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Life cycle assessment as a tool to support decision making in the biopharmaceutical industry: Considerations and challenges

Sri Vaitheki Ramasamy[a,*], *Nigel J. Titchener-Hooker*[a], *Paola Lettieri*[b]

[a] *The Advanced Centre for Biochemical Engineering, Department of Biochemical Engineering, University College London, Torrington Place, London WC1E 7JE, UK*

[b] *Department of Chemical Engineering, University College London, Torrington Place, London WC1E 7JE, UK*

ABSTRACT

The past decade has seen an increasing focus on the issues surrounding climate change and this has triggered international governments to develop environmental legislation and policies for the energy-intensive industries (EIIs) that can help reduce their anthropogenic greenhouse gases (GHG) emissions. The biopharmaceutical industry is a relatively new EII. The industry is important for global health as it is a main provider of affordable new therapies, achieved through the genetic manipulation of living organisms. Historically, attractive financial returns have encouraged the biopharmaceutical industry to focus on employing decision-support tools to estimate the process economics of manufacture. However, as the industry matures, the level of environmental scrutiny is increasing. Therefore, there is a need for the development of environmental tools specific to this industry to help guide the selection of environmentally favourable manufacturing operations. Life cycle assessment (LCA) is a commonly used environmental tool. We study the potential for application in the biopharmaceutical industry as an aid to decision making. Such tools assess the environmental impacts of a product or process over the entire life cycle. This paper reviews the use of LCA in the context of decision-making when applied to evaluate the environmental impact of the biopharmaceutical industry's manufacturing processes.

Keywords: Climate change; Greenhouse gases (GHGs), Biopharmaceutical industry; Life cycle assessment; Decision-support tools; Environmental impacts

1. Introduction

The increasing level of scrutiny placed upon environmental issues, especially rising global temperatures, has triggered governments worldwide to consider sustainable development and climate change more actively (UNEP, 2009). The latter occurs when greenhouse gases (GHGs) trap heat close to the earth's surface causing a change in the earth's temperature (EPA, 2010). Climate change is undesirable as it can lead to catastrophic events such as droughts, floods, water and food shortages, species extinction, and overall unsustainable development (Pandey et al., 2010).

Internationally, governments are focusing on developing legislation, policies and initiatives for organisations to adopt in order to address climate change issues. These are being developed especially for the energy-intensive industries (EIIs) because these are seen as one of the major contributors to GHG emissions. The industries include iron and steel,

Abbreviations: ALCA, attributional life cycle assessment; CIP, cleaning-in-place; CLCA, consequential life cycle assessment; EII, energy-intensive industries; ETS, emission trading scheme; IRR, internal rate of return; ISO, International Organisation for Standardisation; LCA, life cycle assessment; LCC, life cycle costing; LCI, life cycle inventory; LCIA, life cycle impact assessment; NPV, net present value; ROCs, renewables obligation certificates; SIP, steam-in-place; S-LCA, social life cycle assessment.

* *Corresponding author*. Tel.: +44 020 7679 3796; fax: +44 020 7916 3943.
E-mail addresses: sri.ramasamy@ucl.ac.uk, sriramasamy7@gmail.com (S.V. Ramasamy).

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chemical, petroleum, automotive, and the biotechnology industries. Collectively, they are responsible for 45% of all business and public sector GHG emissions (Bullock, 2009; POST, 2012). The Climate Change Act 2008, the EU Emissions Trading Scheme (ETS), the End-of-Life Vehicles (ELV), the Best Practicable Environmental Option (BPEO) and Responsible Care are amongst the list of environmental legislation, policies and initiatives currently instituted for the EIIs as measures to reduce GHG emissions in the UK (POST, 2012; WWA, 2011; Clift et al., 2000).

The biopharmaceutical industry focuses on healthcare, and it is an important contributor to improved global health (Mehta, 2008). The industry employs biological processes to create useful commercial drugs (Mehta, 2008). The main products include monoclonal antibodies, biologics drugs such as growth factors, hormones, fusion proteins, cytokines, blood factors and therapeutic enzymes, and vaccines (Aggarwal, 2010; Mehta, 2008). The industry is characterised by a high growth rate and a strong pipeline of drugs (Mehta, 2008). Worldwide sales of biologics in 2010 were estimated to be in excess of $100 billion, with over 200 biologics currently on the market (Walsh, 2010). As the number of biologic drugs emerging from clinical development rises, manufacturers are now being prompted to find flexible, cost-efficient and environmentally feasible solutions for global scales of production. The industry is recognised as being an EII but has historically been perceived as less energy intensive than others though this is probably conjecture rather than fact.

The biopharmaceutical industry uses a range of manufacturing operations to achieve the exacting standards needed for therapeutic drugs, run in either a traditional mode where equipment is cleaned in-between batches or in single-use mode where no such cleaning is required (Sinclair et al., 2008; Farid et al., 2005). Traditional batch processing still remains the predominant approach to manufacturing with items largely constructed of stainless steel. Therefore, they require assembly, clean in place (CIP), and steam-in-place (SIP) after each production batch (Sinclair and Monge, 2002). Although such traditional technology manufacturing operations are well established, their use is associated with (Shukla and Gottschalk, 2012):

- high levels of water consumption (a study carried out by Sinclair et al., 2008 estimated that for a 1000-L operation scale, around 100,000 L of water is consumed per production batch for reagent preparations and CIP/SIP operations);
- large capital investment; and
- increased manufacturing downtime.

These limitations have sparked interest in the wider adoption of manufacturing alternatives. One such alternative relies upon the deployment of single-use technologies, which employ disposable equipment. The earliest single-use elements adopted in the biopharmaceutical industry were basic filtration components, tubing, and connectors (Langer and Price, 2007). The industry is now increasingly employing single-use bioreactors, mixing devices, membranes, chromatography columns, sampling devices, and probes (Langer and Price, 2007). Such single-use manufacturing process technologies can offer many benefits (Shukla and Gottschalk, 2012; Pierce and Shabram, 2004; Rodrigues et al., 2010; Flaherty and Perrone, 2012):

- a reduction in water consumption (a case study carried out at a biological plant operating at 2 × 2000-L operation scale determined that adopting a fully single-use manufacturing process could result in savings of more than one million litres of water);
- reduction in the facility footprint;
- reduction in the high capital investment associated with stainless steel equipment;
- reduction in the frequency of process cross-contamination; and
- process time reductions.

Process time reduction is an important factor for biologics as timely market penetration can be key to success (Farid et al., 2005). Although, single-use technologies can provide many benefits, there are several limitations associated with this type of manufacturing processes (Sinclair et al., 2008; Eibl et al., 2010; Shukla and Gottschalk, 2012):

(1) Limited production scale; highest volume of bioreactor is 2000 L.
(2) Production of leachables and extractables by the single-use bags that could contaminate the product.
(3) Potential adverse effects to the environment due to the increased solid waste levels inherent in operation with single-use components.
(4) Moreover, it is not clear how the environmental impacts of single-use items contribute to mitigating the consequences of normal operation using extensive water-based cleaning.

In this paper, we address points (3) and (4) and highlighting the challenges to implement these aspects within a quantitative tool.

Presently, the most significant challenge faced by the decision makers in the biopharmaceutical industry is selecting between traditional and single-use manufacturing processes. A number of factors must be evaluated before opting for a particular manufacturing process, and these include the process economics (the capital investment, the cost of goods, net present value (NPV), internal rate of return (IRR), process risks, and also the manufacturing process timeline), all which are functions of the mode of manufacturing selected (Farid, 2007). Over recent years, computer based simulation tools have been used to aid in the process of enabling decision makers to evaluate these factors, and help them decide on the manufacturing processes options to adopt (Farid et al., 2005). Such computer based tools are particularly beneficial in industries where finances are constrained and timelines are exacting, as access to such tools can facilitate more rapid capital investment decisions, cost-of-goods analyses, project management analyses and risk assessments (Farid, 2007). A list of commercially available process economic decision-support tools for applications in the biopharmaceutical industry is provided in Table 1.

Historically, attractive financial returns have encouraged the industry to focus on developing decision-support tools by which to estimate process economics (Farid et al., 2005). Now, with increasing environmental legislation, policies and governmental initiatives associated with climate change have triggered a broader biopharmaceutical industry interest in the environmental contributions made by manufacturing (POST, 2012). Pressure from governmental bodies is not the only factor