HIGH SPEED RAIL: UPDATED

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This briefing outlines some of the key technologies behind high speed rail operations. It also highlights some of the costs and benefits of high speed rail and charts the development of high speed rail in the UK, with a focus on current debate about the future development of a UK high speed rail network. It goes on to look at the development of high speed rail in three other European countries and Japan and concludes with a brief outline of the alternative Maglev transport system.

Kyushu Shinkansen, Tsubame 800: Kyushu Railway Company

The Scottish Parliament

CONTENTS

INTRODUCTION

Professor Rod Smith (Professor of Mechanical Engineering and head of department at Imperial College) stated at The Railway Forum's high speed seminar on 13 June 2008 that:

> If we take an historical view of the development of transport infrastructure in this country, starting with turnpike roads, the canals, the railways, major road infrastructure, the motorway network, dozens of airports, what is the next infrastructure to build? I came to the conclusion a long time ago: it's a high speed rail network (Rail Business Intelligence 2008a)

The development of new lines, possibly including high speed lines, is now being addressed by Network Rail which established a dedicated team at its UK Headquarters in April 2008 charged with developing the case for a new lines programme. Richard Eccles, Network Rail's Head of Route Planning and leader of the new team, stated at The Railway Forum's high speed seminar that:

> We are looking to test the hypothesis, quite simply, that in future when all the next-generation methods of enhancing the network's capacity have been exhausted, and there is still an unfulfilled demand for rail travel, there is an opportunity for intervention in the form of one or more new lines…and the field of study we'll be looking at is those lines that go north and west of London: East Coast, Midland Mainline, West Coast, Chiltern and Western (Rail Business Intelligence 2008)

At that same seminar Jim Steer, Director of High Speed Rail advocacy group Greenguage21, announced that a consortium of interested parties had pledged £750,000 to develop a UK wide high speed rail strategy. This would focus on five routes; London-Birmingham-Manchester; London-Cambridge-Northeast; London-Bristol/Cardiff; Trans-Pennine and Anglo-Scottish.

While the issue of high speed rail is under active consideration by these and other organisations, neither the UK nor Scottish Governments have any clear published policy on high speed rail. Although, in response to a Parliamentary Question on 5 June 2008 Alex Salmond MSP, the First Minister, clarified the Scottish Government's position on high speed rail by stating:

> *Given recent events in the world, there must be a growing realisation that high-speed rail should be considered in all seriousness as the logical, intelligent and environmental way to carry the bulk of journeys between Scotland and however we want to describe the city of London and elsewhere* (Scottish Parliament 2008)

This briefing aims to provide background information on high speed rail technology, the development of high speed rail in the UK and in certain other countries and the possible future development of a high speed rail policy and network in the UK and Scotland.

WHAT IS HIGH SPEED RAIL?

There is no internationally agreed definition of what constitutes a high speed railway. Different railway operators define 'high speed' differently, although speeds tend to range from 125mph to 186mph with the latest lines under development having maximum running speeds of 200mph. However, high speed railways do tend to share certain characteristics including:

- New or substantially upgraded track and associated infrastructure, especially signalling
- No level crossings, to reduce the possibility of accidents
- A wide minimum radius to allow for continual high speed running around curves in the track
- Wide spacing between tracks, to reduce air pressure between passing trains
- High speed rolling stock, designed for continued high speed running and fast acceleration and braking
- Shared operating characteristics, e.g. long distance services with infrequent stopping patterns

The EU (through Directive 96/48/EC and related Technical Specifications for Interoperability) defines a high-speed line as one equipped for speeds of 250 km/h (approximately 150 mph) and above. The UK Institution of Civil Engineers (2005) defines high speed rail as:

> High-speed rail systems consist of trains with onboard engines and steel wheels travelling on steel rails, usually at top speeds of 300 to 350 kilometres per hour.

This is the definition used for the purposes of this briefing.

HOW DOES A HIGH SPEED RAILWAY DIFFER FROM A CONVENTIONAL RAILWAY?

The key differences between a conventional railway, sometimes referred to as a ‘classic’ railway, and a high speed railway are examined below.

Track: High speed railway lines are similar to normal railway lines, with a few key differences. Curves in the line have far larger radii so that trains can continue to travel at high speeds without increasing the centrifugal forces felt by passengers. Lines can incorporate steeper gradients than those found on normal lines, as the high power-to-weight ratio of high speed trains and the momentum of a train travelling at high speed means that they can climb steeper slopes.

High speed running requires a more precise track alignment than on normal railway lines. Ballast is deeper than normal to increase the load-bearing capacity and stability of the track. The rails in high speed track are anchored by more sleepers than normal and a heavier grade of rail is used. In common with most of the UK rail network all high speed lines use continuously welded rail in place of old fashioned jointed rails, which means that the ride remains comfortable at high speeds, without the "clickety-clack" vibrations induced by rail joints.

Signalling: When operating at speeds in excess of 125mph a train is likely to be travelling too quickly for its driver to see and react to traditional lineside signals, hence the 125mph speed limit on UK railways. High speed trains therefore use automated systems of in-cab signalling. Information is transmitted to trains either via electrical pulses sent through the rails (as used on the French TGV system and Eurostar services) or via radio signals (as used on Roma-Napoli high speed line, one of the first lines to use the European Rail Traffic Management System), providing speed, target speed, and stop/go indications directly to the driver.

In general, high speed lines are divided into “signal blocks”, which range in length from a few hundred metres to several kilometers, the boundaries of which are marked by lineside boards. In-cab instruments show the maximum permitted speed for a train's current block, as well as a target speed based on the profile of the line ahead. The maximum permitted speed is based on factors such as the proximity of trains ahead, speed restrictions, the top speed of the train and distance to the next station. As trains cannot usually stop within one signal block, drivers are alerted to slow down gradually several blocks before a required stop.

This system of in-cab signalling is normally automatically enabled/disabled when a high speed train enters or leaves a section of high speed line. The driver will obey normal lineside signals when operating on the 'classic' rail network.

Rolling Stock: Many European high speed trains, e.g. the cross channel Eurostar, older versions of the Spanish AVE and international Thalys, consist of two power cars located at either end of the train with a number of semi-permanently linked passenger carriages between them. Some new high speed trains, e.g. the German ICE3 and newer Spanish AVE, have a distributed power system where a series of engines are located under the floor of carriages along the train, similar to the diesel and electric multiple unit trains currently operating in Scotland.

High speed rail carriages are normally 'articulated', i.e. the bogies[1]are located between the carriages, to reduce the weight of each train and improve stability in the event of a derailment.

High speed trains are all electrically powered, electricity being provided via overhead lines. Electric traction provides quicker acceleration while producing less noise than diesel engines. Electric motors do not produce any direct emissions - although the electricity which powers them may have been generated by a power station which does emit pollutants.

COSTS AND BENEFITS OF HIGH SPEED RAIL

Costs: The financial cost of building an entirely new high speed railway varies according to a series of factors including the price of raw materials and labour and the costs of land and property purchase, particularly where the railway runs through existing urban areas with high land values. In addition, the cost of building tracks through tunnels or over viaducts can be four to six times as expensive as lines running over flat land. The most recent estimated costs for constructing a UK high speed rail network were produced by consultants Atkins in March 2008 (Atkins 2008). They estimated that a west coast route linking London and Birmingham would cost £9bn while an east coast route linking London to a point near Leeds would cost £12bn and a full network linking London with Edinburgh and Glasgow would cost £31bn.

Chapter four of the UK Commission for Integrated Transport's (2005) report High Speed Rail: International Comparisons examines the cost of constructing high speed railways across the world. Costs have varied from an average of around €10m per kilometre for the Spanish AVE Madrid-Lerida line to almost €71m per kilometre for the UK Channel Tunnel Rail Link (CTRL). The report examines why the channel tunnel rail link proved so expensive to build, and identifies a series of factors including high land and labour costs, more onerous environmental and safety regulations in the UK, slow and costly approval processes for major projects in the UK, gold plating of design features in UK projects and inflated UK railway costs. The report concludes that regulatory burdens could be removed by concerted Government effort, and unit costs reduced were a major high speed railway project to be undertaken and effectively managed, in line with best practice.

Iain Croucher, then Deputy Chief Executive of Network Rail, indicated in a speech to the Institution of Civil Engineers on 8 May 2006 that the likely cost of constructing the line would be in the region of £15m to £19m per kilometre, while Ernest Godward, a rail economist from

[1] A 'bogie' is the structure underneath a train to which the wheels and axles are attached.

consultants Scott Wilson, told delegates that the average cost of high speed lines being constructed outside the UK was about £30m to £32m per kilometre.

In addition to financial costs, the construction of a high speed railway will also have an environmental impact, principally on the land taken to construct the railway but also noise from construction and train operations, indirect pollution from electrical power generation and an impact on wildlife and natural heritage. However, many of the negative effects of a high speed railway can be reduced or removed through good planning and physical mitigation measures, e.g. noise barriers.

Benefits: The most obvious benefit of any high speed rail development is greatly reduced journey times. A TGV style north-south UK high speed line linking London, NW England and Edinburgh/Glasgow could produce the following journey times (Department for Transport 2004):

London-Edinburgh:	2hrs 35min
London-Glasgow:	3hrs 0min

In addition, the railway could bring other economic and development benefits, including inward investment, housing and economic development and additional opportunities for tourism. Greengauge21, a campaign group which supports the development of a UK high speed rail network, has produced a useful report entitled High Speed Trains and the Development and Regeneration of Cities (Greengauge21 2006b). This examines the experience of European cities and regions following the introduction of high speed rail services and examines some of the more 'intangible' benefits derived from the development of high speed railways and how these can be maximised.

High speed trains also produce far fewer atmospheric emissions per passenger mile than airliners and road vehicles. Research carried out for Eurostar (Eurostar 2006) found that a passenger travelling between London and Brussels by plane generated almost nine times as much carbon dioxide compared with the rail journey between the two cities, i.e. 106kg per round trip by air compared with 18kg per round trip by train.

Cost benefit analysis: Rail consultants Atkins conducted a study into a UK High Speed Line (Department for Transport 2004) for the Strategic Rail Authority which produced a cost/benefit ratio for a full north-south UK high speed network of 2.04, i.e. for every £1.00 invested in the line £2.04 worth of benefits are produced (Department for Transport 2004). Atkins published an updated version of this study (Because Transport Matters: High Speed Rail) in March 2008 (Atkins 2008), taking account of changes in UK Government transport and rail policy. The update concluded that, even factoring in the latest policy changes, the cost/benefit ratio for a full north-south high speed network remained at around 2.0.

This cost/benefit ratio compares favourably with major Scottish railway projects already approved by the Scottish Parliament, e.g. the Waverley Railway had a cost benefit ratio of 1.21.

HIGH SPEED RAIL IN THE UK

The UK did not follow the lead set by Japan and France in developing a high speed rail network during the 1970 and 1980's. Rather it focussed on developing high speed trains which could use the existing rail infrastructure. Only during the 1990's, following the opening of the Channel Tunnel, did the development of a TGV based high speed line linking the tunnel with London begin, giving the UK its first high speed railway and its first new mainline railway in over 100 years.

The following section looks at the development, in the UK, of the Advanced Passenger Train during the 1970's and 1980's and the development of the CTRL and the Eurostar service which operates along it.

THE ADVANCED PASSENGER TRAIN (APT)

During the 1970's and 1980's British Rail developed two high speed trains. The first was the diesel powered class 43 High Speed Train (HST) which still provides services on the East Coast Main Line, Great Western Line and Midland Mainline. This train, which has passed 30 years in passenger service, uses conventional rail technology and has a maximum speed of 125mph.

The APT programme: Parallel to the development of the HST, British Rail engineers began developing the Advanced Passenger Train (APT) which would have a maximum speed of 155mph. The train was built to run on the classic UK rail network with minimal changes to the infrastructure and incorporated several UK rail innovations including aluminium body shells, articulated bogies, hydrokinetic brakes and hydraulic tilting mechanisms. The tilting mechanism meant that the train could traverse curves 20 percent to 40 percent quicker than conventional trains while the new braking mechanism meant it could still stop within the distances required by existing signalling systems.

To allow for speeds above 125mph the APT would use a simple in-cab signalling system. A receiver on the train would interrogate transponders placed at 1km intervals along the railway. The transponders would transmit the maximum running speed to the train's computers, which would display the information in the driver's cab. Further information on APT technology is available in a British Rail leaflet Tomorrow's Train Today (British Railways Board 1980).

The APT was initially going to be restricted to a maximum speed of 125mph due to timetabling restrictions caused by running alongside slower local trains. The tilting mechanism would allow the APT to maintain a high running speed around the many curves on Britain's main lines and, even restricted to 125mph running, could complete the Glasgow to London journey in 4hrs 15 minutes.

The APT in action: Following testing of a gas-turbine powered APT-Experimental (APT-E) train in the late 1970's, three electric APT-Prototype (APT-P) trains were built and testing began in late 1981. During initial runs the APT-P experienced a series of technical problems and a raft of negative media stories. However, the technical problems were mainly ironed out by the summer of 1982. British Rail intended to roll out a fleet of 60 APT-Squadron (APT-S) trains, which were a refinement of the design of the APT-P, between 1983 and 1987. The APT-S was to have run along the West Coast Main Line between London and Glasgow, Birmingham, Manchester and Liverpool. However, the APT-S never entered service as funding for the APT programme was withdrawn in 1984. The APT tilt technology was sold to the Italian railways and further refined for use in their Pendolino project. Pendolino trains using APT based tilt technology are now used by Virgin Trains on the West Coast Mainline, although they are restricted to 125mph running. The APT held the Glasgow-London rail speed record, four hours and 14 minutes, from December 1981 until 22 September 2006 when a special non-stop Pendolino completed the journey in three hours and 55 minutes.

EUROSTAR AND THE CHANNEL TUNNEL RAIL LINK (HIGH SPEED 1)

Eurostar is the joint UK-French-Belgian high speed rail service linking London with Paris and Brussels via the Channel Tunnel. Eurostar services in the UK are operated by a consortium called Inter-Capital & Regional Rail, consisting of National Express Group, British Airways, SNCF (French National Railways) and SNCB (Belgian National Railways).

Eurostar trains are a derivative of the TGV, built to operate on three different electrical power systems and within the constricted clearances of the classic UK rail network. Further information on Eurostar trains is available on the website of its manufacturer, Alstom (Alstom 2005). Details of Eurostar services are available on the Eurostar website.

The first Eurostar service ran through the Channel Tunnel on 14 November 1994, by which time the French end of the Tunnel was linked to Paris by a double track high speed line (LGV Nord). The UK end of the Tunnel was linked to London by the classic rail network. British Rail had been developing proposals for a high speed line linking the Tunnel with London, known as the Channel Tunnel Rail Link (CTRL) and since renamed High Speed 1, but political and environmental concerns had prevented the line from being built prior to the opening of the tunnel.

Following the break-up and privatisation of British Rail the then Conservative Government decided that the CTRL should be built by the private sector using private finance. In 1996 the UK Government selected London and Continental Railways (LCR), a consortum made up of National Epress Group, Virgin, SBC Warburg, Bechtel and London Electric, to build the CTRL. LCR also assumed responsibility for the operation of the UK part of the Eurostar service.

Originally the CTRL was to have been built in its entirety as a single project. However, in 1998 LCR ran into financial difficulties and a decision was taken to build the CTRL in two sections, one after the other. The construction of each section was to be managed by subsidiaries of LCR - Union Railways (South) and Union Railways (North). Finance for the construction of section 1 was to be supported by the sale of government-backed bonds, with the future funding of phase 2 still to be agreed.

The two sections of the CTRL were:

Section 1 consists of 46 miles of electrified double track running from the Channel Tunnel to Fawkham Junction in north Kent. Section 1 opened on 28 September 2003 and cut the London to Paris/Brussels journey time by around 21 minutes. Eurostar trains continue to use existing suburban lines to enter London, and terminate at Waterloo International station.

Section 2 opened on 14 November 2007, consists of 21 miles of electrified double track running from the end of Section 1 to London's St Pancras station. Section 2 includes two new stations, located at Ebbsfleet and Stratford. The main fatures of this line are a two mile long tunnel under the River Thames near Dartford and a 12 mile long tunnel running into central London. Following the opening of Section 2 all London bound Eurostar trains run into St Pancras International instead of Waterloo International. The opening of Section 2 shaved another 20 minutes off London-Paris/Brussels journey times.

The original intention had been for the CTRL to be owned and managed by Union Railways. However, as part of the 1998 rescue plan it was agreed that Section 1 would be purchased by Railtrack, then owner of the UK national rail infrastructure, along with an option to purchase

Section 2. In return, Railtrack committed to manage and maintain the entire CTRL and St Pancras Station, which had been transferred into the ownership of LCR in 1996.

In 2001 Railtrack announced that, due to its own financial problems, it would not purchase Section 2 once it was completed. This triggered a second restructuring of the project, which would have seen Railtrack own Section 1 and LCR Section 2, but with common management by Railtrack. However, Railtrack went into administration and its interest in the CTRL was sold back to LCR, which then sold the operating rights for the completed line to Network Rail, Railtrack's successor. Under this arrangement LCR will become the sole owner of both sections of the CTRL and St Pancras, as per the original 1996 plan.

Following the completion of the line, ownership has been passed to London & Continental Stations and Property (LCSP) who will be the long term owners of the line with management, operation and maintenance undertaken by Network Rail.

THE IMPACT OF HIGH SPEED 1 ON EUROSTAR USAGE

The full opening of High Speed 1 and St. Pancras International station on 14 November 2007 has resulted in a considearble increase in Eurostar passenger numbers. Eurostar reported (Rail Business Intelligence 2008b) that it carried 18.3% more passengers in the first six months of 2008 than in the same period of 2007. Richard Brown, Eurostar Chief Executive, indicated that:

> …this impressive growth in traveller numbers clearly demonstrates that Eurostar's move to St. Pancras International has opened up high-speed rail services to millions more people across the UK. (Rail Business Intelligence 2008b)

In response to this growing passenger demand Eurostar has added an extra weekday train to Brussels and Paris and boosted weekend services.

FUTURE DEVELOPMENT OF HIGH SPEED RAIL IN THE UK

The Strategic Rail Authority commissioned transport consultants Atkins to undertake a study into whether there was a transport and business case for the development of a north-south high speed rail line in the UK. The results of the study, High Speed Line Study (Department for Transport 2004), which took place between August 2001 and February 2003 were not published until 29 October 2004. The report examines various route options for a high speed line and the potential impact that upgrades to existing intercity rail lines, the introduction of national road user charging and upgrades to regional airports and the highways network may have on the viability of a new high speed network. The study concludes that:

> …there is a good transport case for HSL….On balance, therefore, there is a good business case for HSL, and it is capable of delivering greater net benefits than other rail or highway schemes.

In addition to the Atkins study Greengauge21, the high speed rail campaign group, has published a manifesto (Greengauge21 2006a) and other documents highlighting possible benefits from the construction of a high speed rail line on economic development in the English regions and Scotland. These documents can be found online.

Iain Croucher, then Deputy Chief Executive of Network Rail, indicated in a speech to the Institution of Civil Engineers on 8 May 2006 that Network Rail considered there was a robust business case for a high speed rail line linking London, Birmingham, Manchester, Edinburgh and Glasgow in the future. He stated that any north-south high speed line should:

- Have the capacity to cope with future additional services
- Be based on trains travelling at 300km/hr in order to create a modal shift from air to rail and be environmentally sound
- Have stations at dedicated major urban conurbations

At this conference (Local Transport Today 2006) Network Rail indicated that the likely cost of constructing the line would be in the region of £15m to £19m per kilometre, while Ernest Godward, an rail economist from consultants Scott Wilson, told delegates that the average cost of high speed lines being constructed outside the UK was about £30m to £32m per kilometre.

During the 2005 Budget statement the then Chancellor of the Exchequer, Gordon Brown MP, announced that ex-British Airways chief executive Rod Eddington was to work with the Department for Transport and HM Treasury to advise on the long term impacts of transport decisions on the UK's productivity stability and growth over the next 30 years. The resulting report entitled Transport's Role in Sustaining the UK's Productivity and Competitiveness (Department for Transport 2006c), commonly know as the Eddington Transport Study, was published on 1 December 2006.

While not ruling out the development of a high speed rail network, Rod Eddington made it clear in a speech at the Commonwealth Club on 1 December 2006 (Department for Transport 2006b) that he considered high speed rail, particularly that utilising new or novel technologies, to be a low priority when compared with other possible transport investments, stating:

> Investment will be essential to maintain and improve the transport infrastructure - and the Government and the private sector must work together across all modes to deliver this. The returns from public and private investment can be very high -with benefits four times in excess of costs on many schemes.
>
> But let us be clear. This does not always have to entail large-scale projects. Some of the best projects are small scale - tackling bottlenecks in the existing network - such as rail platform lengthening, roads linking to ports - and walking and cycling schemes. However, I am sure a series of small-scale projects alone will not be able to alleviate major transport pressures over the long term.
>
> Ambitions and dreams of extensive new networks - that will only ever make marginal improvements to connectivity of the UK - are not a priority. Transport policy needs to avoid wasting time and money pursuing alluring new super high-speed motorways or rail networks or pursuing 'grands projets' with speculative returns.

Greengauge21 published a document entitled High Speed 2: A Greengauge21 Proposition (Greengauge21 2007) during June 2007. This recommended the construction of a 150 mile long 300kmph high speed line linking High Speed 1 (London) and Heathrow Airport with Birmingham, where the line would join the classic rail network for onward services along the west coast main line. Greengauge21 predicted that the cost of the line would be £6.6bn at 2007 prices. This rises to £11bn when the 66% optimism bias required by HM Treasury is included in the calculations[2]. This report was clear in its statement that "*The planning and design of High Speed Two in the North West corridor needs to start now*".

The UK Department for Transport published Delivering a Sustainable Railway: White Paper (Department for Transport 2007) on 24 July 2007. The White Paper sets out the UK Government's 30 year strategy for the development of the rail network. It also includes the UK Government's High Level Output Specification (HLOS) and Statement of Funds Available (SOFA) for the period 1 April 2009 to 31 March 2014 – a separate Scottish HLOS and SOFA (Transport Scotland 2007) has been produced by Scottish Ministers for the Scottish rail network.

The White Paper does not propose the construction of any additional high speed lines in the UK, focusing instead on enhancements to the capacity of the current classic network. The White Paper also questions the environmental credentials of high speed rail and mentions un-cited Passenger Focus research which the White Paper states "…*cutting journey time is not a high priority for passengers*".

Consultants Atkins published an updated version of their original High Speed Line Study (Department for transport 2004 entitled Because Transport Matters: High Speed Rail in March 2008 (Atkins 2008). This updated version concluded that the results of the original study effectively stood despite changes to the UK Government transport and rail policy.

Network Rail established a team at their UK headquarters in April 2008 charged with developing the case for a new lines programme. The team is managed by Richard Eccles, Network Rail's Head of Route Planning. This team will be investigating five strategic routes to the north and west of London, i.e. the East Coast main line, Midland Mainline, West Coast main line, Chiltern and Western lines. Network Rail is in the process of appointing a team of consultants to assist in this work. An initial report should be published by summer 2009.

The House of Commons Transport Select Committee published a report, Delivering a Sustainable Railway: A 30-Year Strategy for the Railways (House of Commons 2008), on 16 July 2008. This provided a critique of the rail White Paper and was critical of the position taken by the UK Government on the development of a high speed rail network, stating:

> It is deeply disappointing that the White Paper dodged the decision on high-speed rail. Given the additional capacity and the limited additional cost in building high-speed as opposed to conventional rail lines, we recommend that the Government consider very seriously the possibility of building high-speed lines where new lines are to be constructed. Although there have been encouraging signs of movement in the Government's position since the publication of the White Paper, we firmly believe that this is an area where the Government needs to move into a different gear. We welcome the preparatory study to develop and evaluate options recently announced by Network Rail. Once the study is complete, it will be incumbent on the Government to make decisions and initiate the work without delay. The time frames for the planning, procurement and construction of high-speed rail links are measured in decades rather than years. Hesitation now will mean years of avoidable misery and overcrowding on the network.

[2] HM Treasury requires costings for major transport proposals at a very early stage of development to include a 66% "optimism bias" – i.e. an extra 66% on the total cost to cover any possible cost overruns or unforeseen additional expenses.

HIGH SPEED RAIL IN OTHER COUNTRIES

High speed rail services now operate in many European countries as well as in Japan, Taiwan and South Korea and are at various stages of development in other countries. This section looks briefly at the well developed high speed rail services in France, Japan and Spain. The UK Commission for Integrated Transport (2005) has produced a useful report, High Speed Rail: International Comparisons, which looks at the development of high speed rail systems in the UK and six other countries and lessons learned so far.

France: The French TGV (Train a grande vitesse) operates on Europe's largest network of dedicated high speed lines, currently totalling over 1,550 km in length. The first TGV line (known as an LGV: Ligne a Grande Vitesse) between Paris and Lyon opened in 1981. The LGV network has expanded rapidly since then to incroporate other cities, and eventually other countries including Belgium, The Netherlands, Switzerland and Germany.

LGV's are constructed to allow TGV's to operate at speeds of up to 200mph, although more normally up to 186mph. TGV trainsets are manufactured by Alstom, which also produces the Eurostar which is a TGV derivative. A major programme of LGV construction continues apace, including:

- LGV Est Linking Paris and Strasbourg. The 300km long first phase of the line between Vaires-sur-Marne (near Paris) and Baudrecort opened on 10 June 2007 with the remaining 103km section to Metz currently under construction and due to open in 2014.
- LGV Rhine-Rhône This 425km long line will consist of three branches. Construction began in 2006 with the first 190km branch (linking Mulhouse and Dijon) due to open in 2011.
- LGV Perpignan-Figueres Linking Perpignan in France and Figueras in Spain, this line is currently under construction and is due to open in February 2009. The line will also be used by freight services and will dramatically reduce freight journey times across the Pyrenese. The line will also form a link between the proposed Barcelona-Figueres and Montpelier-Perpignan high speed lines.

In addition to these projects which have entered the construction phase a number of other proposed lines are at an earlier stage of development. In total these projects represent an investment of over 20 billion euros.

TGV services are provided by the state owned Société Nationale des Chemins de fer Français (SNCF) on infrastructure that is owned and managed by the state owned Réseau Ferré de France (RFF). RFF is responsible for the construction of France's new high speed rail infrastructure.

Japan: The Japanese 'bullet train' or Shinkansen[3] (新幹線), which translates as 'new main line', are probably the most famous high speed trains in the world. Japan was the first country to develop new lines dedicated to high speed passenger trains. The first shinkansen line, Tokaido, which links Tokyo with Osaka opened on 1 October 1964 and had an operational speed limt of 125mph, newer trains on the Tokaido line now run at speeds of up to 186mph.

The Tokaido line was a great success, carrying 3m passengers within three years of opening, and a network of shinkansen was proposed linking many areas of Japan. Of the proposed lines six full shinkansen have been built, two 'mini shinkansen' upgrades of existing lines have been

[3] Technically the term Shinkansen refers to the rail infrastructure and not the train itself, which are called 'super-expresses'. However, this distinction is rarely made, even in Japan.

undertaken and two standard guage lines have been adapted to allow shinkansen services to run along them.

Shinkansen services are provided by a series of trains built by Japanese manufacturers, principally Hitachi, Kawasaki Rolling Stock Co. and Nippon Sharyo. Trains in service today have top speeds which vary from around 140mph to 186mph and range in length from 6 to 16 carriages. The Shinkansen network is currently over 2,400 kilometres long with a further 1,300 kilometers of line authorised for construction, of which 500 kilometres (forming four separate lines, three of which are extensions to existing shinkansen lines) are currently being built and due for completion between 2010 and 2015.

Japanese railways are operated by six private regional passenger rail companies, which also own the rail infrastructure on which rail services are provided. These companies were formed following the privatisation of Japanese National Railways during the late 1980's and still receive substantial central government subsidy. However, a different system applies to the Shinaknsen rail lines which tend to cross the boundaries of the regional rail operating companies. These are owned by the Shinkansen Property Corporation which leases facilities to the train operating companies that provide shinkansen services.

Spain: The Spanish Alta Velocidad Española (AVE) operates on a rapidly expanding network of high speed lines. AVE trains began running on the 471 km Madrid-Seville route during April 1992. The 621km Madrid-Barcelona line fully opened on 20 February 2008 and is currently one of the fastest railway lines in the world, with the quickest trains completing the journey in just two hours and 38 minutes.

AVE trains running between Madrid and Seville were built by Alstom while new AVE trains are built by a consortium of three companies, namely Alstom, Bombardier and Siemens. The trains have a maximum speed of 200mph.

The Spanish Government has established a Strategic Infrastructure and Transport Plan: 2005-2020 (Ministerio de Formento 2005) which involves the development of a 10,000km long high speed rail network by 2020. This will ensure that all provincial cities will be less than four hours travelling time from Madrid, and six and a half hours from Barcelona, in addition to opening up international high speed rail corridors with France and Portugal.

AVE services are provided by the state owned railway company Red Nacional de los Ferrocarriles Españoles (RENFE) on infrastructure owned by the state owned Administrador de Infraestructuras Ferroviarias (ADIF). ADIF is responsible for the construction of Spain's new high speed railway infrastructure.

MAGNETIC LEVITATION (MAGLEV)

Background: An alternative to a conventional steel railed high speed rail network is the magnetic levitation transport system, maglev for short. Maglev is a system of transportation that suspends, guides and propels vehicles above a 'guideway' using electromagnetic energy. The only large scale high speed maglev system in commercial operation at present is the 19 mile long Pudong Airport-Longyang Road (on the outskirts of Shanghai) line. This was built by the German company Transrapid AG, a joint venture between Siemens and ThyssenKrupp. The line opened during 2002 and cost $1.2bn to construct. The maximum speed of the line is 267mph and the normal end to end journey time is seven minutes 20 seconds.

However, concerns about the economic and technical viability of maglev trains have been raised by various parties. A Network Rail (BBC 2006) spokesman is on the record as stating:

> Network Rail believes that the incremental benefits of speed provided by maglev are unlikely to generate enough additional passenger revenue to justify the expected higher cost or the risk of unproven technology. For the UK, traditional high-speed technology can deliver fast enough journey times to attract passengers off planes and onto trains.

In addition, the Eddington Transport Study was critical of the development of new transport networks which used new or experimental technology, principally due to concerns about the potential for cost overruns associated with the development of such systems when compared with tried and tested technology.

Technology: Transrapid maglev trains operate via two electromagnetic systems, one to levitate the vehicle above the guideway and another to propel the vehicle, as described below:

- **Levitation:** A magnetized coil runs along the guideway, which repels the large magnets on the train's undercarriage, allowing the train to levitate.

- **Propulsion and braking:** Once the train is levitated, power is supplied to the coils within the guideway to create a system of magnetic fields that pull and push the train along the guideway. The electric current supplied to the coils in the guideway is constantly alternating to change the polarity of the magnetized coils. This change in polarity causes the magnetic field in front of the train to pull the vehicle forward, while the magnetic field behind the train adds more forward thrust.

In addition to the Transrapid system, Japan Railways Central has been developing a Maglev train, using slightly different technology to Transrapid, since the early 1970's. JR Central is committed to the development of a commercial maglev service (Chuo Shinkansen) between Tokyo and Nagoya by 2025. It is predicted that this line would cost at least $44bn to build.

Future Development: Commercial application of maglev technology is in its infancy when compared to conventional high speed railways, where the technology has been in commercial operation for over 40 years. As with many new technologies, concerns have been raised about the reliability of the Transrapid system, particularly following a fatal crash on the Transrapid test track in north-western Germany on 22 September 2006 and a fire on a Shanghai maglev train on 11 August 2006.

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