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Winner of the
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Die Auszeichnung für Bestleistungen im Energiebereich
unter dem Patronat des Bundesamts für Energie

The Hybrid Pneumatic Engine (HPE) –
The Future's Cost & Fuel Efficient Vehicle Propulsion System

Motivation: Reduce CO_2

Policies for dealing with climate change and limited crude oil resources increasingly demand lower fossil energy consumption and consequent CO_2 emissions. This development forces the individual transport sector to come up with innovative solutions to increase drive train efficiencies in order to lower overall fuel consumption. However, these solutions must be affordable to consumers and must not compromise on emissions or safety.

Why are today's cars not fuel efficient?

Today's internal combustion engines are often large, naturally aspirated gasoline engines. They are designed for high peak load levels, following the consumer's demand for good driveability. However, large engines exhibit low efficiencies at part loads at which they are most frequently operated. Furthermore, internal combustion engines cannot transform the energy available during braking phases into usable energy. Therefore, the potential to increase the global efficiency of drive trains is substantial.

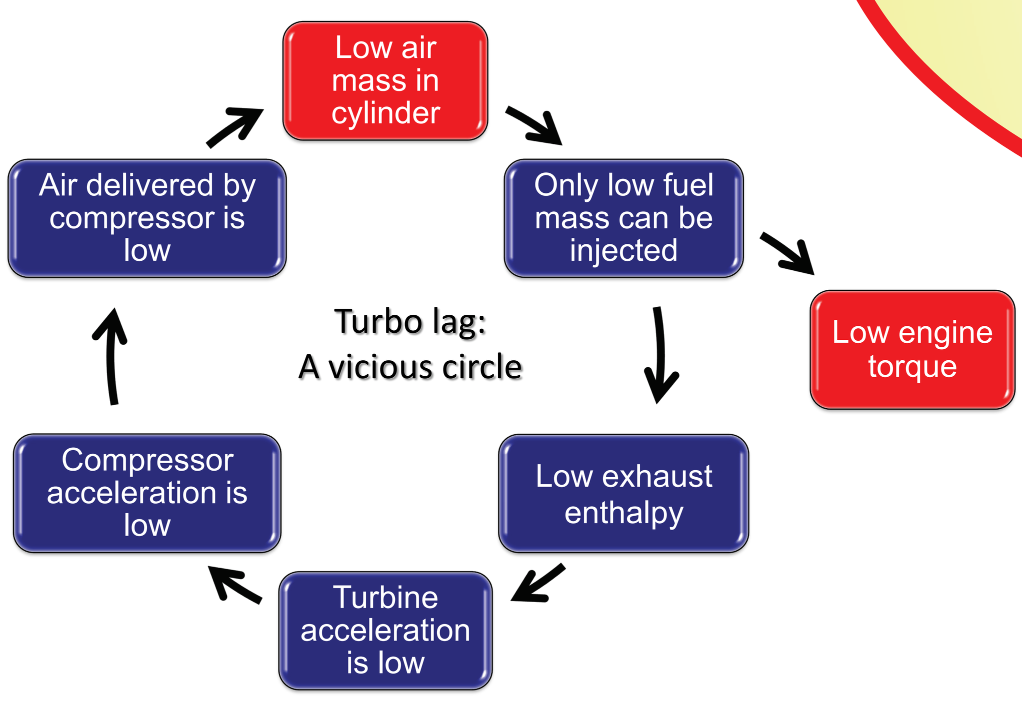
The Idea of Engine Downsizing & Turbocharging

Downsizing internal combustion engines has the potential to reduce fuel consumption significantly. The peak power of a larger naturally aspirated engine can be recovered using a turbocharger. Lower friction and, more importantly, operating the internal combustion engine more frequently in high efficiency regions results in lower fuel consumption.

So why don't automobile manufacturers downsize their engines for maximum fuel efficiency?

Especially for gasoline engines, strong downsizing and turbocharging is associated with a turbo lag. This is the term for a slow engine response to a sudden increase of the driver's torque demand. This driveability aspect and its importance for market acceptance has prevented strong downsizing & turbocharging of gasoline engines so far.

Why is there a turbo lag?



The underlying reason for the turbo lag is the missing air in the cylinder.
A larger turbocharger is more efficient and enables a stronger downsizing, but the associated turbo lag is also larger. This is the reason why automobile manufacturers only consider moderate downsizing if at all.

Pneumatic Hybridization

The most important aspect of pneumatic hybridization is to provide the missing air for breaking the vicious circle of the turbo lag. To achieve this, an air tank is connected to all cylinders to provide pressurized air if necessary to satisfy the driver's torque demand. Therefore, pneumatic hybridization dramatically increases the consumer acceptance of a well-known and recognized fuel saving method.

But where does the pressurized air come from?

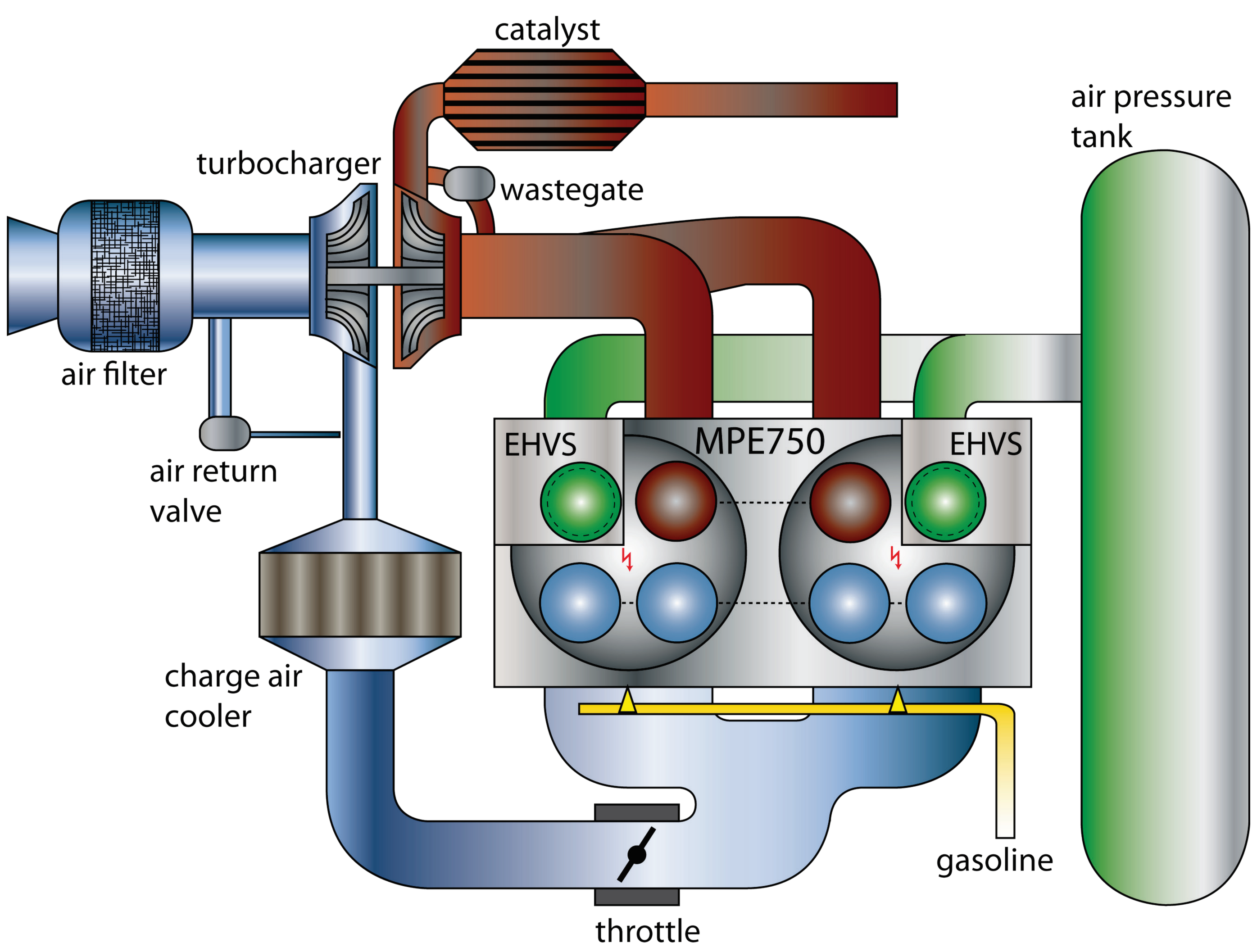
Similar to hybrid electric vehicles, a hybrid pneumatic vehicle can recuperate energy during vehicle deceleration that would otherwise be dissipated in conventional brakes. Here, the internal combustion engine simply works as a pump, using energy from the wheels to pump air into the pressure tank.

But electric hybridization has the same or even more benefits, so how do these approaches compare?

The electric hybridization of drive trains is very expensive. Especially the costs for batteries, electric motors and power electronics dramatically increase the price the consumer has to pay for a more fuel efficient car that has the same power than a normal car. The pneumatic hybridization comes at a small fraction of that additional cost and thus has excellent chances to prevail in the automotive industry.

Pneumatic Hybridization:
The Enabler of Strong Downsizing and Supercharging

Downsized and Turbocharged Hybrid Pneumatic Engine



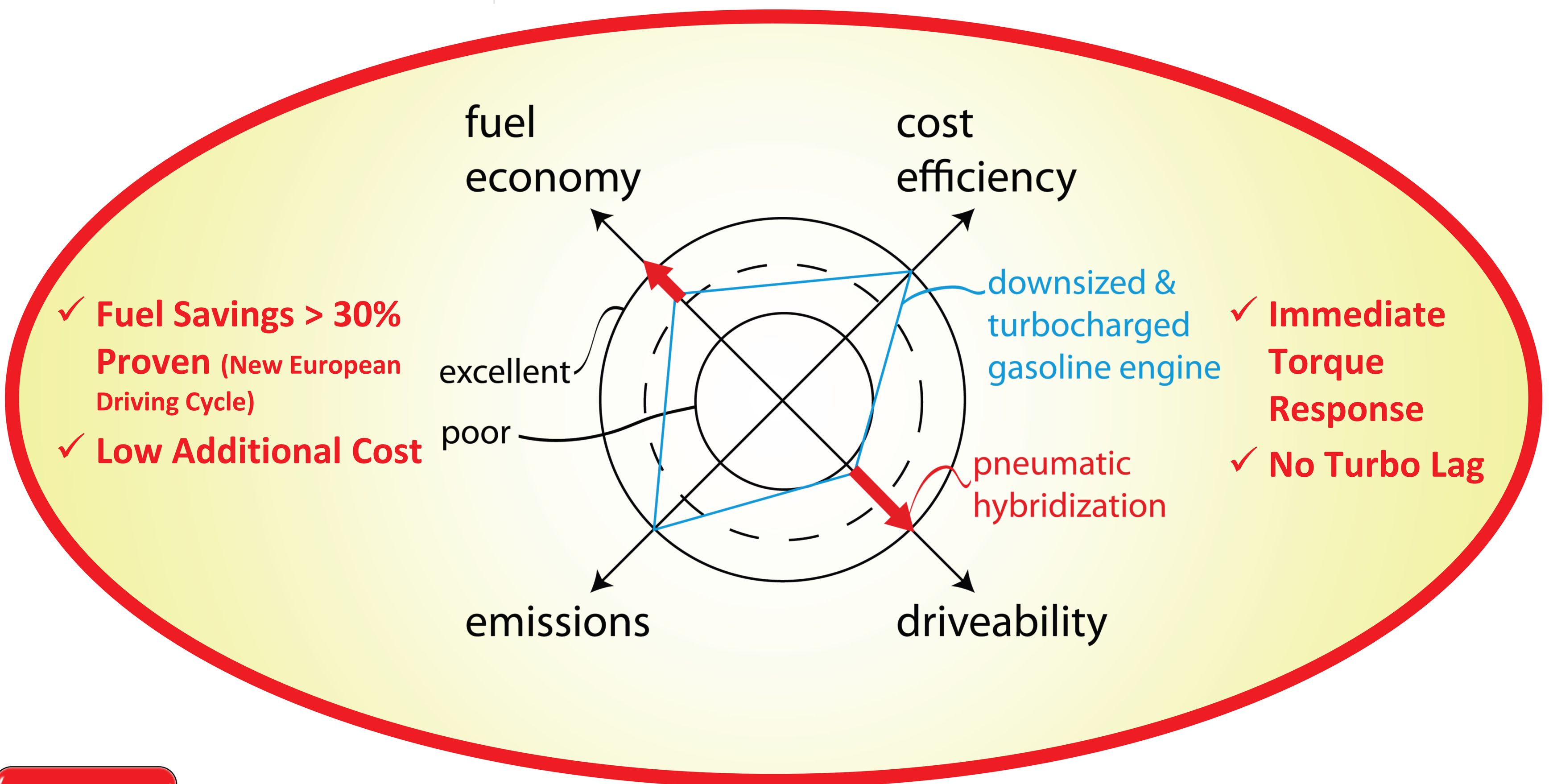
Engine Type

- Gasoline engine, port fuel injection (DI even better)
- Turbocharger choice for minimum backpressure and maximum efficiency
- Number of cylinders: 2 or more
- Exhaust & intake valves: camshaft-driven

Additional Hardware

- Air tank: 20 bar, 20 liter (mid-size passenger car)
- Variable valve actuation system for charge valve (e.g. EHVS in Fig.)

(EHVS = Electro-Hydraulic Valve System)

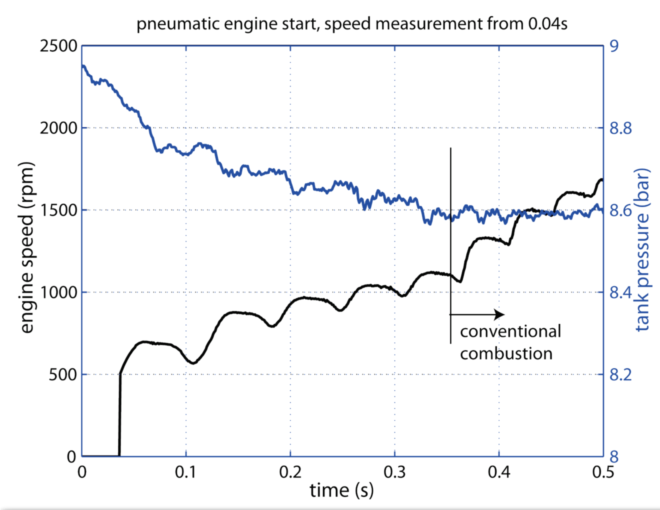


Additional Engine Modes

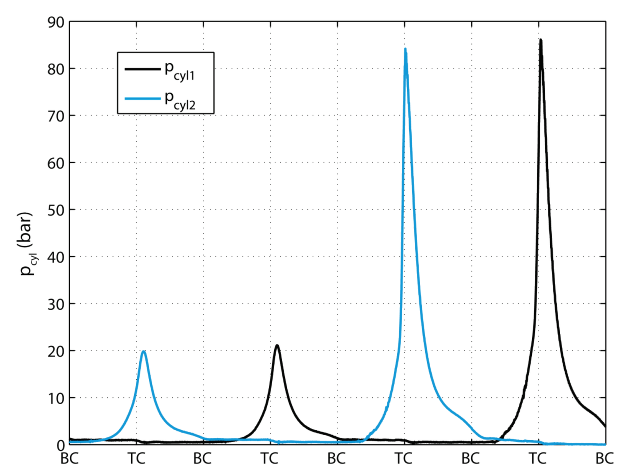
- **Pneumatic Pump Mode:** Recuperation of kinetic energy during braking: engine is used as a pump, air tank is filled
- **Pneumatic Motor Mode:** Uses only compressed air for propulsion, mainly used for engine or vehicle starting (→ no engine idling → saves fuel)
- **Supercharged Mode:** combustion mode that additionally uses pressurized air and additional fuel to boost the engine. Used only for transients to overcome the turbo lag.
- **Recharge Mode (4 or more engine cylinders required):** half of the cylinders combust, the other half is pumping air into the tank. The engine generates torque (operating point shifted).

Measurement Results from a Modified Engine

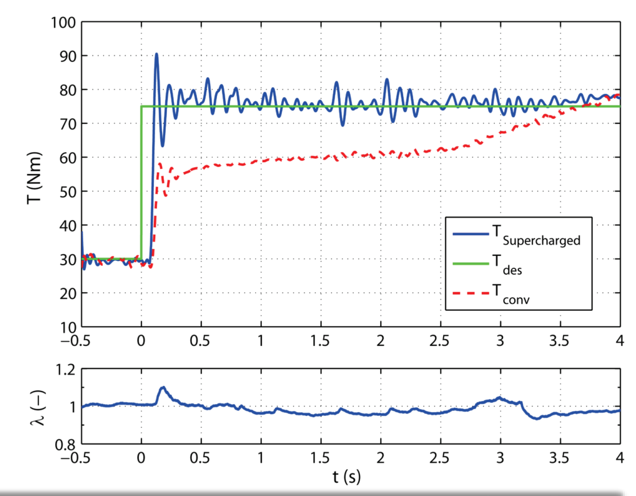
Measurement of a rapid pneumatic engine start, twice as fast as normal start, this justifies elimination of engine idling and thus enables additional fuel savings.



Cylinder pressure measurement: torque step from 10% to 90% load within 1 engine revolution. The driveability of this engine is comparable to that of an electric motor.



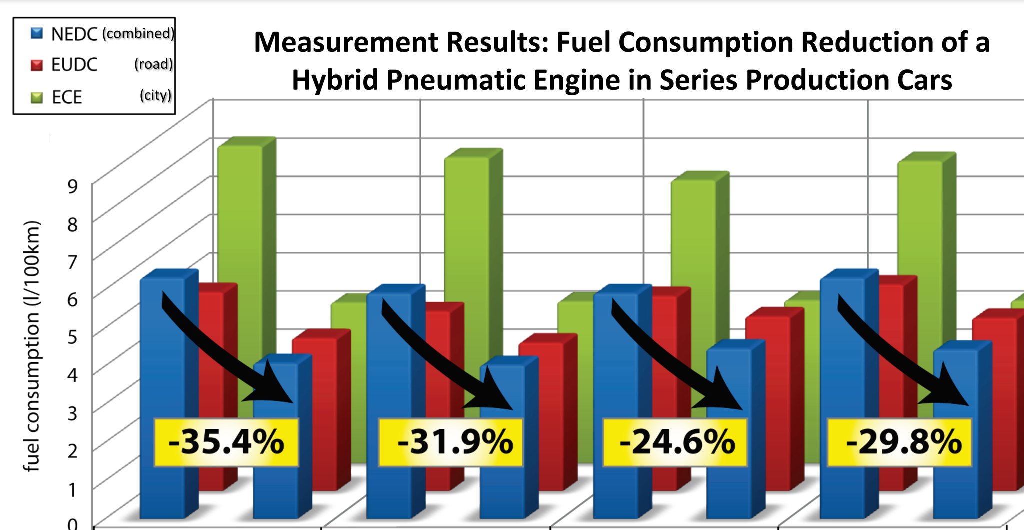
Torque measurement: overcoming the turbo lag with supercharged mode. In red: torque response without pneumatic hybridization reveals turbo lag.



Fuel Consumption Measurement Results and the Cost Aspect

The research group has modified an internal combustion engine to be a hybrid pneumatic engine. This engine was used for vehicle emulation measurements, which have proven that fuel consumption reduction can exceed 30% for the New European Driving Cycle. Engines of the same maximum power are compared.

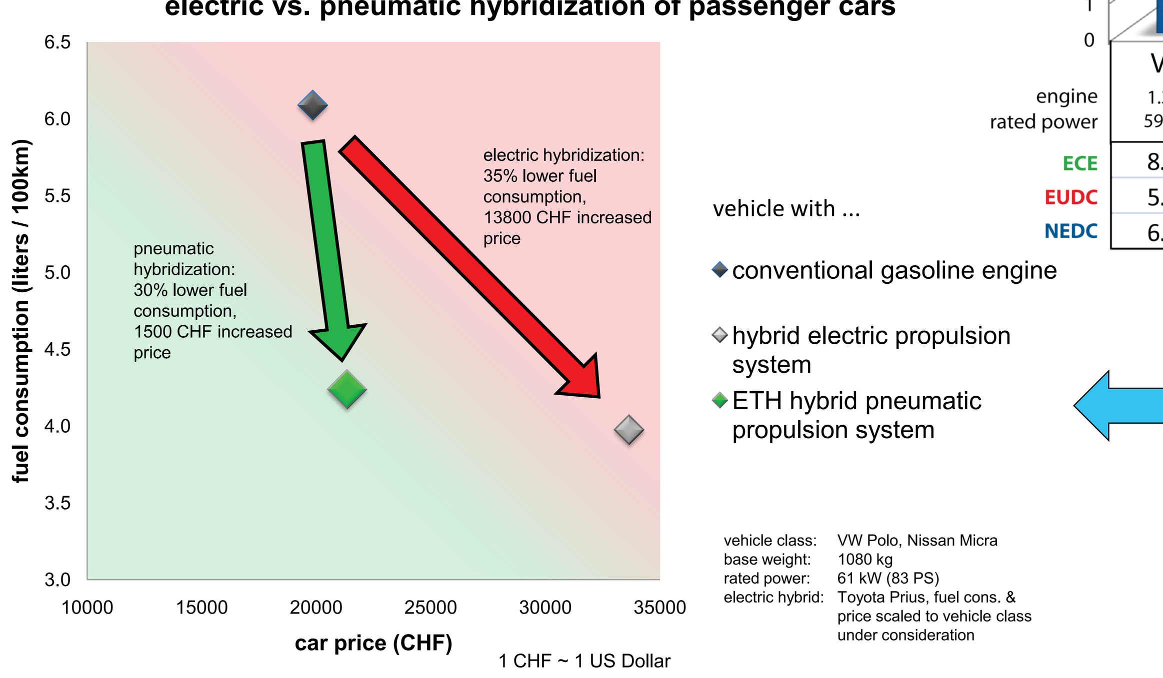
Measurement Results: Fuel Consumption Reduction of a Hybrid Pneumatic Engine in Series Production Cars



	VW Polo `05		VW Polo `09		Nissan Micra		Nissan Micra	
engine rated power	1.39 l 59 kW	Hybrid 0.75l 61 kW	1.39 l 63 kW	Hybrid 0.75l 61 kW	1.24 l 59 kW	Hybrid 0.75l 61 kW	1.39 l 65 kW	Hybrid 0.75l 61 kW
ECE	8.30	4.20	8.00	4.23	7.40	4.25	7.90	4.25
EUDC	5.20	3.99	4.70	3.88	5.10	4.57	5.40	4.52
NEDC	6.30	4.07	5.90	4.02	5.90	4.45	6.30	4.42

l / 100km

electric vs. pneumatic hybridization of passenger cars



1 CHF ~ 1 US Dollar

Compared to hybrid electric vehicles (such as the Toyota Prius), the pneumatic hybridization comes at a fraction of the additional cost. The fuel consumption reduction is comparable to that of a hybrid electric vehicle.