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An assessment of competition for biomass resources within the energy and transport sectors

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Abstract

Bio-energy is expected to become increasingly attractive in the future owing to its potential to contribute to lowering greenhouse gas emissions, increasing rural and regional employment and improving energy security through substituting for oil imports. The volume of sustainable biomass resources that are economically competitive but do not significantly impact on food production is expected to slowly expand as new feedstock varieties and refining pathways are developed. However, these volumes will remain limited relative to total energy and transport sector fuel demand.

Limited biomass resources will be allocated to the sector that is most able to afford them. This will depend on the price of existing fossil fuel products and the relative cost of converting biomass into substitute final fuels such as bio-derived electricity, ethanol blends, biodiesel and bio-derived jet fuel. It will also depend on factors such as the availability and cost of alternative fuel and energy sources, government policies including excise rates, and the emission intensity of each sector.

This paper presents a number of alternative cost curves for bio-energy resource to final energy costs and applies a partial equilibrium model of the electricity and transport sectors, called the Energy Sector Model (ESM), to determine where the limited biomass resources are likely to be allocated under various scenarios. Preliminary projections are presented for biomass uptake in each of the electricity, road and aviation sectors to 2050.

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Introduction

In addition to its crucial contribution to the global ecosystem, biomass is a resource which has a multitude of other uses including food, fibre, building materials and energy. A relatively recent additional end-use, beyond the traditional uses of biomass in space heating and cooking, is bio-energy in the form of liquid transport fuel and electricity.

The recent growth in interest in using biomass as an energy source is being driven by three factors. There is the desire firstly to address the risk of climate change, by reducing greenhouse gas emissions, and secondly to improve energy security and reduce economic exposure to rising fuel prices, by diversifying available sources of transport fuels. Finally, there is the desire to provide opportunities for rural and regional development, which have otherwise tended to be reduced due to the worldwide trend that has seen wealth creation opportunities shift to urban centres.

The growth in demand for bio-energy has been met by concern about the impact of competition for biomass resources on food prices (Gielen et al., 2000; Reilley and Paltsev, 2007). A related concern has been whether some methods used to provide the biomass to energy applications have other negative environmental impacts that outweigh any greenhouse gas reduction benefits (Fritsche, 2009; Tan et al., 2007). These concerns have led to the development of institutions such as the Round Table on Sustainable Biofuels (Scarlat and Dallemand 2011). The principles laid out by such groups are designed to ensure that biofuels production is sustainable, does not negatively impact food security, and makes a positive contribution to greenhouse gas abatement. The application of these principles generally requires bio-energy producers to draw on so called “second generation” biomass resources which consist of agricultural and forestry wastes, and new energy crop varieties which can be cultivated on marginal agricultural land or in mixed cropping systems.

This paper addresses not only on the electricity sector, but focuses on the question of how competition for biomass between electricity and liquid fuels may be resolved. Research in the literature that has previously addressed this issue has typically only addressed competition between electricity and land transport (see for example Gielen 2000). This paper is also concerned with competition within the transport sector, specifically between the road and aviation sectors.

Previous research on the use of biomass has also tended to focus on optimising for greenhouse gas abatement (Tampier et al., 2004; Cowie and Gardner, 2007). This is the most common type of framework for determining the best use of biomass. Such studies have tended to find that greater greenhouse gas abatement results from the use of biomass in electricity generation, at least in the short term and when the existing electricity system is based on fossil fuel, particularly coal which has the highest carbon content.

The paper presents a modelling framework and preliminary modelling results developed for an aviation road map process conducted during 2010. The approach builds on previous market based analyses such as Gielen et al. (2000), but with particular focus on the Australasian region.

While it is not clear that RSB principles will be adopted worldwide, this paper assumes that the competition for biomass resources between the food and energy sectors will likely be resolved. The question of how markets for building materials, or for afforestation for biodiversity or the bio-sequestration of carbon, may be affected by changes in biomass demand are only partially addressed. We assume that biomass (primarily forests) that are currently used as raw materials in building products and other manufactured goods will continue to be directed to those industries. We also assume that some afforestation activities are also consistent with some biomass harvesting in order to optimise growth for both harvested product and carbon storage (Gielen et al., 2000).

Modelling framework

The outputs required by the study are GHG emissions, prices, demand, and fuel consumption by fuel for both the electricity and transport sectors in Australasia.

The primary issue was competition for biofuels so the modelling framework needs to be capable of indicating whether biomass energy sources are best utilised as liquid fuels in aviation and land transport or electricity generation for land transport or grid.

While electricity and land transport are principally domestic industries, an important consideration was whether it was necessary to model the aviation market as a global one. From a fuel supply perspective it was judged that most sustainable biofuel would likely have to be sourced locally, although countries in Europe may source material from Africa, and some taxes that affect fuel choice may be imposed by destination countries. In the Australian context, it was assumed that the international aviation market did not need to be modelled in detail.

Additional features required include the ability to calculate macroeconomic impacts via measures such as Gross Domestic Product (GDP) and industry output. Transport and stationary electricity demand was thus projected using general equilibrium model outputs. For further details see (Graham et al, 2011).

There is also a need to understand bio-refinery product pathways since each biomass type will be suited to a particular type of refining process and each process will have different costs.

Energy Sector Model (ESM)

This study used the Energy Sector Model (ESM). It was originally co-developed in 2006 by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Agricultural and Resource Economics (ABARE). Since that time ESM has been significantly modified and expanded by CSIRO.

ESM is a partial equilibrium (bottom-up) model of the electricity and transport sectors. The model has a robust economic decision making framework that accounts for the cost of alternative fuels and vehicles, as well as detailed fuel and vehicle technical performance characterisation such as fuel efficiencies and emission factors by transport mode, vehicle type, engine type and age. It also has a detailed representation of the electricity generation sector. Competition for resources between the two sectors and relative costs of abatement are resolved simultaneously within the model.

ESM has been applied to the scenario analysis of transport energy futures including: alternative emission targets (e.g., CSIRO, 2008; Graham et al., 2008; Reedman and Graham, 2009), alternative carbon price regimes (e.g., CSIRO and ABARE, 2006; Commonwealth of Australia, 2008) and peak oil scenarios (Graham and Reedman, 2010).

ESM model equations and structure

ESM is solved as a linear program where the objective function to be maximised is welfare, defined as the discounted sum of consumer and producer surpluses over time. The sum of consumer and producer surplus is calculated as the integral of the demand functions minus the supply functions, which are both disaggregated into many components across the electricity and transport markets. The objective function is maximised subject to constraints that control for the physical limitations of fuel resources, the stock of electricity plant and vehicles, greenhouse gas emissions as prescribed by legislation, and various market and technology specific constraints such as the need to maintain a minimum number of peaking plants to meet rapid changes in the electricity load. The main features of ESM include:

- Coverage of all States and the Northern Territory (Australian Capital Territory is modelled as part of NSW) and New Zealand
- Nine road transport modes: small, medium and heavy passenger cars; small, medium and heavy commercial vehicles; rigid trucks; articulated trucks and buses
- Five engine types: internal combustion; hybrid electric/internal combustion; hybrid plug-in electric/internal combustion; fully electric and fuel cell
- Thirteen road transport fuels: petrol; diesel; liquefied petroleum gas (LPG); natural gas (compressed (CNG) or liquefied (LNG)); petrol with 10 per-cent ethanol blend; diesel with 20 per-cent biodiesel blend; ethanol and biodiesel at high concentrations; biomass to liquids diesel; gas to liquids diesel; coal to liquids diesel with upstream CO_2 capture; hydrogen (from renewables) and electricity
- Seventeen centralised generation (CG) electricity plant types: black coal pulverised fuel; black coal integrated gasification combined cycle (IGCC); black coal with CO_2 capture and sequestration (CCS) (90 per-cent capture rate); brown coal pulverised fuel; brown coal IGCC; brown coal with CCS (90%); natural gas combined cycle; natural gas peaking plant; natural gas with CCS (90%); biomass; hydro; wind; solar thermal; hot fractured rocks (geothermal), wave, ocean current and nuclear
- Seventeen distributed generation (DG) electricity plant types: internal combustion diesel; internal combustion gas; gas turbine; gas micro turbine; gas combined heat and power (CHP); gas micro turbine CHP; gas micro turbine with combined cooling, heat and power (CCHP); gas reciprocating engine CCHP; gas reciprocating engine CHP; solar photovoltaic; biomass CHP; biomass steam; biogas reciprocating engine; wind; natural gas fuel cell and hydrogen fuel cell
- Trade in electricity between National Electricity Market (NEM) regions
- All vehicles and centralised electricity generation plants are assigned a vintage in annual increments based on when they were first purchased or installed
- Four electricity end use sectors: industrial; commercial & services; rural and residential
- Time is represented in annual frequency (2006, 2007, …, 2050).

All technologies are assessed on the basis of their relative costs subject to constraints such as the turnover of capital stock, existing or new policies such as subsidies and taxes. The model aims to mirror real world investment decisions by simultaneously taking into account:

- The requirement to earn a reasonable return on investment, represented as a discount rate, over the life of a plant or vehicle
- That the actions of one investor or user affects the financial viability of all other investors or users simultaneously and dynamically
- That consumers react to price signals (price elastic demand)
- That the consumption of energy resources by one user affects the price and availability of that resource for other users, and the overall cost of energy and transport services, and
- Energy and transport market policies and regulations.

The model evaluates uptake on the basis of cost competitiveness but at the same time takes into account the key constraints on the operation of energy and transport markets, current excise and mandated fuel mix legislation, GHG emission limits, existing plant and vehicle stock in each State, and lead times in the availability of new vehicles or plant. It does not take into account issues such as community acceptance of technologies but these can be controlled by imposing various scenario assumptions which constrain the solution to user provided limits.

ESM model outputs

For given time paths of the exogenous (or input) variables that define the economic environment, ESM determines the time paths of the endogenous (output) variables. Key output variables include:

- Fuel, engine, and electricity generation technology uptake
- Fuel consumption
- Cost of transport services (for example, cents per kilometre)
- Price of fuels
- GHG and criteria air pollutant emissions
- Wholesale and retail electricity prices
- Demand for transport and electricity services.

The endogenous variables are determined using demand and production relationships, commodity balance definitions and assumptions of competitive markets at each time step for fuels, electricity and transport services, and over time for assets such as vehicles and plant capacities. With respect to asset markets, the assumption is that market participants know future outcomes of their joint actions over the entire time horizon of the model.

Limitations of ESM

The suggested modelling approach suffers from two major limitations. The first is that it includes many assumptions about the value of parameters that are in reality uncertain and in some cases evolving rapidly. Parameters of most concern include possible breakthroughs in so called “second generation” biofuel production technologies, and the unknown quality and cost of future offerings of fully and partially electrified vehicles. These limitations are only partially addressed by scenario or sensitivity analysis.

A second major limitation is that ESM takes cost as the major determining factor in technology and fuel uptake. Therefore, it cannot capture the behaviour of so-called “fast adopters” who take up new technology before it has reached a competitive price point. For example, most consumers of hybrid electric vehicles today could be considered “fast adopters”. Their purchase cannot be justified on economic grounds since the additional cost of such vehicles is not offset by fuel savings in any reasonable period of time (relative to the cost of borrowing). Nevertheless, hybrid electric vehicles are purchased and such purchasers may be motivated by a variety of factors including a strong interest in new technology, the desire to reduce emissions, or status. As a result of this limitation, ESM’s projections of the initial technology uptake for new technologies could be considered conservative.

However, yet another factor which ESM overlooks is community acceptance, and this limitation might lead ESM to overestimate the rate of uptake of some fuels and technologies. For example, greater use of gaseous fuels such as LPG and the introduction of electricity as a transport fuel might be resisted by the Australian community which over the past century has predominantly used liquid fuels for transport. By design, ESM only considers whether the choice is economically viable.

As a result of these limitations, the projected technology and fuel uptake estimates need to be interpreted with caution. In reality, consumers will consider a variety factors in fuel and vehicle purchasing decisions. However, it is the view of the authors that the projections are nonetheless instructive in that they indicate the point at which the various technology or fuel options should become widely attractive to all consumers.

Fuel Processing Chain alternatives

There are a large number of alternative processing chains for converting biomass energy resources to fuel products that are physically possible. In addition, there are a number of alternative bioenergy resources that could in principle be produced in a given location, and a number of alternative bio-fuels that may be suitable for use for some of a number of alternative means of transport. The situation is further complicated by the fact that various alternative co-products may be associated with some processing chains and bio-energy is only one class of many uses for biomass. Owing to the challenges of assembling sufficiently accurate cost and yield productivity data, only some of these possibilities are represented in the economic modelling. This also reduces the complexity of the modelling and improves the speed of computation.

Fortunately, data are typically more available for those resources, processes, and products of more economic relevance. Relatively accurate figures are typically available for processes that are in commercial production (except where the relevant industrial actors are able to keep them confidential). Moderately accurate figures are available for processes that are under development and close to commercial, and figures are more difficult to obtain for processes that are far from commercial.

This section describes the extent to which details of resource availability and processing pathways were included in the model (see also Graham et al., 2011). An overview is provided in Figure 1.

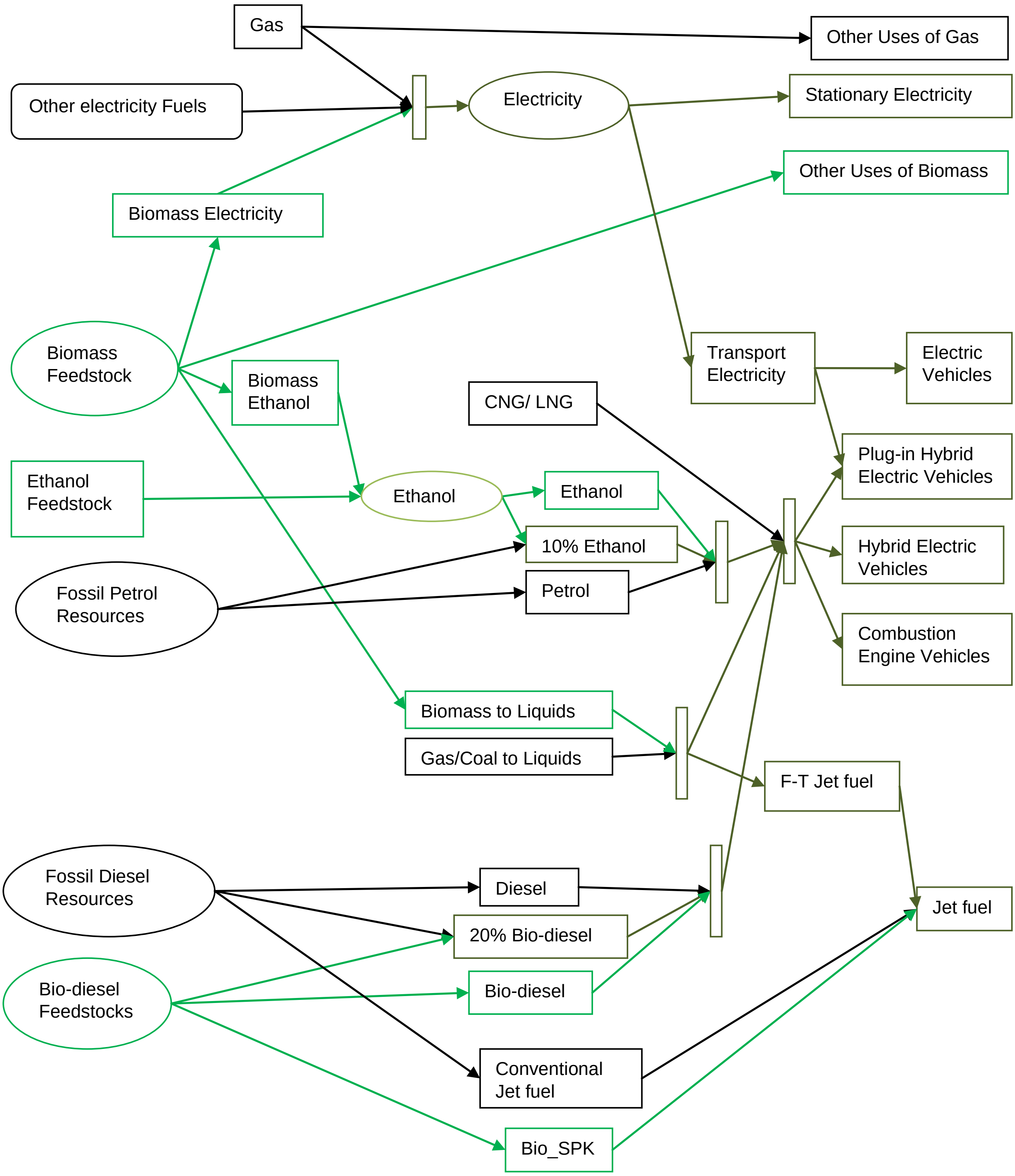

Figure 1: Biofuel Production Pathways

For the purposes of modelling energy production, bioenergy feedstocks can be efficiently classified into one of three chemical types that determine the processes for which it is suitable, namely biomass (lignocellulosic, “woody”, primarily carbon), starches and sugars (carbohydrates, “sweet”), and plant oils (hydrocarbons, “oily”). Plant oils are the least abundant but also require the least refinement to produce useful transport fuels such as diesel. There is also an existing process that enables jet fuel to be produced from plant oil – bio synthetic paraffinic kerosene (bio-SPK). Starches and sugars are more abundant and are typically best suited to the production of ethanol, which can be used as a partial substitute for petrol for road transport. It is not, however, used for aviation applications for various technical reasons including its affinity for water and relatively low energy density and ignition temperature. Only fuels equivalent to existing ones were considered for the aviation industry and within the aviation fuel market only jet fuel was investigated, since the market for aviation gasoline is relatively insignificant.

Lignocellulosic biomass is the most abundant for the lowest cost, but also requires the most processing to reach a state suitable for providing energy services. There are a number of possible uses to which woody biomass is suited. Apart from its non-energy use as a structural material, it may be combusted to provide either direct use as heat, or to generate electricity. A reasonably well-established class of thermochemical processes known as Fischer-Tropsch processes are able to synthesise liquid fuels following the gasification of hydrocarbons such as woody biomass, coal or natural gas. Such synthesis processes can generally be designed to produce one of a range of ratios of fuels suitable for land versus aviation transport applications.

It is also possible in principle to combust either plant oils or starchy/sweet bioenergy feedstocks to produce electricity, or to use them as feedstocks for F-T synthesis. However, given the lower value of electricity relative to transport fuels and the higher costs of F-T processing relative to producing ethanol from starch/sugar or refining plant bio-oils, these processing alternatives can be ruled out prior to modelling analysis on economic grounds.

It is expected that in the future, technologies for processing woody biomass into ethanol will become cost effective and there may become available processes for producing liquid fuels from biomass via lower temperature pyrolysis (at medium scales) rather than higher temperature F-T processes (at larger scales).

In addition to non-conventional biomass sources of road and aviation transport fuel, other non-conventional pathways for fuel production from fossil sources were included, such as Gas-to-Liquids and Coal-to-Liquids (that is, Fischer-Tropsch thermochemical processing) diesel. Note that jet fuel is derived as a co-product of F-T diesel from gas, coal or biomass. Although it is possible to vary the ratio of diesel to jet fuel product (a given production process usually has a fixed nominal production ratio and variation from this nominal ratio is inefficient) for the purposes of modelling, the production ratio was fixed at 20% jet fuel.

Biomass cost-quantity curves

CSIRO has assessed the biomass resources available in Australia and New Zealand (Graham et al. 2011) and processing costs. There are a very wide variety of available feedstocks. As discussed in the introduction we have only focussed on feedstocks which do not significantly interfere with food production or land use. The following two figures show the estimated costs curves for the three sectors of interest in this study. Only the use of lignocellulose is shown since this feedstock can be utilised across all three end uses. The cost-quantity curves for electricity and ethanol for use in road transport are shown (Figures 2 and 3).

It shows that the general shape of the cost curve is the same for the two sectors – this shape is determined by the cost producing and transporting different feedstocks (represented by steps in the curve). However, the conversion technology (biomass to electricity and biomass to ethanol) also influences the final total cost. Note that the ethanol cost curve also includes excise. The cost curve for aviation biofuels would be just above that of ethanol. Aviation biofuels have a lower excise but a higher cost conversion technology to make jet fuel (a type of kerosene).

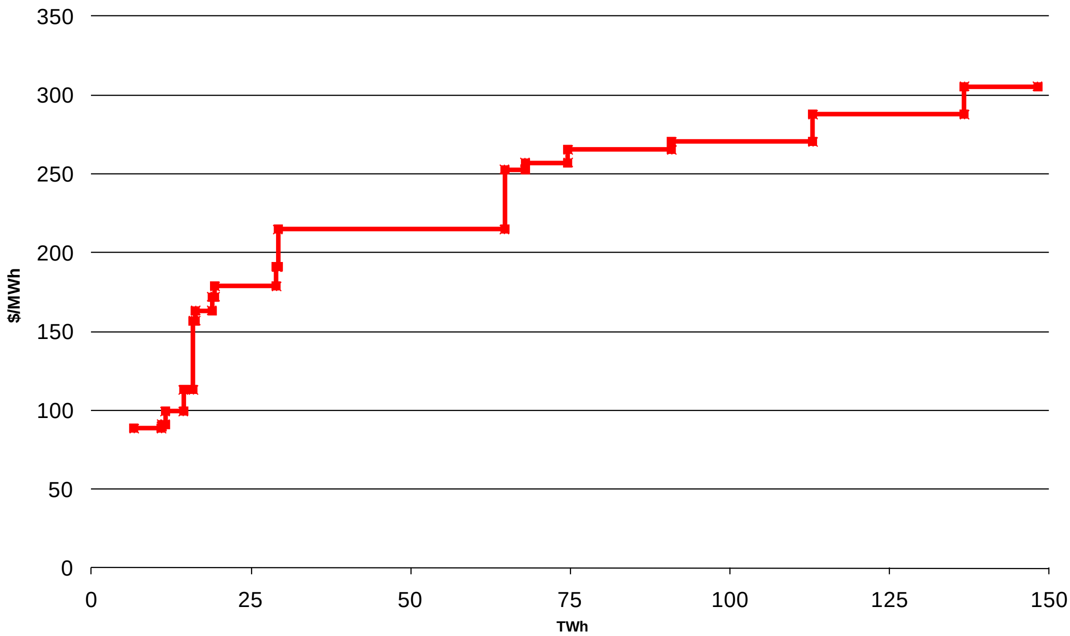

Figure 2: Lignocellulose-based electricity generation cost-quantity curve

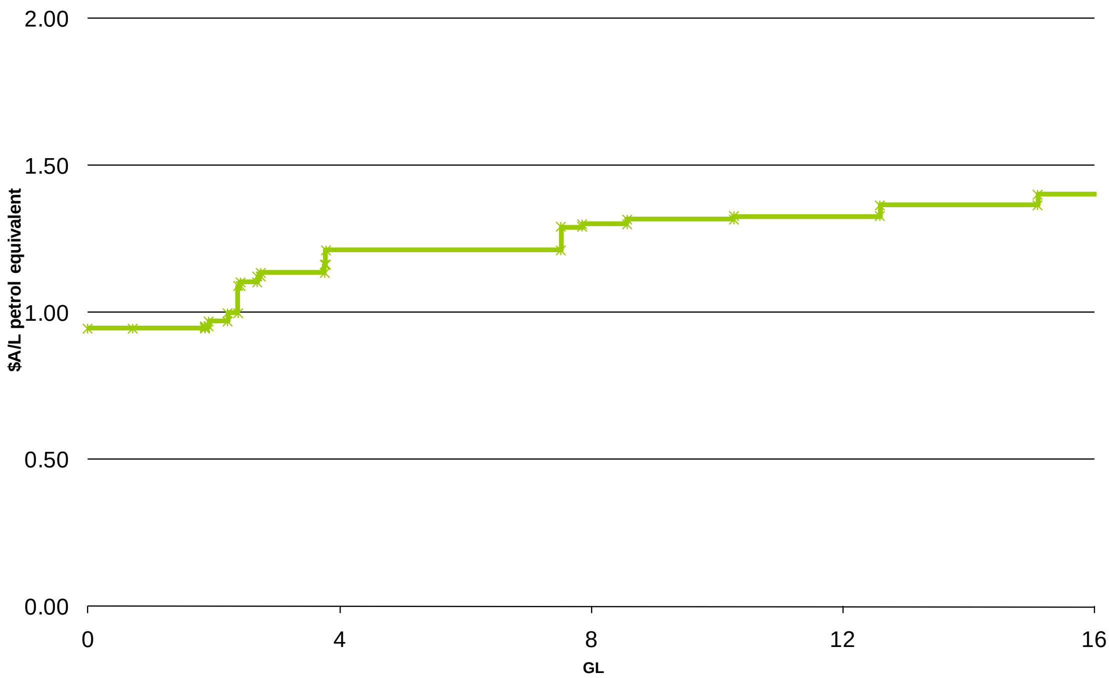

Figure 3: Lignocellolose to ethanol cost-quantity curve

Scenario framework

The carbon price, the oil price, technological change and government intervention were all identified as being strong drivers of the future uptake of biomass in the energy sector (see Graham et al. 2011). A good basis for designing scenarios is to construct a reference case which incorporates things that are likely to happen and to construct scenarios of events that are uncertain but plausible. They may be events that are outside of our control or that we could choose to create. The reference case can then be used to compare the impact of those events or actions.

The reference case contains all of the data assumptions outlined in this document. In addition it assumes the International Energy Agency's reference case oil price (IEA, 2009). This oil price was chosen because it is widely accessible and well known. It also accords well with the slightly more recent Energy Information Administration's forecast (EIA 2010). Our modelling extends to 2050 so for both sources these projections have been extrapolated in Figure 3.

As oil prices increase it is assumed that the price of jet fuel increases slightly faster. This reflects the fact that jet fuel partially competes with diesel production. There is some flexibility but generally a refiner will need to make a choice about what fraction of jet fuel to produce and the trade-off is less diesel. Given the diesel market is so much larger and generally associated with less discretionary end-use consumption, it is reasonable to expect that jet fuel users will have to pay a small premium over other fuels on an energy equivalent basis as oil supply tightens in coming decades.

We choose as our alternative to the reference case a carbon price scenario. In this scenario, a carbon price mechanism is assumed to be introduced and its level is based on the CPRS-5 carbon price projection estimated in the Commonwealth of Australia (2008) report, *Australia's Low Pollution Future*. Under this scenario the carbon price mechanism is assumed to commence in 2013 and result in a $A25/tCO2e carbon price increasing at around 4 percent per annum to $116/tCO2e in 2050 (Figure 4).

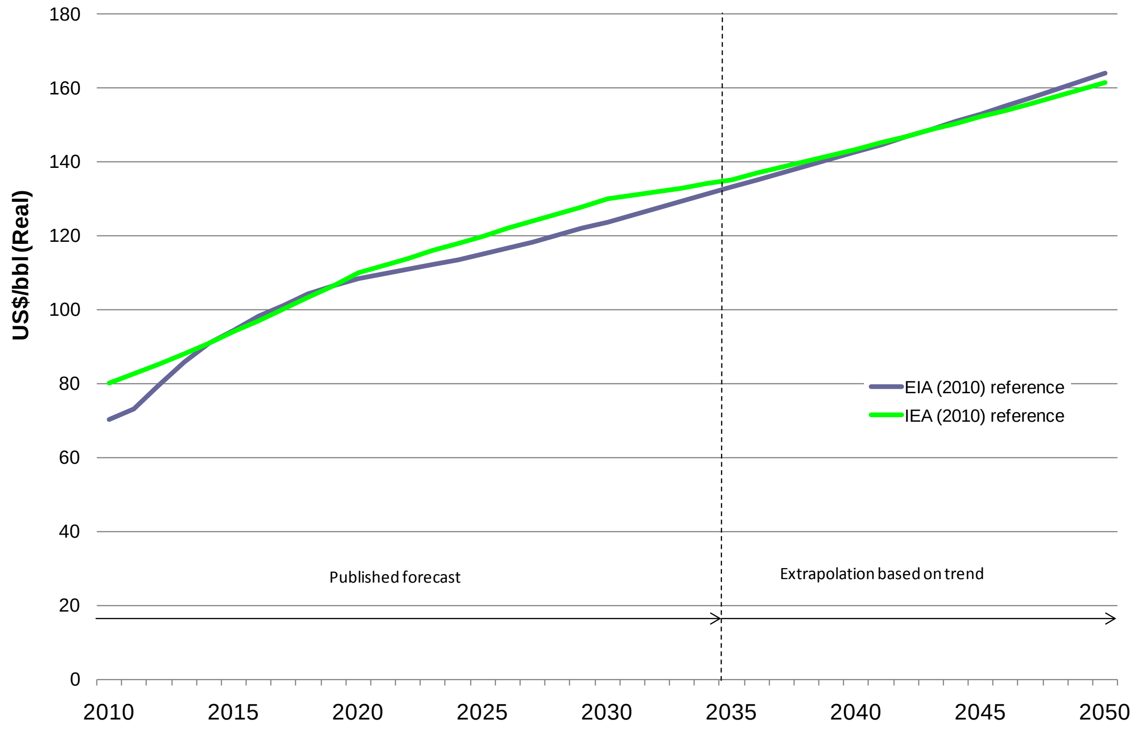

Figure 4: Reference case oil price projections

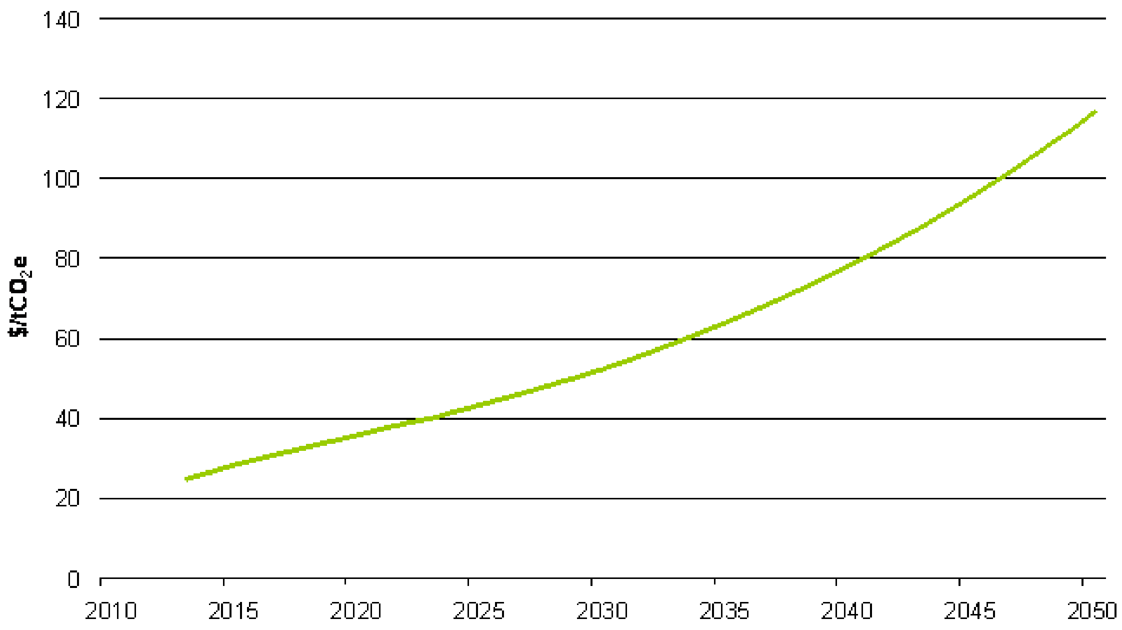

Figure 5: The CPRS-5 carbon price level from 2013 to 2050

Reference case modelling results

Under our reference case assumptions, the modelling projects that available biomass supplies will expand into the electricity and road transport sectors up until 2020. The aviation sector is projected to commence uptake of bio-derived jet fuel from 2025 after which the share of jet fuels that are bio-derived rapidly expands to just under 50 percent of the aviation fuel market by 2050.

In the next decade there is a preference for biomass to grow significantly in the road sector, rather than the aviation sector. This reflects two factors. The first is that it is lower cost to make road fuels from biomass than it is to make jet fuels. All else being equal a biofuel producer can get a greater return from their product in the road market. The second factor is that the government in both Australia and New Zealand provide additional incentives for biomass to be converted to road biofuel through lower biofuel excise rates and mandated road biofuel uptake targets (primarily New South Wales). Note that, in Australia, the excise differences are strongest in the passenger segment. In the freight sector, additional oil-based fuel excise rebates mean that the incentives to take up biofuels are not as strong.

An increasing share in the electricity sector is projected, and this mainly reflects a short term trend as both Australia and New Zealand put in place policies that encourage renewables (e.g. Australia's expanded 20 percent Renewable Energy Target). However, biomass electricity is not specifically targeted and the level of biomass generation in both countries does not expand over the long term due to competition from other renewable and low emissions electricity technologies.

In the period from 2025 the momentum shifts from the road sector to the aviation sector (Figure 6) for several reasons:

1. The excise differences between the sectors become less over time because they are set in nominal terms and are therefore eroded by inflation
2. The road sector commences a significant shift toward full or partially electrified vehicles reducing growth in demand for liquid fuels
3. Biofuel availability has expanded

4. The cost of refining jet fuels has reduced relative to the cost of refining road fuels
5. Synthetic road liquid fuels from fossil sources such as coal and gas are available and are low cost
6. Other low cost electricity generation technologies are available and existing renewable electricity schemes expire

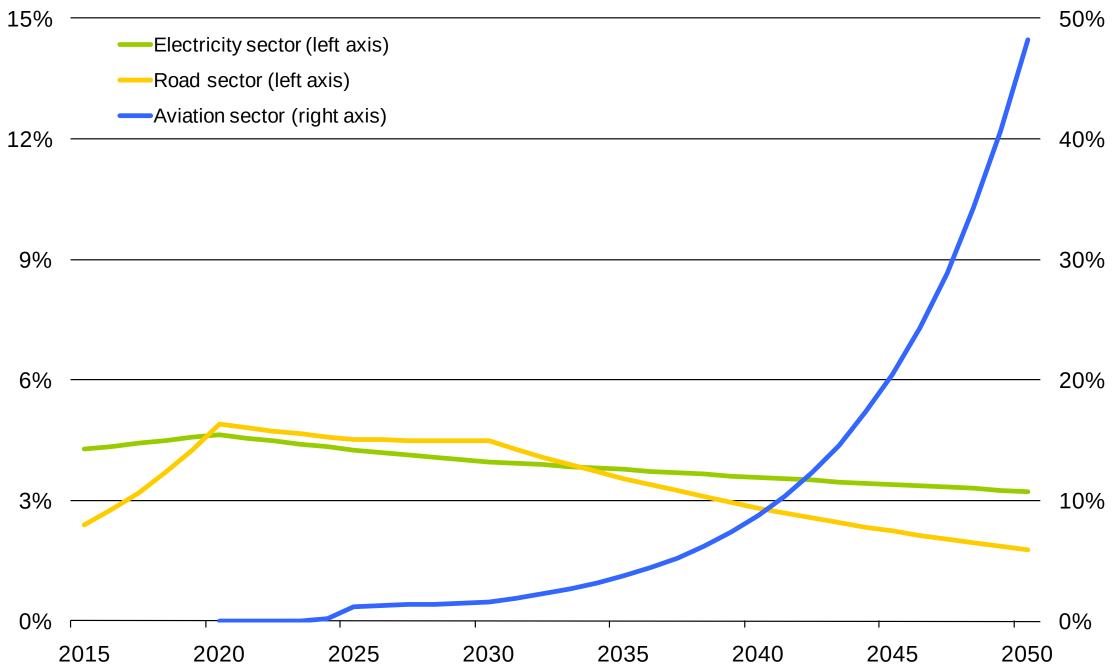

Figure 6: Reference Case - Share of bio-derived fuel uptake in the aviation, road and electricity sectors in Australia and New Zealand

Carbon price scenario modelling results

In the CPRS-5 carbon price scenario, the carbon price has the effect of making biomass more attractive to all end-users relative to fossil fuels, by penalising higher emission fuels. The uptake of biomass is higher in all sectors relative to the reference case. They also take up other available low emission options such as vehicle electrification in road transport and wind, solar and geothermal power in the electricity sector.

The decline in use of biomass in electricity generation over the long term is slower under this scenario and the long term declining trend in road transport is reversed. In the aviation sector, uptake of biofuels occurs at the same time as in the reference case but is much more rapid.

Compared with the reference case, the same trends and drivers are observed except that road transport joins aviation as the long term user of biofuels. It appears that even with access to vehicle electrification, the road sector will still need another source of alternative emission fuels if carbon prices are introduced. The key reason for this is that the carbon price has effectively reduced its options from three to two. Without a carbon price the road sector could take up synthetic liquids fuels made from coal and gas. These feedstocks are relatively abundant and the fuels can be produced for lower cost than biofuels. However, a carbon price penalises these fuels for the significant amount of emissions they produce during their refining process.

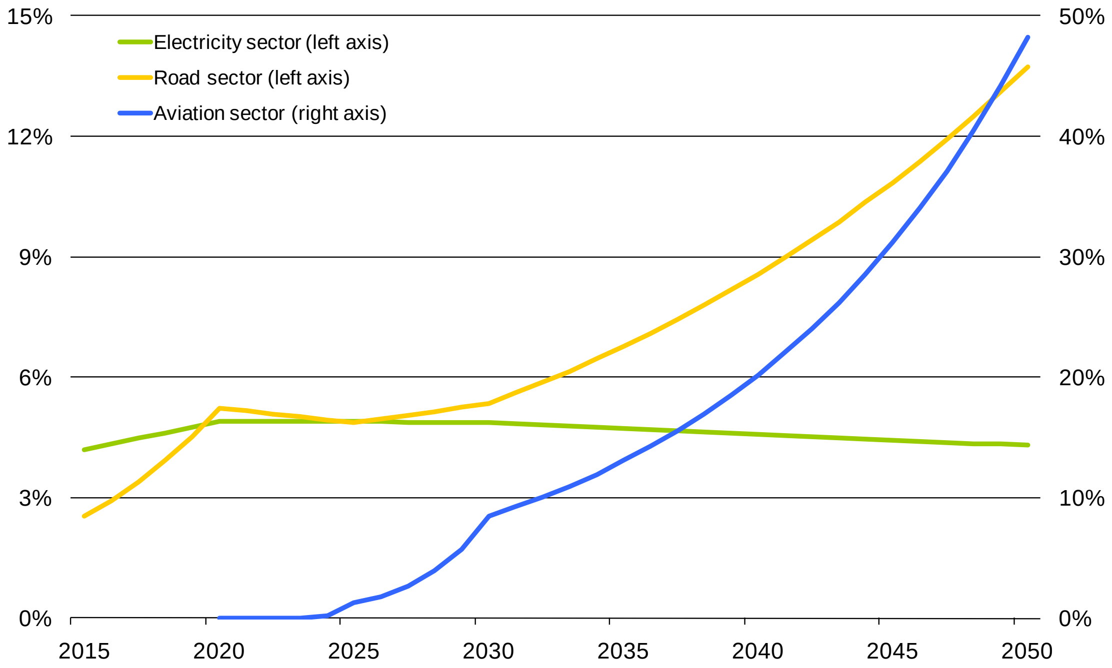

Figure 7: Carbon Price Scenario Case - Share of bio-derived fuel uptake in the aviation, road and electricity sectors in Australia and New Zealand

Discussion

The preliminary modelling presented in this paper has shed light on the likely competition for biomass between and within the stationary energy and transport sectors. In considering which factors are most important in determining the share of biomass in each sector the modelling has identified several. They include the prevailing carbon and electricity prices, the fuel and technology substitutes in each sector, the government polices prevailing in each sector (e.g. excise, renewable targets), the total availability of biomass and the relative cost of biomass to energy conversion technologies.

The modelling has identified that both electricity generation and land and air transport modes will certainly seek to increase their use of biomass in coming decades and as a consequence will create competition for biomass resources. It indicates that there are sufficient available quantities of biomass domestically available at sufficiently competitive prices for biofuels to make a quite significant contribution to Australasian aviation fuel demand, and a smaller relative contribution to the electricity and land transport fuel demand.

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