energies

Use of Co-Solvent in Hydrothermal Liquefaction (HTL) of Microalgae

Yang Han [1,*], Kent Hoekman [1], Umakanta Jena [2] and Probir Das [3]

[1] Division of Atmospheric Sciences, Desert Research Institute (DRI), 2215 Raggio Parkway, Reno, NV 89512, United States; Kent.Hoekman@dri.edu (S.K.H)
[2] Department of Chemical and Materials Engineering, New Mexico State University, Las Cruces, NM 88003, United States; ujena@nmsu.edu
[3] Center for Sustainable Development, College of Arts and Sciences, Qatar University, Doha 2713, Qatar; probir.das@qu.edu.qa
* Correspondence: yangh@nevada.unr.edu or Yang.Han@dri.edu ; Tel.: +1-775-357-5747

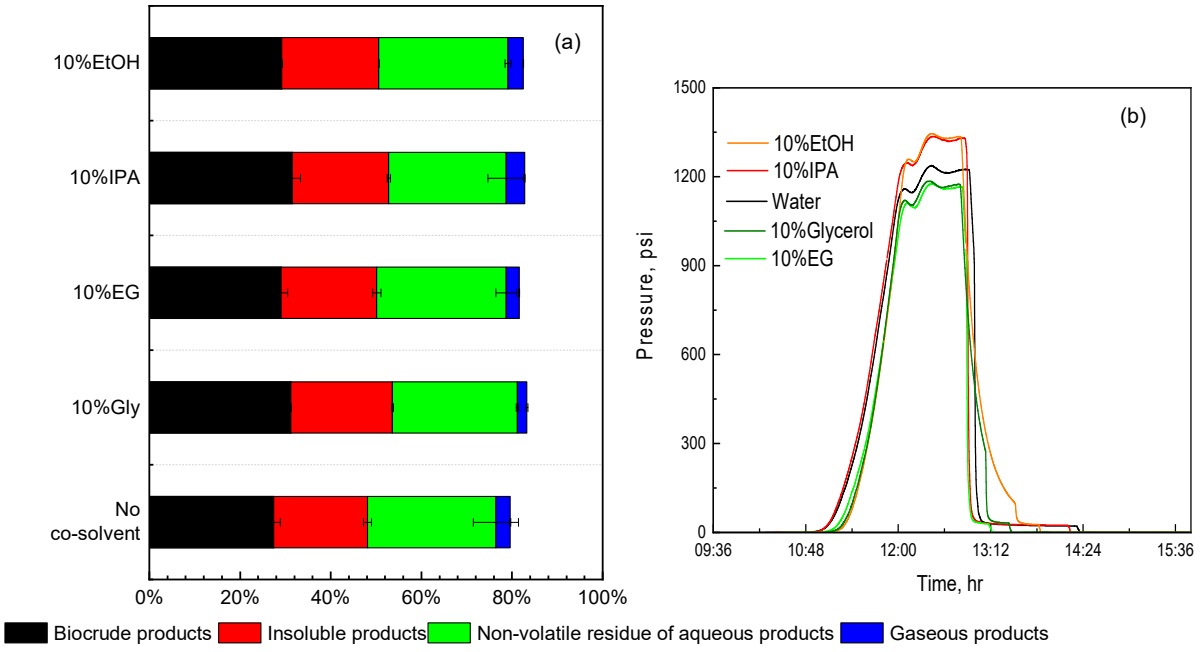

Figure S1. Effects of co-solvents on product yields (**a**) and reaction pressures (**b**) during liquefaction of *Tetraselmis* sp. at 300 °C. (IPA: Isopropyl alcohol; EG: Ethylene glycol; EtOH: Ethanol; GLY: Glycerol). Error bars represent standard deviations from duplicate experiments.

Table S1. Co-solvent effects on product yields (wt.%, dry basis) and properties from HTL treatment of *Tetraselmis* sp. at 300 °C.

Co-Solvent	Biocrude Product Yield, %	Insoluble Product Yield, %	Yield of NVR of Aqueous Product, %	Gaseous Product Yield, %	Total Yield, %	pH of Aqueous Products	HHV of Biocrude, (MJ/kg)	HHV of Insolubles, (MJ/kg)	Viscosity of Biocrude [1], (mm^2/s @40 °C)
None	27.4 ± 1.5	20.7 ± 0.9	28.4 ± 5.0	3.2 ± 0.2	79.6	8.4 ± 0.2	31.1 ± 0.6	8.1 ± 0.3	91.5 ± 30.6
10%IPA	31.5 ± 1.8	21.3 ± 0.4	25.8 ± 4.0	4.1 ± 0.1	82.8	8.5 ± 0.1	31.7 ± 1.9	5.9 ± 0.1	163.8 ± 38.9
10%EG	29.0 ± 1.4	21.4 ± 0.9	28.6 ± 2.3	2.9 ± 0.1	81.6	8.2 ± 0.1	30.1 ± 2.0	6.9 ± 0.9	79.7 ± 0.9
10%EtOH	29.2 ± 0.2	21.4 ± 0.1	28.5 ± 0.7	3.3 ± 0.1	82.4	8.4 ± 0.0	32.0 ± 0.6	5.3 ± 0.7	307.8 ± 27.0
10%GLY	31.2 ± 0.1	22.4 ± 0.2	123.0 ± 0.5	2.1 ± 0.2	178.8	8.3 ± 0.2	32.7 ± 0.6	7.3 ± 0.0	278.8 ± 35.6

Table notes: NVR—Non-volatile residue; HHV—Higher heating value; IPA—Isopropyl alcohol; EG—Ethylene glycol; EtOH—Ethanol; GLY—Glycerol. [1] Viscosity was measured by a Zeitfuchs cross-arm flow viscometer at 40 °C.

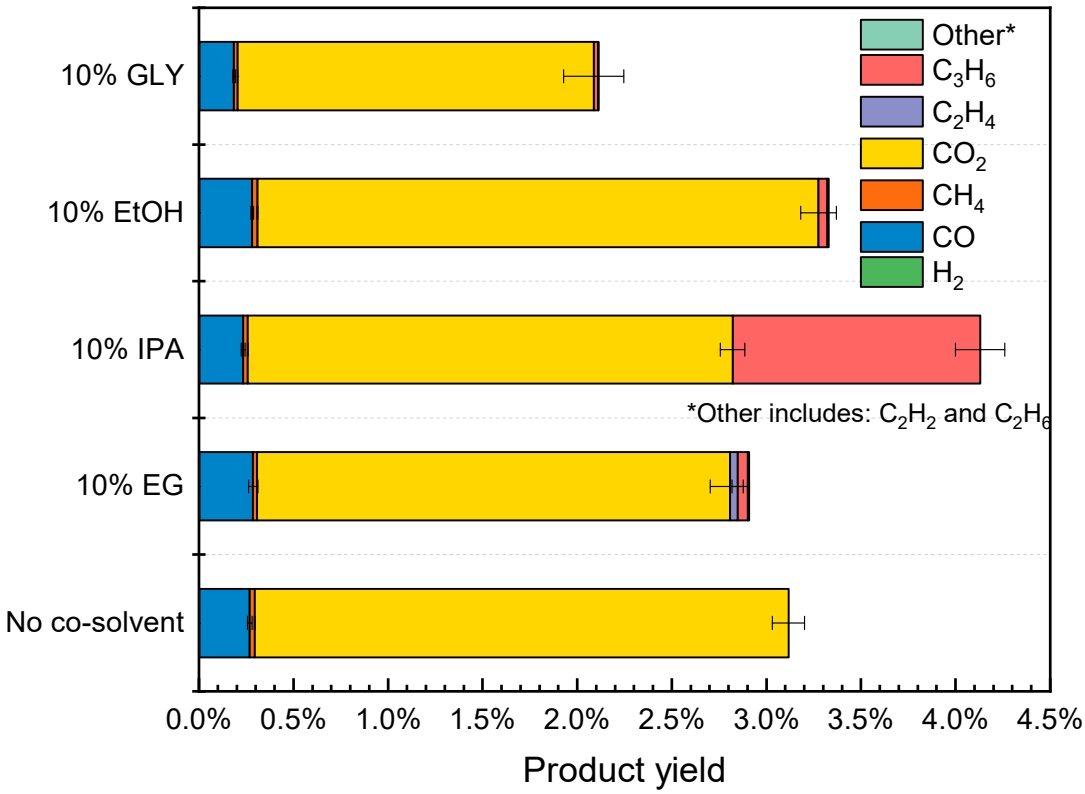

Figure S2. Gaseous products compositions and yields from HTL treatment of *Tetraselmis* sp. at 300 °C with different co-solvent inclusion (IPA: Isopropyl alcohol; EG: Ethylene glycol; EtOH: Ethanol; GLY: Glycerol). Error bars represent standard deviations from duplicate experiments.

Table S2. Effect of varying co-solvent concentrations on the yields (wt.%, dry basis) and properties of different product streams from HTL treatment of *Tetraselmis* sp. at 300 °C.

Co-Solvent	Biocrude Product Yield, %	Insoluble Product Yield, %	Yield of NVR of Aqueous Product,%	Gaseous Product Yield, %	Total Yield,%	HHV of Biocrude, (MJ/kg)	HHV of Insolubles, (MJ/kg)	Viscosity of Biocrude [1], (M^2/s @40 °C)
None	27.4 ± 1.5	20.7 ± 0.9	28.4 ± 5.0	3.2 ± 0.2	79.6	31.1 ± 0.6	8.1 ± 0.3	91.5 ± 30.6
10%IPA	31.5 ± 1.8	21.3 ± 0.4	25.8 ± 4.0	4.1 ± 0.1	82.8	31.7 ± 1.9	5.9 ± 0.1	163.8 ± 38.9
20%IPA	23.8 ± 0.3	23.8 ± 0.4	27.6 ± 4.0	4.3 ± 0.1	79.4	35.5 ± 0.8	6.0 ± 0.3	362.7 ± 1.6
30%IPA	32.4 ± 4.0	22.6 ± 0.3	27.4 ± 1.7	4.6 ± 0.1	87.1	33.2 ± 2.3	3.1 ± 0.6	42.4 ± 0.0
10%EG	29.0 ± 1.4	21.4 ± 0.9	28.6 ± 2.3	2.9 ± 0.1	81.6	30.1 ± 2.0	6.9 ± 0.9	79.7 ± 0.9
20%EG	27.4 ± 1.6	23.3 ± 1.4	29.6 ± 0.9	3.2 ± 0.2	83.5	32.2 ± 1.5	8.7 ± 0.1	72.4
30%EG	28.1 ± 0.8	26.4 ± 0.9	34.2 ± 1.6	2.3 ± 0.0	90.9	31.1 ± 1.2	9.7 ± 0.1	52.4

Table notes: NVR—Non-volatile residue; HHV—Higher heating value; IPA—Isopropyl alcohol; EG—Ethylene glycol. [1] Viscosity was measured by a Zeitfuchs cross-arm flow viscometer at 40 °C.

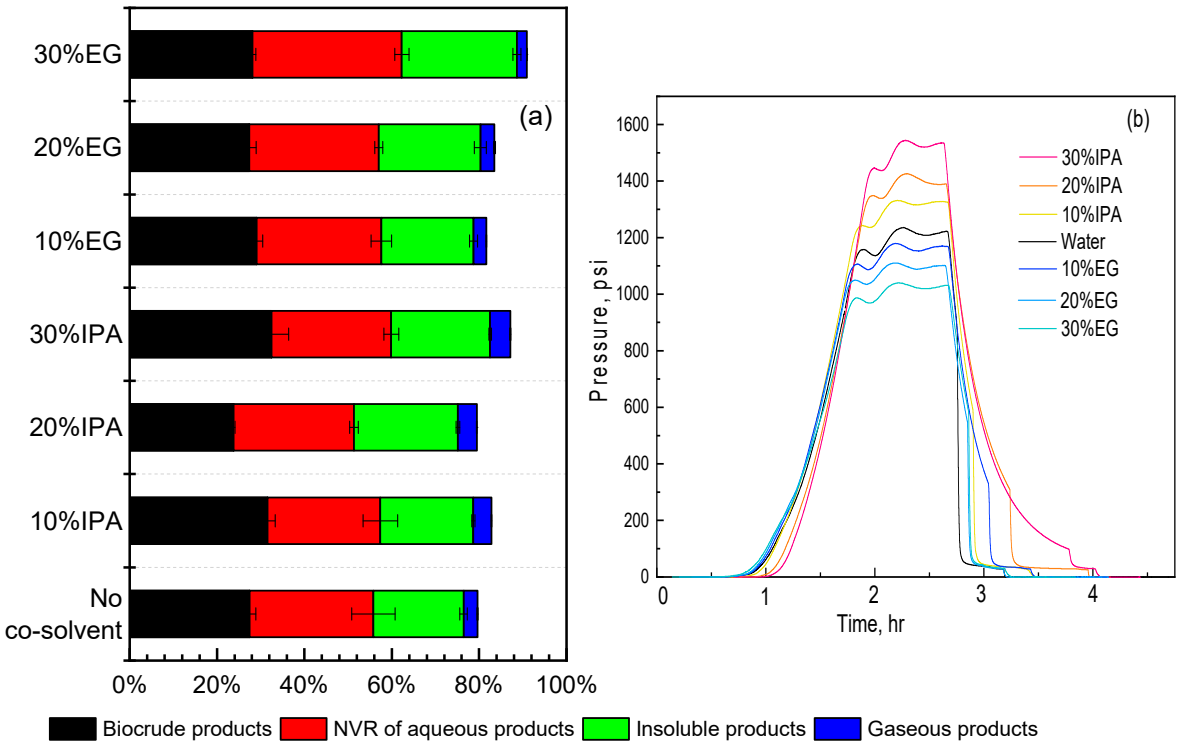

Figure S3. Effects of adding varying co-solvent concentration at 300 °C reaction temperature on product yields during liquefaction of *Tetraselmis* sp. Error bars represent standard deviations from duplicate experiments.

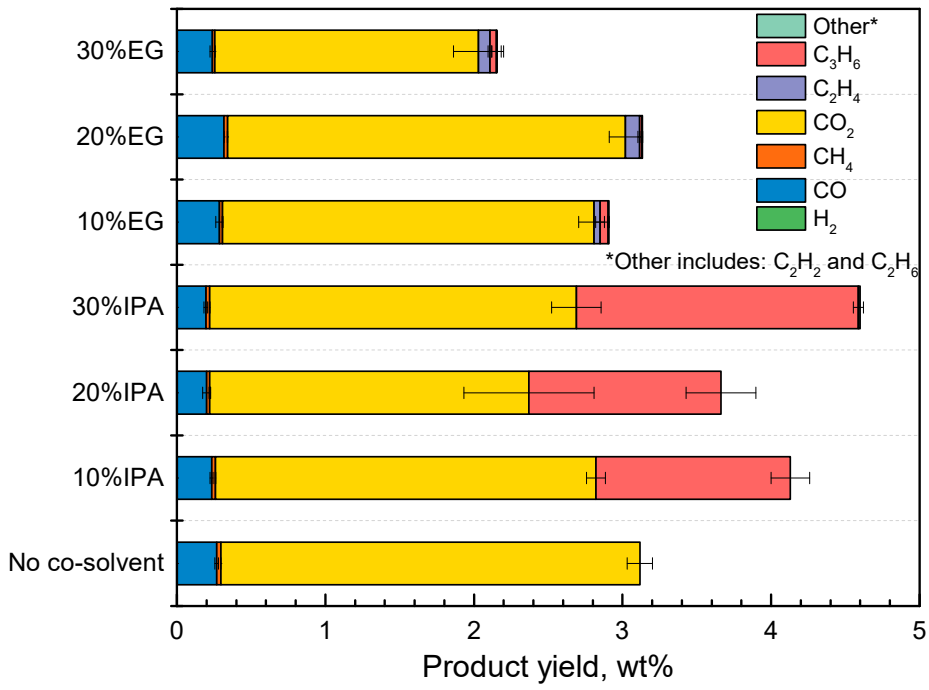

Figure S4. Gaseous products compositions and yields from HTL treatment of *Tetraselmis* sp. at 300 °C for 30 min with varying co-solvent concentration (IPA: Isopropyl alcohol; EG: Ethylene glycol). Error bars represent standard deviations from duplicate experiments.

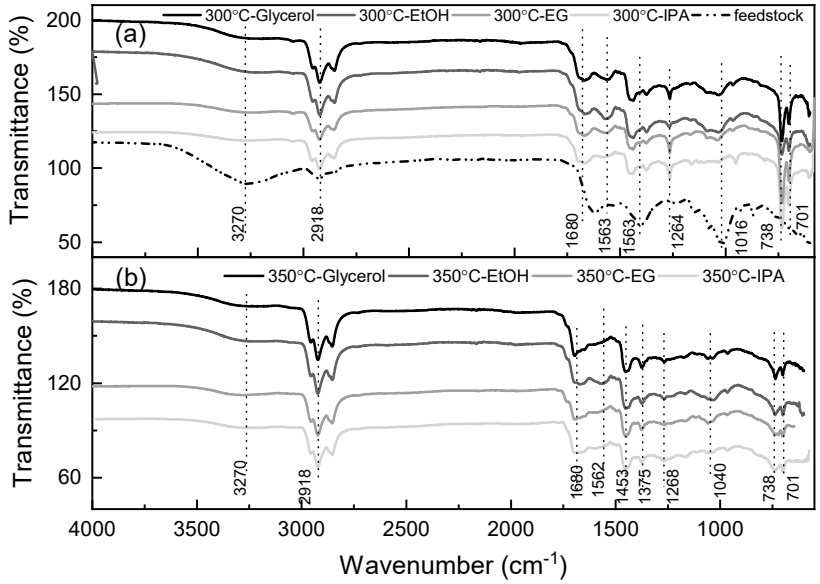

Figure S5. FTIR spectra of biocrude products from HTL treatment of *Tetraselmis* sp. at 300 °C (**a**) and 350 °C (**b**)—with inclusion of different co-solvents at 10% concentration. (IPA: Isopropyl alcohol; EG: Ethylene glycol).

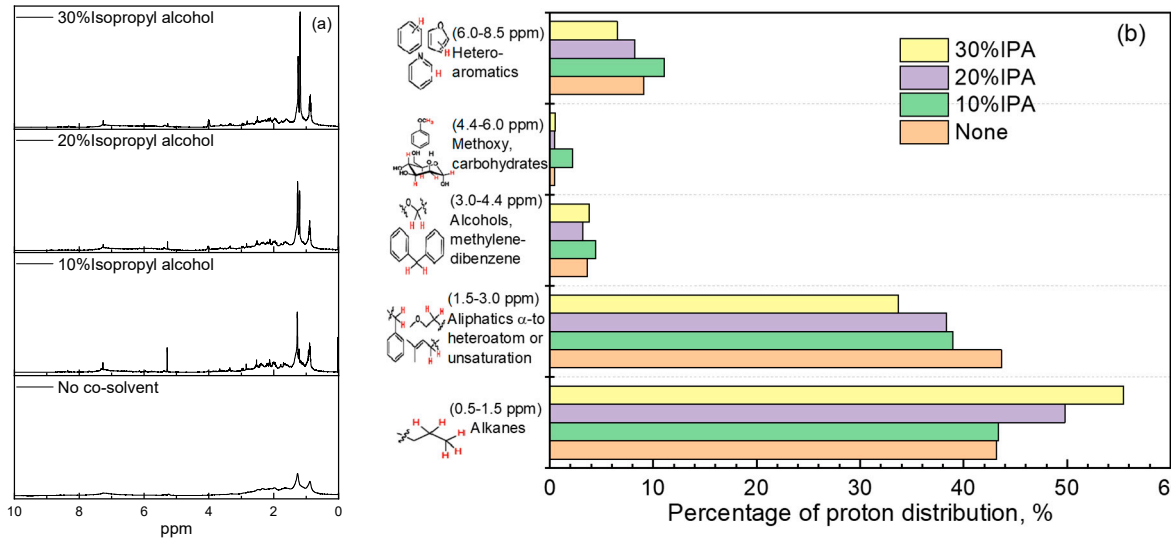

Figure S6. ^{1}H NMR spectra (**a**) and proton distribution (**b**) of biocrude produced from HTL treatment of *Tetraselmis* sp. at 350 °C with varying IPA concentrations.