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The impact of feedstock cost on technology selection and optimum size

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Abstract

Development of biomass projects at optimum size and technology enhances the role that biomass can make in mitigating greenhouse gas. Optimum sized plants can be built when biomass resources are sufficient to meet feedstock demand; examples include wood and forest harvest residues from extensive forests, and grain straw and corn stover from large agricultural regions. The impact of feedstock cost on technology selection is evaluated by comparing the cost of power from the gasification and direct combustion of boreal forest wood chips. Optimum size is a function of plant cost and the distance variable cost (DVC, \$ dry tonne^{-1} km^{-1}) of the biomass fuel; distance fixed costs (DFC, \$ dry tonne^{-1}) such as acquisition, harvesting, loading and unloading do not impact optimum size. At low values of DVC and DFC, as occur with wood chips sourced from the boreal forest, direct combustion has a lower power cost than gasification. At higher values of DVC and DFC, gasification has a lower power cost than direct combustion. This crossover in most economic technology will always arise when a more efficient technology with a higher capital cost per unit of output is compared to a less efficient technology with a lower capital cost per unit of output. In such cases technology selection cannot be separated from an analysis of feedstock cost.

Keywords: Biomass gasification; Direct combustion; Biomass power economics; Scale factor; Optimum size

1. Introduction

One major source of interest in biomass utilization is mitigation of greenhouse gas (GHG). In this, biomass competes with other alternatives, such as wind, solar, and sequestration. If the full potential of biomass to mitigate GHG is to be realized at maximum social benefit, biomass applications must be developed in their most economical form.

For a given source of biomass three factors have a strong impact on the cost of biomass utilization: the end product (e.g. power, heat, ethanol), the technology of conversion, and the scale. In this work we explore the impact of feedstock cost on technology selection and optimum size when a lower efficiency technology with a lower capital cost per unit of output is compared to a higher efficiency technology with a higher capital cost per unit output. Specifically, we look at one end product, electrical power, and evaluate the impact of feedstock cost on the optimal scale and overall power cost for direct combustion and high pressure gasification of boreal forest woodchips. Optimum size is measured by the cost of power, with the sole limitation of maximum size set by electrical grid stability; limitations in biomass feedstock and possible byproduct disposition, e.g. heat, are not considered. This case illustrates a generalizable conclusion: if feedstock cost is low, the less efficient lower cost process is more economic, and at higher feedstock cost the more efficient higher cost process is more economic. Further, feedstock cost can be broken down into two components, one that varies with transportation distance, which we call distance variable cost (DVC) and one that is independent of transportation distance, which we call distance fixed cost (DFC). Cost of transport is the main component of DVC, while harvesting and acquisition (payment to the owner of the biomass) and biomass loading and unloading costs are the main components of DFC. (For a fuller discussion of DVC and DFC see [1].) Note that both DVC and DFC may vary over the life of a project. Competition for

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feedstock can raise DFC, while increasing transportation fuel costs can raise DVC. DFC normally has no impact on the optimum size of a biomass processing plant because it is scale independent. The optimum size for biomass projects arises from a tradeoff between the capital and operating cost efficiency of larger plants versus the rising DVC of fuel for such plants [2]. (Note that biomass power plants are inherently different than most fossil fuel power plants, for which the DVC of fuel is often less as project size increases, due to more efficient use of delivery infrastructure such as a gas pipeline or coal unit train.) For biomass-based plants, because increases in DVC are partially offset by adjustments in optimum plant size, DVC and DFC have asymmetric impacts on the overall cost of output of an optimally sized biomass processing plant.

Biomass power projects have typically been developed at small scale; with the exception of a Finnish plant (near Pietarsaari) with mixed fuel at 240 gross MW (before allowing for consumption of power in the generation plant itself) and a US wood plant at 80 net MW [3,4], all are below 70 MW and many are much smaller. Many authors have calculated economic optimum sizes that are significantly larger than 50 MW (see, for example [2,5,6]; two studies have suggested that at certain biomass yield densities and transportation costs optimum size is in excess of 400 MW [5,6]. Three factors have contributed to the small size of existing biomass power projects. First, biomass supply is limited in some plants, as often occurs when using mill residues such as bark or sawdust. Second, many projects are of a demonstration nature for which size reflects the goal (demonstration rather than economical operation) and the uncertainty of technology. Third, many projects are supported from public funds, and the limitation on funding constrains the selection of size.

In this paper we focus on a biomass source for which availability is high in comparison to plant size. This is true for many agricultural residues (e.g. corn stover in the US Midwest, grain straw in parts of Europe and North America, and wood and forest harvest residues (limbs and tops of trees harvested for pulp or lumber) in boreal forests and other large forested areas). In such areas the correct selection of biomass power plant size will have a strong impact on overall cost of power. The analysis in this paper is based on wood chips but would apply in concept to any abundant biomass source.

One technology available to the developer of a biomass-based electrical power project is high pressure biomass gasification followed by an integrated combined cycle unit that combusts the gas in a turbine and recovers heat for additional power generation in a conventional steam cycle; this is referred to in the literature as BIGCC (see, for example [6–8]), and in this work will be referred to as gasification. A second option is conventional direct combustion of the biomass in a boiler, utilizing a conventional steam cycle; we refer to this as direct combustion.

This study uses a prior model that studied in detail the cost factors for the collection and transportation of wood chips in western Canada [5]. Note that variable trucking cost, the main component of DVC, is \$0.125 dry tonne^{-1} km^{-1}, which is typical of North American costs (for a detailed discussion of trucking costs for biomass, see [9]). All costs in this work are in year 2004 US dollars.

In this study, data for gasification are drawn from information provided by General Electric Corporation (GE) [10] for plant sizes of 20, 40, 250, and 500 MW capacities. Although high pressure gasification of biomass has not been commercially developed on a large scale, detailed designs have been completed and all of the components are well known: gasification is a well established technology, and combustion of low heating value gas in turbines is already practiced, for example with coke oven gas.

Data for direct combustion are drawn from three sources:

- an analysis of existing units, most of small scale and "first of a kind" demonstration units;
- a comparison to large coal fired units;
- an estimate based on extrapolating differences expected between a mature biomass combustion technology and the existing mature coal combustion technology, based on key differences between the processes.

Gasification and direct combustion have different maximum sizes of single units. If sufficient fuel were available there is no evident technical reason why direct combustion power plants utilizing biomass could not be developed to 500 MW of net output and perhaps higher. The maximum size evaluated in this study, a size frequently chosen in North America because of grid stability issues arising from a unit trip. Coal fired direct combustion plants have been commonly built in this size range, and more recently have been developed up to sizes of 900–1000 MW [11]. This contrasts to gasification processes, where materials constraints on turbine size in the combined cycle plant currently limit the maximum size of a single turbine unit firing low heating value gas to 250 MW of output [10]. Above 250 MW, the design would change to two parallel gas fired turbines supplied by two gasifiers, with a common heat recovery steam generator (HRSG) and steam turbine.

Maximum unit size is a critical factor in assessing relative economics because the economy of scale typically changes at the point that a maximum unit size is reached. Scale factor is the most commonly used technique for estimating the impact of size of plant on the cost of a single processing train. Scale factor is the exponent in the commonly used cost estimating formula

$$\text{Cost 2}/\text{Cost 1} = (\text{Size 2}/\text{Size 1})^{(\text{scale factor})}. \tag{1}$$

Scale factor for large projects is a matter of some dispute. Jenkins uses a formula that increases the scale factor with increasing plant size; in his reference case the