Congressional Testimony

The Realities of Nuclear Expansion

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Enthusiasm for nuclear energy has grown significantly in the last five years, prompting a flurry of policy papers, newspaper articles and magazine covers (from the *Economist* to *Fortune* to the *Bulletin of Atomic Scientists*). Although the challenges of nuclear energy haven't changed – proliferation, cost, waste, and safety – the debate is now focused on how nuclear energy can help beat global climate change. Rapidly increasing demand for electricity, rising costs of oil and gas, and concerns about energy security complete the case for the "nuclear renaissance."

The United States is taking an active role in promoting nuclear energy at home and abroad. U.S. policymakers are pursuing:

- Promotion of nuclear energy at home, including reprocessing of reactor spent fuel and subsidies for the nuclear industry;
- Promotion of global nuclear expansion, including nuclear cooperation with states like Russia and India; and
- Limits on the spread of sensitive nuclear fuel cycle technologies such as enrichment of uranium and reprocessing of spent fuel abroad for nonproliferation purposes.

U.S. federal funding for nuclear energy has increased 330% since 2001.[1] Other federal support for the nuclear industry includes loan guarantees, production tax credits, risk insurance and the 20-year extension of the Price-Anderson Act. The 2005 Energy Policy Act contained subsidies for the first 6 new nuclear power plants built in the United States, among other things.

More broadly, President Bush stated in May 2007 that if we're "truly interested in cleaning up the environment, or interested in renewable sources of energy, the best way to do so is through safe nuclear power." Secretary of State Rice told Congress in 2006 that the U.S.-India nuclear cooperation agreement would benefit the environment. In her words, "Nuclear energy is, after all, clean energy and providing India with an environmentally friendly energy source like nuclear energy is an important goal."[2] And the U.S. creation of the Global Nuclear Energy Partnership in 2006 also has contributed to international enthusiasm for nuclear energy.

Added to U.S. government support, prominent environmentalists such as Patrick Moore and Stewart Brand have reversed their earlier opposition to nuclear energy and now embrace it as necessary and desirable.

The result is a confused debate that paints nuclear energy "clean and green," advocates nuclear energy for all, even though some states with nuclear reactors could pose significant safety and proliferation concerns, and suggests that nuclear energy is a path to energy security, while insisting that some states rely on market mechanisms for

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[1] Assistant Secretary For Nuclear Energy Dennis R. Spurgeon, "Federal Support For A Growing Nuclear Power Industry," Remarks to Platts 4th Annual Nuclear Energy Conference, February 5, 2008.

[2] "The U.S.-India Civilian Nuclear Cooperation Agreement," Secretary Condoleezza Rice, Opening Remarks Before the Senate Foreign Relations Committee, Washington, DC, April 5, 2006

fuel supplies instead of developing their own indigenous resources and capabilities. Yet, this approach obscures important policy considerations as the United States and other countries consider nuclear investments on the order of several hundred billion dollars. A first order question is the extent to which nuclear energy can really make a difference in terms of global climate change.

The Pacala-Socolow Nuclear "Wedge"

In 2004, Princeton scientists Stephen Pacala and Robert Socolow published a "wedge analysis" for stabilizing global climate change.[3] Since fossil fuels currently emit 7 billion tons of carbon/year and are projected to double that level through 2050 in the business-as-usual scenario, Pacala and Socolow considered what technologies and/or approaches might help stabilize those emissions at current levels (about 375 ppm). Seven wedges of reduced emissions (a cumulative effect of 25 billion tons through 2050, or one billion tons of carbon/year reduction at the end of that period) were postulated. One "wedge" would ultimately achieve a reduction of 1 billion tons per year (or 25 billion cumulative tons) by 2050.

For nuclear energy to "solve" just one-seventh of the problem – lowering emissions by 1 billion tons per year – an additional 700 GWe of capacity would have to be built, assuming the reactors replaced 700 GWe of modern coal-electric plants.[4] Because virtually all operating reactors will have to be retired in that time, this means building approximately 1070 reactors in 42 years, or about 25 reactors per year.

Current global reactor capacity is 373 GWe or 439 reactors worldwide. In short, one "nuclear wedge" would require almost tripling current capacity.

Mapping Nuclear Expansion

The attached maps (see slide 1) depict estimates of reactor capacity growth for 2030 and 2050, according to three scenarios. The first is a "realistic growth" scenario, based on the U.S. Energy Information Administration figures for 2030.[5] The second is what states have planned for 2030, or a "wildly optimistic" scenario. The third is roughly based on the high-end projections for 2050 done by MIT in their 2003 study entitled "The Future of Nuclear Power." This 1500 GWe scenario lies between the Pacala-Socolow wedge and the Stern Review on the Economics of Climate Change estimates that nuclear

[3] S. Pacala, R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, Vol. 305, August 13, 2004.

[4] The International Panel on Fissile Materials estimates that when compared to an equivalent modern coal plant, 1 GWe of nuclear capacity operating at an average capacity factor of 90% reduces the amount of carbon released to the atmosphere by about 1.5 million metric tons annually. See IPFM, *Global Fissile Material Report 2007*, p. 87.

[5] Neither the U.S. Energy Information Administration nor the International Energy Agency currently provides an outlook on nuclear energy for 2050 because of the level of uncertainty (although the IEA is considering doing this), which prevents a strict comparison of the three scenarios.

energy could reduce carbon emissions between 2 billion and 6 billion tons/year (or 1800GWe – 4500 GWe).[6]

A few caveats with respect to projecting nuclear energy expansion are necessary. Nuclear energy is undoubtedly safer and more efficient now than when it began fifty years ago, but it still faces four fundamental challenges: waste, cost, proliferation, and safety. It is an inherently risky business. Most industry executives will admit that it will only take one significant accident to plunge the "renaissance" back into the nuclear Dark Ages. Because of this, estimates are highly uncertain. For example, the U.S. Energy Information Administration does not use its computer model to estimate nuclear energy growth because, among other things, key variables such as public attitudes and government policy are difficult to quantify and project. That said, estimates tend to extrapolate electricity consumption and demand from gross domestic product (GDP) growth, make assumptions about nuclear energy's share of electricity production and then estimate nuclear reactor capacity.

A "Realistic Growth" Scenario

The United States, France, and Japan constitute more than half of total world nuclear reactor capacity (see slide 1). Yet half of the 34 reactors now under construction are in Asia.[7] Under any scenario, nuclear power is expected to grow most in Asia, because of high Chinese and Indian growth and electricity demand.

Under the realistic growth scenario, the U.S. Energy Information Administration estimates 2030 reactor capacity at 481 GWe. The International Energy Agency (IEA) envisions greater potential for expansion, projecting a range from 414 to 679 GWe in 2030, but the higher number would require significant policy support.

With electricity consumption expected to double by 2030, nuclear energy will have a difficult time just keeping its market share– currently 16 percent of global production.[8] According to the Intergovernmental Panel on Climate Change, with no change in energy policies, "the energy mix supplied to run the global economy in the 2025–2030 time-frame will essentially remain unchanged with about 80% of the energy supply based on fossil fuels."[9] Coal now provides 59% of electricity production, followed by, hydroelectric power at 39 % and oil and gas together provide 25%. Renewables are just 1-2% of total electricity production.

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[6] Nicholas Stern, *The Economics of Climate Change: The Stern Review*, October 2006.

[7] See World Nuclear Association figures, *World Nuclear Power Reactors 2006-08 and Uranium Requirements*, updated January 14, 2008, available a: http://www.world-nuclear.org/info/reactors.html

[8] The EIA's International Energy Outlook 2007 Reference Case Scenario states that electricity generation will rise from 16,464 billion kilowatt hours in 2004 to 30,364 billion kilowatt-hours in 2030 – almost a doubling of generation, with much of that rise coming from outside the OECD states. Electricity generation from nuclear power plants worldwide is projected to increase at an average rate of 1.3 percent per year, from 2,619 billion kilowatt-hours in 2004 to 3,619 billion kilowatt-hours in 2030.

[9] Intergovernmental Panel on Climate Change, Fourth Assessment Report, Working Group III Report: Mitigation of Climate Change, 2007, p. 109

Moreover, regions that have coal tend to use it, particularly for electricity generation, which increases greenhouse gas emissions. The IPCC has noted that "in recent years, intensified coal use has been observed for a variety of reasons in developing Asian countries, the USA and some European countries. In a number of countries, the changing relative prices of coal to natural gas have changed the dispatch order in power generation in favor of coal." Many fear that states such as China and India – both of whom are not subject to Kyoto Protocol targets because they are developing states– will meet their increased demand with cheap coal. Without further policy changes, according to the International Energy Agency, the share of nuclear energy could drop to 10% of global electricity production.

"Wildly Optimistic" Growth Scenario

Although some states, such as Germany and Sweden, plan to phase out nuclear power, the trend line is moving in the opposite direction. This growth scenario does not contain projections based on electricity demand, but instead takes at face value what states have projected for themselves. The result is a total of 700 GWe global capacity (see slide 2) – two-thirds of what one nuclear wedge to affect global climate change would require. The reason these estimates are wildly optimistic is that over 20 nations have announced intentions to install nuclear reactors. Several of these – Turkey, Egypt, and Philippines – had planned for nuclear power in the past, but abandoned such plans for various reasons.

Some of these new nuclear plans are more credible than others and can be differentiated into those that have approved or funded construction; those that have clear proposals but without formal commitments, and those that are exploring nuclear energy (see slide 3).

In the Middle East, these include Iran, Israel, Jordan and Yemen, with potential interest expressed by Syria, Kuwait, and the Gulf Cooperation Council states of Saudi Arabia, Oman, United Arab Emirates, Qatar, and Bahrain. In Europe, Belarus, Turkey and Azerbaijan have announced plans, as well as Kazakhstan. In Asia, Bangladesh, Thailand, Vietnam, Malaysia, and Indonesia have announced plans, and the Philippines has also expressed interest. Venezuela has also declared it will develop nuclear power. In Africa, Morocco, Tunisia, Libya, Egypt, and Nigeria have announced plans to develop nuclear power, and Algeria and Ghana have expressed interest.[10]

More than half of all those states are in the Middle East. Although this could result in reduced carbon emissions, because Middle Eastern states use more oil for

[10] The World Nuclear Association lists 30 nations as considering nuclear power: In Europe: Italy, Albania, Portugal, Norway, Poland, Belarus, Estonia, Latvia, Ireland, Turkey; In the Middle East and North Africa: Iran, Gulf states, Yemen, Israel, Syria, Jordan, Egypt, Tunisia, Libya, Algeria, Morocco; In central and southern Africa: Nigeria, Ghana, Namibia; In South America: Chile, Venezuela; In central and southern Asia: Azerbaijan, Georgia, Kazakhstan, Bangladesh; In SE Asia: Indonesia, Philippines, Vietnam, Thailand, Malaysia, Australia, New Zealand.

electricity production (34%) than elsewhere, this is not where the real electricity demand is coming from.

"Climate Change" Growth Scenario

A rough approximation of where reactor capacity would expand in a climate change scenario is based on the high scenario of the 2003 MIT Study, "The Future of Nuclear Power." For 1500 GW capacity, MIT estimated that 54 countries (an additional 23) would have commercial nuclear power programs. This essentially means a five-fold increase in the numbers of reactors worldwide and an annual build rate of 35 per year. In the event that smaller-sized reactors are deployed in developing countries – which makes eminent sense – the numbers could be much higher.[11] If nuclear energy were assumed to be able to contribute a reduction of between 2 and 6 billion tons of carbon per year as outlined in the Stern Report, the resulting reactor capacity would range between 1800 GWe and 4500 GWe – increases ranging from six times to ten times current capacity.[12] This would require building between 42 and 107 reactors per year through 2050.

Impact on Uranium Enrichment

Such increases in reactor capacity would certainly have repercussions for the front and back ends of the fuel cycle. Almost 90 percent of current operating reactors use low-enriched uranium (LEU). Presently, 11 countries have commercial uranium enrichment capacity and produce between 40 and 50 million SWU. A capacity of 1070 GWe – the one "wedge" scenario – could mean tripling enrichment capacity, requiring anywhere from 11 to 22 additional enrichment plants.[13] A capacity of 1500 GWe would require quadrupling enrichment capacity (see slide 4).[14] Further, if Stern Report nuclear expansion levels are achieved, enrichment capacity would have to increase ten-fold.

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[11] The MIT study used an underlying assumption that the developed countries would continue with a modest annual increase in per capita electricity use and the developing countries would move to the 4000 kWh per person per year benchmark if at all feasible (the 4000 kWh benchmark is the dividing line between developed and advanced countries). Electricity demand was then pegged to estimated population growth. Finally, it was assumed that nuclear energy would retain or increase its current share of electricity generation. The least-off developing countries were assumed in the MIT study not to have wherewithal for nuclear energy. A final caveat in the MIT study is that the 2050 projection is "an attempt to understand what the distribution of nuclear power deployment would be if robust growth were realized, perhaps driven by a broad commitment to reducing greenhouse gas emissions and a concurrent resolution of the various challenges confronting nuclear power's acceptance in various countries." A few countries that the MIT High 2050 case included but we do not are countries that currently have laws restricting nuclear energy. For example, we did not include Austria as a state that will install nuclear reactors, given its 1978 law prohibiting nuclear energy.

[12] This order of magnitude increase was impossible to plot on maps.

[13] Keystone Study.

[14] Calculating enrichment demand requires assumptions about reactor technologies and whether the fuel cycle is open or closed. For example, 1500 GWe light water reactors, using LEU would require 225 million SWU/year. However, 1500 GWe with MOX reactors (1 recycle) would require 189 million SWU/year, and 1500 GWe with fast, thermal reactors would require123 million SWU/year. The MIT Study assumed the same proportion of light water reactors would be built, or 90%.

In assessing where new uranium enrichment capacity might develop, the MIT Study assumed that 18 states would have 10 GWe reactor capacity – the point at which domestic uranium enrichment becomes competitive with LEU sold on the international market – and thus might enrich uranium. (See slide 4 for a more modest approach, with 9 additional countries enriching uranium).[15]

Impact on Spent Fuel Reprocessing

A key question is whether an expansion of nuclear reactors would result in an expansion of spent fuel reprocessing. This is not necessarily the case, because decisions about whether to store fuel or reprocess it depend on several factors: existing storage capacities; fuel cycle approaches (once-through, one recycle, fast reactors) and new technologies; and cost. A shift to fast reactors that can burn or breed plutonium implies an increase in recycling, whether this is traditional reprocessing that separates out plutonium, or options under consideration now that would not separate out the plutonium.

France and Japan now commercially reprocess their spent fuel and recycle the plutonium once in mixed oxide-fuelled reactors. Russia also reprocesses a small percentage of its spent fuel. A troubling development in the last two years from a nonproliferation perspective has been the U.S. embrace of recycling spent fuel under the Global Nuclear Energy Partnership, after a policy of 30 years of not encouraging the use of plutonium in the civil nuclear fuel cycle. Whether or not the United States ultimately reprocesses or recycles fuel, other states are now more likely to view reprocessing as necessary for an advanced fuel cycle.

Constraints on Nuclear Expansion[16]

There are significant questions about whether nuclear expansion that could affect global climate change is even possible. In the United States, as the chief operating officer of Exelon recently told an industry conference, constraints include: the lack of any recent U.S. nuclear construction experience; the atrophy of U.S. nuclear manufacturing infrastructure; production bottlenecks created by an increase in worldwide demand; and an aging labor force.

Lack of construction experience translates into delays, which translate into much higher construction costs. Although reactors typically take at least four years to build, delays can increase finance costs considerably. A recent example – the construction of Okiluoto-3 in Finland – demonstrates that an 18-month delay cost 700 million Euros in a

[15] This calculation is also highly dependent on the price of uranium. For example, other estimates suggest that at a price of $200/kg, the break-even point would only be 5 GWe. See Geoffrey Rothwell, "An Evaluation of the Real Option of Starting to Build a Nuclear Power Plant in Chile in 2020," 18 October 2007, presentation to Centro de Estudios Públicos Santiago de Chile.

[16] See Mycle Schneider, with Antony Froggatt, "The World Nuclear Industry Status Report 2007," January 2008, commissioned by the Greens-EFA Group in the European Parliament, for an excellent summary of the many constraints facing nuclear expansion.

project with a fixed cost of 3 billion Euros.[17] In an analysis for a nuclear industry conference, the consulting firm Booz Allen Hamilton prioritized 15 different risks in new reactor construction. The most significant risks and those most likely to occur included engineering, procurement and construction performance, resource shortages and price escalation.[18]

The atrophy of nuclear manufacturing infrastructure is significant in the United States, but also worldwide. The ultra-heavy forgings for reactor pressure vessels and steam generators constitute the most significant chokepoint. Japan Steel Works (JSW) is currently the only company worldwide with the capacity to make ultra-large forgings (using 600-ton ingots) favored by new reactor designs. Other companies – such as Sfarsteel (formerly Creusot Forge) in France and Doosan Industry in South Korea – have smaller capacities. The purchase of Creusot Forge by AREVA in 2005 means that former customers of Creusot reportedly are shifting to Japan Steel Works, lengthening the two-year waiting list. According to JSW officials, it can now only produce 5.5 sets of forgings per year; this will expand to 8.5 sets in 2010. Even then, nuclear forgings at JSW compete with orders for forgings and assembly from other heavy industries, for example, oil and gas industries, which can be more profitable. China will open new plants, possibly this year, to produce ultra-heavy forgings. In the meantime, using smaller capacity forgings means more components, with more weld seams, and therefore will require more safety inspections, costing utilities more money when the reactors are shut down and not generating electricity. One AREVA estimate is that the daily cost of shutdowns (for inspections or other reasons) is $1 million.

In the United States, a significant portion of supporting industries needs to be rebuilt or recertified. In the 1980s, the United States had 400 nuclear suppliers and 900 holders of N-stamp certificates from the American Society of Mechanical Engineers.[19] Today, there are just 80 suppliers and 200 N-stamp holders. The Nuclear Energy Institute (NEI) notes that some of the decline in N-stamp holders is due to consolidation of companies, but nonetheless is encouraging firms to get recertified. In addition, certain commodities used in reactor construction may also present supply problems, such as alloy steel, concrete and nickel. The cost of these inputs, according to Moody's, has risen dramatically in recent years.

Competition from other electricity and construction projects

According to a 2008 Bechtel estimate, if electricity demand grows in the United States 1.5% each year, and the energy mix remains the same, the United States would

[17] Mycle Schneider, "Myths and Realities on Nuclear Power in the World … and Case Studies France and Turkey," briefing for Heinrich-Böll-Foundation, Istanbul, 20-21 April 2007.

[18] Other risks included delivery delays, materials out of spec; site-related issues; safety related delays; labor productivity; NRC delays; roll-back of incentives; changes in design; late engineering; balance sheet exposure; and project financing availability. Presentation by Tom Flaherty, Booz, Allen, Hamilton to Platt's Fourth Annual Nuclear Energy Conference, Bethesda, Maryland, February 5, 2008.

[19] Jim Harding, "Seven Myths of the Nuclear Renaissance," Presented to Conference on the 50th Anniversary of the Euratom Treaty Brussels, Belgium ,March 7-8, 2007. Available at http://www.nirs.org/nukerelapse/neconomics/jimharding382007.pdf

have to build 50 nuclear reactors, 261 coal-fired plants, 279 natural-gas-fired plants and 73 renewables projects by 2025. All of these will require craft and construction labor. In addition, electricity generation projects will compete with oil infrastructure projects.

In addition, nuclear power construction competes with other large investment projects for labor and resources. Rebuilding from Hurricane Katrina and big construction projects in Texas will continue to place pressure on construction labor forces. A Bechtel executive recently stated that the U.S. faced a skilled labor shortage of 5.3 million workers in 2010, which could rise to a shortage of 14 million by 2020. Adding to this is the retirement of baby boomers, and much slower growth in the number of college graduates.[20] A typical nuclear power plant in the United States takes about 4 years to build, and requires 1400 to 2300 construction workers.

Costs and Financing

Finally, nuclear power reactors are costly to construct. Moody's estimated in October 2007 that the all-in cost of a new nuclear generating facility could range from $5000 and $6000/kw. This compares to valuations of between $2700 to $3500/kW for existing nuclear plants; $1700-$2200/kw for existing coal plants and $700-900/kw for combined cycle natural gas plants. The second least expensive option is integrated gasification combined cycle coal plants at between $3300 and $3700/kw. Even so, Moody's claims it maintains a "relatively favorable bias towards nuclear generation."[21]

Financial analysts suggest that there is certainly enough venture capital available to finance a "nuclear renaissance" but much will be determined by the level of risk. This is where governments get involved. The bottom line is that nuclear power expansion will not be possible without significant government support across the board.

Summary

For nuclear energy to contribute one of seven "wedges" of carbon emission reductions, current capacity would need to triple. This would require building 20 reactors every year for 50 years – a construction rate sustained by the United States for one decade. In the last twenty years, there have been fewer than 10 new construction starts in any given year worldwide.

A significant expansion will narrow bottlenecks in the global supply chain today that include ultra-heavy forgings, large manufactured components, engineering, craft and skilled construction labor, all exacerbated by lack of recent experience in construction, and aging labor forces. While these may not present problems for limited growth, they will certainly present problems for tripling reactor capacity.

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[20] Brian Reilly, Principle Vice President, Bechtel, "Challenges of Construction Labor for New Builds," presentation to Fourth Annual Platt's Nuclear Energy Conference, February 5, 2008.

[21] Moody's Corporate Finance, Special Comment, "New Nuclear Generation in the United States," October 2007.

This is not to say that U.S. and global nuclear infrastructure could not expand to meet demand. However, the prospects of it doing so in the timeframe most important for global climate change are slim. One reason is that risk mitigation remains a primary concern for the industry, and this is likely to result in a "wait and see" approach. As it is, the U.S. nuclear industry continues to press the federal government for additional assistance, including delays in taxing new domestic nuclear industry until national policy objectives for nuclear manufacturing are met; establishing a nuclear work force program; and ensuring American access to other nuclear markets.[22]

Even with the requisite infrastructure, reactors can take between 10 and 15 years between a decision to build and connection to an electricity grid. Many developing states do not yet have the regulatory infrastructure to make this happen even in that time frame.

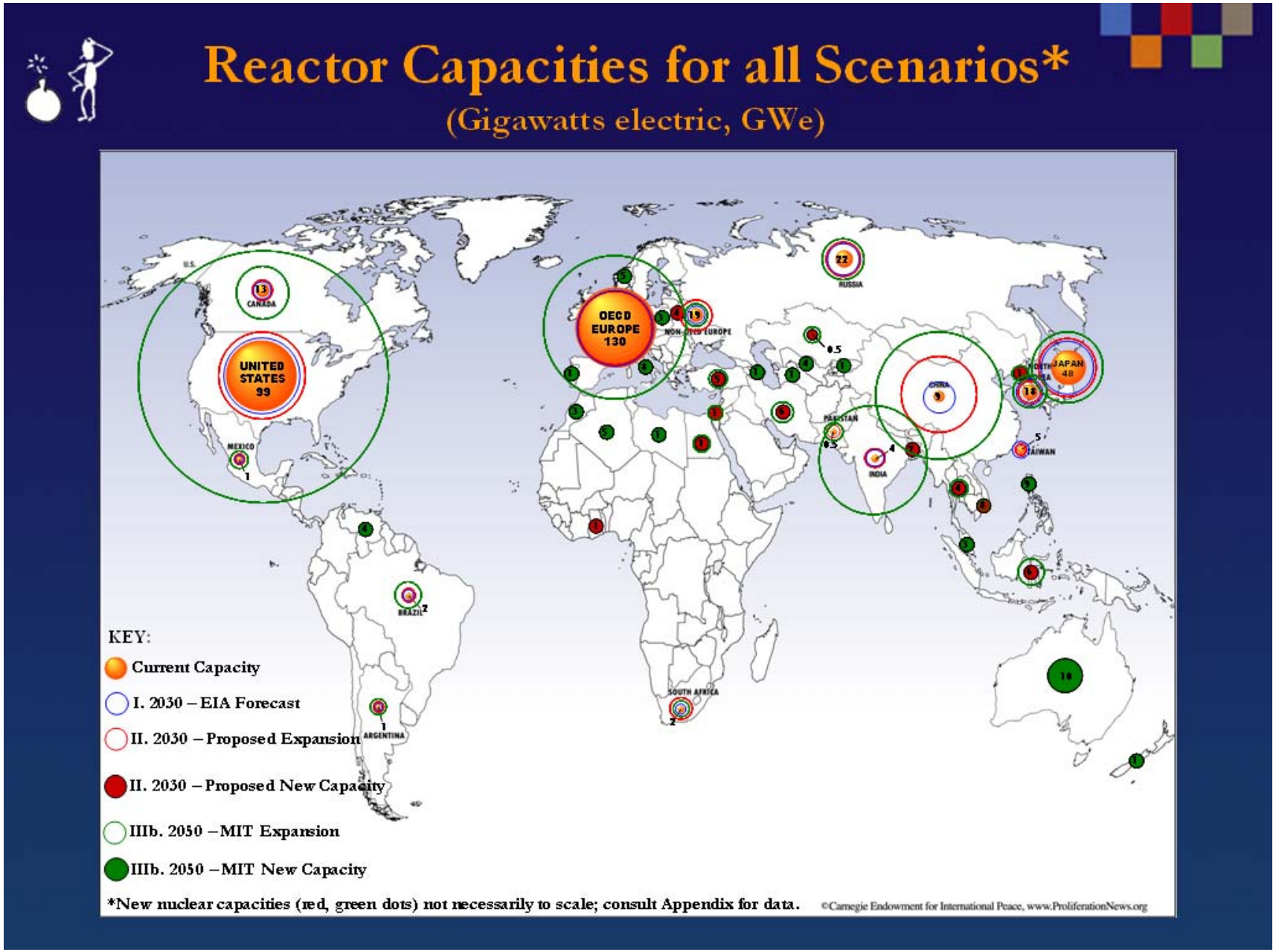
Building one "nuclear wedge" will also require a tripling of uranium enrichment capacity, and will certainly generate a debate about spent fuel reprocessing. Moving beyond the one nuclear wedge expansion to a 1500 GWe scenario, or the even more aggressive Stern Report 1800 GWe-4500 GWe scenario, it is difficult to see how such growth could be accomplished, even in 50 years. The 1500 GWe scenario would require building 35 reactors/year; 1800 GWe would require building 42/year; and 4500 GWe would require building more than 2 reactors per week, or 107/year. The enrichment and storage/reprocessing pressures are similarly daunting, not to mention the cost of all such capabilities.

As the demand for electricity is expected to almost double by 2030, nuclear energy will have a difficult time even keeping its 16% market share of global electricity generation. While a carbon tax will make nuclear energy more competitive, it is not likely to be strongly embraced by electric utilities in the United States, which also operate coal plants.

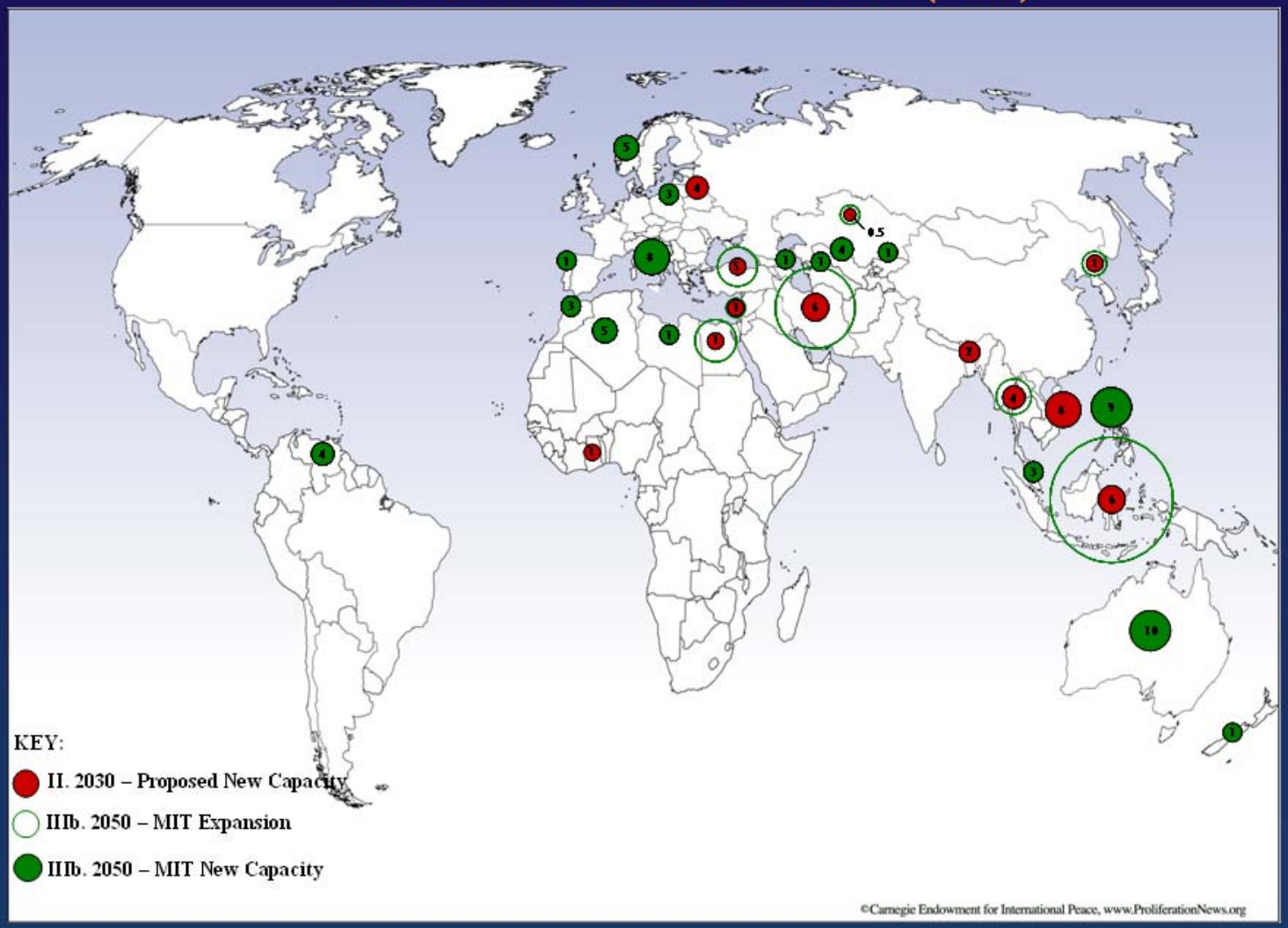
Finally, the proliferation risks of nuclear expansion are not limited just to a three-four-, or five-fold increase in the number of reactors. Some states may move forward anyway, propelled by unrealistic expectations and could acquire uranium enrichment and plutonium separation capabilities under current institutions and rules. Such national fuel production capabilities could introduce even greater uncertainty about proliferation intentions in certain regions like the Middle East, because of the latent nuclear weapons capability in such plants. Efforts to address both supply and demand for such sensitive capabilities need to be redoubled.

[22] See, for example, John A. Fees, President and Chief Operating Officer, BWX Technologies, Inc., "Reviving America's Industrial Base," *NEI Nuclear Policy Outlook*, October 2006, pp. 5, 8.

Appendix: Mapping Global Nuclear Expansion

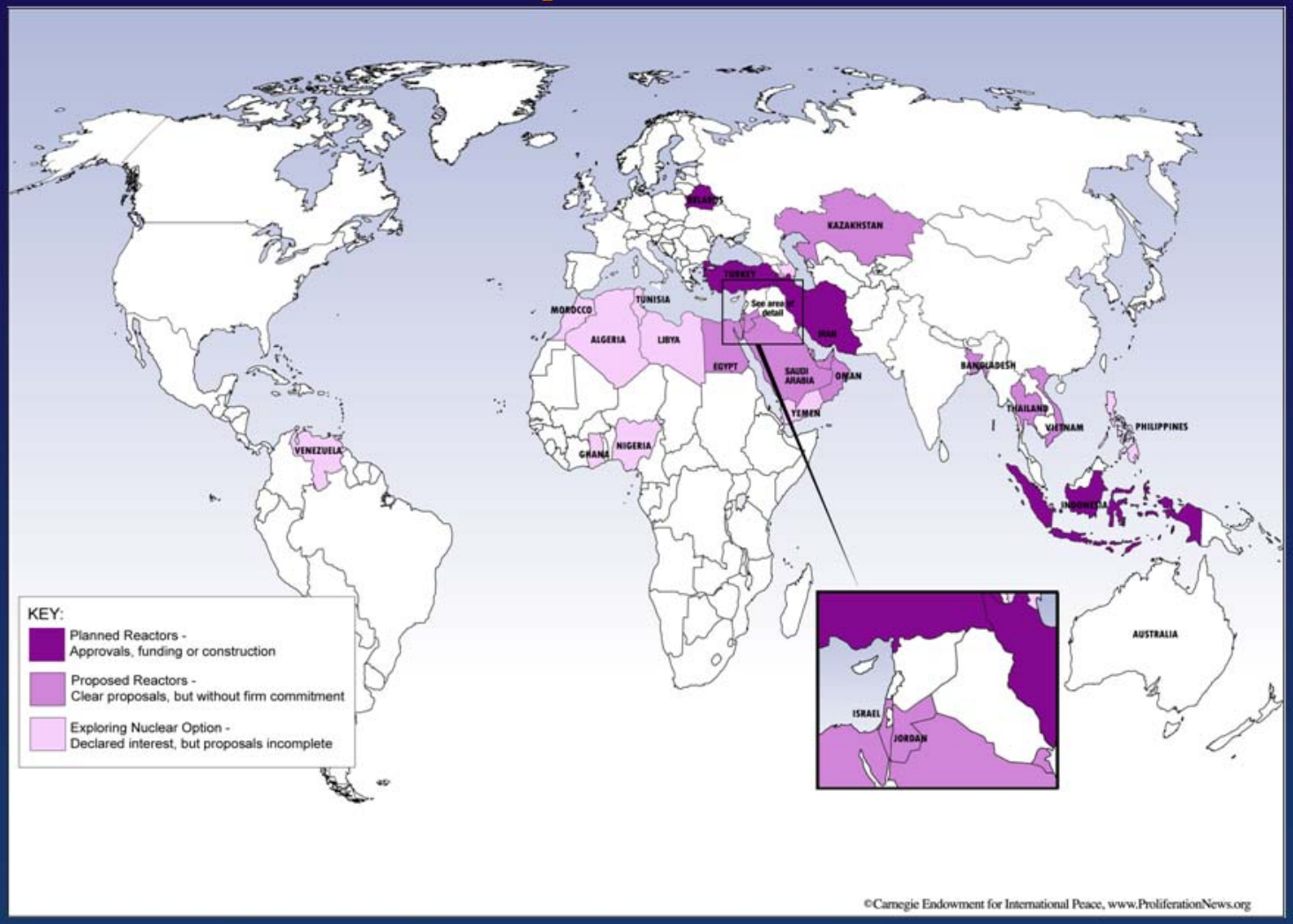


New Nuclear States: Scenarios II and III (GWe)



A Closer Look at "New" Nuclear States

Proposals as of 2008



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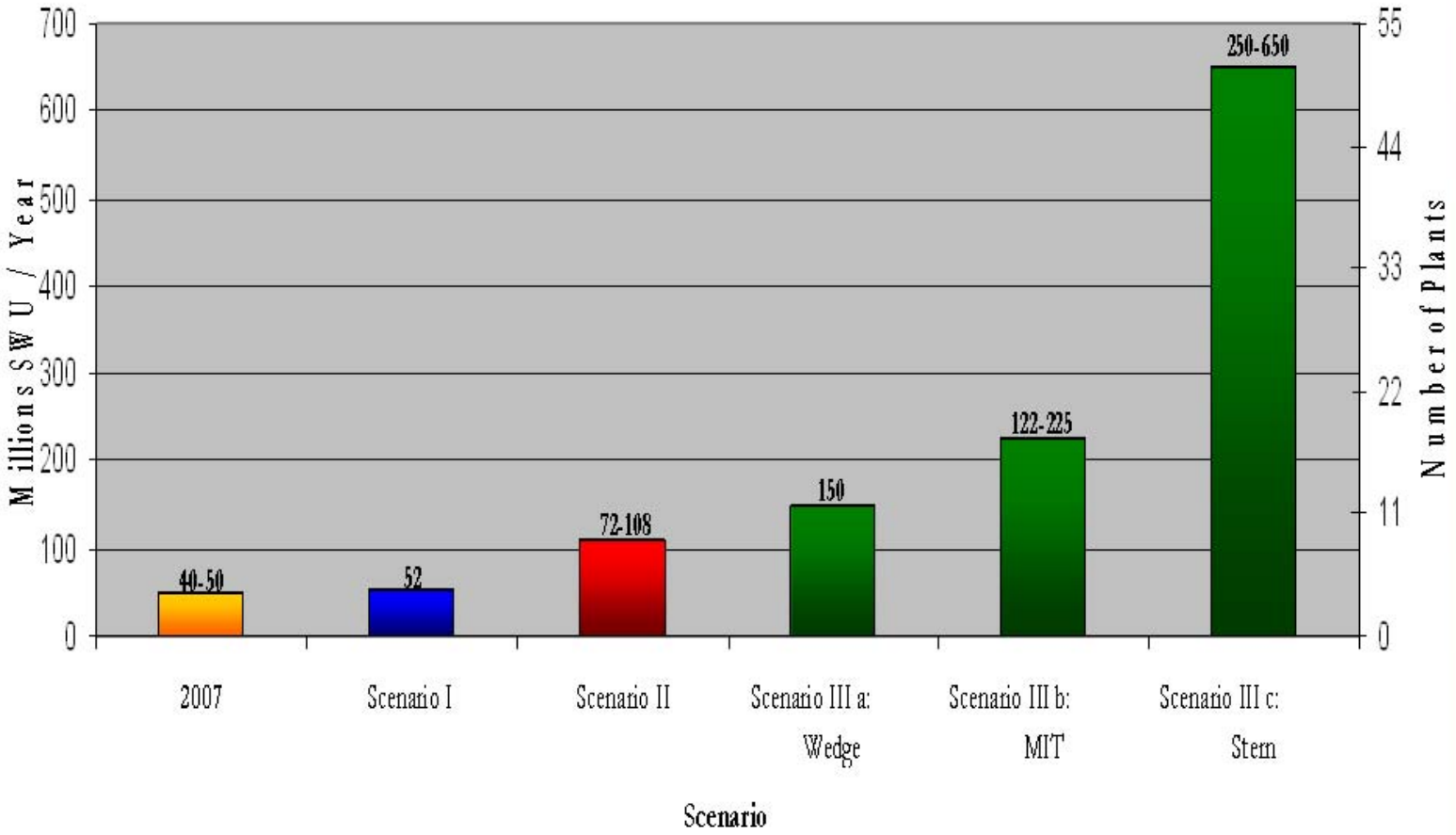
Enrichment Implications*



*See separate Appendix for details. Numbers are rough approximation.

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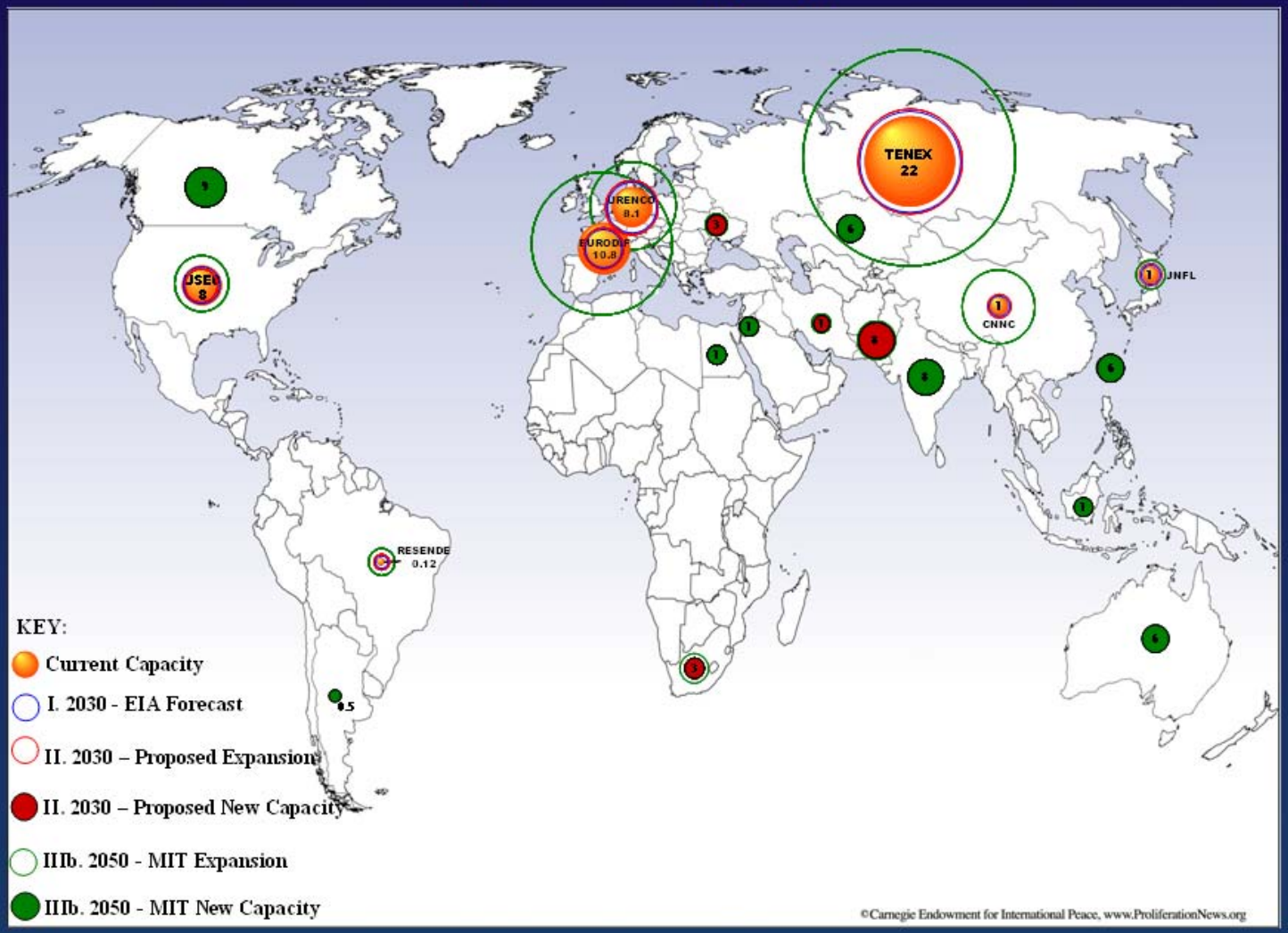
Enrichment Capacities for all Scenarios
(million SWU/year)