Advanced Fuel Production from Camelina Oil

Eleazer P. Resurreccion †,*; Sandeep Kumar ‡; Mason J. Martin †; Paul Jeffrey †; Randy L. Maglinao †; Benjamin J. Rice ¶; Javad Roostaei §; Yongli Zhang §

† Montana State University Northern; ‡ Old Dominion University; ¶ Rice Cartographic, LLC; § Wayne State University

§ Civil and Environmental Engineering, Wayne State University; # Rice Cartographic, LLC

Motivation and Overview

Commercial aircraft utilizes **jet fuel for gas-turbine engines** or **aviation gasoline (avgas) for piston engines**.

- Alternative jet fuel production is achieved via **synthetic paraffinic kerosene (SPK) pathway**, the only method certified by the ASTM.
- **No ASTM-approved** method for renewable avgas production.
- Advanced fuels = biojet fuels, renewable avgas, green diesel.
- Although advanced fuels are non-oxygenated and have carbon chain lengths similar to petroleum, they have **low aromatic content**. Aromatic compounds provide desired **lubricity and seal-swelling properties.**
- Low aromaticity → **catastrophic failure of a jet fuel tank's gasket, use of lead as octane-booster in avgas**.
- The main driver for this work is *to find a renewable "drop-in" or blend to petroleum-based jet and avgas.*

Why *Camelina sativa L.* (camelina)?

- It grows well in Montana and prairie regions of U.S. and Canada.
- It is a low-input crop.
- It is an attractive rotational crop to wheat.
- It has a distinct fatty acid profile and has high protein content.
- It is potential feedstock for various biomaterials.

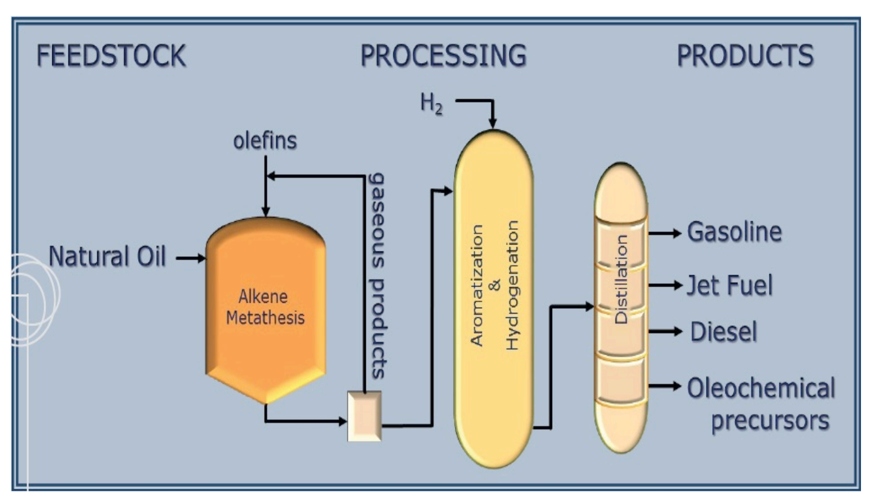


Figure 1. MSUN's patented process for producing biojet fuel and renewable avgas.

MSUN's patented process converts fatty acid methyl esters (FAME) derived from camelina to renewable alkylbenzenes (avgas) and linear alkylbenzenes (LABs) (biojet fuel) via **olefin metathesis** and **tandem dehydrogenation-alkylation,** either as "drop-in" or blend component. The most compelling aspect of this technology is that it yields **high aromatic products** that meets or exceeds jet fuel requirements. It also operates at both **low temperature and low pressure.**

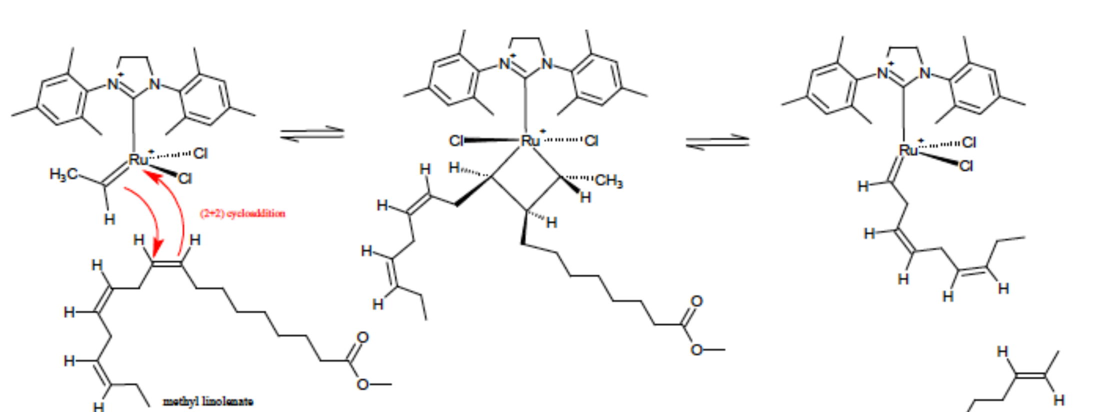


Figure 2. Metathesis of methyl linolenate.

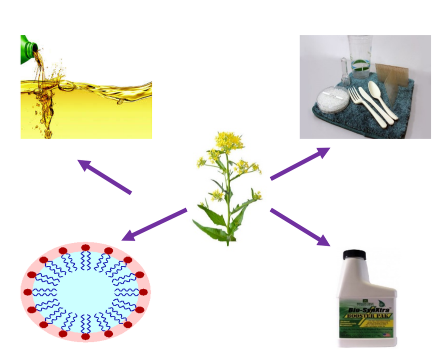


Figure 3. Applications of 1,4-cyclohexadiene, product of olefin metathesis.

Methods

Geospatial Analysis. Land availability was determined using ArcGIS analysis and MS Access SQL query tables. Wheat crop data, solar radiation, monthly temperature, and monthly precipitation was brought into ArcGIS and attribute tables were exported into MS Excel format. The Excel tables were imported into Access. SQL queries implemented growth constraints for camelina. The resulting query tables were then imported back into ArcGIS using the database primary key to produce potential camelina land availability map.

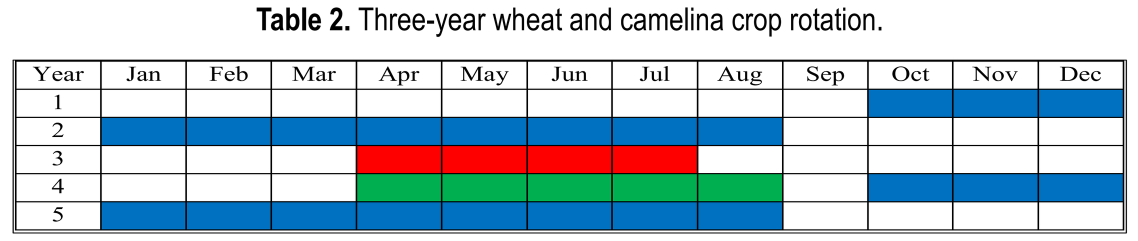
Life Cycle Assessment (LCA) and Technoeconomic Analysis (TEA).

- A functional unit of **100,000 m^3 fuel/yr (175,000 ha)** was considered. The scope is "well-to-pump".
- Energy use + GHG emissions for 3 OMT scenarios: **OMT1: avgas only, OMT2: biojet route 1, OMT 3: biojet route 2**.
- Compared to HRJ/HEFA and PTJ.
- Total initial outlay, annual cash flows, profitability indices, and minimum camelina yield to break-even were calculated.
- Sensitivity analysis of the effects of model inputs to these outputs ('forecasts") were stochastically determined using Monte Carlo analysis at 10,000 simulation runs using Crystal Ball™.
- Impact factors were obtained from either Ecoinvent® database of SimaPro v8 or Argonne National Laboratory's GREET model.

Table 1. Assumptions in LCA and TEA

Assumptions for LCA	Assumptions for TEA
Yield = 1.2 tons/ha-yr	30-year project life
Average lipid = 0.40	12% MARR
70-600 mm rain, -1 to 33 °C, no irrigation	10% meal = feed, 90% bioelectricity
N = 75 kg/ha	Main product stream = advanced fuels

Table 2. Three-year wheat and camelina crop rotation.



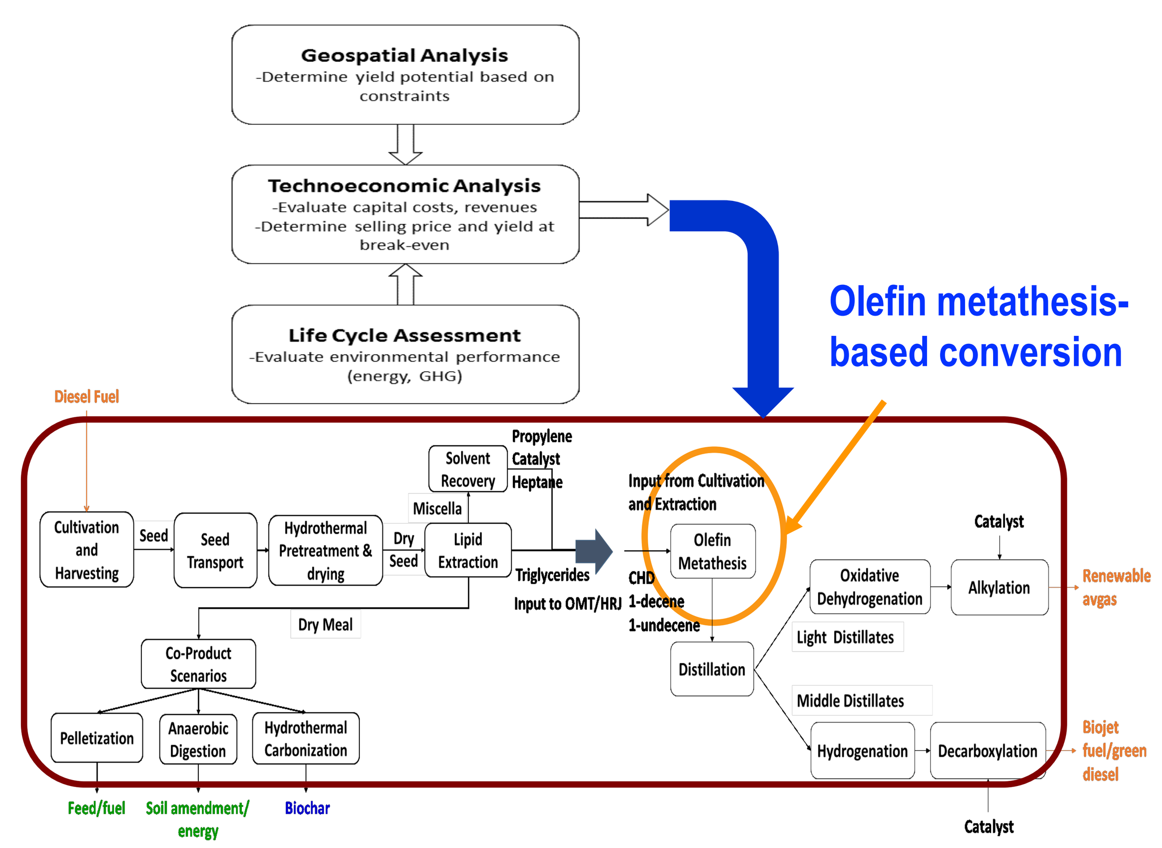


Figure 4. Schematic highlighting a comprehensive, multi-dimensional modeling approach consisting of (1) geospatial analysis, (2) life cycle assessment, and (3) techno-economic analysis.

Results

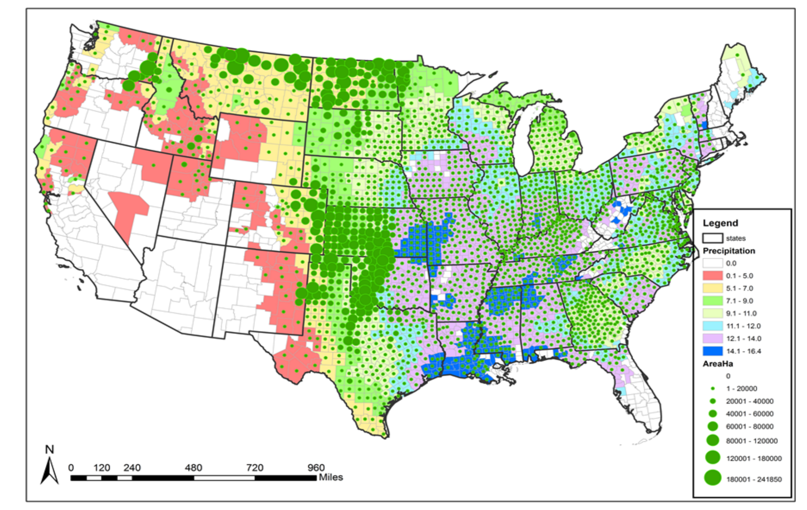


Figure 5. Total potential camelina land area, 2015. Average total precipitation reported over the months of April, May, and June, 2015.

Results

Geospatial Analysis

Land Availability.

- Three-year optimal crop rotation, wheat and camelina.
- Total available land for camelina = **20,156,206 ha (2015)**.

Yield.

- No irrigation was required.
- Solar flux was based upon Montana insolation.
- Average camelina yield = **1.2 tons/ha-yr**.
- "Best-case scenario" = wheat-camelina crop rotation cycle, all wheat fallow land is planted with camelina.

Table 3. Potential average camelina yield for top wheat-producing states and top wheat-producing counties, 2015.

Camelina Yield Potential in Wheat Crop Rotation: 2015					
State	Total Wheat Area (ha)	Potential Avg Camelina Yield (tons)	County	Total County Wheat Area (ha)	Potential Avg County Camelina Yield (tons)
Kansas	3,390,476	4,068,571	Sumner (KS)	121,975	170,764
Texas	2,904,751	3,485,701	Deaf Smith (TX)	99,464	139,250
Montana	2,136,128	2,563,354	Chouteau (MT)	241,850	338,590
Washington	1,000,638	1,200,766	Whitman (WA)	236,252	330,753

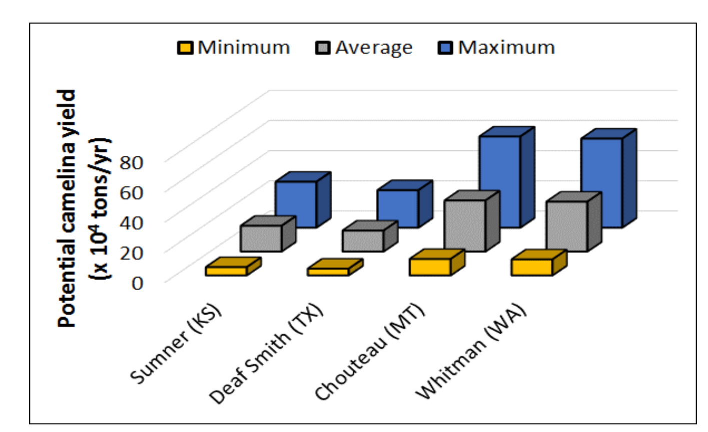


Figure 6. Minimum, likeliest, and maximum camelina yield for top wheat-producing counties in the U.S., 2015.

Life Cycle Impacts

- **Biocrude conversion energy: HRJ << OMT.**
- **Heat: HRJ >> OMT.**
- Process upstream energy is dominated by **fertilizer and hexane.**
- On a net energy balance, it would require OMT and PTJ **substantial process optimization** to compete with PTJ.

- Main products = **Biojet fuel, renewable avgas, green diesel.**
- Co-products = Meal, electricity, LPG/propane, heating oil, residual bunker oil.

- **Total energy input: OMT < HRJ by 10%.**
- Due to chemistry of OMT, output energy: OMT < HRJ by 60% (main products only, not including co-products!)
- GHG emissions in **OMT is 14% less than HRJ.**

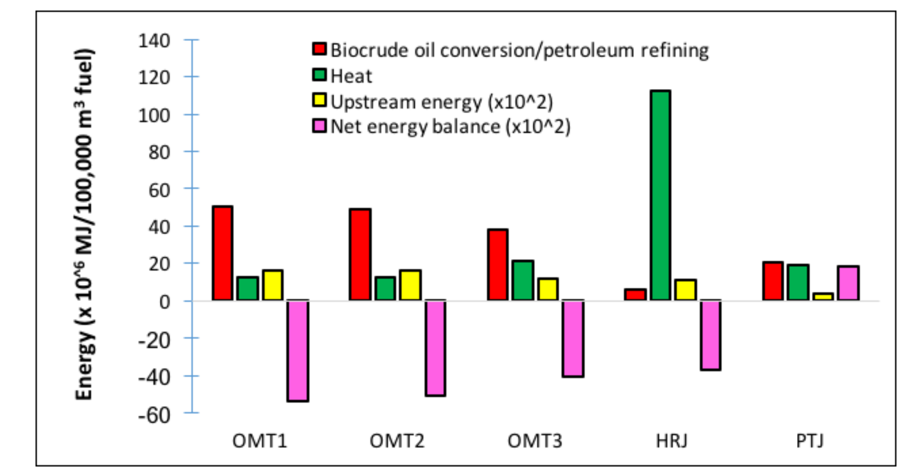


Figure 7. Biocrude oil conversion energy use, heat consumption, upstream energy, and net energy balance for OMT1, OMT2, OMT3, HRJ, and PTJ for 100,000 m3/yr. Note that upstream energy and net energy balance are reported 100x calculated value.

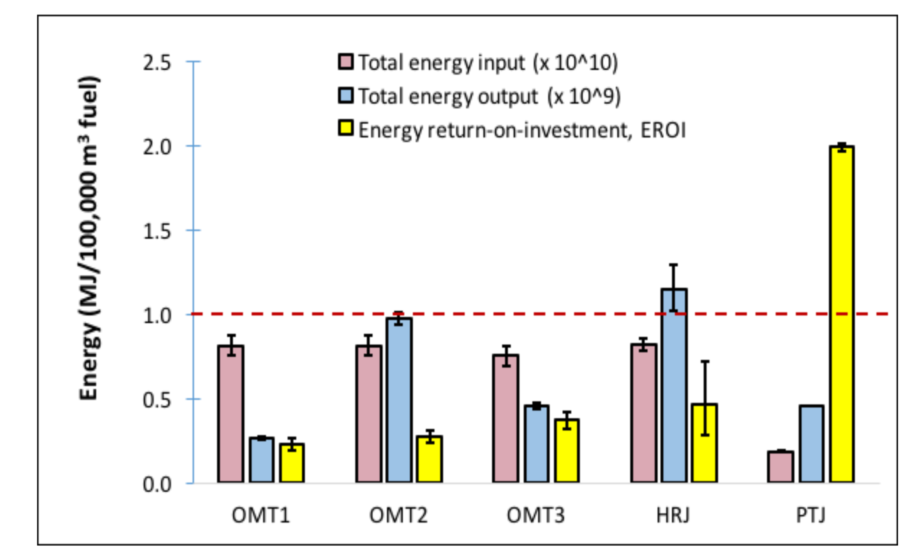


Figure 8. Total energy input, total energy output, and energy return-on investment (EROI). Input energy and output energy are reported 10^{10}x and 10^9x calculated value, respectively.

Techno-economic Implications

- Significant **increase in profitability using OMT**-based advanced fuels.
- Although OMT's main product on an energy value is much lower than HRJ, **its total revenue (including co-products) is higher by 28%.**
- To have **profit, camelina yield ≥ 1.1 tons/ha-yr.**

Table 4. Cost parameters to produce 10,000 m3 fuel/year.

Cost Variable	OMT3	HRJ
Capital cost (S)	171.35 M	174.13 M
Materials/Process cost (S/ha)	371.36	301.81
Revenues (S/yr)	127.49 M	91.53 M
Expenses ($/yr)	80.67 M	72.58 M
Annual net cash flow ($/yr)	46.82 M	18.95 M
PV expected cash flow ($)	264.91 M	84.77 M
Profitability index	1.55	0.49

Conclusions:

Metathesis-based (OMT) fossil-energy use and GHG emissions is 10% and 14% lower than the HEFA's hydroprocessed renewable jet (HRJ), respectively. Geospatial analysis suggests that with respect to the four top wheat-producing states (KS, TX, MT, WA), representing a conservative annual national camelina yield at the "best-case" farming scenario (camelina only, 3-year fallow), <1% total available land will be utilized. Profitability of OMT3 (biojet fuel route 2) is 3x higher than HRJ.