

# A double scotch from the Johnson bar

## Driving a steam locomotive

### Peter van der Linden

---

You could say I know everything about railroads - but it took a lot of training. All railway men have a special place in their hearts for steam locomotives, and I'm no exception. Our newsletter editor suggested that members might like to hear more about steam trains. So, if you're in the mood, put the kettle on for a nice cup of tea, and here goes.

Anyone who's boiled a kettle knows the basics of steam. Though the Greeks speculated about steam power, it was first harnessed in practice by Thomas Newcomen in 1712, and radically improved by James Watt about fifty years later. Steam engines convert the thermal energy of steam into mechanical motion.

### Internal vs. External combustion

Petrol-fuelled engines, such as those that power automobiles, are *internal combustion engines*. These engines produce the high pressure gases inside the engine and use them to move a piston or turbine. An internal combustion engine converts one kind of energy (chemical) into movement. By way of contrast, steam engines are *external combustion engines*. The burning occurs outside the engine. The engine's job is to convert the heat/pressure kind of energy into movement.

In the case of a steam engine, you boil water in a pressurized container. As the water boils, some of it expands and vaporizes into steam. Dry steam occupies sixteen hundred times the volume of the same weight of water at atmospheric pressure! You intuitively know about steam pressure from watching steam lift the lid of a boiling saucepan, but the ratio of water/steam volume is still amazing.

The mechanism of a steam engine is straightforward. Because the boiler is sealed from the outside air, the steam can't escape and it builds up to a high pressure. You can pipe that high pressure steam to a chamber where it can push a piston. (Very old steam engines didn't blow the piston, but condensed the steam to create a vacuum that sucked the piston down the cylinder). At the end of its travel the steam vents any remaining pressure in a quick burst, giving the characteristic "chuff" sound.

Steam engines are cheaper, simpler, quieter, and more reliable than many other kinds of engine. But a steam engine needs large quantities of water, in addition to fuel and all the parts it has in common with a gas-powered engine. As a result the power-to-weight ratio of steam engines (plus supplies) is low. That's why we rarely see steam engines used in applications where the weight matters, like helicopters, airplanes, and mobile or man-portable devices (leaf blowers or hand-held drills).

### Thomas the Tank Engine

One of my favorite books as a child was "Thomas the Tank Engine." But what is a "tank engine?"

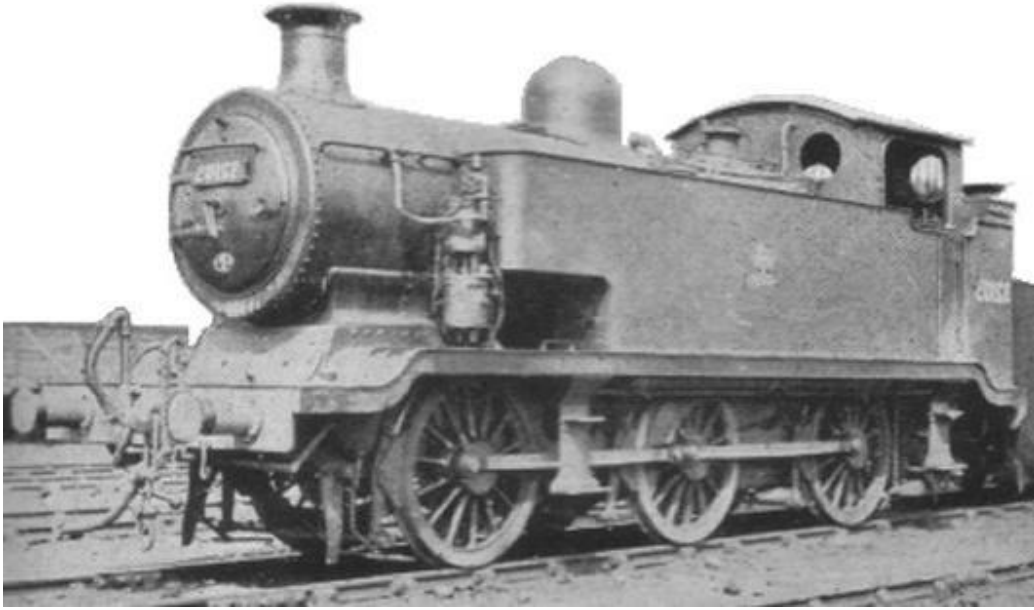


**Thomas**

Most steam locomotives vent the used steam through the smoke stack rather than condensing it, filtering the lubricating

oil out, and reusing it. Ignoring environmental costs, it's cheaper to discard the used water. Locomotives therefore need a reservoir of water which is periodically replenished. Typically, the water and fuel are stored in a separate tender behind the locomotive.

On a tank engine, the water is carried in one or a pair of thousand gallon rectangular water tanks on either side of the boiler, and the fuel (usually coal) is carried in an extension behind the cab. This makes a tank engine smaller, lighter, and less expensive, but it has a shorter range before it needs refueling and rewatering. Tank engines are thus used for shunting work in the depot, and on very short lines.



**The real life Thomas**

So Thomas the Tank Engine is a dirty, dumpy self-contained yard engine for short haul work. The real life model for Thomas was a Class E2 shunting engine built in Victorian times for the London, Brighton and South Coast Railway. Tank engines were very common in England, but are relatively unknown in the United States.

## Crew

All but the smallest locomotives are staffed by a crew of two: the train driver ("engineer" in US parlance) and the fireman. The fireman's job is to ensure that steam is available when required. Steam cannot be created instantly from cold water; considerable time is needed to heat the water to boiling. The fireman's job involves knowledge or prediction of the track ahead so the steam is ready when needed. The driver's job is to use the steam to move the train and its *consist* (US term for the rolling stock load pulled by a train).



**There are a few hundred lubrication points on a steam locomotive, and this is the time-honored ritual of "oiling around" the engine**

Every steam locomotive cab has a water glass that directly shows the level of water in the boiler. Among railroaders, that glass is known as "the most important window on the train". A crew ignores low water at their peril, as it may lead to a spectacular boiler explosion. If you are ever invited into the cab of an engine under steam, the first thing to inspect is the water glass.

## Boiler Explosions

If, like me, you're a big fan of explosions, the thermodynamics of boiler failure are fascinating. Most steam locomotives share a common design. There's a box made out of fire bricks where the fuel burns. The top of the firebox is a half inch thick plate of steel called the "crown sheet" which is also one wall of the boiler.

Under the crown sheet, the fire is roaring at about 2200 degrees Fahrenheit. Over the crown sheet are several thousand gallons of water absorbing the heat, boiling, and turning into steam. The crown sheet temperature stays around 600



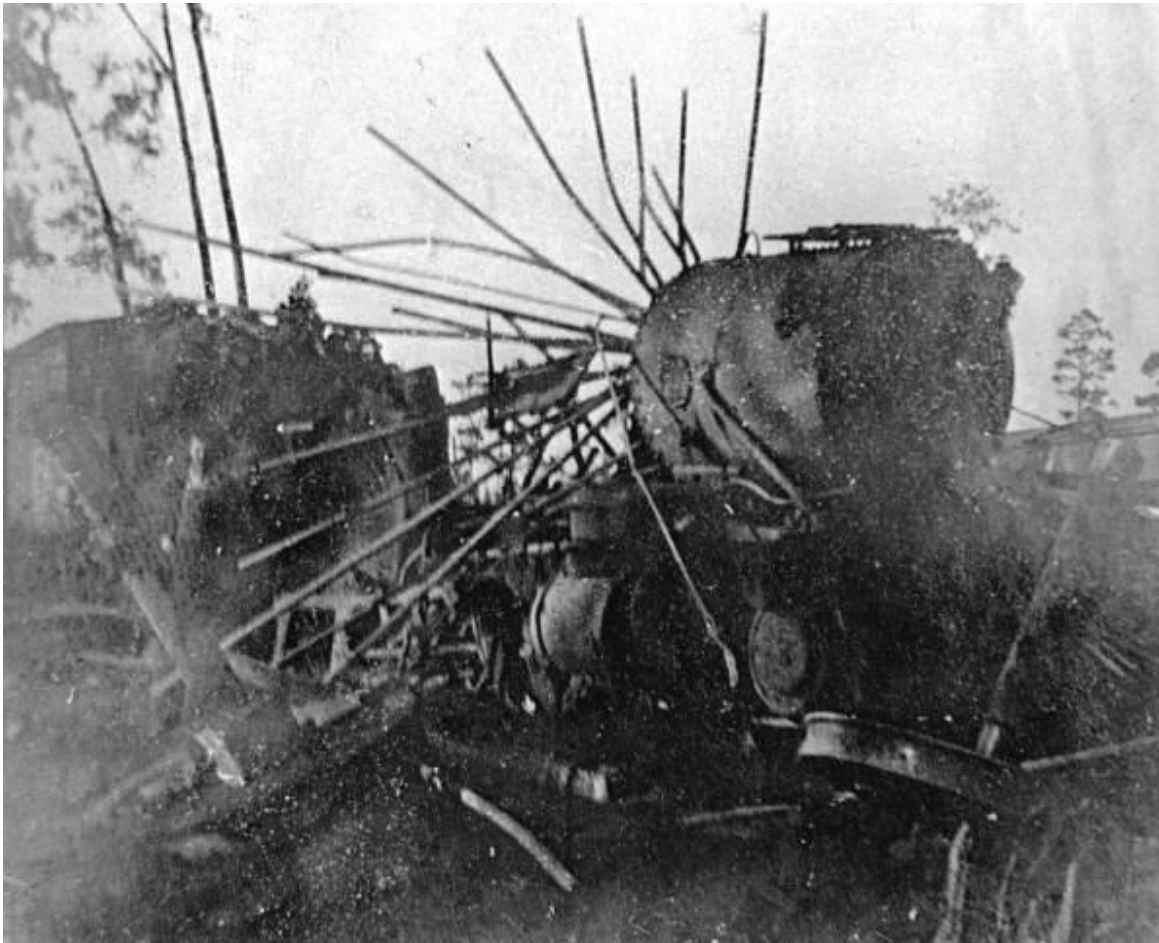
degrees, as the water conducts heat away from it. The boiler is typically shaped like a wine bottle on its side. The crown sheet is at the neck of the bottle, with the firebox under it, and the exhaust gases piped through the boiler to heat the water. The fireman adjusts the supply of fuel to get the water to simmer or come to a full rolling boil, as needed. He periodically adds water to replace the steam that's drawn off.

Because the boiler is a sealed vessel under pressure, the water boiling point is much higher than 212 degrees (everything is in Fahrenheit). Remember that mountaineers have to brew tea with luke-warm water, because water boils at a lower temperature at altitude where the air pressure is lower. In mile-high Denver, water boils 9 degrees lower than at sea level. Similarly, water under high pressure has to be heated more to boil. A steam locomotive boiler operates at a pressure of about 200 pounds/square inch, with the water boiling at 386 degrees.

If the fireman or his equipment fails, and the water level drops so that it no longer covers the crown sheet, this will quickly overheat to the point where the steel loses its tensile strength and goes "plastic". The crown sheet, as part of the boiler, is under a pressure more than ten times greater than the outside air. The steam pressure will rip a hole through the heat-softened crown sheet, opening the boiler to the outside air. But the boiler still holds a couple of thousand gallons of water at 386 degrees - way above boiling point at atmospheric pressure. When the pressure drops, all that water in the boiler instantly flashes into steam.

### You'd better "BLEVE" it

Water turning to steam expands 1600 times in volume -- so 2000 gallons of water instantly vaporises to 3 million gallons of steam! It's confined in a metal tube which bursts explosively. The vast majority of boiler explosions are actually firebox failures caused by too little water. These often happen when crossing the summit of a hill. As the grade changes, water surges away from the crown sheet.



**A boiler explosion broke this locomotive into small pieces and sprayed them, and the crew, over a wide area of Florida.**

The process of hot pressurized water turning into steam can be seen on any car. It's the reason radiators have the warning "don't unscrew this cap while the engine is hot". If you ignore the warning, and unscrew the cap, the pressurized water inside will vaporize and steam up in your face. Casualty departments, police charge sheets, and physics professors refer to this as a BLEVE - Boiling-Liquid Expanding-Vapor Explosion. It also happens when students try to sneak some dry ice out of the lab in a screw-top soda bottle.

Many commercial nuclear reactors are also steam engines. The reactor is the boiler, and it uses nuclear heat to boil water



to make steam which drives a turbine that generates electricity. The biggest accident (so far) in history, the 1986 explosion that destroyed reactor 4 at Chernobyl, was a steam BLEVE explosion. It was caused by forcing operation into an unstable area of the power envelope. The engineers were experimenting to see if the turbine self-generated enough power for a safe shutdown, rather than requiring outside power. It turns out that it didn't.

## Driving that train

The train I'm driving on this occasion is a 2-truck Shay, built in 1912 by the Lima Locomotive Works in Ohio. Many of these locomotives went overseas, but this one worked for a lumber company in Tennessee, then in Georgia, North Carolina, and Virginia, before coming to California in 1962. This is a narrow gauge engine, with some adaptations for use in hilly logging areas.



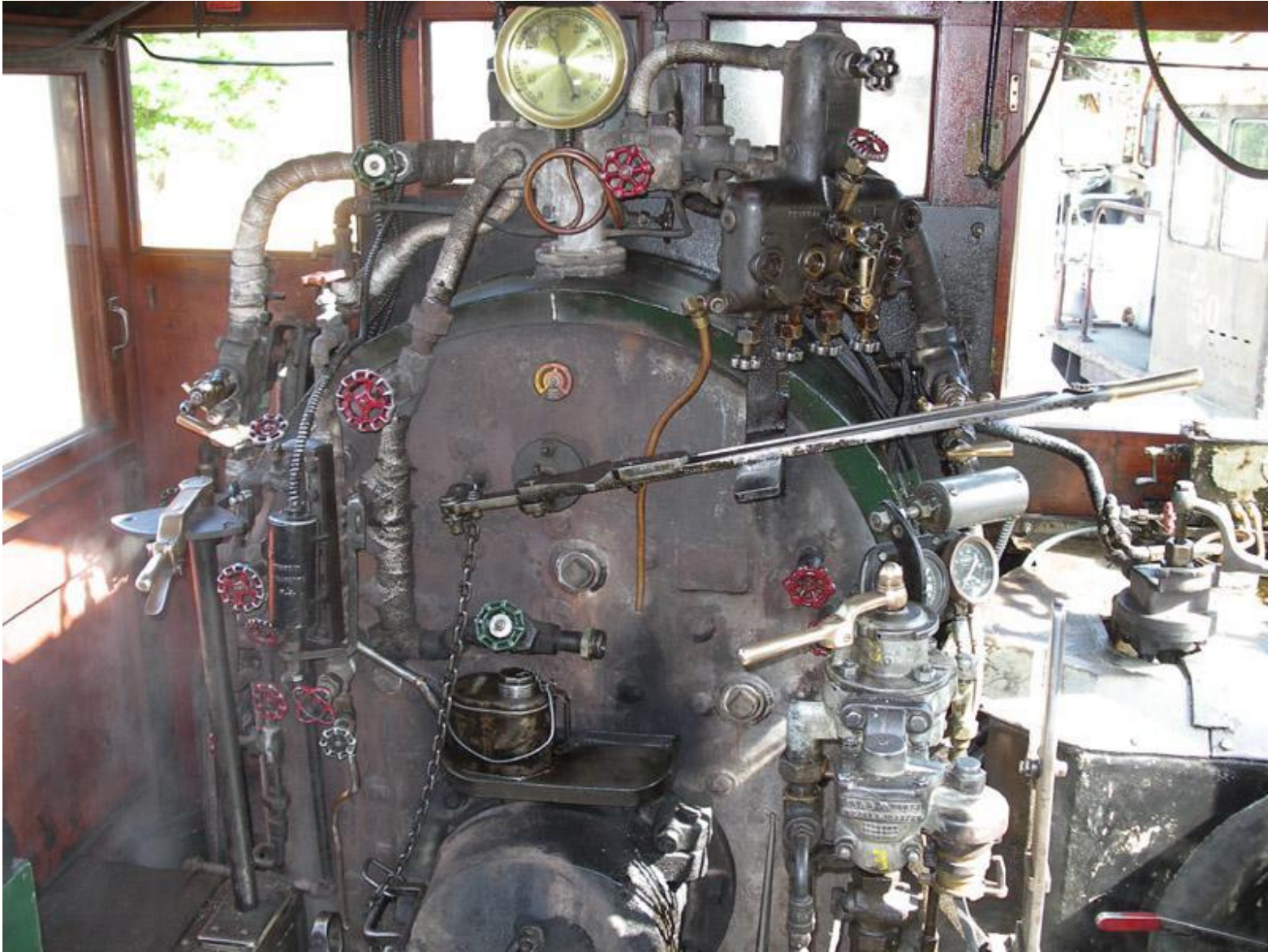
Peter goes loco in Scotts Valley, Calif.



This locomotive is older than all but the very oldest of Rolls-Royce motor cars. It's coming up to 100 years of service. Although it's got odd stuff welded on in random places, it still runs smoothly. Or so they say. It was originally coal-fired, but a conversion to oil was done 40 years ago. The cab lights are 36V. There's no local supplier for that kind of electrics, so replacement bulbs are imported from Romania.

## Locomotive controls

Driving a steam locomotive feels like riding a dragon. The steam chuffs, smoke swirls, the engine shudders, and you feel that you're guiding some living, breathing beast of immense power. The controls are strange, and placed without thought of ergonomics. Nothing is power-operated, everything is moved using your muscles. An eight or ten hour shift on the footplate is a real workout.



**The throttle lever controls the amount of steam**

That big lever running horizontally across the cab from left to right is the "throttle" or regulator. It opens a valve that controls how much steam is piped out of the boiler into the operating cylinders. The chain hanging off its left end is an "aftermarket addition" that lets the fireman open the firedoor underneath without bending down!

There's another critical control called the "Johnson bar" or "reverser". It appears as a thin bar at the bottom right, (I was end on to it when I took this picture). The Johnson bar is a sturdy yard-long ratched lever with hand release, of the kind that old fashioned signal boxes used. (The chunky thing that looks like an aluminum teapot with a brass handle sticking out to the left, is the control for the air brakes).





**The Johnson bar controls when steam flows into the cylinders**

The Johnson bar adjusts the fraction of the piston stroke for which the valves let steam into the cylinder. It also controls whether you pipe the steam in above or below the piston, thus making the engine run backwards or forwards. When the Johnson bar is in the center, no steam is admitted. When it is a little way forward, a little steam flows, moving the engine

slowly forward. If it's a little way back, the engine moves slowly back. When the bar is all the way forward, the engine runs forward with full power. It is a little known fact that steam engines can run every bit as fast in reverse as they can forwards.

The world speed record for a steam locomotive was set in 1938 by the locomotive "Mallard" on a run from Kings Cross. It hit around 126 mph. Shortly afterwards, an engine big end bearing started to overheat, so you know it was running at its maximum. That steam record will never ever be broken, because they no longer build steam locomotives. But imagine tearing down the line at 126mph backwards!

Some steam engines are "double acting" meaning that they feed steam above and below the piston alternately. That blows the piston both ways (up and down the cylinder), so every stroke is a power stroke. Hence the old saying about steam: *torque is cheap*.

## Steam: past, present, and future

Steam makes low demands on technology. The Romans could have developed steam power. They had every element of it - plumbing, hot water, metalwork, piping, engineering. But they also had something else in abundance that made steam power unnecessary: slaves. I can't help wondering how things would have worked out if some Roman engineer had got off his duff, and prototyped a steam chariot.

It's a source of considerable frustration to me. The industrial revolution would have happened 2000 years earlier, and in Rome instead of Manchester. If the Romans had developed steam, today we'd all be travelling in flying cars, instructing our robot maids by video phone. In Latin.

Steam disappeared from railroads mostly because the economics favored other technologies. There are other reasons too. If you think your PC takes too long to boot up, you'll hate the start-up process for a locomotive - it takes several hours to boil thousands of gallons of water to prepare for a run.

Steam locomotives aren't clean, and they vent the combustion gases into the air. I'm old enough to remember steam trains in England, and getting a cinder in my eye from the smoke of a passing train. Driving a steam train is filthy work. Even riding in a steam train gets your clothes dirty.

Steam had a glorious past, but an equally great future may lie ahead. As we face the uncertainties of climate change and energy shortages, wouldn't it be something if every house had a clean solar-powered steam turbine to generate electricity?

## Try for yourself

You can drive this or a similar train at several places in Northern California. See for details: <http://www.roaringcamp.com>.

You can also take a five day course on being a locomotive engineer and fireman. It's offered by the Bluebell Railway in Sussex England. See <http://www.steamway.dircon.co.uk/footplate.html>.

For more steam related downloads visit <http://www.hobbydownloads.com> and <http://www.steamshed.com> or if you are into building your own steam engines check out suppliers for lathes and tooling [here](#).