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# Energy Efficiency of High-speed Rail

## Will higher speed cause increased energy consumption?

Dr. Piotr Lukaszewicz

Prof. Evert Andersson

Div. of Rail Vehicles

Royal Institute of Technology (KTH), Stockholm

# Definitions and delimits – electric train operation

- Energy consumption can be expressed as specific consumption
  kWh/ train-km, Wh/ seat-km, Wh/ pass-km.

- Energy consumption can be measured at the:

  - Pantograph level - intake to the train.
  - Substation level - intake to the railway system.
    Takes into account losses in the train, catenary and substation.
  - Power plant level - takes into account losses from intake powerplant to train wheels.

- May include additional consumption due to idling, stationary vehicle heating, complementary runs, vehicle maintenance, infrastructure needs, etc.

➡ For comparison between different trains and transport modes, it is important to have the same definitions and express the consumption at the same (or similar) level.

➡ We express the electric energy consumption as Wh/pass-km at the substation level. Losses in the train, catenary system and substations are included.

Idling is included, but not stationary heating, maintenance, infrastructure etc.

➡ $CO_2$ emissions (and ofther air pollutions) are expressed as the average for elctric power production on the common Nordic market (DK, N, S, SF)

# Will higher speed cause increased energy consumption?

## Yes – if trains are the same as for lower speeds!
## But they are usually not the same!

**The Swedish case**

- **During the last 10 – 15 years faster trains have been introduced in Sweden. 130 á 160 km/h --> 180 á 200 km/h (25 – 50 %).**

  **New infrastructure + new trains.**

  **Travel times have been reduced by 25 – 40 % on many lines.**

**Examples:**



## Case 1 (long distance):
Stockholm – Göteborg (Gothenburg) (455 km)

| | 1994 | 2004 | |
|---|---|---|---|
| Travel time | 4h 25min | 3h 05min | |
| Stops | 10 | 4 | |
| Configuration | Loco + 8 cars → | Pow Unit + 6 cars | |
| Load factor (%) | 44 | (44) → | 55 |
| Energy per seat-km (Wh) | 48 | 42 | 42 |
| Energy per pass-km (Wh) | 108 | 95 | 77 |

**Energy consumption reduced by 29 %**

**Average speed increased by 44 %**

**Travel time reduced by 30%**


## **Case** 2 (fast regional):
### Stockholm – Västerås (106 km)

| | 1994 | 2004 | |
|---|---|---|---|
| Travel time | 1h 18 min | 53 min | |
| Stops | 2 | 3 | |
| Configuration | loco + 4 cars | 0 + 3 | |
| Load factor (%) | 35 | (35) | 45 |
| Energy per seat-km (Wh) | 42 | 30 | 30 |
| Energy per pass-km (Wh) | 120 | 87 | 68 |

**Energy consumption reduced by 27 - 43%**

**Average speed increased by 44 %**

**Travel time reduced by 32%**


Top speed 130 km/h


Top speed 200 km/h

## Main reasons for lower specific energy consumption (27 – 43%) despite higher speed

1. Improved aerodynamics compared with older trains (leads to about 25% less energy consumption).
2. Regenerative braking (i.e. energy is recovered when braking the train, (measured: 11-17% for these types of trains).
3. Improved use of train length (Case 2): loco -> motor coaches + wide bodies + improved interior space utilization (2.5 -> 3.4 seats/m train)
4. Improved energy efficiency in power supply, partly due to more advanced technologies of the trains (3-7%).
5. Higher load factor (due to more competitive train services).

## How about future high-speed trains (250-300 km/h)?

# Green Train - a R&D program for future high-speed trains for the Nordic market

**Technologies and specifications for ensuring the operation of future passenger trains for Nordic conditions**

- **Winter, mixed traffic lines, flexible train length, wide bodies (optional)**
- **High economic efficiency (20 – 35 % reduced cost per seat-km)**
- **Low environmental impact (noise, energy efficiency)**

**A concept and specification for Green Train will reach completion in 2010.**

**Main partners:**

- **Banverket (National Swedish Rail Administration)**
- **Bombardier Sweden**
- **Association of Swedish Rail Operators**
- **Technical universities (mainly KTH) + consultants**

**Funding approx 15 MEUR (private + public).**

# Green Train possible future:

## Upgraded line (=> new dedicated high-speed line)

### Stockholm – Göteborg (Gothenburg) (455-467 km)

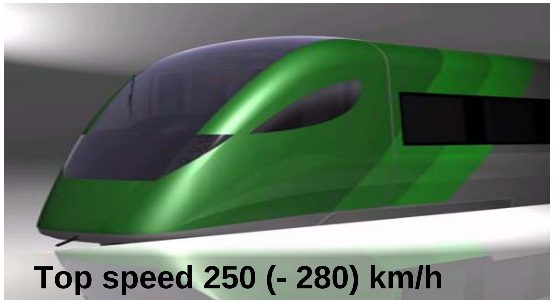
| | 1994 | 2004 | 2015 (- 2020) |
|---|---|---|---|
| Travel time | 4h 25min | 3h 05m | 2h 45m (2h 25m) |
| Stops | 10 | 4 | 4 |
| Configuration | Loco + 8 cars | Pow Unit + 6 cars | Motor coach x 6 |
| Load factor (%) | 44 | 55 | 60 |
| Energy per seat-km (Wh) | 48 | 42 | 30 - 31 |
| Energy per pass-km (Wh) | 108 | 77 | 50 - 52 |

**Energy consumption reduced by 54 %**

**Average speed increased by 83 %**

**Travel time reduced by 45%**






Further improved aerodynamics
Wide carbodies
More regenerative braking power

# Emission of carbon dioxide ($CO_2$) - examples

## Stockholm – Göteborg (Gothenburg) (455-467 km)

| | Per seat-km (g) | Per pass-km (g) | |
|---|---|---|---|
| **Old loco-hauled train (1980 onwards, 160 km/h)** | **4** 1) | **10** 1) | |
| **X 2000 (1990 onwards, 200 km/h)** | **4** 1) | **7** 1) | |
| **Green Train (250-280 km/h)** | **3** 1) | **5** 1) | |
| **Private car (medium-size)** | **32** | **80** | (2 seats occupied) |
| **Airplane (Boeing 737-800)** | **85** 2) | **130** 2) | (load factor 65 %) |

1) Average electric power on common Nordic market (2000 – 2004)
Hydro 53 %; Nuclear 23 %; Thermal 22 %; Wind 2 %.

2) According to NTM (Network for Transport and Environment)

# Are emissions from ''marginal electric power production'' relevant ?

**Short term**

**Trains runs according to a planned and pre-defined time table.**

**Energy consumption is to a very small degree affected by the variation in the number of passengers.**

**Almost no change of energy consumption. Marginal emissions can be neglected.**

**Long term**

**If the rail traffic increases heavily over long term, an additional amount of energy will probably be needed.**

**However, the EU Emissions Trading Scheme will limit the emissions of green house gases. The emissions can be regarded as constant, almost independent of rail traffic needs.**

**The discussion about emissions from "marginal" electric power production make little sense in the future.  The ''marginal emissions'' from rail traffic can be considered to be close to zero.**

**Further, a future cleaner electric power production, will result in less pollution associated with railway traffic.**

# Conclusions

- **Recent Swedish cases show:**

  **Despite higher average speed, the specific energy consumption for modern trains (per passenger-km) is reduced by 25 – 45 %.**

- **The tendency of reducing specific energy consumption will continue with the Green Train, despite further higher average speed.**

- **The following factors are most important**

  **- Reduction of aerodynamic drag**

  **- Regenerative braking on > 50 % axles with high specific power (use regenerative braking as main braking source).**

  **- Efficient space utilization**

  **loco -> motor coaches; wide carbodies / double deckers; efficient interior.**

  **- Load factor (occupied seats divided by total number of seats)**

- **Future cleaner electric power production will result in further reduced (indirect) air pollution from electric rail operations !**

- **Pay attention to how energy (and pollution) is measured or calculated, what is included and at what level.**