The Economics of Coal as a Locomotive Fuel on US Class I Railroads

By John Rhodes
Overview

• Coal-Burning Steam Locomotive: 73% Fuel Savings US Class I RR’s
• $8.9 Billion 2007 Class I Diesel Fuel Bill
• $2.5 Billion Coal Bill Instead
• $6.4 Billion Cost Saving
• 2007 Operating Ratio Could Have Been 67% Instead Of 78%
## Coal and Diesel BTU's per Dollar CY2007

<table>
<thead>
<tr>
<th>Coal</th>
<th>Type</th>
<th>ILB</th>
<th>UIB</th>
<th>CAP</th>
<th>NAP</th>
<th>PRB</th>
<th>The Most Expensive Coal Is 7x Cheaper Than The Cheapest Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.00</td>
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<tr>
<td>$ / Ton</td>
<td>$31.14</td>
<td>$27.26</td>
<td>$46.42</td>
<td>$46.74</td>
<td>$9.84</td>
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<tr>
<td>Lb. / $</td>
<td>64.23</td>
<td>73.37</td>
<td>43.08</td>
<td>42.79</td>
<td>203.26</td>
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<tr>
<td>BTU / Lb.</td>
<td>11,800</td>
<td>11,700</td>
<td>12,500</td>
<td>13,000</td>
<td>8,800</td>
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<tr>
<td>BTU / $</td>
<td>757,868</td>
<td>858,401</td>
<td>538,561</td>
<td>556,269</td>
<td>1,788,702</td>
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<table>
<thead>
<tr>
<th>Diesel</th>
<th>Type</th>
<th>BNSF</th>
<th>UP</th>
<th>KCS</th>
<th>CP(US)</th>
<th>CN(US)</th>
<th>CSX</th>
<th>NS</th>
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</thead>
<tbody>
<tr>
<td>$1.00</td>
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<tr>
<td>$ / Gal.</td>
<td>$2.21</td>
<td>$2.22</td>
<td>$2.15</td>
<td>$2.23</td>
<td>$2.19</td>
<td>$2.13</td>
<td>$2.10</td>
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<tr>
<td>Gal. / $</td>
<td>0.45</td>
<td>0.45</td>
<td>0.47</td>
<td>0.45</td>
<td>0.46</td>
<td>0.47</td>
<td>0.48</td>
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<tr>
<td>BTU / Gal.</td>
<td>163,572</td>
<td>163,572</td>
<td>163,572</td>
<td>163,572</td>
<td>163,572</td>
<td>163,572</td>
<td>163,572</td>
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</tr>
<tr>
<td>BTU / $</td>
<td>73,979</td>
<td>73,609</td>
<td>76,249</td>
<td>73,259</td>
<td>74,710</td>
<td>76,880</td>
<td><strong>77,941</strong></td>
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</tr>
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</table>
Presentation Outline

• Mechanical Engineers of Modern Steam
• The Modern Steam Locomotive
• Important Technologies Of Modern Steam
• American Class I Railroad: Needs
• Maintenance: Modern Steam and Diesel
• Comparisons: Modern Steam and Diesel
• Infrastructure and Servicing: Modern Steam
• Next Steps
• Other Locomotive Alternatives
The Mechanical Engineers of Modern Steam

Pioneers (Deceased):
• Andre Chapelon
• Livio Dante Porta

Current:
• David Wardale
• Phil Girdlestone
• Shaun McMahon
• Roger Waller
• Nigel Day
Andre Chapelon

• French Mechanical Engineer 1892-1978
• SNCF, Steam Locomotive Design Division
• Grandfather Of Modern Steam
• Applied Thermodynamics And Fluid Dynamics To The Steam Locomotive
• Chapelon’s Former Boss, George Chan, From The SNCF Described Him As “The Man Who Gave New Life To The Steam Locomotive”
Andre Chapelon cont.

- 1946 Design And Construction Of The 3-Cylinder Compound: SNCF 242A.1
  - Rebuilt From A 3-Cylinder Simple Locomotive
  - Raised IHP From 2,800 To 5,500; 96% Increase
  - Twice The Thermal Efficiency Of American Steam
Livio Dante Porta

• Argentinean Mechanical Engineer 1922-2003
• Father Of Modern Steam
• Developed 3 Most Important Parts Of Modern Steam:
  • Clean High Efficiency Combustion
  • High Efficiency Exhaust
  • Heavy-Duty Boiler Water Treatment
Livio Dante Porta
Cont.

• 1949 Built “Argentina” From A 4-6-2
  – 2,100 DBHP
  – High Power-to-Weight Ratio: 65 lb. -1 HP
  – 50% Reduction In Fuel Consumption per HP
  – Double The Thermal Efficiency Of American Steam
David Wardale

- 1981 SAR Class 26 #3450 Rebuild Of Class 25NC
  - Raised DBHP From 1,500 To 2,100; 40% Increase
  - 60% Reduction In Coal Consumption
  - 45% Reduction In Water Consumption
  - Double The Thermal Efficiency Of American Steam
  - GPCS
  - Lempor Exhaust
  - Porta Treatment
Phil Girdlestone

- Alfred County Railway Class NGG16A 141 & 155
  - Modern Steam Selected For NG Pulpwood Hauler
  - 90% Availability And Utilization

- Girdlestone & Associates
  - Steam Locomotives & Equipment
  - Design, Manufacture & Consultancy
Shaun McMahon

• Employed By The Rio Turbio Railway
  – Converting Railway To Steam From Diesel
• Consultant Ferrocarril Austral Fueguino Railway
  – Modernized Steam Fleet Of Tourist Hauler
Roger Waller

- Dampflokomotiv-und Maschinenfabrik AG (DLM)
  - Produced 8 Modern Rack Steam Locomotives
  - The Netherlands Is Leasing A Modernized Steam Locomotive From DLM For Passenger Service With An Option To Buy A New Build Steam Locomotive
Nigel Day

• Modern Steam Technical Railway Services
  – Dozens Of Steam Modernizations
  – Grand Canyon Railway 4960 & 29
The Modern Steam Locomotive

Porta Classified Steam Locomotives As Follows:

• **Generation ‘Zero,’** Built Before The 1930’s

• **First Generation (FGS),** Last Built Steam Locomotives: NYC Niagara 4-8-4, South African 25 & 25NC, Etc.

• **Second Generation (SGS),** Locomotives Incorporating The Technological Advances From 1950 To Date

• **Third Generation (TGS),** Yet-to-be Developed Engines
First Generation Steam (FGS)

Generally:
• 6% Thermal Efficiency
• 245-285 PSI, 650°F Steam
• Single Expansion
• One-Piece Cast Steel Frames
• Roller Bearing Axles
• Mechanical & Pressure Lubrication
• Primitive Combustion
• Primitive Exhaust Design
• Primitive Feed Water Treatment
Second Generation Steam (SGS)

Porta’s Outline:
• 14% Thermal Efficiency, Twice FGS
• 290-362 PSI, 840° F Steam
• Compound Expansion
• Advanced Exhaust Design
• Economizer
• Feedwater & Combustion Air Pre-heating
• Gas Producer Combustion System (GPCS)
• Advanced Feed Water Treatment
Third Generation Steam (TGS)

Porta’s Outline:
• 21% Thermal Efficiency, Triple FGS
• 870 PSI, 1020° F Steam
• Triple Expansion
• 3 Stage Feed Water And Combustion Air Heating
• Other Detail Improvements
• 27% Thermal Efficiency With Condensing

By Comparison An EMD SD70ACe, An AC Traction Diesel-Electric, Has 30.2% Thermal Efficiency
## Steam Diesel Cost Comparison

### Steam vs. Diesel Fuel Cost Savings

<table>
<thead>
<tr>
<th>CY2007</th>
<th>14% Thermal Efficiency - 2nd Generation Steam</th>
<th>21% Thermal Efficiency - 3rd Generation Steam</th>
<th>27% Thermal Efficiency - 3rd Gen. w/ Condensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Type</td>
<td>ILB</td>
<td>UIB</td>
<td>CAP</td>
</tr>
<tr>
<td>Diesel Fuel Price</td>
<td>$2.19</td>
<td>$2.19</td>
<td>$2.19</td>
</tr>
<tr>
<td>Gallons of Fuel</td>
<td>0.46</td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td>Diesel Thermal Efficiency SD70ACe</td>
<td>30.2%</td>
<td>30.2%</td>
<td>30.2%</td>
</tr>
<tr>
<td>BTU's per Pound of Coal</td>
<td>11800</td>
<td>11700</td>
<td>12500</td>
</tr>
<tr>
<td>Coal Price</td>
<td>$36.14</td>
<td>$32.26</td>
<td>$51.42</td>
</tr>
</tbody>
</table>

### Average Fuel Cost Steam

- **Cost**: $0.25
- **Savings**: 73%

### US Class I Fuel Cost

- **Cost**: $8,910,422,000
- **Saved**: $6,463,823,138

### Average Percent Savings

- **Savings**: 82%
- **Saved**: $7,279,356,093

### Fuel Cost Saved

- **Saved**: $7,741,743,056
The Economics Look Great. But Can It Pull The Trains?
DBHP Comparison

Graph showing comparison of different DBHP values with varying percentages and acronyms like SD70ACe.
Important Technologies

• The Gas Producer Combustion System (GPCS)

• The Lempor Exhaust

• Porta Water Treatment (PT)
Conventional Combustion

• Coal Burned With 90% Primary Air Through Firebed
The Gas Producer Combustion System (GPCS)

- The Firebed Becomes A Gas Producer By Making It Thick
- Coal+Steam+Air React To Form: CO, H₂ & CH₄ Burned With Air
Environmental Benefits Of GPCS

• Smoke Disappears
• CO & HC Emissions Virtually Disappear
• NOX Emissions Are Very Low
• Sulphur Can Also Be Controlled By Blending The Fuel With A Calcite-Dolomite Mixture
• GPCS Can Burn Essentially Any Reasonable Combination Of Solid Fuels
The Lempor Exhaust

- The Most Efficient Exhaust Ejector To Date
- Heart Of The Steam Locomotive, Since Trevithick, 1804
- Under Development By Porta Since 1952
- Supplanted Chapelon’s Kylchap Of 1926
- Shaun McMahon And Others Continuing Lemprex Exhaust Development
- Lempor Is 2 Or More Times As Efficient As The Traditional American Design (Amount of Draft Created By Each PSI Of Backpressure On The Cylinders)
Porta Water Treatment (PT)

- Outgrowth Of Advanced Treatments Used On The Railways Of France (TIA) And UK (Alfloc)
- Developed For Ferrocarril Nacional General Belgrano Railway, Argentina
- Martyn Bane Of portatreatment.com, Currently Markets The Treatment Outside Of Argentina
- The Chemistry Of The Boiler Water Keeps Any Scale Or Mud-forming Material In Solution Or Suspension
American Class I Railroad: Needs

- Automated Boiler Controls
- Multiple Unit Capability
- Distributed Power And Remote Control Capability
- Traction Control
- Dynamic Braking
- Crew Comfort
Automated Boiler Controls

• Two Person Crews Are Unnecessary
• A Person Can’t Finely Tune Combustion & Evaporation At Optimum Operation
• Power Plants Have Had Automated Boiler Controls For Years
• Allows MU Capability, Distributed Power & Remote Control Operation
Traction Control

• A Computer Compares Speed Of The Driving And Unpowered Wheels
• Restricts Steam Being Exhausted From Cylinders To Keep A Wheel Slip From Occurring
• Available For Decades In Locomotives & Cars
Dynamic Braking

• Counter-Pressure or Compression Brakes Installed On Many Steam Locomotives In Other Countries
• Same Function As Dynamic Brakes
• Most Common Used Type: “Water Brakes”
• Henry Le Chatelier
• Used By D&RGW In The US
Crew Comfort

• Cab Must Be As Comfortable As A Diesel
• Should Include The Following:
  – A Fully Enclosed Cab That Is Not Drafty
  – Air Conditioning, Ventilation And Heating
  – Advanced Sound And Thermal Insulation
  – “Thermal” Pane Windows
  – Wipers & Washers For The Front & Rear Windows
  – A Toilet, Most Likely In The Tender
  – Air Seats Similar To Those On Over-the-Road Trucks
  – Ample Work Space For The Engineer & Conductor
  – Ergonomically Designed Layout Of Controls
  – Microwave And/Or Coffee Pot
Maintenance Benefits Of PT & GPCS

- PT Eliminates The Formation Of Scale
- Boiler Washouts: 6 Month Cycle Not 30 Day Cycle
- Boiler Blowdowns: 2 Month Cycle, Not Every Shift
- Boiler Tubes Can Last 30 Years
- Firebox Plates Can Last 30 Years
- Superheater Elements Can Last 30 Years
- PT & GPCS (No Sandblasting By Unburned Coal):
  - Virtual Elimination Of Boiler Maintenance
  - 91% Of The Maintenance Cost Steam
Maintenance Comparisons cont.

• Prevailing View: Steam Locomotives More Expensive To Maintain Than Diesels
• True Comparing Old Generation “Zero” Steam With New Diesel Locomotives
• FGS Locomotives With One-Piece Cast Frames, Roller-bearings On All Axles & Motion And Complete Mechanical & Pressure Lubrication Were Cheaper To Maintain Than Diesels
• N&W’s New Class J 29% Cheaper Than Southern’s New E6’s
• 1963-1986, SAR Class 25NC Was 20% Cheaper Than Diesel
• Modern Steam Locomotive Should Be As Cheap To Maintain As A Diesel, If Not Cheaper
Operating Comparisons

• Idle Fuel Costs: (2006)
  – $5.40 To $11.40 Per Hour Diesels w/o APU’s
  – $1.22 To $1.48 Per Hour Diesels w/ APU’s
  – $0.27 And $0.89 Per Hour Modern Steam

• Running Time Comparison: (Fill Ups)
  • SGS: 2 Coal + Water And 2 Water Only = 1 Diesel
  • TGS: 1 Coal + Water And 1 Water Only = 1 Diesel
  • Condensing TGS: 1 Coal = 1 Diesel
Infrastructure And Servicing

• 3 Basic Types Of Facilities:
  – Coaling Station: Coal, Water & Sand
  – Watering Station: Water Only
  – Servicing Facility: Modify Existing
    • Lubricating: 30 Days
    • Boiler Blowdown: 60 Days
    • Fire Cleaning: Only for Firebox Inspection
      – Due To V Section Anti Clinker Grinding Grates
    • Boiler Washout: 180 Days
Conclusion

• Cost Savings Justifies Further Investigation
• Technology Is Within Reach
• Railroad Operating Parameters Virtually Unchanged
Next Steps

• Feasibility Study
• New Build Prototype
• Test Locomotive
  – Phase 1: Operations/Economics
  – Phase 2: Emissions
• Preproduction Samples
• Series Production
Other Locomotive Alternatives

• Steam Turbine Electric
  — Coal And Any Solid Fuel
• Gas Turbine Electric
  — Liquefied Coal Gas, LNG Or LPG
• Diesel Electric Conversion
  — Liquefied Coal Gas, LNG Or LPG
Further Resources:

- http://www.portatreatment.com
- http://www.martynbane.co.uk
- http://www.trainweb.org/tusp
- La Locomotive A Vapeur, Andre Chapelon
- Advanced Steam Locomotive Development, L. D. Porta
- The Red Devil, David Wardale
Questions