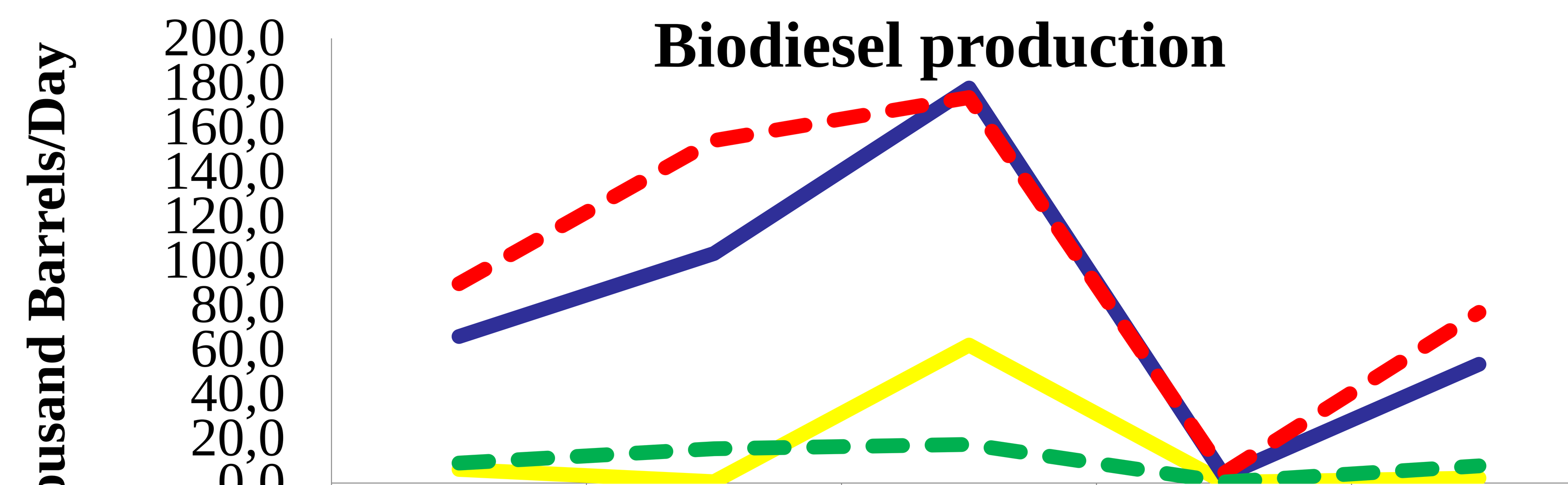
Energy balance and greenhouse gas emissions evaluation on biohydrogen production from crude glycerol by dark fermentation

Vinayak Pachapur[a], Saurabh Jyoti Sarma[a], Ratul Kumar Das[a], Satinder Kaur Brar[a]*, Yann Le Bihan[b], Gerardo Buelna[b], M. Verma[c]

[a]INRS, Centre - Eau Terre Environnement, Québec(QC), Canada
[b]Centre de recherche industrielle du Québec (CRIQ), Québec(QC), Canada
[c]CO_2 Solutions Inc., 2300, rue Jean-Perrin, Québec, Québec G2C 1T9 Canada

Abstract

Biodiesel production across the globe has resulted in proportional increase of crude-glycerol as by-product. Crude-glycerol is a good carbon source for fermentative hydrogen production over other organic wastes. This study compared energy balance and greenhouse-gas emissions during H_2 production using crude-glycerol derived from different feedstock used for biodiesel production. *RESULTS:* The energy balance had significant impact by three factors: inoculum, media and electricity. The net energy (MJ) for different feedstock (vegetable source -174.68, multi-feedstock -127.18 and animal waste -97.08) during H_2 production varied with glycerol content. The highest estimated H_2 production was around 21 cm3 with total production of 2.12 L equivalent fossil diesel and greenhouse-gas reduction around (6.14 kg CO2 eq) from 1 kg of crude-glycerol. The total energy input for industrial enrichment of glycerol (1455.20 MJ) is 4 fold times higher in comparison to maximum total energy input of vegetable feedstock (345.16 MJ).



	North America	Central & South America	Europe	Eurasia	Asia & Oceania
2005	6,1	0,5	62,1	0,3	2,2
2011	65,9	103,2	177,7	3,3	53,4
2020	89,7	154,1	173,4	4,4	76,7
CG in 2020	9,0	15,4	17,3	0,4	7,7

Figure 1: Production of biodiesel across continents during 2005 and 2011, with estimated biodiesel and crude glycerol production for the year 2020.

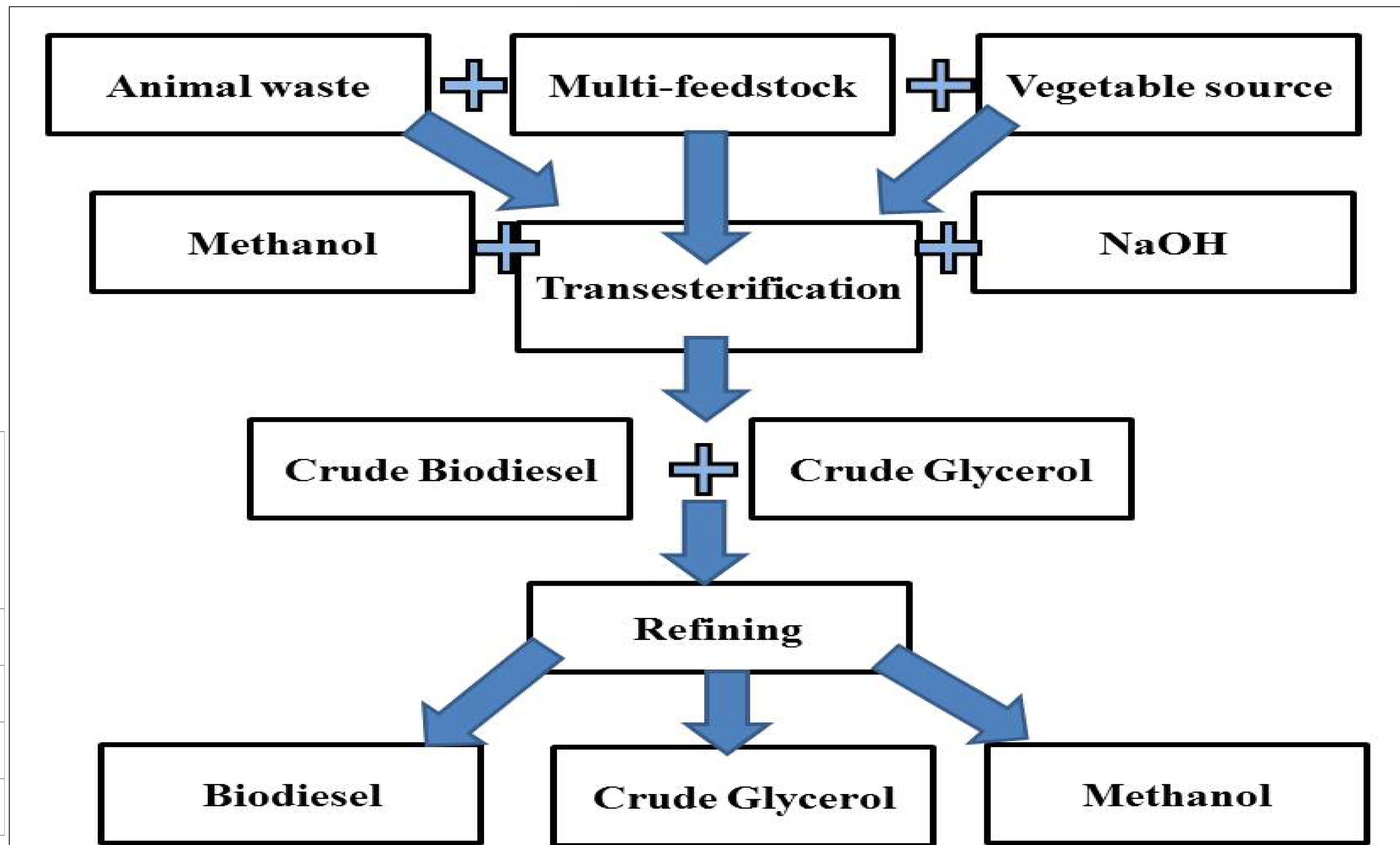


Figure 2: Process details of biodiesel production using different feedstock in biodiesel industries.

Experimental Data					Energy Balance Calculation								
Feedstock	Composition of CG	Microorganisms	Temp/pH	H2 yield (mol/mol glycerol)	Inoculum Step (%)	Media preparation Step (%)	Electricity Consumed (%)	Total energy input (MJ)	Energy credit (MJ)	Net energy (MJ)	Energy output (MJ)	Energy ratio	Ref.
Commercial	Pure	Anaerobic digested sludge	37°C/6.0	0.71	0	37	63	278	105	-173	8	-21	1
Commercial	Pure	*Enterobacter aerogenes*	37°C/6.8	0.89	27	17	56	315	83	-232	8	-28	2
Vegetable source (soyabean, rapeseed, used veg oil)	glycerol: 80%	*Thermotoga neapolitana*	37°C/7.5	2.73	25	25	50	345	85	-260	8	-31	3
Vegetable source (waste vegetable oil)	glycerol 41%	*Enterobacter aerogenes*	37°C/6.8	1.12	27	17	56	315	83	-232	8	-28	4
Vegetable source (rapeseed, sunflower and soya)	glycerol:90%	Microbial mixed culture	37°C/6.8	0.96	16	16	68	258	83	-175	8	-21	5
Animal waste (fried chicken oil)	glycerol: 44%	*Thermoanaerobacterium*	55°C/5.5	0.30	4	10	86	205	82	-123	8	-15	6
Animal waste (meat processing, restaurant waste)	glycerol: 24%	*Enterobacter aerogenes*	37°C/6	0.31	2	0	98	179	82	-97	8	-12	7
Multi-feedstock (soybean, beef tallow, pork lard)	glycerol 84%	Engineered	37°C/6.3	1.02	1	31	68	258	83	-174	8	-21	8
Multi-feedstock (animal fats, recycled cooking oil)	glycerol 82%	*Enterobacter aerogenes*	37°C/6.8	0.85	0	14	85	210	83	-127	8	-15	9-10

Table 1: Biohydrogen productions at lab scale by dark fermentation process using crude glycerol derived from biodiesel production plants which used different feedstock as its raw material. Energy balance (%) summary across each steps during dark fermentation with values of total energy input (MJ), energy credit (MJ) and net energy (MJ) details of different feedstock.

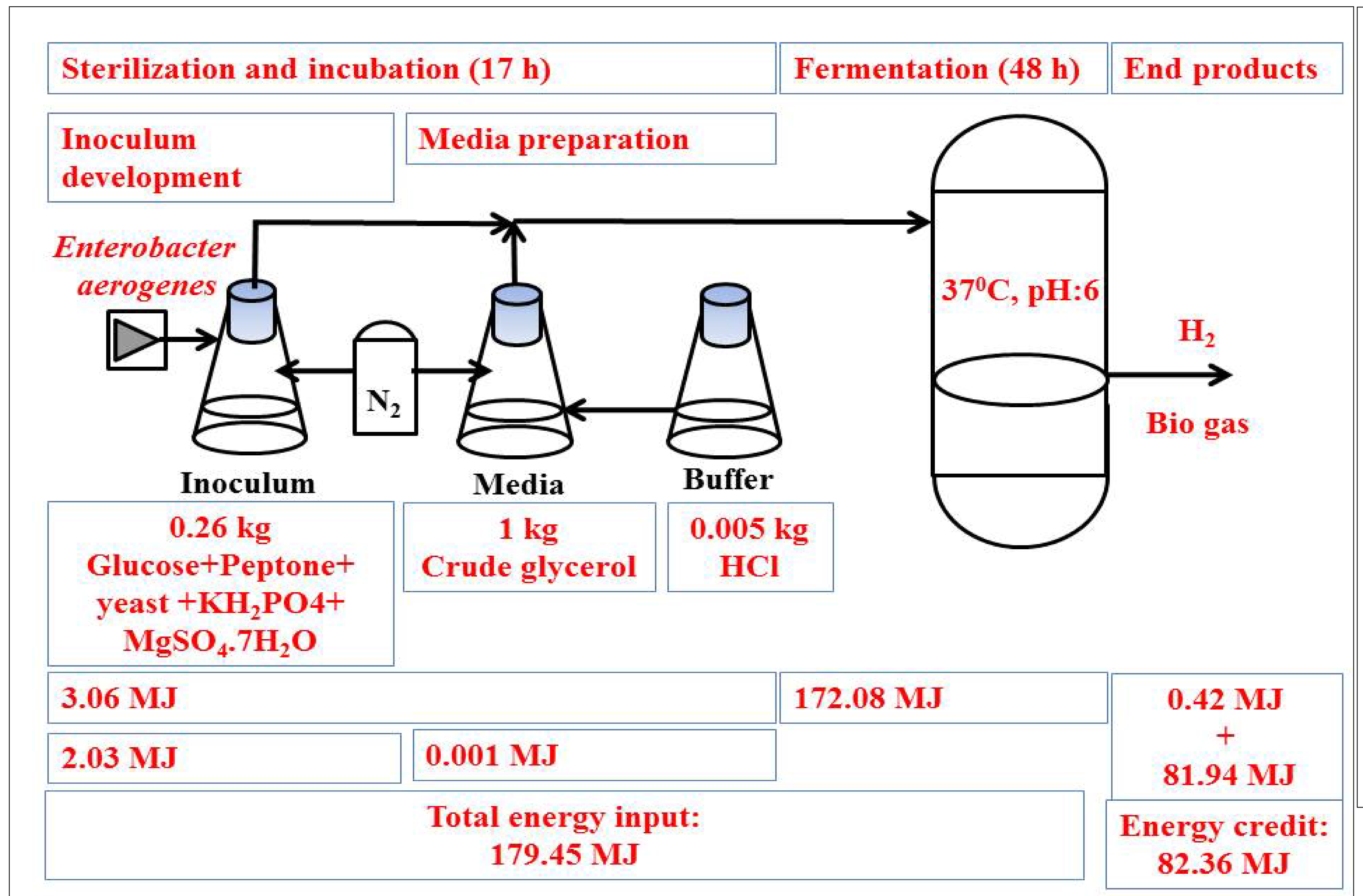


Figure 3: Energy and mass balance values for the CG generated from the animal waste feedstock used in Sarma et al.[10]

Bioconversion Process	Dark Fermentation Benefits	Estimated Benefits for CG produced/day in 2020 across Canada	Estimated Benefits for CG produced/day in 2020 across worldwide
Crude Glycerol	1 kg	44715 kg	594600 kg
Hydrogen	20.57 g	929 kg	12353 kg
Biogas	3414.2 L	16 million L	203 million L
Fossil Fuel replacement	2.12 L	94897 kg	1262115 kg
GHG reduction (CO_2 eq)	7.33 kg	0.3 million kg	4.3 million kg

Table 2: Estimation of environmental benefits from bioconversion of 1 kg of crude glycerol and estimating the results for CG production per day in 2020 across Canada and worldwide.

CONCLUSION: For efficient utilization, bioconversion of crude-glycerol to hydrogen production by dark fermentation can be considered as a suitable option. Minimizing media and inoculum components with crude-glycerol utilization as only carbon source will surely reduce the total energy input. By doing so, the net energy for different feedstock will have a positive value

References
1.Siefert K et al., Int J Hydrogen Energ 34:3671-3678 (2009).
2.Markov SA et al., Int J Hydrogen Energ 36:262-266 (2011).
3.Ngo TA et al., Int J Hydrogen Energ 36:5836-5842 (2011).
4.Ito T et al., J Biosci Bioeng 100:260-265 (2005).
5.Varrone C et al., Int J Hyd Energ 37:1649-16488 (2012).
6.Sittijunda A et al., Int J Hydrogen Energ 37:15473-15482 (2012).
7.Sarma SJ et al., J Chem Technol Biotechnol 88:2264-2271 (2013).
8.Yazdani SS et al., Metab Engg 10:340-351 (2008).
9.Jitrwung R et al., Int J Hydrogen Energ 36:9602-9611 (2011).
10.Jitrwung R et al., Renew Energ 50:222-226 (2013).

Acknowledgement

Financial support from NSERC, CRIQ and INRS-ETE has been acknowledged. SJ Sarma is greatly thankful to FQRNT for financial assistance through a doctoral fellowship (MELS).

Montreal July 13 - 16, 2014

*Author details: Vinayak Pachapur, PhD student,
Telephone: + 418 654 2524 (4477);
E-mail: vinayak.pachapur@ete.inrs.ca