Fuel consumption and emissions investigation on a passenger car, operated with natural gas – hydrogen mixtures

Christian Bach, Thomas Bütler, Mathias Huber
Abteilung Verbrennungsmotoren

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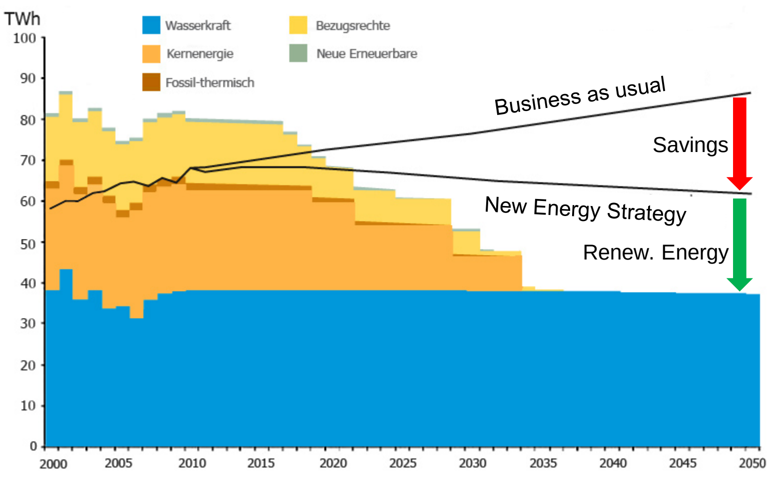
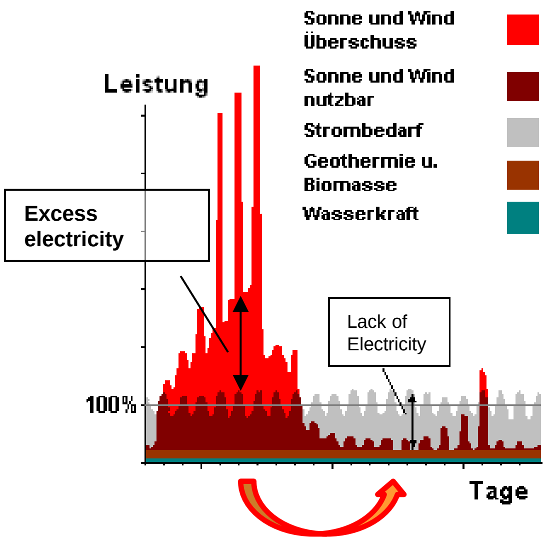
Inhalt

- «Mega-Trend» in the energy sector
- «Mega-Trend» in the vehicle powertrain sector
- HCNG investigation
- E-/H_2-/HCNG-Mobility Demonstrator an der Empa
- Summary

Mega-Trend in the energy sector

The energy turn around





Swiss targets:

- *Energy saving*
  20-25 TWh less end energy consumption
- *Addition of 22.6 TWh renewable energy*
  PV: 10.4 TWh, wind: 4 TWh, geothermal: 4.4 kWh, bio mass: 1.1 TWh, biogas 1.4 TWh, seawage treatment plants: 1.3 TWh
- *Retention of CO_2 targets*
  Until 2012: -10% vs 1990 (CO_2 law)
  Until 2020: -20% vs 1990 (under consultation)

Impact for implementation:

- Production of sufficient renewable energy
- Integration of locally produced electricity (modification of grid)
- Utilization of renewable excess electricity (electricity storage)
- ...

Source: BFE 2012

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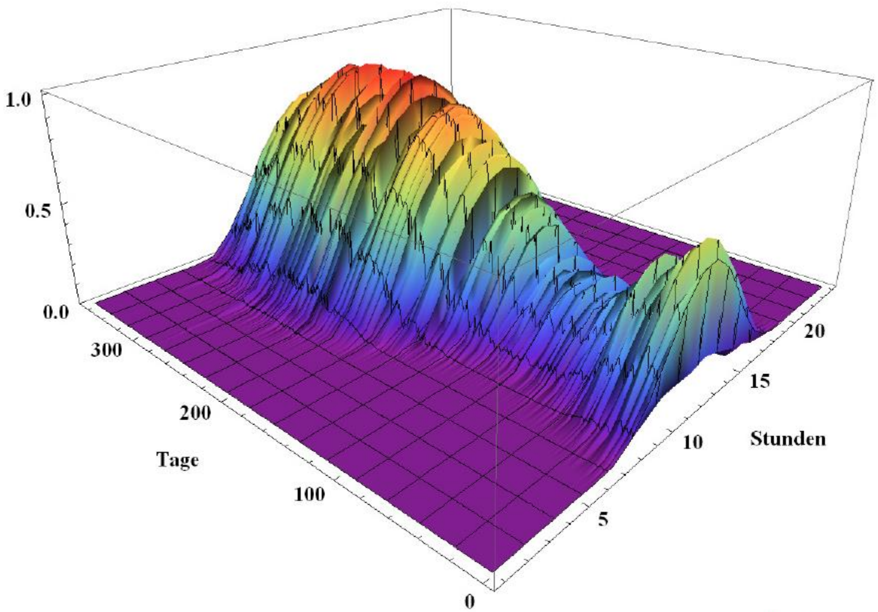
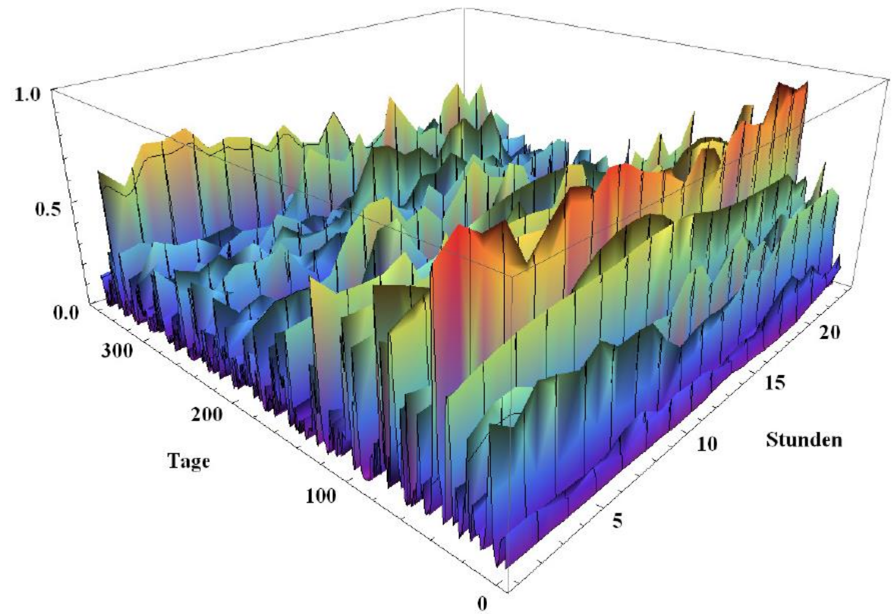
Mega-Trend in the energy sector

Fluctuating energy flows (sun + wind)



Quelle: Prognos 2012

Photovoltaic
Excess electricity in summer



Quelle: Prognos 2012

Wind energy
Stochastic Production

Simulation of electricity supply 2050 (Prognos)

- Approx. 15 TWh strongly fluctuationing electricity
- 9 TWh excess electricity (summer), if CHP/CCP are not controllable
- 4.5 TWh excess electricity (summer), if CHP/CCP are controllable

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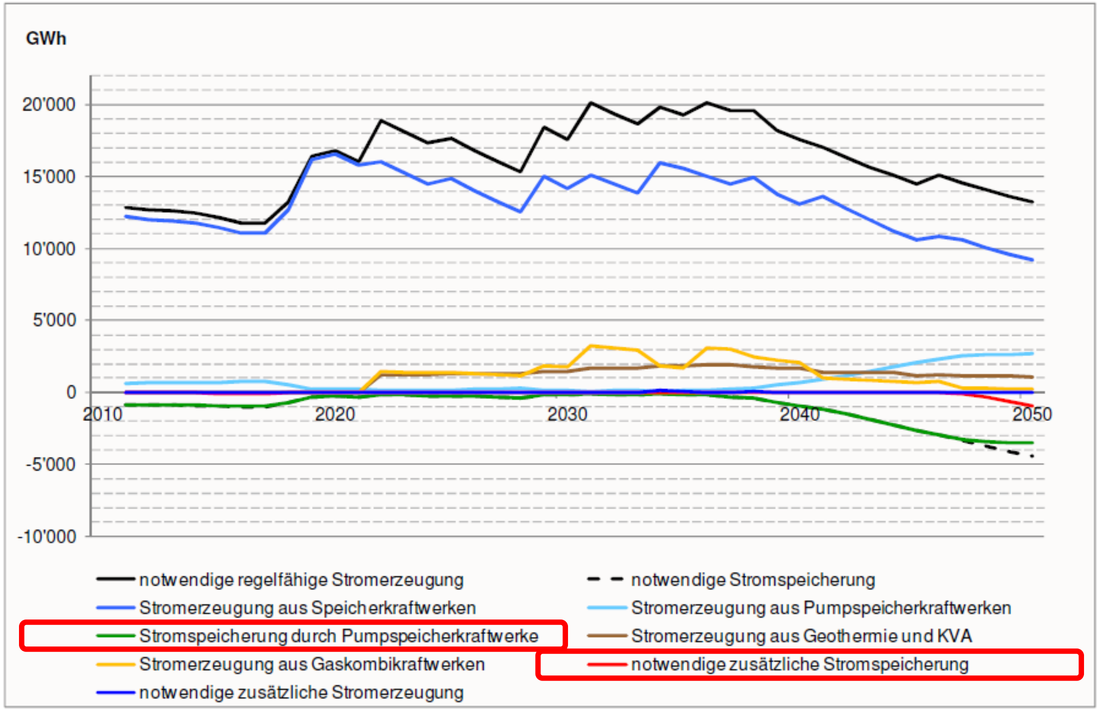
Mega-Trend in the energy sector
Potential of Swiss pumped-storage hydropower plant



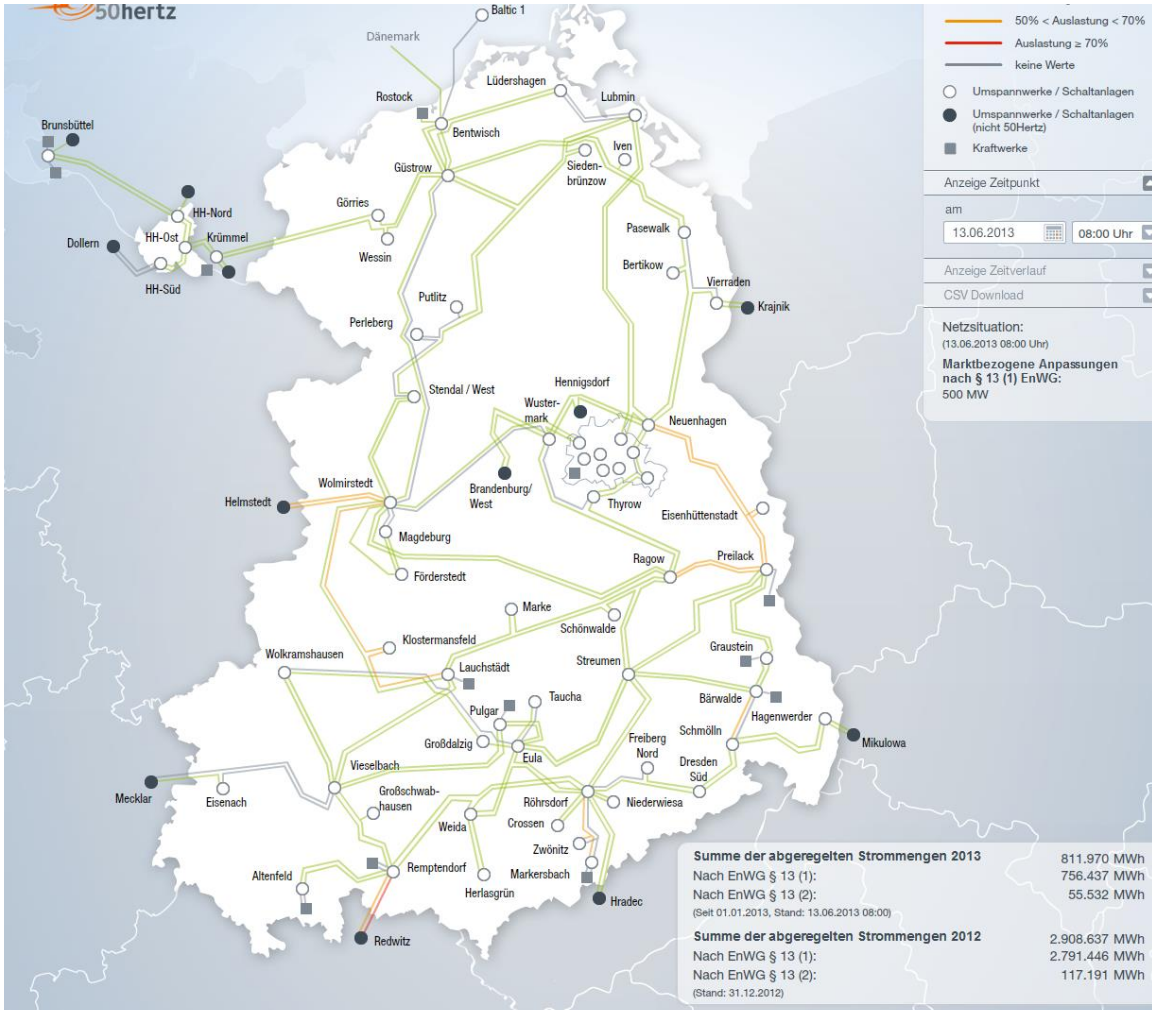
Quelle: Prognos 2012

Electricity storage:

- **Assumptions:**
  - Capacity: 200 GWh
  - Business Case for seasonal storage is possible
- **Storage capacity**:
  - 3.5 TWh
- **Remaining minimum renewable excess electricity:**
  - 1 TWh

Mega-Trend in the energy sector

Wasting of renewable excess electricity



Wasted
renewable excess electricity
2012 in NE-Germany
(50hertz-Grid):

2.9 TWh

Per 1 TWh:

15’000 t H_2
(55’000’000 l-eq. of gasoline)
could be produced

The question is:
how to use?

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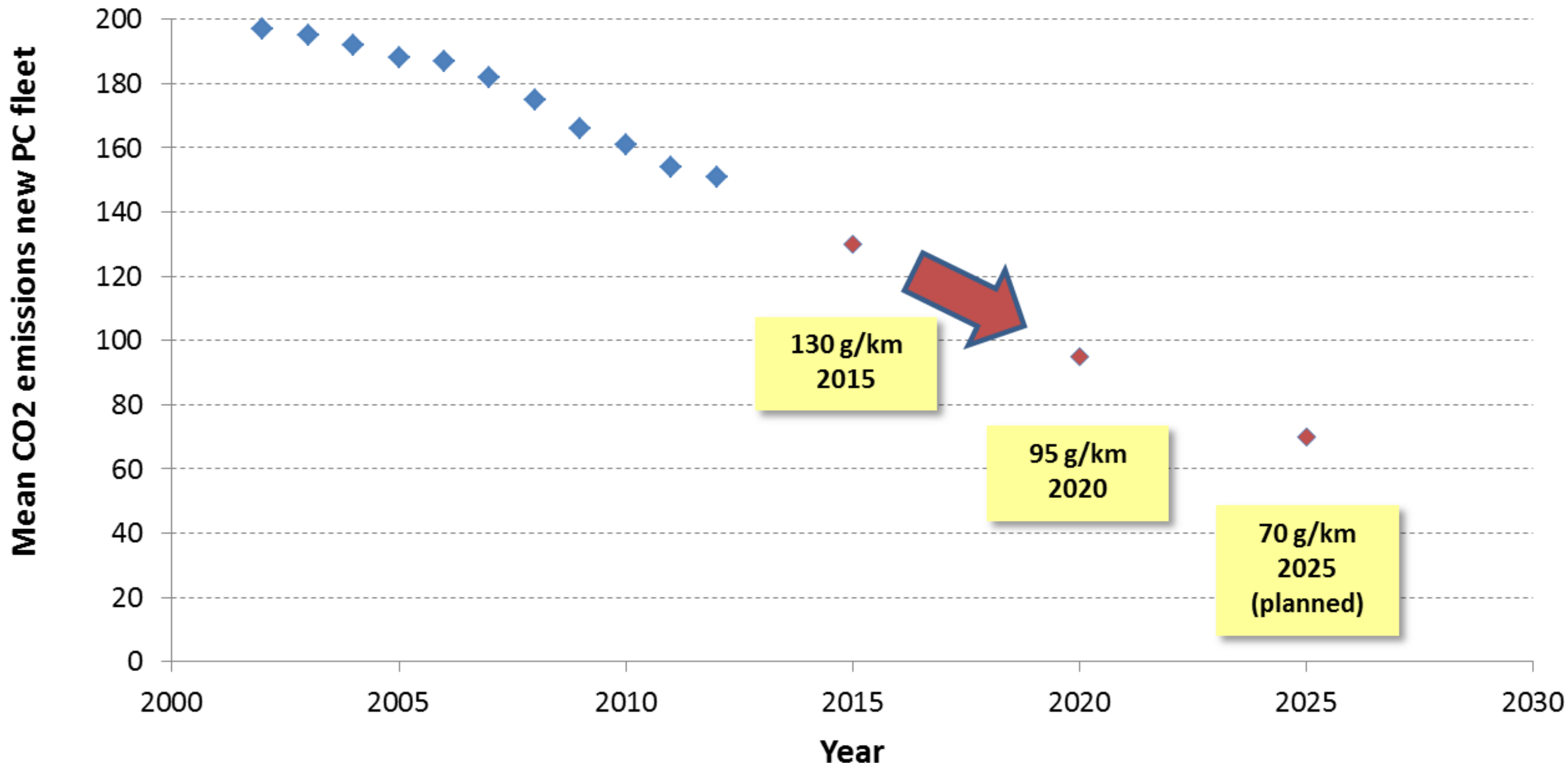
Mega-Trend in the vehicle sector

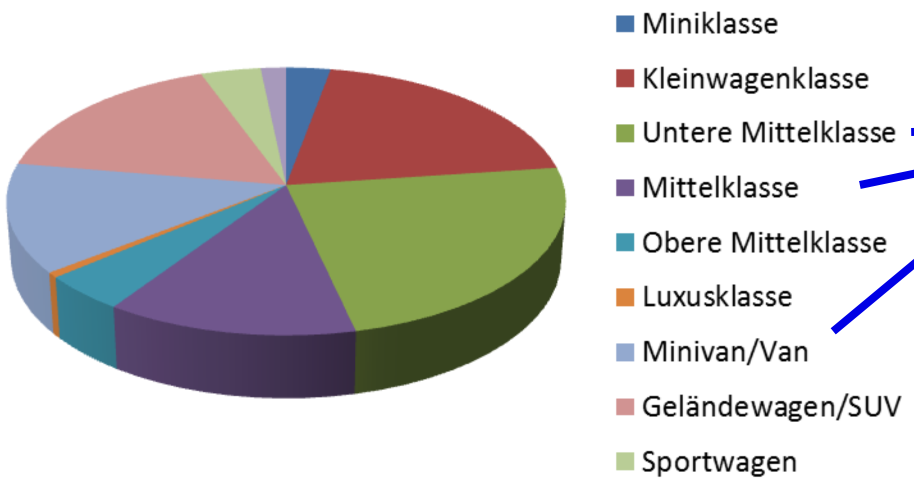
CO_2 reduction of the new passenger car fleet



Source: Auto-Schweiz 2013

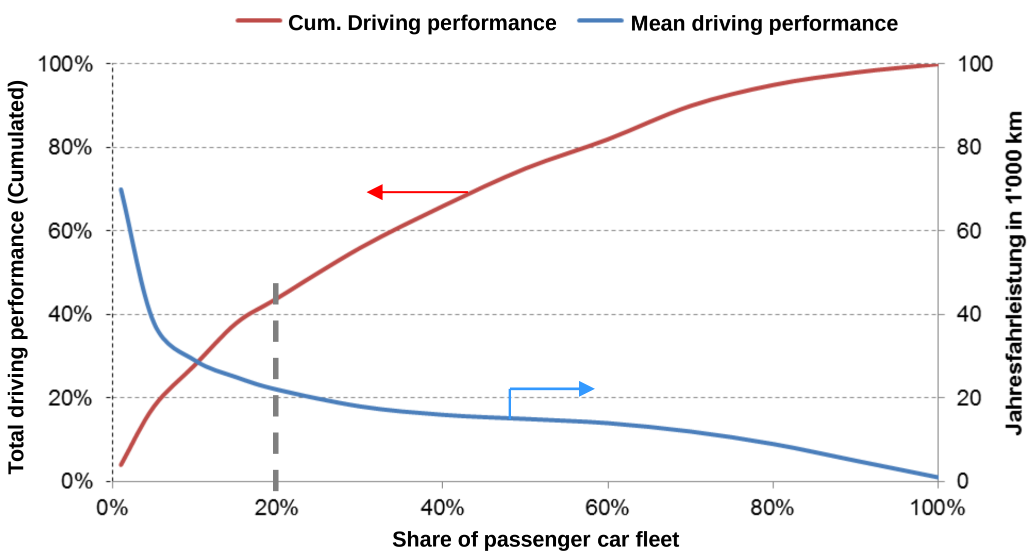
Mega-Trend in the vehicle sector

Midsize passenger cars and high-mileage driving are relevant



Midsize passenger cars:
50% of PC fleet

Source: ASTRA/Mofis, auto-schweiz 2012



High mileage driver:

20% of PC drive >20’000 km/a and perform 44% of the total driving performance (resp. Of CO_2 emissions).

Source: Janssen, Lienin (ATZ 2005)

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HCNG investigation
Test vehicle

- Conventional Euro-4 passenger car
- 2.0 l, stoichiometric 4 cylinder engine
- Conventional TWC

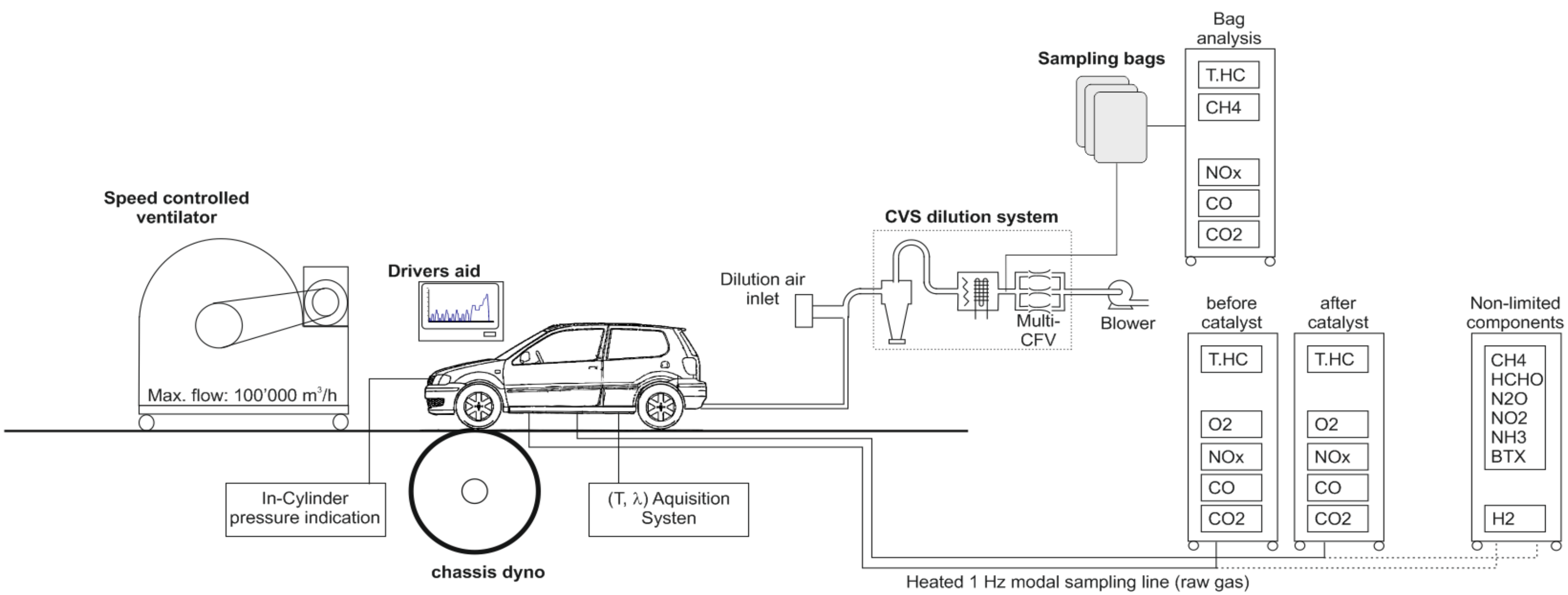
Measurements with:

- Original ECU [**…/org**]
- Modified ignition map [**…/mod**]
  (only in NEDC operation)

HCNG investigation

Chassis dynamometer test setup

Pollutant emission	Sampling system	Measurement device	Manufacturer Type
T.CH	Bag, pre/post cat	H.FID	Horiba MEXA 7400
CO, CO_2	Bag, pre/post cat	NDIR	Horiba MEXA 7400
NO, NOx	Bag, pre/post cat	CLD	Horiba MEXA 7400
CH_4, HCHO, N_2O, NO_2, NH_3, BTX,	pre/post cat	FTIR	Gasmet CR-2000 S
H_2	pre/post cat	MS	V&F H-Sense



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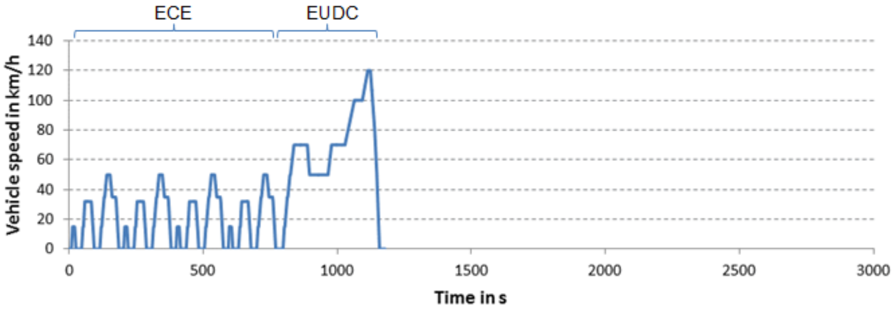
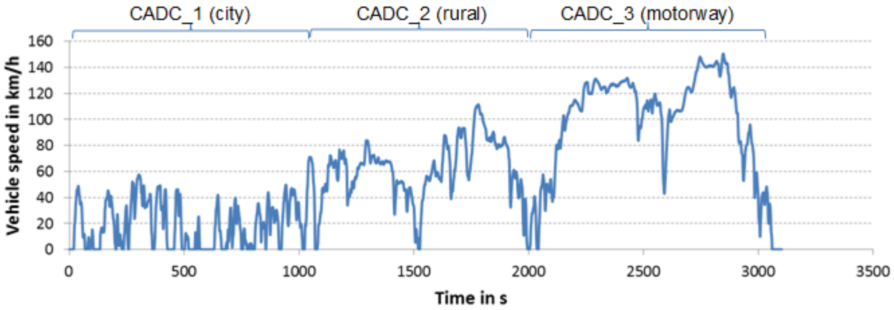
HCNG investigations on a vehicle
Driving cycles and fuels

Official European Driving Cycle (NEDC)



ARTEMIS real-world driving cycle (CADC)



Used fuels

Fuel Designation	Fuel 1 G20	Fuel 2 $HCNG_{4.1}$	Fuel 3 $HCNG_{9.2}$
Vol.-fraction H_2 [vol%]	0	15	25
Vol.-fraction CH_4 [vol%]	100	85	75
Energy-fraction H_2 [E-%]	0	4.1	9.2
Energy-fraction CH_4 [E-%]	100	94.9	91.8
Density at 15°C [kg/m^3]	0.632	0.549	0.494
Net heat value [MJ/kg]	49.65	51.18	52.48

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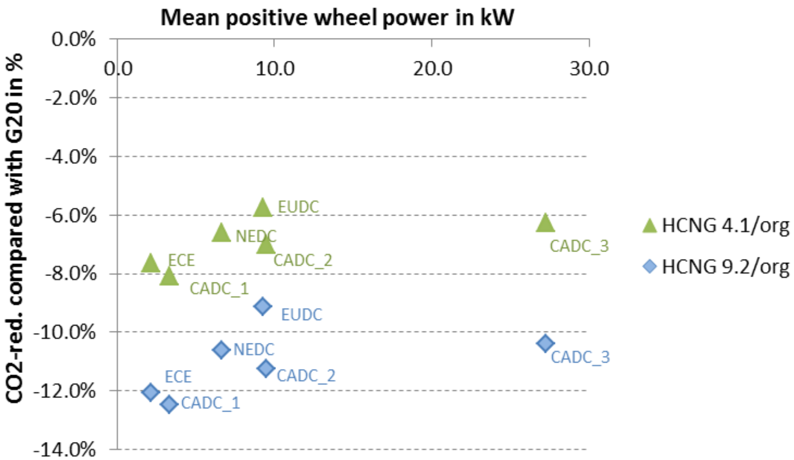
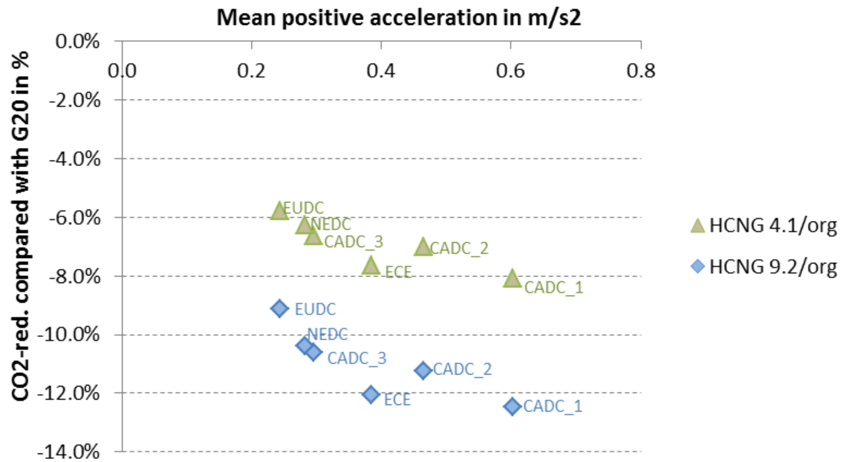
Results

CO_2 emissions (NEDC and CADC)



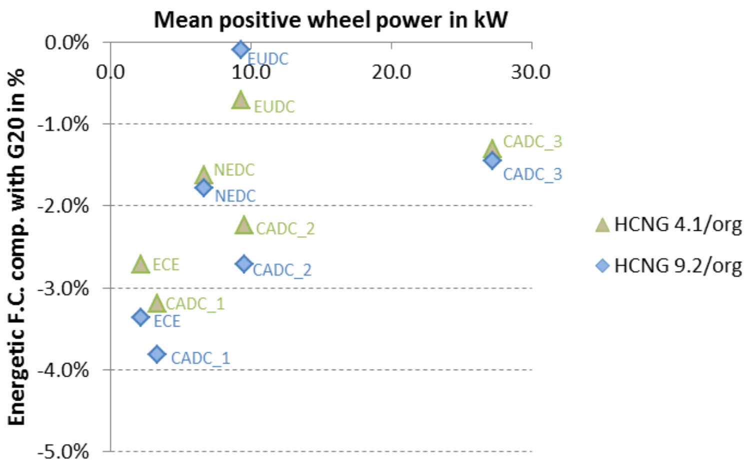


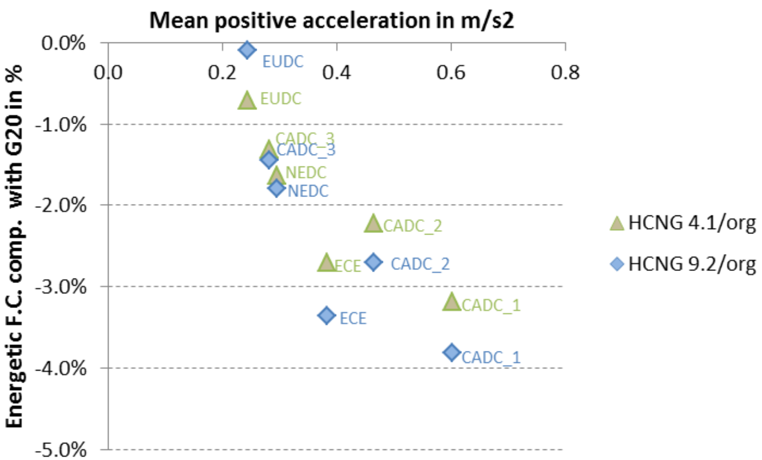
CO_2 reduction:

- Disproportional CO_2 reduction of 5.8 – 8.1% with 4.1 energy-% of hydrogen and 9.2 – 12.5% with 9.2 energy-% of hydrogen
- CO_2 reduction correlates with mean positive acceleration

Results

Energetic fuel consumption (NEDC and CADC)



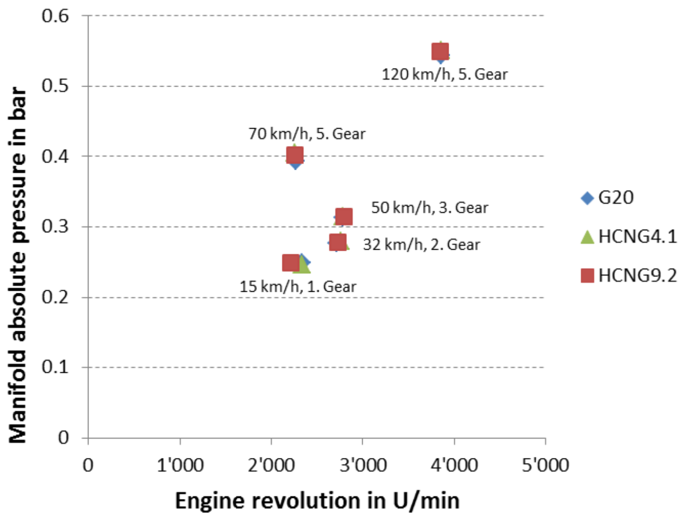


Efficiency:

- Efficiency increase correlates well with mean positive acceleration.
- The highest efficiency increase is observed during city cycles, which are characterized by low loads and frequent accelerations.

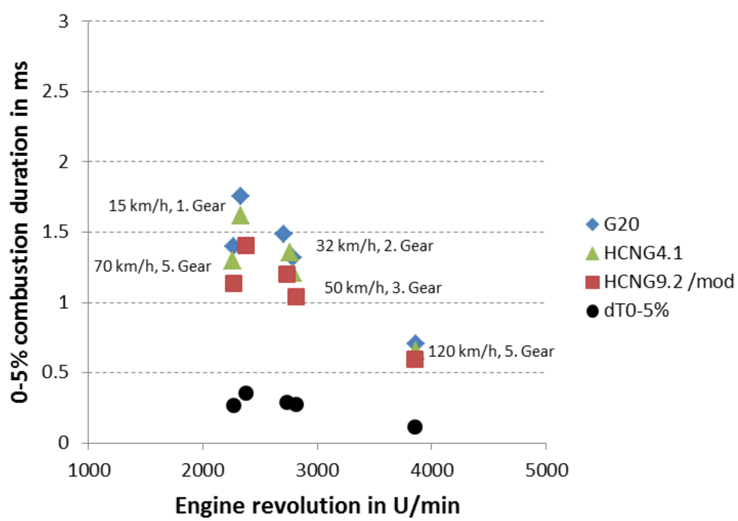
Results

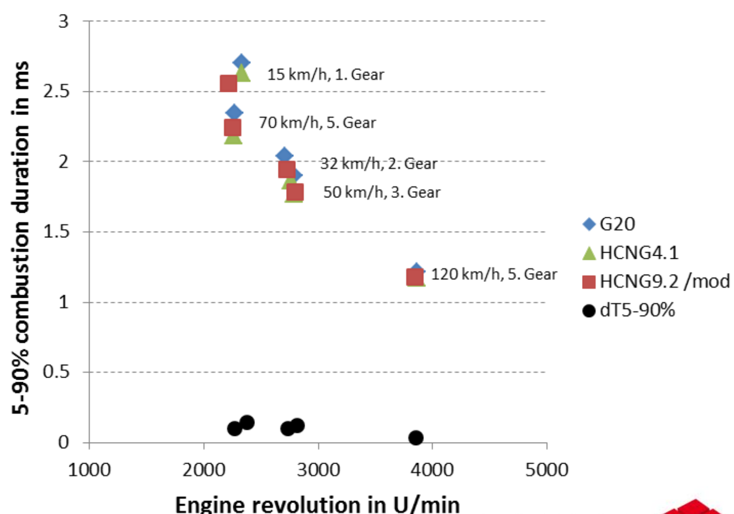
De-throttling and combustion duration (steady state driving)



Efficiency:

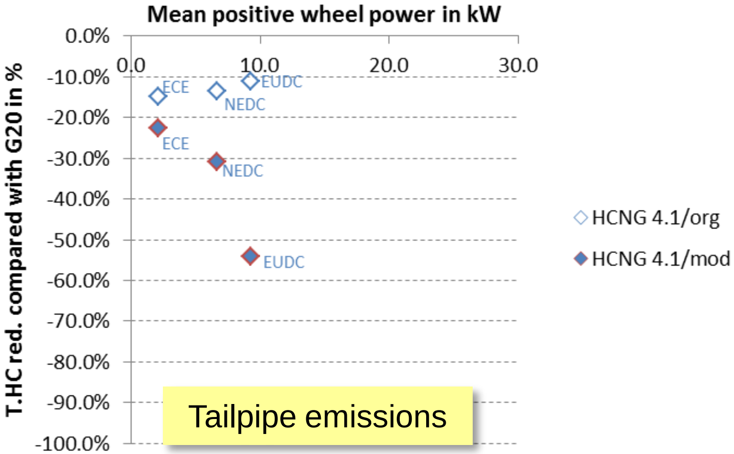
- No de-throttling effect measured
- 0-5% combustion duration reduction, mainly at low load

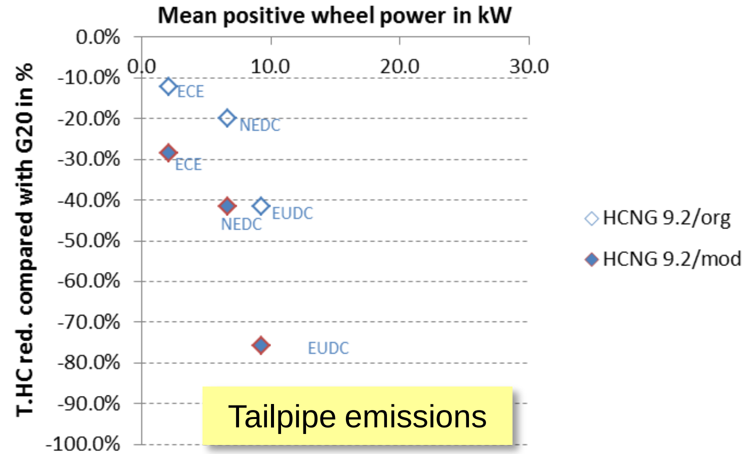


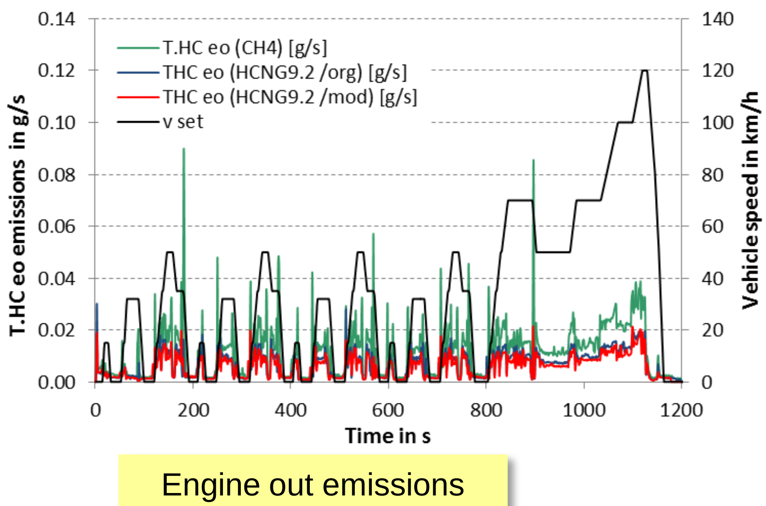


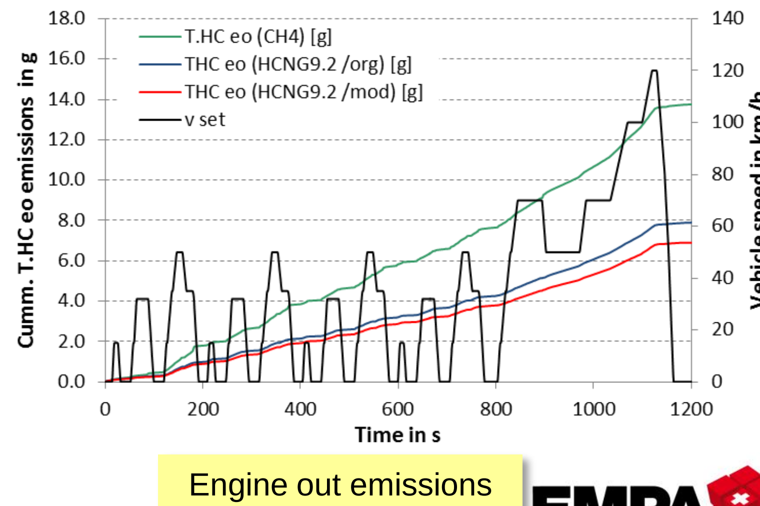
Results (NEDC)

T.HC emissions – strong engine out emissions reduction









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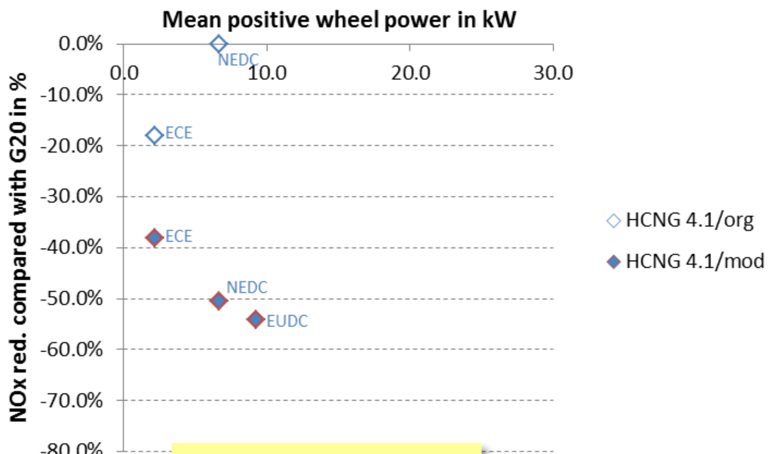
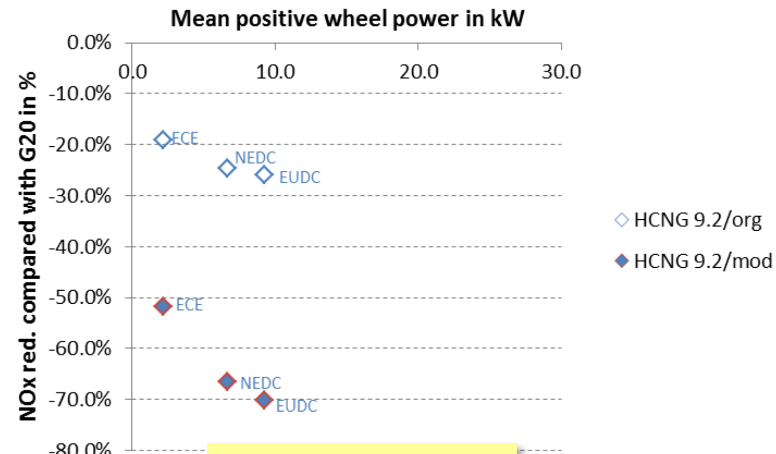
Results (NEDC)

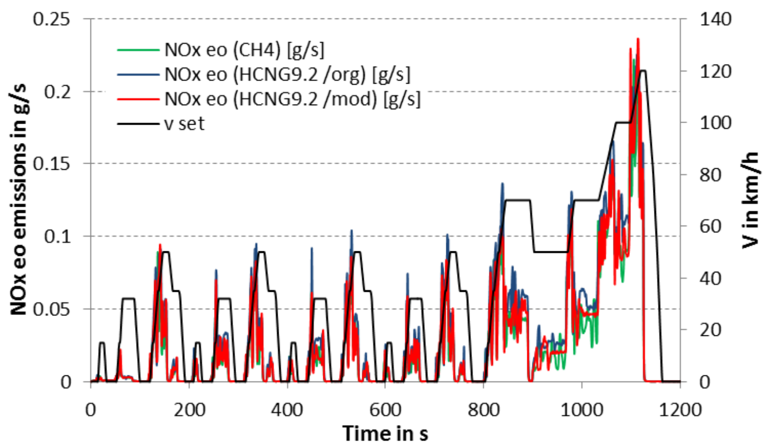
NOx emissions – strong increase in converter efficiency



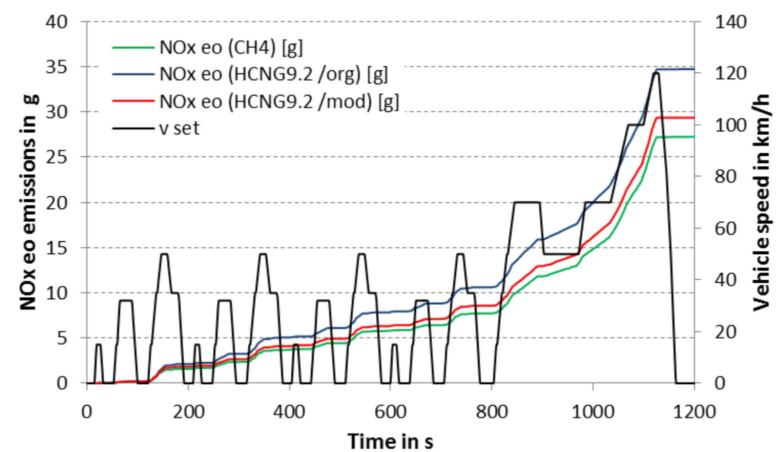
Tailpipe emissions



Tailpipe emissions



Engine out emissions



Engine out emissions

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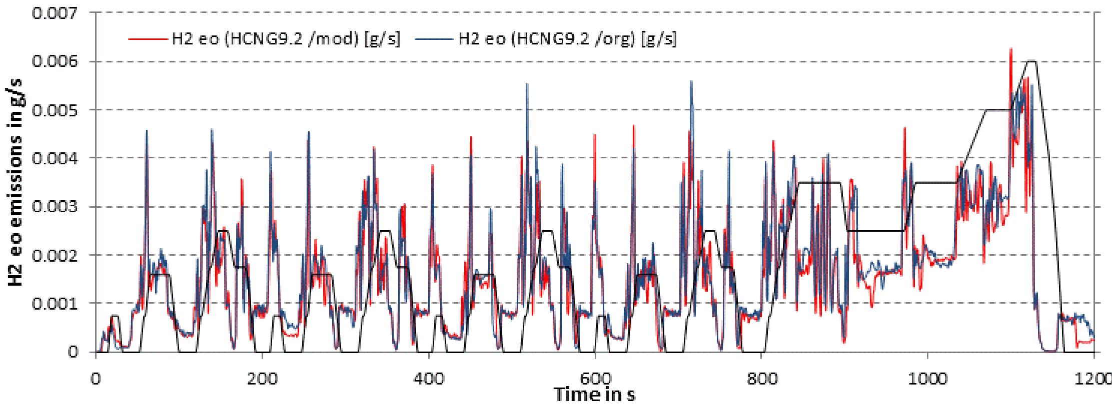
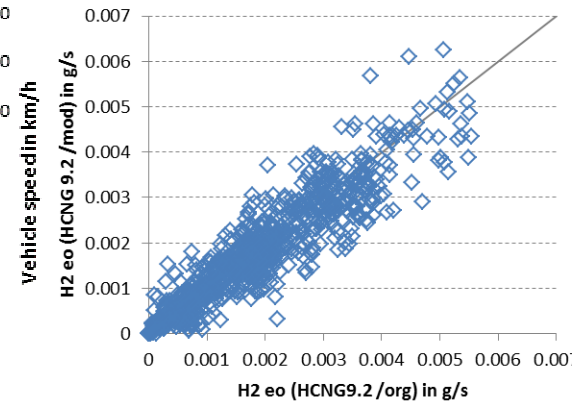
Results (NEDC)

H_2 emissions – no effect for ignition map correction





Engine out emissions

No significant difference for original and modified ignition map:

- NO, NO_2 engine out emissions and ratio
- CO, CH_4, C_3H_8, C_6H_6, C_7H_8, Xylenes, CHOH, N_2O, NH_3
- AFR, O_2, pre catalyst temperatures

- Oxidation state of catalysts under investigation

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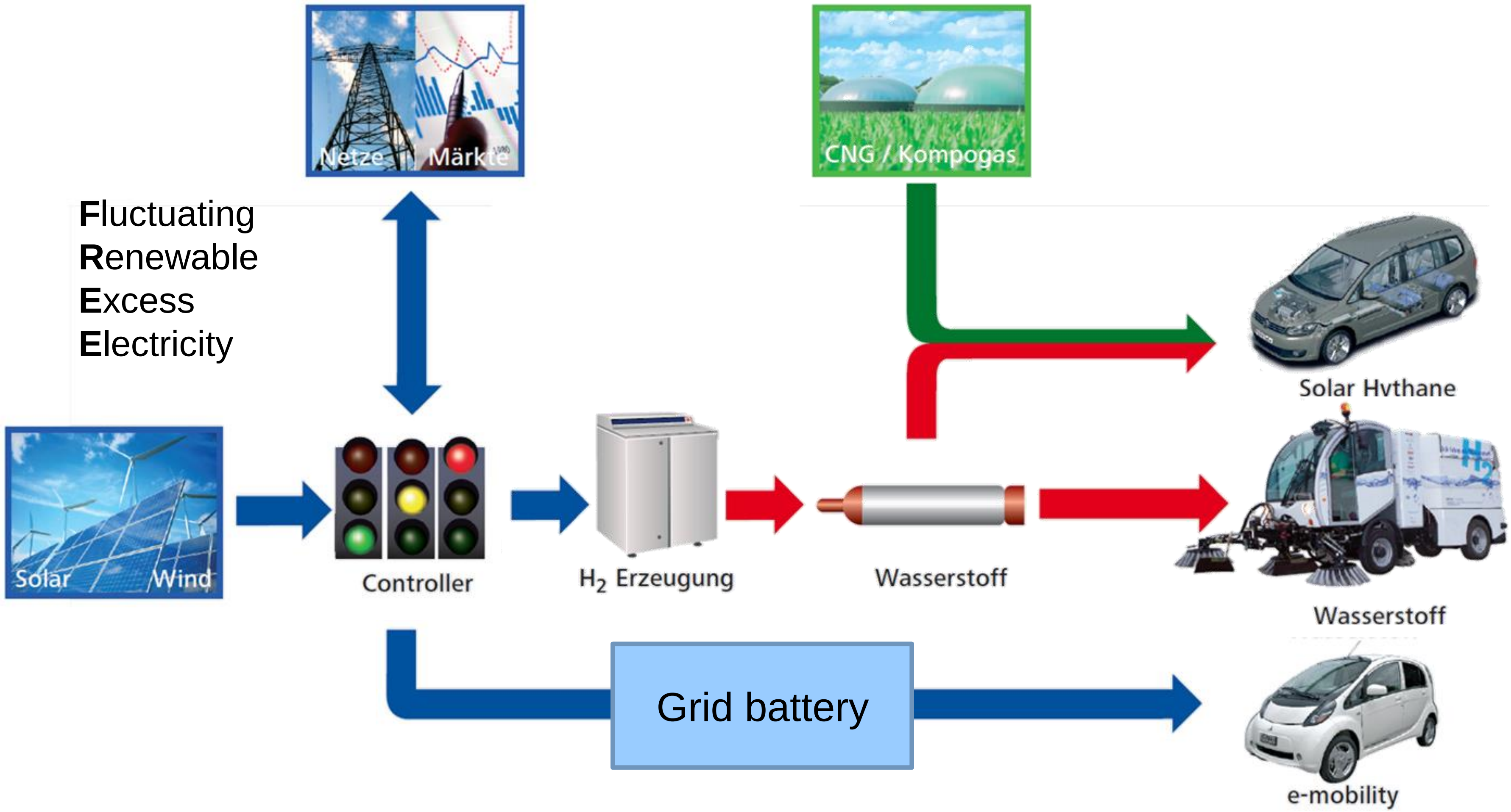
Utilization of “FREE” for mobility

Electricity storage and use

Fluctuating
Renewable
Excess
Electricity



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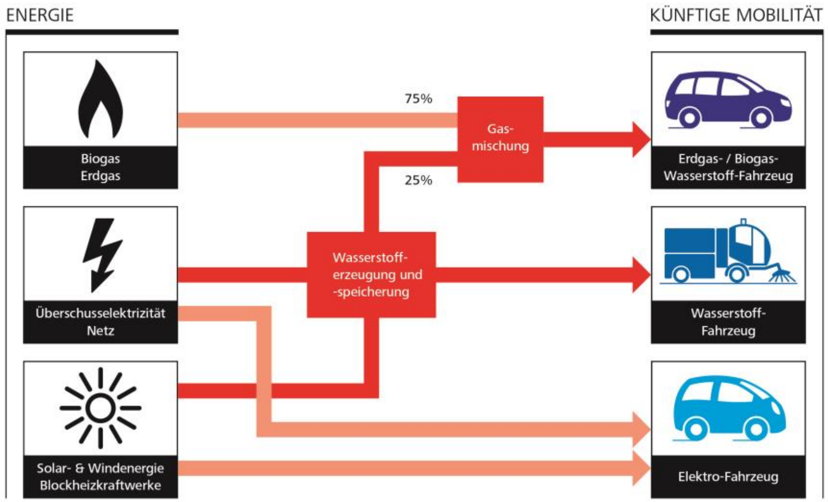
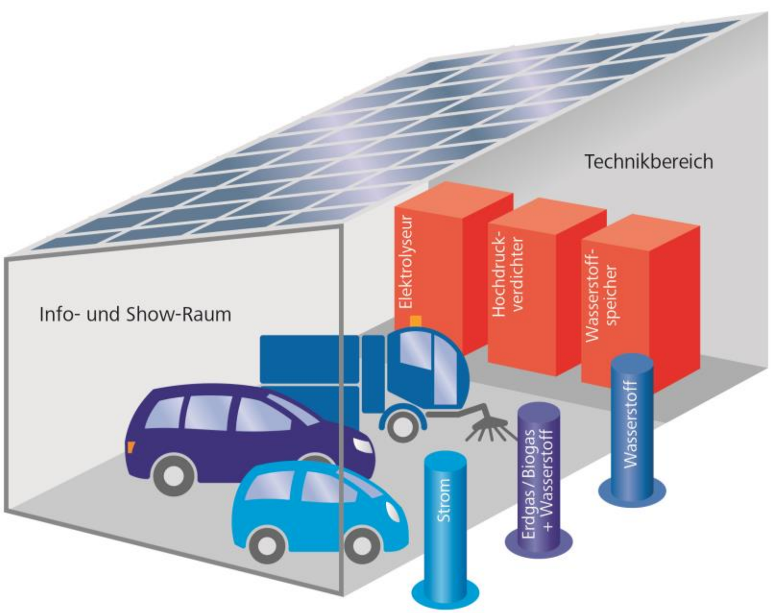
Future Mobility Demonstrator @ Empa

Power-to-H_2 and HCNG blending station





Utilization of Fluctuation Renewable Excess Electricity for Mobility:

- Design, simulation and realization of a decentralized, dynamic electrolytic H_2 production facility
- Design, simulation and realization of a HCNG (high pressure) blending station
- 2 year field testing with HCNG (2 – 25 vol% H_2) regarding:
  - operational behavior
  - catalyst aging
  - oil degradation

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Summary

Energy turnaround will produce huge amount of fluctuating renewable excess electricity. Wasting of this renewable energy has to be avoided.

CO_2 regulations in the mobility sector is one of the most important powertrain development driver. Low carbon and renewable fuels are of increasing interest.

Chemical storage of excess electricity and utilization for mobility is well suited with a high potential for the substitution of fossil fuels.

HCNG is the cheapest technology (fuel and vehicle) for using fluctuating renewable excess electricity.

HCNG investigations show efficiency increase and significant pollutant reduction. However, H_2 embrittlement of vehicle gas supply system has to be solved.

Thank you for your attention!

Thank to my colleagues:

Thomas Bütler
Mathias Huber
Dr. Brigitte Buchmann
Dr. Patrik Soltic
Dr. Michael Bielmann

Contact:
christian.bach@empa.ch

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