

Appendix:
Emission factors for proposed uses of lignite

December 2010



Parliamentary Commissioner
for the **Environment**
Te Kaitiaki Taiao a Te Whare Pāremata

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Introduction

This document estimates greenhouse gas emission intensities ('emission factors') for four proposed products of Southland and Otago lignite: urea, diesel, briquettes and electricity. A summary of these emission factors is tabulated overleaf.

These estimates are based on the best information publicly available. Some relevant data is held to be commercially confidential. In preparing these estimates, Parliamentary Commissioner for the Environment researchers benefited from the advice of Emeritus Professor Gerry Carrington, University of Otago; Dr. Ken Morison, Chemical and Process Engineering Department, School of Engineering, University of Canterbury; and Hale and Twomey Ltd, Wellington. However, the Commissioner takes responsibility for any errors or omissions.

To place these emission factors in context, this appendix also contains estimates of emission factors for the same products from other sources relevant to the New Zealand market. These are also shown on the summary table below.

For all these products, the fundamental question is how much lignite will be consumed in making the product, because burning lignite principally produces carbon dioxide (chemical formula CO₂), a major greenhouse gas. Accordingly, all these estimates are dependent on an estimate of the emission factor for burning Southland and Otago lignite. Sometimes electricity is also used, which also results in some greenhouse gas emissions.

Before making any calculations involving lignite, it is important to realise that not all lignites are the same. Some important properties of lignite vary considerably from deposit to deposit, from batch to batch within the same mine, and may even depend on how the lignite has been handled. These properties include the proportions of water, carbon and ash, and the net energy content of the lignite. Unsurprisingly, those Southland and Otago lignites already being mined appear to have properties in the more desirable end of the lignite range, such as relatively high energy and carbon content.

Lignites yet to be exploited will tend to have less desirable properties. This analysis focuses on one of the largest and most accessible lignite deposits in Southland and Otago, the Mataura field. From the limited amount of information that is publicly available, it appears likely that Mataura lignites typically have properties around the middle of the range for these deposits.¹

Summary Table

Emission factors (tonnes CO ₂ eq/unit)	Made from lignite	Made from existing sources	
Urea (per tonne)	1.3	1.1 Domestic, natural gas	0.8 Imported, natural gas
Diesel (per 1000 litres)	5.8	3.1 Imported crude oil	0.3 Wood
Briquettes (per tonne)	1.7	2.1 Sub-bituminous coal	<0.1 Wood pellets
Electricity (per gigajoule electricity)	0.21	~0 Wind and hydroelectric generation	

1. How much greenhouse gas is emitted when lignite is consumed?

Lignite is a soft brown fuel, the lowest rank of coal. It is characterised by geologically recent origin, incomplete transformation to coal, low heating value and high bed moisture.

A simple way of estimating greenhouse gas emissions from lignite use, is to assume that the lignite is completely burnt in the process, converting all its carbon content into the greenhouse gas carbon dioxide. For Mataura lignite, this generates a typical emission factor for combustion of 1.21 tCO₂/t lignite [Calculation **A**].

Methane, a potent greenhouse gas, is commonly found in deposits of peat, lignite and coal. This methane can be released as 'fugitive' emissions whenever the deposits are opened to the air. Under the current New Zealand Emissions Trading Scheme (ETS) regulations, based on methane emissions the emission factor for lignite mining would be assessed at 0.018 tCO₂eq/t lignite.²

By way of a comparison, a broader range of emissions for a large opencast coal mine in Queensland have recently been calculated.³ Fugitive emissions, electricity use, fuel use, explosive use, low temperature oxidation and waste disposal to landfill were together estimated to result in emissions of 0.02 tCO₂eq/t coal [Calculation **B**]. This approach therefore gives much the same result as applying the ETS regulations.

Either way, combustion is the principal contributor to the emission factor for lignite consumption. This is because shallow deposits use relatively little energy to mine, and naturally contain little methane.

Based on combustion and mining emissions, a typical emission factor for Southland and Otago lignite is estimated at 1.2 tCO₂eq/t lignite.

A:

$$\begin{aligned} \text{Combustion emissions factor} &= \left(\frac{\text{molecular mass of } CO_2}{\text{molecular mass of } C} \right) \times \text{proportion } C \text{ in lignite} \\ &= \frac{44 \frac{g}{mol} CO_2}{12 \frac{g}{mol} C} \times 0.33 \frac{t C}{t \text{ lignite}} \{1\} \\ &= 1.21 \frac{t CO_2}{t \text{ lignite}} \end{aligned}$$

B:

$$\begin{aligned} \text{Mining emissions factor} &= \frac{CO_2 \text{ associated with electricity, fuel, explosives used, fugitive emissions, waste produced, low temp. oxidation}}{\text{coal mined}} \\ &= \frac{47,200 t CO_2 + 30,100 t CO_2 + 1,800 t CO_2 + 209,000 t CO_2eq + 600 t CO_2eq + 6,600 t CO_2}{12,200,000 t \text{ lignite}} \\ &= 0.024 \frac{t CO_2eq}{t \text{ lignite}} \end{aligned}$$

Annual tonnages of CO₂eq and coal are as produced at Mine E in reference 3. At Mine E, emissions also resulted from land clearance and from spontaneous combustion of stockpiled black coal, neither of which is likely to be significant for wet lignite on farmland in Southland or Otago.

2. How much energy is produced when lignite is consumed?

The amount of lignite needed by a process often depends on lignite's energy content. As a basic principle, energy content increases with carbon content but decreases with water content. Some lignites can be very wet – so much so that even allowing them to sit around and air dry in a stockpile can measurably improve energy content by weight.

The lignites commonly mined in New Zealand today can have energy contents of 15 or 16 gigajoules of heat per tonne (abbreviated GJ_{th}/t). For the Mataura field, it appears likely that typical energy content will be less, around $13 GJ_{th}/t$.¹

However, these published energy contents are gross calorific values, as might be determined in a laboratory. For the purpose of this analysis, net energy content is more useful. Net energy content does not include energy lost in steam given off during combustion, which can be substantial for lignites with their high water content. Using a standard equation to estimate net energy content from measured properties,⁴ the typical net energy content of Mataura lignite appears to be about $11.5 GJ_{th}/t$ [Calculation **C**].

It follows that, on an energy basis, Mataura lignite has an emission factor of about $0.11 tCO_2eq/GJ$ (which is $0.38 tCO_2eq/MWh_{th}$) [Calculation **D**]

C:

Net energy = Gross energy – proportions hydrogen, water, oxygen × correction factors

$$\begin{aligned} &= 13 \frac{GJ_{th}}{t} - 21.2 \times 0.023 - 2.45 \times 0.43 - 0.08 \times 0.12 \\ &= 11.5 \frac{GJ_{th}}{t} \end{aligned}$$

This equation comes from reference 4. The parameters for Mataura lignite are from reference 1.

D:

$$\begin{aligned} \text{Emission factor (energy basis)} &= \frac{\text{Emission factor (mass basis)}}{\text{Energy content}} \\ &= \frac{1.23 \frac{t CO_2}{t \text{ lignite}} \{A,B\}}{11.5 \frac{GJ_{th}}{t} \{C\}} \\ &= 0.107 \frac{t CO_2}{GJ_{th}} \end{aligned}$$

Some processes may obtain some process energy from the electricity grid, rather than from the lignite. Some sources of electricity also have significant emission factors. Existing thermal power stations burn coal or 'natural gas' (a petroleum gas, consisting mostly of methane, chemical formula CH₄) and therefore also produce carbon dioxide. Some sources of geothermal steam and natural gas contain a significant proportion of carbon dioxide, which is emitted when they are used for power generation.

The proportions of electricity generated from different sources varies somewhat from year to year in New Zealand, depending on weather and economic conditions. This analysis needs an average emission factor for New Zealand electricity. Taking annual average life cycle emission factors for New Zealand electricity generation for the years 2005-2008,⁵ and averaging them, gives an emission factor for New Zealand electricity of 0.065 tCO₂eq/GJ_e (0.23 tCO₂eq/MWh_e) [Calculation **E**].

E:

$$\begin{aligned} \text{Electricity emission factor} &= \left(\frac{(237.5 + 201.9 + 245.0 + 253.2) \frac{\text{g CO}_2}{\text{kWh}_e}}{4} \right) \times \frac{1}{3600 \text{ s}} \\ &= 0.0651 \frac{\text{t CO}_2}{\text{GJ}_e} \end{aligned}$$

These annual average emission factors are from reference 5.

3. Derivation of emission factors for urea

Urea is a nitrogen-containing fertilizer commonly used in New Zealand. It also has applications in particle-board manufacture and adhesives. Ballance Agri-Nutrients currently operate a natural gas to urea plant at Kapuni in Taranaki, with a nominal production capacity of 260,000 tonnes.⁶ Over the period 2004-2008, New Zealand's urea industry looked like this:

	Tonnes of urea per year
Average Kapuni production ⁷	244,200
Imports ⁸	+ 388,700
Hence, total available	632,900
Applied to land ⁹	- 429,500
Hence, used for something else	203,000

In making urea, some of the carbon from the lignite is incorporated into the urea product, so is not emitted as carbon dioxide until after the urea is used. That carbon dioxide is explicitly subtracted out of this emission factor calculation. Further, applying urea as fertiliser results in a complex chain of direct and indirect emissions of greenhouse gases. Those emissions are not considered here because they depend on how the urea is used – some urea is not even used as fertiliser – and do not depend on how the urea was made. This analysis focuses on emissions from urea manufacture, including fugitive emissions associated with feedstocks.

A proposed lignite to urea plant will have a production capacity of up to 1.2 Mt urea/year. The proposed plant would consume up to 2 Mt/year of lignite.¹⁰ Therefore, dividing one value into the other, lignite consumption in urea manufacture would be about 1.67 t lignite/t urea.

Ballance's Kapuni plant also uses a small amount of electricity, 32 GWh/y, which comes to about 0.43 GJ/t urea,¹¹ and it is assumed that the proposed lignite to urea plant will have similar requirements.

The emission factor for urea from Southland or Otago lignite is estimated at 1.3 tCO₂eq/t urea [Calculation F].

F:

$$\begin{aligned}
 \text{Urea emission factor} &= \text{lignite use} \times \text{lignite emission factor} + \text{electricity use} \times \text{electricity emission factor} - \frac{\text{molecular mass of CO}_2}{\text{molecular mass of urea}} \\
 &= 1.67 \frac{\text{t lignite}}{\text{t urea}} \times 1.23 \frac{\text{t CO}_2}{\text{t lignite}} \{\mathbf{A,B}\} + 0.43 \frac{\text{GJ}}{\text{t urea}} \times 0.065 \frac{\text{t CO}_2}{\text{GJ}} \{\mathbf{E}\} - \frac{44 \frac{\text{g CO}_2}{\text{mol}}}{60 \frac{\text{g urea}}{\text{mol}}} \\
 &= 1.34 \frac{\text{t CO}_2}{\text{t urea}}
 \end{aligned}$$

The last term in the calculation corrects for the carbon remaining in the urea and therefore not released as carbon dioxide from processing.

It is relevant to compare the estimated emissions factor for lignite urea with the emissions factor for New Zealand’s urea made from natural gas.

The Kapuni urea plant currently uses approximately 7 PJ of natural gas each year,¹² half of which is feedstock to the process and half of which is fuel.¹³ Generally, the feedstock gas comes from the Kapuni field via Vector’s Kapuni Gas Treatment Plant, while the fuel gas is from other Taranaki fields such as Maui.¹⁴ Untreated Kapuni natural gas contains a large proportion of carbon dioxide,¹⁵ giving it a relatively high emission factor, whereas Maui gas has only a few percent carbon dioxide, like most commercial fields.¹⁶

In national greenhouse gas inventory calculations, emissions from natural gas treatment and from urea production are accounted for separately. But for this analysis, they are combined and carbon in the urea product is excluded, so that the emissions factor calculation has similar system boundaries to the calculation for lignite. On this basis, New Zealand natural gas urea has an emission factor of 1.1 tCO₂/t urea [Calculation G].

G:

$$\begin{aligned}
 \text{Natural gas urea emission factor} &= \frac{\text{feed, fuel gas use} \times \text{emission factors}}{\text{urea production}} + \frac{\text{electricity use} \times \text{electricity emission factor}}{\text{molecular mass of urea}} - \frac{\text{molecular mass of CO}_2}{\text{molecular mass of urea}} \\
 &= \frac{7 \text{ PJ}_{th} \times \left(\frac{1}{2} 84,100 \frac{\text{tCO}_2}{\text{PJ}_{th}} + \frac{1}{2} 52,800 \frac{\text{tCO}_2}{\text{PJ}_{th}} \right)}{260,000 \text{ t urea}} + 0.43 \frac{\text{GJ}_{th}}{\text{t urea}} \times 0.065 \frac{\text{t CO}_2}{\text{GJ}_{th}} \{\text{E}\} - \frac{44 \frac{\text{g CO}_2}{\text{mol}}}{60 \frac{\text{g urea}}{\text{mol}}} \\
 &= 1.14 \frac{\text{t CO}_2}{\text{t urea}}
 \end{aligned}$$

Natural gas usage in urea manufacture is from references 12 and 13, and the corresponding emission factors are from reference 16. Again the last term corrects for carbon remaining in urea and therefore not released as carbon dioxide from processing.

In recent years New Zealand urea imports have come principally from the Middle East,⁸ where urea is principally made from natural gas. Middle Eastern natural gas will usually have a much lower carbon dioxide content than Kapuni gas, and even taking typical gas processing emissions in developing countries into account,¹⁷ should have a rather lower emission factor. As against that, Middle Eastern electricity generation is generally from fossil sources, and accordingly has a higher emission factor than in New Zealand.¹⁸ As a rough estimate, assuming a similar engineering standard to Kapuni, Middle Eastern natural gas urea could have an emission factor as low as 0.8 tCO₂eq/t urea [Calculations **H,I**].

H:

Middle East natural gas emission factor = combustion emission factor + fugitive emission factor

$$\begin{aligned}
 &= 51,600 \frac{t \text{ CO}_2}{\text{PJ}_{th}} \{5\} + \frac{0.1 \frac{kt \text{ CO}_2eq}{\text{Mm}^3}}{40 \frac{\text{MJ}}{\text{m}^3}} \{16\} \\
 &= 54,100 \frac{t \text{ CO}_2}{\text{PJ}_{th}}
 \end{aligned}$$

The specific emission factor for fugitive emissions in the Middle East is taken to be the approximate upper bound default value for natural gas production in developing countries from volume 2, chapter 4, table 4.2.5 of reference 17, which is dominated by raw CO₂ venting. Note that there is no allowance for storage and transport in this calculation.

I:

$$\begin{aligned}
 &= \frac{7 \text{ PJ}_{th} \times 55,000 \frac{t \text{ CO}_2}{\text{PJ}_{th}}}{260,000 t \text{ urea}} + 0.43 \frac{\text{GJ}_{th}}{t \text{ urea}} \times 0.42 \frac{t \text{ CO}_2}{\text{MWh}_e} \times \frac{1}{3600 s} - \frac{44 \frac{g \text{ CO}_2}{\text{mol}}}{60 \frac{g \text{ urea}}{\text{mol}}} \\
 &= 0.80 \frac{t \text{ CO}_2}{t \text{ urea}}
 \end{aligned}$$

Here Middle Eastern natural gas is assigned an estimated emission factor from calculation H, rounded up to allow for storage and transport. Middle Eastern electricity is assigned an estimated emission factor from the data given for Saudi Arabia at reference 18.

4. Derivation of emission factors for diesel

Here we determine the emission factors of diesels made from lignite and crude oil.

The greenhouse gas emissions generated from diesel can be divided into two parts: upstream and tailpipe. Upstream emissions result from all the processes required to get the fuel from its source to the pump. In the case of conventional fuels this would include pumping crude oil from a reservoir, shipping it to New Zealand, refining it and delivering it to the pump. Tailpipe emissions are those that occur from the fuel when it is burned in an automobile. The emissions intensities determined here are the sum of both upstream and tailpipe emissions.

Currently, around 75 percent of New Zealand's fuels are refined at Marsden Point from imported crude oil. About half of this crude oil comes from the Middle East, and most of the rest is from the Asia-Pacific region, including some domestic production. Some fuels also come from other refineries in the Asia-Pacific region as finished product.¹⁹ Diesel consumption is currently almost 3 billion litres a year,^{16,20} an average of about 50,000 barrels per day (abbreviated bbl/d).

Proposals for lignite-to-diesel plants using the Fischer-Tropsch process have indicated nominal production capacities of 35,000 bbl/day²¹ or even 50,000 bbl/day.²²

An initial techno-economic feasibility study of a Fischer-Tropsch plant at Maitua assumed that the plant would be equipped with carbon capture and storage (CCS) technology. It was calculated that such a plant would consume 6.0 t lignite for every thousand litres of diesel if it produced 10,000 bbl/d, and 5.5 t lignite/kL at 60,000 bbl/d; that is, there is some economy of scale.²³ By interpolation a 35,000 bbl/d plant with CCS would require about 5.7 t lignite/kL diesel.

Since the proposed plant would be powered solely by lignite, it is assumed that deducting the amount of lignite needed to power CCS from that estimate will provide a reasonable estimate of lignite consumption for a Fischer-Tropsch plant without CCS.

Two recent American assessments of Fischer-Tropsch coal-to-liquids plants provide breakdowns of proposed plant energy consumption by process elements. They suggest respectively that 15 percent and 20 percent of plant energy consumption would go toward operating carbon dioxide separation and compression equipment.²⁴ Accordingly, reducing the energy consumption by 15-20% should reduce the lignite consumption to about 4.7 t lignite/kL diesel.

A 35,000 bbl/d Fischer-Tropsch lignite-to-diesel plant in Southland or Otago, without CCS, would result in emissions of about 5.8 tCO₂/kL diesel
[Calculation J]

By comparison the emission factor of ordinary petroleum diesel in New Zealand is about 3.1 tCO₂eq/kL. Of this, approximately 2.7 tCO₂/kL is emitted when the fuel is combusted.⁵ Fugitive and process emissions therefore account for around 0.4 tCO₂/kL, about half of which occurs at the refinery [Calculation **K**].

For another comparison, biodiesel made in New Zealand from wood via Fischer-Tropsch synthesis could have an emission factor of just 0.3 tCO₂/kL. However, it would be difficult and expensive to make any type of biodiesel in the quantities envisaged from lignite.²⁵

Solid Energy has indicated an interest in the technology being developed by an Australian company, Ignite Energy Resources, to 'upgrade' low energy lignite. The Ignite process is a hydrothermal liquefaction, using supercritical water to break down the chemical structure of lignite. It is expected to yield about 1 barrel of coal oil from one tonne of lignite, along with about 300 kg of char.²⁶ This coal oil appears to contain principally phenolic compounds, so while it is said to have a good energy content, it would require substantial hydrotreating and refining to upgrade it into fuels suitable for road vehicles.³¹

Little Ignite information is in the public domain as yet. Ignite claim that their technology will produce "up to 60% less CO₂ than widely available coal-to-liquids technologies."²⁷ Nonetheless, a process involving solids in supercritical water is likely to need significant energy input. Moreover, if a high quality fuel is to be produced, large volumes of hydrogen would be needed, which could only be obtained from fossil fuels such as natural gas or perhaps local coal seam gas, adding significantly to the emission factor for Ignite fuel.

J:

Diesel emission factor = lignite use with CCS × (1 – CCS energy share) × lignite emission factor

$$\begin{aligned} &= 5.7 \frac{t \text{ lignite}}{kL} \times (1 - 0.175 \{24\}) \times 1.23 \frac{t \text{ CO}_2}{t \text{ lignite}} \{A,B\} \\ &= 5.8 \frac{t \text{ lignite}}{kL} \end{aligned}$$

The value for lignite use with CCS is discussed above.

K:

$$\begin{aligned} \text{Fuel refining emission factor} &= \left(\frac{\text{refinery emissions} + \text{hydrogen production emissions}}{\text{fuel refined}} \right) \times \text{fuel energy content} \\ &= \left(\frac{910,000 t \text{ CO}_2 + 240,000 t \text{ CO}_2}{221 PJ \{16\}} \right) \times 38 \frac{GJ}{kL} \{16\} \\ &= 0.20 \frac{t \text{ CO}_2}{kL} \end{aligned}$$

Reference 7 gives annual refinery emissions for 2008 in table 1s1, and total hydrogen production emissions from the refinery and from one other industrial source in table 2(l)s1; it is assumed, with some support from reference 19, that almost all hydrogen production occurs at the refinery.

5. Derivation of emission factors for briquettes

Briquettes are small manufactured blocks used for fuel. In 2009 the South Island used enough coal, mostly of sub-bituminous rank, to generate about 17 petajoules of heat energy (PJ_{th}).¹⁶

One published proposal is for a demonstration lignite briquetting plant with a production capacity of 100,000 t/year in 2011, to supply the domestic market. If successful it would be followed by a commercial scale plant with a production capacity of up to 1 Mt/y, principally for export.²⁸

It appears that this plant would use a drying process developed by Adelaide company GTL Energy. The GTL drying process makes briquettes by a low temperature drying process, without using any binders. Exact details are confidential, but GTL state that it reduced the water content of Southland lignite by 65% in trials, yielding briquettes with 50% greater energy content by weight.²⁹ The net energy content of briquettes would then be about $18.5 \text{ GJ}_{th}/t$ [Calculation **L**] and the commercial scale plant would produce about $18.5 \text{ PJ}_{th}/\text{year}$.

Here it is assumed that the lignite is warmed to working temperature by a briquette-fired burner, then water is removed by a highly efficient heat pump process. At a rough estimate, each tonne of briquettes would require about 1.4 t lignite and 0.20 GJ_e of electricity [Calculations **M** and **N**].

L:

Using the same equation as calculation C, but making some complex corrections to the proportions of the various constituents, in order to account for the water removed by drying:

$$\begin{aligned} &= 1.5 \times 13 \frac{\text{GJ}_{th}}{t} - 21.1 \times \frac{0.023}{1 - 0.43 \times 0.65} - 2.45 \times 0.43 \times (1 - 0.65) - 0.08 \times \frac{0.12}{1 - 0.43 \times 0.65} \\ &= 18.5 \frac{\text{GJ}_{th}}{t} \end{aligned}$$

The drying efficiency of 0.65 is from reference 29.

M:

$$\begin{aligned} \text{Lignite use} &= \frac{1}{\left(1 - \text{water removed} - \frac{\text{heat required}}{\text{briquette energy content} \times \text{burner efficiency}}\right)} \\ &= \frac{1}{\left(1 - \left(0.43 \frac{t \text{ water}}{t \text{ lignite}} \{1\} \times 0.65 \{29\}\right) - \frac{0.25 \frac{\text{GJ}_{th}}{t \text{ lignite}}}{18.5 \frac{\text{GJ}_{th}}{t \text{ briquettes}} \{L\}} \times 0.8\right)} \\ &= 1.42 \frac{t \text{ lignite}}{t \text{ briquettes}} \end{aligned}$$

The last term within the brackets estimates 'parasitic' use of briquettes for warming. Based on expert advice, the heat required for warming up the lignite is assumed to be about $0.25 \text{ GJ}_{th}/t$ lignite, and burner efficiency is taken to be 80%.

Combining these consumption estimates with the emission factors developed above, the emissions factor for briquettes made from lignite is estimated at 1.75 tCO₂eq/t briquettes [Calculation **O**].

By comparison, the emission factor for sub-bituminous coal appears to be about 2.1 tCO₂eq/t coal for about 22 GJ_{th}/t of primary energy.⁵ This is roughly the same as lignite briquettes on an energy basis [Calculation **P**].

N:

Electricity use = lignite use × proportion water × drying efficiency × heat pump electricity requirement

$$\begin{aligned}
 &= 1.42 \frac{t \text{ lignite}}{t \text{ briquettes}} \{\mathbf{M}\} \times 0.43 \frac{t \text{ water}}{t \text{ lignite}} \{\mathbf{1}\} \times 0.65 \{\mathbf{29}\} \times 0.5 \frac{GJ_e}{t \text{ water}} \\
 &= 0.20 \frac{GJ_e}{t \text{ briquettes}}
 \end{aligned}$$

The last term, the electricity requirement for removing water by means of a highly efficient heat pump process, is an estimate based on expert advice to PCE.

O:

Briquette emission factor = lignite use × lignite emission factor + electricity use × electricity emission factor

$$\begin{aligned}
 &= 1.42 \frac{t \text{ lignite}}{t \text{ briquettes}} \{\mathbf{M}\} \times 1.23 \frac{t \text{ CO}_2}{t \text{ lignite}} \{\mathbf{A,B}\} + 0.20 \frac{GJ_e}{t \text{ briquettes}} \{\mathbf{N}\} \times 0.065 \frac{t \text{ CO}_2}{GJ_e} \{\mathbf{E}\} \\
 &= 1.76 \frac{t \text{ CO}_2}{t \text{ briquettes}}
 \end{aligned}$$

P:

As in calculation D;

$$\begin{aligned}
 &= \frac{2.1 \frac{CO_2eq}{t \text{ sub-bituminous coal}}}{22 \frac{GJ_{th}}{t \text{ sub-bituminous coal}}} \{\mathbf{5}\} \\
 &= 0.095 \frac{CO_2eq}{GJ_{th}}
 \end{aligned}$$

Solid Energy has indicated an interest in the technology being developed by an Australian company, Ignite Energy Resources, to 'upgrade' low energy lignite. The Ignite process is a hydrothermal liquefaction, using supercritical water to break down the chemical structure of lignite. It is expected to yield 300 kg of char from one tonne of lignite, along with about 1 barrel of coal oil.²⁶ This char is like a finely powdered high rank coal, so it would seem suitable for heating applications if bound up into briquettes.

Little Ignite information is in the public domain as yet. It is not clear what the energy inputs into the Ignite process are, therefore it is difficult to estimate an emissions factor for char briquettes. Nonetheless, a process involving solids in supercritical water is likely to need significant energy input. Water does not reach its supercritical point until heated to more than 374 °C and pressurised to more than 218 atmospheres, and a lot of the heat will not be recoverable.

Ignite data indicates that, based on combustion alone, char would have an emission factor of 2.9 tCO₂/t char [Calculation Q]. Once emissions from processing are included, char briquettes are likely to have a significantly greater emissions factor than briquettes from low-temperature drying, even on an energy basis at 30 GJ_{th}/t.³⁰

Q:

As in calculation A;

$$\begin{aligned}
 \text{Char combustion emission factor} &= \left(\frac{\text{molecular mass of } CO_2}{\text{molecular mass of } C} \right) \times \text{proportion of } C \text{ in char} \\
 &= \frac{44 \frac{g CO_2}{mol}}{12 \frac{g C}{mol}} \times 0.8 \frac{t C}{t char} \{31\} \\
 &= 2.9 \frac{t CO_2}{t char}
 \end{aligned}$$

A much lower emission factor could be obtained by using a renewable solid fuel such as pelletised wood. Growing, harvesting and hauling wood to a processing plant uses a small amount of diesel,³¹ roughly chipping this wood requires very little additional energy,³² and the wood can be dried for pelleting using a pellet burner.³³ Overall the emission factor should be less than 0.1 tCO₂/t pellets [Calculation **R**]. Pellet-fired boilers should be at least as efficient as briquette-fired boilers of a similar size.³⁴

Good performance might also be expected from another renewable solid fuel, 'torrefied' wood, which has been 'roasted' to remove water, and consequently has fuel properties comparable to lower rank coals.³⁵ Making the same assumptions about growing, harvesting, hauling and hogging the wood as for pellets, and using torrefaction off gases as the principal fuel for pre-drying the wood, but fuelling the torrefier with natural gas, suggests an emission factor around 0.2 tCO₂/t torrefied wood [Calculation **S**].

R:

$$\begin{aligned}
 \text{Pellet emission factor} &= \text{diesel requirement} \times \text{wood use} \times \text{diesel emission factor} \left(1 + \frac{\text{heat requirement}}{\text{pellet energy content} \times \text{burner efficiency}} \right) \\
 &= 0.0055 \frac{\text{kL}}{\text{t green wood}} \{32\} \times 2 \frac{\text{t green wood}}{\text{t pellets}} \times 3.1 \frac{\text{t CO}_2}{\text{kL}} \{5\} \times \left(1 + \frac{2.4 \frac{\text{GJ}_{\text{th}} \{34\}}{\text{t pellets}}}{19 \frac{\text{GJ}_{\text{th}}}{\text{t pellets}} \{16\} \times 0.8} \right) \\
 &= 0.04 \frac{\text{t CO}_2}{\text{t pellets}}
 \end{aligned}$$

The approximate green wood requirement for making pellets is estimated from reference 33. The term in brackets calculates the parasitic consumption of drying pellets using a pellet burner; burner efficiency is again taken to be 80%.

S:

$$\begin{aligned}
 \text{Torrefied wood pellet emission factor} &= \text{diesel requirement} \times \text{wood use} \times \text{diesel emission factor} + \text{gas use} \times \text{gas emission factor} \\
 &= 0.0055 \frac{\text{kL}}{\text{t green wood}} \{32\} \times \frac{119 \text{ t green wood}}{47 \text{ t torrefied wood}} \times 3.1 \frac{\text{t CO}_2}{\text{kL}} \{5\} + \frac{108 \text{ GJ}_{\text{th}}}{47 \text{ t torrefied wood}} \times 0.061 \frac{\text{t CO}_2 \text{ eq}}{\text{GJ}_{\text{th}}} \{5\} \\
 &= 0.018 \frac{\text{t CO}_2 \text{ eq}}{\text{t torrefied wood}}
 \end{aligned}$$

Reference 35 gives, for a modelled torrefaction plant, hourly natural gas and wood consumption relative to an hourly torrefied wood production rate of 47 t/hr. Producing and torrefying wood also entails various minor electricity uses which are not included in this calculation.

6. Derivation of emission factors for electricity

Like any developed country, New Zealand uses a lot of electricity, and there are always plans to add new generation. Solid Energy and Comalco investigated the feasibility of a lignite-fired power plant in Southland in 2004-2005.³⁶

Solid Energy and Comalco envisaged a 500 MW_e power station using Southland lignite and costing \$1-2 billion dollars. It is likely that such generated power would often be transmitted to the North Island, at a considerable cost to the generator. The national grid would also need substantial strengthening to cope with a large new generator in Southland.

Currently, New Zealand's electricity supply is dominated by renewable generation. In 2009, 73 percent of electricity came from hydroelectric, geothermal, and wind resources.³⁷

Electricity can be made from lignite by gasifying it, then burning the syngas in an integrated gas combined cycle (IGCC) power station. Another option is an ultrasupercritical (USCC) power station, but USCC plants must be very large, it is difficult to capture their CO₂ emissions, and because they do not involve gasification, they do not offer any synergies with urea and diesel manufacture. So this analysis assumes a modern IGCC, running on briquetted lignite and with a thermal efficiency of 45%.³⁸ The lignite demand for such a plant should be about 0.17 t lignite/GJ_e [Calculation **T**].

Lignite-fired IGCC is not widely used, but it is proven technology. Examples from around the world include Schwarze Pumpe, Germany, operating since 1956, and Vresova, Czech Republic, since 1968. More recently the Sanghi power station in Gujarat, India, was commissioned in 2002 with a nominal output of 109 MW.

The emission factor for electricity from lignite would be about 0.21 tCO₂/GJ_e [Calculation **U**], which is 0.76 tCO₂/MWh_e.

T:

$$\begin{aligned}
 \textit{Lignite use} &= \frac{\textit{briquette lignite use}}{\textit{briquette net energy content} \times \textit{thermal efficiency}} \\
 &= \frac{1.42 \frac{\textit{t lignite}}{\textit{t briquettes}} \{\mathbf{M}\}}{18.5 \frac{\textit{GJ}_e}{\textit{t briquettes}} \{\mathbf{L}\} \times 0.45 \{\mathbf{39}\}} \\
 &= 0.17 \frac{\textit{t lignite}}{\textit{GJ}_e}
 \end{aligned}$$

U:

$$\begin{aligned}
 \textit{Lignite electricity emission factor} &= \textit{lignite use} \times \textit{lignite emission factor} \\
 &= 0.17 \frac{\textit{t lignite}}{\textit{GJ}_e} \{\mathbf{T}\} \times 1.23 \frac{\textit{t CO}_2}{\textit{t lignite}} \{\mathbf{A,B}\} \\
 &= 0.210 \frac{\textit{t CO}_2}{\textit{GJ}_e}
 \end{aligned}$$

This is about three times higher than the New Zealand average life cycle emissions factor for electricity generation over 2005-2008 (refer Calculation E). Even among thermal generators, a new combined cycle gas turbine (CCGT) power plant would be expected to have lower emissions, at about $0.11 \text{ tCO}_2\text{eq/GJ}_e$ [Calculation **V**].³⁹ Proposed electricity generation projects in the south of the South Island already include over 1000 MW of wind generation and 670 MW of hydroelectric generation,⁴⁰ all with very low operating greenhouse gas emissions.

It is relevant to consider the potential effect of a lignite-fired power station on New Zealand's electricity and wider energy sector greenhouse gas emissions. Running at a capacity factor of 80%, a 500 MW_e plant would emit 2.6 MtCO_2 in a year [Calculation **W**]. Over the same period, the electricity generation subsector emitted an average of $8 \text{ Mt CO}_2\text{eq/y}$, and the whole energy sector around $33 \text{ Mt CO}_2\text{/yr}$.⁴¹

V:

$$\begin{aligned} \text{natural gas electricity emission factor} &= \frac{\text{natural gas emission factor}}{\text{thermal efficiency}} \\ &= \frac{0.0610 \frac{\text{t CO}_2}{\text{GJ}_{th}} \{5\}}{0.58 \{40\}} \\ &= 0.105 \frac{\text{t CO}_2}{\text{GJ}_e} \end{aligned}$$

W:

$$\begin{aligned} \text{Annual emissions} &= \text{output} \times \text{capacity factor} \times \text{running time} \times \text{emissions factor} \\ &= 500 \text{ MW}_e \{37\} \times 0.8 \times (24 \text{ h} \times 365 \text{ d}) \times \left(0.21 \frac{\text{t CO}_2}{\text{GJ}_e} \{U\} \times 3600 \text{ s} \right) \\ &= 2,600,000 \text{ t CO}_2 \end{aligned}$$

Here the capacity factor of 0.8 is considered appropriate for a slow-starting baseload generator.

Endnotes

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According to this reference, lignites from deposits such as Maitai in the north of the Eastern Southland field have higher energy contents and lower moisture contents than lignites from deposits further south. For the Hawkdun lignite field in Otago, where mining has also been proposed, energy content also appears to be generally lower than Maitai. See also:

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