U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Biofuels in Defense and Aviation

March 8, 2017

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Fuels for Distillate and Jet Market

US Liquid Fuels and Products Market Size (billion gallons/year)

	2015	2050	Growth Rate 2015 – 2050 (%/year)
Gasoline	141	114	-0.7%
Diesel	61	64	0.3%
Liquefied Petroleum Gas[1]	39	54	1.0%
Other[2]	31	38	0.7%
Jet Fuel	24	39	1.4%
Residual fuel oil	4	6	0.3%
Total	**300**	**315**	

1. Includes ethane, natural gasoline, and refinery olefins.
2. Includes kerosene, petrochemical feedstocks, lubricants, waxes, asphalt, and others commodities.
Source: Energy Information Administration, "Annual Energy Outlook 2017", Reference Case.

- Defense – Facilitating commercial scale production capacity
- Aviation – Testing and certification of alternative fuels
- Marine – Meeting environmental regulations

DPA Initiative Accomplishments

Project	Location	Feedstock	Capacity (million gallons/year)
Fulcrum	McCarran, NV	Municipal solid waste	10
Emerald	Gulf Coast	Fats, oils, and greases	82
Red Rock	Lakeview, OR	Woody biomass	12

- Fuels are approved for use as jet fuel by ASTM at up to 50/50 blends.
- Fuels successfully demonstrated during Rim of the Pacific (RIMPAC) demonstration in 2012 for ships and planes.
- Fuels can be utilized in Navy's warfighting platforms with no degradation to performance or mission.

Additional Supporting Activities

- As fuels become available Navy will make advanced drop-in biofuels a regular part of its bulk fuel procurement.

- USDA has awarded Fulcrum a $105 million Biorefinery Assistance Program loan guarantee through Bank of America for construction of their facility. The total project cost is $266 million. 147,000 tons/year of MSW will be gasified to synthesis gas followed by Fischer-Tropsch conversion to jet fuel.

- Cathay Pacific Airways has become an investor in Fulcrum and has negotiated a 10 year supply agreement for jet fuel.

- Southwest Airlines has signed a fuel purchase agreement with Red Rock for 3 million gallons/year of jet fuel. Blended product will be used at Southwest's Bay Area operations. 140,000 dry tons/year of woody biomass feedstock will be converted into renewable jet, diesel, and naphtha.

Criteria for Alternative Fuels in Aviation

- Engine re-light at altitude, polar climate, in winter - transport properties of alternative fuels and/or blends have to be within acceptable limits (viscosity, freeze point, fluid flow at low temperatures)
- Flame stability – compounds in alternative fuels should not adversely impact flame stability
- Energy content – should be as high as fossil derived jet fuel or higher
- Emissions
  - Aromatics – too much can cause soot, too little can cause seal swell problems which becomes a maintenance issue
  - Greenhouse gas emissions should be lower than fossil derived jet fuel on a life cycle basis

ASTM Approved Pathways for Alternative Jet Fuels

- Biomass gasification, synthesis gas, Fischer-Tropsch conversion to produce synthetic paraffinic kerosene (FT-SPK) – 50% maximum blend (Fulcrum, Red Rock)
- Fats/oils/greases, oil seed crops, other lipids, Hydro-treated esters and fatty acids (HEFA-SPK) processed into jet fuel – 50% maximum blend, (AltAir, Paramount, California)
- Biochemical conversion of sugars to iso-paraffins (HFS-SIP) – 10% maximum blend (Amyris, farnasene, Brazil)
- Biomass gasification synthesis gas, Fischer-Tropsch conversion with aromatic alkylation (FT-SPK/A) – 50% maximum blend
- Biochemical conversion of sugars to iso-butanol followed by oligomerization to jet components, alcohol-to-jet (ATJ-SPK) – 30% maximum blend (Gevo, Luverne, MN)

Status of ASTM Certification of Alternative Jet Fuel

- **ASTM Certifications in process**
  - Catalytic hydro-thermolysis of lipids to jet fuel – ARA
  - Alcohol to jet – synthetic paraffinic kerosene (bio/thermochemical butanol or ethanol – Lanzatech, Byogy
  - Synthetic kerosene/synthetic aromatic kerosene – catalytic conversion of sugars and aqueous phase reforming to jet fuel – Shell/Virent
  - Hydro-treated esters and fatty acids+ (HEFA)+ - wider cut HEFA with renewable diesel – Boeing
  - Pyrolysis from lignocellulosic feedstocks – UOP, Kior
  - Fischer-Tropsch synthetic kerosene with aromatics – Sasol, Rentech
  - Co-processing – multiple approaches – Chevron, BP, Phillips 66
- **Pathways in future that could enter pipeline**
  - Vertimass – catalytic conversion of alcohols
  - Global Bioenergies – biochemical production of isobutene
  - Algenol – hydrothermal liquefaction of algae

Latest Activities

- **AltAir -** United Airlines has begun using commercial scale alternative jet fuel volumes for regularly scheduled flights from LAX. Purchase 15 mgy from AltAir Paramount over 3 years.
- **Gevo –** Lufthansa agreement for alcohol-to-jet from Luverne, MN facility. 8 mgy from Gevo or up to 40 mgy over 5 years.
- **Fulcrum –** Strategic partnership between United, Cathay Pacific, BP Ventures, Air BP businesses to invest $30 million. 10 year off-take for 50 mgy from plants in North America.
- **Red Rock –** 3 million gallons/year of renewable jet fuel for 3 years for FedEx Express. Southwest purchase agreement from Lakeview, Oregon facility to convert 140,000 dry tons/year of woody biomass into 15 million gallons/year of renewable jet, diesel, and naphtha.
- **Byogy –** AVAPCO biomass-to-ethanol with Byogy alcohol-to-jet process to produce jet fuel from woody biomass. DOE award of $3.7 million to develop demonstration scale biorefinery.
- **UOP –** Petrixo Oil and Gas to produce renewable jet and diesel at new refinery in Fujairah, UAE to convert 500,000 metric tonnes of renewable feedstocks into 1 million tons/year of biofuels.
- **KLM and SkyNRG** for 3 year agreement enabling LAX flights
- Neste, KLM, SAS, Lufthansa, SkyNRG Nordic, and Oslo Airport

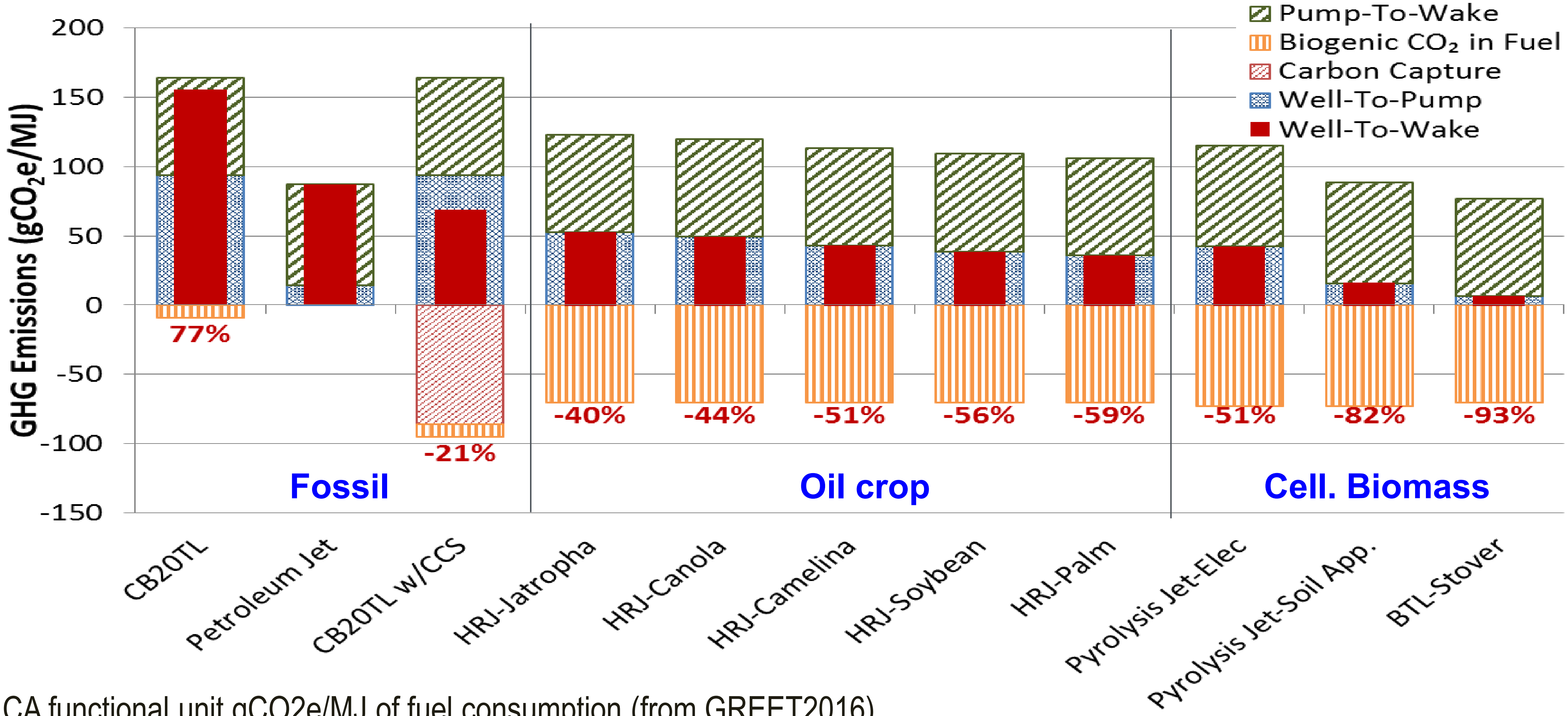
The Issue of Scale

- From IAH there are at least IAH 7 non-stop flights/day to Europe
- Average flight time from IAH to Europe about 10.5 hour, additional 2 hours of fuel requirement for reserve and alternate destination requirements for total 12.5 hours of fuel
- Fuel burn 3,000 gallons/hour for wide-body aircraft
- Assume 20/80 biofuel/fossil ratio
- Fuel burn calculation suggests 19 million gallons/year facility could supply IAH for all 7 flights to Europe

Gas-to-Liquids Micro-Channel Technology

- First distributed scale Fischer-Tropsch product commercially produced at Envia landfill gas and waste biomass GTL plant in East Oak landfill, Oklahoma City, Oklahoma
- Team: Waste Management, NRG, Velocys, Ventech, Envia - to convert gas to paraffin wax, diesel, and naphtha at distributed scale
- Scale: 1,000 barrel/day (15 million gallons/year) compared to conventional Fischer-Tropsch scale of 30,000 barrels/day (460 million gallons/year) or more
- Price: with natural gas at $3.89/million Btu, Velocys can produce diesel at $1.57/gallon (no RIN or LCFS credits)
- Conversion efficiency: 57 – 76 gallons/ton waste biomass
- 15.3 million gallons/year from 200,000 tons of biomass

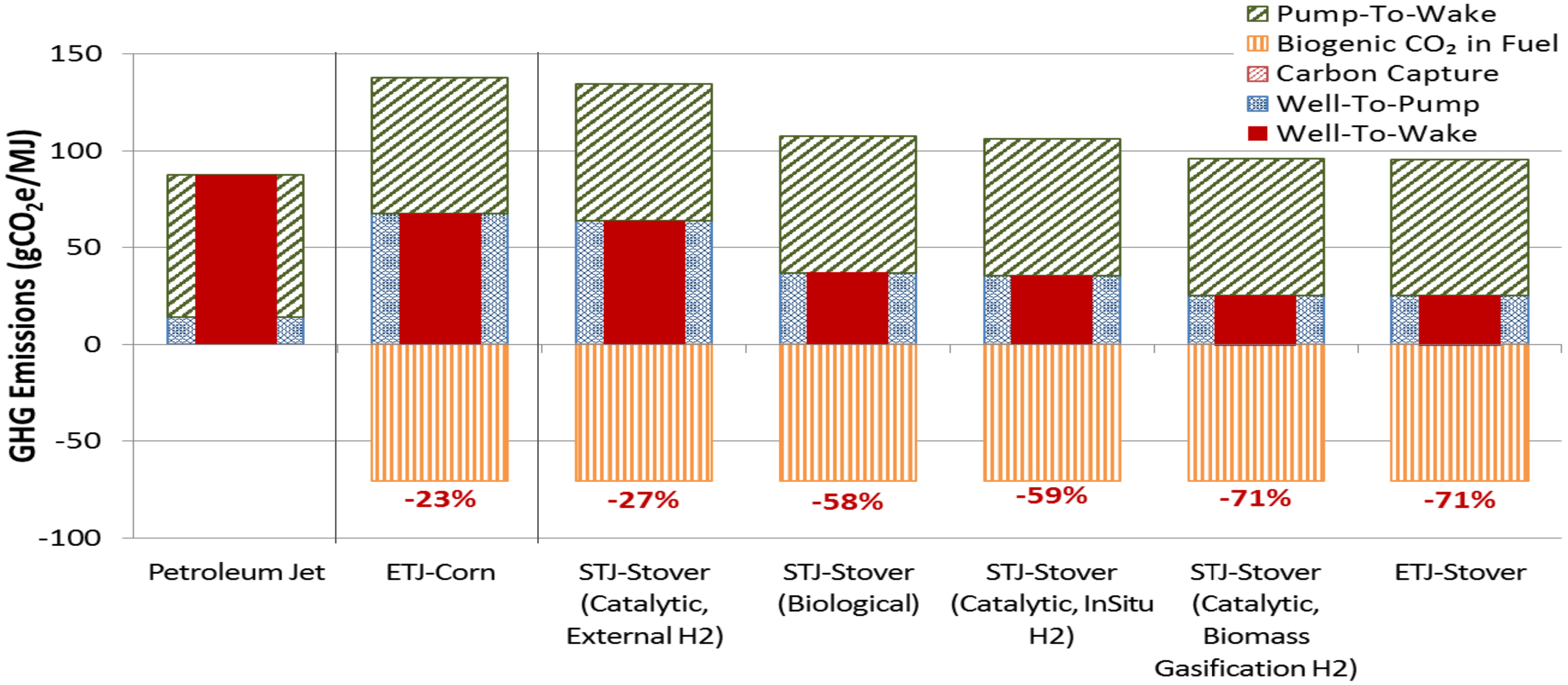
Well-to-Wake GHG Emissions of Alternative Jet Fuels



- LCA functional unit gCO2e/MJ of fuel consumption (from GREET2016)
- LUC-related emissions are not included
- Other key factors: Technology readiness level (TRL), production costs, resource availability and fuel types

Source: simulation results with GREET2016 by ANL

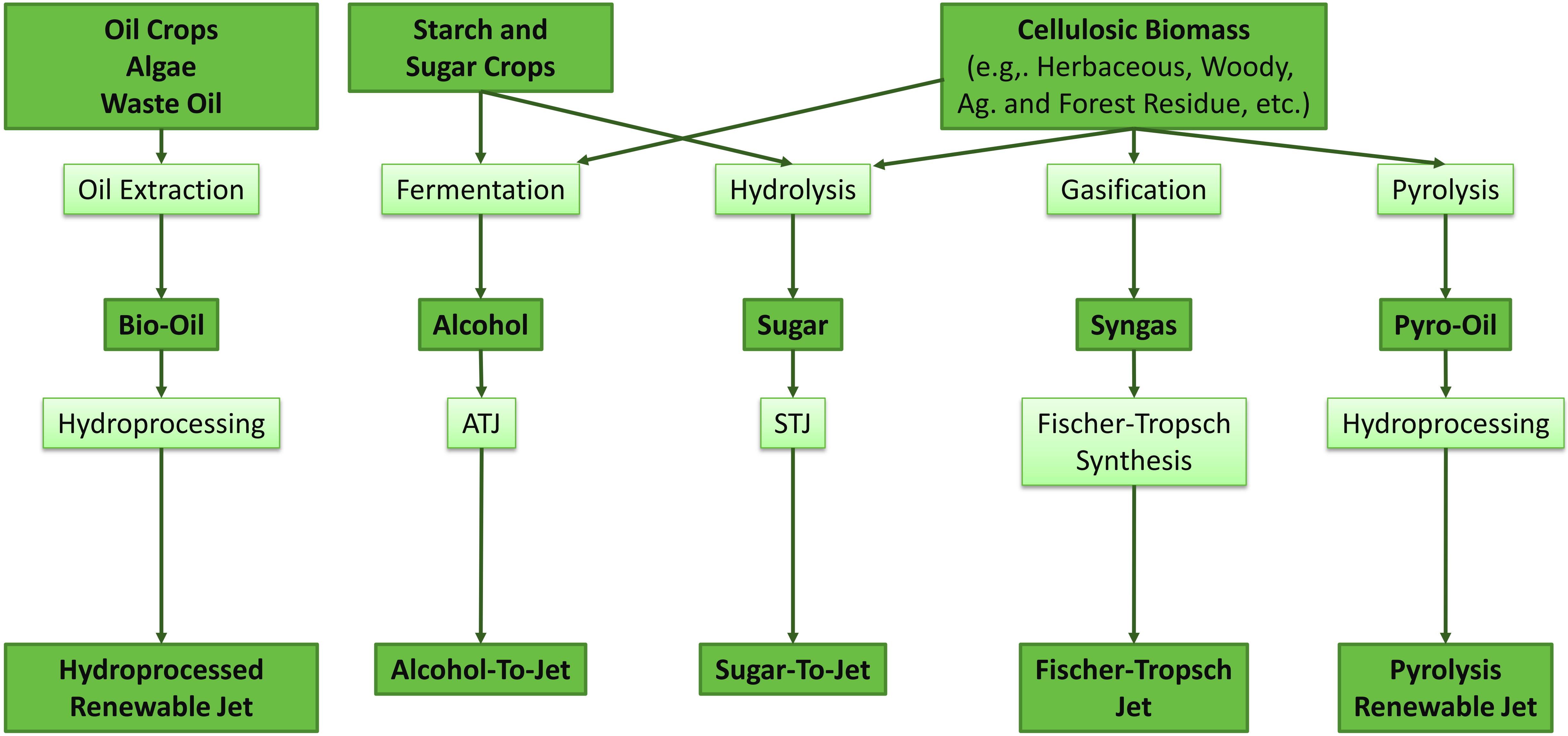
Ethanol-to-jet (ETJ) and Sugar-to-Jet (STJ) GHG Emissions



- Corn-ethanol-based ETJ reduces GHG emissions by 23%, cellulosic by 71% compared to petroleum jet
- Stover-based STJ reduces GHG emissions by 27 – 71% depending on conversion process and hydrogen source
- Note: LUC-related emissions are not included; ETJ-corn could have LUC GHG of 8 grams/MJ; stover pathways do not cause LUC.

Source: Han, Tao, and Wang, 2017 in Biotechnology for Biofuels

Bio-aviation Fuel Pathways by Feedstock



Co-products in the Bio-Aviation Fuel Pathways