ISOTERRA & Biofuels ISOCONVERSION

Advanced Pathways to Renewable Fuels

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Chevron Lummus Global

Outline

- Drivers for Renewable Fuels
- ISOTERRA Process
- Biofuels ISOCONVERSION Technology
- Platform Selection Considerations
- Questions & Answers

19th & 20th Century Energy Transitions

More Additive Than Substitutive

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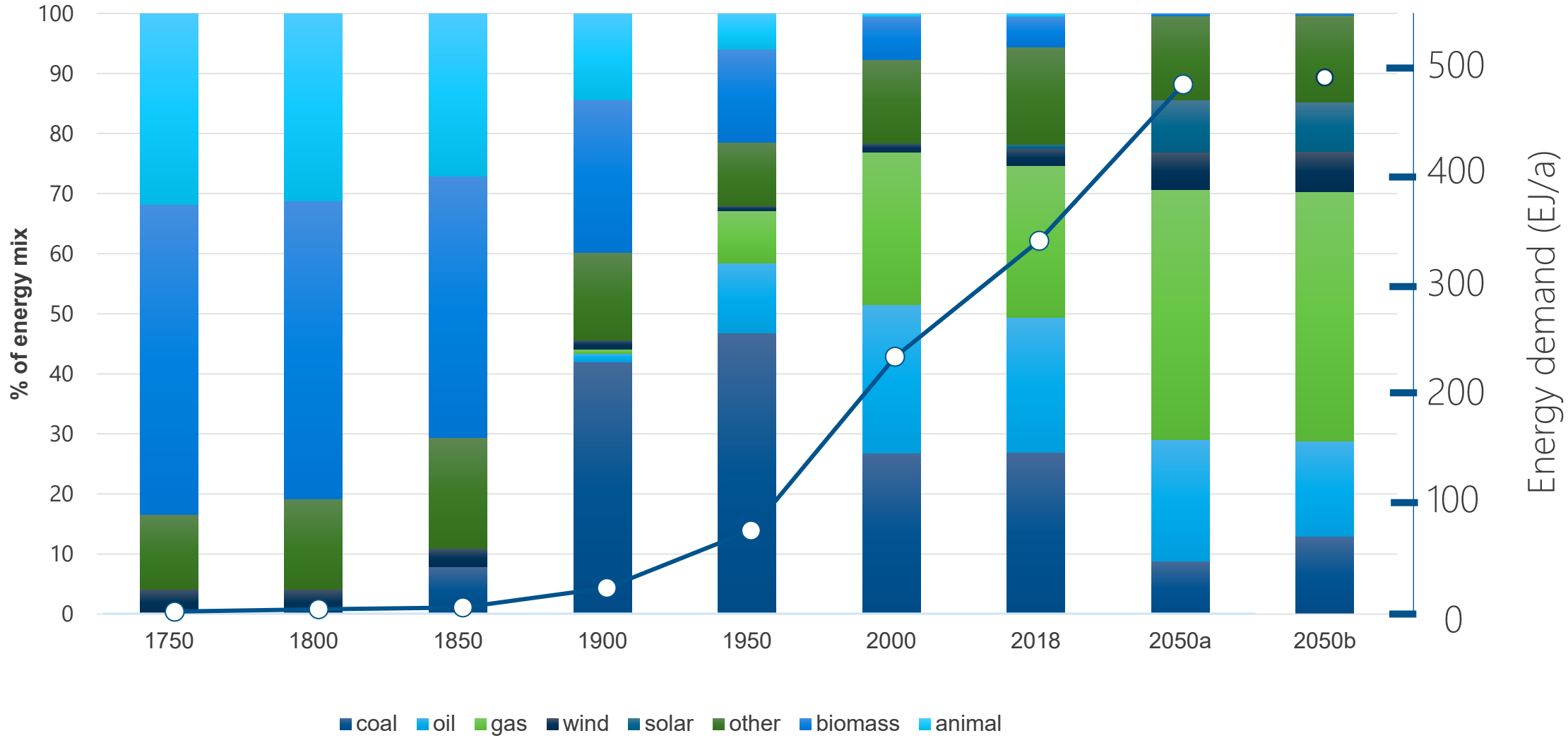

Energy transition research & technologies - Thunder Said Energy

Drivers for 21st Century Energy Transition

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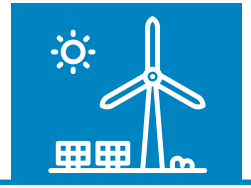
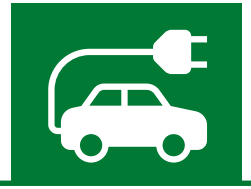


WIND, SOLAR

$0.03 /kwh vs. $0.10 /kwh for fossil fuels
- intermittency

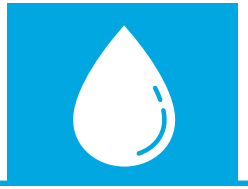


ELECTRIFICATION

EV 70% energy efficient vs. ICE 18%
- storage

CO2, CH4 ABATEMENT

(CCS, CCSU) substitution focus



TIGHT OIL

Source rock has 10 times more oil than reservoir

Electrification: Leapfrogging Into Renewables

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Beyond Petroleum Through Abated Electrification

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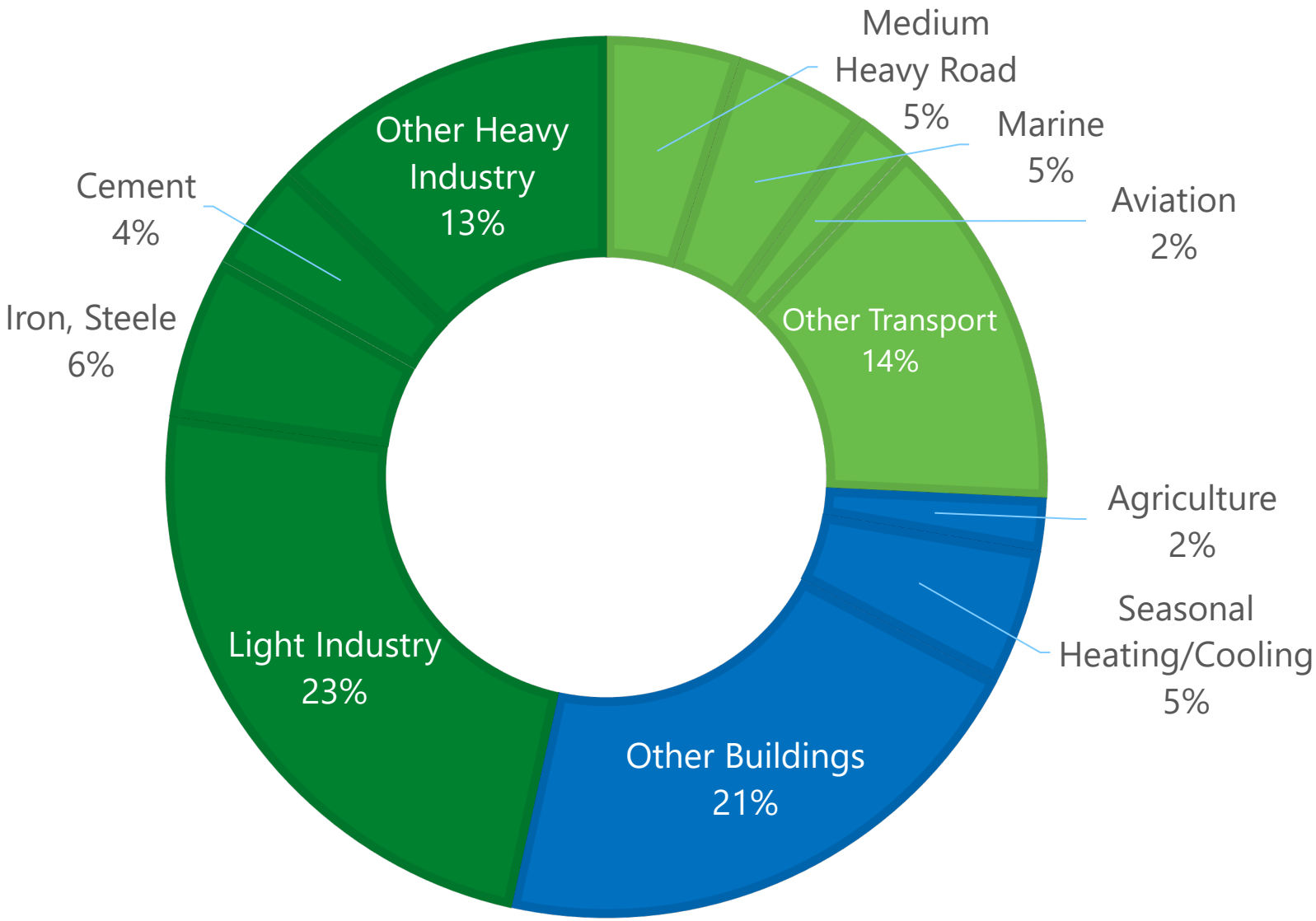
2020

33.9 Gt CO_2
0.04 Gt Abated



2040

6.3 Gt CO_2
>20 Gt abated

Lower Carbon Fuels Where Electrons Struggle

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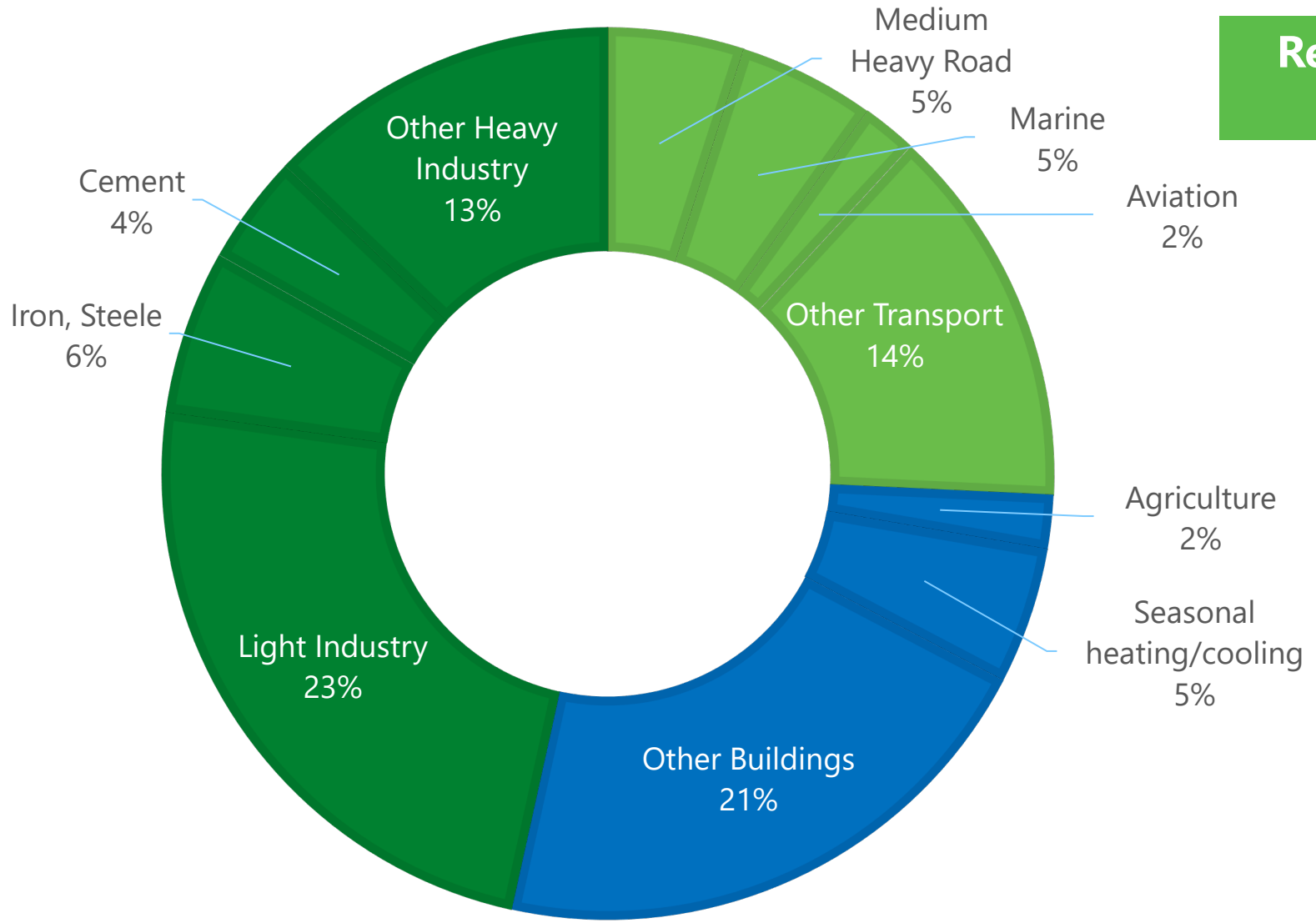

Lower Carbon Fuels are Taking Off

- 2019 Jet Demand (MMbpd) 7.60
- Soybean SAF (Barrel/Acre) 0.80
- Soybean Acreage (B Acres) 2.40
- Global Arable Land (B Acres) 3.90

- **SAF Supply 1-2% of Demand**

Biomass Sources for Fuel are Remarkably Diverse

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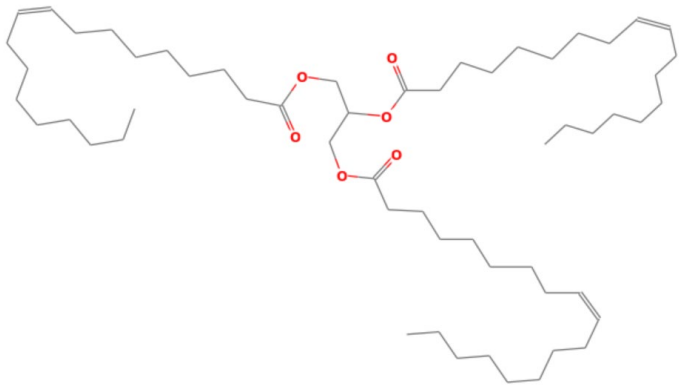
- Triglycerides are Lipids Such as:
  - Vegetable oils *(Corn, Soybean, Canola, Camelina, Palm)*
  - Used Cooking Oil – UCO
  - Animal fat, tallow
  - Vegetable oil processing waste and residue
  - Palm oil mill effluent – POME
  - Fish fat waste
  - Algae oils
- Trigycerides are Esters of Fatty Acids With Glycerol

Triolein

Ester of Glycerol &
Oleic Acid(18:1)



- ...exhibit a widely varying quality
  - Metals (Ca, Na, Mg, K)
  - Phospholipids
  - Free fatty acids
  - Unsaturated side chains
  - Unsaponifiable and plastic content
  - Chlorides
  - Sulfur
  - Nitrogen

Renewable Fuel Sources
Need Clean-up Prior to Hydroprocessing

ISOTERRA Process: Hydrogenation Into Paraffins

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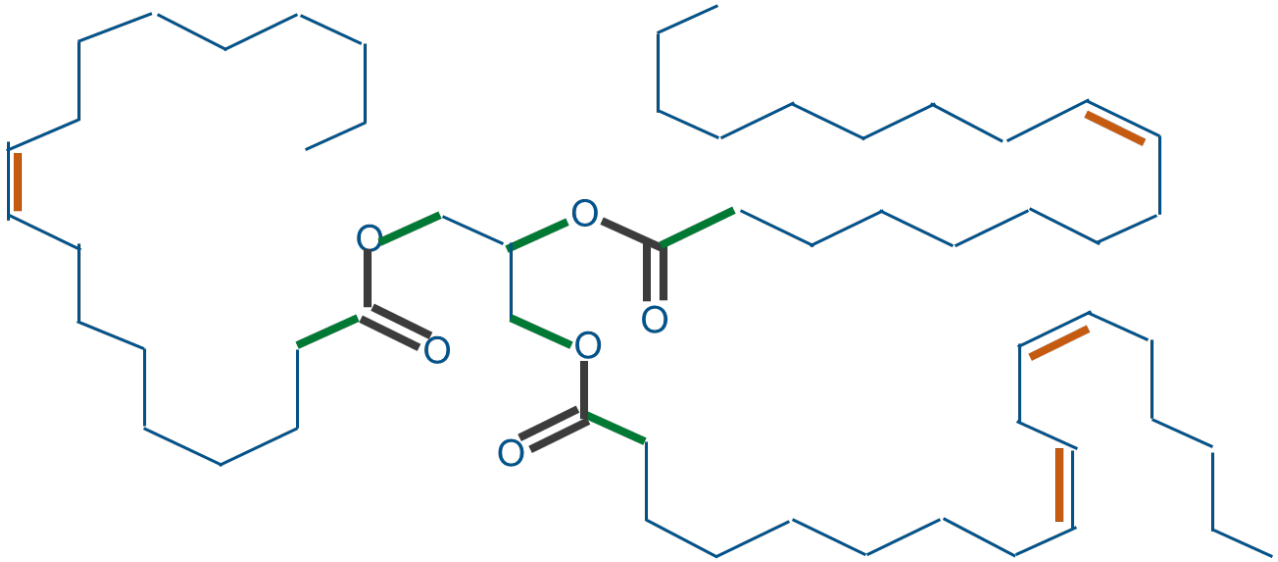

hydrogenation of olefins -4 H_2

decarboxylation CO_2 – 3 H_2

decarbonylation CO, H_2O – 6 H_2

deoxygenation H_2O – 12 H_2

water gas shift

$$CO_2 + H_2 \rightleftharpoons H_2O + CO$$

methanation

$$CO + 3H_2 \rightleftharpoons CH_4 + H_2O$$

Heat Release Through Olefin & Oxygen Hydrogenation Complicates Hydroprocessing

Lipids Require Olefin, Oxygen Removal To Produce Sustainable Aviation Fuel and Renewable Diesel

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	Fatty Acid Content by Carbon Number & Degree of Unsaturation												
	n-C_{12}	*n*-C_{14}	*n*-C_{16}		*n*-C_{18}				*n*-C_{20}		*n*-C_{22}		*n*-C_{24}
Boiling Point (F)	421	489	549		603				649		696		736
Double Bonds	0	0	0	1	0	1	2	3	0	1	0	1	0
Palm	<1	1-2	**32-48**	<2	4-6	**37-53**	6-13	<1	<1	<0.5	<0.2	-	-
Soybean	<1	<1	7-13	<1	1-6	12-27	**52-63**	3-12	0-4	<0.5	<1	<1	-
Tallow	0-2	**2-8**	**23-28**	0-5	**14-29**	**35-50**	1-5	<1	0.1	<0.1	-	-	-
Carinata	-	-	2-5	-	1-3	**8-65**	11-22	5-23	-	-	-	**3-48**	-

Different Products Through Different Processes

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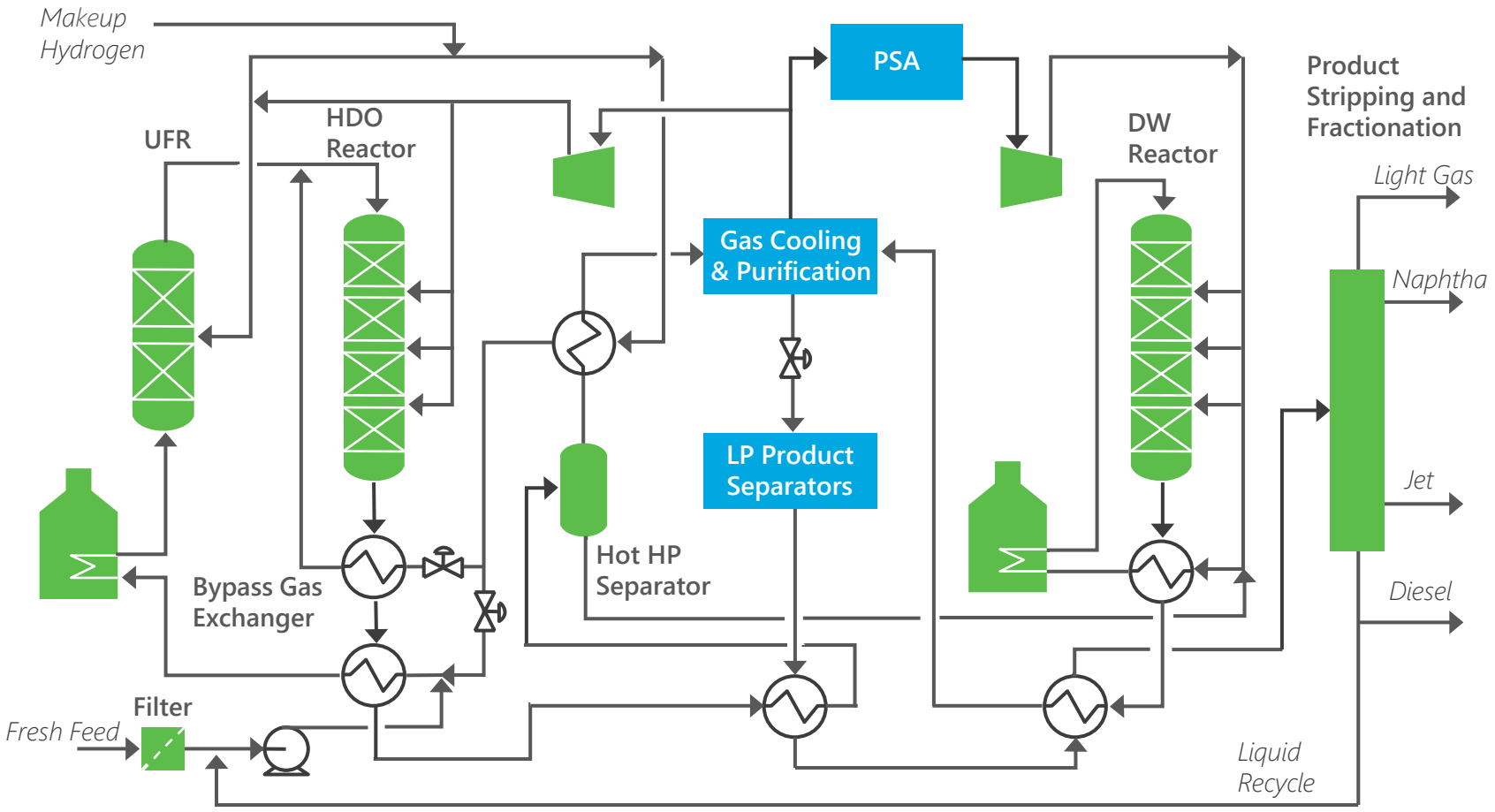
ISOTERRA Process

- Hydrotreating & hydrodewaxing to make paraffinic jet, diesel
- Two-stage configuration for robustness, feed and product flexibility
- Single-stage configuration for better cost-effectiveness
- Enables repurposing existing assets
- At ~20,000 bpd scale

Biofuels ISOCONVERSION Technology

- Aromatization & hydrotreating to make aromatic jet, diesel
- Enables manufacturing lower-carbon-intensity, fully compatible products
- Fully integrated configuration assures cost-effectiveness
- Can be added to existing assets
- At ~5000 bpd scale

ISOTERRA Process With Staged Severities



- Severities can be tailored toward more SAF or renewable diesel
- Up-flow reactor guards against pressure drop in subsequent operations
- Hydrodeoxygenation operates at low recycle ratios (~1:1) for most feeds
- Dewaxing run length benefits greatly from prior removal of $CO/CO_2/H_2O$

Up-flow Reactor to Prevent Upsets

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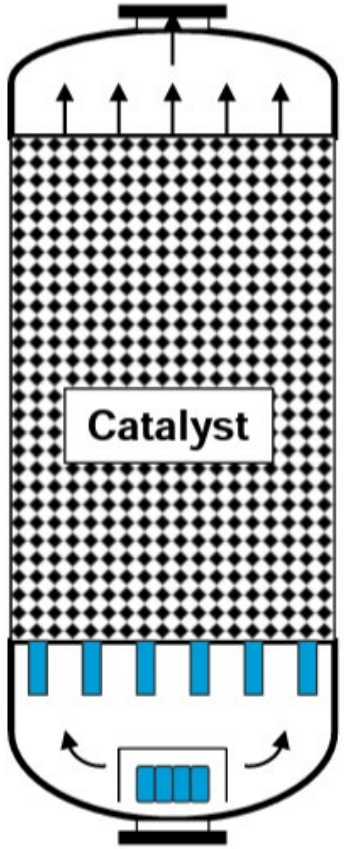
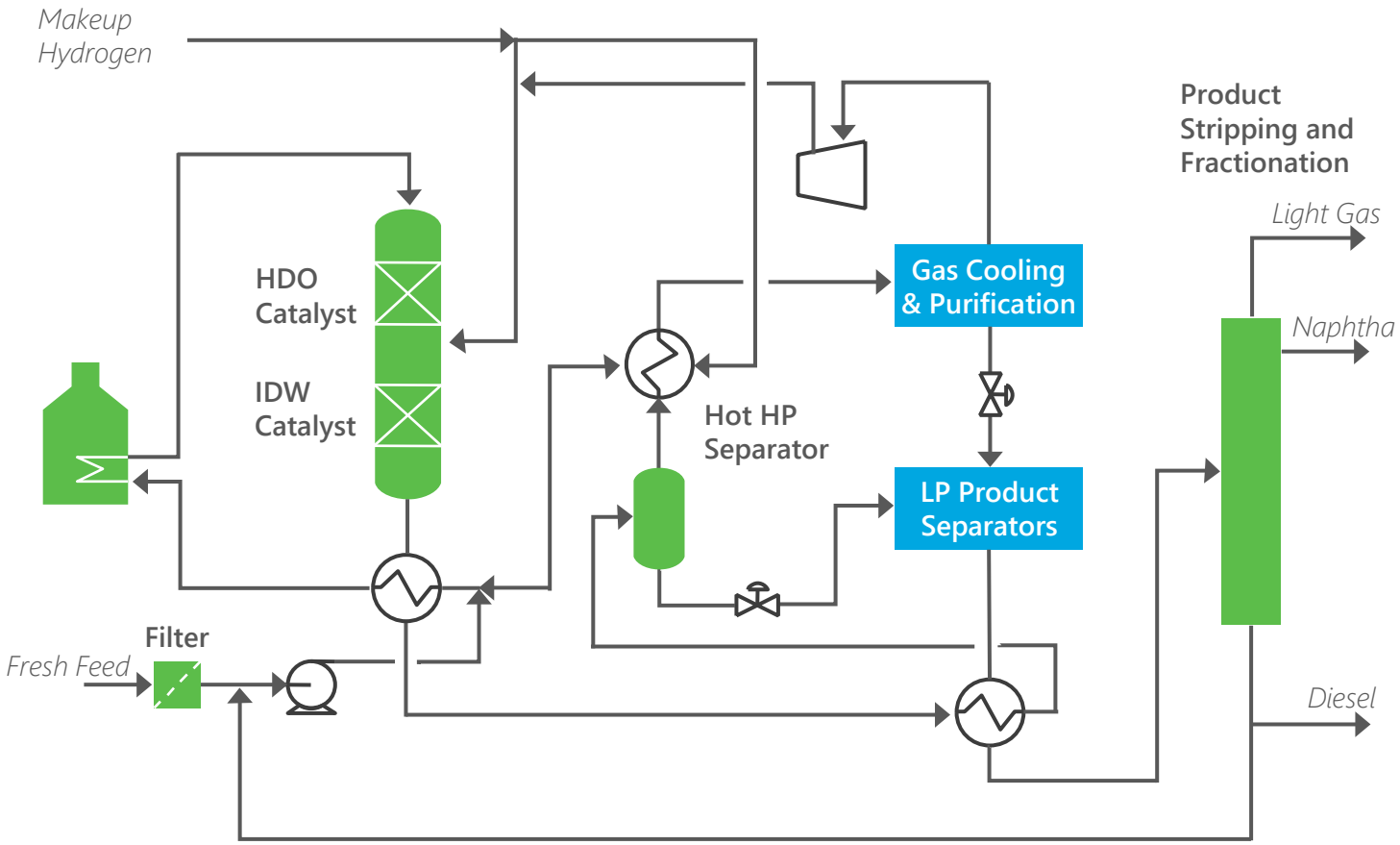
- Both variable feed quality and rapid, exothermic olefin saturation can gum up catalyst beds in downflow operation
- Upwards liquid and gas flows expand the catalyst bed
- Expanded bed impedes clogging, maldistributions, agglomeration and pressure drops
- Expanded bed improves hydrodynamics, heat dissipation
- Liquid wets catalysts more uniformly and more completely
- Gas flow limited to avoid ebullating catalyst bed
- CLG is the only licensor that offers UFR to prevent these upsets



ISOTERRA Single Stage Option



- Single stage configuration provides low CAPEX revamp option for existing hydrotreating facilities
- Distillate product slate is limited to renewable diesel only
- Dewaxing catalyst life is shortened by exposure to high water partial pressure and CO/CO_2 byproducts of hydrodeoxygenation reaction
- Higher liquid recycle ratio, typically 3:1, is required for exotherm control

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Hydrotreater Revamp Considerations

- Liquid recycle controls temperature rise in hydrodeoxygenation reactor – without separate up-flow reactor olefin saturation reactor
- Free fatty acids require alloying up hot section of reactor feed system and hydrotreater
- Aqueous carbonic acid corrosion at low pH or carbonate SCC at high pH managed through pH control of reactor effluent system
- Amine absorbers collect CO2 more than H2S
- Materials recommendations are based on NACE and CLG's internal corrosion studies

ISOTERRA Process Key Advantages

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- ISOTERRA process enables cost-effective production of SAF, HEFA
- Traditional two-reactor configuration well-established
  - 20,000 bpd is the current state-of-the-art
  - feedstock availability limits scale
- Novel single-reactor configuration near-commercial
  - CLG's experience enables deployment at 5,000-10,000 bpd scale

Biofuels ISOCONVERSION Technology

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Jointly developed technology by CLG and *Applied Research Associates* (ARA)

Converts a wide variety of low-cost feedstocks into renewable biofuels

ReadiJet / ReadiDiesel are suitable as 100% drop-ins for conventional Jet/Diesel

Technology demonstrated on large scale and now going commercial

- Yellow Grease
- Brown Grease
- Used Cooking Oil
- Plant Oil
- Animal Fats
- Algae

Low-cost Feedstocks

- Diesel
- Jet Fuel
- Naphtha

Biofuels

ReadiJet ReadiDiesel

Converting Lipids Into Aromatics and Cycloparaffins

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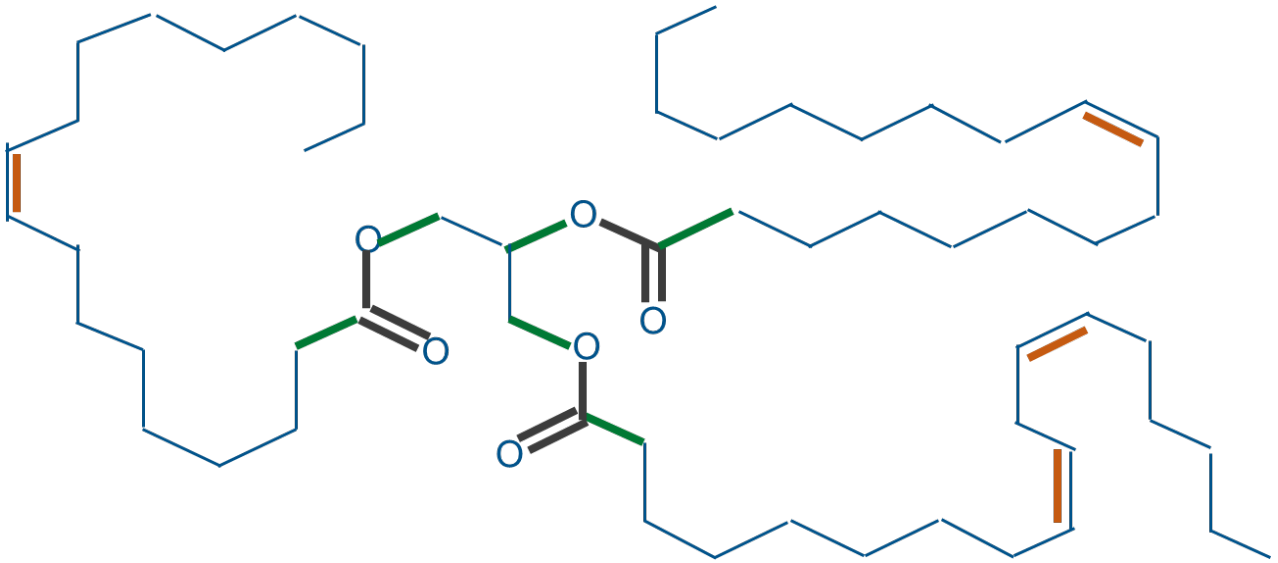

aromatization of olefins +4 H_2

hydrolysis glycerol + 3 FFA

decarboxylation CO_2 + aromatics

Heating in Supercritical Water Simplifies Hydroprocessing to Removal of Remaining Oxygen, Olefins

Biofuels ISOCONVERSION Process Overview

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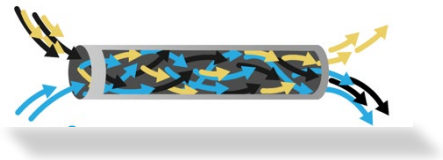
Converts Fats, Oils, & Greases From Plants, Animals, or Algae Into Fully Compatible Renewable Fuels

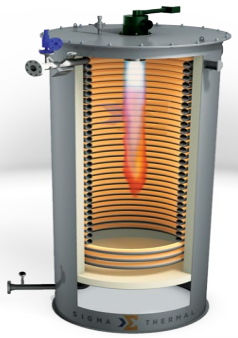
Hydrothermal Cleanup

Rapid metals reduction to produce clean lipids without hydrolysis



Catalytic Hydrothermolysis

Supercritical water conversion process Produces crude oil that contains the same hydrocarbon types as petroleum crude



2 Minutes
Converts fats oils and greases to crude oil

Hydrotreating

Saturates olefins
Removes residual oxygenates

Fractionation

Produces finished fuels:
- Jet and diesel that meet petroleum specs without blending
- Renewable chemicals and naphtha

Conventional
Refinery Processes

Biofuels ISOCONVERSION Block Flow Diagram

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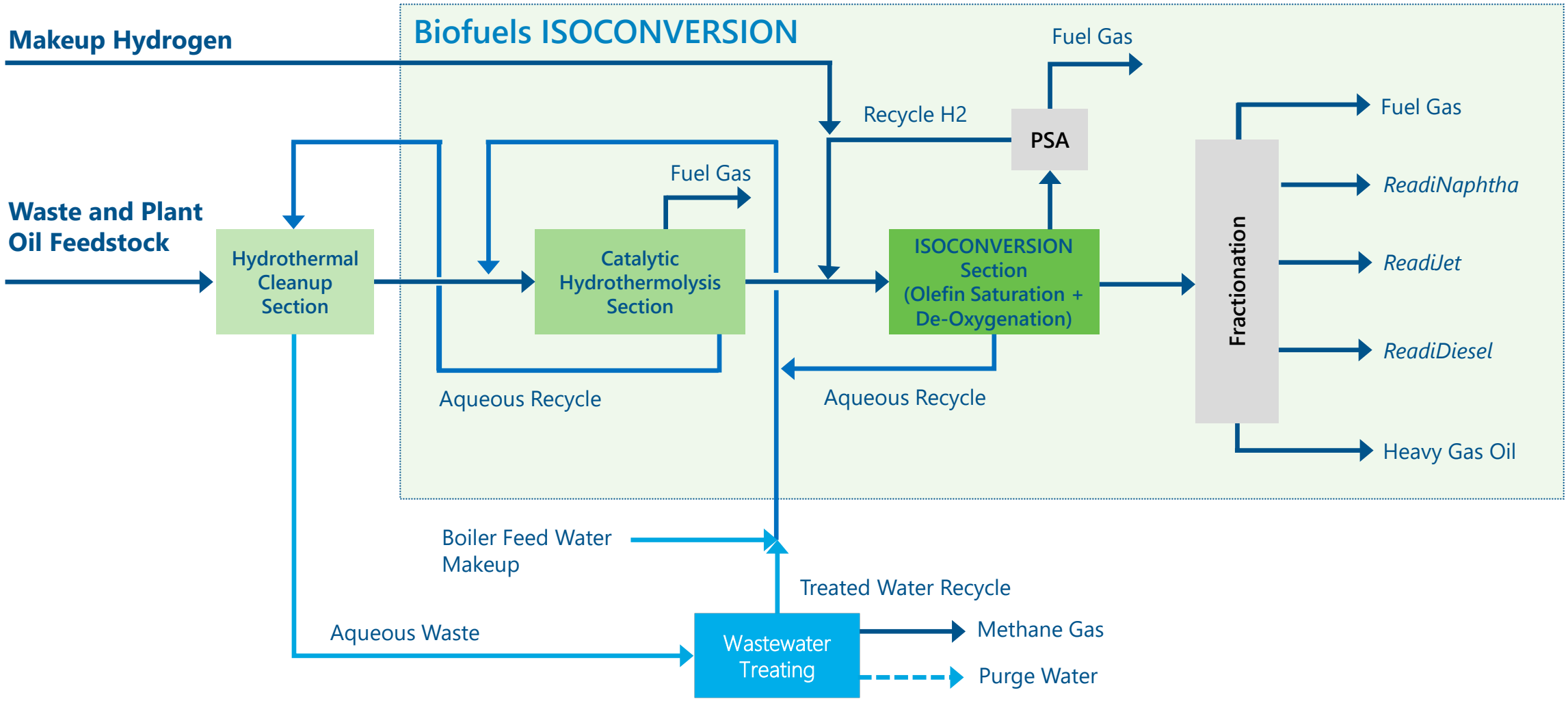

Robust, Low-cost Hydrothermal Clean-up

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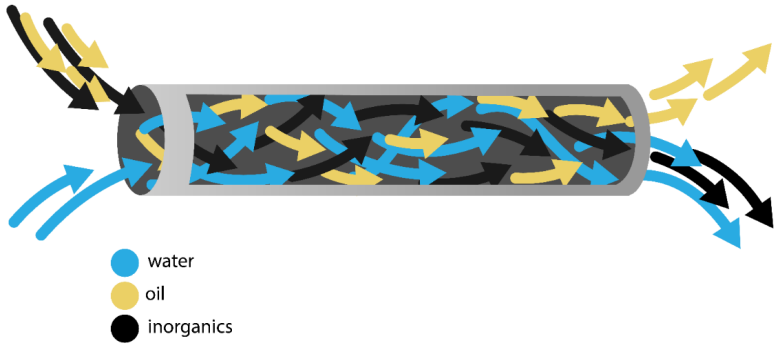
- Conventional refining unit operation
- Rapid hydrolysis of phospholipids
- Rapid acidulation of soaps
- Hydrolysis avoids sedimentation of solid waste
- Reduces contaminants to very low levels:
  - Phosphorus < 2 ppm
  - Metals < 10 ppm
  - Chlorides < 5 ppm
  - Polyethylene < 10 ppm
- Expands feedstock portfolio
- Half the cost of vegetable oil clean-up from food industry



Catalytic Hydrothermolysis Expands Feed Portfolio

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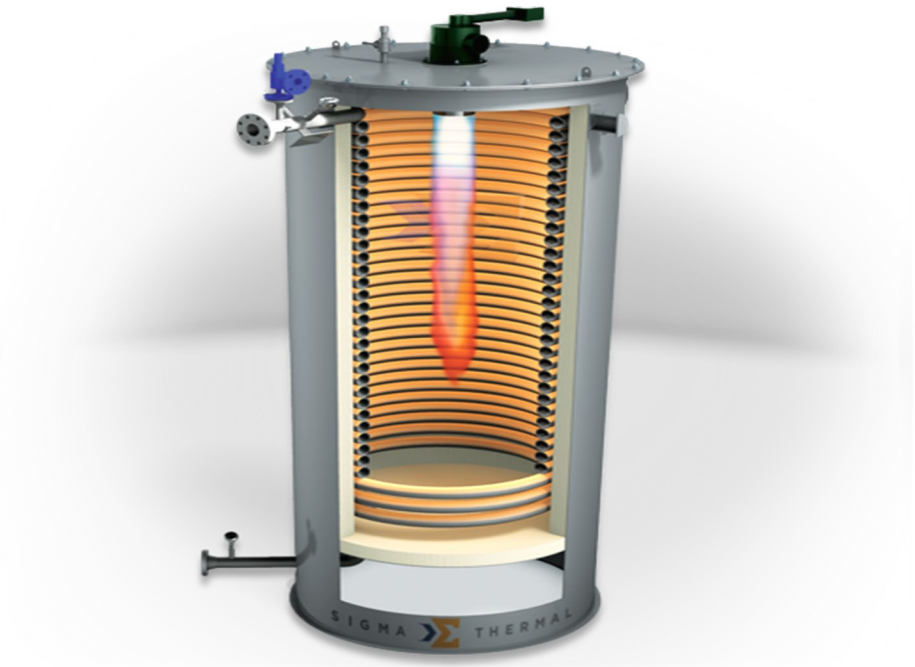
- Deeply cleanses feed
- Aromatizes olefins
- Hydrolyzes triglycerides
  - forms aromatics and cycloparaffins
- Reduces H2 requirement by 25-30%
- Reactions mediated by supercritical water
  - Reduced coke formations
  - Noncorrosive environment
- Serpentine immersed in a fired furnace
- 2000-5000 BPD typical
  - Intense mixing
  - Long preheat followed by short reaction time



ISOCONVERSION Retains Advantageous Aromaticity

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- Retains aromatics and cycloparaffins
- Eliminates residual olefins, oxygenates
- Conventional design:
  - Minimum piece count
  - No expensive noble metal dewaxing catalysts
  - No product recycle
- Renewable fuel products meet current specification
  - SAF and diesel are fully compatible with current engine technology
  - CHJ SAF approved for any lipid-based feedstock

Unique Drop-in Aviation Fuel

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- Sustainable Aviation Fuel (SAF) from Biofuels ISOCONVERSION is uniquely aromatic – ASTM D7566 Annex 6 50:50 blend certified
- 100% ReadiJet certification as aviation fuel in progress
- Multiple flights with 100% ReadiJet were demonstrated
- Biofuels ISOCONVERSION assures consistent SAF quality
- Eliminates need to test and re-certify with feedstock changes

Biofuels ISOCONVERSION Fuels are Similar to Their Petroleum Counterparts

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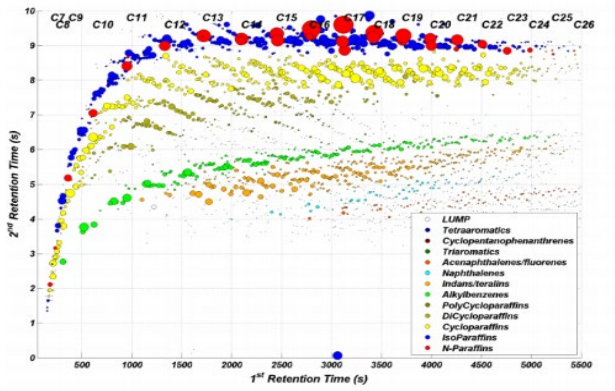
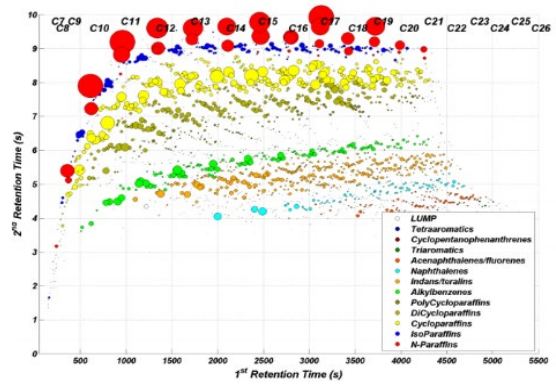
Typical Key Properties				
	Jet Fuel	Readi Jet	ULSD	Readi Diesel
Density, kg/L	0.804	0.803	0.838	0.826
Sulfur, wppm	380	<3	<10	<0.5
Smoke Point, mm	22	25		
Cetane Number			50.1	54.5
Heat of Combustion, MJ/kg	43.3	43.3	43.0	42.7
10% / End Point, °C	182 / 265	180 / 240		
95% Recovery Temp,°C			340	309
Other specifications very similar				

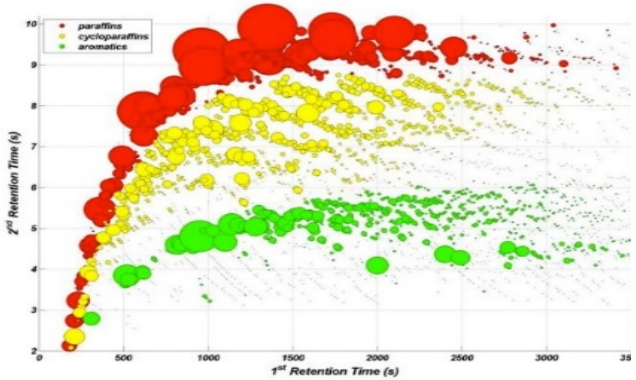
Petroleum Jet Fuel



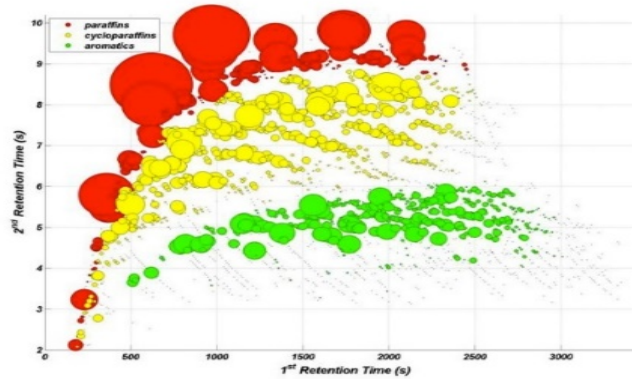
ReadiJet



Petroleum Diesel



ReadiDiesel



Gas Chromatograph – Each bubble represents a different compound, and the size represents its prevalence

- Red bubbles represent paraffin molecules
- Yellow bubbles represent cycloparaffin molecules
- Green bubbles represent aromatic molecules

Biofuels ISOCONVERSION Key Advantages

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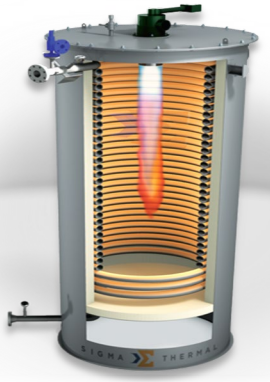
- Cost effective solution for more challenging feeds
  - Ideal for waste fat, oil, grease
  - Tailored toward lower-carbon-intensity (lower-cost) feeds
  - Higher carbon credit products
  - 25-30% lower H_2 consumption
- Produces uniquely compatible fuels
  - More aromatic (and naphthenic) distillates
  - 5-6% higher energy density
  - SAF fully compatible with current jet engines
- Combines proven technologies



Biofuels ISOCONVERSION Commercialization is Taking Off

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Development Phase:

- Blue Sun built and operated 2014-2015
- 100 BPD Supercritical Water Catalytic Hydrothermolysis Unit
- Feed: Distillers Corn Oil (DCO); 120 s residence time
- 160,000 gal of drop-in SAF,
- Marine Diesel produced for US Navy MILSPEC certification as 100% drop in

Commercialization Phase:

Company	Feedstock	Status	Capacity
Euglena (Yokohama (JP))	Algae Oil/Palm oil	On Stream	5
Urban X (Bakersfield (CA))	Brown/Yellow Grease	EDP stage	5,300
Readifuels (Iowa)	Corn oil/Used Cooking Oils	EPC stage	2,650
TBA Western US	Corn oil/Used Cooking Oils	EPC stage	3,200

Solutions Tailored Toward Local, Regional Needs

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Thank you

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