The Economics of Combating Climate Change

2019 EU-US Frontiers of Engineering Symposium

November 20, 2019

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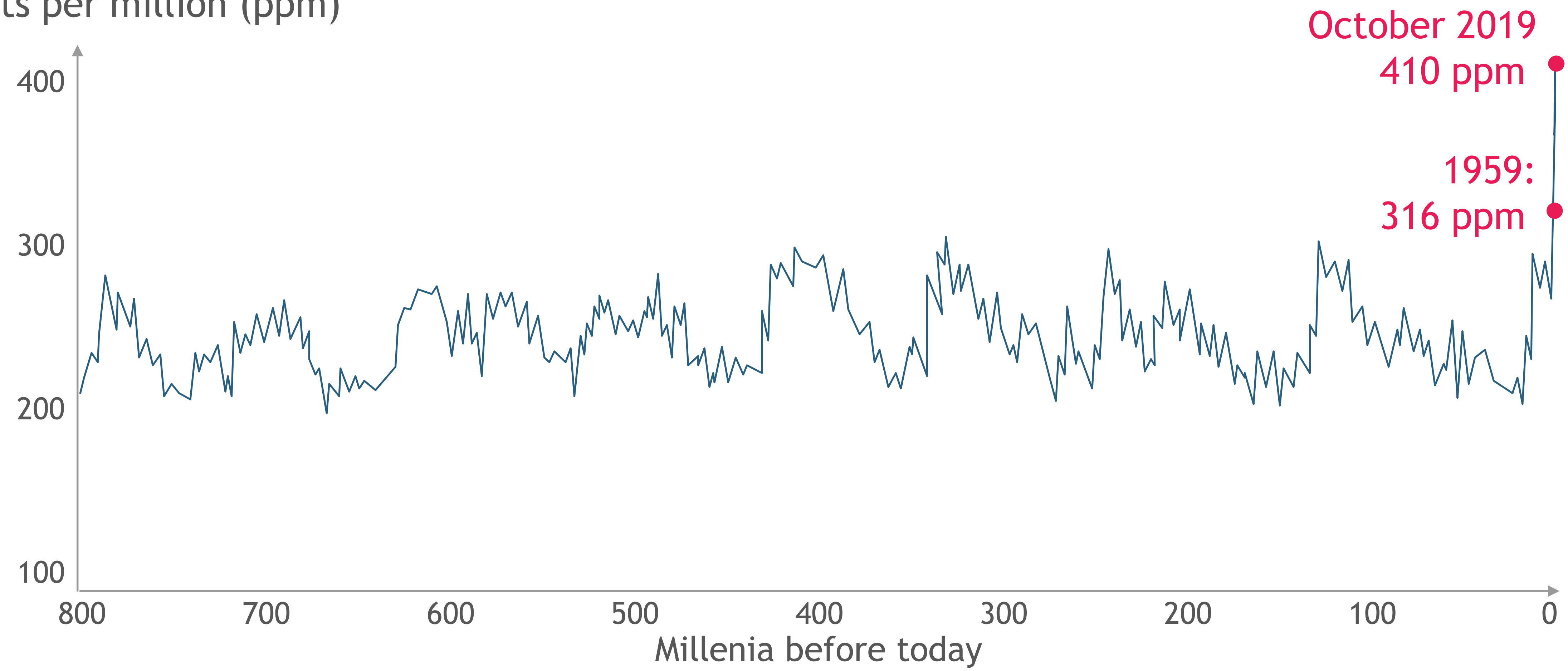
2 | Decarbonizing a country

3 | Global climate impact

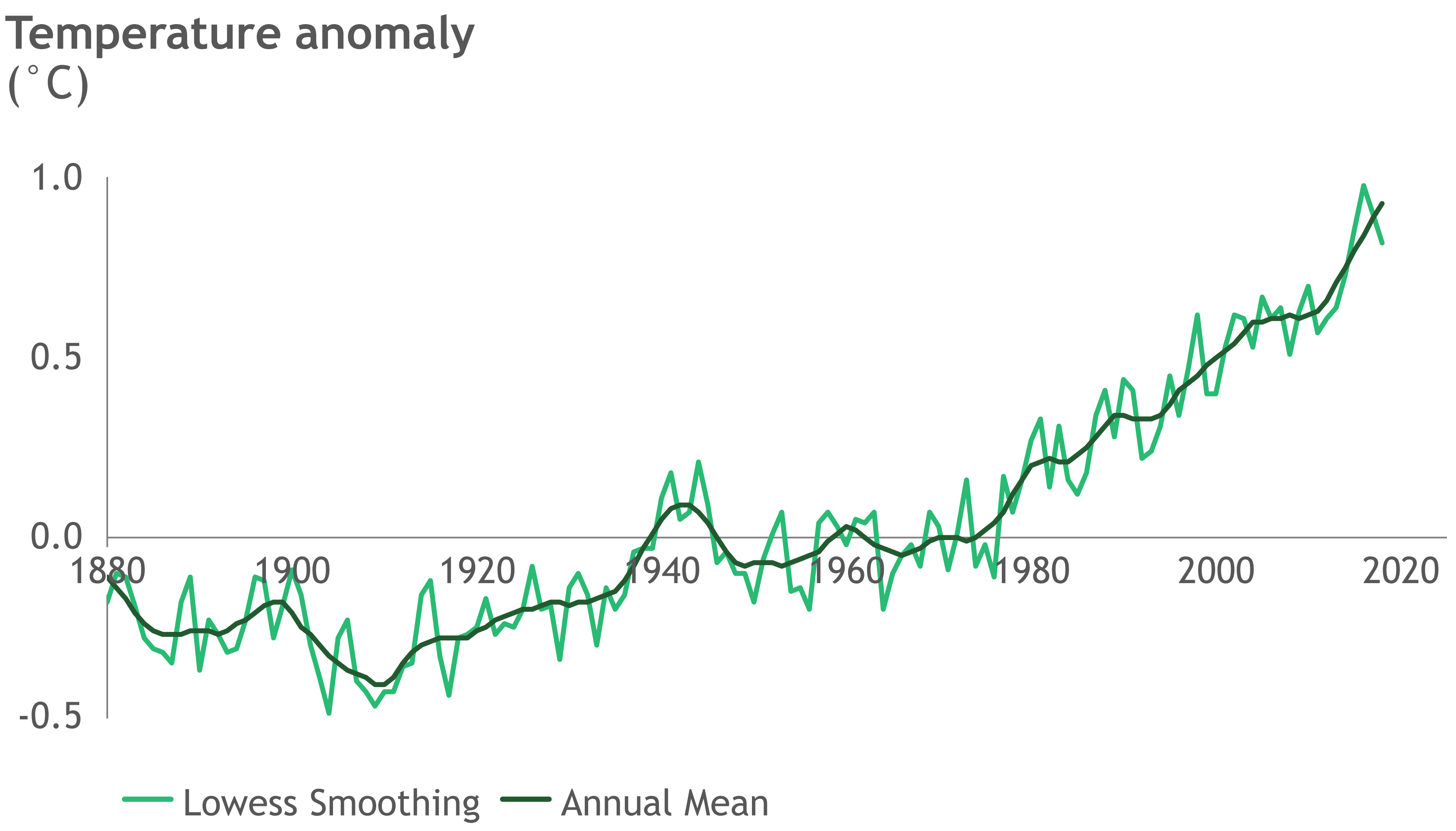
4 | Further research need & outlook

Highest atmospheric CO_2 concentration in a million years

CO_2 concentration in the atmosphere
Parts per million (ppm)



Our planet is getting warmer



2100?

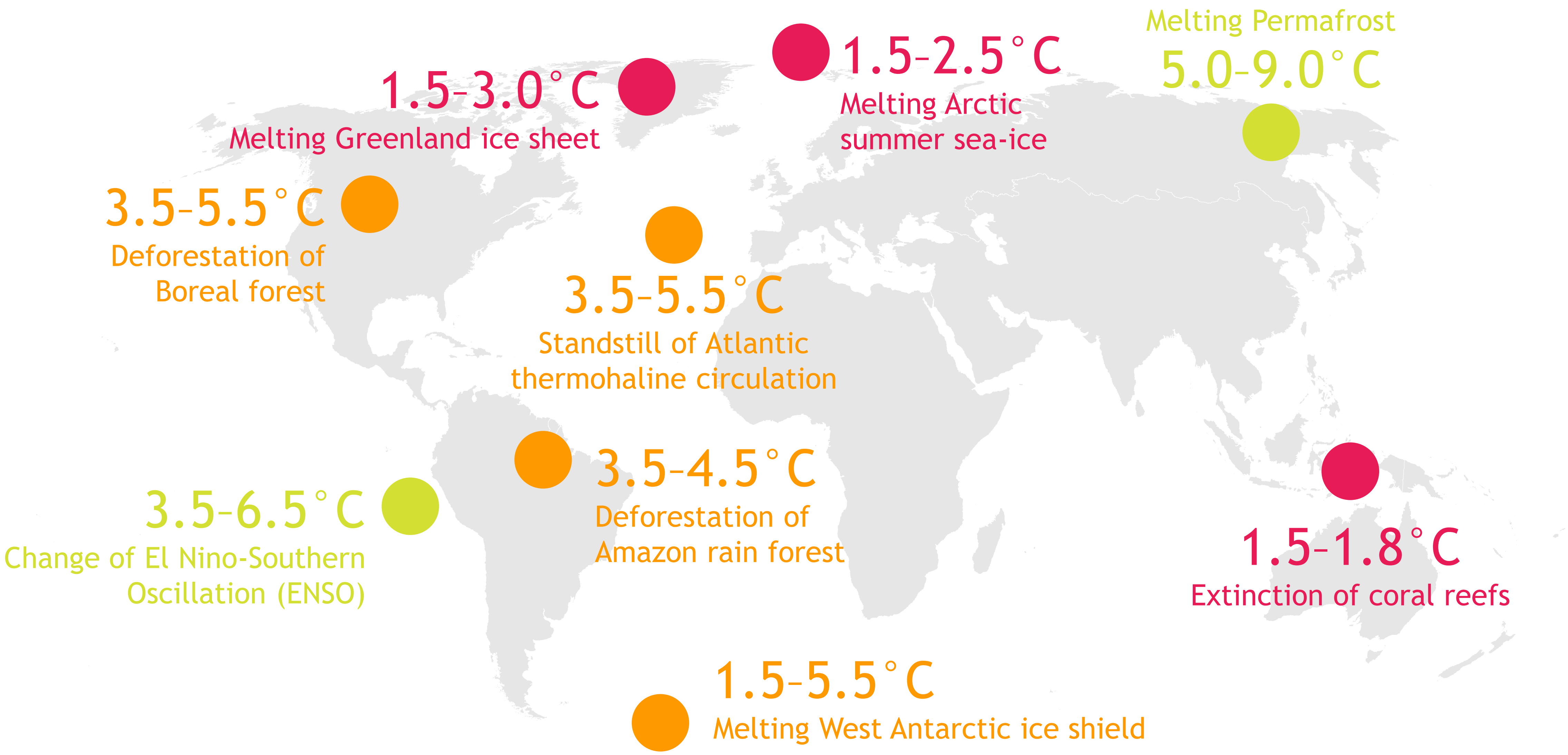
<4.0°C Current policy

<3.2°C Paris INCPs

<2.0°C Paris target

<1.5°C Paris ambition

Several 'tipping points' ahead—of no return?



Heat crisis—and an economic case for action

1.5° Paris ambition

-8 % GDP[1]

+2 months of droughts[2]

2° Paris goal

-13 % GDP[1]

+4 months of droughts[2]

Key 'tipping points'

4+° Current path

-30 % GDP[1]

+>10 months of droughts[2]

Holland, NYC, Bangladesh, ... flooded

Severe food crises risk[3]

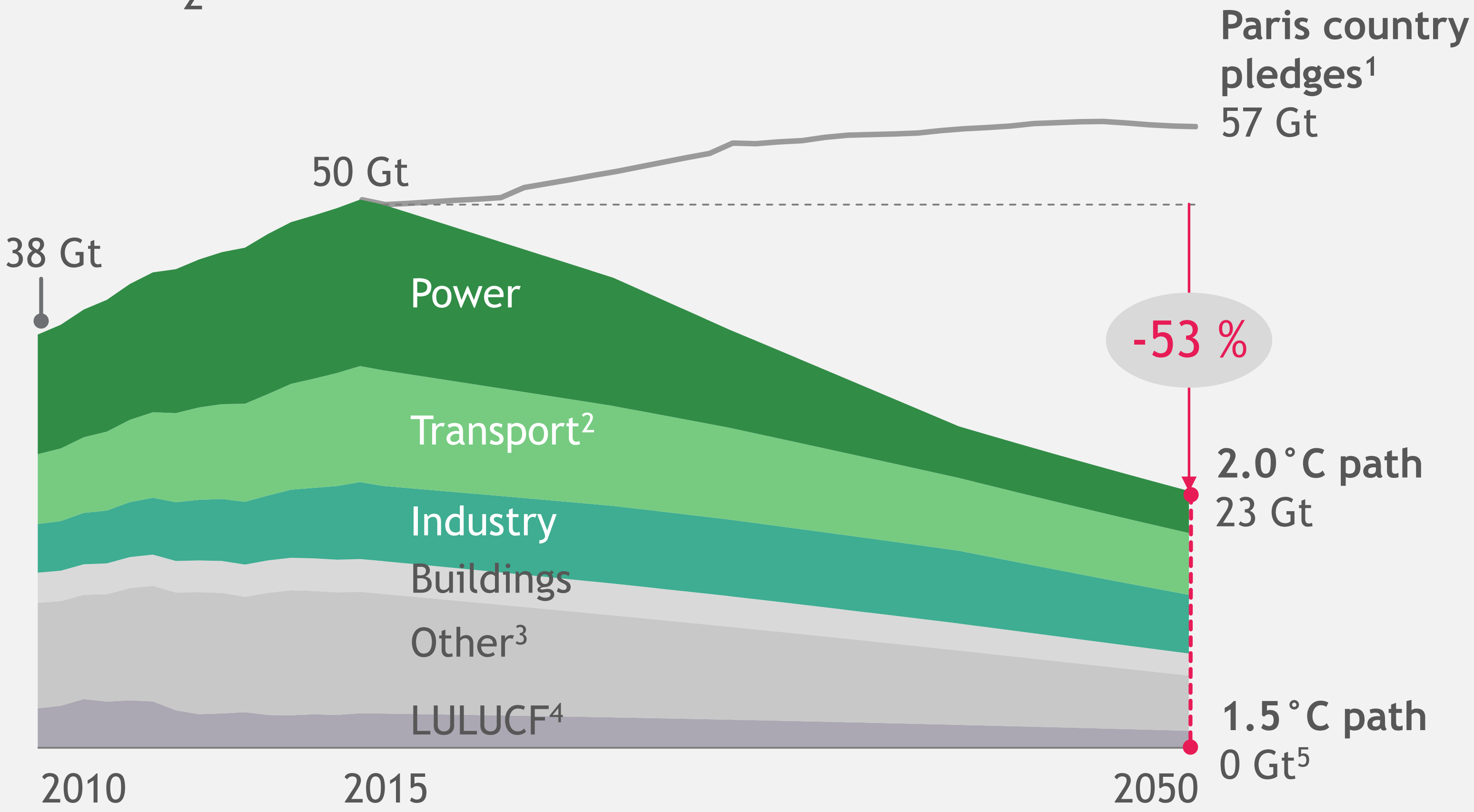
6x wildfire area in US

...

Note: Temperature increase refers to global warming by 2100
1. Per capita, relative to no additional warming 2. Increase in avg. drought duration 3. Severe risk of close-to-annual occurrence
Source: UN Intergovernmental Panel on Climate Change (IPCC); Burke et al

The world needs to act

Global GHG emissions
Gt CO_2e



GDP[6]	$75 trillion	+200 %	$235 trillion
Population	7.3 billion	+30 %	9.7 billion

1. Assumes implementation of current Paris pledges 2. Includes bunkers (international marine and aviation)
3. Agriculture, Waste and Fugitive emissions 4. LULUCF: Land Use, Land-Use Change, and Forestry
5. Net emissions (includes negative emissions levers) 6. GDP in 2010 USD
Sources: IEA, World Energy Outlook 2017; WRI; IMF; World Bank; Climate Action Tracker, BCG analysis

How to decarbonize a developed economy

Background: Climate Paths for Germany

Unique fact base

All sectors

>200 measures

Optimized by greenhouse gas abatement cost

Investments, costs, GDP-effects

Broad validation

~ 10 months

~ 40 workshops

~ 70 associations, corporations

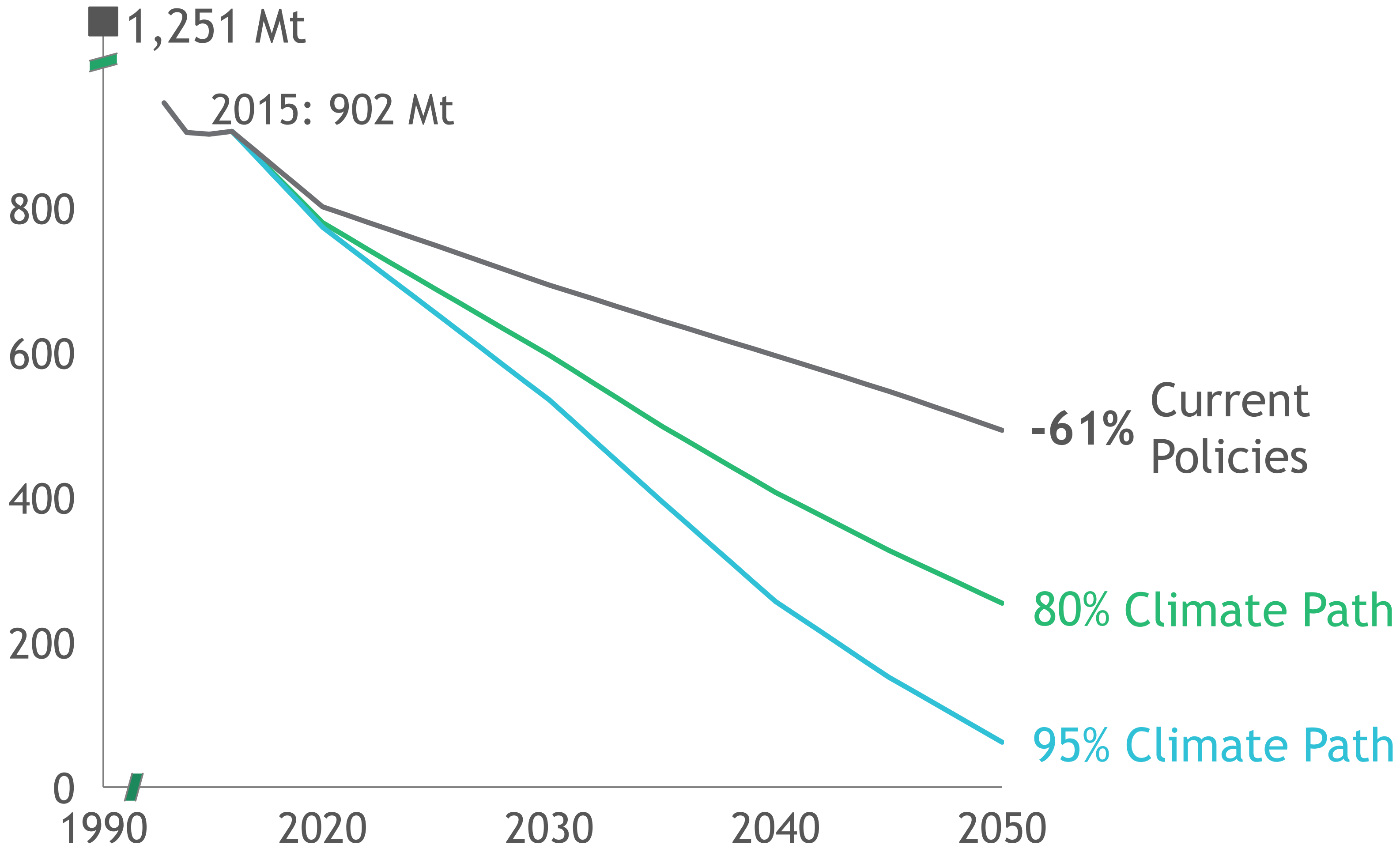
~ 200 industry experts

~ 280 pages

Starting point: 61% greenhouse gas reduction under "current policies" scenario …

Greenhouse gas (GHG) emissions in Germany

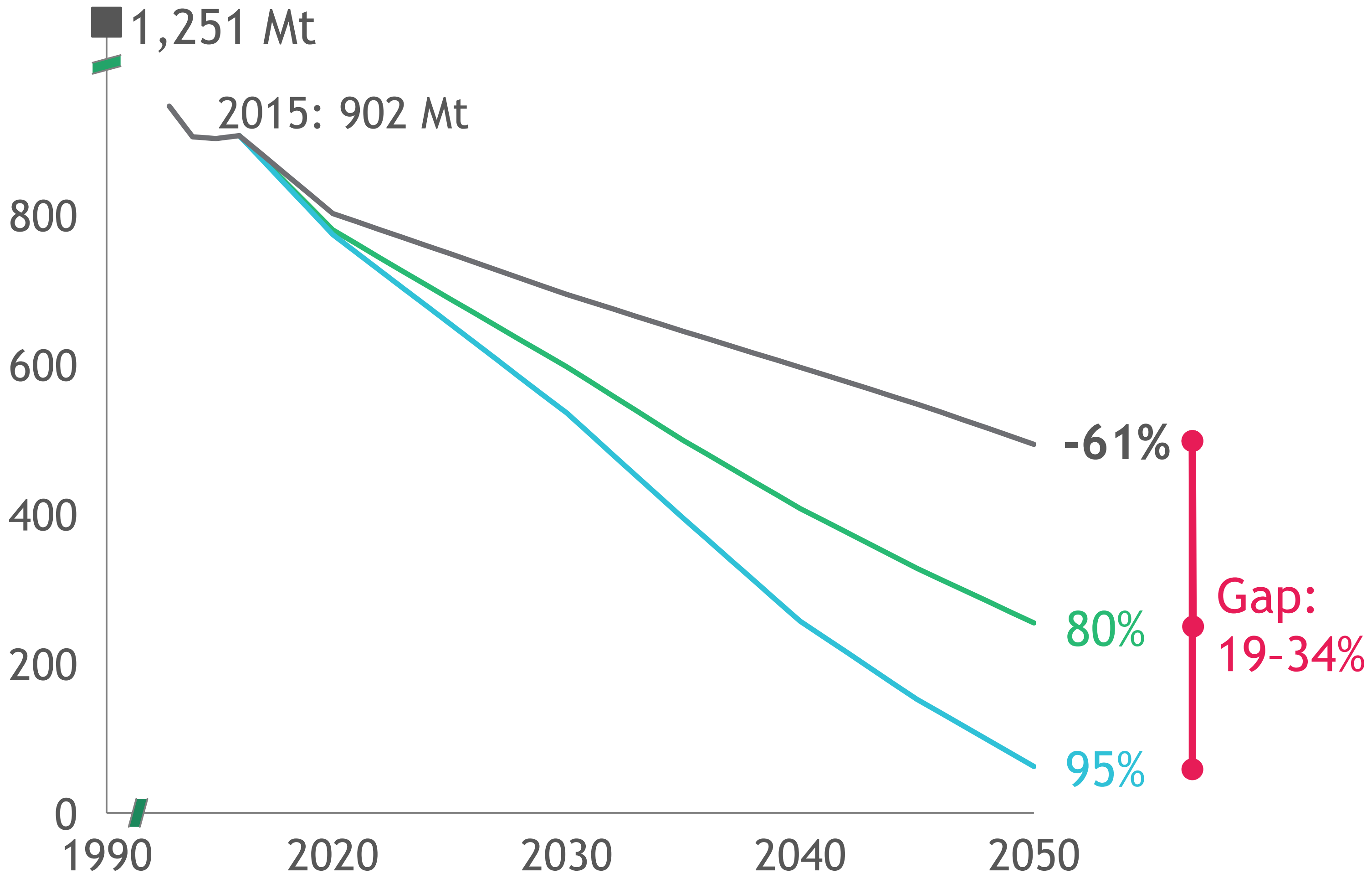
Mt CO_2e



NRT = national reduction targets of the German government (corridor)

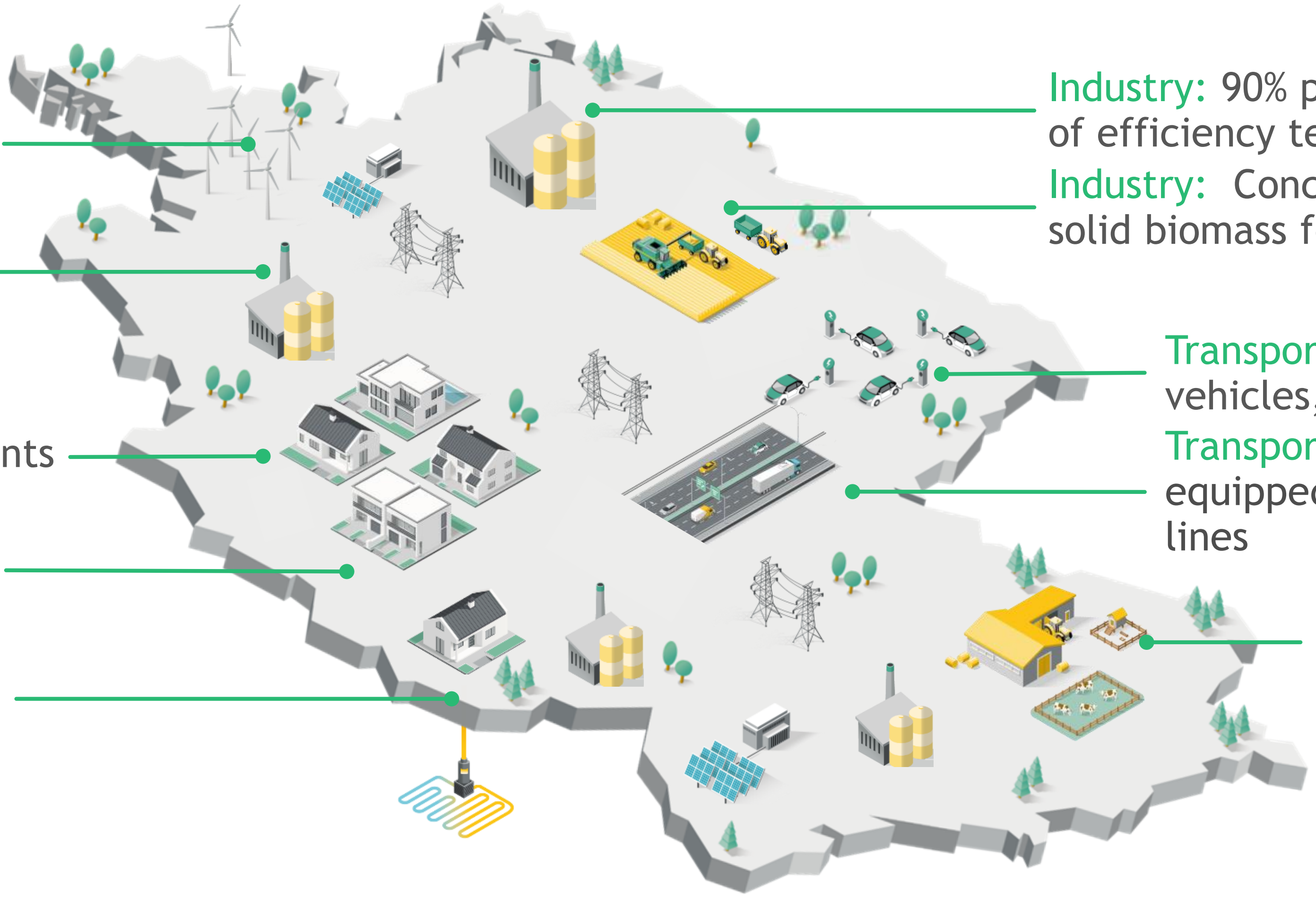
… but major gaps to national reduction targets remain

Greenhouse gas (GHG) emissions in Germany
Mt CO_2e



NRT = national reduction targets of the German government (corridor)

80% path achievable with proven technologies



Energy: 240 GW wind and PV, grid expansion

Energy: Gradual replacement of coal with gas

Buildings: 50% more insulation/refurbishments (1.7% p.a.)

Buildings: Expanded urban district heating

Buildings: 14M heat pumps, mainly in 1- to 2-family homes

Industry: 90% penetration of efficiency technologies

Industry: Concentration of national solid biomass for heat < 500°C

Transport: 26M electric vehicles, 2/3 of passenger cars

Transport: 4,000 km of freeway equipped with truck overhead lines

Agriculture: More efficient use of fertilizer

PV = photovoltaics
All figures refer to 2050

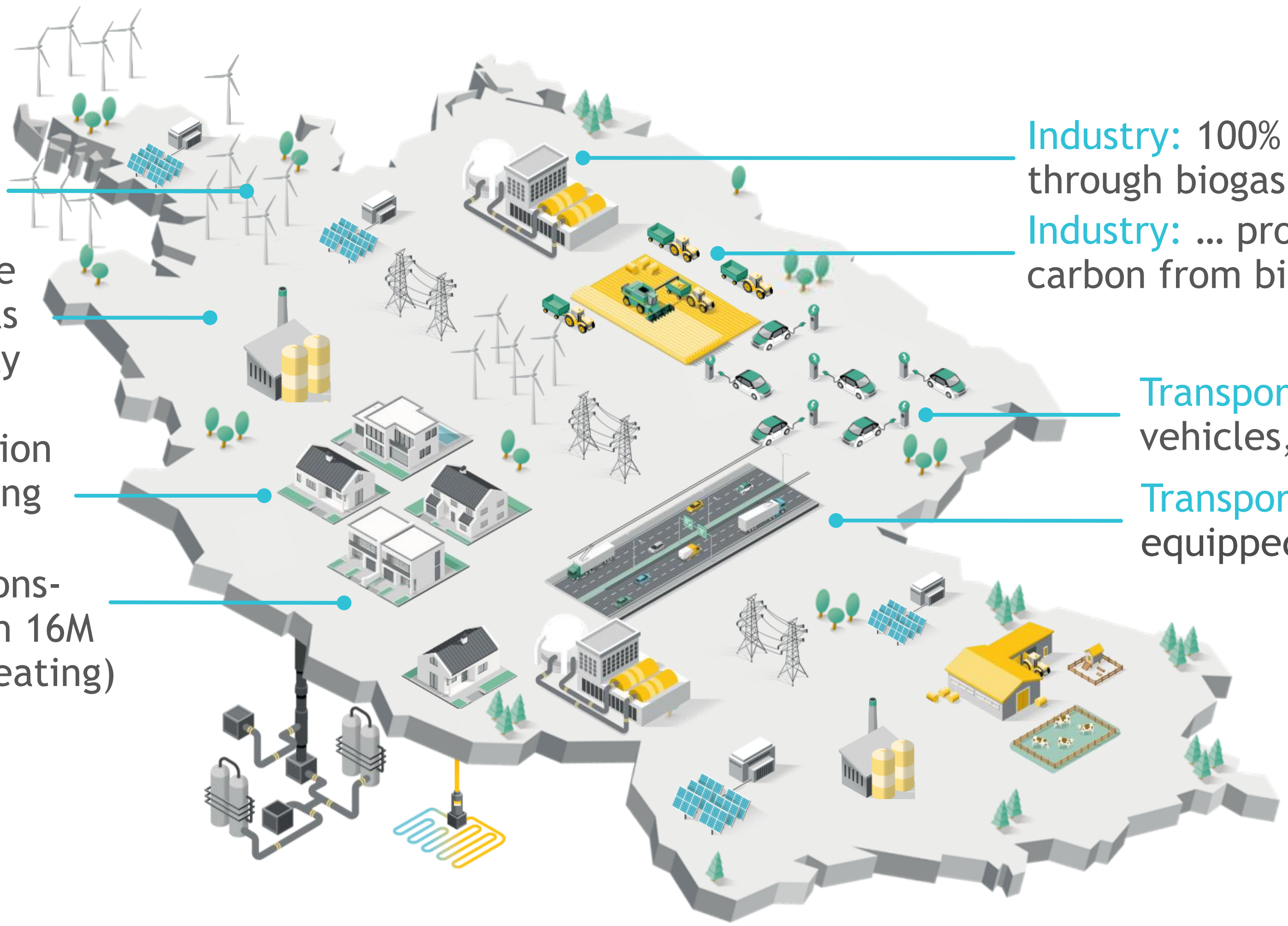
95% path pushes boundaries of technology and acceptance

Power: 292 GW wind and PV, grid expansion

Energy: 100% renewable through PtG, gas grid as seasonal storage facility

Buildings: +70% insulation (1.9% p.a.) – full building stock 2015 refurbished

Buildings: 100% emissions-free heat (esp. through 16M heat pumps, district heating)



Industry: 100% renewable heat through biogas/PtG …

Industry: … produced with recycled carbon from biomass combustion

Transport: 33M electric vehicles, 4/5 of passenger cars

Transport: 8,000 km of freeway equipped with overhead lines

PtL = power-to-liquid, PtG = power-to-gas
All figures refer to 2050

95% path pushes boundaries of technology and acceptance

340 TWh imports of renewable fuels (H_2, PtL, PtG)

Power: 292 GW wind and PV, grid expansion

Energy: 100% renewable through PtG, gas grid as seasonal storage facility

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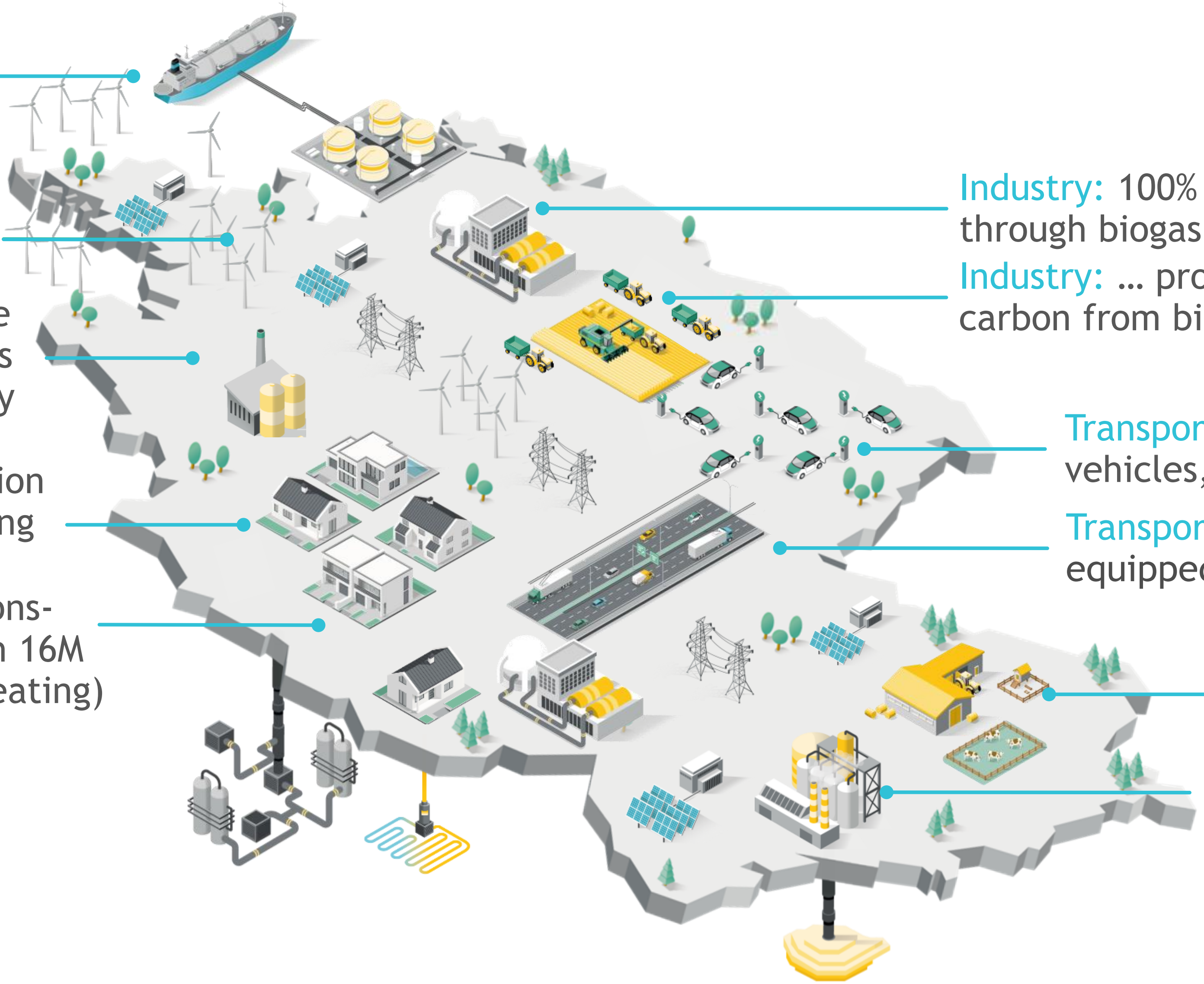

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Agriculture: "Methane pill" for cattle

Carbon capture and storage for cement, and - if H_2 not economically viable - for steel and steam reforming

PtL = power-to-liquid, PtG = power-to-gas
All figures refer to 2050

Reducing emissions with positive impact on GDP

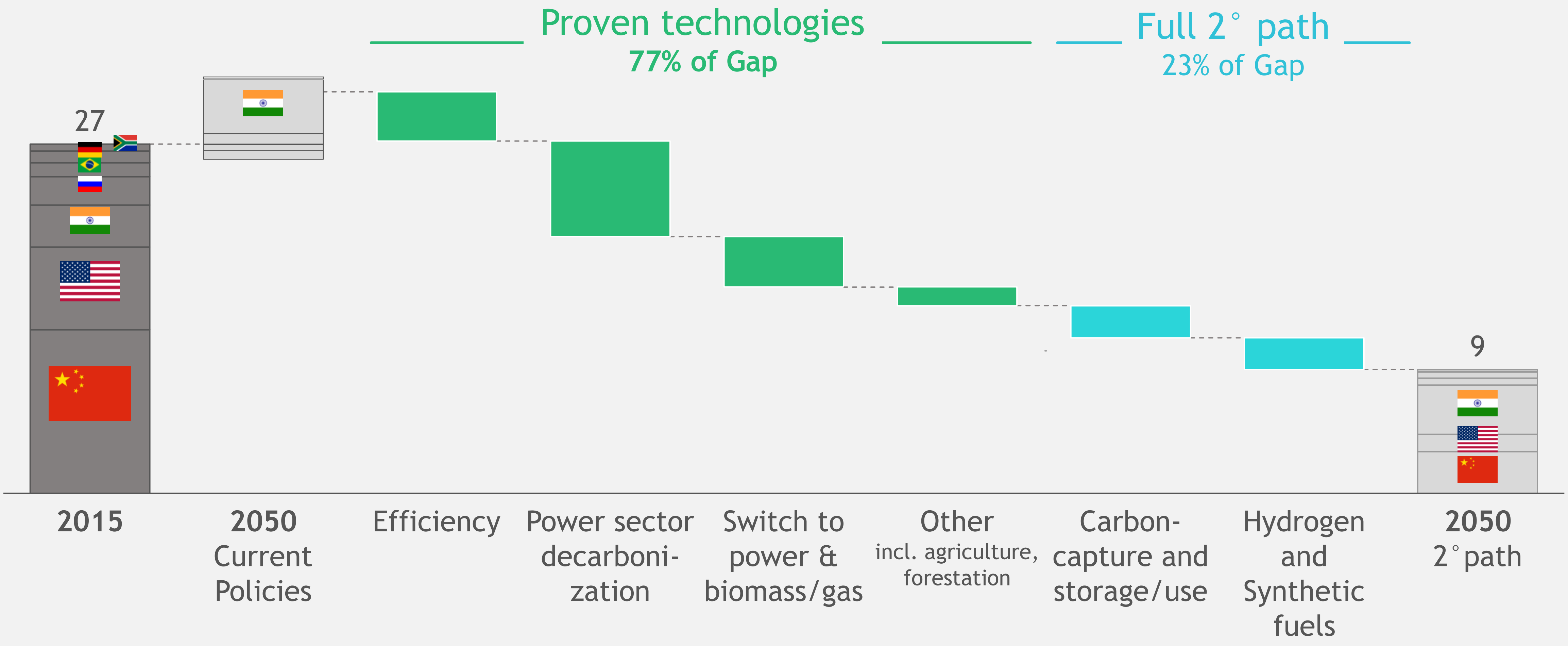
GDP effects in 2050	"Global effort"	"Unilateral"
80% Climate Path: Technically possible and economically feasible	+0.9% GDP in 2050	+0.6% GDP in 2050
95% Climate Path: Only possible with similarly high ambitions in other countries	+0.9% GDP in 2050	Not plausible as a national initiative

Note: All GDP figures with no crowding-out of climate protection investments; percentages refer to relative effect in 2050, not annual GDP growth

Global climate impact

Proven technologies can close 77% of gap to 2°C

Greenhouse gas emissions for selected countries (>60% of global emissions)
Gt CO_2equivalent



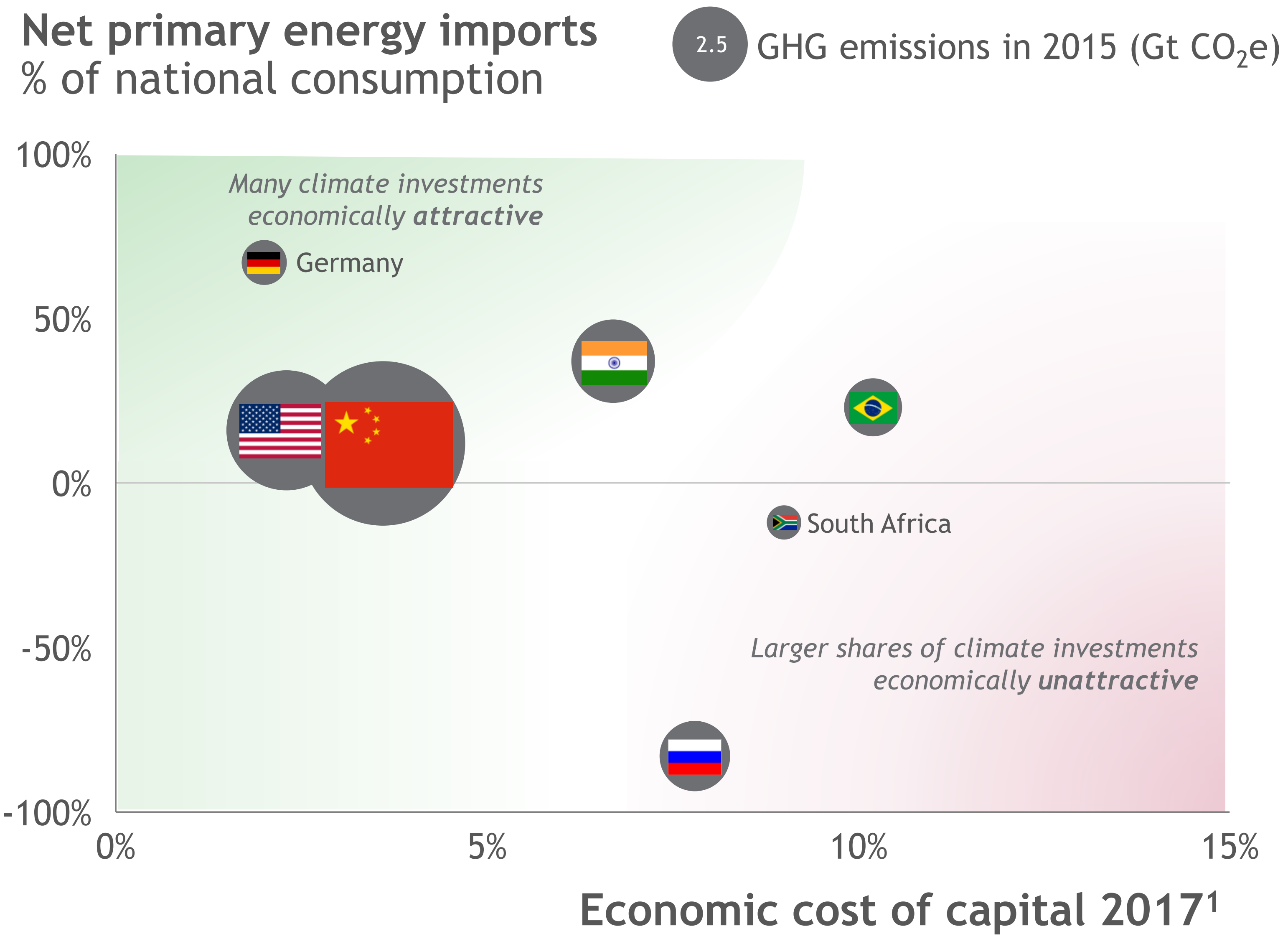
Source: BCG analysis, IEA scenarios

Countries need to invest ~1-2% of their GDP each year

GHG emissions ($Gt\ CO_2e$)		China	USA	India	Russia	Brazil	Germany	South Africa
2050 current policies		13.3	5.6	7.3	2.2	1.2	0.5	0.5
Gap to 2°C (100%)	Proven Technologies	74%	74%	92%	74%	76%	67%	78%
	Full 2°C path	26%	26%	8%	26%	24%	33%	22%
2050 full 2° path		3.7	1.3	3.8	0.5	0.5	0.06	0.1
Avg. annual investment (share of GDP[1])	Proven Technologies	1.0%	1.0%	1.8%	2.2%	1.0%	1.1%	1.9%
	Full 2°C path	1.7%	1.5%	1.9%	6.1%	1.7%	1.5%	3.5%

1. The investments for the full 2° path also include the investments in the proven technology path
Source: IEA, BCG

Climate investments pay off for many countries (macro-) economically, but not for all



1. Yield on 10y government bonds 2017; for Germany: macroeconomic modelling of Climate Paths for Germany study
Source: Oxford Economics, IEA, BCG

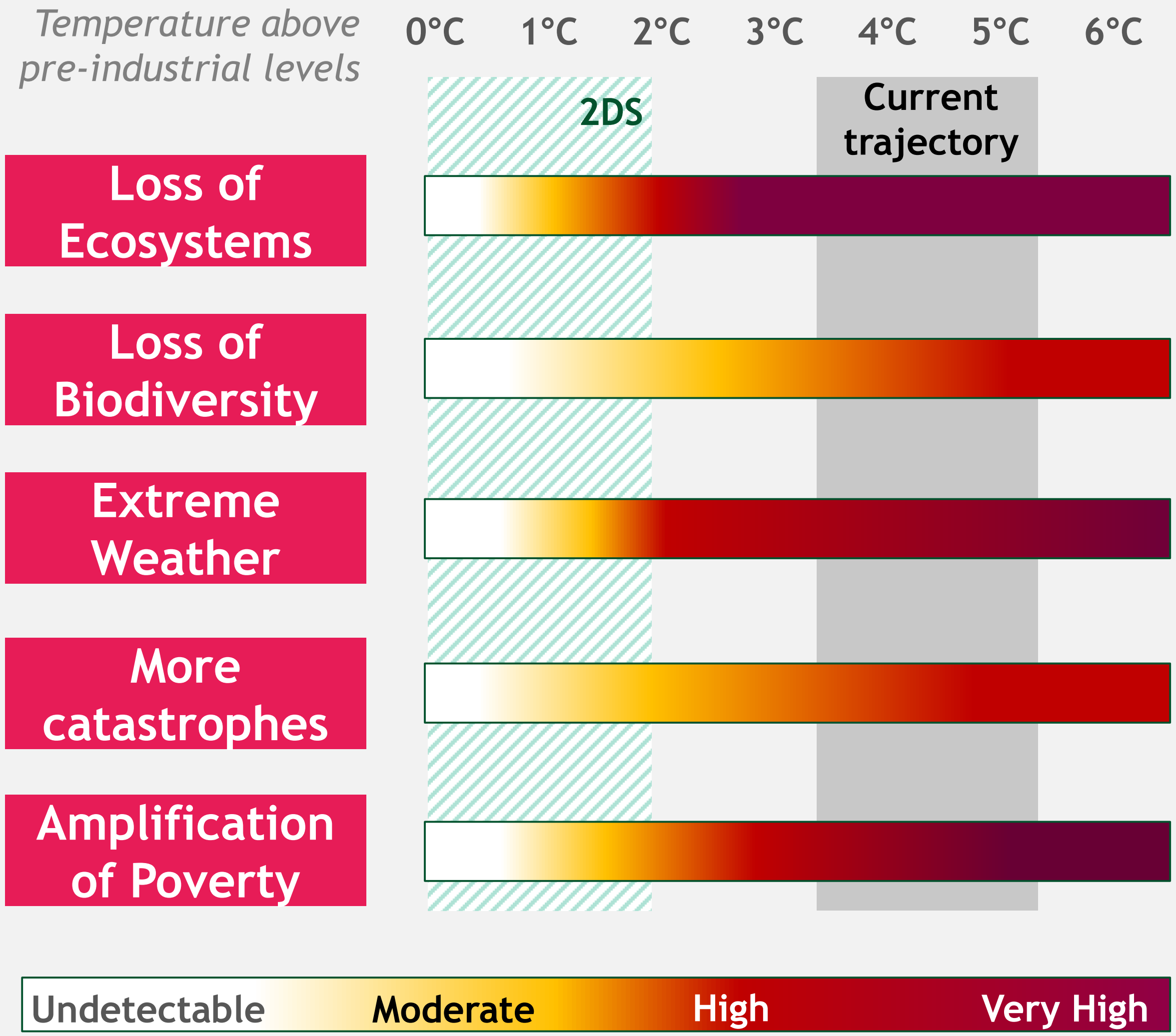
Further research need & outlook

We need more detailed national agendas and a technology & market push in hard-to-abate sectors

Main Takeout	Development and research need
The myth of the early-mover disadvantage • Every country will benefit economically from moving closer to its 2°C contribution	**Fully detailed national climate agendas** • Economically optimized mitigation agendas in broad alignment with national stakeholders • Policy packages that help market actors overcome investment hurdle
But, deep collaboration for 2°C needed • Steep rampup of hydrogen/P2X and CCS • Global investment of ~$75 trillion through 2050 (2% – 6% of countries' annual GDPs) • Catalyzing these investments will require coordinated government action	**Technology & market development** • Hydrogen value chains • Synthetic fuel technology development • Carbon capture and storage • Internat. & national policy instruments for early decarbonization in hard-to-abate sectors (industry, aviation, shipping)

1. As defined by IEA ETP 2017; For agriculture, waste, and fugitives, we used historical trends (source: World Resource Institute) and macroeconomic indicators, and calibrated the results with the median "pledges scenario" time series of the Climate Action Tracker (CAT

Final thought: Even if short of 2°C success, we should go for it



The outcome is not binary

- This is not an 'either-or' situation, 2°, 3°, 4°C likely with vastly different outcomes
- Even short of 2°C success, outcomes below status quo will avoid negative effects

Trade-offs are not linear

- Change above 4-5°C may have compounded, catastrophic effects across sub-systems

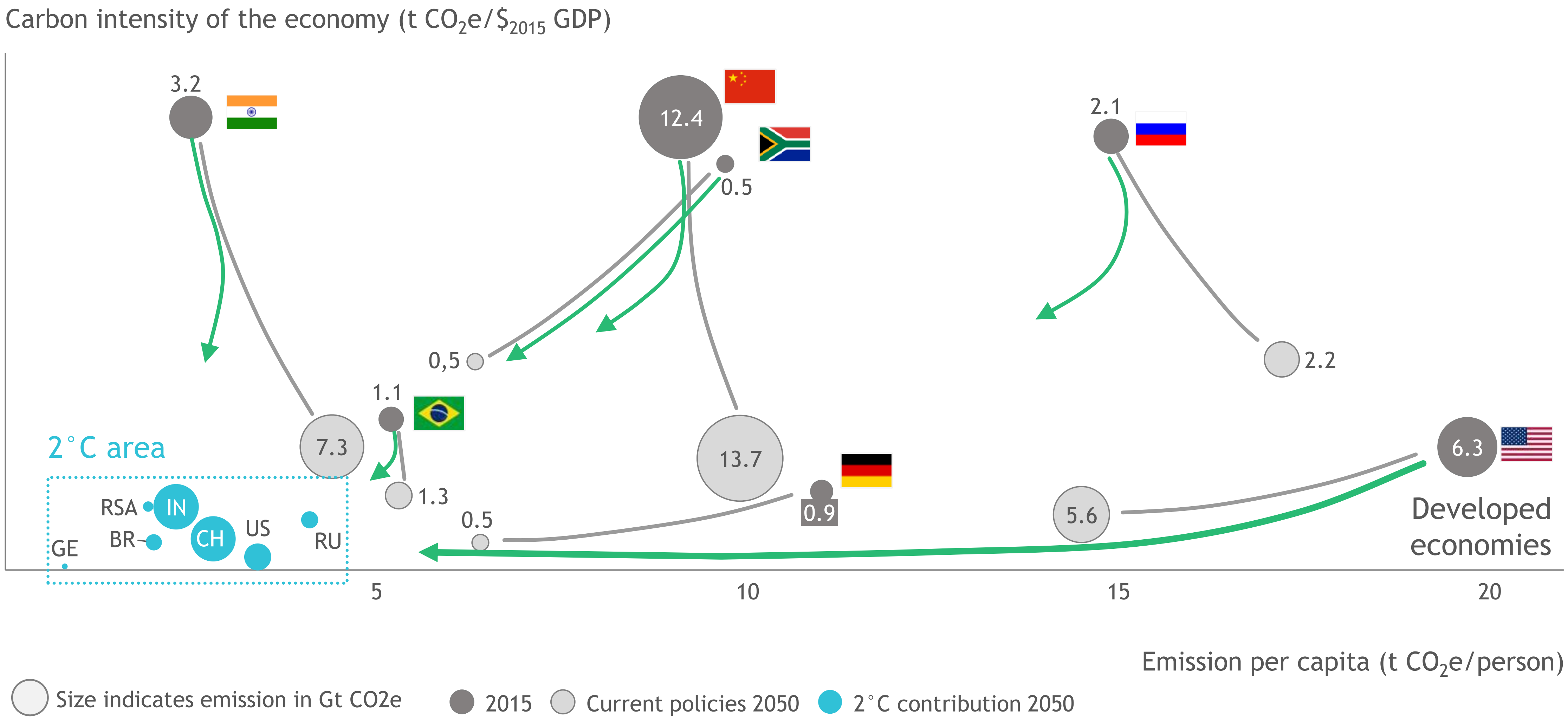
The world does not end in 2050

- Even shooting short of 2°C change, the trajectory for the future will matter

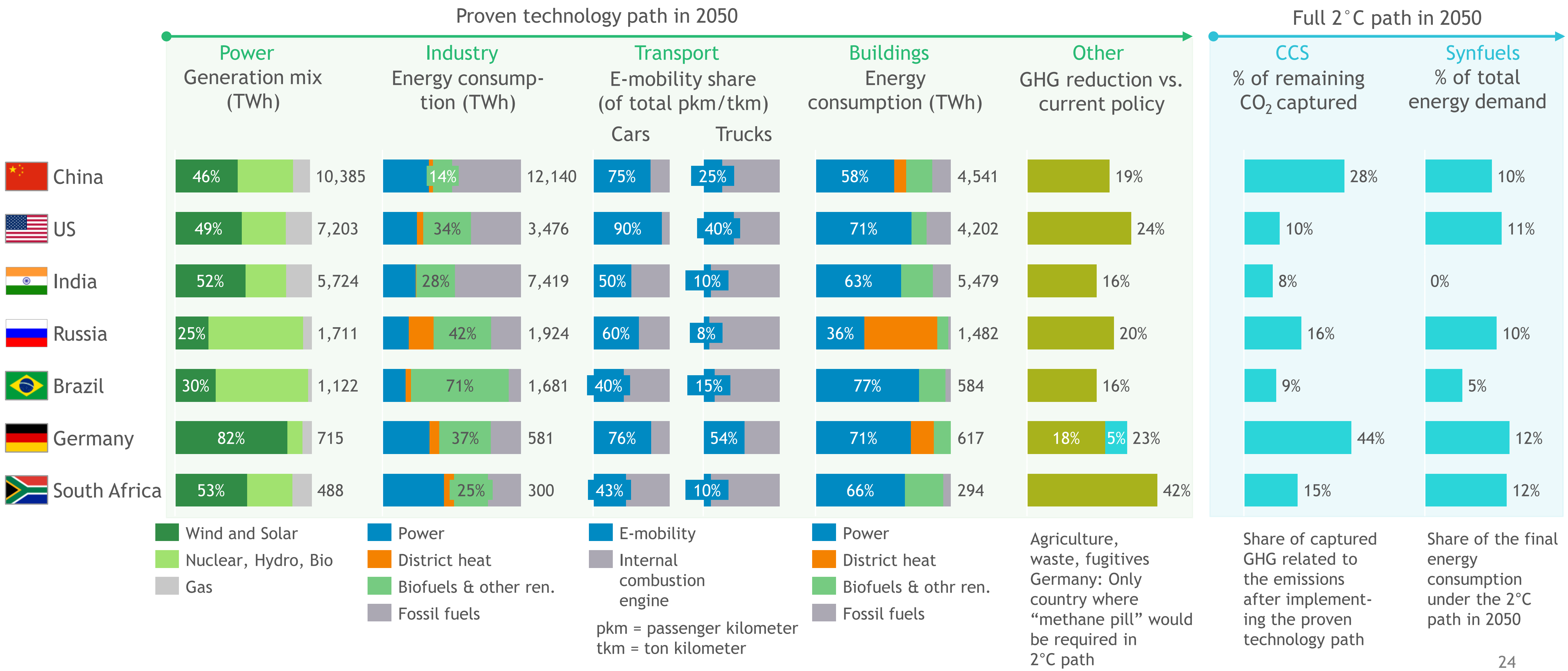
1Source: IPCC AR 5 2014; BCG

Thank you for your attention!

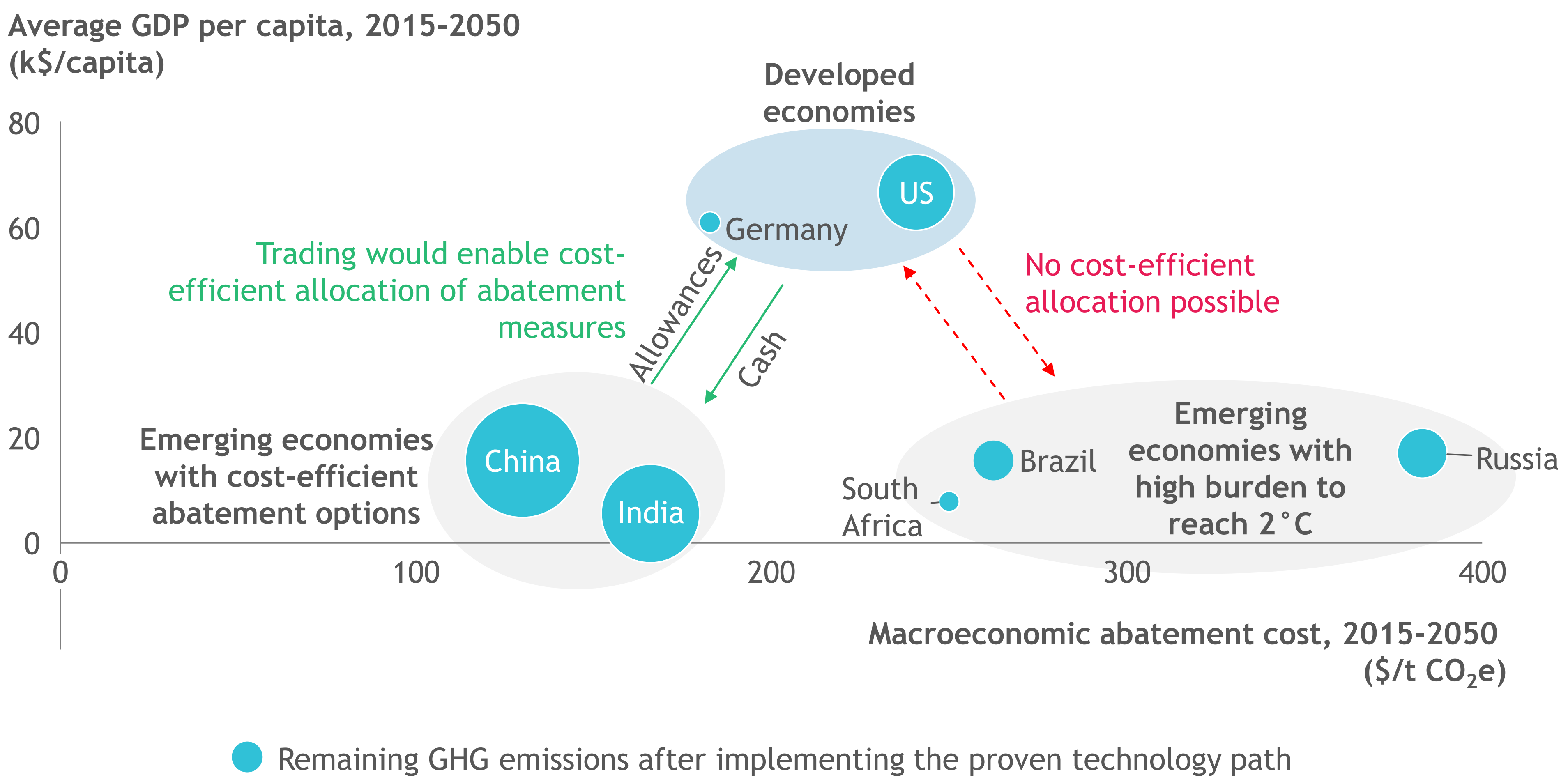
Developed countries need acceleration, others a direction change



Optimal path differs and will require national climate agendas



Emissions trading alone will not help all countries reach their 2°C targets



Note: The costs for emission abatement reflect the average macroeconomic costs for closing the gap between the proven technology and 2°C paths.
Source: International Monetary Fund, World Bank, BCG analysis

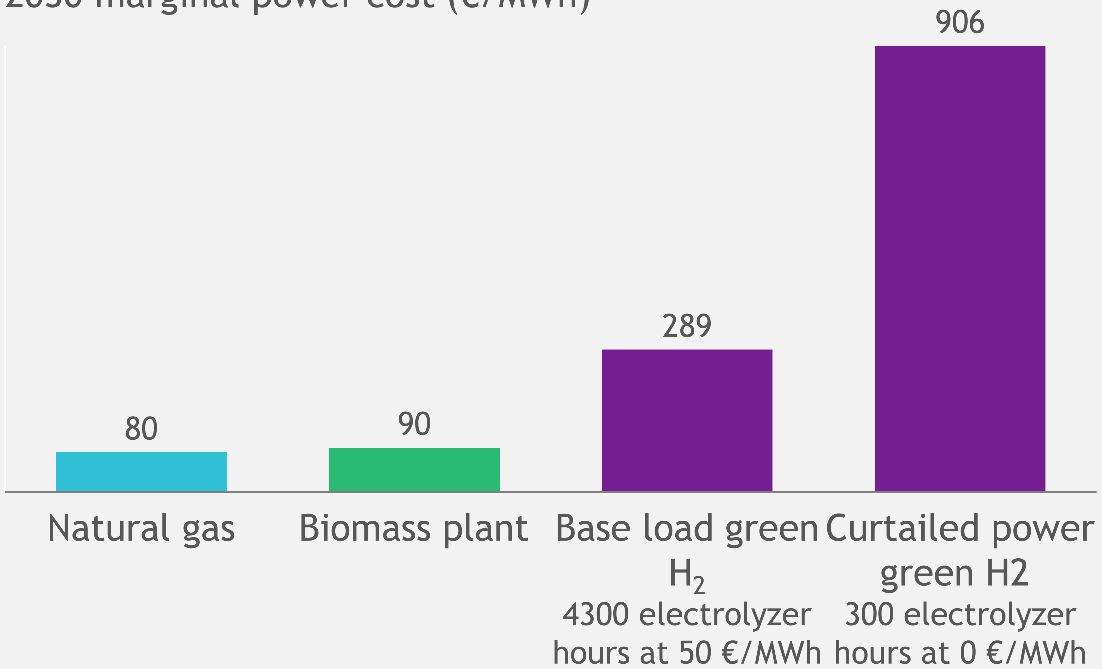
Most hyped H_2 use cases not likely to become mainstream

Illustrative

Power storage

>3 x higher marginal costs (not accounting Capex)

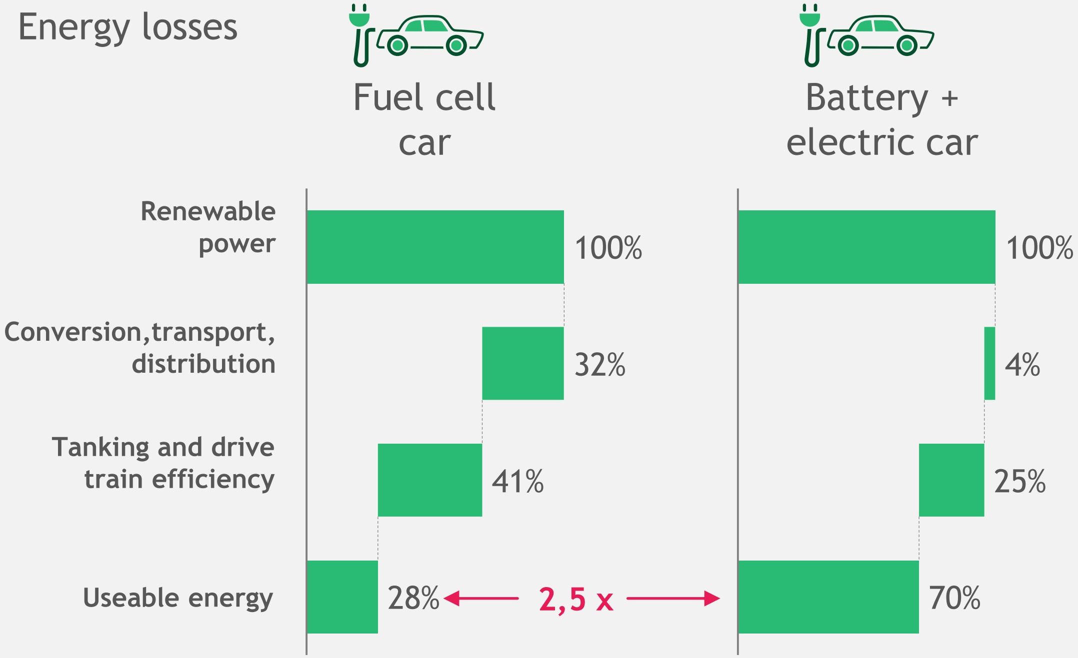
2030 marginal power cost (€/MWh)



Passenger cars

>2.5 x higher power cons. vs. battery vehicles

Energy losses

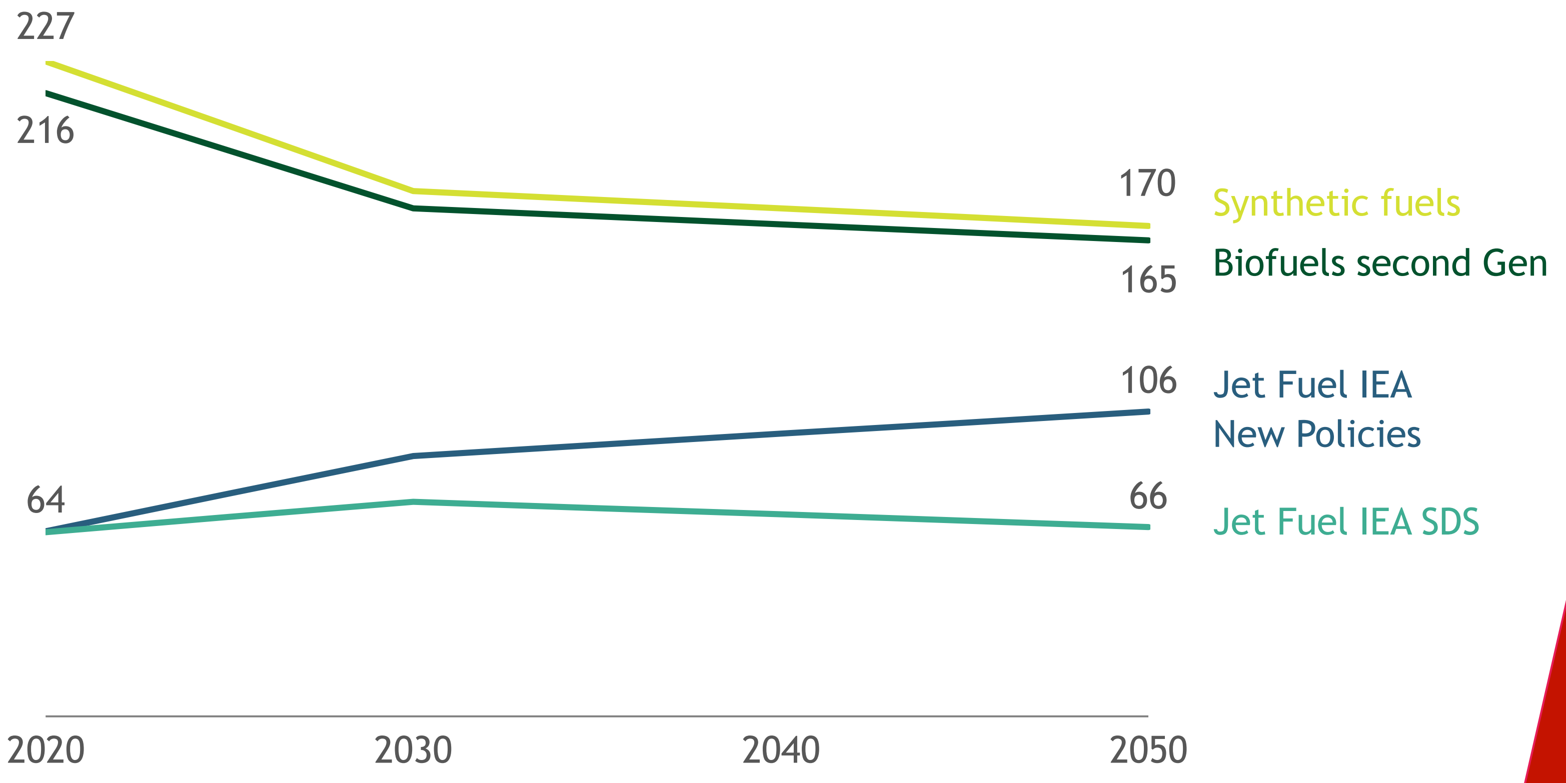


H_2 in industrial processes most promising near-term application

Green H_2 for..	Industry	Transport	Power	Buildings
	H_2 for ammonia, refineries steel, other chemicals	H_2/P2G/L for cars, trucks, ships and planes	H_2 for fuel cells and P2G for seasonal energy storage	H2 in fuel cells or P2G/L for oil and gas boilers
Near-term potential				
	• Large existing use of fossil H_2 • Limited decarbonization alternatives	• Tough competition from BEV in passenger cars • Open technology competition in trucks • PtX only alternative in aviation and shipping	• Arguably among the most expensive generation technologies • H_2/PtG needed in the long run for last-mile decarbonization of flexible power backup generation	• Deep decarbonization achievable through existing technologies (e.g. insulation, heat pumps, solar thermal, green district heating etc.)

Aviation & shipping: More than twice the fuel costs

Price development of selected fuels ($/MWh)



Cost impact of different fuels ($/passenger on a 10-hour flight[1], 2050)

Synthetic fuels:
160-260 $/p

Up to
+160%
fuel cost vs.
jet fuel

Biofuels 2nd Gen:
150-250 $/p

Up to
+150%
fuel cost vs.
jet fuel

1. $ increase in a 10h flight with a Boeing 747 and a total of 524 passengers – calculation done with IEA SDS & New Policies Scenarios
Source: UNEP DTU, IEA, BCG analysis