ARTICLE IN PRESS

Applied Energy xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Unified approach to Life Cycle Assessment between three unique algae biofuel facilities ☆

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HIGHLIGHTS

- Description of the Algae Cluster, a set of three European Commission funded algae biofuel demonstration facilities.
- Discussion of various issues within the LCA of algae biofuels with regard to the methodologies used.
- Development of a common LCA methodology for the comparison of three different algae biofuel demonstration facilities.

ARTICLE INFO

Article history:
Received 13 June 2014
Received in revised form 11 December 2014
Accepted 31 December 2014
Available online xxxx

Keywords:
Algal biofuels
Life Cycle Assessment
Harmonized approach

ABSTRACT

The Algae Cluster is a group of three European Commission funded projects, each building a different demonstration algae biofuel facility up to 10 hectares in size. Each project is carrying out an independent Life Cycle Assessment (LCA) to understand the various environmental impacts of the biofuel production.

A major issue with LCA is that there is a high flexibility on defining metrics such as the boundary conditions, functional unit and impact categories. The LCA practitioners for these three projects have agreed upon a harmonised approach, with the intention of ensuring the projects are comparable. This paper details the logic behind this approach, and shares it with the community.

The purpose of this paper is to introduce the three algae demonstration projects and to present a harmonized methodology for LCA of algae biofuels. With this, work by different researchers may be compared more effectively, making it easier to measure the effectiveness of different strategies in algal biofuels with regard to sustainability.

1. Introduction

1.1. Algae biofuels

Algae based biofuels are one of many options to allow society to move to a low carbon society [1], which is necessary to reduce future levels of anthropogenic climate change. However, as with anything, the production of biofuels from an algae feedstock also goes along with environmental impacts. Life Cycle Assessment (LCA) is the most accepted method to quantify these impacts and thus provide options for reducing identified environmental impacts. This paper introduces three unique algae demonstration facilities, and describes the unifying of the LCA approach for these facilities.

Within the literature there are various good discussions on the differences in LCA methodologies, and the associated difficulties these cause, such as [2,3], including system boundaries, co-product allocation methods, electrical energy sourcing, and life cycle inventory data. An example of the differences caused by these inconsistencies is described in [4], where it is noted how the climate change impact results in the literature vary from 0.75 $kgCO_{2eq}$/MJ [5] to 5.34 $kgCO_{2eq}$/MJ [6] (with many studies producing figures between these extremes).

Due to these differences between studies, meta-analysis techniques have been developed such as the Meta-Model of Algae Bio-Energy Life Cycles (MABEL) discussed in [7]. This model adapts previous LCA studies to align the methodologies. Similar meta-models exist for biofuels, such as the Energy and Resources Group

☆ This paper is included in the Special Issue of Life Cycle Analysis and Energy Balance for algal biofuels and for biomaterials edited by Dr. Kyriakos Maniatis, Dr. Mario Tredici, Dr. David Chiaramonti, Dr. Vitor Verdelho and Prof. Yan.

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http://dx.doi.org/10.1016/j.apenergy.2014.12.087
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Table 1
Different GWP100 levels for methane and nitrous oxide.

Gas	100 year Global Warming Potential (GWP100) [CO_{2eq}]						
	LCIA method				IPCC		
	Renewable Energy Directive [23]	CML 2013[a]	TRACI 2.1	ReCiPe 2013[a]	TAR [24]	AR4 [25]	AR5 [26]
Methane	23	25	25	25	23	25	28
Nitrous Oxide	296	298	298	298	296	298	265

[a] Data taken from GaBi 6.2 from PE International.

(ERG) Biofuel Analysis Meta Model (EBAMM) [8], Additionally, [9] carried out a meta-analysis of 47 LCA studies of biofuels to understand quantitatively the differences and sources of differences in results.

Although the meta-models have made progress with comparing systems, it is favourable for the studies to use the same methodology in the first place, so that the results do not need to be reanalysed through a meta-model. The methodology described here is being implemented by three different LCA practitioners within different demonstration projects. The hope with this work is that a modified version of this methodology will ultimately assist in harmonising algae biofuel LCAs. To our knowledge, this is the first attempt by three separate algae biofuel projects to harmonise their LCA approach.

The aim of the work within this paper is to ensure that the LCA results from the three projects within this work are comparable with each other, without necessitating modification via a meta-model. Thus allowing for the relative environmental advantages and disadvantages of each algae production methodology to be assessed.

1.2. Algae LCA data

One major issue for understanding the impacts of algae biofuel facilities is the lack of real life data. Many articles exist with theoretical LCAs, including [5] (*Nannochloropsis*) and [10–13] (*Chlorella*), but very few contain real data. Two notable exceptions are [14,15], which deal with algae production without the process of refining the raw lipids into biodiesel. The authors have not identified any articles in the peer review literature that refer to real data from industrial scale full algae-biofuel facilities.

[14] implemented an LCA based on data from Seambiotic, Inc., in Israel and Solution Recovery Services (SRS) Inc., based in Dexter, Michigan, USA (now trading as Valicor). These two facilities produce algae for high value products instead of algae biodiesel. Because of this, the transesterification data for the oil to biodiesel conversion used in [14] was taken from the University of Argone GREET 1_2011 model [16]. The boundary conditions of [14] followed a pond to wheels model.

[15,17] discuss work at the university of Texas on *Chlorella* based biofuels. Within these papers, data was utilised from the processing of five large-scale batches at the University of Texas with a total processed volume of ~7600 L. At the University site algae was inoculated in bioreactors, and then fed into raceways. The yield from the algae facility in this case was 0.002 g/(L-day). The work showed an extremely low energy ratio of 9.2×10^{-4}, which the papers put down to the issue that this was a research facility, not optimised for commercial production.

1.3. Differences within LCA studies on algal biofuels

The ISO standards ISO 14044 [18] and ISO 14040 [19] specify the structure for implementing an LCA [20]. However, although these give a general approach and methodology to follow, many elements are up to the particular researcher. These include the boundary conditions, impacts categories and functional unit [21]. The result of this is that many comprehensive LCAs for similar technologies are not easily comparable. Within the algae industry this continues. For example, within [14] the functional unit was 1 MJ of energy produced by combusting the fuel in a compression-ignition direct-injection (CIDI) passenger car. Conversely, [15] used a functional unit of 1 MJ, not dependent on vehicle.

Even the application of similar impact assessment methodologies can lead to different results. For example for calculating the eutrophication potential different approaches exist [20]. The CML methodology uses phosphate equivalent as the categorisation factor, whereas the TRACI methodology uses nitrogen equivalent. This means that studies in different papers (such [6] and [6,22]) cannot be easily compared [2].

Global Warming Potential (GWP) is another example of issues with impact categories; specifically there are slightly different characterization factors of various greenhouse gases. For example, the EU Renewable Energy Directive (RED) [23] uses values for GWP integrated over 100 years (GWP100) for methane and nitrous oxide taken from the IPCC Third Assessment Report [24] published in 2001. However, subsequently the Fourth Assessment Report (AR4) [25] (published in 2007) and Fifth Assessment Report (AR5) [26] (published in 2013) have modified these figures, as understanding of these gases has increased. An additional matter to note is that different methodologies measure different gases. For example, while RED considered three gases (carbon dioxide, methane and nitrous oxide), ReCiPe considers 93 gases. TRACI 2.1 and ReCiPe 2013 both also consider more gases than CML 2013.

The differences between GWP100 values for different LCA methods and the IPCC data are demonstrated in Table 1. The CML 2013, TRACI 2.6 and ReCiPe systems all use the same figures for methane and nitrous oxide, in line with AR4. However, RED uses data from TAR.[1] In the meantime, the latest data is within AR5 (as AR5 has only been released it would be unreasonable to expect impact categories to have been updated).

The result of these differences is that LCA studies for similar unit processes can be difficult to compare.

2. The three approaches

2.1. Algae Cluster

The Algae Cluster (www.algaecluster.eu) is composed of three demonstration projects, "Demonstration of integrated and sustainable microalgae cultivation with biodiesel validation" (InteSusAl), "BIOfuel from Algae Technologies" (BIOFAT) and "Industrial scale demonstration of sustainable algae cultures for biofuel production" (All-Gas), each part funded by the European Commission. Each individual project is in the process of constructing a demonstration algae biofuel facility, each of which will produce algae biofuel using a different methodology. All three facilities will be producing

[1] It is important to note that as stated during the 2nd European Workshop on LCA for Algal Biofuels & Biomaterials, RED is currently under review, and will use the AR5 impacts for greenhouse gases.