



HS2 Traction Energy Modelling	
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Version 1.1

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Acronyms

A, B, C	Resistance coefficients
FRRC	Future Railway Research Centre (Imperial College)
ICE	Inter City Express
km	kilometres
km/h	kilometres / hour
kN	kilonewtons
kV	kilovolts
kW	kilowatts
kWh	kilowatt hour
PBKA	Paris-Brussels-Koln-Amsterdam
R	Resistance (kN)
RSSB	Rail Safety and Standards Board
TGV	Train à Grande Vitesse
V	Velocity (km/h)

1. Introduction

This document summarises the traction power energy assessment for High Speed 2 operation using the HS2 Reference train. This analysis is required to understand the traction energy consumption of the HS2 reference trains for CO2 comparison and also energy consumption comparison in kw-h/seat km.

2. Assumptions

The assumptions used during the assessment are shown in the modelling outputs report at Appendix A, however the main assumptions are:

- Passenger carrying capacity (510 seats)
- Mass of train (382 tonnes)
- Passenger loading (70%)
- Reference train traction and performance parameters
- Route - Euston to Birmingham Fazeley Street
- Gradient profiles, line speed profiles and three tunnel locations as per HS2 Route 3 data
- Maximum line speed of 360km/h
- Two intermediate stops at Old Oak Common and at Birmingham Interchange with dwell times of 2 minutes each
- 400m train is defined as 2x200m coupled reference trains

3. Modelling Approach

The traction energy modelling was undertaken by Imperial College using their Train Energy model (details in Appendix A). The scenarios and sensitivities modelled are summarised below:

Scenarios modelled:

- Two line speed scenarios have been assessed - maximized (i.e. as fast as possible within constraints of train and permitted line speed) and optimised (i.e. with lower line speeds at certain points)
- Journeys in both directions have been modelled (i.e. Euston to Birmingham and return)
- Additional scenario modelled including an additional station stop mid-route
- Scenario modelled for 200m and 400m train (2x200m trains)
- Energy regenerated modelled

Sensitivities assessed:

- Difference due to 100% passenger load compared to 70%
- Difference due to an additional stop at mid point (88km from Euston)
- Effect of optimised driving line speed profile
- Effect of 200m train compared to 400m (2x200m) train
- Effect of plain line running versus running in a notional tunnel (10km length)

4. Key Conclusions

The detailed modelling outputs and conclusions are contained in the report at Appendix A. All results are subject to variation depending on the scenario being assessed. Key conclusions are summarised below:

- A 200m train from Euston to Birmingham with 2 stops consumes 4700kWh energy (after regeneration benefit of 437kWh).
- Energy regenerated varies from 8.5% to 9.8% for the two stops scenarios.
- Net energy consumption per seat-km varies from 0.050 to 0.053 kWh / seat-km for the 200m trains.
- Net energy consumption increases 2% to 4% with an extra third stop.
- Net energy consumption saving of 11% to 13% with the optimised line speed assumption.
- Net increase in energy consumption of 1% for 30% extra passenger load (i.e. 70% and 100% passenger load compared).
- Net saving in energy consumption of 3% to 4% per seat-km with use of 400m train (i.e. 2x200m coupled sets).
- Journey time saving of 3.5 minutes consumes 23% more energy (comparison of 360 km/h operation to 300 km/h operation).
- Additional energy consumption due to operation through a notional 10km tunnel compared with a normal 10km open line at 320km/h:
 - For 12m diameter tunnel: 39% additional energy consumption
 - For 9.8m diameter tunnel: 64% additional energy consumption
 - For 8.5m diameter tunnel: 94% additional energy consumption
- Total annual energy consumption on the line of 150 million kWh based on 0.048 kWh/seat-km and 3.2 billion seat-km (running 50 x 200m trains per day each way).



Appendix A:

Imperial College Final Outputs Traction Energy Modelling

Final Outputs Traction Energy Modelling

7th December 2009

Robert Watson
Anouk Dufour
Diem Tran Thi Ngoc

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• Assumptions

- Scenarios investigated
- Example simulator outputs
- Analysis

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HS2 reference train key assumptions – 200m length train

- Mass of train unloaded : 382 tonnes
- Rotational inertia mass factor : 4%
- Passenger mass fully loaded : 43 tonnes
- Passenger loading : 70% (unless otherwise stated)
- Train length : 200 m
- Ratio of power at the wheel to drawn power from the line : 0.823
- Auxiliary power considered
- Auxiliary Power System efficiency : 85%
- Tractive Effort : Curve for 25 kV for HS2 reference train.
- Braking Effort : Electrodynamic and friction braking curves for HS2 reference train
- Regeneration efficiency: 80%
- Tunnel resistance considered

HS2 reference train key assumptions – 400m length train

- Mass of train unloaded : 764 tonnes
- Rotational inertia mass factor : 4%
- Passenger mass fully loaded : 86 tonnes
- Passenger loading : 70% (unless otherwise stated)
- Train length : 400 m
- Ratio of power at the wheel to drawn power from the line : 0.823
- Auxiliary power considered.
- Auxiliary Power System efficiency : 85%.
- Tractive Effort : Double the tractive effort of the 200 m train.
- Braking Effort : Double the electrodynamic and friction braking of the 200 m train
- Regeneration efficiency: 80%
- Davis equation resistance : Davis equation coefficients variation on 200m train
- Tunnel resistance considered

Route assumptions

Gradient profile

- Gradient profile of Route 3 – Euston to Birmingham Fazeley Street
- Route length: 174 km
- Reverse gradient profile used for Birmingham to Euston

Line speed profile – 2 scenarios

- Maximum line speed profile for Route 3 – Euston to Birmingham Fazeley Street
- Optimised line speed profile, with lower line speeds in certain regions along the line
N.B. Reverse line speed profile used for Birmingham to Euston in both cases

Tunneling

- 3 tunnels as defined in Route 3 – Euston to Birmingham
- Step change of resistance acting on train on entry and exit of tunnels

Stops – 2 scenarios

- 2 intermediate stops at Old Oak Common and Birmingham Interchange
An extra stop 88km from Euston (modelling assumption)
- A dwell time of 2 minutes at each station stop

- Assumptions

• Scenarios investigated

- Example simulator outputs
- Analysis

Scenarios investigated: 200m trains (1 – 10)

Scenario	Line speed	Intermediate stops	Passenger load (%)
Euston - Birmingham			
1	Maximum	2	70
2	Maximum	3	70
3	Optimised	2	70
4	Optimised	3	70
5	Maximum	2	100
Birmingham - Euston			
6	Maximum	2	70
7	Maximum	3	70
8	Optimised	2	70
9	Optimised	3	70
10	Maximum	2	100

200m length trains, 360km/h max train speed

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Scenarios investigated: 400m trains (11 – 18)

Scenario	Line speed	Intermediate stops
Euston - Birmingham		
11	Maximum	2
12	Maximum	3
13	Optimised	2
14	Optimised	3
Birmingham - Euston		
15	Maximum	2
16	Maximum	3
17	Optimised	2
18	Optimised	3

400m length trains, 360km/h max train speed, 70% passenger loading

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Scenarios investigated: max speed study (19 – 32)

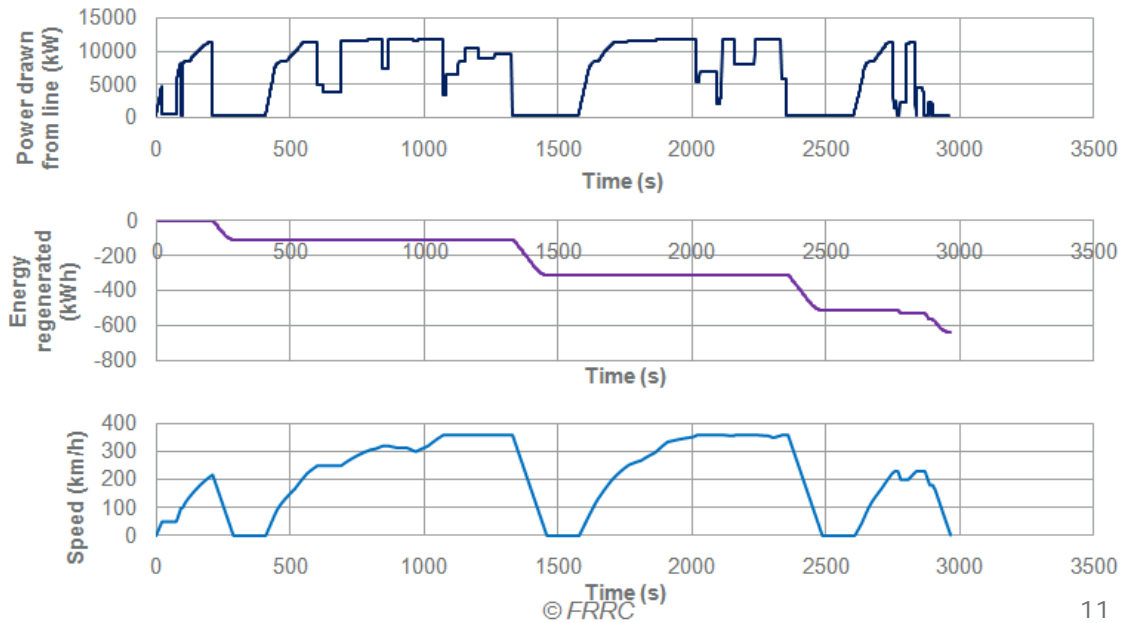
Scenario	Maximum train speed (km/h)
Euston - Birmingham	
19	300
20	310
21	320
22	330
23	340
24	350
25	360
Birmingham - Euston	
26	300
27	310
28	320
29	330
30	340
31	350
32	360

200m length trains, max line speed, 2 intermediate stops, 70% passenger loading

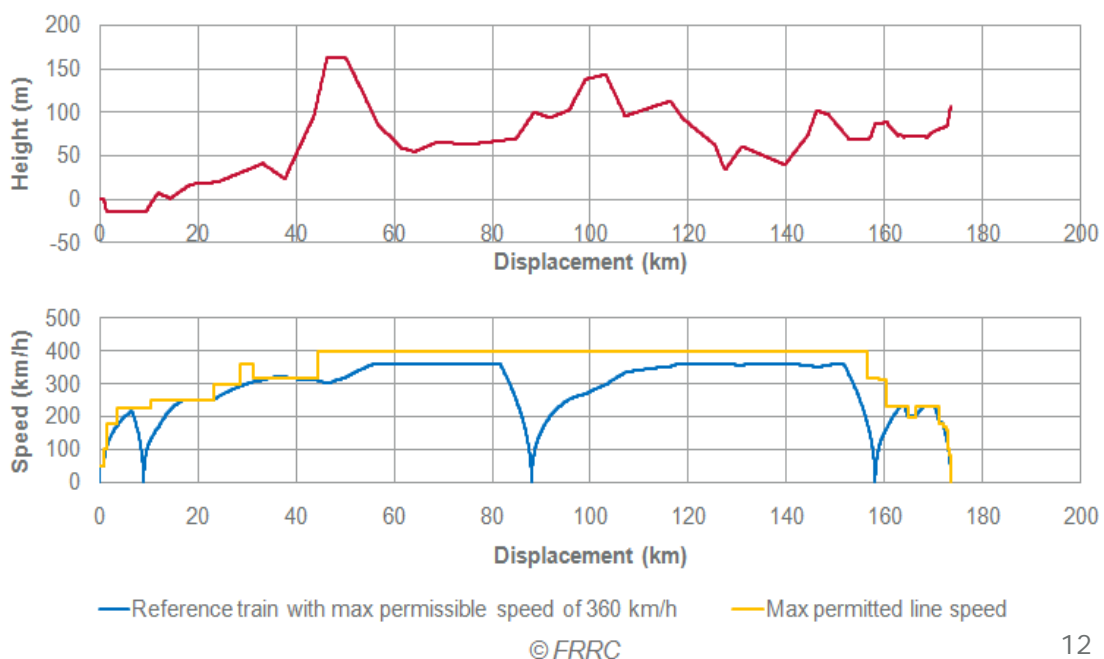
9

- Assumptions
- Scenarios investigated
- **Example simulator outputs**
- Analysis

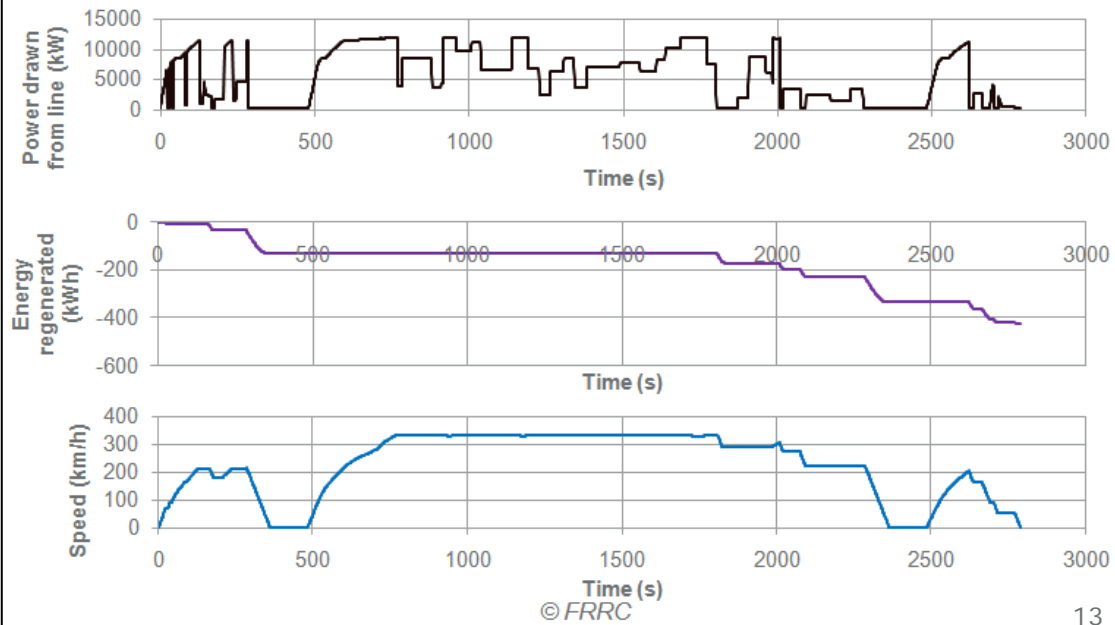
Example simulator outputs: scenario 2



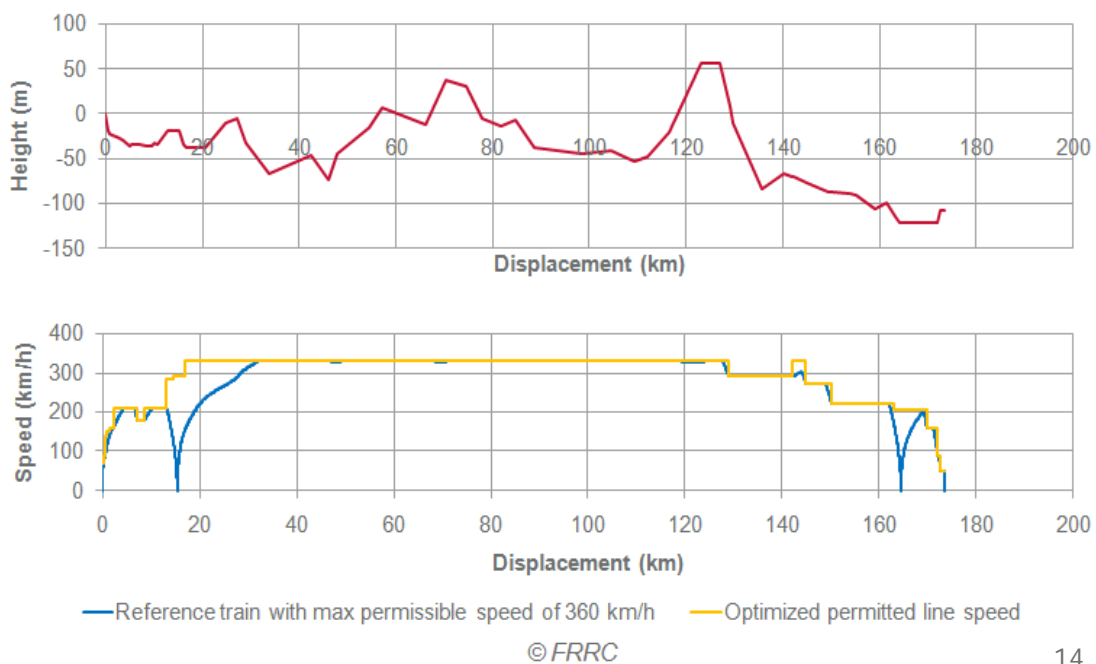
Example simulator outputs: scenario 2



Example simulator outputs: scenario 8

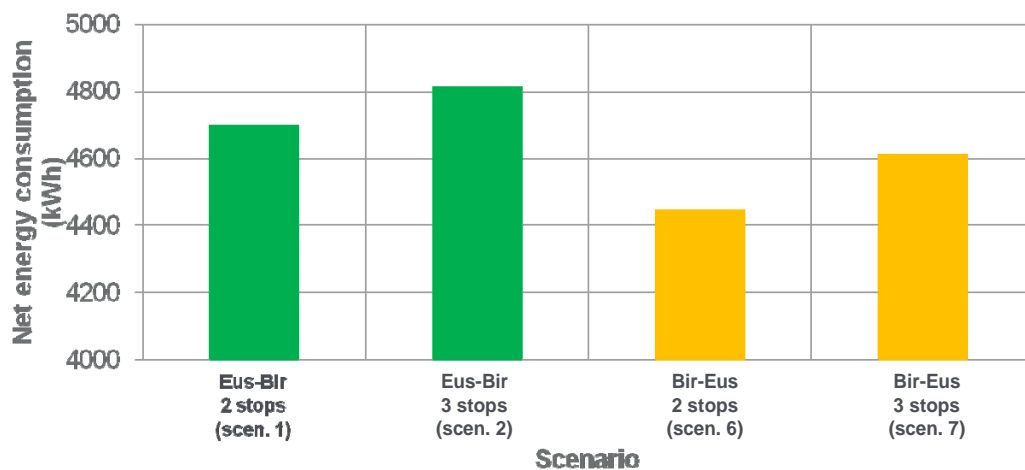


Example simulator outputs: scenario 8



- Assumptions
- Scenarios investigated
- Example simulator outputs
- **Analysis**

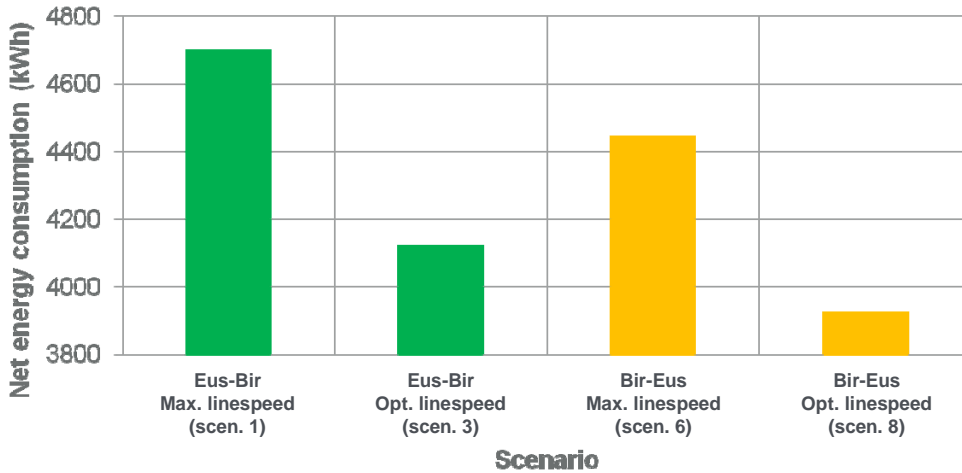
Analysis A – Effect of an extra stop



Estimated 2 – 4 % increase in net energy consumption due to extra stop*

**N.B.: Estimated savings may vary slightly depending on scenarios investigated
Scenarios for comparison with each other shown in same colour*

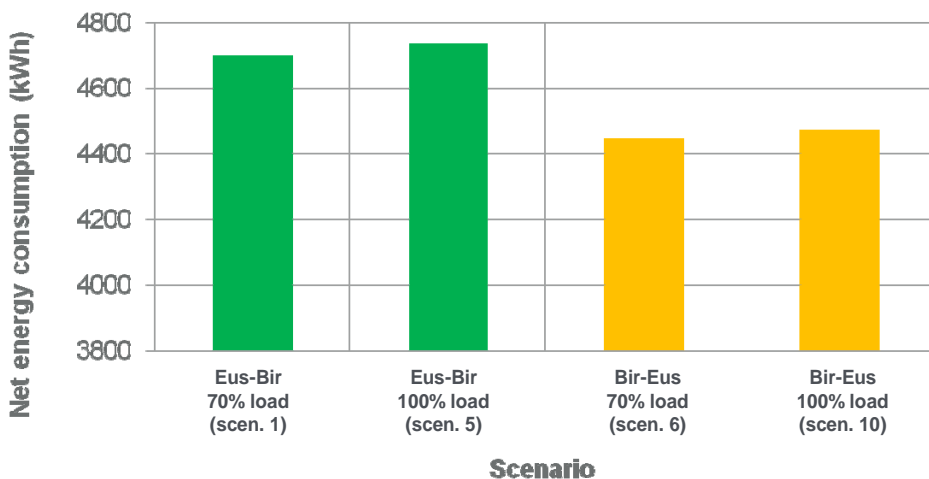
Analysis B – Effect of an optimized line speed profile



Estimated 11 – 13 % saving in net energy consumption due to optimized line speed*

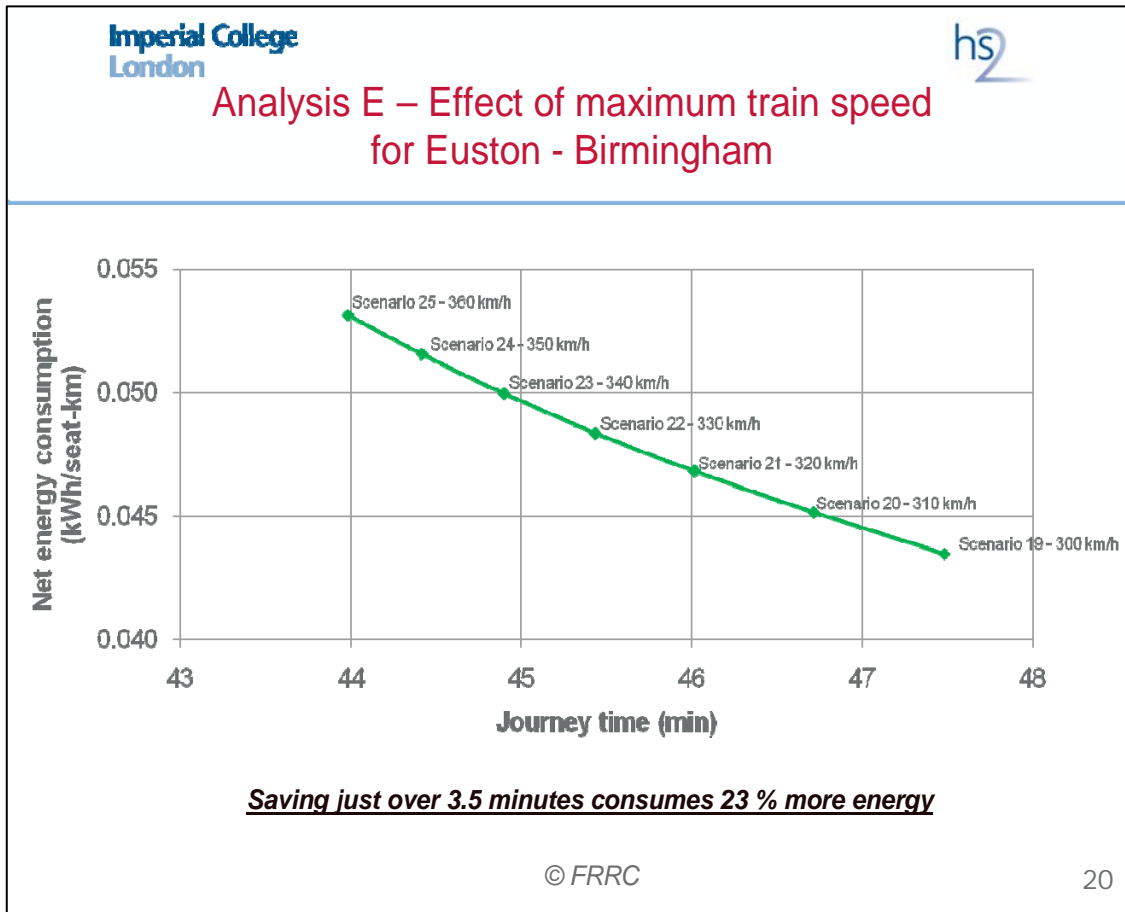
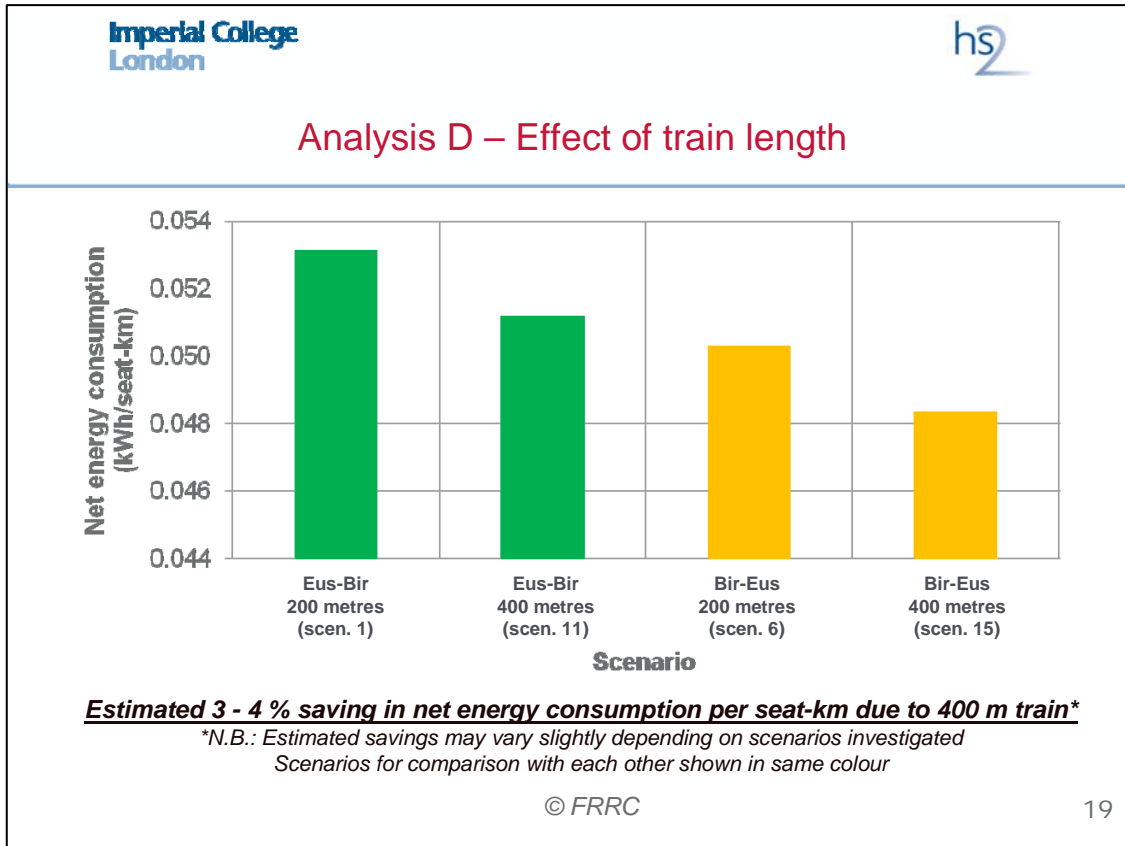
**N.B.: Estimated savings may vary slightly depending on scenarios investigated
Scenarios for comparison with each other shown in same colour*

Analysis C – Effect of passenger loading

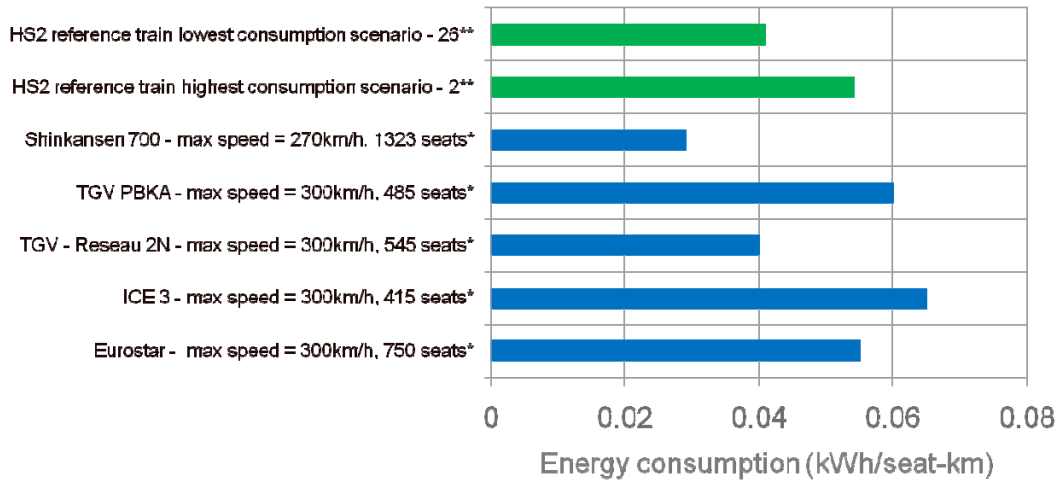


Estimated < 1 % increase in net energy consumption due to 30% extra passenger load*

*N.B.: Estimated savings may vary slightly depending on scenarios investigated
Scenarios for comparison with each other shown in same colour*



Analysis F – Comparison with other high speed trains



* Data from RSSB report :T618 Traction Energy Metrics
** Data from simulations

Analysis G – Effect of a notional 10 km tunnel

Assumptions:

- Speed through the tunnel is constant with $V = 320$ km/h.
- Length of tunnel = 10 km.
- 3 equivalent internal diameters investigated: 8.5, 9.8 and 12 metres.
- Level track.
- 200 metre train.

Tunnel ID	Work done (kWh)	Extra work done due to tunnel (kWh)	% increase in work done due to tunnel
No tunnel	167	N/A	N/A
8.5 metre diameter	324	157	94
9.8 metre diameter	274	107	64
12 metre diameter	232	65	39