THE ECONOMY-WIDE EFFECTS IN THE UNITED STATES OF REPLACING CRUDE PETROLEUM WITH BIOMASS

by

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Abstract

Part of President Bush's energy policy is to encourage research aimed at reducing the cost of biomass-based motor fuels to become competitive with petroleum-based fuels. We use a dynamic, CGE model to investigate the economy-wide implications of successful implementation of this policy. We find in the long-run, 2020, that the U.S. would experience significant benefits arising from: (1) substitution of biomass whose price is likely to fall in the long-run for crude petroleum whose price is likely to rise; (2) reduction in the world price of crude petroleum; (3) an increase in employment; and (4) an increase in export prices.

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The economy-wide effects in the United States of replacing crude petroleum with biomass

Abstract

Part of President Bush's energy policy is to encourage research aimed at reducing the cost of biomass-based motor fuels to become competitive with petroleum-based fuels. We use a dynamic, CGE model to investigate the economy-wide implications of successful implementation of this policy. We find in the long-run, 2020, that the U.S. would experience significant benefits arising from: (1) substitution of biomass whose price is likely to fall in the long-run for crude petroleum whose price is likely to rise; (2) reduction in the world price of crude petroleum; (3) an increase in employment; and (4) an increase in export prices.

1. INTRODUCTION

The United States' capacity to produce crude petroleum domestically peaked in the 1970s. By 1994, crude petroleum imports exceeded 50 per cent of domestic consumption, and reached 65 per cent in 2004.

An important objective of the President's energy policy[1] is to reduce the reliance of the U.S. economy on imported crude petroleum. The policy envisages major domestic production of biomass fuels (e.g. ethanol).[2] Such fuels are not currently cost-competitive in the United States with petroleum-based fuels. However, the President's policy provides subsidisation of research designed to achieve sharp reductions in the costs of biomass fuels over the next decade.

There is a considerable literature on the potential of the U.S. agricultural sector to supply biomass and the implications for the sector of increased demand for biomass (see, for example, Raneses *et al.* [4], Gallagher *et al.* [5] and De La Torre Ugarte *et al.* [6]). The aim of this paper is to

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[1] The Bush Administration's energy policy is spelt out in: National Energy Policy Development Group [1], Department of Energy/Department of Agriculture [2] and White House National Economic Council [3].

[2] See, for example, page 1.14 of Ref. 1, Ref. 2 and page 5 of Ref. 3.

introduce an economy-wide perspective to the biomass literature while at the same time providing an input to the assessment of the President's policy.[3]

We use a detailed, dynamic, computable general equilibrium (CGE) model (the USAGE model[4]) to quantify the economy-wide effects of partial replacement of crude petroleum with biomass as an input to production of motor fuels. We look at how the policy would affect the U.S. economy in 2020. To do this, we first build a benchmark for 2020, that is, a forecast without the President's policy in place. Then we conduct a policy simulation in which we impose substitution of biomass for crude petroleum. By comparing the results in this simulation with those in the benchmark, we deduce the effects of the substitution.

Two points should be made at the outset: one on the economics of our problem and the other on our methodology. With regard to economics, it should be emphasized that our analysis is concerned with the emerald city, not the yellow brick road: we look at the benefits in 2020 of having achieved a substantial transition to biomass fuels, not at the infrastructure costs of the transition. Our aim is to see whether the emerald city is a desirable destination. It is sensible to carry out this investigation before committing substantial efforts to analyzing the yellow brick road.

With regard to methodology, it must be recognized that it is impractical to set out the theory and empirical properties of a CGE model such as USAGE in a journal-length paper. However, this is not necessary for understanding our results. We identify and explain the main USAGE mechanisms responsible for the results via back-of-the-envelope calculations that can be understood without any detailed knowledge of the model.

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[3] Further inputs to the assessment of the President's policy can be found in Department of Commerce [7].

[4] USAGE contains considerable energy detail and is the most disaggregated dynamic CGE model currently available for the United States. It was developed at the Centre of Policy Studies, Monash University, in collaboration with the U.S. International Trade Commission. The theoretical structure of USAGE is similar to that of the MONASH model of Australia (Dixon and Rimmer, [8]). However, in its empirical detail (500 industries versus 100, with specifications capturing particular features of many industries), USAGE goes far beyond MONASH.

The paper is organised as follows. Section 2 describes the benchmark. Section 3 describes the policy simulation. Section 4 contains sensitivity analysis and concluding remarks.

2. THE BENCHMARK

In creating a benchmark for 2020, we use four categories of inputs: (i) technology trends for industries and preference trends for households; (ii) trends in the positions of world demand curves for U.S. exports and supply curves for U.S. imports; (iii) projections for macroeconomic variables; and (iv) projections of prices and quantities for energy products in the United States.

For the present paper, we obtained inputs (i) and (ii) from historical simulations in which USAGE was forced to track data for 1992 to 2004: on output, employment, capital and investment by industry; and on consumption, exports and imports by commodity.[5]

We obtained inputs (iii) and (iv) from the U.S. Department of Energy's reference case (see DOE, [10]). This is a set of forecasts showing how the DOE sees the U.S. economy developing in the absence of major substitution of biomass for crude petroleum. As reflected in the first six rows in column (2) of Table 1, at the macro level the DOE reference case predicts:

- very strong growth in exports (236 per cent between 2004 and 2020, 7.9% a year);
- strong growth in imports (112 per cent between 2004 and 2020, 4.8% a year);
- normal growth in real GDP (66 per cent between 2004 and 2020, 3.2% a year);
- normal growth in employment (15 per cent between 2004 and 2020, 0.9% a year);
- normal growth in investment (83 per cent between 2004 and 2020, 3.8% a year);
- subdued growth in private consumption (57 per cent between 2004 and 2020, 2.9% a year); and

[5] For a detailed description of USAGE historical simulations see Dixon and Rimmer [9].

- very subdued growth in public consumption (27 per cent between 2004 and 2020, 1.5% a year).

While the DOE does not make explicit reference to imbalances in the U.S. trade accounts, it appears that their macroeconomic forecasts are predicated on the assumption that the present imbalances will be corrected. This may come about through tighter U.S. fiscal policy or through reduced willingness by the rest of the world to finance the U.S. current account deficit at its present level. According to USAGE, the DOE reference case assumptions imply:

- a sharp turnaround in the current account [from a deficit of 5.74 per cent of GDP in 2004 to a surplus of 2.43 per cent in 2020 (=5.74 -8.17)]; and
- approximate stabilisation in net foreign liabilities as a share of GDP [a slight increase, from 21.24 per cent in 2004 to 21.75 per cent in 2020 (=21.24 +0.51)].

With regard to energy, for our purposes the most important aspects of the DOE reference case are those concerned with the petroleum refining industry. This is the USAGE industry in which motor fuels are produced. For this industry, the DOE sees strong growth in prices and slow growth in output. As shown in Table 2, the price index for domestically produced motor fuels (includes motor gasoline, jet fuel, distillate fuel and residual fuel) increases by 57.27 per cent between 2004 and 2020 whereas prices in general (measured by the price index for GDP) increase by only 47.77 per cent. Put another way, the price index for motor fuels increases by 6.43 per cent [=100*(1.5727/1.4777-1)] in 2004 dollars, see Table 3. The output of the petroleum refining industry grows in the benchmark by only 1.485 per cent a year, Table 3. This means that the output of petroleum refining declines as a share of GDP: from 2.55 per cent in 2004 to 2.09 per cent in 2020, Table 4.

The dominant input to the petroleum refining industry is crude petroleum. In 2004, inputs of crude petroleum accounted for 71.5 per cent of the industry’s costs, with domestically produced crude petroleum being 22.4 per cent of costs and imported crude petroleum being 49.1 per cent of costs (Table 4). In dollar terms, domestically produced crude petroleum cost the refining industry $63.877 billion and imported crude petroleum cost the industry $140.210 billion. In the DOE reference case the price of crude petroleum increases by 24.40 per cent between 2004 and 2020 relative to the increase in the price deflator for GDP, Table 3.[6] Despite this, both domestic and imported crude petroleum decline slightly as shares in the costs of the petroleum refining industry: 22.4 and 49.1 per cent in 2004 falling to 19.2 and 47.9 per cent in 2020 (Table 4). The DOE sees quite slow growth in the demand for crude petroleum relative to the output of the refining industry (0.5 per cent annual growth in crude petroleum supplies compared with 1.485 per cent annual growth in the output of the refining industry, Table 3). DOE has built into their benchmark some fuel-saving technical change in refining and some substitution of other inputs for inputs of crude petroleum.

3. THE EFFECTS OF REPLACING CRUDE PETROLEUM WITH BIOMASS IN THE PRODUCTION OF MOTOR FUELS

For our policy simulation, we assume that research and development leads to technologies in petroleum refining that allow a considerable substitution of biomass for crude petroleum. Specifically, we assume that by 2020, crude petroleum input per unit of output from the refining industry is reduced relative to the benchmark by 25 per cent. At the same time, biomass per unit of output increases. We assume that the cost, in 2004 prices, of the extra biomass per unit of output in refining is 25 per cent of the cost in 2004 of crude petroleum used per unit of output in refining. That is, we assume that research and development generates a 25-per-cent biomass replacement technology that would just[7] have been competitive in 2004.

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[6] The DOE forecasts incorporate the increase in the price of crude petroleum relative to the GDP deflator (the real price) from $40 per barrel to $60 between 2004 and 2006. Between 2006 and 2014, the DOE forecasts a fall in the real price to $47. Then from 2014 to 2020 the real price is forecast to rise to $50 a barrel.

[7] Our assumption is that at 2004 prices, the biomass-replacement technology produces a unit of fuel (quantity to drive a standard vehicle a standard distance) with the same cost at the refinery gate as petroleum-based fuel. We assume that the current favourable tax treatment of biomass fuel (ethanol) relative to crude-petroleum-based fuel is eliminated by 2020.

There are three aspects of our technology assumption that should be considered: the implied reduction in the cost of biomass fuels; the implied availability of biomass materials; and the implied percentage change in the composition of fuels used to drive light vehicles.

With current technologies, the cost of making a gallon of biomass-based motor fuel (cellulosic ethanol) is about $2 per gallon. Since ethanol has about two thirds the energy of gasoline, the cost of replacing one gallon of gasoline with ethanol is about $3 per gallon. When crude petroleum prices are at $40 per barrel, gasoline costs about $2 per gallon. Thus our assumption of cost neutrality in 2020 at 2004 prices implies a reduction of 33 per cent over the next one and a half decades in the cost of biomass-based motor fuel relative to the cost of petroleum-based fuel. This does not seem an overly ambitious target: the cost of cellulosic ethanol has fallen from about $6 per gallon in 2001 to its current $2 per gallon.

Replacement of 25 per cent of crude petroleum in motor fuels will require the availability in 2020 of about 80 billion gallons of ethanol. The DOE has a target (derived from Aden *et al.*, [11]) of increasing the yield of cellulosic ethanol production from about 65 gallons per dry ton to 90 gallons. With achievement of this target, 80 billion gallons of ethanol will require about 900 million dry tons of biomass in 2020. This is consistent with a best-case scenario presented in Ref. 2.

While ethanol can in theory be used to replace diesel fuel, most of the 80 billion gallons of ethanol would displace gasoline, about 53 billion gallons (=80*2/3). This represents about 31 per cent of U.S. gasoline consumption in the 2020 benchmark. Thus, light vehicles would need to be adjusted to cope with fuels in which about 31 per cent of the energy was derived from biomass materials. This would not pose a major problem: there are already many vehicles in the U.S. that can use fuels with ethanol content up to 85 per cent.

If the present tax arrangements were maintained, then under our technology assumption, even at 2004 prices, consumers would prefer biomass fuels – biomass fuels would be more than competitive (rather than just competitive).

In our simulation, we assume that the biomass used in petrol refining comes from the feedgrains industry (mainly corn). However, the precise composition of the biomass is not important for our results – what matter are our assumptions about the extent of biomass substitution and biomass competitiveness (that is the cost of biomass fuel, whatever its source, relative to the cost of the crude petroleum that it replaces).

3.1 Macroeconomic effects

The macro effects in 2020 of the adoption of 25-per-cent biomass fuel can be seen by comparing columns (2) and (3) in Table 1, or more directly by looking at column (4). The numbers in column (4) indicate that the adoption of 25-per-cent biomass fuel under our assumptions leads to:

- private and public consumption that are 0.363 and 0.368 per cent higher than they would be without the adoption of biomass fuel;
- post-tax real wage rates that are 0.412 per cent higher; and
- a level of real GDP that is 0.158 per cent higher.

Applied to the economy of 2004, these effects are equivalent to:

- increases in consumption (combined private and public) of $36 billion or about $120 per person;
- increases in real post-tax wage rates of about $206 a year for people on average wages; and
- an increase in real GDP of about $18 billion.

There are four factors that contribute to these gains.

(1) *Costs-saving substitution between inputs in petroleum refining.* In the DOE benchmark, the price of crude petroleum increases sharply relative to the price of GDP: by 24.4 per cent between 2004 and 2020. This is adopted in USAGE, Table 3. The USAGE benchmark price of feedgrains declines relative to that of GDP: by 14.27 per cent [=100*(1-0.8573)], Table 3.

This decline in the relative price of feedgrains reflects continuing rapid productivity growth in agriculture. We assume that the substitution of biomass for crude petroleum would not affect costs in 2020 in the petroleum refining industry (the costs of producing motor fuel) if 2004 prices prevailed in 2020. However, with the assumed changes in the prices of crude petroleum and feedgains, the substitution of biomass for crude petroleum significantly lowers the costs in 2020 of supplying motor fuels.

(2) *A reduction in the world price of crude petroleum.* The United States accounts for about a quarter of world consumption of crude petroleum. The substitution of biomass for crude petroleum assumed in our simulation has a noticeable damping effect on world demand for crude petroleum, generating a reduction in its price. This can be seen in Table 3. In the biomass-substitution simulation, the price index for crude petroleum reaches 1.1843 in 2020 rather than 1.2440. Thus, the substitution of biomass causes the price of crude petroleum to fall by 4.8 per cent. In the benchmark for 2020, the United States relies on imports for more than 70 per cent of its crude petroleum requirements (Table 3). Consequently, reductions in crude petroleum prices confer a significant benefit on the U.S. economy.

(3) *An increase in aggregate employment*. The usual assumption made by economists in analyses of the long-run effects of changes in micro-economic policies, such as energy policies, is that there is no effect on aggregate employment. Economists argue that aggregate employment in the long-run, say 2020, is determined by demographic factors that govern the size of the workforce and workforce participation rates. Normally they think of these factors as being independent of micro-economic policies. They assume that successful micro-economic policies cause wages to adjust upwards, leaving aggregate employment in the long-run at the level consistent with demographic factors. However, in our biomass-substitution simulation we have made an exception to the normal practice. This is because biomass substitution

generates a strong long-run increase in agricultural employment, about 35,000 extra jobs in agriculture in 2020. We think that this will have the effect of keeping farmers in work who otherwise would have retired or would have worked their farms less intensively. About half of agricultural labor input is supplied by hired workers. While we assume that agricultural expansion associated with biomass substitution draws these hired workers away from alternative employment, we assume that the increase in owner-operator labor input is not at the expense of alternative employment. Thus we assume that biomass substitution leads to a net long-run increase in aggregate employment of 17,500 jobs or about 0.013 per cent.

(4) *An increase in export prices*. Biomass substitution means that the United States will have a smaller import bill – a reduced volume of crude petroleum imports at a reduced price. With a smaller import bill, the U.S. will need less exports to pay for its imports. As can be seen in Table 1, biomass substitution reduces exports in 2020 by 1.7 per cent. The mechanism that causes this reduction is exchange-rate appreciation associated with reduced U.S. demand for foreign currency. Foreign demand curves for U.S. exports slope downwards, implying that foreigners will pay higher prices when U.S. supply contracts. In USAGE, export demand elasticities are set at –3, implying that a 1.7 per cent reduction in export supply confers a benefit on the U.S. economy by increasing the foreign currency prices of U.S. export products by 0.57 per cent.

The relative importance of the four factors can be ascertained by back-of-the-envelope calculations.

Factor (1) implies a 31 per cent saving [=100*(1-0.8573/1.2440)] applied to a quarter of crude petroleum inputs used in refining. In the benchmark for 2020 these inputs are worth $381815 million (=109249 +272566, Table 2]. Thus, in 2020 dollars the biomass substitution savings are worth about $29.6 billion (=381.815*0.25*0.31).

Factor (2) implies savings to the United States of 4.8 per cent applied to the value of imports of crude petroleum. With biomass substitution, these savings will apply to about three quarters of the 2020 benchmark value of imported crude petroleum inputs to refining. They will also apply to the value of imported crude petroleum used outside the refining industry (e.g. in the production of industrial chemicals). These other uses account for about 11 per cent of crude petroleum imports. Thus the savings to the United States from the reduction in the price of imported crude petroleum are about $11.4 billion in 2020 dollars [=272.566*(0.75 + 1/0.89 – 1)*0.048].

Factor (3) implies extra income to the United States in 2020 of about $2.4 billion. This is a 0.013 per cent applied to the 2020 benchmark aggregate wagebill which is about $18,577 billion.

Factor (4) gives a gain to the United States of 0.57 per cent applied to the aggregate value of exports in the 2020 benchmark which is $5401 billion. Thus in 2020 dollars, the gain is about $30.8 billion.

In combination these back-of-the-envelope calculations suggest that biomass substitution will allow the U.S. to enjoy higher consumption in 2020 of $74.2 billion (= 29.6 + 11.4+ 2.4 + 30.8). With private and public consumption in the 2020 benchmark being $22,085 billion, an extra $74.2 billion amounts to a gain of 0.34 per cent. This is close the USAGE result of 0.364 per cent for combined private and public consumption [=(0.363*8109+0.368*1805)/(8109+1805), Table 1].

3.2 Industry effects

Table 5 summarizes the main industry effects of biomass substitution. It picks out the USAGE industries for which there are significant effects and aggregates the others.

The table shows that the policy causes output in 2020 in Crop agriculture to be 17.54 per cent larger than in the benchmark. The biomass-induced expansion of Crop agriculture causes strong positive effects on Industries producing agricultural inputs (industry 2 in the table). This industry is an aggregation of USAGE industries such as Farm machinery, Fertilisers and Cordage and twine.

Biomass substitution reduces the price of motor fuels, leading to an expansion in demand. This explains the high position in Table 5 of Refined petroleum products.

As explained in the previous subsection, biomass substitution causes the exchange rate to be higher than it otherwise would have been. This reduces the costs to U.S. residents of holidays abroad and increases the cost to foreigners of holidays in the United States Thus biomass substitution has a positive effect on the Foreign holiday industry (an amalgam of services such as international airlines, foreign hotels and foreign shopping) and a negative effect on Export tourism (an amalgam of services supplied to foreign tourists in the United States).

Industries 6, 9, 10, 12 and 13 are shown with negative effects in Table 5. For all of these industries, Crop agriculture (the source of biomass) is a significant direct or indirect input. These industries are harmed by increases in the costs of Crop agricultural products.

All of the remaining industries identified in Table 5 (7, 11, and 14-18) are associated with the U.S. crude petroleum industry. They are shown with negative deviations in Table 5, reflecting lower demand and prices for Crude petroleum.

4. SENSITIVITY ANALYSIS AND CONCLUDING REMARKS

Under the assumptions adopted in our simulation, biomass-substitution confers sizeable benefits on the U.S. economy. The simulated consumption gain of 0.364 per cent (or $36 billion) is much larger than the gains usually associated with microeconomic changes. For example, in a USAGE simulation undertaken by the U.S. International Trade Commission [12] of the effects of almost complete removal of U.S. import restraints, the consumption gain was about 0.2 per cent. However, officials in the U.S. Departments of Agriculture and Energy have made it clear to us that they consider our assumptions to be towards the optimistic end of the feasible spectrum, especially with regard to the availability of biomass. This raises the question of how our results would be affected by changes in our assumptions?

To answer this question we ran three further simulations in which we varied the assumptions concerning the competitiveness and extent of biomass substitution. Rather than assuming that biomass technologies in 2020 are competitive at 2004 prices when crude petroleum was $40 a barrel, we look at a less optimistic situation in which biomass technologies in 2020 become competitive when crude petroleum in 2004 dollars costs $50 a barrel. Rather than adopting the DOE/DA best-case scenario in which sufficient biomass is available in 2020 for 25 per cent crude-petroleum replacement, we look at a situation in which replacement is limited to 18.7 per cent. This lower level of replacement is consistent with proposed ethanol production targets in Ref. 3.

The results of our sensitivity simulations are in Table 6. Moving down the columns of the table, we see that to a close approximation, limiting the extent of replacement has a simple proportional effect on the results.[8] The results in the 18.7-per-cent-replacement row for a given competitiveness assumption are approximately 0.75 times (=18.7/25.0) the corresponding results in the 25-per-cent-replacement row.

Moving along the rows of Table 6, we see that changes in the competitiveness assumption have different proportionate effects on different variables. Going from technology that makes biomass competitive at $40 per barrel to technology that makes it competitive at $50 per barrel reduces the GDP gains by nearly 50 per cent (e.g. from 0.158 per cent to 0.082 per cent in the 25-per-cent-replacement row). At the same time, the consumption gains are reduced by only about 20 per sent (e.g. from 0.364 per cent to 0.288 per cent). Adopting a less favorable technology assumption

[8] In the simulations conducted for this paper, it turns out that the logarithms of the endogenous variables are approximately linear functions of the logarithms of the exogenous variables over the relevant domain of the exogenous variables.

limits the resource savings associated with biomass substitution and therefore limits the expansion in U.S. aggregate output (measured by GDP). On the other hand, varying the technology assumption has only a minor influence on U.S. imports of crude petroleum. Consequently, as we move along a row of Table 6, favorable price effects (the reduction in crude petroleum prices and the increase in export prices) remain in place. These price effects are not important for the GDP gain: they do not enhance U.S. ability to produce. However, they are important for the consumption gain: they enhance U.S. ability to consume. Thus, adoption of a less favorable technology assumption has a much stronger negative effect on the factors in our simulations that underlie the GDP gains than on the factors that underlie the consumption gains.

The minor differences in the results for crude petroleum imports as we move along rows of Table 6 (e.g. from -17 per cent to -19 per cent in the 25-per-cent-replacement row) reflect different levels of stimulation of the petroleum refining industry. With a less favorable technology assumption, there is less reduction in the price of motor fuels (e.g. 6.4 per cent instead of 10.2 per cent in the 25-per-cent-replacement row) and consequently less expansion in demand for motor fuels.

The increases in agricultural employment as we go from the $40- to the $50-per-barrel column of Table 6 reflect increased requirements for biomass per unit of crude petroleum replaced.

Overall, Table 6 indicates that the U.S. will experience significant benefits if it undertakes large scale (say, greater than 15 per cent) biomass substitution for crude petroleum. The more competitive the technology that the U.S. adopts for the creation of biomass fuels, the larger the gains. However, Table 6 shows that significant benefits will remain even if the U.S. fails to find technologies for making biomass fuels that are highly competitive with technologies for making petroleum-based fuels. This is because much of the benefit of switching to biomass fuels comes from reduced dependence on imported crude petroleum, with consequent reductions in its price and increases in the prices of U.S. exports.

Finally, it is worth re-emphasizing that our simulations quantify benefits rather than costs. They imply that achievement of the President's energy policy (reaching the emerald city) is an outcome that will provide compensation for considerable implementation expenditures (costs along the yellow brick road). For a complete analysis of the biomass issue, the approach taken here will need to be supplemented with data on infrastructure costs such as the costs of retrofitting existing vehicles to use high biomass fuels.

Table 1. Macroeconomic effects of replacing crude petroleum inputs with biomass

	Data for 2004	Percent change or change, 2004 to 2020		
		Benchmark	With biomass replacement of crude petroleum	Percentage (or % point) effect of biomass replacement
	(1)	(2)	(3)	(4)
Private consumption ($b, 2004 prices)	8,109	57.392	57.963	0.363
Public consumption ($b, 2004 prices)	1,805	26.505	26.970	0.368
Investment ($b, 2004 prices)	1,968	82.783	83.919	0.622
Exports ($b, 2004 prices)	1,166	236.136	230.455	-1.690
Imports ($b, 2004 prices)	1,849	111.894	111.097	-0.376
GDP ($b, 2004 prices)	11,199	66.060	66.323	0.158
Capital stock ($b, 2004 prices)	26,864	65.264	65.890	0.379
Employment (millions of jobs)	145	15.202	15.217	0.013
Multi-factor productivity, index	1.000	29.357	29.403	0.036
Real post-tax wage rate, index	1.000	31.113	31.653	0.412
Terms of trade, index	1.000	0.093	1.283	1.189
Current account deficit, % of GDP	5.74	-8.168	-8.108	0.061
Net foreign liabilities, % of GDP	21.24	0.510	1.274	0.764

Table 2. The petroleum refining industry: inputs and outputs in current $s

	2004	2020, benchmark	2020 with biomass replacement
	$m	$m	$m
Petroleum refining industry inputs:			
Crude petroleum			
domestically produced	63,877	109,249	88,060
imported	140,210	272,566	212,953
Agricultural products	2	3	67,872
All other intermediate inputs	61,066	150,922	154,064
Cost of employing labor	6,837	11,899	13,209
Returns to capital	5,698	8,332	9,654
Taxes on inputs and production	8,048	15,896	15,702
Total inputs	**285,738**	**568,867**	**561,514**
Value of capital stock	65,064	106,386	117,263
Gross rate of return on capital	8.76%	7.83%	8.23%
Petroleum refining industry outputs:			
Motor fuels	270,950	505,974	494,685
Industrial chemicals	8,625	43,965	43,442
Other products	6,163	18,928	23,387
Total output	**285,738**	**568,867**	**561,514**
Reference variables			
GDP	11,198,922	27,178,673	27,293,765
Price index for domestic motor fuels	1.0000	1.5727	1.4160
Price index for GDP	1.0000	1.4777	1.4819

Table 3. The petroleum refining industry: inputs and outputs in 2004 $s

	2004	2020, benchmark	2020 with biomass replacement
	$m	$m	$m
Petroleum refining industry inputs:			
Crude petroleum			
domestically produced	63,877	73,932	59,380
imported	140,210	184,453	143,596
Agricultural products	2	2	45,767
All other intermediate inputs	61,066	102,133	103,887
Cost of employing labor	6,837	8,052	8,907
Returns to capital	5,698	5,638	6,510
Taxes on inputs and production	8,048	10,757	10,588
Total inputs	**285,738**	**384,968**	**378,634**
Value of capital stock	65,064	71,994	79,071
Gross rate of return on capital	8.76%	7.83%	8.23%
Petroleum refining industry outputs:			
Motor fuels	270,950	342,406	333,570
Industrial chemicals	8,625	29,752	29,293
Other products	6,163	12,809	15,770
Total output	**285,738**	**384,968**	**378,634**
Reference variables			
GDP	11,198,922	18,392,551	18,418,088
Price index for domestic motor fuels	1.0000	1.0643	0.9555
Price index for crude petroleum	1.0000	1.2440	1.1843
Price index for feedgrains	1.0000	0.8573	0.9363
Price index for GDP	1.0000	1.0000	1.0000
Average annual % growth in output of refined petroleum industry, 2004-20		1.485	2.069
Average annual % growth in real GDP, 2004-20		3.149	3.158

Table 4. The petroleum refining industry: inputs and outputs, percentage shares

	2004	2020, benchmark	2020 with biomass replacement
	percent	percent	percent
Petroleum refining industry inputs:			
Crude petroleum			
domestically produced	22.4	19.2	15.7
imported	49.1	47.9	37.9
Agricultural products	0.0	0.0	12.1
All other intermediate inputs	21.4	26.5	27.4
Cost of employing labor	2.4	2.1	2.4
Returns to capital	2.0	1.5	1.7
Taxes on inputs and production	2.8	2.8	2.8
Total inputs	**100.0**	**100.0**	**100.0**
Petroleum refining industry outputs:			
Motor fuels	94.8	88.9	88.1
Industrial chemicals	3.0	7.7	7.7
Other products	2.2	3.3	4.2
Total output	**100.0**	**100.0**	**100.0**
Reference variable			
Refined petroleum industry, % of GDP	2.55	2.09	2.06

Table 5. Effects on industry outputs in 2020 of replacing 25% of crude petroleum with biomass

No.	Industry	Percentage effect
1	Crop agriculture	17.54
2	Industries producing agricultural inputs	8.83
3	Refined petroleum products	7.80
4	Foreign holiday	2.26
5	Other industries	0.05
6	Leather tanning	-2.12
7	Mining machinery	-2.16
8	Export tourism	-2.34
9	Animal agriculture	-2.52
10	Meat packing plants	-3.10
11	Oil & gas field machinery	-3.17
12	Wet corn mills	-4.61
13	Prepared feeds	-4.87
14	Crude petroleum and natural gas	-6.97
15	Maintenance of petroleum and natural gas wells	-7.56
16	Petroleum & natural gas drilling	-7.72
17	Petroleum & natural gas exploration	-7.73
18	Pipelines, crude petroleum	-7.78
	Average over all industries	0.21

Table 6. Effects of biomass substitution under different assumptions for competitiveness and extent

Extent of substitution		Biomass competitive at $40 per barrel	Biomass competitive at $50 per barrel
25.0% requires about 900 billion dry tons of biomass a year	Consumption (% and 2004$)	0.364% ($36 billion)	0.288% ($29 billion)
	Consumption per person (2004$)	$120	$95
	GDP (% and 2004$)	0.158% ($18 billion)	0.082% ($9 billion)
	Average annual wage (% and 2004$)	0.412% ($206)	0.334% ($167)
	Crude petroleum imports (% and barrels per day)	-17%, (-1.7 million)	-19%, (-1.9 million)
	Price of motor fuel (%)	-10.2%	-6.4%
	Agricultural employment (jobs)	37,500	46,000
18.7% requires about 675 billion dry tons of biomass a year	Consumption (% and 2004$)	0.268% ($27 billion)	0.213% ($21 billion)
	Consumption per person (2004$)	$88	$70
	GDP (% and 2004$)	0.118% ($13 billion)	0.061% ($7 billion)
	Average annual wage (% and 2004$)	0.303% ($154)	0.247% ($124)
	Crude petroleum imports (% and barrels per day)	-12%, (-1.2 million)	-14%, (-1.4 million)
	Price of motor fuel (%)	-7.6%	-5.0%
	Agricultural employment (jobs)	28,000	34,500

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