ENERGY TRANSITIONS COMMISSION

ROCKY MOUNTAIN INSTITUTE

CHINA 2050: A FULLY DEVELOPED RICH ZERO-CARBON ECONOMY

EXECUTIVE SUMMARY

THE ENERGY TRANSITIONS COMMISSION

The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape (energy producers, energy-intensive industries, technology providers, finance players, environmental NGOs) committed to achieving the Paris climate objective of limiting global warming to well below 2°C and ideally as close as possible to 1.5°C. Our work combines analysis to define how that objective can be achieved, and engagement with public policymakers, industry initiatives, and individual companies, to encourage and energize action which will ensure change pathways are implemented and targets achieved. The ETC is co-chaired by Lord Adair Turner and Dr. Ajay Mathur. Our Commissioners are listed on the next page.

In China, the ETC partners closely with the Rocky Mountain Institute (RMI)'s Beijing office, which acts as the ETC China secretariat. RMI is an independent, non-partisan non-profit, whose mission is to transform global energy use to create a clean, prosperous, and secure low-carbon future. It is a member of the ETC.

The *"China 2050: A Fully Developed Rich Zero-Carbon Economy"* report was developed by the Commissioners with the support of the ETC and RMI China teams. It draws upon previous analyses from the ETC and broader literature review. It also integrates feedback from several rounds of consultation with representatives of Chinese companies, academia and institutions as well as global companies and institutions operating in China. We warmly thank them for their contributions.

This report constitutes a collective view of the Energy Transitions Commission. Members of the ETC endorse the general thrust of the arguments made in this report, but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse the report.

The ETC Commissioners agree that it is vital that China has a strategy to achieve net-zero emissions by mid-century for the world to deliver the Paris climate objectives, that achieving this goal is technically and economically feasible, and that this transition would benefit the Chinese economy. This agreement between leaders from companies and organizations with different perspectives on and interests in the energy system should give Chinese decision-makers confidence that it is possible simultaneously to grow the Chinese economy and to limit global warming to well below 2˚C, and that many of the key actions to achieve these goals are clear and can be pursued without delay.

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EXECUTIVE SUMMARY

China 2050: A Fully Developed Rich Zero-Carbon Economy

Global climate change threatens major harm to human society across the world. A November 2018 report from the Intergovernmental Panel on Climate Change (IPCC) argued that to avoid extreme harm, the world must limit global warming to less than 1.5 °C[1]. But this is only possible if the whole world achieves net zero greenhouse gas emissions by around mid-century.

The good news, as the global Energy Transitions Commission (ETC) has described in two reports—*Better Energy, Greater Prosperity* (2017) and *Mission Possible* (2018)—is that the technologies exist to make this objective attainable, and at a very small cost to economic growth and consumer living standards. This is true even for "harder-to-abate" sectors of the economy—heavy industry and heavy-duty/long-distance transport—which could be decarbonized at a cost to the economy of less than 0.6% of GDP, and with only a minor impact on consumer prices.

China's welfare is threatened by climate change as much as other nations. And China's energy-intensive development mode for decades has made it a major emitter of greenhouse gases. In per capita terms, China's emissions are in line with the rich developed economies of Europe, although only 45% of the United States' extremely high level. But China's sheer scale makes it in absolute terms the world's largest emitter, with 9.8 gigatonnes of CO_2 per annum accounting for 28% of the global total. For the whole world and for China itself, it is therefore vital that China has a strategy to achieve net zero emissions by mid-century.

1.IPCC (2018), *Global warming of 1.5 °C*

This report shows that it is technically and economically feasible to achieve that objective, that the investment required can easily be affordable given China's high savings and investment rate, and that the impact on China's GDP per capita in 2050 will be minimal. Far from constraining China's ability to meet its objective of being "a fully developed rich economy" by 2050, committing to achieve zero emissions by 2050 will spur investment and innovation that could accelerate progress. It will also deliver large improvements in local air quality and create huge opportunities for Chinese technological leadership in multiple industries.

To achieve net zero emissions will require the total decarbonization of electricity generation and the massive expansion of electricity use, electrifying as much of the economy as possible. It will also require an over threefold increase in the production and use of hydrogen, together with important but more limited roles for increased bioenergy production and for carbon capture and either storage or use. China's natural resources, technological prowess, and savings and investment rates make it possible for these different technologies to deliver a zero-carbon economy, even while China enjoys rapid growth of energy-based services such as transport and residential heating and cooling.

Key sectoral actions to achieve a zero-carbon economy include:

• **Total electrification of surface transport (road and rail services) while supporting a threefold increase in transport use.** Within light duty sectors (autos and vans), electric vehicles (EVs) will soon be economically superior to internal combustion engines, whereas hydrogen fuel cell vehicles (FCEVs) likely will eventually dominate heavy-duty road transport. China's huge high-speed rail network and its extensive subway systems will help to somewhat constrain the growth of road traffic and significantly constrain domestic aviation. All rail travel should be electrified well before 2050. Electrification in these surface transport sectors will result in a decline in final energy demand due to the inherently higher energy efficiency of electric versus internal combustion engines. And decarbonization in these sectors will increase rather than decrease attainable GDP per capita, due to EVs' inherent long-term cost advantage.

• **The use of biofuels, synthetic fuels, hydrogen, or ammonia to drive decarbonization of long-distance international aviation and shipping**, combined with the use of battery electric hydrogen and hybrid options over short distances. These fuels likely will be more expensive than existing fossil fuels, implying somewhat higher international freight rates and airline tickets. However, technological progress and economies of scale could drive substantial cost reductions over time.

• **A shift toward a more circular economy, with far more efficient use and greater recycling of key materials** such as steel, cement, fertilizers, and plastics. Total needs for primary steel and cement production to support construction will inevitably fall as China's population stabilizes and then falls, and as urbanization reaches completion. As a result, steel production from recycled scrap steel would take up 60% of total production compared to its share of less than 10% today. In cement, recycling opportunities are more limited, but improved building design and material quality could reduce total demand by nearly 50% compared with the business-as-usual (BAU) level. Demand for fertilizers could be cut by one-third through much higher but feasible fertilizer use efficiency. And 52% of China's plastics use could come from recycled plastic, with extensive development of both mechanical and chemical recycling.

• **The use of electrification, hydrogen, carbon capture**

and storage (CCS), and bioenergy to achieve full decarbonization of heavy industries such as steel, cement, and chemicals (ammonia, methanol, and high-value chemicals [HVCs]). Direct electrification would be most applicable for industrial processes with a low to medium temperature requirement, while hydrogen and bioenergy can be used to meet intense heat demands. Hydrogen would also be used as a reduction agent for steel and as a feedstock in chemicals production. Biomass could be another important feedstock for chemicals. CCS would play a role in dealing with industrial process emissions and those from remaining fossil fuel use.

• **The wider deployment of advanced heat pump technologies plus state-of-the-art building insulation** to deliver heating and cooling to houses and offices in a zero-carbon fashion, **with long-distance industrial waste heat transportation and biomass also playing a role in specific circumstances.** By 2050, energy efficiency in China's building sector would be significantly improved to ensure economical and effective use of energy in the face of a growing service level, and by then 75% of building heating and cooling would be delivered by electricity. Electrification combined with heat pumps would in turn reduce the final energy demand, given the inherent efficiency benefits of heat pumps, which even today can deliver 4 kWh of heat for each kilowatt-hour of input electricity, with further significant improvement in this "coefficient of performance" likely to be achieved over time.

The combination of reduced demand for steel and cement, more circular use of all materials—including, in particular, plastics—and the inherent energy efficiency advantages achieved by the electrification of both surface transport and building heating will enable China to enjoy a GDP per capita and standard of living of three times the current levels while reducing final energy demand from 88 EJ today (24,000 terawatt-hours [TWh]) to 64 EJ (17,800 TWh) in 2050. Within this, the industry would experience the most significant reduction (minus 30%) but would continue to account for 60% of final energy demand in 2050 (see Exhibit A).

This energy demand could be met in a zero-carbon fashion through the use of four technologies: electricity, which can be made zero carbon if it derives from renewable or nuclear sources; hydrogen, which can be produced in zero-carbon fashion via electrolysis using zero-carbon electricity, and which can also be used in the form of ammonia; bioenergy, which can be used as zero-carbon fuel and feedstock; and the continued use of some fossil fuels, if combined with carbon capture and either storage or use. Exhibit B sets out the different energy mixes that could be used in each sector of the economy in 2050.

Electricity will play the most important role, either used directly or to produce hydrogen, ammonia, or

Under our scenario, China would be able to reduce final energy demand from 88 EJ in 2016 to 64 EJ in 2050, where industry would experience the most significant reduction (minus 30%) but would continue to account for 60% of final energy demand.

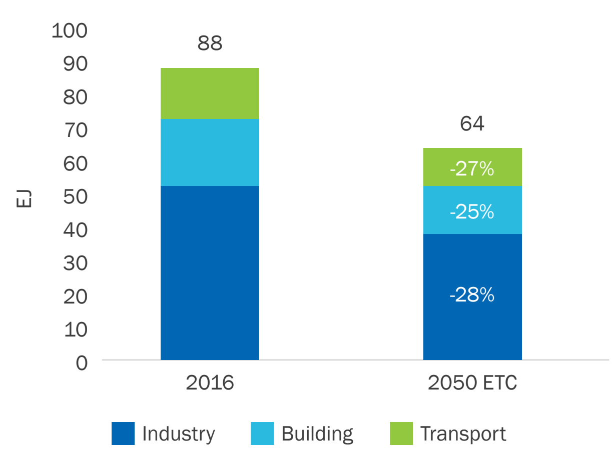


Exhibit A: China's final energy demand by sector (industry, building, and transport)

Source: China Statistics Yearbook;
Rocky Mountain Institute analysis for ETC China

other synthetic fuels. In aggregate, achieving a zero-carbon economy will require an increase in electricity generation from today's 7,000 TWh to something around 15,000 TWh in 2050 (see Exhibit C). In addition, hydrogen use will need to rise from today's 25 million tonnes per annum to more than 81 million tonnes. Making this electricity in a zero-carbon fashion could be achieved with 2,500 GW of solar capacity, 2,400 GW of wind, 230 GW of nuclear, and 550 GW of hydro power. This is technically feasible given China's wind, solar, and hydro resources and the number of coastal sites already identified as suitable for nuclear power plants.

While places with rich solar resources cover two-thirds of its total land area, China would need to devote less than 1% of its land mass to deliver the 2,500 GW of solar energy required within the total mix, and China's estimated wind capacity resources, at 3,400 GW onshore plus 500 GW offshore, exceed the required amount.

Building the required capacity will require a dramatic increase in the annual pace of investment (twice today's rate for solar and three to four times for wind) but the financial cost of this investment would still be less than 0.4% of China's GDP. This is clearly economically feasible in an economy currently investing over 40% of GDP, some of which is wasted on excessive investments in unoccupied real estate, and which will face declining real estate and non-energy infrastructure investment needs as the population stabilizes and urbanization reaches completion.

As Exhibit C shows, the resulting electricity system would derive nearly 70% of its electricity from wind and solar resources, which vary with weather conditions. But a portfolio of grid flexibility and storage options will make it possible to balance supply and demand. A total of 142 GW of pumped hydro storage (PHS) could provide longer duration seasonal backup. Battery storage could grow from today's trivial levels to reach 510 GW in 2050, with costs likely to fall dramatically over time. Production of hydrogen from excess electricity could serve as an effective demand response

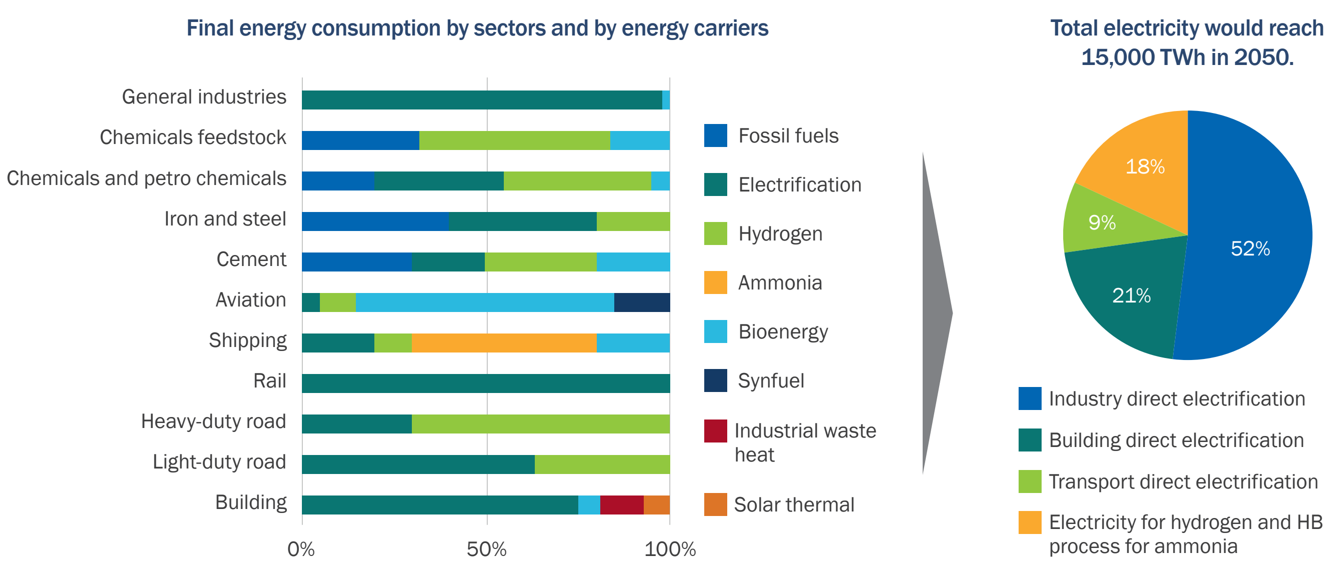


Exhibit B. Snapshot of final energy consumption by sectors and energy carriers in China 2050

Note: HB process = Haber-Bosch process.
Source: Rocky Mountain Institute analysis for ETC China

mechanism, with at least 100 GW of capacity in place. Various categories of demand response—in both the industrial and residential sectors—could play a major role provided that appropriate software systems and market incentives are in place. Thermal plants, powered either by biomass or by fossil fuels with carbon capture applied, will play a limited but still vital role, providing short-term backup while running only a small number of hours per annum.

In addition to electricity and hydrogen, achieving a zero-carbon economy will require the production of about 13 EJ per annum of bioenergy, compared with only 1 EJ today. Achieving this bioenergy supply in a sustainable fashion will prove a major challenge, but in principle China could develop sustainable bioenergy on the scale of 12 EJ to 25 EJ. Given its limited bioenergy resource, China would need to prioritize its use on those sectors where alternative decarbonization options are not available. Aviation is likely a priority sector; trucking is not.

There would also be a limited but still vital need to apply carbon capture to several industrial processes, with the CO_2 either utilized in applications that achieve permanent sequestration (such as new forms of concrete curing) or transported and stored. China's geological capacity for CO_2 storage far exceeds the 1 gigatonne per annum which will be required, and there is sufficient matching between the location of carbon emissions and the location of storage to minimize the requirement for very long distance (greater than 250 km) transport of CO_2.

Given both the reduced final energy demand described in Exhibit A and the switch to the zero-carbon energy mix shown in Exhibits B and C, total primary energy demand could fall by 45% from 132 EJ today to 73 EJ in 2050. This larger fall in primary energy demand than in final energy demand (minus 30%) largely reflects the elimination of the energy losses involved in today's thermal electricity production system. Within this

In aggregate achieving a zero-carbon economy will require an increase in electricity generation from 6,000 TWh in 2016 to something around 15,000 TWh in 2050.

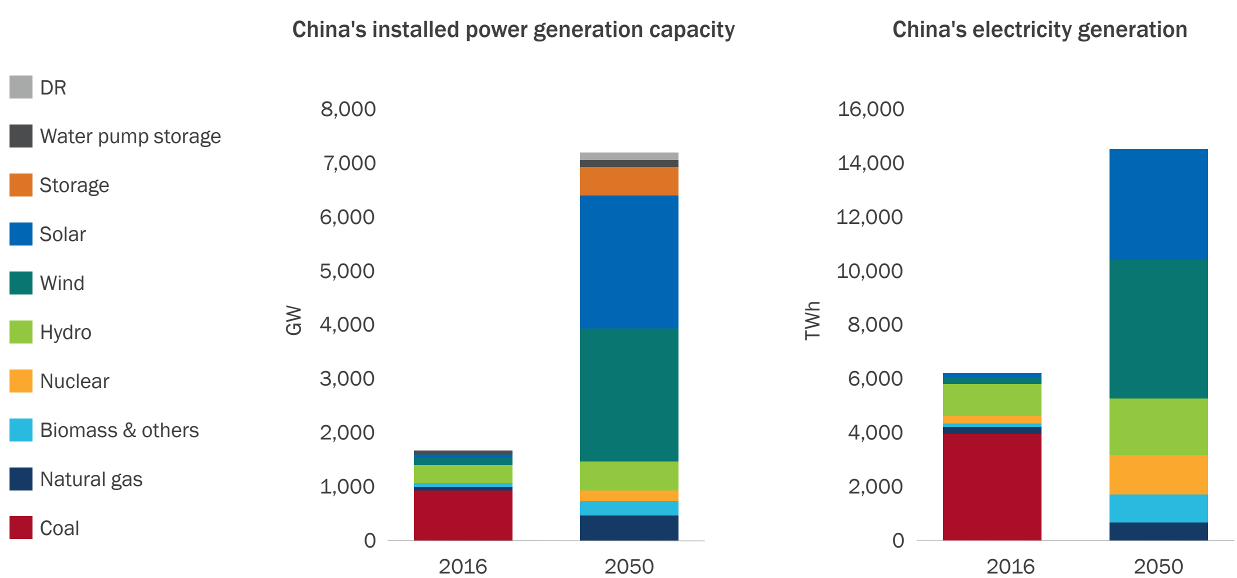


Exhibit C. China's installed power generation capacity and electricity generation mix

Note: HB process = Haber-Bosch process.
Source: Rocky Mountain Institute analysis for ETC China

reduced total, there would be a dramatic change in the sources of energy, with fossil fuel demand falling over 90% while non-fossil energy would expand by 3.4 times (see Exhibit D).

The precise balance between different decarbonization routes and energy supply options will need to reflect evolving technological possibilities and economic developments over time. But the scenario presented here shows that it is possible to achieve zero emissions at a very small cost, with the impact on China's GDP per capita and living standards in 2050 unlikely to exceed 1%.

This cost could indeed be lower still, or even negative, if the very fact of committing to a zero-emissions target induced technological advances and cost reductions not assumed in our calculations.

But this feasible path to a zero-carbon economy will not be achieved without clear targets and forceful public policies. Setting a clear national objective to reach zero emissions by 2050 is essential to provide a framework within which state-owned and private enterprises can make the investments required. But this long-term objective must be supported by short-term targets and investment plans—such as those set out in China's forthcoming 14th Five Year Plan—and by strong policies. These should include:

- Clear policies to support increased investment in zero-carbon electricity system, including generation, transmission, distribution and energy storage systems;
- A national carbon price system to drive decarbonization across the whole economy and particularly in heavy industry;
- Strong regulations to drive the electrification of surface transport and building heating, and to ensure ever improving standards of building insulation;

Total primary energy demand could fall by 45% from 132 EJ today to 73 EJ in 2050, with fossil fuel demand falling over 90% and non-fossil energy expanding by 3.4 times.

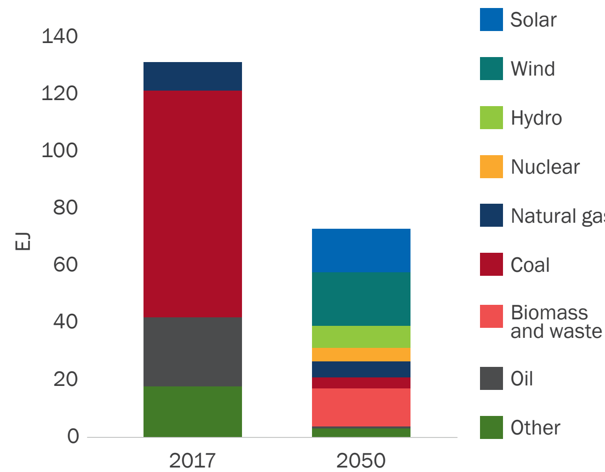


Exhibit D. China's primary energy demand by energy carrier

Source: China Statistical Yearbook; Rocky Mountain Institute analysis for ETC China

- Regulations and incentives to support an increasingly circular economy of materials recycling and reuse, particularly in the plastics sector;
- And public support for the development and early deployment of the new technologies required to build a zero-carbon economy;

China's political and economic system, which combines market incentives with strong state ability to define long-term objectives and support long-term investments, makes it well placed to put these policies in place, to achieve net zero emissions by 2050, and to gain the economic and environmental advantages which would result.

CHINA 2050: A FULLY DEVELOPED RICH ZERO-CARBON ECONOMY

DEMAND-SIDE DECARBONIZATION

DEMAND REDUCTION, ENERGY EFFICIENCY IMPROVEMENT, AND FUEL SWITCH

STEEL

- Scaling up secondary steel production with scrap and EAF;
- Promoting hydrogen direct reduced iron (DRI) and other technologies;
- Applying CCS to traditional steelmaking.

CEMENT

- Improving material efficiency;
- Using zero-carbon energy as heat input;
- Applying CCS for emissions from fossil fuel and production process.

CHEMICALS

- Promoting efficient use of fertilizers and plastics circularity;
- Applying CCS to fossil fuel-based production routes;
- Substituting conventional feedstocks with CO_2 and zero-carbon H_2, or biomass.

SURFACE TRANSPORT

- Controlling travel growth with smart planning and development of subways and railways;
- Promoting electrification for light vehicles and heavy road transport with BEVs and FCEVs.

SHIPPING AND AVIATION

- Applying electric engines for short-distance travels;
- Promoting hydrogen and ammonia as shipping fuels;
- Supporting bio and synthetic jet fuel development and application.

BUILDING

- Stepping up electrification, including expanding use of heat pumps;
- Demanding higher building energy efficiency;
- Utilizing biomass, industrial waste heat, and solar thermal where applicable.

SUPPLY-SIDE DECARBONIZATION

TECHNICALLY AND ECONOMICALLY FEASIBLE

ELECTRICITY

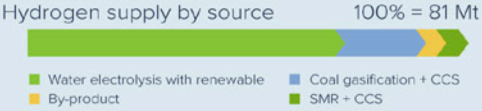
- **0.8%**: China's land for 2,500 GW solar PV
- **70%**: onshore wind resource to utilize
- **660 GW+230 GW**: hydro + nuclear power standing by
- Energy storage, flexible generation,and demand response : to address flexibility
- **>60%**: LCOE reduction for renewables and batteries by 2050

Installed power capacity in 2050 100% = 7,100 GW

HYDROGEN

- **\$20/MWh, \$370/kW** : max electricity price and electrolyzer capital cost for electrolysis to achieve cost parity with coal gasification without CCS
- **2600 TWh**: electricity use to produce 58 Mt hydrogen

Hydrogen supply by source 100% = 81 Mt



BIOMASS

- **17 EJ/a**: max potential biomass resource, considering loss and land use
- **13 EJ/a**: prioritized demand for aviation, chemical, and power generation
- **Supply uncertainties**: resource limitation, land use competition, collection costs and technology improvement

Bioenergy potential supply by source 100% = 17EJ

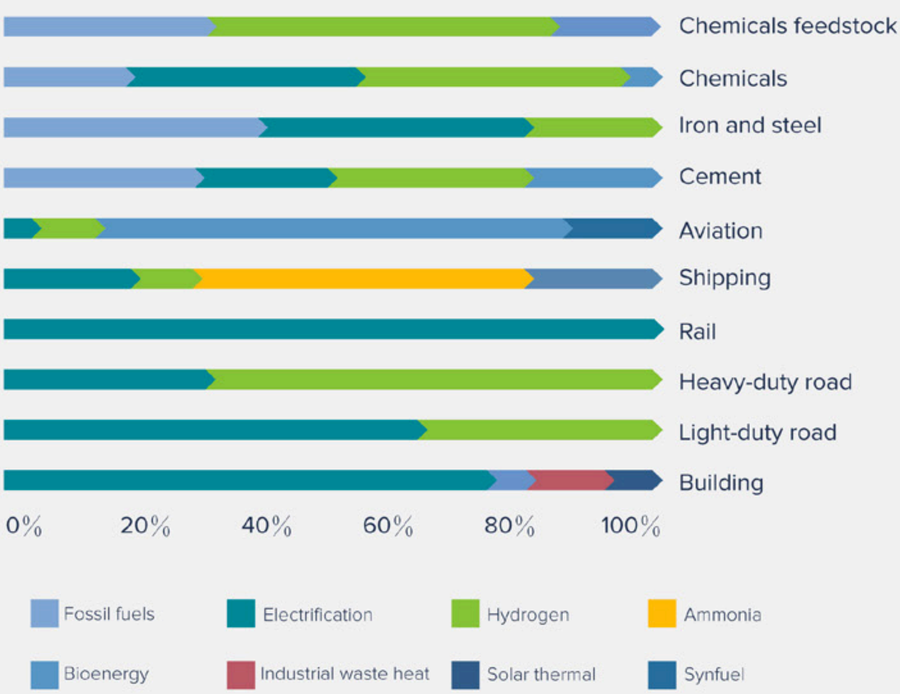
CARBON CAPTURE & STORAGE

- **1,500 Gt**: practical storage capacity
- **\$55/t CO_2**: average total costs of capture, transportation and storage now
- **Cost reduction**: in the future with economies of scale and learning curve effects

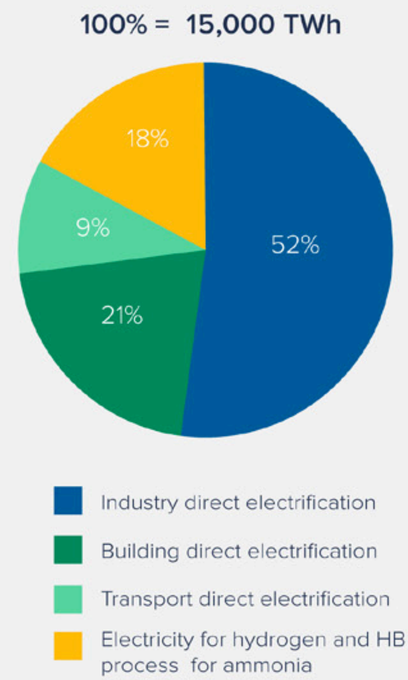
Residual CO_2 emissions by sector 100% = 110 Mt

Meeting these energy demands in a zero-carbon fashion will require a major change in the mix of energy supply, with massive direct or indirect electrification, use of biomass and CCS, and significant reduction of fossil fuels.

Final energy mix in a zero-carbon scenario



Electricity demand by sector



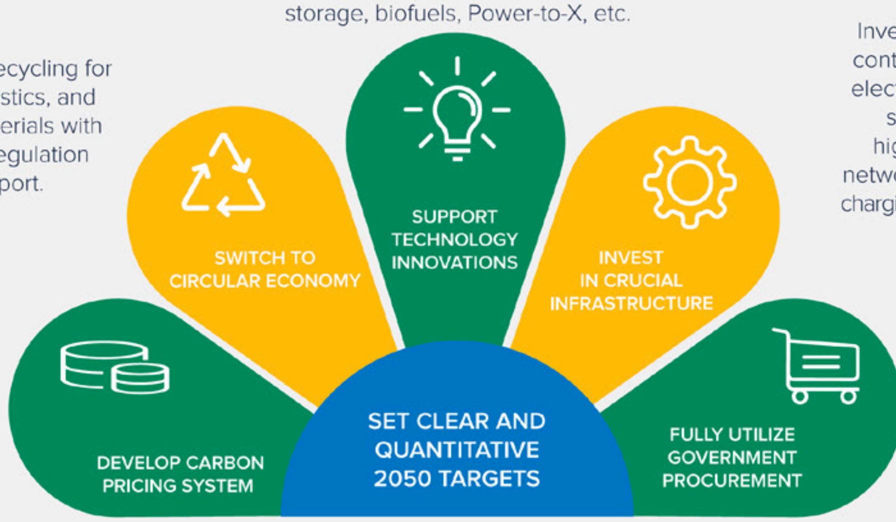
TOTAL INVESTMENT < 1% CHINA'S GDP
With minimal cost to end-users

POLICY INSTRUMENTS

Support R&D and early-stage deep decarbonization technologies in energy storage, hydrogen production and storage, biofuels, Power-to-X, etc.

Promote recycling for steel, plastics, and other materials with strong regulation support.

Invest heavily and continuously in the electricity transmission system, high-speed rail network, and vehicle charging infrastructure.



Accelerate the development of the national carbon market to drive search for least-cost decarbonization solution.

Guide and incentivize procurement of central and local governments and also SOEs to stimulate demand for low-carbon products.

For more information: www.energy-transitions.org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