The future role of synthetic fuels in German road transport



Fields of activity of the German Aerospace Center

- Aeronautics and aerospace
- Energy
- Transport
- Digitisation and security
- Planning and implementation of German aerospace activities
- Project executing agency for research funding

55 institutes nationwide Over 10 000 employees











Overview



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Overview

Motivation

Research project: BEniVer

VECTOR21: scenario and market analysis software

Simulated scenarios and assumptions

Scenario results: new vehicle registrations

Scenario results: vehicle fleet and energy demand

Summary and conclusion



Motivation

- CO₂-equivalent emissions of the **transport sector** amounted to more than **145 million tons in 2021**
- This corresponds to 19.3% of total emissions in Germany
- Due to the German Climate Protection Act from 2021, the German transport sector must reduce its CO₂-equivalent emissions by 48% compared to 1990
- The largest share of CO_2 -equivalent emissions in German transport is caused by the passenger car (59%) and truck sector (38%)
- The use of fossil fuels must be gradually replaced until climate neutrality is achieved in 2045

Emissions from transport in Germany

in million t CO_2 equivalent



Sources: BMUV 2019, BMUV 2018, BMUV 2021, UBA 2021



BEniVer Begleitforschung Energiewende im Verkehr

- Research project accompanying the funding initiative "Energy transition in transport" of the German Federal Ministry of Economic Affairs and Climate Action (BMWK)
- Funding initiative comprises 17 research projects focusing on the production and usage of synthetic fuels made via the Power-to-Liquid process
- Projects cover the different transport sectors of road transport, aviation, and shipping as well as power generation
- BEniVer: Started in June 2018 and runs until May 2023

Aims:

- Comparison and evaluation of project results
- > Networking and communication within funding initiative
- > Development of roadmap for further research, production, and market launch of synthetic fuels



Geförder	t durch: Bundesministerium		
auferund	für Wirtschaft und Klimaschutz Leines Beschlusses		
des Deut: Die Verantwor Veröffentlichus	schen Bundestages tung für den Inhalt dieser ng legt beim Autor.		05.2023



The roadmap will be published in the upcoming days and can be accessed via: https://www.energiesystem-forschung.de/beniver

Gesamtbericht zur

Mai 2023

BEniVer Scenarios



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Model environment within the BEniVer project

- Core objective of BEniVer: Energy demand of German transport sector
- Multiple models included within the project
- Road tranport sector was modeled by the DLR Intitute of Vehicle Concepts with: VECTOR21





Scenario analysis software

VECTOR21: car and truck scenario and market analysis software

- Software developed in-house at DLR simulating future car and truck markets
- Detailed bottom-up market simulation
- Hybrid of an agent-based and discrete choice market penetration model
- Including all types of powertrain technologies
- Simulation of "synthetic fuel only" vehicles was developed within the work of this project





Scenarios considered within the project

- ✓ Climate neutrality in the transport system by 2045
- ✓ Existing political framework conditions
- ✓ Moderate increase in transport demand
- ✓ Efficiency improvement of technologies
- ✓ From 2035, only passenger cars and light commercial vehicles with zeroemissions in DEL and H2
- ✓ In the PtX scenario, up to 10% proven e-fueled passenger cars possible
- ✓ From 2040, only heavy-duty vehicles with zero emissions



The scenario analyses do not represent forecasts or recommendations. They describe possible paths (transformation paths) in the context of the underlying assumptions. Since the start of the project in 2018, the (global) political framework has changed very dynamically in many respects. In particular, the environmental policy changes are very welcome. However, not all legislative changes (especially the 2030 sector targets) could be fully considered in the modelling.



Key framework assumptions

- Increased drop-in of e-fuels assumed
- Constant share of biofuels assumed
- Environmental bonus for xEVs are assumed to last until 2025
- Constant electricity and energy taxes
- Best case PtX production costs assumed in all scenarios
- Until 2045 tax benefits for PtX fuels

	PtX		H2	DEL	
E-fuels: blending proportions	From 2026 1 % fast ramp-up until 2045 (>90 %)		From 2026 <1 % moderate ramp-up to 2045 >90 %.		
Share of biofuels		2020-2050: gasoline 3.7%, diesel 7.8%.			
Passenger car technology costs (€2020)	Battery: approx. 120 €/kWh by 2030 [Avicenne Energy 2020]; Fuel cell system: 58 €/kW by 2050		Battery: about €120/kWh by 2030 [Avicenne Energy 2020] Fuel cell system: €58/kW by 2030 [James et al. 2018].	Battery: about €70/kWh by 2030 [BNEF 2020]; Fuel cell system: €58/kW by 2050 [James et al. 2018].	
Environmental bonus	Premiums until 2025 according to design in March 2022 (e.g. up to €9,000 for BEVs/FCEVs). The possible abolition of purchase premiums for PHEVs was not taken into account in the scenarios.				
Energy carrier	Price component	Values			
Fossil gasoline and fossil diesel	Energy tax	Constant extrapolation of the applicable nominal rates in March 2022 (assumption): Gasoline: €0.65/I; Diesel: €0.47/I			
	CO2 price transport	2021-2026: According to valid law Post-2026: Assumptions GHG100 scenarios (PtX, H2 and DEL): 2030: 100 €/tCO2 (REF: 80 €/tCO2) 2040: 200 €/tCO2 (REF: 100 €/tCO2) 2045: 300 €/tCO2 (REF: 200 €/tCO2).			
Electricity	Purchase price households (passenger cars)	Constant extrapolation of the average real price in 2021: approx. 32 ct/kWh [BDEW 2022b].			
	Purchase price industry (truck)	ca. 21 ct/kWh [BDEW 2022b].			
PtX fuels	Net gas station price FT gasoline / diesel	Source: BEniVer AP2 - TÖA. Production DE. Generic H2 production costs, minimum value (minimum taxes and levies on electricity) Gasoline / diesel 2026: 2.35 €/I / 2.63 €/I; 2040: 1.88 €/I / 2.11 €/I Incl. contribution margin (gasoline: 0.19 €/I; diesel 0.23 €/I).			
	Net gas station price hydrogen	BEniver TÖA cost production DE: Generic H2 prime cost, minimum value 2030: 4.74 €/kg; 2040: 3.96 €/kg; 2045: 2.34€/kg Compression, transport+coverage: 2040: 4.33 €/kg; 2045: 2.51 €/kg			
	Energy tax	0.15 €/GJ (proposal EC Energy Tax Directive [EU 2021/0213] for electricity, advanced biofuels and PtX). From 2045: 10.75 €/GJ (according to proposal minimum tax rate for fossil fuels).			



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Results



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Simulated market potential of different powertrain technologies in GER

- PtX = synthetic fuel Scenario
- Increasing uptake of battery electric vehicles (BEVs) in all scenarios mainly due to CO₂ regulations
- Plug-in-hybrid vehicles (PHEVs) as transition technology
- After 2030: up to 10% proven e-fueled passenger cars possible
- Demand for synthetic fuel vehicles exists even with 40% to 65% higher fuel prices





Simulated market potential of different powertrain technologies in GER

- DEL = scenario of direct electrification
- Faster ramp-up of BEVs compared to PtX mainly because of quicker infrastructure build-up and lower battery prices
- PHEVs get cannibalized by cheaper BEVs in 2030
- No more internal combustion vehicles allowed after 2035
- Only small market potential for fuelcell electric vehicles (FCEVs) due to high vehicle prices





Resulting passenger car vehicle stock

- Based on the modelled purchase decision, BEV vehicle stock will be at 7 to 11 million vehicles by 2030
- In the most optimistic scenario the German policy target of 15 million BEVs will be reached in 2032
- By 2045 there will still be an amount of vehicles with internal combustion engine (ICE) in the fleet





Energy demand of passenger car stock

Model assumptions:

- Slightly increasing mileage by 2024 then constant extrapolation
- Drop-in of syn. fuels from 2026 on with faster ramp-up in PtX than in H2 and DEL

Results:

- Shift of energy demand to electricity; demand for liquid fuels continuously declining
- Higher efficiency of BEVs leads to lower final energy demand
- Demand for syn. fuels in road transport peaks around 2035-2040
- Final energy demand in 2045, as well as cumulative: PtX > H2 > DEL





Annual fuel demand of all road transport sectors in Germany

- Fuel demand in 2045 is driven by the existing vehicle fleet
- In 2045: Passenger car fuel demand still between 3 to 6 million tons
- Commercial vehicles with slower decline in fuel demand [1]
- Busses, special vehicles (emergency vehicles, military, etc.) also account for a persistent demand
- In 2045: Fuel demand in aviation and maritime is up to three times higher than for road transport
- Current diesel needs of German agriculture is at 1.7 million tons (not shown as not a transport sector)
- > Current biodiesel consumption is at 2.5 million tons



[1] Özcan Deniz: Development of a scenario model for the simulation of the technology diffusion in the commercial vehicle market in Germany, 35th International Electric Vehicle Symposium and Exhibition (EVS35), Oslo, Norway, June 11-15, 2022 <u>https://elib.dlr.de/187389/1/EVS35-340138.pdf</u>



Summary and conclusion

- BEVs will play a major role in road transport in all scenarios and sectors
 → A high share of BEVs contributes to an (energy) efficient system
- Climate targets of the transport sector will be extremely challenging to achieve under the existing political and economic conditions
- Without further climate policy measures, synthetic drop-in fuels for existing vehicles with internal combustion engines would be needed to achieve climate neutrality in 2045
- If the necessary quantities of synthetic fuels cannot be provided, more measures for a comprehensive mobility shift (e.g. modal shift, demand reduction, etc.) are required
- There remains a segment for agriculture and special vehicles for which synthetic fuels may be the cheapest defossilisation option





Thank you for your attention



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Backup



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Tabelle 6-1: Annahmen CO2-Emissionsnormen für Pkw, Lnf und Snf

Assumptions CO₂ emission standards for passenger cars, Lnf and Snf

	REF	PtX	H2	DEL
Pkw	2030: -37,5 % (gemäß Verordnung EU 2019/631, in Kraft + An- nahme, dass deutsche Neuzulassungen den 2030 Grenzwert zwei Jahre früher erreichen) Post-2030: sukzessive Verschärfung der Grenzwerte auf -80 % bis 2040 (um bis 2050 THG80-Ziel zu errei- chen)	Grenzwerte wie H2 und DEL Anrechenbar- keit E-Fuels: ab 2030 mög- lich bis zu 10 % der Neu- wagenflotte	2028: Reduktion de um 55 % gegenübe schlag zur Änderur EU 2019/631 vom nahme, dass deuts gen den 2030 Gren früher erreichen) 2034: 0 g CO ₂ (gen Änderung der Vero 2019/631 vom 14. nahme, dass deuts gen den 2035 Gren her erreichen) Keine Anrechenbat	er Flottenemissionen er 2021 (gemäß Vor- ng der Verordnung 14. Juli 2021 + An- sche Neuzulassun- nzwert zwei Jahre mäß Vorschlag zur ordnung EU Juli 2021 + An- sche Neuzulassun- nzwert ein Jahr frü-
Lnf und Snf	Lnf 2030: Reduktion Flottenemissionen um -31 % (Verordnung EU 2019/631; in Kraft) Snf 2030: -30 % gegen- über 2021 (Verordnung [EU 2019/1242 2019], in Kraft) Lnf / Snf: Post-2030: sukzessive Verschär- fung der Grenzwerte, um bis 2050 THG80- Ziel zu erreichen (2040: -50 %, 2050: -80 %)	Grenzwerte wie H2 und DEL Anrechenbar- keit E-Fuels: ab 2030 unbe- schränkt mög- lich	Lnf 2030: Reduktio onen um -50 % (ge Änderung der Vero 2019/631 vom 14. Lnf 2035: 0 g CO2 schlag zur Änderur EU 2019/631 vom Snf 2030: -30% ge ordnung EU 2019/7 Snf 2035: Reduktio onen um 60 % geg 2040: 0g CO ₂ (kon Kommittent der eur EMs [ACEA 2020]) Keine Anrechenbar Neuzulassungen m	on der Flottenemissi- mäß Vorschlag zur ordnung EU Juli 2021) LNF (gemäß Vor- ng der Verordnung 14. Juli 2021) egenüber 2021 (Ver- 1242, in Kraft) on der Flottenemissi- enüber 2021 sistent mit ACEA ropäischen Lkw O- rkeit E-Fuels für nöglich



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Tabelle 6-2: Zentrale Annahmen der BEniVer-Szenarien für den Straßenverkehr

Central assumptions of the BEniVer scenarios for road traffic

	REF	PtX	H2	DEL	
E-Fuels: Beimi- schungsan- teile	Ab 2035 <1 % bis 2045 10 %	Ab 2026 1 % schneller Hoch- lauf bis 2045 (>90 %)	Ab 2026 <1 % moderater Hochlau bis 2045 >90 %	f	
E-Fuels: Spezifische CO ₂ -Emis- sionen	Die Markteinführung im Straßensektor erfolgt v.a. über die THG-Quote (und den CO ₂ -Preis Verkehr), demnach nur mit erneuerbarem Strom produzierte E-Fuels als Erfüllungsoption möglich sind, sowie insg. ca70 % CO ₂ -Re- duktion gegenüber fossilem Referenzkraftstoff eingehalten werden muss (siehe THG-Quotengesetz 2021 ¹⁶ , Entwürfe delegierte Rechtsakten Mai 2022).				
Anteil Biok- raftstoffe		2020-2050: Benzin 3,7%, Diesel 7,8%			
H2 Tank- / Ladeinfra- struktur Pkw, leichte Nutzfahr- zeuge	Ausbau des La- desäulennetz bis 2035 abgeschlos- sen; geringer Ausbau H2-Tank- stellennetz	Wie REF	Ausbau des not- wendigen Lade- säulennetz Infra- struktur bis 2030 abgeschlossen; Ausbau H2-Tank- stellennetz bis 2030 abgeschlos- sen	Ausbau des not- wendigen Lade- säulennetz Inf- rastruktur bis 2030 abge- schlossen; ge- ringer Ausbau der H2-Tank- stellen	
Pkw Tech- nologiekos- ten (€2020)	Batterie: ca. 120 €/kWh bis 2030 [Avicenne Energy 2020] Brennstoff- zellensystem: 58 €/kW bis 2050 ¹⁷	Wie REF	Batterie: ca. 120 €/kWh bis 2030 [Avicenne Energy 2020] Brennstoff- zellensystem: 58 €/kW bis 2030 [James et al. 2018]	Batterie: ca. 70 €/kWh bis 2030 [BNEF 2020] Brennstoffzel- lensystem: 58 €/kW bis 2050 [James et al. 2018]	
Umweltprä- mie	Prämien bis 2025 gemäß Ausgestaltung im März 2022 (z. B. bis zu 9.000 € für BEVs/FCEVs). Die mögliche Abschaffung der Kaufprämien für PHEVs wurde in den Szenarien nicht berücksichtigt.				
Anzahl neu zugelasse- ner Pkw	2021: 2,6 Mio. (KBA) 2022: 2,8 Mio. (VDA-Prognose) 2025: 3,1 Mio.; 2030: 3 Mio.; 2045: 2,9 Mio. gemäß BDI Klimapfade 2.0 [Burchardt et al. 2021]				



Tabelle 6-4: Annahmen für Energiepreise (in €2020, soweit nicht anders angegeben)

Assumptions for energy prices (in €2020, unless otherwise stated)

Energieträ- ger	Preisbestand- teil	Werte	
Fossiles Ben- zin und fossi- ler Diesel	Rohölpreis	Prognosen basierend auf dem Szenario "Sustainable Development", in USD2020 [IEA 2021d]: 2021: 59 USD/barrel (Marktpreis Brent) 2030: 56 USD/barrel 2045: 50 USD/barrel	
	Energiesteuer	Konstante Fortschreibung der geltenden nominalen Sätze im März 2022 (Annahme): Benzin: 0,65 €/I Diesel: 0,47 €/I	
	CO ₂ -Preis Ver- kehr	2021-2026: Gemäß gültigem Gesetz Post-2026: Annahmen THG100-Szenarien (PtX, H2 und DEL): 2030: 100 €/tCO ₂ (REF: 80 €/tCO ₂) 2040: 200 €/tCO ₂ (REF: 100 €/tCO ₂) 2045: 300 €/tCO ₂ (REF: 200 €/tCO ₂)	
Strom	Abnahmepreis Haushalte (Pkw)	Konstante Fortschreibung des durchschnittlichen realen Preises 2021: ca. 32 ct/kWh [BDEW 2022b]	
	Abnahmepreis Industrie (Lkw)	ca. 21 ct/kWh [BDEW 2022b]	
PtL	FT Benzin / Die- sel	Quelle: BEniVer AP2 – TÖA. Produktion DE. Generi- sche H2-Gestehungskosten, Minimalwert (minimale Ab- gaben und Umlagen auf Strom) Benzin / Diesel 2026: 2,35 €/l / 2,63 €/l 2040: 1,88 €/l / 2,11 €/l Inkl. Deckungsbeitrag (Benzin: 0,19 €/l; Diesel 0,23 €/l)	
	Energiesteuer	0,15 €/GJ (Vorschlag EC Energy Tax Directive [EU 2021/0213] für Strom, fortschrittliche Biokraftstoffe und PtX). Ab 2045: 10,75 €/GJ (gemäß Vorschlag Minimumsteu- ersatz für <i>fossile</i> Kraftstoffe)	
Wasserstoff	Tankstellenpreis	BEniver TÖA Kosten Produktion DE: Generische H2 Gestehungskosten, Minimalwert 2030: 4,74 €/kg 2040: 3,96 €/kg 2045: 2,34€/kg Komprimierung, Transport+Deckungsbeitrag: 2040: 4,33 €/kg 2045: 2,51 €/kg	
	Energiesteuer	0,15 €/GJ (Vorschlag EC Energy Tax Directive [EU 2021/0213]) Ab 2045: 10,75 €/GJ (gemäß Vorschlag [EU 2021/0213] Minimumsteuersatz für <i>fossile</i> Kraftstoffe)	



Assumptions of the BEniVer scenarios in terms of mileage

Tabelle 6-3: Annahmen der BEniVer Szenarien in Bezug auf die Fahrleistung

Sektor	2020	2024	2025 - 2050
Pkw	2020-2023: Tatsäch- liche Fahrleistung im Jahr 2020, d.h. 578 Mrd. km [BMDV 2022]	648 Mrd. Fahrzeug-km <mark>[iTP 2021]</mark>	Konstante Fortschreibung der Fahrleistung von 2024
Leichte bzw. schwere Nutz- fahrzeuge	Fahrleistungen 2020: 67 Mrd. km <mark>[BMDV 2022]</mark>	Leicht lineare Fort- schreibung der Fahr- leistungen ab 2020 (im Vergleich mit Ver- kehrsverflechtungs- prognose 2030)	Wie 2024, weitere Fort- schreibung
Sensitivitäts- tests	Pkw / Snf / Lnf: + 10 % Fahrleistungssteigerung bis 2030		



Li-Ion Battery Cost per kWh on pack level





Energy prices incl VAT and CO_2 price

- Diesel in 2030: 1,48 EUR/I
- Syn Diesel in 2030: 2,44 EUR/I
- Gasoline in 2030: 1,57 EUR/I
- Syn Gasoline in 2030: 2,18 EUR/I







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