Will Climate Change Revive Nuclear Power?

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Natural Resources Defense Council

AEI Conference
"Is Nuclear Power a Solution to Global Warming and Rising Energy Prices"

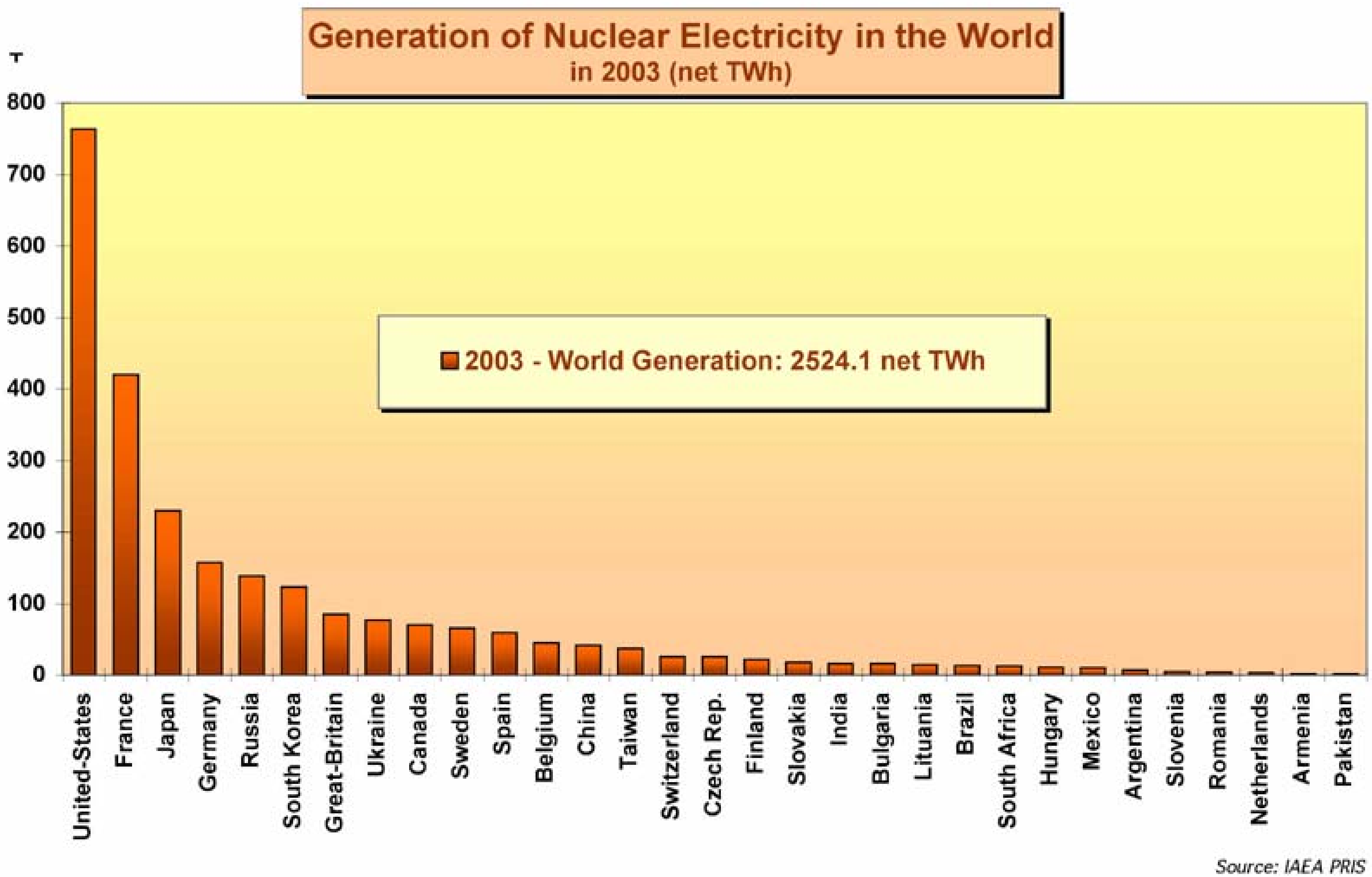
Panel 2: Economic and Regulatory Concerns

Washington, D.C.
06 October 2006

Nuclear Power Plants (2005)

	Units	Capacity (Gigawatt-electric) (GWe)
U.S.	104	100
Worldwide	441	367

Nuclear Provides 16% of global and 20% of U.S. electricity



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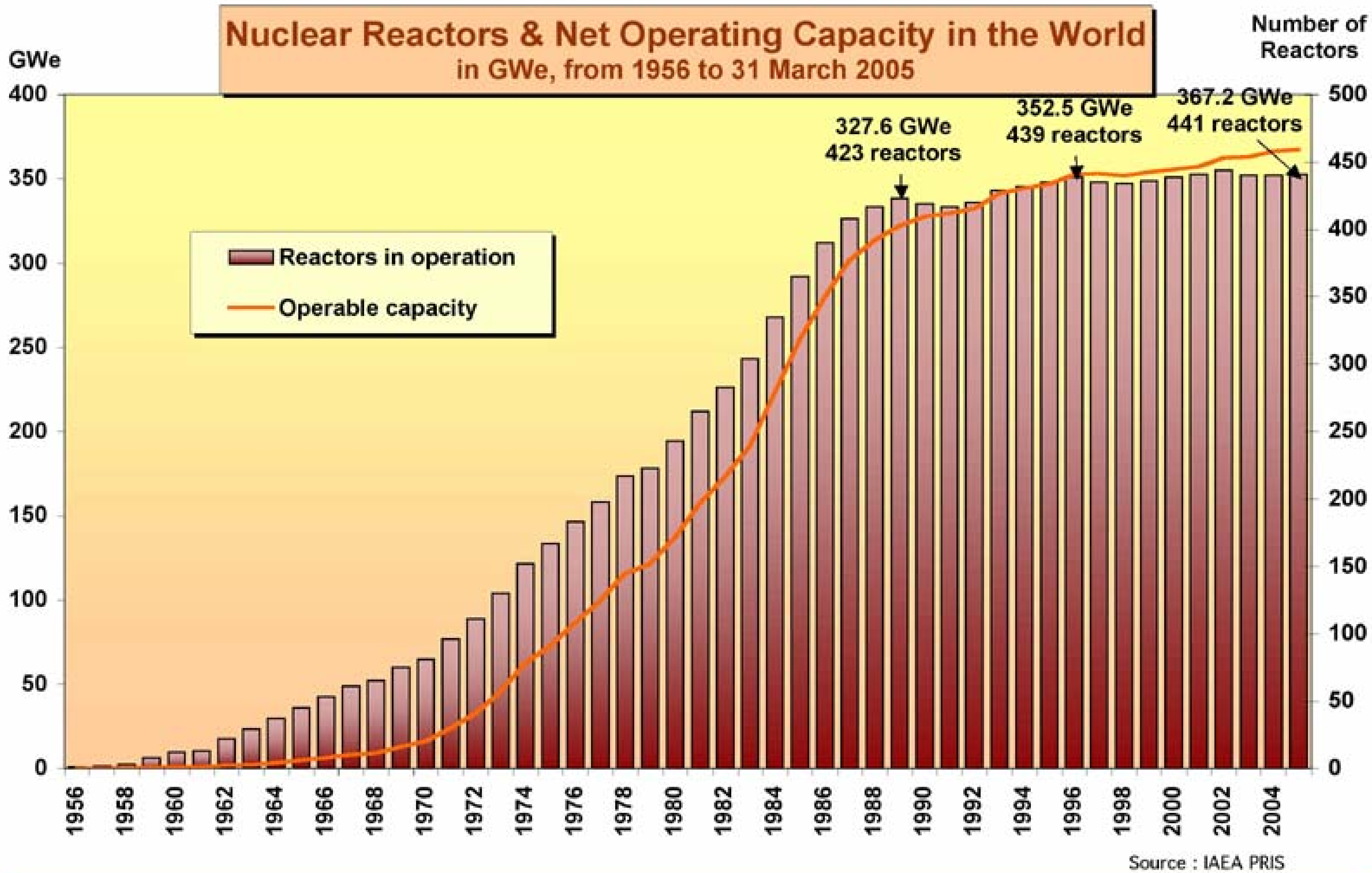
London, 19 April 2005

After 50 years, nuclear energy is still highly concentrated

- Only 31 countries (16%) of UN member states operate nuclear power plants
- Just six countries – USA, France, Japan, Germany, Russia, and South Korea – account for 75% of nuclear electricity produced worldwide
- 22 of the last 31 nuclear plants connected to a grid have been in Asia
- Historical peak of 294 operating reactors in Western Europe-US was reached in 1989



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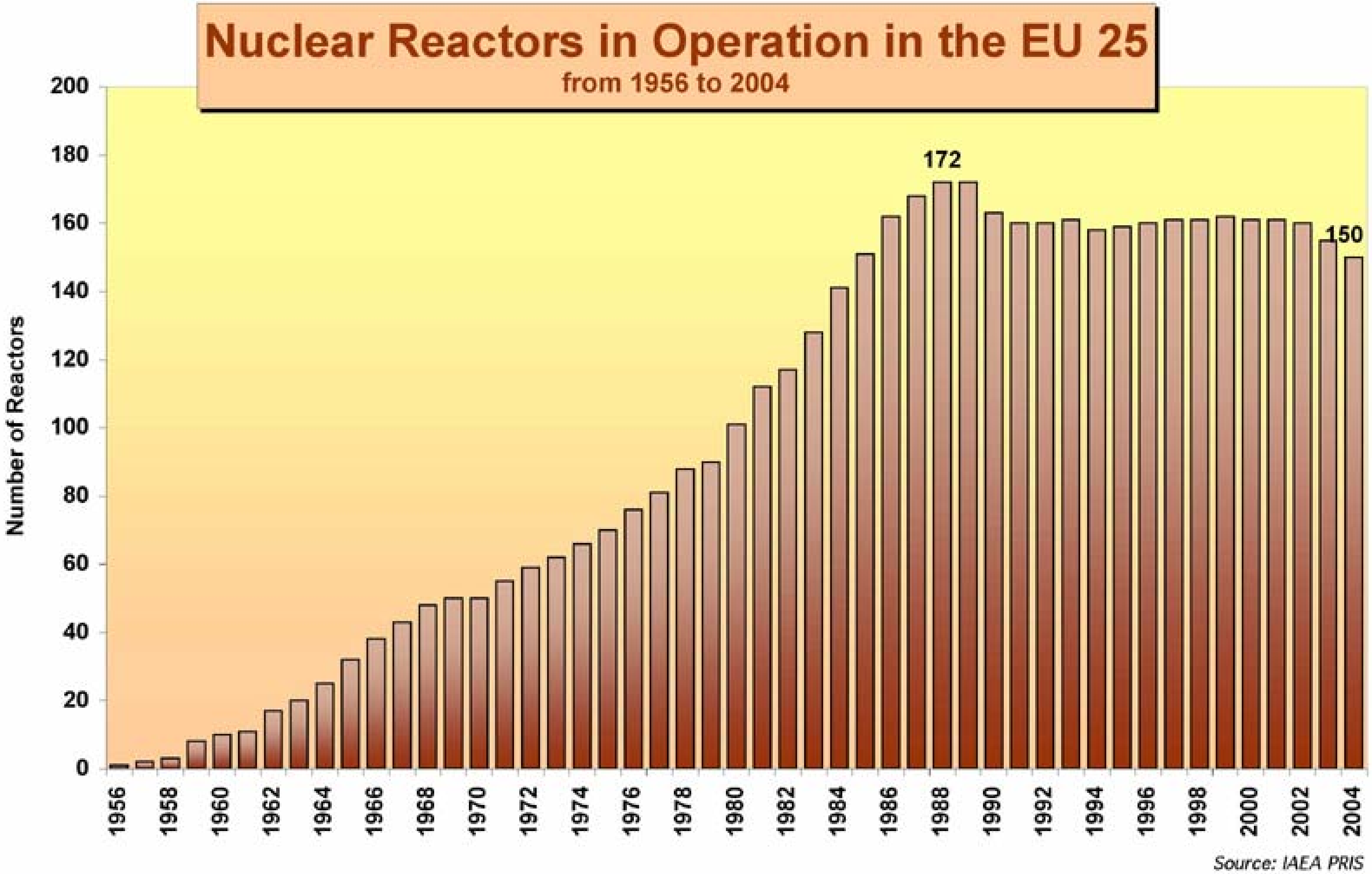
A Static-to-Declining IEA Outlook for Nuclear Energy :

"Worldwide nuclear capacity is projected to increase slightly, <u>but the share of nuclear power in total electricity generation will decline</u>."

"A substantial amount of capacity will be added, but this will be mostly offset by reactor retirements."

"Three-quarters of existing nuclear capacity in OECD Europe is expected to be retired by 2030, because reactors will have reached the end of their life or because governments plan to phase out nuclear power."

"Nuclear power generation will increase in a number of Asian countries, notably in China, South Korea, Japan and India."



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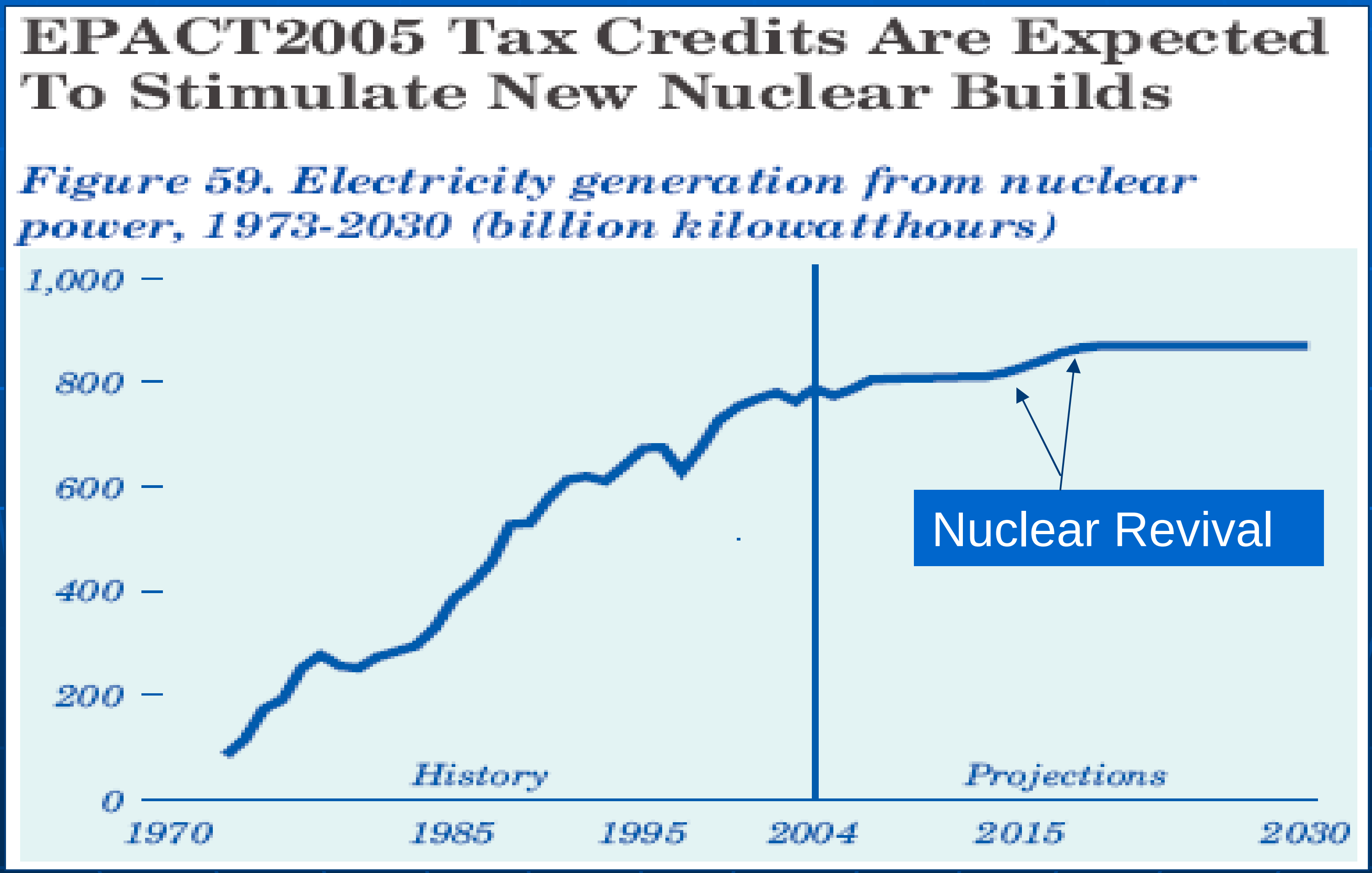
Average World Growth Rate in Net Nuclear Generating Capacity

	1956-1989	1990-2005	2006-2030 (IEE Japan)
Reactors	+ 13/yr	+ 1.2/yr	3-4/yr
Gigawatts	+ 10/yr	+ 2.6/yr	+ 4.6/yr
Nuclear's Share	?	16 %	10 %

US EIA Expects Only 6 GW of New US Nuclear Capacity in Next 25 Years



EIA Forecasts Nuclear Share of US Total Electric Generation Will Decline

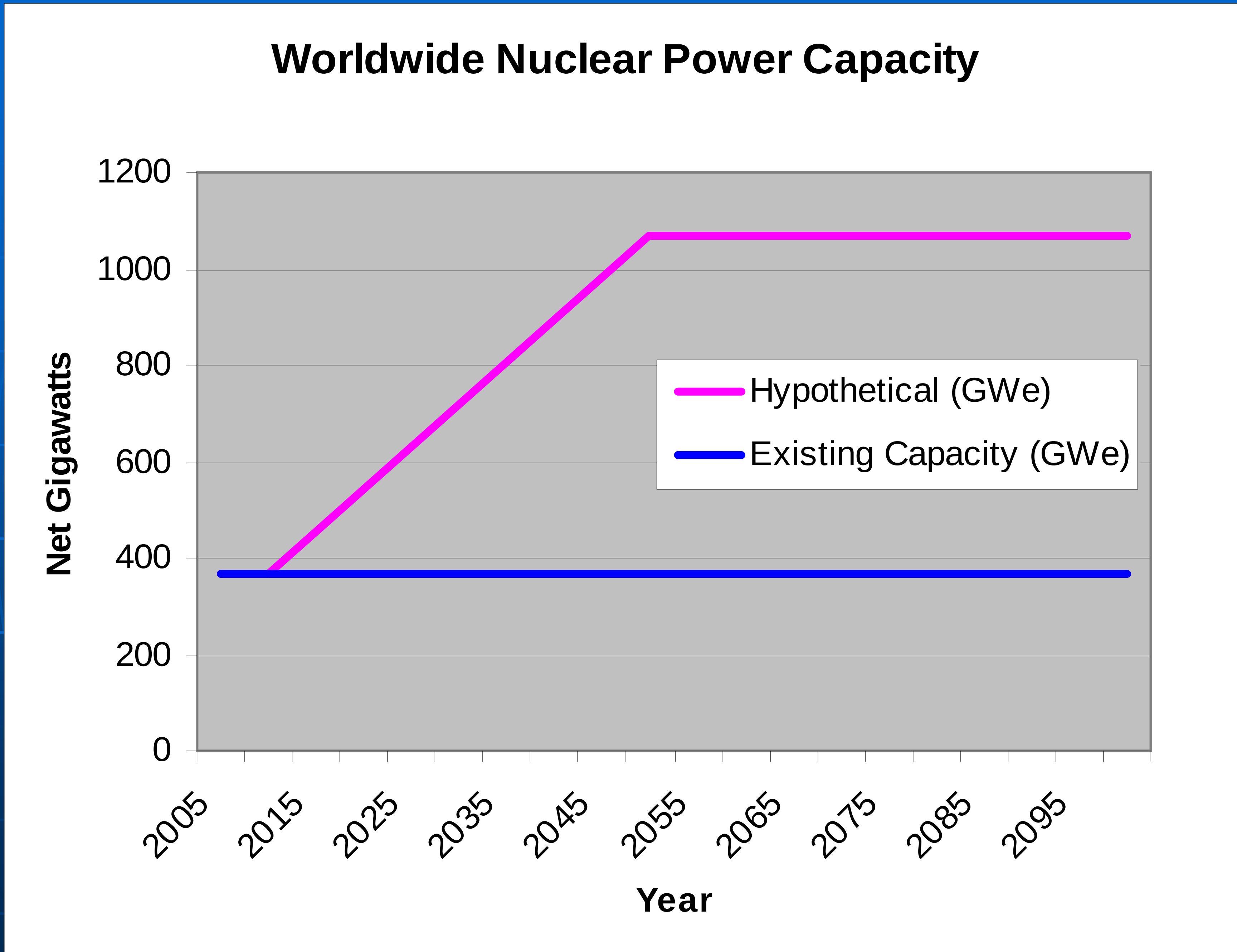
- “In 2030, even with a national average capacity factor of more than 90%, nuclear power accounts for about 15% of total U.S. generation.”

but

- “From 2004 to 2030, 26.4 GW of new renewable generating capacity is added...” (more than 4X nuclear)

Can Nuclear Deliver Serious Amounts of Carbon Reduction?

- Overall Goal: Keep global temp increase to within 2 deg. C above pre-industrialized levels to avert dangerous climate impacts.
- Apply seven complementary carbon-reducing approaches such that each displaces 1 GtC/yr in 2050, stabilizing atmospheric carbon concentration at current level.
- We asked the question: “How much nuclear capacity would be needed to avert carbon accumulation sufficient to warm the atmosphere by 0.2 deg. C. during the second half of this century”
- To achieve this level of carbon displacement, our model suggests that from 2010 to 2050 the world would have to add 700 GWe nuclear worldwide (~15 plants/year), and
- Maintain ~1100 GWe from 2050 through 2100



Worldwide Nuclear Power Capacity
Net Gigawatts
1200
1000
800
600
400
200
0
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year
Hypothetical (GWe)
Existing Capacity (GWe)

Nuclear vs Carbon Reality Check

- ~ 0.2 degrees Celsius avoided requires almost a tripling of current global nuclear capacity within 40 years:
- 1100 nuclear power plants (plant life = 40 years)
- 15 enrichment plants (plant capacity = 8 million “separative work units”/year (SWU/y); plant life = 40 y); 9 plants in a given year
- 14 Yucca Mountains for 973,000 t spent fuel (SF) containing approximately
- 10,000,000 kilograms of plutonium; or
- 50 reprocessing plants if all SF were to be reprocessed (plant capacity = 800 t SF/y and plant life = 40 y)
- Construction of these facilities requires $2.5 - $3 trillion dollars in capital

How Likely is a Nuclear "Revival" on This Scale?

- MIT "Future of Nuclear Power" Study (2003) outlines one path to a nuclear revival by demonstrating that a $100/ton carbon tax could make nuclear competitive with a conventional central station coal plant
- $200/tC could make nuclear competitive with gas-fired combined-cycle generation at moderate to sustained high natural gas prices
- Study did not examine nuclear versus Integrated Coal Gasification Combined Cycle (IGCC) with Carbon Capture and Disposal (CCD) under various carbon tax scenarios

Table 5.1 Costs of Electric Generation Alternatives
Real Levelized Cents/kWe-hr (85% capacity factor)

Base Case	25-YEAR	40-YEAR
Nuclear	7.0	6.7
Coal	4.4	4.2
Gas (low)	3.8	3.8
Gas (moderate)	4.1	4.1
Gas (high)	5.3	5.6
Gas (high) Advanced	4.9	5.1
Reduce Nuclear Costs Cases		
Reduce construction costs (25%).	5.8	5.5
Reduce construction time by 12 months	5.6	5.3
Reduce cost of capital to be equivalent to coal and gas	4.7	4.4

Carbon Tax Cases (25/40 year)

	$50/tC	$100/tC	$200/tC
Coal	5.6/5.4	6.8/6.6	9.2/9.0
Gas (low)	4.3/4.3	4.9/4.8	5.9/5.9
Gas (moderate)	4.6/4.7	5.1/5.2	6.2/6.2
Gas (high)	5.8/6.1	6.4/6.7	7.4/7.7
Gas (high) advanced	5.3/5.6	5.8/6.0	6.7/7.0

Source: MIT Study, “The Future of Nuclear Power,” 2003, p. 42.

MIT Comparative Cost Analysis was too narrow

- Compared nuclear costs only with large central-station fossil power costs, when fastest growing energy market segments are distributed on-site co-generation, end-use efficiency, and renewables (wind and solar), with current or projected lower average delivered costs.
- MIT study did not take account of the fact that carbon taxes or "cap and trade" will also benefit new-technology plants featuring coal gasification combined cycle with carbon capture, and all forms of carbon-neutral distributed generation.

<u>Delivered</u> Costs of Electricity Services

New Nuclear Plant Today (40 yr. Life at 85% capacity factor) = <u>$0.0977/kWh</u>

New Nuclear with 8-yr $0.018/kWh production tax credit = <u>$0.0797/kWh</u>

New "Competitive" Nuclear Post-2021 (assumes 25% capital cost reduction, build in 4 rather than 5 years, zero nuclear risk premium, lowest quartile of O&M costs) = <u>$0.0715/kWh</u>

Compare to:

Recent utility and end-use efficiency programs (CA) = <u>$0.025 - $0.030/kWh (!)</u>

Other Delivered Cost Comparisons

- Nuclear electricity from new plants is <u>at least</u> 2-4 times more costly than improving end-use efficiency, but it's also:
- 1.4x more costly than wind power at $0.0565-$0.0701/kWh;
- 2.4 -3.7x more costly than on-site recovered heat co-generation at $0.026 - $0.04.

Nuclear Revival May Take a While

- Dominion, an energy company based in Richmond, Va., is seeking advance approval of a site for a new reactor (“Early Site Permit”).
- In May 2005, before passage of the EPACT, Thomas E. Capps, the chairman and chief executive, said in a telephone interview, "We aren't going to build a nuclear plant anytime soon.”

“Standard & Poor's and Moody's would have a heart attack," said Mr. Capps, referring to the debt-rating agencies. "And my chief financial officer would, too.“

-- New York Times, May 2, 2005

"Level the Playing Field", or Subsidize?

- So what is the U.S. government's response to new nuclear power plant initiatives that:
  - (a) are still not economically viable despite prior public expenditure of some $85 billion on civil nuclear power development
  - (b) still face other significant obstacles to rapid expansion?
- Answer: Massive Public Subsidies, worth some $10 billion over next 23 years.

EPACT 2005 subsidies mask true costs of new large-scale nuclear plants

- *Existing* nuclear plants can compete favorably with fossil-fuel plants:
  - excessive capital costs have long since been forcibly absorbed by ratepayers and bondholders
  - relatively low operation, maintenance and fuel costs
- BUT, continued high construction costs of *new* nuclear power plants make them uneconomical
  - No successful nuclear plant orders in the United States since 1973.

EPACT Nuclear Results Will Be Delayed, and Relatively Puny

- IRS will distribute future annual production tax credits—covering first 8 years of power production up to maximum of $1 billion per 1000 MW of new capacity—among all "qualifying" new reactor projects that have:
  - applied for a construction/operating license from the Nuclear Regulatory by the end of 2008;
  - begun construction of the reactor building by January 1, 2014, and;
  - received "certification" from Department of Energy that it is "feasible" to place the facility in service prior to January 1, 2021.

Timescale of EPACT Subsidy Program

Highlights Nuclear "Economic Visibility" Problem.

- Difficult to forecast today what energy market will be like in 2019 when new reactors start up
- Subsidy available to each new reactor owner depends on the total number of projects that start construction by 2014
- How many ways can tax credit be divided before commercial viability of each individual project is undermined?
- Will PUC's insist that ratepayers share in the subsidy, further eroding profitability forecasts?

Nuclear Capital Costs Remain Too High

- Cost growth already occurring in the new Areva "European" reactor under construction in Finland
  - 2002 estimate of $2.3 billion for this 1500 MWe (net) reactor had grown to $3.8 by July 2006
  - This number probably does *not* include some "off-balance-sheet" costs of 1.5 -2 billion euros ($1.92 - $2.56 billion) that reactor builder Areva has separately agreed to devote to the project.
- A total project cost near or above $4 billion for the Areva reactor is certain to scare U.S. utilities and merchant plant investors from making an aggressive commitment to nuclear energy in the near term, even with generous EPACT subsidies.

Renewables Already Expanding Faster Than Forecast Nuclear Can Deliver

- Wind power is *already* growing at twice the *likely* growth rate of nuclear over the next decade, and the outlook for wind is for even faster growth.
- Instructive to compare "nuclear renaissance" with rate of growth in wind power – now at 3000 MW per year.
  - To accurately compare, capacity utilization must be factored in: Assume favorable nuclear case: EPACT stimulates 1.5 times the amount of subsidized capacity, then with avg. capacity factor of 0.85 x 9000 MW = 7650 MW/15 years = 510 MW/yr as avg. projected growth for nuclear, but with none of it available for at least 10 years.
  - Wind has a much lower capacity factor, and assuming conservatively no further acceleration in the its rate of growth, then 0.35 x 3000 MW x 15 yrs = 15,750 MW for wind over the same period, or at least 1050 MW/yr, with all of it available each year.
- .

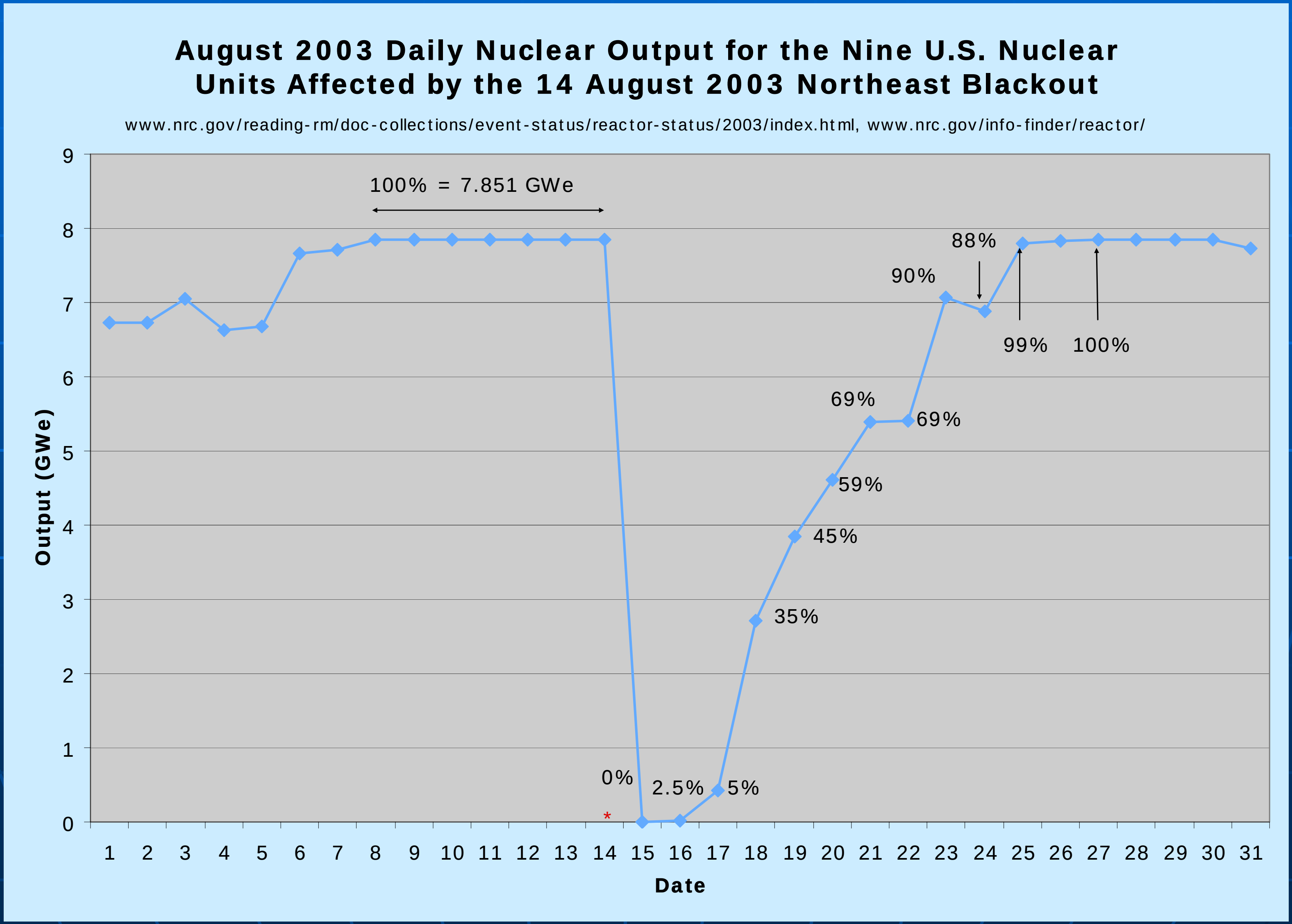
Will CIGS Thin-Film Solar Undercut Nuclear in 10 years?

- 234 sq. ft (15 ft x 16 ft) of roof space covered with 12% efficient PV modules will meet ½ electricity needs of typical home in LA.
- About 300 sq. ft (17 ft. x 18ft) needed in Maine or Atlanta under same assumptions
- Typical residential solar system now costs \$8- \$10 per peak Watt (Wp)
- At least a dozen companies are targeting thin film solar system hardware costs of \$1- \$2/Wp within 10 years (i.e. below planned nuclear plants) and Gigawatt scale production lines
- Increased efficiency of end-use, waste heat cogeneration, sustainable bio-gas generation, small hydro, wind and solar could dramatically restrict future economic case for adding new coal or nuclear base load plants, except as replacements for older polluting/unsafe base load units.

Tax incentives: Solar vs. Nuclear

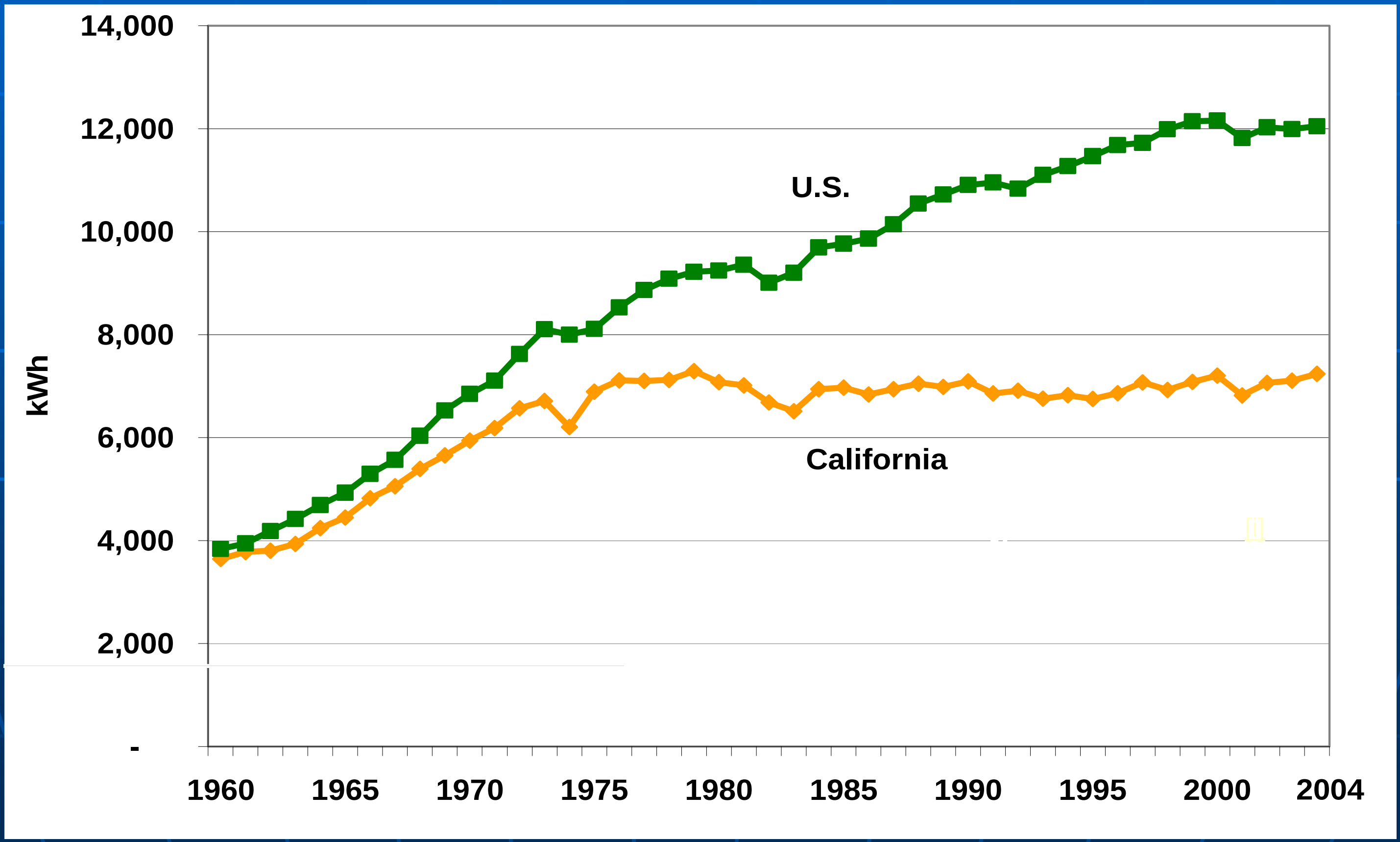
- EPACT 2005 and California both provide incentives worth roughly $1 billion/GW: Which would you rather have:
- California's $3 billion tax credit over 10 years
  - designed to leverage at least 3 GW of rooftop/building integrated solar power, driving down costs and positioning state for preeminence in dynamic global growth industry; OR
- 3-4 large nuclear reactors that entail problems, costs, and face limited global market not substantially different from current reactors

Nuclear Can be “Intermittent” Too



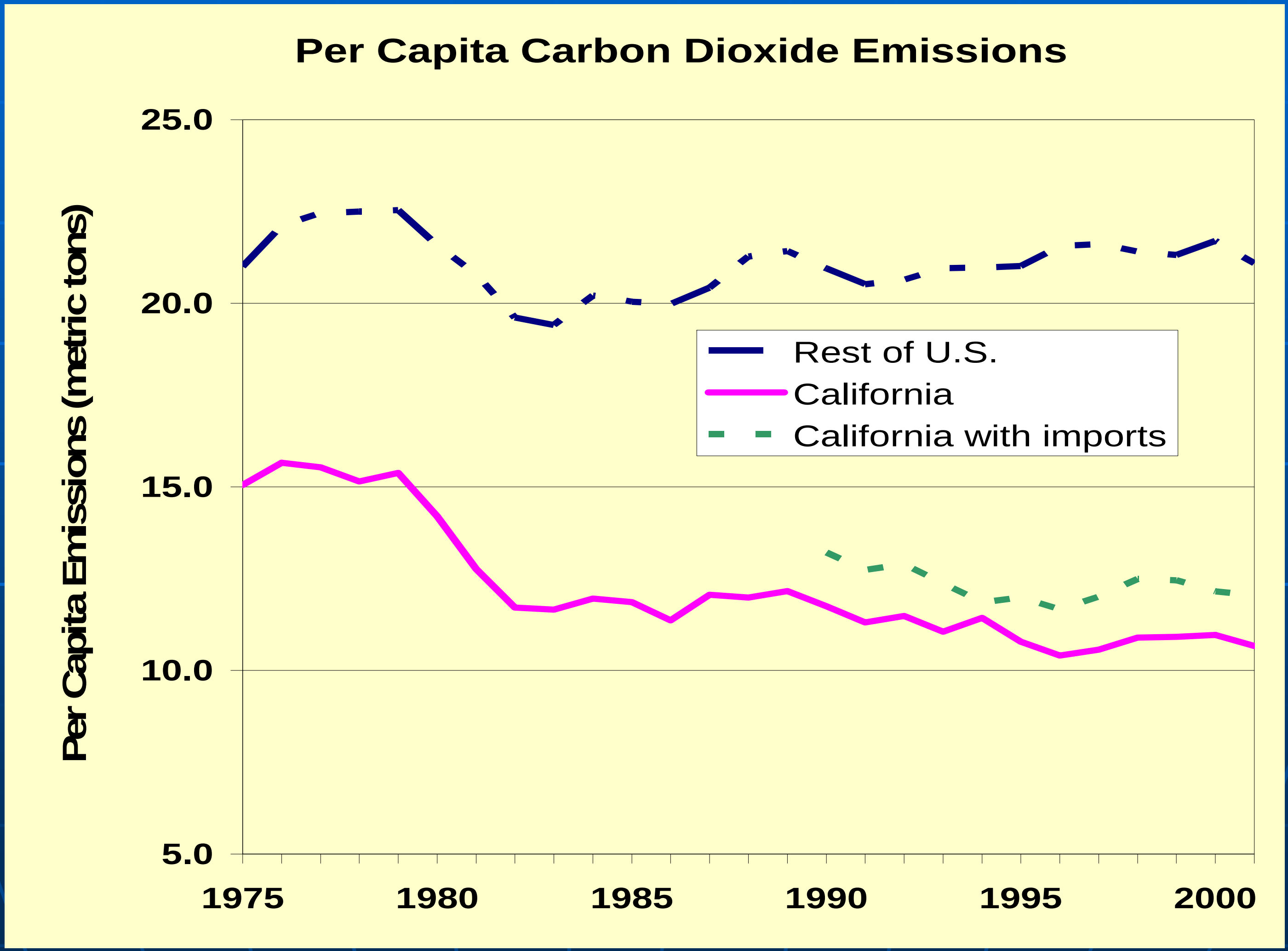
Comparison of Per Capita Electricity Consumed in U.S. and CA

Since 1975 US per capita energy use has increased by 50%, but CA has held roughly constant, saving 12 GW of peak demand growth that would otherwise have been met with grid-connected capacity equivalent to some 15 large nuclear reactors, costing on the order of $45 billion*.



[i] John Wilson, California Energy Commission, November 2005.

California has Achieved 30% Reduction in Per Capita Carbon Dioxide Emissions While the Rest of the U.S. has Remained Essentially Static



The Balance Sheet for New Nuclear Power

The Plus Side

- Very low emissions of carbon and other combustion-related air pollutants (but still some, from uranium mining, milling, enrichment, reactor construction-decommissioning and waste management activities)
- Copious but concentrated source of round-the-clock base-load power
- Low fuel costs compared to fossil alternatives
- If carbon emissions are effectively "taxed" at $100-$200 per ton under a carbon cap-and-trade system, nuclear might compete effectively with coal/gas fired central station power plants.

The Balance Sheet for New Nuclear Power

The Downside (Costs)

- Nuclear is costly low-carbon power ($0.9 - $0.10/kWh delivered)
- 3-4 times more costly than end-use efficiency improvements ($0.025 - $0.030) ;
- More costly than wind and recovered heat co-generation now, and probably solar in 10 years
- Long gestation/construction period and huge capital costs increase risk of market obsolescence and "stranded costs" (i.e. costs that cannot reasonably be recovered by continuing to operate the plant for its planned life)

More Nuclear Downside

- Historical record shows U.S. nuclear generation subject to infrequent but prolonged unplanned shutdowns
  - Recent UCS study documents 51 “year-plus” reactor outages since 1966, 12 since 1995, of which 11 were “safety-related.”
  - To ensure reliability, huge “lumpy” increments of nuclear capacity require costly power grid excess capacity.
- Carries little prospect of increasing U.S.“energy independence” -- bulk of world uranium resources located outside the U.S.

More Nuclear Downside

- Any nuclear power investment may become hostage to the worst performer—or even the average performer on a bad day—in the event of a reactor accident or near-accident anywhere on the globe
- No technically credible licensed path (yet) to opening first long-term geologic repository for safely isolating spent fuel
- Real nuclear “renaissance” will soon require either additional costly, hard-to-establish geologic repositories, or even more costly and hazardous spent-fuel reprocessing

More Downside: Security & Proliferation Concerns

- Nuclear security concerns and risks are heightened in era of transnational terrorism
  - Reactors, spent fuel pools, and cooling water impoundments can be sabotaged or attacked
- Acute proliferation concerns if advanced closed fuel cycles are used
- Proliferation enabling uranium enrichment capability is spreading to additional countries that are not Nuclear Weapon States under NPT (e.g. Iran, Brazil, North Korea)

More Nuclear Downside : Non-Carbon Environmental Impacts

- All stages of nuclear fuel cycle involve harmful, and possibly disastrous environmental impacts (e.g. Chernobyl)
  - Uranium mining and milling leaves piles of toxic residues and contaminates ground and surface waters. Navajo Nation has barred further uranium mining on its lands.
  - Enrichment leaves huge inventory of corrosive depleted uranium hexaflouride that must be disposed of safely
  - Spent fuel reprocessing creates large volumes of difficult-to-manage liquid “mixed” (i.e. chemical-radioactive) waste
- Averting severe damage requires tight regulation, with significant financial penalties for poor environmental/safety performance

More Downside: Managing Reject Heat

- Huge heat dissipation loads require large evaporative cooling withdrawals and/or thermal discharges into already overburdened lakes and rivers (e.g. reactor shut-downs of Summer 2006)
- Alternative is massive and costly fan-driven air-cooling towers with ~ 10% parasitic load
- Climate-change in the direction of hotter-drier summers spells trouble for reactors that rely on cheaper water cooling

Conclusions For Policy

- Most economically efficient way to address nuclear/coal/gas risks and harms is to internalize costs of avoiding/mitigating these in the retail price of electricity and fuels
- Create level energy playing field via carbon cap-and-trade, and regulatory- mining reforms
- Let competitive market deliver the lowest-cost technologies for energy services that can satisfy minimum common criteria for sustainability, public health, and energy security.

END

Economic; Security; Safety; Environment and Public Health Impacts of the Nuclear Fuel Cycle

Uranium Mining & Milling
Radioactive waste;
Chemical toxicity;
Land; water; air pollution;
Environmental justice;
Public & occupational health risks;
Federal subsidies

Uranium Conversion
Proliferation risks (Int'l)

Uranium Enrichment
Proliferation risks (Int'l);
Occupational health risks;
Depleted uranium wastes;
Groundwater; air & land pollution

Uranium Fuel Fabrication
Proliferation risks (Int'l)

Reactor Operations →
Spent fuel/plutonium production;
Proliferation risks (Int'l);
Catastrophic accident risks;
High costs; massive federal subsidies;
Low-level radioactive waste;
Spent fuel storage risks (terrorists);
Air; land & water pollution (minor);
Decommissioning (high volume of low-level waste; insufficient funds for)

Spent Fuel Reprocessing*
Plutonium separation; proliferation (Int'l);
Plutonium diversion; inadequate safeguards;
Safety risks;
High costs; massive federal subsidies;
High- & low-level radioactive waste;
Air; land and groundwater pollution (major);
Decommissioning

Mixed Oxide (MOX) Fuel Fabrication*
Proliferation (Int'l)
Plutonium diversion; inadequate safeguards
Security/Safety concerns
Transportation security (to and from)
High costs; massive federal subsidies

MOX Fuel Transportation →
Security concerns
Public acceptance

Spent Fuel Transportation
Safety and security concerns

Spent Fuel Away From Reactor Interim Storage
Difficult to site; lack of public acceptance;
Defacto permanent solution;
High federal liability

Spent Fuel/High-Level Radioactive Waste Geologic Disposal
Hazardous for millions of years;
Intractable political issues related to siting;
High costs; federal subsidies

* Closed Fuel Cycle Only

To Maintain Current Global Total of 441 Nuclear Plants Requires

- Completion of 8 new reactors per year over the next 10 years, and then
- 20 reactors per year over the following 10 years
- Compare to current global rate: ~1 new plant per year since 2000

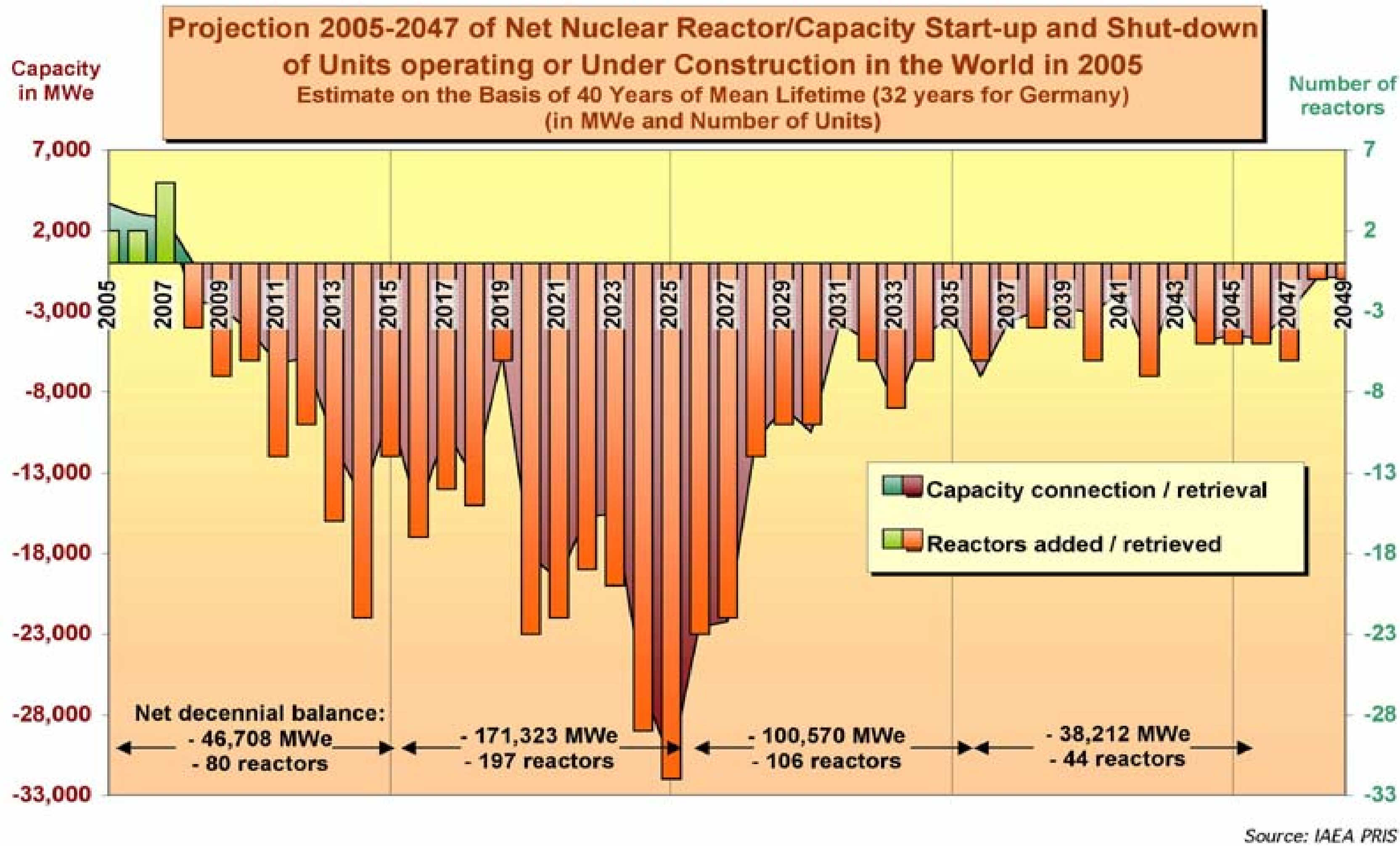


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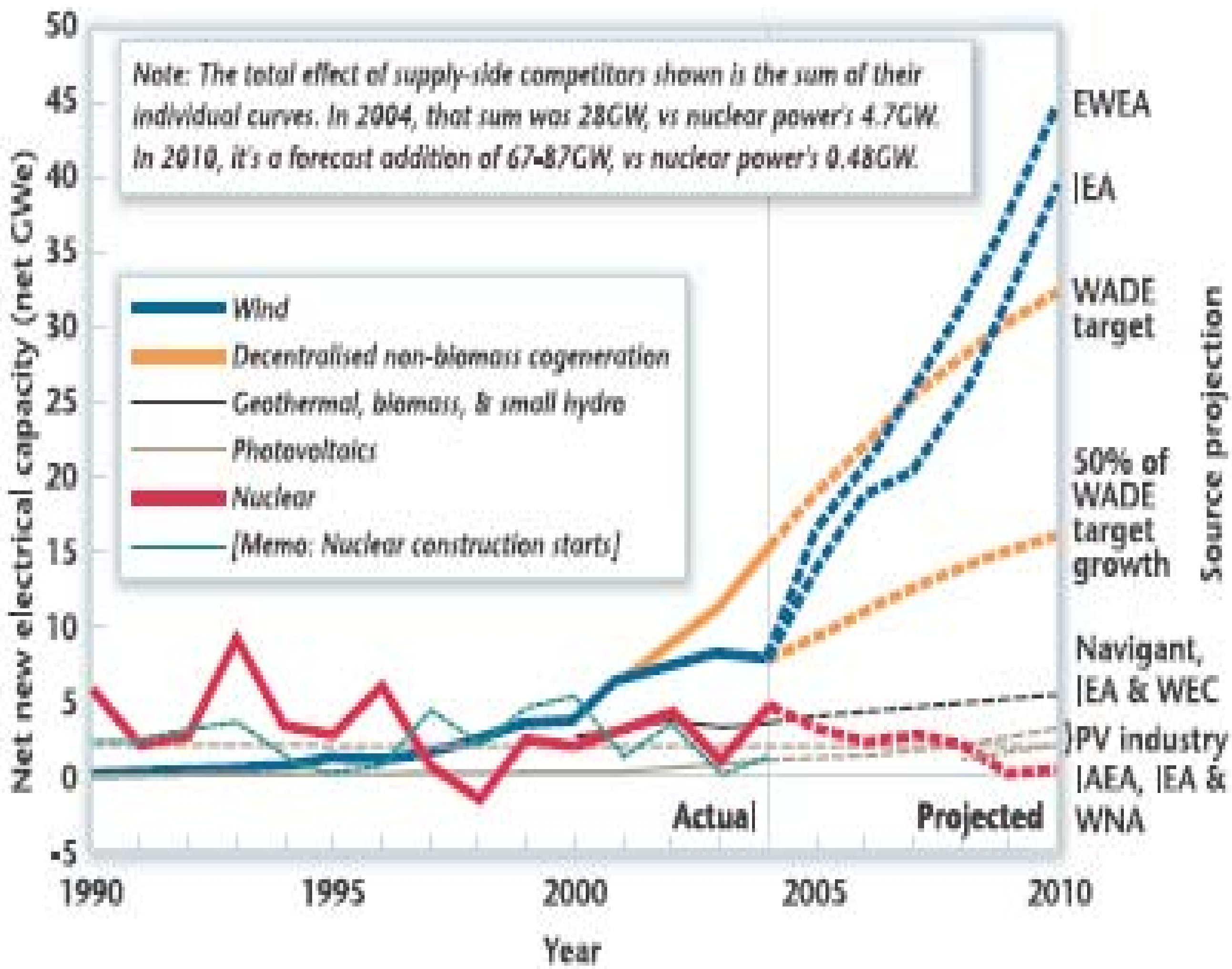
Figure 2:
Global additions of electrical generating capacity by year and technology



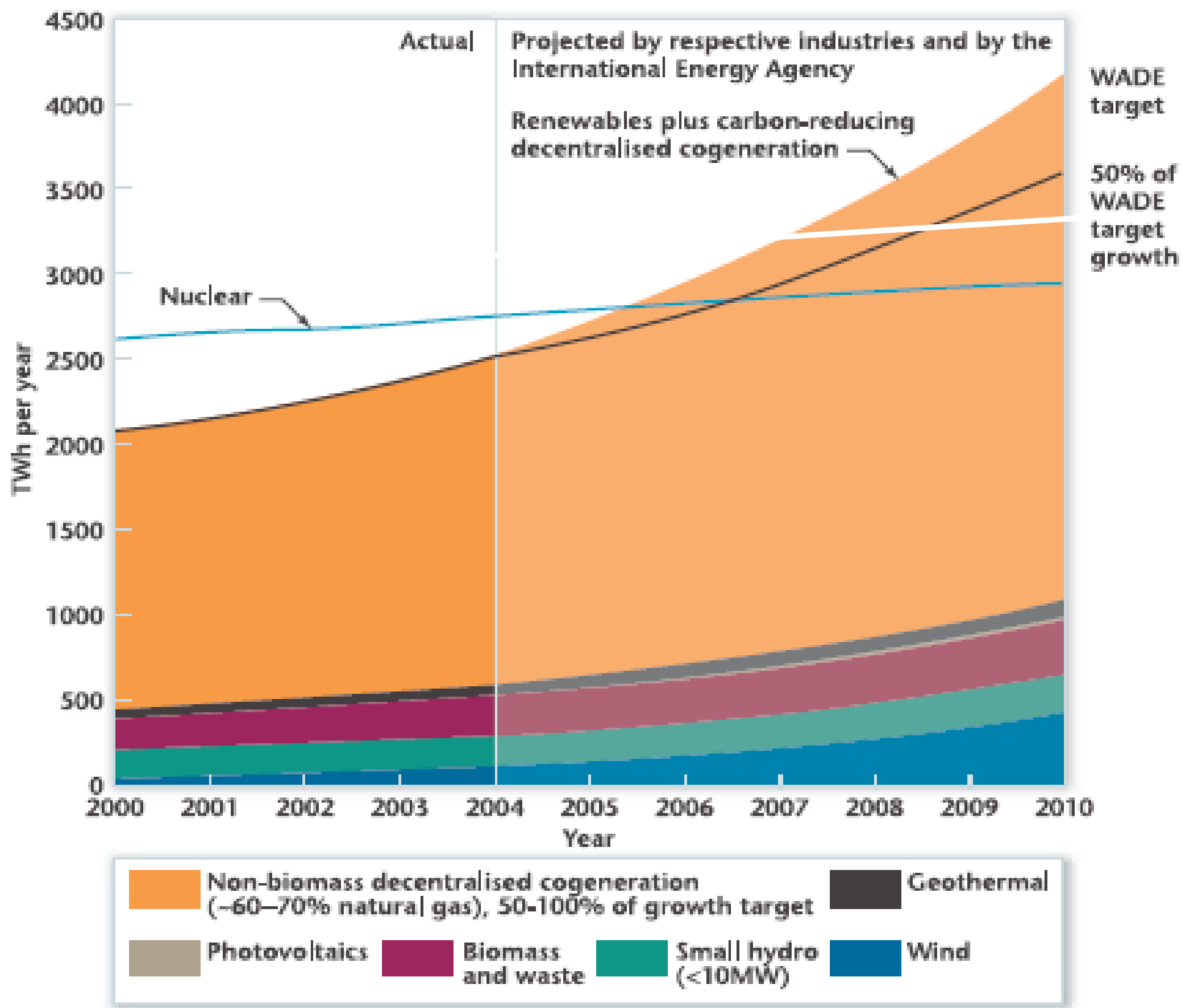


Figure 1: Worldwide electrical output of decentralised low- or no-carbon generators (except large hydro)

Factors in Addition to Generating Cost That Crimp a Nuclear Revival

- No approved licensed path for long-term geologic disposal of spent fuel;
- Added security concerns and risks in an age of terrorism
- Proliferation concerns if advanced fuel cycles are used, or uranium enrichment capability spreads to additional countries
- Long gestation/construction period increases risk of market obsolescence and stranded costs
- Uranium mining, milling, and enrichment can have harmful environmental impacts

More Nuclear Risks

- "The abiding lesson that Three Mile Island taught Wall Street was that a group of N.R.C.-licensed reactor operators, as good as any others, could turn a $2 billion asset into a $1 billion cleanup job in about 90 minutes.” -- Former NRC Commissioner Peter Bradford