

# *Gröna Tåget*

Trains for tomorrow's travellers



“High speed at low cost  
– could it be better?”



Sketch of the exterior (left), and design studies of the front (right)

## Gröna Tåget – trains for tomorrow's travellers

*Gröna Tåget (the Green Train) research and development programme shows that new trains for long-distance and fast regional traffic can be more attractive to travellers and operators. Gröna Tåget is a collection of ideas, proposals and technical solutions that suit the Nordic market well.*

**Gröna Tåget will make it more attractive to travel by train through:**

- Shorter travelling times
- Lower costs, enabling cheaper fares
- An attractive, functional passenger environment with a high level of comfort for all.

The most important aspect as regards the environment is that the train is attractive and that travellers choose the train instead of other modes of transport.

Gröna Tåget is a fast, electric tilting train that can not only maintain higher speeds than conventional trains on sections with curves, but also 300 km/h or more on dedicated high-speed lines.

**The concept also offers operators and infrastructure managers the following advantages:**

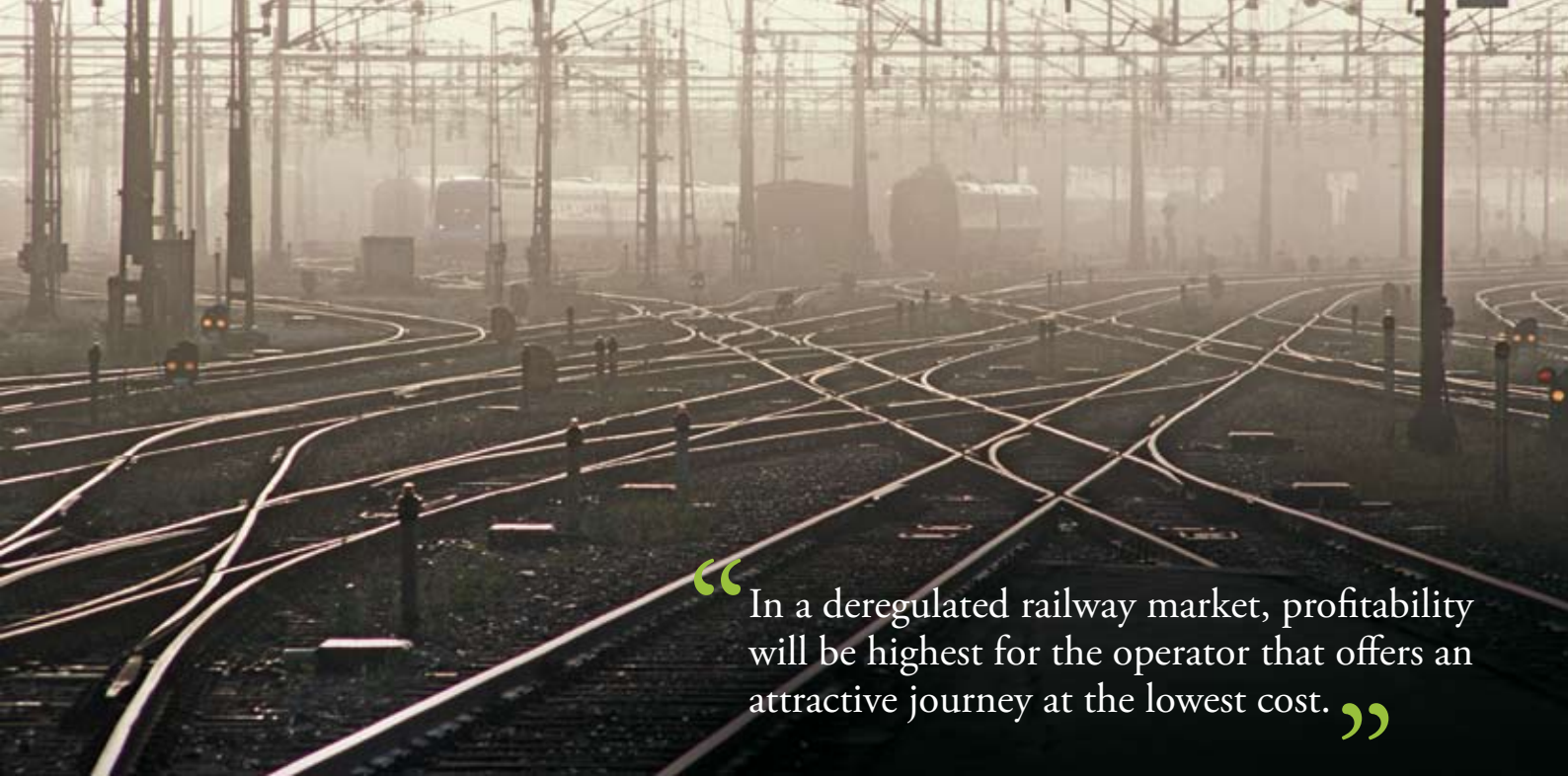
- Flexible train length; capacity according to need
- Many seats in a given train length
- Reliability and accessibility even in the Nordic climate
- Low costs give profitability in a market exposed to competition
- Track-friendliness, which means less wear to track and wheels and enables high speeds on non-perfect track
- Even lower energy consumption and less noise than trains of today.

No other existing train concept fulfils all these requirements. Gröna Tåget can be a new standard train that offers low-cost high speed with an even lower environmental loading.



Example from the design studies, sketch of the bistro

“Gröna Tåget should serve as a bank of ideas, proposals and technical solutions for operators, infrastructure managers and industry.”



“In a deregulated railway market, profitability will be highest for the operator that offers an attractive journey at the lowest cost.”

## Economy and capacity

*Gröna tåget can give lower train operating costs and higher revenues with a more attractive supply that wins over more passengers. This gives better economy and lower fares. New technology and the fact that Gröna tåget is a multiple-unit (it has no locomotive) contribute to lower costs.*

### Better economy gives lower fares

Better space utilisation is important to train operators' economy. A comfortable, functional and space-efficient seat design is proposed. Further, wider trains have more seats in every car.

Gröna Tåget with better space utilization and wide carbodies (3+2 seating in economy class) gives 30% lower total costs compared to the X 2000 with the same level of comfort. Countries where the wide carbody is suitable for operation include the Nordic countries, Russia and China.

The narrower, continental-style body width with fewer seats (2+2 seating in economy class) gives 10-15% higher total costs for the operator than wide trains. An operator with a fleet of wide-bodied Gröna Tåget trains thus has a competitive advantage over operators with narrower trains.

### Track capacity

If the fast trains run at higher speeds, the differences in running times against slower trains such as regional trains and freight trains increase. But with passing stations, just as many trains can be accommodated on double-track lines despite higher speeds and mixed traffic. On single-track lines it is even an advantage from the point of view of track capacity to raise speeds. No new track needs to be laid for Gröna Tåget.

In order to shorten travelling times, conventional lines often need to be upgraded, for example by building grade-separated road/rail intersections, installing a new signalling system (ERTMS/ETCS) and implementing capacity-increasing measures. If there is already so little free capacity on the tracks that more trains cannot be accommodated, wide-bodied trains can contribute to increased capacity. The best way, however, is to supplement the existing tracks with new high-speed links. Bottlenecks are then eliminated at the same time as traffic can be separated. Gröna Tåget is ideal for efficient operations on lines with varying track standard.



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## Market and services

*Train traffic needs to be more attractive to win over travellers. It is primarily travelling times, frequency of service, and fares that need to be improved – which is exactly what Gröna Tåget can make possible.*

### Gröna Tåget is attractive

Gröna Tåget is a high-speed train that is suitable for both long-distance and fast regional services with travelling times from thirty minutes up to four or five hours.

- Short travelling times on sections with tighter curves through good acceleration and tilting
- High top speeds of 250-300 km/h or more on new, straighter lines.

There are other high-speed trains developed for higher speeds on dedicated high-speed lines, but they are not as fast as Gröna Tåget on lines with tighter curves.

### More journeys through better operation

Our studies show that economy of train operations in Sweden is best if Gröna Tåget is built as relatively short trainsets with 240-320 seats (equivalent to 3-4 wide-body cars). These short trainsets can be coupled and decoupled as needed – long trains for peak traffic and short trains at off-peak times. A higher share of seats will thus be occupied.

Examples of possible journey times

### Stockholm – Copenhagen

Type of train	Line standard	3 stops	13 stops
X55/Regina (non-tilting)	Today's track incl. the City Tunnel (655 km), 200 km/h	4:55	5:20
X 2000 (tilting)	Today's track incl. the City Tunnel (655 km), 200 km/h	4:30	5:00
Gröna Tåget (tilting)	Upgraded track (655 km), 250 km/h	4:05	4:35
Gröna Tåget (tilting)	Upgraded track incl. the Eastern Link (630 km) <sup>1</sup> , 250 km/h	3:45	4:20
Gröna Tåget (non-tilting)	New high-speed line (605 km) <sup>2</sup> , 320 km/h	2:50	

<sup>1</sup> The Eastern Link is a planned high-speed link between Södertälje and Linköping (155 km).

<sup>2</sup> A new line between Södertälje and Helsingborg (including the Eastern Link), via a tunnel between Helsingborg and Elsinore, and the Coast Line between Elsinore and Copenhagen.

Examples of possible journey times

### Domestic services in Sweden

	Stops	Possible X 2000	Upgrading Gröna Tåget	New links Gröna Tåget
Stockholm – Gothenburg (455 km)	0	2:45	2:30	2:20
Stockholm – Malmö (614 km)	2	4:00	3:35	3:15
Gothenburg – Malmö (305 km)	3	2:30	2:15	1:55
Stockholm – Sundsvall (402 km)	5	3:20	3:05	2:30
Stockholm – Umeå (737 km) opens 2010	10	5:40	5:05	4:30

Upgrading: Higher speeds, up to 250 km/h, where track geometry allows

New links: Including quadrupling Alingsås – Gothenburg, the Eastern Link on the Stockholm – Malmö line, the Hallandsås tunnel and complete double track Gothenburg–Malmö, and complete double track Stockholm – Sundsvall.

### Lower fares and shorter travelling times

Routes can also be operated with more direct connections. With an attractive service the profit from the increased revenue generated by having more passengers will exceed the slightly higher cost of shorter trainsets and more direct trains.

In Scandinavia, Gröna Tåget can be operated with wide-bodied cars on electrified sections in Sweden, Norway and to Copenhagen via the Öresund link. In a continental-style variant Gröna Tåget can also continue on into Denmark and Germany, giving direct connections with short travelling times on many routes. With Gröna Tåget, train services will be generally more attractive and win over new passengers, mainly thanks to lower fares and shorter travelling times. More

passengers and better utilisation with shorter trainsets will provide scope for enhancing the supply with more frequent trains, which will further increase journey numbers.



Shorter, flexible units enable higher load factors through coupling and uncoupling according to travel demand, and also more direct connections instead of passengers changing trains.

“Gröna Tåget will increase patronage through shorter travelling times, cheaper tickets and an attractive design.”

- Services by Gröna Tåget possible
- ..... Extended services by Gröna Tåget
- ..... Proposed high-speed line (Gröna Tåget)



Design sketch / photomontage of the Gröna Tåget.

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“One of the most unique benefits of trains is the possibility to use the journey time for different onboard activities.”



**Individual seat: RELAX**  
Sound reducing walls, window curtains, adjustable lightning



**Individual seat: WORK**  
Large foldable table, Internet / WLAN, personal reading light.



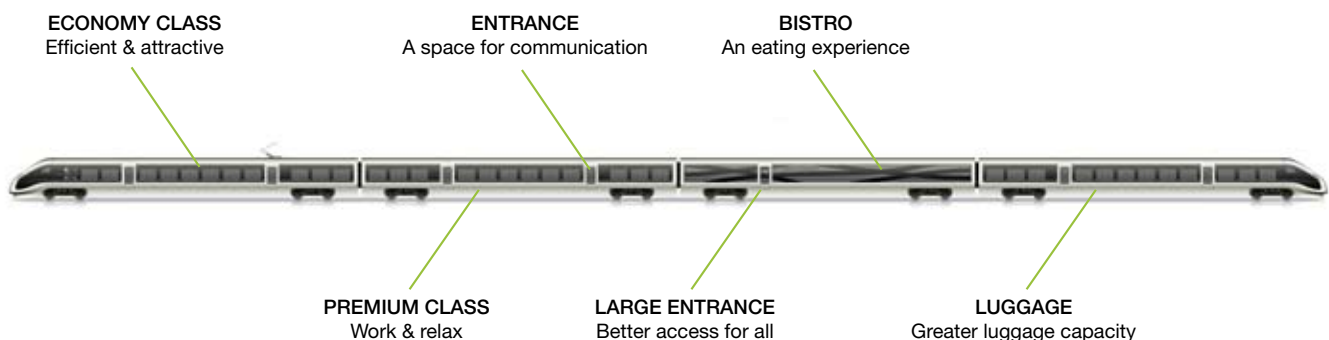
**Lounge module: SOCIALIZE**  
Gives the train a "sozial point".

## Attractive passenger environment

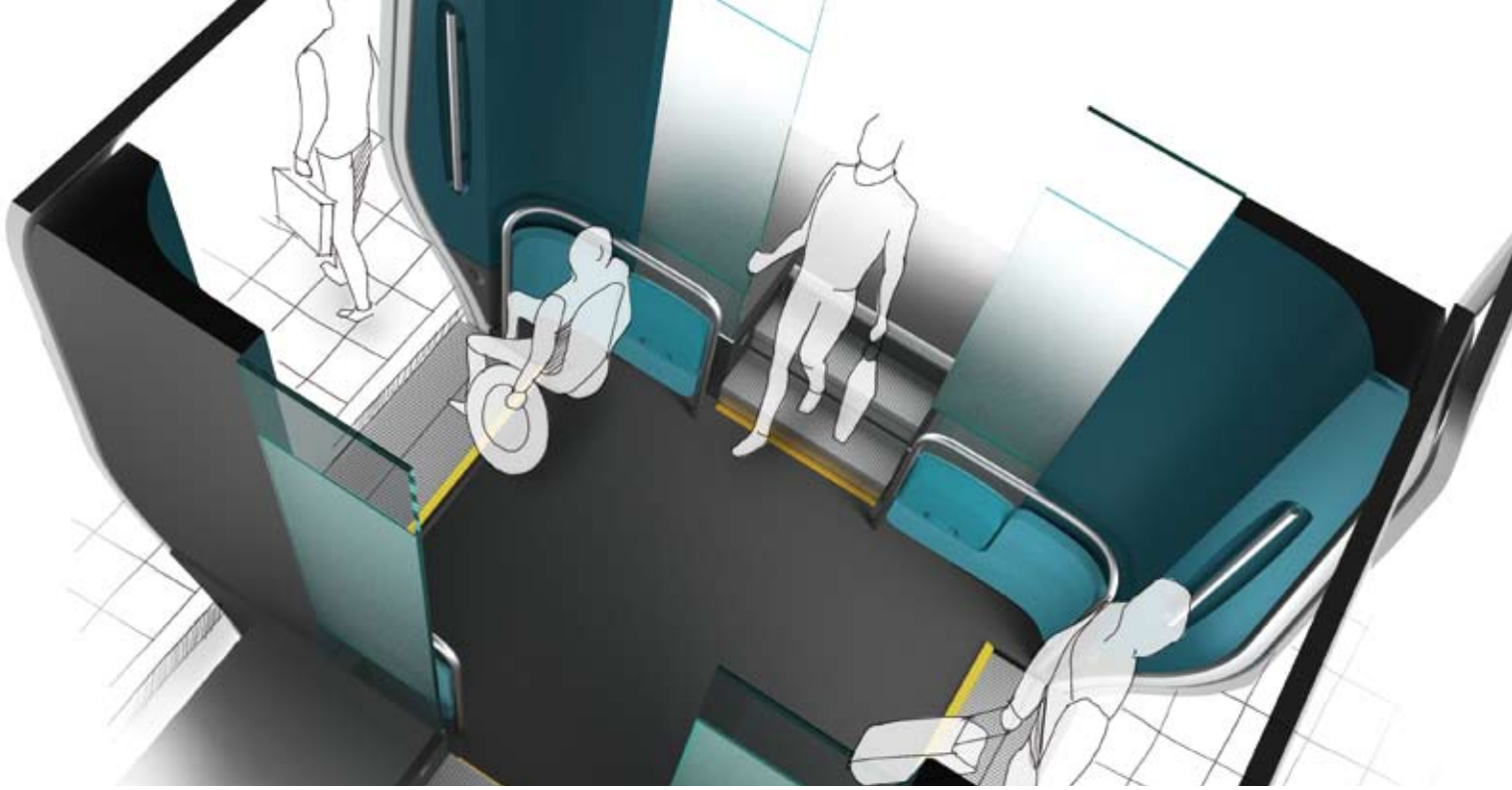
*Konstfack (University College of Arts, Crafts and Design) has developed proposals for the passenger environment of tomorrow's Gröna Tåget. A great many sub-projects with different aims and directions have been conducted with a focus on passengers' behaviour, needs, and perceptions. The purpose of the different design concepts is to constitute an idea bank for manufacturers, operators and other players in the rail industry.*

In all, some 15-16 different designers and design students have been involved in different parts of the Gröna Tåget programme. The objective was not to create a cohesive finished train but gain deeper knowledge of the different parts and functions of the train. This creates scope for separate design studies and penetration of a sub-area without their needing to otherwise relate to the train. The design work has generated hundreds of ideas and design concepts that are ready to be developed into final products and services.

We have focused the design work on six main areas; Economy class, Premium class, the entrance as a space for communication, a large entrance with access for everyone, the Bistro, and greater luggage capacity.







## Design for all

*Our objective is that the train of the future shall be accessible to all, regardless of age or abilities. The Gröna Tåget programme is a good example of how “Design for all” can be achieved in practice, where an efficient process and teamwork between operators, manufactures and designers generate new innovative ideas for the future.*

The entrance is the first impression of the train interior. The time it takes to change passengers at a station is critical. These two parameters were important when creating this large entrance concept - An entrance for all.

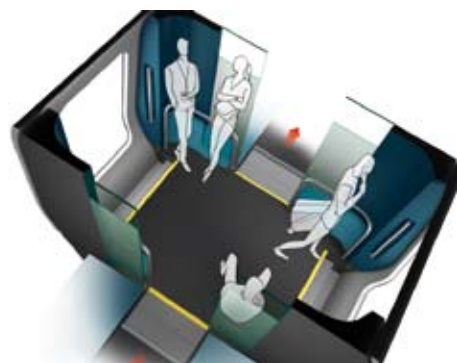
The population is getting older and there are many people with varying needs to bring along different accessories. Many of today's solutions for lifting a wheelchair onboard make you feel uncomfortable. They demand the assistance of train staff and only work for one wheelchair at a time. From the traveller's point of view, we created a “main entrance” where everyone can board easily. From the operator's point of view, this concept is efficient and saves time at every station.



The entrance with its vertically adjustable floor maximizes access for a growing group of elderly travellers, people with children and prams, travellers with heavy luggage, etc.



The floor sinks slowly and adjusts to the level of the platform.



In the upper position the entrance acts as a mini-lounge and you can readily pass with a wheelchair, a pram or a trolley-bar.

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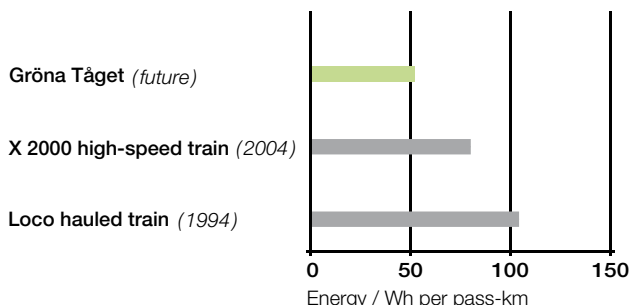
“Energy consumption can be reduced by a further 30%”

## Reducing environmental impact – less energy consumption

*One of the major objectives of the Gröna Tåget programme is to propose technologies and concepts for even better environmental performance, thus maintaining the advantage of rail transportation in relation to other modes.*

### Electric trains - low environmental impact

Electric trains are widely considered to have a low environmental impact in comparison to most other modes of transport. This is in particular due to low energy consumption per passenger-km and the possibility to use electricity produced with zero or low emissions of greenhouse gases and other air-pollutants. However, higher speeds would increase energy consumption dramatically if trains of "low-speed" design were used. The targets for operational speed of the future Gröna Tåget are 250, 280 and 320 km/h, depending on the type of railway line.



In the Gröna Tåget programme, we have analyzed different means of reducing the specific energy consumption, i.e. energy per seat-km or passenger-km.

### This analysis has resulted in the following major recommendations:

- Aerodynamic drag must be considerably reduced in comparison to recent trains (travelling at the same speed).
- Electric regenerative brakes should be used as much as possible as the normal operational brake. This needs high propulsion and braking power installed on at least 50% of the axles.
- Trains with efficient space utilization to lower energy consumption per seat-km. In the Nordic market wide-body trains are recommended as the first option, allowing an additional comfortable seat to be installed in each row.
- Improved energy efficiency in the propulsion system.

With these principles it is possible to achieve low energy consumption - of the order of 50-55 Wh per passenger-km (equivalent to about 0.005 litres of petrol per passenger-km) – at top speeds of up to 280 km/h on both conventional and newly built high-speed lines. These figures imply a reduction of 25 – 35% in relation to present high-speed trains in Sweden (top speed 200 km/h). Energy losses in the railway's electric supply system are included. These measures contribute to a lower environmental impact. They would also pay off in reduced cost for energy consumption.





The “acoustic camera” is a most helpful tool to analyze external noise sources of a train.

## Ensuring low noise at high speed

*Shorter journey times call for trains with faster acceleration and higher speed. Wayside noise would inevitably increase with train speed, if the same train design were used. This challenge must therefore be addressed in the future Gröna Tåget.*

**Achieving low wayside noise levels at high speeds primarily involves two mechanisms:**

- Aerodynamic (flow) noise generated by high air flow velocities over sharp edges, protruding objects, cavities, etc.
- Wheel-rail (rolling) noise generated by small irregularities on the wheel and rail surfaces.

Installing high noise barriers is the traditional way of keeping wayside noise from reaching nearby residents. However, these barriers are costly and visually intrusive. Instead, the noise should be tackled at source, i.e. on the track or on the train.

**What could feasibly be achieved is the following:**

- Bogie skirts. These are beneficial both for smoothing the air flow around the bogie, thus reducing aerodynamic noise, and for shielding out wheel noise.
- Careful design of the front area.
- Shielding and careful design of pantograph and other on-roof equipment.
- Smooth surfaces, including closure of inter-car gaps
- Rail absorbers and low track-side barriers – at least in sensitive areas along the line.
- A combination of bogie skirts and low track-side barriers has a very good overall effect.

A 96-microphone “acoustic camera” was used to locate noise sources and compare the relative effect of different mitigation measures. The results showed that bogie skirts reduce noise emission from the shielded bogie by 2 – 3 dB(A). In combination with rail dampers the total effect is as much as 5 dB and with low trackside barriers even higher, which is perceived as a halving of the noise.

“Bogie skirts reduces both rolling and aeroacoustic noise.”



A bogie skirt on the REGINA Gröna Tåget test train.



## Gröna Tåget is testing tomorrow's high-speed technologies

*The REGINA Gröna Tåget test train is equipped with the latest technology developed for very high-speed traffic in Sweden and other Nordic countries. On Sept 14 2008, it set a new speed record of 303 km/h on standard track on the Skövde-Töreboda section of the Western main line, where top speeds in normal daily operations are otherwise between 160 and 200 km/h.*

With tests being run in different parts of Sweden since 2006, this train – named the REGINA “Gröna Tåget” – is indeed a very special one. Banverket, Bombardier Transportation, KTH as well as train operators, Interfleet Technology and Schunk are involved in the Gröna Tåget research, development and demonstration project together with a number of partners.

The train is one of the world's most advanced studies in ecological technology: it is equipped with components that maximise total train performance and environmentally friendly operations.

The REGINA Gröna Tåget has been in commercial service since January 2009. Before the service test, the test train underwent extensive performance tests, winter tests, tunnel tests, high speed tests and simulated commercial service without passengers.

**The following products and technologies have been tested:**

- Track-friendly bogie for high stability at high speeds and low track forces and wear using radial steering technology.
- Active lateral suspension for greater ride comfort and a wider carbody for more passenger space.
- Permanent magnet motor drive technology for reduced energy consumption.
- High-performance current-collecting pantograph
- Aerodynamic measures to reduce drag for reduced energy consumption.
- Acoustic measures to lower external and internal noise levels.

The project's valuable results can be adapted to markets with similar requirements around the world. At a time when rail operators find themselves increasingly challenged by the pressures of volatile energy costs, operating efficiency and global climate change, the developed and tested technologies can help achieve sustainable mobility today. It helps rail operators to enhance the reliability and performance of their fleets, while at the same time reducing both their carbon footprint and their energy costs.



“A new speed record of 303 km/h on a conventional track.”



“Several measures must be applied compared to a “standard” high-speed train in order to be able to operate in the extremely low temperatures and snow conditions that occur in Sweden and other Nordic countries.”

## Nordic weather conditions

*The reliability, comfort and safety of train operation depend on the one hand on the rolling stock and infrastructure and on the other hand on the weather conditions during operation. Trains considered reliable, safe and comfortable under normal conditions can become unreliable, uncomfortable and risky when operating in extreme weather conditions with excessive snow and/or low temperatures.*

Problems encountered are for example insufficient braking performance if brake pads are affected by snow and ice. If the bogie suspension is blocked by packed snow or ice, this causes an uncomfortable ride and might ultimately result in a higher risk of derailment. Another challenge might be unreliable horn or sliding step operation due to snow and ice accumulation. Inside the train, uncomfortable thermal conditions may occur.

Further, ice blocks falling from the train would cause severe damage to the whole train or to the surroundings. This might also generate a chain reaction with ballast projection, resulting in a risk of severe damage from gravel rocks.

### Special measures needed for harsh winter conditions

When a train is to be operated in countries with Nordic weather conditions this must be considered early in the design phase since many components and systems are affected.

Some examples of special measures are given below

- The steel in the carbody and bogies is changed in order to cope with temperatures down to  $-40^{\circ}\text{C}$  and several components had to be customized for this operational environment.
- The electronics and power electronics must be designed for low temperature storage and use. Preheating is needed in many cases. The cooling system for transformer and converters must also withstand the low temperatures and the cooling effect may need to be modified due to the very low cooling air temperature.
- Properties of rubber change at low temperatures. All rubber parts such as springs, air hoses and seals need to be qualified for low temperature conditions.
- Snow is the major source of problems for a train operating in winter conditions. The snow accumulates in gaps, stagnation regions of the flow and cavities, and causes malfunctioning, added weight and additional wear. Measures must be taken to delay the accumulation of snow in sensitive areas of the suspension, brake rigging, foot steps etc.
- Underfloor equipment must be of robust design in order to withstand the impact of pieces of ice and gravel.
- A train may travel long distances in a relatively short time and the climate can change considerably in a few hours. The temperature gradients can be considerable when operating from the coast to an inland region. The air inside tunnels is often warmer than the ambient air and melts snow, which then freezes to ice when the train exits the tunnel again. This sharpens the need for appropriate measures to be taken along the whole train.







## Carbody tilt – to maintain speed on curves

*Carbody roll inwards reduces the centrifugal force felt by the passengers in curves, allowing the train to negotiate curves at enhanced speed with maintained ride comfort. Roll may be achieved by track cant, or if this is insufficient, carbody tilt. Trains capable of tilting the carbodies inwards on curves are often called tilting trains.*

On most conventional lines narrow curves limit speeds to modest levels. If the train runs too fast, a strong lateral acceleration (or lateral force) will be felt that is unacceptable to passengers, in particular those standing or moving through the train. Personal belongings (books, computers, cups, bottles, etc.) may move and fall to the floor.

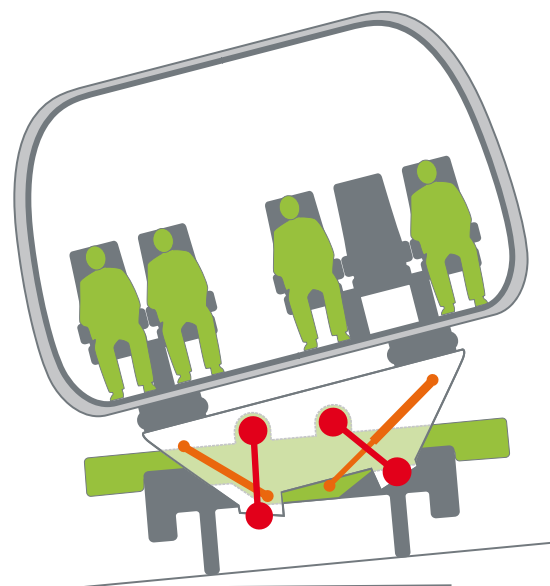
### Shorter travelling time

Carbody tilt is an option in cases where operators want to offer short travelling times on lines with many curves.

Most train operators accept the technology, but motion sickness is a challenge that is still holding back the full potential of tilting trains. The difference between non-tilting and tilting rolling stock has been paid particular attention as tilting trains usually cause more motion sickness than non-tilting ones. Reducing the risk of motion sickness is a challenge in developing a tilting train.

In the Gröna Tåget programme, we have addressed these issues by

- carrying out research on the causes of motion sickness, in particular related to combined motions (rotation and translation) being the result of the train and its interaction with the track;
- trying to design a train with tilt control that satisfies the conflicting requirements regarding low risk of motion sickness, maintained or improved speed performance on curves and good ride comfort (low average lateral acceleration).



Carbody tilt – curves to be negotiated at enhanced speeds with maintained ride comfort

# Track-friendly running gear and suspension

*Considerable resources are invested in maintaining the track and its substructure in operable and safe condition. On many railway lines high-speed trains operate on the same track as heavy freight trains.*

High-speed trains require usually good quality track, while heavy trains risk degrading the track quickly. Winter and the risk of frost upheaval are aggravating factors in the Nordic countries. Further, high-speed trains designed for straight track and wide curves may cause excessive wear on rails and wheels when passing narrow curves on conventional lines.

Therefore, it is important that high-speed trains are track-friendly in the following sense:

- Axle load should be low – to limit impact on track
- Wheelsets should have the ability to steer radially (at least partly) when negotiating narrow curves on conventional lines – to limit rail and wheel wear and squealing.
- Suspension must be designed to maintain running stability even at the highest speeds – i.e. to avoid self-generated violent lateral "hunting" oscillations.
- Suspension should insulate the train against shocks and vibration from the track – to maintain a good ride even on non-perfect track.

A track-friendly train is also friendly to the wheels and thus helps to reduce the train's maintenance costs.

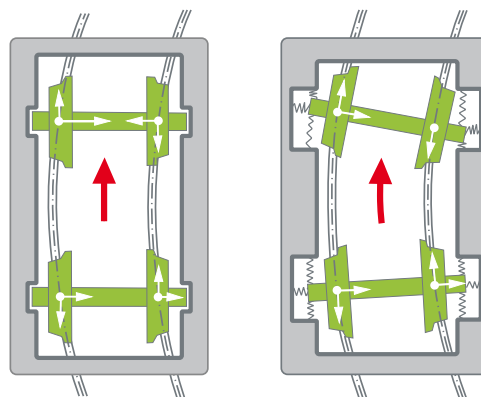
“Radial steering of wheelsets reduces wheel and rail wear in curves and the risk of squealing.”

The Gröna Tåget programme has developed:

- A high-speed bogie stable at speeds up to 300 km/h, with radial self-steering (RSS) properties resulting in low wheel and rail wear in common curves on conventional lines. Vertical and lateral wheel-rail forces are typically only about 60-65% of accepted European limits. A particular variant of this bogie is the Active Radial Steering (ARS) bogie, which allows full radial steering also on very narrow curves.
- Active Lateral Suspension (ALS) that gives a smooth ride through curves, when negotiated with high lateral acceleration. Reduced suspension motion facilitates wider carbodies within the allowed space, enabling e.g. wider seats for passengers.

The RSS and ALS technologies have also been extensively tested in commercial train operation.

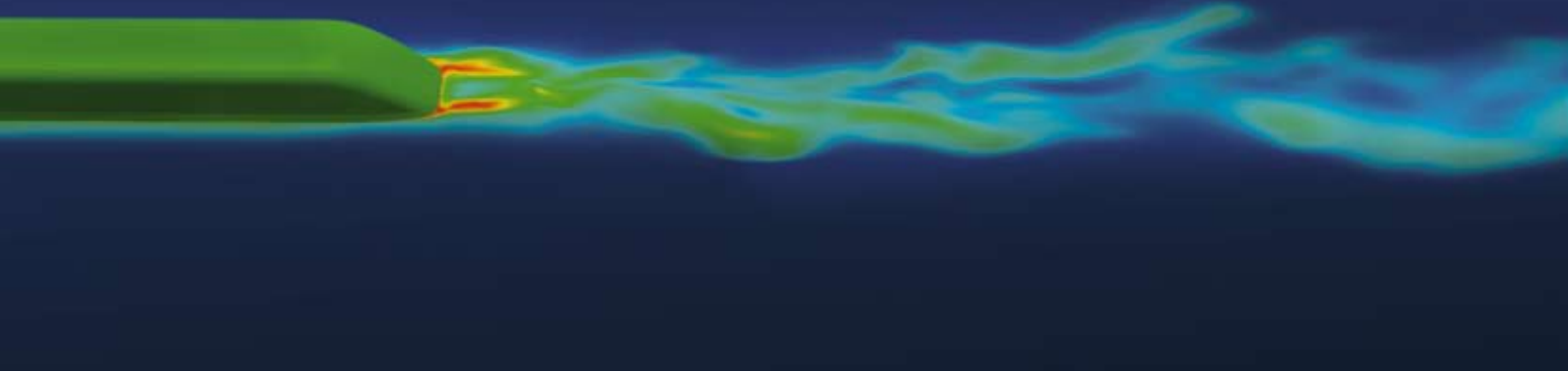
Research has also been done on impact forces between wheels and rails, with high-frequency content up to 1,500 Hz. Instrumented force-measuring wheels are used for this purpose. This is done to gain a better understanding of high peak forces and to prevent damage to wheels and rails.



Radial steering bogies (right) generate less wear and squealing than conventional bogies (left) where leading wheels have an "angle of attack" to the rails.



“Computer optimization reduces aerodynamic drag. This single measure can save up to 15% of the energy consumption.”



## Aerodynamic design optimization

*Designing the outer shape of a train has a major impact on its aerodynamic performance. We have developed a system that helps to optimize rail vehicles' aerodynamic performance using state-of-the-art computer-aided engineering (CAE) tools.*

Traditionally, one way of exploring the set of design modifications with regard to their aerodynamic performance has been to check them experimentally in a wind tunnel. Here, the iterative development of further designs is based on theory and engineering skills. This approach, however, is rather costly and time consuming and in many cases, due to the large number of possible designs, it is unlikely that the truly optimal design can be found without the assistance of automatic tools.

**The goal is to generate a good design:**

- with regard to the slipstream generated along and behind the train
- in respect of the pressure distribution around the front (which can be operating as the rear end).

**Measures and effects:**

- Improvements in respect of slipstream has significant impact on the aerodynamic drag.
- Reducing aerodynamic drag saves up to 15% of the energy in high-speed trains.
- Limiting drag and maximizing cross-wind stability also enables higher speeds, which shortens journey times.

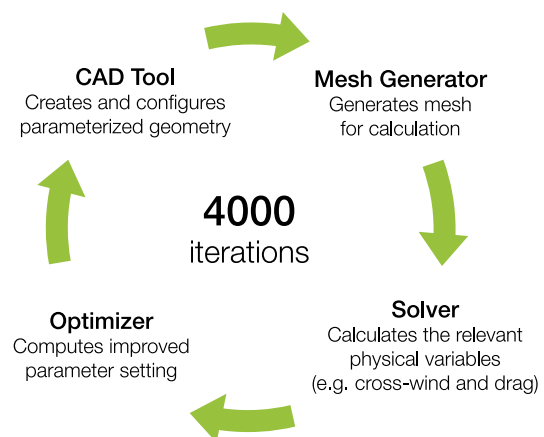
Experience and engineering skills are crucial in aerodynamic design. However, major improvements need systematic investigation and optimization. Several sub-projects with this purpose are therefore being carried out in the Gröna Tåget programme.

Within the framework of the Gröna Tåget programme a comprehensive and innovative optimization process has been developed which helps to develop and build new products by calculating the best way to reduce head-pressure pulse and drag.

**The system is based on genetic algorithms that use:**

- Parameterized, three-dimensional models
- Detailed simulation of head-pressure pulse and drag
- Decisive optimization software

**Objective:** Input to front design including shape constraints. This includes the crash structure, industrial design and ergonomic constraints such as the visibility of signals along the line and the space available for the passenger compartment. It then offers a choice of the best possible solutions to optimize the vehicle's aerodynamic performance.









# Gröna Tåget – research, development and demonstration

*The programme will run from 2005 until 2011. A train incorporating the proposals and technology in the Gröna Tåget (the Green Train) concept can be ready for operation about three years later.*

In the Gröna Tåget programme the following main issues are addressed:

- Economy and capacity
- Market, train services and conceptual design
- Attractive, and functional passenger environment
- Environment – energy and noise attenuation
- Track-friendly running gear and suspension
- Carbody tilt
- Nordic weather conditions
- Aerodynamics
- Electric propulsion and current collection
- Safety and driver's environment

Participating in Gröna Tåget programme are:

- Banverket (*The Swedish National Rail Administration*)
- Bombardier Transportation
- Train operators
  - Branschföreningen Tågoperatörerna (*The Association of Swedish Train Operating Companies*)
  - SJ AB
  - Tågkompaniet
- Transitio (*Rolling stock leasing company*)
- Vinnova (*The Swedish Governmental Agency for Innovation Systems*)
- Higher education and research institutions:
  - KTH (*Royal Institute of Technology*)
  - Chalmers University of Technology
  - Konstfack (*University College of Arts, Crafts and Design*)
- VTI (*Swedish National Road and Transport Research Institute*)
- Consultants, such as Interfleet Technology and Transrail
- Sub-suppliers, such as Schunk and Liebherr



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