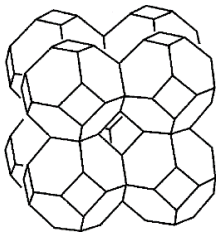
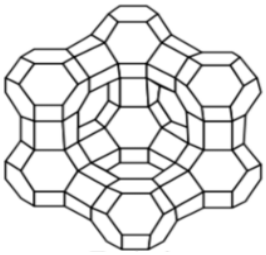
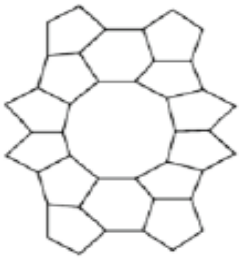
catalysts

Supplementary Materials

Structural features of HS zeolite and common zeolites used in biodiesel production

Table S1. Motive catalytic application of hydroxy sodalite over common biodiesel zeolite catalysts.

Zeolite	**HS**	**Zeolite (Na)X (FAU)**	**ZSM-5**	**Reference**
Structure				Miteva and Stoyanova [66]; Daramola, et al. [67]
Structure type (pore size)	4-rings (2.8 Å)	12-ring (7.3Å)	10-rings (32Å)	Xu, et al. [68]; Nanganoa, Mbadcam and Kang [34]; Miteva and Stoyanova [66]
Si/Al ratio	0.84–1	1–1.5 (1.23)	16–50	Golbad, Khoshnoud and Abu-Zahra [43]; Ferreira Madeira, Ben Tayeb, Pinard, Vezin, Maury and Cadran [26]; Sun, Lu, Ma, Han, Fu and Ding [21]

Textural properties of produced catalysts

Table S2. Textural properties of F-HS, post-synthesis ion exchange-modified F-HS (K/F-HS) and of direct method-derived HS.

Synthesis method	Sample	Surface area (m^2/ g)			Pore volume (cm^3/g)		Pore size[e] (nm)
		Total[a]	Meso.[b]	Micro.	Total[c]	Micro[d]	
Fusion	F-HS	45.0	42.2	2.7	0.148	0.018	12.99–15.31
Ion exchange	K/F-HS	25.8	25.0	0.8	0.0614	0.00081	9.5–12.2
[f]**Direct**	HS	13.2	12.6	0.56	0.08	0.00042	22.24–27.58

F-HS: indirect fusion-derived HS zeolite; F-HS: Post-synthesis ion exchange modified HS zeolite; [a] Obtained by BET equation / method at $p/p^0 = 0.99$; [b] Measured by t-plot method, which defines pores in the sample of 2–50 nm (mesopore) and <2 nm (micro) in width [47]; [c] Estimated at from adsorbed amount at $p/p^0 = 0.99$ or derived from BJH adsorption isotherms as "cumulative volume of pores"; [c] Derived from single point adsorption isotherms as "cumulative volume of pores"; [d] Measured by t-plot method; [e] Average pore diameters or width derived from adsorption isotherms using BJH method; [f] HS Sample obtained from CFA via Direct hydrothermal synthesis method [48].

Ion exchange post-modification of HS zeolite

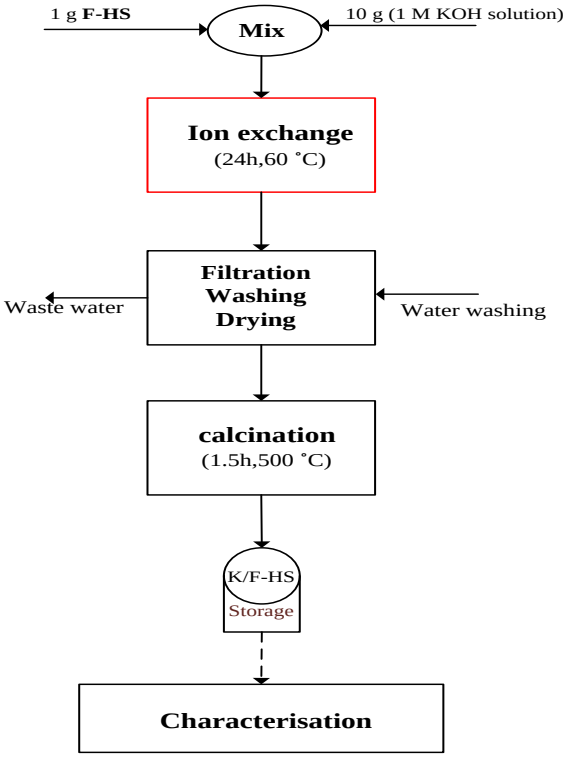


Figure S1. Schematic flow diagram of ion exchange post-synthesis modification of HS zeolite.

Biodiesel production

Schematic process flow

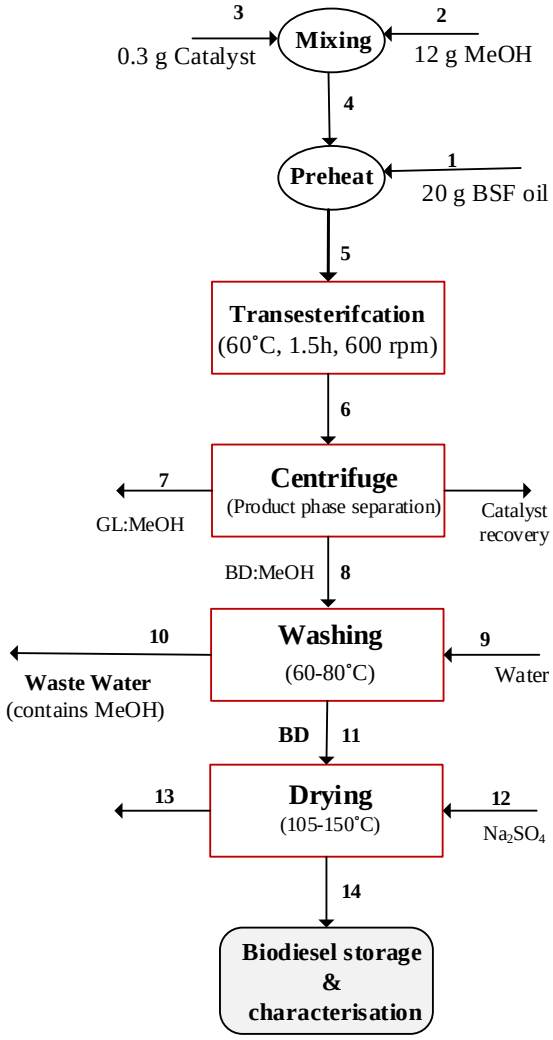


Figure S2. Process flow illustration of biodiesel production from waste-derived BSF oil using synthesised catalysts (BSF = waste-derived maggot oil; MeOH = methanol; GL= glycerol).

Techno-economic evaluation data

Table S3. Estimated unit cost of raw material and biodiesel products.

Component material	Cost ($/kg)*	Source/Reference
[a] BSF oil	0.52	Hajjari, Tabatabaei, Aghbashlo and Ghanavati [10]
NaOH Pellets AR (98.5%)	16.91	WorldofScience [69]
Methanol (MeOH)	-	-
Process water (P. H_2O)	0.002	CCT [70]
Wastewater treatment	0.00000137	Hong, *et al.* [71]
[b] HS	77.64	
Biodiesel	0.5/L	You, Shie, Chang, Huang, Pai, Yu and Chang [4]
[c] BSF biodiesel (NaOH-Trans.)	0.58	
[d] BSF biodiesel (F-HS Trans.)	0.57	

[a] BSF oil, assumed same as WCO = $0.52/kg

Density of NaOH-transesterified biodiesel = 0,862 g/mL; 1L = 0,862 [6]

Density of F-HS Transesterified biodiesel = 0,877 g/mL; 1L = 0,877 kg (Table 5)

[c]&[d] Biodiesel cost in $/kg = $ 0.5/L multiplied by respective density values

[b] Price of HS taken as that of Molecular sieves, 13X; chemical equation $Na_{86}[AlO_2)_{86}(SiO2)_{106}] \cdot xH_2O$, $77.64

*Prices converted to US dollar ($), based on standard prices in South Africa (ZAR, rands) : USD-to-ZAR 2022 average exchange rate of $1 = R16.32

Table S4. Mass balance and material cost comparison between biodiesel production using NaOH conventional homogenous catalyst and HS novel heterogeneous catalyst.

	Catalyst	
Operating conditions	NaOH	F-HS
Catalyst weight (wt. %)	1.5	1.5
MeOH/oil ratio (*n*/*n*)	15:01	15:01
Temperature (°C)	60	60
Components (Input) (g)		
BSF oil	20	20
Catalyst mass	0.3	0.3
Methanol	11.95	11.95
Process wash water	231.95	223.7
Components (Output) (g)		
Mass of biodiesel	13.99	16.82
Biodiesel yield (%)	69.93	84.10
Components (**kg/kg biodiesel**)		
BSF oil	1.430	1.189
Catalyst	0.021	0.018
Methanol	0.85	0.71
Process washwater (BD purification)	16.59	13.30
Biodiesel	1.00	1.00
***Component ($/ kg biodiesel**)		
BSF oil	**0.74**	**0.62**
Catalyst	**0.363**	**1.385**
Methanol	-	-
Process washwater (influent)	**0.033**	**0.027**
Wastewater (effluent) treatment	**2.27×10^{-05}**	**1.82×10^{-05}**
Biodiesel (based on Table S3)	0.58	0.57
Reference	[a] Previous work [6]	This work

[a] Only NaOH catalytic performance referenced from previous work; cost analysis conducted in this study

* Costing component difference between catalysts usage, e.g. with regards to BSF oil

$$= \frac{|Cost\ of\ component\ over\ NaoH - Cost\ of\ component\ over\ F-HS|}{cost\ of\ component\ over\ NaoH} \times 100 = \frac{0.74-0.62}{0.74} \times 100 = \sim 19.35\ \%$$