



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

ENERGY PRODUCTION FROM ALGAL BIOMASS-1

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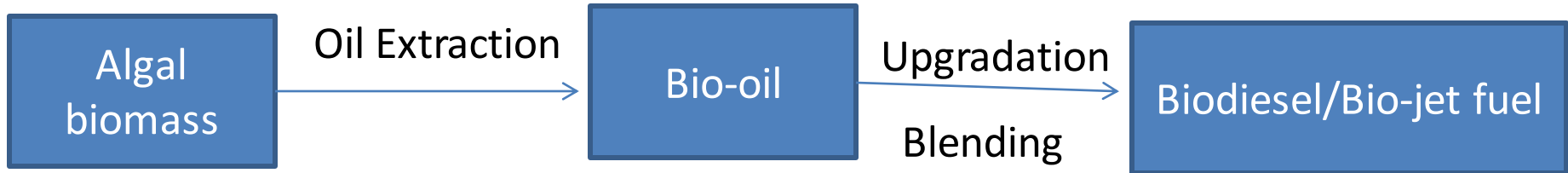
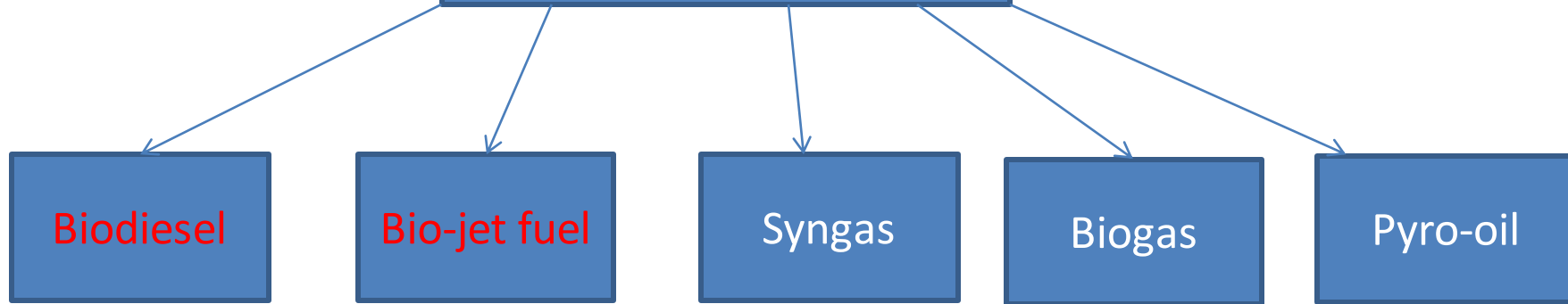


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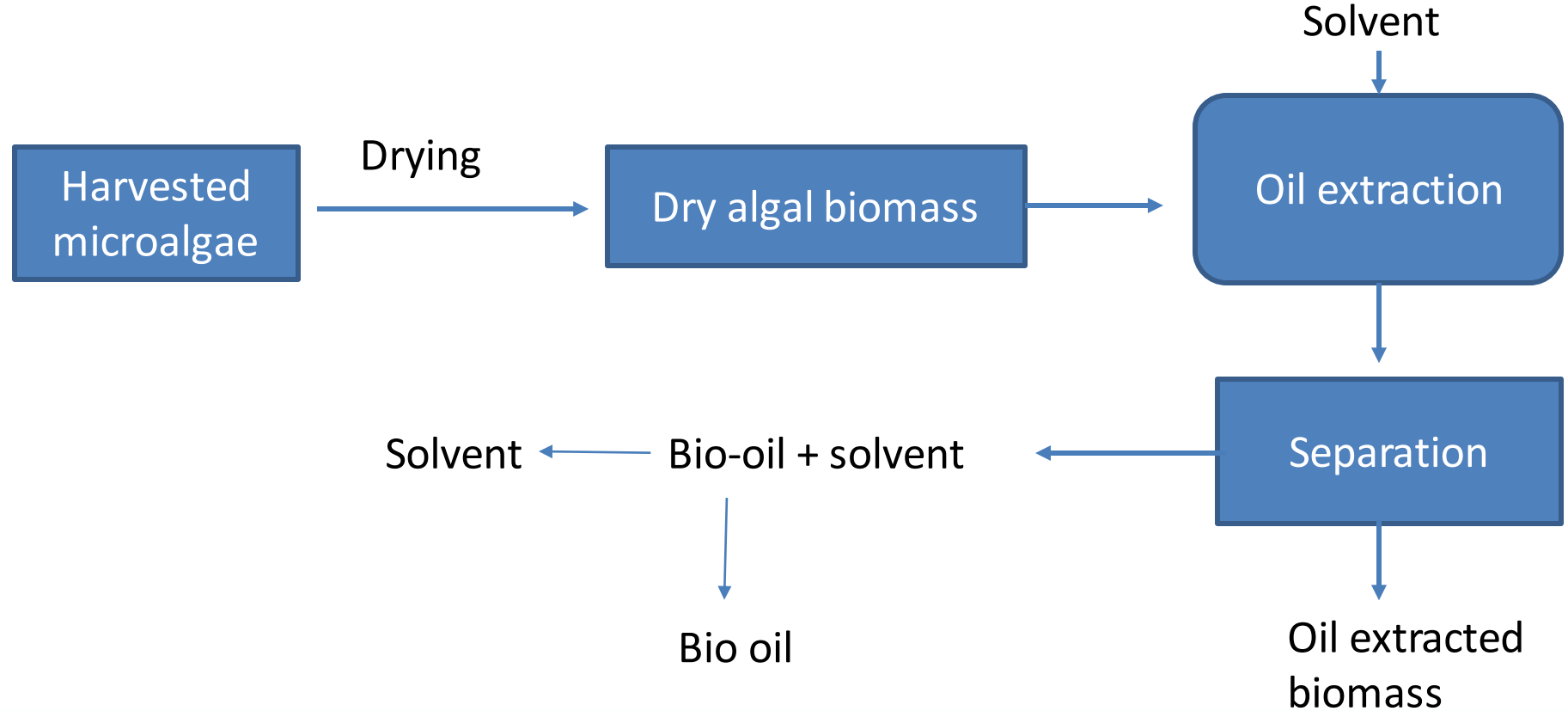


Important energy production routes for algal biomass

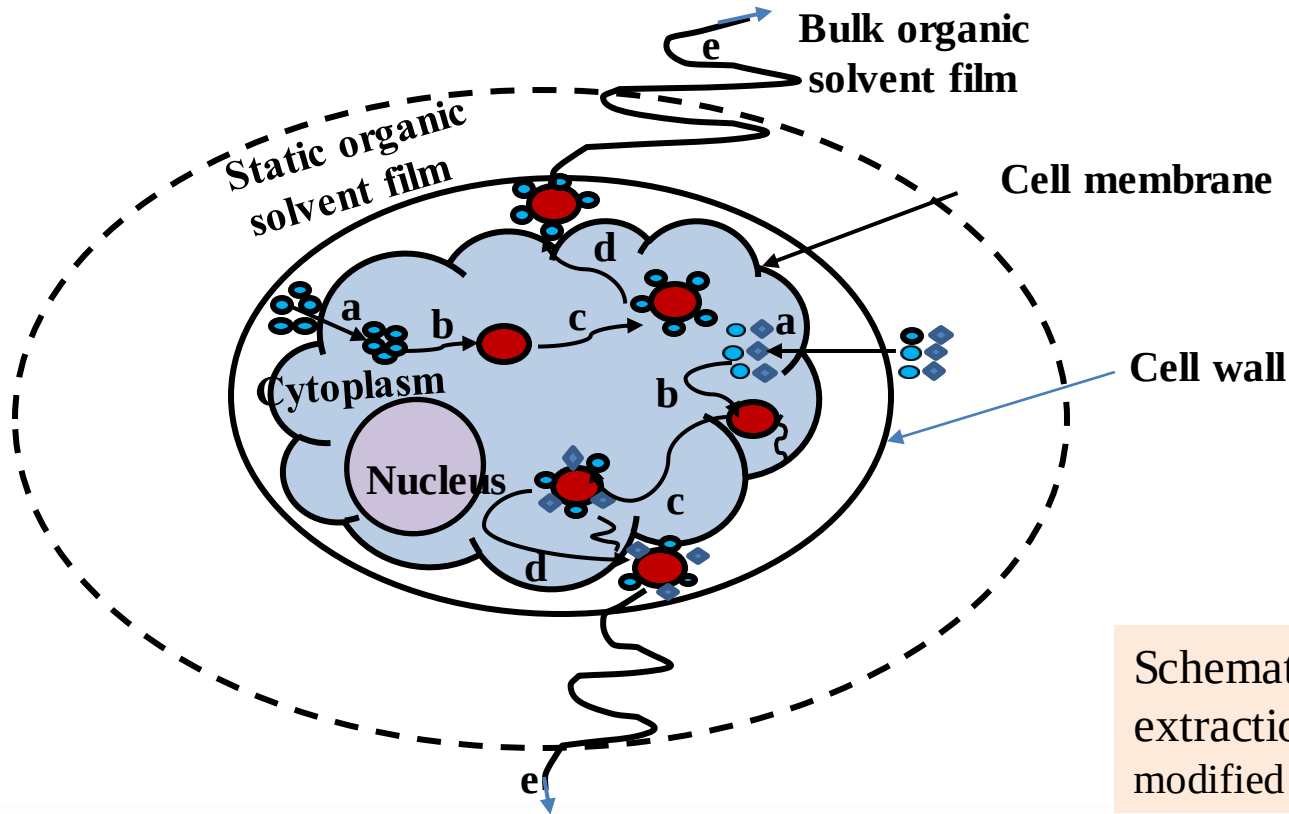


Bio oil production from algal biomass

Conventional route



Mechanism of oil extraction using solvent



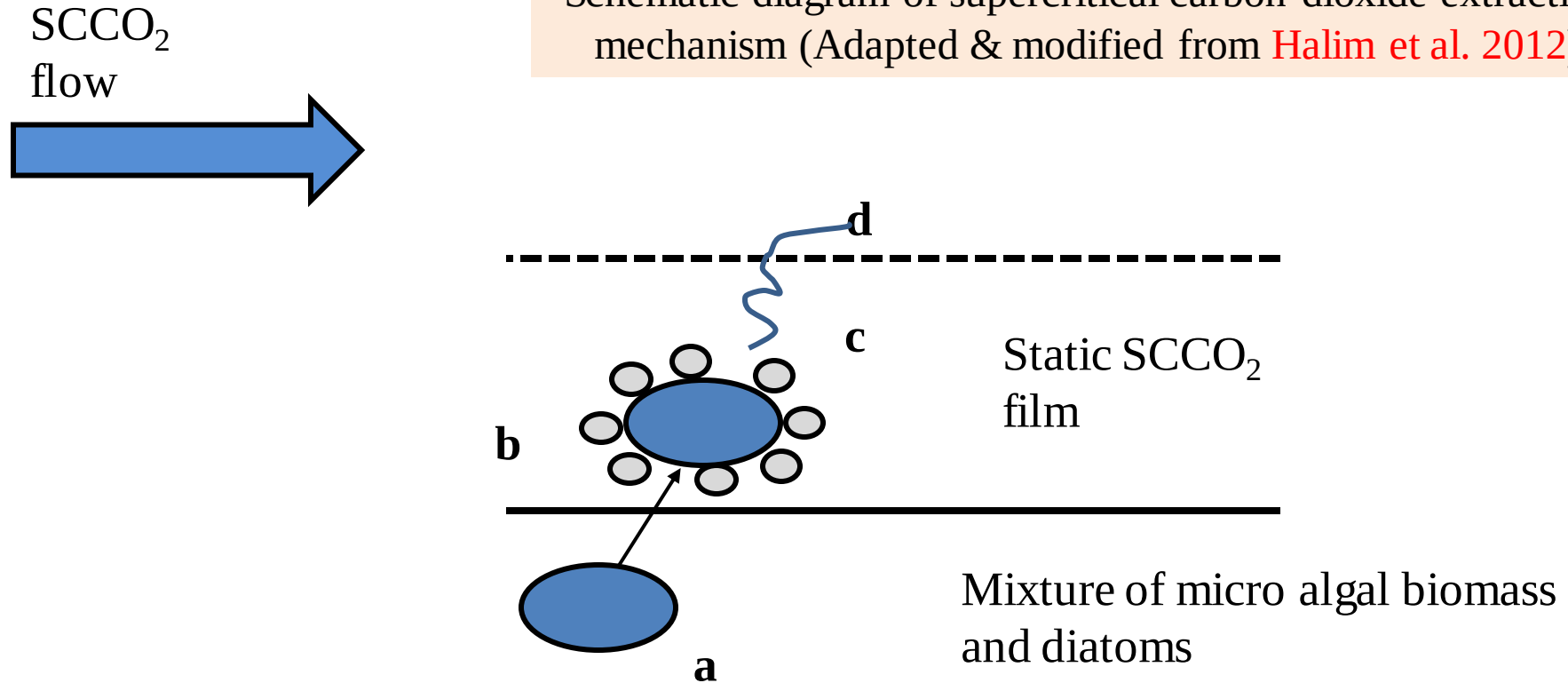
Schematic diagram of solvent extraction mechanism (Adapted & modified from Halim et al. 2012).

Extraction of micro algal lipids using organic solvents

Micro algae species used	Operating conditions / solvent
<i>Chlorella sp.</i>	Extraction method: Soxhlet extraction and Batch extraction Solvents: Methylene chloride/ methanol (2:1 v/v); ; Soxhlet extraction:- methylene chloride/ methanol (2:1 v/v); chloroform/ methanol/50 mM phosphate buffer (35:70:28 v/v/v/); ; Chloroform/methanol (2:1 v/v); hexane/ isopropanol (3:2 v/v); Solvent to biomass ratio: 75 – 1000 ml solvent per g of biomass
<i>Botryococcus braunii</i>	
<i>Phaeodactylum</i>	
<i>Tricornutum</i>	
<i>Chlorococcum sp.</i>	

Mechanism for supercritical CO₂ extraction

Schematic diagram of supercritical carbon-dioxide extraction mechanism (Adapted & modified from Halim et al. 2012)



Some studies on the extraction of micro algal lipids by supercritical carbon dioxide

Microalgae	Operating conditions	Remarks
<i>Nannochloropsis</i> sp.	Extraction pressure(bar):- 400, 550, 700; Temp (°C):- 40, 55; SCCO ₂ flow rate:- 0.17 kg/min; Time:- 360 min; polar modifier ,amount:- None	Increase in lipid extraction with Pressure at constant T Increase in lipid extraction rate with temperature at constant P.
<i>Spirulina Platensis</i>	Extraction pressure(bar):- 316, 350, 400, 450, 484; Temp (°C):- 40, 55; SCCO ₂ flow rate:- 0.7 L/min;; Time:- 26.4, 40, 60, 80, 94 min; Polar modifier (amount):- Ethanol; 9.64, 11, 13, 15, 16.36 mL	Optimum condition-400 bar, 13.7 mL ethanol and 60 min.

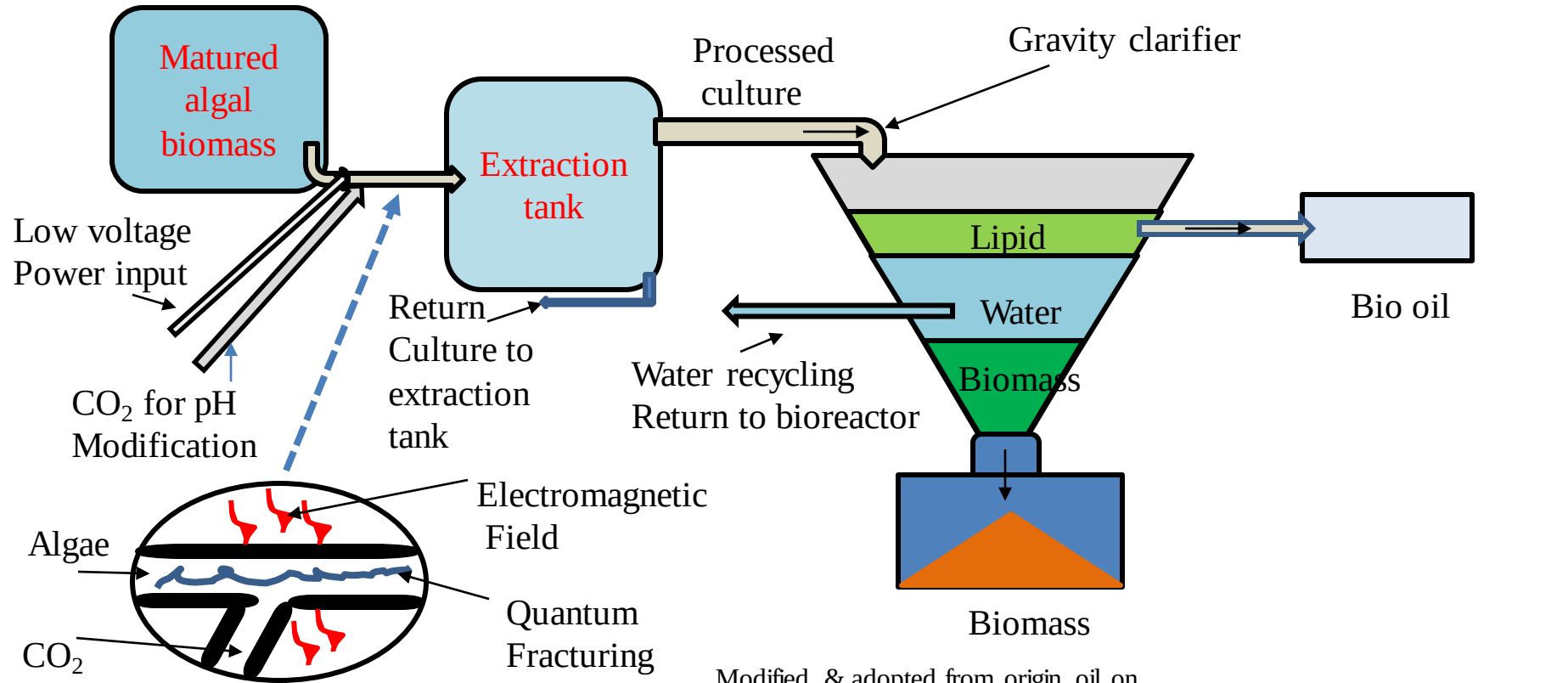


Some studies on the extraction of micro algal lipids by supercritical carbon dioxide

Microalgae	Operating conditions	Remarks
<i>Chlorella vulgaris</i>	Extraction pressure (bar):-200, 350; Extraction temp (°C):-40, 55; SCCO ₂ flow rate:- 0.41/min; Time:- 500 min	Lipid yield increased with P at constant T It decreased with T at constant lower P (200 bar) and increased with T at constant high P (350 bar), Optimum condition- 350 bar and 55 °C
<i>Spirulina maxima</i>	Extraction pressure(bar):- 100, 250, 350; Temp (°C):- 50, 60; SCCO ₂ flow rate:-not specified; polar modifier ,amount:- ethanol, 10 mol % of CO ₂	Similar effect of temperature and pressure on total lipid yield like <i>Chlorella</i> <i>vulgaris</i> Optimum condition-350 bar, 60 °C with ethanol addition (10 mol%).



Single step oil extraction

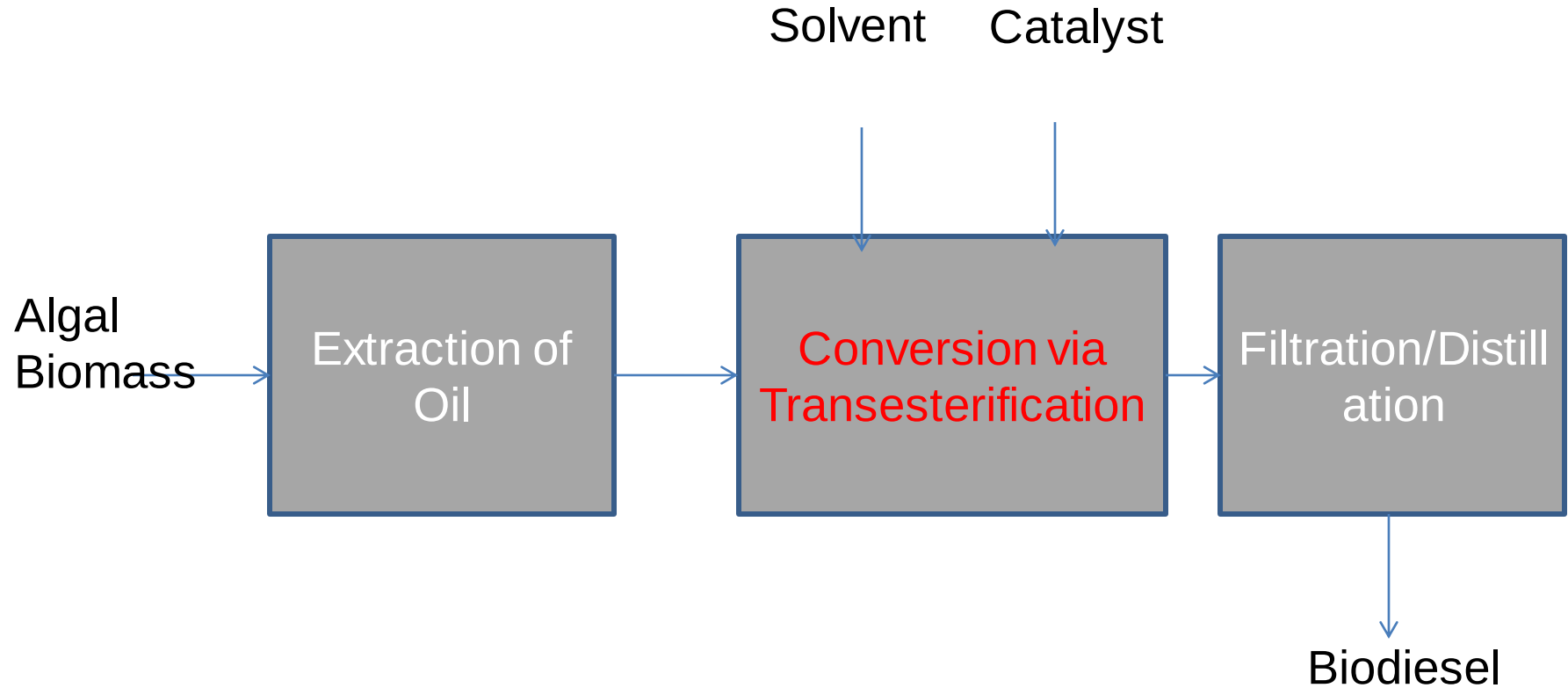


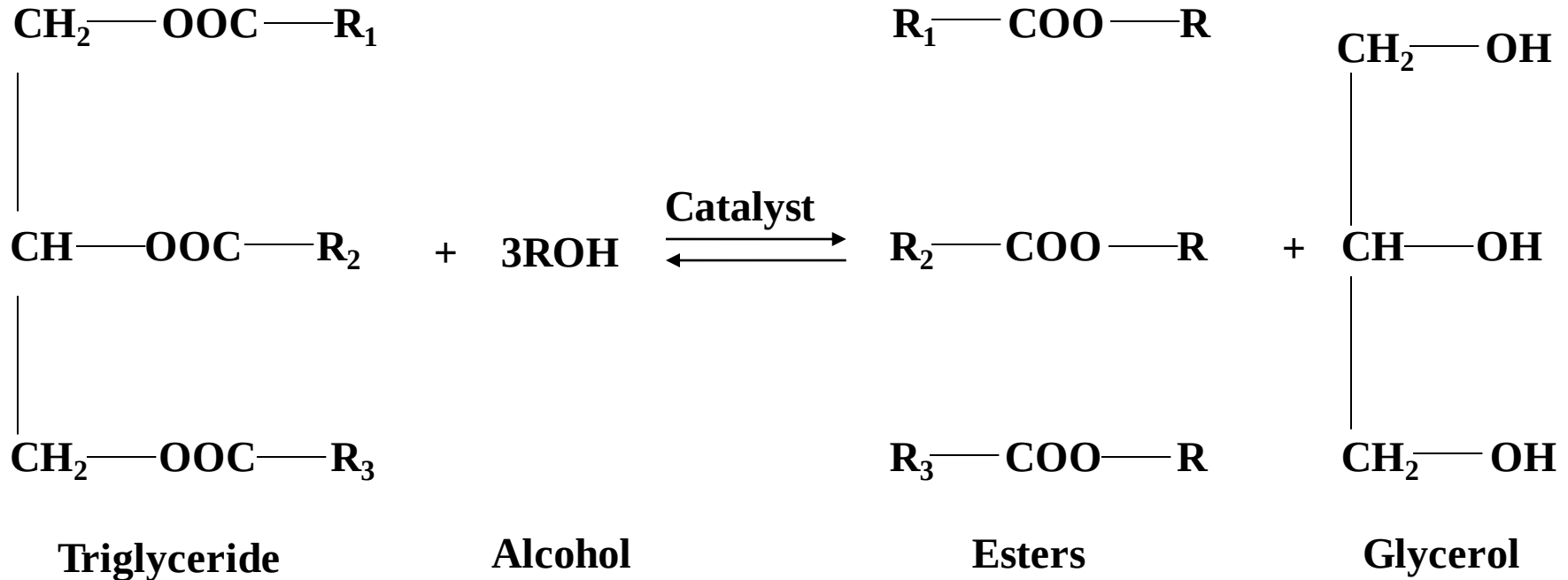
Modified & adopted from origin oil on

http://www.originclear.com/pdf/OriginOil_NAA_30_Apr_2009.pdf, Accessed on 11-11-2017



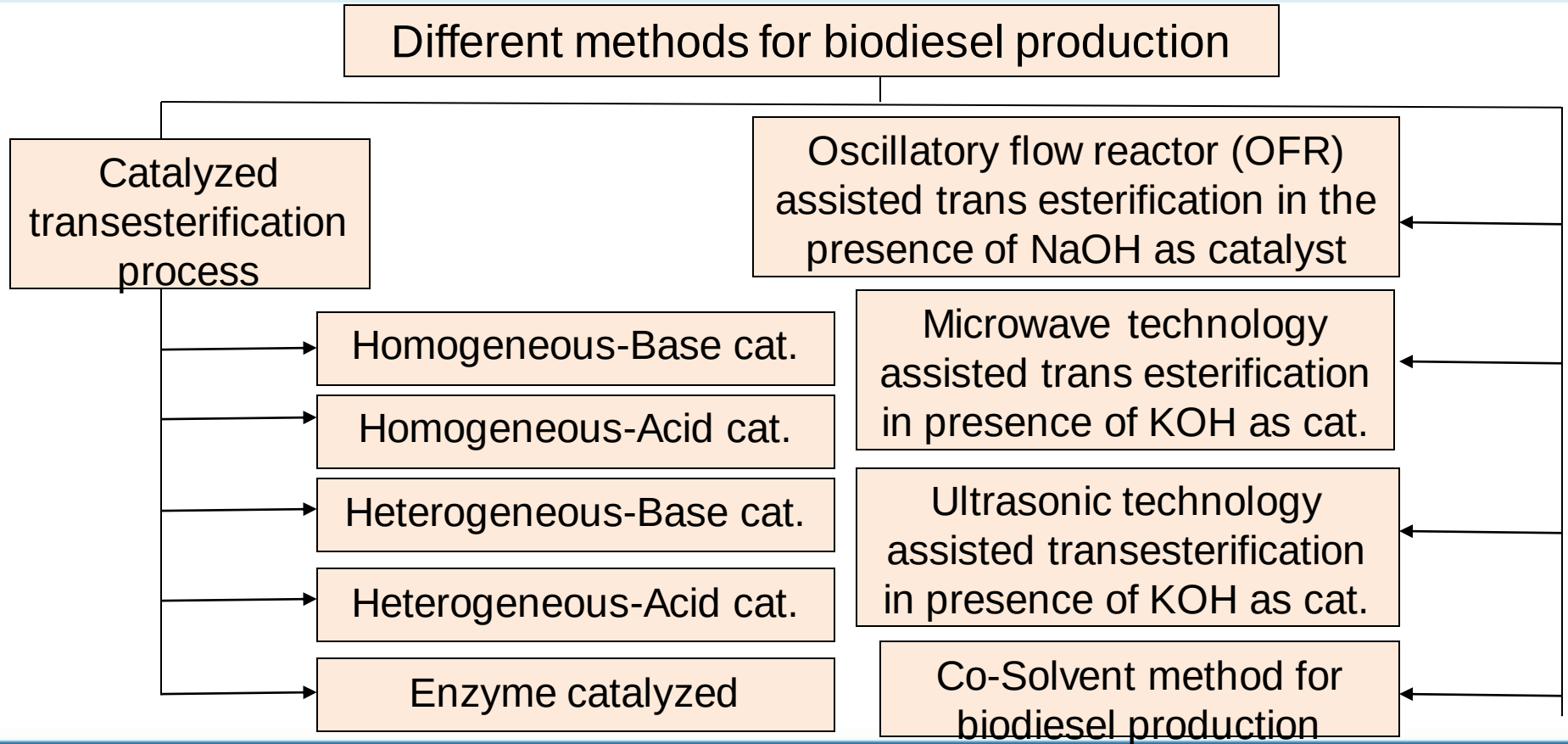
Biodiesel production route through algal biomass



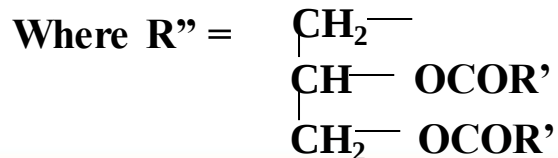
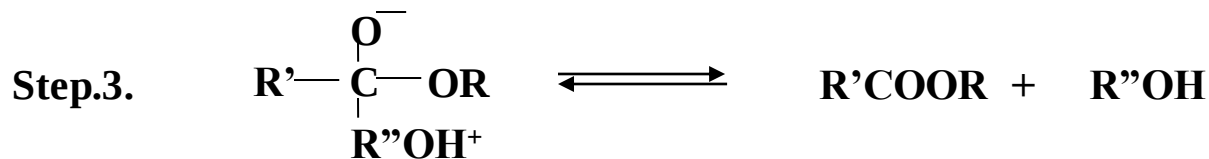
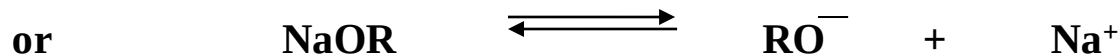


Schematic of transesterification reaction, where, R_1 , R_2 and R_3 are long chains of carbons and hydrogen atoms, called fatty acid chains.

Different types of transesterification processes



Mechanism of base catalyzed transesterification



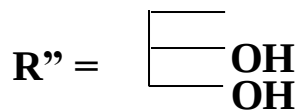
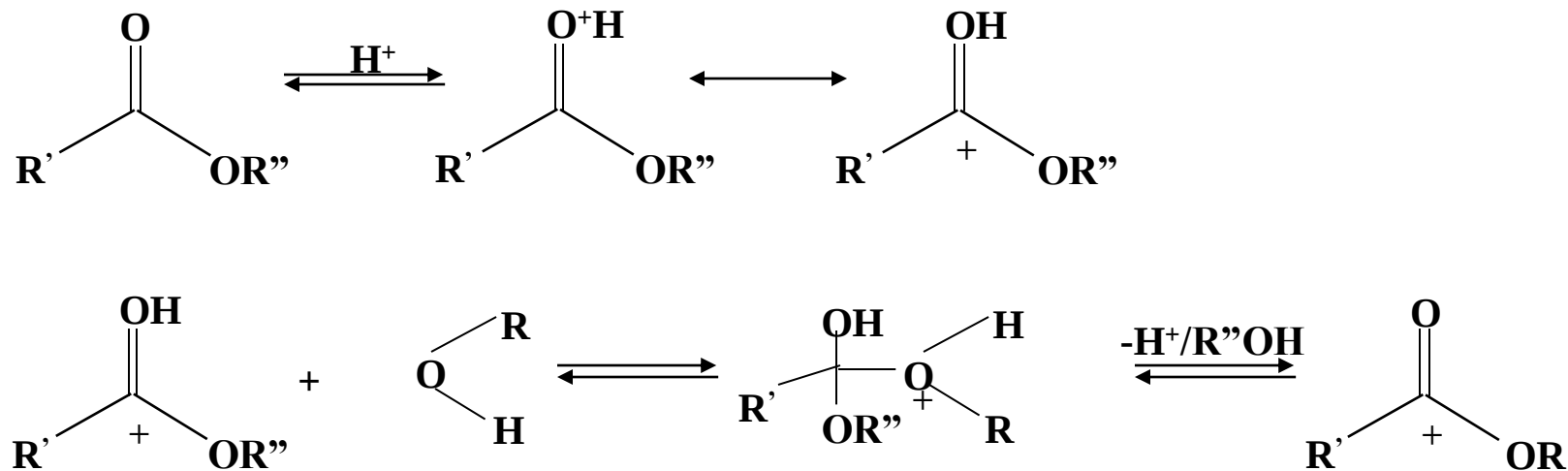
$\text{R}' = \text{carbon chain of fatty acid}$

$\text{R} = \text{alkyl group of the alcohol}$

Schuchardt U. et al., 1998.



Mechanism of acid catalyzed transesterification



R' = carbon chain of fatty acid

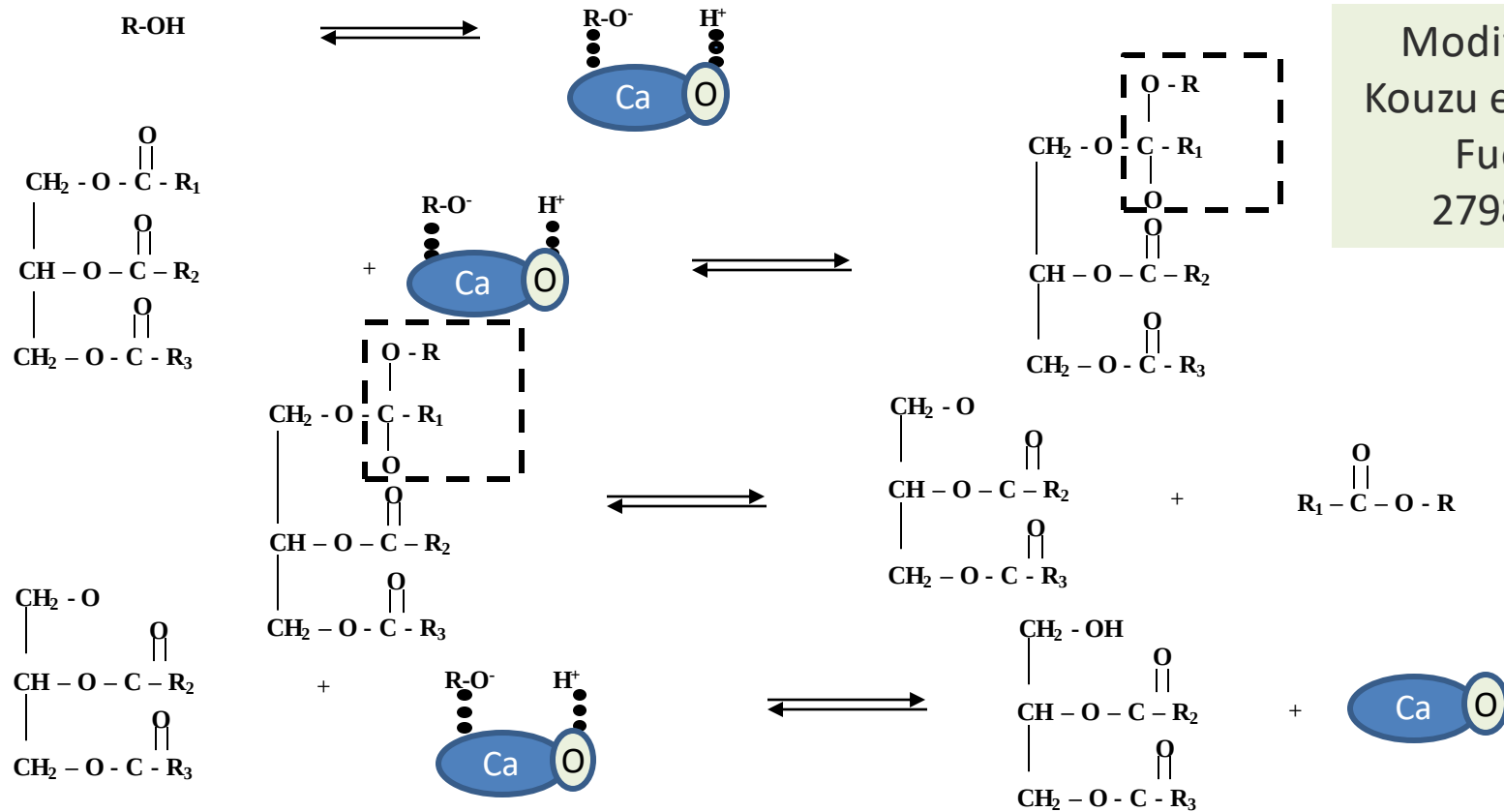
R = alkyl group of the alcohol

Schuchardt U. et al., 1998.



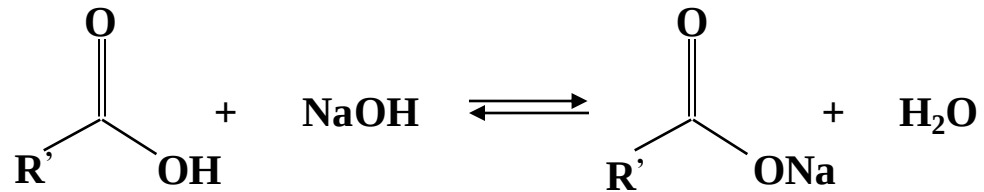
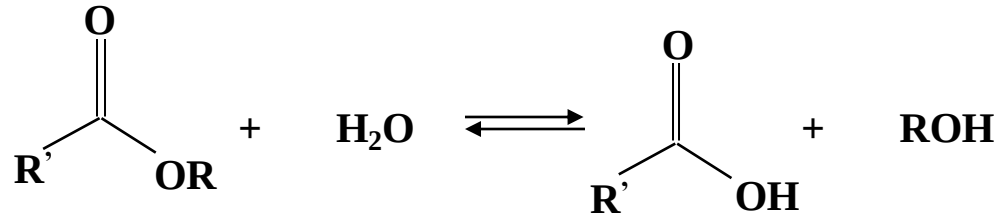
Mechanism of transesterification with heterogeneous catalyst

contd..



Modified from
Kouzu et al., 2008,
Fuel (87)
2798–2806

1. Oil temp.
2. Reaction temp.
3. Ratio of alcohol to oil
4. Catalyst type & conc.
5. Intensity of mixing
6. Purity of reactions



R' = Carbon chain of the fatty acid

R = alkyl group of the alcohol

Soni et al., 2012

Comparison among base, acid and enzyme catalyzed esterification reactions

Characteristic	Base catalyzed	Acid catalyzed	Enzyme catalyzed
Reaction rate	↑↑↑	↑↑	↑
Effect of free fatty acid in oil	↑↑	-	-
Cost of catalyst	↑	↑↑	↑↑↑
Catalyst used	NaOH, KOH	H ₂ SO ₄ , HCl	Lipozyme IM 60, Novozyme 435
Chances of deactivation of cat.	↑↑	↑	↑
Possibility of catalyst recovery	↑	↑↑	↑↑↑
Problems in product recovery	↑↑↑	↑↑	↑
By-products	↑↑	↑	-
Effect of alcohol used	-	-	↑

Soni et al., 2012

Comparison of different types of transesterification processes

Processes	Advantages	Disadvantages
Catalyzed transesterification	• Primitive and mostly used process • Well proven • Various types of catalysts such as homogeneous, heterogeneous, biocatalysts etc. can be used	• Performance can be highly affected with catalyst types
Catalyzed transesterification using co-solvent	• Improved solubility and high mass transfer rate between oil , solvent and catalyst	• Co-solvents are volatiles and are not environment friendly • Solvent separation from final product increases production cost

Soni et al., 2012

Comparison of different types of transesterification processes

Processes	Advantages	Disadvantages
Oscillatory flow reactor (OFR) assisted catalyzed transesterification	Improved heat and mass transfer between medium	Not well proven
Microwave technology assisted catalyzed transesterification	Energy requirement is less	Scale up is difficult
Ultrasonic technology assisted catalyzed transesterification	- Improved mass transfer rate between media - Cost effective	Not well proven Soni et al., 2012

Thanks

