Transitioning New Zealand to Renewable Energy

Ian Mason[2]*, Harry Gates[1]*, Henna Chua[1], Allan Miller[1]

[1] Electric Power Engineering Centre (EPECentre), University of Canterbury

[2] Department of Civil and Natural Resources Engineering, University of Canterbury

* Presenting authors

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Abstract

This paper investigates the potential for replacing fossil fuels in the stationary energy and transport sectors in New Zealand with renewably-generated electricity. The purpose is to quantify the amount of new electricity generation required and to assess the likely greenhouse gas reductions in relation to achieving New Zealand's climate change targets. Alternative means of meeting the 2030 target by using bioenergy resources, planting forests and purchasing offshore carbon credits were considered. This paper reports a scoping exercise to give an idea of the size of the transition and the potential gains.

In 2014, 130,225 GWh worth of replaceable non-renewable fuels were used for transport, heating, pumping and non-renewable electricity production. After excluding aviation, shipping and heavy vehicles, approximately 84,900 GWh/y of fossil fuel energy would need replacement. By applying efficiency factors for current fossil fuel technology and replacement electrical technology, including employing heat pumps for < 100 °C applications, it was estimated that these uses would require 41,620 GWh of electricity. This is a 53% reduction in delivered energy requirements, but requires new generation equivalent to New Zealand's 2014 electricity production. A reduction in New Zealand's greenhouse gas emissions of about 25.4 Mt CO_2-e was estimated. This is approximately 85% of the commitment in New Zealand's Nationally Determined Contribution (NDC) following the 2015 Paris agreement.

When fuel costs were compared on an end-use energy basis, electricity was 2.5-5.5 times lower in cost than fossil petrol for battery electric vehicles, 1.6-2.8 times as expensive as woodchips for boiler-based systems, and 0.5-0.9 times the cost of wood chips for heat pump applications supplying low-grade heat. Bioenergy will likely make a significant contribution to medium- and high-grade process heat applications, but will be constrained by resource and land area limitations. Forestry planting on marginal land could make a substantial contribution to the NDC in the medium term.

It was concluded that a significant opportunity for the electricity industry exists in principle to contribute to a transition to renewable energy and to New Zealand's climate targets. In the immediate future the promotion of energy efficiency, battery electric vehicles and heat pumps in low-grade process heat, space heating and water heating application is suggested. Further research into the prospects for electricity to contribute to medium- and high-grade process heat, to conduct full life cycle and security of supply analyses, and to better understand the relative contributions of electricity, bioenergy, forestry and carbon credits to a low-carbon future is recommended.

Introduction

Prior to the United Nations Climate Change Conference in Paris, December 2015, the New Zealand Government proposed a reduction in greenhouse gas (GHG) emissions by 2030 of 30% below those produced in 2005 via its Intended Nationally Determined Contribution (INDC). This is equivalent to an 11% reduction on 1990 GHG emission levels [1]. When the NZ Government ratified the agreement on 4 October, 2016, the INDC became a Nationally Determined Contribution (NDC) [2]. New Zealand's gross GHG emissions in 2005 were 83.7 Mt CO_2-e, thus the NDC commitment implies a 2030 target of 58.6 Mt. This target is net, so assuming a business-as-usual scenario in which 88.9 Mt gross GHG emissions are emitted in 2030 [3], removal of 30.3 Mt is required. The NZ Government has stated that the target will be met "*through a mix of domestic emission reductions, the removal of carbon dioxide by forests, and participation in international carbon markets.*" [1] .

New Zealand's gross GHG emissions and total primary energy supply have trended upwards since 1990 [4, 5]. The energy sector, which includes stationary energy, transport and electricity generation, makes up the largest of the non-agricultural GHG sources (Fig. 1a). Transport contributed the largest share of energy sector emissions in 2013, with significant contributions from manufacturing and electricity generation (Fig. 1b). Total energy sector emissions in 2013 were 31.5 Mt. CO_2-e [6]. Therefore New Zealand's NDC could be met if almost all energy sector emissions were removed.

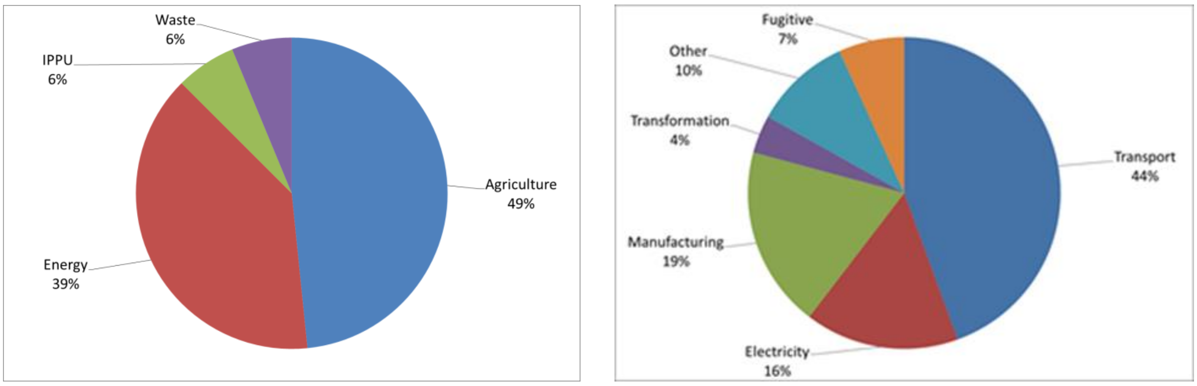

Figure 1: a) New Zealand's GHG emissions by sector in 2013; b) breakdown of energy sector emissions. (data from [6, 7])

Previous studies have demonstrated the technical feasibility of decarbonizing energy systems. In the Zero Carbon Australia 2020 stationary energy study [8], a 100% renewable energy supply was modelled at hourly intervals over a 2 year period in conjunction with historic demand. Primary energy input decreased from 3950 PJ/y to about 1600 PJ/y, a 59% reduction. Electricity was the major energy carrier, followed by biomass and a small contribution from direct solar. Similarly, in their hourly modeling for the Danish Government's "Fossil-Fuel-Free by 2050" policy, Danish researchers demonstrated that primary energy requirements would fall from 980 PJ/y in a reference scenario to approximately 420 PJ/y in 2050, or a 57% reduction [9].

The present research has been carried out to investigate the potential to replace fossil fuels and eliminate that source of GHG emissions in the New Zealand energy sector using renewable electricity. The paper aims to quantify the additional renewable electricity requirements for such a transition, the associated reduction in GHG emissions, and the potential contributions from bioenergy, forestry and carbon credits.

Methodology

Data sources

Energy use data was obtained from the Ministry of Business, Innovation and Employment (MBIE) and the Energy Efficiency and Conservation Authority (EECA) [4, 10]. The non-renewable fuels considered were: coal, natural gas, aviation fuel/kerosene, LPG, fuel oil, diesel and petrol. Energy end use categories were taken from the EECA data base. Process efficiency data were sourced largely from the US Department of Energy (USDOE), plus professional associations and commercial suppliers (a full listing is provided in Appendix A). Energy density or specific energy values were chosen to represent the characteristics of the most prominent fuel types in New Zealand. Aviation data were taken from a study of the use of liquid hydrogen produced via electrolysis for all domestic and international fueling [11]. GHG emissions were estimated using information from the Ministry for the Environment's 'Voluntary Corporate Greenhouse Gas Emissions Reporting' document [12]. The calendar year 2014 was selected as the study period as this was the most recent year for which data was available.

Initial bioenergy resource estimates were based on a gross calorific value for softwoods of 19.2 MJ/kg and a hydrogen content of 6.25% [13]. This gave a net calorific value (NCV) for clean softwood chips at 10% moisture content of 15.81 GJ (4.39 MWh)/tonne. Industry data for Pinus Radiata of 4.14 MWh/tonne at 20 percent moisture and 2.35 MWh/tonne at 50 percent moisture content (Kevin Franks; pers. comm.) was adopted for comparative purposes. Forestry rotations were assumed to take 29 y (the average of 26-32 y [14]) and the whole tree yield from Pinus Radiata to be 425.8 tonne-DM/ha. [15]. Wood chips prices were obtained from [16].

Definitions

Delivered energy was defined as the heat content of the energy carrier (e.g. petrol, coal, electricity) delivered to the site (e.g. home, building, business) where it is used. End-use energy was defined as the energy available for use after conversion of delivered energy e.g. heat output from a boiler.

Assumptions

- Each efficiency value for a given process and fuel represented all such processes in New Zealand during the study period.
- The efficiency of 'mobile motive power' off-road engines was considered the same as that for land transport (based on energy output at the wheels); 'mobile motive power' was assumed to be largely made up of non-road industrial vehicles e.g. tractors and diggers.
- Stationary motive power was based on the shaft output of non-renewable powered engines.
- Efficiency values for LPG and natural gas were considered to be the same. This also applied to fuel oil and diesel.
- Electric resistance heating in all cases was assumed in the first instance.
- Electric replacements for heavy vehicles and ships were assumed initially.
- Black liquor and geothermal energy were considered to be renewable resources.
- Electricity transmission and distribution losses were taken as 7.5% (MED, 2008).

Calculations

Present end-use energy was calculated from delivered fossil-fuel energy and existing process efficiencies. Required electrical delivered energy was then determined by back-calculation, using appropriate efficiencies for the replacement electrical technologies.

Results

Renewable Electricity

In 2014, approximately 130,225 GWh of non-renewable delivered energy was used to satisfy stationary energy, electricity and transport demand (Table 1). If the same energy services were provided using electricity, 85,319 GWh of delivered electrical energy would be needed. Assuming average overall transmission and distribution losses of 7.5% [17], required generation would be approximately 92,237 GWh/y. On this basis a 32% reduction in delivered energy was predicted, however for the electricity sector, an increase in output equivalent to approximately 218% of 2014 generation would be required.

Table 1: Non-renewable energy and replacement electrical energy for 2014 (GWh)

Energy Use		Non-Renewable Energy	New Renewable Electrical Energy
Transport	Land[a]	50710	15189
	Sea	2163	1195
	Rail	631	185
	Air[b]	13750	28555
Motive power	Mobile	9345	2918
	Stationary	398	174
Process Heat	> 300 C	9357	8261
	100-300 C	14295	11703
	< 100 C	1643	1345
Space Heating	< 100 C	5438	4431
Water Heating	< 100 C	2789	2342
Cooking	100-300 C	628	531
Pumping	Pumping	101	46
Electricity[c]	Coal, gas	18979	8446
TOTAL		130225	85319

Notes: [a] includes heavy vehicles (10438 GWh) [b] based on data from [11]; [c] delivered energy back-calculated from reported electrical energy

In order to explore the short-medium term prospects for renewable electricity use, applications considered likely to require long-term development viz.- the electrification of heavy vehicles, the electrification of shipping and the use of electrolytic hydrogen for air transport were excluded. In addition, the use of heat pumps with a mean COP of 2.5 for low grade process heat, water heating and space heating applications (i.e. < 100 ^{o}C) was introduced. Coal and gas energy used in electricity generation were also subtracted. In this short-medium term scenario the non-renewable delivered energy to be replaced was 84,895 GWh/y, and additional required electricity generation was approximately 41,620 GWh/y (including transmission losses), or 99% of 2014 generation.

The overall saving in delivered energy through electrification was 54%. A breakdown of savings according to end use illustrates that major gains may be anticipated in almost all categories (Figure 3). Key to these improvements are: a) the replacement of internal combustion engines; and b) the use of heat pump technology in low-grade heat applications.

Emissions Reduction

For our short-medium term scenario approximately 25.4 Mt CO_2-e could potentially be eliminated. This represents 85.5% of the 2030 target. About 3.3 Mt CO_2-e would remain due to heavy vehicles and shipping continuing to use fossil fuels, plus approximately 3.5 Mt CO_2-e from aviation.

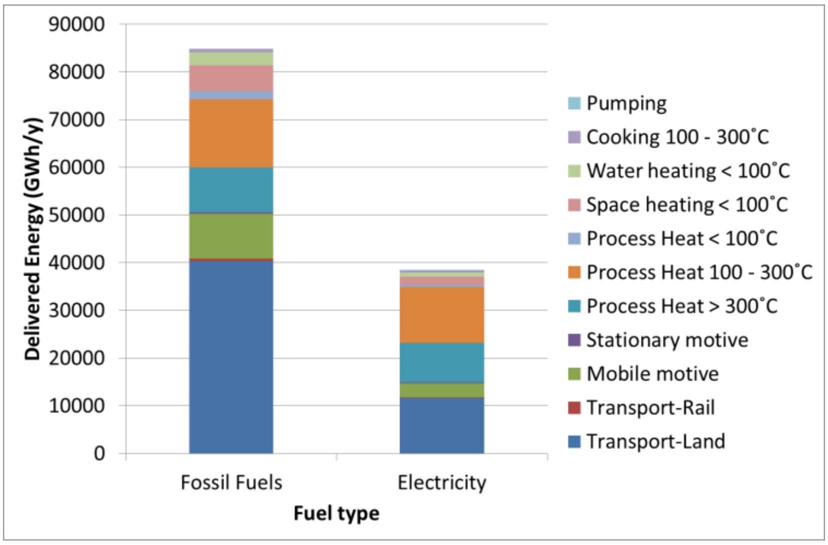

Figure 2: Delivered fossil-fuel and electrical energy for the short-medium term scenario

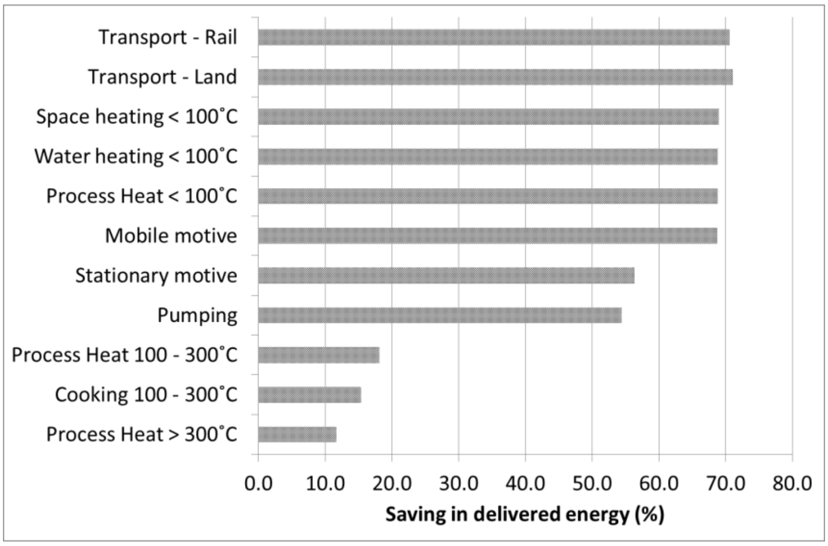

Figure 3: Savings in delivered energy for the short-medium term scenario

Bioenergy

The provision of all process heat, water heating and space heating requirements using wood chips would remove approximately 20,890 GWh/y from the additional electricity demand, and require 39,173 GWh/y of delivered energy from biomass, assuming identical conversion efficiencies to those for fossil-fuels. Using clean softwood chips at 10% moisture content, approximately 8.9 million tonne/y of woodchips would be needed. For Pinus Radiata wood chips at 20% and 50% moisture contents, the requirements would be 9.5 million tonne/y and 16.7 million tonne/y respectively. When using sources such as forestry arisings (biomass left after harvesting), lesser net calorific values of the order of 7.1 GJ/tonne (2 MWh/tonne) may be anticipated [16]. To produce these quantities of woodchips using Pinus Radiata, and assuming recovery of the whole tree, would require the annual harvesting of 18,550 ha and allocation of 31% of New Zealand's 1.72 million ha of plantation forestry. Alternative crops such as Miscanthus would require the use of arable land, and thus may be less suitable.

Fuel Prices

The comparative end-use energy costs of electricity and woodchips vary according to the application. For battery electric vehicles, fuel costs were 2.5-5.5 lower than for an equivalent ICE, depending on the electricity price (Table 2). However, as a direct replacement for woodchips in boiler systems, electricity was found to be 1.6 to 2.8 times more expensive in commercial and industrial examples. Where heat pumps were specified for low-grade heat production the costs of electricity and wood chips were approximately equivalent for a commercial application, but half the cost for our industrial scenario.

Table 2: Fuel cost comparison on end-use energy basis

Application	Fuel	Cost				Comments
		Purchase	Units	End-use	Units	
Transport	Petrol	200	c/l	102	c/kWh	Eff. 0.22
	Electricity	30[a]	c/kWh	40	c/kWh	Eff. 0.75
	Electricity	14[b]	c/kWh	19	c/kWh	Eff. 0.75
	Petrol	200	c/l	13	c/100 km	6.5 l/100 km [c]
	Electricity	30	c/kWh	5.5	c/100 km	5.5 km/kWh [d]
	Electricity	14	c/kWh	2.5	c/100 km	5.5 km/kWh [d]
Heat via boiler systems	Wood chips	11.5[e]	$/GJ(NCV)	5.2	c/kWh	Eff. 0.80
	Electricity	14[f]	c/kWh	14.7	c/kWh	Eff. 0.95
	Electricity	8[g]	c/kWh	8.4	c/kWh	Eff. 0.95
Heat via heat pumps	Electricity	14	c/kWh	4.7	c/kWh	COP 3.0
		8	c/kWh	2.7	c/kWh	

Notes: [a] full rate; [b] night rate; [c] Toyota Corolla (81 kW); [d] Nissan Leaf (80 kW); [e] mid-range [16]; [f] commercial rate; [g] industrial rate;

Discussion

For our short-medium term scenario an approximate doubling of 2014 electricity production would be required, which if supplied by renewable resources, would achieve about 85% of New Zealand’s 2030 target under the Paris climate change agreement. While this project has not considered where such new renewable generation might come from, or how quickly it could be built, we note that renewable generation projects “in the pipeline” in 2015 could potentially generate around 15,000 GWh/y [18], leaving a further 26,580 GWh to be found. The latter would require about 7.6 GW of on-shore wind generation at a capacity factor of 0.4. Alternatively using off-shore wind generation for which there is evidence of capacity factors of over 0.55, 5.5 GW installed capacity is indicated. Given that other renewable energy sources would likely be utilized, it appears at this stage that generating the required electricity would not be limited by a lack of energy resources.

Based on fuel costs alone, medium- and high-grade heat applications using resistance or inductive heating do not appear financially favorable at present. Thus an immediate focus on battery electric vehicles, low-grade heat pump applications and energy efficiency is suggested. In this case additional electricity production over that “in the pipeline” will reduce to about 3250 GWh/y. Energy efficiency improvements are one of the three “no-regrets” policies adopted by the European Union, along with “more renewables” and “improved energy infrastructure” [19]. In the built environment, improved thermal performance of building envelopes will not only save money, but facilitate the transition from combustion technologies to the use of heat pumps. Ground-source heat pumps typically have higher coefficients of performance than air-source systems and can be especially appropriate where ground water is available as an energy resource. One high temperature heat pump manufacturer has reportedly achieved temperatures of up to 150˚C, albeit from a 90 ˚C source [20]. This improvement surpasses previous technologies which peaked at around 100˚C. A combined energy efficiency and ground/water source heat pump approach to space heating is already present in professional engineering practice and a recent report suggests that, where appropriate, heat pump solutions will be low to medium cost [21]. The interest in, and number of, electric vehicles in New Zealand continues to increase [22] and their uptake is being promoted by the present government.

A stronger case for electrification of medium- and high-grade heat applications may emerge from full lifetime cost analyses incorporating security of supply and fuel-quality issues for woodchips and other bioenergy resources. Where boiler systems are nearing end-of-life, substitution of traditional hot water or steam as energy carriers with electrically-based alternatives may then become attractive. Further research is required in this area. The considerably cheaper fuel costs for battery electric vehicles are well known and decreasing purchase costs are widely anticipated.

Bioenergy will likely make a significant contribution to a renewable energy transition in New Zealand [21]. The use of bioenergy will reduce the amount of new renewable electricity generation needed, although this will be offset slightly by new electricity demand for biofuel production. However, our analysis has demonstrated that sufficient quantities of woodchips to fully replace fossil fuels in the process sectors are unlikely to be available. In terms of the available resource, competition from processors wishing to make Fischer-Tropsch fuels from wood residues may be expected. Availability of forestry residues in the central North Island has previously been estimated at 6000 dry tonnes/d, or 2.19 million tonne/y, from which a yield of about 13 PJ (3610 GWh/y) of unrefined biofuel or about 16% of 2014 diesel demand, may be expected. Existing competition from valuable non-energy crops, for example the export of forestry products in 2015 was worth about NZ$4.8 billion [23], will also limit the land available for bioenergy crops.

In terms of carbon sequestration by photosynthesis, an analysis of highly erodible land suitable for tree planting has indicated that about 1,312,000 ha is potentially available [24]. At a sequestration rate of 19 t-CO_2/ha.y [14], about 1,594,740 ha or 22% more land than available would be needed in order to meet the 2030 target of 30.3 Mt-CO_2. If the uptake rate was increased to 23.1 t-CO_2/ha.y, the available area would then be sufficient. The likelihood of this quantity of land being available in time to meet the 2030 target is yet to be determined. Further research is required to model the extent and likely impact of permanent or semi-permanent forest sinks on new renewable electricity generation requirements.

The purchase of foreign carbon credits in order to meet the 2030 target has been indicated as part of the government's strategy. The likely extent of their use, and consequent impact on future electricity demand, requires further research. However it has been noted that increasing global demand for these credits will bolster the carbon price, and their availability may become limited or uneconomic, as other countries decide to hold them for their own purposes. Hence, over reliance on such credits carries a high level of risk [21].

Conclusion

In 2014 New Zealand consumed approximately 130,225 GWh of fossil fuels in the transport, stationary energy, motive energy, pumping and electricity sectors. In a short-medium term future scenario, from which aviation, shipping and heavy transport were excluded, and heat pumps were employed for < 100 ^{o}C heating, it was determined that the 84,900 GWh of fossil fuel energy employed in 2014 could be replaced by 41,620 GWh of electricity. A consequent removal of 25.4 Mt CO2-e or about 85% of New Zealand's NDC for 2030 under the Paris Climate agreement was estimated.

Electricity has lower end-use energy costs than fossil petrol in light vehicle transport, and wood chips for the provision of low grade heat when heat pumps are used. Due to the present high cost of end-use energy from boiler-based systems when using electricity, wood chips or other bioenergy resources are likely to be the preferred option for medium- and high-grade process heat applications in the short-medium term. However, full life cycle costs and security of supply issues may make electricity more competitive in the long term and more research is recommended in this area. Forestry plantings on erosion-prone land have the potential to make a substantial contribution to New Zealand's NDC, whilst over-reliance on the purchase of offshore credits carries a high level of risk.

In principle, a significant opportunity for the electricity industry to contribute to a transition to renewable energy, and to New Zealand's climate change mitigation commitment, exists. In the immediate future the promotion of energy efficiency, battery electric vehicles and heat pump applications in low-grade process, space and water heating is suggested. Further research into the prospects for electricity to contribute to medium- and high-grade process heat production, and to better understand the relative contributions of electricity, bioenergy, forestry and carbon credits, is recommended.

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Appendix A: Efficiency Values and Sources

Table A1: Efficiency Values for Current and Future Technologies.

End Use	Fuel							
	Coal	Fuel Oil	Natural Gas	LPG	Diesel	Petrol	Electric Replacement	Efficiency Sources (S)
High Temperature Heat (>300 C), Process Requirements	0.903	0.896	0.857	0.857	0.887	0.75	0.98	2, 5, 8, 13
Intermediate Heat (100-300 C), Cooking	0.60		0.55	0.55			0.65	4
Intermediate Heat (100-300 C), Process Requirements	0.80	0.76	0.77		0.76		0.95	1,9
Low Temperature Heat (<100 C), Process Requirements	0.80	0.76	0.77	0.77	0.76		0.95	1,9
Low Temperature Heat (<100 C), Space Heating	0.80	0.76	0.77	0.77	0.76		0.95	1,9
Low Temperature Heat (<100 C), Water Heating	0.80	0.76	0.77	0.77	0.76		0.925	1, 3, 6, 9, 10
Motive Power, Stationary		0.45			0.45	0.30	0.902	7, 14, 23, 27
Motive Power, Mobile		0.45	0.47	0.47	0.45	0.30	0.902	12, 14, 15, 23, 25, 26
Pumping					0.45	0.30	0.902	7, 14, 23
Transport, Land			0.16	0.187	0.28	0.22	0.82	12, 21, 22
Transport, Rail	0.14				0.25		0.85	11, 19, 20
Transport, Sea		0.49			0.45	0.14	0.75	16, 18, 24

Efficiency References (S): Data Sources

The following links were not all used in *Table A1* but their information provided guidance for making assumptions of efficiencies.

S1. http://invenoinc.com/file/CIBO-Steam-System-Efficiency-and-Boilers.pdf - Page 7, Table 1.
S2. http://energy.gov/sites/prod/files/2014/05/f16/steam15_benchmark.pdf
S3. http://www.johnwoodwaterheaters.com/en/products/residential/3-Oil_Fired_Water_Heaters/10-Oil_Fired_Water_Heaters
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S7. https://www1.eere.energy.gov/vehiclesandfuels/pdfs/basics/jtb_diesel_engine.pdf
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