The return of the steam loco?

The coming oil energy "crunch" could change the face of railways, by bringing back the steam locomotive. But a modern steam loco would be quite different from the dirty, smelly designs of past years. Just how different is revealed in this article.

by PROF. M. THRING, DR J. SHARPE and P. Le SUEUR*

When the steam railway locomotive reached the peak of its development, in the 1930s, it was only a step away from those of early 19th-century design, though bigger and more powerful. Engines of that sort, with hardly any updating, still run today. It is no wonder that the emergence of diesel and electric locomotives led people in the industrialized countries to regard steam locomotives as old-fashioned and obsolete. Other countries followed the trend, with a few notable exceptions, and steam rapidly began to disappear from the world's railways.

This, no doubt, would have been the end of the story, except for one vital factor — the energy crisis, and the oil shortage in particular. Without oil, at least with present technology, there could be no motor-cars and no aeroplanes. The world would be heavily dependent upon its railways for land transport, but without oil for the diesel locomotives.

Electrification, using coal-burning or nuclear power stations is one answer, but there are many railways that would be prohibitively expensive to electrify. For these, another form of power would be needed.

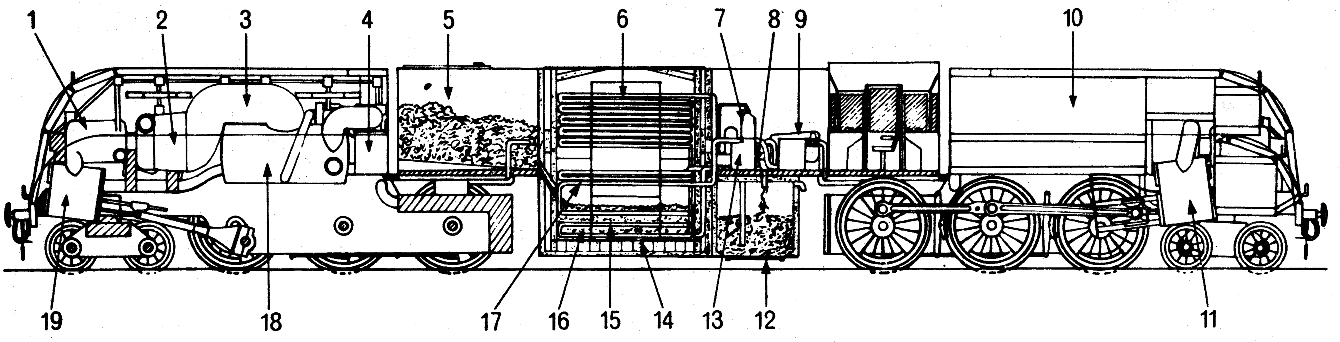
To raise steam is easy but, to many, the idea of actually going back to this tradition is repellent. True, the steam locomotive was dirty and smelly; its ash had to be emptied and it needed stoking, oiling and lighting up hours before it began to work. Its thermal efficiency was at best only eight per cent, but it did have many advantages often overlooked today: it was reliable, its failures seldom leading to complete immobility; it could produce a vast, instantaneous power, and it lasted seemingly for ever. It was also capable of running with remarkably little overhaul (though at the expense of efficiency), a fact appreciated in countries where skilled fitters were few and fuel was plentiful.

But, most important of all, it could run on anything that could be burnt, including coal, oil, wood, gas, peat and sugar-beet.

Here, then, is one possible form of railway power for the future. But we need a steam locomotive that has all the important advantages and none of the big disadvantages of the conventional machine. Above all, it should have a thermal efficiency comparable with that of diesel and electric locomotives.

Our research project, sponsored by the UK Science Research Council, is concerned with the mathematical modelling of steam cycles that could be applied to an advanced, efficient steam railway locomotive. Although we have not yet completed the mathematical model, a very promising design of locomotive has already emerged.

Our main aim was to design a locomotive that would burn coal instead of oil. Coal-burning gas turbines



1	Compressor
2	Turbine
3	Exhaust branch
4	Hot well
5	Coal bunker
6	Feed heater tubes
7	Starting gas cylinder
8	Feed pump
9	Auxiliary turbine
10	Radiator panels
11	LP cylinder
12	Emptying hatch
13	Heat accumulator
14	Distributor plate
15	Bed evaporative tubes
16	Fluidized bed
17	Superheater tubes
18	Condenser
19	HP cylinder

Sectional elevation of the proposed locomotive. It is designed for a maximum continuous power output of 2.5MW with an overall thermal efficiency of 24.5 per cent. Overall length would be around 27 metres.

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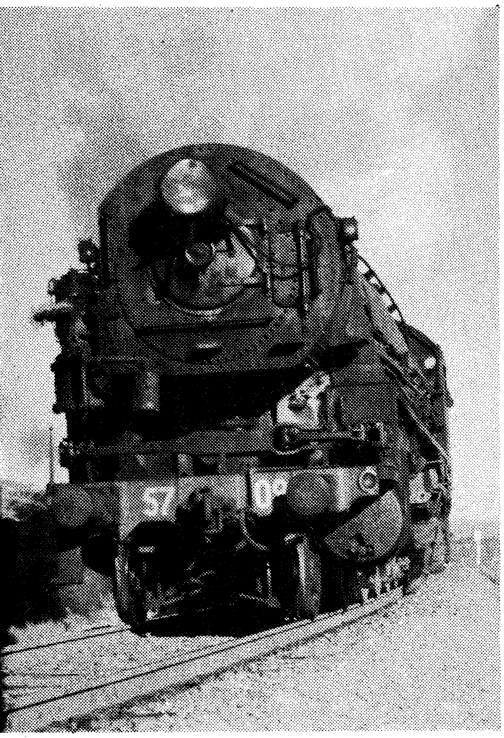
*Department of Mechanical Engineering, Queen Mary College, University of London.



Perhaps things will never be quite like this again, but we couldn't resist publishing the above picture of one of the old D57 "Mountain" type locomotives. The D57 weighed 230 tonnes and was one of the most powerful steam loco classes built in Australia.

were considered but there are big problems of erosion of their blades. It soon became clear that an expansion engine using a conventional Rankine cycle, with water for the working fluid, would be the best choice. Other fluids could be used, but their merits are small compared with their cost, scarcity, and danger in use.

Having decided on a steam locomotive, our next step was to find ways to raise its thermal efficiency from the usual eight per cent to the diesel's 20 per cent or so. With a Rankine cycle, this can be done in two ways: by raising the boiler pressure and by reducing the engine exhaust pressure. Railway engineers had appreciated this in the 1920s and 1930s, and many unconventional locomotives were designed in attempts to attain a better overall cycle efficiency by one or other of these means.

To raise the boiler pressure above about 2MPa (megapascals) needed a water-tube rather than a fire-tube boiler. This allowed very high pressures to be used, but to keep the termperatures to a reasonable level for a long boiler life, we finally settled on a mean pressure of 4.5MPa. We had to reduce the exhaust pressure and, bearing in mind that a conventional steam locomotive exhausts to the atmosphere, in this instance we had to arrange to exhaust below atmospheric pressure or to a vacuum. This meant condensing the exhaust steam. The lower the condenser pressure, the higher the cycle efficiency, so we chose a pressure of 7kPa (kilopascals), because this gave us the lowest condenser temperature that would still allow cooling by atmospheric air.

We planned to pump the condensate back to the boiler, which meant complete recycling of the water, apart from the small steam losses through glands and stuffing boxes, so we could use softened water to contribute to long boiler life.

The next aim was to ensure pollution-free combustion at maximum efficiency, with automatic stoking and ash removal. All this could be achieved by employing fluidized bed combustion.

A fluidized bed comprises a quantity of inert material, such as sand, supported on a perforated 'distributor plate'. When air is blown through the plate, large bubbles form and agitate the bed, causing it to bubble up and behave rather like a boiling liquid. In this instance, the motion of the locomotive would aid the fluidization.

Coal sprinkled on such a bed burns at about 900°C and very efficiently heats evaporation tubes immersed in the bed. The hot gases leaving the bed can be used in gas turbines, but for reasons already stated we planned to use them to superheat the steam instead, and to heat the feed water.

A fluidized bed produces virtually no pollution. Its temperature is too low for ash to fuse or for impurities such as potassium and sodium to vaporize, while the large amount of excess air in it prevents carbon monoxide forming. Adding limestone to the sand stops sulphur dioxide being given off.

Ash is removed by blasting the mixture of sand and ash from the bed into a cyclone, with an injector operated by bleeding off some of the fluidizing air. Separated by centrifugal action, the ash rises in the cyclone and is deposited into an ash well ready for emptying. The sand falls into a sand well and is returned to the bed by another air injector.

The bed does not need expensive pulverizing machinery. It can burn coal in lumps of any size up to 25mm and, with only simple adjustments, can be made to burn any other fuel. A hopper or screw is all that is needed to feed in the fuel, which spreads itself across the bed; this is in contrast to the accurate stoking that an ordinary grate needs. The combustion efficiency is better than 98 per cent and the bed can be started up from cold in about 30 minutes, using propane gas mixed with the fluidizing air and ignited by an electric spark.

For railway traction it is necessary to have a large starting torque, with lower torques at running speeds. Reciprocating steam locomotives always provided this, which is why we chose a reciprocating engine for our design. However, at the low-pressure end of the cycle the volume of the steam is so enormous that reciprocating engines cannot handle it. A turbine can accept far larger volume flow rates and is ideally suited to the low-pressure end, but it develops its maximum torque at its top speed, which, as had been found in the past, means having a complicated gear box or an intermediate transmission system, either electrical or hydraulic, to adapt it to locomotion.

Trying to match the direct high-pressure cylinder drive with a low-pressure turbine and associated transmission was soon found to be highly undesirable. Therefore, we adopted a system originally invented by Gotaverken, a company in Sweden, for use on steamships. It uses the turbine power to drive a steam compressor, which compresses and reheats the steam between the high-pressure and low-pressure cylinders of the reciprocating engine. The theoretical loss through using mechanical power to heat the steam is less than the loss in a turbine transmission used for propulsion.

In our proposed system, each engine unit condenses its own steam in a conventional shell-and-tube condenser cooled by circulating water. The water is cooled in radiators built around the outer shell of the locomotive, by the surrounding air. Of all the condensing systems used in locomotives in the past, this one has proved the most successful; the total space it takes is far less than when direct air-cooled condensers are used, because the heat transfer is better. These condensers can also provide the heating for the train.

The turbines also drive the radiator cooling fans, the cooling-water pumps and the 'wet-air' pumps but, to make the boiler unit self-contained, an auxiliary turbine is included to drive the blower for fluidizing the bed and the reciprocating feed pump. A direct-current motor drives the blower when starting from cold, drawing its supply from batteries which are recharged by the same machine working as a generator when the auxiliary turbine is running. The auxiliary turbine exhaust is mixed with the incoming feed water to provide first-stage feed heating.

The locomotive is designed to be controlled by only one lever, in addition to the 'dead man's handle' and the brakes. The lever activates a hydraulic control system, synchronizing the operation of the locomotive's various parts. The cylinders' poppet valves and cut-off controls are intended to be hydraulically operated, too. If anything should fail, the driver could over-ride the automatic system and continue operating the undamaged parts of the locomotive by means of a complete set of manual controls.

Our work on the economics of the locomotive proves that it would be superior in all ways to diesel and electric traction. First and foremost, its overall thermal efficiency has been calculated as 24.5 per cent. This is equivalent to a diesel locomotive's peak efficiency, but if we plot our locomotive's efficiency against speed the curve is flatter than a diesel's, which means that our machine would be the more efficient over most of the range of operating speeds.

The capital cost would be less than that of a diesel, which has a large, complex engine. All the steam-cycle components are available 'off the shelf', and have been tried and tested in other branches of engineering. It would be cheaper than an electric system, of course, which has to include the electric conductor and installations. The steam machine would need no more maintenance than a diesel does; it would be cleaner and would produce less pollution, as already explained.

It would be more reliable too, rarely stopping dead as a diesel does when it breaks down, or an electric locomotive when the overhead wires fall down. What is more, the eyesore of miles of

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overhead wires and catenary masts would be avoided.

The locomotive we are now studying is a 2.5MW (3350 horse-power) express freight and semi-fast passenger locomotive. It would be ideally suited to such duties, particularly on the sort of long hauls found in India, Australia, Russia, China, Africa and the Americas, where electrification is unlikely to be worthwhile. It might have applications in Europe, too.

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