COALITION for SUSTAINABLE RAIL

The Development of Modern Steam 3: The “Rio Turbio Railway” and GPCS

Ing. S.T. McMahon & Davidson Ward

Edited: Wolf Fengler, MSME, Martyn Bane & John T. Rhodes

About the Coalition for Sustainable Rail

The Coalition for Sustainable Rail (CSR) is dedicated to the refinement of solid biofuel technologies for use in the world's first carbon-neutral higher speed locomotive. Our team is a combination of the University of Minnesota and Sustainable Rail International (SRI), a U.S. 501c(3) nonprofit dedicated to the research and development of modern steam locomotives. A scientific and educational organization, CSR's mission is to advance biofuel research and production; to research and develop sustainable railroad locomotives; to promulgate associated sustainable technologies; and to support and conduct non-partisan educational and informational activities to increase awareness of sustainable railroad locomotives.

About CSR's White Paper Program

Working in conjunction with the University of Minnesota (U of M), the Porta Family Foundation, and other not-for-profit rail and biomass research organizations, CSR's White Paper Program is bringing works pertinent to biofuel, modern steam locomotive and transportation research into the public discourse.

Cover Image - *This photograph by William E. Botkin depicts a photo charter on the FIRT on March 26, 1996 - just prior to the shutting down of steam operations. It is interesting to note the glow of the overfire jets and the slight smoke - evidence of the demodernization of the locomotives in later years. The image has been flipped for reproduction.*

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Foreword

Dear Reader:

Resource extraction and railroading have been intimately tied since the formation of the very first, non-powered railways in the late 18th Century. However, it was in the mid 20th Century that the *Yacimientos Caboniferos Fiscales* (YCF or Argentine Coal Board) undertook the construction of a 255 km (158.5) mile long railroad from the coal mines of Rio Turbio to the port of Rio Gallegos.

Known officially for most of its existence as the *Ramal Ferro Industrial de Rio Turbio* (RFIRT or Rio Turbio Industrial Railroad), the line operated with exclusive steam power from its opening in 1951 until the late 1990's, after which time it was dieselized.

This narrow gauge railroad (750 mm or 2' 5.5") operated more like a mainline coal hauling line as would be seen around the world today. Unit trains of coal up-to 2,000 tons were hauled by single steam locomotives that weighed only 48 tons.

Of significant importance to the development of modern steam is the fact that Engineer Livio Dante Porta served as General Manager of the railroad from 1957 until 1960, during which time he worked to perfect many of the key developments crucial to the theory of modern steam locomotion, including the important Gas Producer Combustion System.

I have had the pleasure of being involved with this line from 1999, both with Porta prior to his death, and afterward. I have operated some of the locomotives in recent years and have worked to help preserve what remains of the unique operation. This image at LEFT is of me in the engineer's seat of locomotive 107 on a test run.

The detailed look at the history of this operation provided in this white paper encompasses work carried out by Porta over many years, and some that I have undertaken over the past fifteen years. I was also retained in the mid 2000's to serve as a Project Director to oversee the extension of the line through to Chile and to further develop the existing steam locomotives for use on the extension and on the existing mainlaine. It provides, in hard numbers, the power a well-designed, advanced steam locomotive can produce on even the poorest quality of coal.

Your interest in the work of the Coalition for Sustainable Rail (CSR) is of key importance to our mission, allowing us to continue to educate the public and our supporters on the intricacies of modern steam, energy and biofuel development.

If you have yet to consider donating to CSR to support our mission, I urge you to do so today. Your contribution will allow our experts to continue producing high quality educational material and to conduct research which is bringing advanced steam into the 21st century: www.csrail.org/support

With all Sincerity,

Ing. S.T. McMahon
Director of Engineering

Summary:

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1. Constructing the Railroad

The only coal deposits of significant size in Argentina are located in the extreme southwestern corner of the Santa Cruz province, a region of the country that is as arid as it is rugged. With extreme winds of nearly constant 100 kmh (60 mph) and gusts of up to 220 kmh, it is a forbidding region in which to consider developing, let alone building, a railroad.

Since the late 19th Century, the government of Argentina had been aware of coal deposits along its border with Chile, but it was not until the 1940's that it had the right combination of demand and technology that it began to exploit those deposits. While the country had previously relied upon coal supplied from Great Britain, the onslaught of World War II increased demand and made reliable shipment of coal across the Atlantic nearly impossible. With a country needing energy desperately, the *Yacimientos Caboniferos Fiscales* (YCF or Argentine Coal Board) opened the first mine at Rio Turbio in 1943.

A "Chuffi," *as they were referred to by the locals, is shown here in the only known photograph of an S6 in service in Argentina. - W. Rolli Photo*

Only 1% remain *of the original 100-truck order. This photograph taken by Fred M. Springer in 1996 shows a profile view of the three-axle steam-powered sentinel. The boiler sits behind the front axle between the frame and stoker-fed coal. The plaque on the dump bed says this truck operated from 1951-1961.*

Prior to completion of the *Ramal Ferro Industrial de Rio Turbio* (RFIRT or Rio Turbio Industrial Railroad), YCF relied upon trucks to transport coal from the remote mine to port for shipment to larger metropolitan regions. Originally hauled by gasoline-powered trucks, the mine management made the decision in 1950 to acquire a fleet of steam-powered trucks manufactured by Sentinel (Shrewsbury) Ltd. of Shrewsbury, England.

The fleet of approximately 100 S6-type steam trucks ("steam waggons") employed a coal-fired boiler that fed steam to a four-cylinder under floor engine that in turn employed an overhead worm-drive axle to power the three-axle vehicle. Designed in part by famous U.S. steam automobile engineer Abner Doble, the S6 employed a high-efficiency water tube boiler to supply steam to the cylinders. Of the order of 100, however, about 50 never made it from Buenos Aires to Rio Gallegos, toiling instead on behalf of the government in the capital.

The steam wagons operated in caravans of 10-15 vehicles to transport coal on a 12 hour journey from the mine to the Port of Rio Gallegos. It was readily apparent to the managers of the mine, however, that the amount of coal and water it took to operate the Sentinels was prohibitive, and a more efficient means of moving coal from the inland mine needed to be devised.

By the late 1940's, a few potential rail alignments from the mines at Rio Turbio to the port at Rio Gallegos had been devised, but a route that followed the broad Rio Turbio and Rio Gallegos River valleys was found to have the lowest gradient profile.

The owner of the mine at Rio Turbio, which at the time was the national oil company (*Yacimientos Petroliferos Fiscales* or YPF) was interested in constructing the railroad as economically as possible, and it took little time to identify a fleet of 750 mm gauge (2'5.5" gauge) steam locomotives and rolling stock that had sat unused further up the coast at Puerto Madryn since delivered new in 1922. Stockpiled with equipment was 300 km (186 miles) of rail that was 17.36 kg/m (35 lb/yard) – approximately 60% lighter than the 57.05 kg/m (115 lb/yd) rail most U.S. railroads were using on their mainlines at the time.

A testament to the head engineer of the rail line, the ruling grade eastbound (loads) is only 0.3% and the ruling grade westbound (empties) is 0.6%. With three major river crossings and substantial fills, the rail line was built and graded as would be any modern railroad, albeit as a steam-hauled narrow gauge route.

The construction of the railroad began in May 1950 when approximately 50,000 tons of materials were delivered to Rio Gallegos which, at the time, had yet to be developed into a port. Given the extreme climate of the region, active construction could only take place during the warm weather months of October to April. Interestingly enough, 250,000 broad gauge crossties meant for use on the 1,676 mm (5'6") gauge lines in northern Argentina were delivered to the port and cut in half, resulting in 500,000 ties suitable to support the narrow gauge system.

The line was constructed using both rail equipment and truck transportation, and by September 1951 the 255 km (158.5) mile long railroad was opened for service. A formal opening and dedication of the railroad took place on November 25, 1951 and the line was dedicated as the *Ramal Ferro Industrial Eva Peron* (RFIEP or Eva Peron Industrial Railway) named for then-President Peron's wife. Following a military coup in 1955, the railroad was renamed the RFIRT or Rio Turbio Industrial Railway.

Despite rail operations beginning nearly a year earlier, it took until August 1952 for construction of the Port at Rio Gallegos to be completed, which meant trainloads worth of coal and material were transferred to ship via the beach. The YCF purchased two surplus WWII amphibious assault vehicles to aid in the transport of coal and, certainly, in its transloading of coal prior to completion of the port.

The Port of Rio Gallegos *consisted of a large coal-transloading dock that protruded out into the mouth of the Rio Gallegos ("Gallegos River"), shown here in a photograph by Jim Hebson taken in March 1991.*

2. Porta's Arrival

The rail line was constructed and operated with the aforementioned never-used equipment, consisting of 1922-built rolling stock, starting with the very first work trains in 1950. The locomotives from this group were a fleet of eight 2-8-2s, one 0-6-0T and one 0-6-0 tank crane all manufactured by Henschel & Sohn, G.m.b.H. in Kassel, Germany. They were originally built as wood-burning locomotives, but with a change out of the grates and modification of the tenders, they were converted to burn the coal mined in the region.

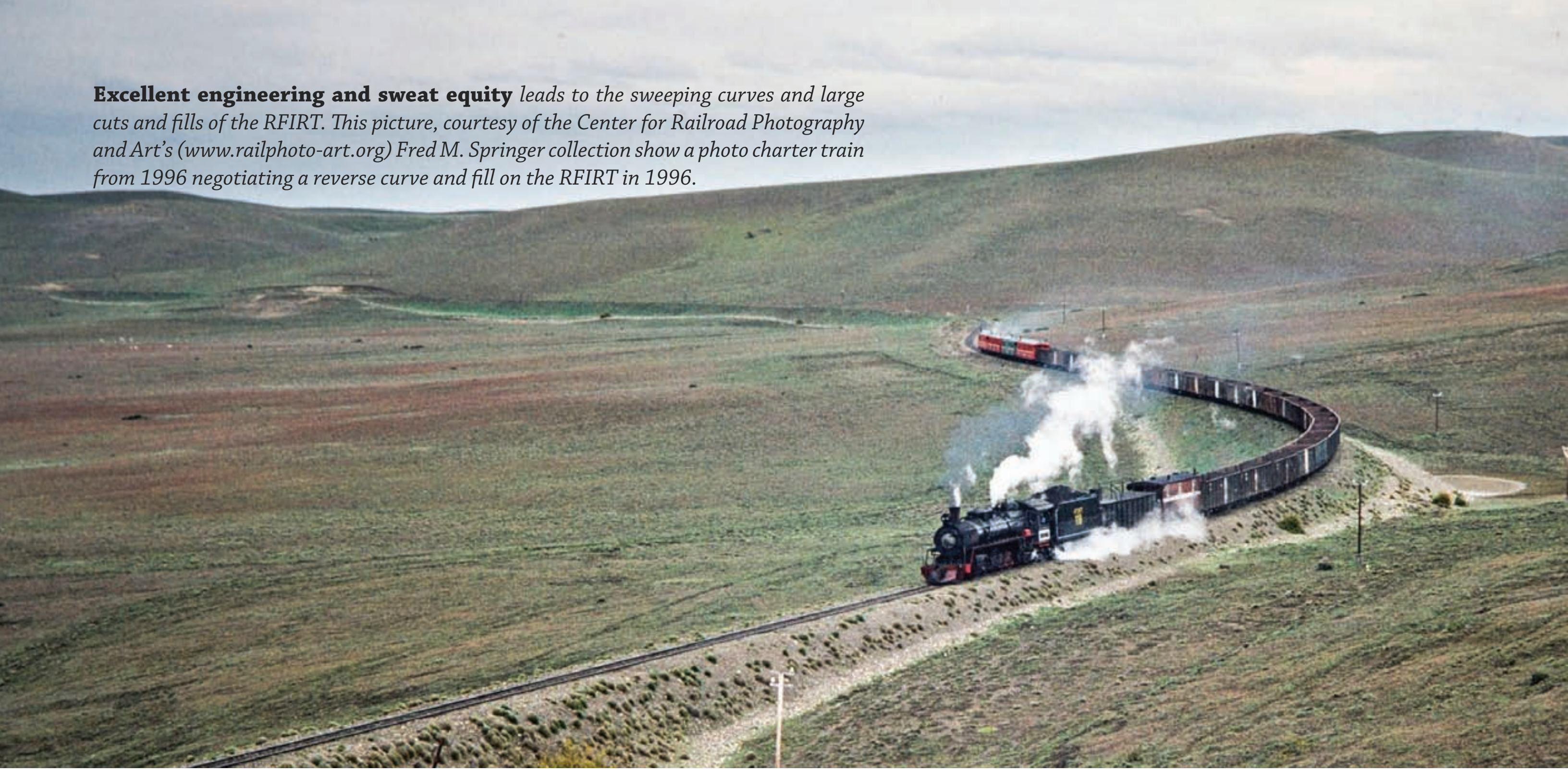
Despite being essentially new-old stock when they arrived on-site, the locomotives were immediately found to be under powered for the service at hand. The larger 2-8-2-type locomotives could only haul 96 tons of coal on a given run, and despite having eight locomotives of that type on the property, the railroad had only capacity to run one train per day in each direction.

Given that the Argentinean railroads were nationalized in 1948 under President Juan Peron, management at RFIRT were aware of the success Skoda-built 2-10-2-type locomotives had hauling trains on the meter-gauge *Ferrocarril General Manuel Belgrano*. Management at RFIRT contacted Mitsubishi and ordered ten locomotives of scaled-down size. Ten locomotives, numbers 101-110, were delivered new to RFIRT in 1956.

On paper, the new Mitsubishi locomotives were to make 940 horsepower compared to the 411 horsepower produced by the Henschel 2-8-2's. Once the locomotives arrived on the railroad, however, they proved to be much less attractive. The poor coal quality caused issues with clinker buildup on the grates, when worked at high throttle carryover of coal particles was excessive, and the performance was much lower than 940 horsepower. In fact, tests proved the locomotives could barely produce 700 horsepower – the RFIRT had to solve the problem.

Following the ousting of President Juan Peron in 1955, Ing. L.D. Porta was in need of new employment. The RFIRT management contacted Porta and asked him to serve as General Manager of the railroad and to address the issues presented by the new 2-10-2 locomotives. When Porta arrived in 1957, the traffic on the RFIRT was hauled primarily by the new locomotives, but he came prepared to revolutionize its throughput.

Second cousin to the RFIRT *is the Ferrocarril La Trochita in Patagonia, a 750mm-gauge line that is used to haul tourists to this day. This double-headed train is hauled by 2-8-2 locomotives of similar size and manufacture of those that built the RFIRT, shown here crossing the Rio Chico. - Juan Macri Photo*



Excellent engineering and sweat equity *leads to the sweeping curves and large cuts and fills of the RFIRT. This picture, courtesy of the Center for Railroad Photography and Art's (www.railphoto-art.org) Fred M. Springer collection show a photo charter train from 1996 negotiating a reverse curve and fill on the RFIRT in 1996.*

3. Locomotive Development

Porta continued his development of advanced steam technology while serving as General Manager of the RFIRT. Of perhaps most significance to the field was his development of the Gas Producer Combustion System (GPCS) which combined a thick firebed and the admission of secondary air over the fire (as already partially applied to the experimental 4-8-0 described in CSR's last White Paper) with the addition of steam to the primary air to control clinkering [SEE DIAGRAM ON TOP OF PAGE 8].

Work refining the GPCS began with three of the 2-10-2's, to which a GPCS and Kylpor exhaust system were applied. These modifications increased the rated drawbar power of those three locomotives to 1,200 hp from the previously-tested 697 hp and eliminated the clinker problem. In fact, the power to weight ratio became an excellent 28 hp/ton, output that could be sustained indefinitely without stopping for fire cleaning and without risk of lineside fires. The arid setting of Santa Cruz meant the locomotives could operate without ash pan doors such that the ashes dropped on the track whilst running. Frequent, light grate shaking maintained a uniform, active firebed thickness while in operation.

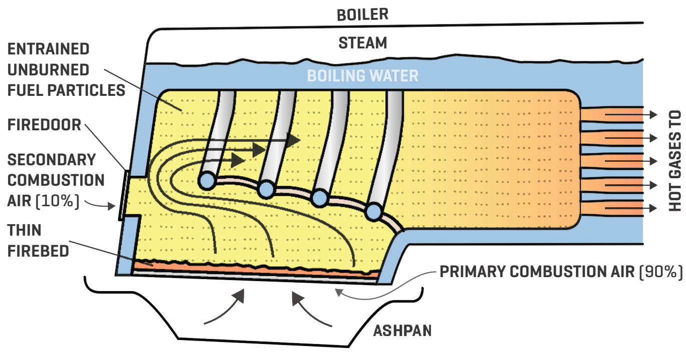
Porta eventually modified nine of the original ten locomotives to match the first three, leaving one locomotive as a "control" in the research he undertook.

Following what he had learned from these modifications, Porta developed a series of specifications for a second batch of ten 2-10-2's that were built new and supplied by Mitsubishi in 1963, perhaps the only fleet of "modernized" locomotives ever delivered by a production locomotive manufacturer. The new designs included the same set of alterations plus a number of other improvements to the boiler, valves, pistons and sanding gear.

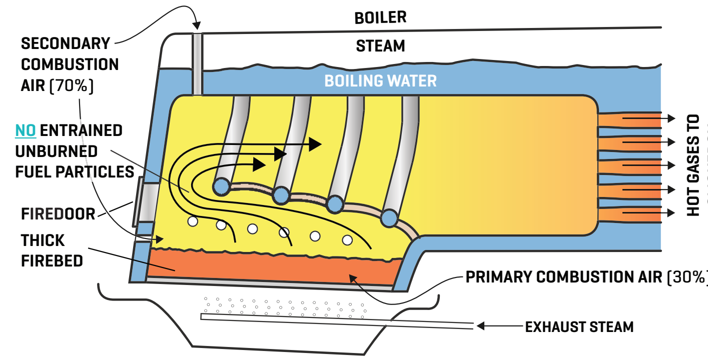
The number of small tubes was reduced, from 108 for the first batch to 88 for the second, to increase the proportion of gases passing through the large tubes carrying the superheater elements, which are of standard A type and eighteen in number. Maximum steam temperature was 410 - 420°C when working hard. Boiler tubes were welded to the tube plate and there is no record of tube leakage or replacement of fractured boiler stays, despite wide variation in steam demand and winter temperatures as low as -20°C.

On the new locomotives, some 70% of the total air required for combustion was admitted as secondary air above the firebed via intake ducts through the side sheets and the firedoor, which was kept open continuously. Further, approximately 3-4% of exhaust steam from the cylinders was introduced into the ashpan for mixing with the primary air, amounting to about 30% of the total.

Traditional Firebox



GPCS Firebox

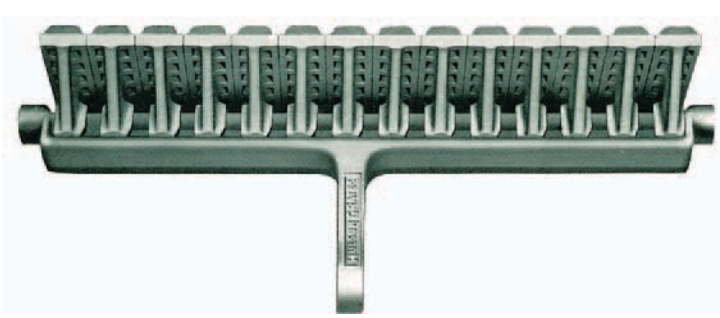


Boiler efficiency as recorded on official tests reached 78 - 80% assisted by the use of a long brick arch arranged to prevent carryover of coal particles entrained by the draught. Combustion was virtually complete and tube cleaning almost eliminated. The grate was of the Hulson type and the ashpan was self-emptying. Sustained evaporation rates of about 22,000 lb/hour were maintained for several hours with this small boiler having an evaporative heating surface of only 950 ft.^{2} and effective grate area of 22.5 ft^2, burning slack coal with a calorific value of 9,000 – 10,000 BTU/lb.

Steel pistons were provided with six narrow piston rings manufactured to standard diesel quality and workmanship. The Fukao gland packings used gave extremely good results and enabled steam tightness to be maintained over nearly 400,000 km (248,550 miles) running.

Axleboxes were provided with side bearings to accommodate piston thrust, wear of about 0.007 in. per 1,000 miles running being taken up by placing shims between bearing and box at periodic inspections every 12,500 miles. Axleboxes were spring-pad lubricated oil bearings. Bronze wedges and horn cheeks were provided which did not require renewal during the working life of the locomotives. An interesting feature was the adoption of Walschaerts valve gear arranged to give increasing lead with increasing forward gear cut-off, the opposite to what most engineers had hitherto thought was correct.

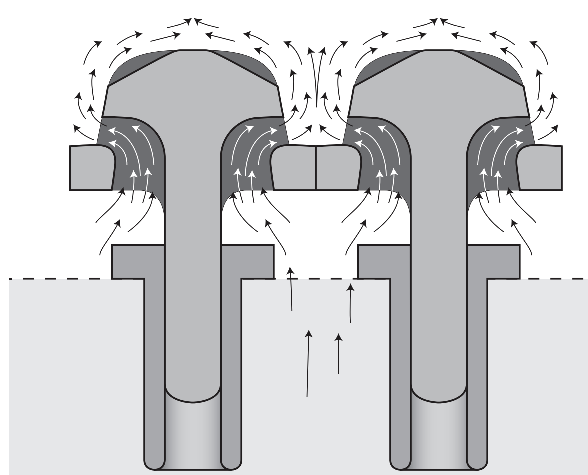
Locomotives of the second series (numbers 111-120) were able to sustain a drawbar power of some 1,000 kW (1,341 hp) at 50 km/h (31 mph) - the maximum speed



Hulson Grate Tuyere* Unit. *Designed to allow combustion air through 12% to 26% of the entire grate surface.*

Bottom view *of Hulson Tuyere Units mounted on a carrier bar which was mounted across the width of the firebox in multiple rows.*

Air flow diagram and lateral section *showing how combustion air flows around individual Hulson Tuyere Units.*



** A tuyere is a tube, nozzle or pipe through which air is blown into a furnace or hearth.*

A thicker fire *than would be advisable on a traditional locomtoive was facilitated by the GPCS, as this photo of a Rio Turbio 2-10-2 in action can attest. - Collection of S.T. McMahon*

Overfire jets *are shown here in the firebox of RFIRT 107. The demodernization over time by shop crews is shown as the left two jets have been seal welded with stay bolts placed in the centers. - S.T. McMahon*

due to track conditions and poor railcar springing - and all the improvements were gradually incorporated into the locomotives of the first batch as they were given major overhauls, with the exception of No. 106.

All of the modernized 2-10-2's normally handled 1,500 – 1,700 ton coal trains unaided, with the maximum load taken by one locomotive in normal service being 2,000 tons. Some locomotives accumulated 12,000 km (7,456 miles) per month, indicating having run 47 one-way trips, or a total of 24 days of moving time in a 30 day period! This feat is to a large extent attributed to the good detail design of the locomotives which resulted in high power capacity, good fuel economy (despite poor fuel quality), and good reliability. Some measure of the reliability achieved can be gauged from a few statistics supplied by Porta, copied below.

Tests carried out over the full length of the line showed the overall boiler efficiency in normal service to be 80% when burning Rio Turbio coal of about 24 MJ/kg lower calorific value, and dynamometer car tests found the drawbar specific coal consumption when burning coal of 31.4 MJ/kg lower calorific value to be 0.37 kg/MJ, giving an overall drawbar thermal efficiency of 8.6% for a complete trip.

In 1960, Porta moved back to Buenos Aires to join the *Instituto Nacional de Tecnologia Industrial* (INTI) where he worked for the next 22 years as head of the thermodynamics department. He maintained a close working relationship with the Rio Turbio Railway and was able to continue to apply his developments there for some years to come. For example, the cyclonic GPCS (GPCS with the brick arch and secondary air inlets arranged to give cyclonic gas flow in the firebox to centrifugally separate entrained coal particles from the rising gas stream) was experimentally fitted to 2-10-2 No. 118 during the mid 1960's. It was during tests on this locomotive, using maize-size coal of 11% ash composition, that a double-headed train of 3,190 tons was pulled. On that run, No. 118 took the full load except on the steepest grades and managed 30 - 35 km/h on level track at 35% cut-off.

1. Period between white-metalling of coupled axle bearings = 120,000 km (74,564.5 miles); total life of these bearings > 480,000 km (298,258 miles)(180 x 10^6 coupled wheel revolutions).
2. Distance between tire reprofilings = 70,000 km (43,496 miles)(850 mm diameter coupled wheels frequently operated on the limit of adhesion. Porta applied a ‘high adhesion' tire profile to these locomotives, turning the main driver tires 3 mm larger in diameter than those of the coupled wheels.)
3. Superheater elements: no replacement in 500,000 km (310,686 miles)(maximum steam temperature normally 400°C, absolute peak 420°C).
4. Boiler tubes: 10% repaired in 400,000 km (248,548.5 miles) due to longitudinal cracks because of overexpanding during assembly, otherwise zero repairs.
5. Boiler shell and firebox plates: zero repairs in the first twelve years of service.
7. Broken stays: zero in 400,000 km (248,548.5 miles.)
8. Main steam pipe joints: no leakage in 400,000 km (248,548.5 miles.)
9. Life of piston rod packings – 400,000 km (248,548.5 miles.)(150 x 10^6 coupled wheel revolutions).
10. Steam leakage (all sources): maximum of several locomotives tested = 1.7% of the rated maximum evaporation with piston and valve rings 70,000 km (43,496 miles) old.

Broad side view: *taken by Fred M. Springer during a 1996 photo charter, this shot of locomotive 104 shows a reverse move. The steam blowing out is most-likely exhaust from the stoker motor. This photo was taken just-prior to abandonment of steam on the line. Photograph courtesy of the Center for Railroad Photography & Art (www.railphoto-art.org).*

As of yet in this White Paper, the reader has been provided a great deal of facts and figures concerning the engineering of the various 2-10-2 locomotives of the RFIRT. The following table of *Comparative Technical Specifications* lays out the differences between the as-built locomotives, of which the 106 remained unmodified, the modified 1956-built locomotives and the new-build, 1963-manufactured locomotives.

Comparative Technical Specifications			
Locomotive Number(s)	106	101-105,107-110	111-120
Year Manufactured	1956	1956	1963
Manufacturer	Mihara Engineering Works, Mitsubishi Heavy Industries, Japan		
Wheel Arrangement	2-10-2		
Gauge	750 mm (2'5.5'')		
No. of Cylinders	2		
Cylinder Dimensions	419x441.3mm (16.5''x17.325'')		
Driving Wheel Diameter	850 mm (33.5'')		
Boiler Pressure	1372 kPa (199 PSI)	1565 kPa (227 PSI)	1565 kPa (227 PSI)
Number of Tubes	108	108	88
Number of Flues	18	18	18
Superheater Type	A		
Heating Surface	NA	NA	88.3 m3 (950 ft3)
Grate Area	2.1 m2 (22.5 ft2)		
Fuel	Sub Bituminous Coal (~14% Ash, 10,000 BTU/lb)		
Effective Firebox Volume	3.54 m3 (125 ft3)	3.54 m3 (125 ft3)	3.54 m3 (125 ft3)
Adhesive Weight	38 tons		
Locomotive Weight	48 tons		
Maximum DB Power	520 kW (697 hp)	895 kW (1,200 hp)	1,000 kW (1,341 hp)
DBHP per Ton	14.5	25	28
Specific Fuel Consumption	2.3kg (4.5 lb)/DBHP*hr	1.2 kg (2.64lb)/DBHP*Hr	1 kg (2.2lb)/DBHP*Hr
Rated Tonnage	800 tons	1,200-1,500 tons	1,500-2,000 tons

Alf Sollund

A broken and abandoned *flatcar is shown in this picture taken February 27, 2014. The railroad still operates to some extent today.*

4. Decline and Current Status

Due to the remoteness of the operation and harsh climate, it was difficult to retain staff. Over time, this continual turnover in employees and skillsets led to the entire fleet of locomotives on the RFIRT being demodified by staff.

This gradual demodernization also led to increasing costs of operation and decreased reliability of the locomotives. Due to changes in the electricity generation methods in Argentina, demand for Rio Turbio coal began to decline in the 1980's. By 1988, YCF sold off its fleet of ships and began using commercial liners to transport coal from the far south to end users further north. Around that time, RFIRT also changed its names to *Ferrocarril Industrial Rio Turbio* (FIRT).

Following ever decreasing demand for coal, the Argentinean government sold a ten year concession to operate the mine and its industrial railroad to a private consortium of companies known as the *Yacimientos Carboniferos Rio Turbio SA* (YCRT) in 1994. Politically, the continual operation of the mine and nearby power plant was supported by a healthy government subsidy to the YCRT, which allowed the line to stay in operation.

Santiago Matamoro

Shortly after privatization, YCRT acquired four ex-Bulgarian State Railways diesel-hydraulic locomotives to replace the steam locomotive fleet. The use of the twenty steam engines declined and mainline steam was abandoned in 1996 and steam switching duties ended in 1997. YCRT also developed a new branch line to a port at Punta Layola, located a few kilometers southwest of Rio Gallegos on a location that allowed deeper berths. This new branch and port eventually led to the closing of the facilities at Rio Gallegos, which in turn enabled extensive vandalism of the structures and rolling stock.

According to local reports, the steam equipment in best condition has been transported to Rio Turbio for storage and to deter further vandalism. Equipment ownership was transferred to the municipality and they are under the supervision of coauthor S.T. McMahon.

By the year 2000, the YCRT hauled one train per week and, due to poor management, the concession was terminated in 2002, following which the mine and railroad were re-possessed and operated by the government. In 2004, a tragic mine explosion resulted in the death of 14 workers and led to a temporary shutdown of both railroad and mine. Since that time, additional diesel locomotives have arrived from Bulgaria [LEFT] and bright red and white hoppers have been recently acquired.

What will happen in the future - it is unsure. Proposals to operate steam come-and-go, but with uncertainty about Argentina's political state, any definite plans for steam are far off.

5. Accounts of U.S. Travelers in Argentina

Editors Note: *The following is a brief essay and corresponding photographs provided to CSR by supporters Jim Hebson and Ben Anderson (shown on board the RFIRT below center). Their story depicts an adventure from a different time and place. Enjoy.*

Personal Reflections on the Ferrocarril Industrial Rio Turbio

Ben Anderson and Jim Hebson

Upon arriving in Buenos Aires from the United States in March 1991 for an extended exploration of Ferrocarriles Argentinos, we learned that the Argentinian railroad workers had gone on strike, shutting down the entire system with little prospect of an early resolution. Stunned by this setback at the very beginning of our trip, we began to consider alternative railway subjects to explore.

During these deliberations, we recalled hearing about an obscure coal-hauling railroad known as the Ferrocarril Industrial Rio Turbio (the "FIRT"), which ran between the Argentinian port of Rio Gallegos (the capital of Santa Cruz, the southernmost province of Argentina) and the coal mines at Rio Turbio, near the border with Chile. Both the railroad and the mines were operated by *Yacimientos Carboniferos Fiscales* ("YCF"), the Argentine state coal company.

The special purpose, point-to-point railroad was totally isolated, far from the southernmost extreme of the integrated Argentinian system. We further recalled that the FIRT was a 2-1/2 foot (750 mm) gauge, 100% steam powered railroad featuring large 2-10-2 Santa Fe-type locomotives, certainly an exotic railroad in an exotic location.

The two of us speculated that because the FIRT, located in the southernmost part of Patagonia, was isolated from the Argentinian railroad system, its operation might not have been affected by the strike, but we needed to confirm that fact. We obtained the address of the YCF headquarters in Buenos Aires and set out to obtain whatever information we could.

In those pre-security conscious days, we entered the building and wandered the empty corridors trying to decide which office to try, but before we could do so, an employee came down the hall, and we put our question to him. We were informed that the FIRT was indeed operating, and the employee graciously offered to introduce us to the railroad management. That chance encounter resulted in an afternoon of extraordinary hospitality as we met with executives at increasing levels of authority, including an elderly Swedish engineer who had worked on the construction of the FIRT as a young man in 1949. We were enthusiastically encouraged by all we met to undertake the long journey from Buenos Aires to Rio Gallegos to see the FIRT in action.

We left the YCF building that afternoon with the all-important, door-opening "Letter of Introduction" (to the railroad's general manager) in hand and made arrangements to fly to Rio Gallegos as soon as possible.

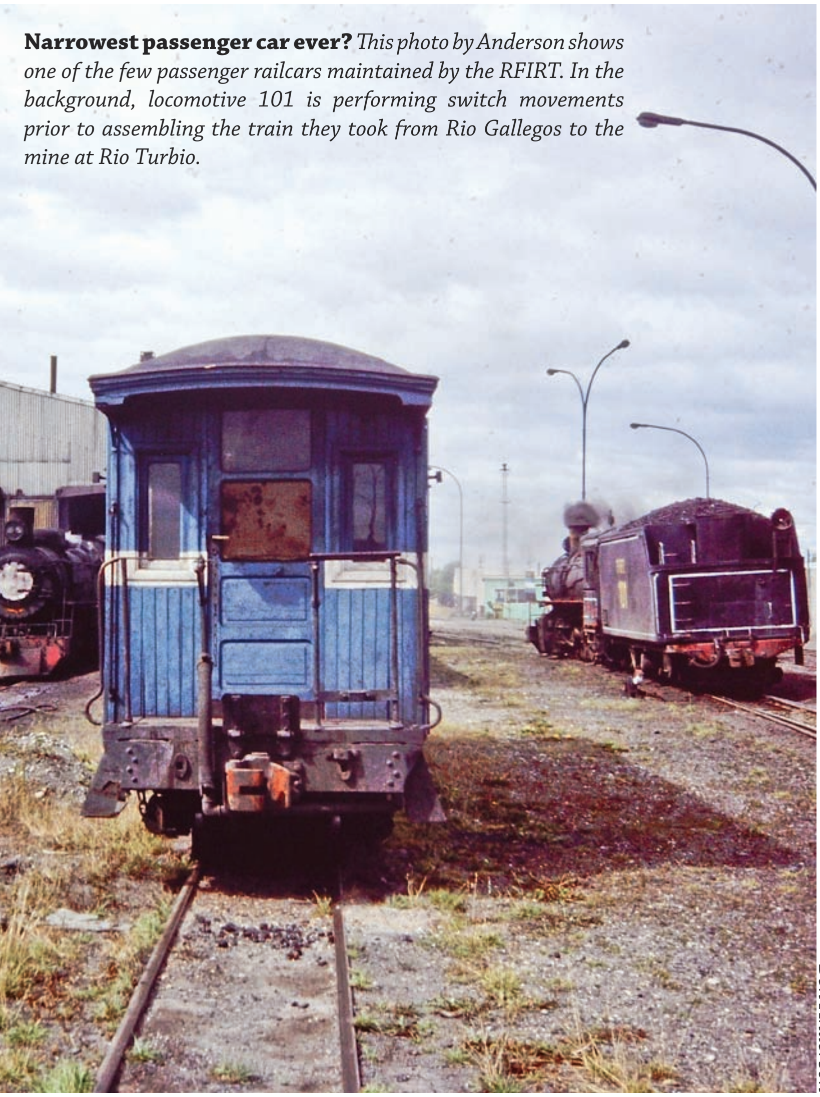
In Rio Gallegos, the warm hospitality of FIRT began with in-depth inspection tours of the engine terminal, shops and coal handling equipment. We then met with officials to discuss the engineering and operational aspects of this highly unusual railroad. At the conclusion of the meeting, our host apologized that the FIRT did not carry passengers. (Because the railroad was dedicated solely to hauling coal, we had not expected that it did.) We were therefore delighted when our host announced that, if we would like, the railroad would be pleased to accommodate our interest in the FIRT by putting a special business car on the next westbound (empty) train so that we could examine the entire 153-mile main line and the coal facilities at Rio Turbio itself.

Jim Hebson

Contrast of old and new. *At the coal terminal of Rio Gallegos, YCF operated a relatively-modern coal transfer system to create stockpiles of coal from which ships would be loaded. This equipment is still in operation today.*

Jim Hebson

Rotary dump narrow gauge. *Like many modern coal-hauling railroads, the RFIRT employed coal gondolas that were dumped using the rotary dumper shown above - each railcar is emptied by being flipped upside down.*



Narrowest passenger car ever? *This photo by Anderson shows one of the few passenger railcars maintained by the RFIRT. In the background, locomotive 101 is performing switch movements prior to assembling the train they took from Rio Gallegos to the mine at Rio Turbio.*

Ben Anderson

Jim Hebson

Turning driving wheels *is a practice still performed on all manner of rail equipment to maintain a proper profile. In this photo, the machinist has already reprofiled the driver tires and appears to be surfacing the axle.*

When we presented ourselves at the yard on the morning of the day of departure, the railroad was a beehive of activity. We watched in anticipation as one of the 2-10-2 locomotives pulled a diminutive wooden coach – the “special business car” - from a shed.

Our host explained that he assumed we would like “our” coach placed directly behind the locomotive, better to observe the operation of a hard working 2-10-2 steam engine. In addition to our special car, the train consisted of a guard’s van, a long string of empty coal hoppers, and an out-of-service, deadheading 2-10-2 (at the end of the train) with its rods removed for the trip.

Our wood paneled coach was comfortably equipped with a lounge area, a table, a pot belly stove, bunks, and a galley. We were accompanied on our journey by the Chief Mechanical Officer.

The outbound trip took twelve hours, as the vast Patagonian landscape unfolded with sweeping curves, gentle grades and distant hills, with occasional stops for water at desolate windmill-driven pumps, engine servicing, and a meet with an inbound train at Estacion Capa.

Patagonian Hi-Rail. *With tracks so narrow, this home-built hi-rail truck got the job done.*

150 kmh wind power *replenished line-side water tanks for the trains.*

The meet at Estacio Capa *provided a taste of the train the authors would ride in return the following day.*

Ben Anderson

Jim Hebson

Jim Hebson

Upon arrival at Rio Turbio at 9 P.M., our host accompanied us to a local restaurant for dinner and then welcomed us to stay at the FIRT bunkhouse for the night. After breakfast at the bunkhouse in the morning, we departed Rio Turbio. Once again a single 2-10-2 was sufficient for the task.

Late that night the bright lights of Rio Gallegos illuminated the clear Patagonian sky, signaling our final approach and the end of our trip on the "southernmost railroad in the world."

Jim Hebson

The mine at Rio Turbio *is nestled in a broad valley just 5 km (3.1 mi) from the border with Chile . Just 2.3 km (1.4 mi) further down the line is the maintenance facility and town of Rio Turbio.*

Ben Anderson

Ridge side water stop. *Locomotive 101 gets the authors' empty coal train underway after a water stop beside one of many gravity-fed water spouts on the RFIRT.*

Jim Hebson

The loaded return trip *follows the tried and true "empties uphill, loads downhill" mentality of bulk commodity railroading. This shot taken from the first car behind the locomotive shows the 50+ car train snaking through the beautiful, albeit barren, valley landscape that the RFIRT called home.*

6. Conclusions

Why should a railroad in the extreme south of Argentina, one with locomotives one quarter the size of locomotive 3463, be investigated by the Coalition for Sustainable Rail (CSR)? Aside from the fact that the coauthor has spent a great deal of time on site and has access to the complete engineering history of the locomotives, the technological developments undertaken in such a rugged and remote place have important implications to the work CSR pursues.

The following are but a few of many important examples.

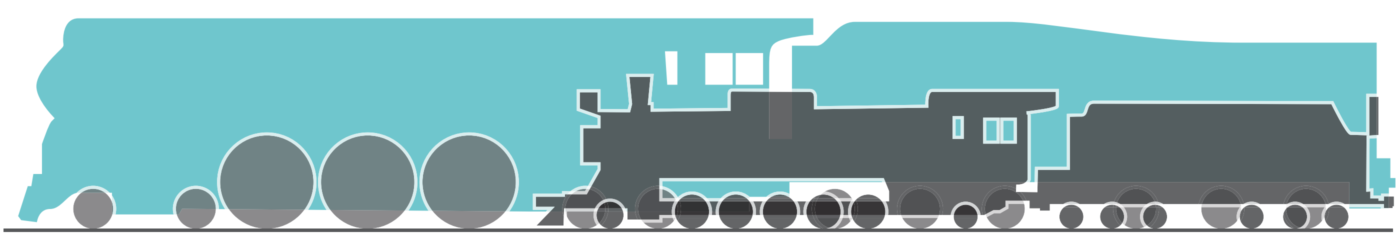
Gas Producer Combustion System Though perfected with further research on other railroads, the fact that Porta was able to use a coal of such marginal value and combust it efficiently in the upgraded firebox directly relates to the combustion of a fuel such as torrefied biomass in advanced steam locomotives. The controlled combustion of the GPCS aids also in boiler maintenance - the lack of particle carry over alleviates the scouring of boiler surfaces that on traditional solid fuel locomotives eroded tube sheet, staybolt, flue and saddle bolt surfaces, all of quantifiable benefit in the research surrounding advanced steam. On the RFIRT, the GPCS contributed to the ability to operate 250,000 miles (400,000 km) with no broken staybolts, no superheater replacement and no firebox / boiler shell replacements.

Modern Piston Packing The advanced, multi-ring piston design employed by Porta on the Rio Turbio locomotives was able to withstand 150 x 10^6 revolutions without need for replacement. What was once a significant source of waste steam and maintenance has now been engineered as a long-term, sealed solution. On locomotive 3463, which has 84" driving wheels, the aforementioned revolutions equates to 624,750 miles (1,000,500 km) of operation leak free.

Power to Weight Ratio The calculated power to weight ratio of the RFIRT 2-10-2s of 28 drawbar horsepower (DBHP) per ton is something that is not matched by the advanced diesel-electric locomotives of today. The most common production diesel-electric locomotives in the U.S. feature between 16 and 24 DBHP/ton, proving an advanced steam locomotive can also, literally, pull its weight against the competition.

Advanced Exhaust As with the *Argentina*, Porta employed a modification of the Kylchap Exhaust system known as the Kylpor on the Rio Turbio 2-10-2s, an efficient exhaust which facilitated the use of a thicker fire bed as required by the GPCS. The testing and implementation associated with the exhaust was of crucial importance in developing more advanced exhaust systems, a derivation of which will be employed by CSR on the test version of locomotive 3463.

Importance of Institutional Knowledge Without the dedication and hard work of L.D. Porta, none of the developments associated with the RFIRT would have happened. The railroad might have, in fact, not succeeded. But it is only through institutional knowledge, that is the passing down of fact-based steam locomotive engineering, that the technology can remain achievable. After much turnover at RFIRT, locomotives were demodernized by staff that knew not or cared not why they had been engineered as they had, and as such the competitive edge of the steam locomotive was lost. The fact all of Porta's developments took place after the last mainline steam engine in the U.S. dropped its fire speaks to the need to educate many on the strength of good design, for much has happened in the 50 years since the first modernization of the Rio Turbio 2-10-2s.



Putting things in perspective, *this comparative diagram shows the outline of a Rio Turbio 2-10-2 next to that of the proposed, modified locomotive 3463. With a firebox 22% the size of that on 3463, the RFIRT 2-10-2s could create more than 1,300 dbhp, or 36% of the DBHP of the as-built 3460-class.*

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