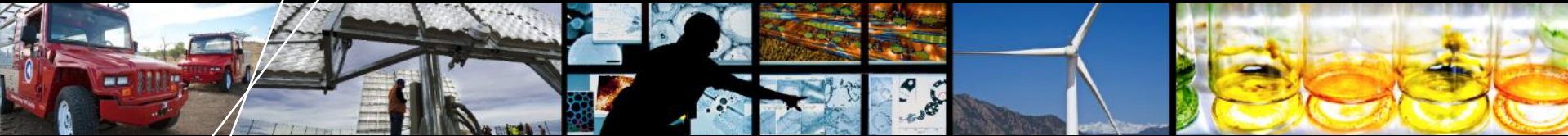


Renewable Diesel Fuel



Robert McCormick and Teresa Alleman

July 18, 2016

Renewable Diesel Fuel Nomenclature

- **Renewable diesel goes by many names:**
 - Generic names
 - Hydrogenated esters and fatty acids (HEFA) diesel
 - Hydrogenation derived renewable diesel (HDRD)
 - Green diesel (colloquialism)
 - Company trademark names
 - Green Diesel™ (Honeywell/UOP)
 - NExBTL® (Neste)
 - Soladiesel_{RD}® (Solazyme)
 - Biofene® (Amyris)
 - HPR Diesel (Propel branded product)
 - REG-9000™/RHD
- **Not the same as biodiesel, may be improperly called second generation biodiesel, paraffinic biodiesel – but it is incorrect and misleading to refer to it as biodiesel**

RD is a Very Broad Term

- **Renewable diesel (RD) is essentially any diesel fuel produced from a renewable feedstock that is predominantly hydrocarbon (not oxygenates) and meets the requirements for use in a diesel engine**
- **Today almost all renewable diesel is produced from vegetable oil, animal fat, waste cooking oil, and algal oil**
 - Paraffin/isoparaffin mixture, distribution of chain lengths
- **One producer ferments sugar to produce a hydrocarbon (Amyris – more economical to sell this hydrocarbon into other markets)**
 - Single molecule isoparaffin product

RD and Biodiesel

- **Biodiesel is solely produced through esterification of fats/oils**
- **RD can be produced through multiple processes**
 - **Hydrogenation (hydrotreating) of fats/oils/esters**
 - Fermentation of sugar
 - Co-processing with petroleum
 - Biomass pyrolysis/hydrotreating
 - Catalytic upgrading of sugar
 - Biomass-to-liquids (FT diesel)
 - Biogas-to-liquids (GTL/FT diesel)

No fuel is being produced at commercial scale by these processes, but they are coming in the future

Identifying RD

- **RD is chemically identical to components present in conventional diesel fuel**
- **Identification can reliably be made through radiocarbon dating**
 - Method compares amount of fossil carbon with renewable carbon in a sample, per ASTM D6866
 - RD100 is 100% renewable (modern) carbon
 - Petro-diesel contains no radio carbon (fossil carbon)
 - Method would not differentiate between biodiesel and RD – although biodiesel content can be determined using ASTM D7371
- **Radiocarbon analysis is relatively expensive and not commonly used in the market today**

Producers

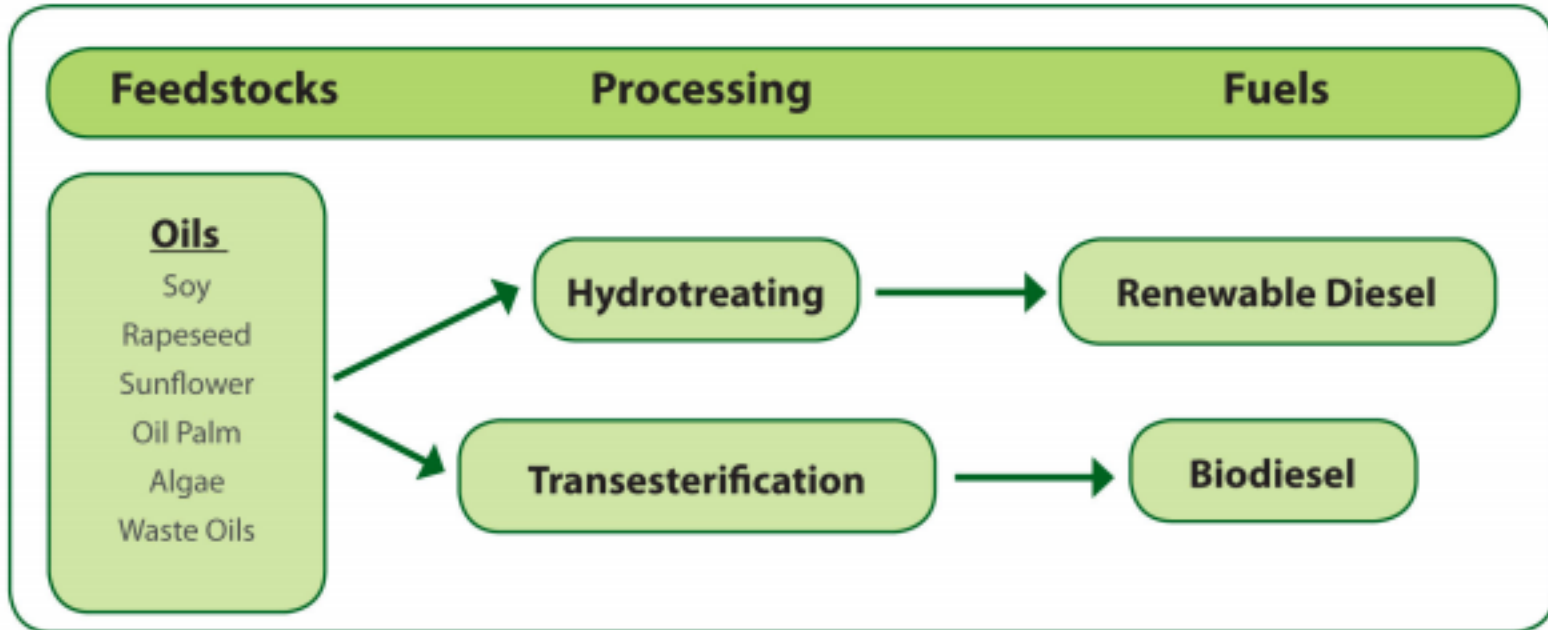
Producer	Company Size	Annual Production Volume (gal)	Plant Location(s)	Notes
Neste	Large	680 Million	Porvoo, Finland Rotterdam, The Netherlands Singapore	Finnish Petroleum Refiner, >\$9B sales in 2014
REG	Medium	75 Million	Geismer, LA	Large portfolio of biodiesel and renewable chemical plants
Eni S.p.A.	Medium	125 Million – 150 million additional in 2016	Italy	Largest petroleum refiner in Italy. Offering RD15 at 3500 stations (UOP process)
Diamond Green	Medium	160 Million – expanding to 275 million	Norco, LA	Partnership between Valero and Darling Industries (UOP process)
AltAir Paramount	Medium	42 Million (jet and diesel)	Los Angeles, CA	On Paramount Petroleum refinery site (UOP process)
Solazyme	Small	Unknown	Peoria, IL Brazil	Microalgae oil feedstock
Amyris	Small	Unknown	Sao Paulo, Brazil	Microbial engineering
East Kansas Agri-Energy	Small	3 Million – planned to be online fall 2016	Garnett, KS	Integrated RD/ethanol plant, under construction
ENVIA Energy	Small	Unknown	Oklahoma City, OK	Landfill methane to GTL-RD (JV including Waste Management, Inc.) – RFS pathway approved by EPA



RD from Fats and Oils

Generic Production Processes

Renewable Fuels Creation Process

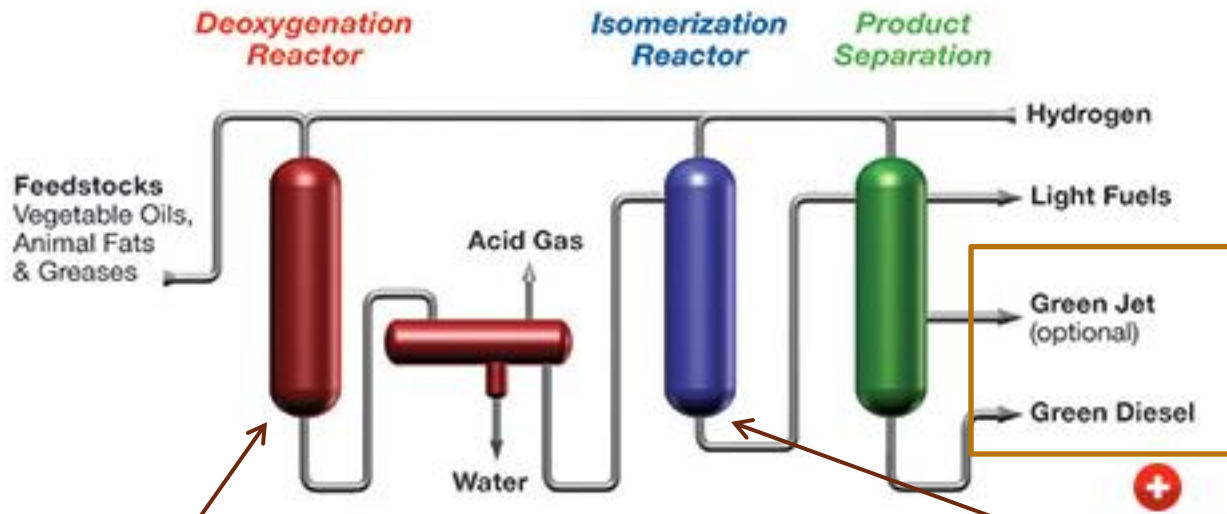


- RD production is similar to steps in petroleum refining
- Higher capital cost relative to biodiesel so requires larger economy of scale

http://www.dieselforum.org/files/dmfile/renewablefuelsfactsheet_01.30.13.pdf

UOP Green Diesel™ Process

UOP/Eni Ecofining™ Process



Step 1 produces n-paraffin mixture with cloud point of 20°C or higher (not liquid at room temperature) and cetane >100

Step 2 converts n-paraffins to isoparaffins with some cracking to naphtha and gas. Cloud point can be varied (lower CP means higher naphtha yield) cetane >70

- UOP is not a producer but a technology vendor
- Process is thought to be typical of other processes for fats and oils conversion
<http://www.uop.com/processing-solutions/renewables/green-diesel/>

General Properties

- **Some RD properties can be varied with customer/market demand**
 - Highly paraffinic fuel
 - Very high cetane number (<70)
 - Zero aromatics
 - Cloud point can be varied widely
 - Depends on ratio of n- to iso-paraffins in fuel
 - Right now in the US, range is -35°C (-31°F) to -9°C (16°F)
 - Sulfur is very low, but measurable
 - Stability is excellent
- **Co-products:**
 - Naphtha co-product: low-octane gasoline, less valuable than the diesel or jet
 - Renewable jet fuel
 - Fuel gas (likely burned on site for process heat)

Compatibility

- **When RD meets ASTM D975 properties, it is considered the same as conventional diesel fuel**
 - Meets requirements for CARB Diesel (zero aromatic/high cetane)
- **Completely fungible with petroleum diesel**
- **Lack of aromatics *may* be problematic**
 - Use of renewable jet is limited to 50% to ensure a minimum aromatic content of finished fuel
 - Minimum aromatics needed for elastomer swell to ensure sealing in the fuel system
 - Full approval for 50% blends of renewable jet from FAA and ASTM
 - On-road diesel may follow suit with a limit on minimum aromatic content of fuel

Interactions with Modern Diesel Vehicles

- **RD100 *may* be an issue for elastomer swell on fuel wetted parts**
 - Not much data yet
- **Lubricity must be addressed with additives – similar to conventional ULSD**
- **Little data on use with diesel emissions control systems**
- **Volvo Trucks NA, Mack, Mercedes Benz (heavy trucks) all approve RD in all their engines**
 - Most manufactures approve fuels meeting D975

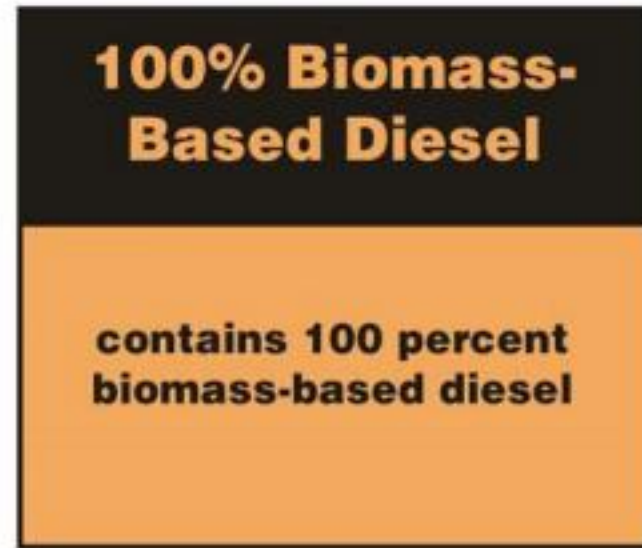
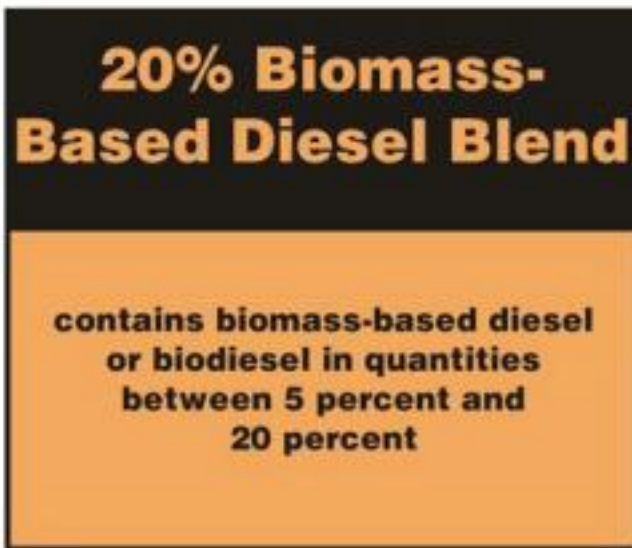
Emissions Effects

- **Very little data available**
- **High cetane number and low aromatic content correlate with reduced NOx and PM, potentially reduced toxic compounds**
 - CARB diesel is required to have higher cetane and lower aromatics than 49 state diesel
 - RD is accepted as CARB diesel
- **Performance with modern emission controls unknown – but seems unlikely to be problematic**

Pump Labeling

- **Regulated by FTC to ensure consistency**
- **Diesel with less than 5 vol% RD does *not* need a separate label (meets D975)**
- **Blends between 6 vol% and 20 vol% are labeled as within this range**
- **Blends above 20 vol% must include exact blend content (i.e. 70 vol% RD)**
- **100 vol% RD must also be labeled**
- **Requirements are identical to those for biodiesel**

Example Labels



Public Availability (Incomplete List)

- **Propel markets RD blends in California stations as Diesel (HPR) – Diesel (High Performance Renewable)**
 - 18 stations in N. CA
 - 13 stations in S. CA
- **REG-9000™/RHD and Diamond Green Diesel also being sold into US market**
- **Neste is importing to the US - largest global producer and largest source of RD in US**

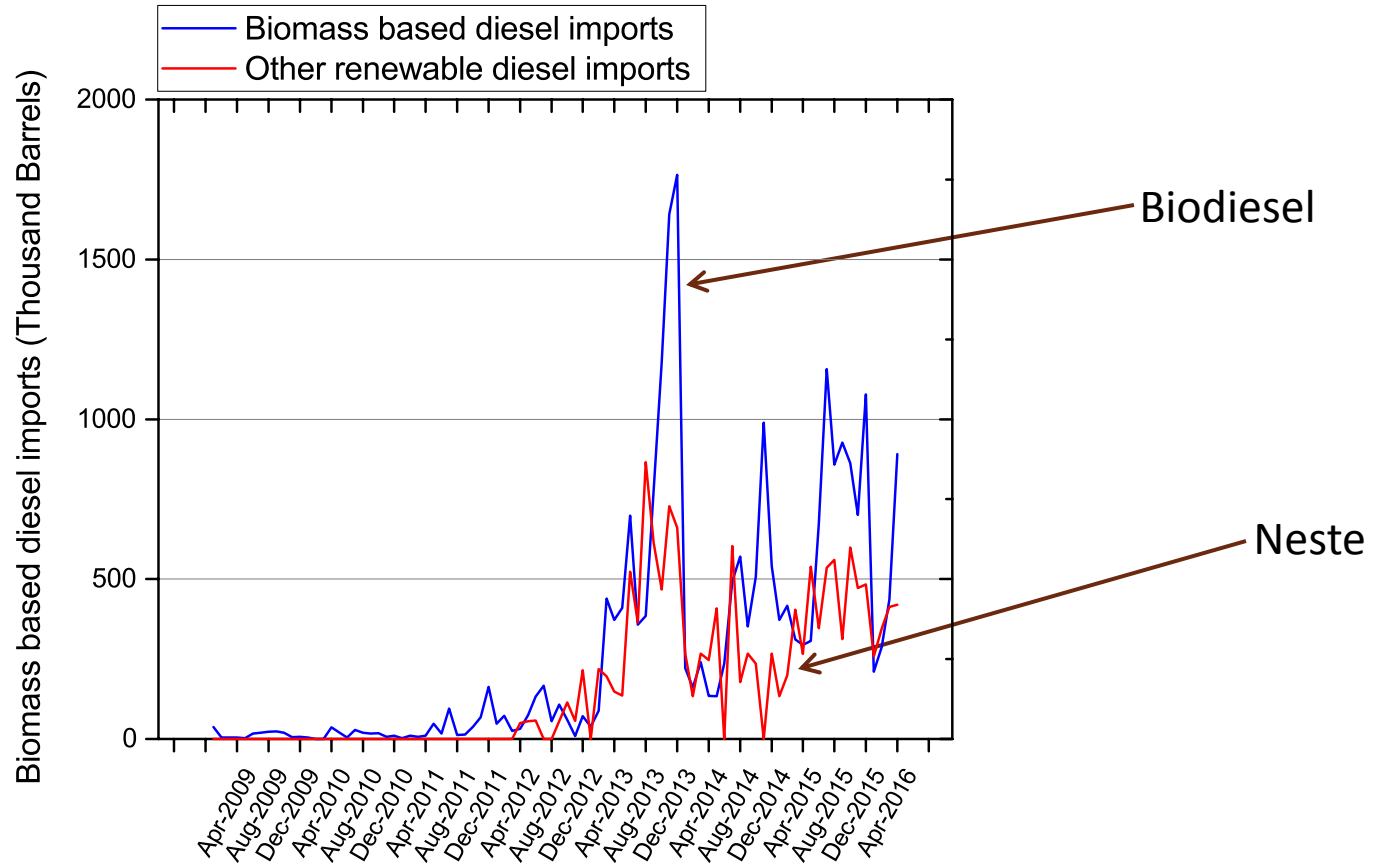
Fleet Use Examples

- **UPS has announced intent to purchase 46 million gallons of RD for fleet use nationwide**
 - May be encountering issues with availability
 - <http://www.hardworkingtrucks.com/ups-nyc-renewable-diesel-facing-availability-issue/>
- **United Airlines announced \$30 million investment in renewable jet fuel**
 - Regular commercial flights from LAX began in March 2016
 - <http://newsroom.united.com/2016-03-11-United-Airlines-Makes-History-with-Launch-of-Regularly-Scheduled-Flights-Using-Sustainable-Biofuel>
- **CA Department of General Services requires state agencies to buy renewable diesel when making bulk fuel purchases for diesel-powered vehicles and equipment**
 - <http://www.dgs.ca.gov/dgs/Newsroom/tabid/72/ArticleID/48/State-Greens-Government-Fuel-Purchases.aspx>
- **Many cities in CA have switched fleets to RD (Oakland, San Francisco, others)**
- **Corvallis and other cities/agencies in Oregon. Oregon requires all diesel to be B5 or RD5**

Regulatory Information

- **Renewable diesel is a qualified EAct fuel, when used as 100% replacement for diesel**
 - *“...fuels other than alcohol, derived from biological materials;”*
 - For RDxx blends the renewable portion of the fuel is counted as alternative fuel and receives EAct credits (treated the same as biodiesel blends)
- **RD has multiple approved pathways under Renewable Fuel Standard (RFS)**
 - Type of RIN generated depends on a number of factors
- **Eligible for blender’s tax credit so may actually find RD99**

Imports



RD production worldwide = 28,500 thousand barrels annually (approx)*

Petroleum imports = 748,000 thousand barrels annually (approx)**

*<http://www.rendermagazine.com/articles/2015-issues/december-2015/biofuels/>

**http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_EPOORDO_im0_mbb1_m.htm

Other renewable diesel imports are exclusively from Singapore (Neste)

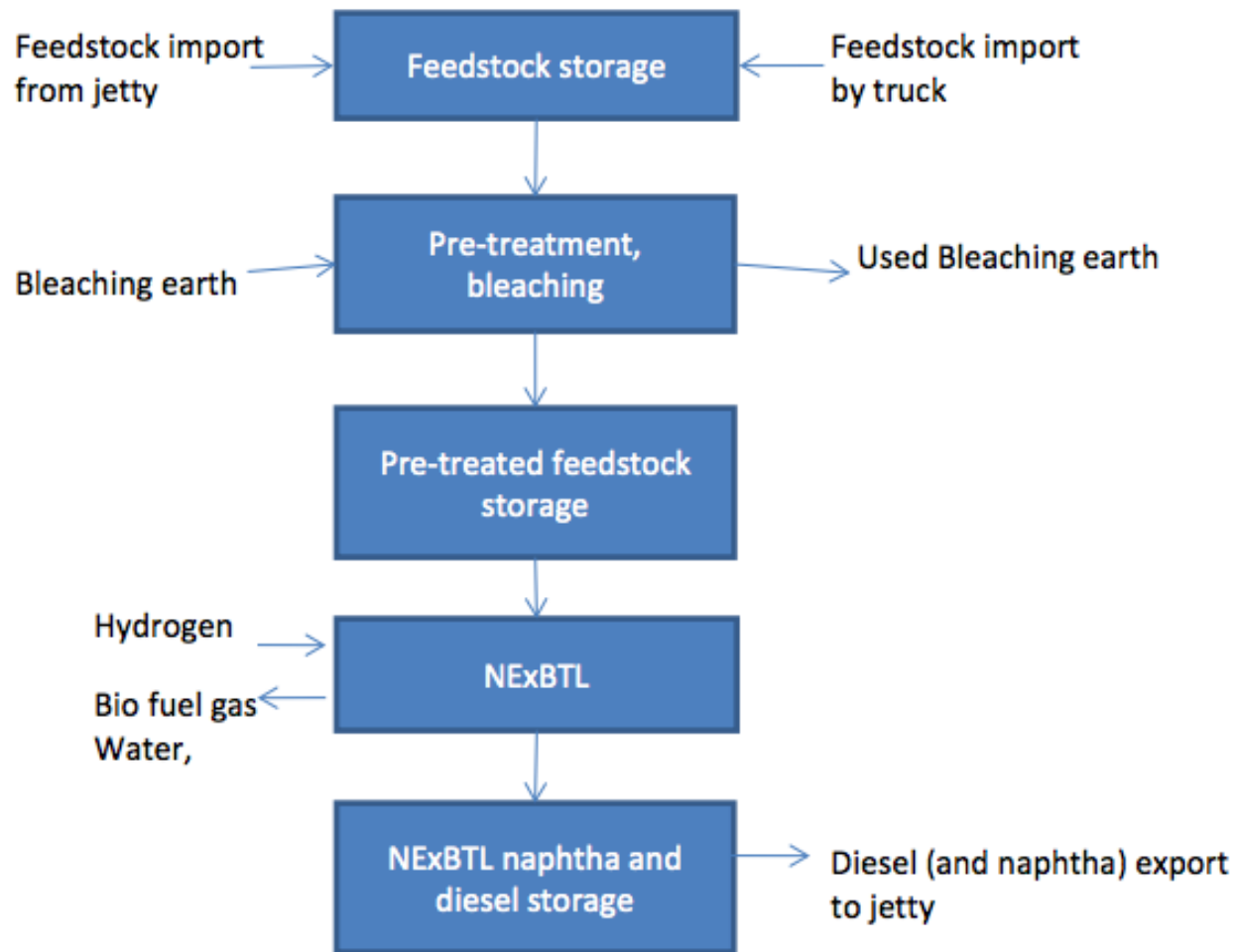
The Future of Renewable Diesel

- **All signs point to increases in renewable diesel production and use in the US**
 - California is leading the country in adoption/mandate of RD
 - Price is similar to biodiesel – but price not tracked by EIA or commercial data providers (to our knowledge)
- **Lack of aromatics *may* become an issue as more and more RD enters the market**
 - More data may be needed, especially with materials compatibility (or if problems start to occur in the field)



Backup

Neste NExBTL[®] Process



<http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/neste-aus-rpt-031513.pdf>

Renewable Fuel Standard

- **Sets required volumes of renewable fuels from 2010 forward**
 - Obligated parties are any refiner/importer in 48 contiguous states or Hawaii
 - Must meet calculated renewable volume obligations (RVO)
 - Use C14 testing to verify renewable content
 - Gallons are tracked by Renewable Identification Numbers (RINs)
 - Each gallon of renewable fuel receives an equivalence value (how many gallon-RINs are generated per physical gallon of fuel)
 - RINs can be used to show compliance for multiple categories
 - Exception is D7 RINs, which cannot be combined with D3/D4
 - Average value of RINs (9/18/15)
 - Cellulosic (D3/D7): \$0.645
 - Advanced biofuel (D5): \$0.445
 - Ethanol (D6): \$0.33
 - Average value of RINs (7/14/16)
 - Cellulosic (D3/D7): \$1.2500
 - Advanced biofuel (D5): \$0.9875
 - Ethanol (D6): \$0.9275

RIN Background

By statute, the RFS program includes four categories of renewable fuel, each with specific fuel pathway requirements and RIN D-Codes:

- **Advanced Biofuel (D-code 5)**
 - Can be made from any type of renewable biomass except corn starch ethanol.
 - Must reduce lifecycle greenhouse gas emissions by at least 50%; compared to the petroleum baseline.
- **Biomass-based Diesel (D-Code 4)**
 - Examples include biodiesel and renewable diesel.
 - Must reduce lifecycle greenhouse gas emissions by at least 50%; compared to the diesel baseline.
- **Cellulosic Biofuel (D-Code 3 or D-Code 7)**
 - Renewable fuel produced from cellulose, hemicellulose or lignin.
 - To be eligible for D-Code 7 RINs the fuel must be cellulosic diesel.
 - Must reduce lifecycle greenhouse gas emissions by at least 60%; compared to the petroleum baseline.
- **Renewable Fuel (D-Code 6)**
 - Includes ethanol derived from corn starch, or any other qualifying renewable fuel.
 - Fuel produced in new facilities or new capacity expansions (commenced constructed after December 19, 2007) must reduce lifecycle greenhouse gas emissions by at least 20%; compared to the average 2005 petroleum baseline.

<http://www.epa.gov/otaq/fuels/renewablefuels/new-pathways/what-is-a-fuel-pathway.htm>

Equivalence Value

- **Renewable fuels are assigned equivalence values (EV) under the RFS**
- **EV(ethanol) = 1**
- **EV(biodiesel) = 1.5**
- **EV(non-ester renewable diesel) = 1.7**
 - Assumes a lower heating value > 123,500 BTU/gal
- **RD with other EVs had to receive approval from EPA**
 - $EV = (R/0.972) * (EC/77,000)$
 - Where:
 - R = renewable content
 - EC = energy content, BTU/gal

EPA Generally Approved Pathways

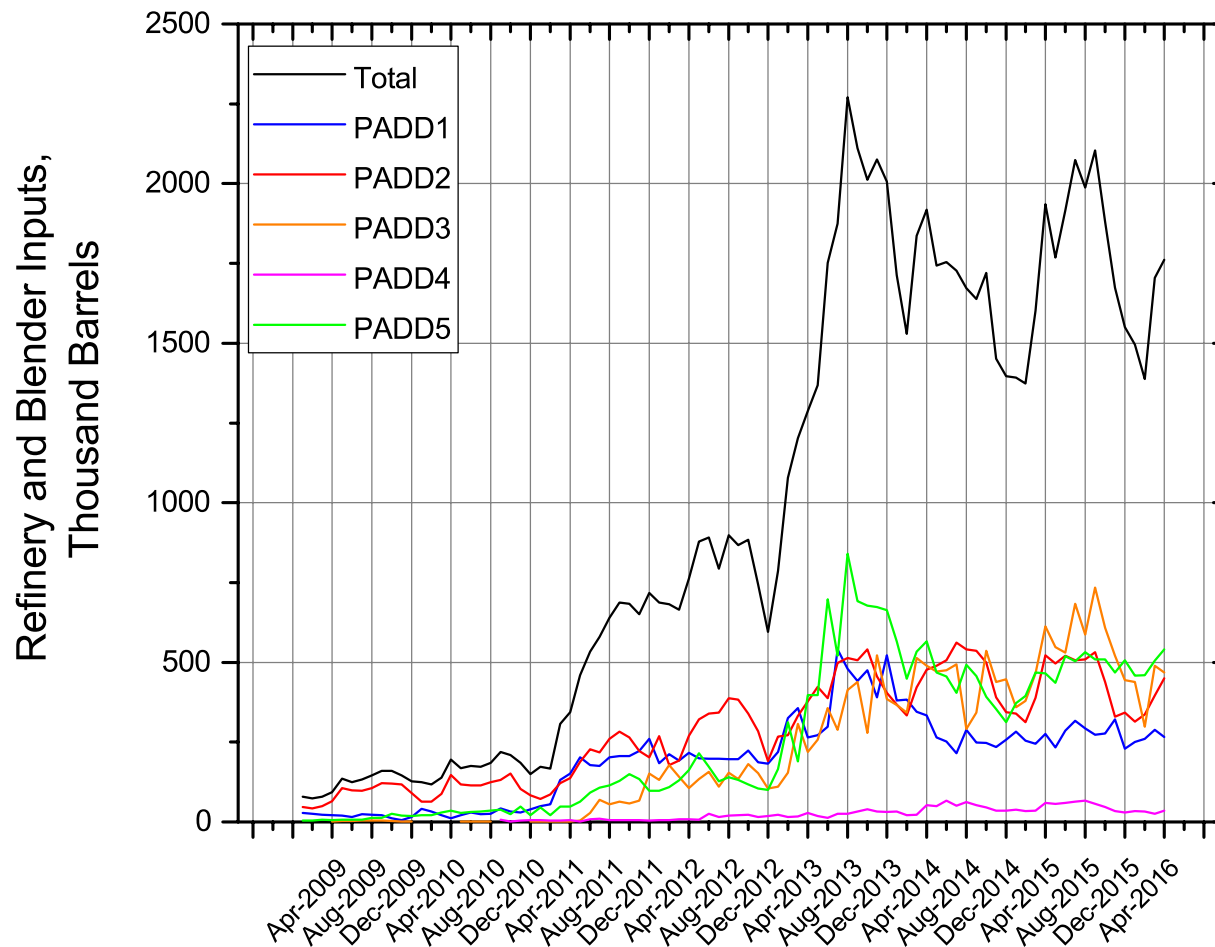
Generally Approved Pathway	RIN Type
F (Hydrotreating excluding co-processing with petroleum)	D4 (Biomass-based diesel)
H (Hydrotreating including only co-processing with petroleum)	D5 (Advanced)
L (Any process converting cellulosic biomass)	D7 (Cellulosic biofuel or biomass-based diesel)
P (Any process using non-cellulosic portions of food waste and non-cellulosic portions of annual cover crops)	D5 (Advanced)

Petition Approved Pathways

Pathway Assessments	RIN Type
Triton Energy (December 2010)	D4
Global Energy Resources (April 2011)	D4
Changing World Technologies (June 2011)	D4
Viesel Fuel (September 2011)	D4
Sustainable Oils (March 2013)	D4 or D5
BP Biofuels North America (March 2013)	D3 or D7
ENVIA Energy (May 2015)	D3 or D7

Ensyn Corp. recently received EPA approval to legally sell fuel in the US. This approval is separate from approval to generate RINs.

Inputs Into US Refineries/Blenders



http://www.eia.gov/dnav/pet/pet_pnp_inpt_a_EPOORD_yir_mbbl_m.htm

Speculate this is due to meeting RVOs, value of RINs, green marketing, and/or blending into current diesel barrels