Global energy consumption due to friction in passenger cars, transportation and industry

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OUTLINE

1. Introduction
2. Friction related energy losses in passenger cars
3. Energy losses in all transportation
4. Friction energy losses in paper machines
5. Overall global energy losses due to friction
6. Potential solutions and future perspectives
Root causes of friction losses across all scales in passenger cars

- Global Level
  - Advanced Industrial, Developing Industry, Agricultural Countries
- National Level
  - Transport, Power Plants, Industry, Domestic, Other
- Societal Sector Level
  - E.g. for Transport: Road, Rail, Marine, Aviation
- Societal Sub-Sector Level
  - E.g. for Road: Engines, Transmissions, Wheel/Road Contact etc
- Machinery Level
  - E.g. for Road: Engines, Transmissions, Wheel/Road Contact etc
- Component Level
  - E.g. for Engines: Bearings, Gears, Seals, Piston-Ring etc
- Tribocoupling Level
  - BL, EHD, HD, Adhesive Slidign, Abrasive, Cutting etc
Methodology for calculation of friction losses in passenger cars on global level

1. Total energy consumption worldwide 2009: \(11\,164\, \text{Mtoe/a}\)

2. Global consumption of crude oil for cars 2009: \(1083\, \text{Mtoe/a}\)

3. Global oil fuel energy used in passenger cars: \(22\,085\,000\, \text{TJ/a}\)

4. Divide by number of cars worldwide: \(612\, \text{million cars}\)

5. Energy used in one global average car: \(36\,000\, \text{MJ/a}\)
Definition of the global average passenger car 2010

- Manufactured in 2000
- 75 kW four-cylinder, in-line, four-stroke engine
- 1.7 dm³ engine capacity
- 1500 kg weight
- Gasoline fuelled by 70%, diesel fuelled by 30%
- Engine oil viscosity class SAE 5W40 (age < 1 year)
- Tyre coefficient of rolling friction approx. 0.02. (Summer tires, size 185/65R15, age 4 years, average tyre pressure, on average road)
- Frontal area approximately 2.3 m²
- Drag constant 0.345 (average for passenger cars of 2000 model)
- Hydro mechanical power steering
- Air condition with compressor in 25% of the cars
- Manual 5-speed gearbox. Oil SAE 75W-90 of 10 years age
- Front wheel drive
- Driving brakes based on friction linings and drums or discs
The global average driving conditions in 2010

- 13,000 km annual driving distance
- 60 km/h average speed
- Average fuel consumption 8 litres/100 km
- 12 kW engine power output on an average
- 300 g/kWh fuel efficiency (@ 12 kW)
- 2.5 kg CO₂ emissions per fuel litre burned, or 200 g/k
- Average braking power: 2.4 kW
- Engine oil temperature estimate: 80°C
- Gearbox oil temperature estimate: 60°C
- As an average for 612 million cars
Energy balance during four stages in typical car operation

(a) Kinetic energy ($E_{\text{kin}}$) increase
(b) Engine and transmission friction
(c) Tyre friction and air drag
(d) Braking friction
Running resistance

- Uphill driving, here compensated by subsequent downhill
- Effect of wind direction, here self-compensated
- Acceleration forces compensated by subsequent retardation
- Tyre rolling resistance $F_r = m \times g \times \mu_r$
- Drag force, $F_d = \rho \times v^2 \times A \times C_d / 2$

**Tribology**
- $m$ = mass of vehicle
- $g = 9.81$ m/s$^2$
- $\mu_r$ = coefficient of tyre rolling friction

**Aerodynamics (not tribology)**
- $\rho$ = density of air
- $v$ = velocity of the vehicle
- $A$ = drag area
- $C_d$ = drag constant
Power losses from air drag and tyre rolling friction as function of speed

\[ P = (F_d + F_r) \times v \]
Fuel energy dissipation in passenger cars as approximated for a speed of 60 km/h

**FUEL**

- **Exhaust** 33% => convection of heat and gases
- **Cooling** 29% => conduction and dissipation of heat
- **Air drag** 5% => gas shear => heat
- **Friction** 33% => heat & material degradation

**Potential energy** (chemical)

Transformation to:
- kinetic energy
- thermal energy
- phase transition
Passenger Car Energy Consumption

- Fuel Energy: 100%
  - Energy to move the car: 21.5%
  - Engine: 11.5%
    - Thermal energy losses: 12 kW
  - Mechanical power: 38%
  - Cooling: 29%
  - Exhaust: 33%
  - Friction losses: 33%
    - Mechanical power: 38%
    - Engine: 11.5%
      - Transm.: 5%
      - Rolling resist.: 11.5%
      - Brakes: 5%
      - Air drag: 5%
    - Exhausst: 33%
    - Cooling: 29%
    - Friction: 33%
      - Air drag: 5%
      - Energy to move the car: 21.5%
Friction losses in the main car components as part of the total friction losses of the car

Tyres 35% RF

Engine 35%

Transmission 15%
- gears 55% EHD
- bearings 20% EHD
- viscous 20% VL
- seals, forks 5% ML
- valve train 15% ML
- bearings, seals 30% HD
- piston assembly 45%
- HDsqueeze 40%
- EHD 40%
- ML 10%
- BL 10%

Brakes 15% SF

Literature data scatter

35% (12–45%) to overcome the rolling friction in the tire-road contact,
35% (30–35%) to overcome friction in the engine system,
15% (7–18%) to overcome friction in the transmission system, and
15% (10–18%) to overcome friction in the brake contact.
Break down of frictional energy losses in the global average passenger car with respect to the tribocontact mechanisms

The 11 863 MJ to overcome friction is distributed as:
- **4 152 MJ (35%)** in the **tire-road contact**
- **4 152 MJ (35%)** in the **engine system** distributed as:
  - **1 868 MJ (45%)** in the piston assembly distributed as:
    - 747 MJ (40%) in HD tribocontacts
    - 747 MJ (40%) in EHDS tribocontacts
    - 187 MJ (10%) in ML tribocontacts
    - 187 MJ (10%) in BL tribocontacts
  - **1 246 MJ (30%)** in bearings, seals, etc., mainly in HD tribocontacts
  - **623 MJ (15%)** in the valve train, mainly in ML tribocontacts
  - **415 MJ (10%)** by pumping and hydraulic viscous losses
- **1 779 MJ (15%)** in the **transmission system** distributed as:
  - **356 MJ (20%)** to viscous losses
  - **979 MJ (55%)** to gears in EHDSR tribocontacts
  - **356 MJ (20%)** to bearings in EHDR tribocontacts
  - **89 MJ (5%)** to seals, forks, etc., in ML tribocontacts
- **1 779 MJ (15%)** in the **brakes** to produce the brake force
# Friction losses in passenger cars categorised according to type of tribocontact

<table>
<thead>
<tr>
<th>Friction loss source type</th>
<th>Energy consumed (MJ/car/a)</th>
<th>Fuel used (liters/car/a)</th>
<th>Percentage (%)</th>
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</thead>
<tbody>
<tr>
<td>Tire-road contact</td>
<td>4,152</td>
<td>119</td>
<td>35</td>
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<tr>
<td>Hydrodynamic lubrication</td>
<td>1,993</td>
<td>57</td>
<td>16.8</td>
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<tr>
<td>Mixed lubrication</td>
<td>899</td>
<td>26</td>
<td>7.6</td>
</tr>
<tr>
<td>EHD lubrication, sliding</td>
<td>747</td>
<td>21</td>
<td>6.3</td>
</tr>
<tr>
<td>EHD, sliding and rolling</td>
<td>979</td>
<td>28</td>
<td>8.2</td>
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<tr>
<td>EHD lubrication, rolling</td>
<td>356</td>
<td>10</td>
<td>3.0</td>
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<tr>
<td>Boundary lubrication</td>
<td>187</td>
<td>5</td>
<td>1.6</td>
</tr>
<tr>
<td>Viscous losses</td>
<td>771</td>
<td>22</td>
<td>6.5</td>
</tr>
<tr>
<td>Braking contact</td>
<td>1,779</td>
<td>51</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11,863</strong></td>
<td><strong>340</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
Trends in friction reduction for different lubrication mechanisms and rolling friction with reference to passenger car applications
EMERGING TECHNOLOGIES FOR FRICTION REDUCTION IN PASSENGER CARS

- **Advanced coating structures**
  DLC, TS, nano-composites etc:
  - dry in vacuum superlubricity $\mu = 0.001$
  - lubricated 10-50% friction reduction

- **New surface texturing methods**
  Laser surface texturing:
  - 25-50% friction reduction
  - 4% engine fuel reduction

- **New boundary lubrication additives and fluids**
  Glycerol mono-oleate in PAO vs DLC:
  - $\mu = 0.005$ in pure glycerol
  Nanomaterials as additives like WS2, MoS2, H3BO3
EMERGING TECHNOLOGIES FOR FRICTION REDUCTION IN PASSENGER CARS

- Low viscosity fluids
  Polyalkyl glycols

- Ionic liquids
  25-50% friction reduction with IL

- Biomimetics
  Biomolecular protein additives
  Brushes of charged polyelectrolytes
  Porcine gastric mucin, glycoprotein mucin
  \( \mu = 0.001-0.04 \)

- Low friction tyre design
  High pressure, small width etc
Methodology for calculation of friction losses in passenger cars on global level

1. Global consumption of crude oil for cars 2009: 1083 Mtoe/a

2. Global oil fuel energy used in passenger cars: 22 085 000 TJ/a

3. Divide by number of cars worldwide: 612 million cars

4. Energy used in one global average car: 36 000 MJ/a

5. Energy used to overcome friction in one average car: 11 860 MJ/a = 340 l/a

6. Friction losses in car sub-systems: tyres, engine, transmission and brakes

7. Friction losses in car components: gears, bearings, seals, piston, pumping etc

8. Friction losses in various tribocontacts: HD, EHD, BL, ML, VL etc

9. Estimation of friction efficiency (= coefficient of friction) for each friction loss source for car 2000, car 2010, lab 2010 and car 2020

10. Friction loss reduction potential for each friction loss source

11. Energy saving potential for one average car by using today’s advanced commercial (37%), best lab (61%) and best future solutions (70%)

12. Potential savings globally by using today’s advanced commercial (350 000 M€), best lab (575 000 M€) and best future solution (660 000 M€)

13. Potential savings in regions e.g. for Europe by using today’s advanced commercial (60 200 M€), best lab (99 600 M€) and best future solution (114 000 M€)
FUEL CONSUMPTION AND POTENTIAL FRICTION SAVING IN PASSENGER CARS GLOBALLY

Gas and diesel oil used to overcome friction 208 000 million liters/a

Energy used to overcome friction 7.3 million TJ/a

Potential savings by today’s best commercial 348 000 M€/a
Potential savings by today’s best solution 576 000 M€/a
Potential savings by future (10 a) best solution 659 000 M€/a

Realistic oil fuel savings (18% reduction) 117 000 million liters/a
Realistic CO₂ savings 290 million tonnes/a
Realistic savings after 10 years focused actions 174 000 million €/a
# Worldwide and regional/national potential savings by implementation of advanced friction control technologies

<table>
<thead>
<tr>
<th></th>
<th>Energy Saving (TJ/a)</th>
<th>Cost Saving (10^6 euro/a)</th>
<th>Oil Fuel Savings (10^6 litre/a)</th>
<th>CO₂ Emission Reduction (10^6 kg/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>World</strong></td>
<td>4 086 000</td>
<td>174 000</td>
<td>117 000</td>
<td>210 000</td>
</tr>
<tr>
<td><strong>Industrialized countries</strong></td>
<td>2 452 000</td>
<td>104 000</td>
<td>70 200</td>
<td>126 000</td>
</tr>
<tr>
<td><strong>Industrially developing countries</strong></td>
<td>1 430 000</td>
<td>61 000</td>
<td>41 000</td>
<td>73 500</td>
</tr>
<tr>
<td><strong>Agricultural countries</strong></td>
<td>204 000</td>
<td>8 700</td>
<td>5 900</td>
<td>10 500</td>
</tr>
<tr>
<td><strong>EU</strong></td>
<td>707 000</td>
<td>30 100</td>
<td>20 200</td>
<td>36 300</td>
</tr>
<tr>
<td><strong>USA</strong></td>
<td>887 000</td>
<td>37 800</td>
<td>25 400</td>
<td>45 600</td>
</tr>
<tr>
<td><strong>China</strong></td>
<td>424 000</td>
<td>18 100</td>
<td>12 200</td>
<td>21 100</td>
</tr>
<tr>
<td><strong>Japan</strong></td>
<td>204 000</td>
<td>8 700</td>
<td>5 900</td>
<td>10 500</td>
</tr>
<tr>
<td><strong>UK</strong></td>
<td>81 000</td>
<td>3 500</td>
<td>2 300</td>
<td>4 200</td>
</tr>
<tr>
<td><strong>South Africa</strong></td>
<td>25 600</td>
<td>1 100</td>
<td>740</td>
<td>1 300</td>
</tr>
<tr>
<td><strong>Finland</strong></td>
<td>10 200</td>
<td>430</td>
<td>300</td>
<td>500</td>
</tr>
</tbody>
</table>
MEANS TO REDUCE ENERGY CONSUMPTION IN CARS

Friction reduction:
- 10% tire rolling friction reduction => 3% energy savings
- 10% engine friction reduction => 3% energy savings
- 10% transmission friction reduction => 1.5% energy savings

Weight reduction and design:
- 10% weight reduction => 8.3% energy savings
- 10% frontal area reduction => 2.2% energy savings

Driver actions:
- 10% speed reduction (110>100 km/t) => 16% energy savings
- 2 atm > 2.5 atm tire pressure => 3% energy savings
Background

Article “Global energy consumption due to friction in passenger cars”

by

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“Reducing energy losses as a result of friction is also possible [12] (Fig. 2). Advances in cost-effective technologies such as tribology, tyres, braking and waste-heat energy recovery, and aerodynamics could potentially lead to efficiency improvements of 20% in the short term and more than 60% over a longer term (15–25 years).”
Global energy production and consumption 2011

Global energy consumption 2011:
12 275 Mtoe

- Coal 27%
- Oil 33%
- Gas 21%
- Biofuels 11%
- Nuclear 6%
- Hydro 2%

Transport 62%

Global crude oil consumption 2011:
4 060 Mtoe

- Passenger cars 28%
- Raw material 17%
- Trucks 12%
- Buses 4%
- Marine 8%
- Aviation 7%
- Industry 9%
- Other 12%
- Rail 3%

Mtoe = million tonnes of oil equivalent
4. Friction energy losses in paper machines
A typical paper machine vs passenger car
Paper machine energy flow

**Incoming energy**
- Electricity 30%
- Fuel 3%
- Thermal (steam) 67%

**Energy transformation**
- Converted to mechanical energy
- Burning of fuels

**Energy consumption**
- Friction losses
- Viscous losses
- Paper formation
- Leakage
- Process heating by steam
Global statistics, year 2012:
- 8525 paper and paperboard machines average
- 140 TJ/a electrical energy per machine

An average global paper machine and its operating conditions, operating cycles

Component level: mixer, pump, blower, vacuum pump, sectional drive, …

Tribocontact level & friction factor:
- dry contact / boundary / mixed / hydrodynamic lubrication
- water / oil
- sliding / rolling

POTENTIAL SAVINGS WITH NEW TECHNOLOGY TO REDUCE FRICTION:
Energy, CO₂ emissions

New tribological techniques & lower friction factors
AN AVERAGE GLOBAL PAPER MACHINE

- Built 1960 and rebuilt 1980,
- Design speed is 1200 m/min,
- Width is 6.5 m (trim width 6.0 m)

- Typical product is newsprint
- Basis weight 50 g/m2
- Annual production is 130–140 000 tonnes/a
- Electrical energy consumed 140 TJ/a
- Specific electric energy consumption is 440 kWh/tonnes
- In operation 300 days/year
- Stock composition is 70–80% mechanical pulp
The average global paper machine details

- **Electrical motors**: 72 pieces, average rating 173.7 kW, power efficiency 85%.
- **Transmissions**: 72 pieces, average power efficiency 82%.
- **Pumps**: 28 pieces, average rating 50 litres/s water at 3 bar pressure, power efficiency 65%.
- **Vacuum pumps**: 11 pieces, average rating 2 m³/s air at -43 kPa pressure, power efficiency 67%.
- **Blowers**: 6 pieces, average rating 30 m³/s air at 50 Pa pressure, power efficiency 63%.
- **Agitators**: 7 pieces, average power efficiency 82%.
- **Pipes** (incl. valves etc.); length: 16 km. The main part of the energy consumption occurs in the short circulation system, wire section and press section.
- **Roll system**: 22 drive rolls and 113 passive rolls.
- **Rolling bearings**: the energy losses are distributed as 50% from seal friction, 33% from rolling friction and 17% from churning of the lubricant.
Energy break down in the global average paper machine

<table>
<thead>
<tr>
<th>Global average paper machine</th>
<th>Motors</th>
<th>Transmissions</th>
<th>Pumps</th>
<th>Vacuum pumps</th>
<th>Blowers</th>
<th>Agitators</th>
<th>Pipes</th>
<th>Roll system</th>
<th>Total energy</th>
<th>Total %</th>
</tr>
</thead>
<tbody>
<tr>
<td>140 TJ/a</td>
<td>140,0</td>
<td>119,0</td>
<td>37,5</td>
<td>17,6</td>
<td>4,3</td>
<td>7,7</td>
<td>38,6</td>
<td>34,0</td>
<td>140,0</td>
<td>100,0</td>
</tr>
<tr>
<td>Total energy flow, TJ/a</td>
<td>140,0</td>
<td>119,0</td>
<td>37,5</td>
<td>17,6</td>
<td>4,3</td>
<td>7,7</td>
<td>38,6</td>
<td>34,0</td>
<td>140,0</td>
<td>100,0</td>
</tr>
<tr>
<td>Percentage, %</td>
<td>100,0</td>
<td>85,0</td>
<td>26,8</td>
<td>12,6</td>
<td>3,1</td>
<td>5,5</td>
<td>27,6</td>
<td>24,3</td>
<td>102,0</td>
<td>7,3</td>
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<td>Roll bearing (EHDR)</td>
<td>1,7</td>
<td>3,6</td>
<td>2,0</td>
<td>1,2</td>
<td>0,3</td>
<td>0,1</td>
<td>0,0</td>
<td>1,4</td>
<td>10,2</td>
<td>7,3</td>
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<tr>
<td>HD bearing (HD)</td>
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<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
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<td>3,7</td>
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<td>Gears (EHDSR)</td>
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<td>9,8</td>
<td>9,8</td>
<td>7,0</td>
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<td>Seals (BL)</td>
<td>0,6</td>
<td>0,9</td>
<td>1,3</td>
<td>0,9</td>
<td>0,2</td>
<td>0,0</td>
<td>0,0</td>
<td>2,8</td>
<td>6,8</td>
<td>4,9</td>
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<td>Doctor blade (BL)</td>
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<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>4,6</td>
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<td>3,3</td>
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<td>Fabric sliding (BL&amp;HD)</td>
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<td>0,0</td>
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<td>0,0</td>
<td>9,6</td>
<td>9,6</td>
<td>6,8</td>
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<tr>
<td>Total friction losses</td>
<td>2,3</td>
<td>14,3</td>
<td>3,3</td>
<td>2,2</td>
<td>0,5</td>
<td>0,1</td>
<td>0,0</td>
<td>22,1</td>
<td>44,8</td>
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<td>Viscous losses</td>
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<td>6,6</td>
<td>2,2</td>
<td>0,0</td>
<td>1,3</td>
<td>0,0</td>
<td>5,8</td>
<td>19,4</td>
<td>13,9</td>
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<td>Leakage</td>
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<td>3,9</td>
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<td>Electric losses</td>
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<td>0,0</td>
<td>0,0</td>
<td>17,6</td>
<td>12,6</td>
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<td>Air drag</td>
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<td>0,2</td>
<td>1,8</td>
<td>1,3</td>
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<td>Hysteresis losses</td>
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<td>Mass transportation</td>
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<td>31,8</td>
<td>0,0</td>
<td>31,8</td>
<td>22,7</td>
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<td>Total losses</td>
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<td>13,1</td>
<td>6,2</td>
<td>1,5</td>
<td>1,4</td>
<td>31,8</td>
<td>28,6</td>
<td>121,4</td>
<td>86,7</td>
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<td>Slice jet</td>
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<td>0,0</td>
<td>4,7</td>
<td>4,7</td>
<td>3,3</td>
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<tr>
<td>Dewatering/pressing</td>
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<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>1,1</td>
<td>5,4</td>
<td>6,5</td>
<td>4,7</td>
<td>4,7</td>
</tr>
<tr>
<td>Mixing</td>
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<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>6,3</td>
<td>1,1</td>
<td>0,0</td>
<td>7,4</td>
<td>5,3</td>
<td>5,3</td>
</tr>
<tr>
<td>Delivered energy</td>
<td>119,0</td>
<td>101,1</td>
<td>24,4</td>
<td>11,4</td>
<td>2,8</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Energy break down in the global average paper machine

- **Electrical Energy** 100%
  - Short Circulation System 22%
  - Wire Section 26%
  - Press Section 33%
  - Dryer Section 12%
  - Calender, Reel, Winder 7%

- **Motors** 15%
  - Transmissions 13%
  - Pumps 9%
  - Vacuum Pumps 4%
  - Blowers 1%
  - Agitators 2%
  - Pipes 23%
  - Roll System 20%
  - Paper Mass Processing 13%

- **Roll Bearings** 7%
  - HD Bears 3%
  - Gears 7%
  - Seals 5%
  - Dr Blade 3%
  - Fabric Sliding 7%
  - Viscous Flow 14%
  - Leakage 4%
  - Electric Losses 12%
  - Air Drag 1%
  - Hysteresis 1%
  - Mass Transportation 23%
  - Dewatering, Mixing, Jeting, Pressing 13%

- **Friction losses** 32%
  - EHDR 23%
  - HD 8%
  - EHDSR 22%
  - Oil BL 15%
  - Water BL 32%

- **Total energy losses** 64%

- **Mass transportation** 23%

- **Paper production** 13%
Friction in paper machine tribocontacts

- Boundary lubrication, water
- Boundary lubrication, oil
- EHD sliding & rolling, oil
- Hydrodynamic lubrication, oil
- EHD rolling

Graph showing friction coefficients over time for different lubrication conditions and types of contact.
EMERGING TECHNOLOGIES FOR FRICTION REDUCTION IN PASSENGER CARS

- **Advanced coating structures**
  DLC, TS, nano-composites etc:
  - dry in vacuum superlubricity $\mu = 0.001$
  - lubricated 10-50% friction reduction

- **New surface texturing methods**
  Laser surface texturing:
  - 25-50% friction reduction
  - 4% engine fuel reduction

- **New boundary lubrication additives and fluids**
  Glycerol mono-oleate in PAO vs DLC:
  - $\mu = 0.005$ in pure glycerol
  Nanomaterials as additives like WS2, MoS2, H3BO3
Wire and doctor blade friction in paper machine
## Annual savings and energy reduction in paper machines

<table>
<thead>
<tr>
<th></th>
<th>Short term (10 years)</th>
<th>Long term (20-25 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings/reduction from the present state (%)</td>
<td>11.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Reduction in electrical power consumption (GWh)</td>
<td>38 125</td>
<td>77 246</td>
</tr>
<tr>
<td>Energy demand reduction (TJ)</td>
<td>137 679</td>
<td>278 683</td>
</tr>
<tr>
<td>CO₂ emission reduction (million tonnes CO₂)</td>
<td>34.7</td>
<td>70.3</td>
</tr>
<tr>
<td>Economical savings (million euros)</td>
<td>20 200</td>
<td>40 920</td>
</tr>
</tbody>
</table>
Summary

Globally
- 15 – 25 % of the total energy consumption worldwide is used to overcome friction (100 milj. TJ/year)
- 7 000 milj. tonnes of CO₂ emission originates from work to overcome friction

Transport
- about 30% of the fuel energy is used to overcome friction
- 18% potential savings can be achieved in short term (5 years) by implementing new tribological solutions
- friction losses in electric cars are ½ of those in IC cars

Industry
- about 20% of the industrial energy is used to overcome friction
- 11% potential savings can be achieved in short term (5-10 years) by implementing new tribological solutions
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Thank You