Deep decarbonisation of the German industry via electricity or gas? A scenario-based comparison of pathways

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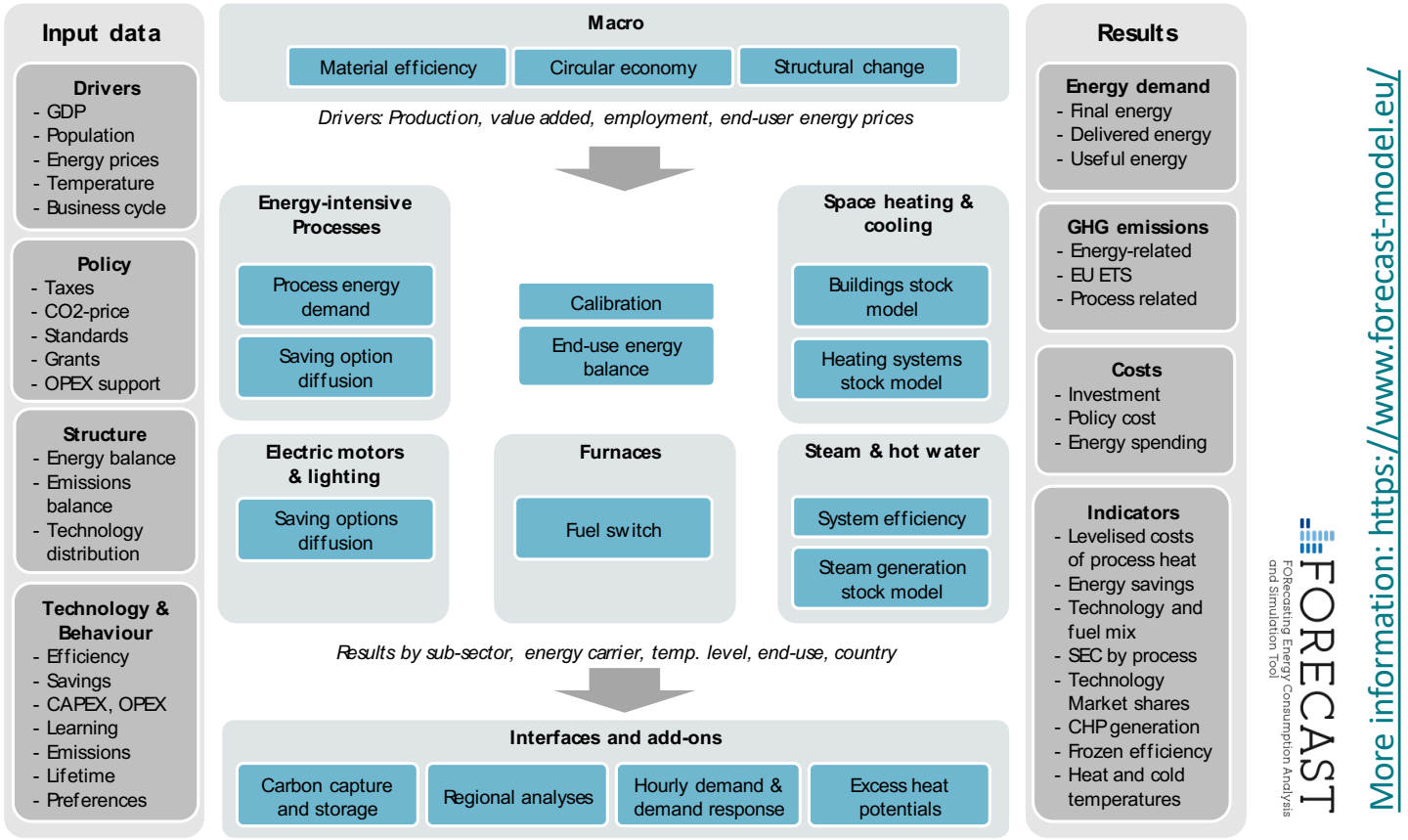
Method:
FORECAST model is used to calculate pathways to 2050

Broad scope of mitigation options included:

- Energy and process efficiency
- Energy carrier and process switch
- Recycling and circularity
- Material efficiency and substitution



FORECAST
FORecasting Energy Consumption Analysis and Simulation Tool

More information: https://www.forecast-model.eu/

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We define 2 scenarios to calculate with FORECAST model

2 scenarios are defined

	Focus Electricity	Focus Gas
Economic growth	Continuous economic growth, slow change in physical production	
Energy and process efficiency	BAT + selected innovations > TRL5	
Energy carrier and process switch	Towards electricity (and hydrogen) incl. innovations > TRL5	Towards PtG incl. innovations > TRL5
Recycling and circularity	Ambitious improvements (e.g. in steel and plastics)	
Material efficiency and substitution	Additional increase in material efficiency ~10% for major products	

FORECAST
FORecasting Energy Consumption Analysis and Simulation Tool

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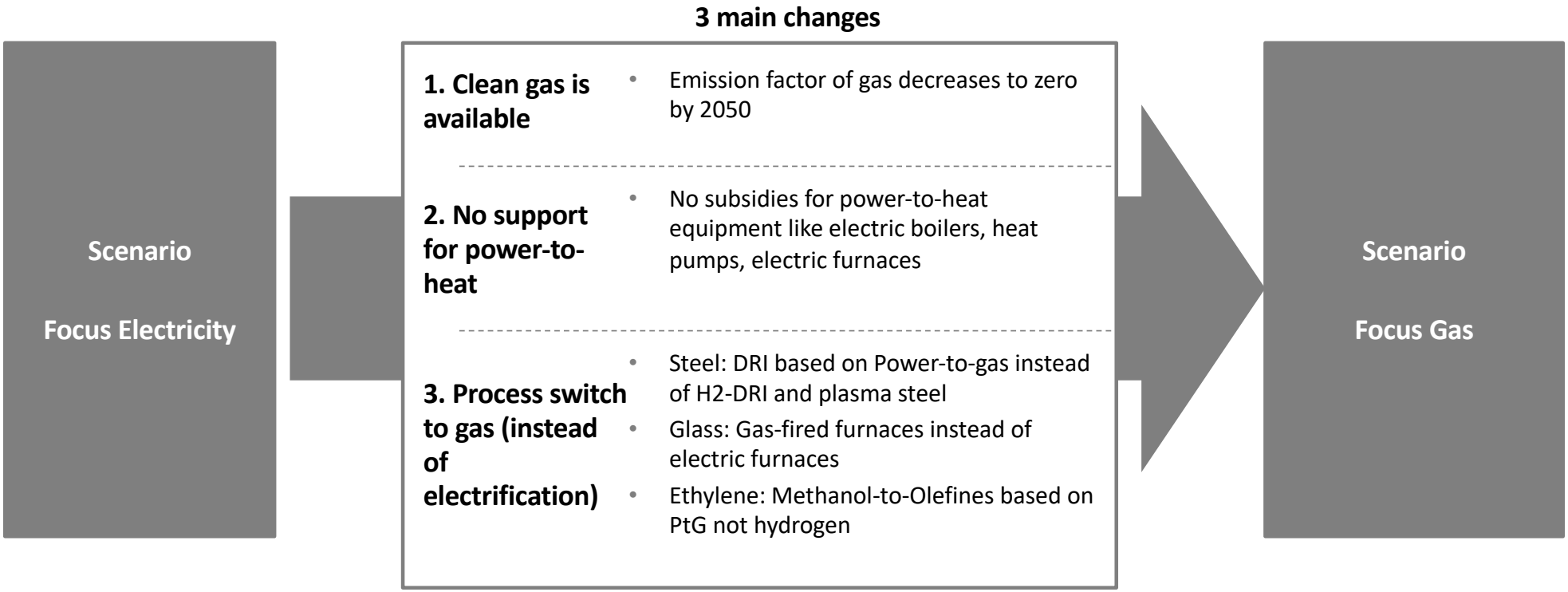
Mitigation options are defined per sector – scenario **Focus Electricity**

	Energy and process efficiency	Energy carrier and process switch	Recycling and circular economy	Material efficiency and substitution
Iron and steel	BAT, thin slab or strip casting	H_2-DRI, plasma steel	Electric steel share increases from 30 to 60% (scrap-based secondary route)	Efficient steel use Substitution
Chemicals	BAT, oxygen depolarized cathode, selective membranes	Electric boiler, H_2 for olefines, methanol, ammonia, some biomass for feedstocks	Increased recycling of plastics reduces primary use by 30%	Reduction and substitution of plastics consumption Reduction of ammonia use in fertilizers
Cement	BAT	Biomass, low-carbon cement types	-	Reduction of cement use, minimum clinker share
Glass	BAT, oxy-fuel, excess heat use	Electric furnace	Increase of flat glass recycling	Material efficient glass use for container glass
Paper	BAT, innovative paper drying, enzymatic pretreatment, black liquor gasification	Electric boiler, biomass, district heating, heat pumps	Paper recycling increases from 77 to 86%	Material efficient paper use
Others	BAT, innovative cross-cutting technologies	Electric boiler, large scale heat pumps	-	-

With 3 changes from scenario *Focus Electricity* to *Focus Gas*



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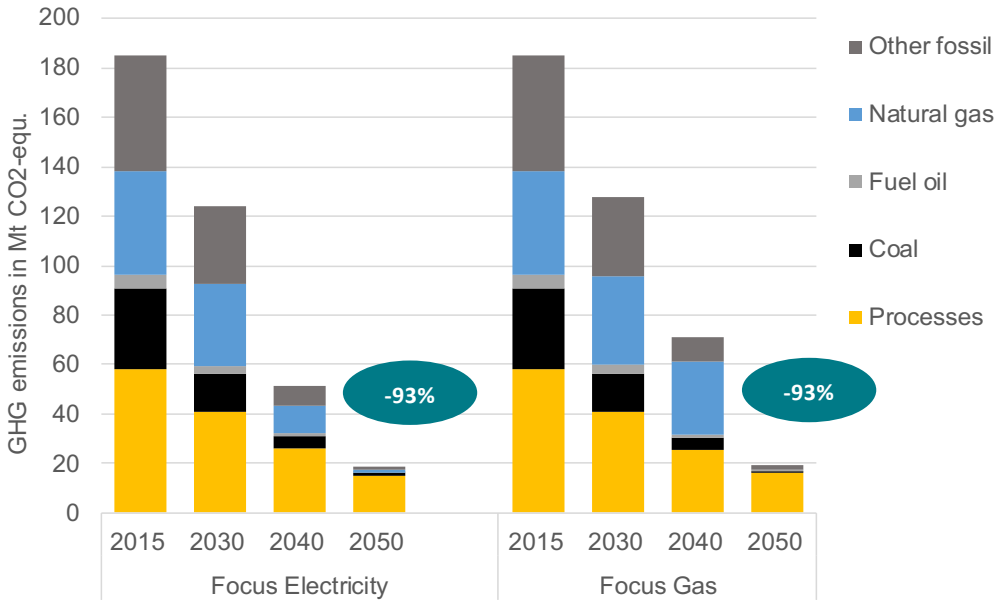
Results: Both scenarios phase out fossil energy carriers by 2050

- Reduction by 2050 versus 1990
  - -93%
  - 2050 remaining emissions mainly process-related
- Reduction by 2030 versus 1990
  - ~ 55% (compare sector target 51%)
- Substantial differences between scenarios around the year 2040

GHG emissions by source



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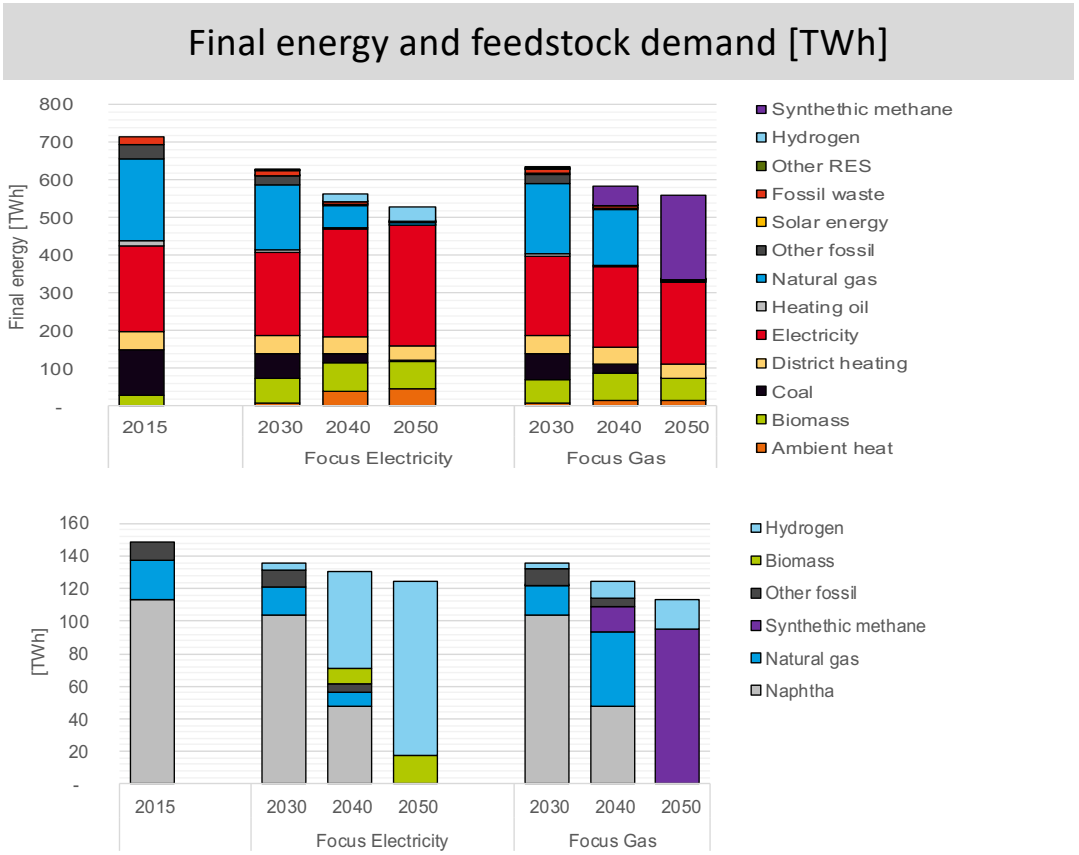
Electricity and PtG dominate the energy mix in 2050

- Final energy demand decreases by about 160 (Focus Gas) and 200 TWh (Focus Electricity)
- Fundamental change in supply mix by through 2050:
  - Focus Electricity: Electricity (60%), biomass, H2, district heating and ambient heat
  - Focus Gas: PtG, electricity, biomass and district heating
- Feedstock use in 2050
  - Focus Electricity: 107 TWh Hydrogen
  - Focus Gas: 112 TWh PtG



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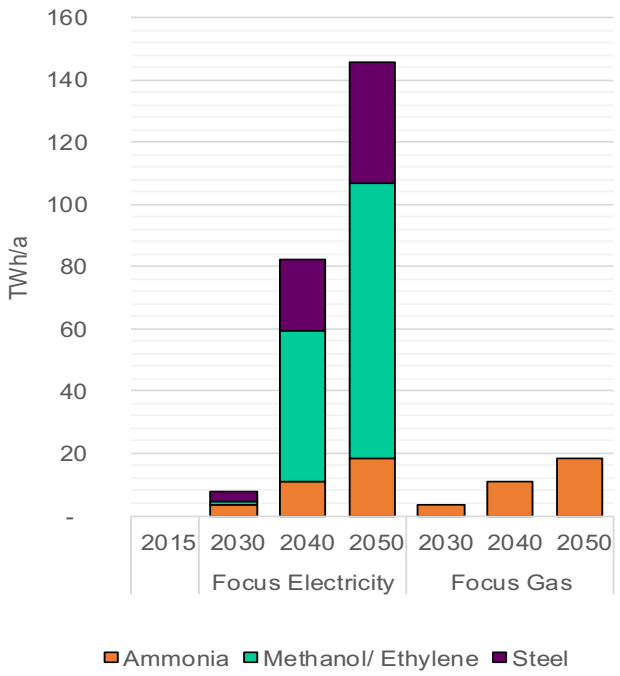
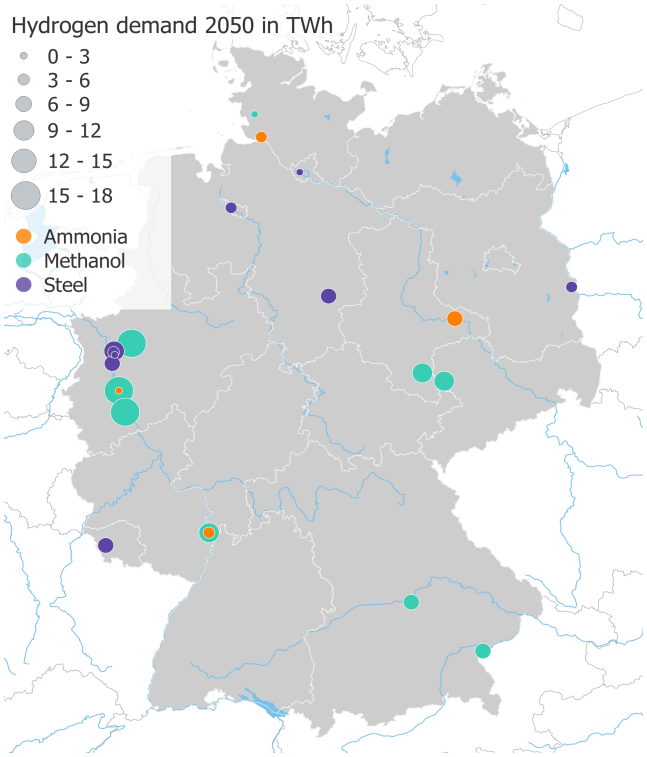
Hydrogen demand is distributed to only few sites

Hydrogen demand both scenarios



Hydrogen demand 2050 scenario Focus Electricity



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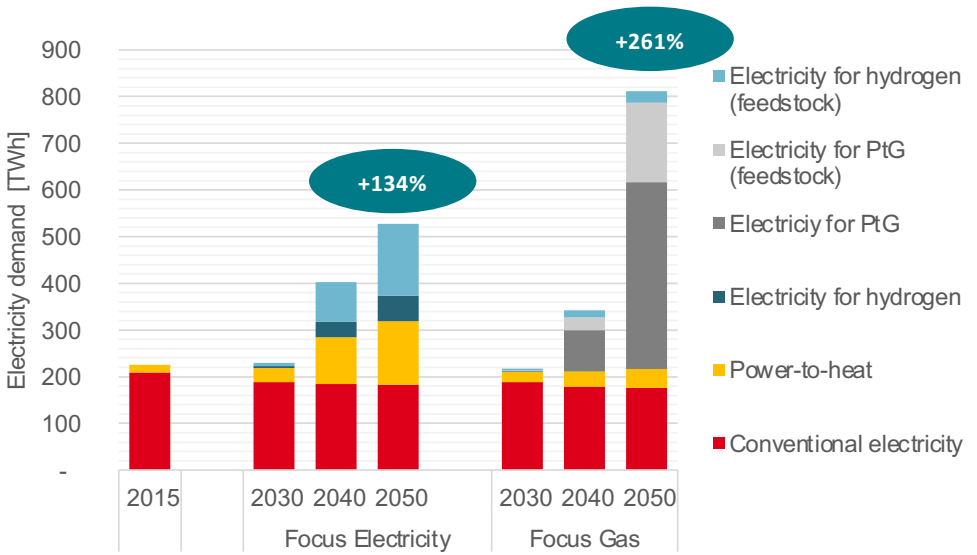
Hydrogen and PtG are drivers of electricity demand

- Focus Electricity in 2050
  - Electricity Power-to-heat: + 120 TWh versus 2015
  - Electricity for H2: + 200 TWh
- Focus Gas in 2050
  - Electricity Power-to-heat: + 25 TWh
  - Electricity for PtG: + 570 TWh
  - Electricity for H2: +25

Electricity demand incl. use for hydrogen and PtG



Assumptions for conversion efficiencies: Elektrolysis 70%, Methanisation: 80%

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Summary: Deep decarbonisation possible and RES electricity is key

Agenda	Results
1 Method	■ Bottom-up simulation of 2 scenarios: *Focus Electricity* VS *Focus Gas* ■ Both are ambitious in energy and material efficiency, circularity and innovative new processes (> TRL 5)
2 GHG paths	■ Emission reduction of 93% achieved in both scenarios - without CCS ■ Remaining emissions mainly process related
3 Hydrogen and PtG	■ Renewable hydrogen (~150 TWh in *Focus Electricity*) ■ and PtG (337 TWh in *Focus Gas*) are key for decarbonisation

4 Electricity demand	■ Renewable electricity is a prerequisite for both scenarios:
	  ■ *Focus Electricity*: 140 TWh for power-to-heat + 200 TWh for hydrogen electrolysis
	  ■ *Focus Gas:* 570 TWh for PtG plus 40 for PtH and 25 for H2

5 Conclusion	■ *Focus Gas* shows higher electricity demand and potentially higher costs at the supply side ■ *Focus Electricity* has higher need for intervention at industry/plant site

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Thank you for your attention!

See also related work at EU level:

Fleiter, T.; Herbst, A.; Rehfeldt, M.; Arens, M. (2019): **Industrial Innovation: Pathways to deep decarbonisation of Industry. Part 2: Scenario analysis and pathways to deep decarbonisation**. ICF and Fraunhofer ISI.
https://www.isi.fraunhofer.de/de/competence-center/energietechnologien-energiesysteme/projekte/pathways.html#tabpanel-3

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Backup

Industrie: Fortschritte bei Kreislaufwirtschaft und Materialeffizienz in allen Branchen

Annahmen zur Kreislaufwirtschaft

Produkt	Recyclingquoten bis 2050
Stahl	Elektrostahl von 30% auf 60%
Kunststoffe/ Ethylen	Kunststoffrecycling: +15%
Glas	Steigerung Flachglasrecycling
Papier	Altpapierrecycling von 77% auf 86%
Aluminium	Steigerung Sekundäraluminium von 54% auf 58%

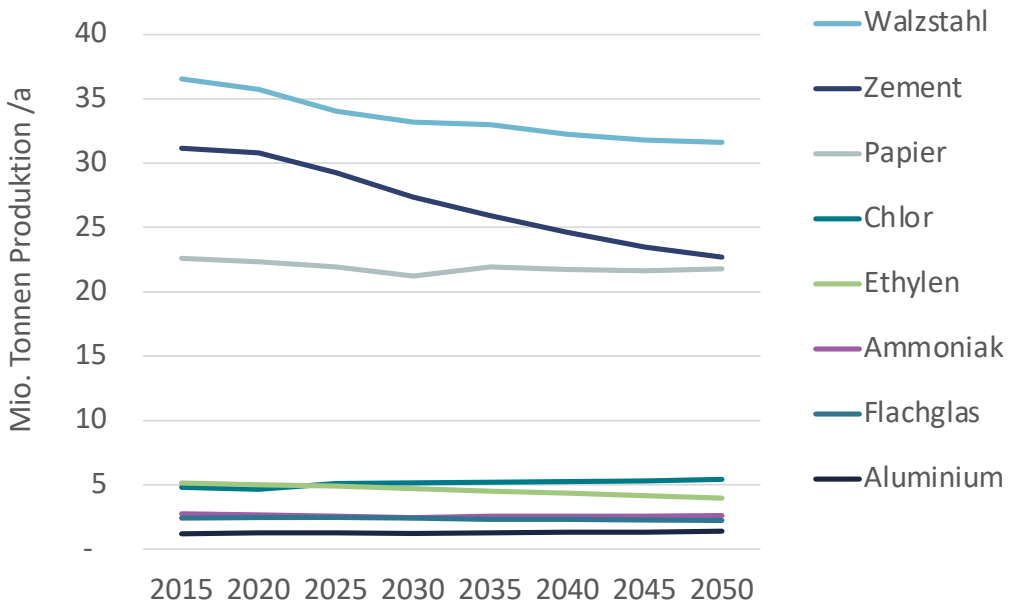
Annahmen zur Materialeffizienz

Produkt	Rückgang Produktion 2050 ggü. Ref	Hintergrund
Rohstahl	10%	Nachfragereduktion: Effizientere Produktverwendung und Materialsubstitution, z.B. in der Automobilindustrie
Aluminium	3-5%	Nachfragereduktion; ausgenommen Kupfer (steigender Bedarf elektrische Leiter für z.B. Motoren kompensiert Effizienzfortschritt)
Papier	10%	Nachfragereduktion: Trend zu papierlosen Anwendungen
Behälterglas	10%	Nachfragereduktion durch Materialeffizienz in der Produktgestaltung
Zement	10%	Nachfragereduktion durch Materialeffizienz in der Bauwirtschaft
Klinker	6%	Rückgang Klinkeranteil in der Zementproduktion von 0,73 in 2015 auf 0,68 in 2050
Kalk	30%	Starker Rückgang, da große Abnehmer entfallen: Hochofen (~50% Anteil), Rauchgasentschwefelung(~20%)
Ammoniak	24%	Nachfragereduktion Mineraldünger (Präzisionslandbau, verbesserte Stickstoffaufnahme)
Kunststoffe, Ethylen	15%	Nachfragereduktion Massenkunststoffe (z.B. Verpackungen)

Industrie: Es wurde eine relative konstante Produktion energieintensiver Grundstoffe hinterlegt

- Wertschöpfung der Industrie:
  - 1% p.a. bis 2050
  - Struktureller Wandel: Schnelleres Wachstum in Chemie/Maschinenbau, langsameres Wachstum in Grundstoffindustrien
- Tonnen-Produktion:
  - Kontinuierliche Entwicklung, teilweise leichte Reduktion aufgrund von Materialeffizienz und Nachfragetrends (siehe Grafik rechts)

Annahmen zur Tonnenproduktion ausgewählter Grundstoffe



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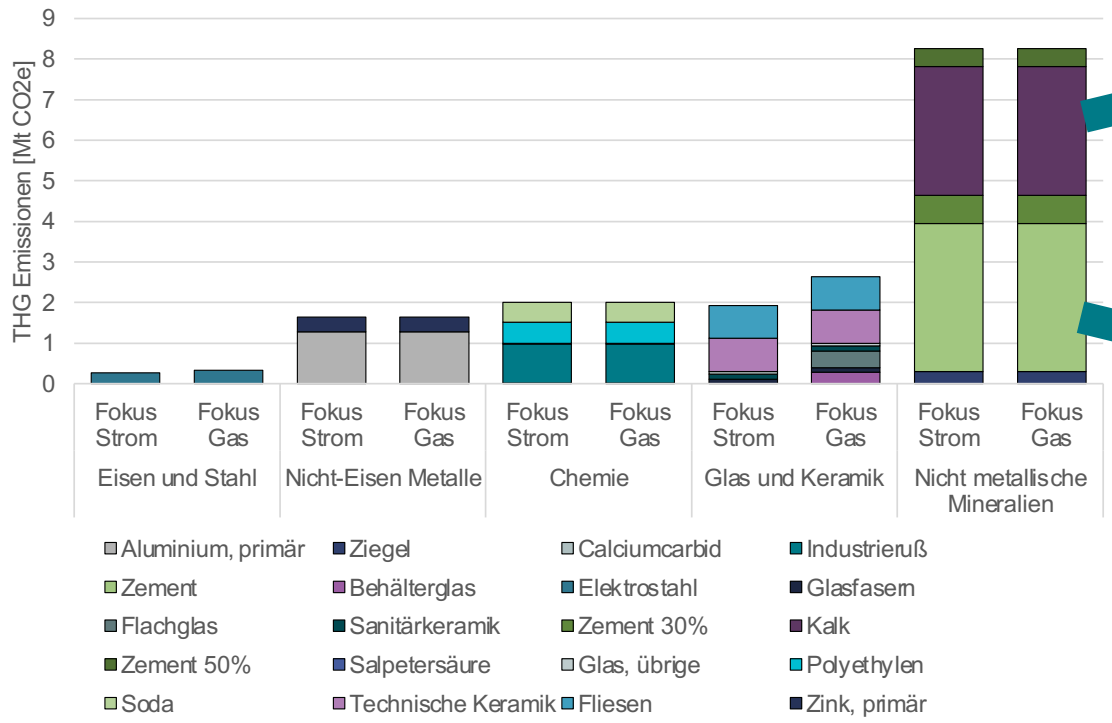
Prozessbedingte Emissionen in 2050 durch Zement und Kalk bestimmt

Verbleibende THG-Emissionen aus Prozessen in 2050 [Mt CO2e]



Kalk
-> Weitere Reduktion über CCS?

Zement
Bereits hohe Minderung erreicht durch: Mat-Eff, Reduktion Klinkerfaktor, Innovative CO2-arme Zementsorten

-> Weitere Reduktion über CCS?

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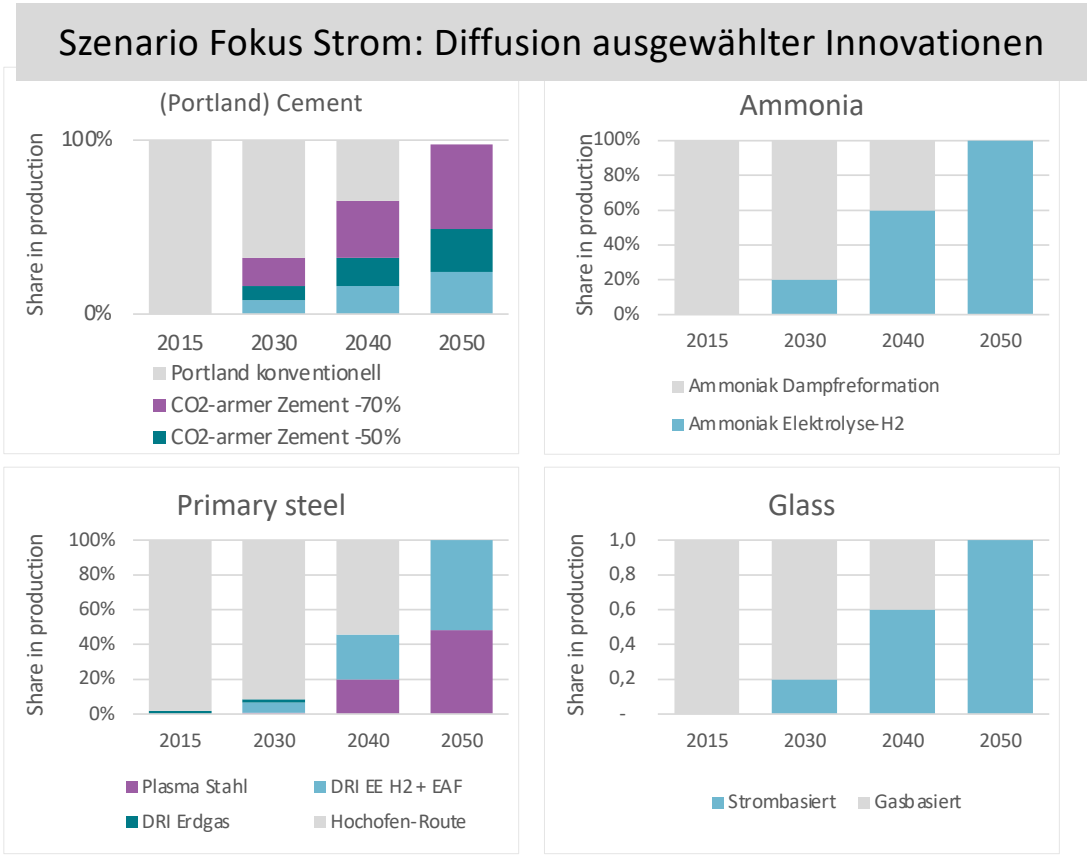
Industrie: Die Diffusion innovativer CO2-armer Verfahren ist umfassend bis 2050

- Innovative low-carbon processes considered in
  - Cement
  - Steel
  - Ammonia
  - Ethylene
  - Methanol
  - Glass
- Market introduction at industrial scale in 2025/2030
- Complete conversion of plant fleet by 2050



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Overview of process switch

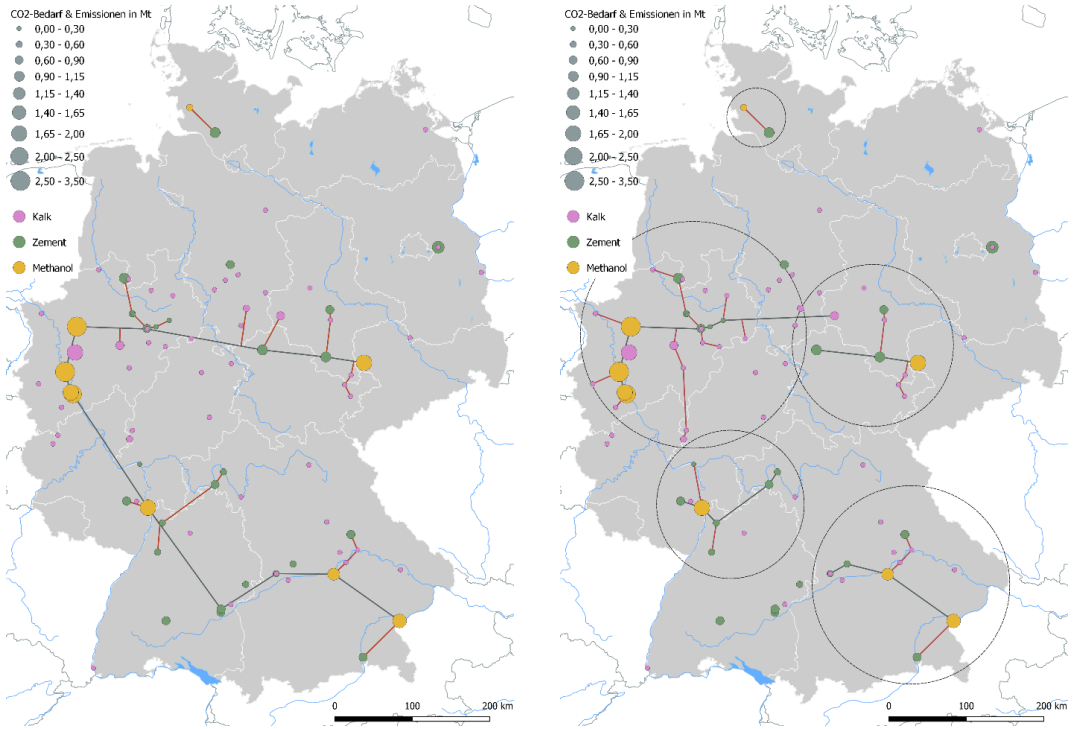
Sector	Low-carbon technology (LCT)	Reference technology	TRL of LCT	GHG reduction compared to ref. technology [%]	Diffusion (Focus Gas if different)		Sources
					2030	2050	
Steel	H_2-DRI + EAF	Blast furnace route	7	Up to ~95%[1] (remaining fossil fuel use in the EAF)	4% (0%)	21% (0%)	(Vogl et al. 2018; Fischedick et al. 2014; ASTIER et al. 1982; Arens and Vogl 2019)
Steel	Plasma Steel	Blast furnace route	3-4	Up to 100%[1]	0.5% (0%)	20% (0%)	(Hiebler and Plaul 2004)
Cement	Low-carbon cement (-30%, high Belite share)	Portland Cement (Alite-based)	8-9	25-30%	3.6%	12.3%	(Chan et al. 2019)
Cement	Low-carbon cement (-50%, Calcium-Silicate-Hydrate)	Portland Cement (Alite-based)	7	50%	3.6%	12.3%	(Chan et al. 2019)
Cement	Low-carbon cement (-70%, recarbonating)	Portland Cement (precast concrete)	8-9	30-70%	7.2%	24.5%	(Chan et al. 2019)
Glass	All-electric melting	Natural gas (Regenerative burner)	6-7	Up to 100%[1]	20 (0%)%	100% (0%)	(Rehfeldt et al. 2020)
Chemicals	Electrolysis-H_2 as feedstock for ammonia	Feedstock: Natural gas (Steam reforming)	7	Up to 100%[1]	20%	100%	(Bazzanella and Ausfelder 2017)
Chemicals	H_2-Methanol (with CCU)	Natural gas steam reforming	7	Up to 100%[1, 2]	15%	100%	(Bazzanella and Ausfelder 2017)
Chemicals	Ethanol from biomass	Ethanol from biomass	9	-	-	-	(Bazzanella and Ausfelder 2017)
Chemicals	MtO (C2-C4-synthesis from methanol)	Steamcracking (Naphtha)	8-9	<0 to > 100%[1, 2]	0% (0%)	65% (100%)	(Bazzanella and Ausfelder 2017)
Chemicals	Bio-Ethylene (from ethanol)	Steamcracking (Naphtha)	8-9	Up to 100%	0% (0%)	35% (0%)	

Kernergebnisse und Schlussfolgerungen Industrie

- Minderung von 90% ggü. 1990 möglich - in beiden Szenarien
- Wichtigste Voraussetzungen
  - Neue CO2-neutrale Herstellungsverfahren sind ab 2025/2030 marktfähig und erreichen 100% Bestandsdiffusion bis 2050 in den Grundstoffbranchen
  - Grüner Strom ist verfügbar und Elektrifizierung oder synthetisches Gas verdrängen fossile Energieträger
  - Grüner Wasserstoff versorgt Chemie und Stahlindustrie (Infrastruktur)
  - Kreislaufwirtschaft setzt sich weiter durch: Elektrostahl wird für Qualitätsstähle verwendet, Ausbau von Kunststoffrecycling und Baustoffrecycling
  - Materialeffizienz entlang der Wertschöpfungskette steigt, besonders in der Bauwirtschaft
- Ausblick: Minderung von 95%+ verlangt Reduktion verbleibender Emissionsquellen bei Prozessen (Zement und Kalk) ggfs. über CCS

Two alternative networks for CCU in Cement and methanol

- Using CO2 from cement plants for methanol production



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