Advanced Steam Traction Trust

ASTT'S TRIALS AND RESEARCHES INTO COAL SUBSTITUTES

Ian Gaylor & John Hind

Introduction

- Background – John
- BVR Trials – Ian
- KWVR and ELR Trials – John
- Trial Record Sheets – John
- BVR and Standard Gauge Correlation – Ian
- Structured Idea Management – Ian
- Future Funding - John

Background – John Hind

- Alternative fuel trials
  - Summer 2021 – Summer 2022
    - Initiative by the BVR
    - Working with the Heritage Railway Association
  - September 2021 – Stapleford using N&P Product
    - Lab results awaited
  - November 2021 – BVR using 'improved' Coal Products
    - Based on results from June trials
    - 14/2/2022 – KWVR – 1st Standard Gauge using Coal Products
  - **24/2/2022 – the world changed!!**

Background – John Hind

- Concerns about continuing supply of lump coal and prices
  - Russia invades Ukraine
  - Ffos-y-fran supplies in jeopardy
- New emphasis on alternative fuels
- Everyone trying to find a solution!
- Put in place a questionnaire in the form of a Trial Record to collect data in a consistent way

Background – John Hind

- Narrow Gauge
  - Brecon Mountain
  - Bure Valley Railway
  - Talyllyn Railway
  - Welshpool & Llanfair
  - Whipsnade Light Railway
- Standard Gauge
  - Chatham Dockyard
  - Dean Forest
  - East Lancashire Railway
  - Isle of Wight Railway
  - Keighley & Worth Valley
  - Severn Valley Railway

- Sent out to HRA members March 2022
- Trial Record Sheets - 29 received from 6 standard and 5 narrow gauge railways
  - Hargreaves - Trevithick Ovoids
  - CPL Products – HB3, HB4, Wildfire
  - Ffos-y-fran – 1 response
    - Test at Bure Valley included as a comparator against the manufactured fuels
- Wood log based fuel – 1 response from Chatham Dockyard
  - Separated out from the anthracite fuels as it is an 'outlier'
  - Suggests that this a viable fuel for shorter lines with smaller locomotives and loads
- Feedback sent out to HRA members in May 2022
- Further trials in May and June at KWVR and BVR

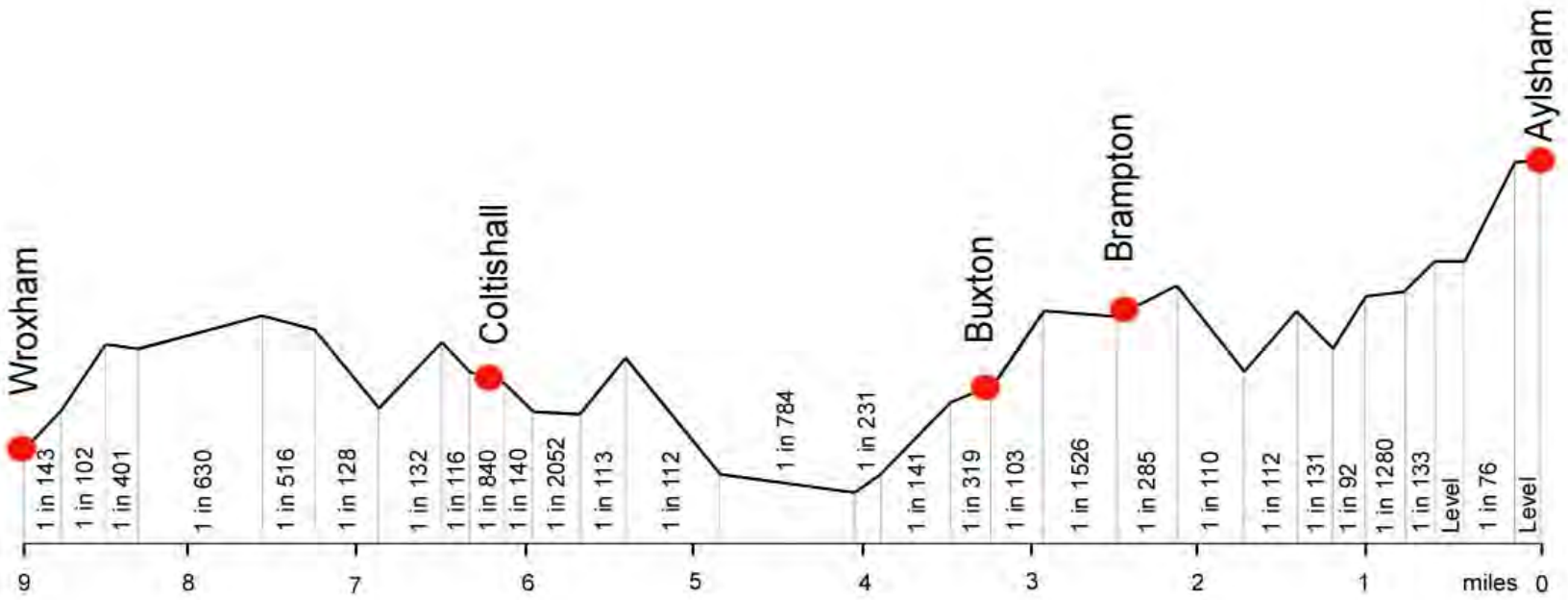
Background – John Hind

- Other trials took place but Trial Record Sheets not sent in but verbal or e-mail feedback
  - NYMR – CPL Wildfire
  - Ffestiniog – Trevithick Ovoids

BVR Trials

Background

The fuel trials were held at the Bure Valley Railway, BVR, over a nine mile line with switch back gradients :-



Gradient profile

Background

A critical parameter determining performance is the required maximum firing rate of the fuel which can be broadly categorised as follows:-

- 10-30 lbs/sqft grate/hr – *'Undemanding work'* e.g. park and short museum lines etc
- 30-80 lbs/sqft grate/hr – *'Average operating conditions'* for many heritage lines
- 80-120 lbs/sqft grate/hr – *'Demanding work'* e.g. continuous steeply graded lines often using relatively small locomotives with large loads

Objective Phases 3 and 4

The overall objective of Phases 3 and 4 of the fuel trials was to assess the performance of six varieties of synthetic *Ecoal* compared to natural *Steam Coal* under 'Demanding work' conditions

- The steam coal used as a baseline comparator was *Ffos-y-fran bituminous steam coal* tested in Phase 2
- Phase 3 trials were carried out on 21-22/3/22 and Phase 4 on 20-21/6/22
- The six sample fuels in briquette form supplied by Coal Products Ltd, CPL, were:-
  - *Ecoal50*
  - *Heritage blend 3*
  - *Heritage blend 3 (low chlorine)*
  - *Wildfire*
  - *Wildfire (low chlorine)*
  - *Heritage blend 4*

Phase 3 and 4 trial arrangements

The tests were carried out in accordance with a previously agreed 'Preliminary fuel trial test methodology' with variations to the train consist:-

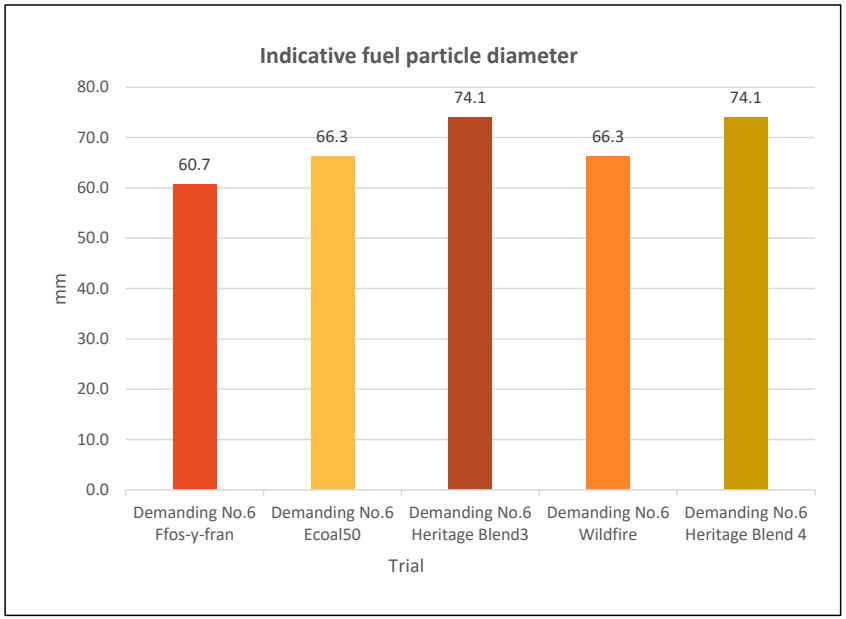
- For consistency the locomotive was No.6 Blickling Hall and the Driver was Scott Bunting
- Phases 3-4 Train consist was as follows:-
  - BVR No.6 'Blickling Hall'
  - 2 - 4 wheel brake van
  - 2 – 4 wheel Generator car
  - 16 – Bogie carriages
  - BVR No.3 (unpowered diesel locomotive)
- Total weight of consist approx. 71.8 tonnes

BVR Test Train

Normal length of a service train

Fuel equivalent particle diameter

The indicative particle diameters were determined by measurement and calculation as follows:-

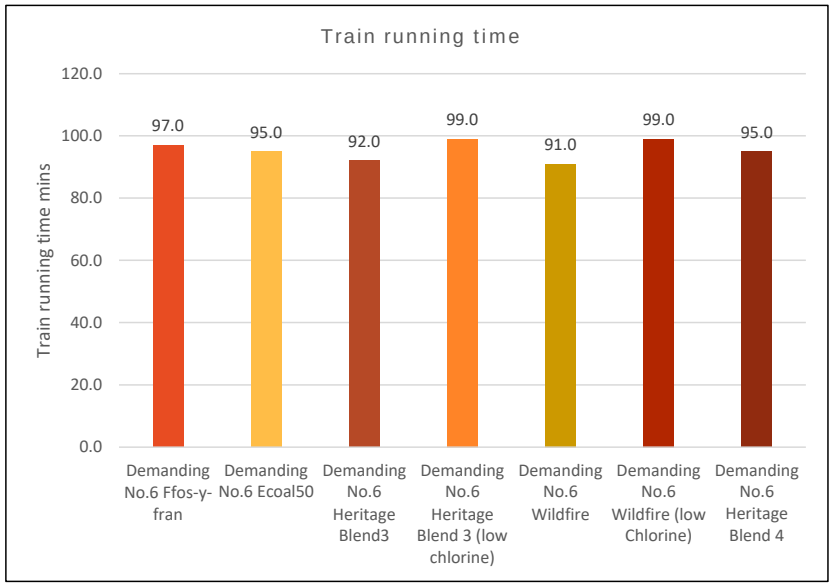


Note that the indicative particle diameters may vary for both the coal and Ecoal samples because:-

- The *Ffos-y-fran coal* particle sizes have a natural variation despite screening
- The *Ecoal* briquettes maybe subject to some breakage and/or manufacture using different forming rollers

Trial conditions

Train running times aimed to achieve the scheduled service time of 90 mins but because of track conditions were as follows:-



Running time observations:-

- Generally running times were fairly consistent and close to scheduled service time of 90 mins
- Scheduled time in Phase 2 for *Ffos-y-fran* was exceeded by 7 mins due to poor railhead conditions
- Scheduled times in Phases 3 and 4 were exceeded by 1-9 mins as the locomotive was operating close to the adhesion limit

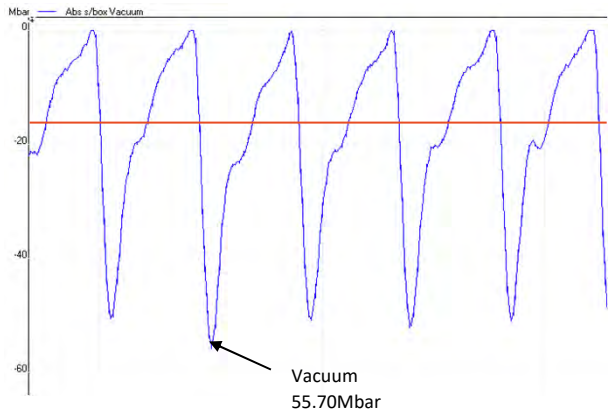
Maximum firing rate

The maximum firing rates with Ffos-y-fran fuel and loco No.6 was found to be when climbing Wroxham bank :-

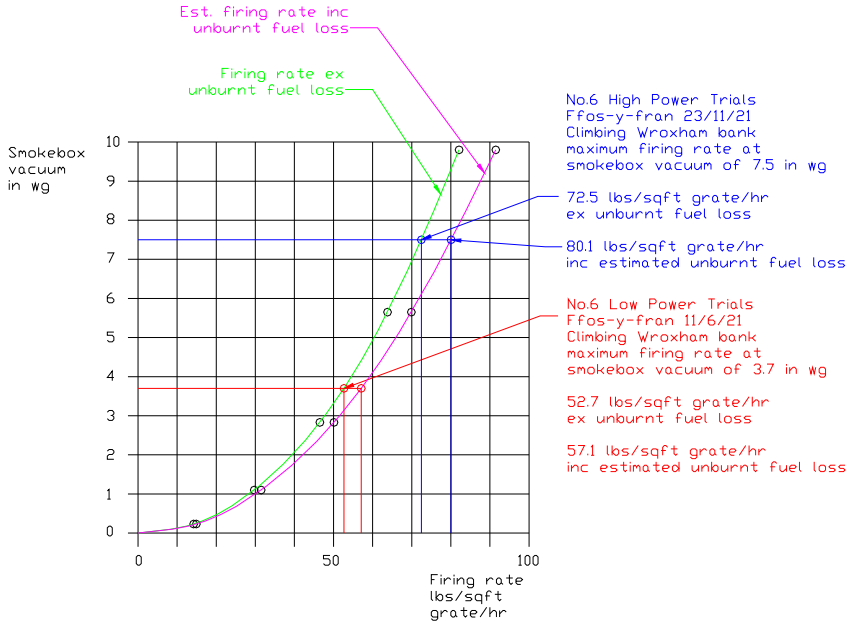
- The smokebox vacuum was continuously measured using electronic transducers
- From this data the average smokebox vacuum was calculated
- From modelling of boiler performance at the average smokebox vacuum the maximum combustion rates were determined including an estimated allowance for unburnt fuel loss
- Combustion rates for *Ecoal* were also based on the average smokebox vacuum data and the fuel consumption per litre of water evaporated
- It should be noted that due to an instrumentation problem the smokebox vacuum recorded for *Wildfire* was not recorded on Wroxham bank but instead approaching Aylsham Bypass where the locomotive is not working as hard and is therefore lower than results for the other fuels

Maximum firing rate

The maximum firing rates with Ffos-y-fran fuel and loco No.6 was found to be when climbing Wroxham bank :-



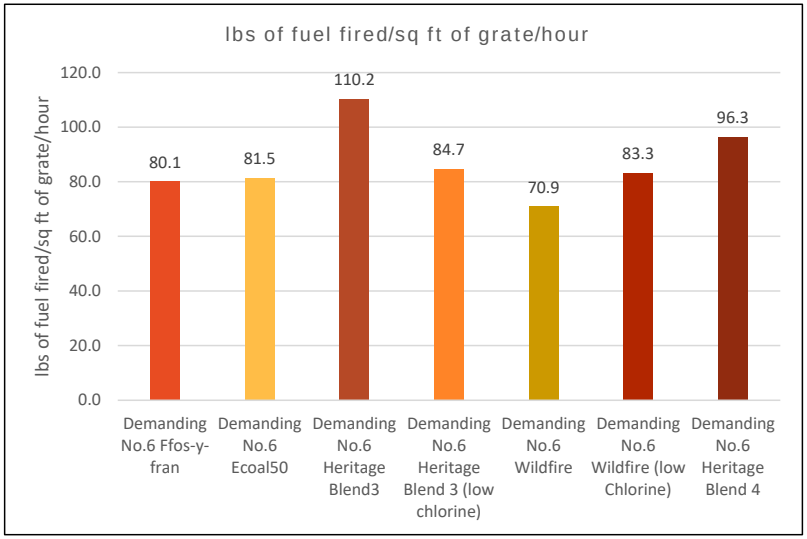
Smokebox vacuum trace for loco No.6 Under 'Demanding Conditions'



Firing rate v smokebox vacuum for loco No.6

Maximum firing rate

The maximum firing rates are based on the smokebox vacuum measurements and modelling from the trials of Ffos-y-fran coal in loco No.6:-



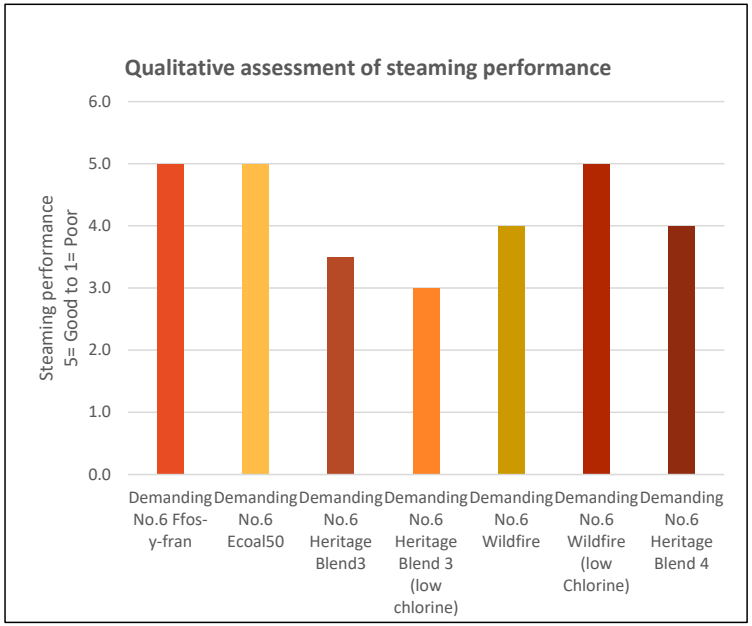
Estimate calculations consider:-

- The modelled firing rates v the smokebox vacuum
- An estimation of the unburnt fuel losses in the Ffos-y-fran trial and the weight of fuel required to evaporate the water i.e. efficiency of energy utilisation for the other test fuels

All the firing rates fall within the 'Demanding work ' category (apart from Wildfire for reasons previously noted) but because of the limitations of the test and modelling processes the firing rates should be considered <u>indicative</u> rather than absolute

Qualitative assessment of locomotive steaming

The sample fuels were compared on a qualitative basis by observation of locomotive steaming performance from the footplate using *Ffos-y-fran coal* as a baseline:-

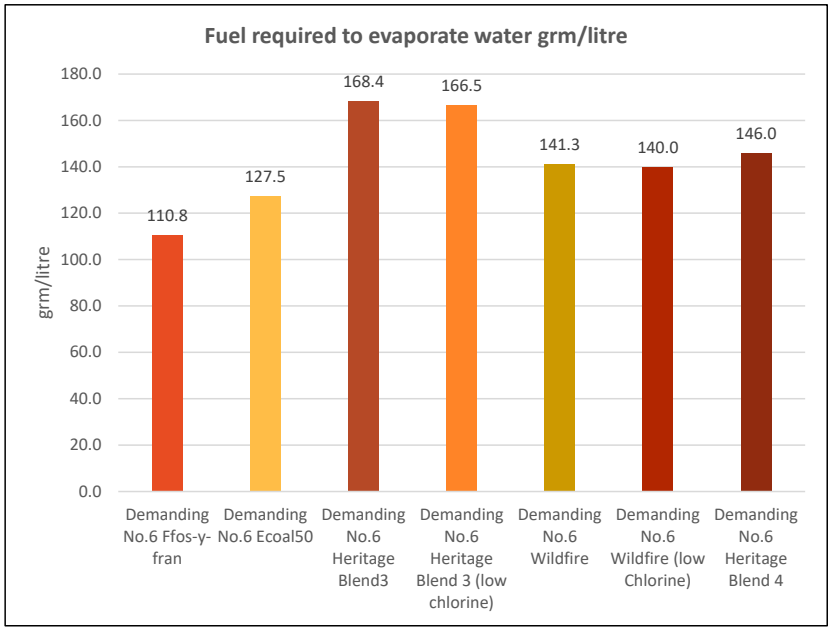


Conclusions:-

- With *Ffos-y-fran , Wildfire (Low chlorine) and Ecoal 50* the locomotive steamed freely
- With *Wildfire and Heritage blend 4* the locomotive steamed satisfactorily
- But with *Heritage blend 3, and Heritage blend 3 (Low chlorine)* steaming was only adequate

Fuel required for evaporation

The *Ecoal* sample fuels were compared with Ffos-y-fran coal to assess the quantity of fuel required by weight to evaporate a litre of water at the working boiler pressure of 150-180 psig:-

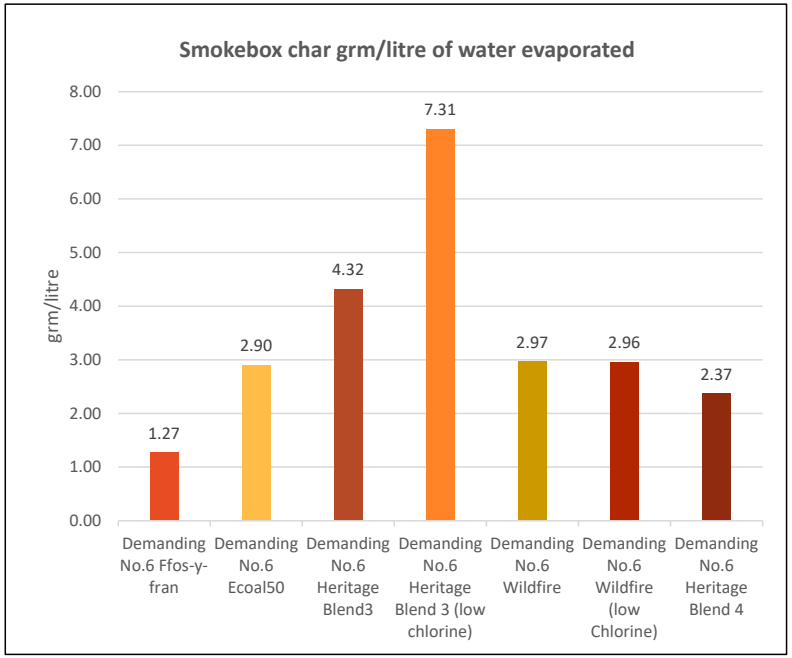


Conclusion:-

- The consumption of *Ecoal* samples was greater than *Ffos-y-fran*

Unburnt fuel losses

The *Ecoal* sample fuels were compared with *Ffos-y-fran coal* to assess the unburnt fuel losses in the boiler exhaust gas:-



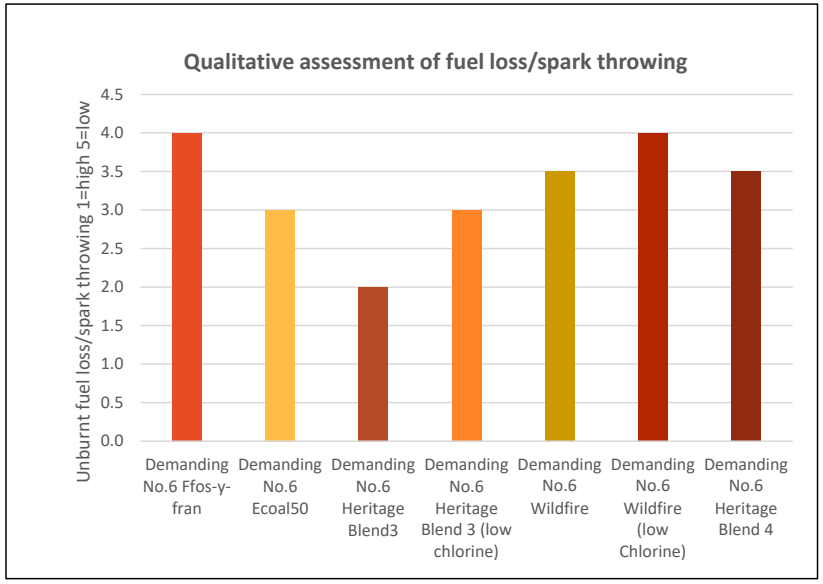
- The locomotive was fitted with wire mesh basket spark arrestor
- The quantity of smokebox char was compared by weight per litre of water evaporated @150-180 psig

Conclusion:-

- The Ecoal sample fuels have greater unburnt fuel losses which can be observed from the increased quantity of smokebox char

Qualitative unburnt fuel losses

The *Ecoal* sample fuels were compared with *Ffos-y-fran coal* to assess the unburnt fuel losses in the boiler exhaust gas:-



- In addition to the measurement of the weight of smokebox char a qualitative assessment of spark throwing was made by the Driver
- The qualitative assessment has an approximately inverse correlation with the measurement of the weight of smokebox char (see previous slide) and maybe due to either the nature of assessment or the particle size created by combustion and therefore the quantity of particles emitted

Unburnt fuel losses

The negative impact of unburnt fuel loss is fourfold:-

- All fuel that is ejected from the locomotive chimney unburnt is a waste both financially and in terms of energy
- Particles which are large enough to hit the ground glowing present a fire risk when the lineside is dry or may burn bystanders and train crew
- Small particles may present a respirable pollution risk and produce unacceptably dark colouration in the exhaust
- Unburnt gaseous components maybe malodourous or harmful

Note that greenhouse gas is not created by the solid proportion of the fuel which is unburnt and the origins of this fraction (i.e. fossil or sustainable) should be considered when making an environmental assessment.

Firebed clinker

Fire preparation and cleaning:-

- The clean grate was initially protected by a light covering of 3-4 shovelfuls of beach shingle to prevent clinker adhering to the firebars
- The locomotive was then lit up using *Ffos-y-fran coal* for the baseline test trip
- The fire was then cleaned of clinker down to the bars using traditional methods with a pricker and clinker shovel and the hot clinker weighed
- For the *Ecoal* tests the fire was lit up using the same method with the first test fuel of the day
- After the first test trip was completed the fire was cleaned of clinker and rebuilt with the next *Ecoal* test fuel ready for the second trip
- The clinker from the second test trip was removed from the dead fire the following day

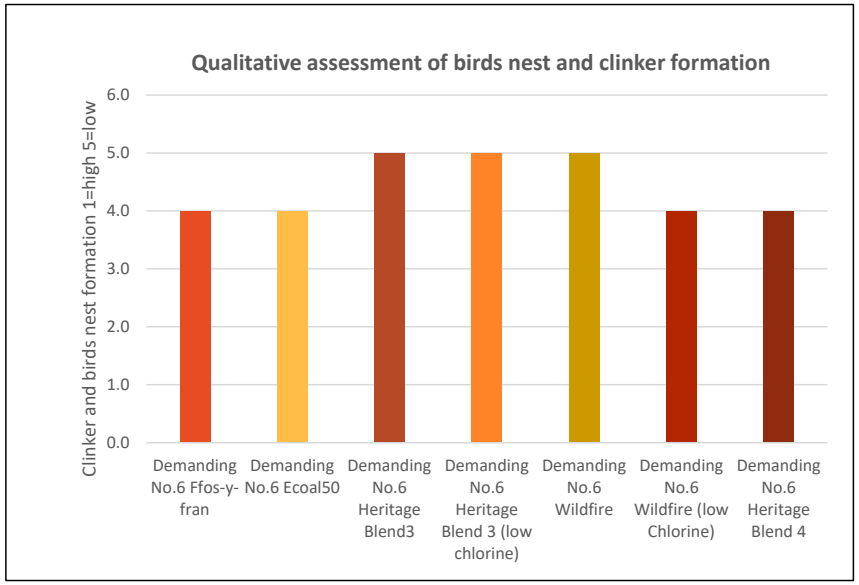
Firebed clinker

Clinker measurement issues:-

- The clinker is contaminated with beach shingle which effects the weight of the sample and the presence of the stone was particularly noticeable in the clinker from the *Ecoal* samples where the cold grate was completely cleaned
- Cleaning of the grate with the fire alight never completely removes all the clinker and therefore this effects the clinker samples by:-
  - Reducing the weight of the clinker sample from the first test fuel of the day
  - Increasing the weight of the clinker sample from the second test fuel

Firebed clinker

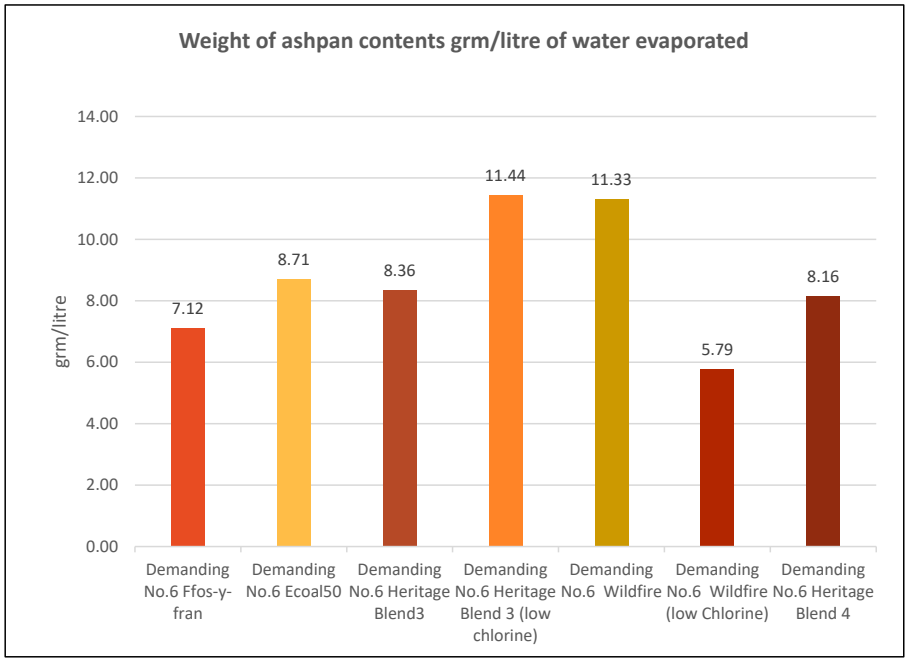
For the reasons given no quantative data is provided as this could be misleading however the qualitative impressions of the footplate crew are:-



- *Ecoal50, Wildfire (Low chlorine) and Heritage blend 4* produced around the same amount of clinker as *Ffos-y-fran coal*
- *Heritage blend 3, Heritage blend 3 (Low chlorine) and Wildfire* produced slightly less clinker than *Ffos-y-fran coal*
- Birds nest formation was not an issue for any of the fuels

Ashpan contents

The *Ecoal* sample fuels were compared with *Ffos-y-fran coal* to assess the quantity of ash and char in the ashpan:-



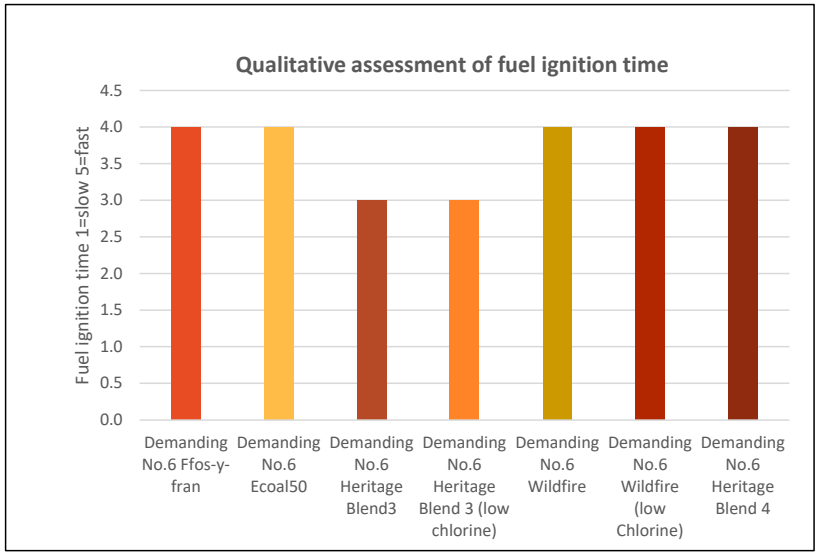
- The quantity of ash and char was compared by weight per litre of water evaporated @150-180 psig

Conclusion:-

- With one exception the *Ecoal* sample fuels have a greater quantity of ash and char in the ashpan than the comparative *Ffos-y-fran coal* baseline test
- *Heritage blend 3 (Low chlorine) and Wildfire* had a significantly higher ash quantity than the other fuels
- *Wildfire (Low chlorine)* has a low quantity of ash but this maybe because of increased unburnt fuel loss compared to other samples

Fuel ignition time

The qualitative impressions of the footplate crew for fuel ignition time are:-

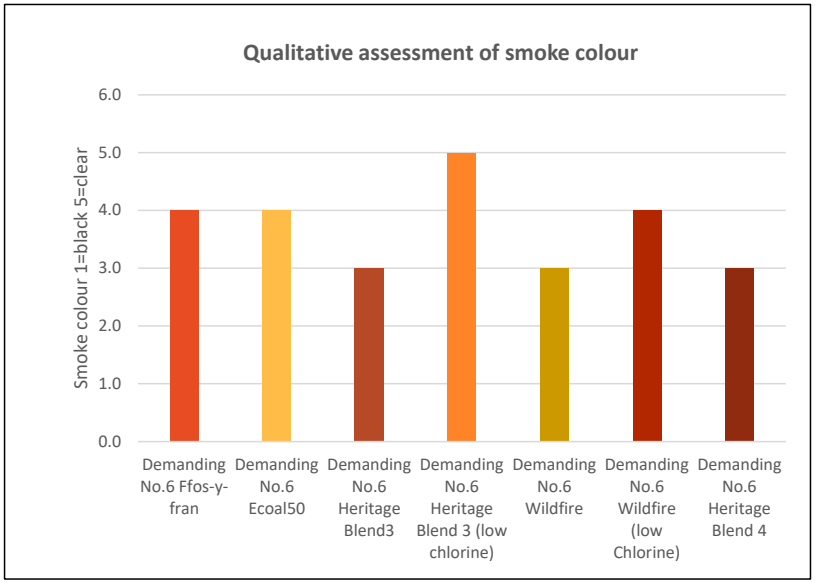


Conclusion:-

- All the *Ecoal* sample fuels had a comparative ignition time to that of *Ffos-y-fran coal* apart from *Heritage blend 3 and Heritage blend 3 (Low chlorine)* which was slightly slower

Qualitative assessment of smoke colour

The qualitative impressions of the footplate crew for smoke colour are:-

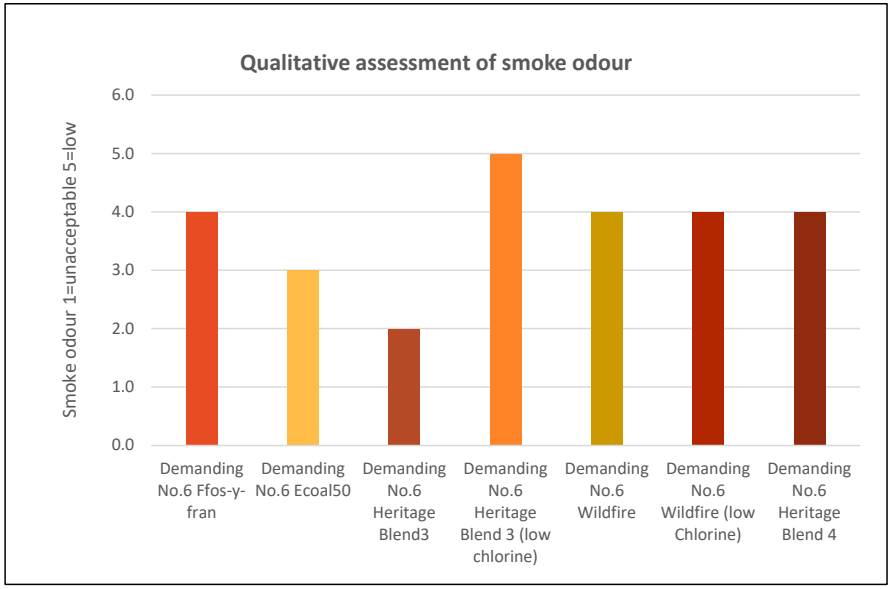


Conclusion:-

- *Ecoal50 and Wildfire (Low chlorine)* had a comparative smoke colour to that of *Ffos-y-fran coal*
- *Wildfire and Heritage blends 3 + 4* produced slightly more smoke although this was controllable
- *Heritage blend 3 (Low chlorine) produced* less smoke than *Ffos-y-fran coal*

Qualitative assessment of smoke odour

The qualitative impressions of the footplate crew for smoke odour are:-



Conclusion:-

- *Heritage blend 3* had a distinct odour which was not very pleasant especially when coasting with low draught
- *Ecoal50* had a feint sulphurous smell when coasting with low draught
- *Wildfire, Wildfire (Low chlorine)and Heritage blend 4* were similar to Ffos-y-fran
- *Heritage blend 3 (Low chlorine)* had a very low odour

Fuel composition and calorific value

Proximate analysis information and calorific values provided by CPL:-

PROXIMATE - Steam Engine Fuel	Moisture (ar)	Ash (db)	Volatile (db)	Sulphur (db)	Fixed Carbon	Gross Calorific Value kJ/kg (Typical) (db)	Crush Strength	Solid Density kg/m3 (db)	Bulk Density loose Gross kg/m3 (db)	Carbon	Cholrine	Hydrogen	Nitrogen
Natural Coals													
Ffos-y-Fran	3.2	5.5	13.3	0.92	78	32824	150-200kg	1298.6	739.5	88.6	0.07	4.41	1.5
Production Stock													
Ecoal50	9.5	7	20	1.85	73	33675	200kg	1157.5	677.8	80.7	0.31	3.98	1.61
Wildfire	1.1	6	19.7	1.97	74.3	31636	240kg	1055.3	667.7	80.9	0.18	3.91	1.43
Trial Blends													
Heritage Blend 1	19.3	7.7	12.4	1.14	79.9	31041	XXXX	XXXX	XXXX	XXXX	0.18	XXXX	XXXX
Heritage Blend 2	7.8	7.2	12.5	0.82	80.3	30887	200kg	1236.3	677.9	XXXX	0.24	XXXX	XXXX
Heritage Blend 3 Smokeless (Feb 22)	3.9	7.6	16.7	0.81	75.7	29648	288kg	1129.5	683.3	81.2	0.28	2.9	1.33
Heritage Blend 4 NON Smokeless (Feb 22)	1.2	6.4	26	0.84	67.6	29433	120kg	1112.8	682.6	77.4	0.3	3.68	1.34

(ar) as received
(db) dry basis

Fuel composition and calorific value

Ash fusion temperatures provided by CPL:-

	Ffos	Ecoal50	Wildfire	HB1	HB2	HB3	HB4
ASH FUSION TEMPERATURES REDUCING							
Initial Deformation Reducing °C	1300	1240	1190	1190	1220	1270	1270
Softening Temperature Reducing °C	1320	1280	1270	1200	1250	1320	1280
Hemispherical Temperature Reducing °C	1350	1300	1340	1210	1260	1340	1290
Flow Temperature Reducing °C	1370	1300	1360	1230	1270	1350	1310
ASH FUSION TEMPERATURES OXIDISING							
Initial Deformation Oxidising °C	1290	1250	1240	1180	1270	1240	1270
Softening Temperature Oxidising °C	1350	1260	1270	1220	1300	1320	1280
Hemispherical Temperature Oxidising °C	1370	1270	1290	1230	1310	1340	1300
Flow Temperature Oxidising °C	1390	1280	1340	1250	1320	1370	1330

Summary conclusions *Ecoal* trials– *Phases 3 and 4*

***Six varieties of Ecoal were* tested against *Ffos-y-fran coal* under '*Demanding work conditions'* and based on the results of the tests and observation from the footplate we conclude:-**

- Steaming capability ranges between free and adequate
  - With *Ffos-y-fran , Wildfire (Low chlorine) and Ecoal 50* the locomotive steamed freely
  - With *Wildfire and Heritage blend 4* the locomotive steamed satisfactorily
  - But with *Heritage blend 3, and Heritage blend 3 (Low chlorine)* steaming was only adequate
- The consumption of all *Ecoal* samples was greater than *Ffos-y-fran* with *Ecoal50* showing the least increase at 15.1% and *Heritage blend 3* the greatest at 52%
- Unburnt fuel loss is higher as indicated by the greater amount of smokebox char and/or increased spark and cinder throwing
- A thicker firebed was required as the particle diameter was greater than steam coal
- The firebed took longer to reach operating temperature after leaving Aylsham
- All the firing rates fall within the 'Demanding work ' category

Summary conclusions *Ecoal* trials– *Phases 3 and 4*

***Six varieties of Ecoal were* tested against *Ffos-y-fran coal* under '*Demanding work conditions'* and based on the results of the tests and observation from the footplate we conclude:-**

- Ignition time was similar for all the fuels apart from *Heritage blend 3 and Heritage blend 3 (Low chlorine)* which were slightly slower
- Smoke colour was acceptable
  - *Ecoal50 and Wildfire (Low chlorine)* had a comparative smoke colour to that of *Ffos-y-fran coal*
  - *Wildfire and Heritage blends 3 + 4* produced slightly more smoke although this was controllable
  - *Heritage blend 3 (Low chlorine) produced* less smoke than *Ffos-y-fran coal*
- There was little apparent clinker and no birds nests formed on any of the tests
- Ash and char in the ashpan was generally increased with all the *Ecoals [*with the exception of *Wildfire (Low chlorine)]* with *Heritage blend 3 (Low chlorine)* showing the greatest increase

Summary conclusions *Ecoal* trials– *Phases 3 and 4*

***Six varieties of Ecoal were* tested against *Ffos-y-fran coal* under '*Demanding work conditions'* and based on the results of the tests and observation from the footplate we conclude:-**

- The qualitative impressions of the footplate crew for smoke odour are:-
  - *Heritage blend 3* had a distinct odour which was not very pleasant especially when coasting with low draught
  - *Ecoal50* had a feint sulphurous smell when coasting with low draught
  - *Wildfire, Wildfire (Low chlorine)and Heritage blend 4* were similar to Ffos-y-fran
  - *Heritage blend 3 (Low chlorine)* had a very low odour
- The Eco credentials of all but Ecoal50 would probably not enable users to make a marketing claim

Any environmental benefit of a reduced coal content with the balance derived from renewable sources, *maybe partially or completely offset by increased consumption*

The reasons for the increased Ecoal fuel consumption compared to natural coal requires future investigation as this has *financial, fire risk, health and environmental implications*

BVR Environmental Award

ELR & KWVR Trials

KWVR Trials

Test Engines

HB3 Low Chlorine – tested on 78022 & 5643
Wildfire Low Chlorine – tested on 78022, No6 and 51456

ELR – L&YR Class 23 - 51456

GWR 5643

L&YR 52322

KWVR – BR Standard 2MT - 78022

Objective

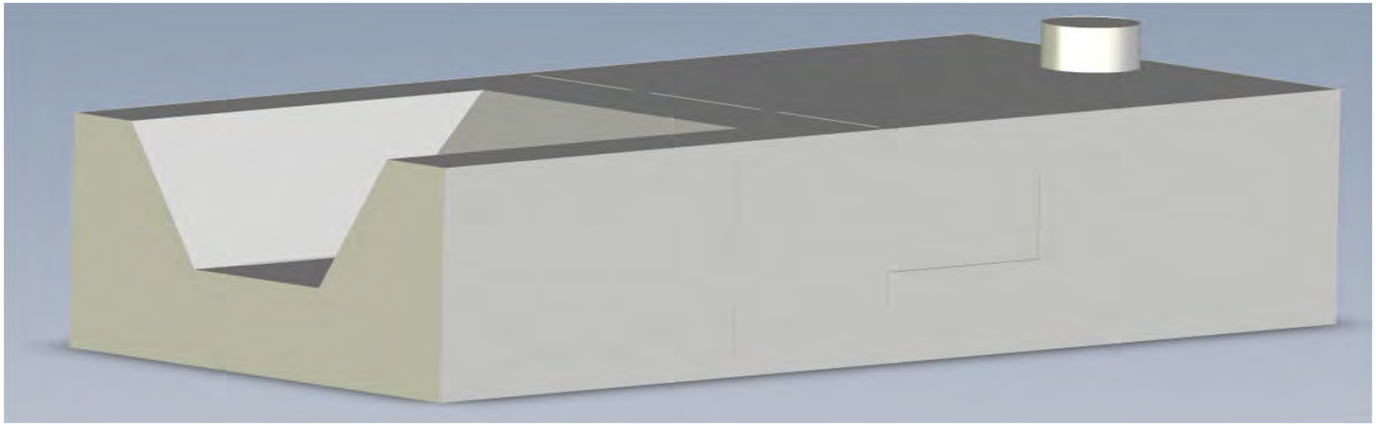
The overall objective of the fuel trials was to assess the performance of CPL fuels compared to natural *Steam Coal (Shotton/Ffos-y-fran)*.

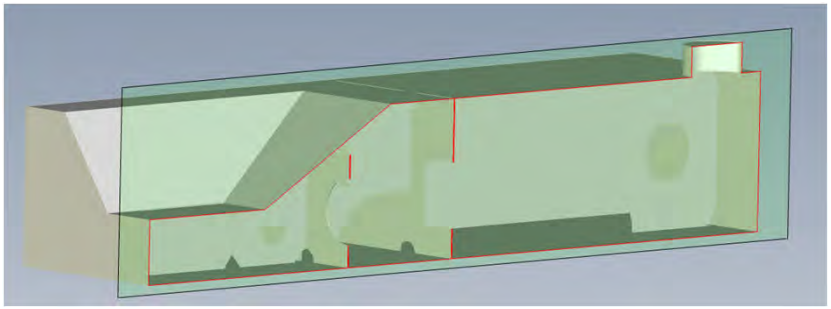
Feedback to CPL results to improve performance

Trial arrangements

- Train 1 - 3 coaches plus diesel – 231.1 tons
- Once viability of the fuel was proved on the first run, the diesel was removed and two additional coaches were added
- Train 2, 3 and 4 – 5 coaches - 245.1 tons
- Data was collected on Trains 2,3 and 4
- Data is presented for Trains 2,3 and 4 in the uphill direction only
  - ie Keighley to Oxenholme
- The trials were with Ecoal Heritage Blend 2
- Comparative trials with coal are planned at a later date

78022 Tender Tank CAD Model



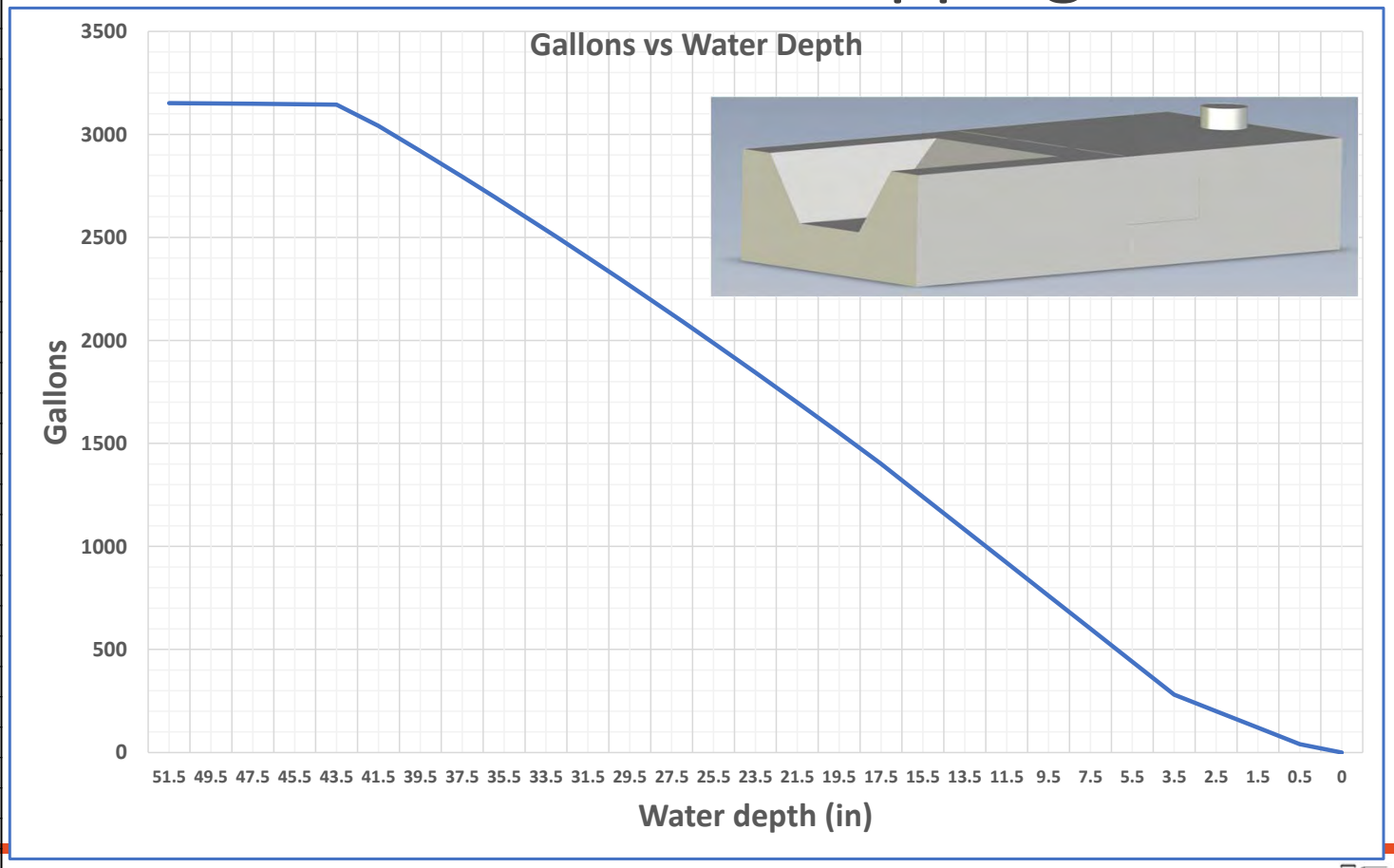


Test Method

- Fuel Consumption
  - Measured by counting number of shovels fired
    - Prior to the test, 10 shovelfuls of coal were weighed and the average shovelful calculated
- Water Consumption
  - The tender tank has been replaced in preservation and the water scoop mechanism removed, with the result that the tender is 152 gallon greater in capacity.
  - A CAD model of the tank was produced and the volume of the tank at different levels calculated. From this a chart of water capacity against depth of water was produced.
  - Water levels were measured at either and the line and using the chart water usage was calculated

78022 Tender Tank Mapping

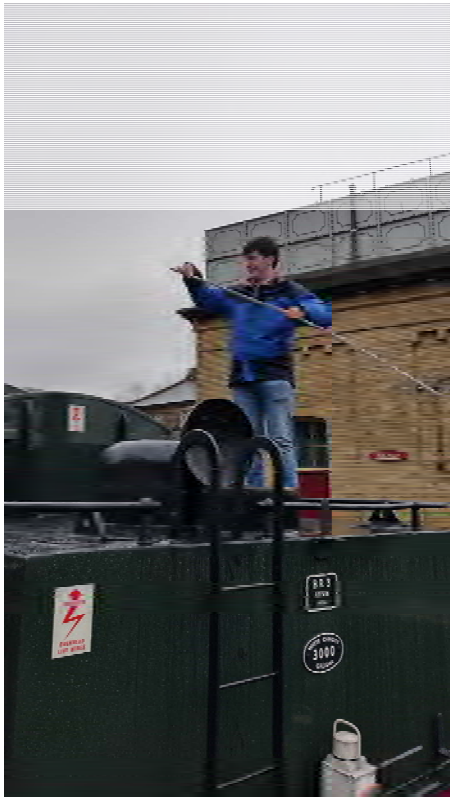
Water Depth		
in	in	Gallons
51.5	0	3152
49.5	2	3150
47.5	4	3148
45.5	6	3146
43.5	8	3145
41.5	10	3041
39.5	12	2919
37.5	14	2794
35.5	16	2667
33.5	18	2536
31.5	20	2403
29.5	22	2267
27.5	24	2128
25.5	26	1987
23.5	28	1844
21.5	30	1699
19.5	32	1551
17.5	34	1401
15.5	36	1241
13.5	38	1081
11.5	40	921
9.5	42	760
7.5	44	600
5.5	46	440
3.5	48	280
2.5	49	200
1.5	50	120
0.5	51	40
0	51.5	0



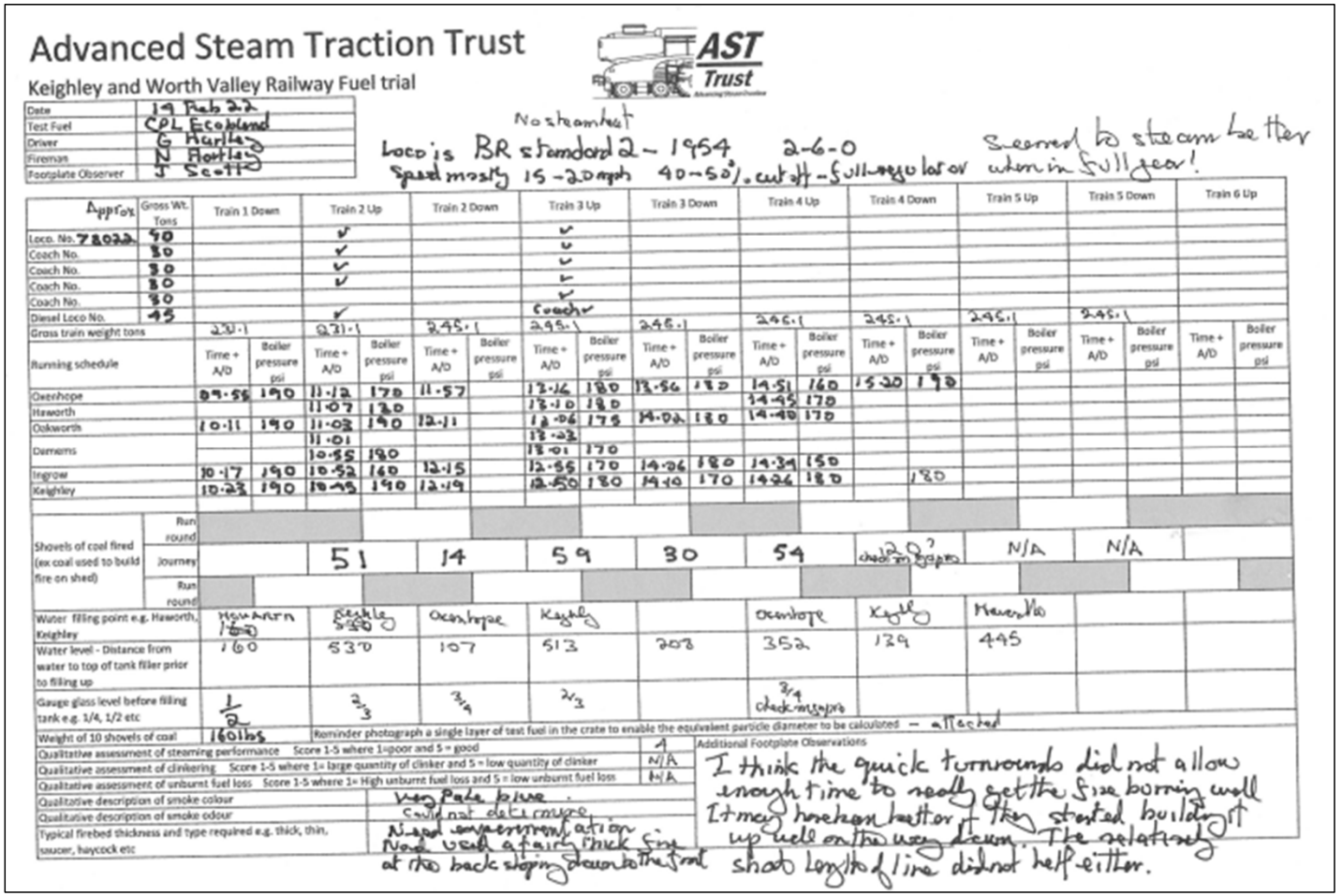
Limitations of the Test Method

- Measurements of coal fired are not precise as it relies on averages rather than an absolute measures.
- Water use measurements are subject to error because the boiler water level varied between ¼ and full when tender water levels were measured.
- Because the coal fired and the water usage measurements are proximates the results from these trials should be looked on as INDICATIVE only
- Could not measure smokebox char or firebox ash or clinker.

4000 kg of biocoal,averaging shovelful's, 'tender dipping'



Footplate Observer Log



Advanced Steam Traction Trust

AST Trust

Keighley and Worth Valley Railway Fuel trial

Date	19 Feb 22
Test Fuel	CPL Ecobland
Driver	G Hurlay
Fireman	N Hartley
Footplate Observer	J Scott

No steam test

Loco is BR standard 2 – 1954 2-6-0

Speed mostly 15 – 20 mph 40 – 50% cut off – full regulator

Seemed to steam better when in full gear!

Approx	Gross Wt. Tons	Train 1 Down		Train 2 Up		Train 2 Down		Train 3 Up		Train 3 Down		Train 4 Up		Train 4 Down		Train 5 Up		Train 5 Down		Train 6 Up	
Loco. No. 78022	50			✓				✓													
Coach No.	30			✓				✓													
Coach No.	30			✓				✓													
Coach No.	30			✓				✓													
Coach No.	30							✓													
Diesel Loco No.	45			✓				Coach ✓													
Gross train weight tons		220·1		221·1		245·1		295·1		246·1		246·1		245·1		245·1		245·1			
Running schedule		Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi	Time + A/D	Boiler pressure psi
Oxenhope		09·55	190	11·12	170	11·57		13·16	180	13·56	180	14·51	160	15·20	190						
Haworth				11·07	180			13·10	180			14·45	170								
Oakworth		10·11	190	11·03	190	12·11		12·56	175	14·02	180	14·40	170								
Damems				11·01				12·23													
				10·55	180			12·01	170												
Ingrow		10·17	190	10·52	160	12·15		12·55	170	14·06	180	14·34	150								
Keighley		10·23	190	10·45	190	12·19		12·50	180	14·10	170	14·26	180		180						
Shovels of coal fired (ex coal used to build fire on shed)	Run round																				
	Journey			51		14		59		30		54		check in cages		N/A		N/A			
	Run round																				
Water filling point e.g. Haworth, Keighley		Haworth 160		Keighley 530		Oxenhope		Keighley				Oxenhope		Keighley		Haworth					
Water level - Distance from water to top of tank filler prior to filling up		160		530		107		513		208		352		139		445					
Gauge glass level before filling tank e.g. 1/4, 1/2 etc		1/2		2/3		3/4		2/3				3/4 check in cages									
Weight of 10 shovels of coal		160lbs		Reminder photograph a single layer of test fuel in the crate to enable the equivalent particle diameter to be calculated – attached																	
Qualitative assessment of steaming performance		Score 1-5 where 1=poor and 5 = good																		4	
Qualitative assessment of clinkering		Score 1-5 where 1= large quantity of clinker and 5 = low quantity of clinker																		N/A	
Qualitative assessment of unburnt fuel loss		Score 1-5 where 1= High unburnt fuel loss and 5 = low unburnt fuel loss																		N/A	
Qualitative description of smoke colour		Very Pale blue.																			
Qualitative description of smoke odour		could not detect smoke.																			
Typical firebed thickness and type required e.g. thick, thin, saucer, haycock etc		Need experimentation Now used a fairly thick fire at the back sloping down to the front																			

Additional Footplate Observations

I think the quick turnrounds did not allow enough time to really get the fire burning well It may have been better if they started building it up well on the way down. The relatively short length of line didn't help either.

KWVR

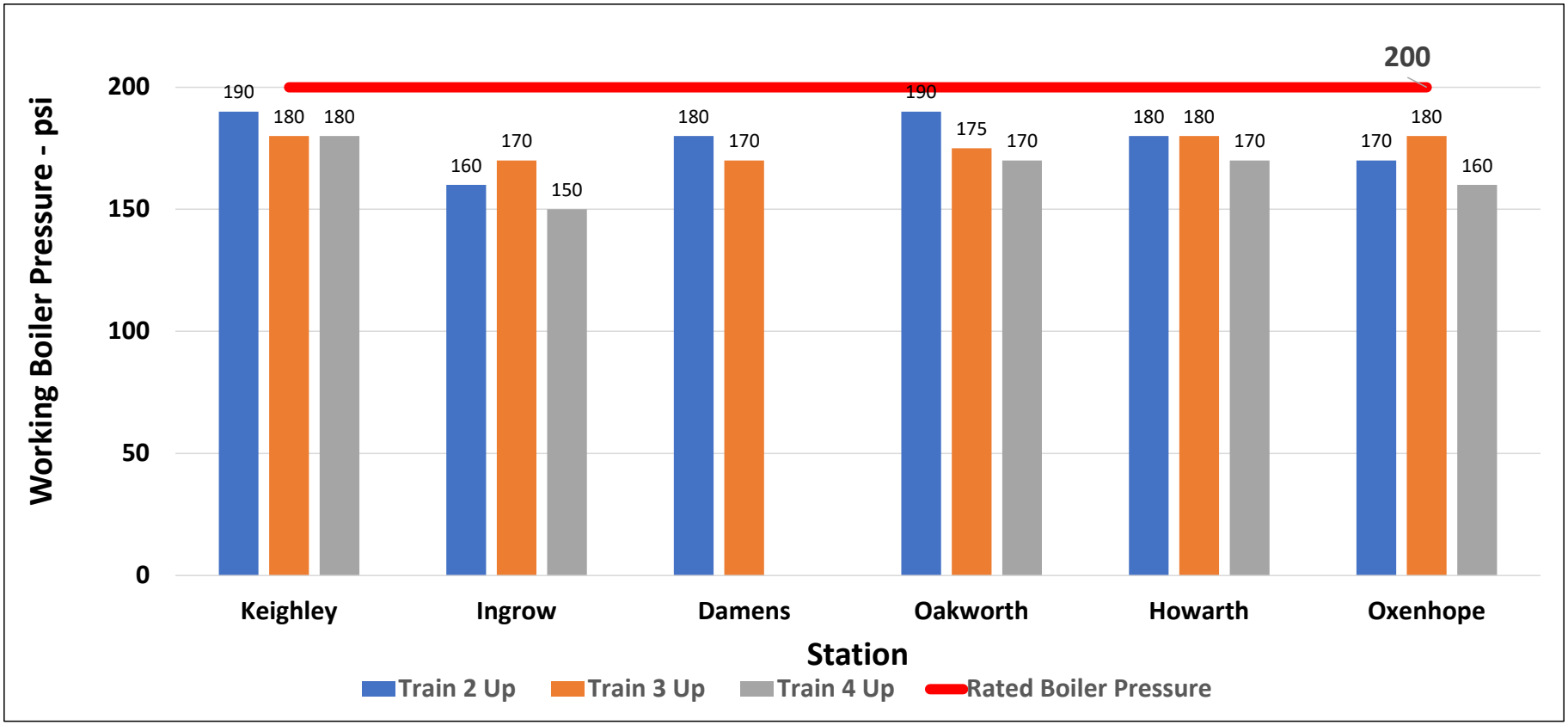
- First time an Ecoal product had been tried at the KWVR
- With familiarity better results may be possible
- Post the test on 15/2/22 when the locomotive was being prepared for its next duties
  - clinker was found in the firebed
  - a green patina was seen in areas of the firebox
  - a blue/white deposit was seen in the firebox and the smokebox (also seen on the BVR trials)

Data	Train 2 up 10.45 Ex Keighley	Train 3 up 12.50 Ex Keighley	Train 4 up 14.25 Ex Keighley
Timetable – Keighley to Oxenhope	25 mins	25 mins	25 mins
Actual Times – Keighley to Oxenhope	27 mins	27 mins	26 mins
No of Shovels*	51	59	54
Weight of Fuel Fired - lbs	816	944	864
Water Consumed – gallons**	530	513	352

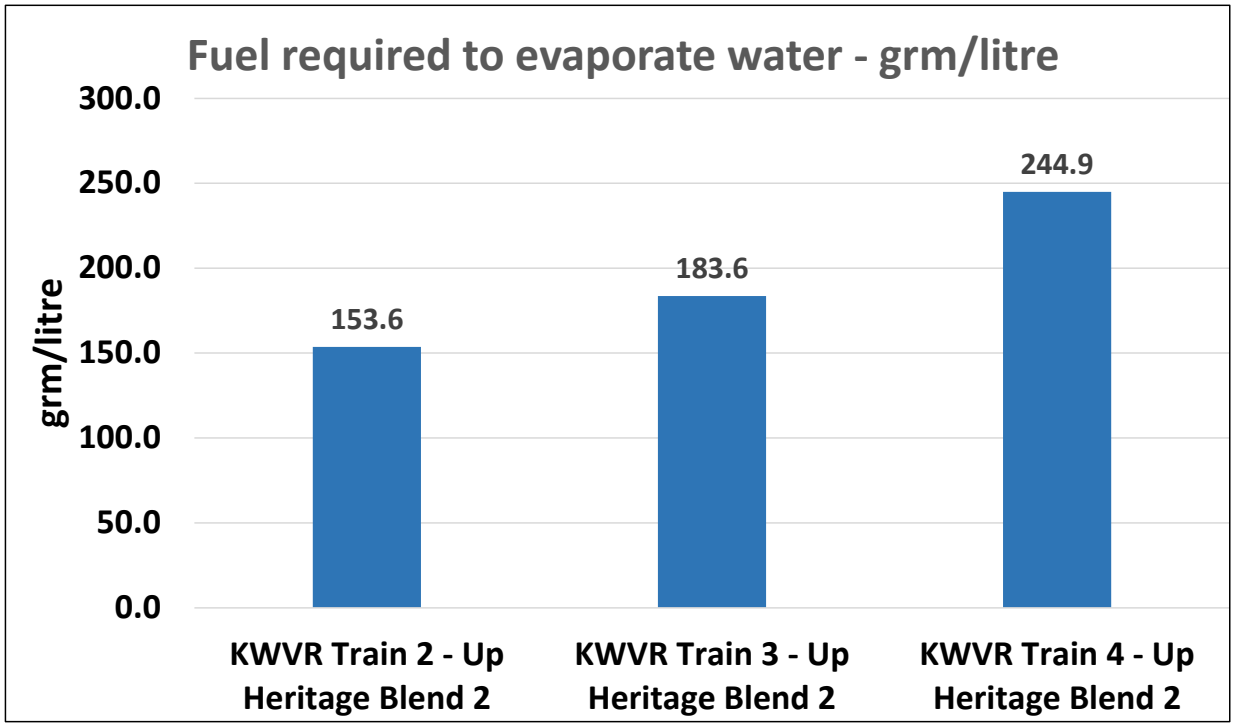
*A test prior to the first train found that the weight of 10 shovels was 160lbs

** Water consumption was measured by dipping the tank to establish water level. A CAD model of the tank was used to give gallons vs water level

Boiler Pressure – Heritage Blend 2



Fuel required for evaporation



Observation:-
The evaporation deteriorated throughout the day – ie more fuel was shovelled to evaporate the water on each run – possibly because of the formation of clinker throughout the day

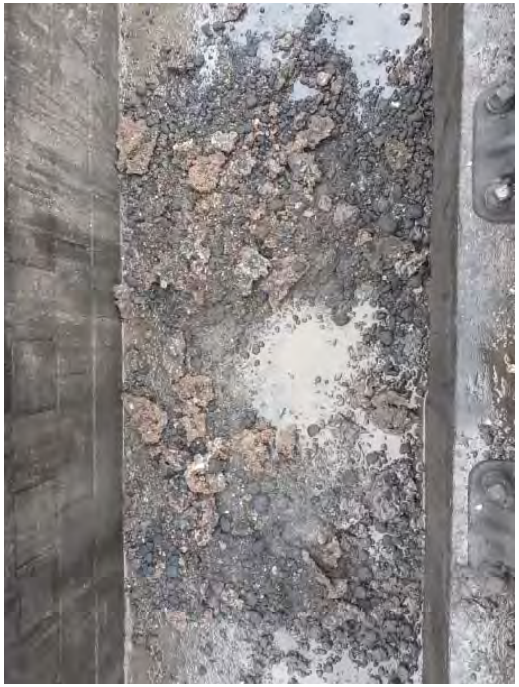
Firebed condition during cleaning– 15/2/22

Before dropping fire

Front half after dropping back half

Remains of fire recovered from grate

Clinker



Ash from hopper

Clinker

Clinker

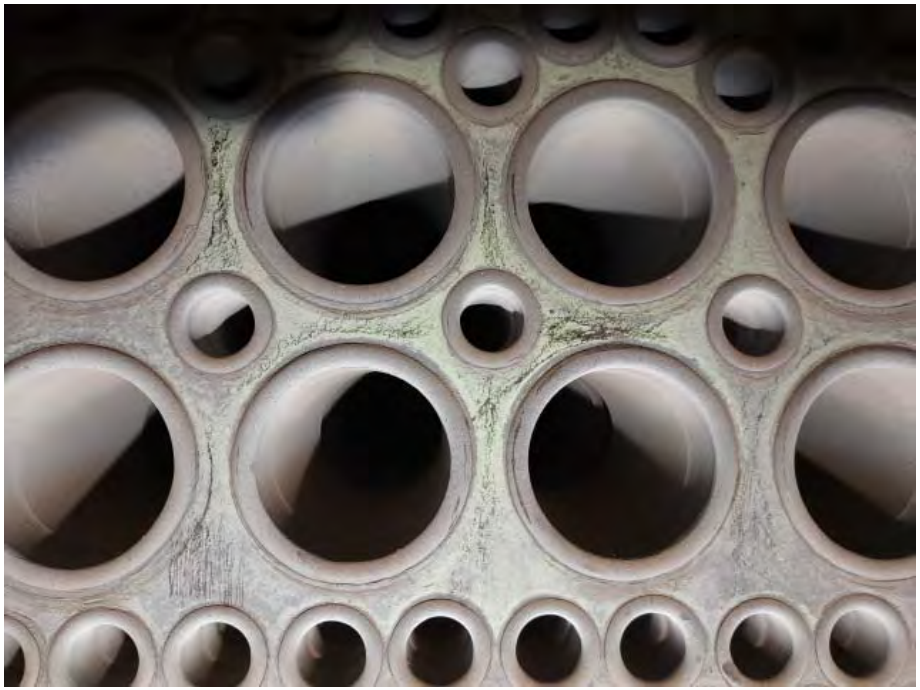
78022 - Firebox – 15/2/22

Normal Firebox
NB with new brickarch, so no deposits under brickarch

Firebox – 78022 – 15/2/22
With pre-existing deposits under brickarch

78022 Firebox – Green Patina - 15/2/22

Firebox Tubeplate



Close up - Firebox Tubeplate

78022 – Smokebox – blue/white colour – 14/2/22

Smokebox Colours - 78022 & Smokebox BVR No6

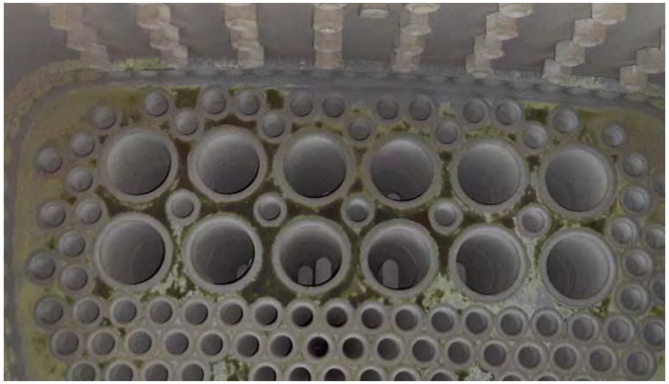
78022

BVR No6

Side by side comparison of tubeplates

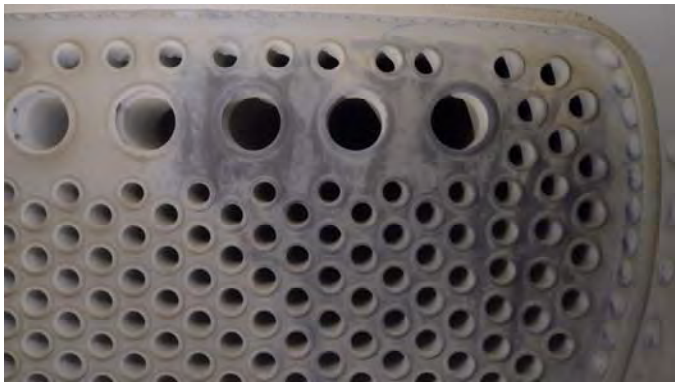
78022 – HB2

A thin patina, light green in colour around upper parts of the tube plate that could be washed off with water



78022 – HB3

A heavier patina , darker green in colour that could be washed off with water



5643 – HB3

Dusty yellowish tinged coating on tube plate that could be rubbed off with a cloth to reveal normal colour from burning coal

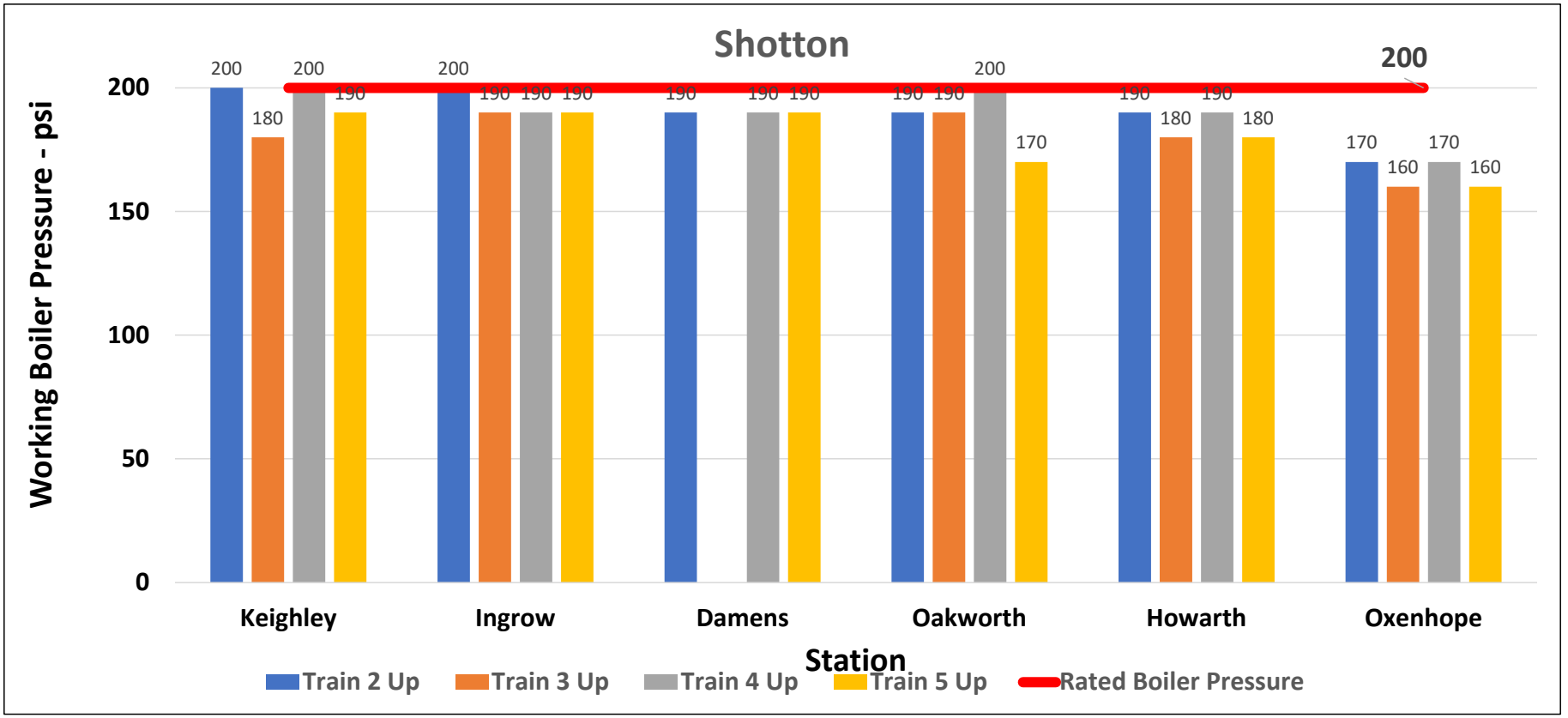
Data – Shotton Coal – 25/02/22 Keighley to Oxenhope Fuel figures include amount to make up fire at Keighley	Train 2 up 10.50 Ex Keighley	Train 3 up 12.30 Ex Keighley	Train 4 up 14.25 Ex Keighley	Train 5 up 16.00 Ex Keighley
Timetable – Keighley to Oxenhope	25 mins	25 mins	25 mins	25 mins
Actual Times – Keighley to Oxenhope	31 mins	29 mins	31 mins	29 mins
Running Times – Keighley to Oxenhope	23 mins	24 mins	23 mins	25 mins
No of Shovels*	87	76	70	70
Weight of Fuel Fired - lbs	855	747	688	688
Water Consumed – gallons**+	470	445	476	476

*A test prior to the first train found that the weight of 10 shovels was 98.3lbs

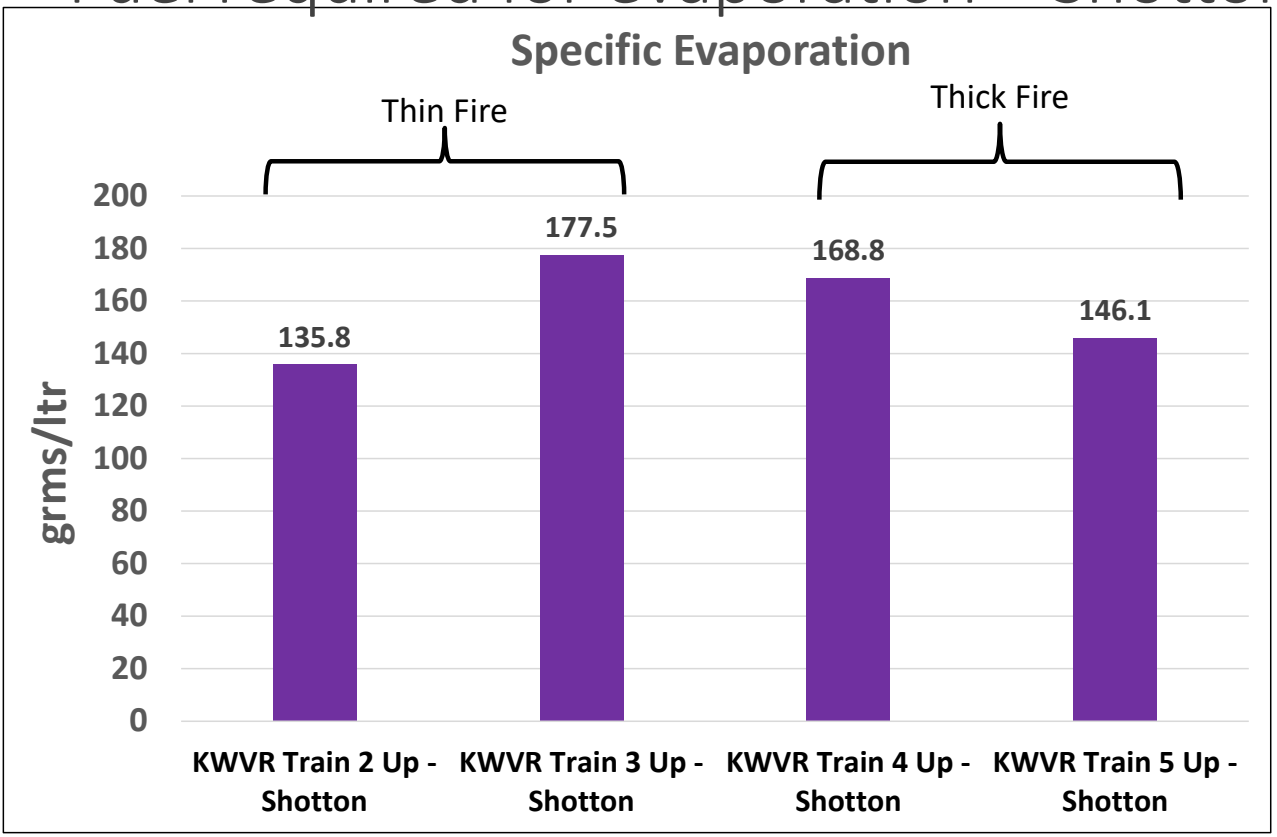
** Water consumption was measured by dipping the tank to establish water level. A CAD model of the tank was used to give gallons vs water level.

+Boiler water level when tender water level was measured varied between 1/4 and ¾ full and leads to an inaccuracy in water consumption

Boiler Pressure – Shotton Coal – 25/02/22



Fuel required for evaporation – Shotton Coal – 25-2-22



Observation:-

a) For Trains 4 & 5 the driver and fireman exchanged duties

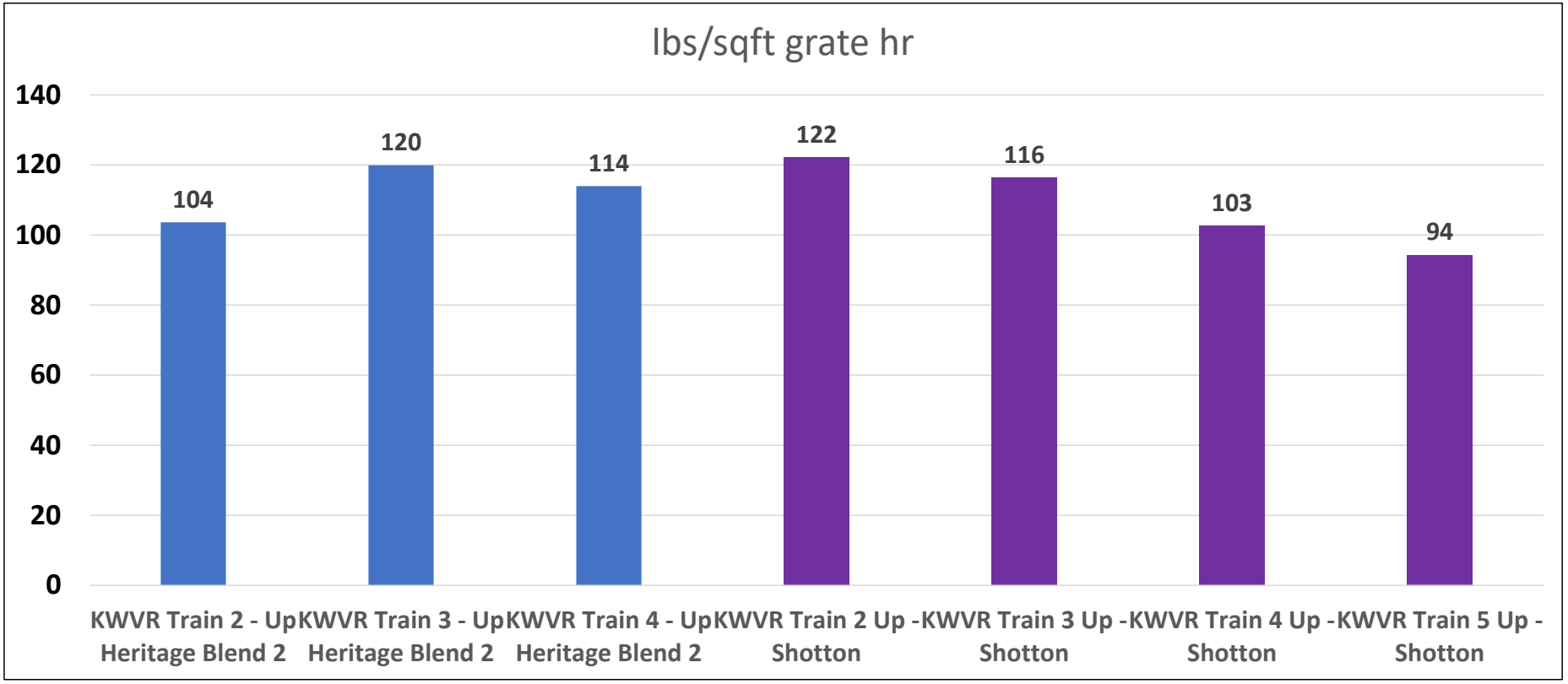
b) Trains 1 & 2 were run with a thin fire and a little and often technique and not built up on down run

c) Trains 3 & 4 were run with thick fire which was built up on the down run

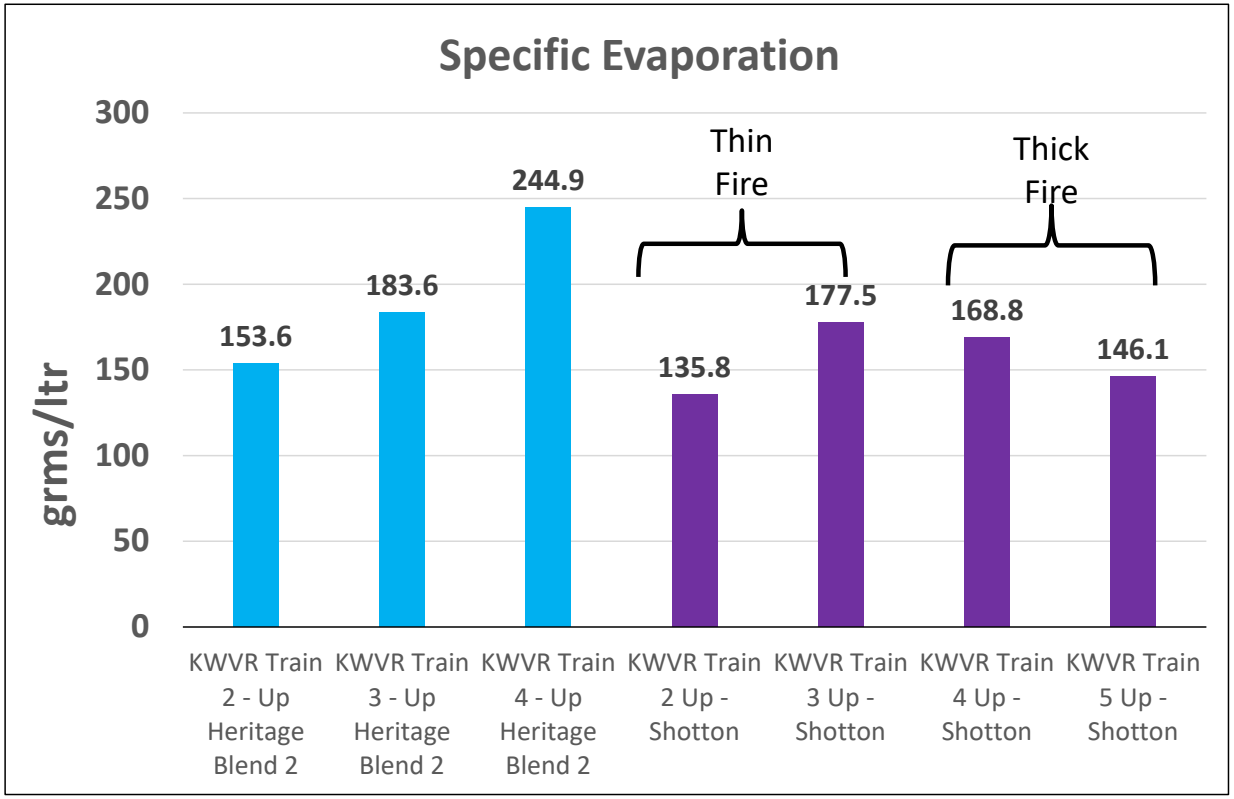
   i. *This has not been taken into account in this chart*

Firing Rate

all uphill runs are in the 'Demanding Rate Category



Comparison – Heritage Blend 2 & Shotton



Observation:-

a) For Trains 4 & 5 the driver and fireman exchanged duties
   a) For Trains 4 &5 the weight per shovel was less than Trains 2 &3, however it was not measured.
b) Trains 1 & 2 were run with a thin fire and a little and often technique and not built up on down run
c) Trains 3 & 4 were run with thick fire which was built up on the down run
   i. *This has not been taken into account in this chart*
d) Heritage Blend 2 - the evaporation deteriorated throughout the day – ie more fuel was shovelled to evaporate the water on each run – possibly because of the formation of clinker throughout the day

Chlorine content

- At the KWVR, after using CPL Heritage Blend 2 during the post trial firebox examination of 78022, a green patina was noted in the firebox. This was again seen post the trials with HB3 and Wildfire.
- To date this has not been reported on other locomotives that have used the CPL Products
- Chlorine contents of these fuels was high compared with coal:-

Fuel	Chlorine Content
Heritage Blend 2	.24%
Heritage Blend 3	.28%
Wildfire	.18%

Coal	Chlorine Content
Ffos-y-fran	.07%
Kazak	.08%
Shotton	.02%

- After feedback from the HRA and users, CPL changed the binder and the production process to reduce the chlorine content and these are now :-

Fuel	Chlorine Content
Heritage Blend 3 (R)	.03%
Wildfire (R)	.02%

- On the basis of two tests on 78022, the green patina has been eliminated with the use of low chlorine fuels

78022 Firebox condition – side by side comparison

Pictures courtesy of Ralph Ingham KWVR

Firebox Tubeplate with high chlorine HB3

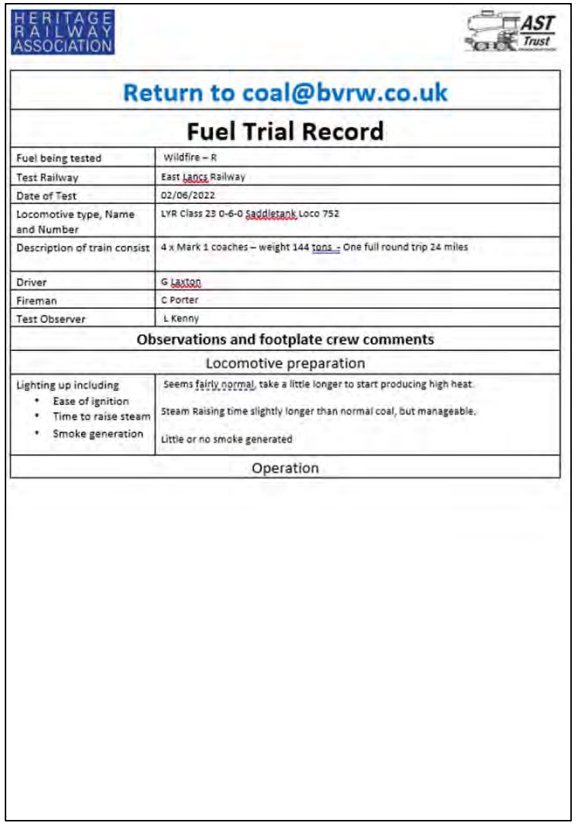
Firebox Tubeplate with low chlorine Wildfire

A problem with ovoids

Trial Record Sheets

JOHN HIND

Example of Fuel Trial Record Sheet - ELR



HERITAGE RAILWAY ASSOCIATION

AST Trust

Return to coal@bvrw.co.uk

Fuel Trial Record

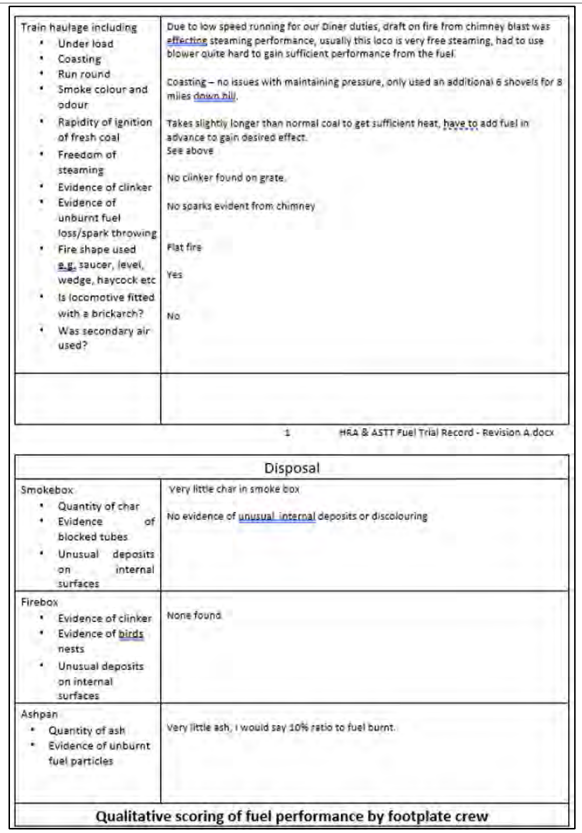
Fuel being tested	Wildfire – R
Test Railway	East Lancs Railway
Date of Test	02/06/2022
Locomotive type, Name and Number	LYR Class 23 0-6-0 Saddletank Loco 752
Description of train consist	4 x Mark 1 coaches – weight 144 tons – One full round trip 24 miles
Driver	G Laxton
Fireman	C Porter
Test Observer	L Kenny

Observations and footplate crew comments

Locomotive preparation

Lighting up including • Ease of ignition • Time to raise steam • Smoke generation	Seems fairly normal, take a little longer to start producing high heat. Steam Raising time slightly longer than normal coal, but manageable. Little or no smoke generated

Operation

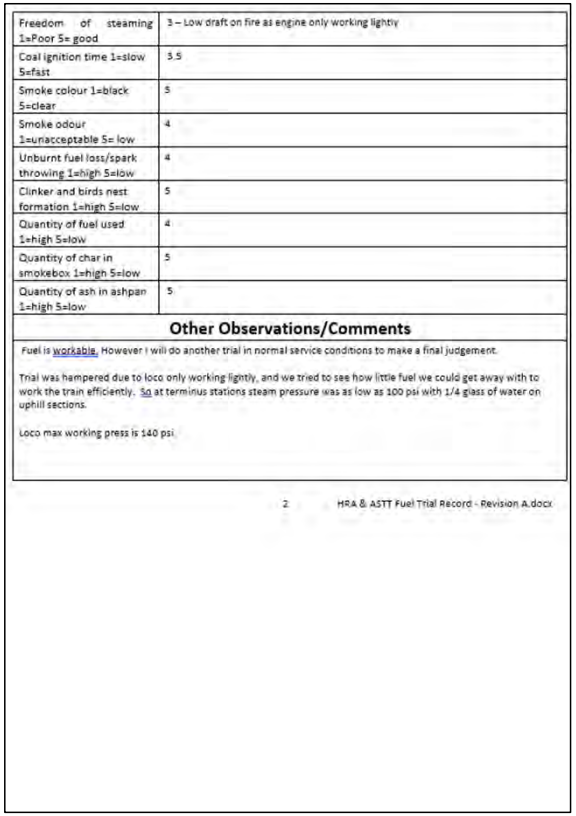


Train haulage including • Under load • Coasting • Run round • Smoke colour and odour • Rapidity of ignition of fresh coal • Freedom of steaming • Evidence of clinker • Evidence of unburnt fuel loss/spark throwing • Fire shape used e.g. saucer, level, wedge, haycock etc • Is locomotive fitted with a brickarch? • Was secondary air used?	Due to low speed running for our Diner duties, draft on fire from chimney blast was effective steaming performance, usually this loco is very free steaming, had to use blower quite hard to gain sufficient performance from the fuel. Coasting – no issues with maintaining pressure, only used an additional 6 shovels for 8 miles down hill. Takes slightly longer than normal coal to get sufficient heat, have to add fuel in advance to gain desired effect. See above No clinker found on grate. No sparks evident from chimney Flat fire Yes No

Disposal

Smokebox • Quantity of char • Evidence of blocked tubes • Unusual deposits on internal surfaces	Very little char in smoke box No evidence of unusual internal deposits or discolouring
Firebox • Evidence of clinker • Evidence of birds nests • Unusual deposits on internal surfaces	None found
Ashpan • Quantity of ash • Evidence of unburnt fuel particles	Very little ash, I would say 10% ratio to fuel burnt.

Qualitative scoring of fuel performance by footplate crew



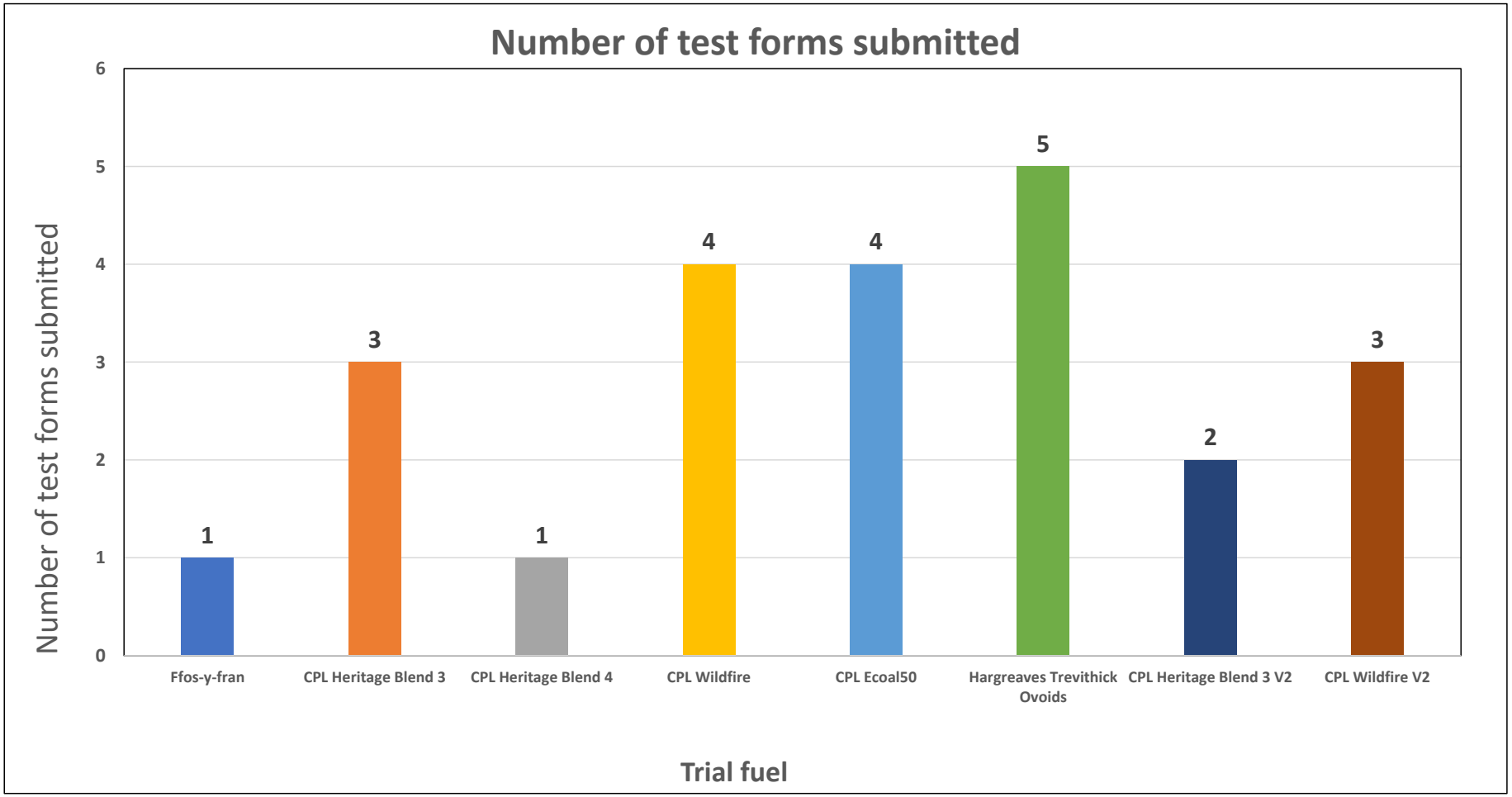
Freedom of steaming 1=Poor 5= good	3 – Low draft on fire as engine only working lightly
Coal ignition time 1=slow 5=fast	3.5
Smoke colour 1=black 5=clear	5
Smoke odour 1=unacceptable 5= low	4
Unburnt fuel loss/spark throwing 1=high 5=low	4
Clinker and birds nest formation 1=high 5=low	5
Quantity of fuel used 1=high 5=low	4
Quantity of char in smokebox 1=high 5=low	5
Quantity of ash in ashpan 1=high 5=low	5

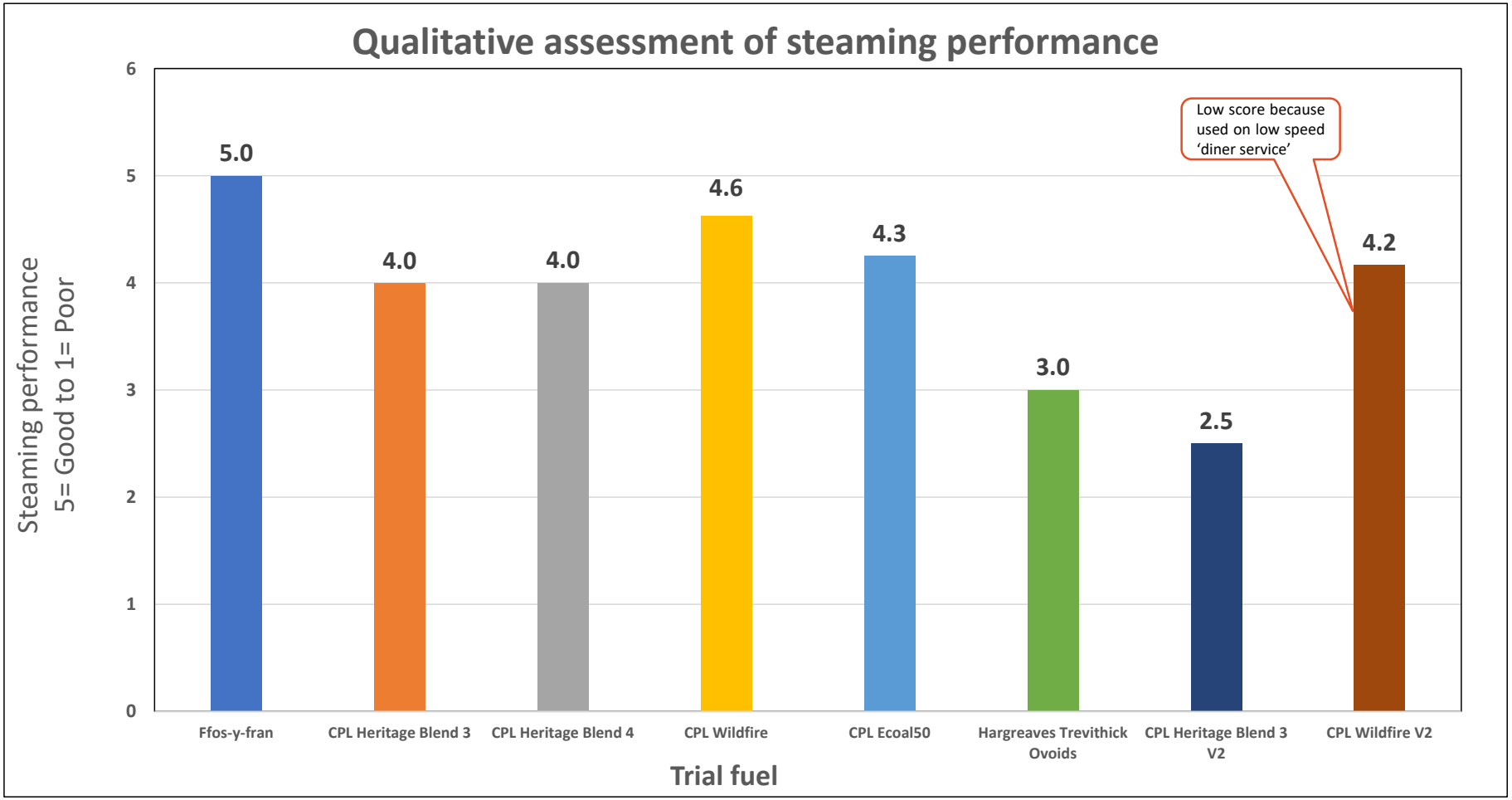
Other Observations/Comments

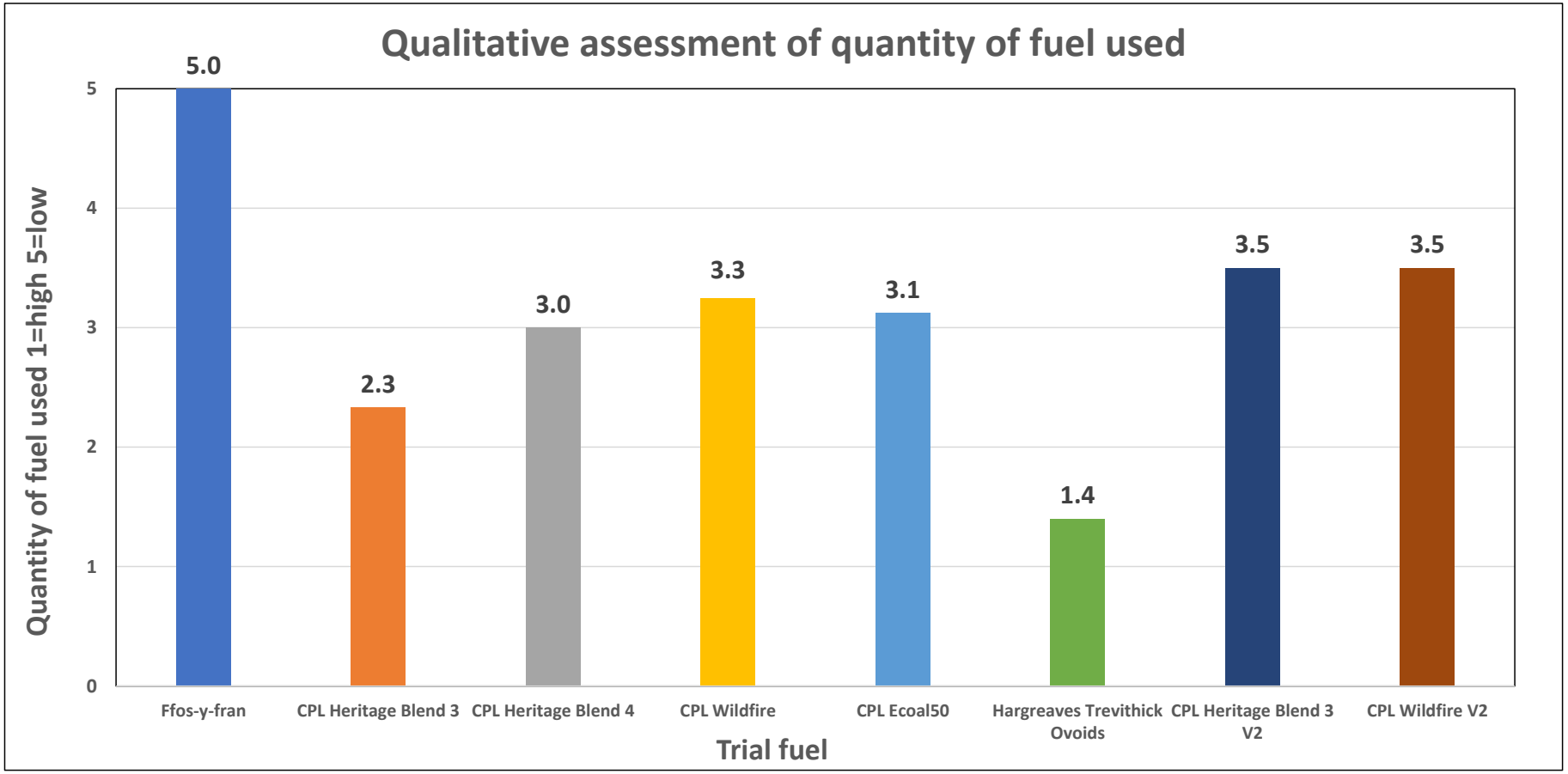
Fuel is workable. However I will do another trial in normal service conditions to make a final judgement.

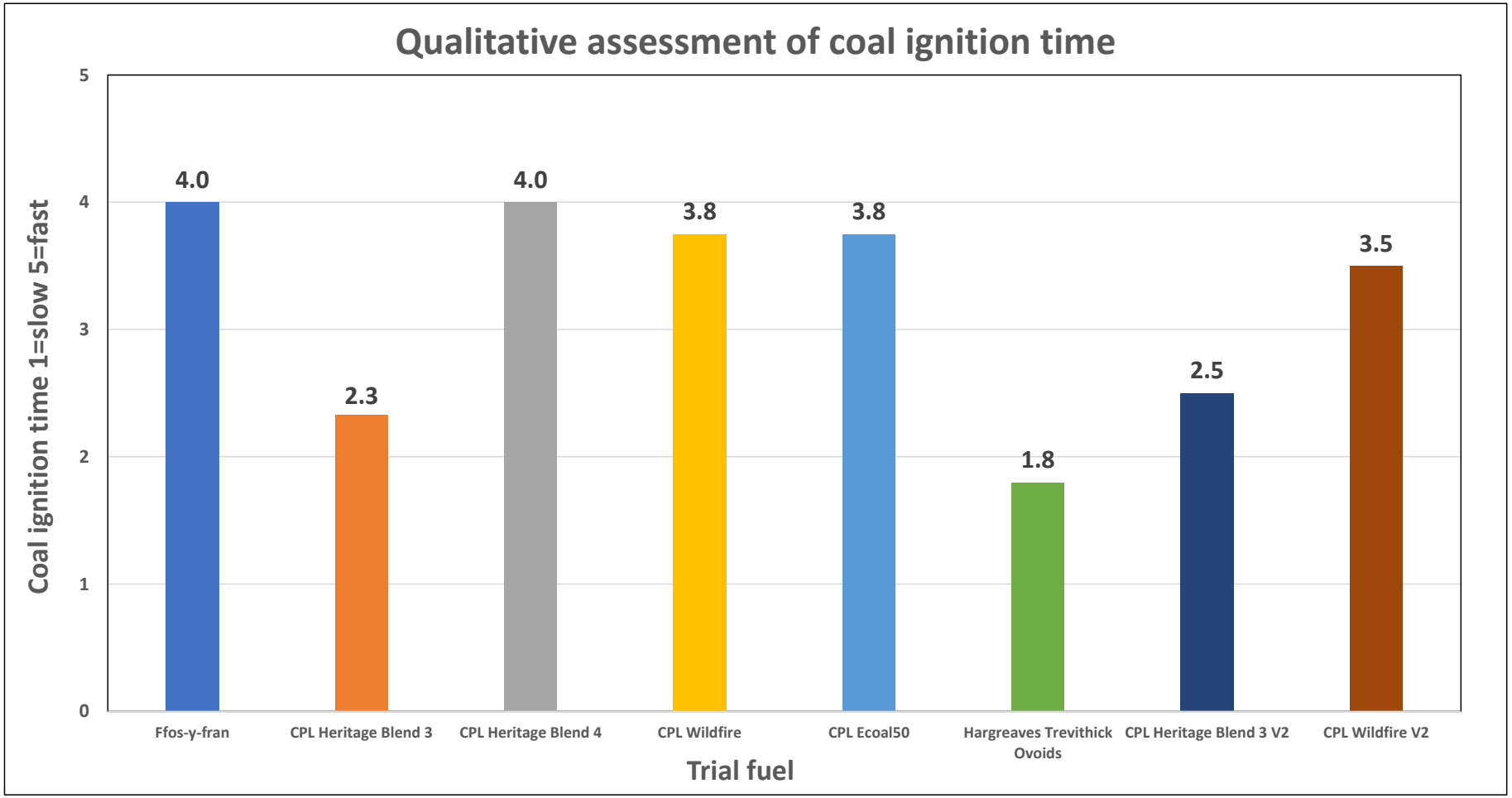
Trial was hampered due to loco only working lightly, and we tried to see how little fuel we could get away with to work the train efficiently. So at terminus stations steam pressure was as low as 100 psi with 1/4 glass of water on uphill sections.

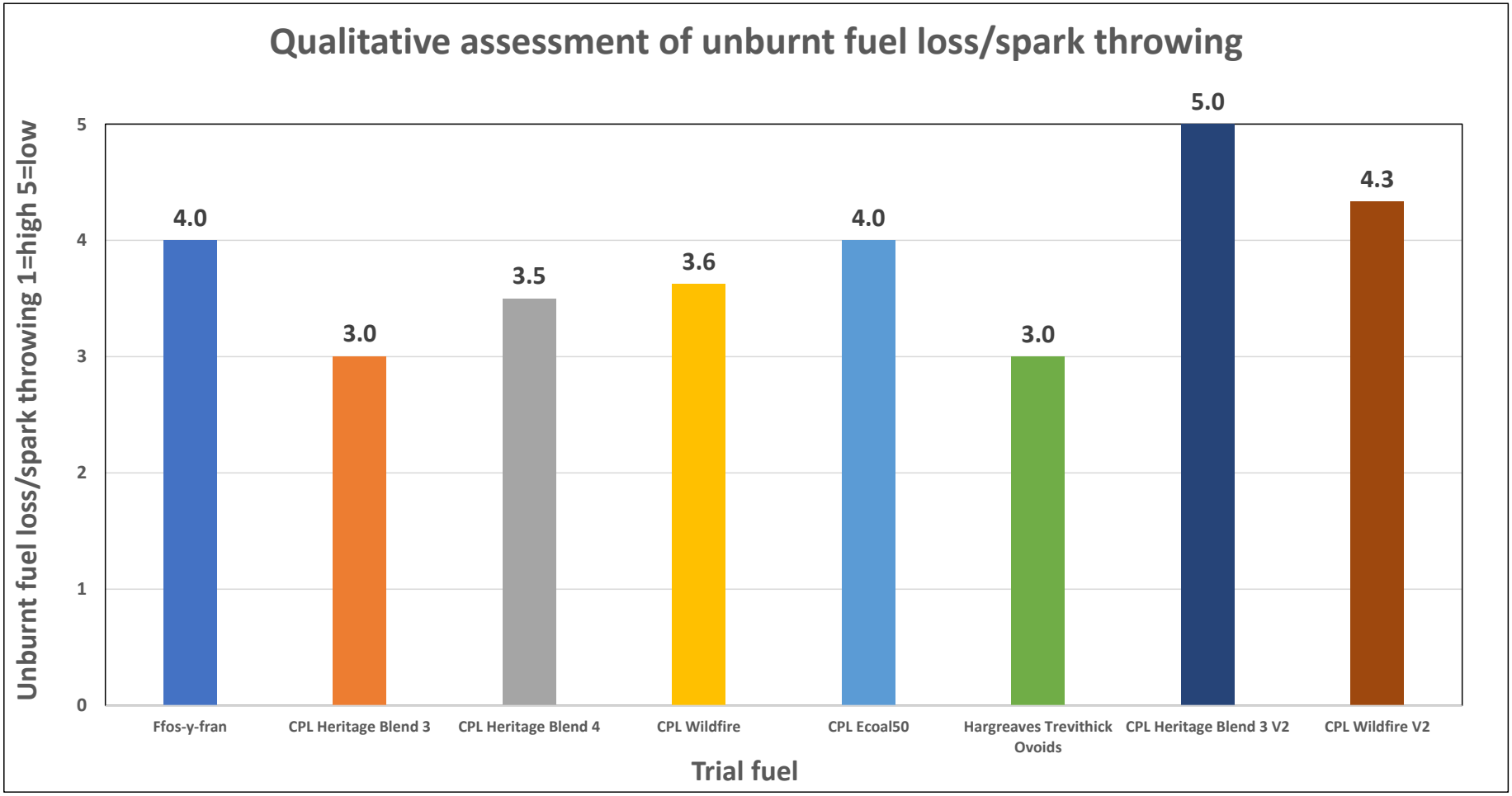
Loco max working press is 140 psi

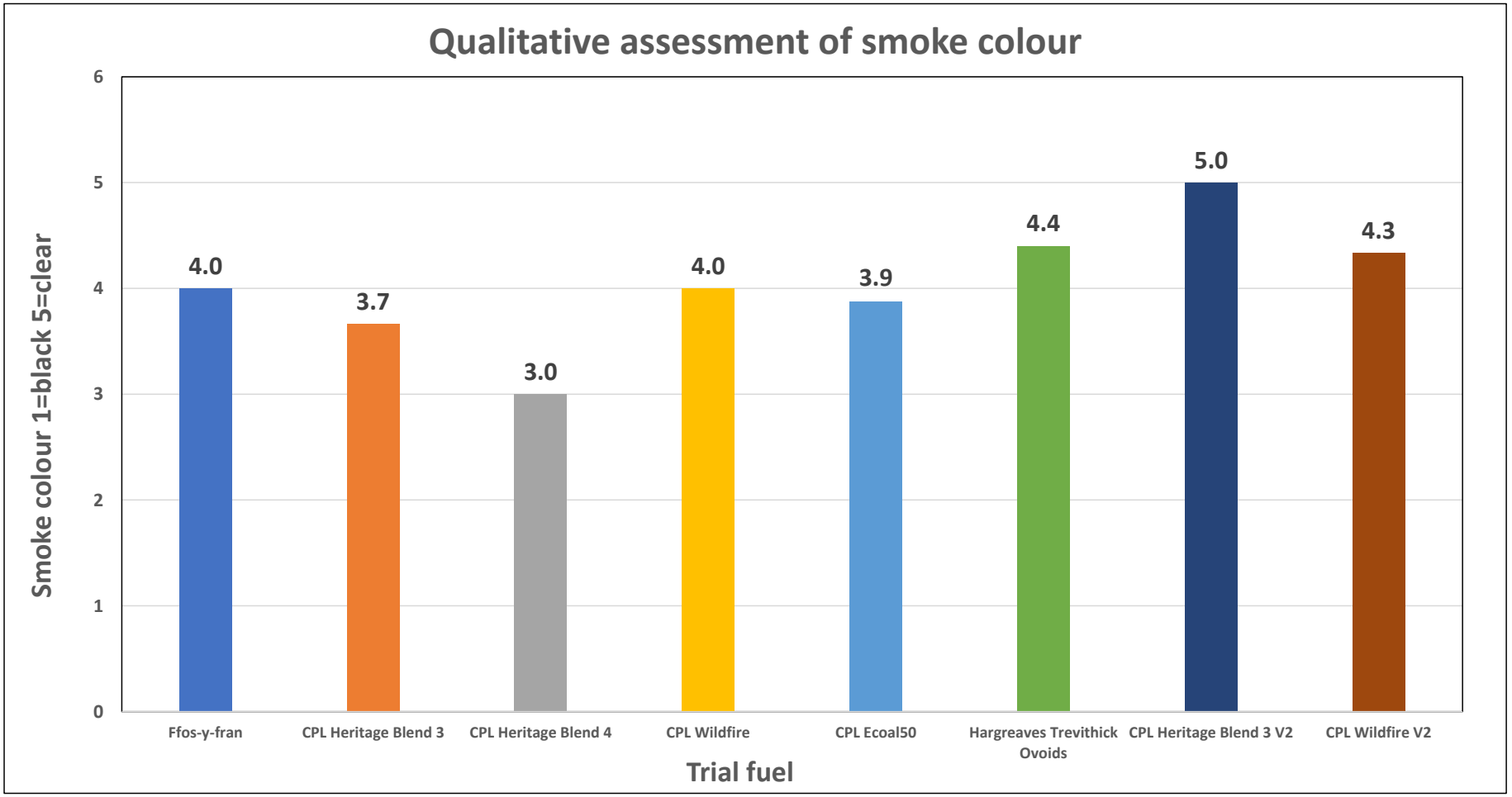

Number of test forms submitted
Number of test forms submitted
0
1
2
3
4
5
6
1
3
1
4
4
5
2
3
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel

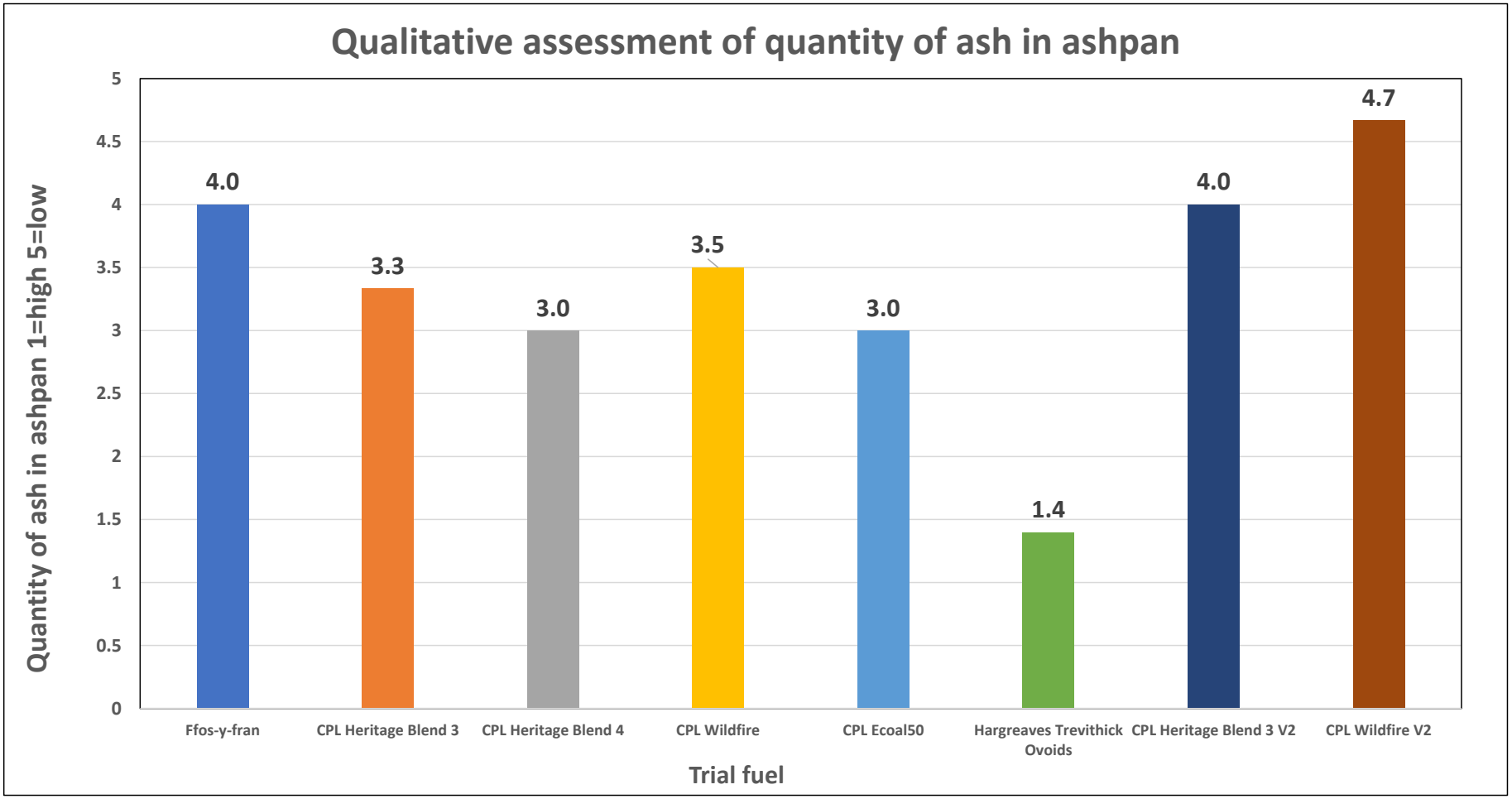

Qualitative assessment of steaming performance
Steaming performance
5= Good to 1= Poor
6
5
4
3
2
1
0
5.0
4.0
4.0
4.6
4.3
3.0
2.5
4.2
Low score because used on low speed 'diner service'
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel

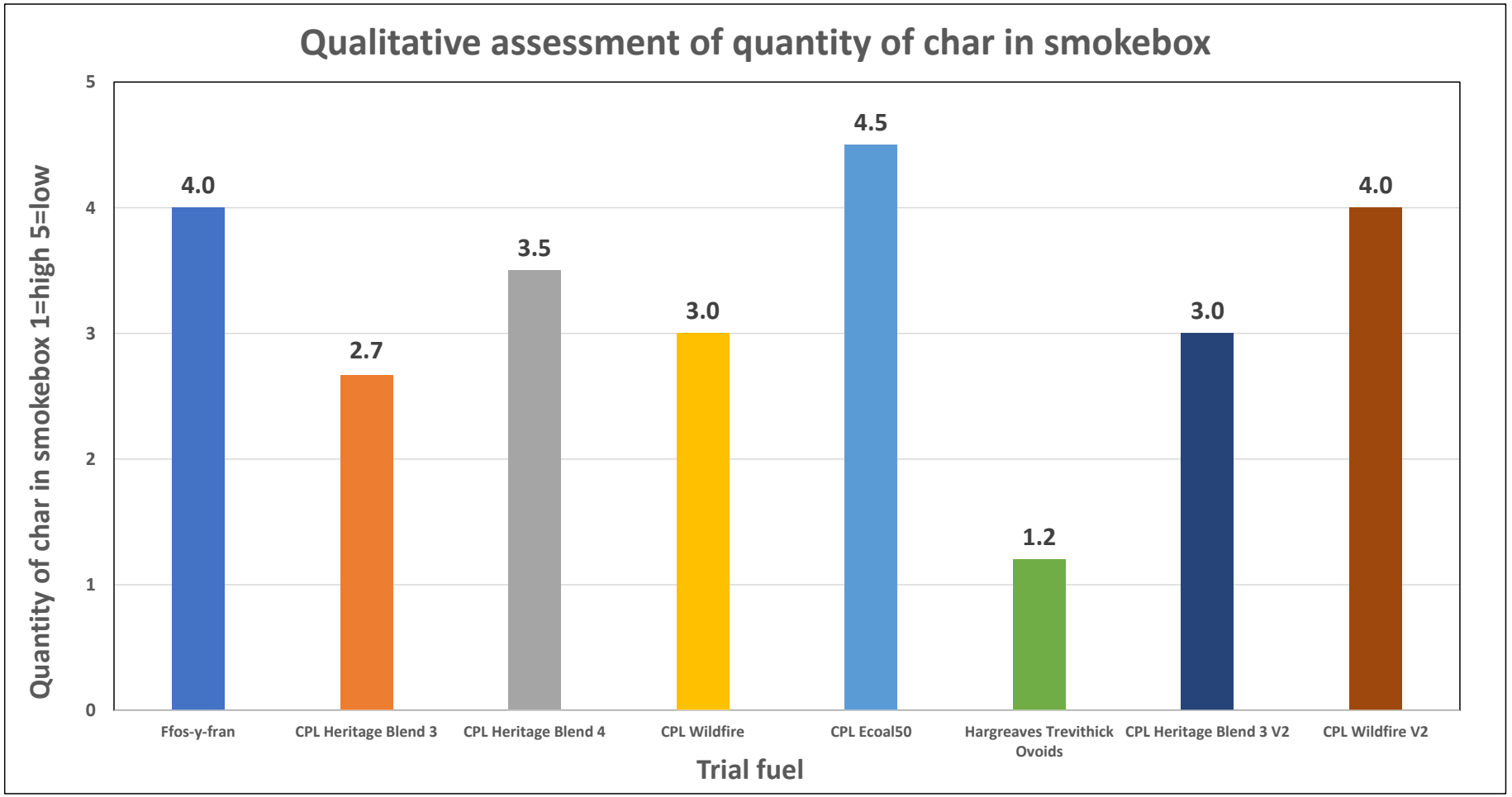

Qualitative assessment of quantity of fuel used
Quantity of fuel used 1=high 5=low
0
1
2
3
4
5
5.0
2.3
3.0
3.3
3.1
1.4
3.5
3.5
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel

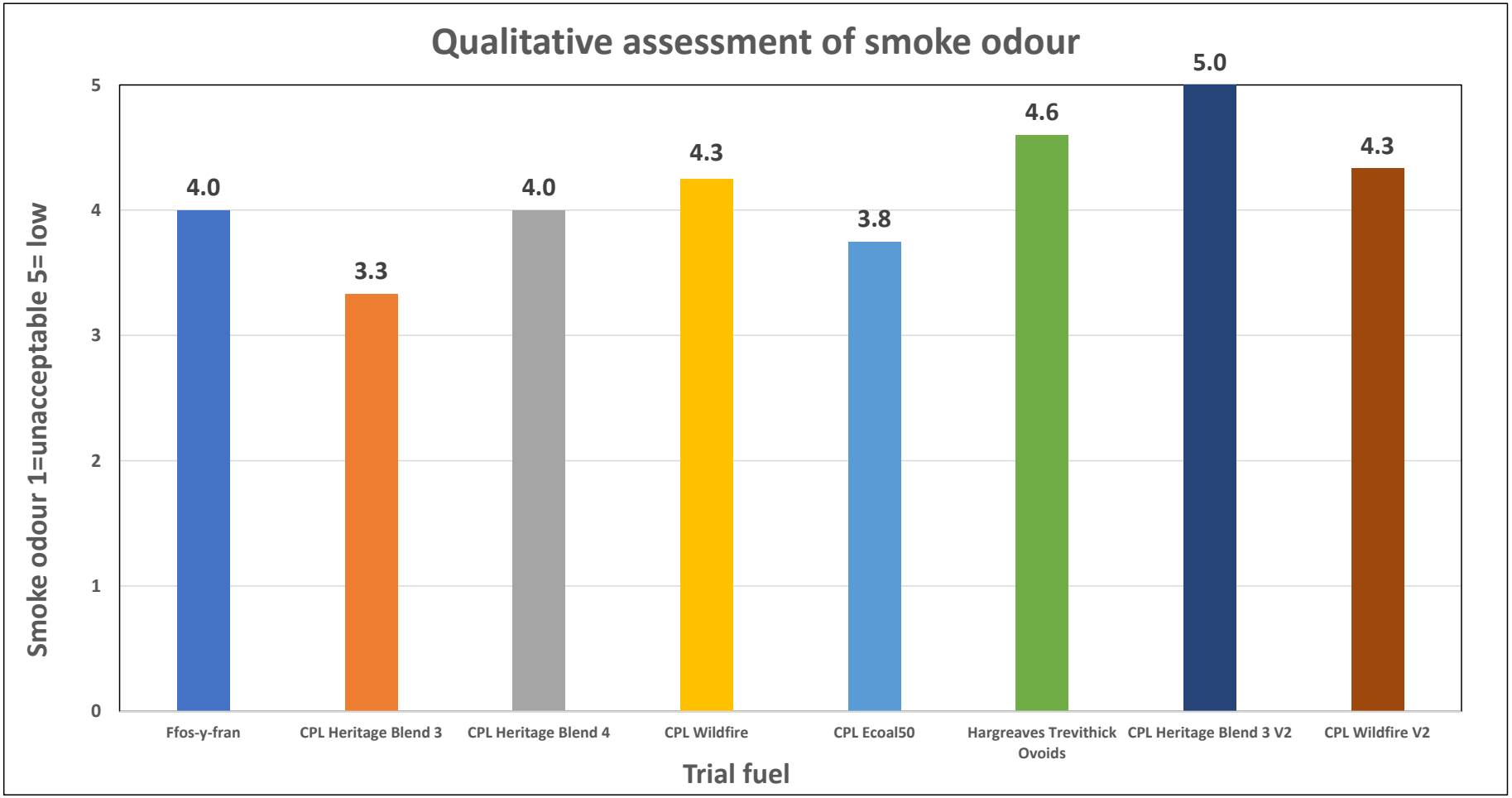

Qualitative assessment of coal ignition time
Coal ignition time 1=slow 5=fast
5
4
3
2
1
0
4.0
2.3
4.0
3.8
3.8
1.8
2.5
3.5
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel

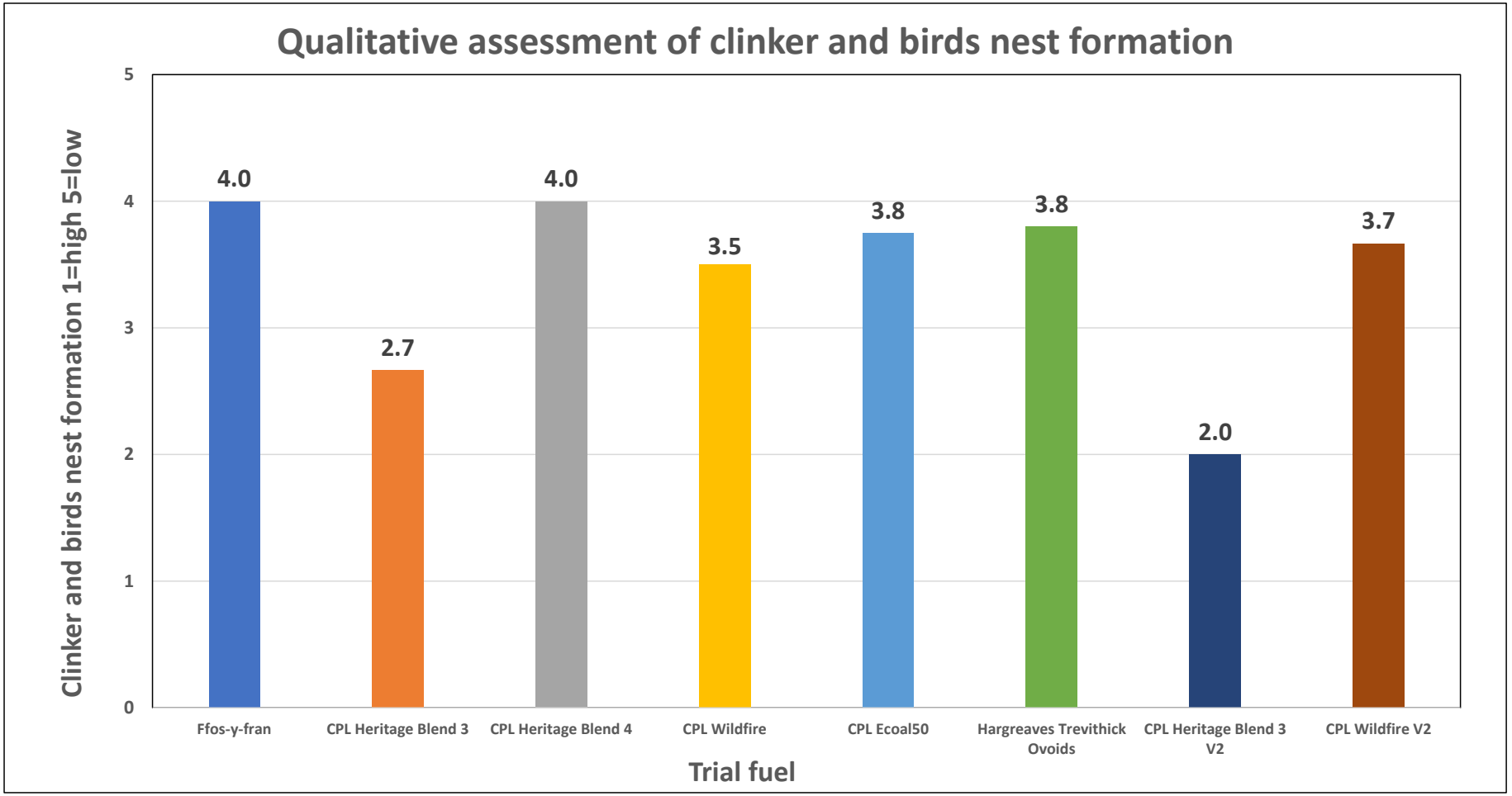

Qualitative assessment of unburnt fuel loss/spark throwing
Unburnt fuel loss/spark throwing 1=high 5=low
0
1
2
3
4
5
4.0
3.0
3.5
3.6
4.0
3.0
5.0
4.3
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel


Qualitative assessment of smoke colour
Smoke colour 1=black 5=clear
0
1
2
3
4
5
6
4.0
3.7
3.0
4.0
3.9
4.4
5.0
4.3
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel


Qualitative assessment of quantity of ash in ashpan
Quantity of ash in ashpan 1=high 5=low
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
4.0
3.3
3.0
3.5
3.0
1.4
4.0
4.7
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel


Qualitative assessment of quantity of char in smokebox
Quantity of char in smokebox 1=high 5=low
5
4
3
2
1
0
4.0
2.7
3.5
3.0
4.5
1.2
3.0
4.0
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel


Qualitative assessment of smoke odour
Smoke odour 1=unacceptable 5= low
0
1
2
3
4
5
4.0
3.3
4.0
4.3
3.8
4.6
5.0
4.3
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel


Qualitative assessment of clinker and birds nest formation
Clinker and birds nest formation 1=high 5=low
5
4
3
2
1
0
4.0
2.7
4.0
3.5
3.8
3.8
2.0
3.7
Ffos-y-fran
CPL Heritage Blend 3
CPL Heritage Blend 4
CPL Wildfire
CPL Ecoal50
Hargreaves Trevithick Ovoids
CPL Heritage Blend 3 V2
CPL Wildfire V2
Trial fuel

BVR & Standard Gauge Correlation

IAN GAYLOR

BVR & Standard Gauge Correlation

To validate the relevance of results obtained from testing 15” gauge locomotives at the BVR for other gauges a comparison with boiler performance of a standard gauge locomotive was made: -

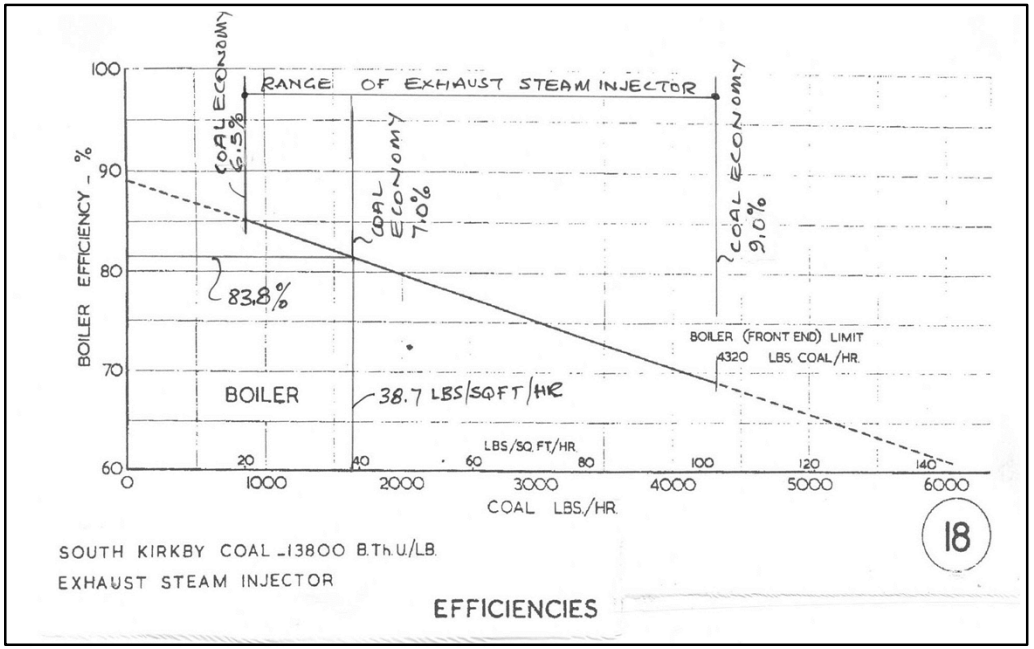
Comparison of the fuel required for evaporation for BVR No.6 burning low volatile Ffos-y-fran coal v a Britannia burning South Kirby high volatile coal shows that at the same firing rate (allowing for the use of an exhaust steam injector) boiler efficiency is almost identical:-

Fuel	Moisture % (ar)	Ash % (db)	Volatile % (db)	Sulphur % (db)	Fixed Carbon % (db)	Gross Calorific Value BTU/lb (Typical) (db)	Gross Calorific Value BTU/lb (Typical) (ar)	Information source
Ffos-y-fran	3.20	5.50	13.30	0.92	78.00	14114	13678	CPL
South Kirby	3.24	4.83	35.87	1.19	59.30	14256	13800	BR Report 10800 dated April 1953

ar = as received

db = dry basis

Proximate analysis of fuels



Rugby test boiler efficiency chart with additional annotations

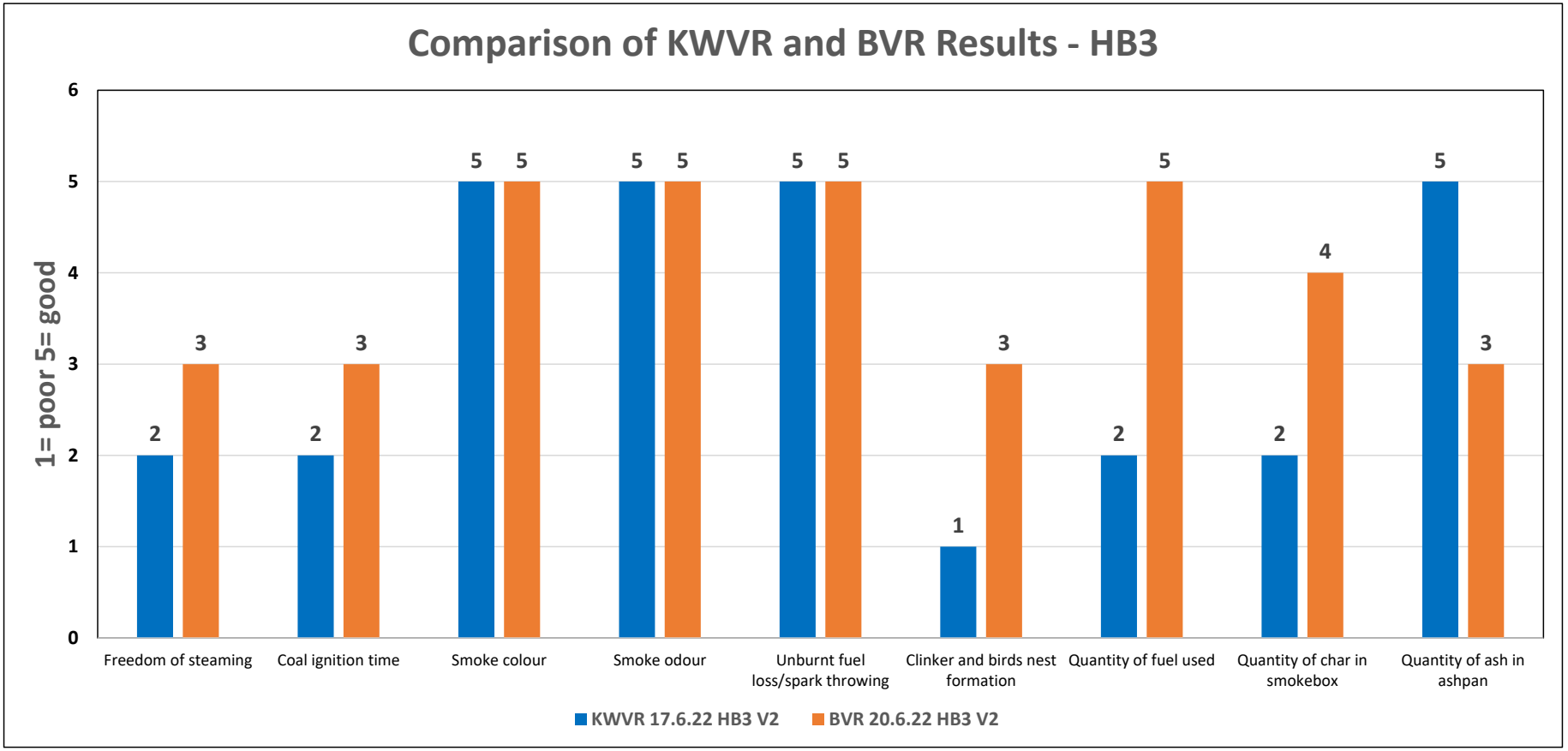
BVR & Standard Gauge Correlation

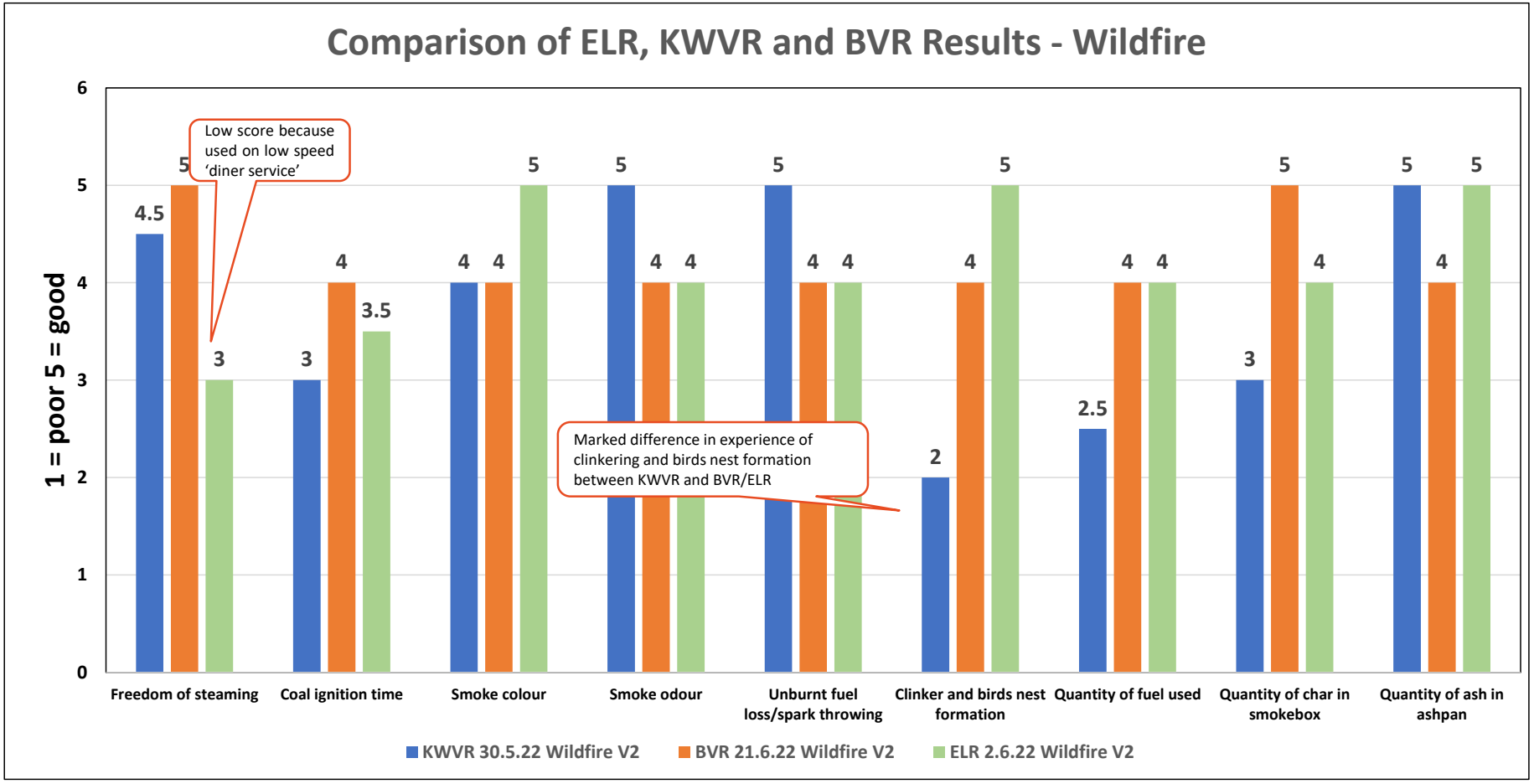
To validate the relevance of results obtained from testing 15” gauge locomotives at the BVR for other gauges a comparison with boiler performance of a standard gauge locomotive was made: -

	BVR No.6	Britannia	Notes
BVR No.6 'Demanding work', Peak firing rate Ffos-y-fran lbs/sqft grate/hr	80.1		See ASTT presentation (Energy of evaporated steam for BVR No.6 assumes a water feed temperature of 50 deg.F)
BVR No.6 'Demanding work', Average firing rate Ffos-y-fran lbs/sqft grate/hr	38.7		
Energy contained in fuel fired BTU	3426164		
Energy req'd to evaporate water BTU	2706888		
Grate area sq ft	4.0		
		42.0	See chart 18 BR Report 10800 dated April 1953
Boiler efficiency with exhaust steam injector %		83.8	
Benefit of coal economy from exhaust steam injector %		7.0	
Boiler efficiency without exhaust steam injector %	**77.6**	**78.3**	**Identical within limitations of calculations**

Comparison of BVR and Rugby test results

Thus the comparable results of the BVR study with historic Rugby tests for a Britannia illustrates the relevance of the scientific insights gained at small scale regardless of locomotive size which reduces the cost and size of equipment required to undertake future testing.


Comparison of KWVR and BVR Results - HB3
1= poor 5= good
0
1
2
3
4
5
6
2
3
2
3
5
5
5
5
5
5
1
3
2
5
2
4
5
3
Freedom of steaming
Coal ignition time
Smoke colour
Smoke odour
Unburnt fuel loss/spark throwing
Clinker and birds nest formation
Quantity of fuel used
Quantity of char in smokebox
Quantity of ash in ashpan
KWVR 17.6.22 HB3 V2
BVR 20.6.22 HB3 V2

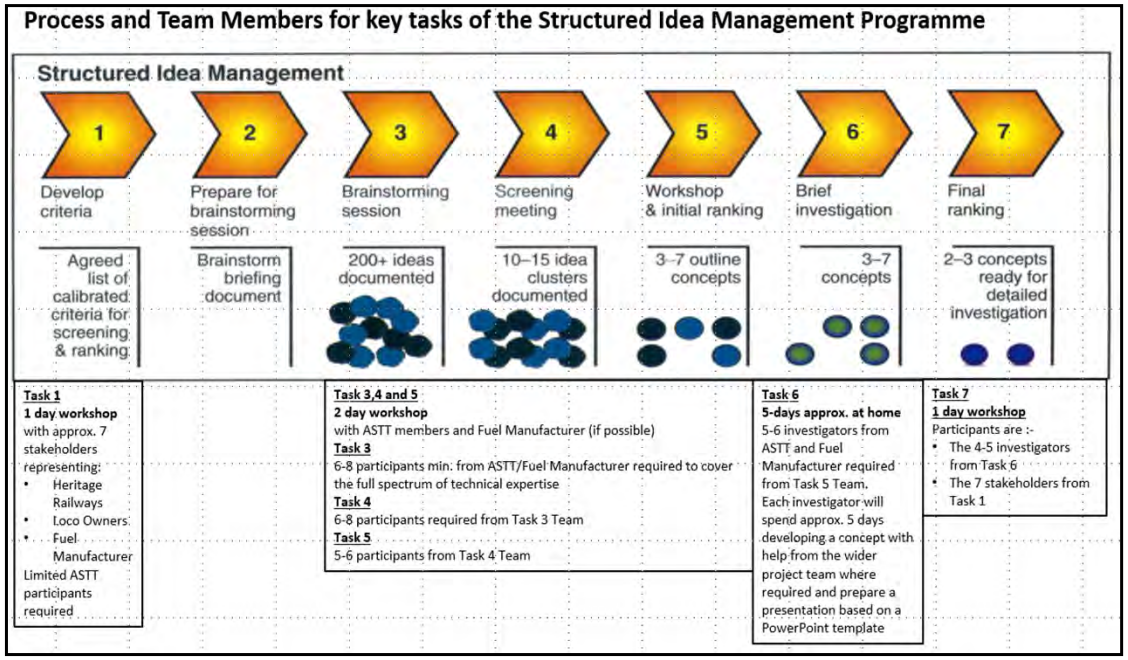

Comparison of ELR, KWVR and BVR Results - Wildfire
1 = poor 5 = good
0
1
2
3
4
5
6
Low score because used on low speed 'diner service'
Marked difference in experience of clinkering and birds nest formation between KWVR and BVR/ELR
4.5
5
3
3
4
3.5
4
4
5
5
4
4
5
4
4
2
4
5
2.5
4
4
3
5
4
5
4
5
Freedom of steaming
Coal ignition time
Smoke colour
Smoke odour
Unburnt fuel loss/spark throwing
Clinker and birds nest formation
Quantity of fuel used
Quantity of char in smokebox
Quantity of ash in ashpan
KWVR 30.5.22 Wildfire V2
BVR 21.6.22 Wildfire V2
ELR 2.6.22 Wildfire V2

Development Strategy for Carbon Neutral Fuel

IAN GAYLOR

Considering Phase One in detail

Concept generation: -



- The concept generation process will be undertaken using the proven 'Structured Idea Management' Methodology as illustrated in the graphic
- This will involve stakeholders from coal users in the heritage community, experts in combustion and chemistry and potential industrial partners, in a series of workshops and desk top studies to confirm needs, identify ideas, and filter them down to 2 to 3 concepts that have a chance of success.

Development strategy for a Carbon Neutral fuel

A limited number of carbon neutral fuels are in the very early stages of development but experience suggests that the best approach may not have been identified:-

ASTT believe that to ensure success we should consider other potential technical solutions using the programme outlined below:-

Phase One

- Involvement of stakeholders from coal users in the heritage community, experts in combustion and chemistry and potential industrial partners, in a series of workshops and desk top studies to confirm needs, identify ideas, and filter them down to 2 to 3 concepts that have a chance of success.

- This will be supplemented by locomotive testing using 21st Century tools and techniques to better understand current combustion conditions and define key functional success factors for a sustainable carbon neutral coal replacement.

Indicative cost and timescale £300,000 - £400,000 over 9 to 12 months

A carbon Neutral fuel has application in the heritage sector but also the much larger domestic market

Development strategy for a Carbon Neutral fuel

ASTT believe that to ensure success we should consider other potential technical solutions using the programme outlined below:-

Phase Two

- Laboratory testing, combustion trials and small-scale trials of the concept fuels on small locomotives.
- In parallel, a study of the manufacturing method for the concepts, confirmation of industrial manufacturers together with their available production capacities and interest in collaborating to commercialise a product.

Indicative cost and timescale £500,000 over 9 to 12 months to be confirmed during Phase One.

A carbon Neutral fuel has application in the heritage sector but also the much larger domestic market

Development strategy for a Carbon Neutral fuel

ASTT believe that to ensure success we should consider other potential technical solutions using the programme outlined below:-

Phase Three

- Larger scale manufacture of the fuel, testing and optimisation of the fuel on a wider range of locomotives and uses to ensure a viable product which meets the needs defined in the First Phase. Much of this would be paid for by one or more fuel manufacturers and only consultancy support would need funding.

Indicative cost and timescale £200,000 over 9 to 12 months to be confirmed during Phase Two.

A carbon Neutral fuel has application in the heritage sector but also the much larger domestic market

Considering Phase One in detail

In depth testing of combustion conditions:-

- To date ASTT has obtained useful scientific data with the limited resources by carrying out tests at three scales 10.25”, 15”, and standard gauge and for these purposes 15” gauge is considered to be the most appropriate as:-
  - Only modest quantities of test fuel are required - 200 kg
  - Measurement and instrumentation of a large range of parameters is possible because of the small scale
  - High and low volatile fuels can be tested
  - With additional resources for stationary testing there is scope for further data gathering e.g. capture and analysis of unburnt fuel loss
  - Test results have been validated as relevant for all sizes of locomotive (see following slides)

Considering Phase One in detail

In depth testing of combustion conditions using static testing could possibly be undertaken using BVR Locomotive No.6 under sustained 'Demanding work conditions' as follows:-

- Locomotive would be placed on front dead centre on one side and handbrake applied.
- On the opposite side (mid stroke) the crosshead would be clamped to the motion bracket to prevent pounding of bearings during the test and the eccentric rod removed
- A custom eccentric rod coupled to a variable speed electric motor with a counter balanced crank of the same radius as the return crank would be mounted on a frame clamped to the rails/rear wheels such that when the motor rotates it drives the expansion link
- The motor should be capable of rotating at up to twice the normal maximum speed of the driving wheels and in this way when steam is applied and the motor rotates an appropriate number of exhaust beats/minute is achieved
- In operation the steam consumption can be controlled using the regulator and reverser

Considering Phase One in detail

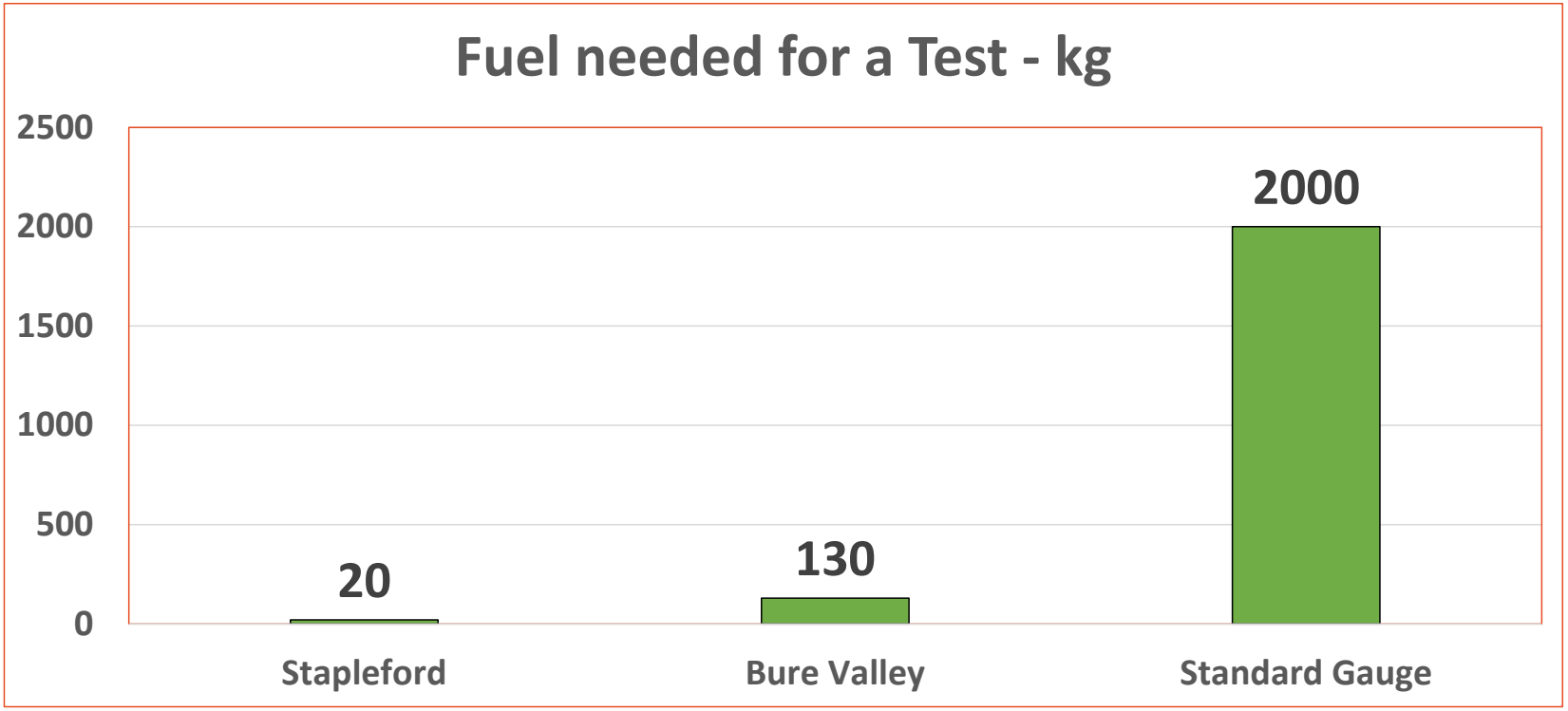
In depth testing of combustion conditions using static testing could measure the following parameters:-

- Water consumption (by measuring water level in tank and feed temperature using a thermometer)
- Fuel consumption (using a spring balance)
- Smokebox vacuum (using pressure transducer)
- Smokebox gas temperature (using a hand held infra red thermometer through a sightport)
- Flue gas analysis including particulate content (using a commercial hand held gas analysis unit)
- Firebox flame temperature (using a hand held infra red thermometer through a sightport in the fire door)
- Weight of clinker (using a spring balance)
- Weight of ashpan ash/char (using a spring balance)
- Weight of smokebox char (using a spring balance)

Future funding

JOHN HIND

Future Funding – quantity matters



Future Funding

As the Heritage Rail sector does not generate sufficient funds to develop a sustainable fuel to secure the long-term future of the sector external funding is needed to develop an alternative fuel to coal.

- The All Party Parliamentary Group for Heritage Rail and the HRA have raised awareness with Government
- For the short term existing fuel suppliers might be prepared to contribute however the size of the Heritage Rail Market opportunity in isolation and the relatively small size of the suppliers may make this very limited
- For the longer term and given the additional attractive domestic market opportunity ASTT has:-
  - Provided HRA with a summary strategy development programme
  - Used in two submissions

Future Funding – Support for HRA

- National Heritage Lottery Fund funding review for 2024 onwards
  - Used for informing discussions in two consultation meetings
  - The final consultation response form was limited in the scope of what it asked
  - The full document not submitted at that stage, but will be helpful in any further discussions
  - Strategy Review will report during 2023
- Railway 200 celebration of 200 years of railway – HMG Initiative
  - Has been helpful in informing discussions.
  - Final Railway 200 proposal is in the drafting stage
    - There will be a high-level overview of the proposals from five working groups.
    - HRA awaiting copy of the draft.
  - Expectation of some form of response from government by the end 2022

Questions

Barriers

- Cost
  - Same costs as coal but not the same performance
- Continued availability of coal
- Not taking emission seriously
- Clinker on heavily worked engines