Energy Harvesting – Running Mobile Devices Longer

Source: MAN

Energy Harvesting in the Automotive Field – as much Philosophy as Technology

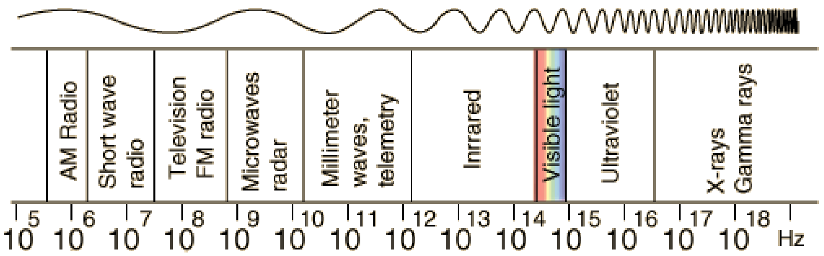
Kurt Hug
http:www.ti.bfh.ch

27.10.10

Piezoelectric road harvests traffic energy to generate electricity

Source: http://www.gizmag.com/piezoelectric-road-harvests-traffic-energy-to-generate-electricity/

Blog harvesting



There's nowt from nowt

You know what? This is a perpetual motion machine. It violates the **2nd law of thermodynamics**

They should be made to test the fuel consumption of the vehicles using this road.

Using "waste" energy to generate electricity makes perfect sense to me!

Source: http://www.gizmag.com/piezoelectric-road-harvests-traffic-energy-to-generate-electricity/

Google harvesting about entropy and 2nd law of thermodynamics

Our master’s voice

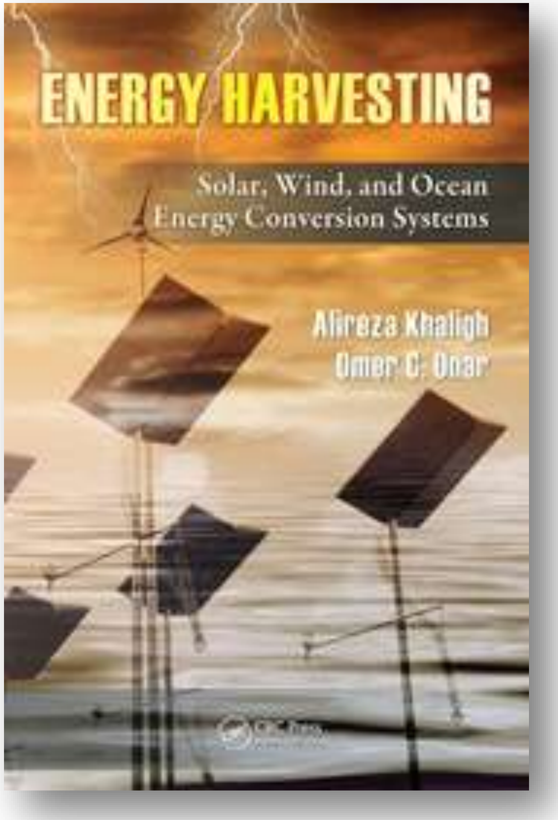
So we have to talk about what we mean by disorder and we mean by order.... We measure “disorder” by the number of ways that the inside can be arranged, so that from the outside it looks the same.

The logarithm of that number of ways is the entropy

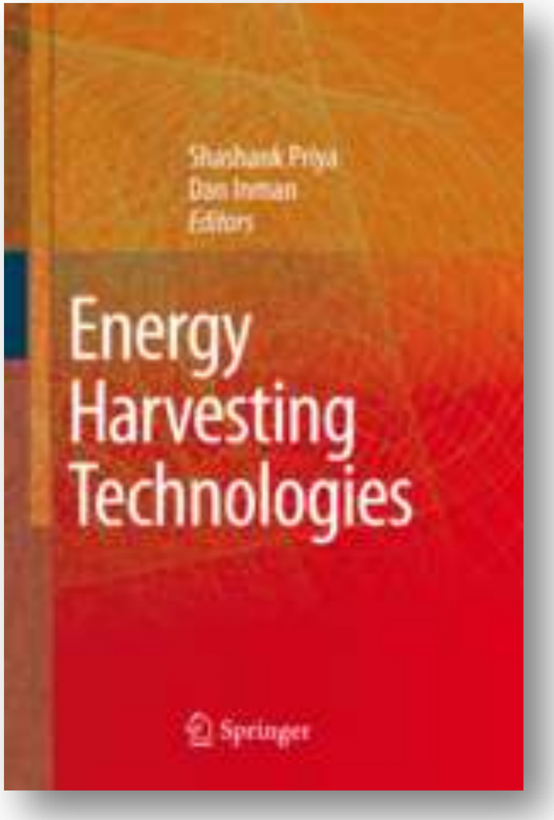
$$dS \geq 0$$

Source: Richard Feynman, Feynman Lectures on Physics "Order and entropy" (vol I section 46-5)

Definition of energy harvesting, not an easy task, part I



CRC Press Taylor & Francis 2010 [1]



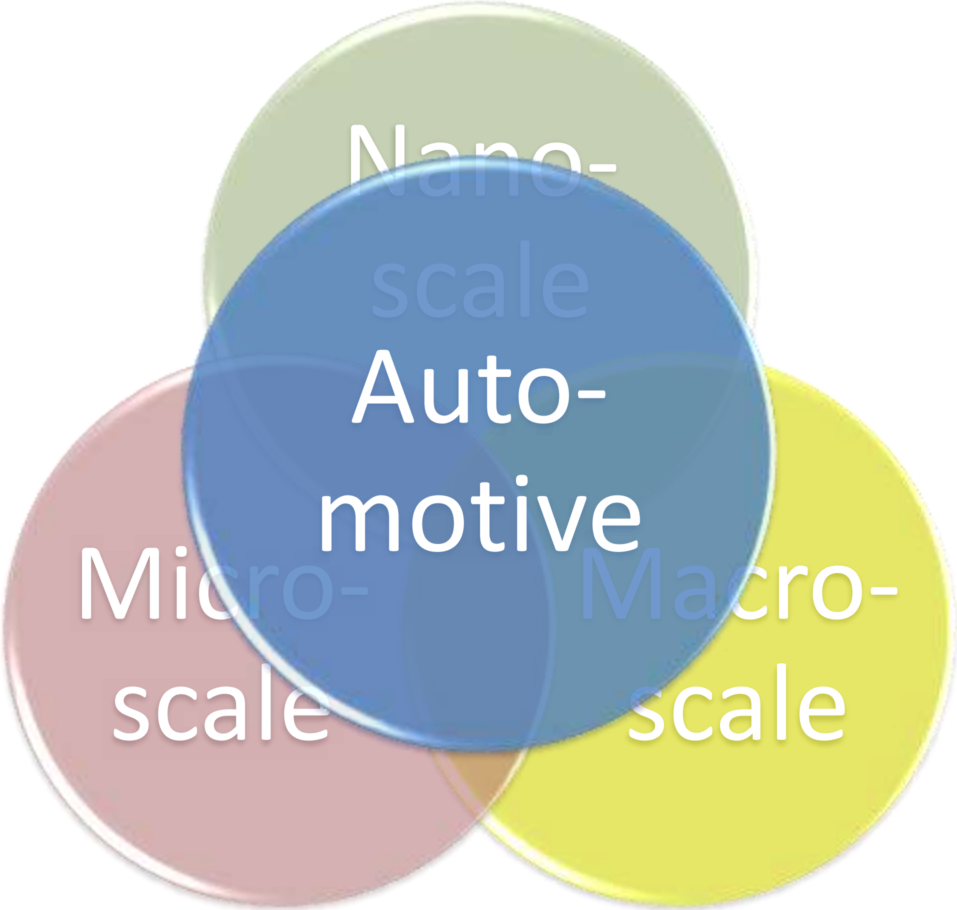
Springer Science Media 2009 [2]

Definition of energy harvesting, not an easy task, part II

Macro vs. Micro	Energy Sources	Solutions	Ultimate Goal
Macro	Renewable energy (e.g. solar, wind)	Energy management solutions	Reduce oil dependency
Micro	Energy from the environment (e.g. vibration, body heat)	Ultra-low-power solutions	Perpetual devices

Source: Energy Harvesting, Texas Instruments, ULP meets energy harvesting, white paper

Energy harvesting in the automotive field



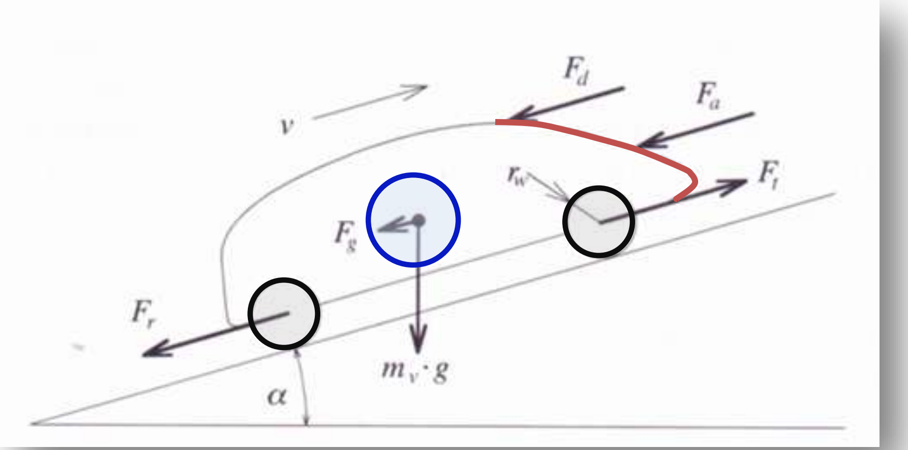
Sufficiency
Reduction

Piezoelectric energy
Thermoelectric energy

Solar energy
Wind energy

Where is it used?

The vehicle motion equation (Newton's second law)



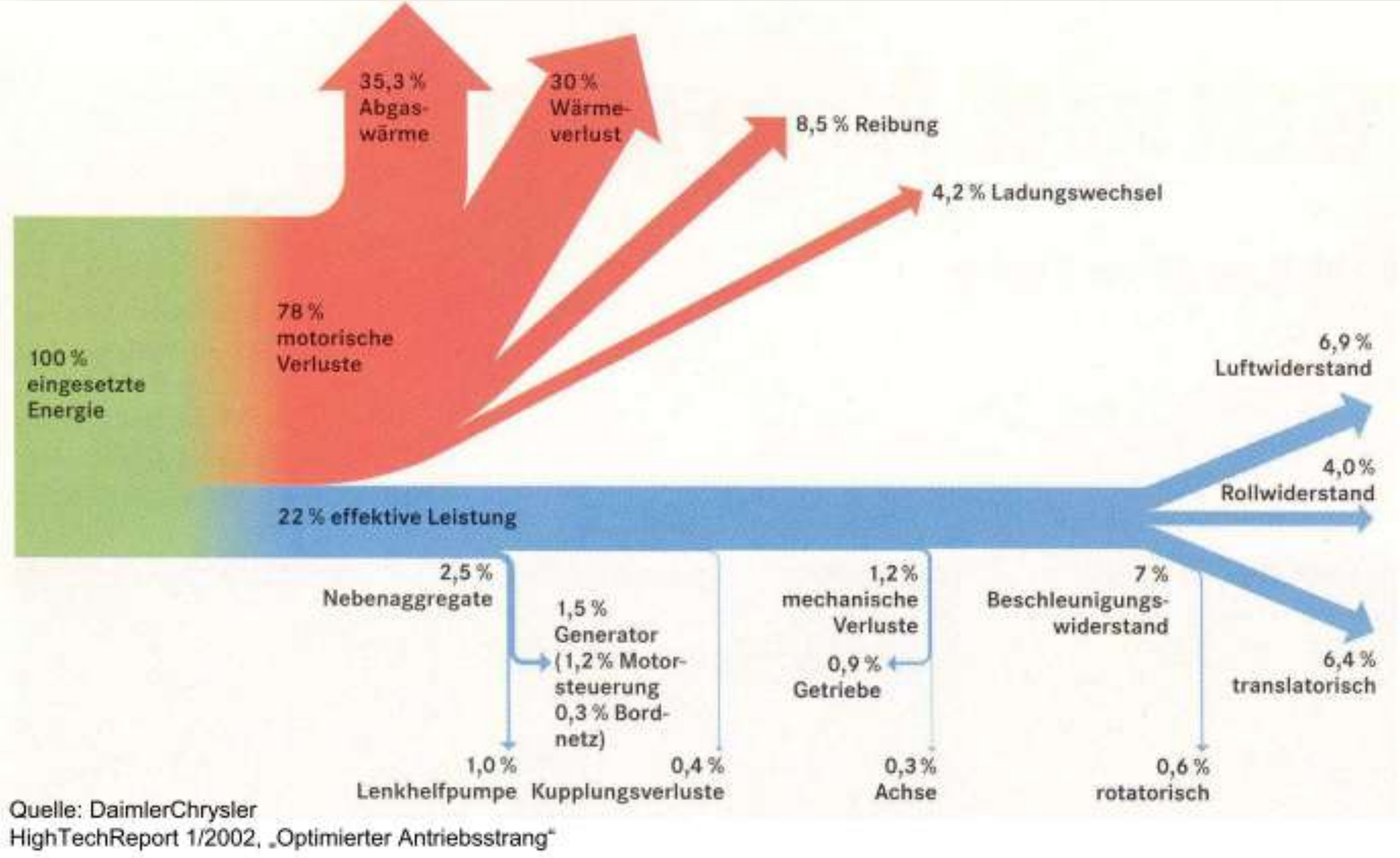
$$m_v \frac{d}{dt} v(t) = F_t(t) - \left(F_a(t) + F_r(t) + F_g(t) + F_d(t)\right)$$

$$\overline{E}_{MVEG-95} \approx 1.9 \cdot 10^4 \cdot A_f \cdot c_d + 840 \cdot m_v \cdot c_r + 10 \cdot m_v \quad (kJ/100\,km)$$

MVEG: Motor Vehicle Emission Group

Picture: L. Guzzella

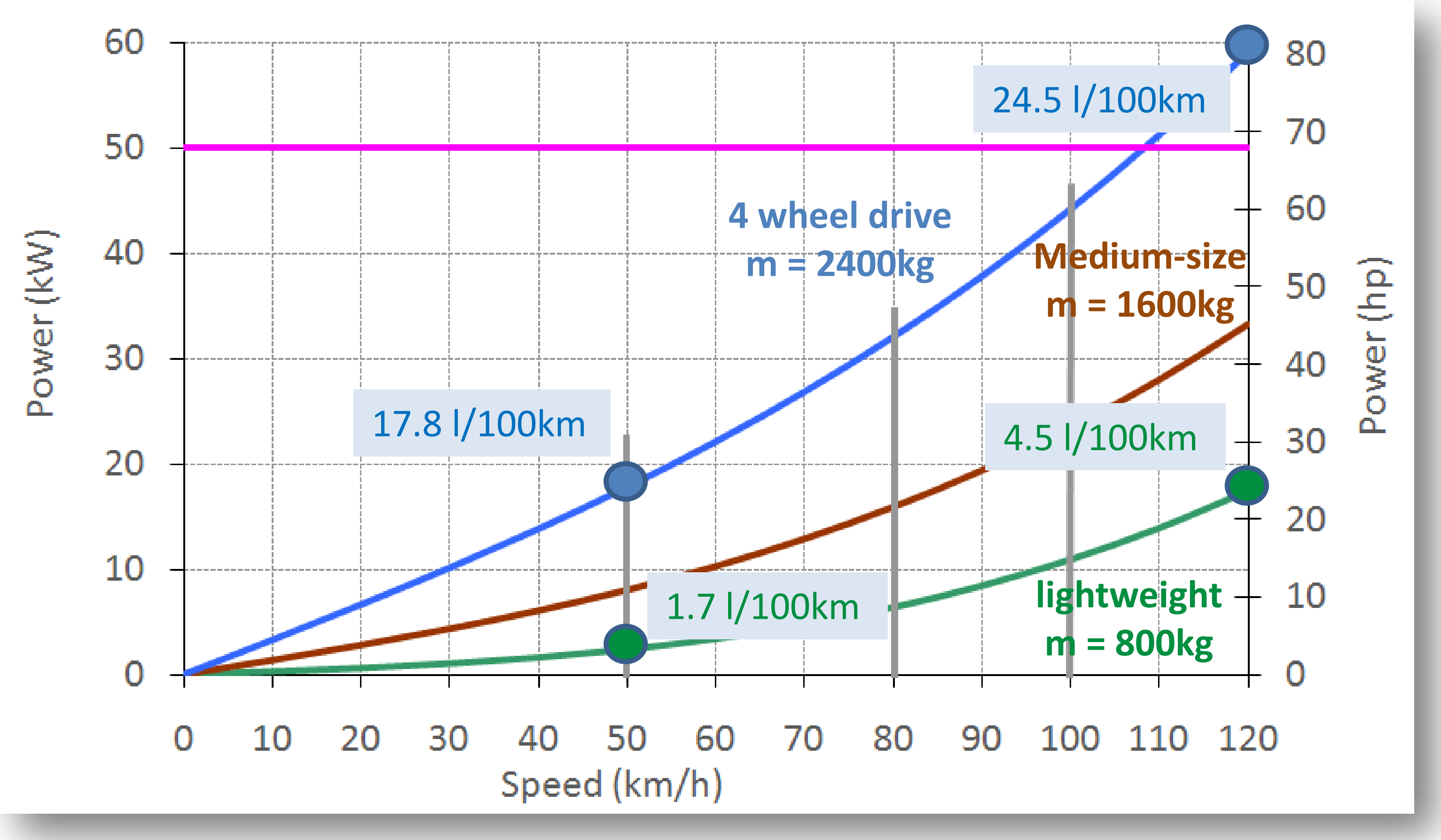
And where is it wasted?



Quelle: DaimlerChrysler
HighTechReport 1/2002, „Optimierter Antriebsstrang“

Source: Prof. Leohold, Uni Kassel

And how much is needed?

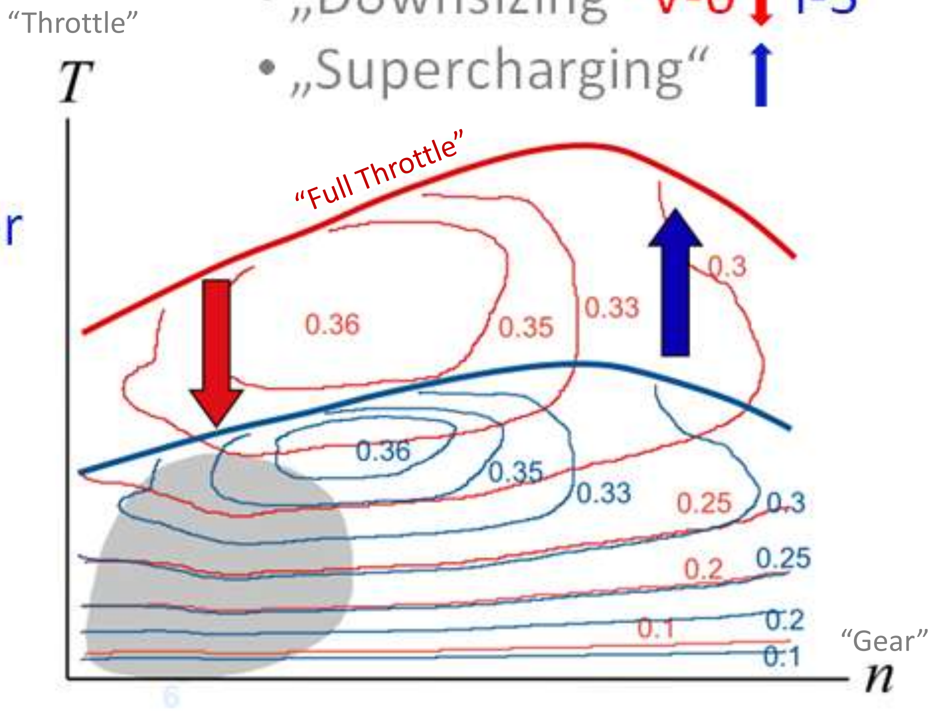


Influence of propulsion principles and mass on engine performance

DSC, an example from the CO2-reduction community

Replace a **V-6**
by an **I-3**
with **turbocharger**

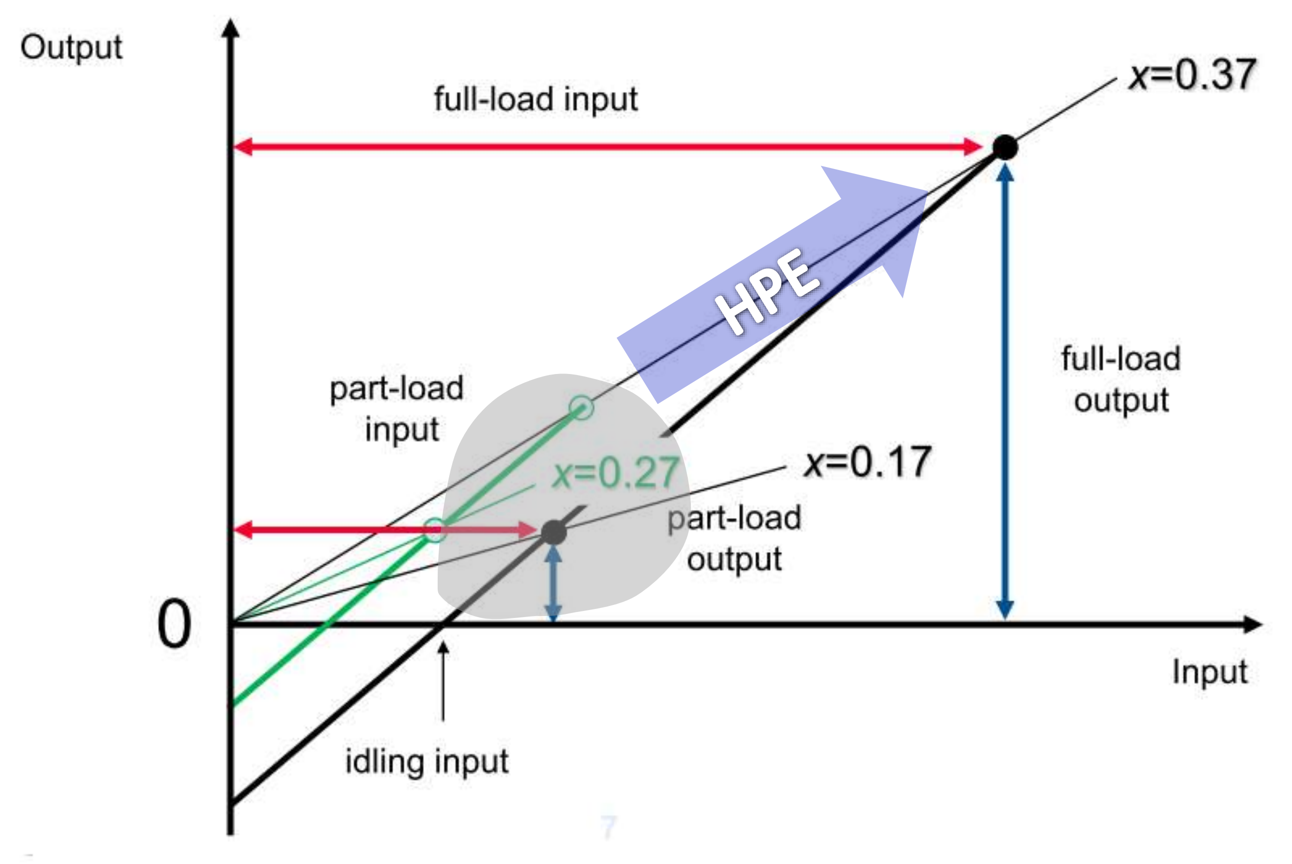
- „Downsizing“ **V-6** ↓ **I-3**
- „Supercharging“ ↑



DSC: Downsizing and Supercharging

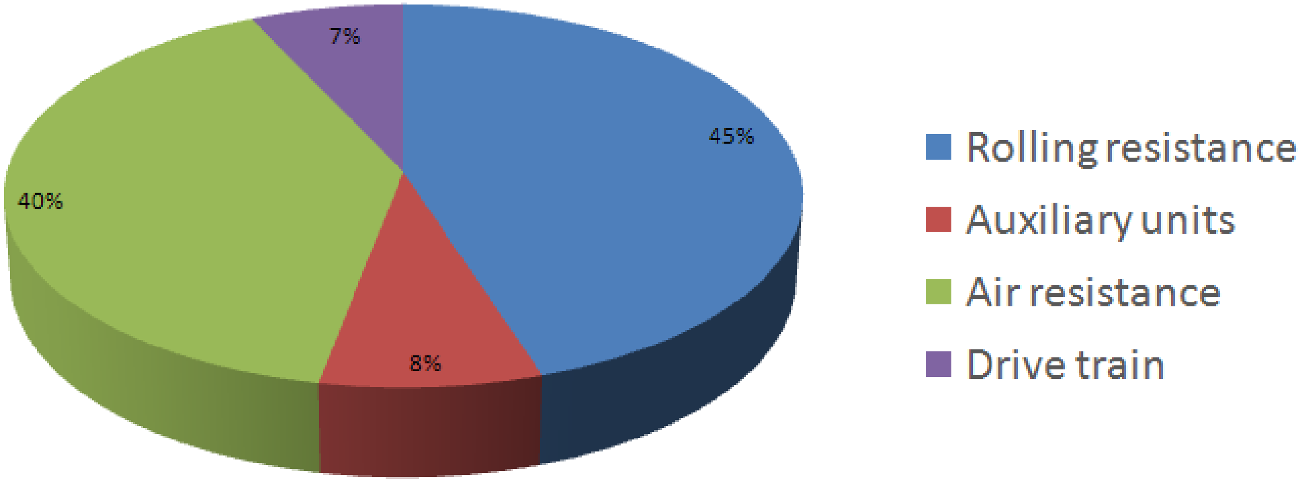
Source: Downsized and Supercharged Hybrid Pneumatic Engine, L. Guzzella, C. Onder, ETH, SAE

DSC explained



Source: Downsized and Supercharged Hybrid Pneumatic Engine, L. Guzzella, C. Onder, ETH, SAE

40 tons @ 85km/h on a level stretch



Share of energy consumption for semi-trailer truck

Source: ATZ 07-08 / 2009 Volume 111

Dolphin, an example from the CO2 reduction community

The Dolphin Concept

Source: ATZ 07-08 / 2009 Volume 111

SSL, light from the Silicon Valley

	DRL with LED	DRL conventional
Power consumption	2 x 7 W	2 x 150 W
Fuel consumption	0.014 l / 100 km	0.3 l / 100 km
CO2 reduction	0.36g CO2 / km	7.86g CO2 / km

SSL: Solid State Ligthing
DRL: Daytime Running Lamp

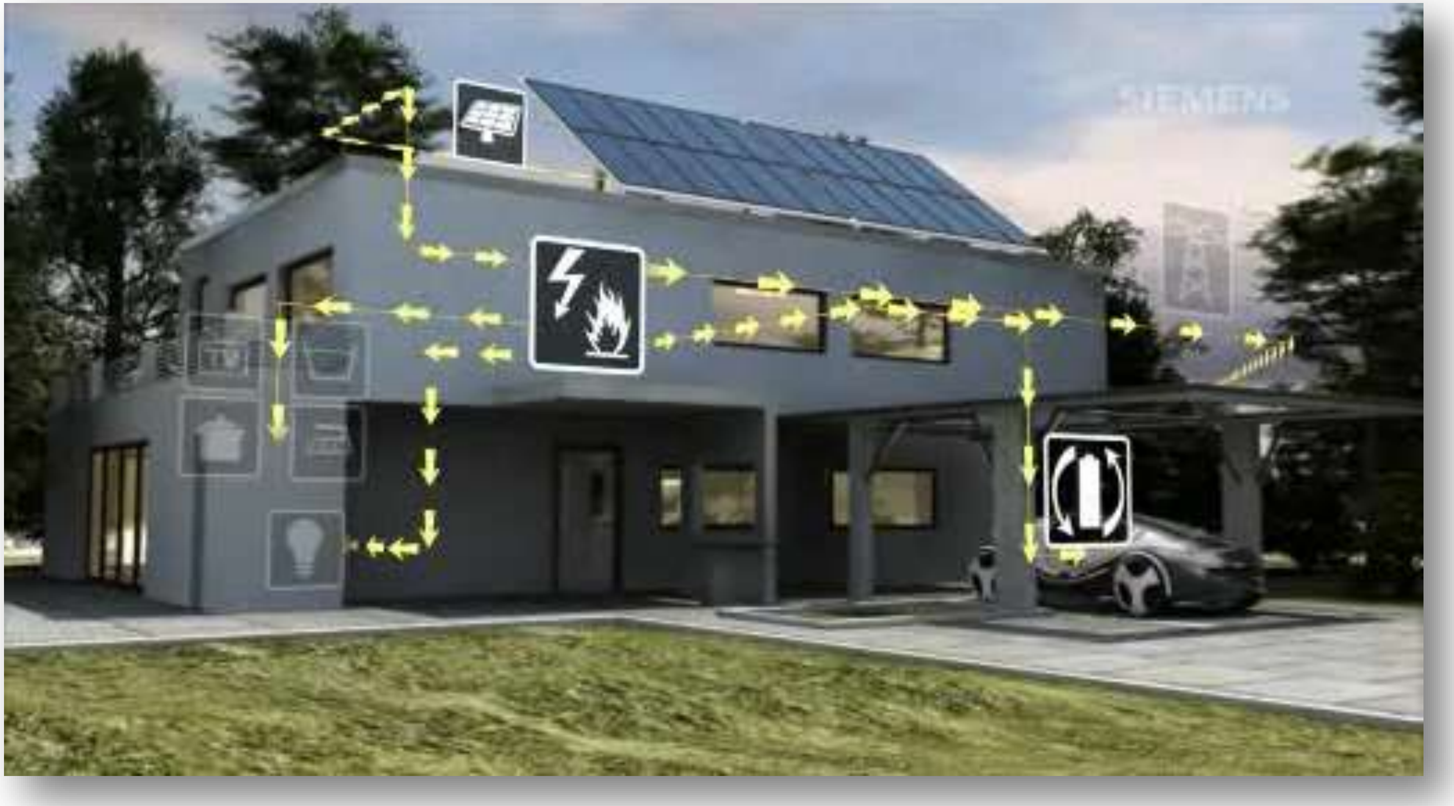
Source: Automotive Lighting Reutlingen

Two examples from the macro-scale community

Operational Nominal and Standard Conditions for PVs	
Nominal Conditions	Standard Conditions
Irradiation: $G_{a,ref} = 800W/m^2$	Irradiation: $G_{a,0} = 1000W/m^2$
Ambient temperature: $T_{a,ref} = 20°C$	Cell temperature : $T_0^C = 25°C$
Wind speed : $s_w = 1m/s$	

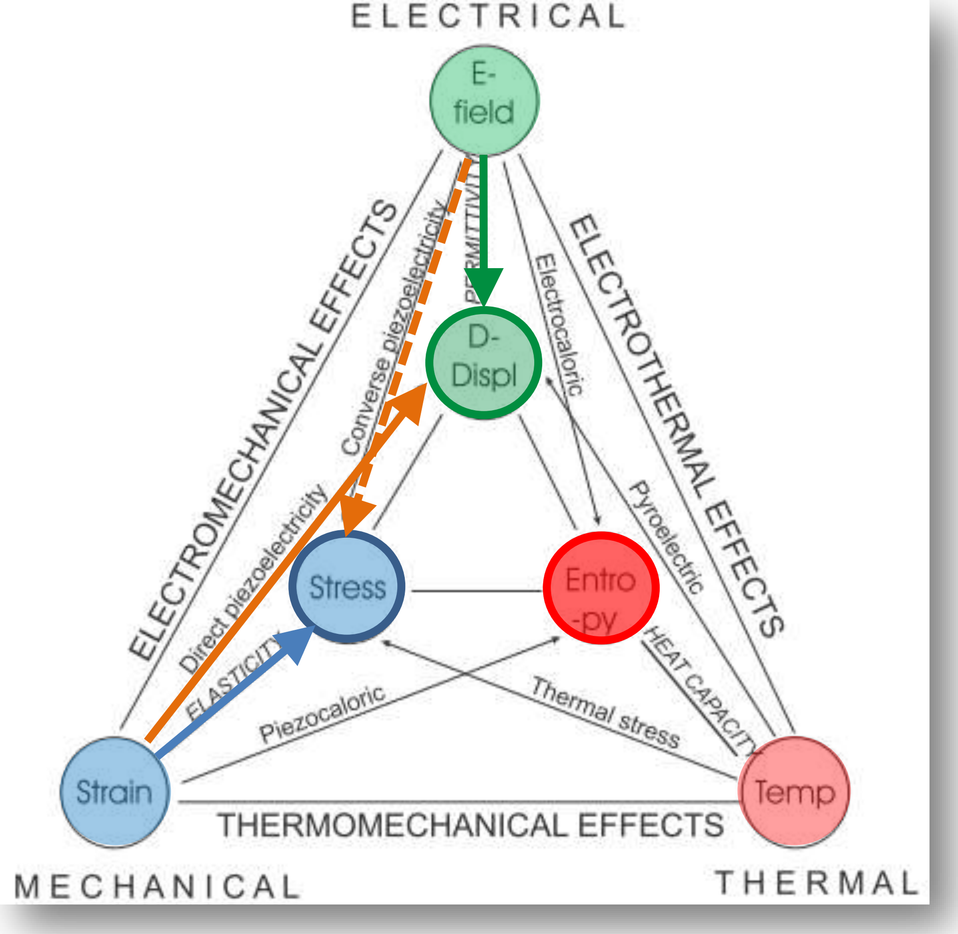
Spirit of Biel/Bienne III, 3. Rank, World Solar Challenge 1993

And a better approach



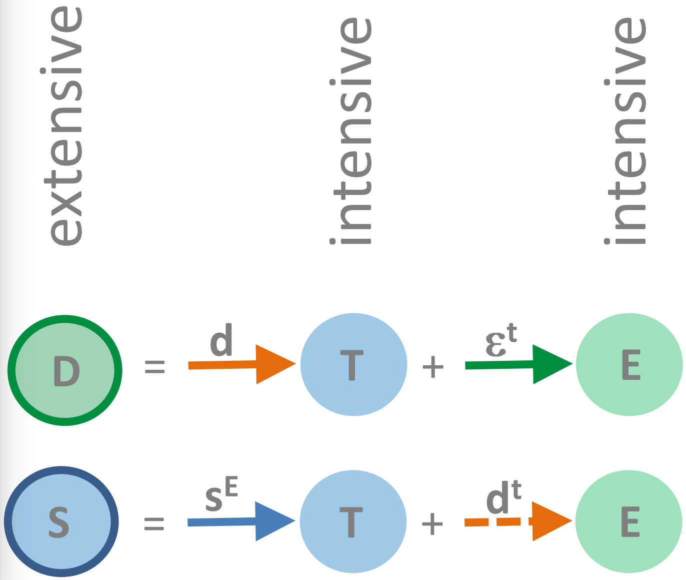
Source: Siemens Energy

Mr. G. Heckmann from Göttingen presents (1925)



The interaction between thermal, mechanical and dielectrical quantities

The piezoelectric equation



$$D = \xrightarrow{d} T + \xrightarrow{\varepsilon^t} E$$

$$S = \xrightarrow{s^E} T + \xrightarrow{d^t} E$$

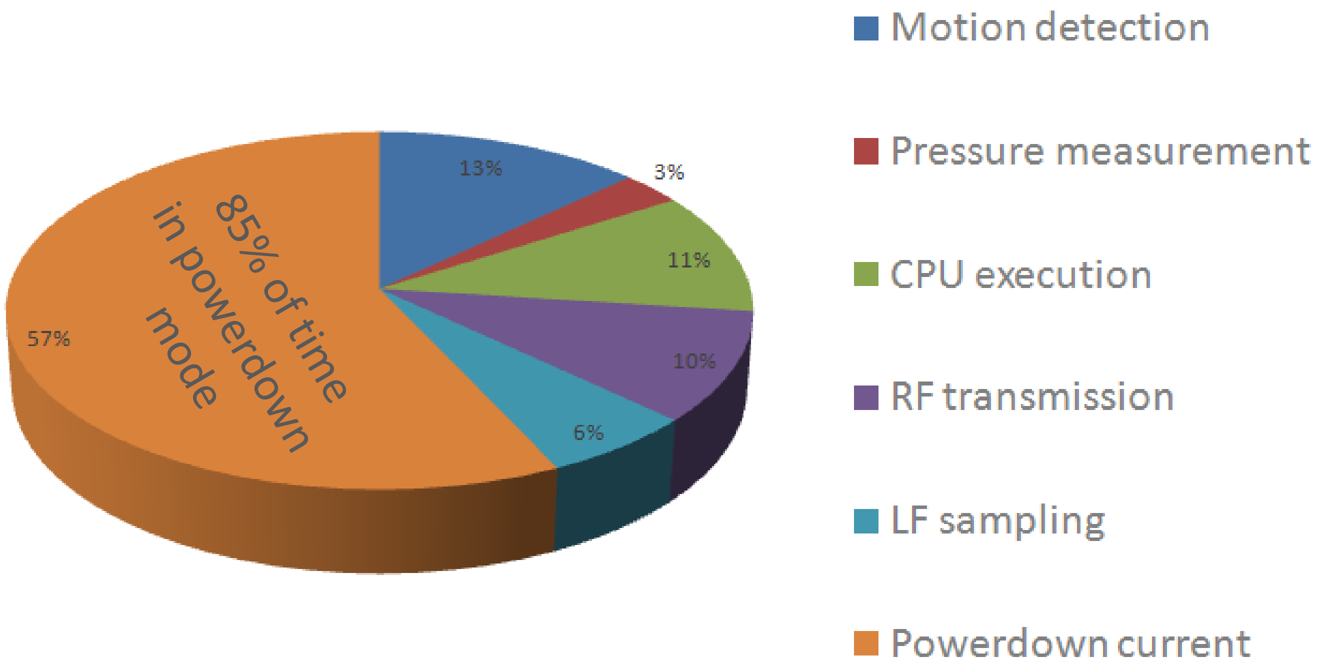
TPMS, an example from the micro-scale community

Feature	NHTSA	ISO	OEM
Pressure Warning	“Throttle” 25% under recommended inflation pressure	TBD	10% under recommended inflation pressure
Response Time	20 min	3 min	1 min
Min. Operate Speed	50km/h	25km/h	20km/h
Module Life	-	6yr / 100000km	10yr / 150000km
Malfunction Warning	Yes	Yes	Yes
Temperature Range	-	-40°C – +85°C	-40°C – +125°C

TPMS: Tire Pressure Monitoring System; NHTSA: US National Highway Traffic and Safety Administration

Source: Advanced Microsystems for Automotive Applications [3]

Leakage seems to be the principal job of the battery



Share of energy consumption over lifetime of a TMPS module

Source: Advanced Microsystems for Automotive Applications [3]

Do you know a battery sustaining those conditions?

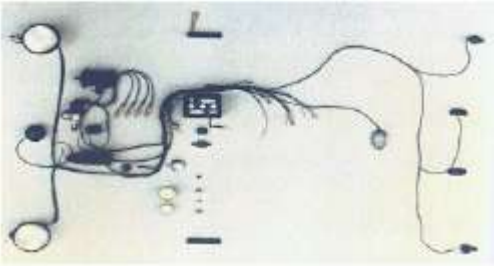
Requirements for TPMS power supply	
Lifetime	10 years “87600hours”
Operating temperature	-40°C – +125°C
Voltage range	2V … 3.6V
Pulse current	8mA – 10mA
Duty Cycle (run mode)	1:500 – 1:1000
Self discharge	≤ 1%/y
Vibration robustness	Continuous (5Hz - 2000Hz)
Acceleration robustness	max. 1500g – 2000g
Humidity	5% – 95%

Source: Advanced Microsystems for Automotive Applications [3]

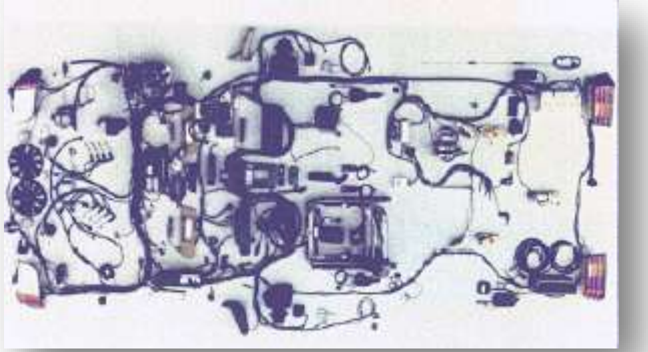
A vibration harvester might deliver enough <power> [3,4]

Type of energy conversion	Advantages	Disadvanatges	Practical max. energy density[4]	Assumptions[4]	Comments
Piezoelectric	No voltage source needed Voltages > 1V	Low coupling coefficient for thin film piezo. Process integration? Reliability issues	$D_E = 17.5 mJ/cm^3$	PZT-5H factor of safety 2	High Energy density for bulk material, but need for thin film process
Electromagnetic	No voltage source needed	Voltages < 1V MESM integration? Permanent magnets and coils needed	$D_E = 4 mJ/cm^3$	$B = 0.1T$ $\mu = \mu_0$	Better performance at higher frequencies and limitations for micro scale
Electrostatic	MEMS integration Voltages > 1V	Voltage source needed. Parasitic capacitances Mechanical stops	$D_E = 4 mJ/cm^3$	$E = 30V/\mu m$	Lower energy density, but fully MEMS compatible process

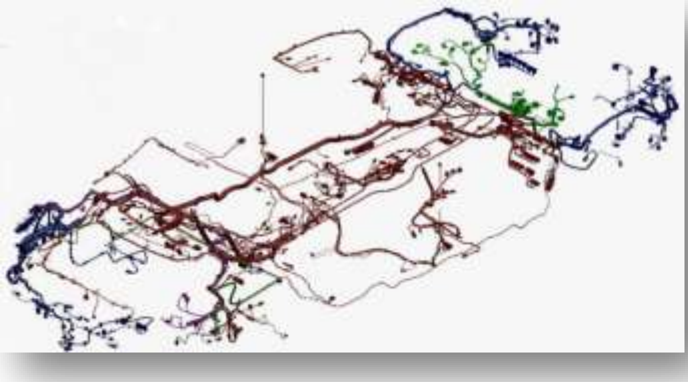
The history of wiring harnesses



1949, Mercedes 170

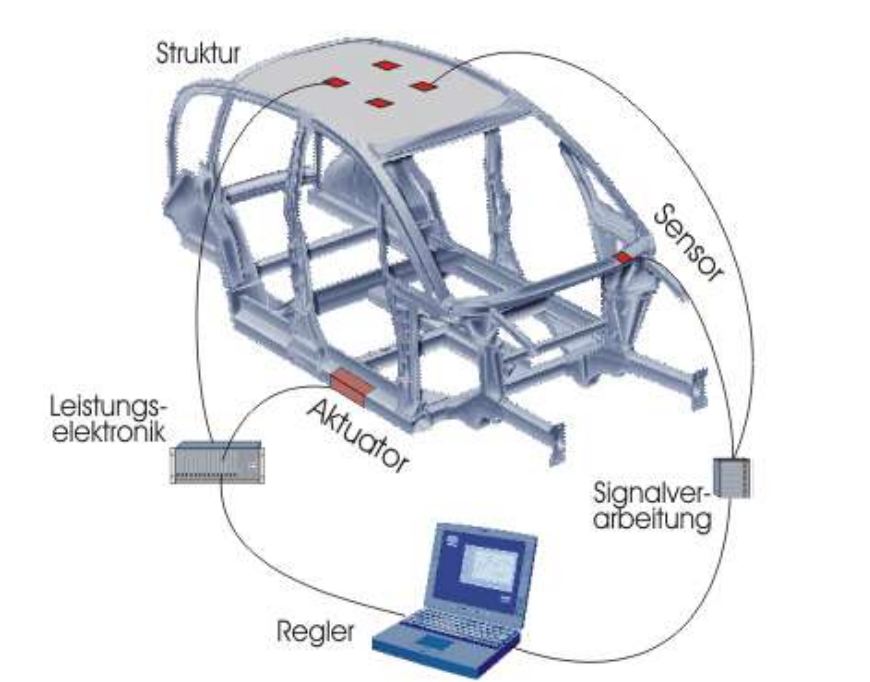


1991, Mercedes S-Class



2010, VW

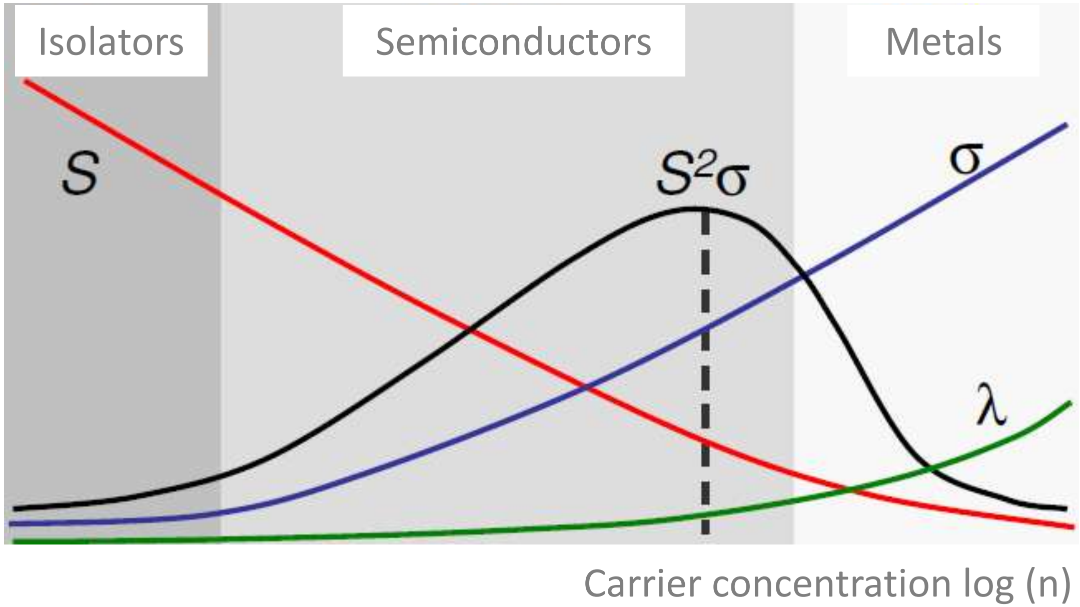
Where vibrations occur, there are not only problems but also mechanical oscillation energy, which can be used after converting into electric energy. This technology could e.g. be used in air conditioning systems or airbags [1].



and 2020 adaptronics?

Source: ATZelektronik worldwide Edition: 2010-03 [1] ; http://www.adaptronik.fraunhofer.de/ [2]

ZT the figure of merit

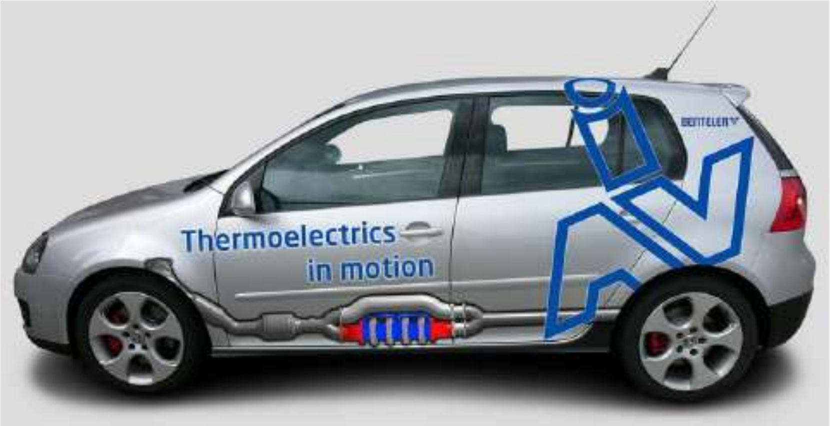


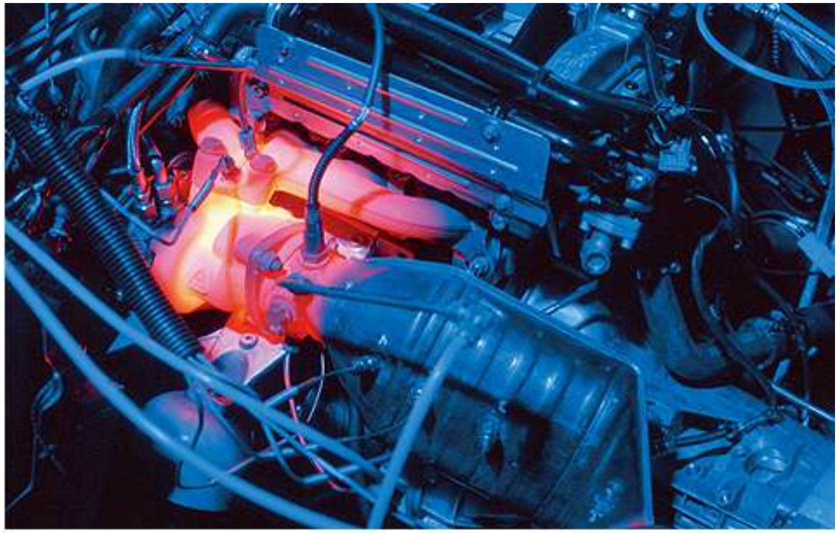
$$ZT = \frac{S^2 \cdot \sigma \cdot T}{\lambda}$$

σ: specific electrical conductance
λ: specific thermal conductance

Source: ATZ Livetext, Thermoelektrische Abwärmenutzung in KFZ, D. Jänsch, M. Laudien, J. Kitte

Thermoelectrics goes Automotive



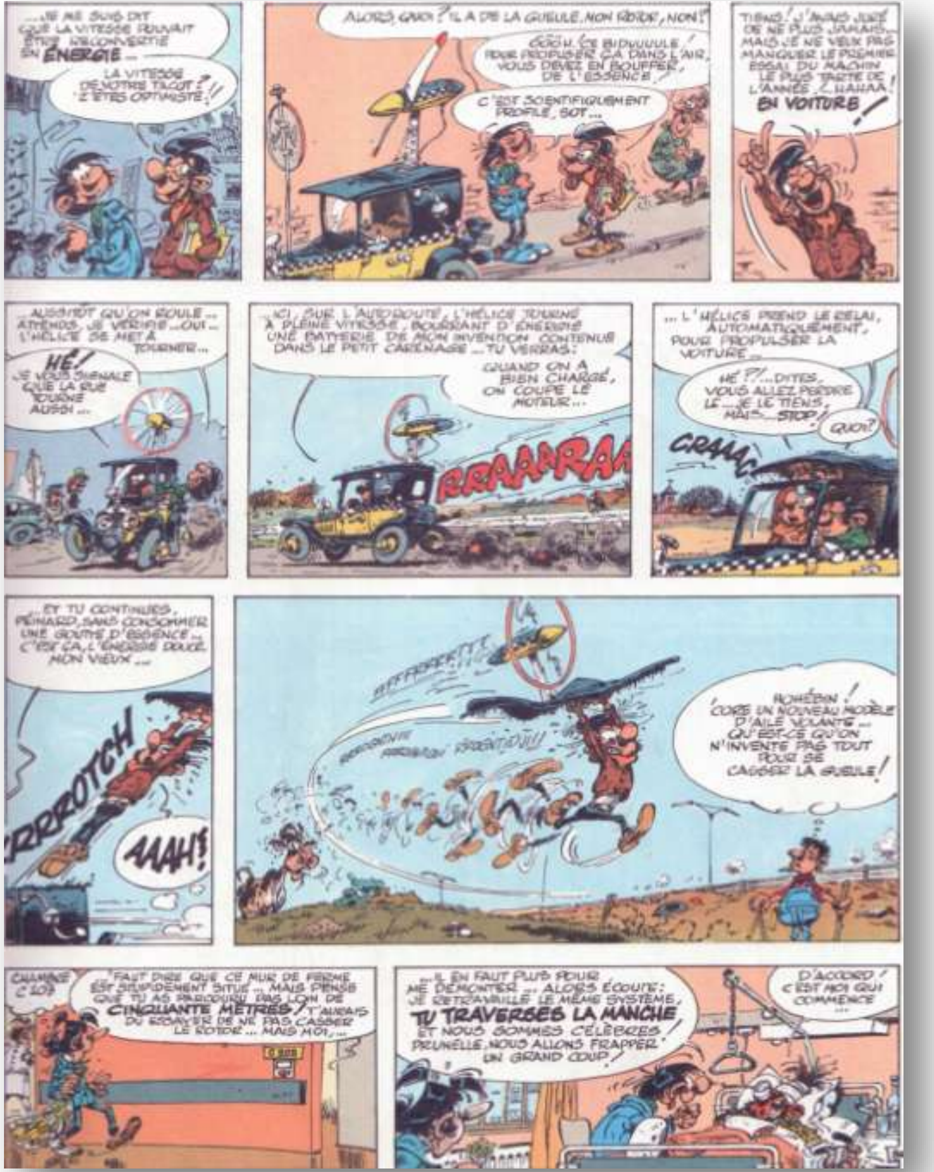


Source: Thermoelectrics goes Automotive, 2nd Int. Conference: 9 – 10 December, 2010 Berlin, iAV

Déjà vu in 1982

Thank you for your attention

Source: Gaston 14, La Saga des Gaffes; Editions Jean Dupuis, 1982



Source: Gaston 14,
La Saga des Gaffes;
Editions Jean Dupuis, 1982

[1] Alireza Khaligh, Omer C. Onar, *Energy Harvesting, Solar, Wind, and Ocean Energy Conversion Systems*, Boca Raton: CC Press, Taylor & Francis Group (2010), ISBN 978-1-4398-1508-3.

[2] Shashank Priya, Daniel J. Inman*, Energy Harvesting Technologies*, New York: Springer Science + Business Media (2009), ISBN 978-0-387-76463-4

[3] J. Valldorf, W. Gessner, Advanced Microsystems for Automotove Applications 2007, Berlin Heideberg New York: Springer (2007), ISBN-13 978-3-540-71324-1

[4] S. Roundy, P.-K. Wright, J.M. Rabaey, *Energy Scavenging for wireless sensor networks*, Kluewer Academic Publisher, pp. 47 – 50

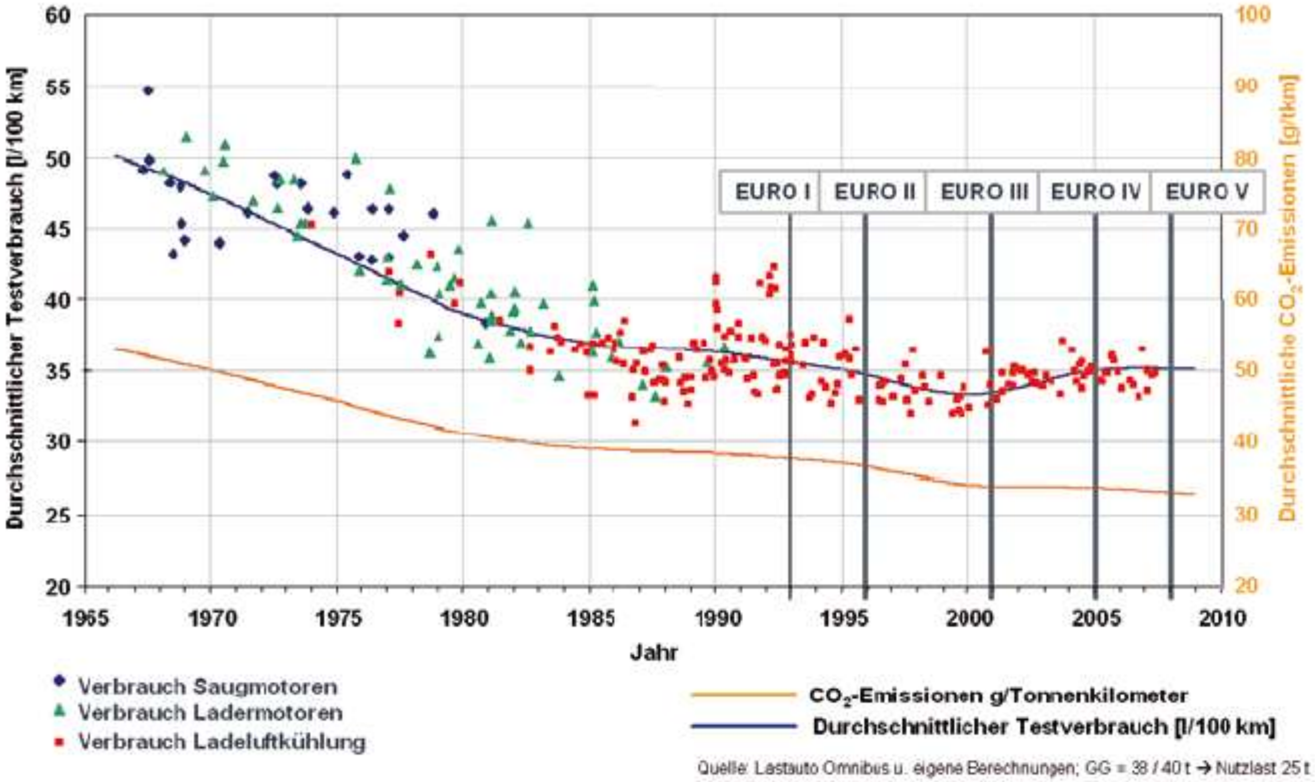
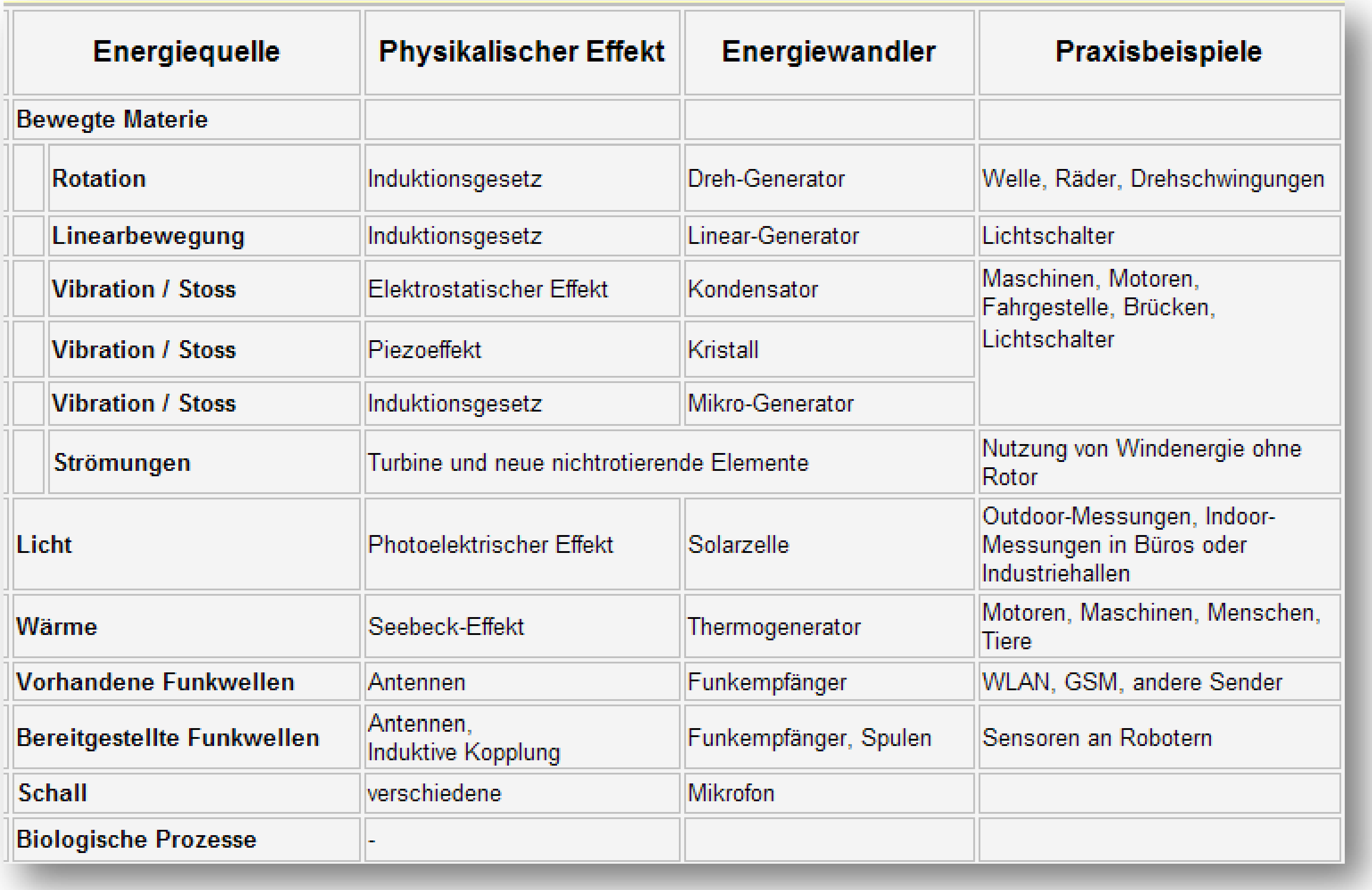
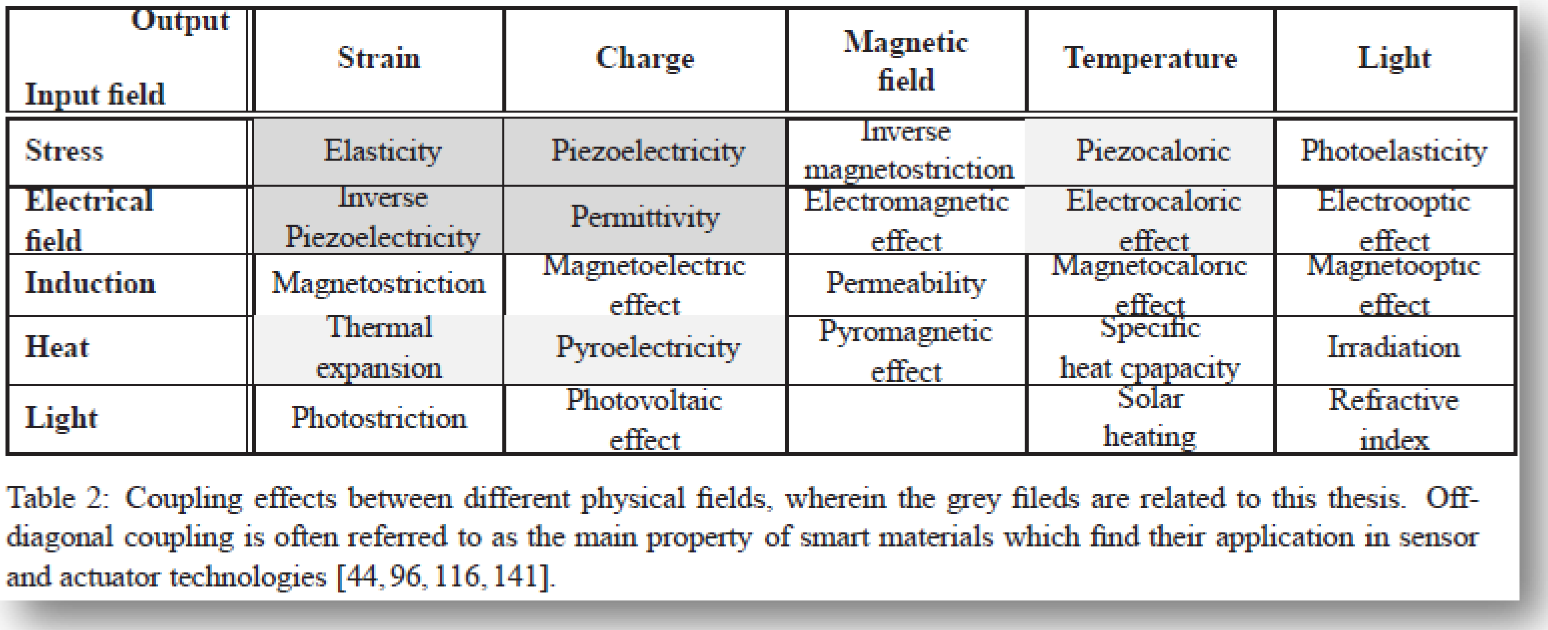


Bild 1: Durchschnittlicher Verbrauch von 40-t-Sattelzügen (1965-2008)

Source: The Design and Aerodynamics of Commercial Vehicles



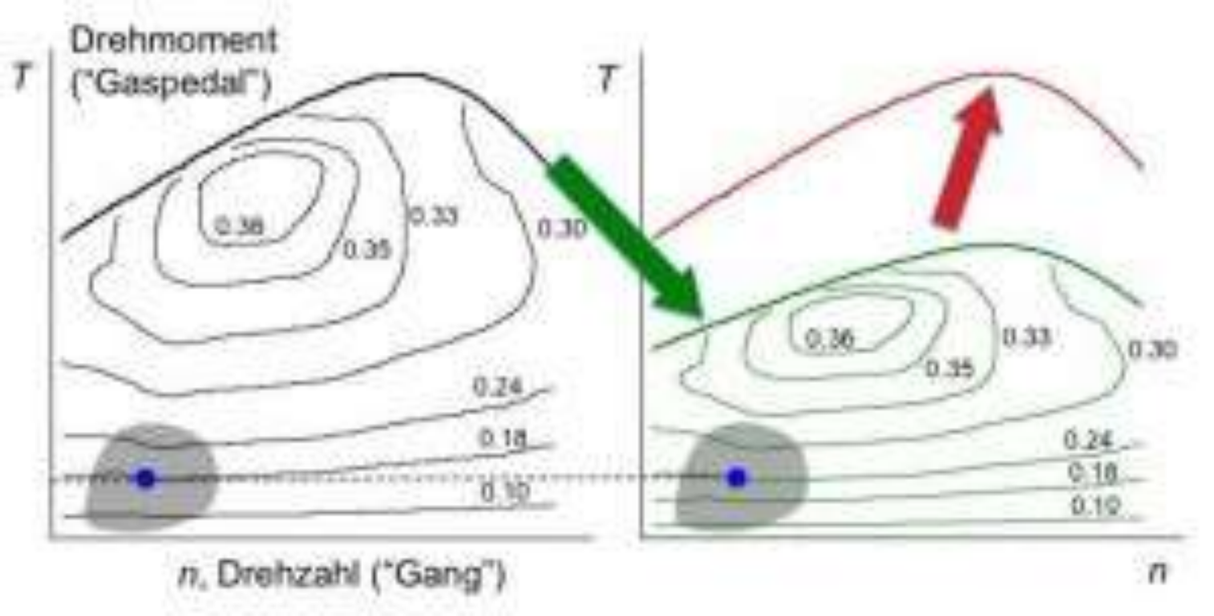
Energiequelle	Physikalischer Effekt	Energiewandler	Praxisbeispiele
Bewegte Materie			
Rotation	Induktionsgesetz	Dreh-Generator	Welle, Räder, Drehschwingungen
Linearbewegung	Induktionsgesetz	Linear-Generator	Lichtschalter
Vibration / Stoss	Elektrostatischer Effekt	Kondensator	Maschinen, Motoren, Fahrgestelle, Brücken, Lichtschalter
Vibration / Stoss	Piezoeffekt	Kristall	
Vibration / Stoss	Induktionsgesetz	Mikro-Generator	
Strömungen	Turbine und neue nichtrotierende Elemente		Nutzung von Windenergie ohne Rotor
Licht	Photoelektrischer Effekt	Solarzelle	Outdoor-Messungen, Indoor-Messungen in Büros oder Industriehallen
Wärme	Seebeck-Effekt	Thermogenerator	Motoren, Maschinen, Menschen, Tiere
Vorhandene Funkwellen	Antennen	Funkempfänger	WLAN, GSM, andere Sender
Bereitgestellte Funkwellen	Antennen, Induktive Kopplung	Funkempfänger, Spulen	Sensoren an Robotern
Schall	verschiedene	Mikrofon	
Biologische Prozesse	-		

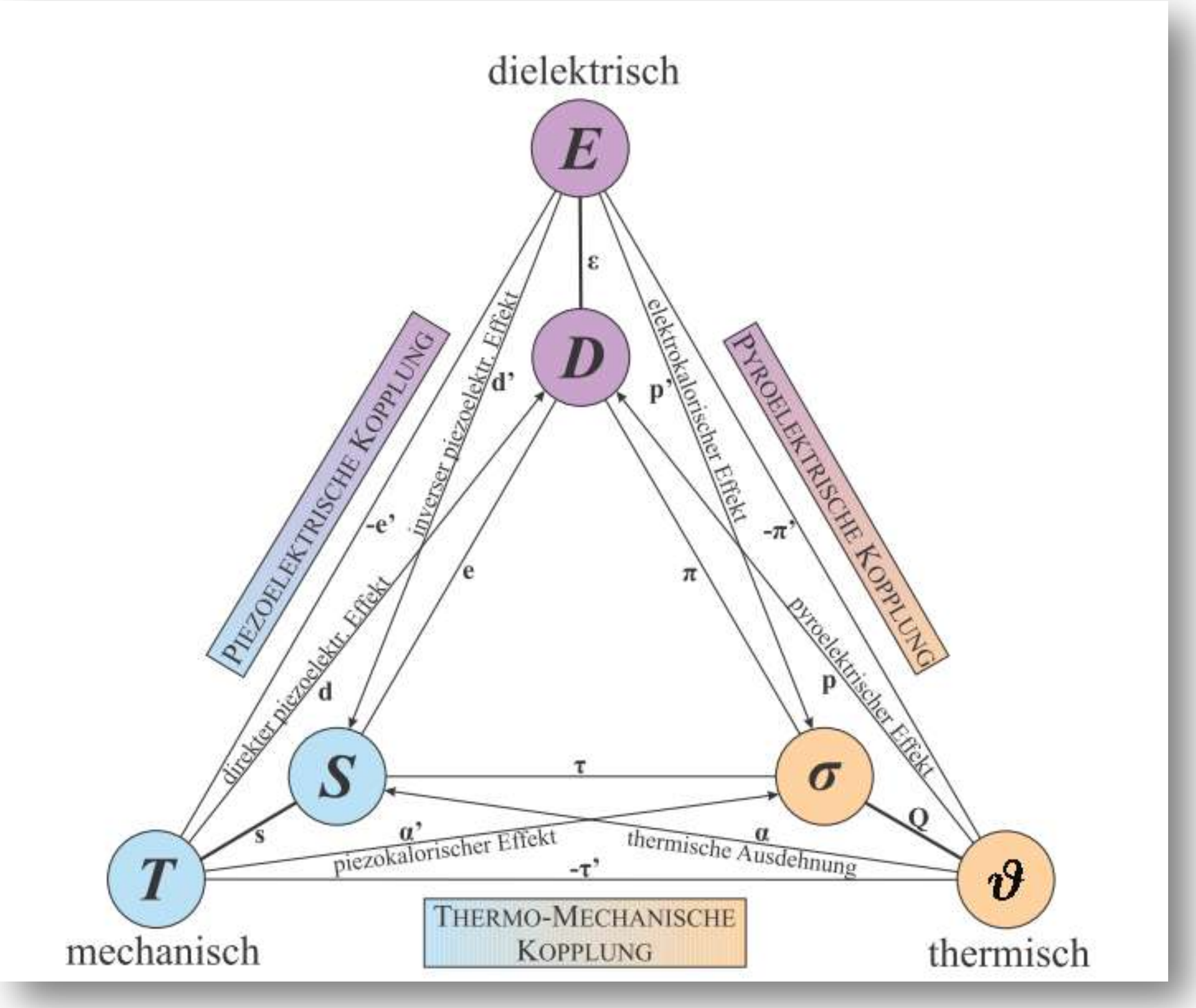


Output Input field	Strain	Charge	Magnetic field	Temperature	Light
Stress	Elasticity	Piezoelectricity	Inverse magnetostriction	Piezocaloric	Photoelasticity
Electrical field	Inverse Piezoelectricity	Permittivity	Electromagnetic effect	Electrocaloric effect	Electrooptic effect
Induction	Magnetostriction	Magnetoelectric effect	Permeability	Magnetocaloric effect	Magnetooptic effect
Heat	Thermal expansion	Pyroelectricity	Pyromagnetic effect	Specific heat cpapacity	Irradiation
Light	Photostriction	Photovoltaic effect		Solar heating	Refractive index

Table 2: Coupling effects between different physical fields, wherein the grey fileds are related to this thesis. Off-diagonal coupling is often referred to as the main property of smart materials which find their application in sensor and actuator technologies [44, 96, 116, 141].


MAN


Drehmoment
("Gaspedal")
T
0.36
0.35
0.33
0.30
0.24
0.18
0.10
n, Drehzahl ("Gang")
T
0.36
0.35
0.33
0.30
0.24
0.18
0.10
n


dielektrisch
E
ε
D
d'
p'
PIEZOELEKTRISCHE KOPPLUNG
inverser piezoelektr. Effekt
elektrokalorischer Effekt
PYROELEKTRISCHE KOPPLUNG
-e'
e
π
-π'
direkter piezoelektr. Effekt
d
pyroelektrischer Effekt
p
S
τ
σ
s
Q
α'
piezokalorischer Effekt
α
thermische Ausdehnung
-τ'
T
ϑ
mechanisch
THERMO-MECHANISCHE KOPPLUNG
thermisch