NUCLEAR ENERGY

# China-U.S. cooperation to advance nuclear power

## Mass-manufacturing and coordinated approvals are key

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With China having the largest fossil fuel $CO_2$ emissions today and the United States being higher in per capita emissions (see related energy consumption in the first figure), these countries have a strong mutual interest in stabilizing climate and reducing air pollution. Yet even Germany, despite sizable subsidies of renewable energies, gets only a small fraction of energy from them (see the first figure). Historically the fastest growth of low-carbon power occurred during scale-up of national nuclear power programs (see the second figure). Some studies project that a doubling to quadrupling of nuclear energy output is required in the next few decades, along with a large expansion of renewable energy, in order to achieve deep cuts in fossil fuel use while meeting the growing global demand for affordable, reliable energy (*1*–*4*). In light of this large-scale energy and emissions picture, climate and nuclear energy experts from China and the United States convened (see Acknowledgments) to consider the potential of increased cooperation in developing advanced nuclear technologies.

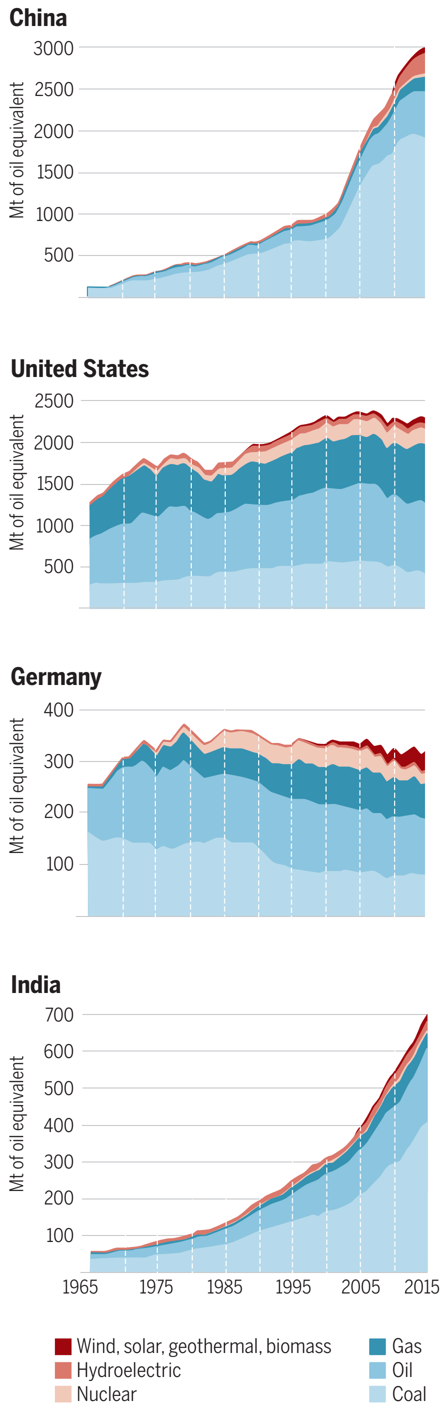
Barriers to expansion of nuclear energy include high construction costs relative to coal and gas; a long time to build conventional large nuclear plants (about 4 to 7 years in Asia versus 1 or 2 years for coal-fired plants); and public concern about reactor safety, waste disposal, and potential for weapons use. Innovative nuclear technologies can help address some of these issues. A large reduction of cost and construction time, essential to accelerate deployment rates, likely requires mass manufacturing, analogous to ship and airplane construction. Such an approach lends itself to product-type licensing, which avoids the long delay and costs associated with case-by-case approval. Passive safety features are available that allow reactor shutdown and cooling without external power or operator intervention. Other innovative designs use fuel more efficiently and produce less nuclear waste, can directly supply energy to industrial processes that currently rely on fossil fuels, can be ordered in a range of scales to suit a variety of needs and geographies, and can reduce or eliminate cooling-water requirements. Some of these developments could be deployed on a large scale by 2030–2050, a time when deep reductions in global carbon emissions will be needed, even as much of the world's current nuclear fleets are approaching the end of useful life.

U.S.-China cooperation to accelerate nuclear energy innovation has potential to deliver benefits to both countries and the world. Test sites at U.S. Department of Energy laboratories are needed to perform experiments in existing test reactors and to build and demonstrate advanced designs. China's growing demand for electricity, even though slowing, and its need to displace large amounts of existing coal-fired capacity provide the large market for nuclear reactors that is needed to drive down unit costs.

Innovative concepts are emerging in both countries. Recent reactor development in the United States is entrepreneurially driven, in a departure from the traditional model in which nuclear innovation flowed outward from government. Technologies under development include small modular light-water, molten salt, gas-cooled, and liquid-metal–cooled reactors. China has recently made major investments in several nuclear innovation projects, including high-temperature gas reactors, thorium-fueled molten salt reactors, sodium-cooled fast reactors, and accelerator-driven subcritical systems.

Current China-U.S. cooperation includes collaboration between a U.S. company (TerraPower) and the China National Nuclear Corporation to demonstrate traveling-wave reactor technology, as well as the cooperation of Oak Ridge National Laboratory, U.S. universities, and the Shanghai Institute of Applied Physics to develop molten salt reactor technologies, including near-term options for fluoride salt–cooled, solid-fuel, high-temperature reactors. Molten salt technology, which has large potential but remains immature, provides a particularly large opportunity for U.S.-China cooperation.

Development of large floating nuclear plants—constructed in shipyards before being towed and anchored 10 to 20 km off-




**Energy consumption in four nations.** Data source (6). See supplementary materials.

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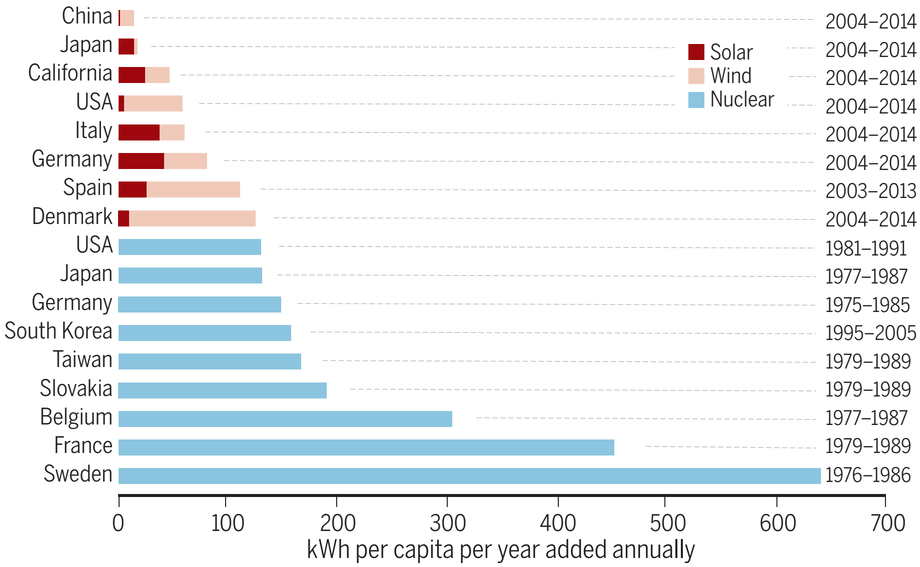
shore—has promise to reduce cost, speed deployment, reduce tsunami and earthquake risk, and enhance security. Recent studies show that gigawatt-scale plants can be deployed on robust floating platforms using technology developed for deep-water drilling in the severe weather conditions of the North Sea (*5*). Such power plants could be constructed more rapidly than conventional reactors. China's shipyards already build most of the world's large deep-water platforms and could be adapted to the large floating reactor application.

Further suggestions to accelerate progress include (i) test sites for prototype projects providing access to innovators from China, the United States, and other countries; (ii) joint development of open-source architecture for major advanced plant subsystems—such as a standards-based specification for reactor modules of all types that would address general safety criteria, fuel lifetime, transportability, and so on, as well as open-source codes for advanced reactors; (iii) joint programs to develop, demonstrate, and license advanced non–light-water reactors; (iv) agreement on a regulatory approach that encourages technical innovation in safety assurance, as opposed to detailed prescriptive specifications, also "stage gates" of approval rather than a single review that can require hundreds of millions of dollars in preparation. Jointly funded projects would be governed by the regulations of the host country.




**Average annual increase of carbon-free electricity per capita during decade of peak scale-up.** Energy data from (*6*) except California renewables data from (*7*). Population data from (*8*). See supplementary materials.

However, obstacles to broader Sino-U.S. nuclear cooperation must be overcome. Obstacles and benefits are both illustrated by recent developments in light-water reactor technology. China-U.S. cooperation was instrumental in development and demonstration of the U.S.-invented AP1000, an 1150-MWe advanced light-water reactor with passive safety features now being deployed in both countries.

As counterpoint, recent charges brought by U.S. authorities under nuclear export control laws—claiming that light-water reactor design information was illegally transferred to Chinese nuclear organizations—is a reminder of the competing strategic economic and security interests of the two countries and the fact that Chinese and U.S. nuclear firms are commercial competitors.

Collaboration in next-generation technologies requires government and industry in both countries to balance interests in cooperation and competition. Joint projects may require participating commercial firms to decide on the intellectual property they are willing to transfer. Regulators in the two countries may choose to align safety standards, which would expand market opportunities for suppliers in both countries, or promulgate their own regulatory criteria, which might benefit their own suppliers by creating barriers to suppliers from the other country but limit their available market.

One barrier our U.S. authors recommend for review is U.S. policy requiring specific authorization for exports of civilian reactor technologies to China, in contrast to general authorization allowed for exports to Japan, South Korea, France, and the United Kingdom. The protracted review process makes cooperation between U.S. and Chinese industry difficult and slow and impedes joint efforts to improve key areas for civil reactor technologies, such as passive safety.

Efforts to overcome obstacles to expanded U.S.-China cooperation in the development of advanced nuclear power technologies are justified by the large potential benefits. Each country has a major stake in the other's success in reducing its carbon emissions, and each has a major stake in the achievement of enhanced nuclear safety in the other country and the rest of the world. In light of this potential, a review of U.S. export policy for civilian reactor technology is warranted with the goal of differentiating and managing U.S.-Chinese commercial intellectual property exchanges, while also creating a stronger mutual foundation for coordinating U.S. and Chinese support for vital international nuclear nonproliferation and security objectives.

Climate science reveals that the world is approaching limits on fossil fuel emissions, if climate is to be stabilized. Future workshops will include climate and nuclear experts from countries such as Indonesia and India, which—with the third greatest $CO_2$ emissions and population projected to pass China's in 2021 (*6*)—has rapidly growing energy needs that are fossil fuel–dependent (see the first figure). ■

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## ACKNOWLEDGMENTS

Our essay draws upon discussions at the Workshop on Advanced Nuclear Energy to Address Climate Change and Air Pollution, 17 to 20 December 2015, Wanning, Hainan, China. The Chinese Academy of Sciences funded local workshop costs. Travel costs of a majority of non-Chinese participants were paid by the U.S. nonprofit Climate Science, Awareness and Solutions, Inc., with funding from Gary L. Russell. P.P.'s research group receives funding from the U.S. Department of Energy and the Shanghai Institute of Applied Physics to work on advanced molten salt reactor technologies.

## SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/353/6299/547/suppl/DC1

10.116/science.aaf7131

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*Science* **353** (6299), 547-548.
DOI: 10.1126/science.aaf7131