Energy supply in the earlier industrial era

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Cover design: The 'Spindletop gush' at Beaumont Texas in 1901

Dedicated to:

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Student of the author's at UNSW.

Contents

Preface

It is difficult to claim to have an in-depth knowledge of a subject if such knowledge is restricted to the present and the recent past. Information and insights on a particular topic from the past can, in a well informed mind, be reprocessed and contribute to the topic in the present and, even more importantly, in the future. This is saying no more than Lewis Carroll's maxim:

'It's a poor sort of memory that only works backwards'

This monograph of a little under 8000 words is an attempt to outline fuel supply from the late eighteenth century, when steam power was first becoming prevalent, up to immediately before the First World War. The treatment is quantitative, there being a number of calculations relevant to fuel performance. Prices are brought up to date by use of a recognised index accessible on the Web. The importance of the availability of crude oil from circa 1860 onwards is brought out, and growth in the oil industry over the next several decades analysed. Social and political themes feature centrally.

The text is structured as a monograph having sections instead of chapters. It is directed primarily at those with professional involvement in energy supply. Those seeking to understand the role of energy supply in world affairs – more important now than it ever was – might also benefit from the text. I shall welcome comments from readers.

J.C. Jones
Aberdeen, April 2010.

1 Introduction

Fuel utilisation over the period from the late eighteenth century to the early twentieth, spanning therefore three to four generations, is discussed in this text. Information presented will be given new perspectives by being assessed against knowledge which was not available at the respective periods under discussion. It is intended that this will make for continuity of ideas with the present time when energy prices are a very strong factor on the world economic scene.

2 The early late eighteenth and early nineteenth centuries

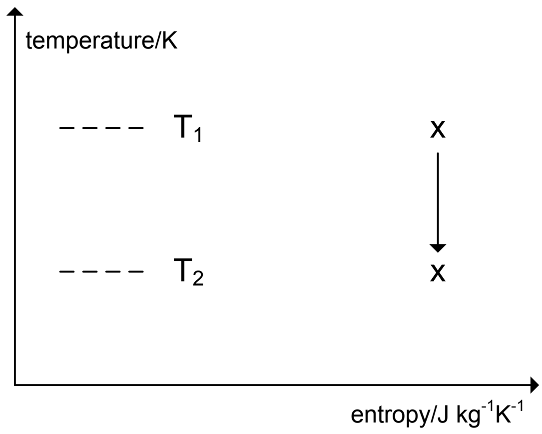
2.1 Preamble

The first census for England and Wales was carried out in 1801. The population was on the basis of it given as 8.9 millions, and this has been retrospectively corrected to 9.2 millions [1]. The population of London was 0.9 millions. The national population had risen to about 12 millions by 1810 [2]. In 1801 coal production in Britain was about 12 million tons per year. That is more than a third the current production rate but only about a tenth of the rate at the time of the First World War. Such variations in coal production over a period of two centuries clearly have an economic basis and if an economic one then also a social one. At the present time the coal reserves of Great Britain are very far indeed from being depleted and 'disused mines' are scattered about the country. Coal will therefore feature in the earlier part of this text as will coal products including coal gas and coke. Steam for steam engines was raised from coal, and the contribution made by steam technology to industrialisation will be explained. We note that in the early nineteenth century, the period under discussion in this section of the text, there was no commercial oil production anywhere in the world. Oil therefore belongs to later parts of text.

2.2 Newcomen's steam engine in original and more advanced forms

This was the first steam engine, having come into being circa 1712. It long predates knowledge of thermodynamics which later enabled more advanced steam engines and steam turbines to come into service. Huge amounts of electricity are at the present time made from steam turbines. These operate according to a Rankine cycle, developed by William Rankine (1820–1872). The Rankine cycle is expressed as a temperature-entropy diagram, in which the work performing step is accompanied by a reduction in entropy. Newcomen himself could not have described his engine in such terms. Such a description will be attempted below after a qualitative account has been given.

In Newcomen's engine steam is admitted at the base of a vertical cylinder containing the piston, which is raised by the pressure of the steam. Once the piston is at full height, corresponding to the total swept volume, liquid water is admitted with the result that the steam condenses. The pressure inside the cylinder consequently falls and the piston returns to its original position. Referring to the diagram below, the basis of the work done is that in the limit where the process indicated by the two crosses is reversible all of the energy effect becomes work, and this is equal to the enthalpy change accompanying the step. It is often stated that in such an engine work is done 'by the atmosphere', on the basis that once the pressure inside the cylinder has dropped atmospheric pressure causes the piston to descend. However the quantity work done can only be calculated from the properties of the *steam* as shown below and explained in this paragraph.



The basic Newcomen engine underwent a modification attributable to James Watt and effected in 1769.

The efficiency of a steam engine is simply:

mechanical work out/heat in

and an *upper limit* of the efficiency of the engine is that of a reversible Carnot cycle working between the same temperature [3], which is:

$$1 - T_2/T_1$$

where T_2 and T_1 are temperatures corresponding to the upper and lower crosses on the figure as shown. Now the steam is saturated at 1 bar and will have a temperature, fixed by the phase rule[1], of 373K. Condensation is to water in equilibrium with vapour at outdoor temperatures, say 20°C (293K). The efficiency so calculated is:

$$1 - (293/373) = 0.21 \text{ or } 21\%.$$

As stated this is an upper bound and appertains to a reversible Carnot cycle. Reversibility in the thermodynamic sense is best expressed as being conditions such that the equation of state is also the equation of path, so that at every point along the step indicated by an arrow in the figure the same equation of state would apply.

The Newcomen/Watt engines would have been highly *ir*reversible in their operation, and any irreversibility reduces efficiency. In fact the steam engines of that time were characterised by much lower efficiencies than the upper limit calculated, and it is believed that values were sometimes as low as 2%. It has to be remembered that this was at a time before the Laws of Thermodynamics were known. Watt was nevertheless aware that some engines gave better mechanical return on heat than others, therefore there was such a thing as ‘efficiency’, but this was not a major factor in engine usage at this period.

2.3 Fuel for steam power in the early 1800s

2.3.1 Rate of steam usage

By 1800 British industry was using steam power at a rate of 20000 h.p., very largely in the textile industries where it was replacing water power [4]. This converts to approximately 15000 kW and from this figure it should be possible to estimate the coal requirement. This is attempted in the shaded area below, where an efficiency of 5% has been used for the steam devices.

$$15000 \text{ kW} \equiv 15000 \times 10^3 \text{ W of mechanical work requiring:}$$

$$(15000 \times 10^3/0.05) \text{ W of heat} = 3 \times 10^8 \text{ W of heat}$$

For coal of calorific value ≈ 20 MJ kg^{-1}, annual coal consumption given by:

$$\{3 \times 10^8 \text{ J s}^{-1}/(20 \times 10^6 \text{ J kg}^{-1})\} \times 10^{-3} \text{ tonne kg}^{-1} \times (3600 \times 24 \times 365) \text{ s year}^{-1}$$

= 0.5 million tonne per year approx.

The figure calculated must be compared with the figure of 12 million tons for UK coal production[2] given in section 1.1. The comparison shows that only something like 4% of the coal was being diverted to steam engine applications. Most of the remainder was being used to make coke for iron production from ore. There was coal gas as a by-product, and as early as 1807 this was used for street lighting in London's Pall Mall [5].

2.3.2 The cost of coal in circa 1800

In the period under discussion Tyneside was one of England's leading coal producing regions, employing about 10000 miners in 1800. According to reference [6], in 1801 coal from Tyneside sold for ten shillings and four pence per ton, 52.5p (£0.525) per tonne in modern currency and units. The Brent price for a barrel (bbl) of crude oil on the day this is being written is $77.92 per barrel, or £47.77 per barrel. In the calculations in the boxed areas below these are compared on the basis of price per unit energy. First we consider the crude oil at the current price. We note that a barrel is 0.159 m^3 and use 925 kg m^{-3} and 44 MJ kg^{-1} respectively for the density and calorific value of the crude oil.

Heat released on combustion of 1 barrel =

$$1 \text{ bbl} \times 0.159 \text{ m}^3 \text{ bbl}^{-1} \times 925 \text{ kg m}^{-3} \times 44 \text{ MJ kg}^{-1}$$

= 6.5 GJ of heat to one significant figure

We now consider Tyneside coal at the 1801 price, noting that Tyneside coal was (is) of high quality and would have had a calorific value of not less than 25 MJ per kg[3].

Quantity of Tyneside coal required to release on combustion

$$6.5 \text{ GJ of heat} = [6.5 \times 10^{9}/(25 \times 10^{6})] \times 10^{-3} \text{ tonne} = 0.26 \text{ tonne}$$

$$\text{Cost} = £(0.26 \times 0.525) = £0.137$$

The boxed calculations indicate that heat obtainable from burning a barrel of oil at the current price of £47.77 would have been obtainable from coal costing £0.137 at the 1801 price. The ratio of the current price to the 1801 price is:

$$(47.77/0.137) = 350$$

From sources such as [7] and [8] it can easily be determined that the purchasing power of the pound decreased by a factor of about fifty between the early nineteenth century and the early twenty-first, therefore the factor of 350 is reduced to one of about seven. However, modern steam devices are much more efficient than those used in the early nineteenth century; the latter had efficiencies 5% or lower, and such efficiency was not seen as being important in that period provided that a particular engine was suitable for its assigned task. In mechanical energy terms therefore the cost ratio becomes something like 40 to 50. One only has to compare miners' wages at a time before the industry was closely regulated with investment in infrastructure for offshore oil production to appreciate why a factor of this magnitude applies.

There were 50000 coal miners in Britain by 1800 [9]. It was a dangerous occupation, and the catalogue of fatal mining accidents during the period under discussion is dismal and introduces another dimension to the rise of coal production to satisfy an expanding industrial base. The table below gives details of four such accidents. A reader should be aware that coal beds release methane ('firedamp') abundantly and that this has very often been the cause of fatal accidents in mines.

Location	Details	Reference.
Wallsend Pit, Tyneside 1803.	Explosion, 13 fatalities. Average age of the victims 17 years.	[10]
Hurlet Pit, Paisley Scotland 1805.	Explosion, 14 fatalities. Victims ranging in age from 12 to 60. 'Mortcloth money' paid (see discussion below).	[11]
Oxclose Colliery, Tyneside 1805	Explosion, estimated 38 fatalities. Victims ranging in age from 8 to 55.	[12]
Whitehaven, Cumberland	One of a succession of serious accidents at this site.	[12], [13]

Consistently with the use of a Tyneside coal in the pricing discussion earlier, an example from that region of England is in the first row of the table. The second row appertains to an explosion at a mine in Scotland in 1805. The dead had funerals in which the Scottish tradition of draping a mortcloth over the coffin was observed. Mortcloth money to cover all or part of the cost was paid in amounts ranging from four pennies to three shillings and ten pennies (£1.04 to £12.00 at the current value of the pound [7]). Moving to the Oxclose Colliery accident, if it really is so that the youngest victim was eight years old the mine owner was in violation of the Factory Act of 1802, which set nine years as the minimum age at which a child could undertake employment. Its scope went beyond factories to any paid employment and it set maximum working hours and standards of working conditions. It was in fact only enforced in relation to apprentices learning a trade. The promoters of the Act were concerned only with apprentices and not with child labourers even though its scope undoubtedly took in the latter.

The discussion so far has been concerned with Great Britain. In the table below some corresponding facts for other parts of the world are given.

Europe

Silesia	Government owned Royal Coal Mine developed over the period 1791–1797 [14]. Significant coal production and utilisation in the period under discussion, aided by construction of a major canal over the period 1792–1812 [15].
Belgium	Significant coal production in the period under discussion [16].
France	Major production, largely by the Anzin Coal Company which operated a mine near Valenciennes [17].

British Empire

India	Raninganj in western Bengal the scene of the first Indian coal mining in 1774. Production during the period under discussion very modest because of the availability of cheap imported coal from England [18].
Canada	Limited production at Cape Breton NS during the period under discussion [19].
Australia	Coal discovered in what is now called the Hunter Region in 1797. Convict labourers sent there in 1804.

USA

Pennsylvania	Coal production for about 50 years by the period under discussion [20].
Virginia	By the period under discussion several mines in operation near Richmond [21].
West Virginia	Commencement of coal production in 1810 [22].

One gets the impression from the three rows immediately above that coal production at this time in the US was sluggish. That this is so is supported by the US figures for the mid Nineteenth Century given later in this monograph when coal and oil at that period are compared.

Industrialisation, with its revolutionary effects on the way of life in the major countries, was under way in the period of interest in this first part of the essay. The next part will deal with the period between 1810 and the availability of oil in circa 1870. The author sometimes sees this period as the 'dark ages' in fuel and energy matters and will attempt to throw a little light on them!

3 The Period 1810–1870

3.1 Background

The period covered in this part of the text spans what was known in the UK as the Regency period and ends over 30 years into Queen Victoria's reign. At the beginning of the period covered, the Napoleonic Wars were taking place. Over the years 1810 to 1870 the population of the UK increased from 10 to just over 20 millions [23]. Over the same period the Australian colonies increased hugely in population and in what we'd nowadays call infrastructure and were part of the enormous British Empire. We saw previously how coal was the prevalent fuel in the first decade of the nineteenth century. To trace its expansion over the period covered in this second part will provide for a seamless discourse.

3.2 New applications of coal

In considering this we first recall from what has already been said that in the first decade of the nineteenth century most coal was used to make metallurgical reductant, although a not insignificant amount was used in raising steam. These purposes to which coal can be put increased over the period under discussion, and there was also proliferation of coal gas production. A crucially important factor during the period under discussion is introduction and expansion of the railways. Use of coal as a feedstock for organic chemicals manufacture, technology originating in Germany, began towards the end of the period covered in this part of the text.

3.3 Thermodynamic analysis of early steam locomotives

An early steam locomotive might have used coal or coke to raise the steam. To a greater extent in the US than in Europe, wood fuel was used for this purpose. Stephenson's Rocket was built during this period, making its debut in 1825 [24]. Its own weight was 4 tons, and when hauling a mixed payload of persons and goods making the total weight 17 tons it averaged 12 miles per hour. It ought to be possible from this to estimate the coal consumption, and this is in the shaded area below.

work done per hour = 17×10^3 kg $\times$ 9.81 m $s^{-2} \times 12 \times (8/5) \times 1000$ m

$= 3 \times 10^9$ J

rate of work = $(3 \times 10^9/3600)$ W = 800 kW approx ($\equiv$ 1070 horsepower). We estimate that conversion of heat to work was 5% and that the coal was of calorific value[4] 25 MJ kg^{-1}

rate of consumption of coal = $[800 \times 10^3$ J $s^{-1}/(25 \times 10^6)$ J $kg^{-1}] \times 1/0.05$

= 0.64 kg s^{-1}

distance travelled in 1 s = 12/3600 miles

coal consumption = 0.64/(12/3600) kg per mile =

200 kg per mile or 440 lb per mile.

That the bottom line in the above calculation is of the correct order of magnitude the reader can confirm from figures on the Web for early steam locomotives, e.g. [25]. In the days of the Rocket there was no preoccupation at all with greenhouse gas emissions. It is however interesting retrospectively to calculate them for the Rocket and such a calculation is set out below.

A figure of 200 kg per mile was in the main text arrived at for the coal consumption of the Rocket. If the coal was 85% carbon, the release of carbon dioxide per mile is:

$(200 \times 0.85 \times 44/12)$ kg = 620 kg

Now the US railroad operator Amtrak works to an emission limit of 180 g per passenger mile [26]. To meet this the Rocket would have had to convey:

620000/180 = 3400

passengers, and it obviously held very many fewer than that. The comparison is not altogether of like with like, as Amtrak in the early 21st Century do not of course use steam locomotives. Any *steam* usage is in the generation of electricity, with efficiencies of 30% or better. Even so it shows that (hypothetical) attempts to reintroduce locomotives like the Rocket at this time would be unacceptable in carbon dioxide emission terms.

3.4 Coal production internationally in the mid Nineteenth Century

UK coal production in 1850 was 50 million tons [27], a factor of six higher than the US production at that time [28] and significantly higher than the recent UK annual production of about 30 million tonnes [29]. To what purposes was the coal mined in 1850 put? Less than ten percent of it was exported leaving the remainder for domestic use [27]. Only about 1 million tons of the 1850 production was processed to make fuel gas [30]. Of the order of 20 million tons was being used in homes for heating and cooking [31]. That leaves a comparable amount for use in factories and by the railways. There was no coal combustion to make electricity until several decades later.

These facts will receive further analysis, but first we review coal production in parts of the world other than the UK and the US at the time of our discussion. This information is in tabular form below.

Country or region.	**Amounts of coal.**
Whole world, 1850	Total production ≈ 170 million tons, estimated by the present author from a graph in [32]. This signifies that UK production at this time was about 30% of the world total.
India	Production of 0.09 million tons in 1846 [33].
Australia.	0.07 million tons produced in 1851 [34]. (European population of Australia at this time about half a million.)
Canada	3 million tons produced in 1867 [35]
North Rhine-Westphalia.	1 million tonnes produced in 1839 rising to > 2 million tonnes in 1853 [36].
Austria-Hungary Dual Monarchy.	1 to 2 million tons consumed within Austria per annum. Consumption about an order of magnitude lower in Hungary. See reference [37].
Russia.	Just over half a million tons in 1860 [38].

China and Japan were also in the coal production business during the period of interest. Hashima Island is in the East China Sea, off the part of Japan known as the Nagasaki Prefecture. Coal was discovered at Hashima Island, which had not previously been occupied by persons, in 1887. The coal there is bituminous in rank and has good coking properties. In 1890 Hashima was acquired by Mitsubishi which had, in 1881, purchased the mine at Takashima, an island also off the Nagasaki Prefecture. This was a period when industrial and military expansion in Japan were rapid, and by the approach of WW1 Hashima was the scene of coal production at a level of 150000 ton per year and the population of the island, comprising mine employees and their families, was 3000.

One might have expected this to be an advantageous time for Japan: once oil became dominant she was at a major *dis*advantage through not having any significant reserves of it. The effects of that have continued until the present time. China had the advantage that a significant proportion of her coal was (is) anthracite, which tends to attract a higher price than bituminous coals.

Tabular presentation is also suitable for prices of particular coals in the mid Nineteenth Century. Such information is in the table below. The Measuring Worth Calculator [7] has again been used in adjusting the prices to present-day values.

Details.	**Price**	**Price at the current value of unit currency**
Lehigh Pennsylvania, 1820.	$8.40 per US ton [39].	$159 per US ton.
N. American anthracite, 1840.	$7 per US ton [40].	$180 per US ton
Pennsylvania coal for railroad use, 1850s.	$3.35 to $3.50 per US ton [41].	$92 per US ton.
South Wales UK, 1850.	Eight shillings and sixpence per ton [42].	£36 per ton.

Note that in the earlier part of the period of interest coal was expensive in the US. The *later* part of the period of interest takes in the American Civil War. There were fuel demands by both sides, and these had the effect of raising the price of coal. There was also an indirect effect of the Civil War on the price of coal. Railroads for freighting coal increased in importance during the War and these themselves had a coal requirement. Return on unit amount of coal purchased for railroad use increased very significantly over the War years.

3.5 Producer gas

Producer gas is made by passing either air or air and steam through a bed of hot coal or coke (a 'gas producer'). The first commercial gas producer entered service in 1823. The resulting fuel gas contains carbon monoxide and hydrogen as the flammable constituents but is heavily diluted by nitrogen from the influx air. Its calorific value is 4 to 5 MJ m^{-3}, compared with 20 MJ m^{-3} from 'coal gas' discussed previously. Nevertheless, producer gas when burnt in air (involving even more diluent nitrogen) is capable of melting steel. By the mid 19th Century producer gas was being used in the steel industry in England. Its advantages are that it can be made where it is needed and that poor coal which is suitable neither for direct burning nor for coking might be used as feedstock.

3.6 Oil from shale

Shale features later in this essay, but readers should be aware that illuminating oil was being prepared from shale by about 1840 in countries including France and Scotland, so the view that shale oil predates conventional oil is correct. Shale oil production in Scotland was at Pumpherston in the Lothians, and continued until the 1960s. It was close to the Grangemouth refinery, still the only refinery in Scotland and now operated by Ineos [43].

Proliferation of coal for locomotives has been a dominant theme in this discussion. The intrinsic superiority of liquid fuels for very many applications came with the commencement of the oil industry. That is the topic of the next part of the monograph.

4 Enter Oil

4.1 Introduction

A natural event at which to 'start the clock' in terms of the oil industry in 1859, the year of the celebrated Drake well in Pennsylvania. This was not the first commercial oil well in the world – that was about a decade earlier in a location distant from the USA[5] [44] – but it has captured the imagination of subsequent generations to a remarkable degree so its use to commence an oil timeline is appropriate.

4.2 The 1860s and 1870s

4.2.1 Introduction of oil pipelines in the USA

Drake's well certainly heralded an exciting new product in the US, so much so that the 1860 oil production was 25000% higher than the 1859 [45]. Between 1862 and 1911 the average annual increase in oil production in the US was 25% [45]. In these very early days the cost of transportation of oil was restricting sales. The need for pipelines was recognised, and the first such pipeline was installed in Pennsylvania in 1865 [46]. It was made of two inch diameter wrought iron pipe in fifteen feet sections joined together by welding, and the welded joints were pressure tested. It conveyed 81 barrels (bbl) per hour[6], using a steam pump operating at 10 h.p. These data will be evaluated in the shaded area below.

Note will be taken of the fact that a barrel is 0.159 m^3 and a value of 900 kg m^{-3} will be used for the density of the oil. This gives as the rate of work:

$$81 \text{ bbl} \times 0.159 \text{ m}^3 \text{ bbl}^{-1} \times 900 \text{ kg m}^{-3} \times 9.81 \text{ m s}^{-2} \times [5 \times (8/5 \times 1000)/(24 \times 3600)] \text{ m} = 10.5 \text{ kW} \equiv 8\text{h.p.}$$

therefore agreement with the 10 h.p. given above is evident. As the pipe was fairly narrow it is quite reasonable to suppose that frictional losses would have been about 20%.

Our discussion at this stage is just at the end of the American Civil War, dates for which are usually given as 1861 to 1865. Between 1865 and 1866 there was a sharp increase in oil production in the USA, from 2.5 million barrels in 1865 to 3.6 million in 1866 [47].

4.2.2 Formation of the Standard Oil Company

In 1870 John D. Rockefeller, then thirty-one years of age, set up in Cleveland Ohio the Standard Oil Company. He had in fact been conscripted to serve in the Civil War (on the Yankee side, obviously) but instead took the perfectly regular alternative of paying for a substitute. He first got into the oil business during the Civil War years, so acquiring the capital necessary for expansion once Standard Oil was formed. By 1870 there was a great deal of refining already taking place in Cleveland, and Standard Oil bought out most of the refineries in what in US commercial history is often called the 'Cleveland Massacre'. In fact 22 of the 26 refineries in Cleveland were acquired by Standard Oil at this time [48]. Refineries were on a much smaller scale than those which were later to come into service, and the largest one in Cleveland at that time had a capacity of 1500 barrels per day at a time when the total USA production of oil was about ten times that [47]. Throughout the 1870s Standard Oil continued to acquire assets, for example expanding into Kentucky in 1873 by acquiring 50% of Chess, Carley & Company, distributors of petroleum products.

Standard Oil therefore began what we'd now call downstream operations and by 1878 owned 90% of the refining capacity of the USA [49]. By then it had expanded into a number of other states including Pennsylvania. In 1878 Standard Oil refined about 14 million barrels annually, and in so doing earned $33 million.

It is of interest to evaluate the refining cost, bearing in mind that the primary saleable product from oil refining at this time was the kerosene fraction for use as illuminating oil. Prior to the period of the discussion tallow – animal fat having several constituents in common with modern biodiesels[7] – would have been used for such a purpose, and at the period of the discussion there was also significant use of coal gas as a fuel for illumination. Calculations relevant to refining costs are in the shaded area below.

14 million barrels refined at a cost of $33 million in 1878

⇓

Refining cost 42 cents per barrel

⇓ *Measuring Worth Calculator*

$9.35 bbl^{-1}$ at the current value of the dollar

Now in the US in 2008 gasoline sold at a typical price of $3.25 per US gallon and 7% of this was refining costs [50]. A gallon of gasoline originated from about 2.3 gallons of crude oil [51] giving a refining cost of $7.50 per barrel of crude.

⇓

$\$7.50\ \text{gallon}^{-1} \times 0.07 \times 42\ \text{gallon bbl}^{-1} = \$22\ \text{bbl}^{-1}$

Two points in the above calculation can be linked. One is that the figure of 1 gallon of gasoline per 2.3 gallons of crude oil, representing a 43% yield of gasoline, is not for straight-run gasoline alone but for straight-run gasoline plus FCC (fluid catalytic cracked) gasoline from the naphtha as well as naphtha simply reformed. Similarly there are further processes on the other fractions, for example sulphur removal from diesel. Such processes were not of course available in 1878, and advantageous though they certainly are they add to refining costs. That our calculations have predicted a factor of two difference between refining costs for 1878 and for 2008 is totally consistent with this.

4.2.3 Other oil companies

In the table below are details of four other oil producing concerns – three in the US and two elsewhere – in business in the 1860s and 1870s.

Company or organisation.	Country	Details
Seneca Oil Company	USA	Set up in 1858, previously the Pennsylvania Rock and Oil Company. Under that name it hired E.L. Drake.
Columbia Oil Company	USA	Set up in 1861 by Andrew Carnegie in Oil Creek Valley Pennsylvania, close to the scene of the Drake well and having a business connection with it [52].
Freedom Oil Works Co.	USA	Set up in 1879 in Beaver County Pennsylvania [53] to produce illuminating oil and lubricating oil.
Grozny Oil	Russia	Annual production in the 1860s ≈ 200 tonne (1400 bbl) [54].
Ploieşti Refinery	Romania	257 tonne (1800 bbl) of locally produced oil processed in 1857 [55].

Standard Oil had a presence in California by the end of the 1870s (see section 4.3). Texas did not become an 'oil state' until the turn of the century by which time Mexico, where exploratory drilling began in 1869, had become a major producer. Each of these will be discussed in its due place in this text.

Venezuela is a major oil producer and was, about 60 years later than the period covered by this text, one of the founding members of OPEC.

4.3 Expansion between 1880 and 1900

US crude oil production in 1880 was 26 million barrels. In 1900 it was 63 million barrels [47]. This represents growth by an average of 1.9 million barrels per year. Worldwide, production was 150 million barrels in 1900 [56]. One of the most significant activities outside the USA was discovery in of oil in Sumatra, part of the modern Indonesia, in 1885 [53].

California entered the oil industry at this time [57]. Previously there was no major production further west than Ohio. The first significant discovery of oil in California was at Pico Canyon, Los Angeles County, in 1875. The company having made the discovery were California Star and Oil Works [58]. 'California Star' was later acquired by the Pacific Coast Oil Company, who by 1880 had a refinery processing 600 barrels of Californian crude oil per day.

Other oilfields in California included that at Ventura County and that at Kern County: the latter became the most productive in the State. As more crude oil was produced worldwide, the need for transportation of it became clear. A steel tanker with a capacity of 6500 barrels entered service in California in 1895. It was called the George Loomis. By this time there had already been tanker transportation of crude oil in the Caspian region. Standard Oil established a presence in California as noted above, and were in competition with Pacific Coast. Lacking the capital and the influence of Standard Oil, Pacific Coast Oil was acquired by Standard in 1900 although it continued to trade under the Pacific Coast name. Standard Oil purchased a 500 acre block of land in San Francisco in 1901 for the building of a refinery [59]. This was called the Richmond refinery, and when it began production in 1902 its capacity was 10000 barrels per day. It received crude oil solely from California. The Richmond refinery is still in operation, and its current capacity is 20 to 25 times its capacity in 1902.

The period currently being discussed takes in the invention of the internal combustion engine. The strongest claimant to the title of 'inventor of the motor car' is Karl Benz (1844–1929) whose 'Patent Motorwagen', powered by an engine operating on an Otto cycle, made its debut in Germany in 1885 [60]. Obviously the motor car had a huge effect on the oil industry. It meant not only that more oil needed to be produced and refined but that the most valuable product was no longer kerosene but gasoline.

4.4 The early years of automobile manufacture

The car manufacturing industry in Germany began with Benz' 1886 model, and shortly afterwards Gottlieb Daimler entered the industry [61] and cars and light trucks were produced. Manufacture had expanded to about 900 units per year by the beginning of the 20th Century [62]. There was plenty of locally produced fuel. In an arrangement strongly reminiscent of the car industry in more recent times, Daimler cars were being produced under licence in the USA.

The Ford Motor Company was formed in Detroit 1903. Initially production was three units per day, comparable to the 900 per year by Daimler at this time. The Buick Motor Company was formed in 1905 and was renamed General Motors in 1908 [63]. As with Germany, there was quite sufficient locally produced fuel. This was not so in Japan, where car production began in 1907 [64]. Hatsudoki Seizo Company was set up in Osaka by a group of scholars from the local university. This too is very reminiscent of more recent times, 'spin-off companies' from academic activity now being numerous across a very wide range of applied science and engineering disciplines. The difference between the Japanese situation and the US and German is that Japanese operators of cars in this period would have had to rely wholly on *imported* gasoline. The Hatsudoki Seizo Company, like Ford and General Motors, continues to the present time now being known as Daihatsu.

Effects on oil production of the introduction of the motor car were far-reaching; the following figures are taken from [65]. US oil production in 1900 was 63 million barrels. This rose to 210 million barrels in 1910, an increase of 230%. A remarkable fact of this period is the drop in the price of oil, which in 1900 was $1.19 per barrel equivalent [7] to $31.38 per barrel at the 2008 value of the dollar. In 1910 the price was $0.61 per barrel, equivalent to $14.26 per barrel at the 2008 value of the dollar. Over this period the oil fields of Texas had expanded, and this might be one factor in the behaviour of the price. Investment in the Texan oil fields at this time was huge and companies setting up in Texas provided strong competition to Standard Oil. Such companies included Gulf Oil, which traded under that name until it merged with Chevron in the 1980s. Humble[8] Oil, initially an independent Texan company, later affiliated with Standard and the 'descendant' of this arrangement is Exxon.

As already explained, gasoline was now the primary product of crude oil refining. It was recognised that there would be great economic benefits from modifying some of the higher boiling fractions to make them suitable for blending with gasoline. This is how the technology of cracking came into being. A US patent for cracking of heavier petroleum material to make gasoline extender was granted in 1913.

4.5 The Mexican oil industry

Mexico began to produce crude oil commercially in 1901 and to export it in 1911. Production was at oil fields close to the town of Tuxpán. One of the participating companies was Pearson, now a huge publishing and media organisation having ownership for example of Penguin Books and Thames Television. Pearson had involvement in Mexican oil from 1901 and traded as Mexican Eagle. Shell and Standard Oil were amongst the other oil companies active in Mexico during the period under discussion.

4.6 Fuel gas usage at this period

Natural gas sometimes occurs with oil ('associated gas') and sometimes without there being any oil ('non-associated gas'). US production of natural gas in 1900 was 128000 million cubic feet, equivalent in heat release terms to 20 million barrels of oil. In 1910 the figure was 509000 million cubic feet, equivalent in heat release terms to 80 million barrels of oil. By the beginning of the 20th Century there was a significant natural gas pipeline network in the US.

There was also much manufactured fuel gas in the US and in Europe, and indeed in some distant British possessions including Singapore, by this time. Producer gas and 'coal gas' have already been described and these too made a significant contribution to energy requirements in the early 20th Century.

5 A glimpse into the 'future'[9]

Whilst it is preferable for a coverage on this scale (8000 words) to restrict itself to a precisely specified period, it is of interest to conclude it with an anticipation of what followed that period. That is the purpose of this final section. Such events would have been in the future to those alive in the period covered by this essay hence the use of that word in inverted commas in the title of this final section.

Immediately following the period covered by this monograph came WW1 which, of course, brought with it its own energy needs. The motor car proliferated at this time, not only in the US but also in Japan.

Toyota[10] and Nissan cars became available at about the time of WW1, fuel for them being imported largely from the then Dutch East Indies. Coal production was on a large scale in countries including the UK, the USA, Germany, China and Japan.

6 Concluding remarks

It was stated early in this text that continuity with more recent times including the present was intended to be one of its themes. Accordingly a few points from the very end of the period covered will be examined for such continuity. One is that Toyota and Nissan are now amongst the world's largest car makers having manufacturing plants in many countries. Another is that although Japan still has large amounts of coal she no longer mines it, importing it instead from Australia, Indonesia and the US. Another is that although China still produces coal the mining industry there has a lamentable safety record. Perhaps the most surprising point to be made here is that at the period when this discussion closes, that is, at about the time of WW1, there was still no oil production in the Middle East, nor was there to be for about another 20 years. These are all points which an interested reader can, using the almost unlimited resources of the Internet, follow up for him/herself.

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8 Postscript

Surely science and technology become all the more interesting and intellectually satisfying when the 'human aspects' are given their due place. Lewis Carroll was quoted in the preface to this book and Neil Armstrong, the first man to set foot on the moon, will be quoted in this postscript:

'One small step for a man, one giant leap for mankind'[11]

What could express more clearly and more appealingly than that the principle that the rewards of advancement belong to the entire human race and not to any individual or even country?

At the time of the moon landing in July 1969, oil availability was fairly stable and the gas guzzler was still prevalent in the US. The following year two scenes of hydrocarbon production commenced operation each of which is of major importance at the present time: the North Sea and the Bass Strait. Nevertheless there was vulnerability, and it was only three years later that action by the OPEC countries following US military involvement in Israel (the '1973 oil embargo') led to the first petrol rationing in the UK since WW2.

This sort of interplay between the engineering and technology of fuel production and social and political events has been emphasised in several parts of this book, which is why both the American Civil War and WW1 feature. It is a challenge to the writer to link such events closely to the engineering and technological principles. That there not only is such a link but that it is a strong one the breakage of which can cause world affairs to go awry is clear. For evidence of this one need look no further back than mid 2005. Production difficulties caused by a series of Gulf Coast hurricanes including Katrina and an insatiable desire for crude oil by China in preparation for the Beijing Olympics caused the price of crude oil to be unprecedentedly high, with all the knock-on effects of that on world trade.

In these times we not only have to meet energy needs but also to do so in a way consistent with greenhouse gas reductions. This requires international co-operation and co-ordination on a scale never before attempted as it is the very planet which is at risk and regional and national interests have to be overridden. This monograph sets the scene long before such matters were on the agenda, yet is helpful in understanding how and why the carbon dioxide level of the atmosphere rose by about 100 p.p.m. between the early 19th and early 21st Centuries. Here surely is an example of how knowledge from the past provides guidance for the future, and at the present guidance in respect of fuels and their emissions is of the highest importance.

9 Endnotes

1. The phase rule was not of course known in the period under discussion.

2. The Imperial ton and the metric tonne differ by just under 2%. There is nothing to be gained by distinguishing them in approximate calculations such as those on this page.

3. The calculation below also features, in slightly different form, in an article by the author currently in press with 'Open Thermodynamics Journal'.

4. The train operated in England's north east. Note the statement previously that coal from this region was of good calorific value.

5. It was on the Caspian coast and began production in 1847.

6. It was in 1865 that the unit 'barrel' was first formally used. It is 42 US gallons.

7. Hence the term ,which in these present times of massive R&D into biodiesels still prevails, 'fatty acids'.

8. The aspirate was omitted in pronunciation: 'Umble'.

9. This theme is continued in the postscript.

10. Toyota himself had made his fortune by developing and manufacturing a new kind of weaving loom, and later moved into vehicle manufacture. A resident of Aberdeen is likely to be aware that Mitsubishi was founded by an adventurous young Aberdonian who set off to Japan in search of wealth in the second half of the Nineteenth Century. His name was Glover. The company which he set up after a number of mergers became Mitsubishi. Japan was never of course a British possession but a number of enterprising people from Britain did go there at that time and set up businesses. Gilbert and Sullivan's *Mikado* is reminiscent of the English-speaking community in Japan at that time. There is limited basis for comparison with Siam (Thailand), which was also the destination of hopeful British migrants at that time. The story *Anna and the King*, known in its musical form as *The King and I*, is set in the Siam of this period. The difference between Japan and Thailand is that the former became a manufacturing country whereas the latter was only a trading centre strategically placed in relation to places such as Singapore and Sumatra. More on this in Joseph Conrad's novel *Youth*.

11. The author is aware that the precise form of the words uttered by Armstrong has been disputed.