3rd Australasian Engineering Heritage Conference 2009

Gas Engines in Victorian Industry, 1870-1950

M.S. CHURCHWARD, BE, MEngSc
Senior Curator, Engineering & Transport, Museum Victoria

SUMMARY: *In 1866, the German engineer, Nikolaus August Otto, was awarded a patent for his 'free piston atmospheric gas engine', which he presented the following year at the Paris Exhibition, winning the Grand Prize. It was to become the world's first commercially successful internal combustion engine design. Manufacture of Otto atmospheric gas engines had began in Germany and Britain by 1869 and within five years Otto engines were being used in Victoria. After the introduction of the improved 'four-stroke' Otto gas engine in 1876, the invention was further popularised, becoming an economical and efficient alternative source of industrial power to steam engines for small-scale enterprises.*

Following the 1850s gold-rushes, Victoria had become the key centre of manufacturing in Australia and its industrialists were early adopters of gas engines. In 1880, 5% of all mechanically-powered factories in Victoria were using gas engines and by 1901 the proportion had reached 30%. Although oil engines and electric motors were to provide increasing competition as the newest sources of industrial power, gas engines continued to play a key role in Victorian industry well into the 20th century. The introduction of the suction gas producer was of particular importance, enabling gas engines to be freed from their earlier dependence on reticulated town gas supplies enabling their application in a wide range of rural industries.

KEYWORDS:*Gas Engines; Gas Producers; Industrial Power; Internal Combustion Engines*

1. ORIGINS OF THE GAS ENGINE

Arguably the origins of the internal combustion engine date back to the 1670s, when the Dutch scientist Christiaan Huygens carried out experiments aimed at harnessing the force created by exploding gunpowder in an enclosed cylinder fitted with a piston.[1]

During the first half of the 19th century numerous patents were taken out for various experimental internal combustion engine designs, however, the Belgium engineer Jean Joseph Étienne Lenoir, is generally attributed with having developed the first pratical internal combusiton engine design with his 1860 patent that described a single-cylinder two-stroke engine burning a mixture of coal gas and air ignited by a "jumping spark" from a Rühmkorff coil. Lenoir's engine looked almost identical to standard double-acting horizontal steam engine of the period and the design of most of its components were borrowed directly from steam engine technology, including two slide valves that emitted the gas and air mixture to the cylinder and discharged exhuast gases. Unlike later two-stroke internal combustion engine designs the fuel-air charge was not compressed before ignition and this limited both its efficiency and power output.

On a wave of initial public enthusiasm and publicity a company was floated to manufacture Lenoir engines in Paris and production was also commenced under licence by the Reading Gas Works in London. Fewer than 500 engines were built, however, over the following decade as customers soon found that they were excessively noisy and consumed up to 3 cubic meters of gas per HP-hour making them uneconomic to operate.[2]

Further developing the ideas pioneered by Lenoir and others, the German engineer Nikolaus August Otto developed the first commercially successful internal combustion engine design which he patented in Prussia in February 1866, and subsequently in other German States, Britain, France, the United States and other European countries. The following year Otto and his business partner Eugen Langen publicly demonstrated the engine at the Paris Exposition Universelle where it was independently tested against the Lenoir engine and convincingly won the Gold Medal Grand Prize recording less than half the gas consumption of it's predecessor. Although it also worked on a two-stoke cycle with no compression of the fuel/air mixture before combustion in other respects the two designs were quite disimilar. Otto's design was single-acting with it's single-cylinder encased in an elaborate Grecian Ionic styled column and used a naked flame for ignition instead of a spark. The most important distinction, however, was the free-piston and over-running ratchet mechanism that Otto devised to improve the engine's efficency. This allowed the piston to rise freely under the explosive force of the burning gas, with the motive power being generated only during the downward stroke by atmospheric pressure acting on the upper face of the piston.[3] (Figure 1)

Although branded the 'rattling monster' or 'devil's machine' by its detractors, the Otto-Langen free-piston atomspheric engine did prove to be the first gas engine design that could successfully compete with steam engines, particularly for small power applications. Its main disadvantage was the noise and vibration created whenrunning and its tendency to crack foundations from the recoil force or eject the piston violently out the top of the cylinder when it misfired.

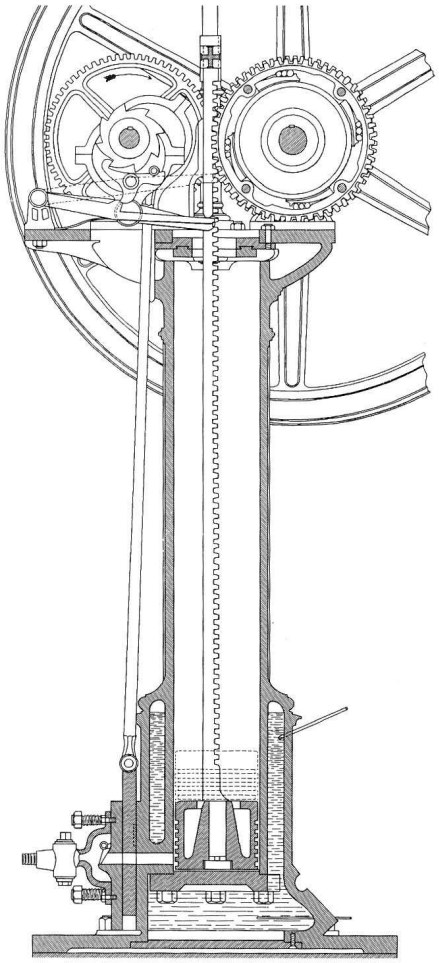


Figure 1. *Sectional View of the Otto-Langen 1866Free-Piston Atmospheric Gas Engine*
Source: Hardenberg, H.O. (1999), p.326

By 1868, Otto and Langen had established a purpose-built factory in Colgne where full scale production of the engines began. In August 1869 Crossley Bros, of Manchester, signed a licence agreement giving them exclusive manufacturing rights for Otto-Langen free piston atmospheric gas engines sold throughout Britain and all British Colonies, including Australia. Crossley's were to become the most significant foreign manufacturer of Otto-Langen engines, producing around 1,300 in total over the next ten years and contributed several of their own patented improvements to the design. This is the first type of gas engine that is believed to have been imported into Australia. Although no original examples used in Victoria have survived, the Powerhouse Museum in Sydney hold an incomplete example, built around 1875.[4] They also hold a rare example of the original Otto-Langen design. Believed to be one of the first ten examples built by their firm N.A. Otto & Co, in Cologne, around 1867, it was acquired by the University of Sydney from Germany in 1914.[5]

It is not known precisely when the first gas engines were imported or set to work in Victoria, but as early as 1873 the machinery merchants H.P. Welch & Co, of Queen Street, Melbourne, were advertising in local press offering "ATMOSPHERIC GAS-ENGINES (Otto and Langen's patent), manufactured by Crossley Bros, Manchester."[6]

Newspaper advertisements for new and second-hand "Otto" atmospheric engines suggest that the most common size in use at this time ranged from ¼ to 1 horsepower, while a typical price for a second-hand ½-horsepower engine with tank & fittings was quoted at £80. Another advertisement for a second-hand "Crossley's patent" gas engine quoted the key selling point "Starts immediately" alongside indicative running costs of "4d daily".[7]

In 1872, after publically floating the Cologne manufacturing firm as Gasmotoren-Fabrik Deutz AG, Eugen Langen recruited two new staff members who would play a key role in the later development of the Otto engine. Gottlieb Daimler, became prouction manager and was assigned the task of reorganising the factory to cut production costs, while the talented young design engineer August Wilhelm Maybach was set to work simplfying and improving the original Otto-Langen engine design.By late 1876, Maybach had assisted Otto in a complete transformation of the atmospheric free-pistion gas engine into the first 'modern' internal combustion engine. Dubbed the "Silent Otto" to emphasise its significantly quieter running characteristics, the new design was publically launched at the Paris Exposition Universelle of 1878, again to great public acclaim.[8]

Unlike it predecessor, the new "Silent Otto" engine had a horizontal cylinder and a more conventional connecting rod and crank coupling between the piston and revolving power shaft. More importantly it operated on a four-stroke cycle and utilised pre-compression of the fuel/air charge in the cylinder before ignition creating significantly better fuel ecomony and smoother running. (Figure 2)

Crossley Bros again obtained the British manufacturing rights, jointly patenting the new design with Otto in Britain in 1877, and would subsequently contribute significant improvements of their own. In Victoria, it was not until 26 June 1878, that a patent for the new design was lodged by Nicholas August Otto of Gas Motoren Fabrik-Deutz for *"Improvements in gas motor engines"*.[9]

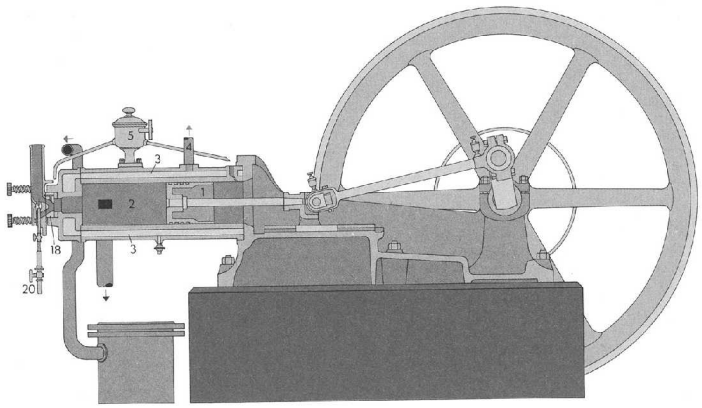


Figure 2. *Sectional View of the Otto Silent Four-Stroke Gas Engine of 1876*
Source: Strandh, S. (1979), p.143[10]

It is perhaps a testament to the speed of 19th century communications and the extent to which local engineers kept abreast of the latest overseas developments, that in October 1877, the Victorian Government Printing Office send an order to Crossley Bros in Manchester for a 'New "Otto" Silent Gas Engine, one-horse-power, with Water Vessel'. A reply from the manufacturer indicated '*The "Otto" silent Gas Engine has not been sufficiently tested to warrant it being sent - the substitution of an atmospheric Gas Engine is suggested.'* John Ferres, the Government Printer responded with a hand-written annotation

> *'I was induced to ask for the "Otto" Gas Engine because of the excellent testimonials given of it in the "Engineer", "Printer's Register" and other works. I would recommend that the Agent General be requested to send the "Atmospheric" engine instead of the "Otto". - J. Ferres'*[11]

2. EARLY GAS ENGINE USE IN VICTORIAN MANUFACTURING

Gas powered manufacturing works were first separately listed in the *Victorian Statistical Register* in 1878, when 24 installations were recorded. Half were located in the central City of Melbourne municipality and the remainder scattered across three inner suburbs and the country towns of Ballarat, Bendigo, Castlemaine, Geelong and Hamilton.

In October 1879, the Victorian Government exempted *"Engines of which gas is the direct motive power"* from the general 25% import duty levied on steam engines and general machinery.[12] This action, together with the new "Otto Silent" design, appears to have had an immediate impact, with the number of gas-powered factories increasing rapidly from 29 in 1879, to 41 in 1880 and 76 in 1881. By the mid 1880s, Victoria had over 150 factories employing gas engines, representing about 13% of all mechanically powered manufacturing works.[13] (Appendix A & B)

The most significant early concentration of gas engines occurred in the printing industry with printing works, stationery and account-book manufacturers accounting for 75% of all gas engine powered manufacturing works recorded in 1878. Although this percentage would decline over subsequent years, a decade later in 1888, the printing industry still contributed 43% or 106 of the 255 gas-powered manufacturing works in Victoria. The early adoption of gas engines in printing works followed similar trends in the trade in Britain and the United States. The introduction of continuous rotary printing presses, ruling machines (for printing account books and ledgers),power guillotines, binding machines and ink-mixing machines around this time all generated a new demand for mechanical power in printing workshops. Whilst most of the machines were designed to be either manually or mechanically powered, the introduction of a small engine provided immediate benefits in reducing the wages required for manual labour and increased output.

Other Victorian industries that saw early concentrations of gas-powered works included foundries and engineering workshops, boot & shoe manufacturers, clothing factories, aerated water and ginger beer manufacturers, chicory, coffee & spice mills, chaff mills, manufacturing jewellers and watchmakers.

Clothing Manufacturers Beath, Schiess & Co,were a typical example of the early adopters. By 1882, they were employing Crossley gas engines at two factories in Collingwood and another off Flinders Lane in the city, for driving sewing machines and "cutting cloth by machinery, with a machine that has been patented in the colony, a band knife on the principle of the hand saw." The cloth was formerly cut by hand with shears, the introduction of the machinery enabling the proprietors "to lower the cost of production without lowering wages as far as the manufacturer is concerned."[14]

The average installed horsepower of engines in factories employing only gas-power in 1880 ranged from 1.0 to 6.5 horsepower.[15] The machinery employed by many factories in the above industries was limited in its power requirements, typically ranging from ½ to 2-horse-power. In this power range, even the early atmospheric gas engines provided a more cost-effective alternative to steam power. The gas engine also had a natural advantage in that it was small enough to fit within a cramped inner city workshop, while the vertical format and limited weight of many early gas engines allowed them to be bolted directly to the floor alongside printing machinery, sewing machines or other equipment, with no need for a separate boiler house or large external brick chimney.

3. GAS ENGINES AT THE EXHIBITIONS

Just as the earlier international exhibitions, hosted in London, Paris, Philadelphia and Vienna had become showcases for the world's latest technological innovations, so the Intercolonial and International Exhibitions held in Melbourne during the late 19th century were a key vehicle of the dissemination of the latest developments in mechanical marvel. Many of the thousands of visitors who thronged through the pavilions of Melbourne's exhibitions probably had their first experience of witnessing a gas engine at work during the exhibition.

At the Intercolonial Exhibition held in Melbourne in September 1875, W.H. Masters & Co displayed a Raymond sewing machine driven by a "Nicholson's sewing-machine *engine*" which it was claimed could be operated at the cost of only "halfpenny per hour with gas, and a penny burning kerosene". By way of justification the commentary added "When it is borne in mind that the constant use of the sewing machine treadle is injurious to the female constitution, the value of this miniature engine will be recognised."[16] It is possible that this was actually a hot air engine rather than an internal combustion engine.

As early as 1879, just a year after the "Otto Silent" engine was publicly displayed for the first time at the Paris exhibition, local agents Messrs Bright Brothers & Co,offered the loan of an "Otto" silent gas engine for driving working models on display at the Intercolonial Juvenile Industrial Exhibition in Melbourne.[17]

At the Melbourne International Exhibition held from 1 October 1880 to 30 April 1881 in the new Melbourne Exhibition Building, gas engines were a key feature amongst the mechanical exhibits. In the British Court, Bright Brothers & Co, of Flinders St displayed three horizontal gas engines for the latest "Otto Silent" design manufactured by Crossley Brothers, Manchester, rated in the sizes of 1, 3½ & 6 nominal horsepower. In reporting on the exhibits *The Argus* noted purported advantages of the gas engine as being: *"less objectionable from an insurance point of view than the steam engine", "ready at a moments notice, require no attention except occasional cleaning and oiling"* and *"cost at the present price of gas in Melbourne about twopence per horse-power hour ...* [which] *hardly exceeds the cost of coal for small steam engines."*[18]

The smallest "Otto Silent" gas engine made Crossley Bros at this time was the half-horsepower model. For those requiring mechanical power in smaller amounts, the exhibits also included an example of Bisschop's vertical gas engine, rated at two manpower (equivalent to about ¼ horsepower), shown by the machinery merchants McLean Brothers & Rigg. Another slightly larger gas engine on the same principle, made by Mignon & Rouart of Paris, was shown in the European annexe. Invented by the Dutch-born Paris engineer, Alexis de Bisschop, this engine was somewhat of a technical oddity, having more in common with small hot air engines than later gas engines. Technically it was a single-acting atmospheric engine like the Otto-Langen design operating on a two-stroke cycle, but incorporated a slider-crank mechanism that provided a much simpler and quieter running motion than Otto's ratchet mechanism. (Figure 3) Although patented in 1875, "teething problems" delayed production and it made its first public appearance at the Paris Exhibition. Mr Andrew of J.E.H. Andrew & Co, Stockport, was so impressed when he saw the engine running at the exhibition that he purchased the British manufacturing rights. Despite their high gas consumption (in some cases up to seven times that of the Otto-Langen engine of equivalent power) the simplicity of construction and low cost of the Bisschop engine saw it remain a popular source of mechanical power in small workshops until displaced by the electric motor in the 1890s. Over a 16 year period from 1878-1894, some 2,000 Bisschop engines in sizes from 1 to 4 manpower were made at the Stockport Gas Engine Works and quite a number appear to have been sold in Australia. Surviving examples exist in the collections of both the Powerhouse Museum and Museum Victoria.[19]

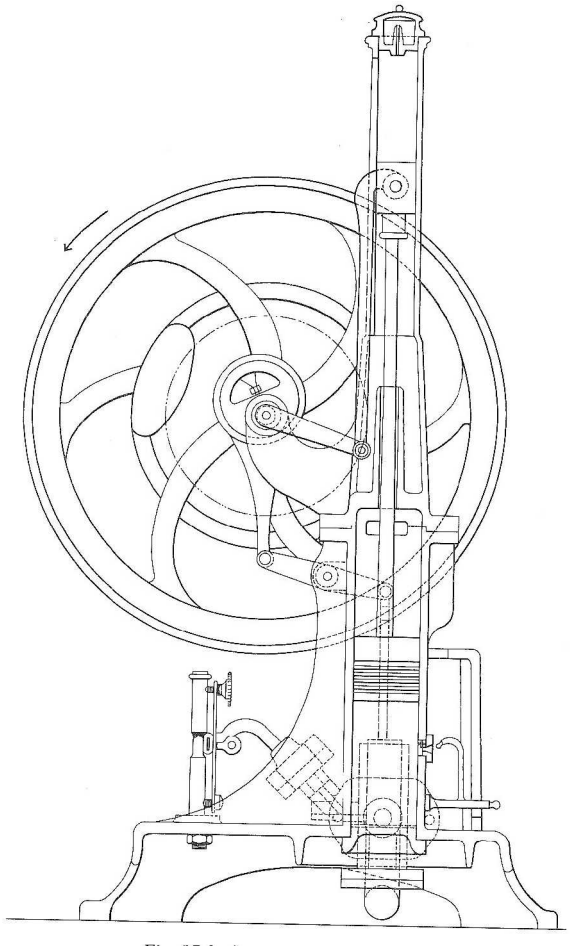


Figure 3. *Sectional View of the Bisschop 1875 Atmospheric Gas Engine*
Source: Hardenberg, H.O. (1999), p.380

The Engineer's Conversazione, was an early example of a more specialised trade fair organised by the newly formed Victorian Engineers' Association in December 1883. Once again hot air engines were featured amongst the variety of mechanical exhibits, but this time *"the well-known Otto silent gas-engine* [was] *conspicuous by its absence"*. Instead two new designs made their first appearance in Victoria. The first was a 2-horsepower engine made to Dugald Clerk's patent design by Thomson, Sterne & Co, of Glasgow, exhibited by Mr Dempster of Post Office Place. To avoid infringing Otto's patent, Clerk's design was based on a two-stroke cycle and utilised a double cylinder configuration, in which the gas and air charge was drawn initially into an auxiliary cylinder, known as the displacer, and was slightly compressed before being transferred to the power cylinder where ignition took place. Both cylinders were driven from the same crankshaft, with the displacer crank about 90 degrees in advance of the power cylinder crank. The design achieved moderate commercial successful over the following decade. Mr Dempster also displayed a two-manpower Bisschop's engine made by J.E.H. Andrew & Co.[20]

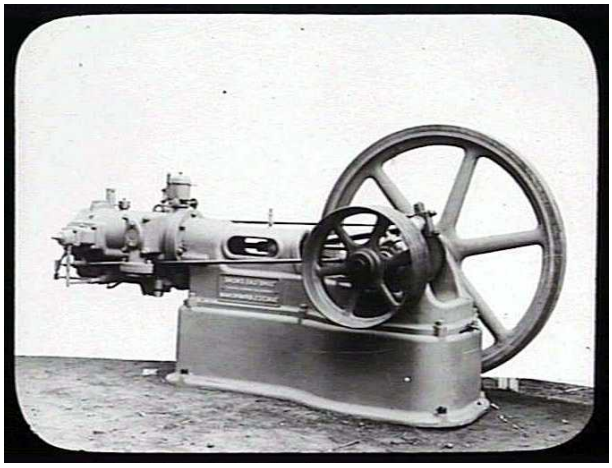


Figure 4. *Tangye Robson Two-Stroke Gas Engine*
Source: Museum Victoria

The second new design was another two-stroke engine, manufactured by Tangye Brothers, of Birmingham, to a design patented by James Robson of Surrey, England, in 1877. Tangyes developed the original Robson patent into a practical design, which they first exhibited at Bingley Hall, Birmingham, in 1880. It differed from other early gas engines in that it employed a single cylinder that was enclosed at both ends much like a steam engine. One end of the cylinder worked as a pump to compress the charge of air and gas, forcing it into a receiver from where it was admitted to the power end of the cylinder at the end of the exhaust stroke. Not long before the exhibition Tangye Bros had opened their own Melbourne sales office in Cornwall House, Collins Street, from where they sold a wide range of machinery from gas engines, steam engines and boilers to hydraulic jacks, pulley blocks, crab winches, pumps and lathes. They continued to manufacture the "Robson's patent" gas engine until after the Otto patent expired when they switched to a four-stroke design and continued to be a major supply of gas engines in Victoria well into the 20th century.[21] (Figure 4)

By far the greatest mass display of gas engines ever presented in Victoria was produced for the Melbourne Centennial International Exhibition, which ran from 1 August 1888 to 31 January 1889. Crossley Bros Ltd, of Manchester, through their Melbourne agents Alex Cowan & Co, mounted an exhibit of no less than 13 "Otto" gas engines ranging in size from their smallest ¼-horsepower vertical engine to a large horizontal engine rated at 9 nominal horsepower, but capable of developing 18 indicated horsepower. Four of the smaller engines shown were examples of Crossley's compact "Domestic Motor", a vertical single-cylinder design in which the cylinder was enclosed in a simple tapered cast-iron column supporting an overhead crankshaft and flywheel. Designed specifically to occupy the minimum possible floorspace, the Crossley "Domestic Motor" was a direct successor to the earlier vertical Otto-Langen design and like the former was a popular power source in small workshops. The Powerhouse Museum collection holds two examples of the Crossley "Domestic Motor" and Museum Victoria holds an engine of very similar design made by Purnell, of Scotland.[22]

Amongst the horizontal Crossley "Otto" engines shown were two examples, rated at ¾ & 2-horsepower, incorporating the latest improvements "never before exhibited". These modifications were added by Crossley to the origin Otto design and patented in Victoria in July 1888. They included an incandescent hot-tube for ignition, heated by a small Bunsen burner flame; modern style poppet valves in place of earlier slide valve; and an inertia governor allowing speed adjustment of up to 100 rpm, in place of the order style revolving governor. Other horizontal Crossley "Otto" engines on display were shown working a variety of machinery including an electric dynamo, a two-throw pump feeding an illuminated water fountain, a 'Lightfoot's' dry air refrigerator, a small goods hoist and a working display of bakers' and confectionery making machinery.[23]

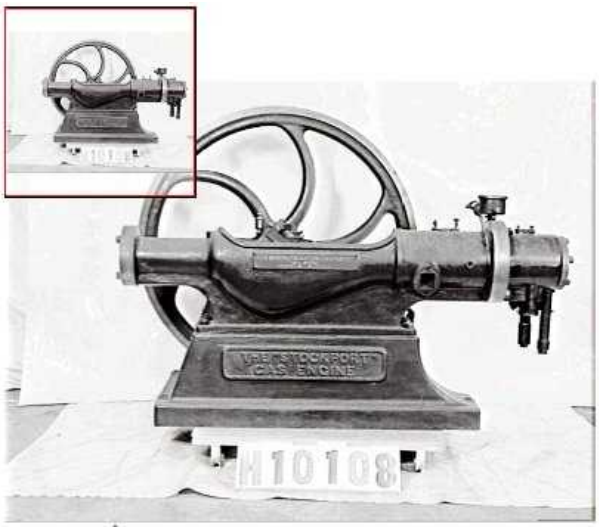


Figure 5. *Stockport Two-Stroke Horizontal Gas Engine*
Source: Powerhouse Museum, H10108

Nearby J.E.H. Andrew & Co Ltd, displayed seven of their tandem 'Stockport' gas engines based on Dugald Clerk's patent, in sizes rated at ¼, ½, 1, 2, 4, 6 and 8-horsepower. Two of these engines were shown driving dynamos of the Australian Electric Co, producing power for lighting of the exhibits at night (the exhibition remained open till 9 pm over the summer months) and for driving an electric motor powering other machinery exhibits. Two of the smaller 'Stockport' engines were also fitted with latest hot-tube ignition, which dispensed with the slide valve previously required to admit the flame into the cylinder to attain combustion. Andrew & Co had commenced making their 'Stockport' two-stroke engines in 1882, producing over 6,000 in total by 1888 for "electric lighting, hoisting, printing machinery & innumerable other work", in sizes from ¼ to 100-horsepower. They would continue building them until 1892, when production was switched to the "Otto" four-stroke design. A partially incomplete example of the Andrew & Co 'Stockport' tandem engine is held by the Powerhouse Museum.[24] (Figure 5)

Over the decade following the Centennial Exhibition, the number of gas engine powered factories in Victoria would double - from 263 to 520 – and the proportion of mechanically-powered factories using gas engines rose from 15% to 20%. Over the same period the number of steam-powered factories in Victoria declined by 11% - from 1,403 to 1,247.[25] (Appendix A & B)

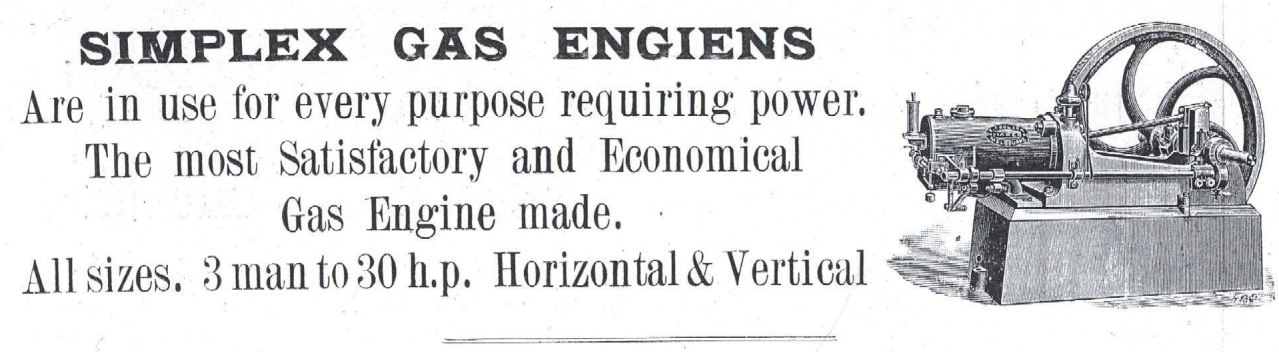
4. MANUFACTURE OF GAS ENGINES IN VICTORIA

Given the strength of Victoria's local engineering industry dating back to the 1840s, it is surprising that it took almost a quarter of a century before local firms began building gas engines. The first locally made steam engine had been turned out by Langlands Foundry in 1845, just four years after the introduction of steam engines in Victoria. By 1860 over a dozen firms were building steam engines, including several on the goldfields at Ballarat, Bendigo and Castlemaine.[26]

Early gas engine designs were based on steam engine technology of the period and shared many common components and features so there was no technical reason why local firms could not have built gas engines once they'd mastered the basic operating principles. Initially the demand for gas engines was probably too small to warrant local manufacture, but by the mid 1880s there was a thriving repair trade in gas engines providing a basis that could have been extended into manufacture, as had earlier happened with steam engines. It appears that it was the risk of patent infringement – either real or imagined – that initially deterred local manufacture.

Curiously no evidence has been found that Otto's original atmospheric free-piston design was ever patented in Victoria, however the later "Silent" four-stroke design was covered by Otto's Victorian Patent No.2533 of 26 June 1878. Both Crossley Bros and Gasmotoren-Fabrik Deutz vigorously defended their patent rights with threats to sue and, in many case overseas, infringement lawsuits. Though there is no evidence of any lawsuits being pursued against Australian firms, the "patented" aspect of the design featured heavily in local advertising and together with Crossley Bros dominance of early gas engine sales in Victoria (estimated to have been as high as 80% over the first decade), this created the impression that local manufacture was not possible.[27]

The exemption of gas engines to the 25% import duty from October 1879, certainly created further disincentive towards local manufacture, and had the unintended side effect of undermining demand for small steam engines. William Brown had been operating a thriving engineering business from 1857 in Collingwood and later from a central city workshop making small stationary steam engines for a variety of customers. In 1882, he complained to the Royal Commission on the



Tariff that he had not received a single steam engine order since the duty on gas engines was removed three years earlier.[28]

The deluge of litigation around Otto's 1876 patent in Europe, eventually saw the patent overturned in Germany in 1886, but it remained in force in Britain until 1891 and in Victoria until 1892.[29]

E. Coulson & Co are the earliest recorded firm known to have manufactured gas engines in Victoria in any significant numbers. The business was established in 1893 by Edmund Coulson who began operating from a small workshop at 88 Little Collins Street West, advertising as:

[30]

E. COULSON, GAS ENGINE and PRINTERS' ENGINEER, 88 Little Collins-street west.

Specialist for the removal and erection of gas engines and printing machinery. Repairing in all departments. Slide valves re-surfaced. Orders by post promptly attended to; and work guaranteed.

Figure 6. *Excerpt from an E. Coulson Advertisement for 'Simplex' Gas Engines, circa 1900*
Source: Museum Victoria

By 1896, Coulson had relocated to larger premises at 116 A'Beckett Street, Melbourne and begun manufacturing his own design of gas engines under the "Simplex" brandname.[31] In 1897, Coulson applied for two Victorian patents, No.14166 for *"Improvements applicable to gas and oil engines"* and No.14530 for *"Improvements in hydro-carbon engines, partly applicable to gas engines."*

By 1898, Coulson had established a display stand at the Royal Agricultural Society's showgrounds, where he mounted an impressive display of portable and stationary patent "Simplex" gas and oil engines. It was reported that E. Coulson & Co were making portable & stationary gas engines in sizes of 1 to 20 BHP, with *"over 140 of these engines in use in this colony"*. The report also noted that *"This engine is of the latest improved tube ignition type, fires under high compression without timing valve. It is very economical and complete."* The report also stated that "Simplex" oil engines, in sizes 2-manpower to 9 nominal horsepower, vertical or horizontal, where also offered, although *"Owing to the very large demand for this firm's "Simplex" Gas Engine during the past 12 months, the oil engine have not been pushed to the extent its merits justified, but with increased facilities now offered, oil or gas engines can now be produced in any quantities for quick dispatch."*[32] (Figure 6)

By August 1899, E. Coulson was advertising "Simplex" gas engines from 3-man to 30-horsepower, with the claim that over 200 were at work in Victoria. At the Melbourne Show the same year it was noted that his "Simplex" oil engine was in it's third year of "practical working". By 1900, advertisements claimed that over 300 "Oil, Gas & Steam Engines" were at work. By 1901, "Simplex" gas engines of up to 50 horsepower were offered, however, thereafter production appears to have concentrated largely on portable & stationary oil engines. In 1905, Coulson undertook a somewhat novel contract to refit the Port Phillip Bay steam ferry *PS Queen*, that involved removing the vessel's steam plant and paddlewheels and fitting in its place an imported suction gas producer and 160 horsepower gas engine with screw propulsion.[33]

The second Melbourne firm to become involved in the local manufacture of gas and oil engines was operated by H.V. Hampton. Hampton had a long association with the engineering trade in Melbourne dating back to 1872, having worked for a period as manager for Mr J. Crighton, engineer, Victoria Street, Carlton where he was involved in the manufacture, installation and repair of a variety of machinery for the sawmilling, brick-making, printing, tile-making, pipe-making, and jam & confectionery industries. In 1884 he established his own business and by 1890 was operating the Victory Gas Engine & Engineering Works in Bright Street, South Melbourne, near Princes Bridge, offering "to Execute Repairs to all kinds of Engines and Machinery" with "A stock of engines on hand." – which presumably were imported.[34]

While the precise date at he began making gas engines is unknown it appears to have been around 1897, after moving to new premises on the corner of Elizabeth & Therry Streets, Melbourne. Like Coulson, he first mounted a display at the Royal Melbourne Show in 1898, exhibiting both oil and gas engines of his own make. In a report from the Show it was noted that *"An oil engine on a somewhat different principle to those at present in use is also among the latest inventions of Mr Hampton's establishment. The simplicity of this engine cannot be surpassed, being worked with the aid of only one valve."* The report also noted that:

> *"An improved type of gas engine know as the "Victory" was also displayed. This kind of engine is highly appreciated at butter factories, as there is an entire absence of smoke or dust. Steam (sic) can be raised in a few minutes, and is easily regulated without fear of explosion. Within a very short space of time 300 odd engines have commanded a ready sale."*[35]

In 1899, H.V. Hampton applied for a Victorian No.15882 for *"Improvements in oil explosion engines"* and it was reported that *"The Victory Gas Engine can be found working in almost every part of Melbourne and suburbs, and the Victory Oil Engine is coming rapidly to the front…"*. Aside from the engines, Hampton also carried on a thriving general engineering business making wood-working machinery, jam manufacturers' machines, canning machinery and the "Victory" bone crusher and "Daisy" Green Bone Cutter that found a ready demand with poultry farmers.[36]

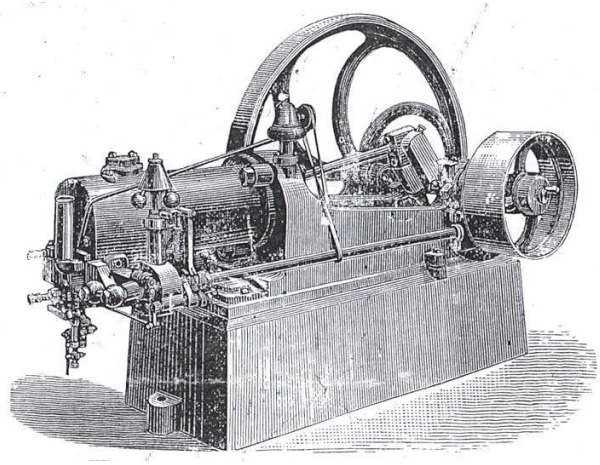


Figure 7. *H.V. Hampton Gas Engine, circa 1900*
Source: Museum Victoria

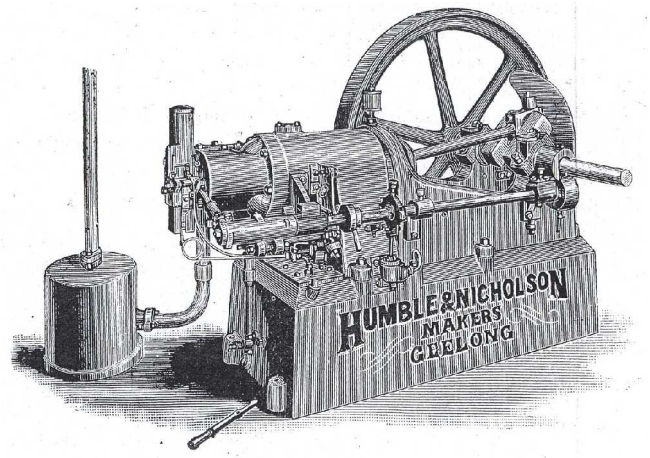


Figure 8. *Humble & Nicholson Oil Engine, circa 1900 Their gas engines were made to a similar design.*
Source: Museum Victoria

Most of both E. Coulson's and H.V. Hampton's early output of engines appears to have found customers in the small workshops and factories of printers, boot & shoe makers, clothing manufacturers, engineering works, food manufactories and butchers around central Melbourne and inner suburbs like Fitzroy and Collingwood. After 1901, the output of both firms concentrated largely around portable and stationary oil engines, with country industries becoming increasingly important customers. Several examples of the oil engines made by both firms have survived in private collections, but no surviving gas engines have been found.

William Humble & Ward Nicholson, of the Vulcan Foundry, Geelong, also applied for a Victorian patent for *"An improved oil or gas engine"* in 1899. Founded by Humble & Nicholson with John Simmonds in 1861, the Vulcan Foundry was one of Victoria's largest engineering works by the 1890s manufacturing a wide range of mining machinery, steam engines, boilers, agricultural and railway equipment and other products. They had also developed a reputation for pioneering new products, being amongst the first firms in Victoria to manufacture portable steam engines, compound steam engines and refrigerating machinery. By August 1899, Humble & Nicholson were advertising "Oil and Gas Engines, to requirements". It is not known how many oil and gas engines Humble & Nicholson built. The last identified advertisement for their oil and gas engines is dated 1900 and no known examples have survived.[37]

During the first decade of the 20th century several new engineering firms were established in Victoria that went on to develop significant reputations manufacturing petrol, kerosene and oil engines. Only one of these businesses is known to have also made gas engines. In June 1911, A.H. McDonald & Co, of Burnley Street, Richmond were awarded a contract by the State Rivers & Water Supply Commission of Victoria, to manufacture a 20 horsepower single-cylinder vertical suction gas engine and gas producer, to drive a water-pump for the Wycheproof Town Water Supply, at a cost of £405/10/2. Apparently it was made by the firm at a loss, perhaps because of inexperience or a desire to establish a new product line. The engine gave over a decade of reliable service pumping 10,000 to 12,000 gallons per day against a head of 120 to 130 feet while consuming only a bag of coke a day. Later the same year an 80 horsepower four-cylinder gas engine with the same basic cylinder design was manufactured for an unknown customer and McDonald's also built two 10 horsepower gas engines for driving machinery in their own works which operated on town gas. A small number of additional gas engines were built by McDonald's over the years up to 1921 but they never became a substantial product line. Instead the firm developed its reputation and success on the manufacture of stationary petrol engines and tractors, diesel engines and diesel road rollers, with the latter product line produced up to 1985.[38]

5. GEOGRAPHIC DISTRIBUTION OF GAS ENGINE USE

The geographic distribution of gas engines in Victorian manufacturing during the early decades reflected both the main areas of concentrated manufacturing activity and those areas within the distribution area of established gasworks. Reticulated town gas produced by retorting black coal in gas works was the only economical source of gas for motive power until at least the 1890s.

From 1878, when gas engines were first recorded in the *Statistical Registers*, until the mid 1880s, between two-thirds and three-quarters of all gas engines recorded were working in the Melbourne metropolitan area, concentrated mostly in around the Central Business District and inner suburbs.

In the country districts the early use of gas engines in manufacturing was concentrated in larger towns which already had established gasworks. It was not until 1888, that any gas engines were recorded at work in towns without gasworks.

By 1890, the main concentrations of gas engines outside Melbourne were in the regional cities of Ballarat (14), Bendigo (13) and Geelong (9), all major regional manufacturing centres. The somewhat unexpected exception was Warrnambool, with 10 gas-engine powered factories, perhaps reflecting the early predominance of clothing manufacturers in the south-western coastal town which would later become the home of the famous clothing firm Fletcher Jones. All other regional towns and shires had no more than 4 gas-powered factories and in total only 25% of gas-powered manufacturing works were situated outside Melbourne.

Within the Melbourne metropolitan area, it was the City of Melbourne municipality, encompassing the Central Business District and inner areas of West Melbourne, Carlton, East Melbourne and Jolimont that had the greatest concentration of gas engines. The inner city was also the most concentrated manufacturing precinct, with around 20% of all Victoria's factories during the 1870s and 1880s, but it also claimed a disproportionate share of gas engines – between 45 and 66% of all gas-powered factories throughout these decades. Given the nature of inner city industry before 1900, this trend was understandable. Much of the inner city was a maze of small factories and workshops nestling cheek by jowl along the city's back lanes and alleyways, often in close proximity to warehouses, showrooms and retail outlets. Most of these businesses had neither the space to house a steam engine and the necessary adjuncts of a boiler and large brick chimney, nor sufficient machinery to justify employing steam power.

Outside the inner city, it was predominately the inner suburbs of Collingwood, Fitzroy, North Melbourne, South Melbourne, Richmond and Prahran that had the most significant concentrations of gas engines by 1890. Collingwood and Fitzroy both had significant concentrations of clothing and footwear factories, while Richmond and Prahran had lots of clothing and food manufacturing works and South Melbourne had engineering, joineries and woodworking shops. All these industries were early adopters of gas engines.

While the overall number of steam powered factories in Victoria witnessed a 10% decline during the 1890s (from 1,417 to 1260), gas power witnessed its strongest decade of growth, rising from 323 to 630 works. In the City of Melbourne municipality the number of gas-powered factories exceeded the number of steam-powered factories by 1895.

By 1901 gas power had reached a peak were it was utilised in 30% of all mechanically-powered factories, but challenges from new emerging power sources were on the horizon. Electric motors were first recorded as a source of factory power in the 1895 *Statistical Register* and by 1901 there were 42 factories using electric power – mainly in the inner city where access to the emerging power supply grids was readily available. Although reticulated electricity supplies were available in the Melbourne central business district from the mid 1880s and in the major regional cities of Ballarat, Bendigo and Geelong a decade later, manufacturers were initially slow to adopt the new power source. At this time most of the supply was distributed as direct-current, which was ideally suited for the connection to electric motors, but early power supplies were designed primarily for lighting, and customer tariffs were set too high for electricity to effectively compete with either steam or gas engines, despite the convenience. In March 1902, the Metropolitan Gas Co introduced a 20% tariff reduction on gas used for driving gas engines after the Melbourne City Council's Electricity Supply Department began selling electricity for motive power at a lower rate than the standard lighting tariff.[39] Within another decade there would be over 1,000 electric motor-powered factories in the State, making it second only to steam power in importance (Appendix A & B).

Oil engines had also began make in impact as another alterative source of industrial power for rural and inner city manufacturing, with 59 oil engine powered factories recorded by 1901. While oil or liquid-fuelled internal combustion engines rapidly gained a foothold in rural industries like farming, their role in manufacturing was more gradual, taking almost three decades to overhaul the number of gas engine-powered factories.[40]

Despite the number of gas engines in use by the first decade of the 20th century, most installations remained comparatively small, averaging just 6.2 horsepower in 1905, with typical installations ranging from 1 to 10 horsepower. By comparison, the average steam power installation in factories was 33.4 horsepower and even electric powered factories averaged 7.5 horsepower. Gas power was still predominately the motive power of choice for smaller factories and workshops with 10 or less employees, but this was about to change as Victoria entered the second era of gas engines.

6. SUCTION GAS PRODUCERS

While electricity was rapidly becoming the motive power of choice for inner city factories during the first decade of the 20th century, another technological change was afoot that would extend the use of gas engines for another three decades and transform them from a compact low cost power source for inner city factories and workshops into an efficient cost effective power source for many rural industries. During the decade from 1905, the combined horsepower of gas engines used for motive power in Melbourne's metropolitan factories increased from 3,827 to 10,560, while in country towns the growth was even more dramatic rising from 686 to 7,315 horsepower. The total number of gas engine powered manufacturing works in Victoria peaked at 883 in 1913 and thereafter began a gradual decline, however, the combined horsepower of these installations continued to rise for another decade peaking at around 19,330 horsepower in 1920. This trend saw the average horsepower of gas engine installations used in Victorian manufacturing increase from less than 5 horsepower in 1905 to 25 horsepower by 1919.

This transformation was largely brought about by the introduction of the gas producer – a free standing self-contained unit that could generate gas for motive power directly from any carbon-based fuel at a cost far cheaper than the tariff for coal gas or town gas supplied by gas companies. Whilst the process of producing combustible gas through the burning of anthracite (black coal) or coke with a limited air supply had been known since the late 18th century, it was the British engineer Joseph Emerson Dowson who first patented a practical gas producer in 1878. After further experimentation Dowson demonstrated his gas producer running a small 3 h.p. Ottto gas engine at a meeting of the British Association for the Advancement of Science at York in 1881. The British patentees of the Otto gas engine, Crossley Bros of Manchester, were sufficiently impressed to assist in the further development of the concept and in 1882 when they established their new gas engine manufacturing works at Pottery Lane, Openshaw, in east Manchester, the works were powered by a 150 horsepower gas engine plant of their own make supplied by three Dowson gas producers.[41]

The original Dowson gas producer design was a pressurised system that forced steam generated in a small auxiliary boiler together with a limited air supply into a retort burning anthracite, producing a combustible gas that consisted of about 49% nitrogen, 25% carbon monoxide, 19% hydrogen, 5% carbon dioxide and 1% methane and other hydrocarbons. The gas had a calorific value of about 1,400 calories (5.55 BTU) per cubic metre.

Initial fuel consumption rates of around 2 lb anthracite per engine BHP-hour were produced but by the mid 1880s this had been reduced to around 1.4 lb per BHP-hour.[42] The resulting gas was much lower in calorific value than convention coal gas, but could be made at about one-tenth of the cost.

In 1891, a further improvement to the gas producer was initiated when the French engineer M. Léon Bénier, patented the idea of using the suction from a gas engine to draw the air and steam through the gas producer. In his first practical design demonstrated in 1894, a reciprocating air pump coupled to the crankshaft of a two-stroke gas engine sucked gas from the producer with each stroke and forced it into the engine cylinder on the return stroke.

Other engineers subsequently refined the concept – dispensing with the separate air pump and its attendant friction load and instead using the intake stoke of a four-cycle engine to suck the gas through the producer. Further refinements were also made to the way the water was vapourised into steam, the point where the steam and air were admitted into the retort and the temperature of the incoming air in order to optimise the calorific value of the gas produced, An improved scrubber was also added to remove tar and dust and cool the gas. The resulting "suction gas producer" had the advantage that it dispensed with the separate steam boiler and gas holder required by the original Dowson design and was by nature self-regulating, in that the volume of gas produced was in direct proportion to the work being done by the engine. A greater load on the engine increased the suction at the engine intake, which in turn drew more air and steam through the producer generating gas at a faster rate, while when the engine dropped back to an idle, suction dropped off and gas generation correspondingly fell.

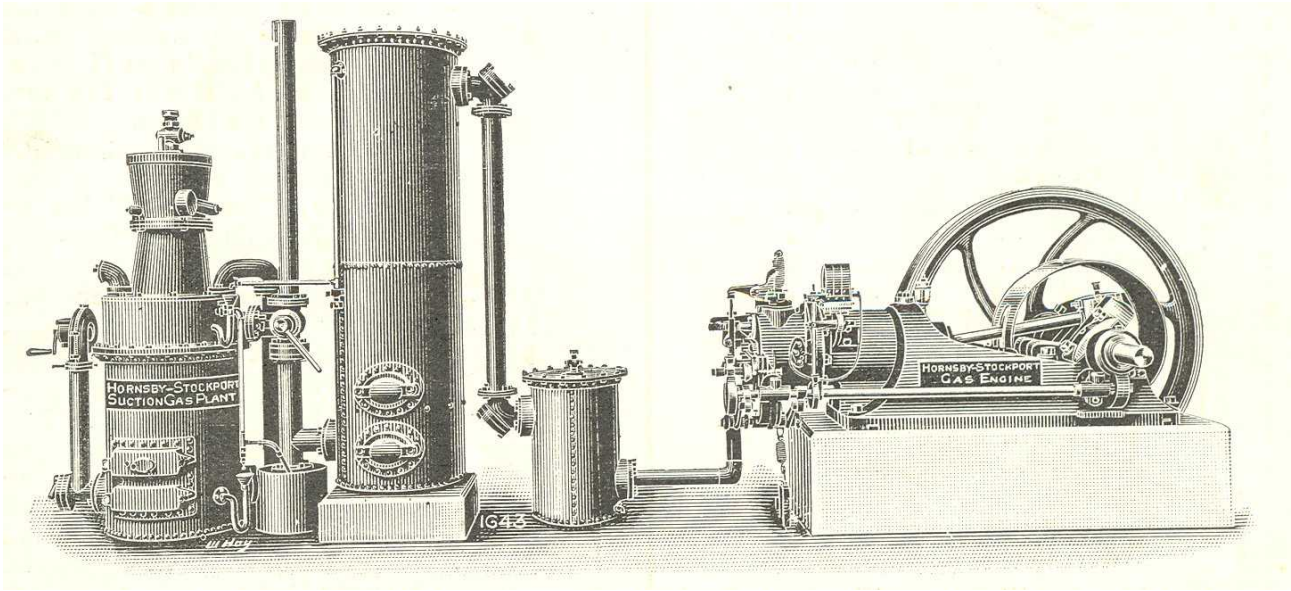


Figure 9. *A Typical 'Hornsby-Stockport' Suction Gas Producer & Gas Engine, circa1905*
Source: Museum Victoria

Suction gas producers also had an additional safety feature in that because they operated under a partial vacuum there was less risk of noxious carbon monoxide or explosive gases leaking than in the earlier style of pressurised gas producer. Suction gas producers were also more versatile as they could be successfully run on cheaper fuels like charcoal, brown coal briquettes, fire-wood and even saw-dust, as well as the anthracite coal and coke used in early pressurised gas producers.

Suction gas plants also had another distinct advantage because as the size of the units increased, thermal efficiency and fuel economy improved, further reducing operating costs. For gas engines running on town gas there was little reduction in gas consumption per BHP-hour with increasing engine size and operating costs remained relatively fixed. Whereas gas engines running on town gas had predominately been adopted by small workshops and factories with limited power needs, once suction gas plants became available these were a positive incentive to increase the horsepower of installations. For over a decade, suction gas engines would provide the very lowest cost of power for large installations.

By 1905 several of the leading British gas engine manufacturers including The Campbell Gas Engine Co Ltd, of Halifax; Crossley Bros Ltd, of Manchester and Tangyes Limited, of Birmingham were offering suction gas plants in Australia.[43]

In 1905, a significant new manufacturer entered the market when R. Hornsby & Sons acquired the Stockport Gas Engine Works of J.E.H. Andrew & Co. Originally founded as a small blacksmithing shop at Grantham, Lincolnshire, the firm changed its name to Richard Hornsby & Sons in 1828 and began developing into a specialist manufacture of ploughs and agricultural implements. By the 1840s Hornsby were also producing portable steam engines and threshing machines and a decade later had established a thriving export trade to Victoria selling portable and stationary steam engines, boilers, mining machinery, farm implements and harvesting machinery. In the early 1880s they became one of the first British manufacturer to establish their own branch offices and showrooms in Melbourne and Sydney. In 1891, R. Hornsby & Sons became the first major British steam engine manufacture to acknowledge the turning tide and invest in the large-scale manufacture of internal combustion engines after signing a licensing agreement with Herbert Akroyd Stuart, inventor of the vaporising hot-bulb engine. Large numbers of the Hornsby-Akroyd oil engine were sold through the Melbourne branch of R. Hornsby & Sons from 1893, with some 5,000 at work throughout Australia by 1910.[44]

After taking over the Stockport Gas Engine Works, Hornsby extensively redesigned all gas engine models produced and began aggressively marketing the improved "Hornsby-Stockport" gas engines and suction gas producers from mid-1906. They had soon captured a substantial share of the Australian market for larger gas engines and by 1911 had over 400 Hornsby gas engines and suction gas plants, with a combined capacity of 20,000 BHP, at work throughout Australia. In 1918, R. Hornsby & Sons Ltd merged with another Lincolnshire engine builder Ruston, Proctor & Co Ltd, forming Ruston Hornsby Ltd. Production of gas engines continued at the Stockport plant until 1932.[45]

7. GAS ENGINES IN THE ELECTRIC POWER SUPPLY INDUSTRY

In 1896, the Victorian Government passed legislation giving municipal councils throughout Victoria the right to establish electric power supplies for both public and private use within their local government area. Councils were required to apply for approval to install an electricity supply through an order-in-council, an could elect to either establish the service themselves or sign an agreement with a private company to establish and operate the service on their behalf. Most councils, particularly in rural Victoria were slow to respond. Many of the larger towns by this time enjoyed an established town gas supply which adequately provided for the needs of public street lighting and home lighting. There was little incentive to commit to a major capital investment for what many saw as simply the duplication of an existing service.

By 1905, while much of Melbourne enjoyed an extensive reticulated electricity supply, provided by two central power stations run by the Melbourne City Council and Melbourne Electric Supply Company, only five regional towns had a public electric power supply – Nhill (from 1891), Ballarat and Bendigo (from 1896), and Inglewood (from 1905).[46] All these supplies were provided by steam-powered generating plant, but steam-power was relatively expensive install and operate, particularly for smaller towns with only a limited initial demand for power.

The introduction of suction gas engine technology at this time would provide a major stimulus for rural power supply offering a significantly cheaper alternative to steam power. Over the next decade up to the outbreak of the First World War, 59 further regional towns inaugurated local electricity supplies and all but two of these either wholly or in part used suction gas engines to drive their generators. Wonthaggi relied on a steam-powered electricity supply from the Victorian Railways State Coal Mines, while Leongatha drew electricity from the local butter factory's steam power plant.[47]

A survey of the equipment installed has shown that R. Hornsby & Co suction gas engines were by far the most predominant source of motive power, with 47 units totalling 2,926 horsepower installed in 39 power stations – representing 69% of all suction gas engines and 59% of overall horsepower installed by 1915. In the initial years the trend was even more notable, with Hornsby's claiming in their publicity brochures to have supplied 81% of the 22 suction gas engines installed for electric lighting in country Victorian towns by 1911.

Tangyes Ltd were the next most prominent with 13 engines installed in 9 power stations by 1915 – representing 17-18% of both the overall number of engines and horsepower installed. Other brands represented were Kynoch Limited, of Birmingham (6 engines – 8%),Hindleyand Gardner (both 3 engines – 4%), Premier (2 engines – 3%), Crossleys Ltd and Robson (both 1 engine – 1%). Engine sizes installed ranged from 16 to 108 BHP, with the average being 65 BHP. (Table 1)

1905-15	No Estb	No Units	Total HP	No Estb	No Units	HP
Hornsby	39	47	2,926	71%	62%	59%
Crossley	1	1	65	2%	1%	1%
Gardner	2	3	228	4%	4%	5%
Hindley	2	3	250	4%	4%	5%
Kynoch	4	6	376	7%	8%	8%
Premier	1	2	152	2%	3%	3%
Robson	1	1	65	2%	1%	1%
Tangye	9	13	870	16%	17%	18%
Total	55	76	4,932	-	100%	100%

Table 1. *Summary of Suction Gas Engines Installed in Victorian Country Power Stations, 1905-15.*

Hamilton were the first Victorian country town to install a gas-engine power supply, with the Hamilton Electric Supply Co Ltd installing a 50 horsepower Hornsby suction gas engine and producer in December 1905. By 1912 they had installed a second Hornsby gas engine of 100 horsepower and another of the same size again would be installed by 1920. Some councils sought tenders for both steam and suction gas powered plant, such as the Shire of Hampden who advertised for the "Supply and erection of High Speed Steam Engine and Boiler, &c" or "Suction Gas Plant and Gas Engine" for Electric Light Works at both Camperdown and Terang in July 1908. Within a few years, however, enough experience had been gained of running and installation costs for councils to directly specify suction gas plant.[48]

About half of the country electricity supplies established during this period were funded both private power supply companies on behalf of municipal councils or drawn from a local industry such as a dairy factory or flourmill. The remainder were directly funded and operated by the councils themselves. Most installations were initially similar, consisting of a single 50-80 horsepower gas engine with a flat-belt driven dynamo or generator supplying direct-current power at via a 2-wire or 3-wire distribution system at around 230 or 460/230 volts. Aside from municipal street lighting (usually by incandescent lamps), power was provided to private homes for lighting and sometimes to local industries for lighting or motive power. It was not until the 1920s that most households began installing other electric appliances such as stoves, heaters, hot water units and toasters. During the early years most municipal power stations only operated during daylight hours, with a bank of large accumulators or lead-acid batteries in glass tanks being provided to supply current overnight or whenever the plant was shut down for maintenance or repairs. Capital expenditure ranged from around £3,000 to £11,000 depending on the size of installation, with most of the funds spent on generating and distribution equipment. In most cases the powerhouse itself was little more than a corrugated-iron clad timber-framed shed.[49]

As demand for electricity grew, a second or third engine and generator was often installed. By 1920, reliance on storage batteries for overnight supply and peak demand was falling out of favour due to maintenance costs and limited service life. Instead an additional smaller auxiliary engine and generator was often installed after experience showed that a suction gas engine on light load could be left to run unattended for 4-6 hours overnight if a larger capacity gas producer holding adequate fuel was available.

Industry	Installations	Engines	Total BHP	Avg BHP	% All Engines	% Total BHP
Breweries	5	5	478	95.6	4%	6%
Brick & Pottery Works	5	5	499	99.8	4%	6%
Chaffcutting Works	4	4	116	29	3%	1%
Clothing Factor-ies	1	1	66	66	1%	1%
Electricity Sup-ply	32	36	2,266	62.9	26%	26%
Engineering	10	12	468	39	9%	5%
Flock Manufac-turing	1	1	100	100	1%	1%
Flour Milling	8	8	482	60.3	6%	6%
Ham & Bacon Curing	4	5	412	82.4	4%	5%
Mining	12	12	702	58.5	9%	8%
Miscellaneous Works	2	2	94	47	1%	1%
Printing Works	1	1	28	28	1%	0%
Pumping & Irrig-ation Works	6	7	261	37.3	5%	3%
Refrigeration	25	31	2361	76.2	23%	27%
Sawmilling	2	2	67	33.5	1%	1%
Tanneries	2	2	128	64	1%	1%
Woodworking, Coachbuilding, &c	3	3	78	26	2%	1%
Totals	**123**	**137**	**8607**	**63**	**100 %**	**100 %**

Table 2. *Summary of Suction Gas Engines Sold by R. Hornsby & Sons in Victoria, 1905-1913.*
Source: Ruston-Hornsby Order Books, Museum Victoria

8. GAS ENGINES IN OTHER RURAL INDUSTRIES

By 1915, gas engines installed in country power stations represented two-thirds of the combined horsepower of all gases engines use manufacturing works outside Melbourne, however, suction gas engines and gas producers also found a strong demand in other rural industries. Although no overall figures are available on the numbers of gas engines used in non-manufacturing industries like mining and pumping for town water supplies and irrigation, some indication of their importance to other rural industries has been gained through an analysis of order books from the former Melbourne agency of Ruston Hornsby held in the collections of Museum Victoria.

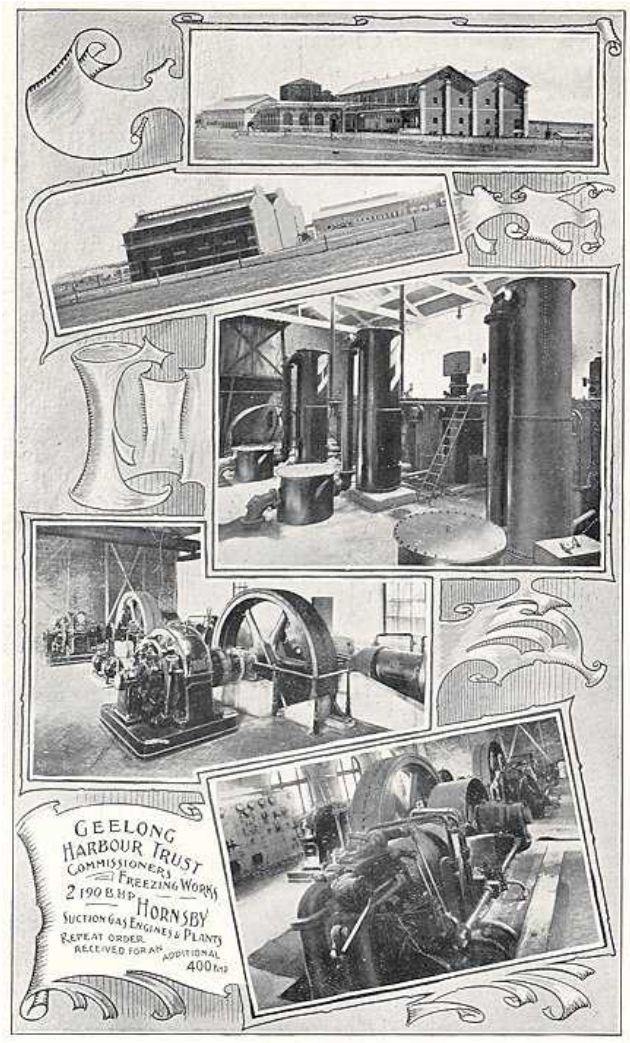


Figure 10: *R. Hornsby & Sons Suction Gas Plant at the Geelong Harbour Trust Freezing Works. Powering refrigeration plant for country meatworks, dairy factories and fruit coolstores represented almost a quarter of all Hornsby suction gas sales up to 1915.*

Source: Ruston-Hornsby Collection, Museum Victoria

9. CONCLUSIONS

Although gas engines never provided the principal source of motive power for Victorian industry, their introduction and use from the 1870s provided an important transition between steam technology and the later introduction of liquid-fuelled internal combustion engines and electric motors, which would become the principle source of industrial power in the 20th century.

Gas engines initially provided a cheap and effective source of mechanical power factories and workshops with smaller power requirements and played key role in the early mechanisation of several industries such as printing, clothing manufacture and boot & shoe making. They also provided a basis of local engineering skills and manufacturing expertise that would subsequently be developed into the large-scale manufacture of internal combustion engines in Victoria.

By 1905, the gas engine had entered the second era of its development and impact on Victoria. As the demand for smaller gas engines in inner city and suburban workshops declined the introduction of suction gas producers made the use of large gas engines more cost effective and the technology had a new lease of life providing versatile and low cost power for a variety of rural industries including in particular rural electricity supplies, water pumping, refrigeration and mining. For a quarter of a century the suction gas engine was the cheapest of all industrial power sources with an ability to throb away tirelessly for hours on end on literally the wiff or a half bag of coke or a few shovels full of charcoal.

It is ironic that as their era as an industrial workhorse drew to a close in the late 1930s, a new use for gas producers and gas-powered internal combustion engines was being discovered as a low-cost power source for running road vehicles and tractors during the petrol rationing of the Second World War.

10. ACKNOWLEDGMENTS

This assistance of David Crotty, Colin Heggen, Rohan Lamb, Miles Pierce and David Yandell in contributing ideas and information of the my research in complying this paper is gratefully acknowledged.

11. REFERENCES

See next page

[1] T.K. Derry & Trevor I. Williams, *A Short History of Technology From the Earliest Times to A.D.1900*, Oxford University Press, 1960.

[2] Horst O. Hardenberg, *the Middle Ages of the Internal Combustion Engine 1794-1886*, Society of Automotive Engineers Inc, Warrendale, Pennsylvania, USA,1999, ch.26, pp.235-266; Étienne Lenoir From Wikipedia: http://en.wikipedia.org/wiki/%C3%89tienne_Lenoir#cite_note-0#cite_note-0, viewed 26-10-2009; Georgano, G.N. *Cars: Early and Vintage 1886-1930* (London: Grange-Universal, 1990), p.9.

[3] Horst O. Hardenberg, *the Middle Ages of the Internal Combustion Engine 1794-1886*, Society of Automotive Engineers Inc, Warrendale, Pennsylvania, USA,1999, ch.33, pp.319-342.

[4] B1283 Otto-Crossley vertical free piston atmospheric gas engine, 1870-1880 http://www.powerhousemuseum.com/collection/database/?irn=207306&search=crossley+gas+engine&images=&c=&s=#ixzz0W4CTJpcm

[5] B1214 Otto-Langen vertical free piston atmospheric gas engine, 1867-1868http://www.powerhousemuseum.com/collection/database/?irn=207174&search=otto+gas+engine&images=&c=&s=#ixzz0W4Du1pwm

[6] *The Argus*, 10 Dec 1873, p.7, col.5, Machinery.

[7] *The Argus*, 12 Oct 1876, p.7, 12 Jul 1877, p.1 & 21 Jul 1877, p.10.

[8] Horst O. Hardenberg, *the Middle Ages of the Internal Combustion Engine 1794-1886*, Society of Automotive Engineers Inc, Warrendale, Pennsylvania, USA,1999, pp.335-339 & ch.42, pp.465-474.

[9] Victorian Patent No.2523, 26th June 1878 A.D. OTTO, Nicolaus August, of Gas motoren Fabrik-Deutz, at Deutz, in the German Empire, engineer, for *"Improvements in gas motor engines."*

[10] Sigvard Strandh, *Machines An Illustrated History*, Rigby Limited, Melbourne, 1979, p.143.

[11] PROV – personal communication from Peter Marsh, 20 August 2009.

[12] *The Argus*, 30 Jul 1879, p.6 "The New Tariff" & 22 Oct 1879, p.6 "Exemption List". The Victorian Import Duty on Engines and General Machinery had first been introduced at 5% *ad valorem* on 6 Feb 1867, rising to 10% from 6 Mar 1867, 20% from 2 Aug 1871 and then 25% from 13 Jul 1879. M. Churchward, *The Portable Steam Engine in Victoria*, unpublished report for Museum of Victoria, Oct 1990, revised May 1991.

[13] Henry Heylen Hayter, Government Statist, *Victorian Statistical Register –Part VI Production*, published annually in *Victorian Parliamentary Papers*.

[14] *Tariff Report of the Royal Commission*, evidence of Robert Spencer Easton, Beath, Schiess & Co, Clothing Manufacturers, Q30038-30045, published in *Victorian Parliamentary Papers*, 1883, 2nd session, vol.4, no.50.

[15] *Victorian Statistical Register –Part VI Production*, 1880, pp.44-47.

[16] *The Argus*, 3 Sep1875, Intercolonial Exhibition Supplement – Sewing Machines. See also adverisement for same *The Argus*, 3 Sep 1875, p.8.

[17] *The Argus,* 3 May 1879, p.8 "Intercolonial Juvenile Industrial Exhibition". The exhibition opened in basement of Melbourne's new Eastern Market on 23 December 1879.

[18] *The Argus,* 17 Dec 1880, p.56 "Steam and Gas Engines".

[19] Horst O. Hardenberg, *the Middle Ages of the Internal Combustion Engine 1794-1886*, Society of Automotive Engineers Inc, Warrendale, Pennsylvania, USA,1999, pp.379-382; B1286 Bisschop gas engine http://www.powerhousemuseum.com/collection/database/?irn=207321#ixzz0W9c9NbXW; Museum Victoria, ST 009795, Gas Engine - J.E.H. Andrew, Stockport, Bisschop's Patent, Vertical, circa 1880.

[20] *The Argus,* 21 Dec 1883, p.5 & 24 Dec 1883, p.7 "The Engineers' Conversazione"; H10108 Dugald Clerk, Stockport two-stroke horizontal gas engine., 1882–1892 http://www.powerhousemuseum.com/collection/database/?irn=230837&search=h10108&images=&c=&s=#ixzz0W9ykoiHD.

[21] *The Argus,* 24 Dec 1883, p.7; 26 Aug 1884, p.7 & 24 Aug 1885, p.3.

[22] *The Argus,* 9 Aug 1888, p.15; B998 Gas engine, 'Domestic Motor', by Crossley Bros, Manchester, 1885-1890 http://www.powerhousemuseum.com/collection/database/?irn=215302&search=domestic+motor&images=&c=&s=#ixzz0WDNrF5JV ; B2091 Gas engine, 'Domestic Motor', by Crossley Bros, Manchester, 1885-1890 http://www.powerhousemuseum.com/collection/database/?irn=210659#ixzz0WDOJxKND.

[23] *The Argus,* 9 Aug 1888, p.15 & 2 Oct 1888, p.47. Victorian Patents No.5986 & 5987, 19 July 1888.

[24] *The Argus,* 9 Aug 1888, p.15; H10108 Stockport two-stroke horizontal gas engine., 1882-1892 http://www.powerhousemuseum.com/collection/database/?irn=230837&search=stockport&images=&c=&s=#ixzz0WBaU8uHD; ST 015372, Gas Engine - Vertical, Hot-Tube Ignition, Purnell, Scotland, 1892.

[25] *Victorian Statistical Register – Production*, 1888 & 1898.

[26] M.S. Churchward, *The Victorian Steam Heritage Register*, Museum of Victoria, 1994, pp.13-15; M.S. Churchward, *The Influence of Gold Mining on the Development of Engineering Manufacturing in Victoria during the 19th Century*, M Eng Sc Thesis, University of Melbourne, 1988.

[27] *Tariff Report of the Royal Commission*, evidence of Robert Spencer Easton, Q30042-30045.

[28] *Tariff Report of the Royal Commission*, evidence of William Brown, Q26830-26902.

[29] Horst O. Hardenberg, *the Middle Ages of the Internal Combustion Engine 1794-1886*, ch.42, pp.465-474.

[30] *The Argus*, 16 May 1893, p.1 Machinery.

[31] *The Argus*, 16 Sep 1896, p.2; Sands & McDougall Melbourne Directory.

[32] *Farmer & Grazier*, 1898 Show Report…

[33] *The* Argus, 31 Aug 1899, p.8 Machinery; Farmer *& Grazier*, 1899 & 1901 Show Report…Board of Works Report; *The* Argus, 10 Jul 1906, p.5 Refitting S.S. Queen.

[34] *The Argus*, 2 Sep 1890, p.3.

[35] *Farmer & Grazier*, 1898 Show Report…

[36] *Farmer & Grazier*, 1899 Show Reports…Board of Works Report;

[37] *The Argus*, 31 Aug 1899, p.8 – Machinery; Victorian Patent No.16484 of 1899, *"An improved oil or gas engine"*; M.S. Churchward & P. Milner, *Some Engineering Establishments in Victoria, 1842-1945*, University of Melbourne, Technology Report TR-88/5, 1988…Board of Works Report

[38] K.N. McDonald, *A.H. McDonald – Industrial Pioneer*, privately published, 1988, pp.31-35.

[39] Ray Proudley, *Circle of Influence – A History of the Gas Industry in Victoria*, Hargreen Publishing Co in association with Gas & Fuel Corporation of Victoria, 1987, pp.112-3.

[40] The number of oil engine powered factories in Victoria first exceeded gas engine powered factories in 1925 (432 cf 413), while in terms of combined horsepower, oil engines in manufacturing to not exceed the contribution of gas engines until 1928 (13,330 hp cf 10,886). *Victorian Year Book, 1925 & 1928*.

[41] Dowson, J.E. & Larter, A.T., *Producer Gas*, Longmans & Green, London, 2nd edition, 1907; *The Maitland The Maitland Mercury & Hunter River General Advertiser*, NSW, 2 June 1883, p.2, "Economical Gas Generators and Engines."

[42] Dowson, J.E. & Larter, A.T., *Producer Gas*, Longmans & Green, London, 2nd edition, 1907

[43] *The Argus*, 30 Sep 1905, p.1; 25 Aug 1906, p.9; *The Advertiser (Adelaide)*, 13 Sep 1905, p.15.

[44] M. Churchward, *The Portable Steam Engine in Victoria*, unpublished report for Museum of Victoria, Oct 1990, revised May 1991; M.S. Churchward, *The Victorian Steam Heritage Register*, Museum of Victoria, 1994, p.186; Richard Brooks, Martin Longdon & Lesley Colsell, Lincolnshire Built Engines, The King's England Press, 1986.

[45] *The Hornsby Gas Engine & Suction Gas Plant*, R. Hornsby & Sons Ltd, Grantham, England, 1911 (Museum Victoria trade literature collection TL 006722); Michael Pointer, *Ruston & Hornsby, Grantham, 1918-1963*, BG Publications, 1977

[46] *Electrical Progress in Australasia – A Review of the Progress made in the Application of Electricity to Power, Traction and Lighting*, Australian Mining Standard & Electrical Record, special edition 5 May 1909, George Kerr Nelson for Critchley Parker Pty Ltd, Melborne; Peter G. Tait, *Tait's Electrical Directory of Australia and New Zealand for 1912-1913*, The Mining & Engineering Review, Melbourne, 1912.

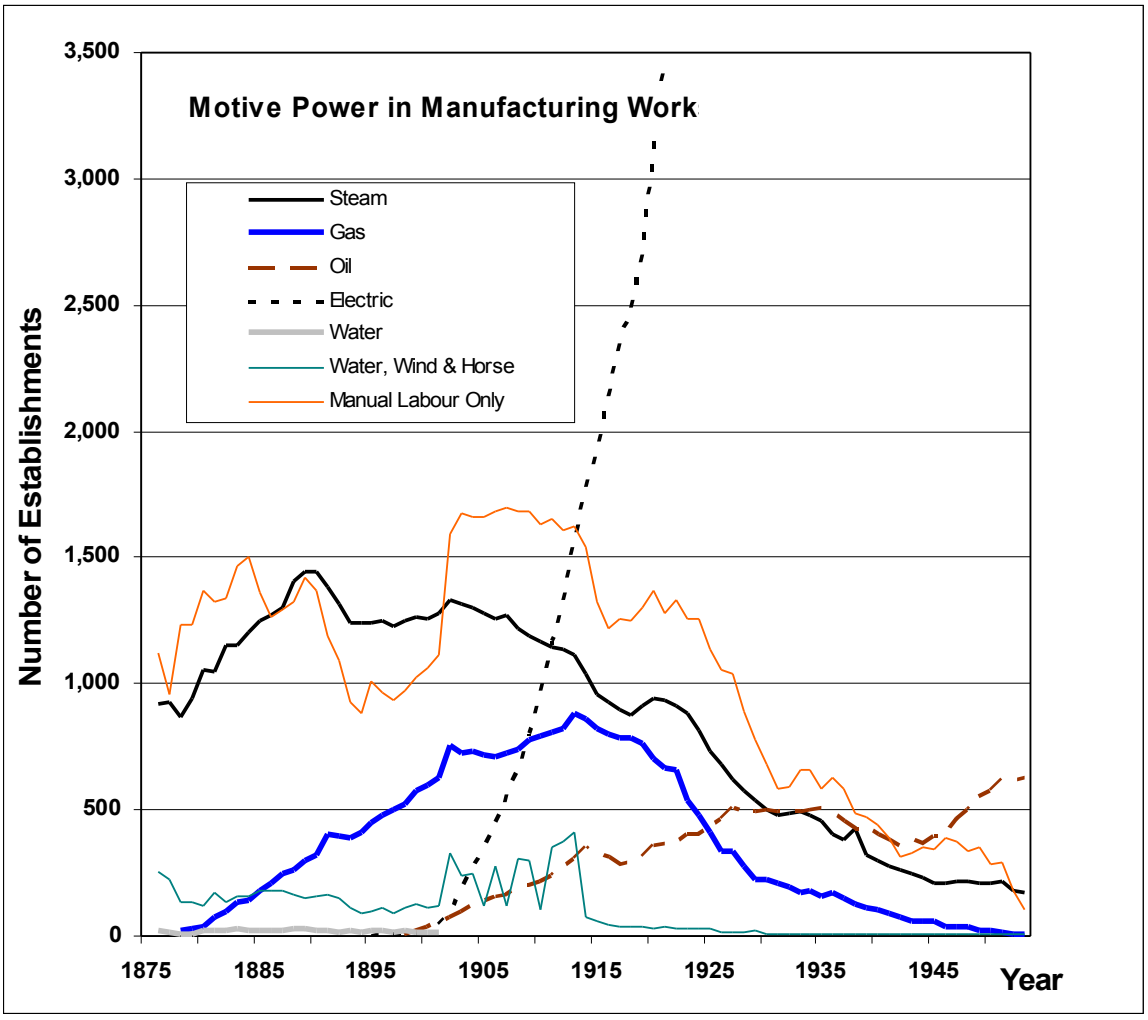
[47] Data compiled from Peter G. Tait, *Tait's Electrical Directory of Australia and New Zealand,* 1912, 1915, 1920 & 1929; G.B. Lincolne, "Electricity Supply in Victoria", published typed & bound report for SECV., c.1956.

[48] *The Argus*, 4 Jul 1908, p.3 & 27 Jul 1908, p. – Tenders – Shire of Hampden.

[49] *Tait's Electrical Directory of Australia and New Zealand,* 1912, 1915, 1920 & 1929. For a detailed description of a typical installation see, Rohan Lamb, "Dandenong Power Station – A History", *Steam Supreme*, Melbourne Steam Traction Engine Club Inc, Apr 2000.

12. APPENDICES

Appendix A: Sources of Motive Power Used in Victorian Manufacturing Works, 1875-1955
Source: *Victorian Statistical Registgers, 1875-1915; Victorian Year Books, 1901-1955*



Appendix B: Proportion of Mechanically-Powered Victorian Manufacturing Works Using Power Sources, 1875-1955

Source: *Victorian Statistical Registers, 1875-1915; Victorian Year Books, 1901-1955*