Financial and Sustainability Metrics of Aviation Biofuels

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Outline

- About Us
- Key Drivers
- Options to replace petroleum-derived jet fuels
- Production Technologies and Feedstocks
- Potential Supply and GHG Impacts
- Financial Assessment
- Conclusions

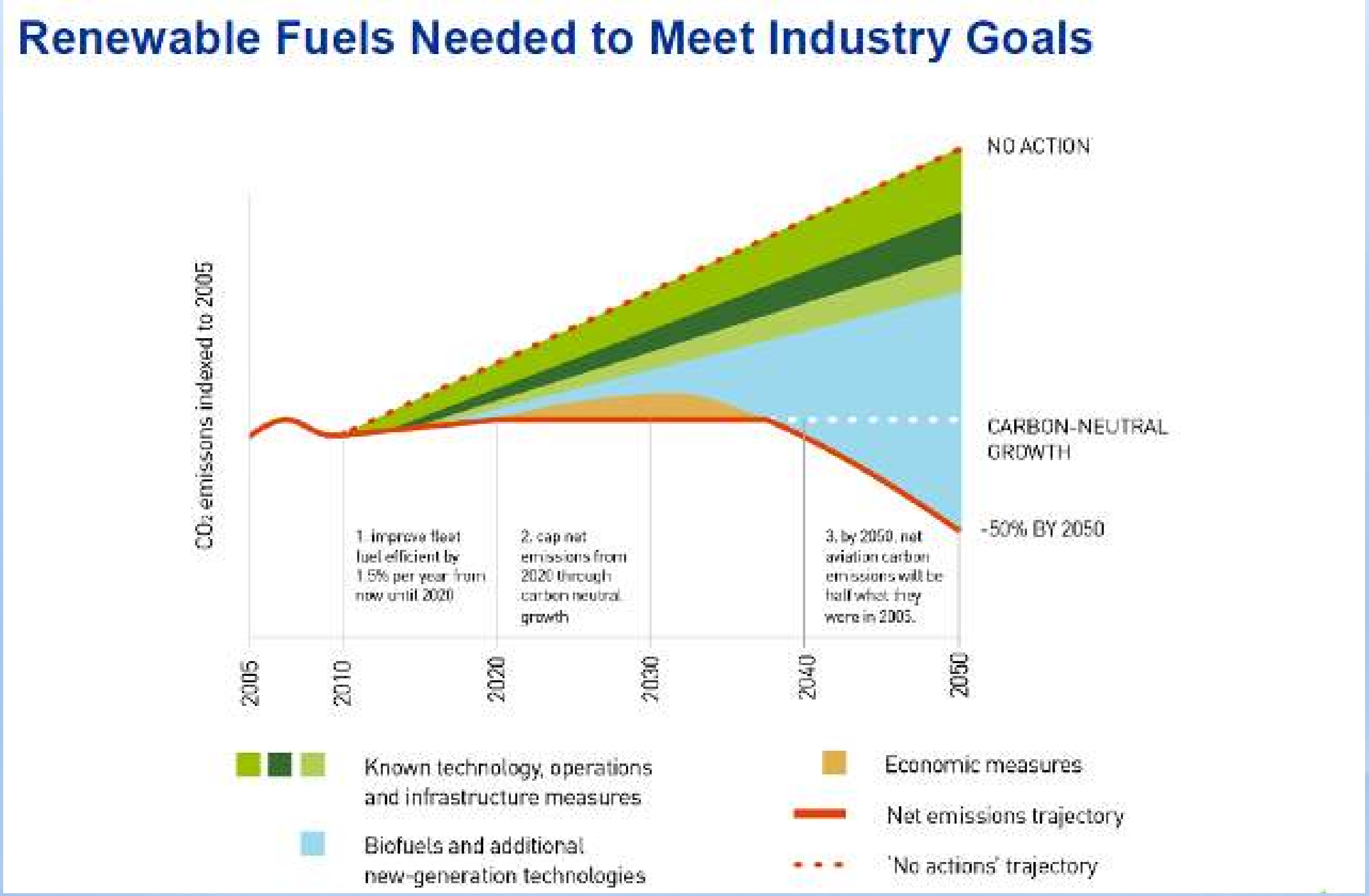
About Our Research Group

- Collaboration with Heather MacLean (UofT Civil Engineering)
- Focus on process design, development and evaluation for renewable fuels technologies
- Life cycle assessment, including GHG emissions, feedstock assessments, land use, air quality
- Technoeconomic assessment of various process and feedstock options

Key Drivers and Constraints

- GHG Emissions Targets
- Fuel Properties and Fuel Transport
- Availability of Feedstocks and Land Requirements
- Production Cost!

Targets for Carbon-Neutral Growth



Lift-Off Requires Key Developments Along Entire Value Chain

The road to biojet fuel requires a value chain approach

Feedstock Production

Feedstock Logistics

Bio Jet Fuel Production

Bio Jet Fuel Trading

Bio Jet Fuel Logistics

Bio Jet Fuel End Users

SUPPLY CHAIN DEVELOPMENT

- No silver bullet, explore multiple feedstock/technology pathways;
- From demonstration to commercial plants;
- Feed government policy & incentives;
- Secure investments;
- Secure certification;
- Secure economic, social and ecological sustainability.

CREATE DEMAND

- Operate demonstration flights (series);
- Aggregate demand from customers;
- Aggregate airline & airport demand;
- Green government travel.

TECHNOLOGY OPTIONS

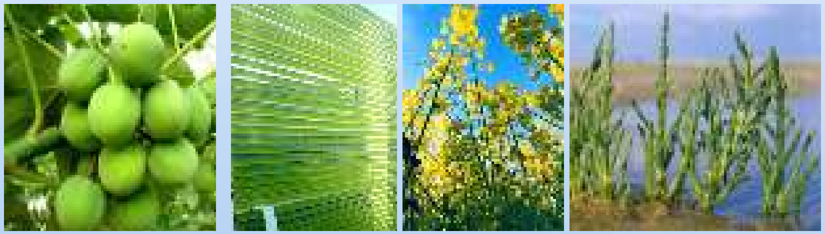
Proposed Options to Replace Jet Fuels

- **Bio-SPK:** Alkanes produced by hydrogenation of vegetable oils and tallow
  - Isomerization needed for cold-flow
- **FT-SPK:** Alkanes produced by gasification followed by Fischer-Tropsch reaction
- **ATJ – Alcohols to Jet Fuels**
  - Produce ethanol or butanol first, then catalytically convert to Jet Fuels
- **SIP – Sugars to Paraffins**
  - Production of farnesene/farnesane from sugars via fermentation and hydrogenation

Potential Feedstocks

Feedstock Oils **Carbohydrates**
Soybean Sugar Cane, Beets
Corn Grains
Canola/Rapeseed Lignocellulosic Feedstocks
Camelina/Carinata
Palm Oil **Others**
Beef tallow MSW
Pork lard
Used cooking oils
Algae
Jatropha
Cottonseed
Sunflower

Pathways to Aviation Biofuels



OIL FEEDSTOCK

Oil Extraction
Hydrotreatment
Hydrocracking
Separation

Hydroprocessed Esters and Fatty Acids (HEFA) PATHWAY

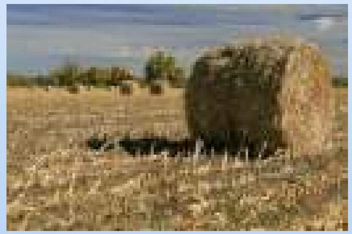
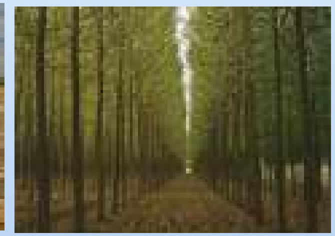
LIGNOCELLULOSIC FEEDSTOCK

Gasification
Fischer-Tropsch
Synthesis
Hydrocracking
Sep

FT PATHWAY

BIO- SYNTHETIC PARAFFINIC KEROSENE (Bio-SPK)

Pathways to Aviation Biofuels


LIGNOCELLULOSIC FEEDSTOCK

Hydrolysis
Fermentation to Alcohols
Catalytic Processing

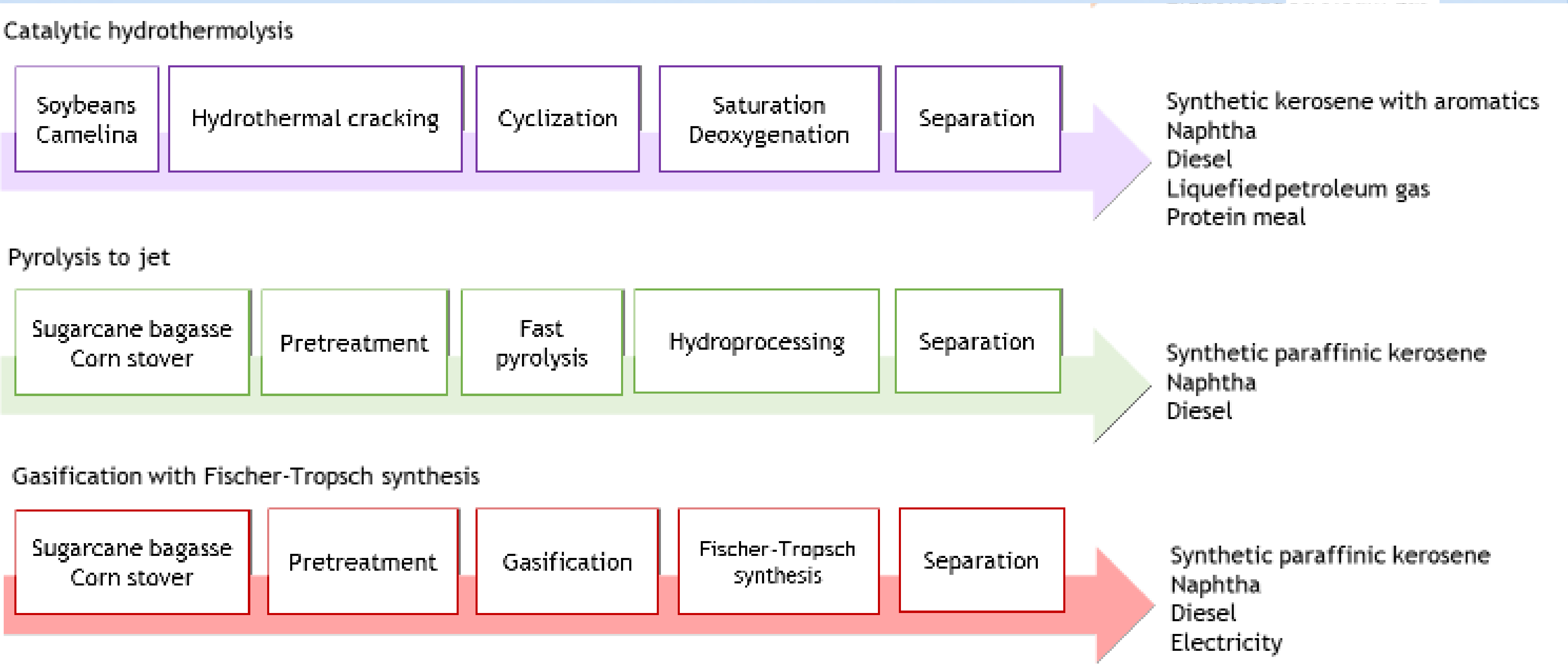
ALCOHOL TO JET (ATJ) PATHWAY

Hydrolysis or sugar production
Fermentation/Catalysis to Alkanes
Hyd
Aror
Sepa

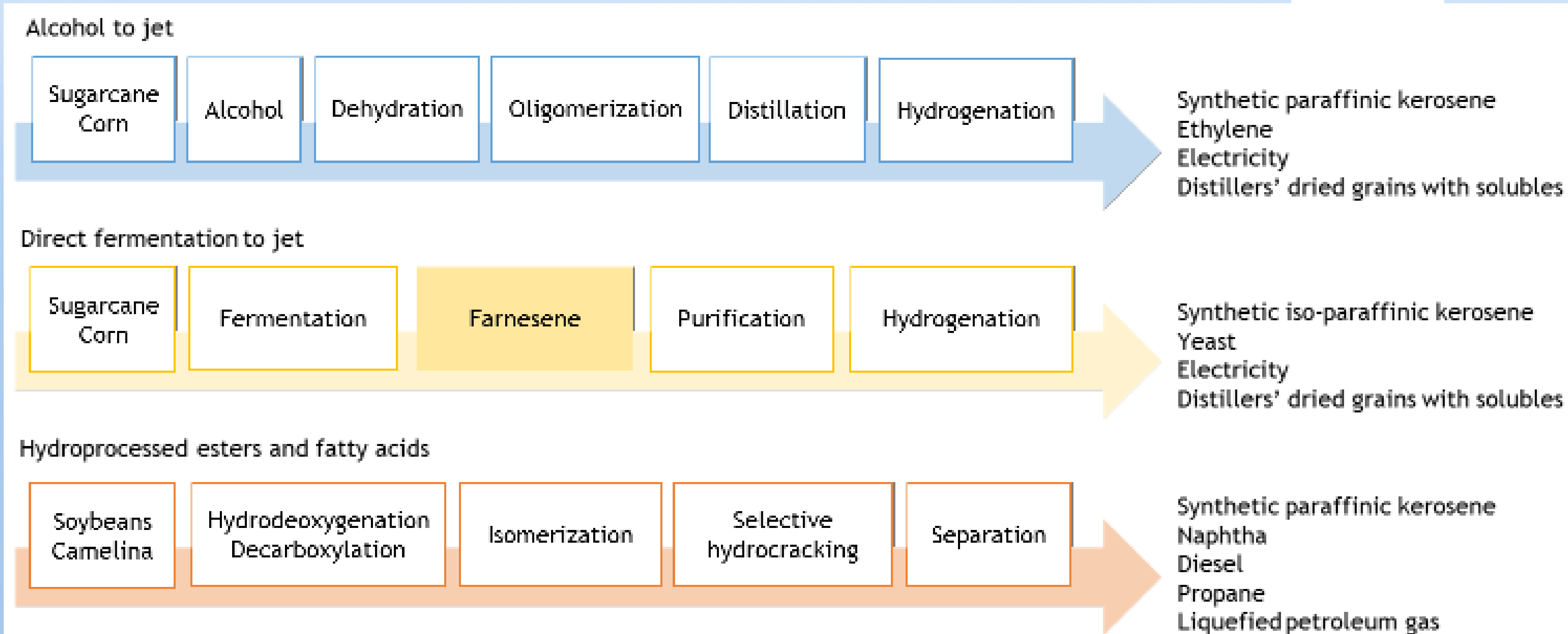
LIGNOCELLULOSIC ALKANE PATHWAY

RENEWABLE JET FUELS

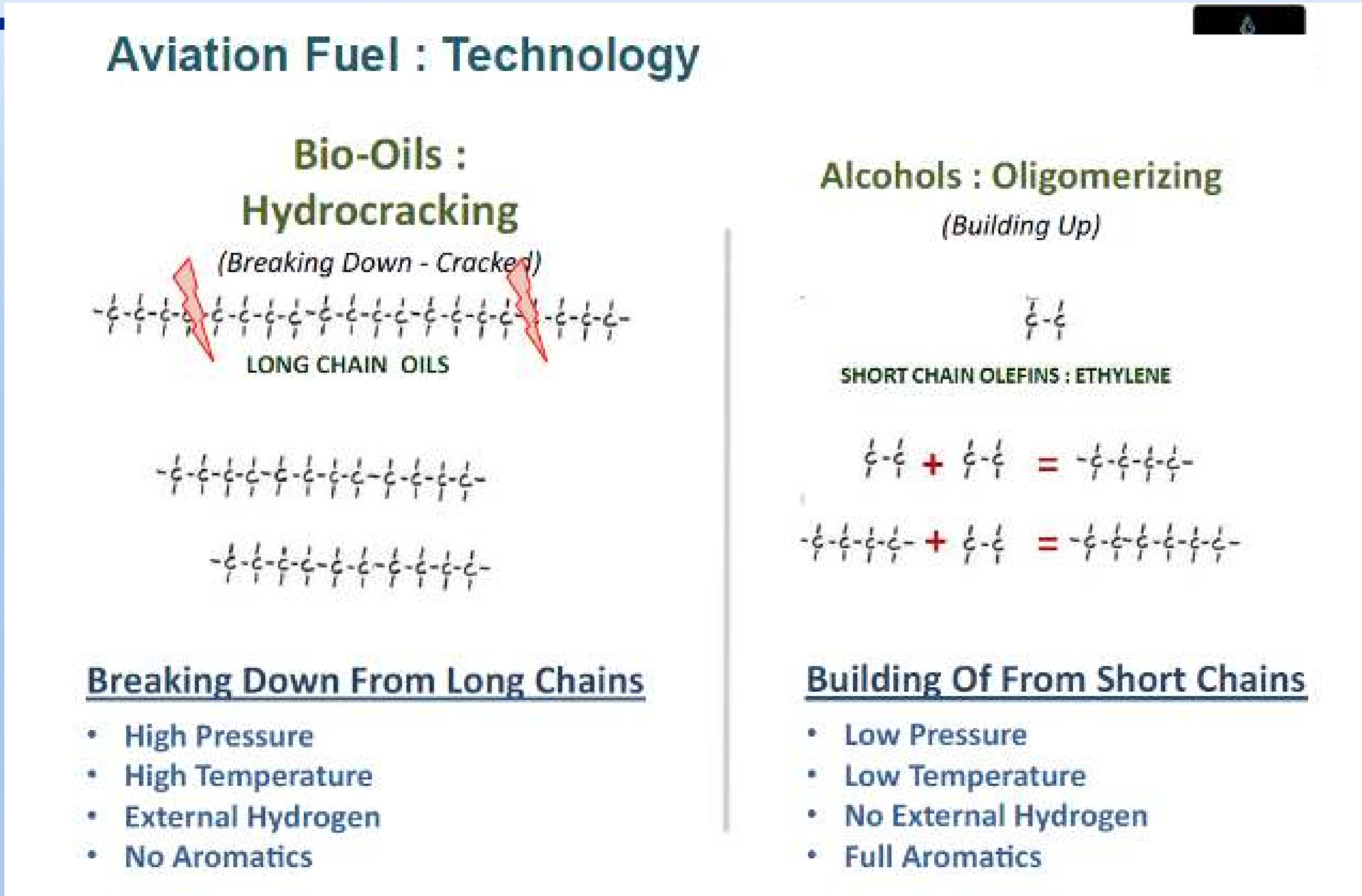
Comparison of Different Pathways



Comparison of Different Pathways

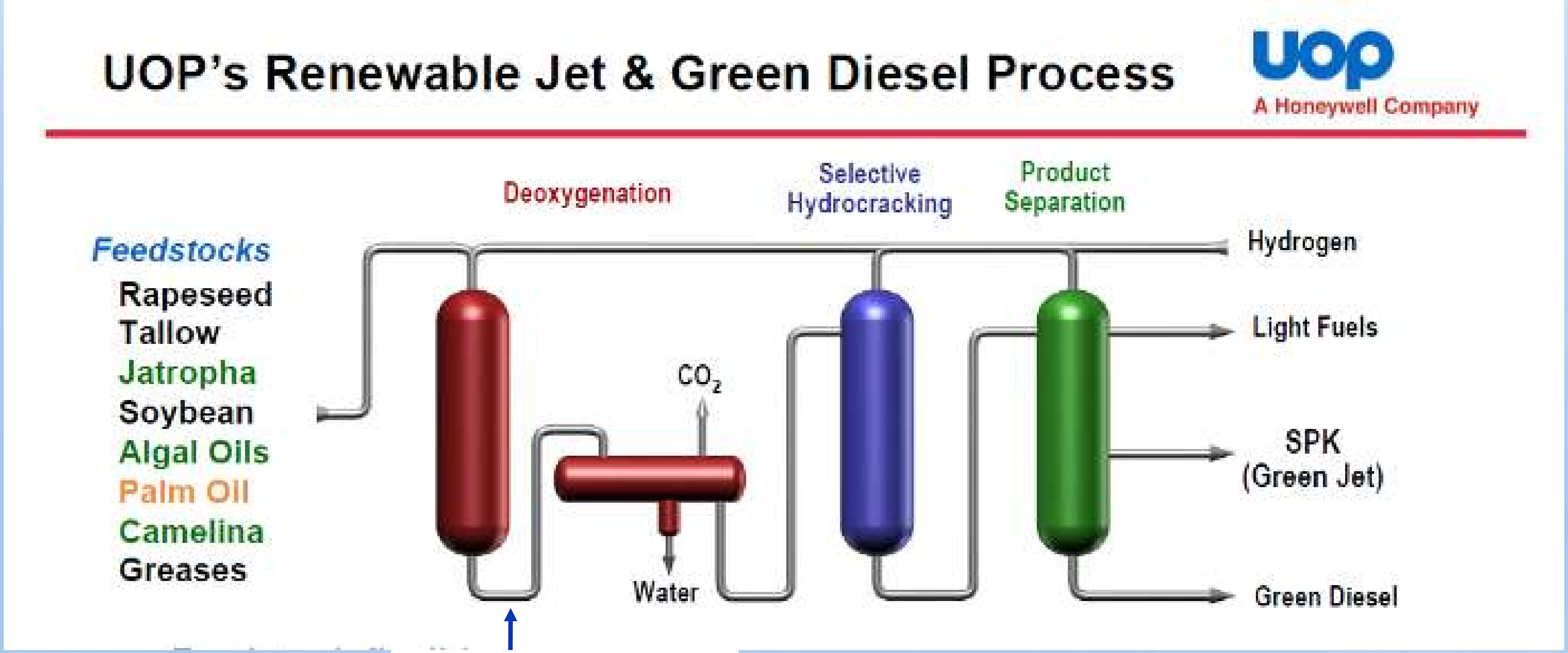


Comparison of Oils vs CHOs



Production Processes Using Lipids

Bio-SPK Process Units

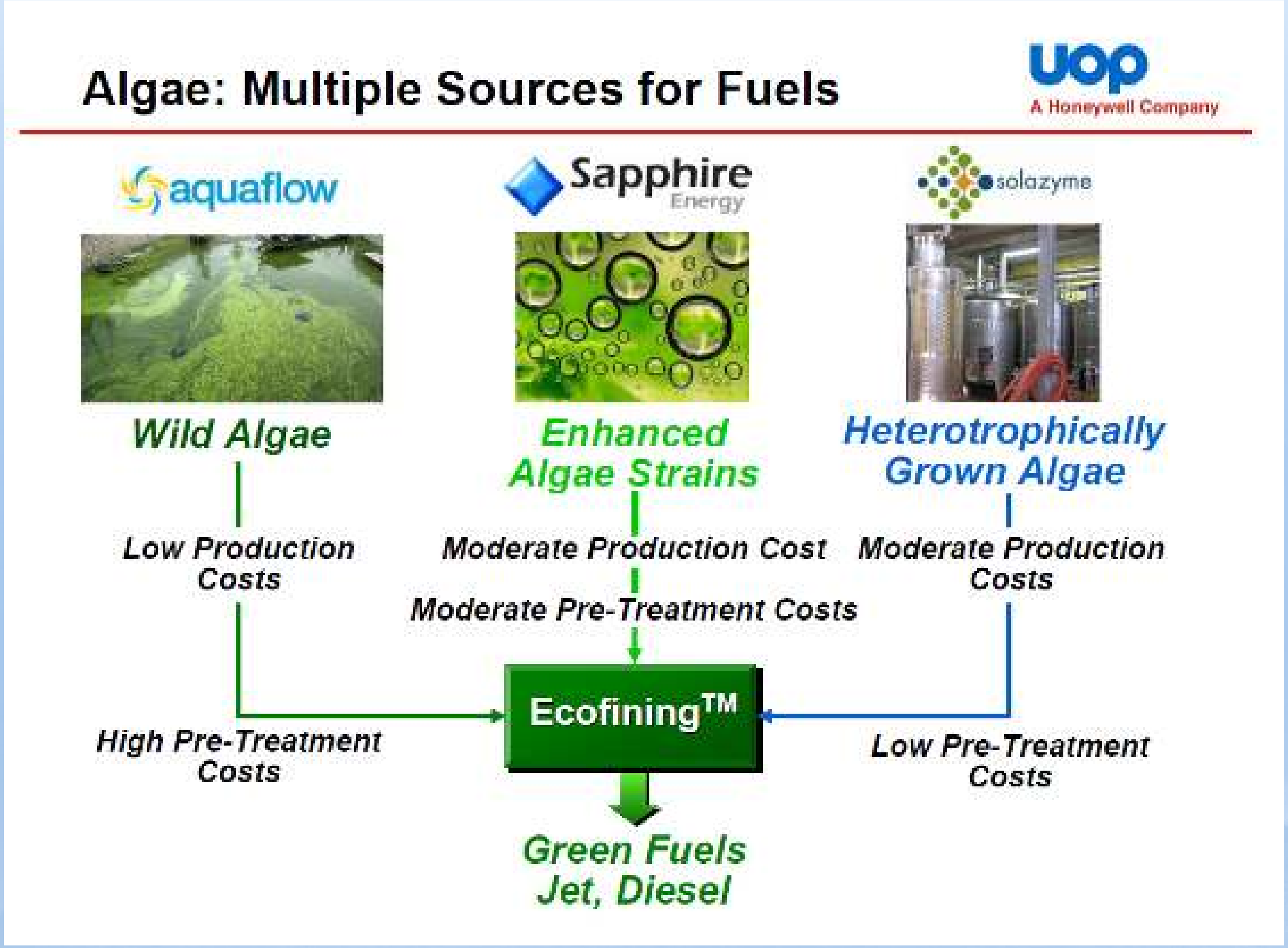


Green diesel, light HC, CO_2, H_2O

Challenges with Bio-SPK

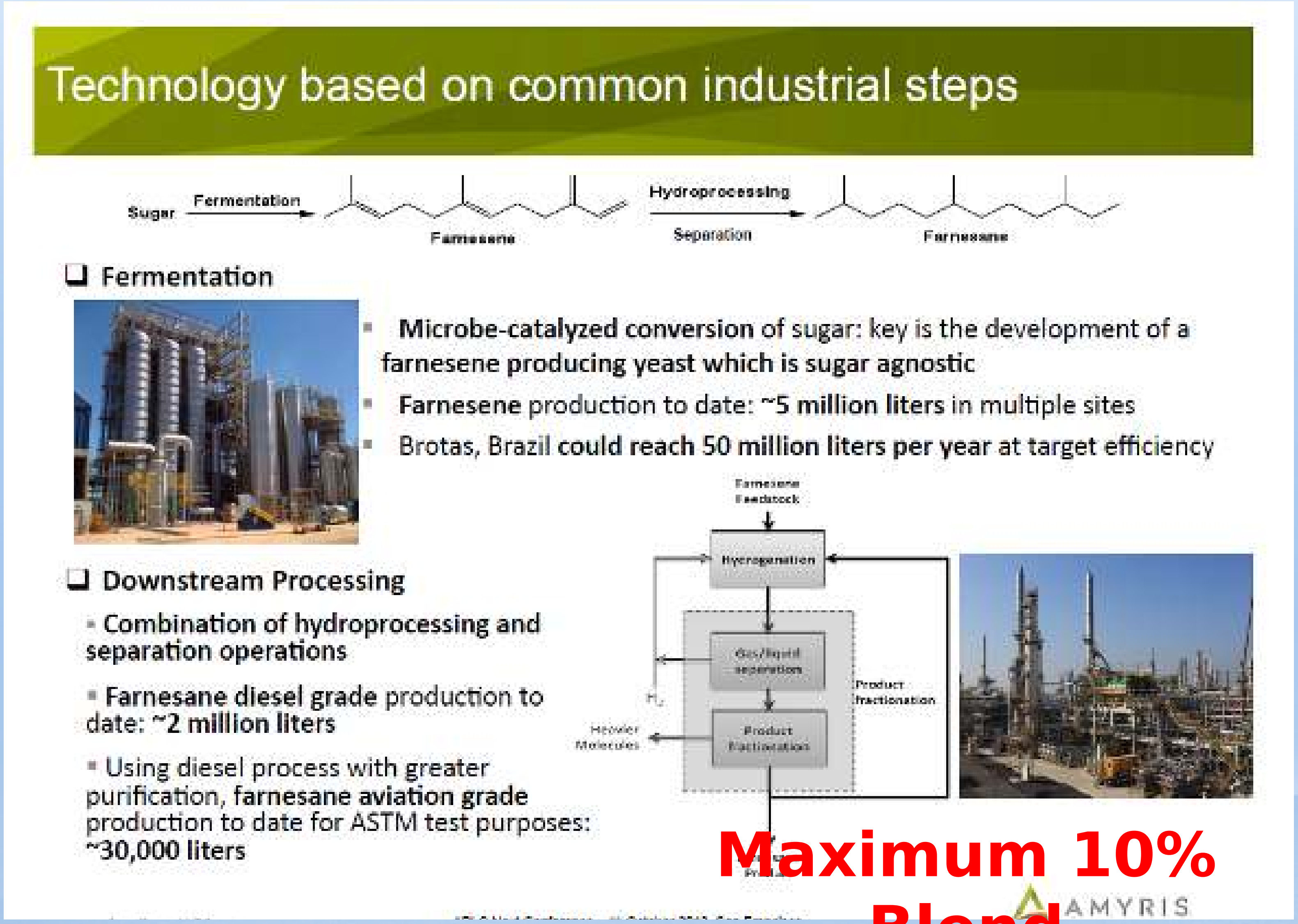
- High cost of feedstock oils
  - More costly to produce than renewable diesel, which, in turn, is more costly to produce than biodiesel, which requires subsidies to be competitive with petrodiesel
- Need source of hydrogen
- No aromatics
  - Limited GHG reduction

Algal Feedstock Players



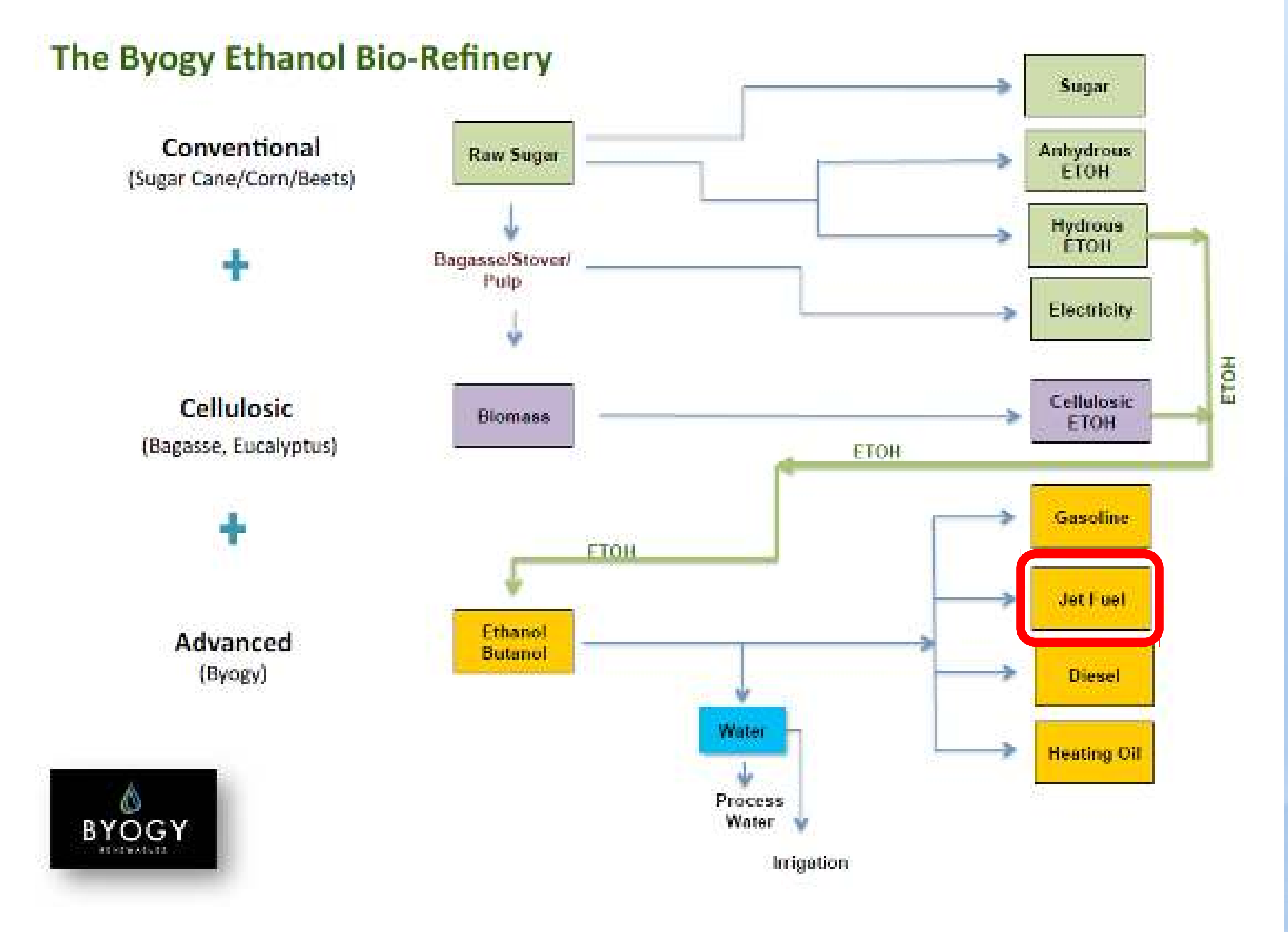
OTHER OPTIONS USING SUGARS

Amyris
Farnesane from Biomass-derived Sugars



Maximum 10% Blend

Byogy and Gevo
Alcohol to Jet Platform

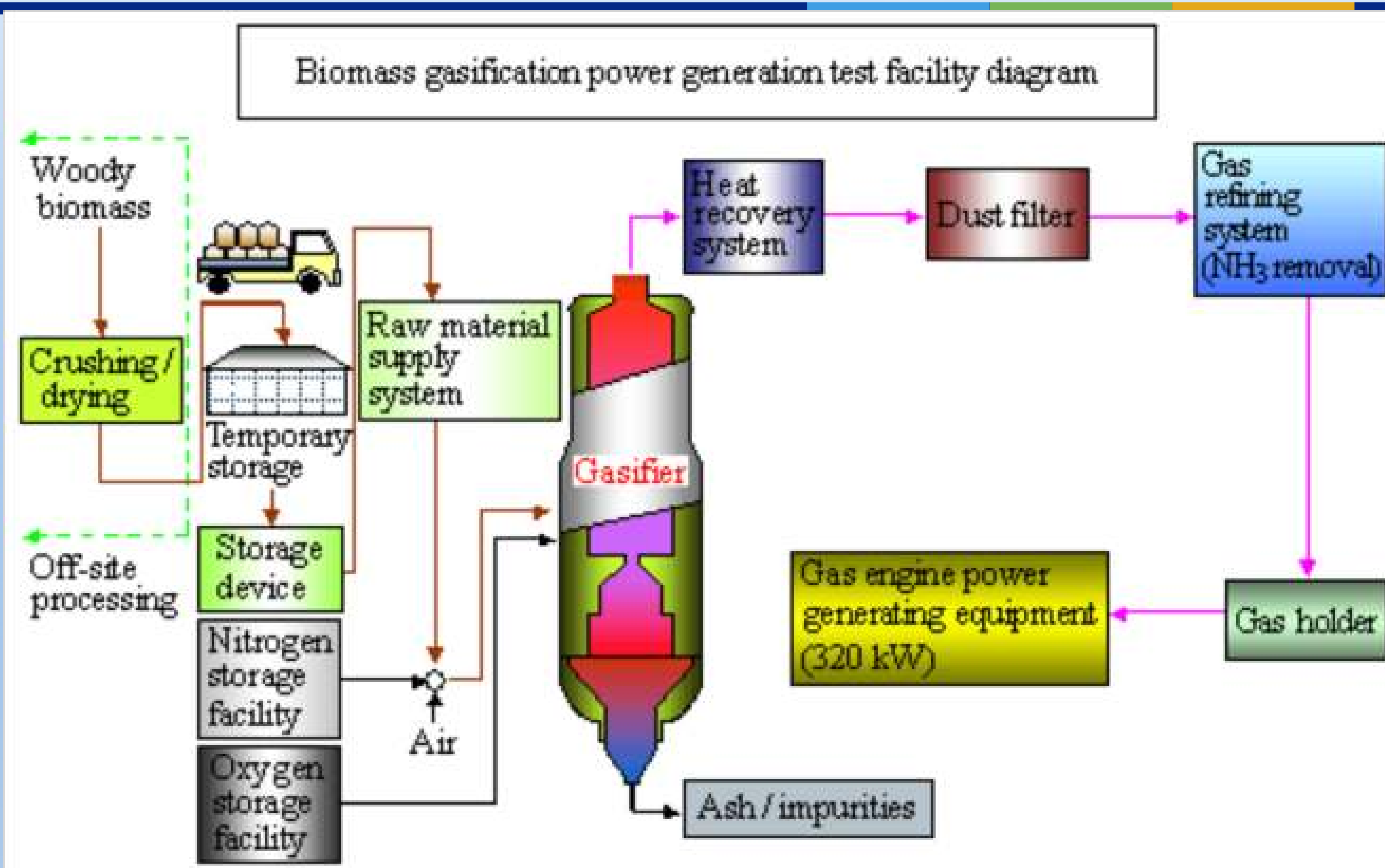


Challenges with Platforms Using Sugars

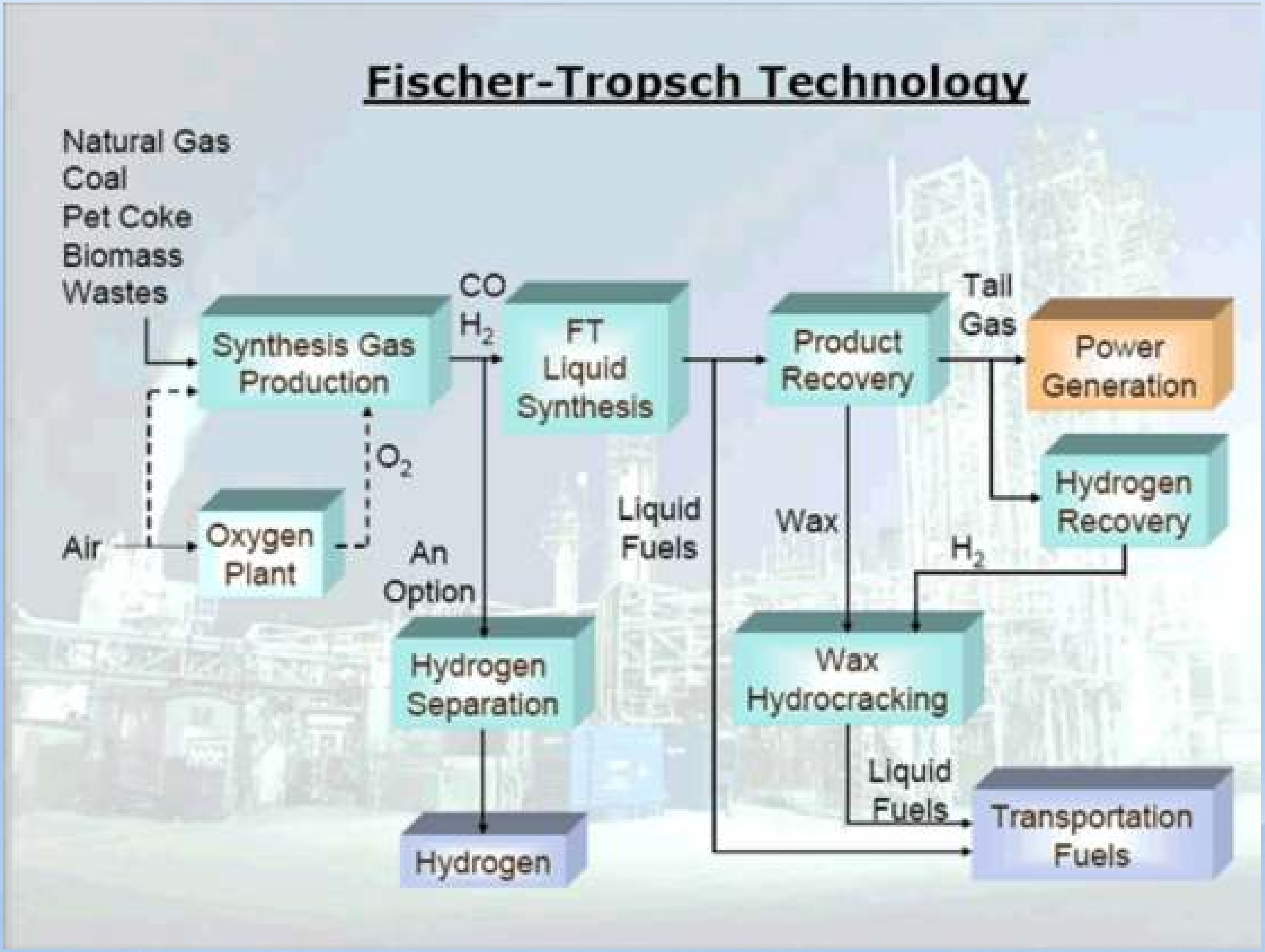
- Need inexpensive sugar source
- To get significant GHG reductions, need cellulosic biomass – but conversion technology is still being developed
- Will be more costly than making alcohols from same sugars

OPTIONS FROM SYNGAS

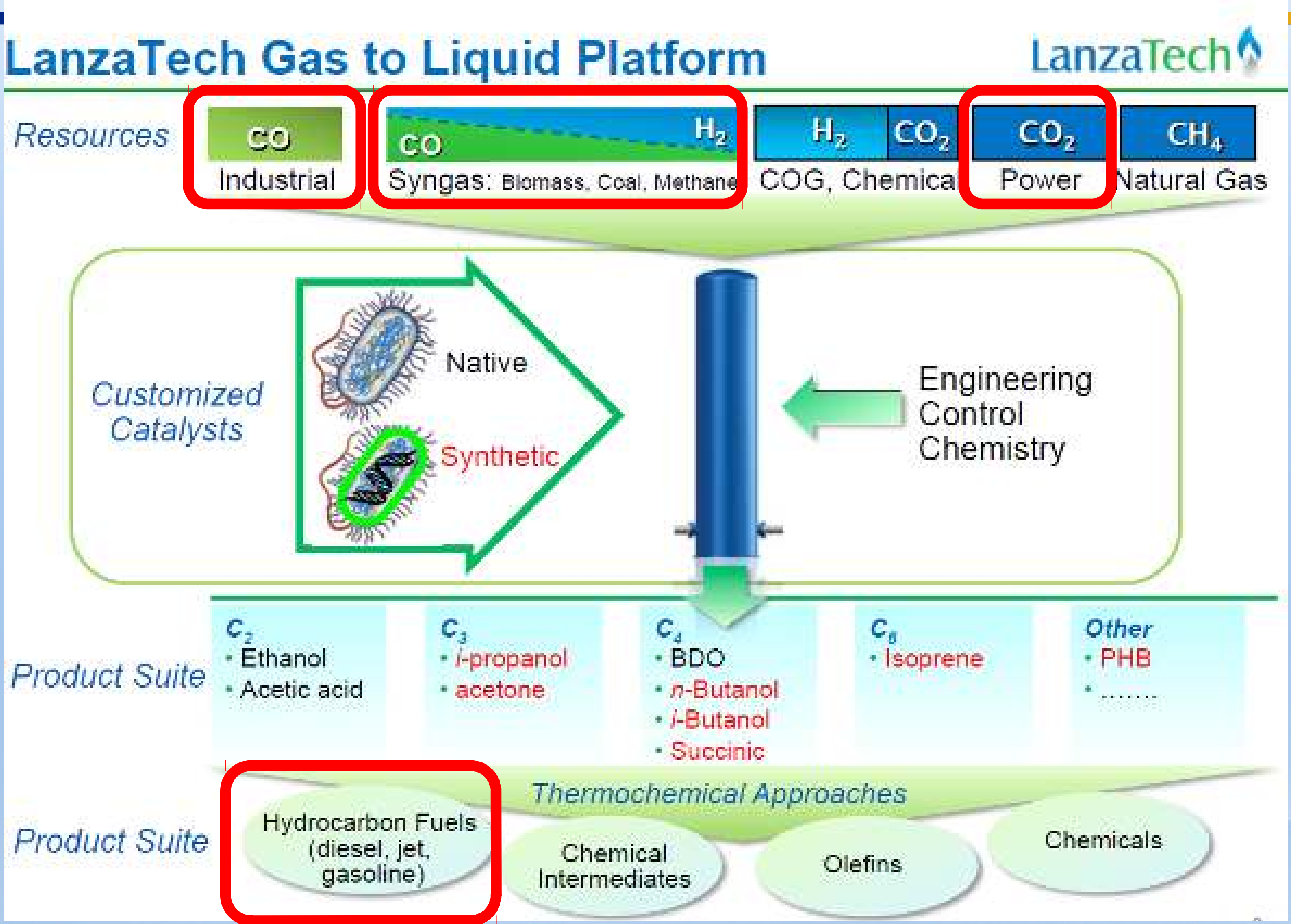
Step 1
Syngas Production from Biomass Gasification



FT Process Step 2
Convert Syngas into Alkanes

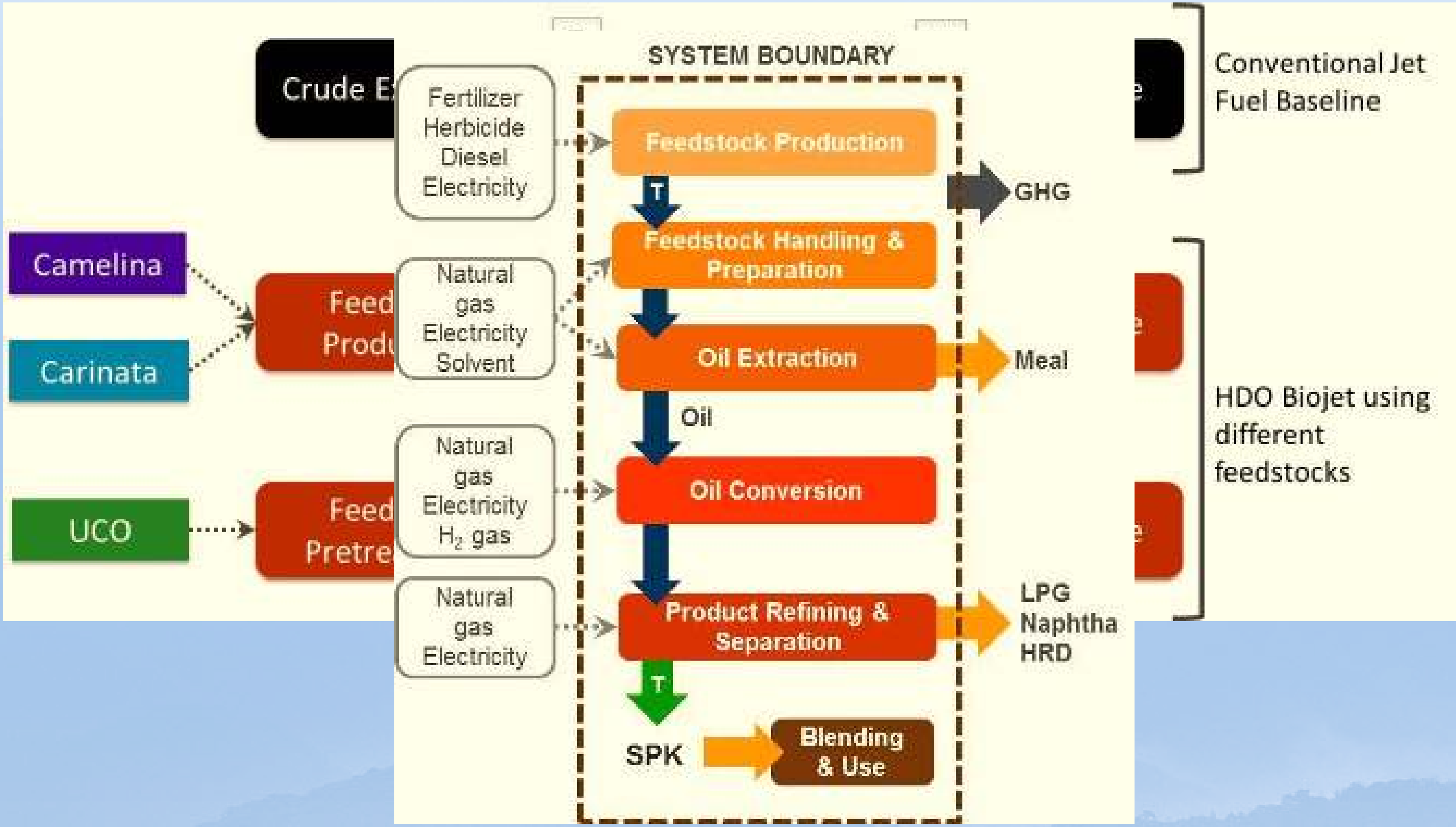


Lanzatech Thermo/bio-catalysis of Platform Chemicals

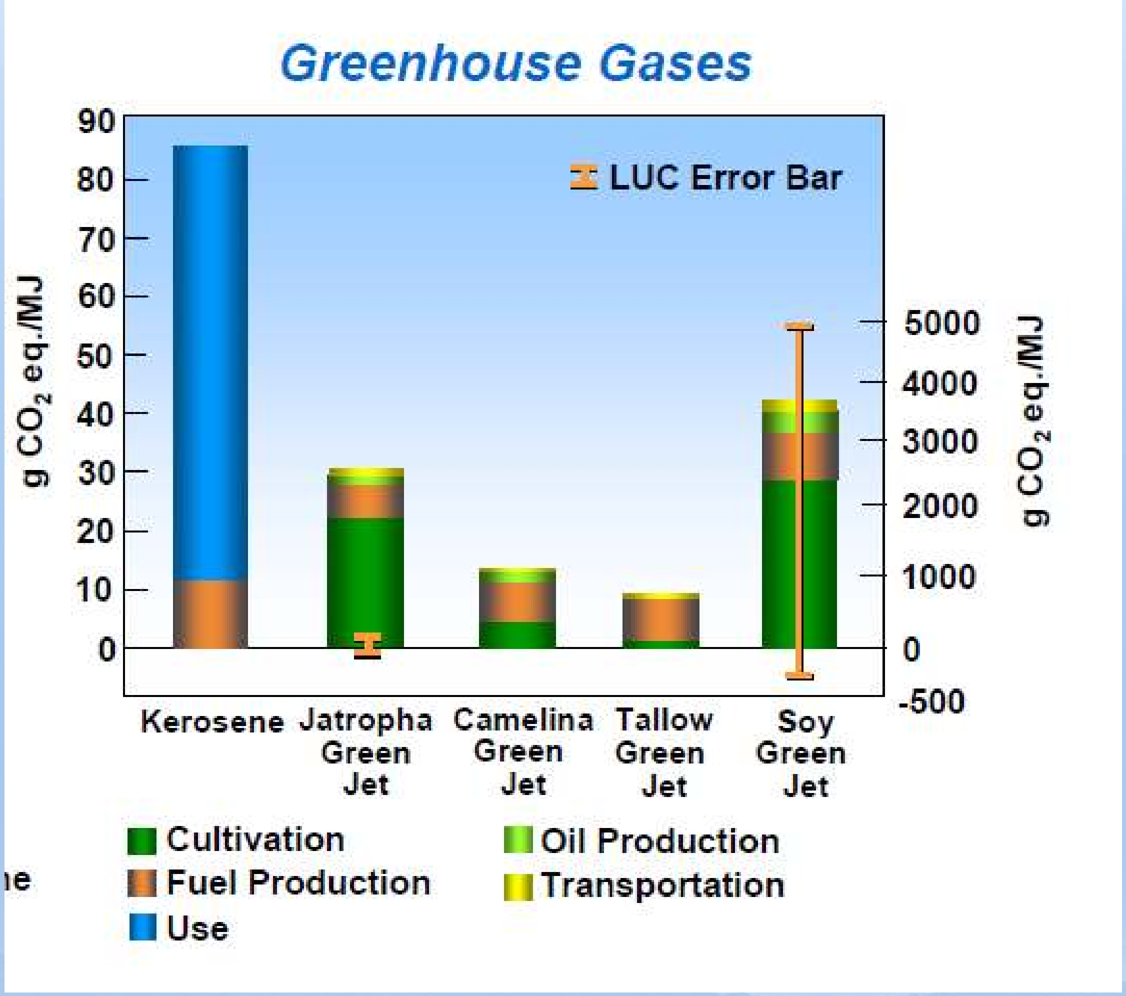


GHGS, LAND USE, SUPPLY/DEMAND METRICS

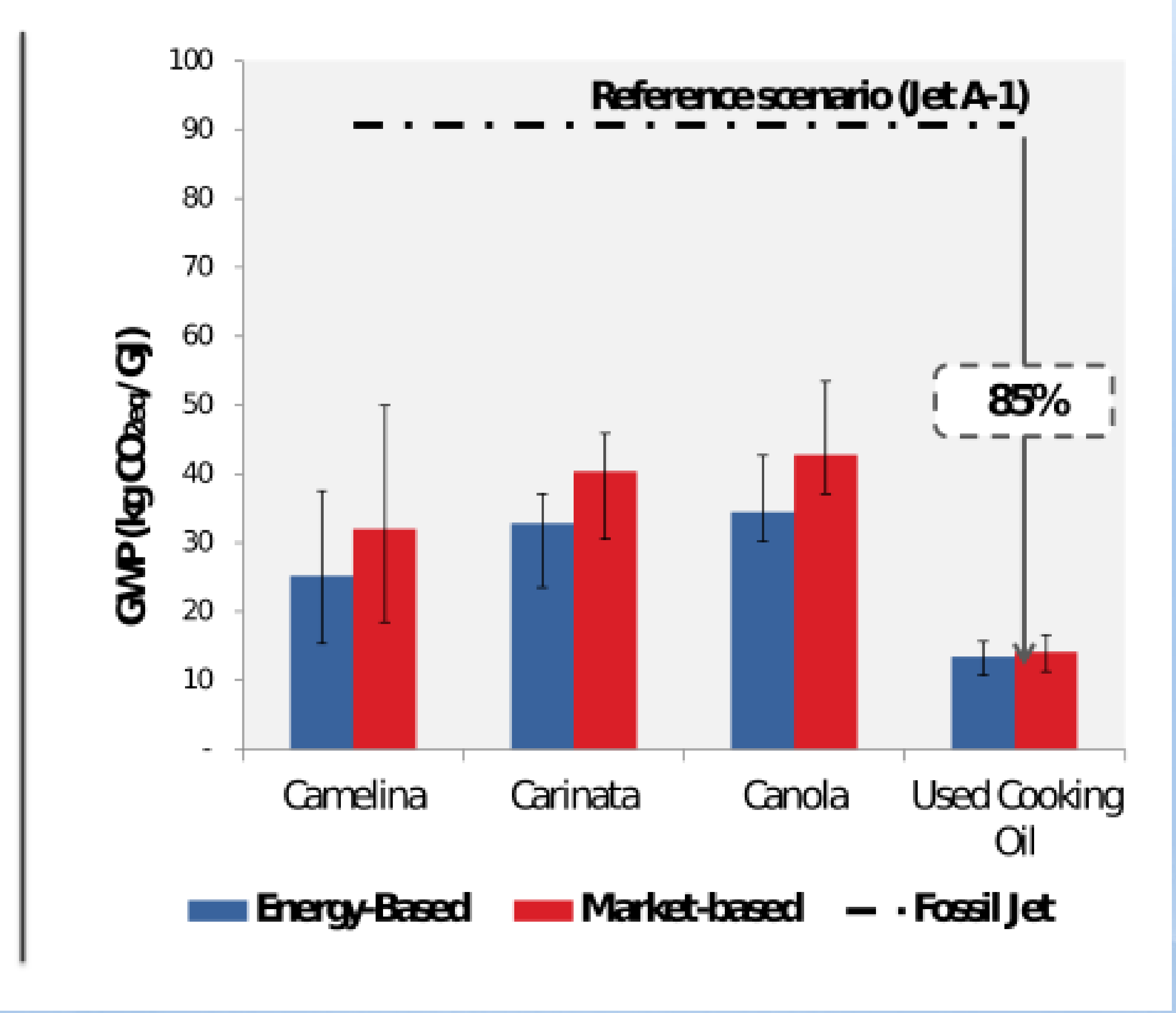
LCA Boundaries



GHG Emissions of Renewable Jet Fuel



GHG Profile for Bio-SPK from Camelina, Carinata, UCO

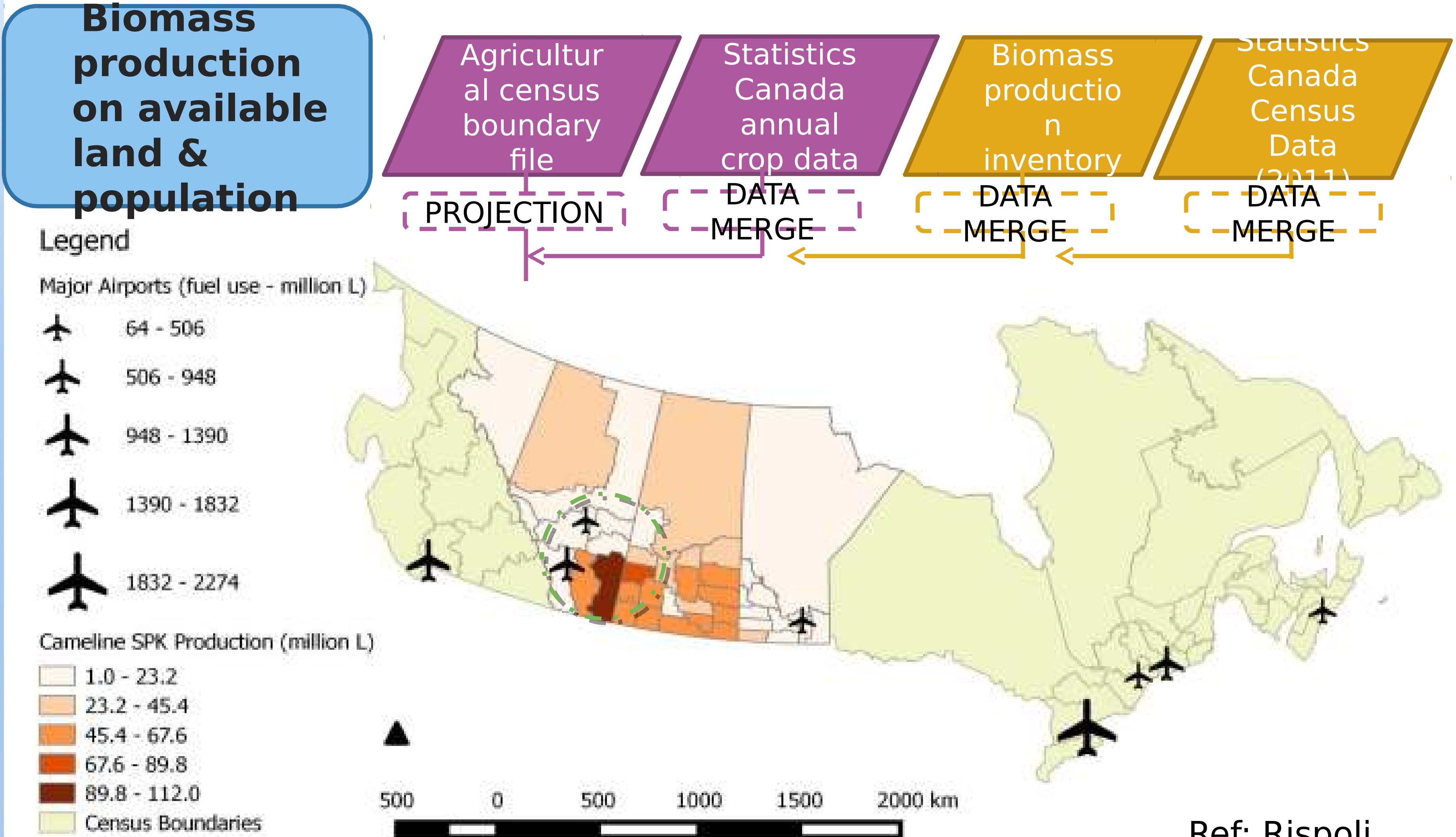


See also poster from Jon Obnamia on GHG emissions profile of canola-based jet fuel

Land Use Implications

- Highly dependent upon productivity of feedstock
  - Oilseeds: 2 – 3 tonnes/Ha, with 20 – 45% useable oil
  - Crop Residues: 2 – 4 dry tonnes/Ha, with 60 – 95% useable content
  - Dedicated Energy Crops: 5 – 35 dry tonnes/Ha, with 60 – 95% useable content
  - Sugarcane: 15 – 20 dry tonnes/Ha, with 15 – 25% useable content

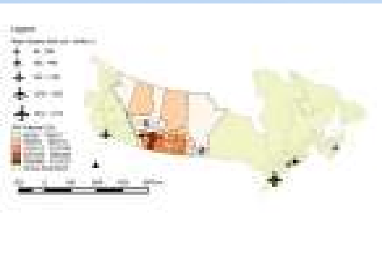
SUPPLY/DEMAND ASSESSMENT



Ref: Rispoli, 2015

SUPPLY/DEMAND ASSESSMENT

Potential jet fuel displacement & emission reduction



EXCEL LCA MODEL

- *average values*
- *energy-based allocation*

	Amount produced	% Fuel Displaced	% Fuel Displaced	Potential Emission reduction	
	Million L	All Major Airports	Calgary Airport	From SPK Production MT CO_2	% of Canada's aviation emissions
Carinata SPK	2,158	38%	416%	2.5	29%
Camelina SPK	1,295	23%	250%	1.3	16%
UCO SPK	52	1%	10%	0.1	1%

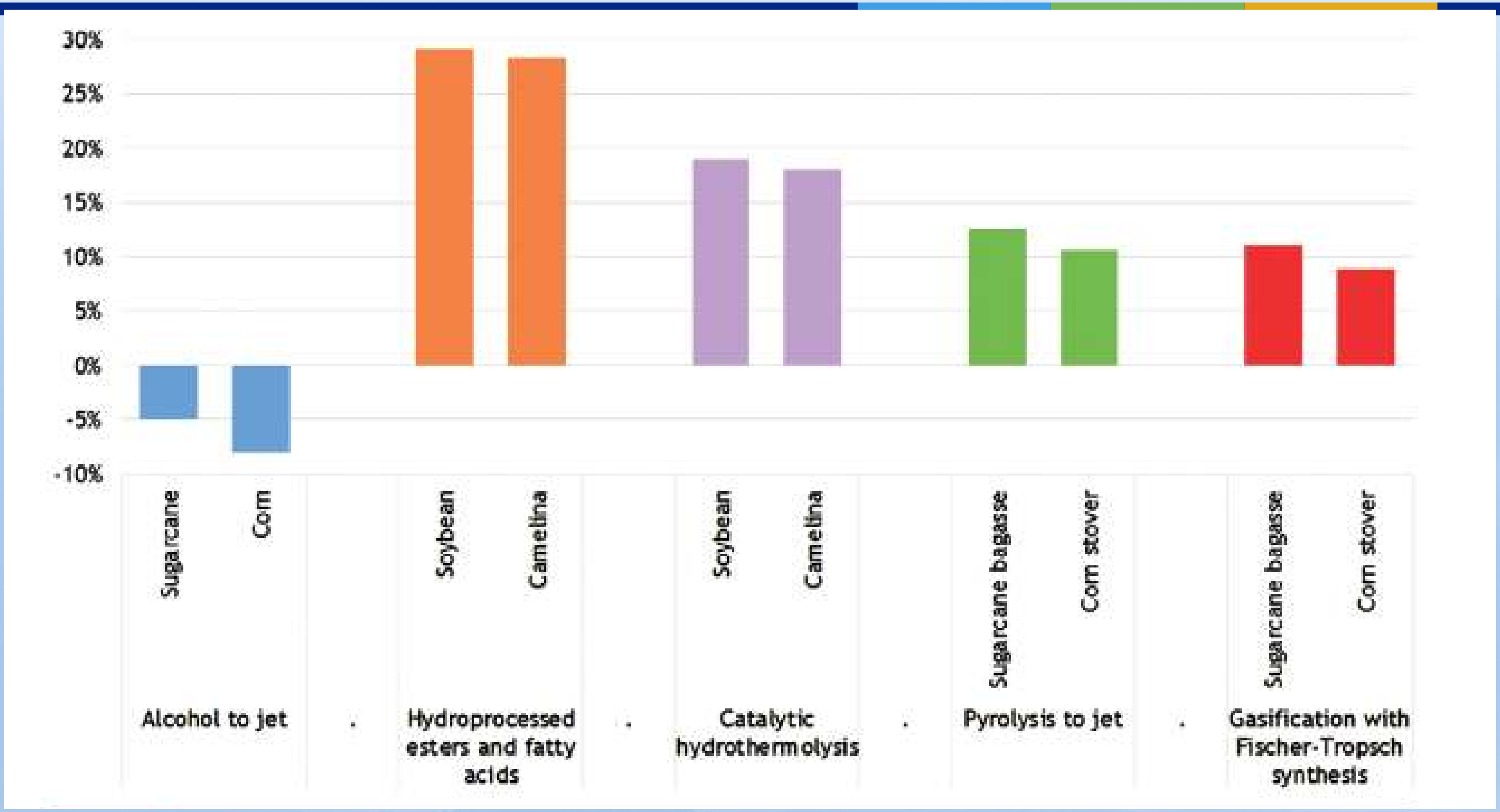
Ref: Rispoli, 2015

FINANCIAL METRICS

Key Financial Issues

- Cost-competitiveness largely relies upon high crude oil prices
- Feedstock represents 70 to 90% of the overall production cost
  - Low-cost feedstocks are key – benefit for MSW and FT/ ATJ processes
- Low cost sugar platform
  - Amyris, Virent, Solazyme, Byogy
- Intermediates (alcohols, etc.) already expensive
  - High value co-products and lower cost feedstocks may help financial viability
- High capital for gasification + FT
  - Interesting biological alternatives – will they prove out?

IRR For Select Renewable Jet Fuel Pathways



Ref: Pereira et al., BIOFPR, 2017

Financial Metrics:
Renewable Jet vs. Renewable Diesel

	HRJ	HRJ	HRJ	HDRD	HDRD	HDRD
	Camelina	Carinata	UCO	Camelina	Carinata	UCO
Feedstock price $/tonne oilseed	314	346	–	314	346	–
Feedstock price $/tonne oil	897	786	449	897	786	449
CAPEX ($MM)	411	411	387	246	246	205
OPEX ($MM)	331	292	179	323	286	172
Total Revenue ($MM)	440	382	263	439	380	260
Fuels	259	262	264	259	259	260
Meal	181	121	–	181	121	–
IRR (%)	17	14	14	28	23	25
NPV ($MM) (15% MARR)	35	–29	–26	195	121	123

Ref: Chu et al. Applied Energy 2017

Underlying Challenge

- Using crude oil as feedstock, production of jet fuel is no more expensive than producing diesel or gasoline
- By comparison, using the same renewable oil feedstock, producing renewable jet fuels is (and may always be) more expensive than producing renewable fuels that displace gasoline or diesel
  - Near-term: Biojet as co-product of renewable diesel refinery
  - Growth in production likely requires direct investment from end users

Summary

- Various platforms for conversion of biomass-derived oils, sugars, and biomass
  - Most are technically viable
  - GHG reductions on the order of 50 to 80%
- Feedstock supply is limiting
- Financial feasibility uncertain
  - Camelina and carinata show promise
  - Algae, used cooking oil have limited potential

What does the Future Hold?

- Current feedstocks are expensive or limited supply
- Need new, low cost oil-rich feedstocks, and low cost sugars
- Financial metrics will dictate path

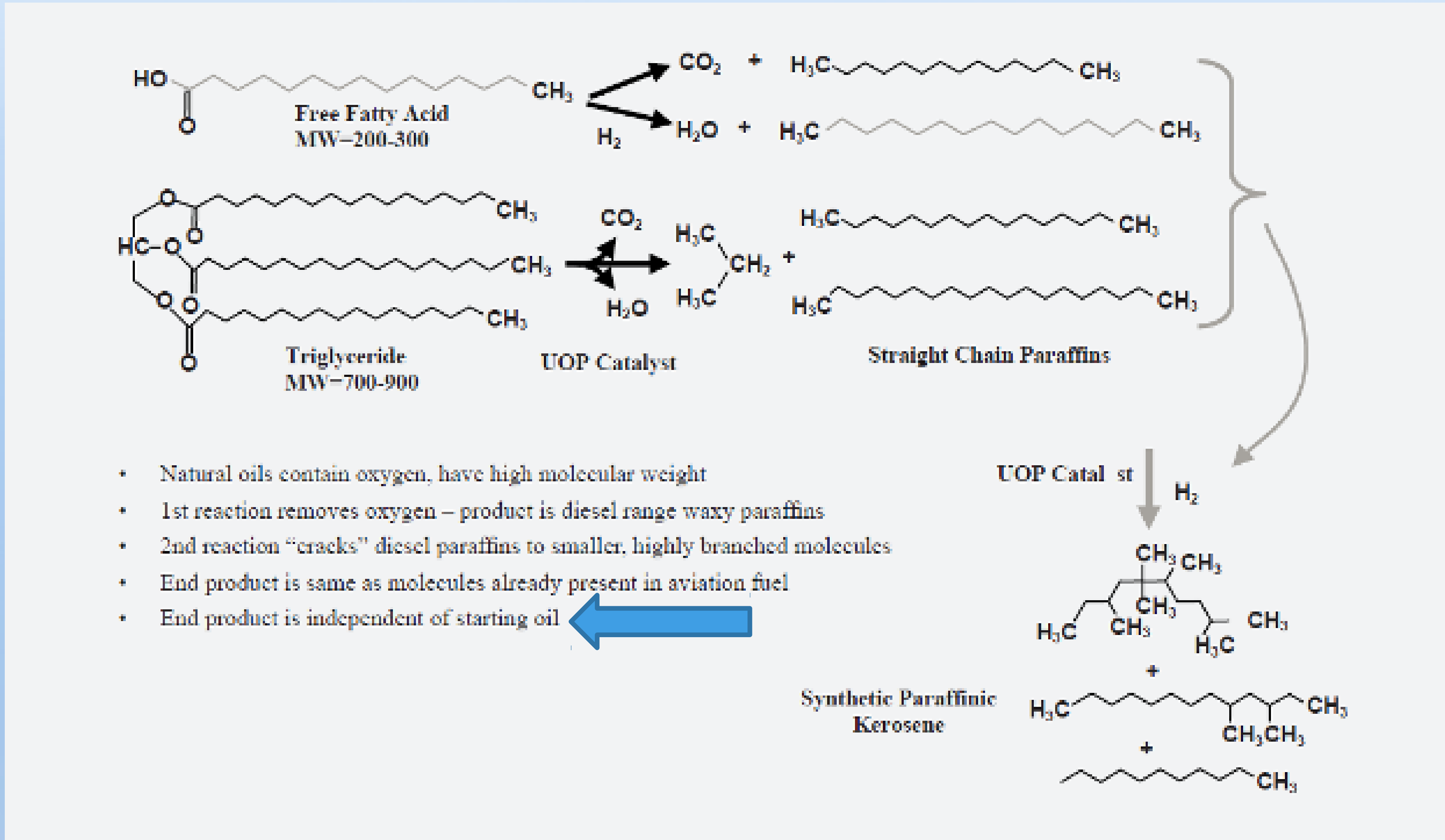
Acknowledgements

- Collaborators, Students, PDFs
  - Heather MacLean
  - Pei Lin Chu, Katherine Rispoli, Hajar PourBafrani, Jon Obnamia, Lucas Pereira
- Funding
  - NSERC CREATE
  - BiofuelNet
  - ASCENT

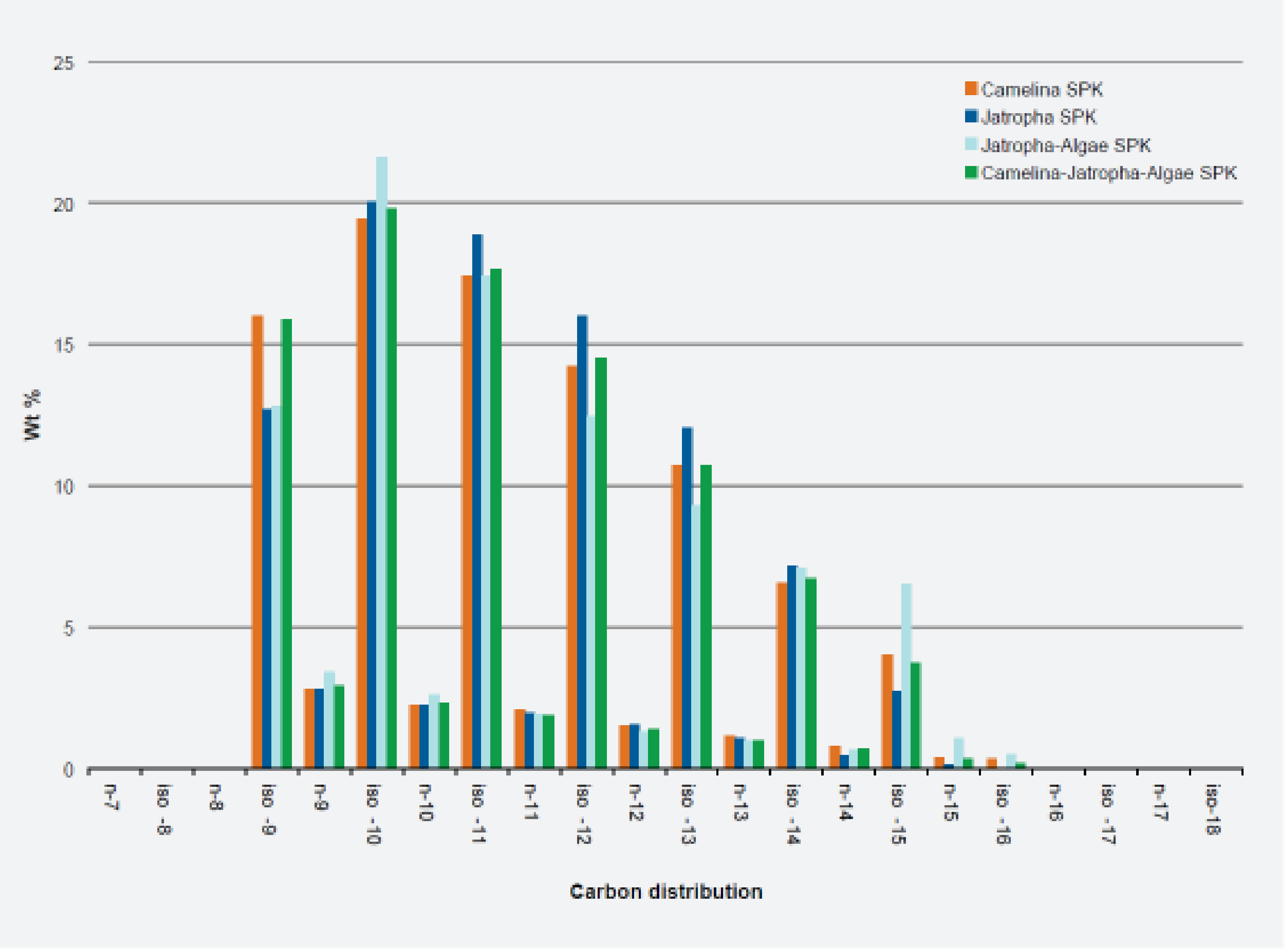
Cost of Biojet from Previous Techno-Economic Studies

Publication	Pathway	Feedstock	Price, US$/L
Pearlson	HDO	Soybean oil	1.00-1.16
Agusdinata et al, 2011	HDO	Camelina	0.91
	Gasification-FT	Algae	4.61
		Corn stover	0.77
		Switchgrass	1.20
		SRWC*	1.49
Klein et al., 2013	HDO	Algae	8.45
		Pongamia pinnata	2.35
	Advanced fermentation	Sugarcane molasses	1.89
Staples et al., 2014	Advanced fermentation	Sugarcane	0.61-2.63
		Corn grain	0.84-3.65
		Switchgrass	1.09-6.30
Seber et al., 2014	HDO	Waste oil	0.84-0.97
		Tallow	1.02-1.14
		Soybean oil	1.15-1.27

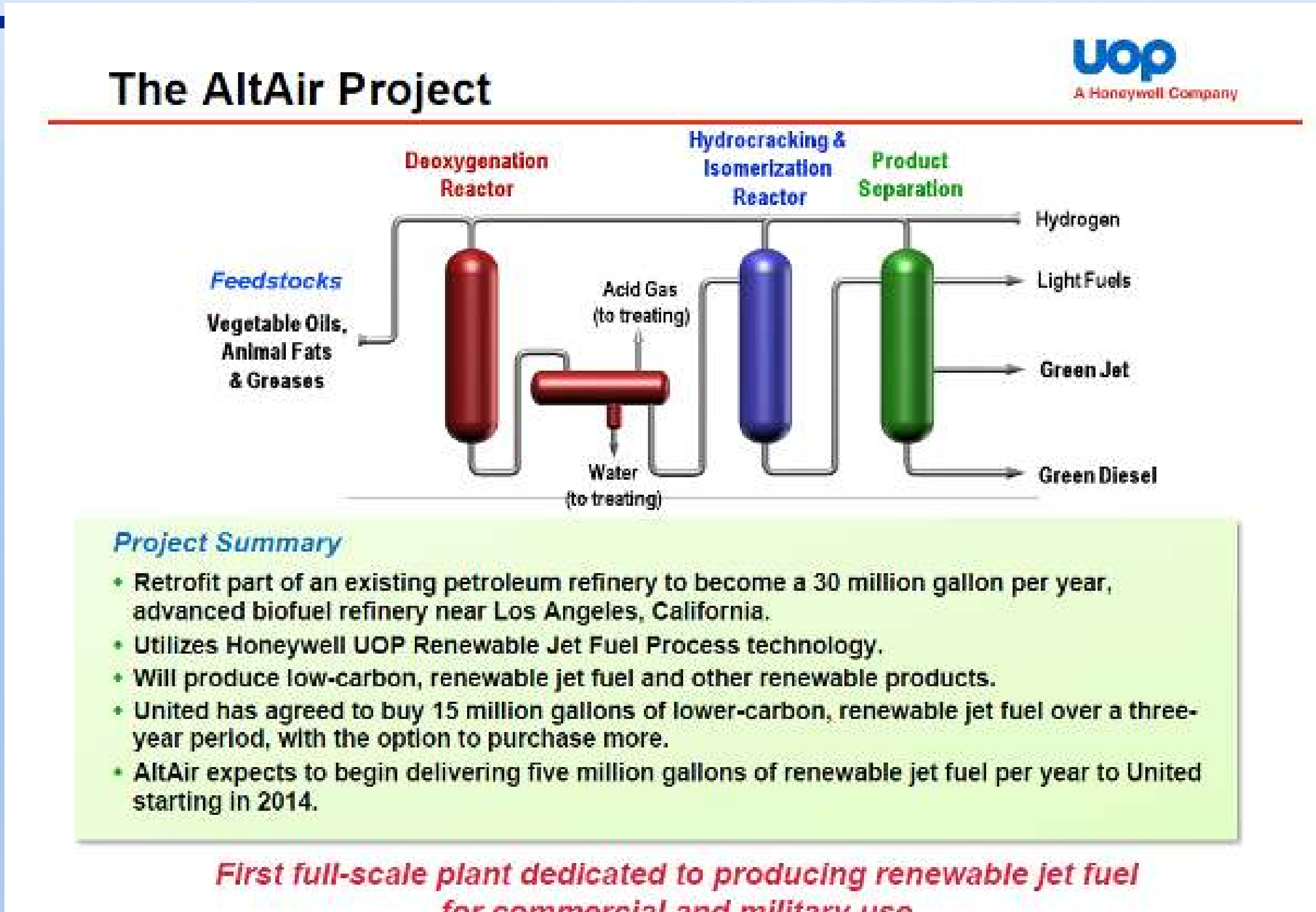
Chemistry for Bio-SPK production



Feedstock Affects Carbon Profile of Bio-SPK Product

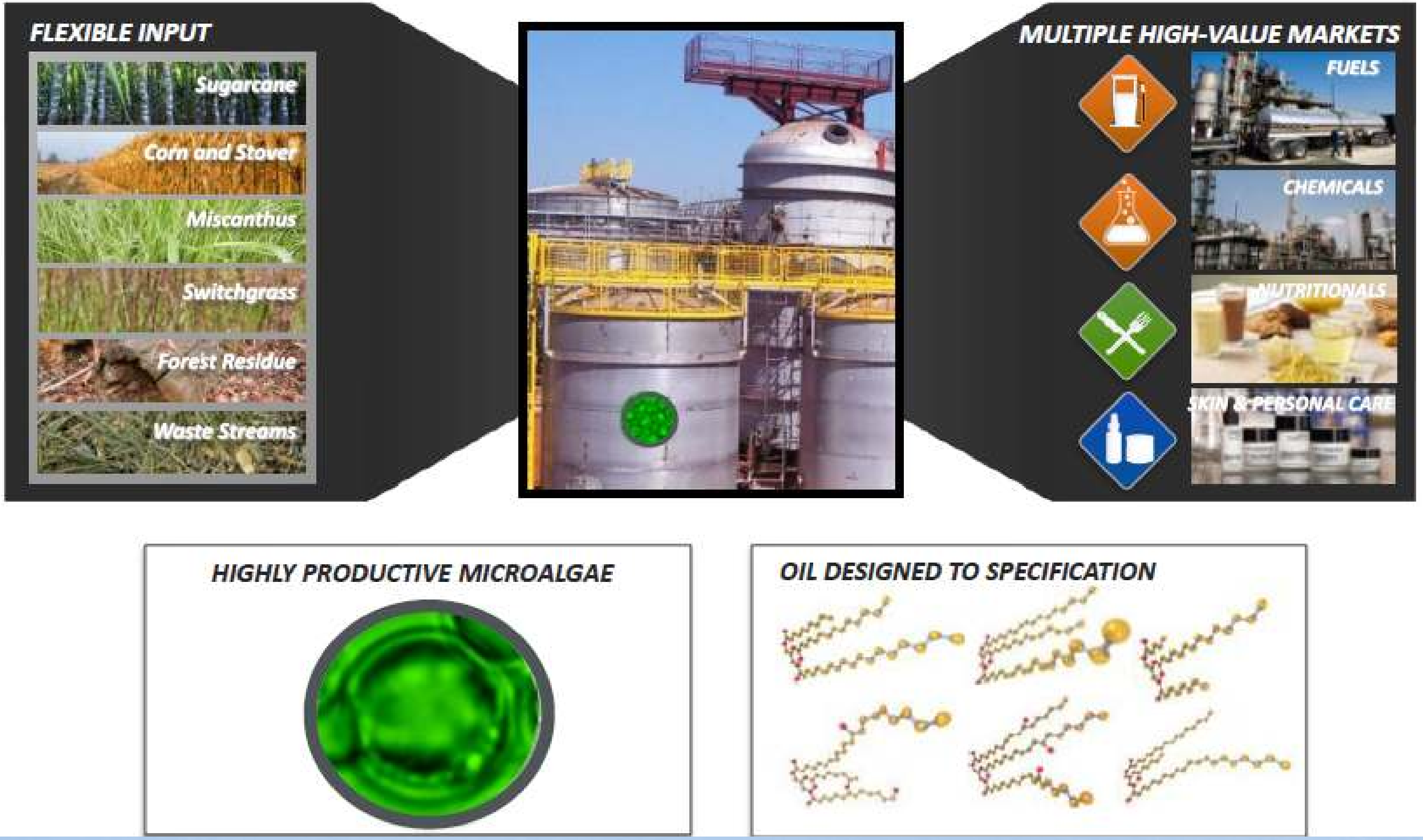


AltAir
Commercial Biorefinery Using UOP Technology

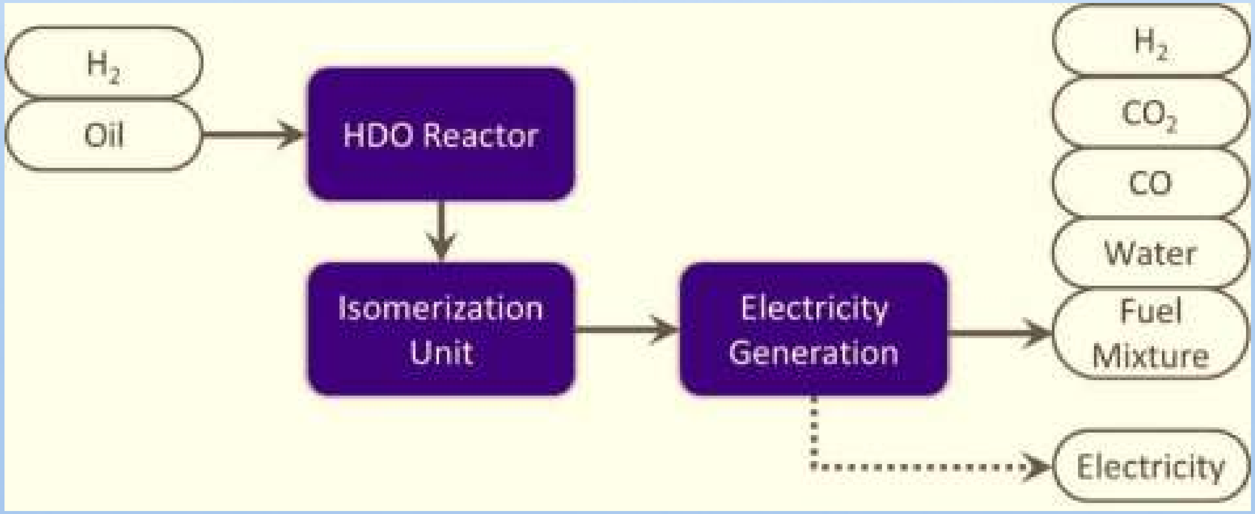


Solazyme
Biomass CHOs to Algal Lipids to Alkanes

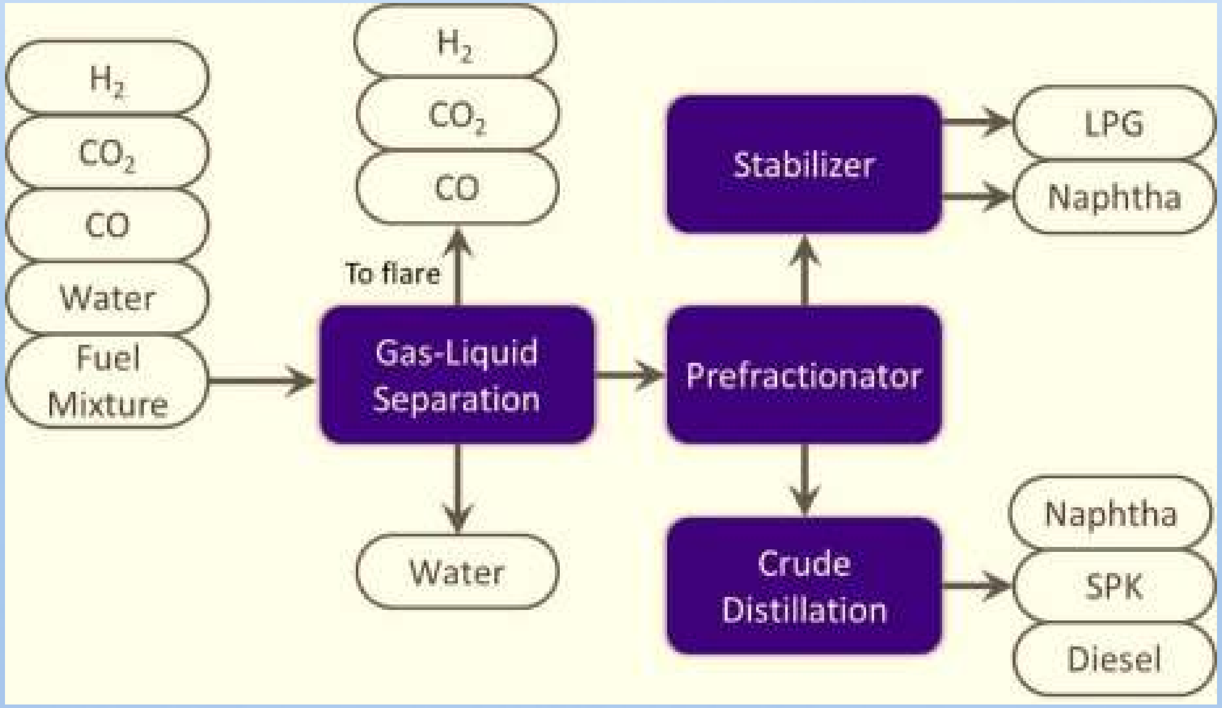
Solazyme utilizes plant sugars to manufacture tailored algae for a variety of applications



Oil Conversion



Product Purification



Product Distributions

	Camelina	Carinata	UCO	Pearlson Soyoil	Han et al. Soybean	Han et al. Palm	Han et al. Rapeseed	Han et al. Jatropha	Han et al. Camelina
Input									
Oil	1000	1000	1000	1000	1000	1000	1000	1000	1000
H_2 gas	30.0	25.8	26.3	40	50	40	46	45	53
Output									
CO_2	101	95	104	54	N/R	N/R	N/R	N/R	N/R
CO	2.7	2.5	2.7	N/R	N/R	N/R	N/R	N/R	N/R
Water	36	34	37	87	N/R	N/R	N/R	N/R	N/R
LPG	88	79	69	102	146	130	109	145	140
Naphtha	127	145	147	70	113	125	136	114	110
Kerosene	535	537	529	494	740	740	760	740	750
Diesel	140	132	138	233	N/R	N/R	N/R	N/R	N/R

Utility Summary

Total Process Energy	Thermal energy, MJ/tonne oil	Electricity, kWh/tonne oil
Camelina	5715	227
Carinata	5185	170
UCO	2835	73
Pearlson, Soyoil	10843	88
Han et al., Soybean	13693	67
Han et al., Palm	9311	67
Han et al., Rapeseed	12718	64
Han et al., Jatropha	11346	66
Han et al., Camelina	13693	67

Did you find the common thread?

- Most (all?) renewable jet fuels have another renewable fuel as an intermediate
  - Additional processing
  - Yield losses
  - No additional product value