Climate Change and Sustainable Growth

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ENERGY TRANSITIONS COMMISSION

The climate and economic challenge

Technologies – getting to net zero emissions

The shape of the future global economy

Economic costs and investments

Policies to deliver zero carbon economy at low cost


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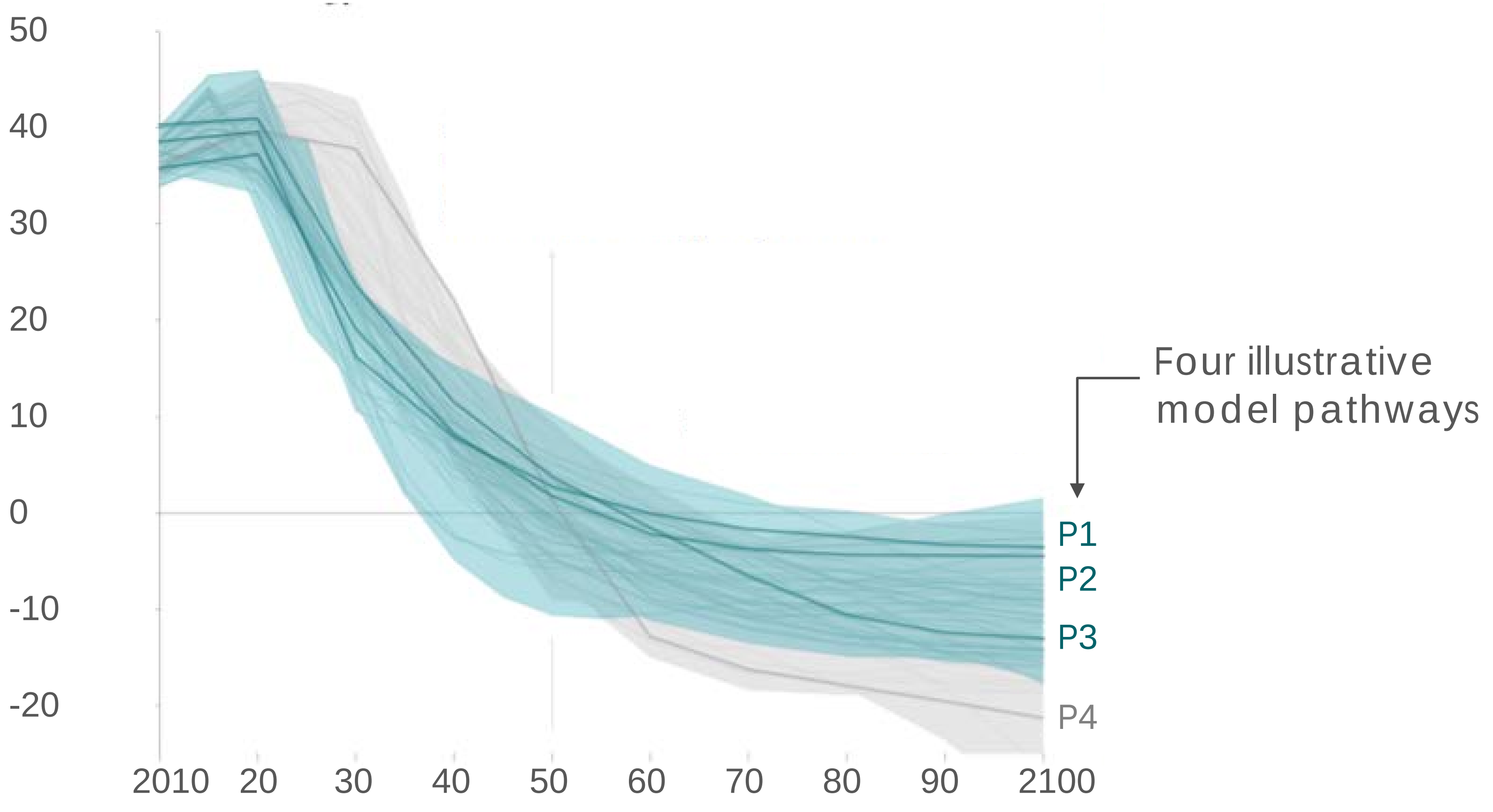
In the beautiful Midwest, wind chill temperatures are reaching minus 60 degrees, the coldest ever recorded. What the hell is going on with Global Warming? Please come back fast, we need you!

sky news **Australia swelters as temperatures approach 50˚C**

To limit global warming to 1.5˚C global CO_2 emissions must fall to net zero by around 2050

Global emissions pathways in the IPCC 1.5˚C report

Gt CO_2/year



Source: IPCC (2018), *Global Warming of 1.5˚C*

It is technically and economically feasible for the global economy to reach by 2050 net-zero carbon emissions from the energy and industrial systems without relying on offsets from land use

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How to meet the challenge – getting to net zero emissions:

Decarbonising electricity

Decarbonising heavy industry

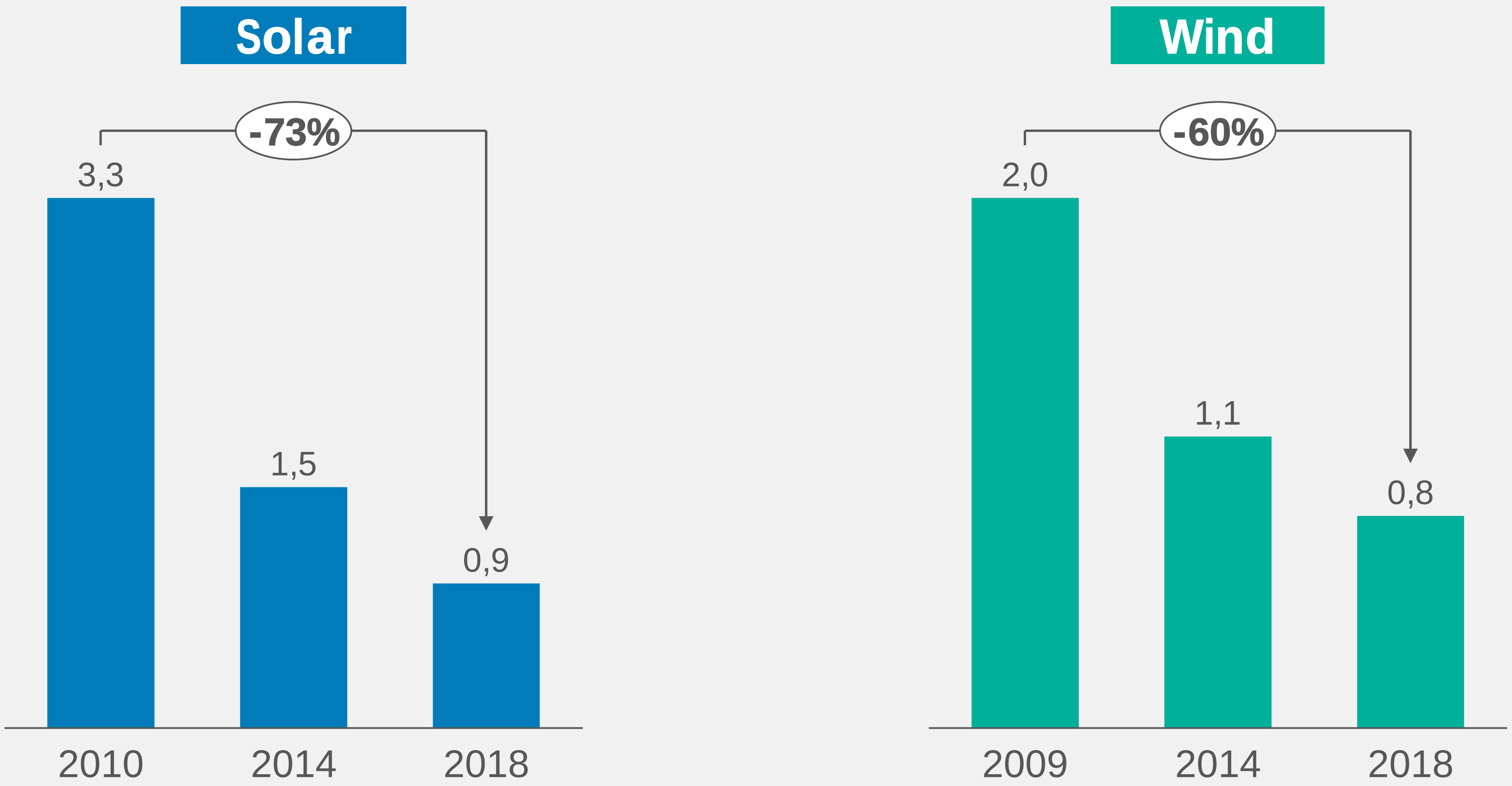
Decarbonising transport

Costs to consumers and industry

Continually falling costs of solar panels and wind turbines, combined with lower financing costs...

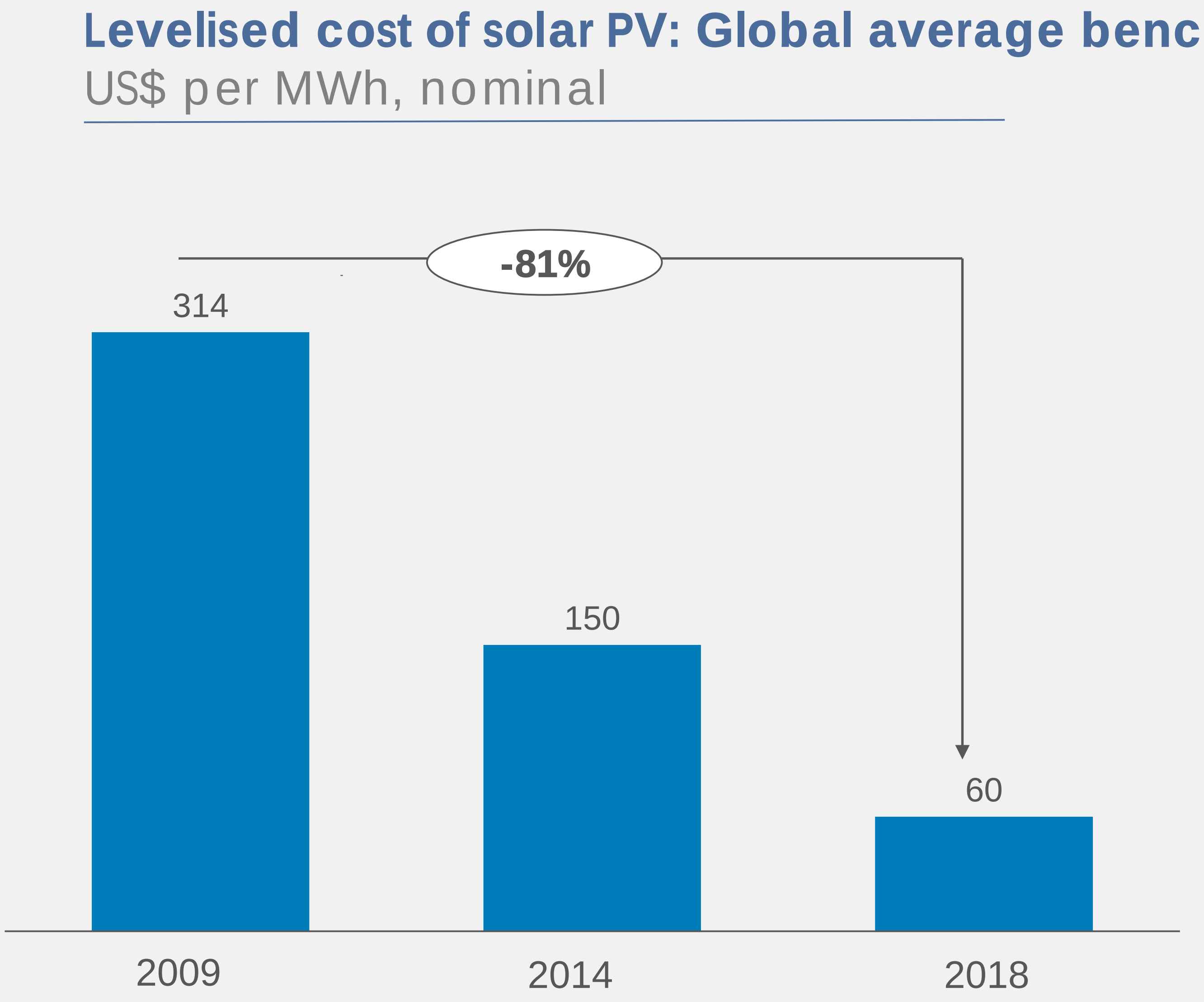
Cost of renewable capacity: Global average benchmark

US$m per MW, 2017 (real)



Source: Bloomberg New Energy Finance (2017)

… has driven a dramatic fall in 'levelised cost' estimates

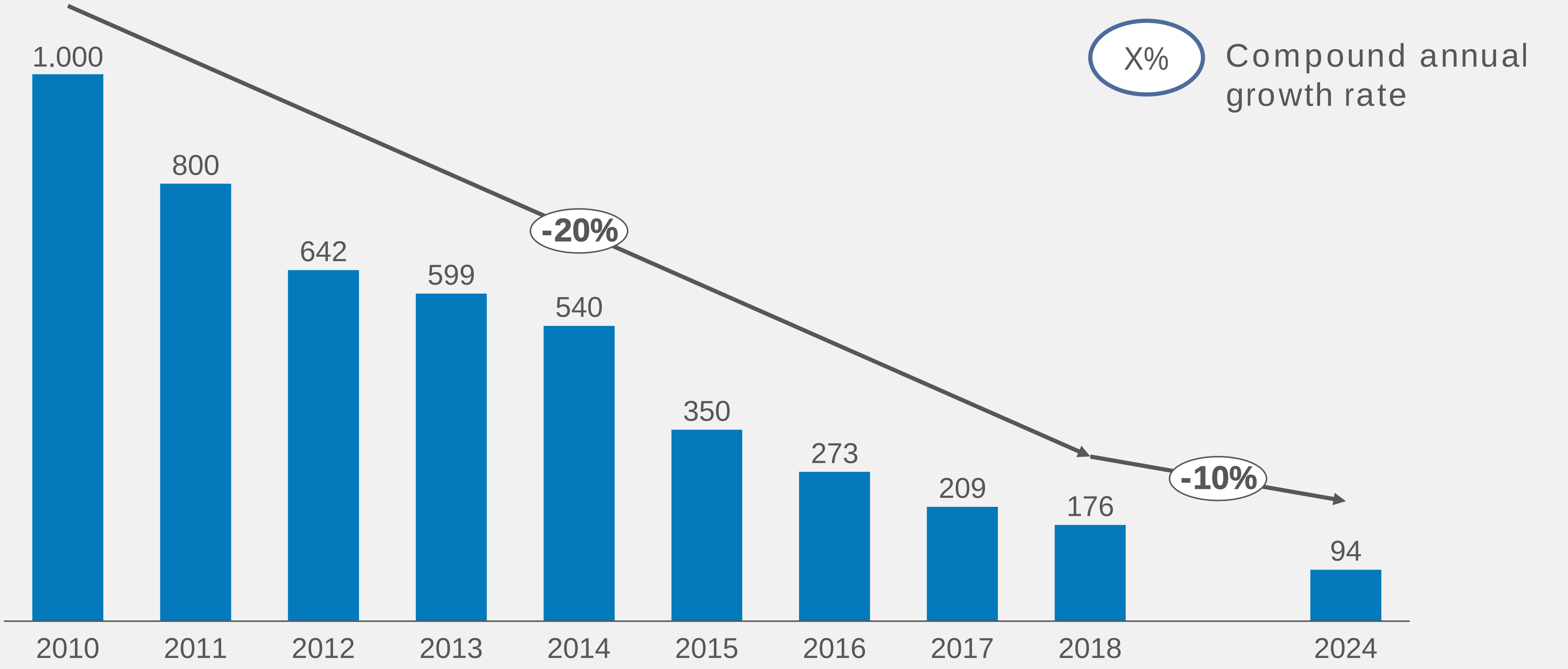


Source: Bloomberg New Energy Finance (2017)

Battery prices have fallen by 20% p.a. since 2010 and will likely fall below US$100/kWh by 2024

Battery prices – Observed
US$/kWh of storage

Battery prices – Outlook
Predicted



Source: Bloomberg New Energy Finance (2017)

Flexibility and back up in a near total renewable electricity system

Category of flexibility challenge	Solutions
'Ramping – meeting rapidly increasing power demand as renewable supply fades (e.g. at end of day)	Wide area interconnection Batteries increasingly economic solution to ramping and daily variation
Daily hour by hour variations in — Demand (e.g. in residential homes) — Renewable supply	Dispatchable hydro Nuclear as baseload Flexible thermal plants with carbon capture Hydrogen
Seasonal variations in — Demand (e.g. winter home heating peaks) — Supply (e.g. Indian Monsoon)	Demand management in • Industry • Buildings • Transport (E.V. batteries)

Average cost of electricity in 85% renewable power system: 2030

US$/MWh

US$70/MWh

Maximum in most geographies even if flexibility provided only by batteries and gas peaking plants

US$55/MWh

Achievable in most geographies which use:

- Dispatchable hydro
- Nuclear
- Sophisticated demand management

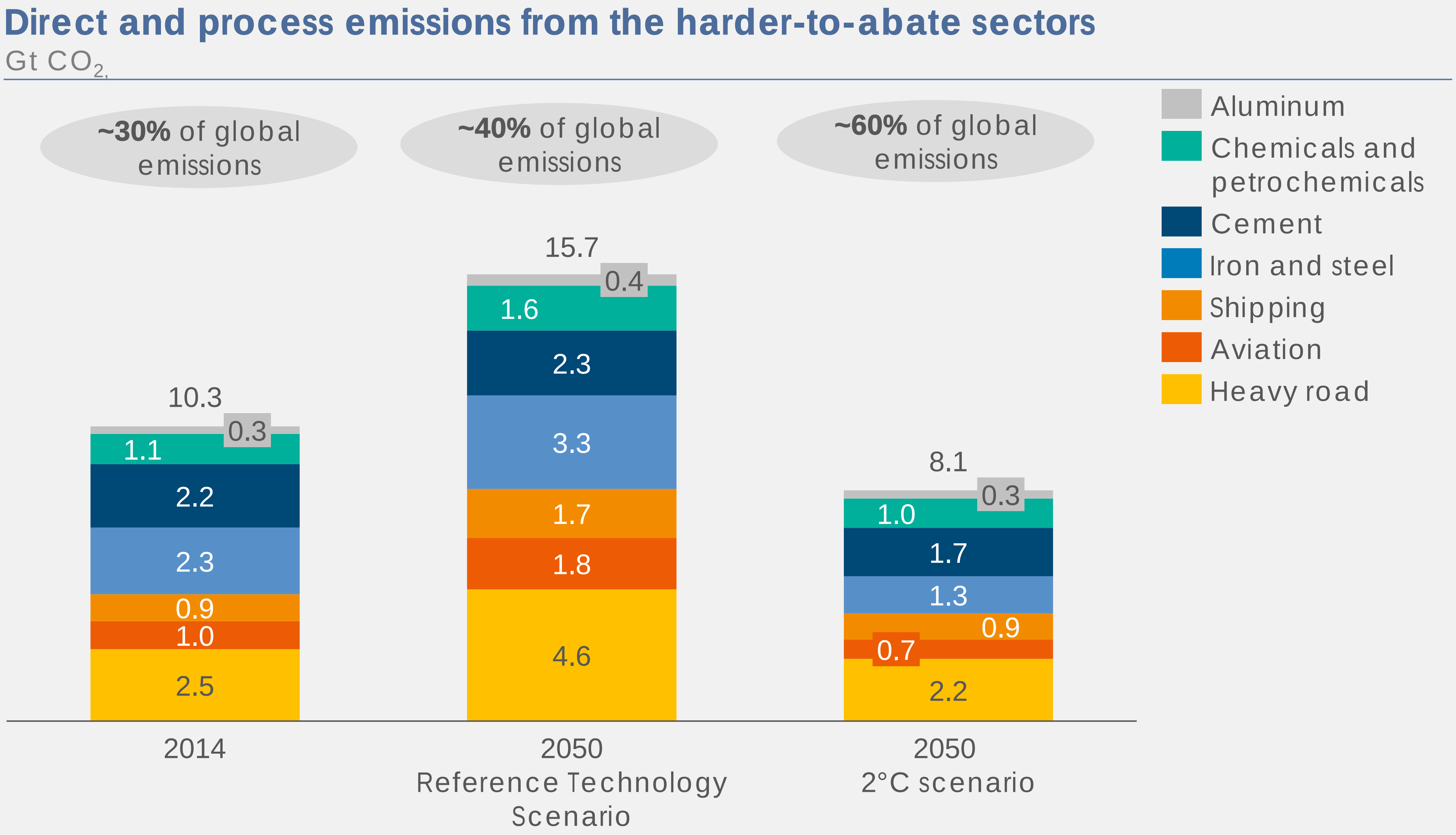
<US$35/MWh

In favorable geographies

- Chile
- North Africa
- Middle US states
- China?

Source: Energy Transitions Commission (2017), *Low-cost, low-carbon power systems*

Without forceful action emissions from harder-to-abate sectors could reach 60% of the total by mid-century



Source: IEA (2017), *Energy Technology Perspectives*

How to meet the challenge – getting to net zero emissions:

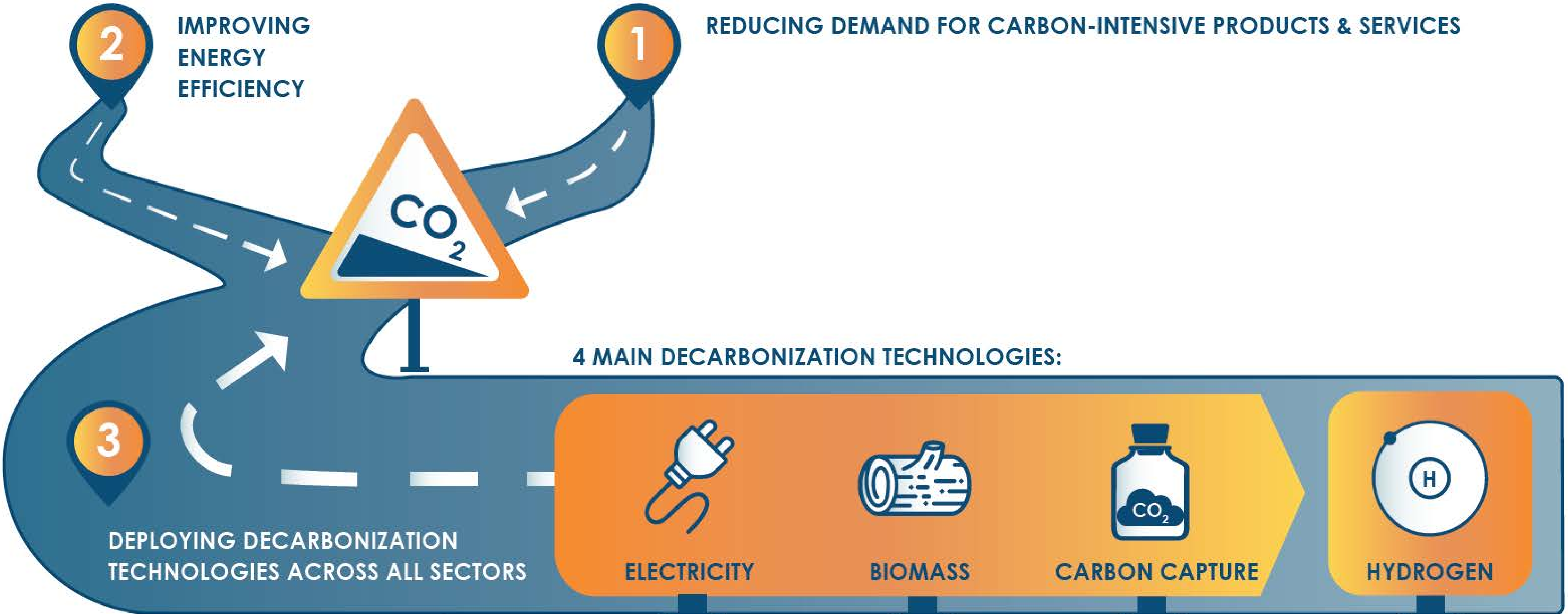
Decarbonising electricity

Decarbonising heavy industry

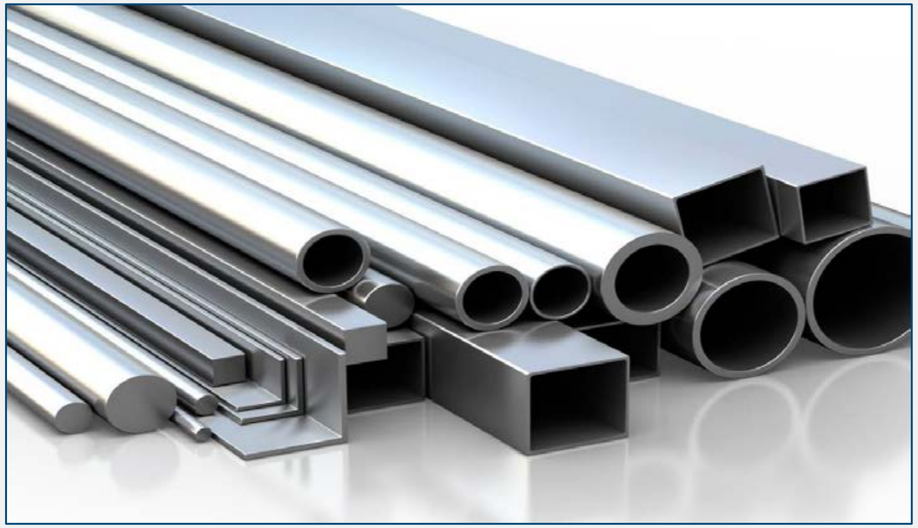
Decarbonising transport

Costs to consumers and industry

Three routes to net-zero carbon emissions



There are technically feasible options to decarbonize steel production



Current Processes

- Blast furnaces using coking coal as
  - Intense heat
  - 'Reduction agent' to remove oxygen from iron ore
- Direct reduction using syngas
- Electric arc furnaces to recycle steel

Options to decarbonise

— Adding carbon capture and storage to coking coal blast furnace

— Using hydrogen as the 'reduction agent' and the heat source

— Electrolysis

— Greater recycling via electric arc furnaces

… and to decarbonize cement production

Current Process

$C_aCO_3 \rightarrow C_aO + CO_2$

Fossil fuel based heat input

Options to decarbonise

- Reduced use via more efficient building design
- New cement chemistries reducing limestone input
- Electrification of heat input
- Bioenergy heat input
- Carbon capture and storage
  - With possible use of oxycombustion

There are very large opportunities to reduce primary plastics demand via recycling ; and production can also be decarbonised

Current Processes

- Steam cracking based production of monomers from ethane, naphtha or coal gasification
- Polymerisation

Options to decarbonise

— Shift to 'circular economy' with large scale

- Mechanical recycling
- Chemical recycling

— Electrification of heat input

— Carbon capture and storage

— Multiple new electro-chemical routes, e.g., 'methanol to olefins'

How to meet the challenge – getting to net zero emissions:

Decarbonising electricity

Decarbonising heavy industry

Decarbonising transport

Costs to consumers and industry

There are technically feasible options to decarbonise the long distance and heavy duty transport sectors

Most probable options

	Short haul	Long haul
Heavy-road transport	Battery electric vehicles	Battery electric vehicles (with or without catenary wiring) or Fuel-cell electric vehicles
Shipping	Battery electric vehicles or Fuel-cell electric vehicles	Ammonia or Hydrogen Biofuels or Synfuels
Aviation	Battery electric vehicles or Fuel-cell electric vehicles	Biofuels or Synfuels

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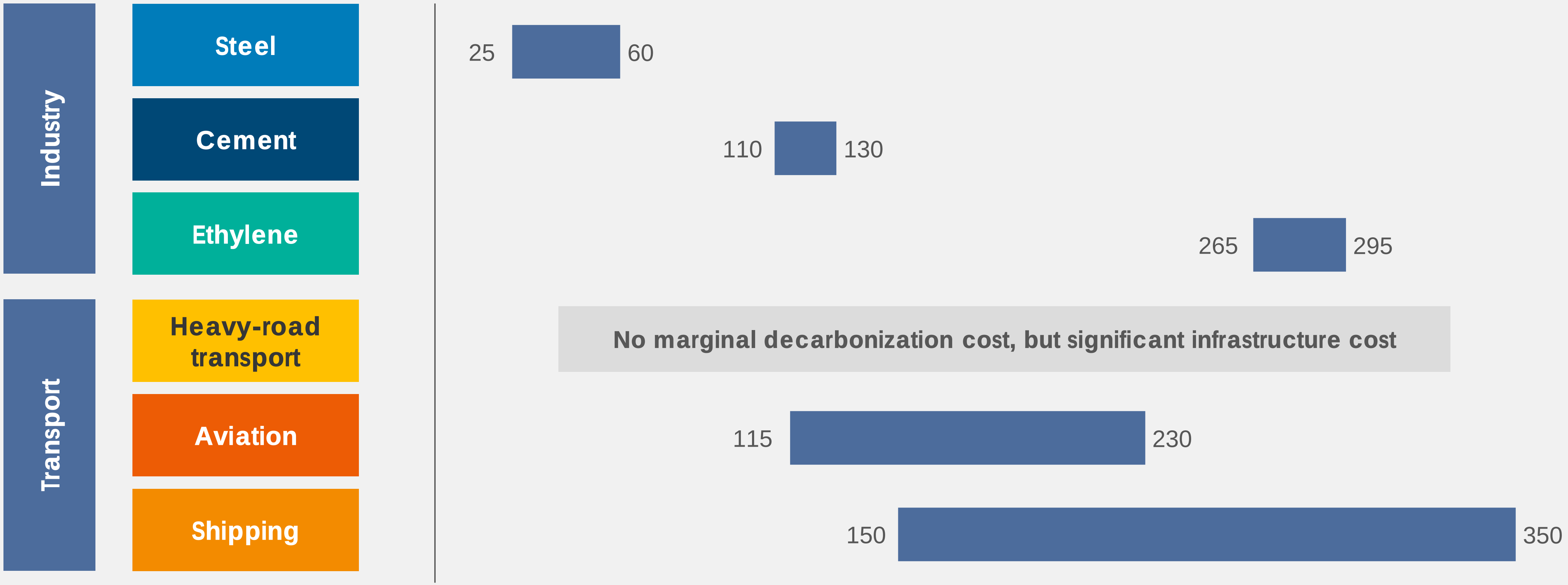
Costs to consumers and industry

Costs of supply-side decarbonization vary greatly by sectors

Supply-side abatement cost in a low-cost and high-cost scenarios

US$/tonne CO_2



Source: Industry: McKinsey & Company (2018), *Decarbonization of industrial sectors: the next frontier* / Shipping: UMAS analysis for the Energy Transitions Commission (2018) / Other transport sectors: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

In some cases there could be a significant impact on intermediate product costs ...

Impact on intermediate product cost
US$ / % price increase

Sector	Product	Impact	%
Industry	Cement	+$100 per tonne of cement (+$30 per tonne of concrete)	+100% (+30%)
Industry	Steel	+$120 per tonne of steel	+20%
Industry	Plastics	+$500 per tonne of ethylene	+50%*
Transport	Heavy-road transport	No price impact	None
Transport	Shipping	+$4 million on typical bulk carrier voyage call per annum	+110%
Transport	Aviation	+$0.3-0.6 per liter of jet fuel equivalent	+50-100%

*Assuming an initial price of US$1000/tonne for ethylene, although the price of ethylene is very volatile.
Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

…. but with a minimal impact on most end consumer prices…

Impact on final product cost
US$ / % price increase

Industry	Plastics	+$0.01 on a bottle of soda	<1%
Industry	Steel	+$180 on the price of a car	+1%
Industry	Cement	+$15,000 on a $500,000 house	+3%
Transport	Heavy-road transport	No price impact	None
Transport	Shipping	+$0.03 per kilogram of imported sugar	<1%
Transport	Aviation	+$40-80 on a 6,500-km economy class flight	+10-20%

Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

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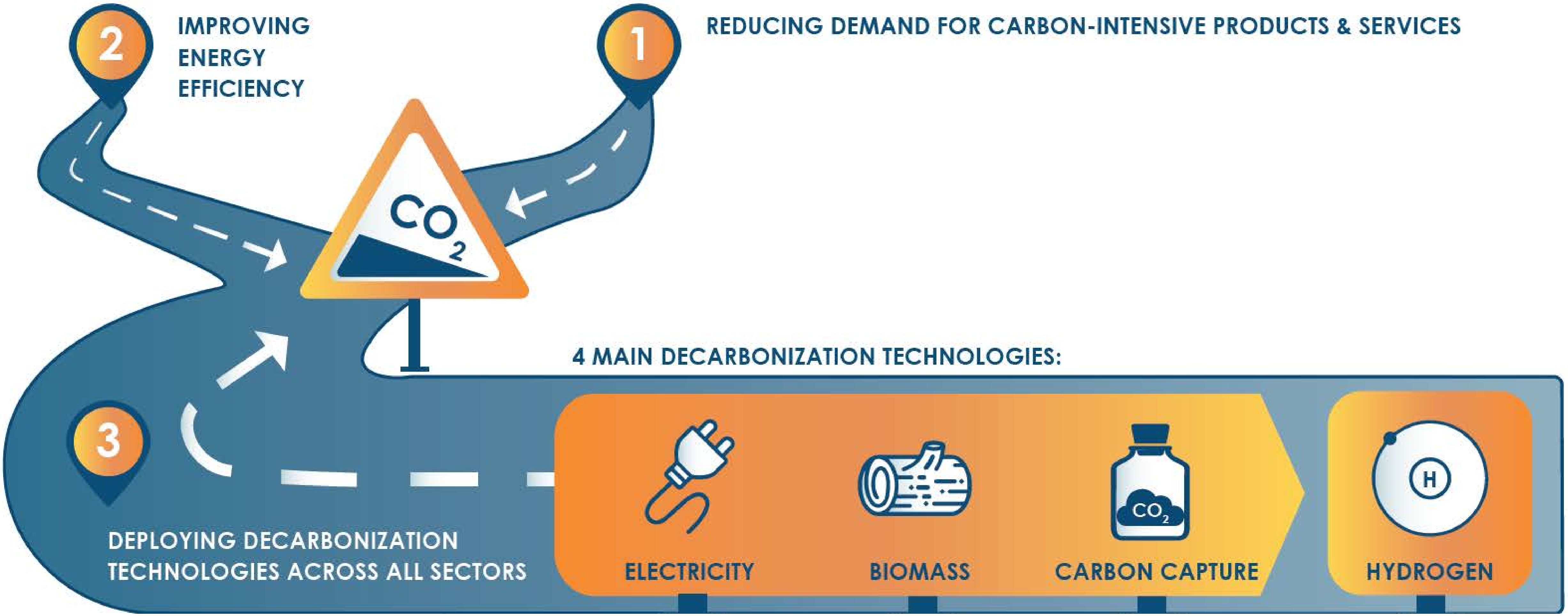
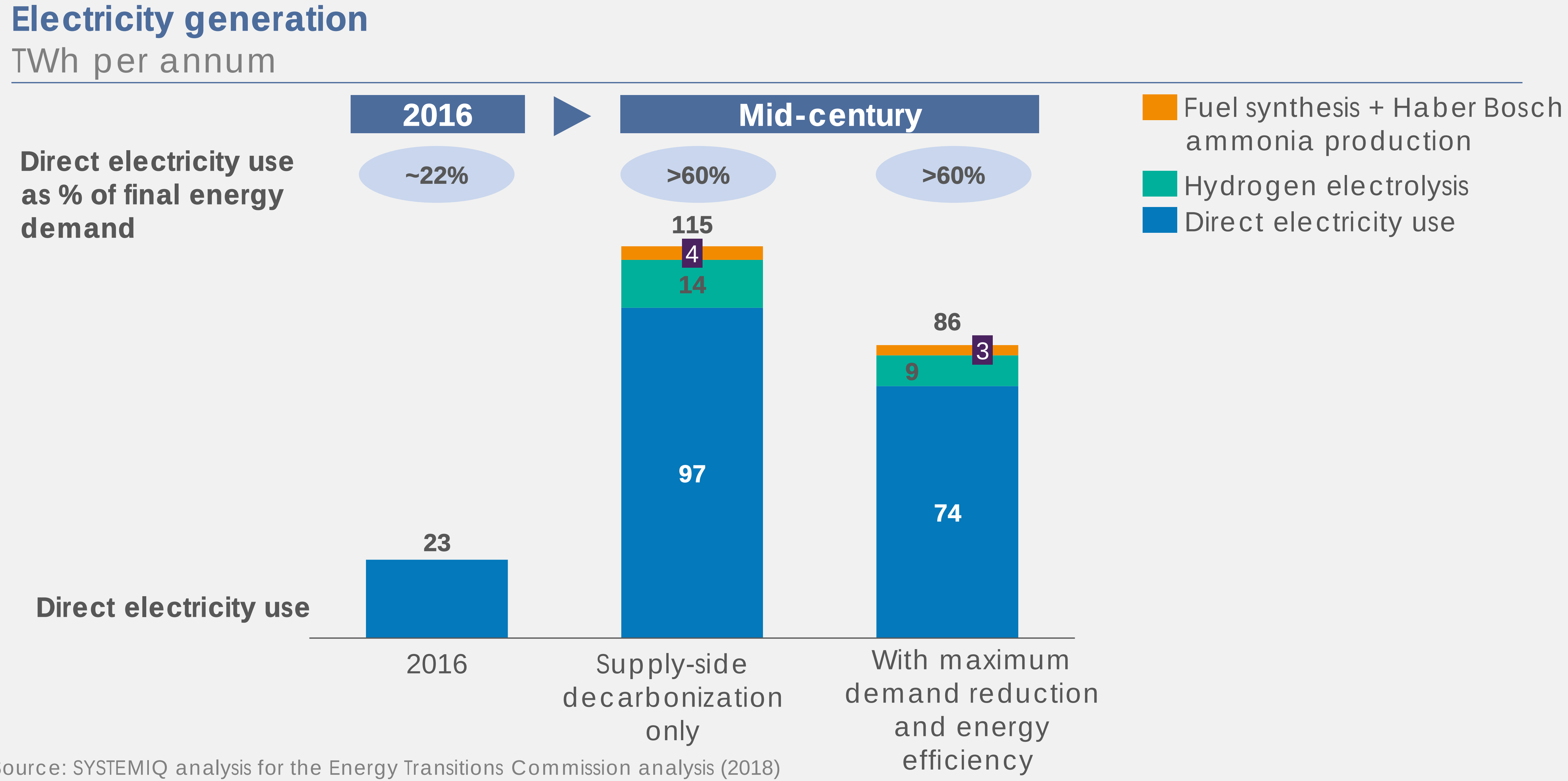
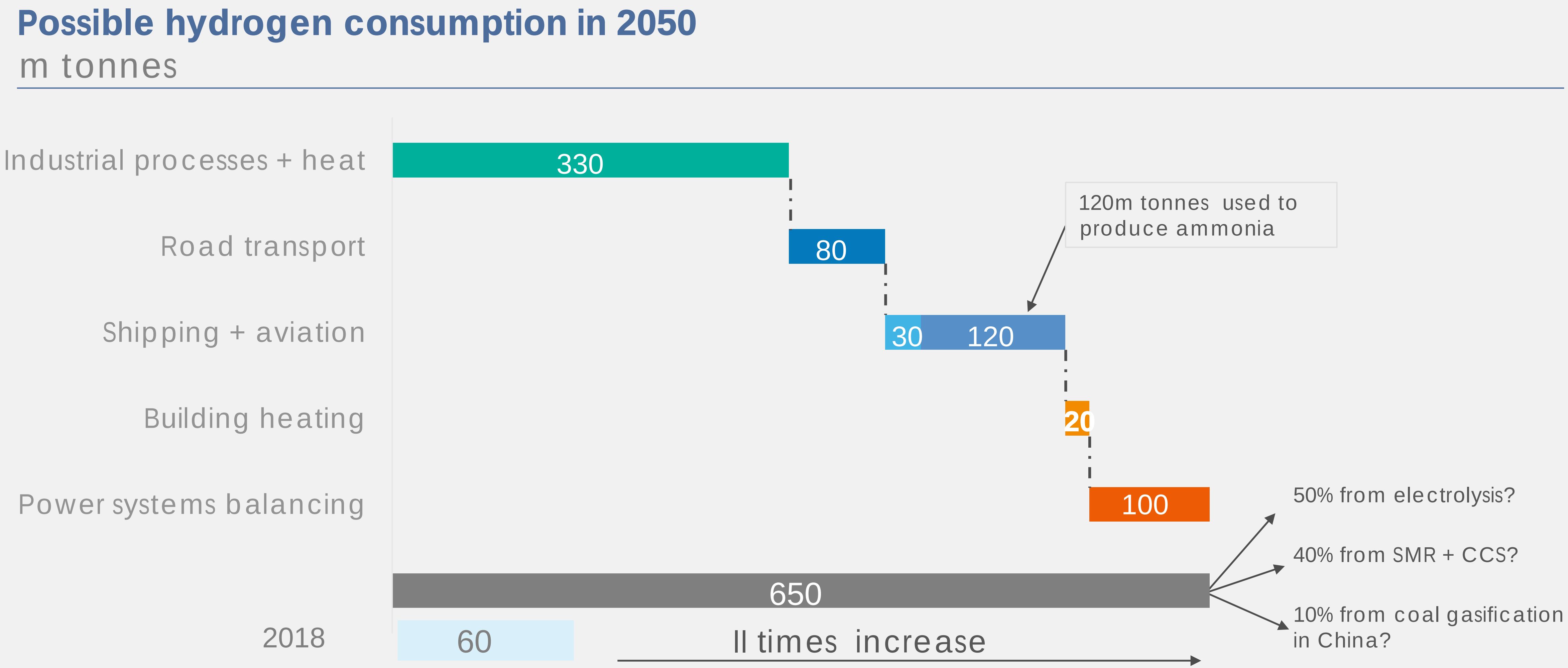


Achieving a zero-carbon economy will require about 4-5x more electricity generation....



Source: SYSTEMIQ analysis for the Energy Transitions Commission analysis (2018)

A zero carbon global economy will require a massive increase in the role of hydrogen



Land area requirements for massive solar deployment

Average land use for solar PV in US in 2017: *

- About 32Km^2 per GW
- About 1.6 hectares per GWH

Will reduce with further technical advance

100,000 TWH would require 1.6m Km^2 which:

= about 1% of global land area
= about 0.3% of global surface area (land + ocean)

** Source: NREL, Land Use Requirements for Solar Panel Plants in the US, June 2013*

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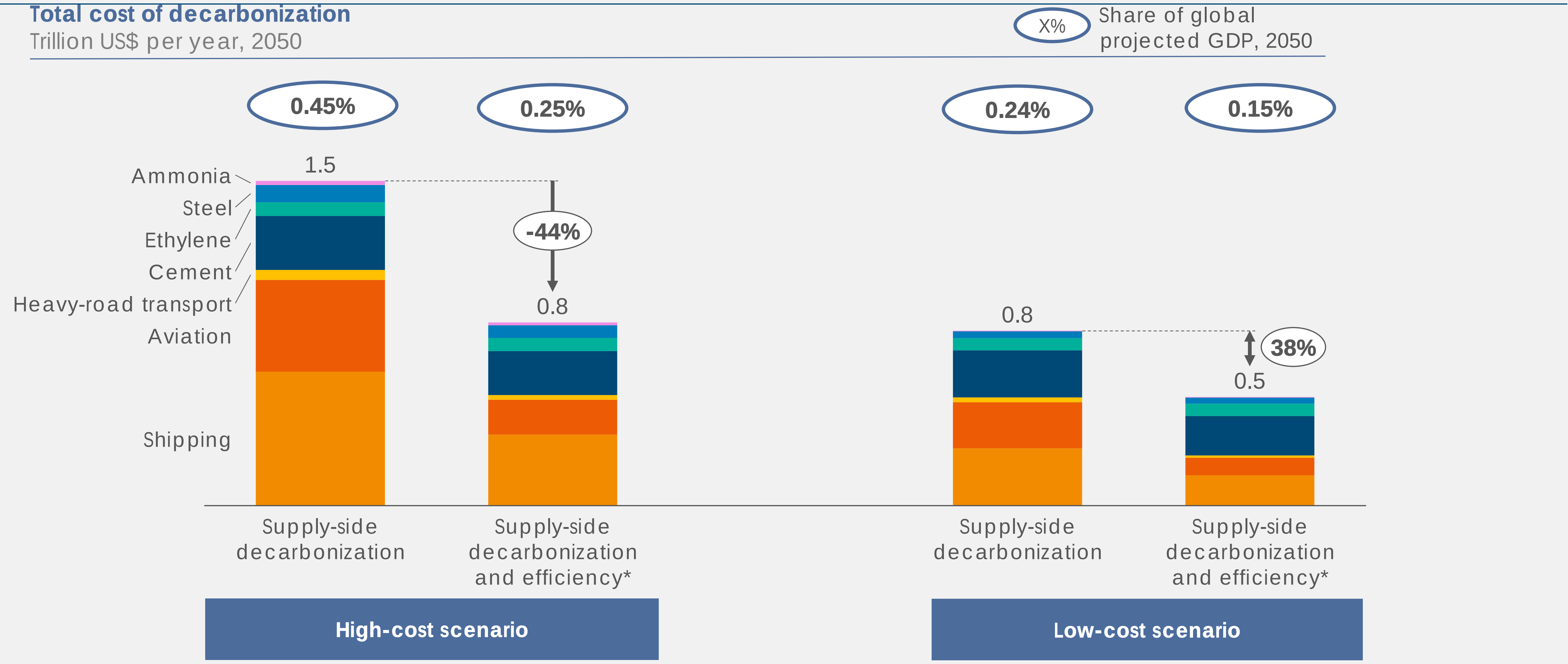
- **Costs small relative to GDP**
- **Incremental investment small relative to global savings and investment**
- **Financing challenges**

Decarbonizing harder-to-abate sectors would cost less than 0.5% of global GDP



Note: The term "efficiency" covers energy efficiency, materials efficiency, materials circularity, and demand management in transport.
Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018) based on McKinsey & Company (2018), *Decarbonization of industrial sectors: the next frontier* and Material Economics analysis for the Energy Transitions Commission (2018)

Incremental investment in macro context

Annual additional investment 2020-2050

Range of estimates: $0.2tr -$1.8tr

Median ~ $0.9tr

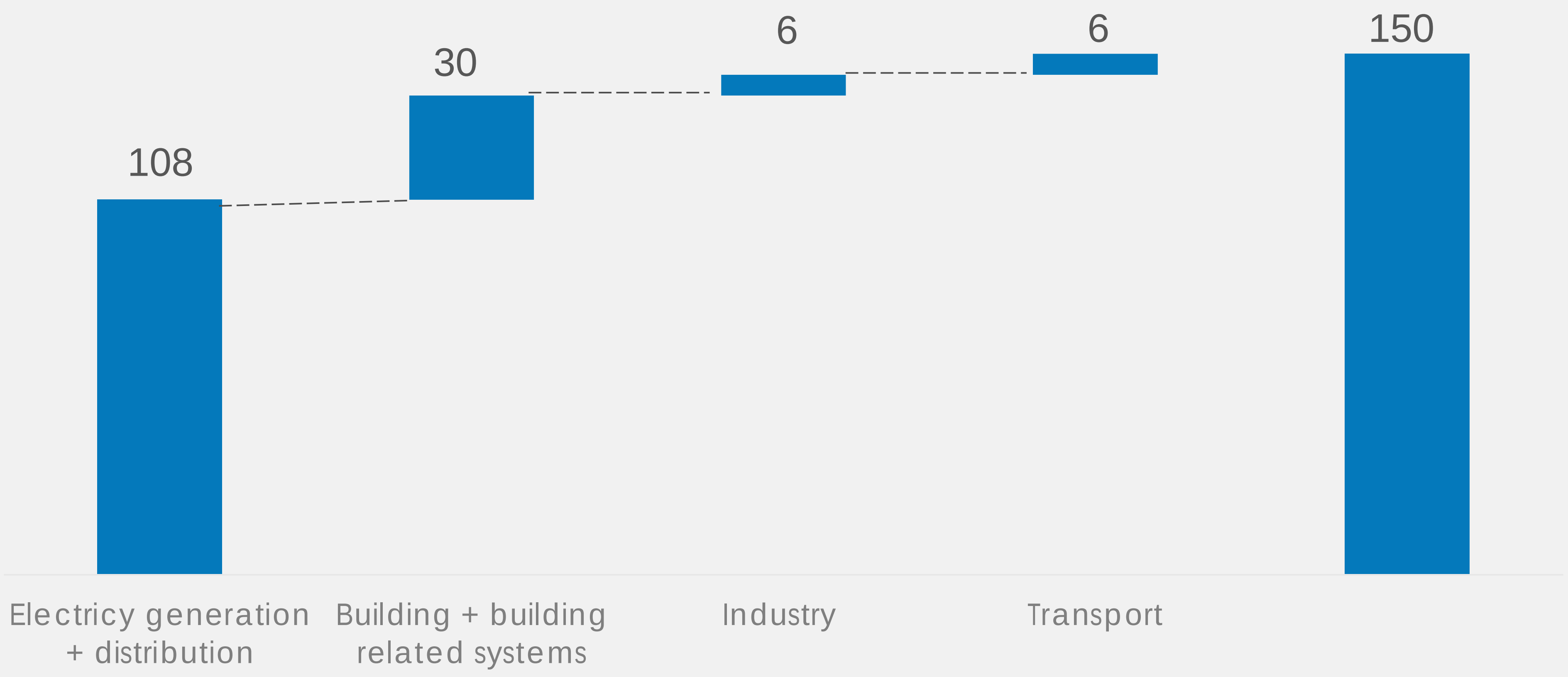
<1% of global GDP

< 4% of global savings

Current long term real interest rates < 0%

Additional investment needed to achieve zero carbon in EU

€bn per annum 2020-2050



Financing challenges

- Large investments in electricity system with zero marginal costs – and thus zero marginal prices in some current market structures >> need for managed contract structures to minimise return requirements and total cost
- Large investments needed in emerging economies where long term capital less available/more expensive >> role for development banks and other public/private partnerships
- Large investments needed in buildings where complex value chains and principal agent problems may create poor incentives for long term focus >> regulation essential
- Smaller investments needed in industrial plant and equipment, but will not happen if competitiveness concerns undermine business case >> carbon prices or regulation key with mechanisms to avoid international disadvantage (e.g. border tariff adjustments)

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Policy levers

Ambitious non negotiable long term targets - net zero emissions by mid century

Clear overall strategy – maximum electrification

Initial subsidy for key technologies - driving economy of scale and learning curve effects

Carbon prices - ideally global
- but domestic, differentiated and downstream also possible
- with border carbon tariffs if needed

Regulations more effective in some sectors e.g buildings

Blunt targets valuable e.g ban ICE car sales from 2030

R&D support for new technologies which could radically reduce transition cost

Priorities and opportunities in technology development

Solar PV	Driving further improvements in yield (20% → 30%) via new chemistries (e.g. perovskites)
Hydrogen electrolysis	Driving cost reduction via massive economy of scale ($850 per KW → $200)
Hydrogen recycling	Reduced costs and increased efficiency
Nuclear fusion?	May become economic in 2030s
Batteries	• Further cost reduction($150 per kwh → $50 per kwh) of lithium ion and gradual improvement in energy density (250 Wh per kg → 500) • New chemistries to achieve major increase in energy density and charging rates
Heat pumps	Improving coefficients of performance in very cold weather
Carbon capture	New solvents and process designs to reduce cost
3rd Generation biofuels (for aviation)	Reducing cost of production from woody biomass, wasted, algae and other potentially sustainable sources