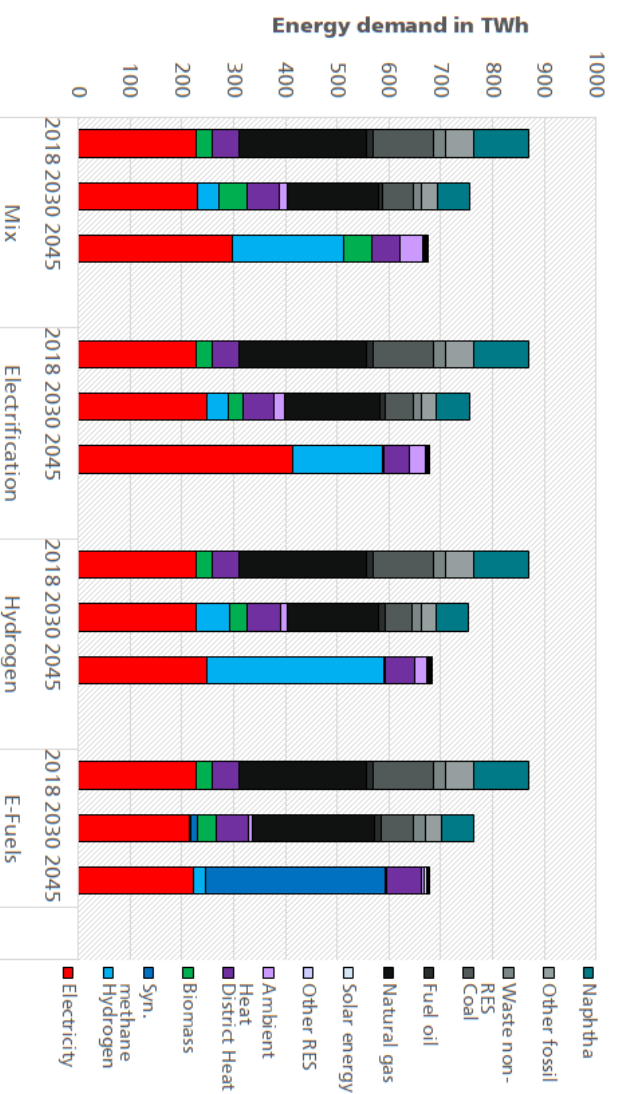
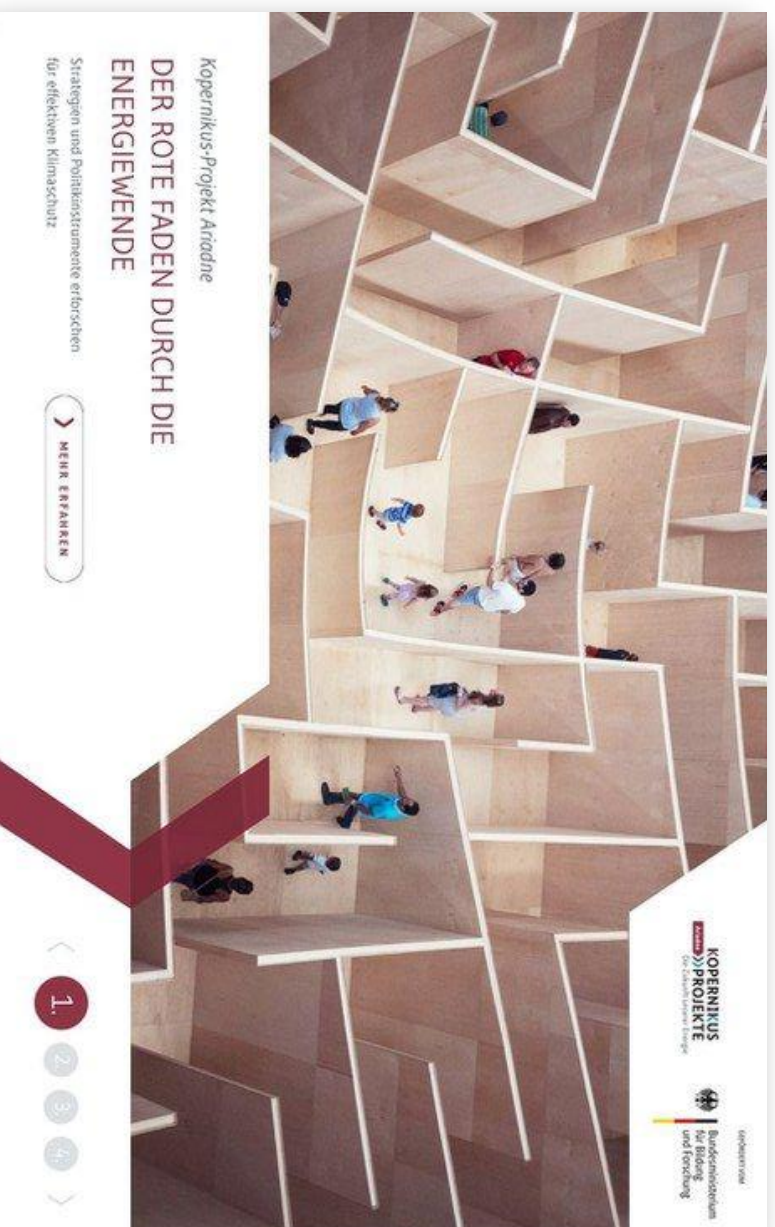


Pathways to a near carbon-neutral German industry sector by 2045

Andrea Herbst, Tobias Fleiter, Matthias Rehfeldt, Marius Neuwirth
Fraunhofer Institute for Systems and Innovation Research ISI
eeeee Summer Study on energy efficiency, 6-11 June 2022

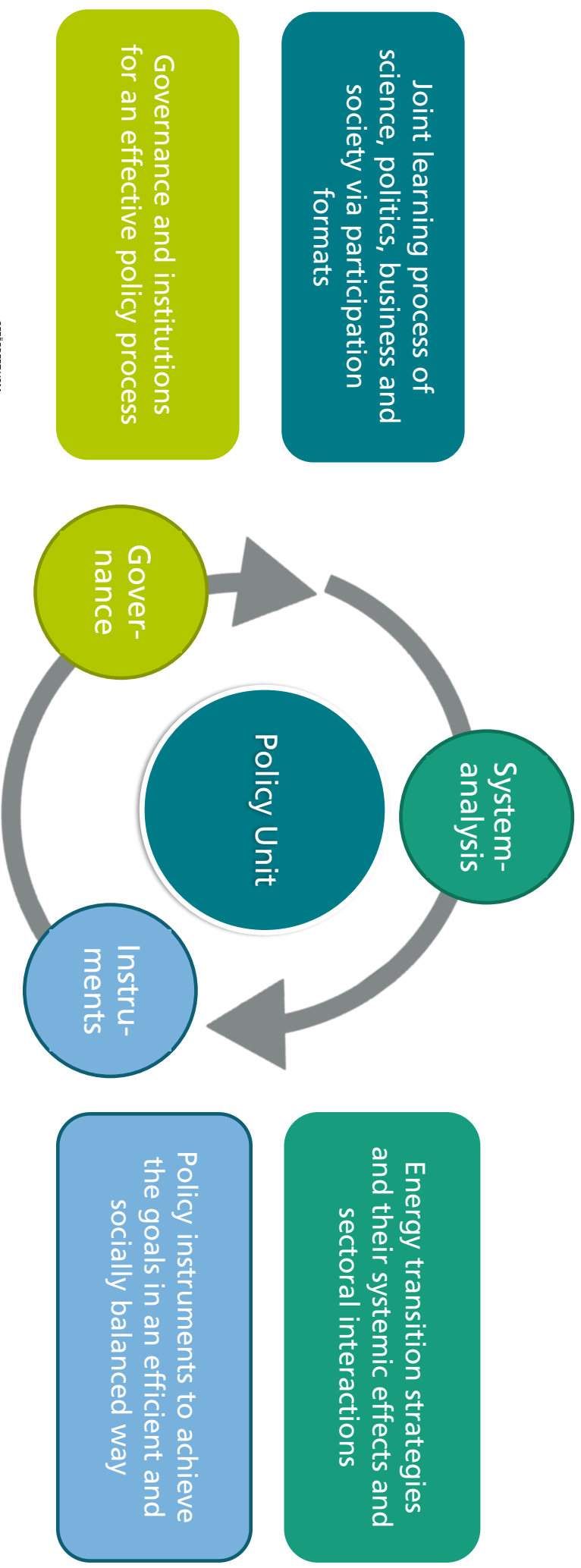


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Ariadne analyses how policy measures work in a joint learning process between science and society



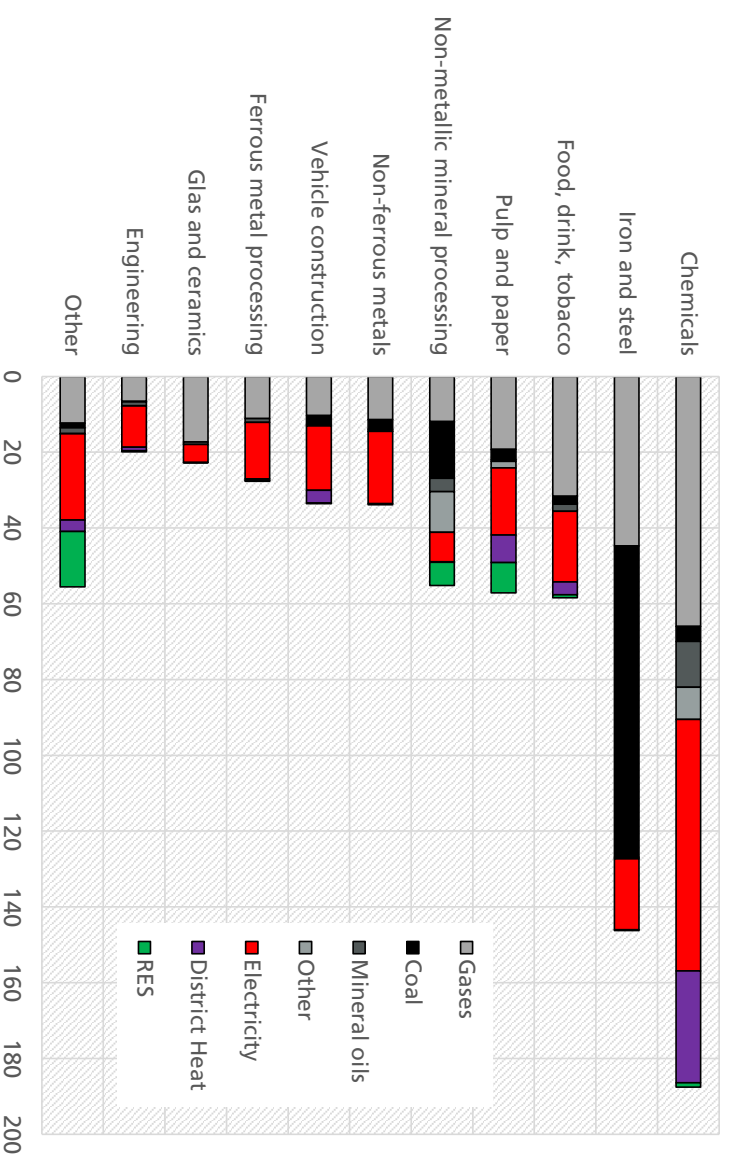
GEFÖRDERT VOM

OUTLINE

- **Introduction**
- Methodology & Scenarios
- Results
- Conclusions

Industry is responsible for about 23% of GHG emissions in Germany

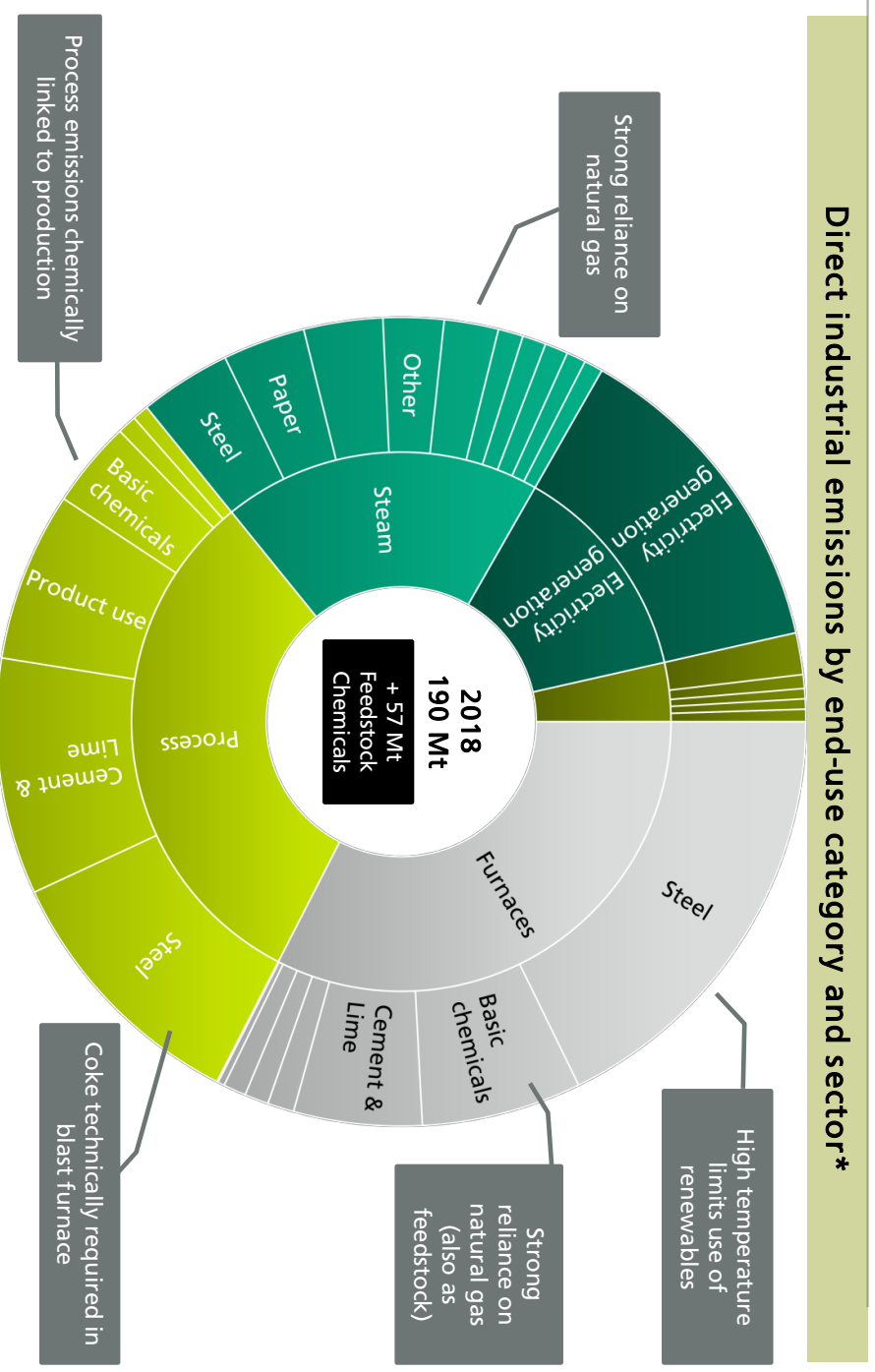
Industrial final energy consumption by economic sector [2019, TWh]



- > **70 % of industrial energy demand** is generated in **energy-intensive industries**
- > **Interim target for industry:**
 - > **118 Mt-CO₂eq. in 2030**
 - > Reduction of ~57% compared to 1990
- > **Technology paths and political framework** under discussion

Climate neutrality in 2045 requires profound change

- > **Diverse challenges** across all application areas
- > **New CO₂-neutral production processes** address important sources of emissions
- > But **action is needed in all areas**

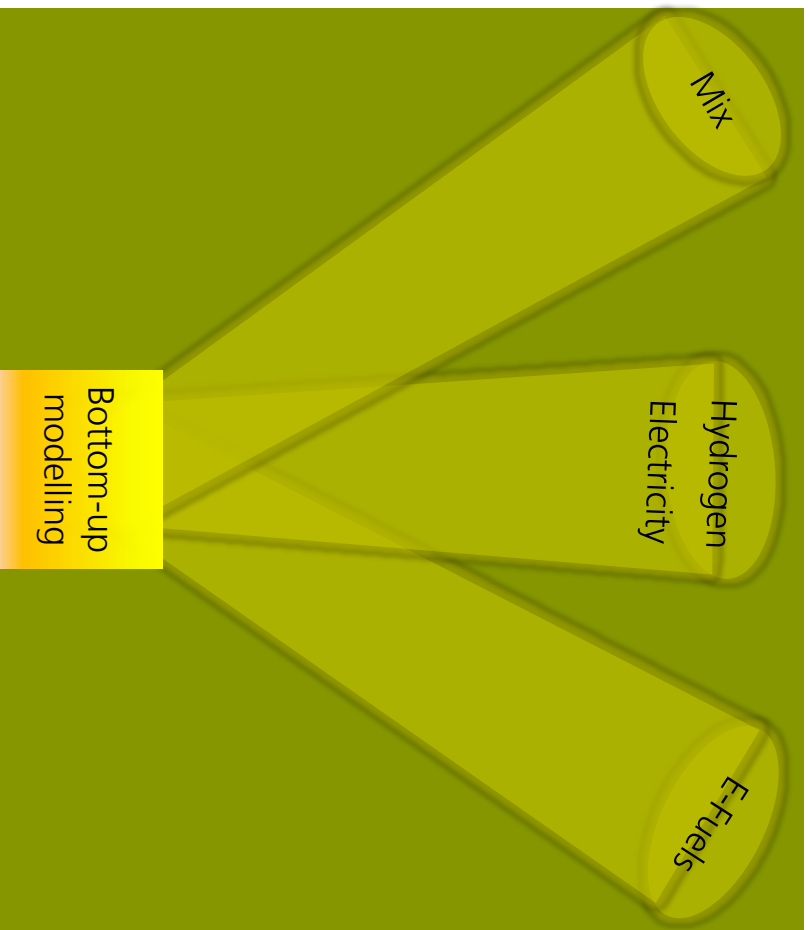


* Excluding refineries; Source: Fraunhofer ISI

OUTLINE

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Gaining knowledge through comparison



Central questions

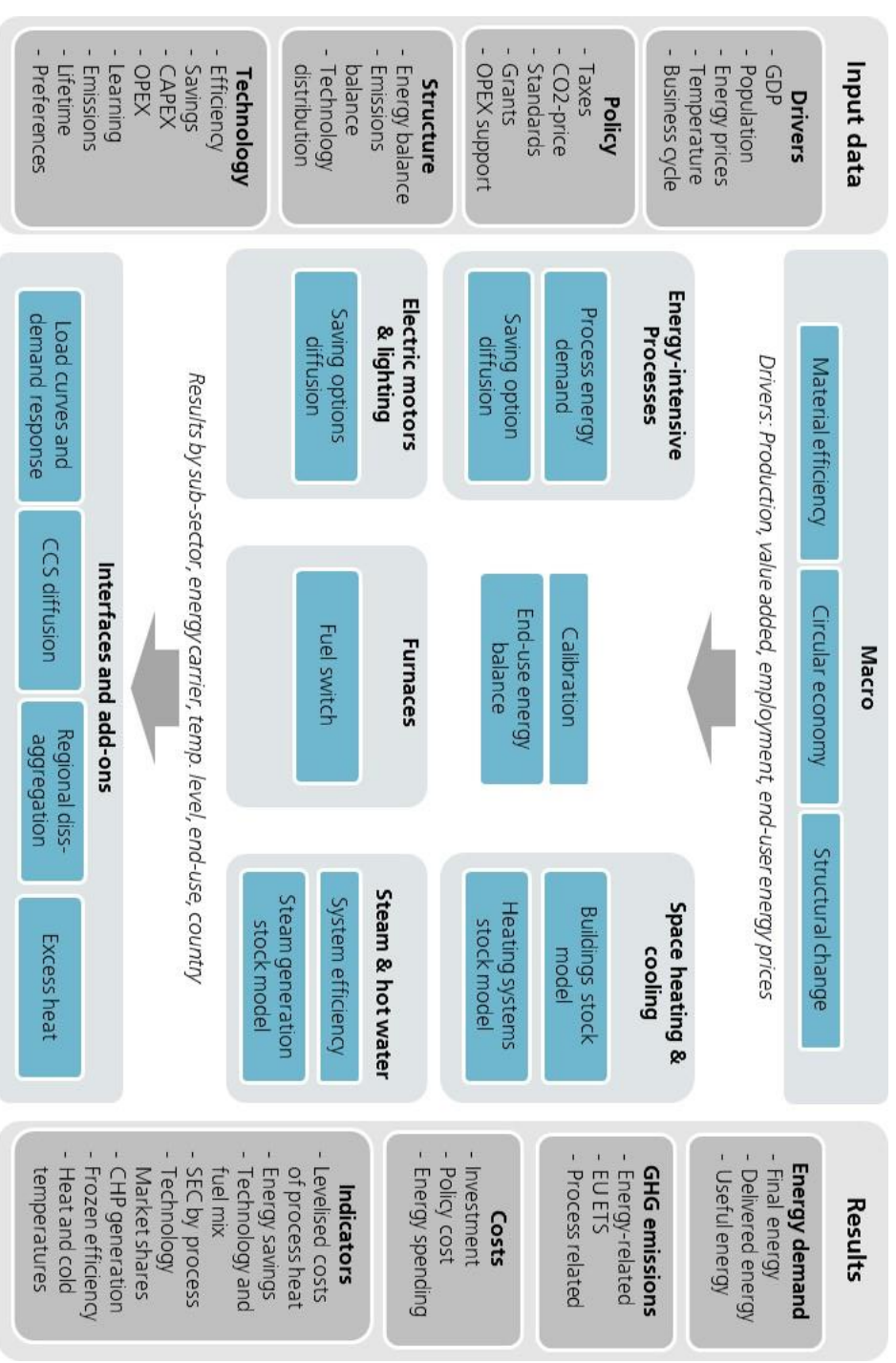
- › What could different (technology) paths to a nearly climate-neutral industry by 2045 look like?
- › What role does the use of electricity and hydrogen play in the different scenarios?

Approach

- › Comparison of the decarbonization of the energy system via different technology approaches
- › Modelling of the transformation pathways until 2045 with a detailed bottom-up model

Bottom-up modelling of energy demand & GHG emissions

- › **High technology resolution**
- › Consideration of all **important abatement options**
- › Energy and greenhouse gas balance
- › **Annual results** until 2045



FORECAST
 FORecasting Energy Consumption Analysis
 and Simulation Tool

<https://www.forecast-model.eu>

Alternative pathways to a near carbon-neutral industrial production by 2045

All GHG-neutral Scenarios

- GHG reduction in the industrial sector >95%.
 - Economic development (+1% p.a.)
- Ambitious energy and material efficiency + high shares of secondary production
 - Avoid use of biomass in technology focus scenarios
 - Avoid CCS



Mix

- No clear technology focus



Electrification

- Direct electric solutions preferred
- Hydrogen as feedstock

Hydrogen

- Hydrogen widely available
- Use preferred in terms of energy and feedstock



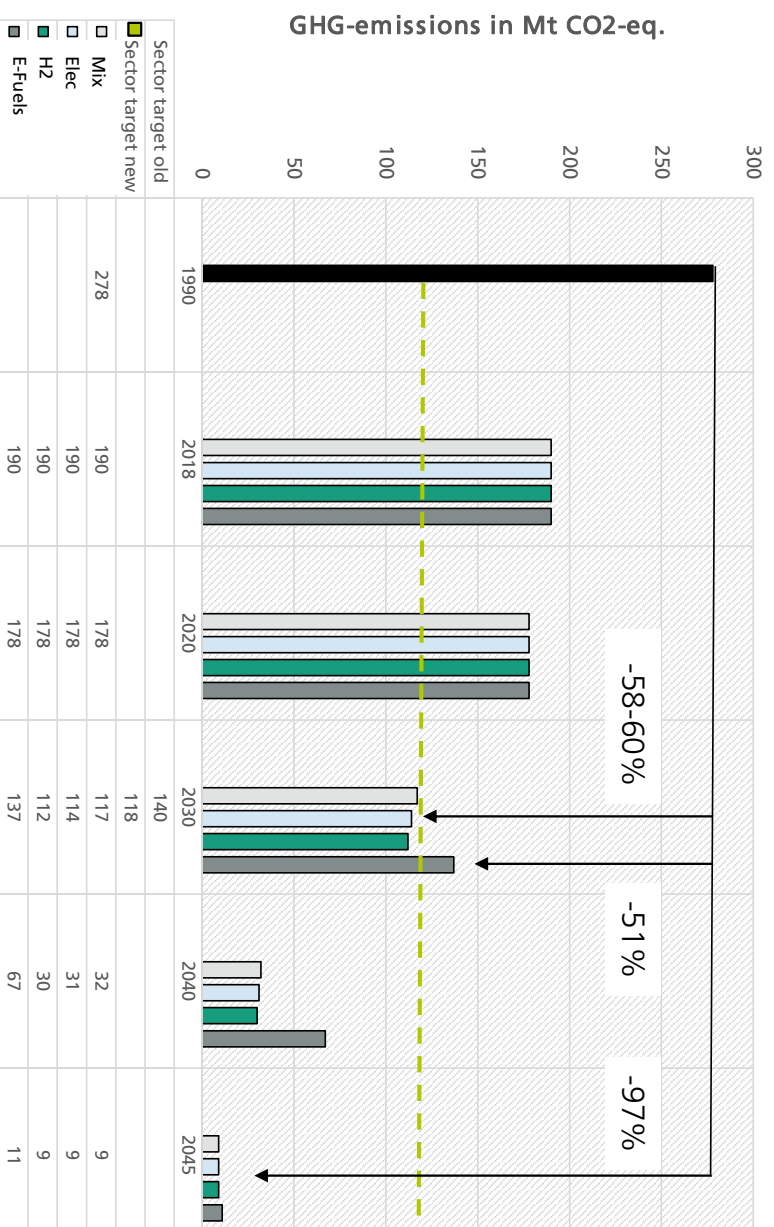
E-Fuels

- Synthetic methane widely available
- Preferred for energy and feedstock

OUTLINE

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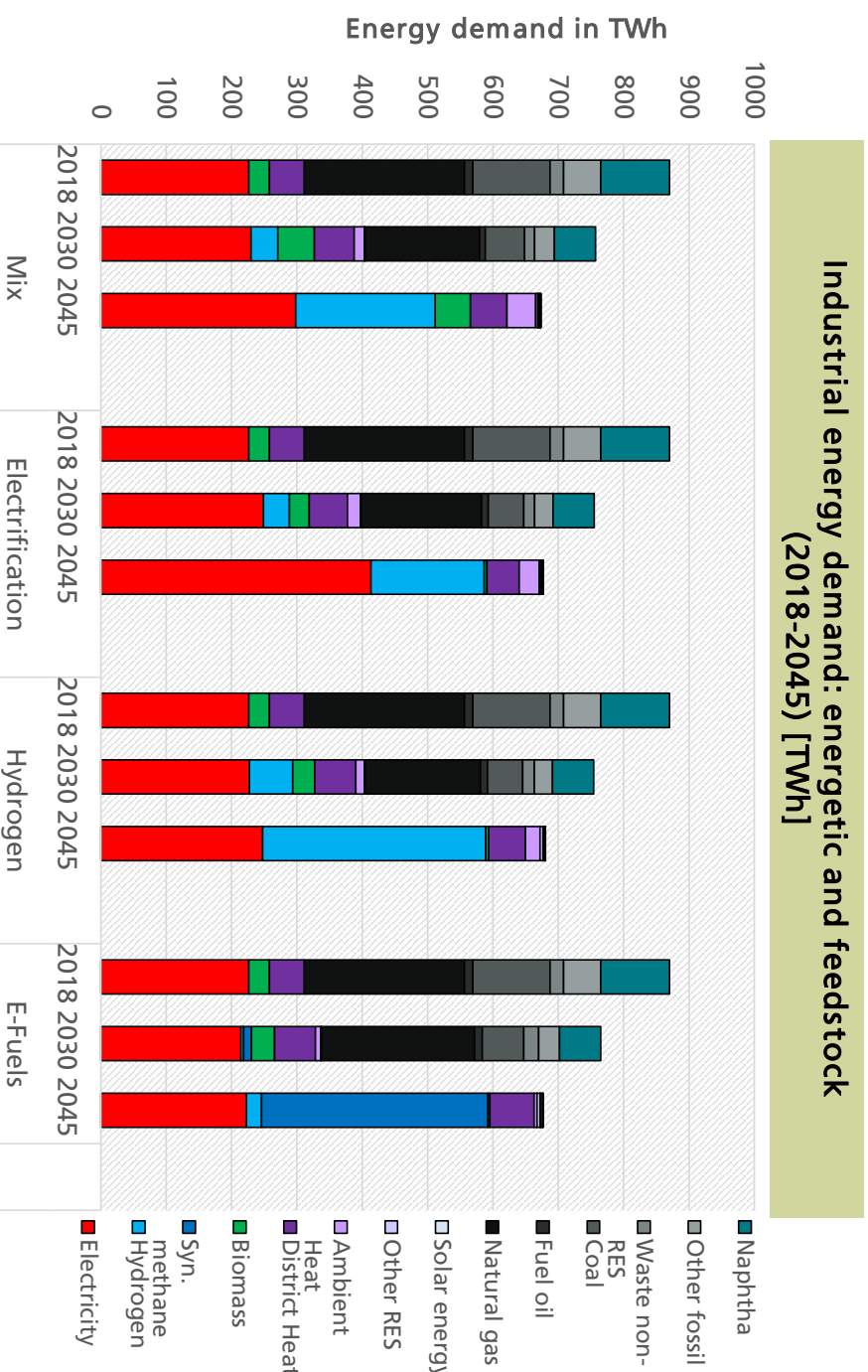
2030 target for industry is achieved in nearly all scenarios



- > **Reduction in 2030:**
 - > 51 to 60% compared to 1990
 - > Slower reduction in the E-Fuel scenario
- > **Near carbon-neutral in 2045:**
 - > 96 to 97% reduction compared to 1990
 - > Only a few Mt of **process emissions** (9-11 Mt)
 - > **Smaller source types** (e.g. ceramics)

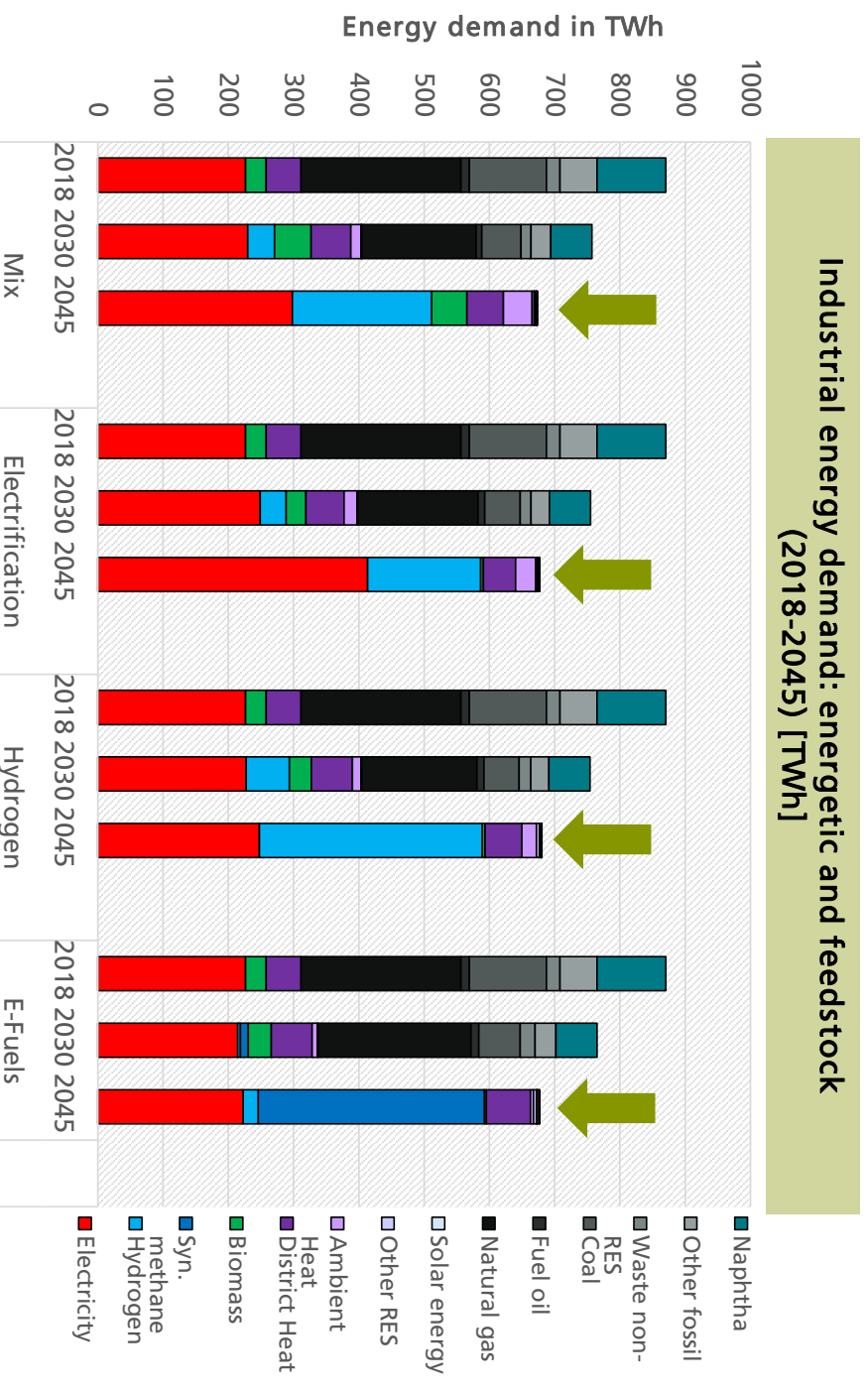
Industrial transformation requires high volumes of CO2-neutral energy carriers

- › **Energy & material efficiency, circular economy and CCU/S**
- › **H2 use in CO2-neutral processes**
- › **Extensive use of CO2-neutral energy carriers in residual process heat**



Industrial transformation requires high volumes of CO2-neutral energy carriers

- › **Energy & material efficiency, circular economy and CCU/S**
- › **H2 use in CO2-neutral processes**
- › Extensive use of **CO2-neutral energy carriers** in residual process heat
- › **Reduction of energy consumption ~20% vs. 2018**



Ambitious changes to the entire industrial production system

		Mix	Electricity	Hydrogen	E-Fuels
CCS	Steel, Chemicals, Cement and lime		no		CCS for cement
CCU	Cement and lime		Cement and lime as CO ₂ -source		no
Process switch to low-carbon primary processes	Steel		H ₂ -DRI		PtG-DRI
	Cement	Low carbon cement + waste, clinker factor	Electric clinker & lime kilns	Low carbon cement + H ₂ fired furnaces	Low carbon cement + gas
	Chemicals	MtO, H ₂ methanol, H ₂ electrolysis ammonia			MtO + PtG methanol, H ₂ electrolysis ammonia
	Glass	H ₂ fired smelter	Electric smelter	H ₂ fired smelter	Gas fired smelter
Fuel switch	Industrial furnaces	H ₂ , electricity, waste	Electricity dominant	H ₂ fired furnaces	Gas dominant
	Steam and hot water	Mix	Electricity dominant	H ₂ fired steam	Gas dominant

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	Glass	H2 fired smelter	Electric smelter	H2 fired smelter	Gas fired smelter
Fuel switch	Industrial furnaces	H2, electricity, waste	Electricity dominant	H2 fired furnaces	Gas dominant
	Steam and hot water	Mix	Electricity dominant	H2 fired steam	Gas dominant

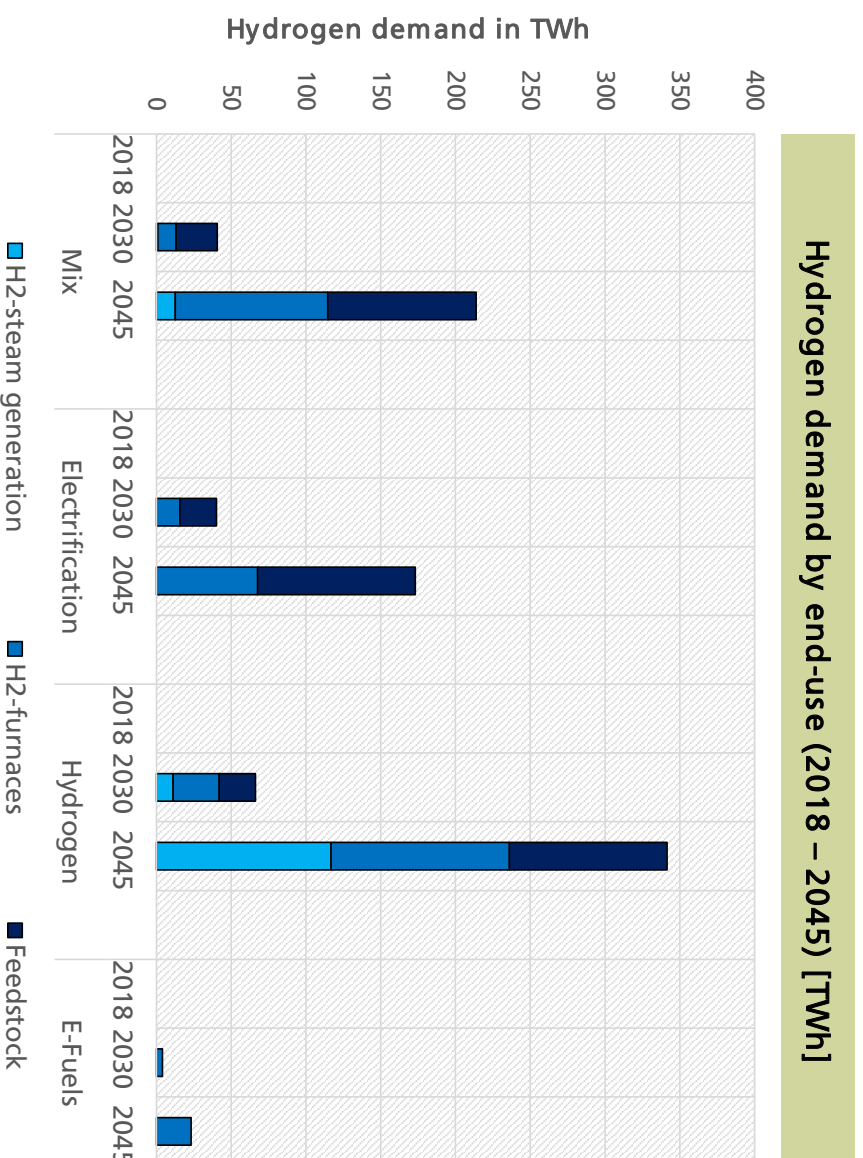
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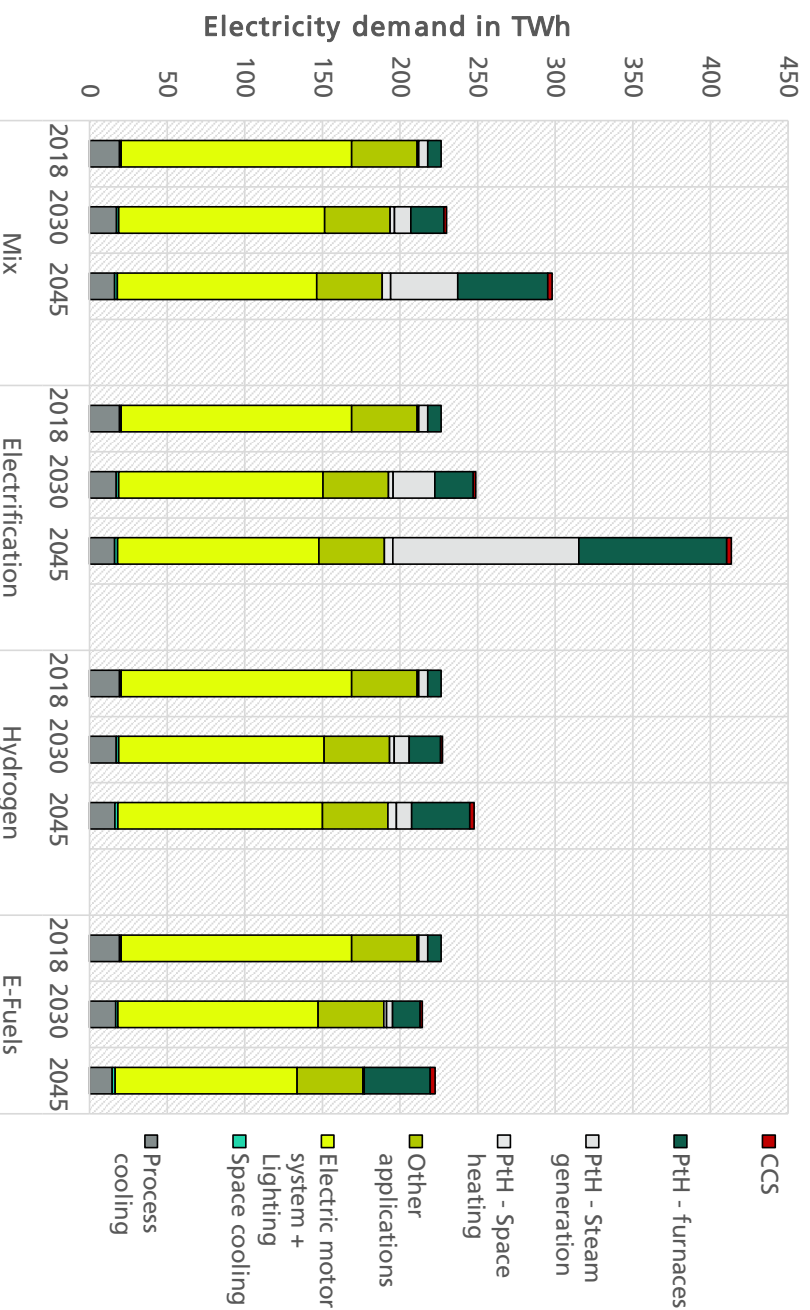
Robust hydrogen demand especially in the steel and chemical industry



- > **New CO2-neutral processes:**
 - > Steel, ammonia, methanol/olefins
 - > ~170 TWh H2 demand in 2045
- > Demand distributed among **few industrial locations**
- > Use for remaining process heat:
 - > + 169 TWh = **342 TWh in 2045**
 - > **High number** of locations

Electrification of steam generation and industrial furnaces drives electricity demand

Electricity demand by end-use (2018 – 2045) [TWh]



> Decreasing demand for conventional applications

> Doubling of demand in the electricity scenario:

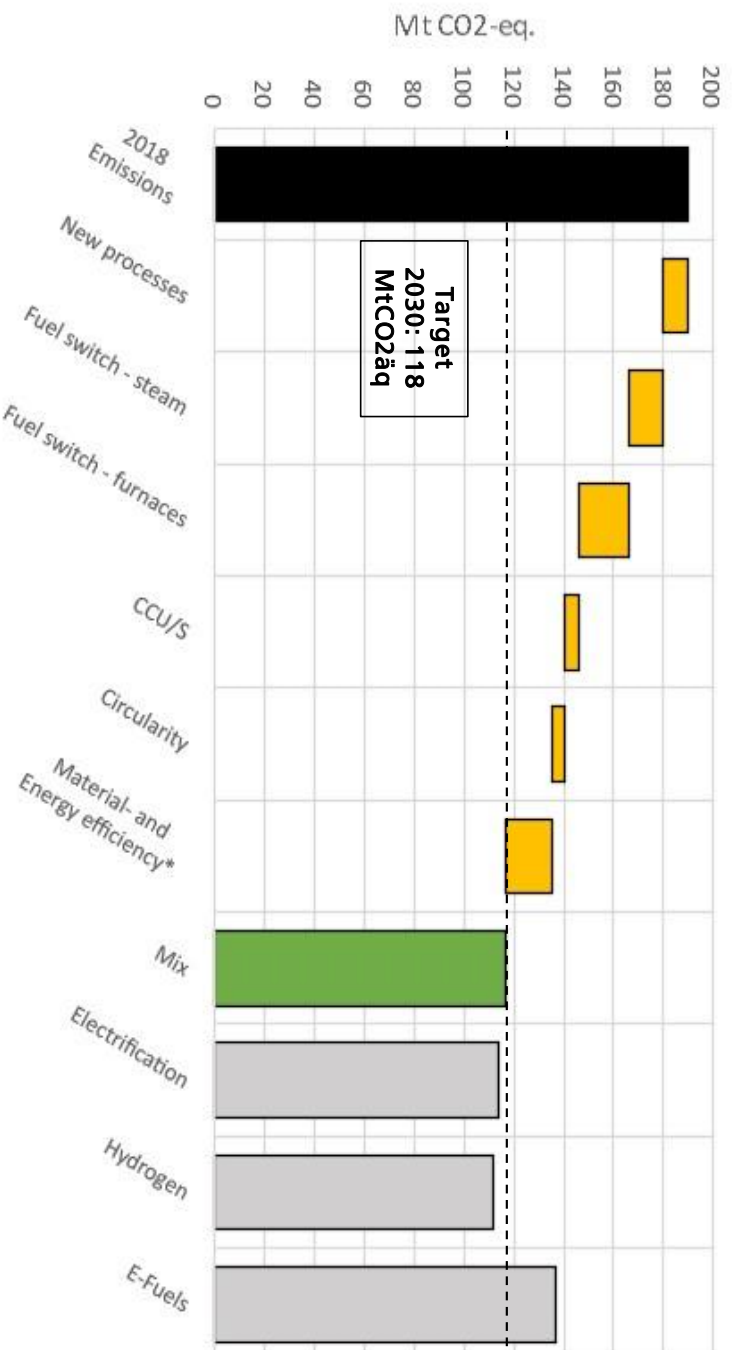
> 226 to 413 TWh in 2045

> Hydrogen & E-Fuel scenarios:

> Efficiency gains and electrification balance each other out

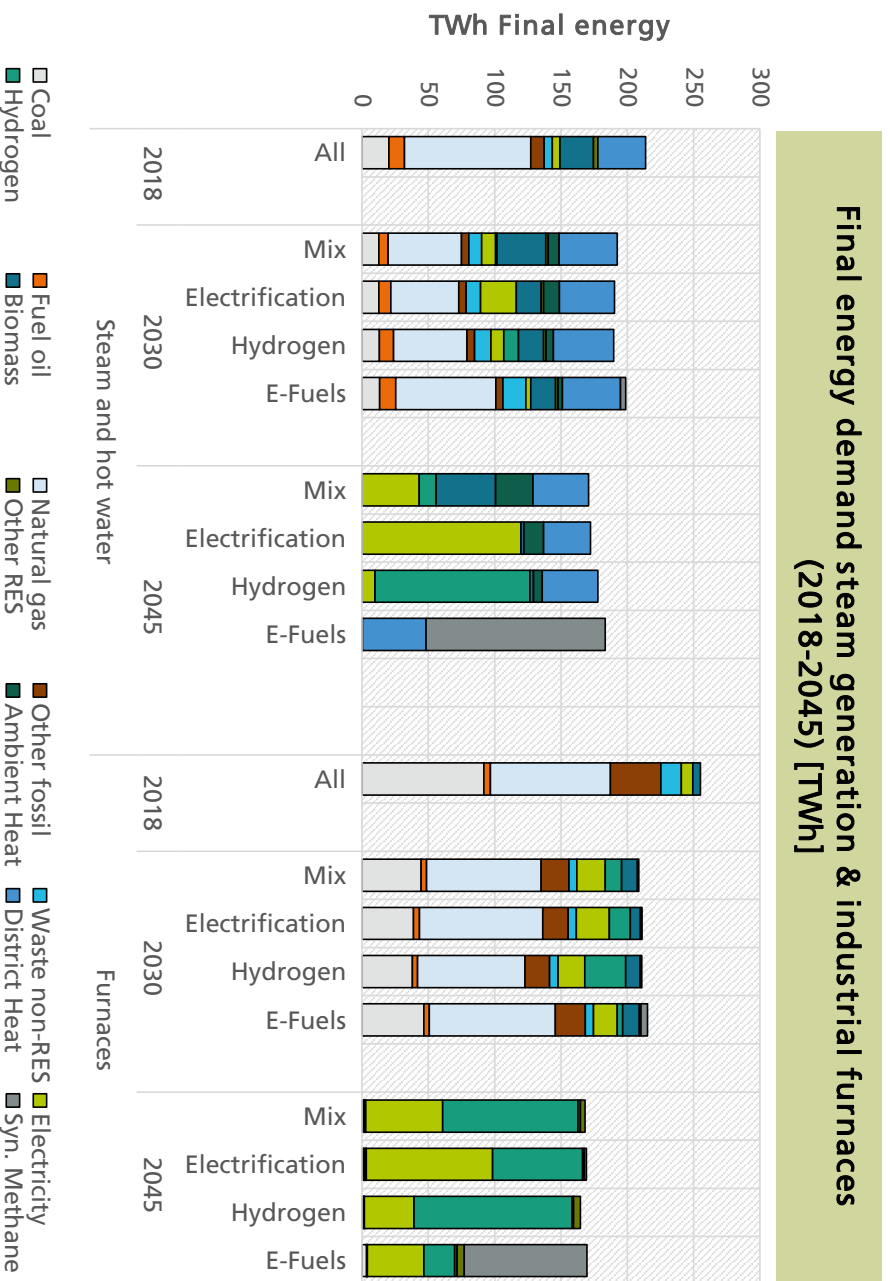
The time horizon until 2030 is crucial to achieve climate neutrality by 2045

Contribution of individual abatement options to emission reductions by 2030 compared to 2018 [Mix Scenario]



- > Scaling and economic operation of **CO2-neutral processes**
- > **Fuel switch** as most effective field of action by 2030 (30 Mt)
- > Use of **CCU/S in cement and lime** production (6 Mt)
- > Expansion of energy and material **efficiency & circular economy** (20 Mt)

CO2-neutral process heat supply is a key strategy for decarbonising industry



- > **475 TWh** in 2018 - mostly **natural gas and coal**
 - > Furnaces: 255 TWh
 - > Steam generation: 215 TWh
- > **Significant changes in steam generation**
 - > High-temperature heat pumps, biomass, electric boilers and hydrogen
 - > **Price difference** determines profitability
 - > **Investments** only account for a **small share** of the total costs

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Climate neutrality in 2045 is possible, but will require considerable effort

- › Central challenges are:
 - › the higher **operating costs of CO2-neutral technologies**
 - › the **expansion of infrastructure**
 - › the **reduction of uncertainties** regarding large strategic investments
 - › a **clear perspective** for the economic, large-scale industrial operation of **CO2-neutral processes**

Climate neutrality in 2045 is possible, but will require considerable effort

- › This requires a fundamental change of course:
 - › **CO2-neutral processes** must be **marketable and economical** as early as 2025/2030
 - › **CO2-neutral energy sources** must be available
 - › Rapid and large-scale **conversion and expansion** of **transport infrastructures** for hydrogen and electricity
 - › Consideration of **large industrial customers**
 - › Ambitious increase in **energy and material efficiency** as well as **circular economy**
 - › **Expansion of the regulatory framework**

Thank you for your attention

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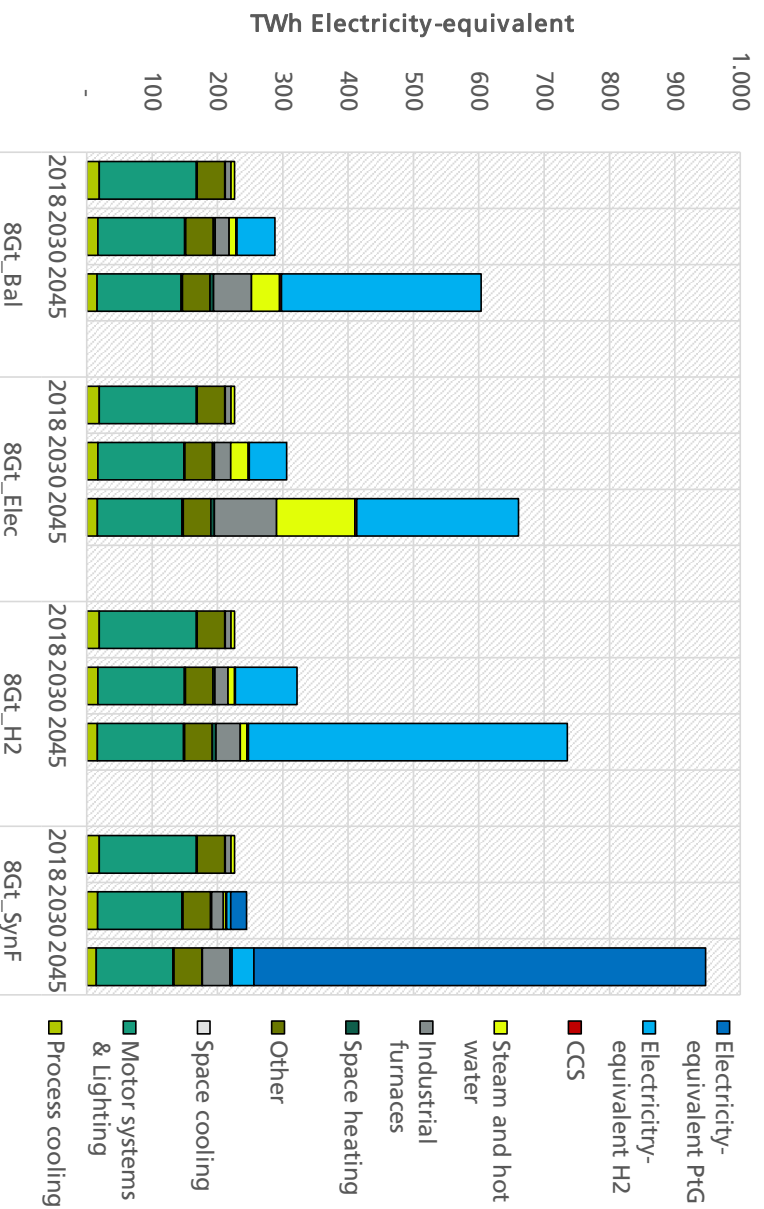
<https://www.isi.fraunhofer.de/de/themen/wasserstoff.html>

<http://www.forecast-model.eu>

<http://www.isi.fraunhofer.de>

Electricity equivalents for H2 and PtG generation change the picture completely

Electricity demand by application incl. H2 and PtG (2018 – 2045) [TWh]



- > Hydrogen and PtG are produced in a **CO2-neutral** way via electrolysis
- > Very high **electricity demand**
 - > Today 200 TWh
 - > **600 to 950 TWh until 2045**
- > Outside the system boundary used by the industrial sector
- > **Provision** of CO2-neutral secondary energy sources of central importance
- > Significant quantities **already required by 2030**
- > **Bi-valent demands** as a starting point?

Technology overview: H2 and electricity

Subsektor	Prozess/ Produkt	Konventionelle Technologie	H2-Alternative	TRL	Elektrische Alternative	TRL
Rohstoffliche Verwendung						
Grundstoff- chemie	Ammoniak	Dampfreformierung	Synthesegasbereitstellung aus H2	8-9	-	
	Methanol	Dampfreformierung	Synthesegasbereitstellung aus H2 und CO2	8-9	-	
	Olefine (HVC)	Steam Cracker	Methanol-to Olefins	8-9	Elektr. Cracker	5-6
Raffinerien	Rohölverarbeitung	Dampfreformierung	H2 aus Elektrolyse	8-9	-	
Bereitstellung von Prozesswärme						
Metalle	Rohstahl	Hochofen	Eisenerz-Direktreduktion (H ₂ -DRI)	5-7	Elektrolyse	4
	Nicht-Eisen Metalle	Erdgas-befuenerter Ofen (Teilweise bereits elektrische Öfen)	H2-befuenerter Ofen	4-5	Elektr. Ofen	5-7
	Gießerei					
	Walzen / Weiterverarbeitung					
Glas	Behälterglas	Erdgas-befeuerte Glasschmelzwanne	H2-befeuerte Glasschmelzwanne	4-5	Elektr. Glasschmelzwanne	6-8
	Flachglas					
Zement und Kalk	Zement	Erdgas-befuenerter Ofen	H2-befuenerter Ofen	4-5	Elektr. Ofen	4-5
	Kalk					
Alle	Dampferzeugung	Erdgas-betriebener Dampferzeuger	H2-betriebener Dampferzeuger	9	Elektr. Dampferzeuger (<500°C)	9
					Elektr. Wärmepumpe (<150°)	8

Reinvestitionsbedarf in Anlagen ausgewählter Produkte (oben) u. Marktdiffusion neuer Verfahren im Mix (unten)

