

Professor John Holdren's Complete Post:

I am sorry to be slow in joining this interaction. But I do have a few thoughts to add to the mix.

Much, although not all, of the discussion so far has been contributed by the two camps at opposite ends of the spectrum of opinion about nuclear energy:

The enthusiastic "pro" side: "A large contribution from nuclear energy is not only clearly feasible, eminently affordable, and better than most anything else from the standpoint of safety and public health, but so important to addressing the climate-change challenge that the world simply cannot do without it."

The determinedly "anti" side: "A large contribution from nuclear energy is probably not feasible (because of resource constraints and public acceptance), if feasible then still probably not as cheap as renewables, and in any case undesirable because of waste, safety, and proliferation; and we can meet the climate challenge without it."

Like a few others in this discussion, I find myself somewhere in the middle. I believe it will be EASIER to surmount the climate-change challenge if we can get a substantial contribution from nuclear than if we cannot; but that, with additional difficulty, the lack of such a contribution from nuclear could be compensated by getting somewhat larger contributions than would otherwise be needed from the combination of end-use efficiency, renewables, and advanced fossil-fuel technologies that capture and sequester CO₂.

I also believe that it will turn out to be either infeasible or irresponsible to GET a significantly expanded contribution from nuclear unless its own challenges of waste management, safety (including terrorism vulnerability), and proliferation are addressed with greater wisdom and determination than this country or any other has demonstrated up until now. The motto "fix it or forget it" is germane here; the nuclear option needs fixing in some important respects if it is to be viable on the needed scale, and if we succeed in expanding it WITHOUT fixing it I believe that we or our successors will end up regretting that we did.

Many of the points that underpin my position have already been made in this discussion, but let me repeat or elaborate on a few that I think are especially important.

1. NEITHER NUCLEAR NOR ANYTHING ELSE IS A SILVER BULLET. Every known option has limitations and liabilities. There are lots of ways to get relatively modest reductions in GHG emissions (compared to "business as usual"), but trying to get very large reductions from any one class of options tends to run into rising marginal costs even if not also rising risks and side effects. This is a powerful argument for a "portfolio" approach. It is not necessarily an argument that no option is too costly or too risky to be excluded, but it does suggest that major potential contributors should not be dismissed simply because they have some liabilities; we need to look very hard at how the liabilities of all of the major potential contributors might be reduced.

2. THE HIGH COST OF NUCLEAR IS NOT A VALID REASON FOR RULING IT OUT. There is considerable potential for reducing CO2 emissions in ways that are cheaper than doing it with nuclear energy – including end-use efficiency opportunities that have NEGATIVE cost (because they more than pay for themselves with energy savings) -- but this potential is not enough to get us on a 450 ppm or even a 550 ppm stabilization trajectory. One needs to think about this in terms of what economists call a "supply curve", in which one arrays the available contributions to supply (in this case the supply of CO2 reductions) from cheapest to costliest, each represented by a block whose height is the unit cost and whose width is the magnitude of the contribution available at that cost. A rational society buys the cheapest blocks first, but, if the available cheap contributions are not enough to do what is required, one has to buy some of the more expensive blocks, too. The recent quite detailed studies of emissions-reduction options by the McKinsey people, which express the results in supply-curve terms, indicate that the world could get something like 25-30% of the reductions it needs by 2030, in order to be on an emissions trajectory toward stabilization of concentrations at 450 ppm of CO2-equivalent, from negative-cost efficiency measures; but the rest would need to come from (mostly supply side) options that have positive costs ranging up to \$50 per tonne of CO2 or so. The existence of the cheap stuff doesn't mean you don't have to buy the expensive stuff, too. One doesn't have to agree with all of the McKinsey assessments of contributions and costs in detail to end up with what I think is the robust conclusion that we are going to need to do a considerable amount of relatively costly things along with the cheap and profitable things that are available. My own estimate is that nuclear is going to come out in the range of \$15-30 per tonne of CO2 avoided, and that if cost were the only consideration we'd want to buy as much of it as we could get. Carbon capture and sequestration from coal-burning power plants is likely to be \$30-50 per tonne of CO2 avoided, in my judgment, and we're probably going to want to buy as much of THAT as we can get, too. (Of course, cost is not the only consideration, about which more below.)

3. THE OVERALL "SCALE" PROBLEM IS HUGE. In formulating their original "wedge" model, Socolow and Pacala looked at an emissions trajectory designed to stabilize atmospheric CO2 at around 500 ppm. This was the basis of the conclusion that it would be good enough to hold emissions roughly constant out to 2050 (assuming big declines thereafter), instead of the doubling of those emissions expected from 2000 to 2050 under a "business as usual" (BAU) projection that already included considerable increases in end-use efficiency and low- or no-carbon energy supply. The difference between BAU and flat emissions, they pointed out, amounted to seven "wedges" of emissions reduction, each of which was avoiding 1 billion tonnes of carbon per year (3.67 billion tonnes of CO2 per year) by 2050 or so. Now that the center of gravity of informed opinion is that the world needs to aim to stabilize not at 500 or 550 ppm but at 450 ppm or less, the seven wedges needed by 2050 or so become nine or more.

For nuclear energy to provide just one of the (say) nine wedges that are needed from now to 2050 or 2055, seven hundred new 1-gigawatt power plants that would be coal-burners under BAU would need to be nuclear instead. (These are incremental nuclear plants, that is, beyond the nearly 400 GWe of nuclear capacity in operation today. Thus there would need to be about 1100 1-GWe nuclear plants by 2050-55 in order to get from nuclear one ninth of the CO2 emission reductions we need by then. Getting from nuclear TWO ninths of what we need would mean 1800 1-GWe nuclear plants in operation by the 2050s.)

There's an even more straightforward way to get at what a "significant" additional contribution from nuclear energy means. Start from the fact that nuclear energy today supplies about one sixth of the world's electricity. Let's say we define as "significant" an expansion that would double nuclear's electricity share from one sixth to one third. Under BAU world electricity growth expands about 2.5-fold over the next 50 years. So doubling nuclear's share of a 2.5-times-bigger pie means a 5-fold growth in nuclear. Five times today's 370 GWe makes 1850 GWe.

Such numbers are at the high end of the ranges that serious studies of global nuclear expandability have considered to be even remotely feasible. I know of no such study suggesting that faster expansion than this could be managed. Thus it is apparent that nuclear energy at most can take a bite out of the problem; there is no way that it can be as much as a third of the solution over the next 50 years, never mind most of the solution.

4. EXPANDING NUCLEAR ENOUGH TO TAKE A SIGNIFICANT "BITE" OUT OF THE PROBLEM WILL POSE BIG CHALLENGES IN PROLIFERATION CONTROL. Here are some numbers I ran a couple of years ago for a scenario in which nuclear doubled its global electricity share from 1/6 to 1/3 between 2000 and 2050, entailing nuclear expansion from 350 GWe in 2000 to 1700 GWe in 2050:

If the reactors were all LWRs on the once-through fuel cycle, enrichment of their fuel would require about 250 million SWU per year. If one tenth of one percent of this enrichment work were diverted to production of High Enriched Uranium (HEU), this would suffice to make twenty gun-type or 80 implosion type HEU nuclear bombs per year.

If half of the reactors were recycling their plutonium in order to reduce uranium mining and enrichment requirements, the associated flow of directly weapon-usable plutonium would be about 170,000 kilograms per year. If one tenth of one percent of this plutonium flow were diverted to weaponry, this would suffice for 30 plutonium bombs per year.

It's doubtful that today's monitoring can provide assurance of non-diversion at even the 1% level, never mind 0.1%.

These sorts of numbers matter in part because not all of the capacity, in a nuclear energy expansion this large, is going to be in countries that already have nuclear weapons. A sizable part of it would have to be in countries that don't, and for which proliferation is therefore a concern. (Separated plutonium is a proliferation hazard wherever it occurs, moreover, since it can be stolen and used directly in weapons by those who steal it or by others to whom they sell it.) In my judgment, the only way to keep the lid on a proliferation temptation of this magnitude is to put ALL of the world's uranium enrichment capacity and ALL of the plutonium separation capacity under multinational control, so the countries involved can watch each other. Just confining enrichment and separation capacity to the existing nuclear-weapon states will never fly, for reasons others in this dialogue have already elucidated. But, so far, most of the weapon states have not accepted IAEA Secretary General ElBaradei's conclusion that universal

multilateral control is the only way to go. (They'd be happy to have everybody ELSE do this, but this insistence on perpetuating the first-class-citizen/second-class-citizen distinction among nations is a non-starter in the eyes of the rest of the world.)

5. WASTE MANAGEMENT WOULD ALSO BE A HUGE CHALLENGE UNDER SO LARGE AN EXPANSION OF NUCLEAR ENERGY. A fleet of 1700 once-through LWRs would produce 34,000 tons of spent fuel per year – a nominal Yucca Mountain's worth every two years. While I personally believe that handling a waste-management task of this magnitude is technically feasible, whether publics will acquiesce in the siting of the needed number of facilities and degree of waste transport through their communities that this would entail is at least questionable. The proposition that reprocessing and recycling would solve this waste problem is a snare and a delusion, moreover, at least with currently available technologies. More about that later, perhaps.

6. TODAY'S REACTORS ARE SAFER THAN YESTERDAY'S, AND TOMORROW'S WILL PROBABLY BE SAFER STILL, BUT THE DANGER OF A LARGE RADIOACTIVITY RELEASE ENGINEERED BY KNOWLEDGEABLE AND DETERMINED TERRORISTS IS MORE DIFFICULT TO REDUCE. There are ways to do this, but the industry and its regulators alike have been reluctant to embrace them – I believe out of concern that doing so will inflame public fears and thereby thwart nuclear expansion. But if not embracing them leads to terrorists' succeeding in orchestrating a large release, THAT is likely to shut off nuclear's expansion prospects for decades.

To arrive again at the bottom line that I previewed at the beginning of this intervention: It would be nice to have nuclear's contribution to meeting the climate-change challenge, but making that contribution feasible and sustainable will require addressing proliferation, safety, and waste management with greater insight and determination than have been evident to date. Whether we will get our act together and pull this off is, to me, still very much an open question.