ENERGY TRANSITIONS COMMISSION

A new electricity era:
How to decarbonize energy systems through electrification

An analysis of electrification opportunities in transport, buildings and industry prepared by Climate Policy Initiative and Copenhagen Economics for the Energy Transitions Commission

January 2017

Disclaimer

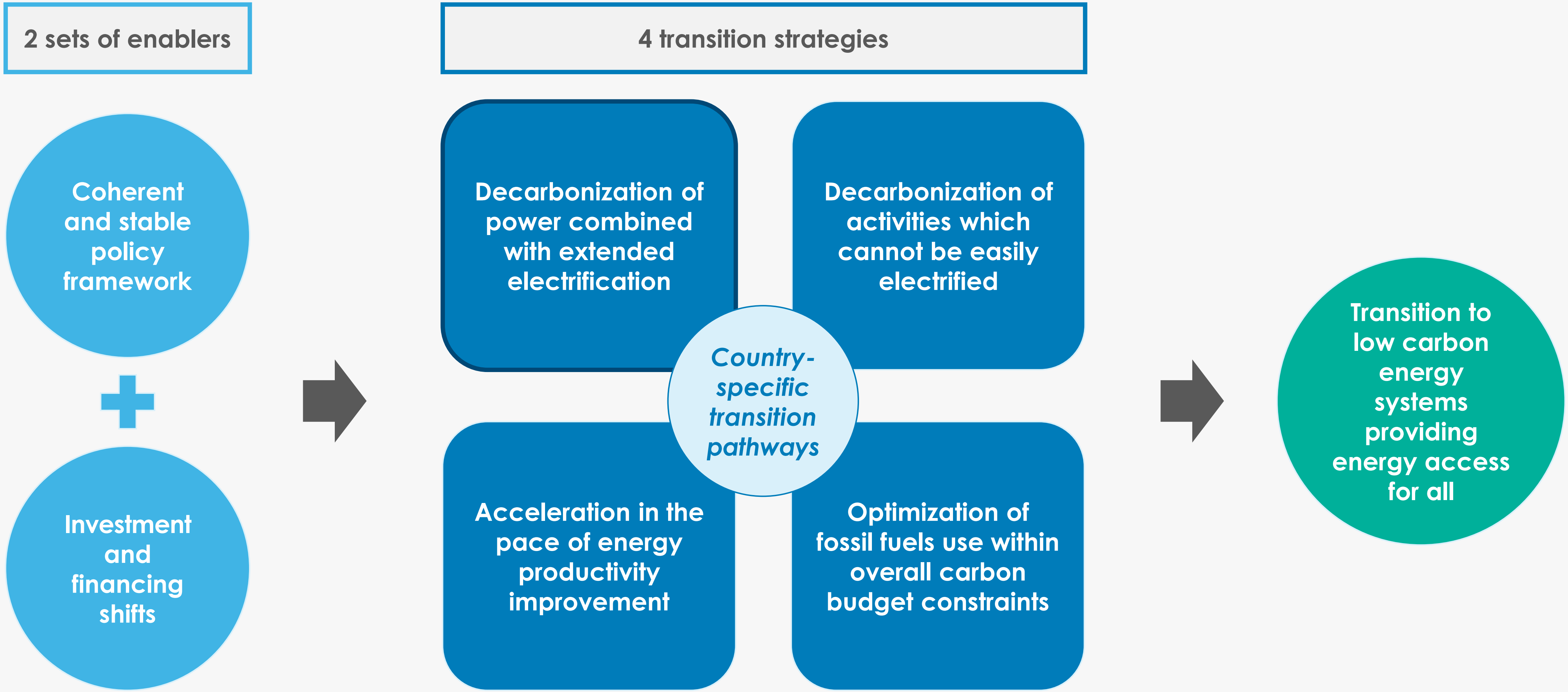
This working paper has been produced by Climate Policy Initiative and Copenhagen Economics in support of the work being undertaken by the Energy Transitions Commission (ETC). It has contributed to the ETC's report Better Energy, Greater Prosperity available on the ETC website.

Climate Policy Initiative and Copenhagen Economics have sole responsibility for the content and findings of this document (as established at the bottom of each page), which should not be interpreted as recommendations made by the ETC.

Contact us at: info@energy-transitions.org
Follow us on: Twitter, LinkedIn and Facebook

This research paper supports the work of the Energy Transitions Commission by analyzing electrification opportunities in transport, buildings and industry

The Energy Transitions Commission believes that accelerating energy transitions to low carbon energy systems providing energy access for all will require rapid but achievable progress along 4 dimensions. This research paper investigates how extended electrification can contribute to CO_2 emissions reduction in a low carbon power system.



Key findings

In a low-carbon power system, electrification could reduce fossil fuel use by at least 10-20% and lead to a 2-4 GT decrease in carbon emissions by 2040

Extended electrification of transport, buildings and industry can play an important role in displacing fossil fuel consumption and reducing CO_2 emissions by:

- Extending the benefits of a decarbonized power supply to a wider set of economic activities,
- Improving energy productivity through a reduction of conversion losses.

By 2040, a concerted push for greater low-carbon electrification has the potential to:

- Reduce fossil fuel use by at least 10-20%,
- Lead to at least 2-4 GT decrease in carbon emissions.

Transport presents the most sizeable near-term electrification opportunity, driven by light duty vehicles and short-range heavy duty vehicles, but cost and charging infrastructure remain important barriers to overcome.

Buildings are already electrified to a relatively large degree, with technology widely available across all end-uses, but additional electrification opportunities are likely to face significant cost competitiveness and behavioral change barriers.

Industry is the biggest consumer of fossil fuels beyond power, but is also the most difficult sector to electrify as end uses are very heterogeneous, significant innovation is required to develop electrified processes, and deployment support is then needed to lower costs.

Key levers to accelerate electrification are:

- Investment in transport infrastructure, especially charging infrastructure for electric vehicles and rail infrastructure,
- Reinforcement of buildings standards and development of appropriate financing mechanisms for electrified heating,
- R&D and deployment support for electrification of industrial processes.

Go to detailed findings

Short-term opportunities for electrification are concentrated in the transport and buildings sectors, while innovation is required to accelerate electrification in the industry sector

	Transport	Buildings	Industry
% of total fossil fuel use today	32%	15%	53%
Fossil fuel displacement potential by 2040	**High** 10-30% of baseline use = 14-45 EJ (from almost no electrification today)	**Moderate** 35% of baseline use = 17EJ (from already high level of electrification today)	**Low** (not measured / limited in the short term due to lack of cost-competitive technology)
Key short-term opportunities	▪ Light Duty Vehicles (LDVs) ▪ Short-haul Heavy Duty Vehicles (HDVs)	▪ Water and space heating ▪ Cooking	▪ Electric arc furnace in steel-making ▪ Low grade process heat
Availability of technology	▪ LDVs and short-haul HDVs: available ▪ Rail: available but dependent on public infrastructure/planning ▪ Aviation and sea: breakthrough technologies needed	▪ Required technologies are widely available across the sector	▪ Significant innovation required to develop alternative technologies for a variety of processes/industries ▪ Deployment support then needed to drive cost reduction
Key barriers	▪ High upfront cost for individual buyers ▪ Development of charging infrastructure	▪ High upfront cost for households ▪ Misaligned incentives ▪ Behavioral change required	▪ High upfront cost for companies ▪ Heterogeneous processes ▪ Significant investment required to develop new technologies

Go to transport section

Go to buildings section

Go to industry section

Electrification potential
Detailed findings

In a low-carbon power system, electrification can help reduce CO_2 emissions significantly by accelerating the decarbonization of energy supply and improving energy productivity

At present, **78% of energy used by key non-power sectors (industry, transport and buildings) comes from fossil fuels**, of which 17% comes from electricity generated from fossil fuels.

Decarbonization of the power supply coupled with greater electrification of these sectors has the **potential to significantly reduce fossil fuel use and CO_2 emissions**.

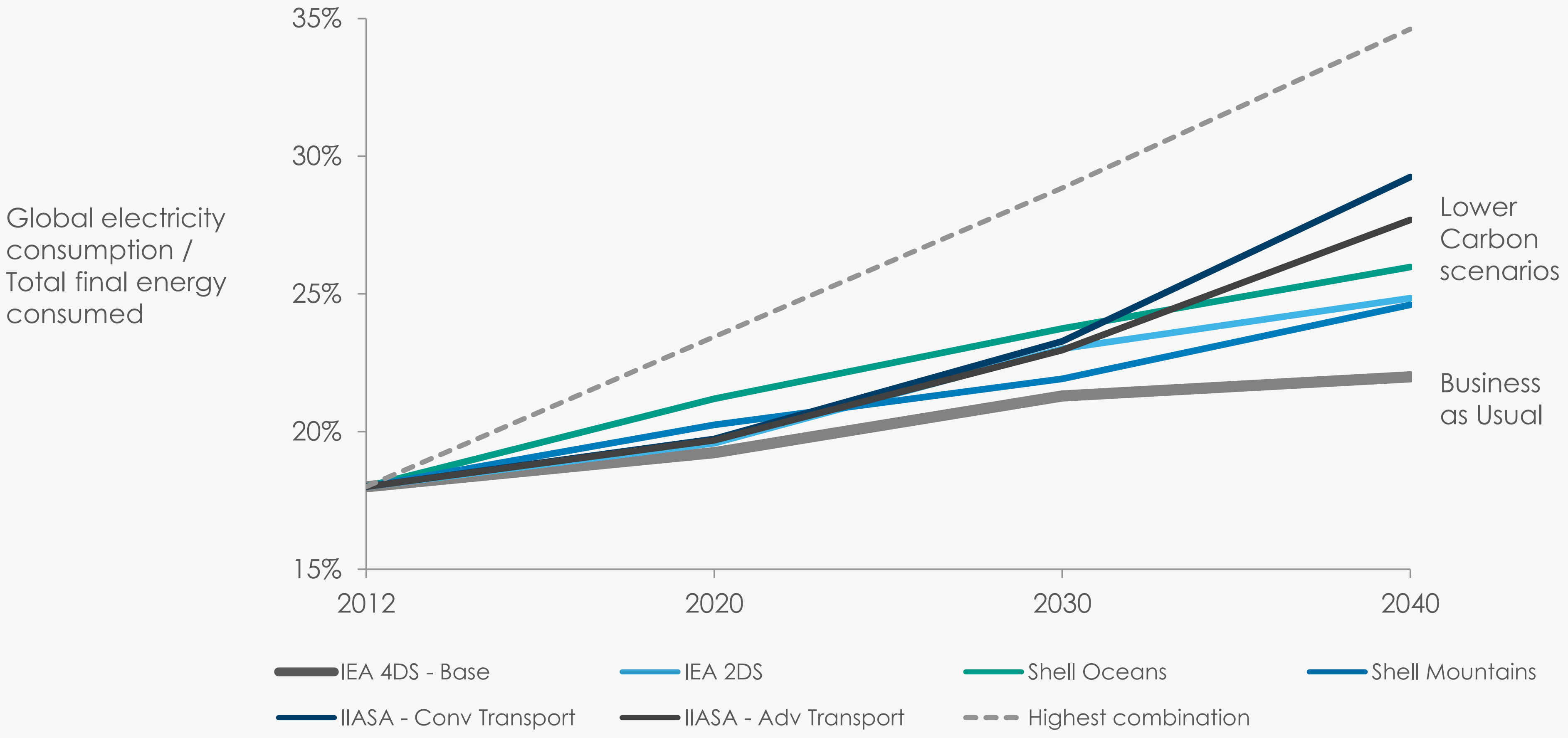
Low-carbon electrification has **two direct benefits:**

1. **Energy productivity benefits**: electricity delivers an equivalent energy service with less energy input, because it avoids conversion losses associated with burning fossil fuels.

2. **Decarbonization benefits**: greater electrification of a number of energy end uses, when coupled with decarbonization of the power supply through renewables, hydro, nuclear, or CCS/U, has the potential to accelerate decarbonization by extending the benefits of decarbonization to a broader range of economic activities.

Electrification is forecast to increase over the next 25 years even under business as usual assumptions, but there is an opportunity to increase electrification further

Share of electricity in final energy demand in different scenarios (2015-2040)

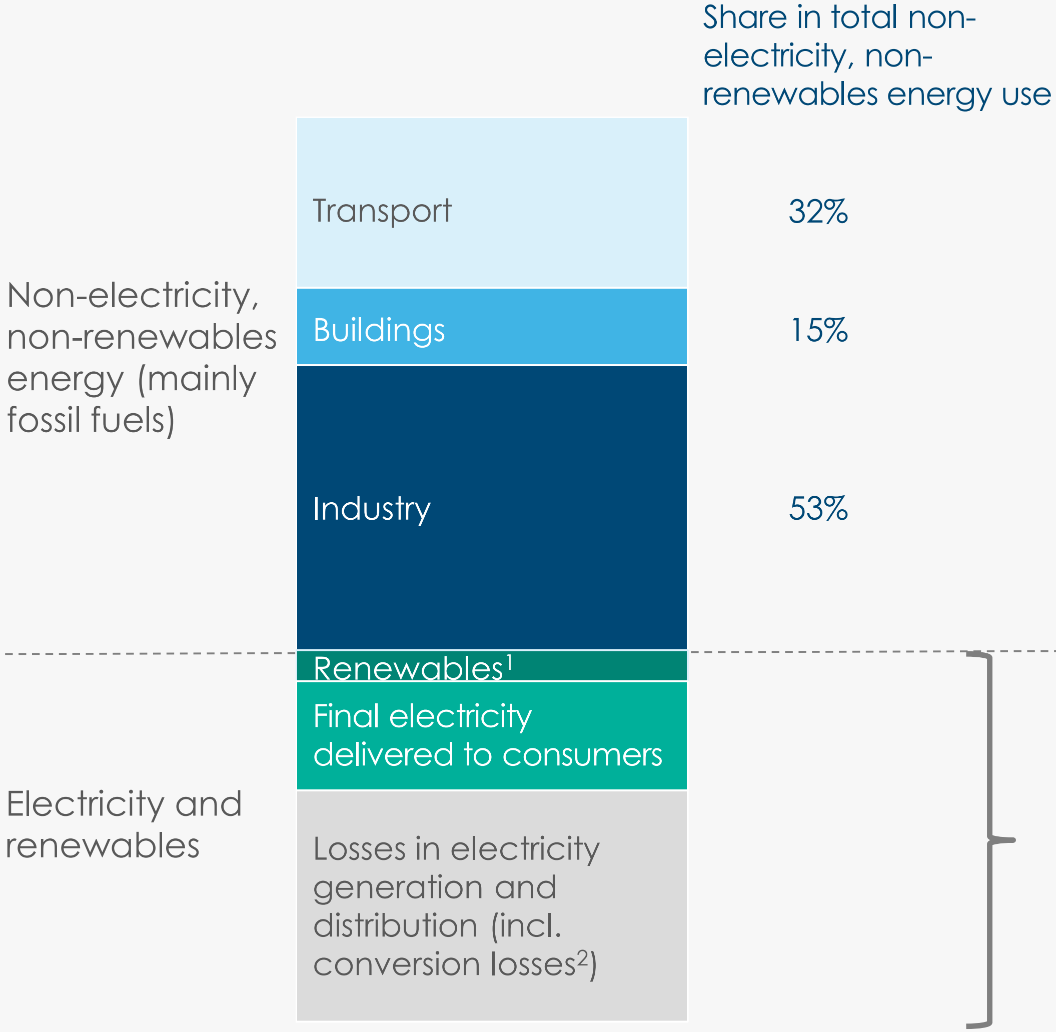


SOURCE: CPI Analysis based on data from US DoE International Energy Outlook (2016)

Electrification opportunities exist across the main fossil fuel consuming sectors, i.e. transport, residential and commercial buildings, and industry

Energy consumption by type of energy supply

EJ, 2012

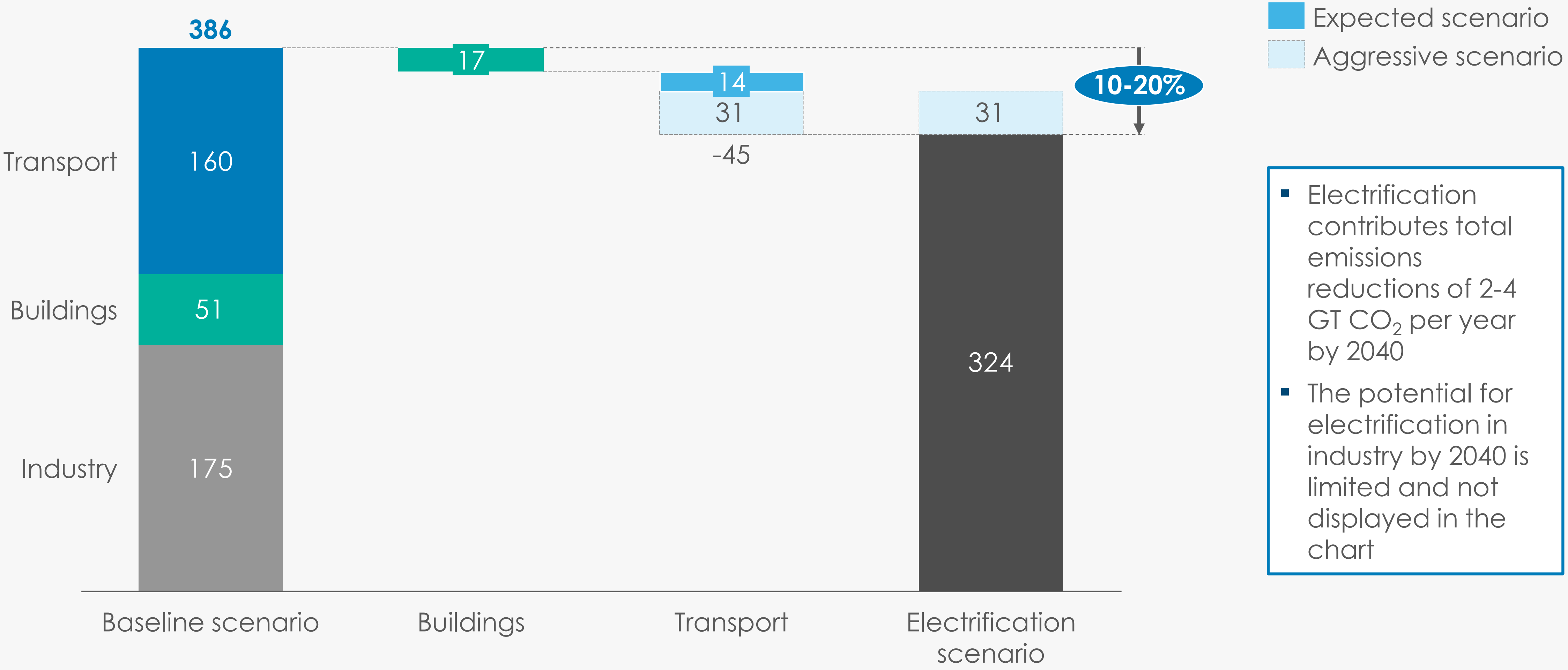


Key near-term electrification opportunities	Displacement Potential
▪ Light duty vehicles ▪ Short-haul Heavy duty vehicles	High
▪ Space and Water Heating	Moderate
▪ Electric arc furnace for steel making ▪ Low grade process heat	Low
▪ Decarbonization of the power supply (renewables, nuclear, hydro, CCS/U, etc.)	

SOURCE: CPI analysis / 1 Direct, non-electricity use of renewables, e.g. wood and biomass / 2 Conversion losses in fossil fuels based power generation

Broader electrification has the potential to reduce fossil fuel use by 10-20%

Fossil fuel use in transport, buildings and industry by 2040, EJ



- Electrification contributes total emissions reductions of 2-4 GT CO_2 per year by 2040
- The potential for electrification in industry by 2040 is limited and not displayed in the chart

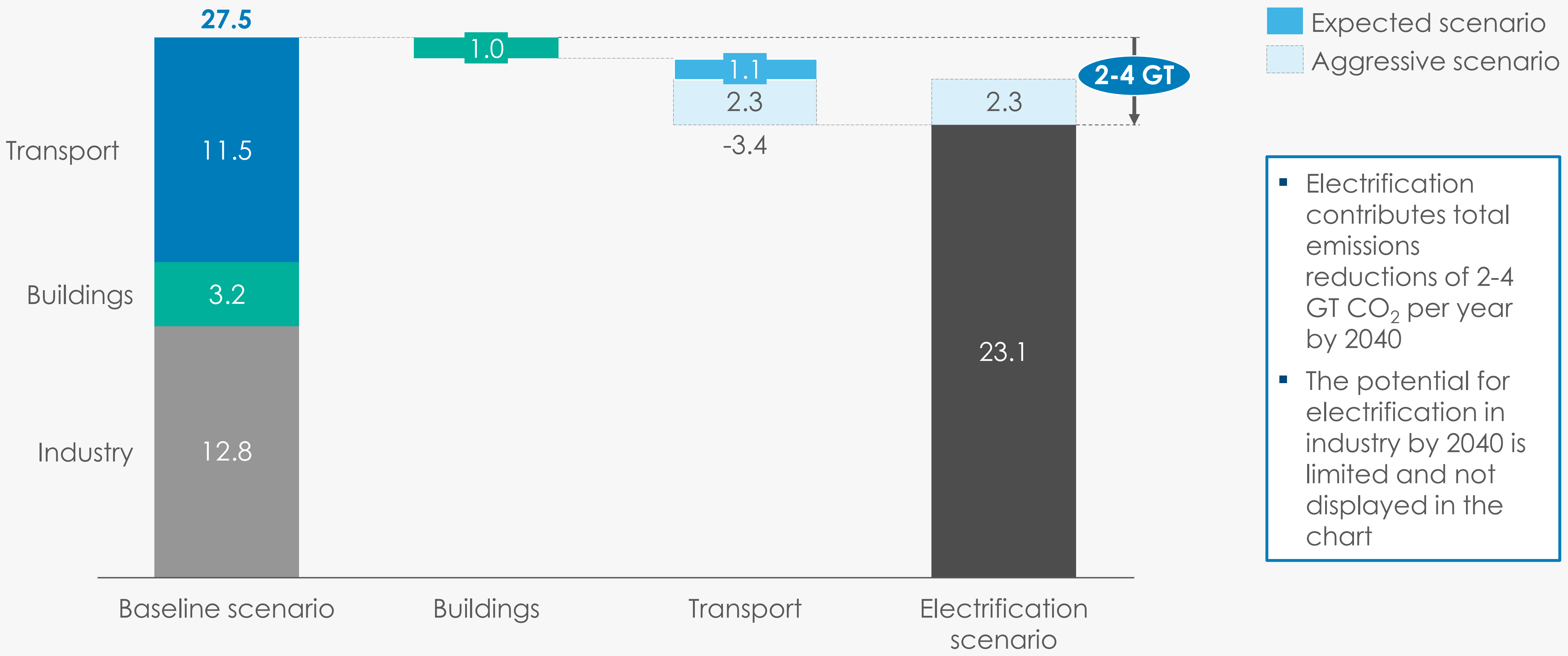
NOTE: Potential for electrification in industry is limited and has not been analyzed in detail. The total potential for reduced fossil fuel use through electrification is therefore somewhat larger than what is shown in the above chart. The scenario only includes fossil fuel savings from increased electrification. Other potential for fossil fuel savings, such as energy productivity improvements, are not included.

SOURCE: Copenhagen Economics analysis based on data from IEA, ETP (2016) and the Global Calculator.

See assumptions

Broader electrification has the potential to reduce CO_2 emissions by 2-4 GT by 2040

Emissions from fossil fuel use from transport, buildings and industry by 2040, GT CO_2



- Electrification contributes total emissions reductions of 2-4 GT CO_2 per year by 2040
- The potential for electrification in industry by 2040 is limited and not displayed in the chart

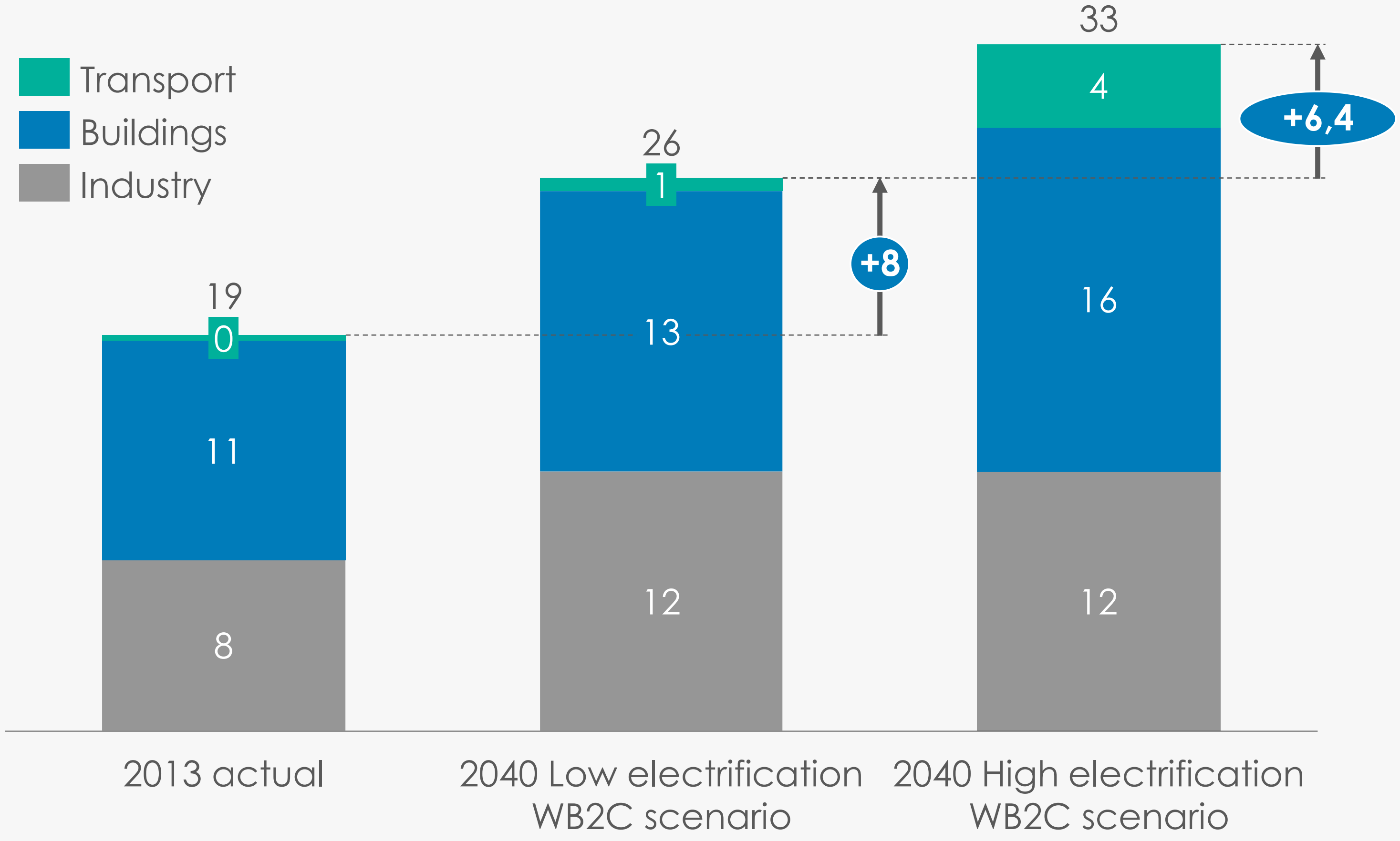
NOTE: Potential for electrification in industry is limited and has not been analyzed in detail. The total potential for reduced fossil fuel use through electrification is therefore somewhat larger than what is shown in the above chart. The scenario only includes fossil fuel savings from increased electrification. Other potential for fossil fuel savings, such as energy productivity improvements, are not included.

SOURCE: Copenhagen Economics analysis based on data from IEA, ETP (2016) and the Global Calculator.

See assumptions

Broader electrification could increase electricity requirements by over 25% in 2040

Electricity demand from transport, buildings and industry, 1000 TWh



- Additional 6,400 TWh required for an ambitious electrification scenario by 2040 compared to a low carbon scenario with limited electrification.
- This adds ~25% to 2040 electricity production.
- It represents an increase of 14,400 TWh compared to current electricity production.

NOTE: *Low electrification WB2C scenario* shows the expected electricity use in a WB2C scenario, including all efficiency and productivity gains, but assuming no further electrification compared to current levels. *High electrification WB2C scenario* shows the expected electricity use in a WB2C scenario with further electrification in transport and buildings, assuming an average of the expected and aggressive electrification cases in the transport sector. Potential for electrification in industry is limited and has not been analyzed in detail. The total potential increase in electricity demand is therefore somewhat larger than what is shown in the above chart.

SOURCE: Copenhagen Economics analysis based on data from IEA, ETP (2016) and the Global Calculator.

See assumptions

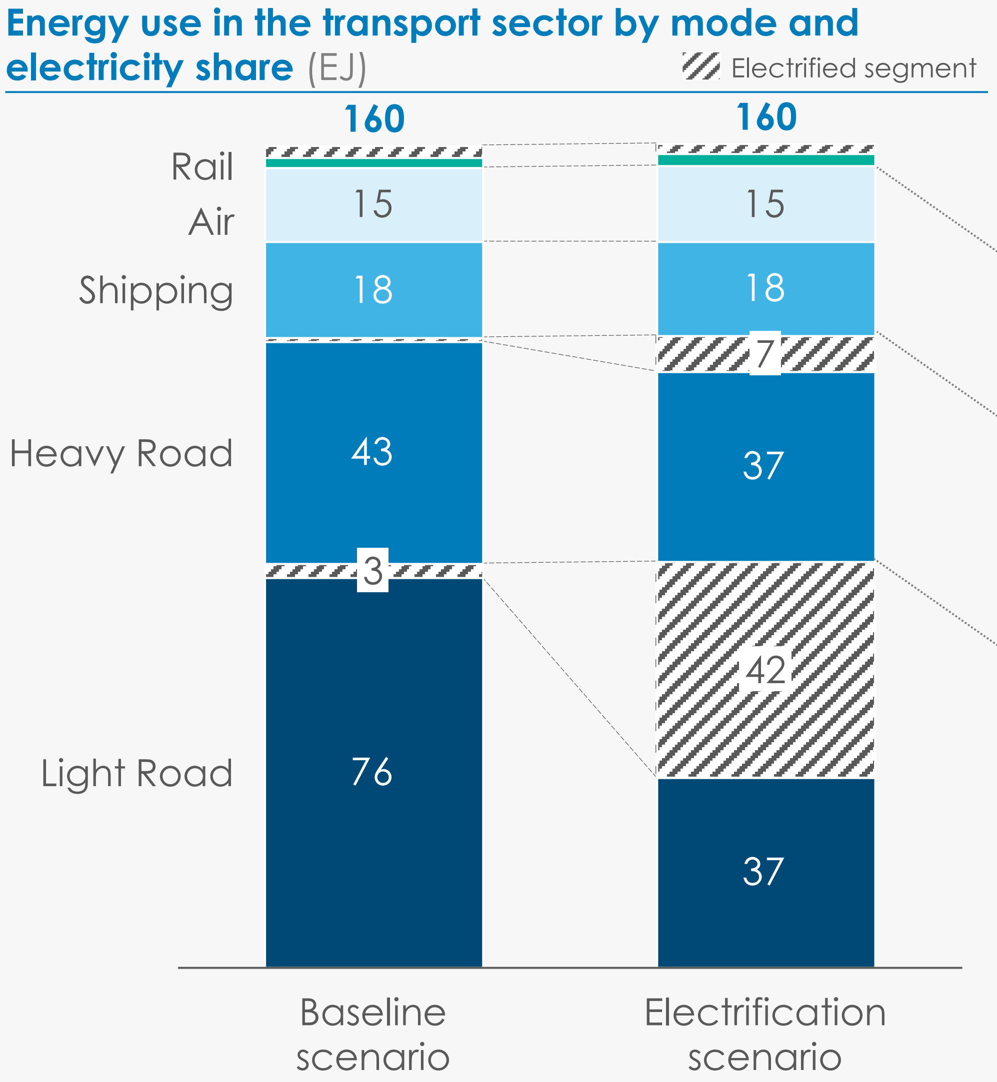
Key policy levers to accelerate electrification include investment in transport infrastructure, reinforcement of standards, appropriate financing, R&D and deployment support

Sector	Key policy levers
Transport	▪ Support to the build-out of charging infrastructure for electric vehicles ▪ Build-out of electrified rail infrastructure to enable modal shift ▪ Continued investment in battery technology development to improve range and performance while lowering cost ▪ Development of shared vehicle business models to drive higher vehicle utilization and increase turnover
Buildings	▪ Equipment energy standards on manufacturers to drive market towards most efficient space heating, space cooling, and water heating technologies (primarily heat pumps) ▪ Appropriate financing solutions (e.g. property assessed clean energy finance, on-bill financing) to overcome agency issues in buildings energy improvements
Industry	▪ Focused R&D and deployment support to decarbonize industry ▪ Support to greater recycling of scrap steel to drive greater share of electric arc furnace in steel industry

SOURCE: CPI Analysis

Electrification in transport

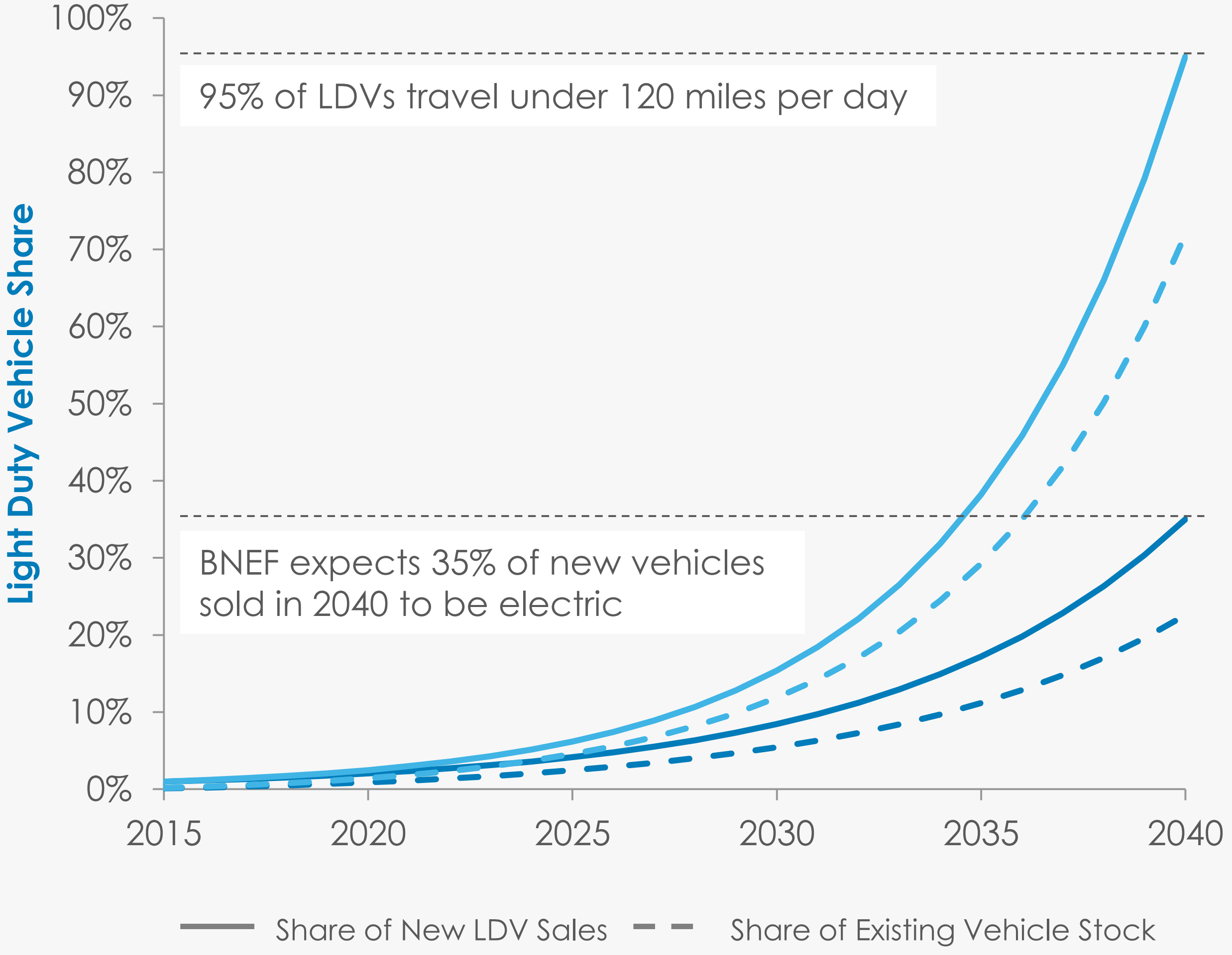
In the transport sector, 10-30% of fossil fuel use can be replaced through electrification by 2040, driven by light road and short-haul heavy road vehicles



Electrification options	Technology availability	Other barriers
▪ Can in principle be substantially electrified; potential for additional electrification through modal shift	Moderate	Moderate
▪ No or little electrification potential	Low	High
▪ Potential of up to 2% (heavy-duty) and 5-10% (light-duty) ▪ Additional potential with hybrid electric vehicles	Moderate	Moderate
▪ Substantial share of trips can in principle be served by electric vehicles ▪ Actual uptake will depend on relative cost, market scaling, stock turnover, and consumer norms ▪ More than 50% electrification possible by 2040 in an aggressive case	Moderate / High	Low

Note: Non-electrified segments include, in addition to fossil fuels, hydrogen and biogas.
SOURCE: Copenhagen Economics analysis based on data from IEA, ETP (2016) and the Global Calculator.

Light Duty Vehicles are expected to be the biggest driver of electrification in transport: electric vehicles could represent at least 23% and up to 72% of LDVs by 2040

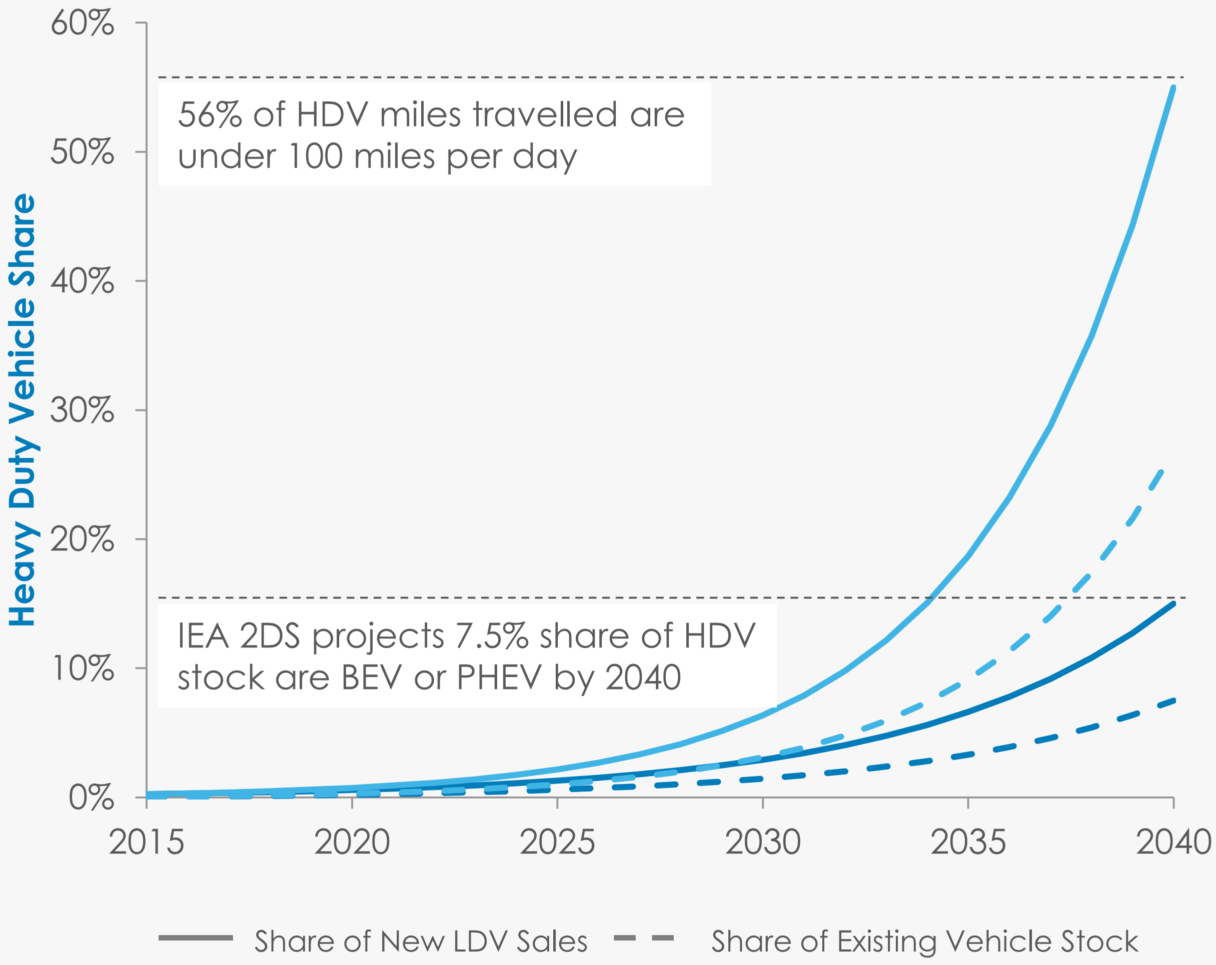


Aggressive electrification case:
- 72% of LDVs electrified by 2040
- 20%+ CAGR in new sales
- Accelerated turnover of vehicle stock due to increased utilization (e.g. sharing) – 7-year vehicle life
- All daily travel under 120 miles/day ultimately electrified

Expected electrification case:
- 23% of LDVs electrified by 2040
- 15% CAGR in new sales
- 10-year vehicle life
- Reaches BNEF expected share of 35% of new vehicle sales by 2040 (consistent with IEA 2Ds)

SOURCE: CPI analysis based on data from BNEF, US National Household Transportation Survey (NHTS), IEA ETP 2016

Additional electrification is possible in short-range Heavy Duty Vehicles: electric vehicles could represent at least 7.5% and up to 27% of HDVs by 2040



Aggressive electrification case:
- 27% of HDVs electrified by 2040
- Accelerated turnover of vehicle stock due to increased utilization – 10-year vehicle life
- All daily travel under 100 miles/day ultimately electrified

Expected electrification case:
- 7.5% of HDVs electrified by 2040
- 12-year vehicle life
- Reaches level of penetration similar to IEA 2 degree scenario

SOURCE: CPI analysis based on data from NREL Fleet DNA, IEA ETP 2016

High capital costs, development of the charging infrastructure and urban planning are the key barriers to the near-term electrification opportunities in the transport sector

Subsector	Cost barriers	Infrastructure barriers	Other barriers
Light Road	▪ Total cost of ownership nearing parity (depending on fuel cost) ▪ Further battery cost reduction needed for upfront cost parity with ICEs (expected by mid 2020s)	▪ Development of charging infrastructure, particularly in dense urban environments ▪ Fast charging needed to support high-utilization shared fleet	▪ Perceived range limitations - can be overcome with technology improvements and greater vehicle sharing models
Heavy Road	▪ Total cost of ownership nearing parity for short-haul, high utilization fleets (e.g. bus, garbage, local delivery) ▪ High capital costs relative to fossil fuel based options	▪ Fast-charging needed to support high-utilization fleets	▪ Range limited by weight, size and cost of battery needed for heavy vehicle – battery improvements needed to expand market share
Rail	▪ Electric rail infrastructure currently limited to specific regions (generally with high population density and high rail mode share) ▪ To expand mode share, significant additional investment in electric trains, overhead lines and other infrastructure needed		▪ Modal shift to rail depends on behavioral and urban planning drivers

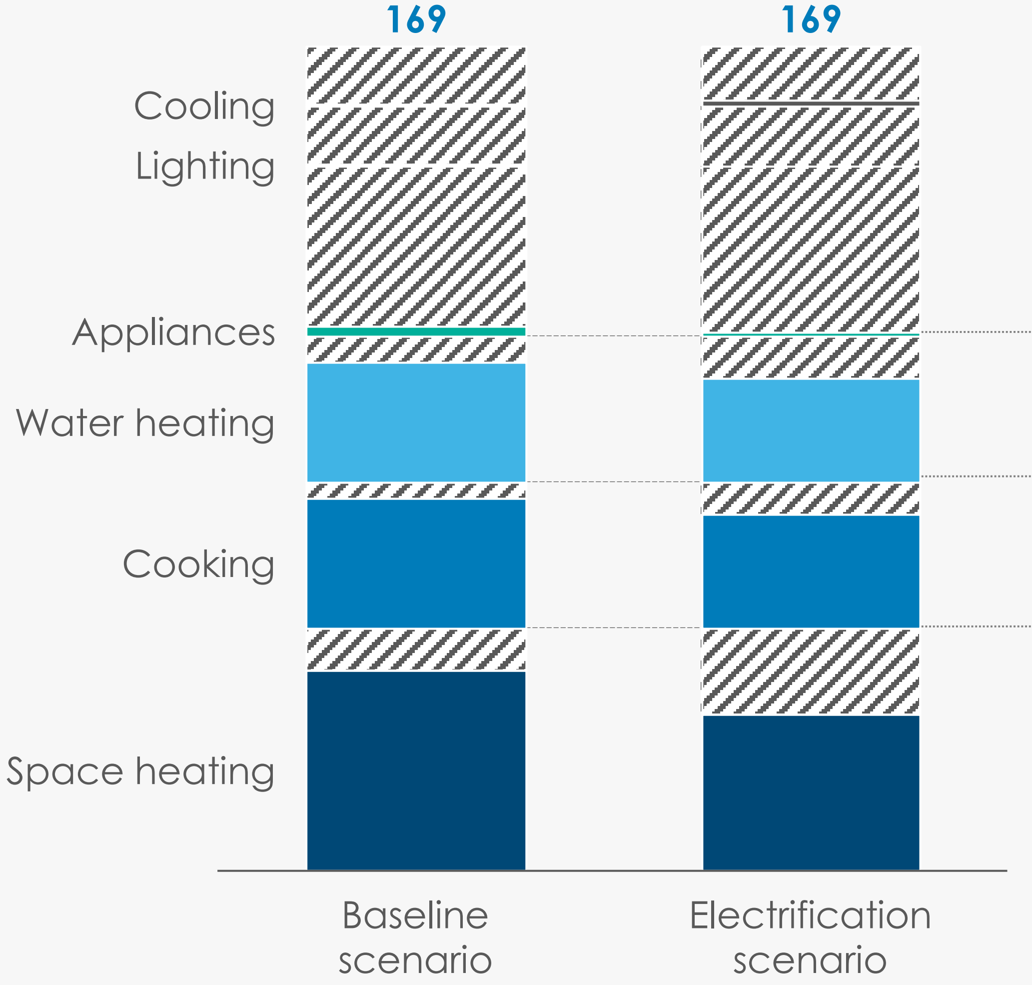
SOURCE: CPI Analysis

Electrification in buildings

In the buildings sector, 35% of fossil fuel use can be replaced through electrification by 2040, driven by water heating, space heating and cooking

Energy use in the buildings sector by mode and electricity share (EJ)

Electrified segment



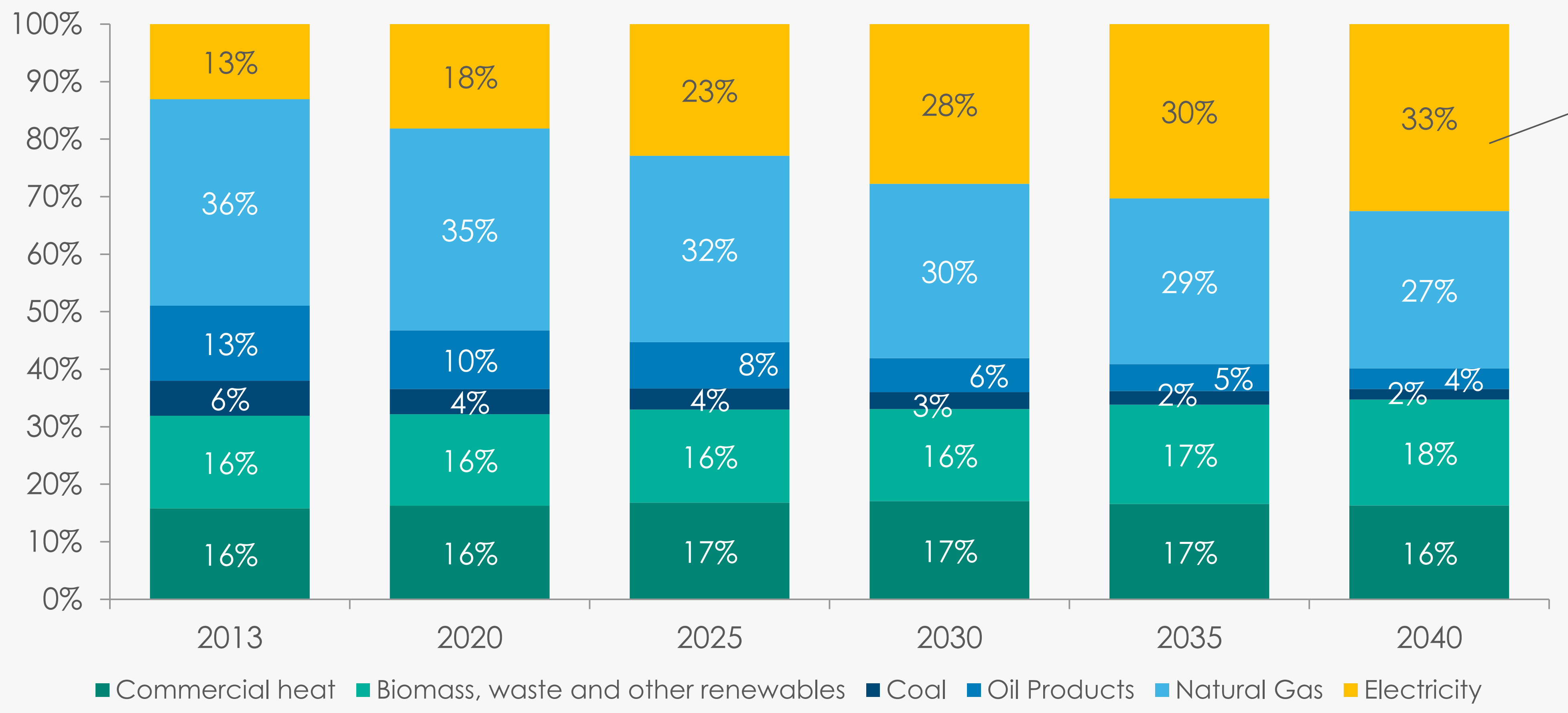
Electrification options	Technology availability	Other barriers
▪ Already substantially electrified and limited additional potential	High	Low
▪ A quarter of water heating could be provided by electricity by 2040, notably through heat pumps	High	Moderate
▪ One-sixth could be electrified, but other solutions continue to dominate & solar could be another option	High	Moderate
▪ 30% could be provided through heat pumps and direct electricity	High	High

Note: Non-electrified segments include, in addition to fossil fuels, commercial heating, biomass, waste and other renewables.
SOURCE: Copenhagen Economics analysis based on data from IEA, ETP (2016) and the Global Calculator.

See assumptions

Up to one-third of space heating can be provided by electricity by 2040 vs. 13% today

Share of space heating service provided by source

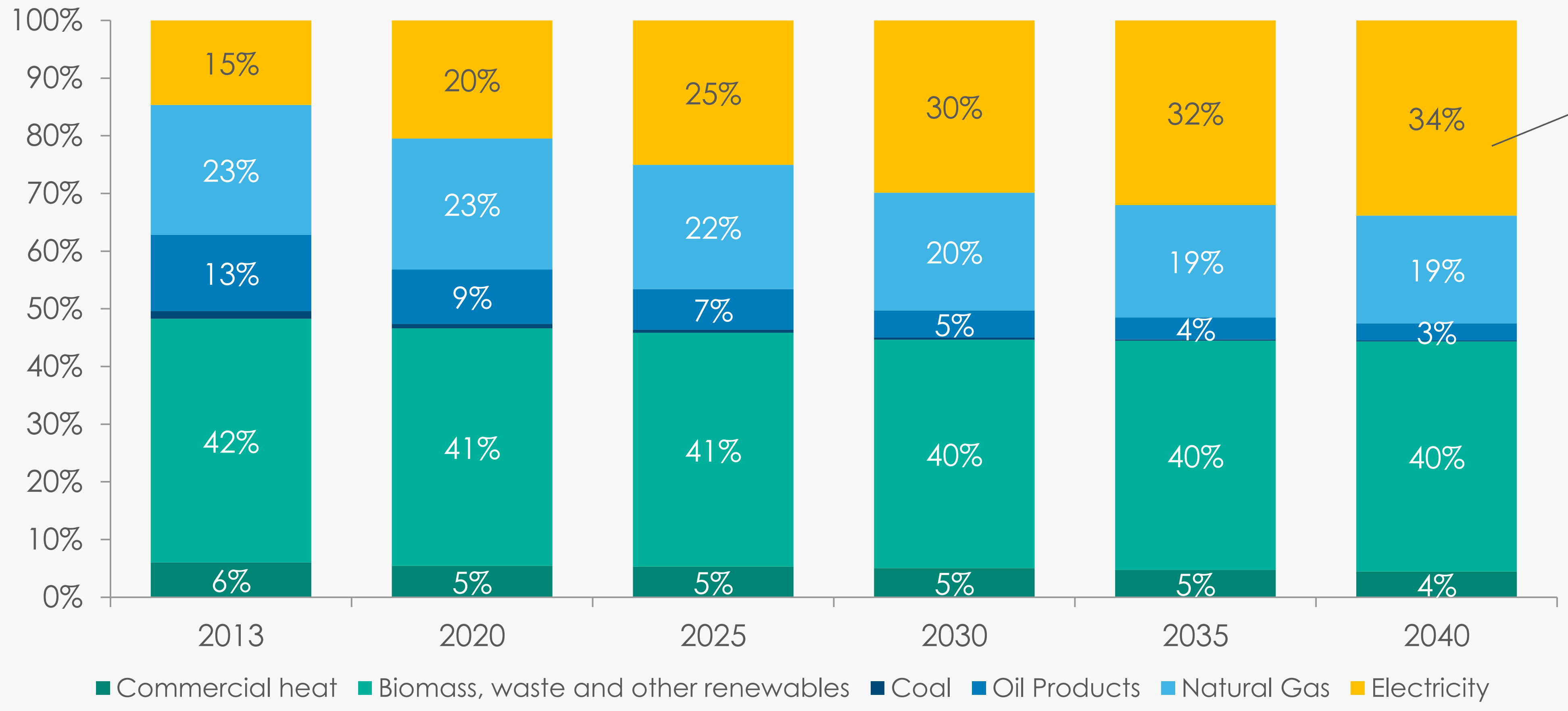


Electricity provides 33% of total space heating demand by 2040 – 50% excluding biomass and commercial / district heating

SOURCE: CPI analysis based on data from IEA ETP 2016, 2DS
Calculation of implied shares assumes doubling of average electrical space heating efficiency from 2013 to 2040, from 100-200% heat output per energy input.

Up to one-third of water heating can be provided by electricity by 2040 vs. 15% today

Share of water heating service provided by source



Electricity provides 34% of total water heating demand by 2040 – 60% excluding biomass and commercial / district heating

SOURCE: CPI analysis based on data from IEA ETP 2016, 2DS
Calculation of implied shares assumes doubling of average electrical space heating efficiency from 2013 to 2040, from 100-200% heat output per energy input.

High capital cost, low turnover rates and lack of incentives are the key barriers to the near-term electrification opportunities in the buildings sector

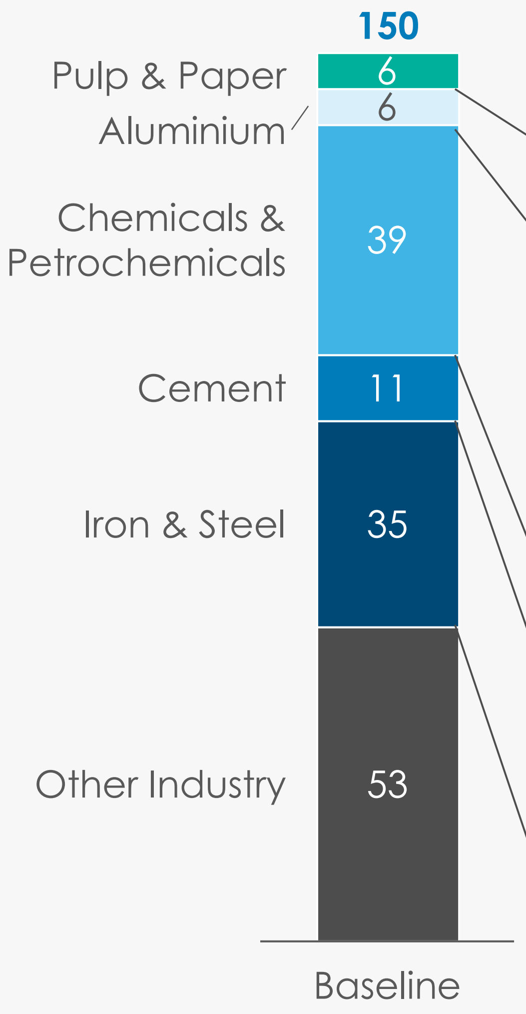
Subsector	Cost barriers	Deployment challenges	Other barriers
Space heating	▪ Heat pumps cost-effective in many regions – most cost-effective where long heating and/or cooling seasons result in high utilization ▪ High capital cost of heat pumps relative to other heating options	▪ Space heating upgrades often coupled with building retrofits ▪ Tenants not incentivized to reduce energy costs or upgrade buildings equipment ▪ Equipment lasting 10-15 years, resulting in low turnover	▪ Heat pumps will not operate efficiently in all climates
Water heating	▪ Cost effectiveness of resistive water heating determined by relative fuel prices ▪ High capital cost of heat pump water heaters	▪ Water heating upgrades often coupled with building retrofits ▪ Tenants not incentivized to reduce energy costs or upgrade buildings equipment ▪ Equipment lasts 10 years, resulting in low turnover	▪ Direct solar hot water likely more cost-effective in many regions
Cooking	▪ Low-cost and readily available options	▪ Electricity infrastructure required to offset use of biomass for cooking ▪ Other renewable alternatives (e.g. solar) may be cheaper	▪ Consumer preference for gas (or biomass) for cooking

SOURCE: CPI Analysis

Electrification in industry

The technical potential for electrification in industry could be high, but significant innovation and deployment is required to decrease cost of alternative technologies

Energy use in industry by 2040 (EJ)

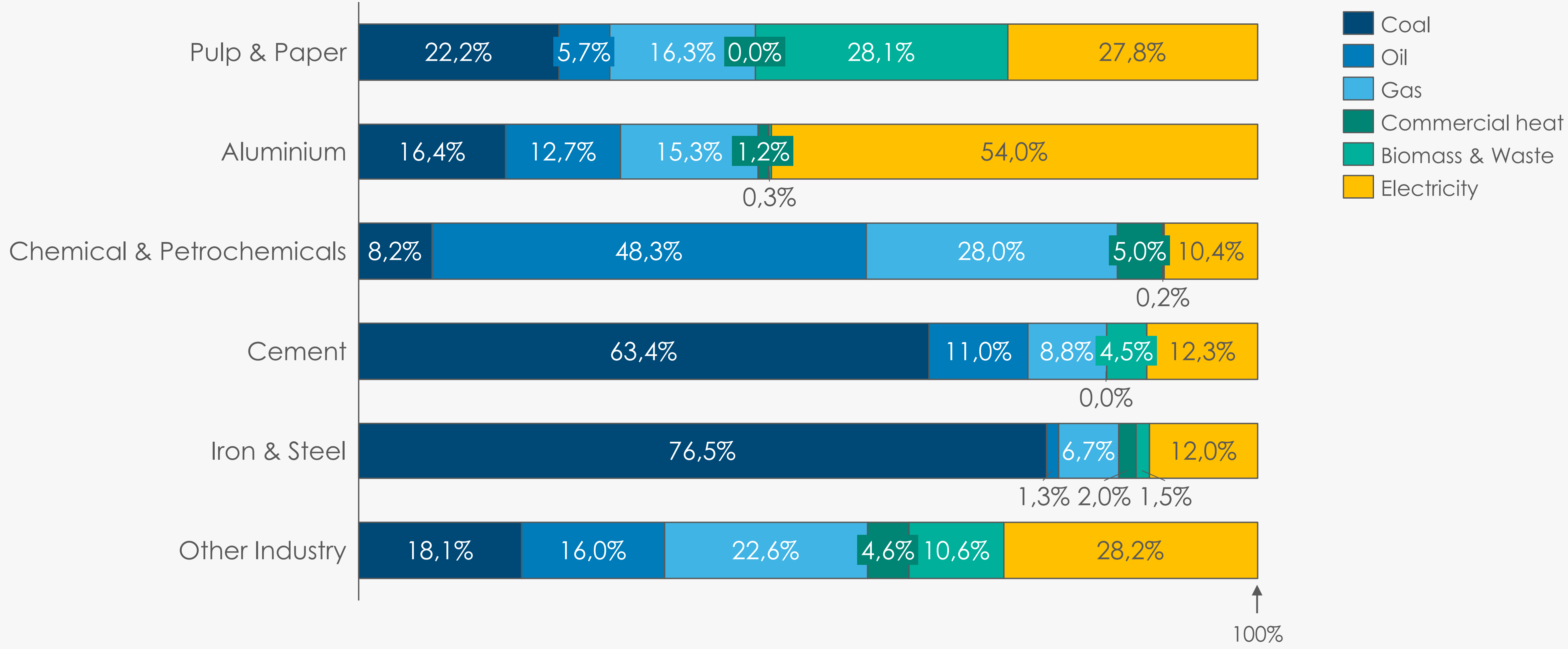


Electrification Options: Industry/Process	Electrification Options: Alternative technology	Technical opportunity (% of final process energy)	Technology availability
Pulp & Paper drying	Electro-thermal technologies (induction, electric arc, etc.)	85%	Moderate
Alumina production *(bauxite reduction)*	Electro-thermal dryers or syngas firing (grid electrolysis)	25%	Low
Chemicals & Petrochemicals cracking	Electro-thermal furnaces	65%	Low
Olefin production *(ethylene, propylene)*	Methane-to-olefins (MTO) from syngas and oxidative coupling of methane (OCM)	n/a	Moderate
Ammonia production	Grid electrolysis	n/a	Moderate
Cement production *(clinker calcination)*	Electro-thermal dryers or syngas firing (grid electrolysis)	80%	Low
Recycled steel production	Electric arc furnace (EAF)	25%	High
Iron ore reduction	DRI (hydrogen or gas) or electro-winning	70%	Moderate / High

SOURCE: Copenhagen Economics analysis based on data from IEA, ETP (2016) and the Global Calculator.

Current use of electricity in each sector varies due to different underlying processes

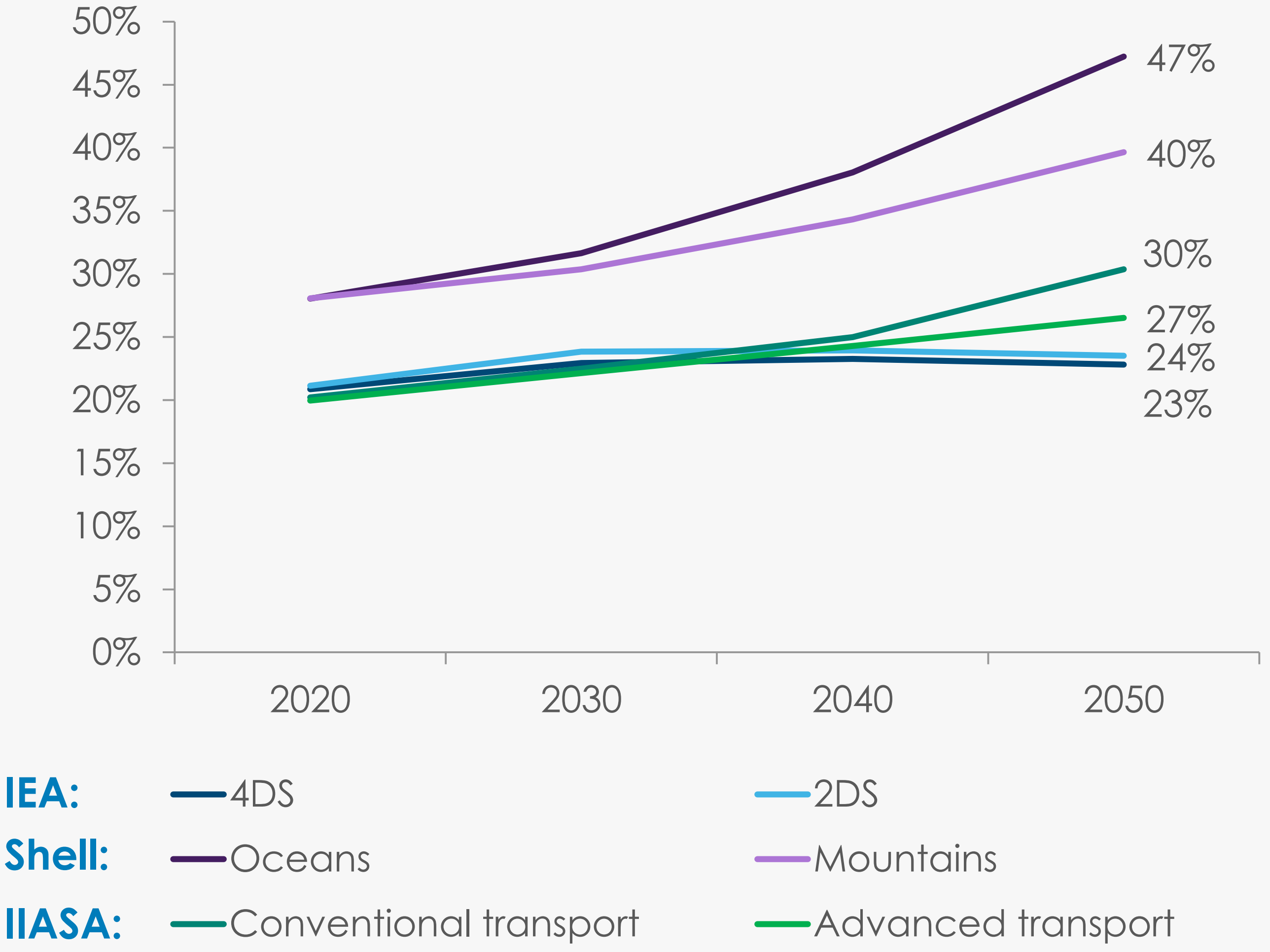
Share of final energy by source in 2013



SOURCE: CPI analysis based on data from IEA ETP 2016

Energy scenarios diverge on electrification in industry, especially in the long-term, due to different sectoral definitions and sets of assumptions

Electricity share of final energy consumption in industry



Key differences:
- Sectoral definitions
- Demand and sectoral mix assumptions (e.g. relative share of electricity-intensive manufacturing)
- Availability and cost of electrification technologies
- Availability and cost of efficiency and other carbon mitigation options

SOURCE: CPI analysis based on data from IEA ETP 2015, Shell New Lens Scenarios, IIASA GEA

Steel recycling and low-grade process heat present the most likely near-term electrification opportunities in industry, but market barriers remain high

Industry	Potential levers	Challenges
Steel production	▪ Increase use of electric arc furnace for recycled steel production ▪ Increased share of scrap steel (currently ~25% of steel output) ▪ Decrease in primary steel production	▪ Sufficient scrap supply at reasonable prices ▪ Transport costs ▪ Metallurgical impurities
Low-grade process heat	▪ Electric heat in food processing ▪ Electric heat for paint drying in automotive manufacturing ▪ Heat pumps to capture and use waste heat	▪ Relative cost of electricity vs. other fuels

SOURCE: CPI analysis based on Lechtenbohmer et al. (2015)

Appendix – Scenario assumptions

Key assumptions

We have made the following key assumptions when deriving the scenarios presented in this document:

	Baseline scenario	Electrification scenario
Description	The baseline scenario is a proprietary scenario which assumes that increased population and prosperity lead to a rapid increase in energy services across sectors. Share of renewables is unchanged. A slight increase in electrification is included (22% share of final energy demand in 2040 vs. 17% in 2013).	The electrification scenario is an hypothetical scenario which changes the energy use mix, but assumes constant energy consumption levels (i.e. it does not consider energy productivity gains or other parameters that would reduce energy consumption in a well below 2˚C scenario).
Share of renewables	13% share of renewables in power and heating	34% share of renewables in power and heating
Transport	Transport needs grow by ~80% with economic growth, trade, and urbanization.	15-30% of fossil fuel displacement driven by • Light Duty Vehicles (LDVs): 72% electrification in Aggressive case, 23% in Expected case • Heavy Duty Vehicles[1] (HDVs): 27% electrification in Aggressive case, 7.5% in Expected case
Buildings	Building energy services grow by 50-70% with large increases in the built area.	33% fossil fuel displacement driven by: • Water Heating: 34% electrification • Space Heating: 33% electrification
Industry	Industrial production increases by 20-80% in steel, cement, and chemicals.	Zero electrification assumed for the purposes of this analysis due to the uncertainty of future pathways.

SOURCE: Copenhagen Economics analysis / 1 For the purposes of this document, the Heavy Duty Vehicles category also includes Medium Duty Vehicles.