Transformation pathways to greenhouse gas neutrality of gas networks and gas storages after COP 21

Modeling of cost-optimal transformation pathways for the greenhouse gas neutrality of the gas networks and gas storages within the technology paths “green/GHG-neutral” hydrogen and “green/GHG-neutral” methane

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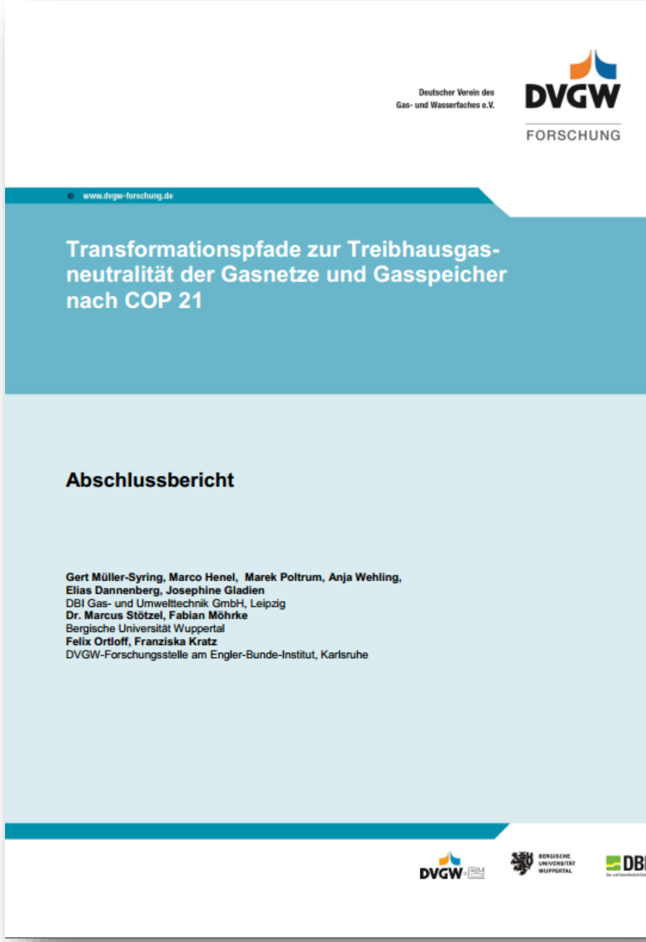
CO_2 and H_2 Technologies for the Energy Transition

28th meeting of the EU-Russia Gas Advisory Council’s Work Stream on Internal Market Issues (GAC WS2)| Brussels | 29th March 2019

AGENDA

- Motivation/project aim
- Development of the demand of RE-PtG gases in general (all sectors)
- Excursus electricity sector “Kalte Dunkelflaute”
- Transformation paths to GHG neutral gas networks and storages
  - Calculation model, terminology, scenario definition
  - Results
- Conclusions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Transformationspfade zur Treibhausgas-neutralität der Gasnetze und Gasspeicher nach COP 21

Abschlussbericht

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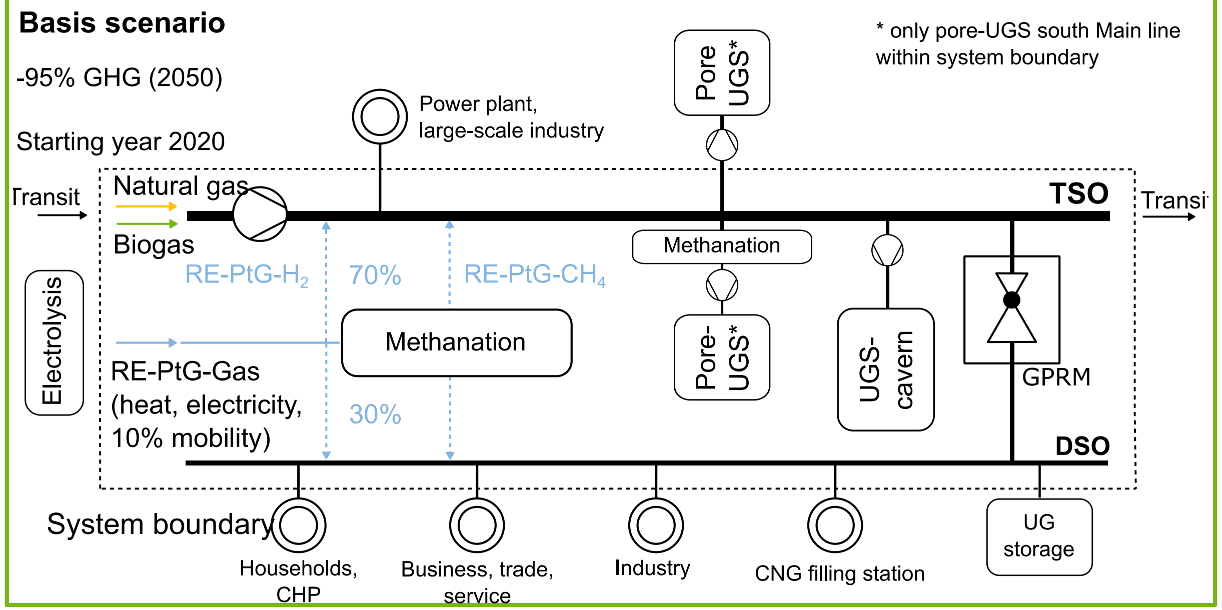
Aim

- Determination of cost-optimal **transformation paths**, including additional costs, for a transformation of **gas grids and gas storages** to GHG neutrality within the technology pathways admixture of renewable power-to-gas hydrogen (RE-PtG-H_2) and renewable methane (RE-PtG-CH_4)

System depiction



Background

- **Greenhouse gas neutrality** as a way to COP21 climate targets (limiting global warming to below 2 °C) can be supported by renewable power-to-gas (RE-PtG) gases

Focus (see System depiction)

- Statement only for gas networks and storage
- Gas use in all sectors and hydrogen production outside the system boundary

Development of the demand of RE-PtG gases

Methodology

- Literature analysis to compare relevant studies

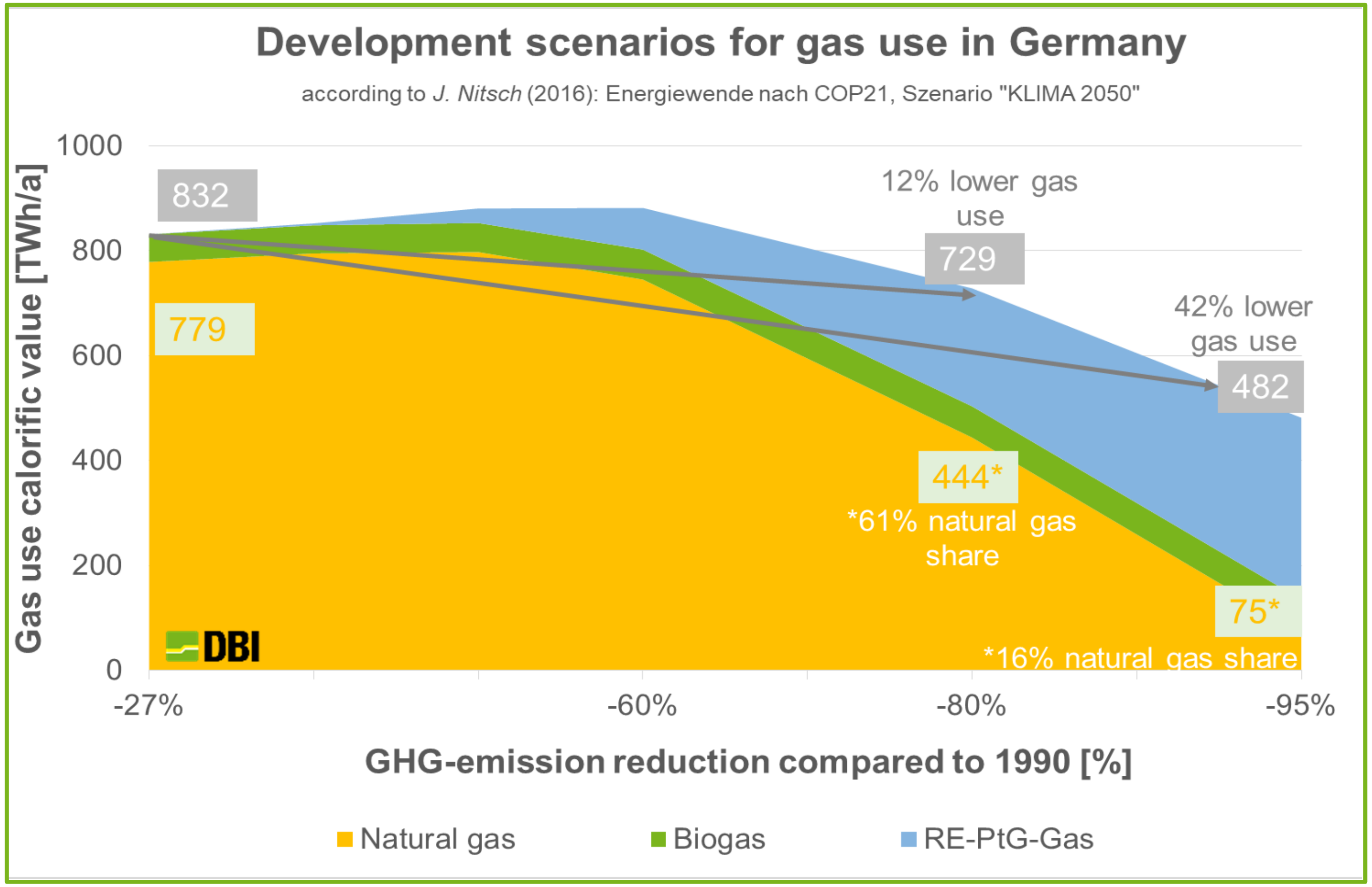
Criteria

- Selection of only **the most recent** studies (as of January 2017) post-analysis of even younger Studies revealed no added value
- **Development up to 2050** and GHG reduction to -95%
- Selection of studies which consider the development of natural gas or PtG gases; not just anticipating an “all-electric world”
- Preferably for all parameter selection of the same study, since comparability is given and the use of an average from different studies is methodically unclean (different assumptions underlying)

Studie	Jahr	Entwicklung Gase			Nutzung/ Sektoren				THG-Ziele	Zahlen-werte
		Erdgas	Biogas	EE-PtG-Gase	Strom	Wärme	Verkehr	NEV		
Klimaschutz durch Sektorkopplung (Enervis)	2017									
Wärmewende 2030 (Agora)	2017									
Erneuerbare vs. Fossile Stromsysteme (Agora)	2017									
dena-Netzflexstudie (dena)	2017									
KonStGas (BMWi)	2016									
Energiewende nach COP21 (Dr. J. Nitsch)	2016									
Klimaschutzbeitrag des Verkehrs bis 2050 (UBA)	2016									
Energieversorgung des Verkehrs (UBA)	2016									
Sektorkopplung durch die Energiewende (V. Quaschning)	2016									
Renewbility III (Öko-Institut, DLR, Ifeu, Infras)	2016									
Renewables in Transport - Kraftstoffstudie II (LBST)	2016									
Klimaschutzszenario 2050 (Öko-Institut, ISI)	2015									
MKS Kurzstudie (DLR, Ifeu, LBS, DBFZ)	2015									
CO_2-Ziele der Bundesregierung im Wärmebereich unrealistisch (pwc)	2015									
Strom- und Gasmarktdesign zur Versorgung des Straßenverkehrs mit Wasserstoff (Jülich)	2015									
Windgas-Studie (Greenpeace)	2015									
Energieeffizienzstrategie Gebäude (BMWi)	2015									
Interaktion EE-Strom, Wärme, Verkehr (IWES)	2015									
Geschäftsmodell Energiewende (Fraunhofer IWES)	2014									
Klimaschutzszenario 2050 (Öko-Institut, ISI)	2014									
Energiereferenzprognose (Prognos, EWI, GWS)	2014									
Klimafreundlicher Verkehr in Deutschland (WWF)	2014									
Treibhausgasneutrales Deutschland im Jahr 2050 (UBA)	2014									
eMobil 2050 (Öko-Institut)	2014									
Shell PKW-Szenarien bis 2040 (Shell, Prognos AG)	2014									
Agora Energiewende Speicherstudie	2014									
Treibhausgasneutraler Verkehr 2050 (Öko-Institut)	2013									
Energie- und gesamtwirtschaftliche Auswirkungen... (ZfeS)	2013									
Energiesystem Deutschland 2050 (Fraunhofer ISE)	2013									
BMU-Leitstudie 2011 (DLR, Fraunhofer, IFNE)	2011									
Systemanalyse (DVGW)	2011									

wird ausreichend betrachtet	wird teilweise/eingeschränkt betrachtet	wird unzureichend betrachtet

Development of the use of RE-PtG gases
Results & Key Messages



Note: gas demand for EE-PtG gases is not divided into EE-PtG-h2 or EE-PtG-CH4 in the underlying scenario; Allocation will be made in the context of this study

- **Fossil natural gas**
  - increased demand from the electricity sector up to 60%-GHG reduction (plus 235%)
  - Material use is at-95%-GHG responsible for the bulk of the demand for fossil natural gas
- **RE-PtG-Gas**
  - due to 95%-GHG-reduction of about
    - each 25% to the traditional sectors of heat and electricity and
    - 50% on transport
  - Ramp-up of demand begins in traffic, heat and electricity follow with a slight time delay
  - RE-PtG-Gas (electricity) contain demand for cover in "Cold Dark doldrums“ (winter times without sun and wind)
- **Biogas**
  - Demand about constant over the entire viewing period

Excursus electricity sector
“Kalte Dunkelflaute”

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Literature Analysis

- Evaluation of studies according to criteria:
  - Consideration of GHG-reduction-targets
  - Covered sectors (electricity, heat, traffic, material utilisation)
- **Selection** of the **study „Die Energiewende nach COP 21“** Author: **Dr. Joachim Nitsch / Scenario „KLIMA 2050“**
  - criteria fully (green) / partially (orange) / not (red) covered
  - Current German climate targets are taken into account

Studie	Jahr	Verbund-betrachtung	Berücksichtigung THG-Minderungziele	Betrachtung Sektoren			
				Strom	Wärme	Verkehr	NEV
Erneuerbare vs. Fossile Stromsysteme: ein Kostenvergleich (Agora Energiewende 2017)	2017						
Die Energiewende nach COP 21 - Aktuelle Szenarien der deutschen Energieversorgung (Nitsch 2016)	2016						
Sektorkopplung durch die Energiewende (Quaschning 2016)	2016						
Szenariorahmen Netzentwicklungsplan 2030 (NEP 2030), 2016	2016						
Wege zur Transformation des deutschen Energiesystems bis 2050 (Fraunhofer ISE 2015)	2015						
Speicher für die Energiewende (Agora Energiewende 2014)	2014						
Roadmap Speicher (Fraunhofer IWES 2014)	2014						
Nutzen von Smart-Grid-Konzepten unter Berücksichtigung der Power-to-Gas-Technologie (DVGW 2014)	2014						
Potenziale von Power-to-Gas Energiespeichern (Jentsch 2014)	2014						
Möglichkeiten zum Ausgleich fluktuierender Einspeisungen aus EE (BET 2013)	2013						
Energiespeicher für die Energiewende (VDE/ETG 2012)	2012						
„Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global“ (BMU-Leitstudie 2011)	2011						
Wege zur 100 % erneuerbaren Stromversorgung (SRU 2011)	2011						

Quelle: Eigene Darstellung (BUW)

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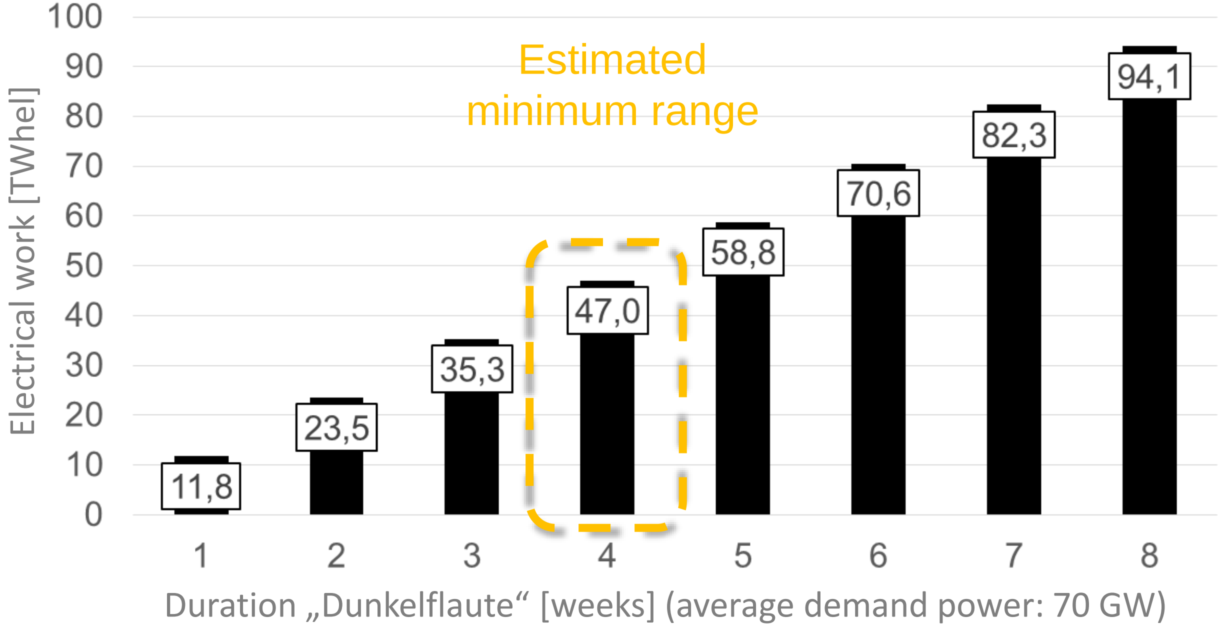
Estimation of the PtG demand for the coverage of “Dunkelflauten” in future energy systems



Required backup power from power plants

- 60-70 GW (Wind-gas-study 2015)
- 70 GW (Backup-power of power plants, BMU 2014)
- Ca. 65 GW (required. power conv. Power plants. on the 01/24/2017)
- → Chosen: **70 GW**

Required duration

- No exact limitation possible according to literature
- **Several weeks** per year (Leopoldina-study 2016, ew 2017)

Estimation

- Duration: ca. four weeks → ca. 47 TWh_{electr}
- 47 TWh_{electr} for „Dunkelflaute“ < 60 TWh_{electr} lt. study „Die Energiewende nach COP 21“ / Sz. „Klima 2050“

CALCULATION MODEL, TERMINOLOGY, SCENARIO DEFINITION

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Target calculation model

Identification of the **cost-optimal transformation path** for gas networks and storage (TSOs/UGS, DSOs) for the integration of EE-PtG gases demand within the technology pathways **admixture of "green" PtG-H_2** and **admixture of "green" PtG-CH_4**, taking into account the Climate targets up to 2050

Gas infrastructure calculation model for the integration of "green" PtG gases

Development Gas Demand	Resources Gas Infrastructure	Technology Development	Technology Paths	Boundary Conditions	Scenarios
According to Nitsch (2016): Energiewende nach COP21, Szenario "Klima 2050" For each sector	Quantity structure Age structure Useful life H_2-tolerance gas infrastructure Adjustment costs	Methanisation CO_2-sources Injection station	Admixture "green" PtG-H_2 Admixture "green" PtG-CH_4	Division PtG-feed TSO / DSO Starting year Annual steps Throughout Germany	Trend scenario Basis Scenario Sensitivities

Transformation paths GHG-neutral gas networks and storages
Calculation Model – Economic Terminology

Replacement investments:	GasNEV-regular exchange of assets at the end of their regulatory depreciation period and replacement by the most modern, available alternative in terms of hydrogen tolerance (further operation technically possible)
Extraordinary costs for H_2-feeding:	Extraordinary investment with the sole aim of prematurely increasing the hydrogen tolerance of the gas grids and reservoirs, or to build and operate hydrogen feed-in systems for the gas grid feed-in of „green“ PtG-H_2
Methanation grid:	Extraordinary costs in the construction and operation of methanization plants as well as methane feed-in systems in order to supply “green” PtG-CH4 to the grid
Methanation Pore-UGS:	Extraordinary costs in the construction and operation of methanation plants before pore-Untergrundgas store in order to methane the hydrogen content over 5 Vol.-% in the gas flow to be stored in the pore-ugs due to the unexplained hydrogen tolerance of the Underground plant. (cf. slide 32)
Cost-optimal transformation path:	**The cost-optimal transformation path means the result path of the optimization with the least additional cost.**

Extraordinary costs of hydrogen injection

Hydrogen-induced adaptation of gas networks and storage

and „green“ hydrogen-injection (CAPEX + OPEX)

\+ **Extraordinary Methanation costs** grid

CAPEX und OPEX (fix, CO_2-supply, conversion losses)

And “green” Methan-injection (CAPEX + OPEX)

\+ **Extraordinary methanation costs for the operation of pore-UGS**

CAPEX and OPEX (fix, CO_2 – supply, conversion losses)

= **Additional costs for greenhouse gas neutrality of Gas networks and storage**

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Trend scenario (Benchmark)

Which adaption path for higher hydrogen tolerances for gas networks and gas storage facilities (TSO / UGS, DSO) can be achieved by 2050, if **only replacement investments** are used and **climate targets are not taken into account**?

Basis scenario

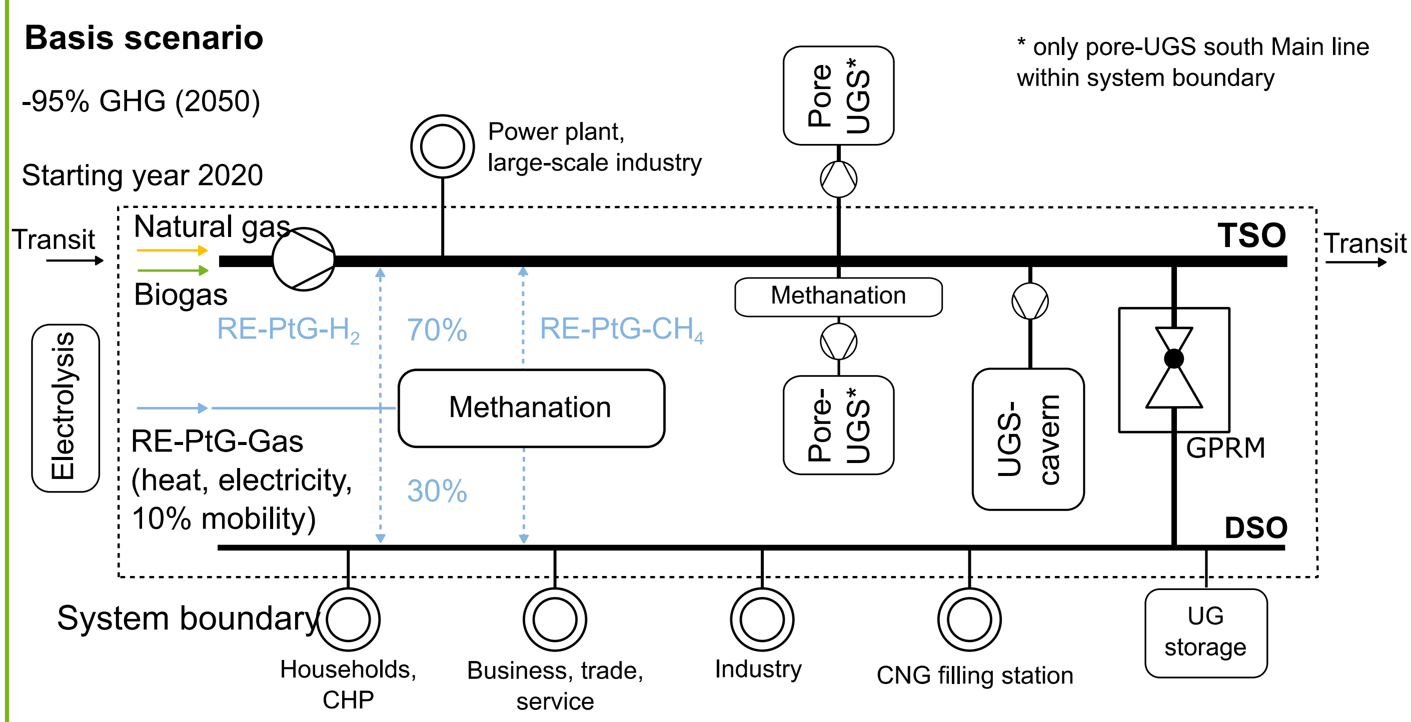
Which is the cost-optimal adaption path for gas networks and gas storage (TSO / UGS, DSO) for the integration of demanded “green” PtG gases (“green” hydrogen and “green” methane) in a realistically assumed basis scenario **considering the 2°C climate target until 2050**?

Sensitivities

How sensitive are the results of the basis scenario to selected changes of individual assumptions or boundary conditions?

Transformation paths GHG neutral gas networks and storage
Basis scenario – definition

System depiction



TSO: Transmission System Operator; DSO: Distribution System Operator
Biogas: includes not only biomethane but also mine and sewage gases

Description

- 95% GHG-Reduction by 2050
- **Inject "green" PtG-gases to 70% in TSO and to 30% DSO**
- **10% "green" PtG-gases (traffic) in the gas network**
- Porous rock UGS in South Germany included (H_2 share of the gas to be stored is methanised); in North Germany porous rock UGS will be decommis-sioned because economically not viable.
- **No limitation of the H_2-concentration specified**

RESULTS

TRANSFORMATION PATHS GHG NEUTRAL GAS NETWORKS AND STORAGE
SUMMARY – BARS – OVERVIEW

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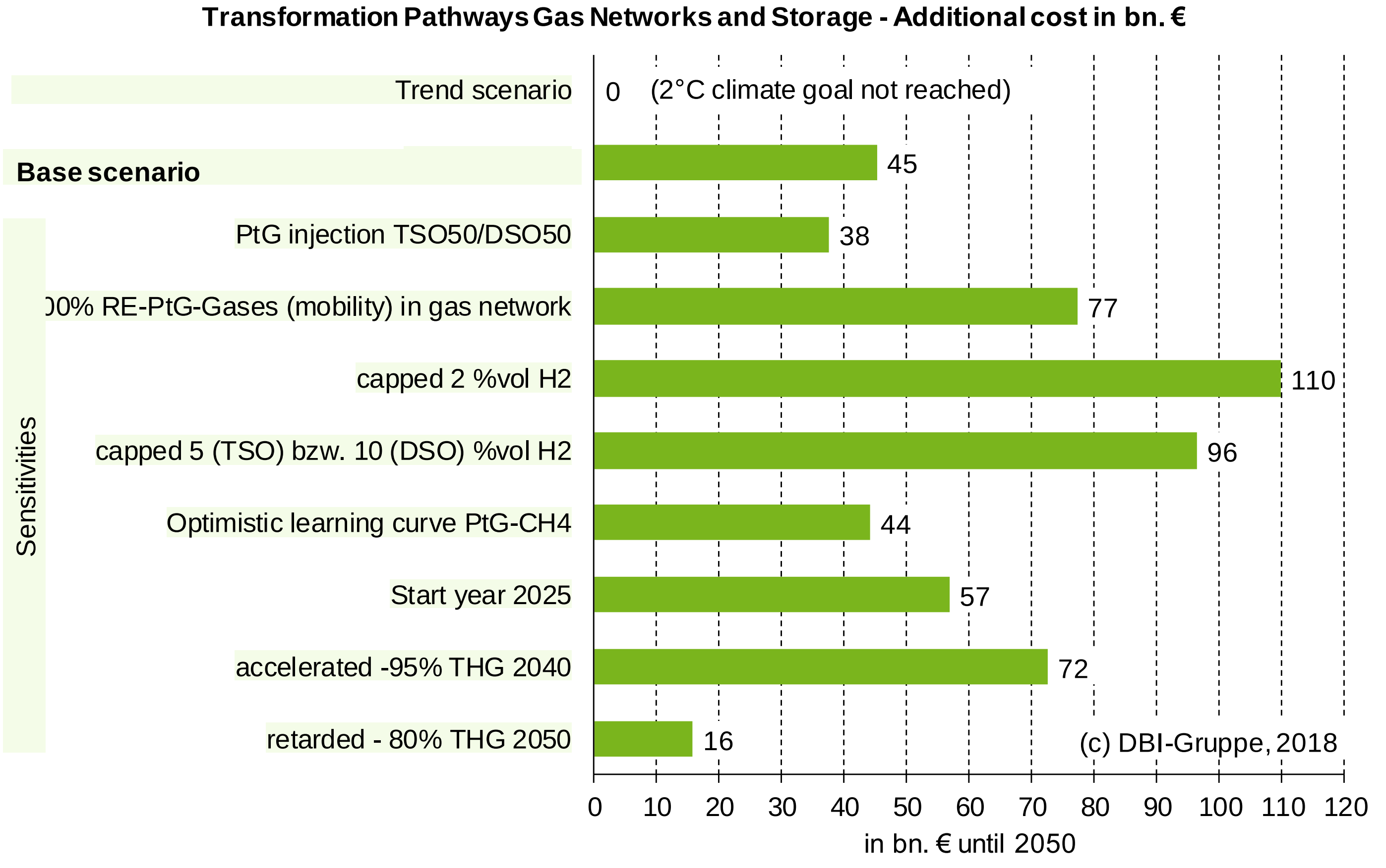
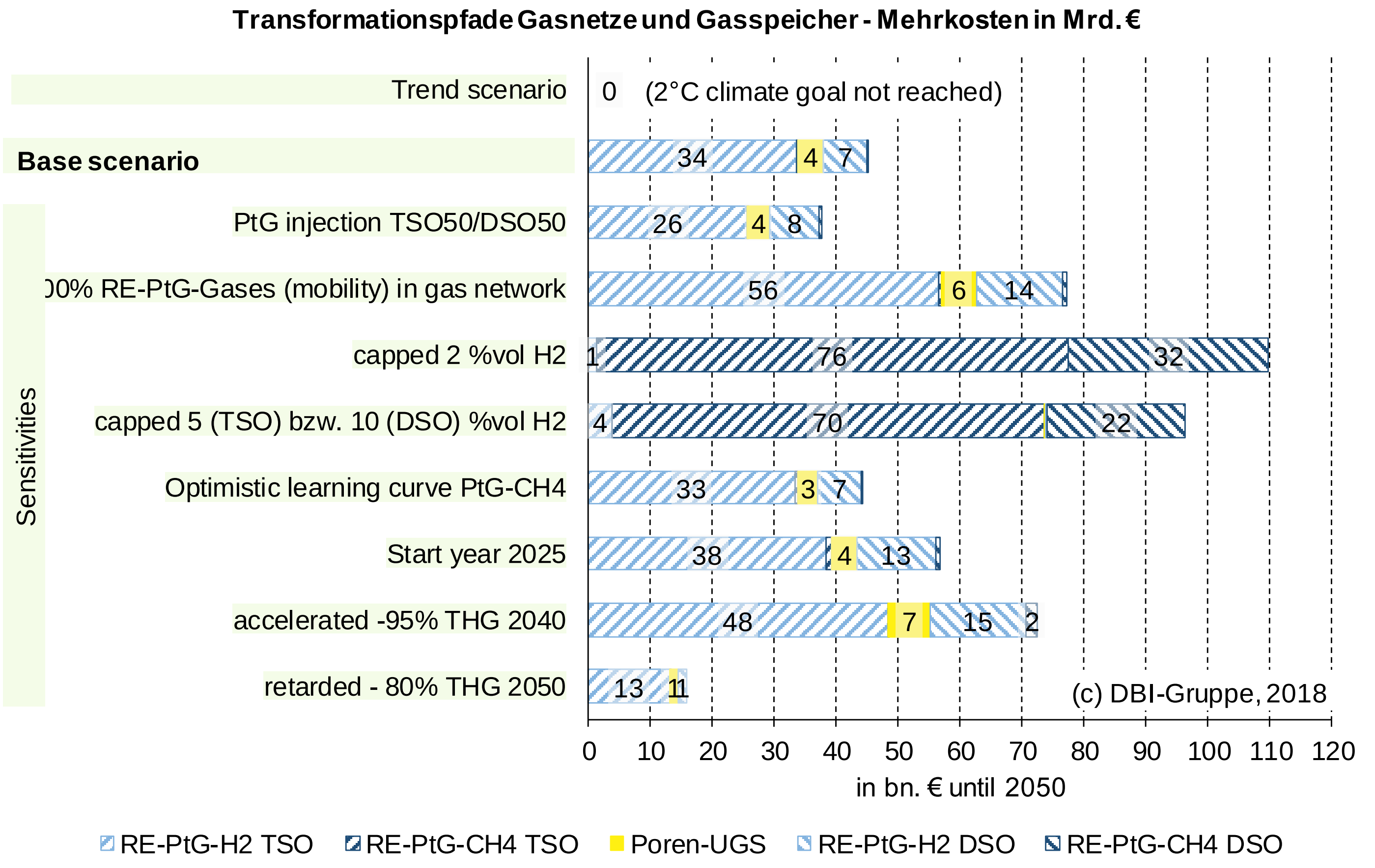


Note: scenarios definition S. Slide 10 (trend scenario), Slide 13 (base scenario) and slide 28 (sensitivities)

Key findings

- Using replacement investments (trend scenario) only, no greenhouse gas neutrality can be achieved up to 2050
- In the base scenario, additional costs amounting to € 45 bn are required (vs € 192 bn total replacement investment)
- The higher the proportion of RE-PtG gases fed at TSO/UGS level, the higher the required additional costs
- The system integration of PtG gases from the transport sector leads to absolute higher additional costs, PtG gas quantities specific additional costs are smaller
- A limitation of hydrogen injection leads to significant increases in the required additional costs in the infrastructure compared to the basic scenario
- If the transformation is started 2025, the required additional costs up to 2050 increase by about another € 12 billion

Transformation paths GHG neutral gas networks and storage
Summary – Overview



Note: "green" PtG-H2 equals extraordinary costs of Hydrogen-feed-in; "green" PtG-CH4 corresponds to methanation costs net; Pore UGS corresponds to methanation costs (for definitions, see slide 8)

Key findings

- In the basic scenario, the cost-optimized integration of the "green" PtG-gases for gas networks and gas storage takes place predominantly as hydrogen (Excluding hydrogen production and adaptation costs for gas use)
- The vast majority of the required additional costs must be made at the level of the transport networks and underground gas storage facilities
- Even with optimistic technology development of methanation, the adjusting of the gas infrastructure for higher hydrogen concentrations remains the cheaper alternative
- Limiting the hydrogen content leads to the strong use of the methanation technology path at considerable additional costs

CONCLUSIONS

CONCLUSIONS

- In order to support the 2 °C aim of the Paris climate agreement (-95% GHG compared with 1990), the gas industry should develop a strategy for the supply of GHG neutral gases in a timely and proactive manner
- Within the technology paths "green" PtG-H_2 and "green" PtG-CH_4, a sufficient integration of GHG neutral gases in the sense of the climate targets can be achieved, which is strongly supported by UGS (keeping UGS in the infrastructure is important for the energy transition – security of supply)
- For gas networks and reservoirs (excluding gas use and generation of "green" PtG-H_2), the transformation of costs is optimally achieved mainly via the admixture of "green" PtG-H_2, overall modelling is planned
- The additional costs for the infrastructure transformation amount to at least EUR 45 billion (2020-2050), with a five-year delay in the transformation leading to an increase in additional costs of about 25%
- Legislators and regulatory authorities should support the transformation through regulatory creditability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Transformationspfade zur Treibhausgas-neutralität der Gasnetze und Gasspeicher nach COP 21

Abschlussbericht

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Energie mit Zukunft.
Umwelt und Verantwortung.

THANK YOU FOR LISTENING!

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BACK UP

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Question Trend scenario

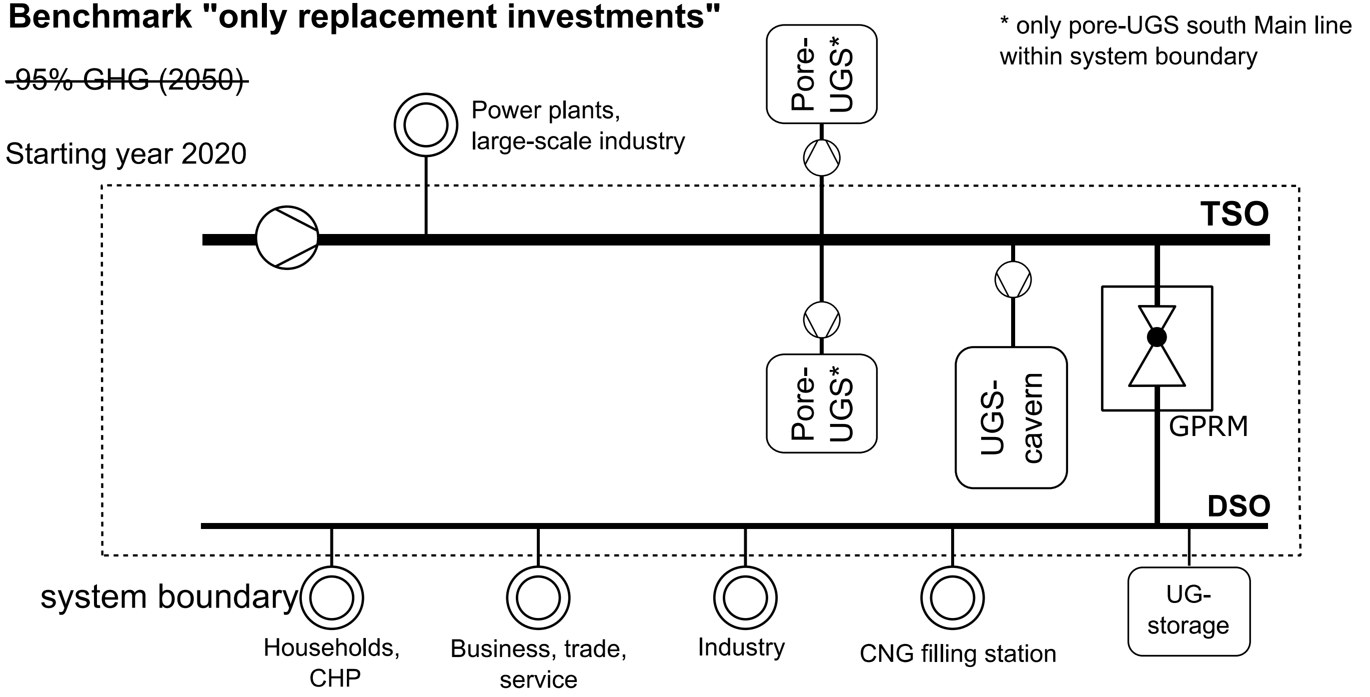
Which adaption path for higher hydrogen tolerances for gas networks and gas storage facilities (FNB / UGS, DSO) can be achieved by 2050, if only replacement investments are used and climate targets are not taken into account?

System depiction

Benchmark "only replacement investments"

~~95% GHG (2050)~~

Starting year 2020

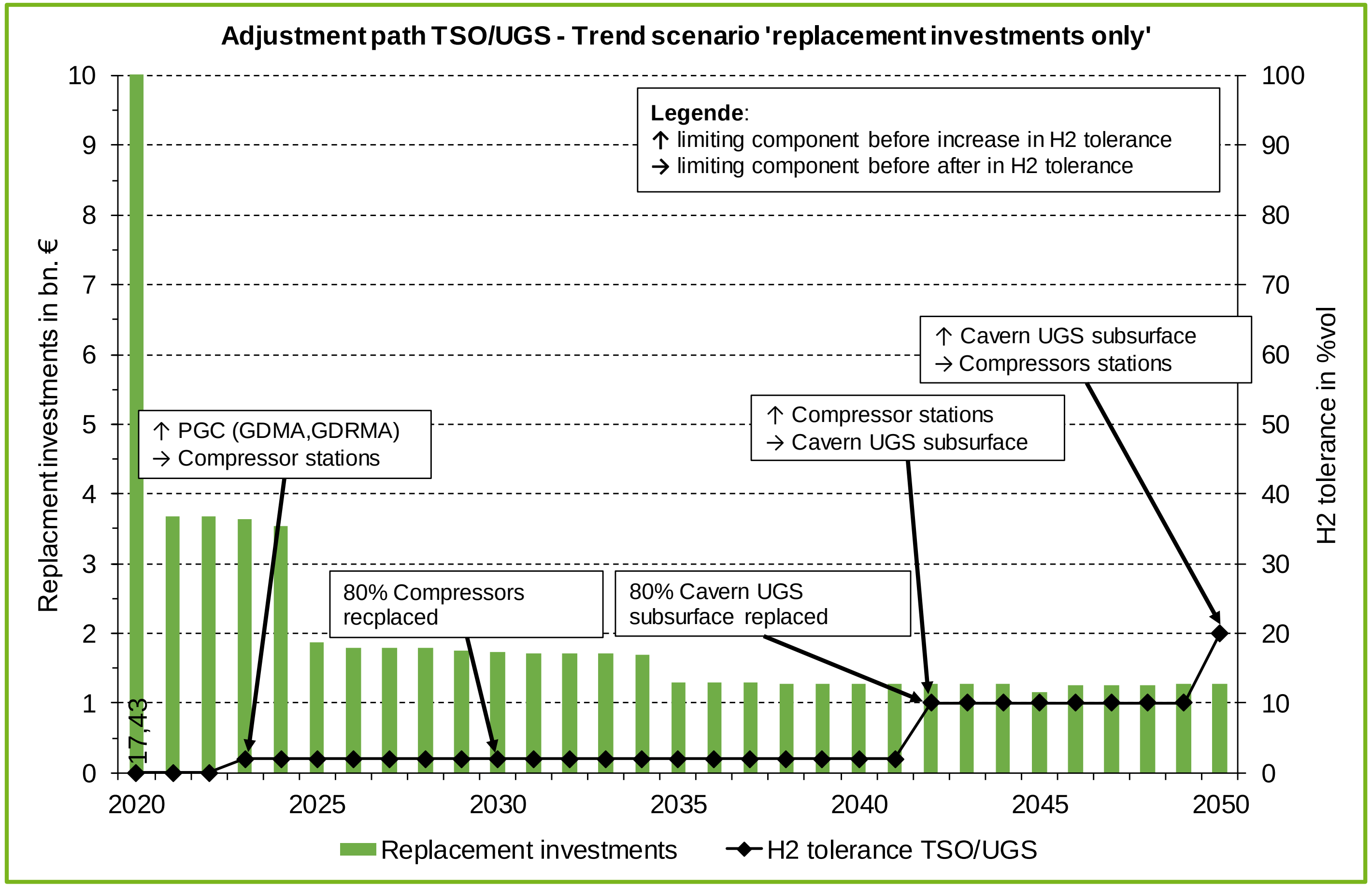


Description

- „Natural or regular exchange of elements in the natural gas infrastructure (exclusively through replacement investments)
- Assumption: When replacement investments take place, hydrogen most tolerant variant is installed at natural gas equivalent costs
- No consideration of climate targets/demand in the context of replacement investments
- No spatial-regional dissolution of the gas infrastructure within Germany
- Only pore-UGS South Main Line in operation (see slide 32)

→ Serves as a benchmark for optimized transformation paths (s.b.)

TRANSFORMATION PATHS GHG NEUTRAL GAS NETWORKS AND STORAGE
TREND-SZENARIO – RESULTS – TSO/UGS

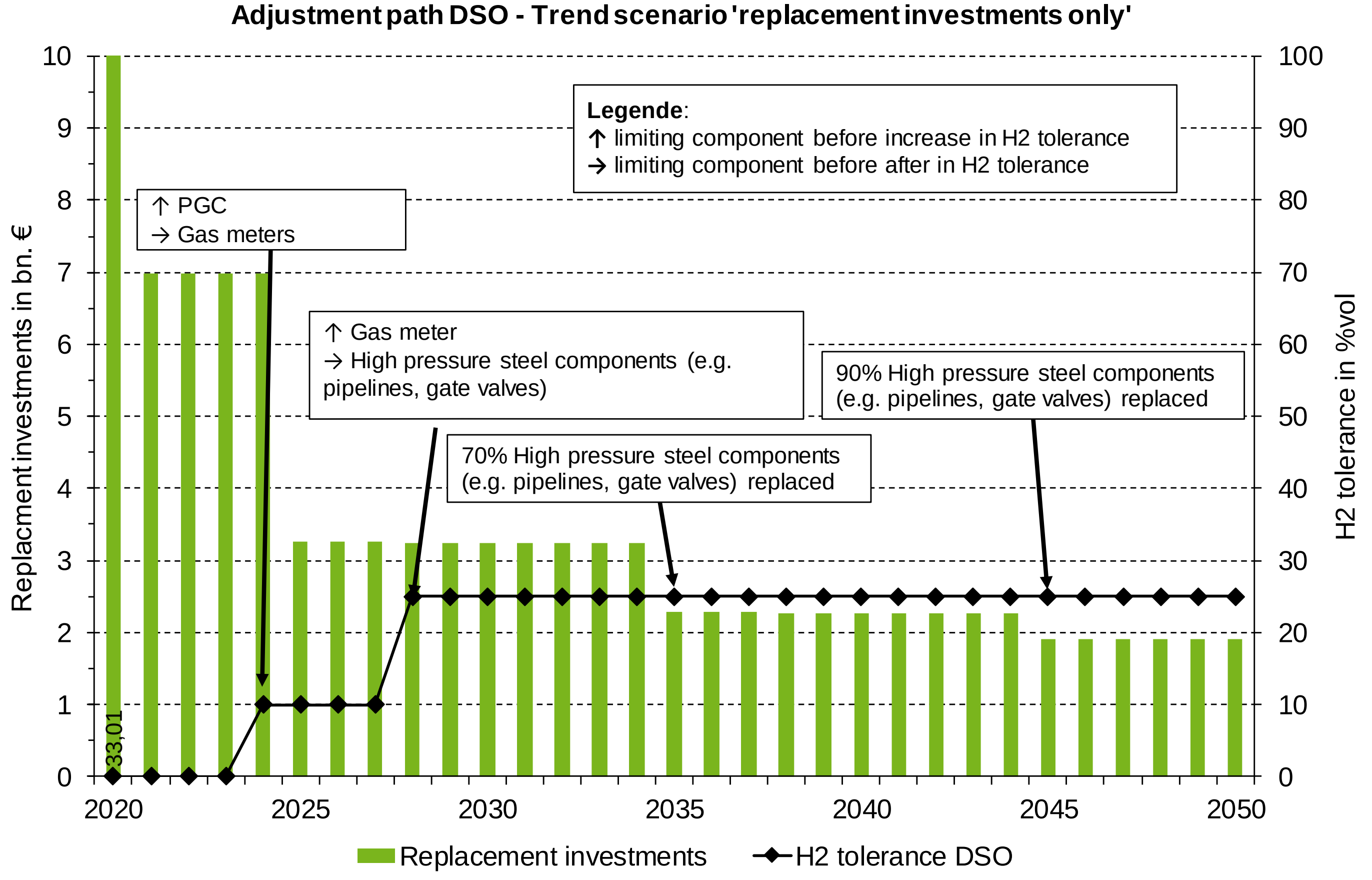


adaption path without extra costs compared to regular operations:

- **Starting year 2020:** H2 tolerance at **0 Vol.-%** (PGC, runtime 3 years)
- **from 2023** all PGC are replaced → H2-tolerance at **2 Vol.-%** (gas turbine in Compressor station transmission system + UGS, runtime 22 years)
- **from 2042** all Gas turbine drives are replaced → H2-tolerance at **10 Vol.-%** (Cavern storage, pore storage all fit)
- **from 2050** all cavern UGS are updated → **20 Vol.-%** (Compressor 2. Expansion stage)
- **Model viewing without regional resolution: In the past, large parts of the gas networks and reservoirs have a higher H2-tolerance (s. Text field chart)**

Note: In the quantity cost framework, investment-intensive elements such as pipes and compressors are deposited with an age structure. Less investment-intensive elements, such as PGCs, are oriented towards the average age of infrastructure; In the model, prior to 2020, regulatory depreciation of assets still in operation are exchanged in the first year of 2020

Transformation paths GHG neutral gas networks and storage
Trend-Szenario – Results – DSO



adaption path without extra costs compared to regular operations:

- **Starting year 2020:** H2-tolerance at **0 Vol.-%** (PGC, runtime 3 Jahre)
- **from 2023** all PGC are replaced
  → H2-tolerance at **10 Vol.-%** (V: GDRMA, GZ, MU)
- **from 2028** all GDRMA are replaced
  → H2-tolerance at **25 Vol.-%** (a.o. steel-pipelines >16bar)
- Continuously up to 2050

→ **Early increase to 10 or 25 Vol.-% h2 tolerance can be achieved in the distribution network for total Germany without extra cost**

→ **Model viewing without regional resolution: In the past, large parts of the gas networks and reservoirs have a higher H2-tolerance**

Note: In the quantity cost framework, investment-intensive elements such as pipes and compressors are deposited with an age structure. Less investment-intensive elements, such as PGCs, are oriented towards the average age of infrastructure; In the model, prior to 2020, regulatory depreciation of assets still in operation are exchanged in the first year of 2020

TRANSFORMATION PATHS GHG NEUTRAL GAS NETWORKS AND STORAGE
BASE-SZENARIO – RESULTS – TSO/UGS

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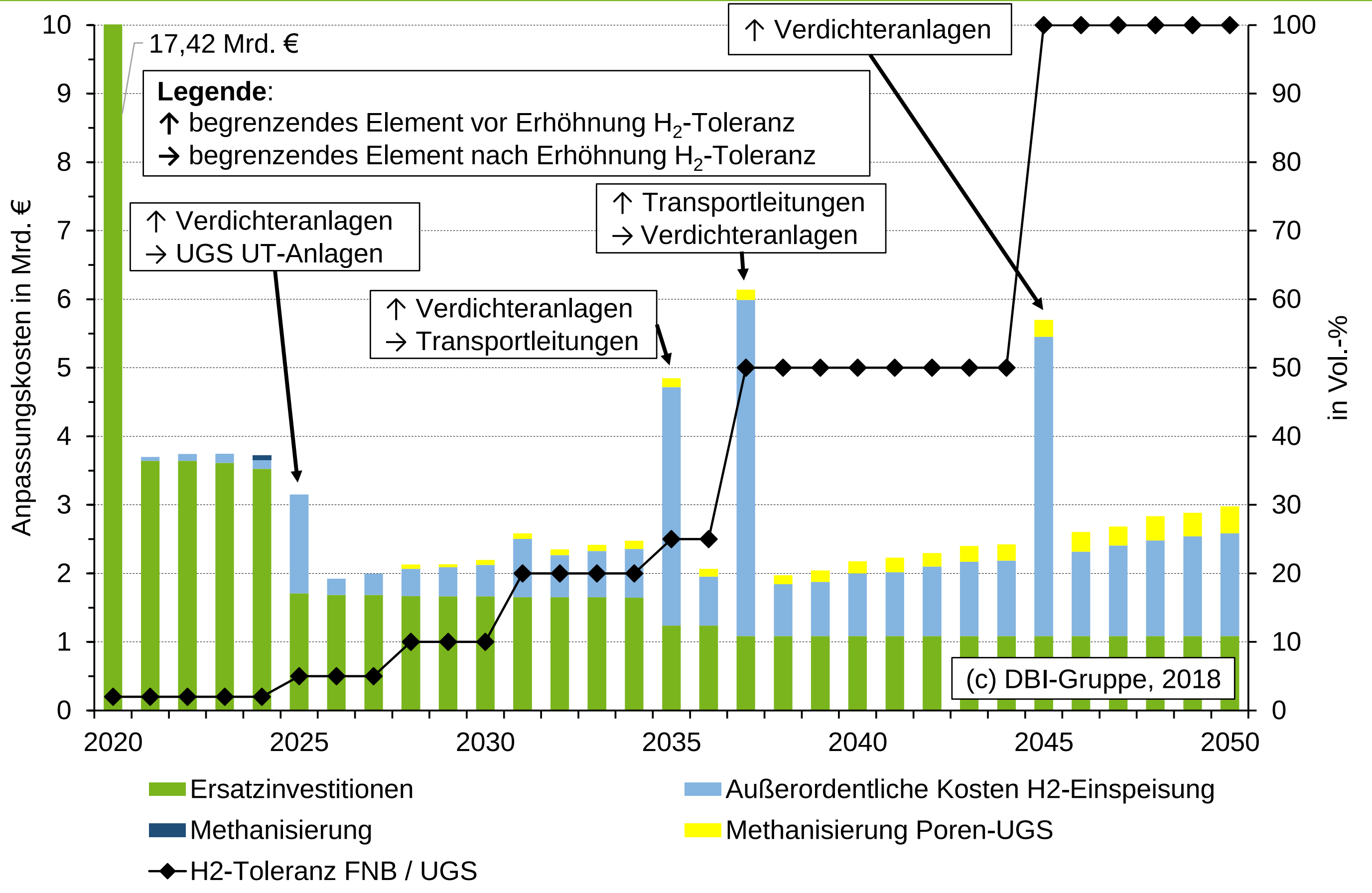
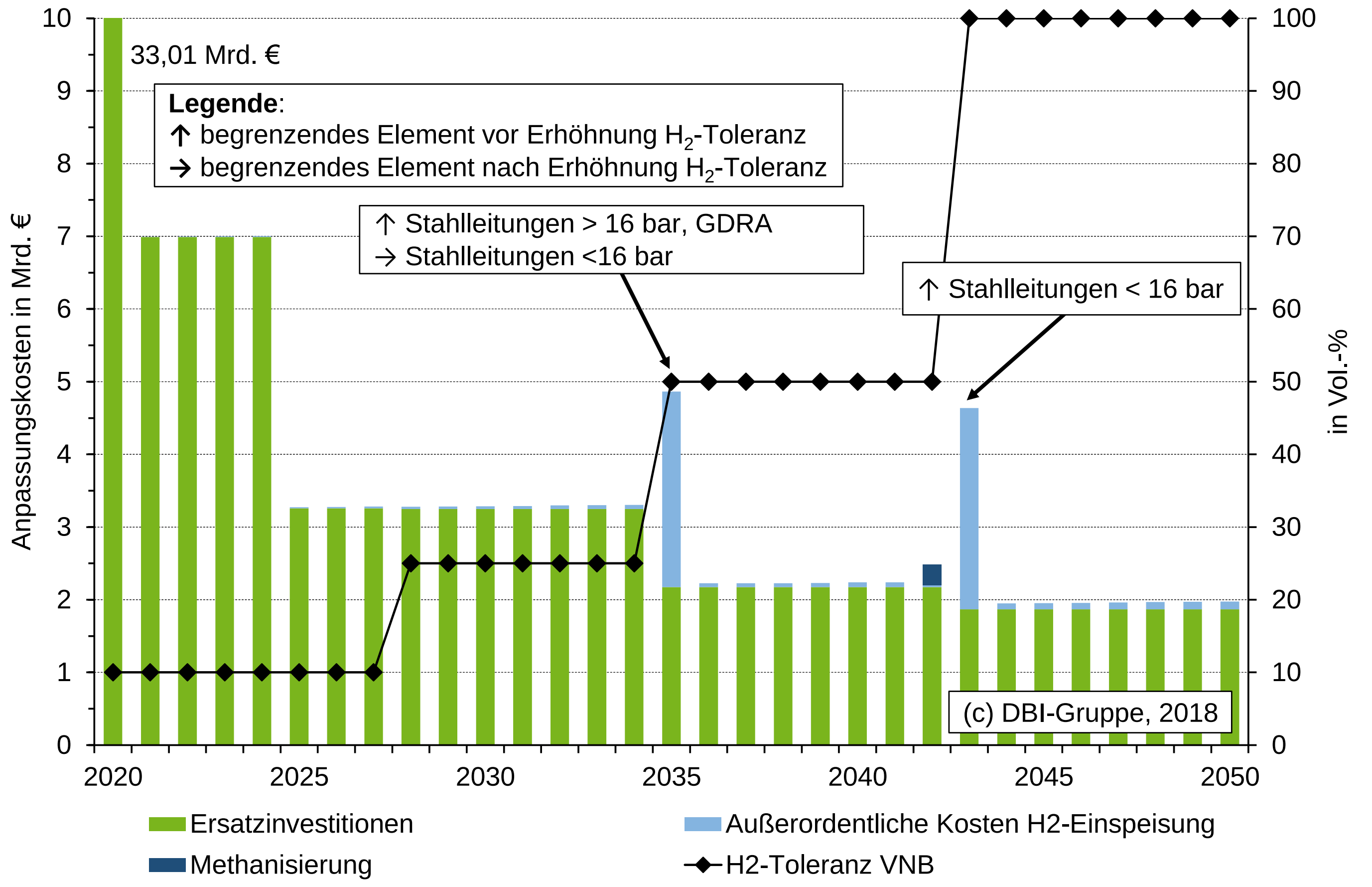


- In addition to replacement investments, the TSO / UGS infrastructure requires special measures to integrate the "green" PtG-gases
  - There, only the technology path "green" PtG-H_2 is used
- The H_2-tolerance of the network level jumps several times because of the use of extraordinary investments of the H2 supply
  - 2025: from 2 to 5 Vol.-%
  - 2035: from 20 to 25 Vol.-%
  - 2037: from 25 to 50 Vol.-%
  - 2045: from 50 to 100 Vol.-%

Replacement investments:	Replacement of a line, machine or system at the end of its regulatory depreciation periodAußerordentliche Investitionen H2-Einspeisung:
Extraordinary investments H2 feed-in:	Extraordinary investment with the sole aim of raising the hydrogen infrastructure's hydrogen tolerance at an early stage
Note:	The model exchanges assets that are being written off before 2020 and are still in operation in the start of 2020

Transformation paths GHG neutral gas networks and storage
Base-Szenario – Results –DSO



- The DSO level can often recieve the FNB incoming gas mixture without any special measures
- Exceptions are the years 2035, 2042 & 2043, in which special measures become necessary
  - Mainly the technology path “green” PtG-H_2 is used(2035 & 2043)
  - The technology path „green“ PtG-CH_4 is used in 2042
- Already in the starting year the jump from 0 to 10 Vol .-% takes place by exchange of all PGC over extraordinary investments of the H_2-feed-in (10 million €).

Replacement investments:	Replacement of a line, machine or system at the end of its regulatory depreciation periodAußerordentliche Investitionen H2-Einspeisung:
Extraordinary investments H2 feed-in:	Extraordinary investment with the sole aim of raising the hydrogen infrastructure's hydrogen tolerance at an early stage
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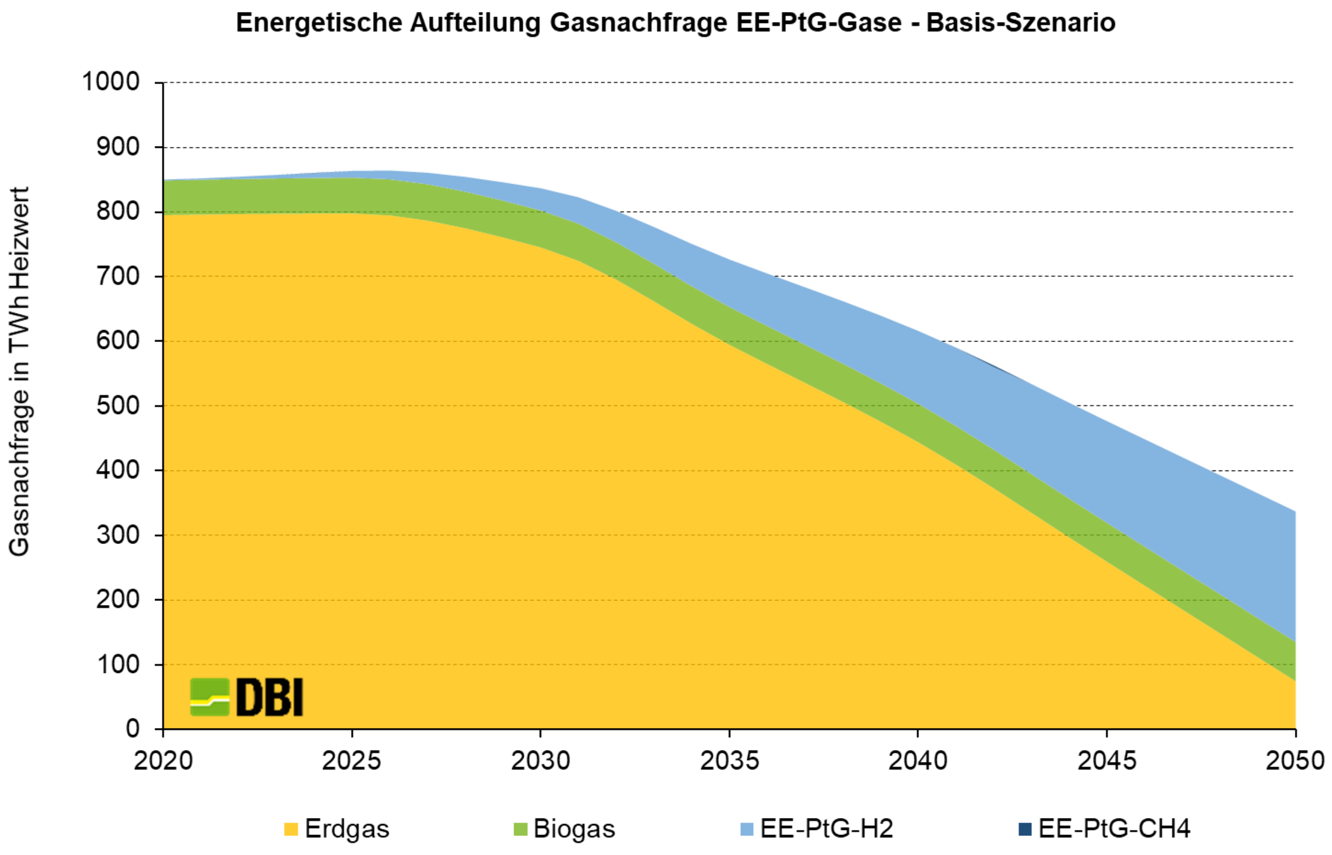
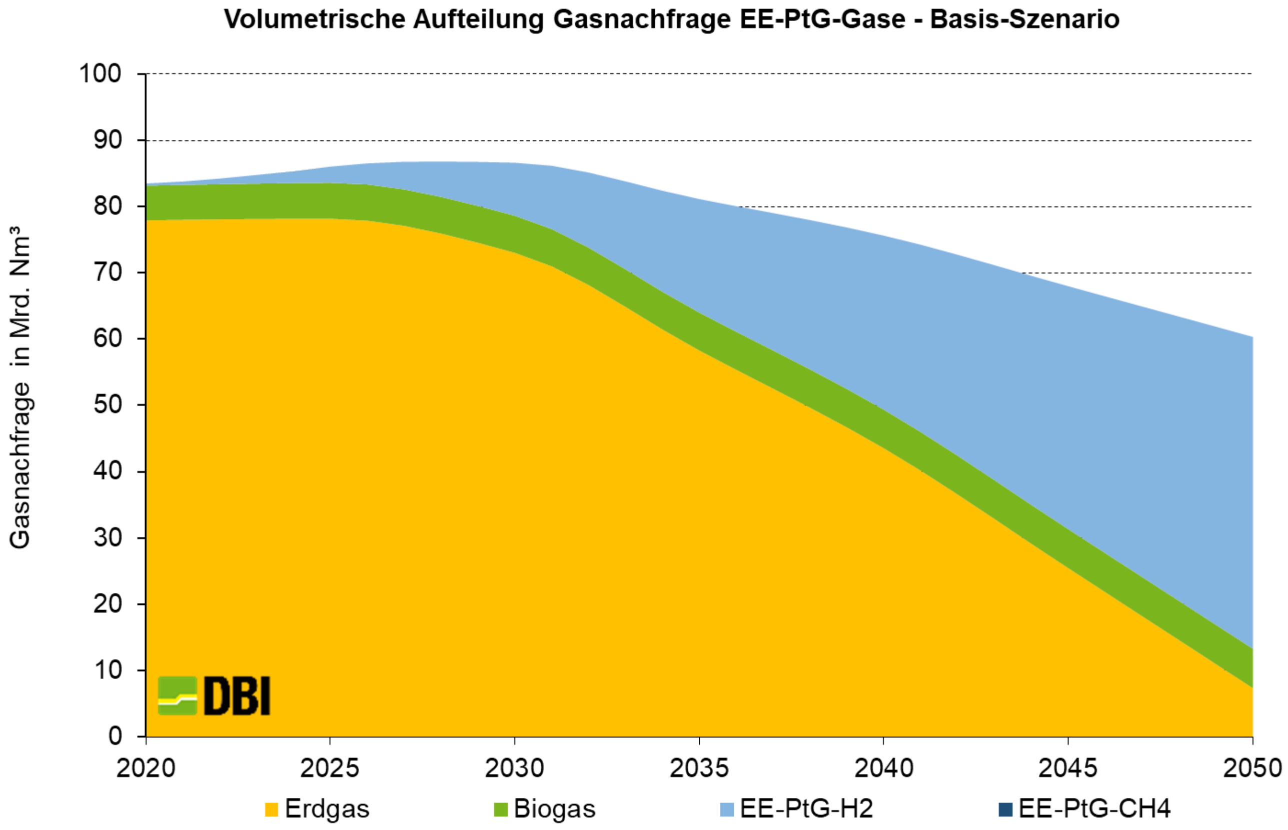
Transformationspfade THG-Neutralität Gasnetze und Gasspeicher
Basis-Szenario – Ergebnisse



Biogas: umfasst neben Biomethan auch Gruben- und Klärgase

- Ein nennenswerter Hochlauf der PtG-Gase findet erst ab 2025 statt
- Alle EE-PtG-Gase werden im kostenoptimalen Pfad als Wasserstoff (EE-PtG-H_2) integriert

Transformationspfade THG-Neutralität Gasnetze und Gasspeicher
Basis-Szenario – Ergebnisse



Biogas: umfasst neben Biomethan auch Gruben- und Klärgase

- Alle EE-PtG-Gase werden im kostenoptimalen Pfad als Wasserstoff (EE-PtG-H_2) integriert
- Volumetrisch ergibt sich dadurch zunächst eine bis etwa 2030 (ca. 85 Mrd. Nm³/a) leicht steigende transportierte Gasmenge
- Anschließend geht das transportierte Gasvolumen bis 2050 auf etwa 60 Mrd. Nm³/a zurück

Transformationspfade THG-Neutralität Gasnetze und Gasspeicher
Basis-Szenario – Ergebnisse

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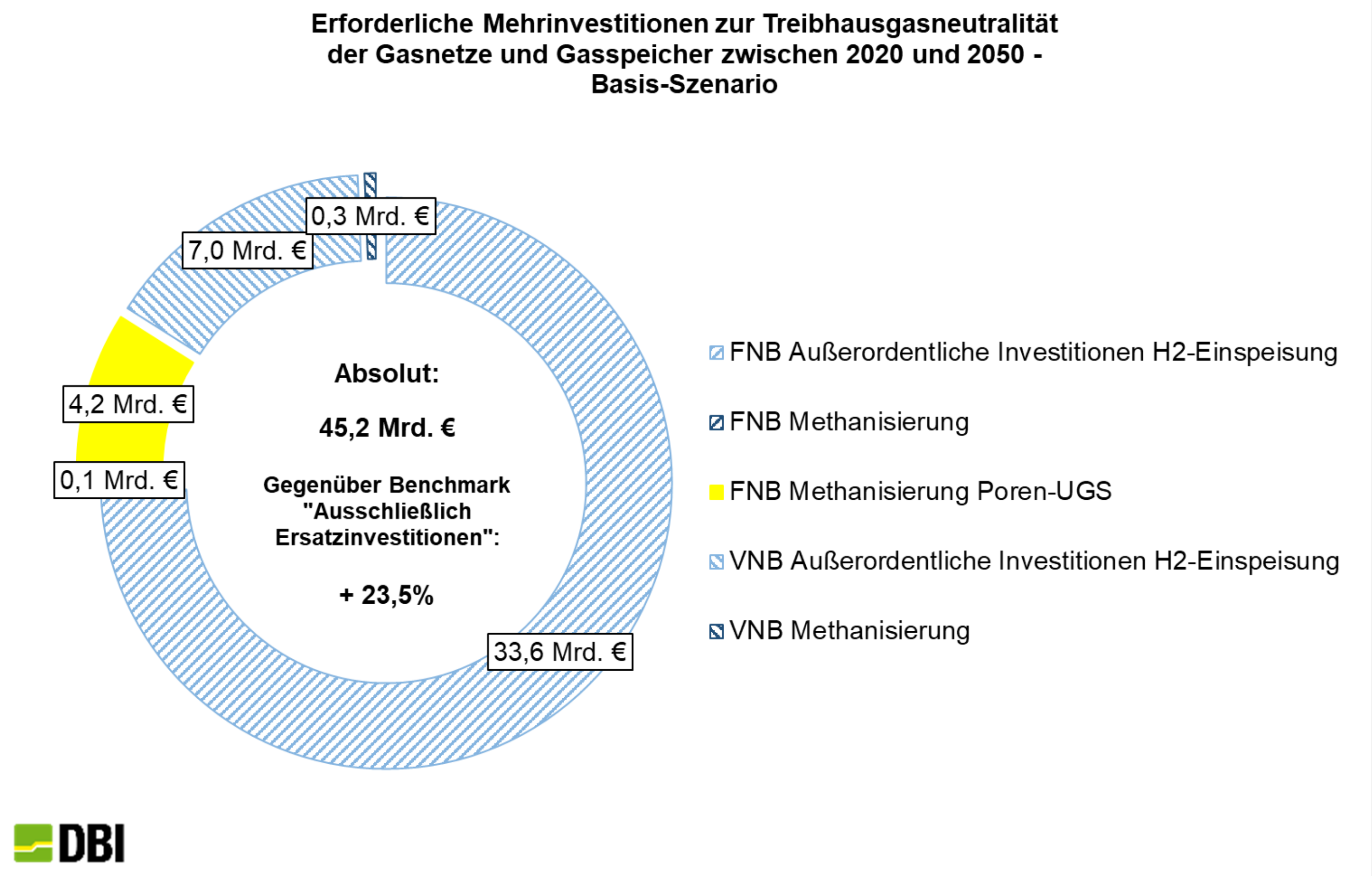

- Die Integration der EE-PtG-Gase erfordert seitens der Gasnetze und Gasspeicher **Mehrinvestitionen von 45,2 Mrd. €** zwischen 2020 und 2050
- Die Mehrinvestitionen entfallen vor allem auf den Technologiepfad EE-PtG-H_2 durch Außerordentliche Investitionen der H_2-Einspeisung
- Diese werden vornehmlich auf FNB/UGS-Ebene fällig

Mehrinvestitionen:	Summe aller Investitionen, die über Ersatzinvestitionen hinaus erforderlich sind, zur Integration der EE-PtG-Gase
Ersatzinvestitionen:	Austausch einer Leitung, Maschine oder Anlage am Ende ihrer Abschreibungsdauer
Außerordentliche Investitionen H2-Einspeisung:	Außerordentliche Investition mit dem alleinigen Ziel die Wasserstofftoleranz der Gasinfrastruktur frühzeitig zu erhöhen

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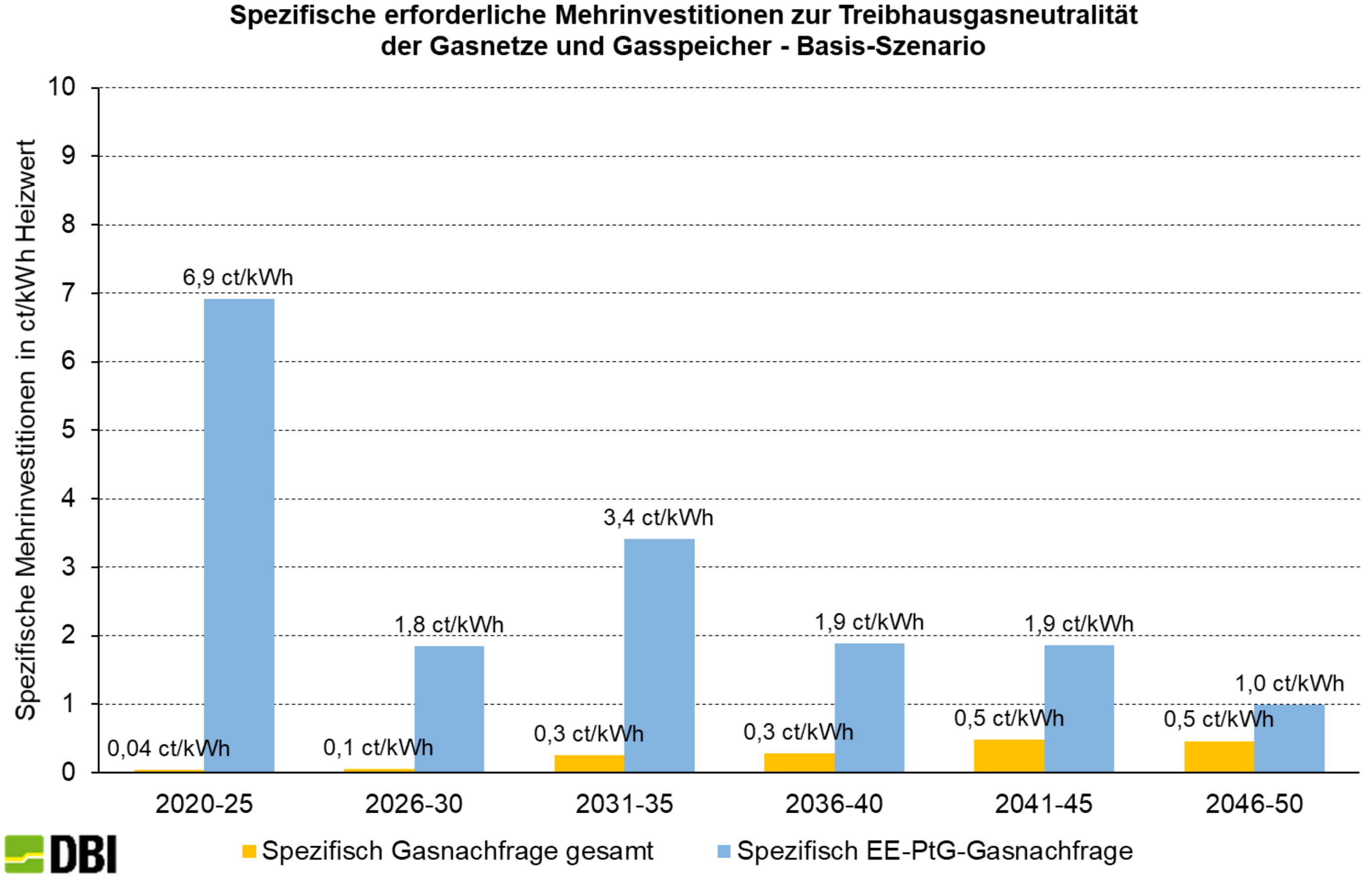
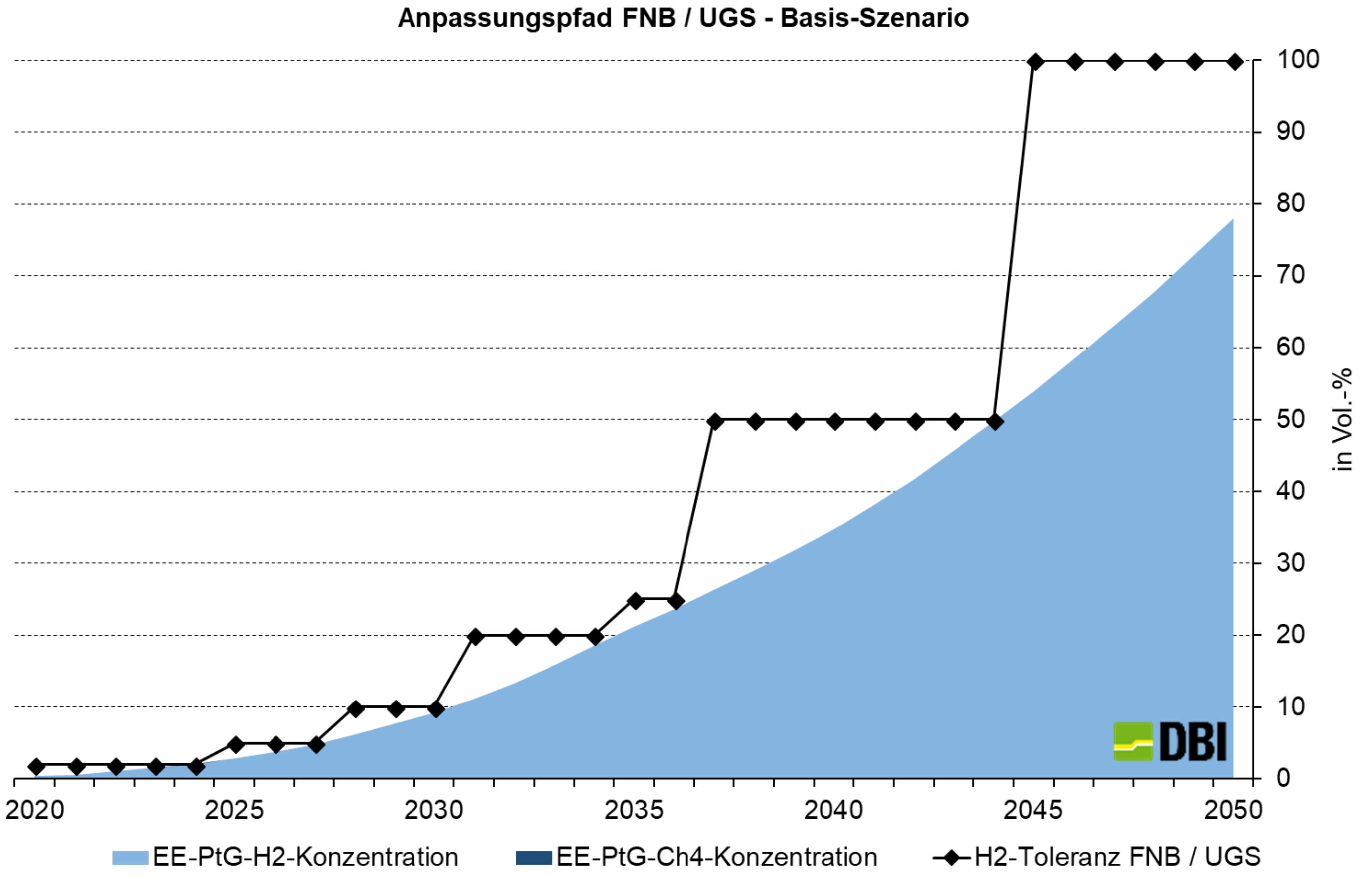


- In der Darstellung links werden die erforderlichen Mehrinvestitionen jeweils für Fünfjahres-Zeitfenster als auf eine Gasnachfrage bezogene Größe abgetragen
- Bezogen auf die **gesamte Gasnachfrage** (orange) zeigt sich, dass die Mehrinvestitionen jeweils 0,5 ct/kWh nicht übersteigen
- Bezogen auf die EE-PtG-Gasnachfrage ergeben sich spezifische Mehrinvestitionen zwischen knapp 7 (2020-25) und 1 ct/kWh (2046-50)

Mehrinvestitionen: Summe aller Investitionen, die über Ersatzinvestitionen hinaus erforderlich sind, zur Integration der EE-PtG-Gase

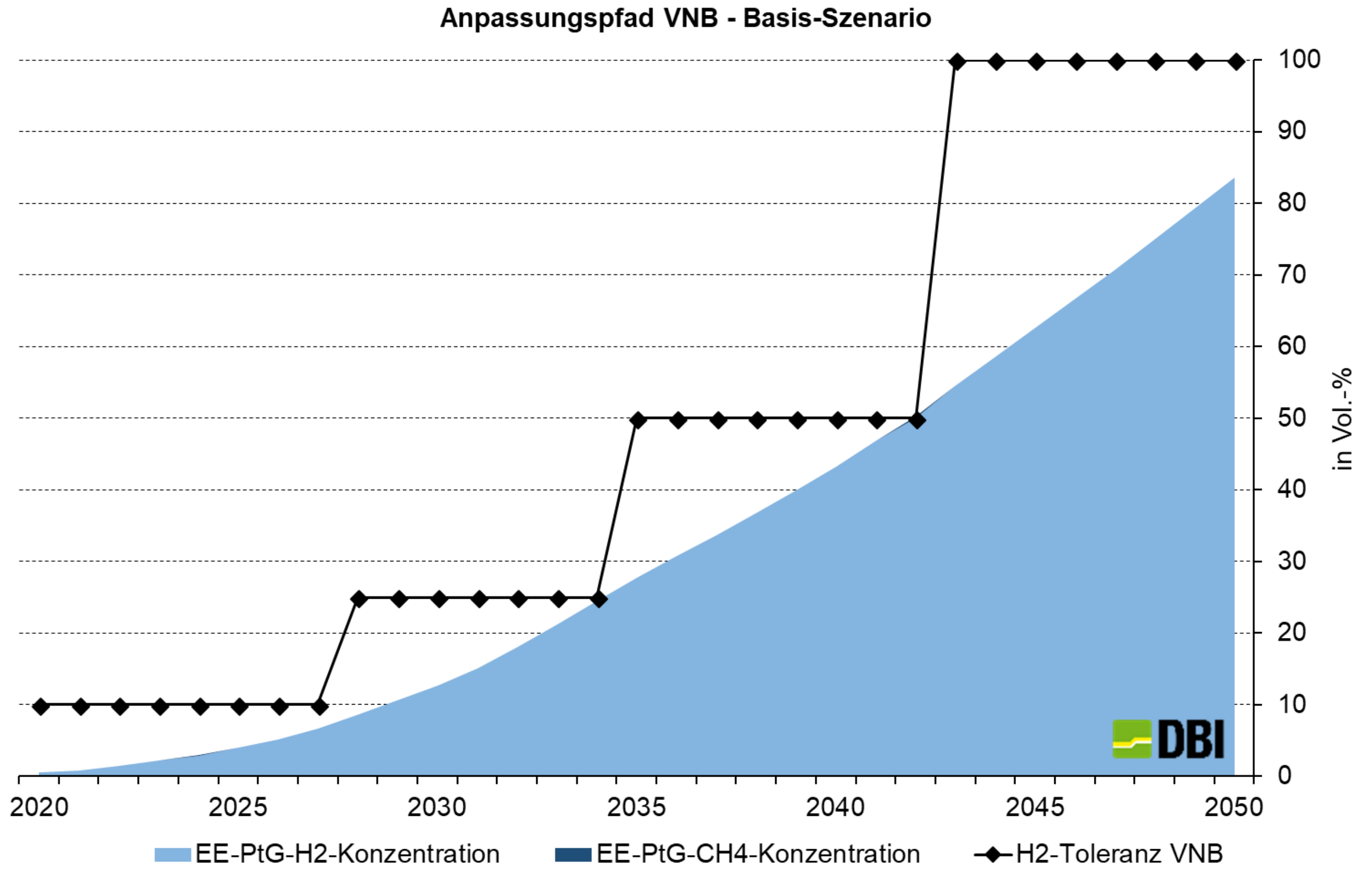
TRANSFORMATIONSPFADE THG-NEUTRALITÄT GASNETZE UND GASSPEICHER
BASIS-SZENARIO – ERGEBNISSE



Annahme: Gasinfrastruktur als „Ideal gerührter Behälter“ (vgl. Kupferplatte Stromsystem)

- Die FNB/UGS-Ebene nimmt die nachgefragten EE-PtG-Gase ausschließlich als Wasserstoff (EE-PtG-H_2) auf

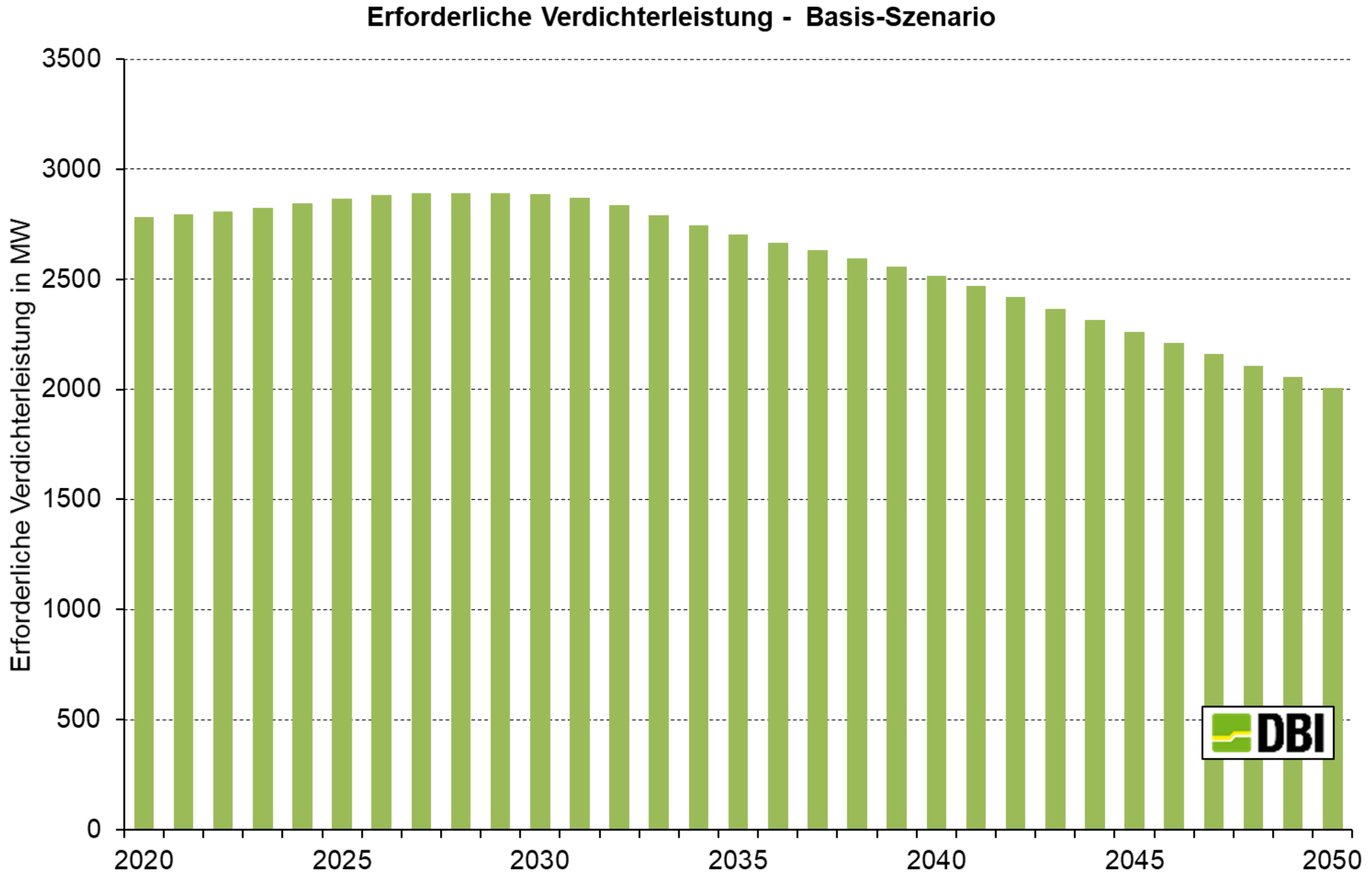
TRANSFORMATIONSPFADE THG-NEUTRALITÄT GASNETZE UND GASSPEICHER
BASIS-SZENARIO – ERGEBNISSE



Annahme: Gasinfrastruktur als „Ideal gerührter Behälter“ (vgl. Kupferplatte Stromsystem)

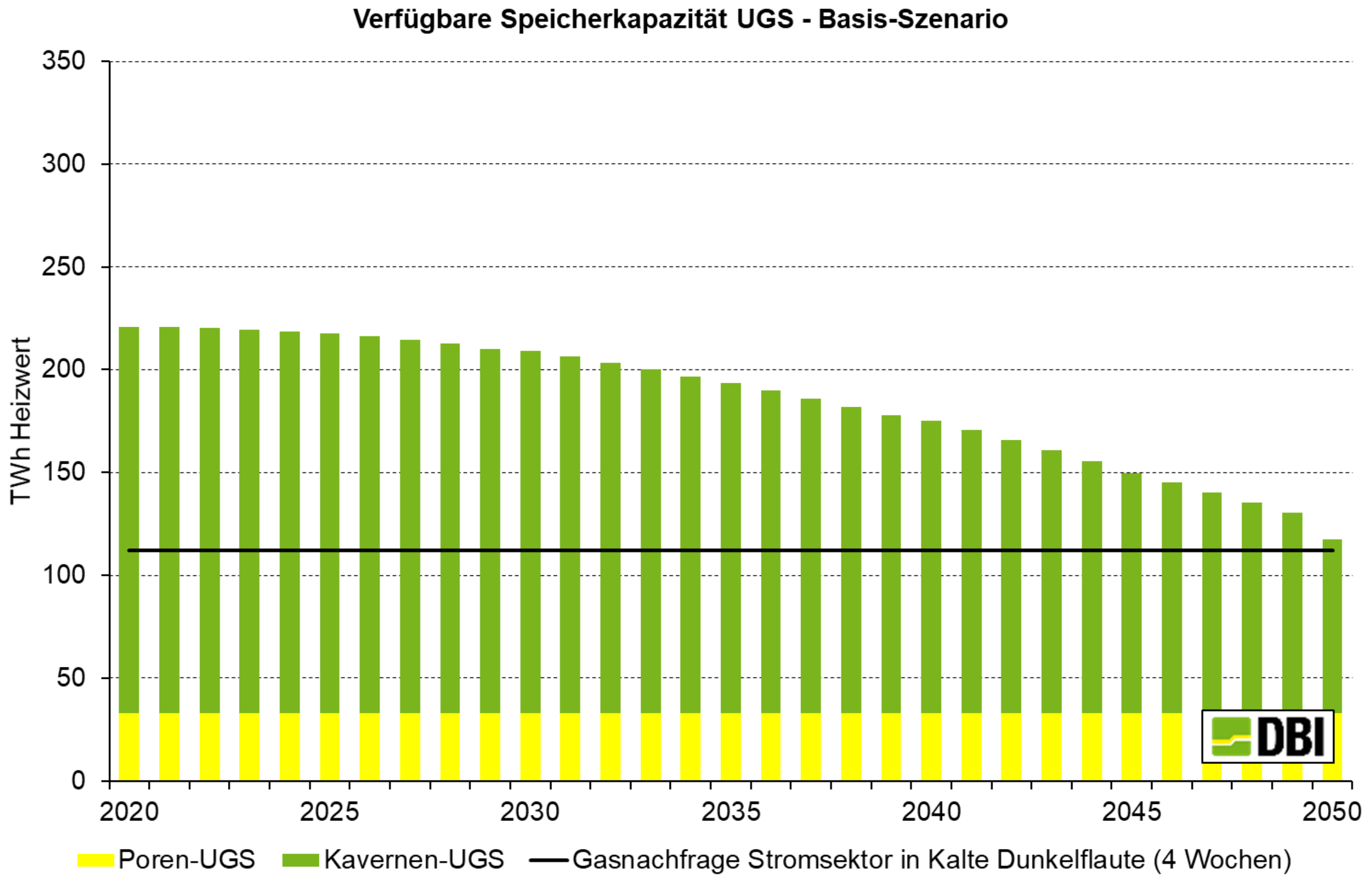
- Die VNB-Ebene nimmt die nachgefragten EE-PtG-Gase nahezu ausschließlich als Wasserstoff (EE-PtG-H_2) auf
- Allein am Schnittpunkt zwischen schwarzer H2-Toleranz-Kurve und blauer H2-Konzentration-Fläche wird geringfügig der Technologiepfad EE-PtG-CH_4 genutzt

TRANSFORMATIONSPFADE THG-NEUTRALITÄT GASNETZE UND GASSPEICHER
BASIS-SZENARIO – ERGEBNISSE



- Bei der erforderlichen Verdichter-Leistung überlagern sich mehrere Effekte
  - Geringere Dichte von H2
  - Höherer spezifischer Verdichtungsaufwand
  - Zurückgehende Gasnachfrage

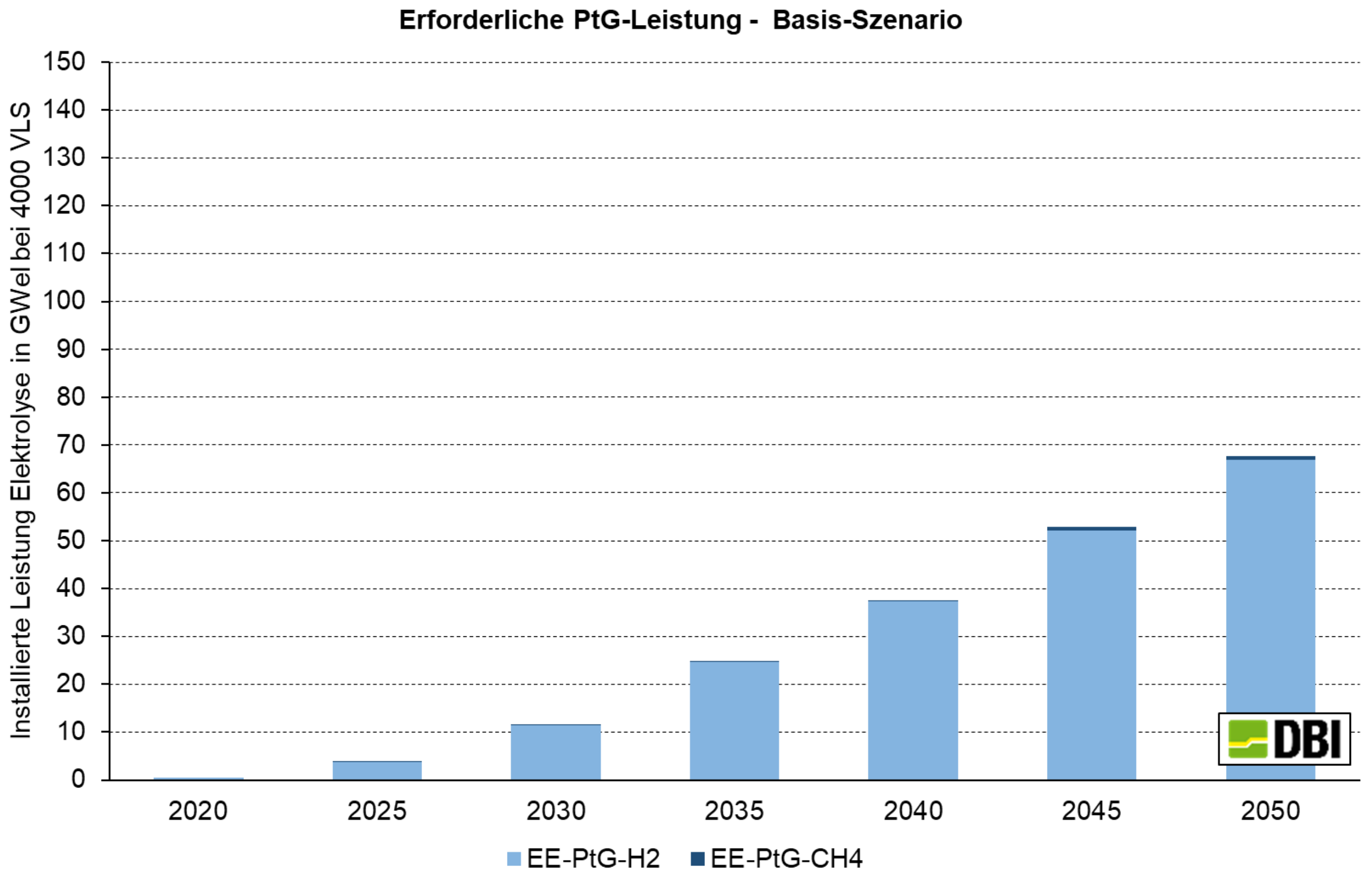
Transformationspfade THG-Neutralität Gasnetze und Gasspeicher
Basis-Szenario – Ergebnisse



- Die Speicherkapazität der Kavernen-UGS nimmt mit zunehmendem H_2-Anteil im Gasgemisch ab
- Die Speicherkapazität der Poren-UGS bleibt unverändert durch die Methanisierung des H_2-Anteils im einzuspeichernden Gasgemisch
- Die in einer „Kalten Dunkelflaute“ stromsystemseitig benötigte $\text{Energiemenge}_{\text{Heizwert}}$ kann zu jedem Zeitpunkt eingespeichert werden

Annahme: Speicherkapazitäten und Betriebsweisen sowie stromsystemseitige Anforderung bei „Kalten Dunkelflauten“ gleichbleibend bis 2050; es werden ausschließlich Poren-UGS südlich der Main-Linie berücksichtigt

Transformationspfade THG-Neutralität Gasnetze und Gasspeicher
Basis-Szenario – Ergebnisse



Annahme: 4000 Volllaststunden/a

- Für die nachgefragten EE-PtG-Gase ist 2050 eine Installation von knapp 70 GW Elektrolyse-Leistung erforderlich (bei 4000 Volllaststunden)
- Diese werden nahezu ausschließlich zur Bereitstellung von Wasserstoff zur direkten Beimischung genutzt

TRANSFORMATIONSPFADE THG-NEUTRALITÄT GASNETZE UND GASSPEICHER
ZUSAMMENFASSUNG – TABELLARISCH – H_2-TOLERANZ

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		Gesamt 2050			Mehrkosten 2050						
					FNB/UGS			VNB		Gesamt	
		Erforderliche PtG-Leistung	Verfügbare Speicherkapazität	Ersatz-investititonen	EE-PtG-H_2	EE-PtG-CH_4	Poren-UGS	EE-PtG-H_2	EE-PtG-CH_4		
		GW_{el}	$TWh_{Heizwert}$	Mrd. €	Mrd. €	Mrd. €	Mrd. €	Mrd. €	Mrd. €	Mrd. €	$\%_{Ersatzinvest.}$
Trend-Szenario				197	0					**0**	
Basis-Szenario		68	118	192	34	0	4	7	0	**45**	**+ 24%**
Sensitivitäten	**PtG-Einspeisung FNB50/VNB50**	68	126	193	26	0	4	8	0	**38**	**+ 19%**
	100% EE-PtG-Gase (Verkehr) im Gasnetz	117	107	187	56	0	6	14	1	**77**	**+ 41%**
	gedeckelt 2 Vol.-% H_2	81	219	196	1	76	0	0	32	**110**	**+ 56%**
	gedeckelt 5 (FNB) bzw. 10 (VNB) Vol.-% H_2	80	215	195	4	70	0	0	22	**96**	**+ 49%**
	Optimistische Lernkurve PtG-CH4	69	118	192	33	1	3	7	0	**44**	**+ 23%**
	Startjahr 2025	70	118	172	38	1	4	13	1	**57**	**+ 33%**
	beschleunigt -95% THG 2040	68	118	185	48	0	7	15	2	**72**	**+ 39%**
	verzögert - 80% THG 2050	37	133	196	13	0	1	1	0	**16**	**+ 8%**

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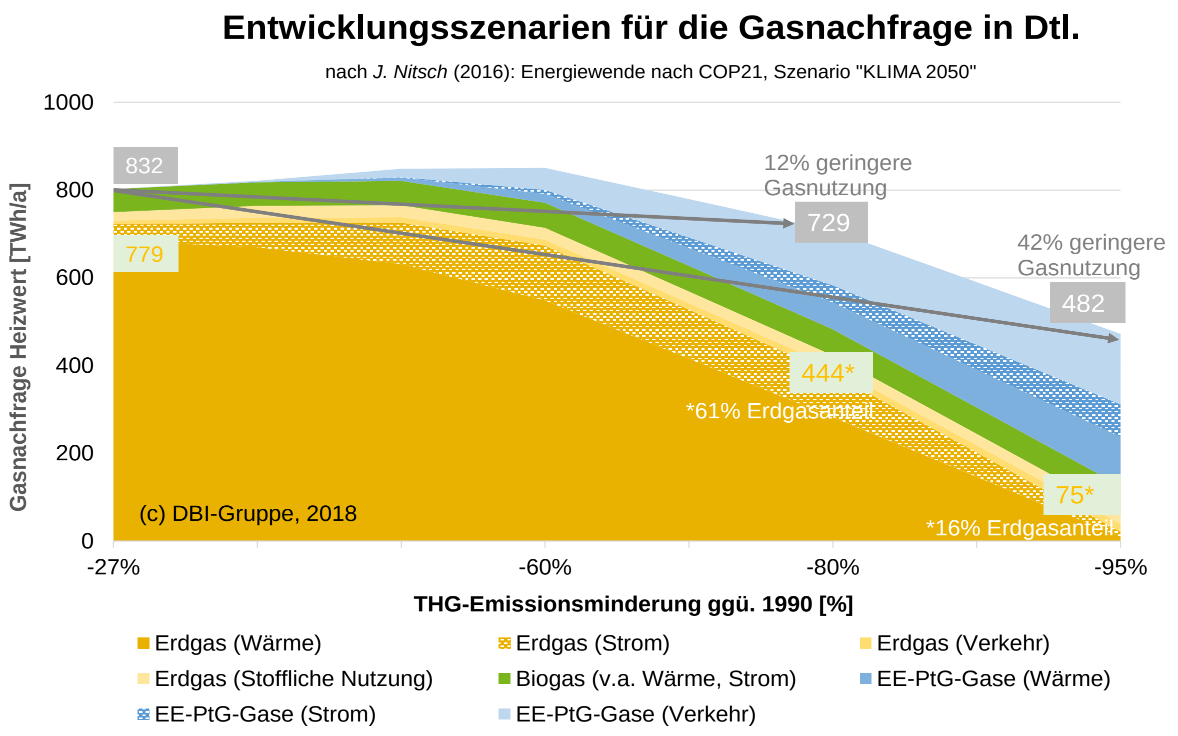
Dealing with Question: „In what way „green" PtG-gases (traffic) in Gas infrastructur?"



Note: Gas demand for "green" PtG-gases not split according to "green" PtG-H_2 or "green" PtG-CH_4 in the underlying scenario; Allocation is made in this study

- Question:
  - To what extent can a wired transport of demand for "green" PtG gases from transport sector (light blue left) be expected? How much %?
- Which „green" PtG-gas (H_2, CH_4) is in demand?
- No reliable solution derivable from available sources (State May 2018)
- Approach:
  - Base-Szenario:
    - 10% „green" PtG-gas (transport) im Gasnetz
  - Sensitivity „green PtG-gas (transport):
    - 100% „green" PtG-gas (transport) in gas grid
  - Distribution of gas type is made by model