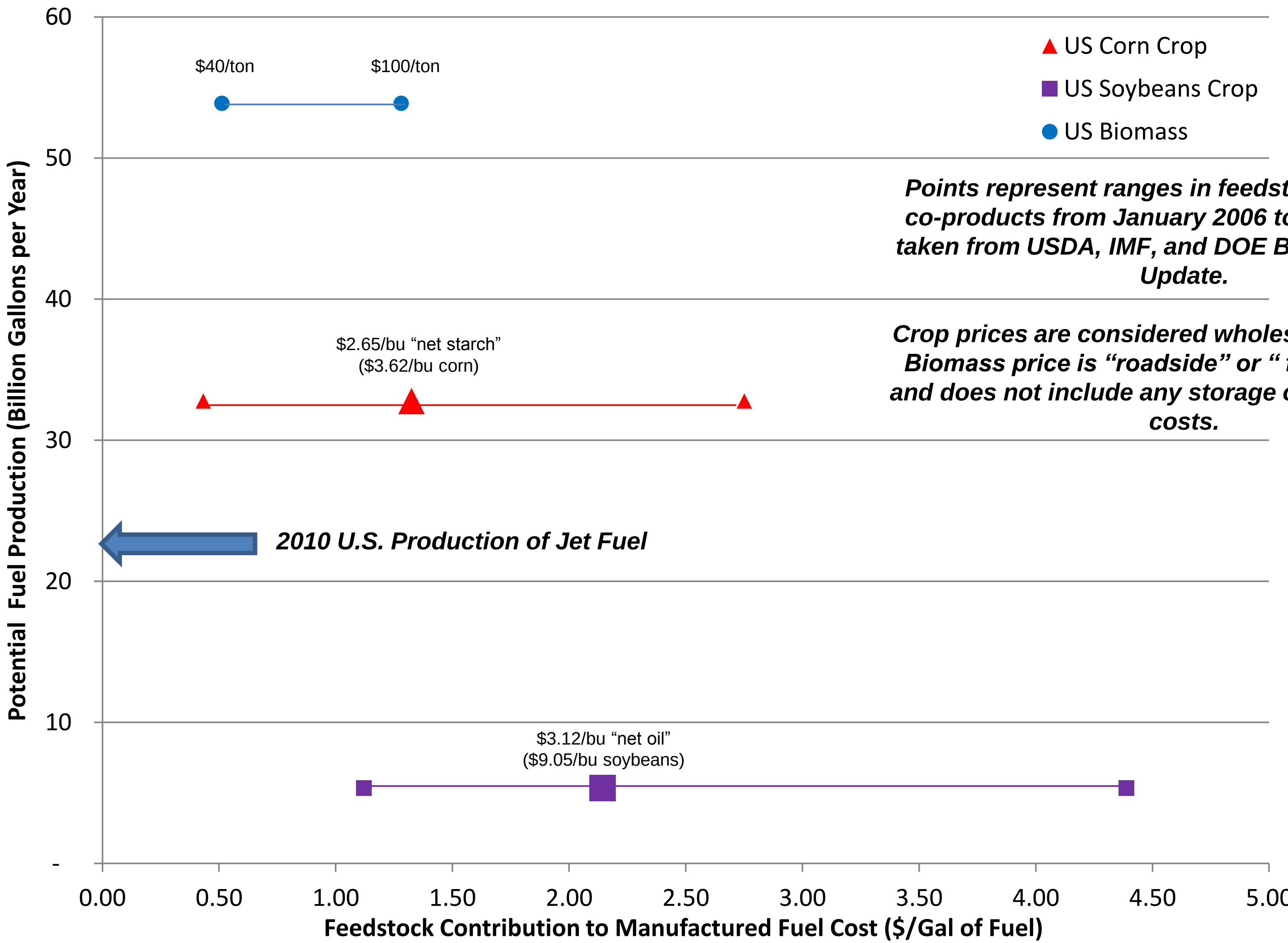
Virent D-86 comparison to Jet-A



High thermal stability ensures low levels of impurities

U.S. Market Potential Vs. Feedstock Cost

Projected Feedstock Availability in 2022



Points represent ranges in feedstock prices less co-products from January 2006 to present. Data taken from USDA, IMF, and DOE Billion Ton Study Update.

Crop prices are considered wholesale prices while Biomass price is “roadside” or “ farmgate” price and does not include any storage or transportation costs.

Recent Developments – Jet Fuel Award

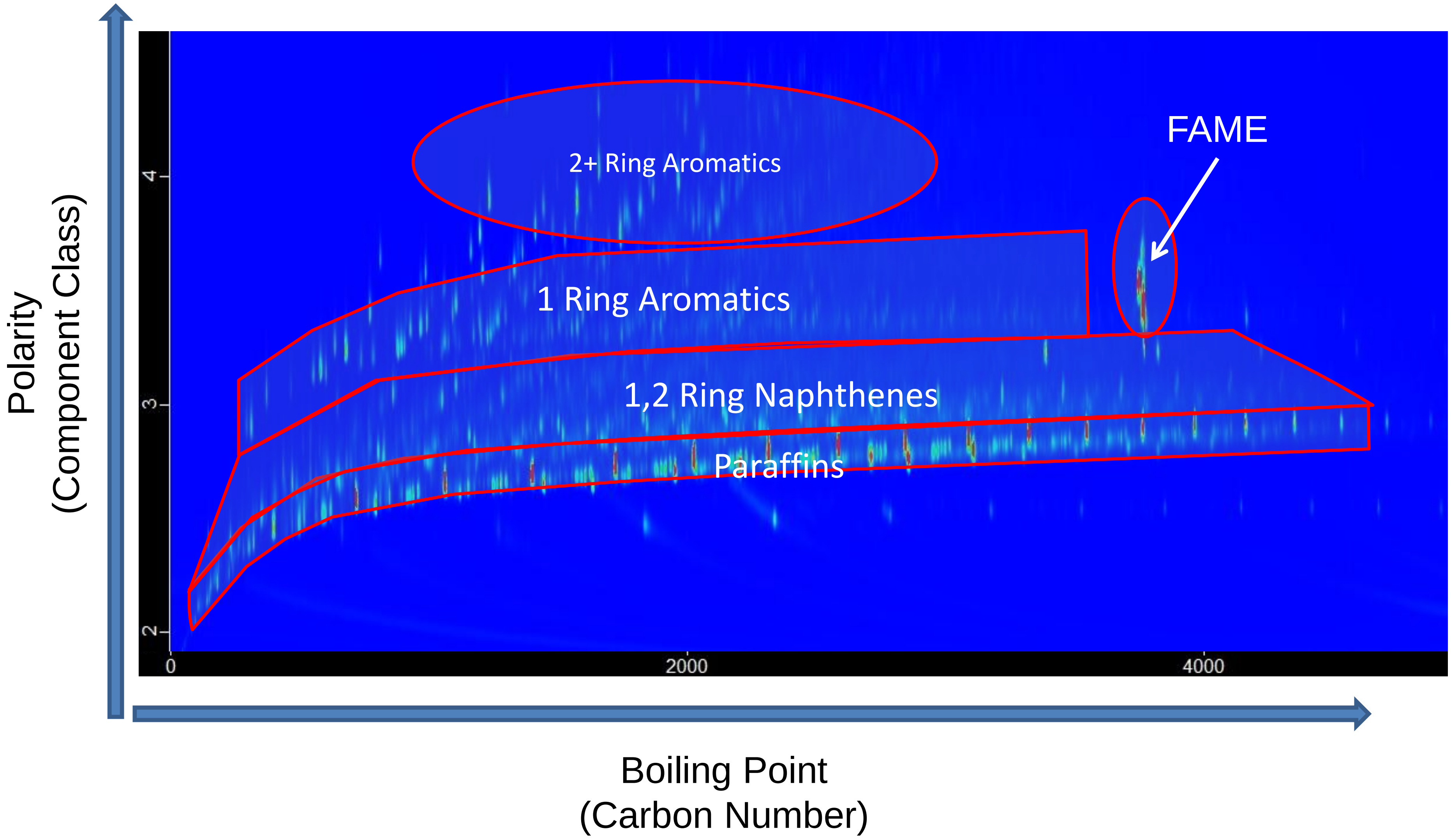
DOE Award

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

Project Partners

- VIRENT ➡ Jet fuel production
- NREL (National Renewable Energy Laboratory) ➡ Corn stover processing
- Northwestern University ➡ Modeling

Conventional Diesel GC-GC Analysis



Contribution of Component Classes to Diesel Performance

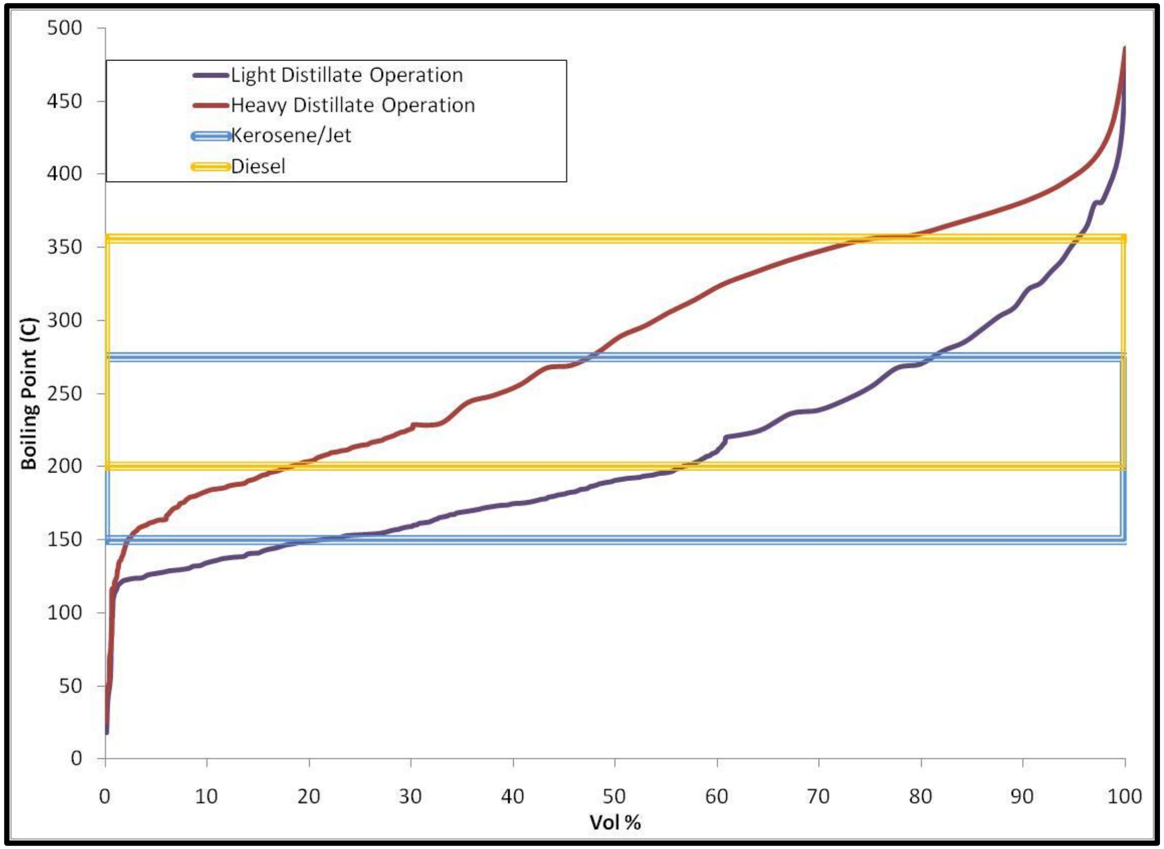
	n-Paraffins	*i*-paraffins	Naphthenes	Aromatics*	FAME
Cold Flow	-	++	++	++	-
Cetane	++	+	+	-	+
Density	-	-	+	++	++
Volumetric Heating Value	-	-	+	++	-
Energy Content	++	++	+	-	-

Broad component range mixtures and classifications
to meet current diesel specifications

*Polynuclear aromatics increase particulate emissions

Adapted from "Diesel Fuels Technical Review" available from Chevron

Virent's Renewable Diesel Properties



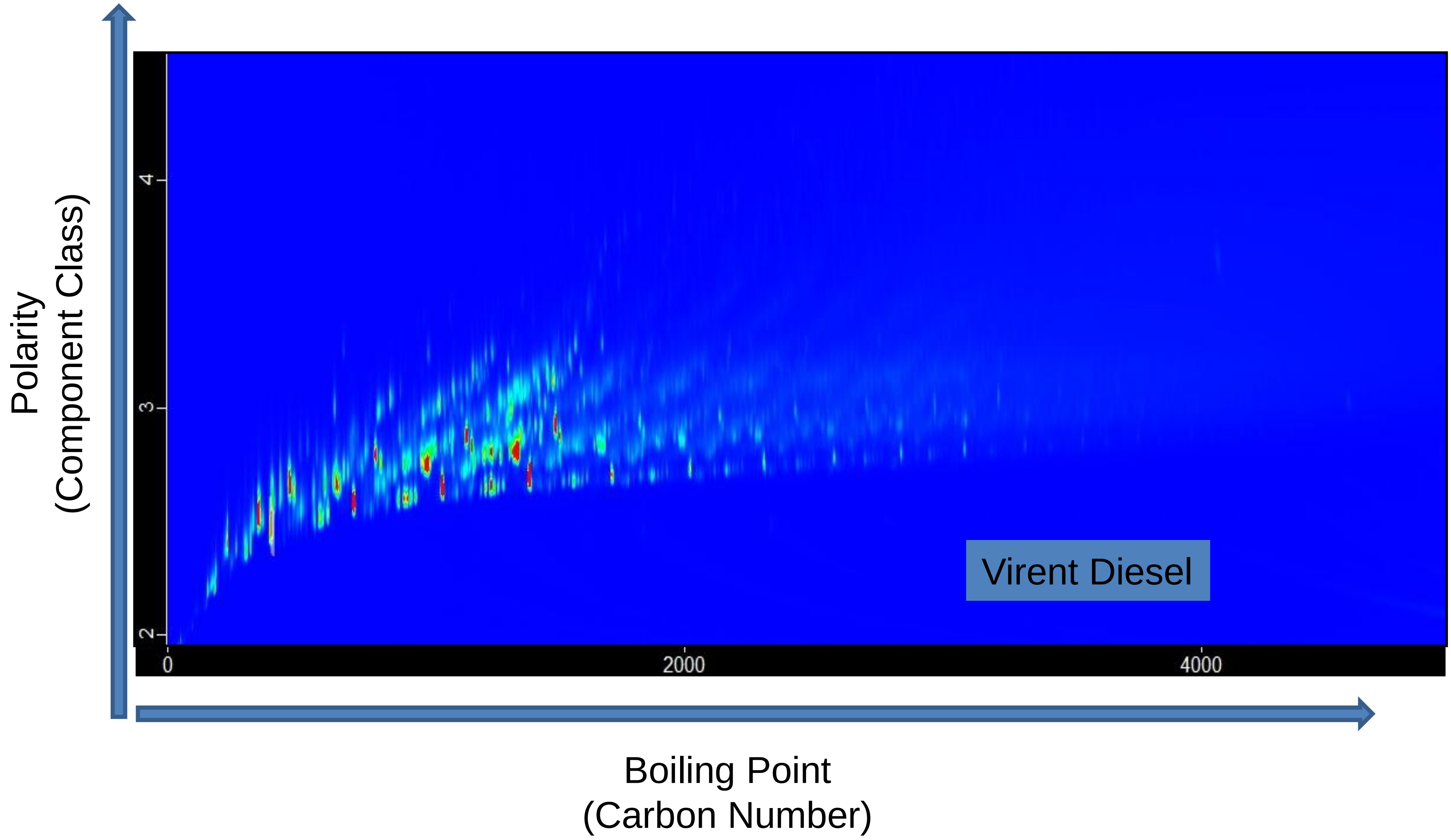
<u>Virent's Renewable Diesel</u>

Aromatics by HPLC – 8.6%

Derived Cetane 45

Cloud Point <-60°C

Virent Diesel GC-GC Analysis



Virent Diesel Specification Compliance

	ASTM D975 #2 Diesel	*EN 590*	Virent Diesel
Cloud Point	Varies	Varies	<-60°C
Flash Point	>52	>55	56°C
Cetane	>40	>51	45
T95		<360	<340°C
Density	-	820-845 Kg/m^3	Conforming

- Inherently excellent cold flow properties
- High blend potential
- No PNAs ➔ expected low PM emissions
- Cetane can be increased through operational controls

VIRENT™

Virent is replacing crude oil. **Visit our [website](#) to learn how.**