Sustainable Biodiesel Production

Veera Gnaneswar Gude, Ph.D., P.E.

Georgene Elizabeth Grant

James Worth Bagley College of Engineering
Mississippi State University
Civil & Environmental Engineering

Mississippi State University

Mississippi State, MS 39762

Prafulla Patil, Ph.D.

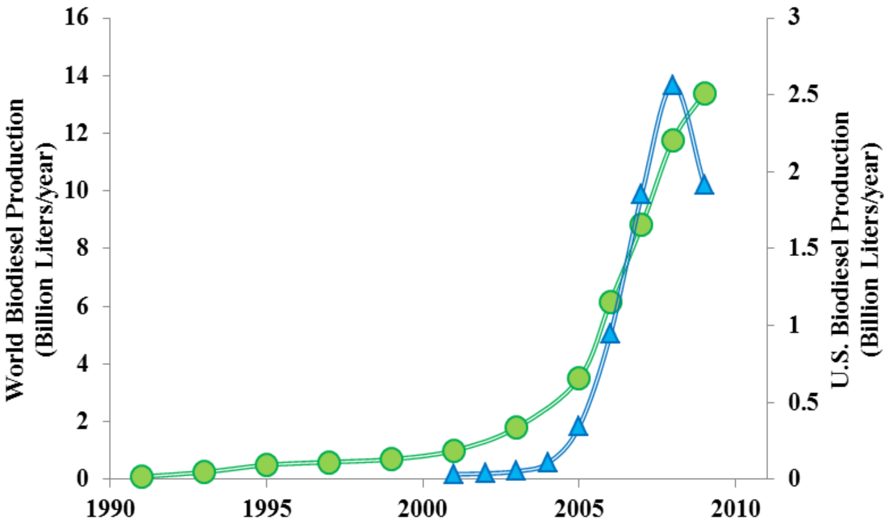
Prof. Shuguang Deng

New Mexico State University

Las Cruces, NM 88003

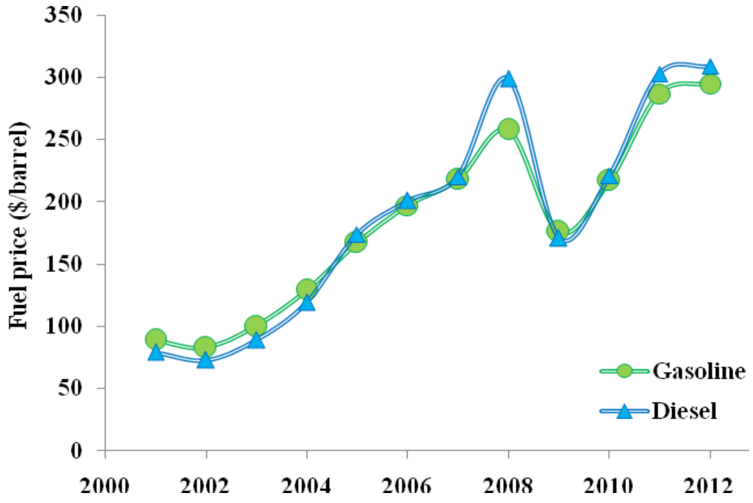
Biodiesel Production

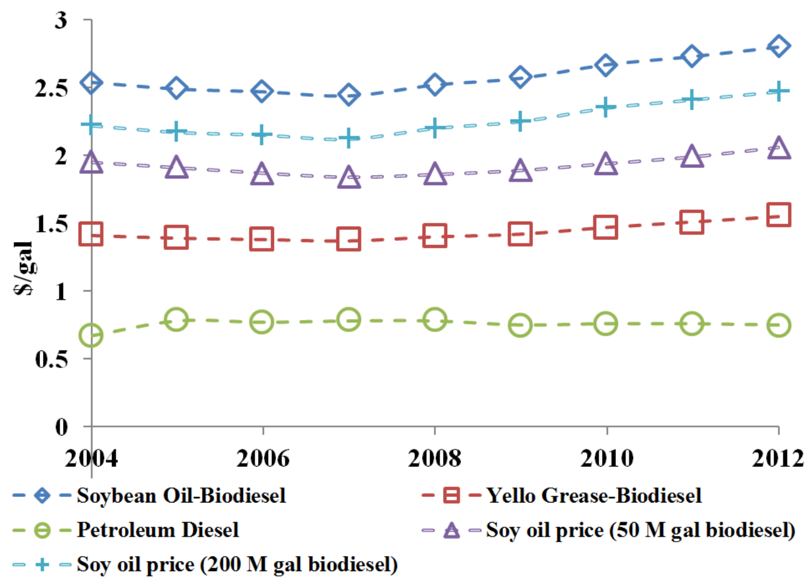
- The world biodiesel production has increased by more than 10 times (between 2001 and 2010) while the U.S. biodiesel production has increased exponentially (by 200% every year).



Oil Prices for Biodiesel Production

- Biodiesel production increase can be directly related to the escalating gasoline and diesel prices over the past decade which are expected to rise in the future.
- Projections for increase in oil prices (feedstock) with increased biodiesel production





Biodiesel Production

- Current biodiesel technologies are not sustainable. This is mainly due to:

  1) high feedstock cost (up to 75-80% of the total biodiesel cost)

  2) energy intensive process steps involved in their production

  - Food vs. Fuel issues
  - Energy vs. Environment issues

Sustainable Biodiesel Production

For biodiesel to substitute conventional gasoline as an alternative transportation fuel should:

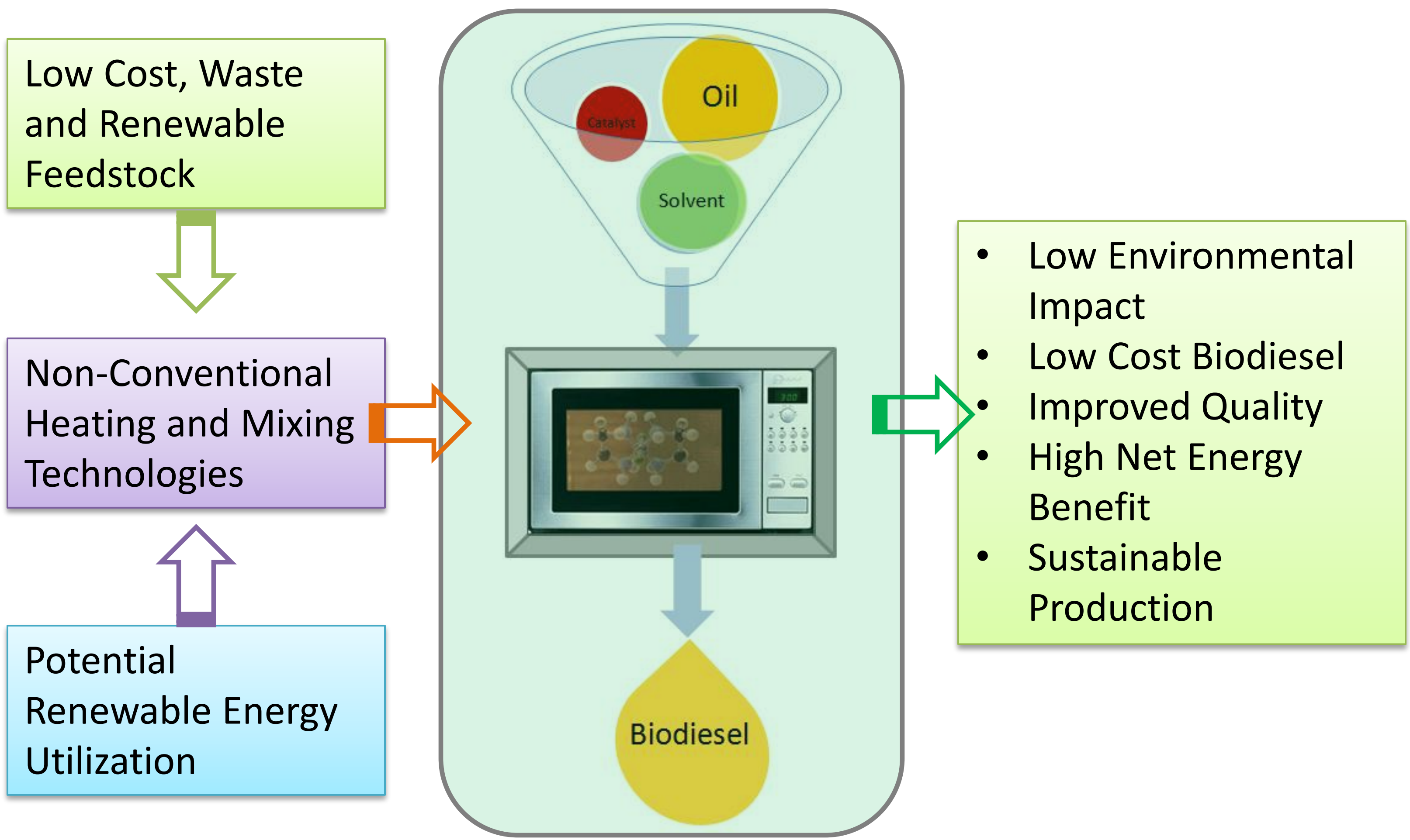
(i) have superior environmental benefits

(ii) be economically competitive

(*iii*) have meaningful supplies to meet energy demands, and

(*iv*) have a positive net energy balance ratio (NER)

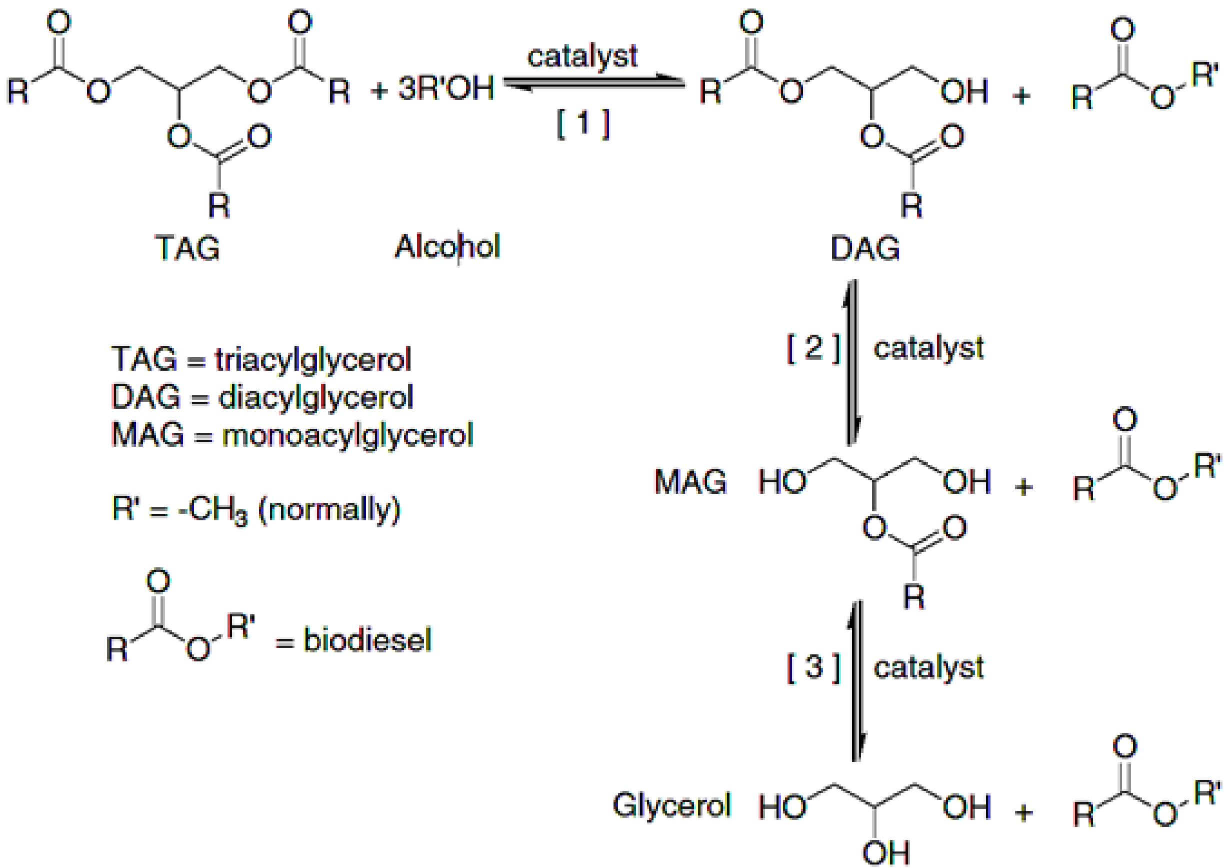
Sustainable Biodiesel Production



Biodiesel Feedstock and Methods

Waste Cooking Oil		Virgin Oils	
Advantages	Disadvantages	Advantages	Disadvantages
Low cost (free or low cost feedstock)	High FFA	Low FFA	High cost feedstock (up to 80% of total cost)
No environmental pollution	High processing cost due to mass transfer restrictions	Low processing cost	Some environmental pollution due to cultivation, fertilizers and processing
High Net Energy Ratio			Low Net Energy Ratio
Algae		**Other Terrestrial Plants**	
High growth High oil yield Water recycling possible Nutrient recycling possible Wastewater cultivation Environmental-friendly, removes CO_2	Complex process techniques	Simple processing	Very slow growth Low oil yield High water requirements High nutrient requirements Limitations apply Some environmental pollution for cultivation
Non-Conventional Heating		**Conventional Heating**	
High efficiency (> 75%; ex: microwaves and ultrasonics)			Low efficiency (~35%; fossil fuel based, electricity to heat)
Low chemical usage			High chemical usage
Low energy consumption due to fast and easy processing	High capital costs?	Low capital costs?	High energy consumption
Precise process control	Technology know-how	Well-known and established heat sources	Complex process control
Small plant footprint		Large plant footprint	

Oils to Biodiesel

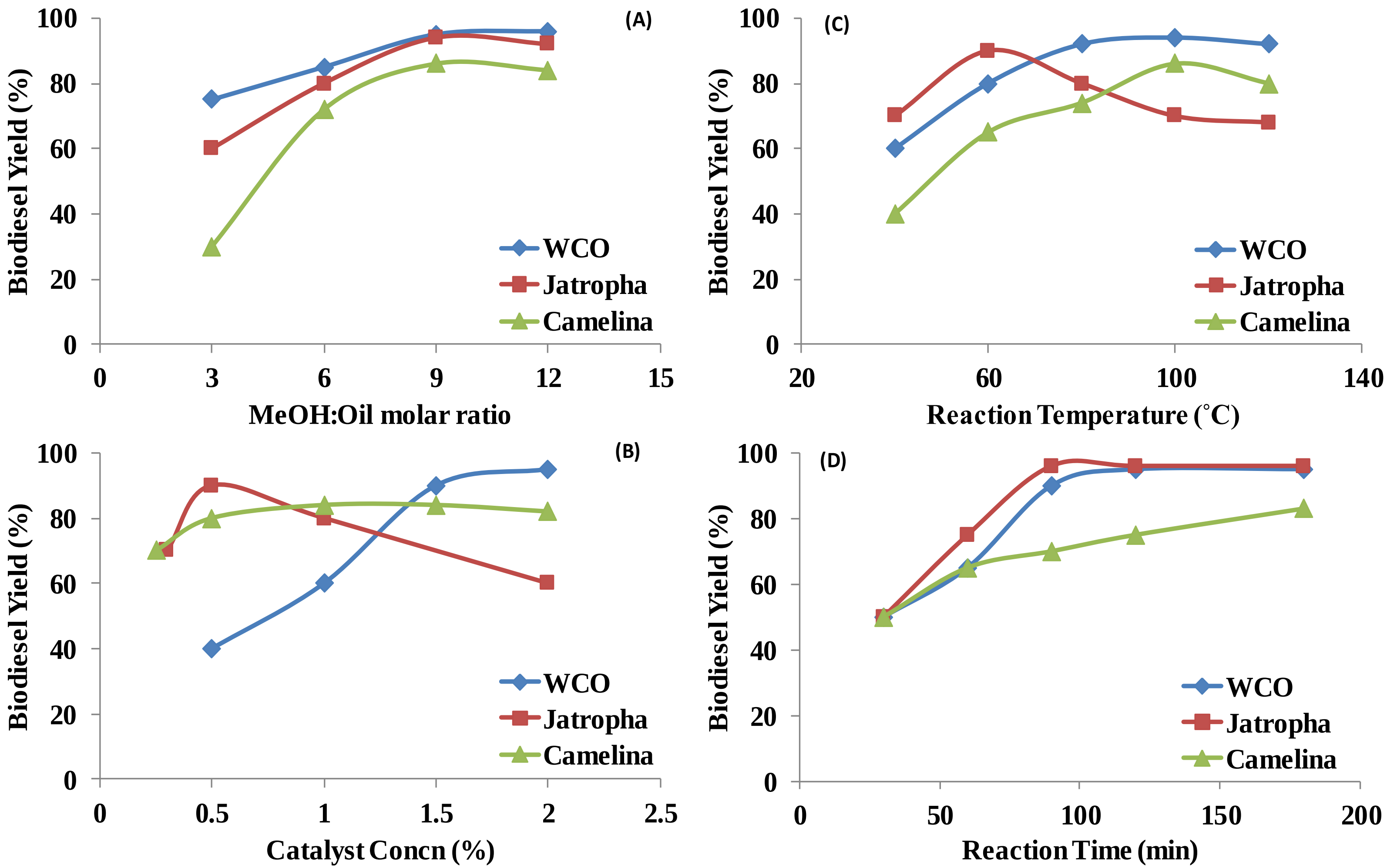


Transesterification

Biodiesel from Low Cost Feedstock

- Waste cooking oils
- Low cost and maintenance crops
  - ❖ *Jatropha Curcas*
  - ❖ *Camelina Sativa*

Biodiesel from Low Cost Feedstock



Process optimization

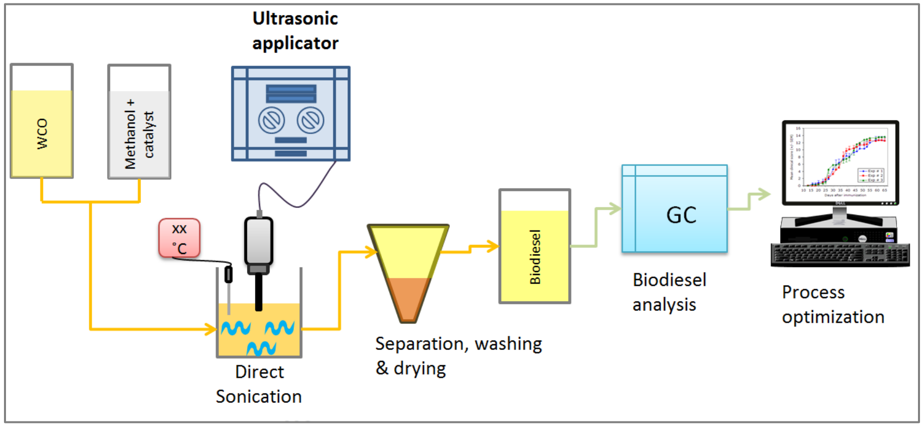
Feedstock	**Waste Cooking Oil**	*Jatropha Curcas*	*Camelina Sativa*
Process	Two-step (step 1-acid esterification and step 2-alkali transesterification)		One-step (Alkali transesterification)
Catalyst	$Fe_2(SO_4)_3/H_2SO_4$ (Step 1), KOH (Step 2)		BaO
Optimized Parameters [MeOH:Oil, Catalyst (wt%),Temp-°C, Time- min]	9:1, 100°C, 2% $Fe_2(SO_4)_3$ (step 1), 9:1, 100°C, 0.5% KOH, (step 2)	6:1, 0.5% H_2SO_4, 40±5°C (step 1), 9:1, 2% KOH, 60°C (step 2)	9:1,1%,100°C,180min
Biodiesel Yield (%)	96	90	84

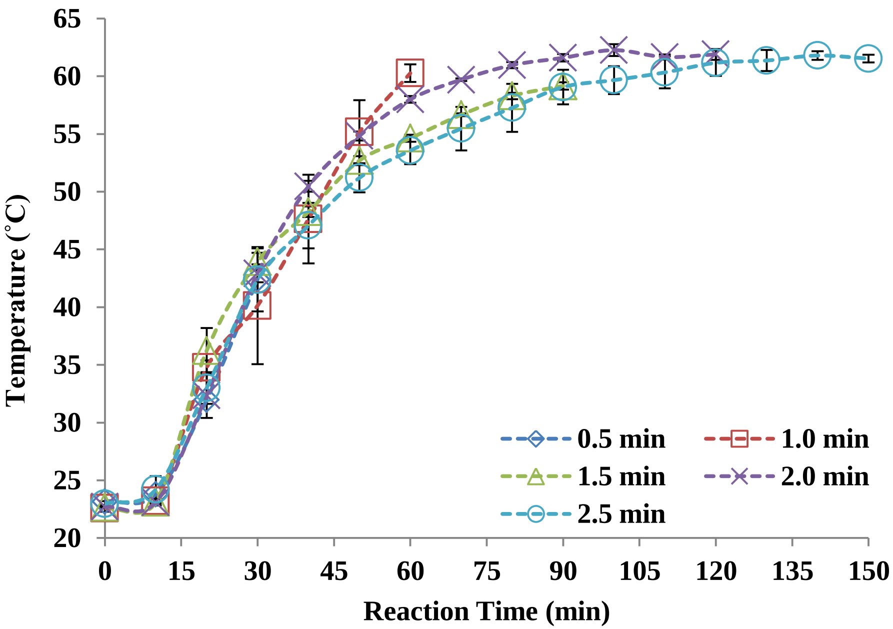
Non-Conventional Heating

Conventional heating	Microwave heating	Ultrasonic heating
Thermal gradient	Inverse thermal gradient	Thermal gradient due to mixing
Conduction and Convection currents	Molecular level hot spots	Microbubble formation and collapse (compression and rarefaction cycles)
Longer processing times	Very short and instant heating	Relatively very short reaction times, not as quick as microwaves
No or low solvent savings	No or low solvent reactions possible	Solvent savings possible
Product quality and quantity can be affected	Higher product quality and quantity possible	Same as conventional heating
Separation times are long	Very short separation times	Less than conventional heating
High energy consumption	Moderate to low consumption	Moderate to low consumption
Complex Process configuration	Very simple process	Moderate complexity

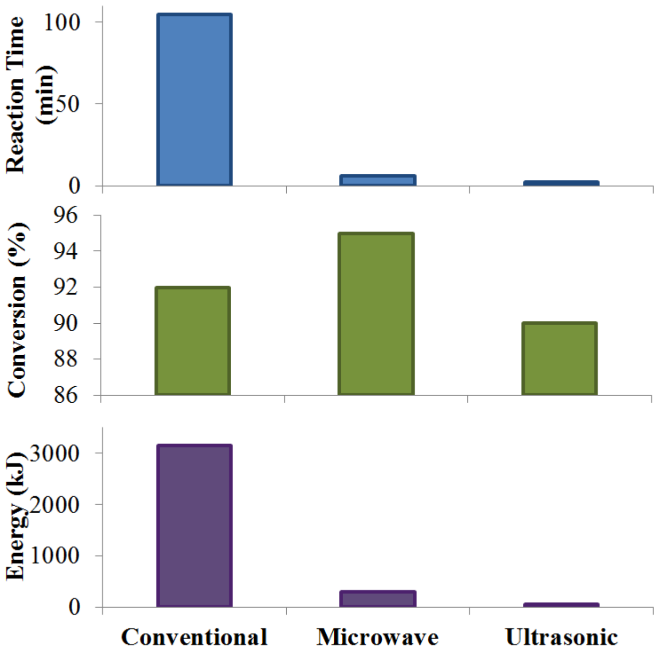
Ultrasonic Conversion


Ultrasonic effect



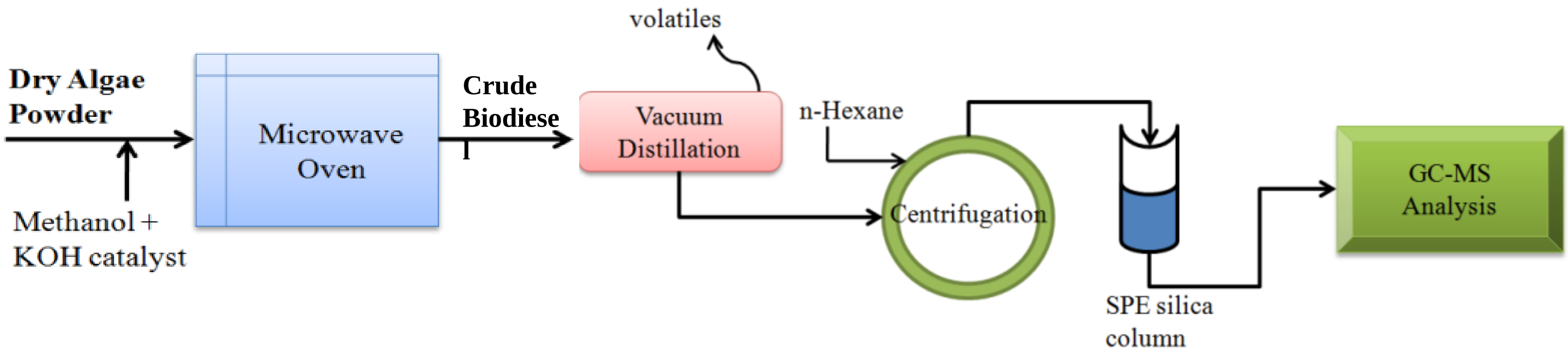


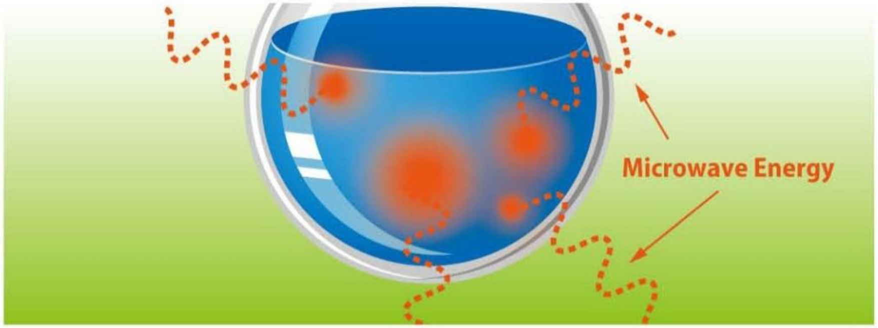
Novel Heating Methods



- Low energy requirements
- Short reaction times
- Short separation times
- High product quality
- Easy operation

Algae: Microwave Process



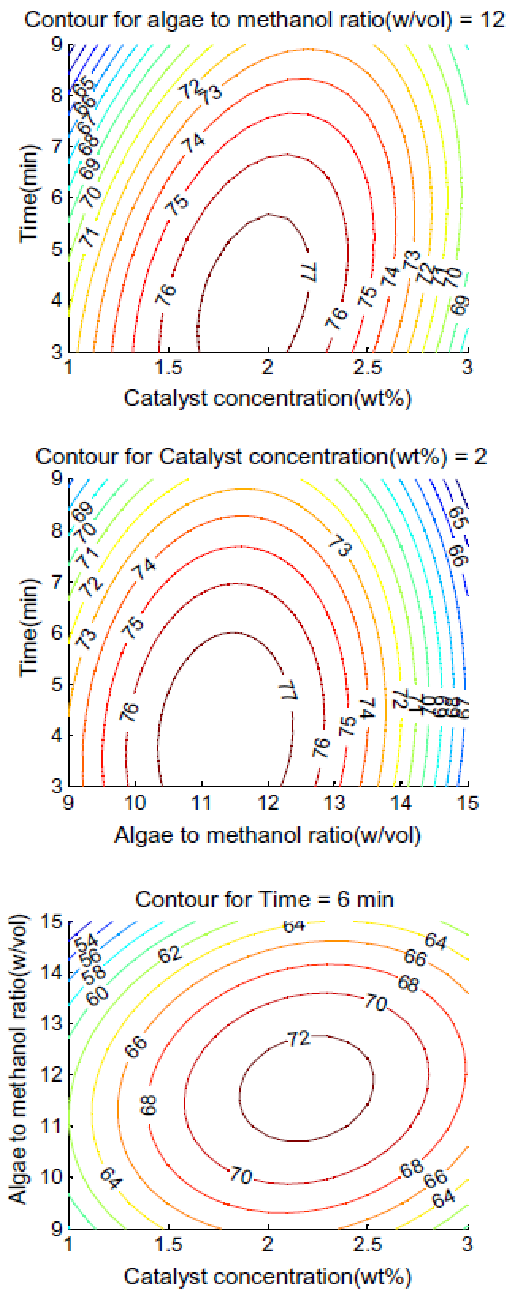


Microwave heating

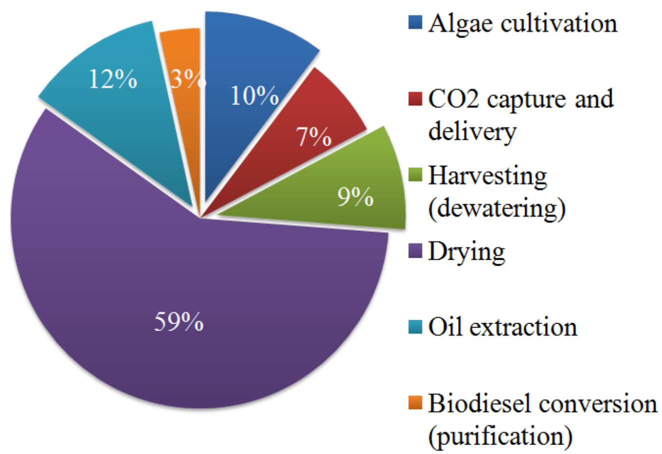
Algae: Process Optimization

- Optimal conditions:
  - Dry algae to methanol ratio of 1:12 (wt./vol.),
  - KOH concentration of 2% (wt.%) and
  - Reaction time of 4–5 min at a reaction temperature around 60–64 C
  - The maximum FAME yield of 80.13% (based on total lipid content)

Microwave irradiation is more effective in the destruction of the cells and accelerates better the transesterification reaction in a shorter reaction time.



Algae: Renewable Feedstock



- Energy various steps of biodiesel production:

1) Cultivation;
2) Feedstock processing;
3) oil extraction;
4) oil conversion into biodiesel; and
5) separation and purification.

Net Energy Benefit Ratio (NER)

Energy required for each operation (GJ/ton)	Sturm &Lamer 2011	Batan et al. 2010	Lardon et al. 2009	Stephenson et al. 2010
Cultivation	9.7	0.8	5.7	7.2
Flocculation	3.0			0.5
Centrifugation	15.0	10.7	–	2.0
Belt filter press	12.2		11.9	–
Oil extraction				
Electricity	–	21.8	3.9	0.3
Heat	–	–	10.2	2.3
Lipid conversion				
Electricity	–	9.7	–	0.2
Heat	–	–	0.9	1.6
Net energy ratio		**0.66**	**0.88**	**2.04**

NER for Different Feedstock

Fuel Type	NER	Reference and Note
Petroleum diesel	0.83	Sheehan et al., 1998a,b
Corn ethanol	1.34	Shapouri et al., 2002
1st Generation	1.98 (Only RME[a])	From oilseed rape,
bio-diesel	3.45 (RME + meal + glycerin)	UK (USDA, 2003)
	1.84 (only bio-diesel)	From soybean, USA
	3.2 (Biodiesel + meal)	Sheehan et al., 1998a,b
	2.42 (Only PME[b])	From palm, THA
	3.58 (PME + meal + glycerol)	Pleanjai & Gheewala, 2009
Algal fuel	1.87[c]	Stephenson et al., 2010
	1.50[d] (2.38[e])	Xu et al 2011
	1.37[d] (1.82[e])	Xu et al 2011

[a] Rapeseed methyl ester; [b] Palm methyl ester; [c] Lipid productivity = 20 ton ha^{-1} $year^{-1}$; [d] The base case;
[e] Assuming low temperature (< 100 °C) heat is available from an upstream fossil fuel combustion process.

Conclusions

- Biodiesel can be produced with minimum environmental pollution by using renewable feedstock.
- Net energy benefit of the biodiesel production process can be increased by using high oil yielding and low energy consuming feedstock (low maintenance, low cost).
- Biodiesel production costs can be reduced by utilizing locally available waste cooking oils and by utilizing process by-products as raw materials in other chemical processes.
- Utilizing renewable feedstock such as algae will reduce the environmental emissions and facilitate nutrient recovery and wastewater reuse and recycling.
- Non-conventional technologies such as microwaves and ultrasonics have potential to reduce the energy footprint of the biodiesel processes.