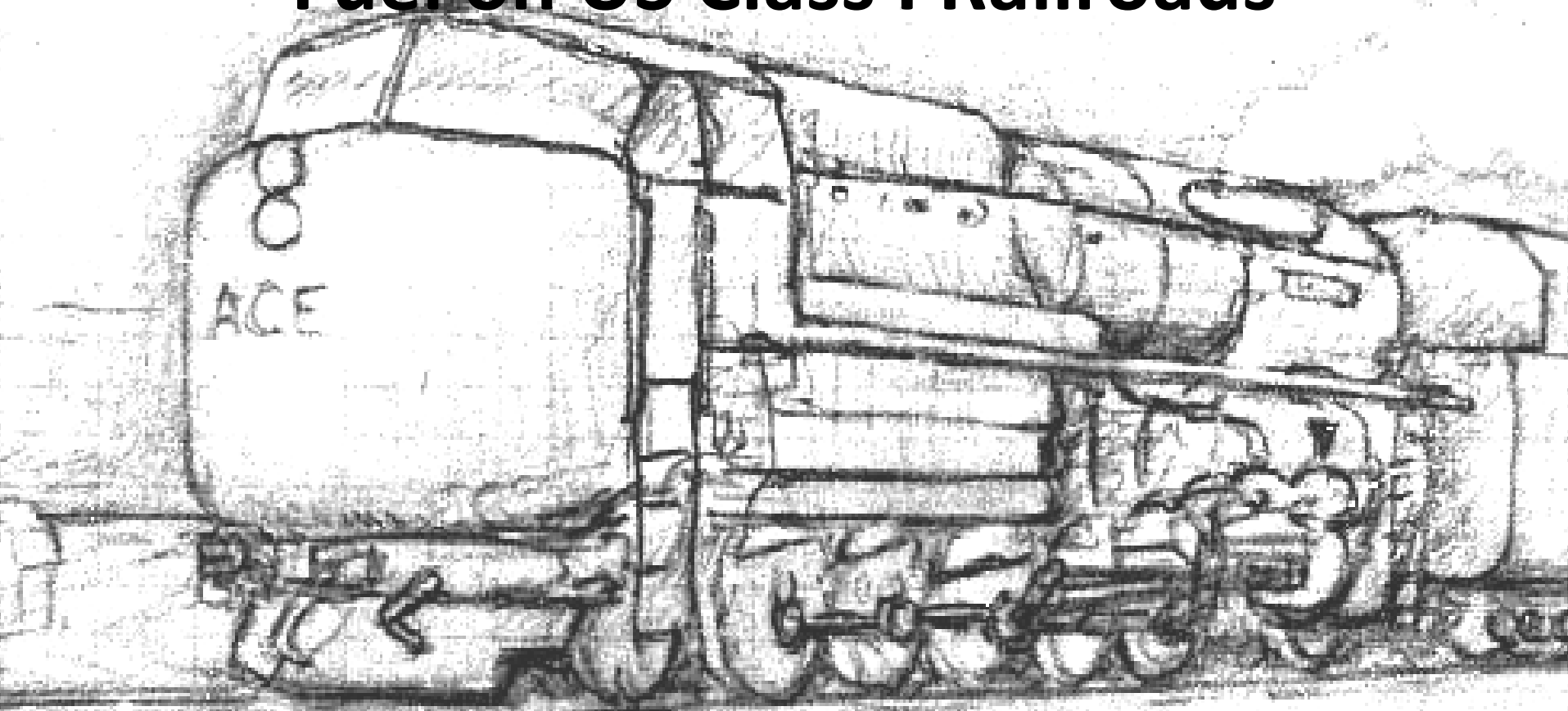
The Economics of Coal as a Locomotive Fuel on US Class I Railroads



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

Coal	Type				
	ILB	UIB	CAP	NAP	PRB
$1.00	**$ 1.00**	**$ 1.00**	**$ 1.00**	**$ 1.00**	**$ 1.00**
$ / Ton	$ 31.14	$ 27.26	$ 46.42	$ 46.74	$ 9.84
Lb. / $	64.23	73.37	43.08	42.79	203.26
BTU / Lb.	11,800	11,700	12,500	13,000	8,800
BTU / $	757,868	858,401	***538,561***	556,269	1,788,702

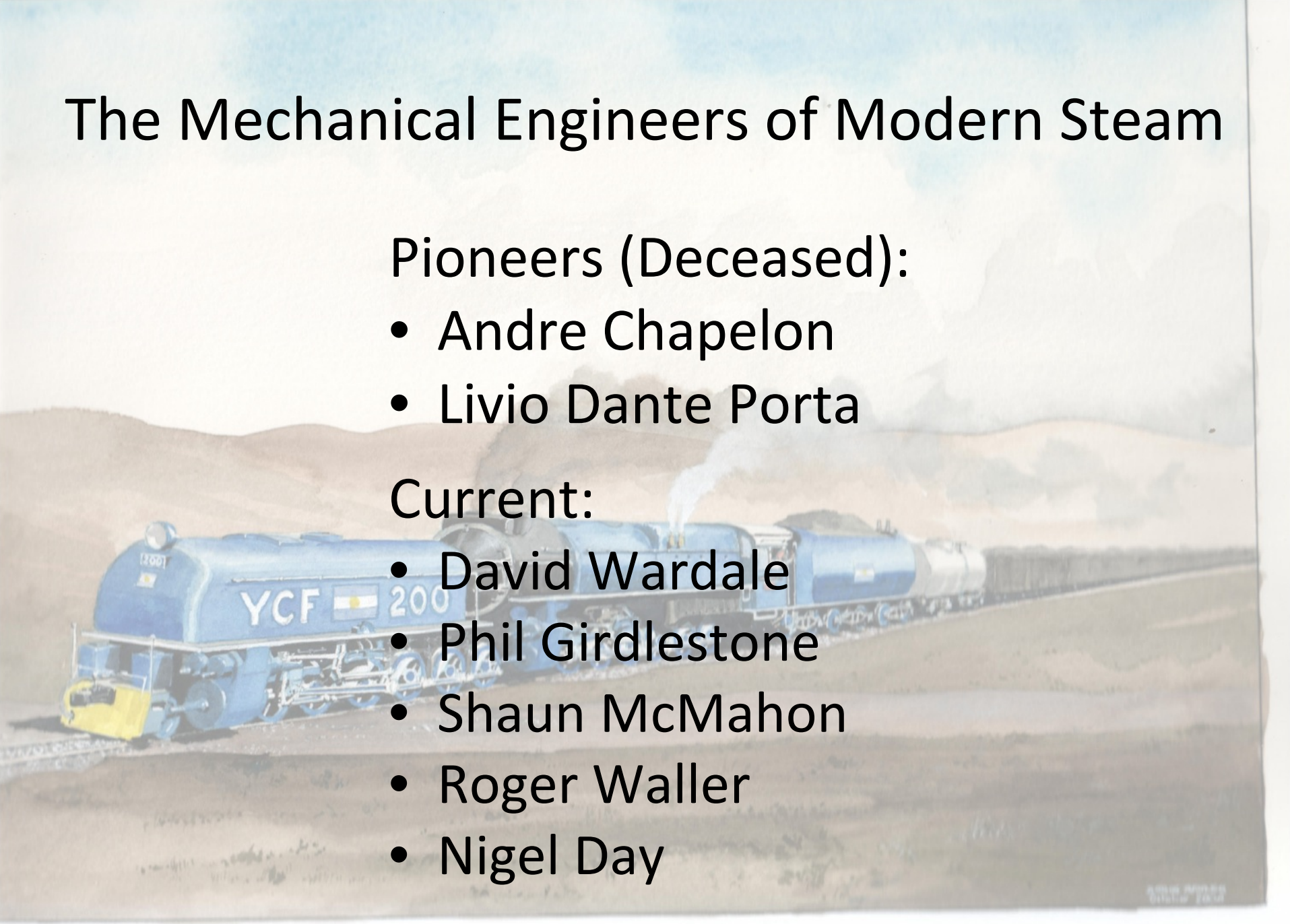
The Most Expensive Coal Is 7x Cheaper Than The Cheapest Diesel

Diesel	Type						
	BNSF	UP	KCS	CP(US)	CN(US)	CSX	NS
$1.00	**$ 1.00**	**$ 1.00**	**$ 1.00**	**$ 1.00**	**$ 1.00**	**$ 1.00**	**$ 1.00**
$ / Gal.	$ 2.21	$ 2.22	$ 2.15	$ 2.23	$ 2.19	$ 2.13	$ 2.10
Gal. / $	0.45	0.45	0.47	0.45	0.46	0.47	0.48
BTU / Gal.	163,572	163,572	163,572	163,572	163,572	163,572	163,572
BTU / $	73,979	73,609	76,249	73,259	74,710	76,880	***77,941***

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:

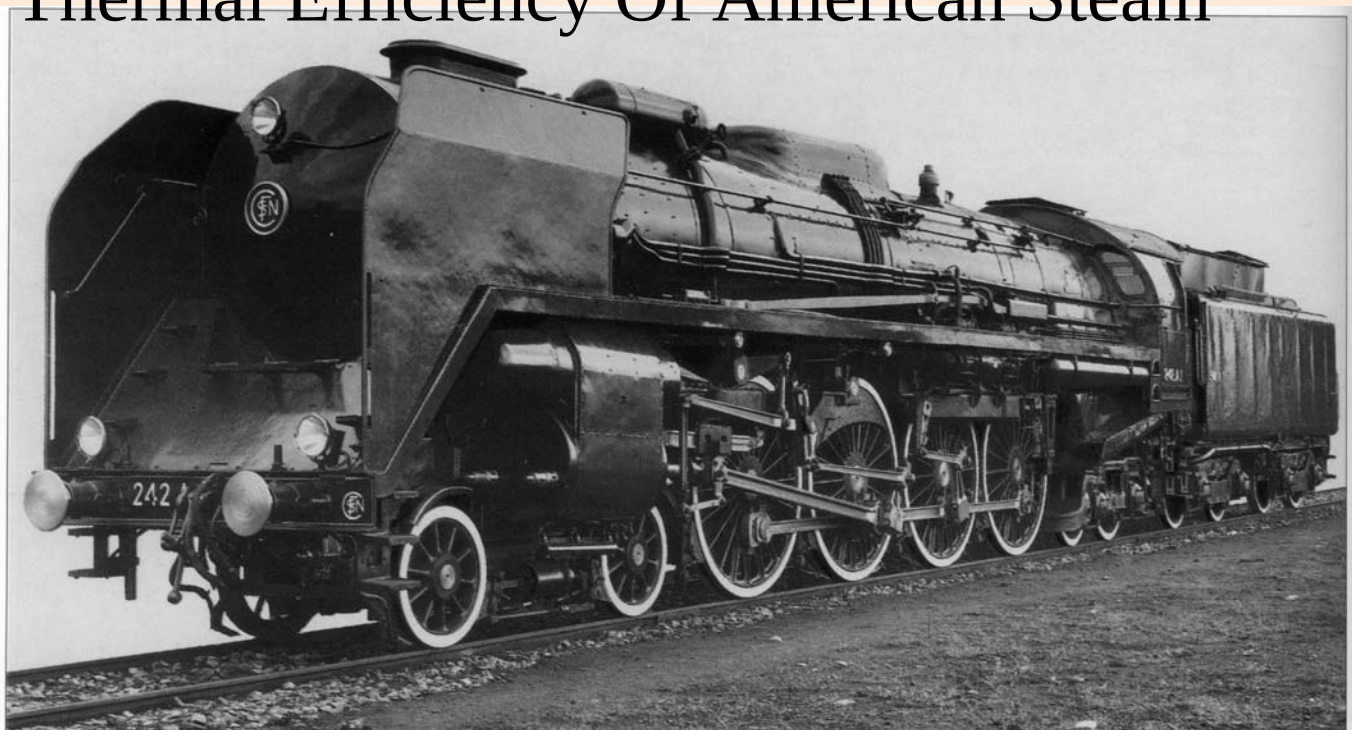
- David Wardale
- Phil Girdlestone
- Shaun McMahon
- Roger Waller
- Nigel Day

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)

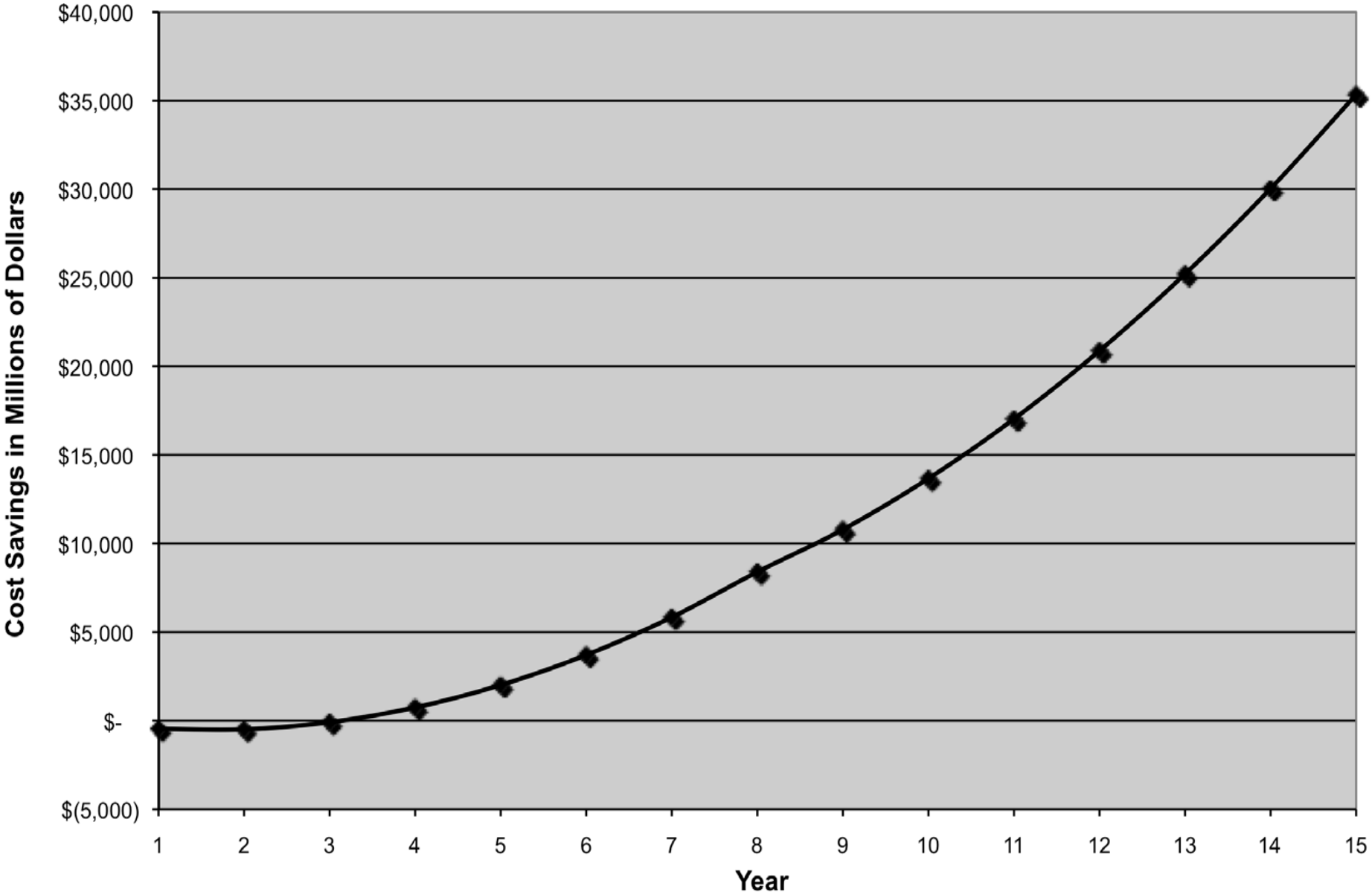
Porta's Outline:

- 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

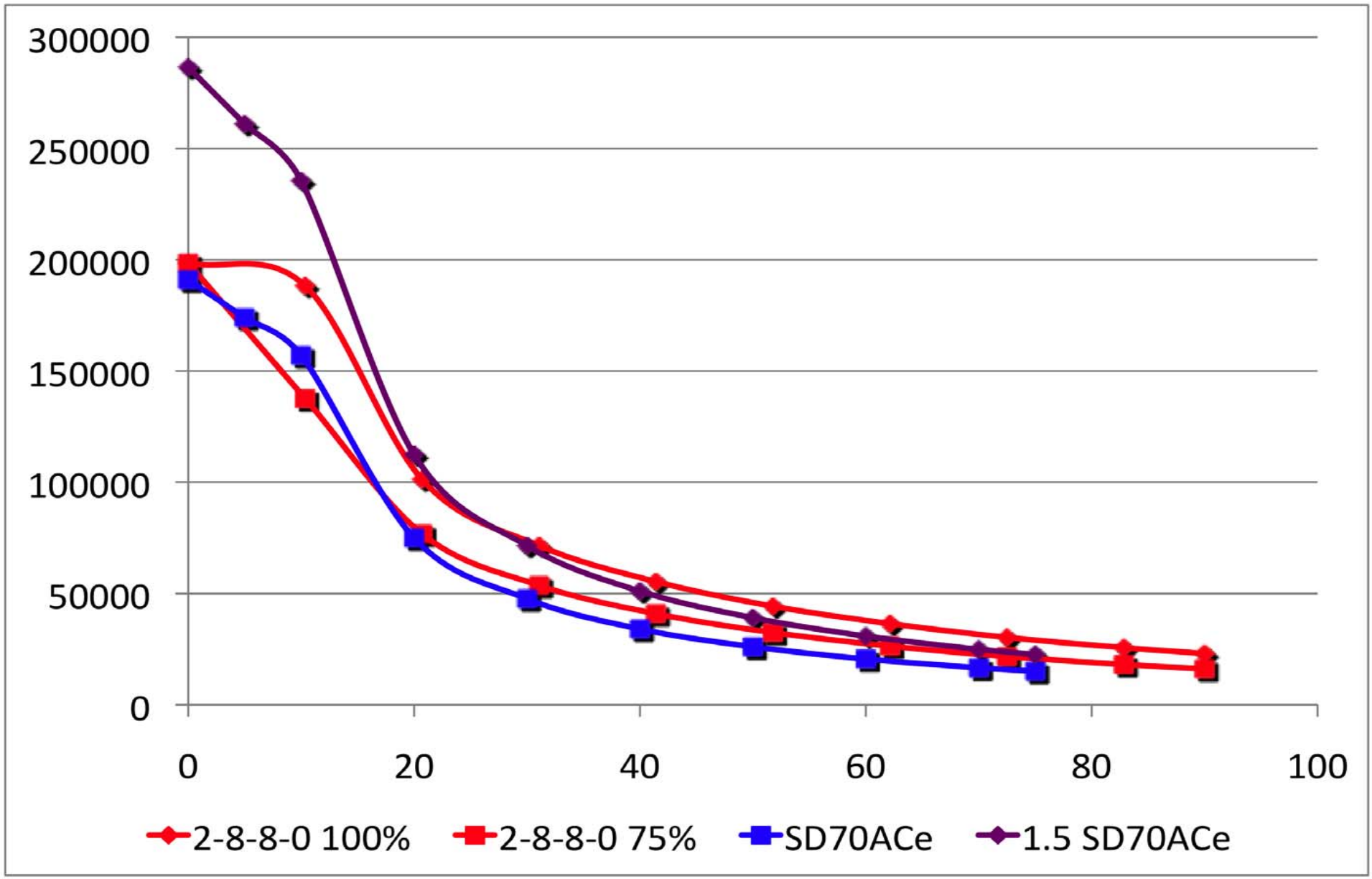
Steam Diesel Cost Comparison

Steam vs. Diesel Fuel Cost Savings												
CY2007	**14% Thermal Efficiency - 2nd Generation Steam**				**21% Thermal Efficiency - 3rd Generation Steam**				**27% Thermal Efficiency - 3rd Gen. w/ Condensing**			
Coal Type	ILB	UIB	CAP	NAP	ILB	UIB	CAP	NAP	ILB	UIB	CAP	NAP
Diesel Fuel Price	$ 2.19	$ 2.19	$ 2.19	$ 2.19	$ 2.19	$ 2.19	$ 2.19	$ 2.19	$ 2.19	$ 2.19	$ 2.19	$ 2.19
Gallons of Fuel	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Diesel Thermal Efficiency SD70ACe	30.2%	30.2%	30.2%	30.2%	30.2%	30.2%	30.2%	30.2%	30.2%	30.2%	30.2%	30.2%
BTU's per Pound of Coal	11800	11700	12500	13000	11800	11700	12500	13000	11800	11700	12500	13000
Pounds of Coal	13.65	13.77	12.89	12.39	9.10	9.18	8.59	8.26	7.08	7.14	6.68	6.43
Coal Price	$ 36.14	$ 32.26	$ 51.42	$ 51.74	$ 36.14	$ 32.26	$ 51.42	$ 51.74	$ 36.40	$ 32.26	$ 61.89	$ 52.04
Gallons of Water	11.09	11.09	11.09	11.09	7.39	7.39	7.39	7.39				
Average Fuel Cost Steam	**$ 0.25**				**$ 0.16**				**$ 0.13**			
Average Percent Savings	**73%**				**82%**				**87%**			
US Class I Fuel Cost	**$ 8,910,422,000**				**$ 8,910,422,001**				**$ 8,910,422,002**			
Fuel Cost Saved	**$ 6,463,823,138**				**$ 7,279,356,093**				**$ 7,741,743,056**			

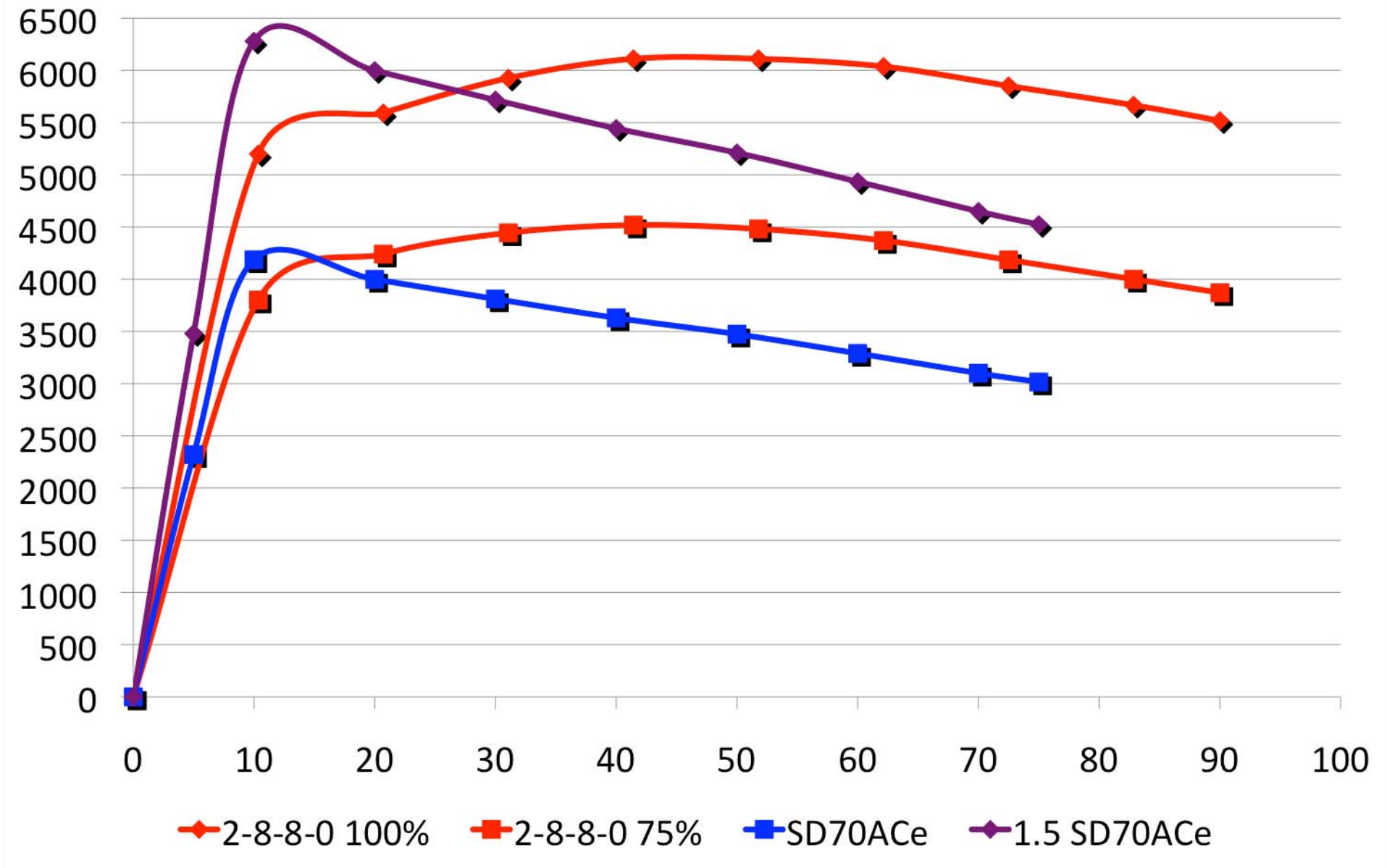

Cumulative Cost Savings Steam
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$-
$(5,000)
Cost Savings in Millions of Dollars
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Year

The Economics Look Great. But Can It Pull The Trains?

DBPull Comparison



DBHP Comparison

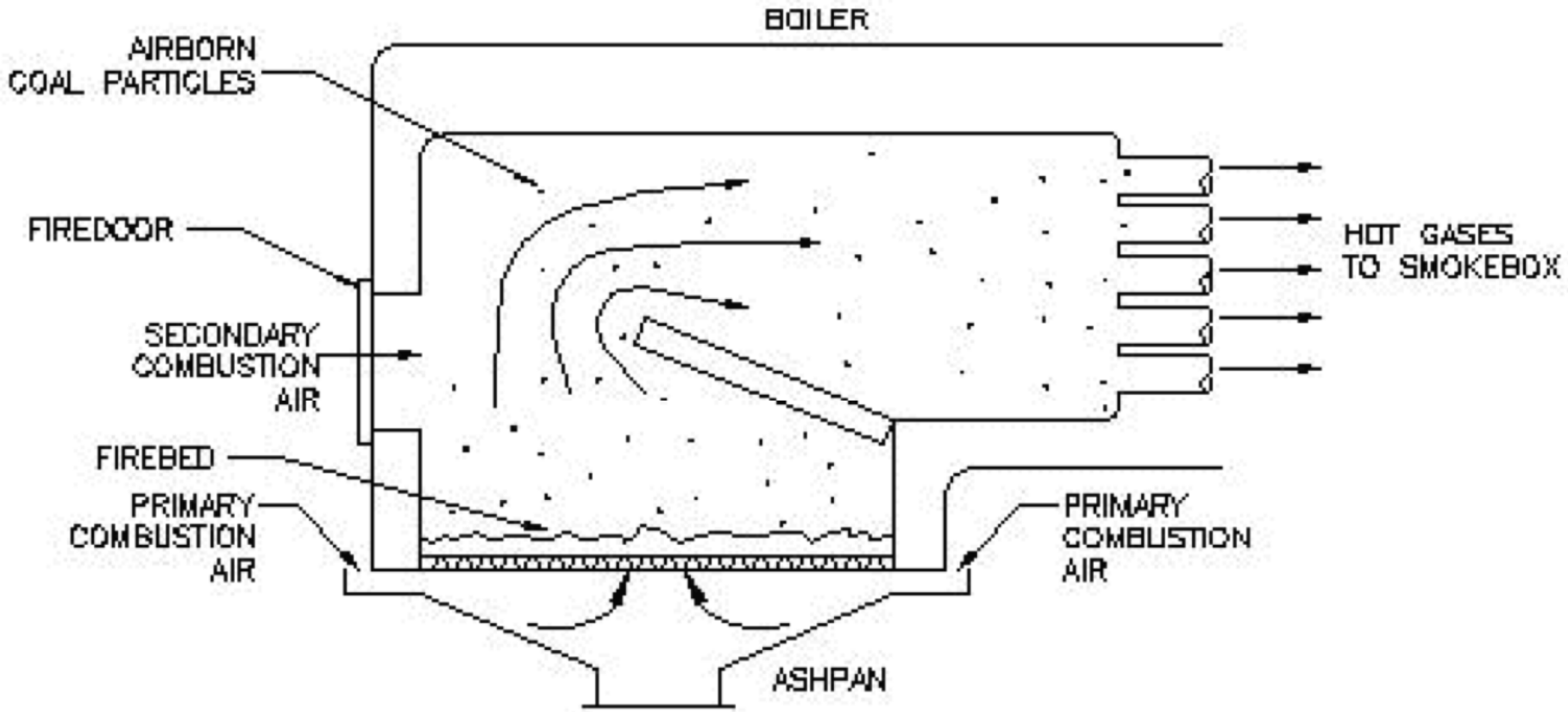


Important Technologies

- The Gas Producer Combustion System (GPCS)
- The Lempor Exhaust
- Porta Water Treatment (PT)

Conventional Combustion

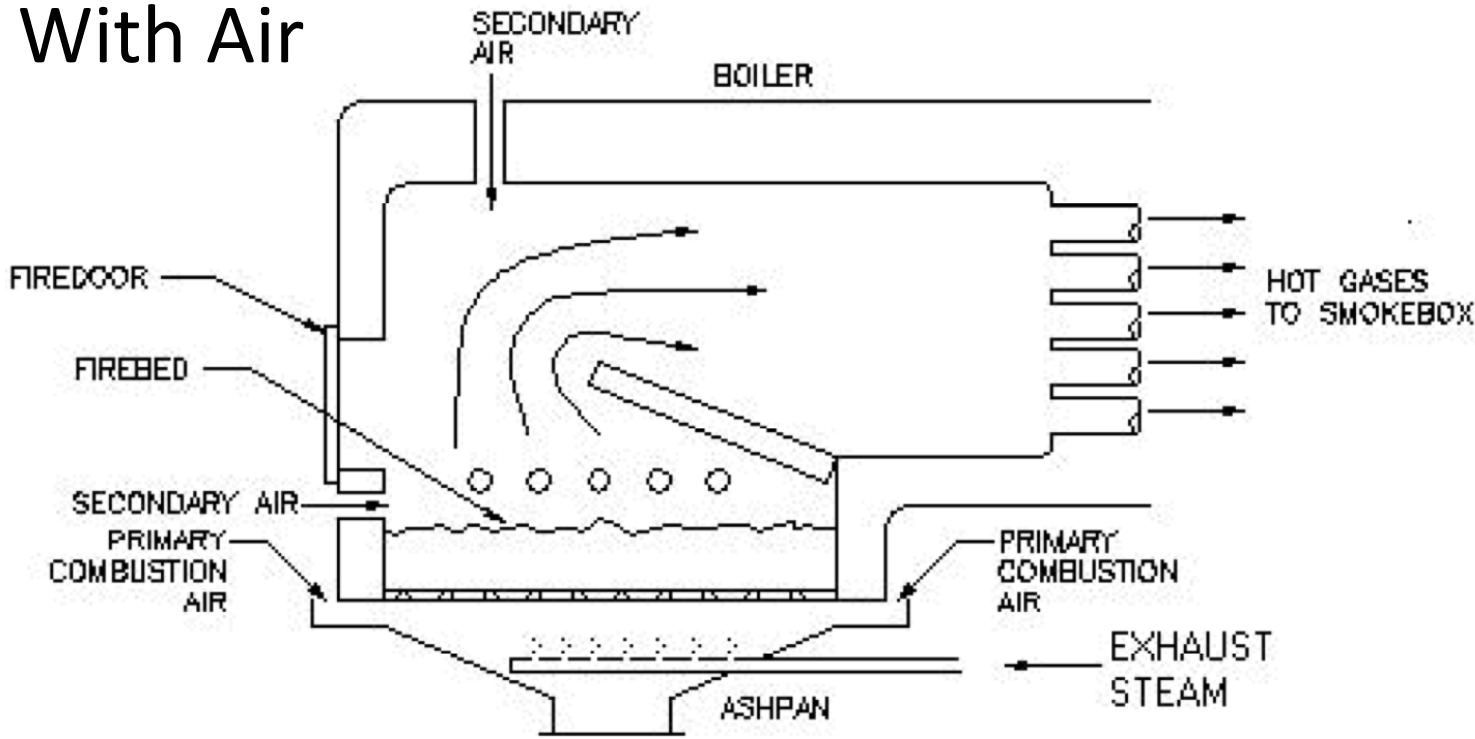
- Coal Burned With 90% Primary Air Through Firebed



CONVENTIONAL FIREBOX

The Gas Producer Combustion System (GPCS)

- The Firebed Becomes A Gas Producer By Making It Thick
- Coal+Steam+Air React To Form: CO, H_2 & CH_4 Burned With Air

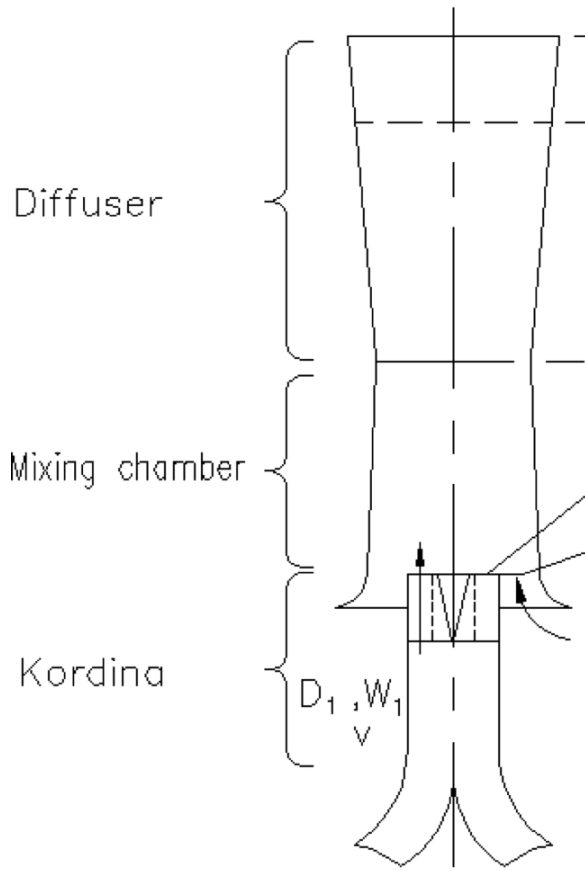


Environmental Benefits Of GPCS

- 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