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Potential of seaweed as a feedstock for renewable gaseous fuel production in Ireland

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ABSTRACT

Resource depletion and mitigation of climate change are the driving forces to find alternatives to fossil fuels. Seaweeds (macroalgae) have been considered as a promising alternative source of biofuels due to higher growth rates, greater production yields and a higher rate of carbon dioxide fixation, than land crops. A comparatively easily depolymerized structure, lack of need of arable land and no fresh water requirement for cultivation, make seaweed a potential feedstock for gaseous biofuel production. Biomethane potential of seaweed is greatly dependent on its chemical composition that is highly variable due to its type, habitat, cultivation method and time of harvest. *Saccharina latissima* and *Laminaria digitata* are the highest biomethane yielding Irish brown seaweeds. Seaweed harvested in July (northern hemisphere) was estimated to give gross energy yields in the range 38–384 GJ ha^{-1} yr^{-1}; higher values are dependent on innovative cultivation systems. An integrated model is suggested where seaweed can be co-digested with other feedstock for the sustainable production of gaseous fuel to facilitate EU renewable energy targets in transport.

1. Introduction

World primary energy consumption is expected to double by 2050 with a 1.6% annual growth rate [1]. In 2001, energy consumption by 6.1 billion people was 13.5 TW; 86% derived from fossil fuels. In 2050, the population is expected to be 9.4 billion and energy demand 40.8 TW. It is likely that environmental pollution will grow with population and energy growth. This has led to a focus on alternative and renewable sources of energy [2]. The European Commission (Directive 2009/28/EC) proposed a reduction in the greenhouse gas emissions through the use of transport biofuels at a level of 10% of primary energy in transport by 2020 [3]. In 2012, an EC proposal [4] suggested limiting first generation biofuels (from food crops) to 5% RES-T (renewable energy supply in transport). In 2013, it was proposed to be raised to 6% [5] and that advanced biofuels (such as from seaweed) should represent at least 2.5% of RES-T; In 2015 this target was reviewed and set to 1.25% [6].

Life cycle analysis of biofuels benefits from utilization of carbon dioxide during growth of biomass [7]. Biodegradability, low toxicity, and low pollutant emissions offer advantages over petroleum-based fuels [8]. Biofuels are classified on the basis of biomass feedstock. First generation biofuels are produced from food commodities (such as corn and sugar cane), second generation biofuels are from lingo-cellulosic biomass (including agricultural residues such as straw) and third generation biofuels generated from algae [9]. First generation biofuels suffer from the food-versus-fuel debate [10]. Second generation biofuels do not use food crops, but may require land. Technical barriers still exist in breaking down second generation substrates to fermentable sugars [11]. Biological techniques may be used to overcome these barriers [12].

Macroalgae (seaweed) can exhibit higher growth rates, greater production yields [13] and higher rate of carbon dioxide fixation [14] than land-based energy crops. Seaweeds do neither need arable land nor fresh water for cultivation [15]. Negligible quantities of hemicellulose and lignin [8] facilitate easy depolymerisation [16]. Seaweeds are amenable to co-digest with a variety of feedstocks such as dairy slurry, agricultural waste, food waste and microalgae and are suitable for liquid and gaseous biofuel production [8]. Seaweed biofuels can produce more gross energy yield per hectare than most land-based energy crops. For instance, rapeseed biodiesel (first generation) can generate 1350 L (44 GJ) of biodiesel per hectare per annum [17]; willow biomethane (second generation biofuel) can generate a gross

Abbreviations: AD, anaerobic digestion; BI, biodegradability index; BMP, biomethane potential; CSTR, continuous stirred tank reactor; BNG, bio-natural gas; SMY, specific methane yield; TMP, theoretical methane potential; TRL, technology readiness level; VFA, volatile fatty acid; VS, volatile solids

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energy yield of ca. 130 GJ ha^{-1} yr^{-1} [18]. The yields of seaweeds (wet weight: wwt) per hectare are variable depending on species and growing conditions. Definitive data is not known or accepted yet but according to Christiansen [19], it can be up to 130 t wwt per hectare. The gross energy per hectare of seaweed biomethane can be estimated as 230 GJ $ha^{-1}yr^{-1}$ if a specific methane yield (SMY) of 330 L CH_4 kg^{-1} volatile solids (VS) is achieved [20].

Ireland is an island with a temperate oceanic climate off the west coast of Europe with a very significant coastline (7500 km) allowing access to a large source of seaweed [21]. Irish brown seaweeds (such as *Laminaria digitata and Sacharina latissima*) are rich in organic matter. Existing harvesting potential of various seaweed ranges from 35 t wwt ha^{-1} yr^{-1} to 300 t wwt ha^{-1} yr^{-1} [21]. Energy demand in the transport sector in Ireland is expected to be of the order of 188 PJ in 2020; according to the EU, 1.25% (2.35 PJ) should be from advanced biofuels, such as seaweed, by 2020 [22]. The target may be achievable by applying innovative technologies using seaweed as an alternative substrate for gaseous fuel production.

The objective of this paper is to synthesise the literature on seaweed biomethane and assess the resource and applicability for a temperate

Fig. 1. Seaweeds found on the Irish coastline.