Cost-Efficient Greenhouse Gas Reductions: Nuclear is No Silver Bullet

After COP21: Are Nukes Our Best Investment to Reduce C02?

Nonproliferation Policy Education Center

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The Nuclear Way
Strong Statements, Strong Supporters

"We have no time to experiment with visionary energy sources; civilisation is in imminent danger and has to use nuclear - the one safe, available, energy source - now or suffer the pain soon to be inflicted by our outraged planet."
-James Lovelock, British environmentalist, 2004

"Nuclear power paves the only viable path forward on climate change."
-James Hansen, Kerry Emanuel, Ken Caldeira and Tom Wigley, scientists, 2015

"*We won't meet the carbon targets if nuclear is taken off the table."*
-Jeffrey Sachs, Director, Earth Institute, Columbia University, 2015

Bill Gates and others – invested $1.3 billion in private capital to advance nuclear technologies over the past 10 years.

US (government-led) buildouts: **John McCain**: 45 reactors (2008); **Lamar Alexander**: 100 reactors (2015).

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Nuclear Buildout

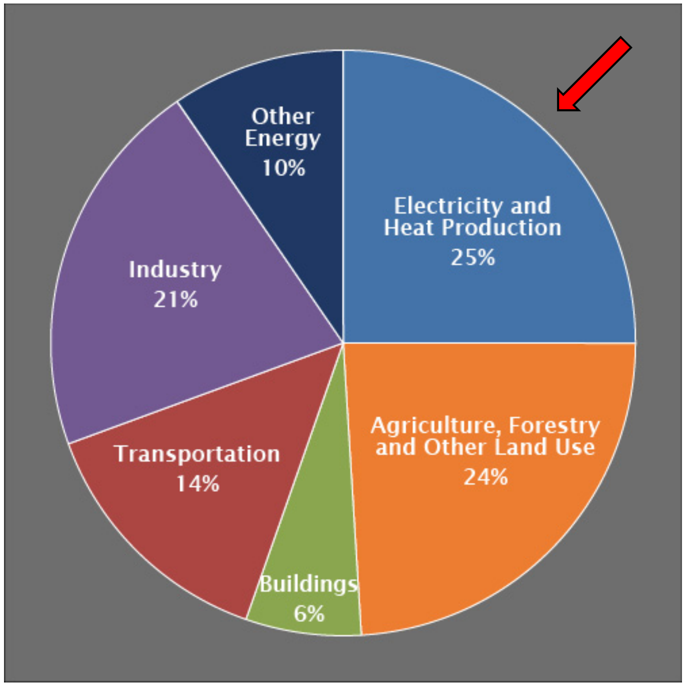
But the Big Money is Mostly Other People's

- Nuclear in NEA's 2 degree scenario (2015 *Technology Roadmap*):
  - 930 GW of new reactors globally (about 40% is replacement) by 2050.
  - Cost of $4.4 ***trillion*** even excluding many baseline nuclear subsidies (e.g., waste, accident risk, financing decommissioning).
  - Much of this backstopped by public loans, loan guarantees, direct investment, or long-term power purchase guarantees.
- This buys a 13% of the needed ghg reductions ***within the power sector only***.
  - Efficiency and DSM would kick in roughly 30%.
  - Wind and solar, 28%.

Efficient Mitigation

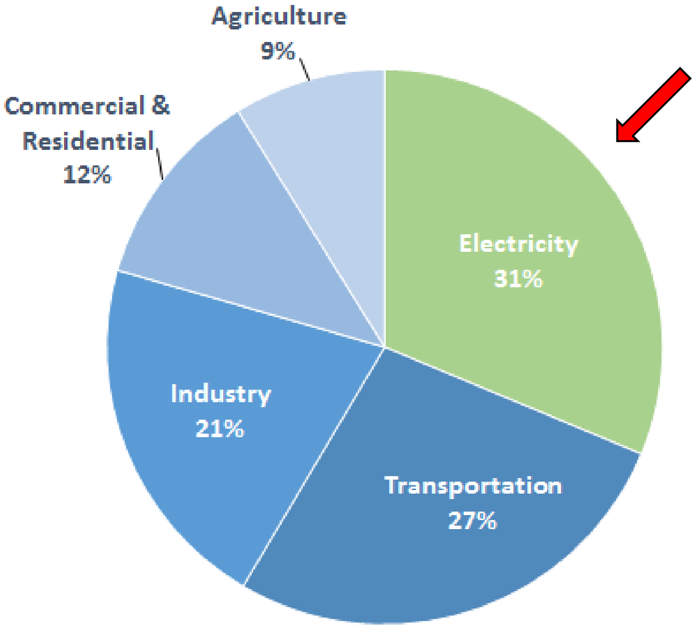
ghg Reductions Not Just about Electricity

Global ghg Emissions



IPCC 2014, based on 2010 emissions data.

US ghg Emissions



US EPA inventory, 2014 emissions data

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Efficient Mitigation

Cheaper is Better; Sooner is Better

- These may not be:
  - In the power sector;
  - In the United States;
  - Have the delivery risk that new nuclear does.
- Climate feedback loops on warming and in technical innovation both favor quick reductions.
- "All-of-the-above" carbon strategy does not work if driven by public subsidies, risk bearing.

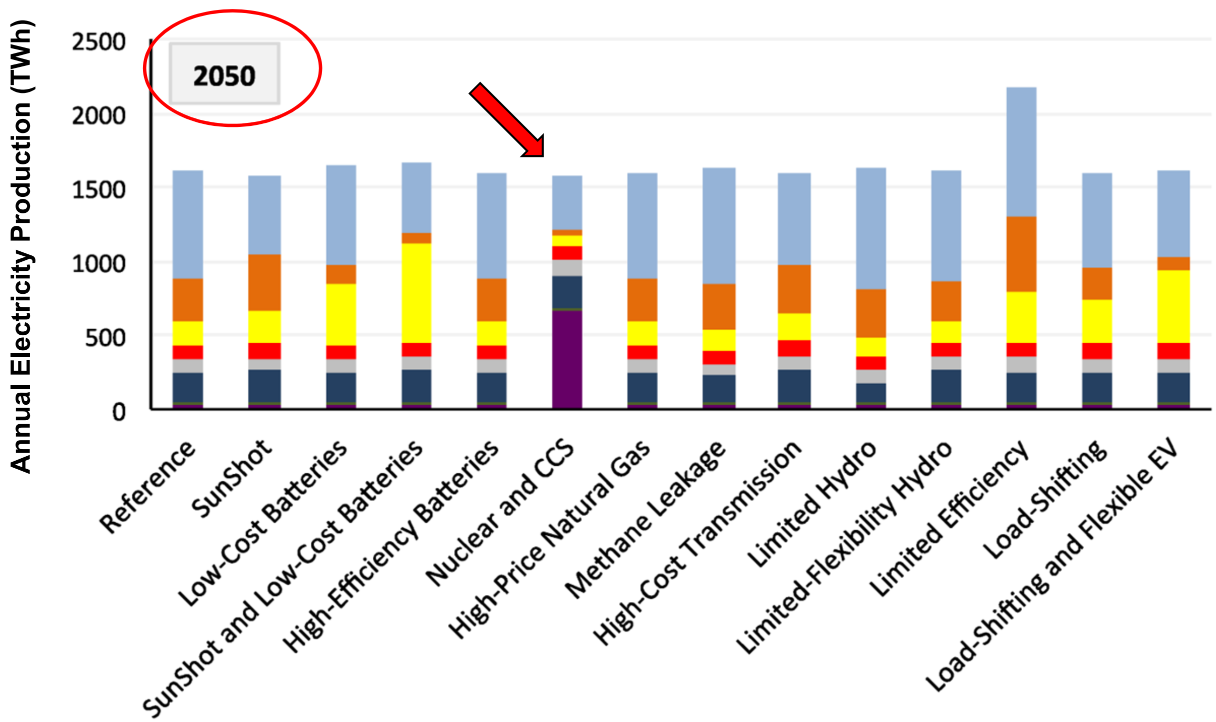
Efficient Mitigation

Timing of Reductions Matters a Great Deal

"Scenarios with aggressive and early emission reductions achieve far lower cumulative emissions by 2050. In some BAU scenarios, California has more than twice the cumulative emissions in 2050 as in the mitigation case. ***From a climate perspective, the obvious implication is that near-term reductions are preferable to delayed reductions."*** *(Emphasis added).*

-Morrison et al., review of nine different abatement/power dispatch models related to California, in "Comparison of Low-Carbon Pathways for California," *Climatic Change,* 2015

Low Carbon Power Balancing in WECC*: Nuclear Not the Solution



- ~No nuclear prior to 2050.
- Only in 2050 if freeze innovation in other power sources.
- Late and expensive abatement has high opportunity cost.

Source: Mileva et al., "Power system balancing for deep decarbonization of the electricity sector," *Applied Energy,* Jan. 2016.

*Western Electric Coordinating Council includes part or all of 14 Western states, the provinces of Alberta and British Columbia, and northern Baja California in Mexico.

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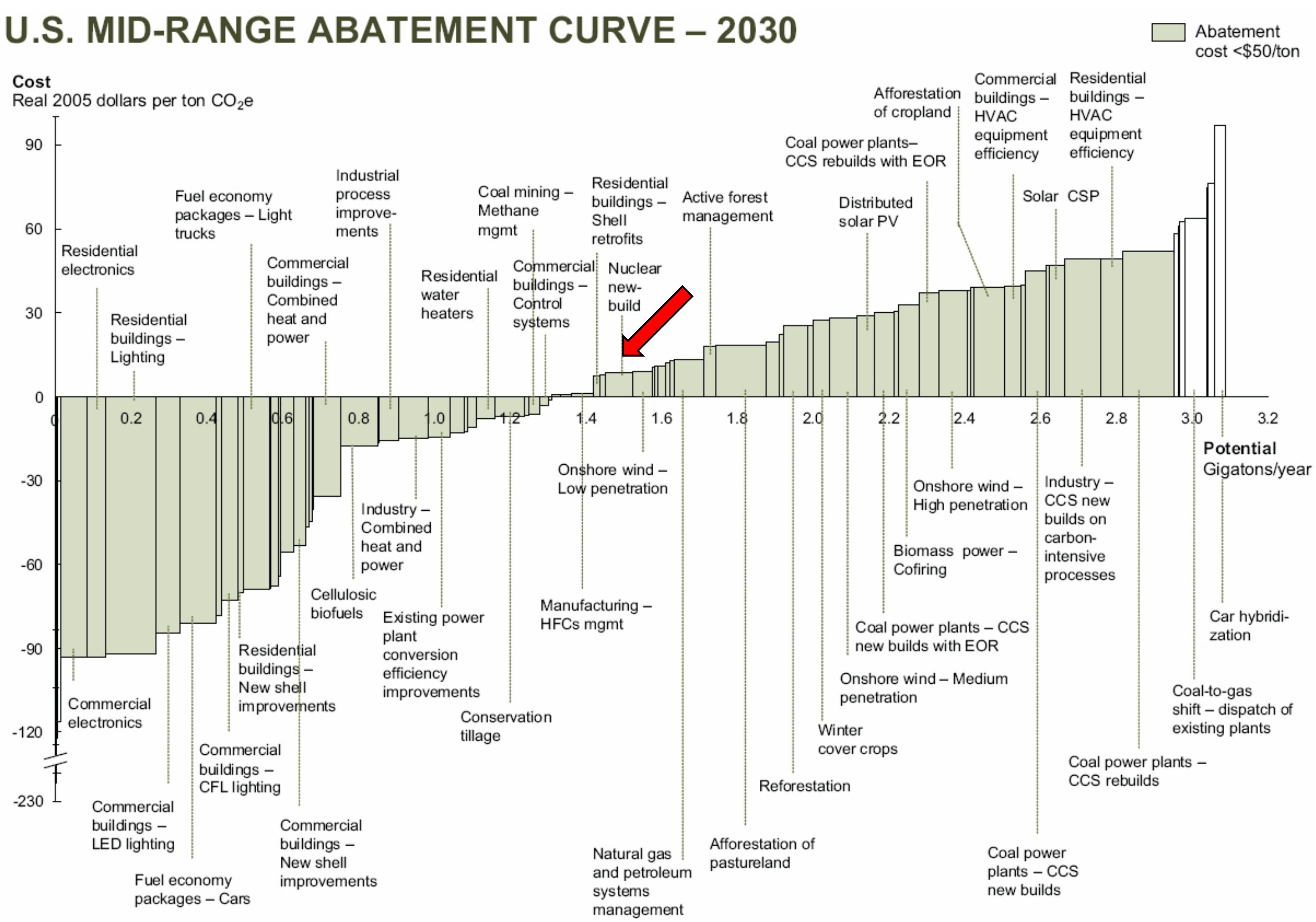
Efficient Abatement (US Curve) - 2007
New Nuclear Seems Low Cost for Power Sector



Source: McKinsey & Company, *Reducing US Greenhouse Gas Emissions: How Much and at What Cost?*, 2007.

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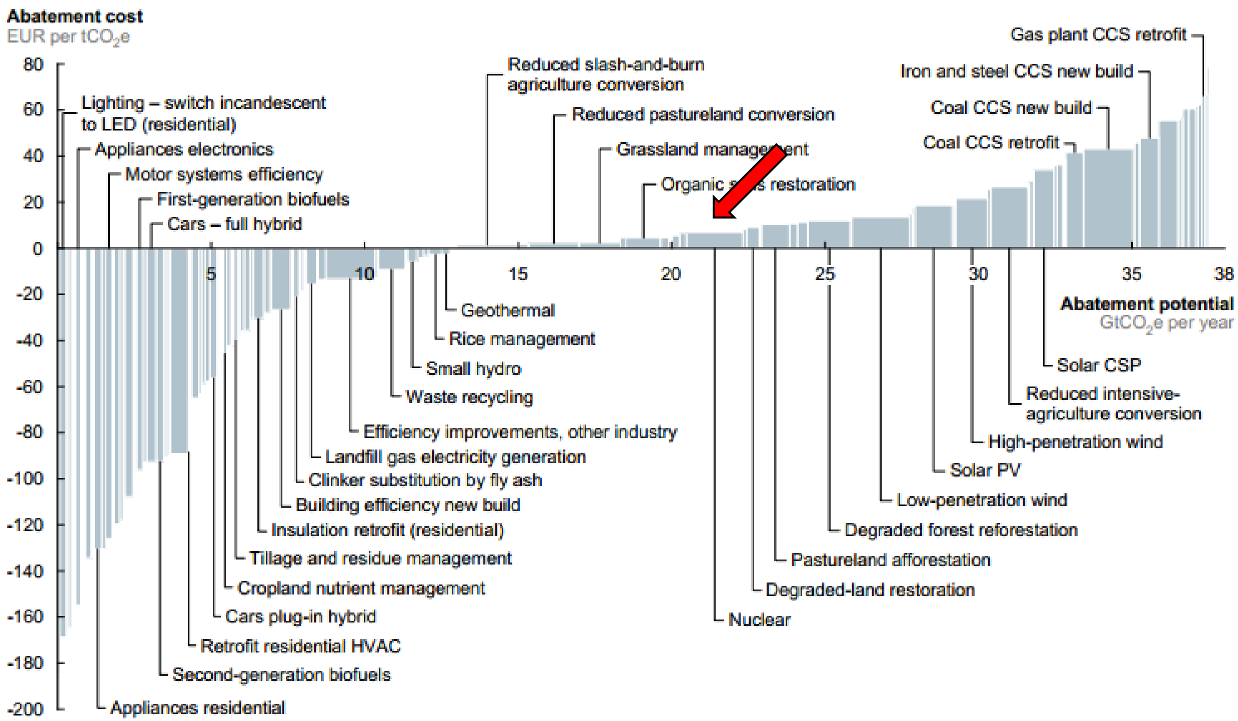
Efficient Abatement (Global Curve) – 2009
New Nuclear Still Looks Good for Power Sector

GHG abatement cost curve is beyond business as usual in 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below EUR 80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play

Source: McKinsey & Company, *Impact of the financial crisis on carbon economics: Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve*, 2010.

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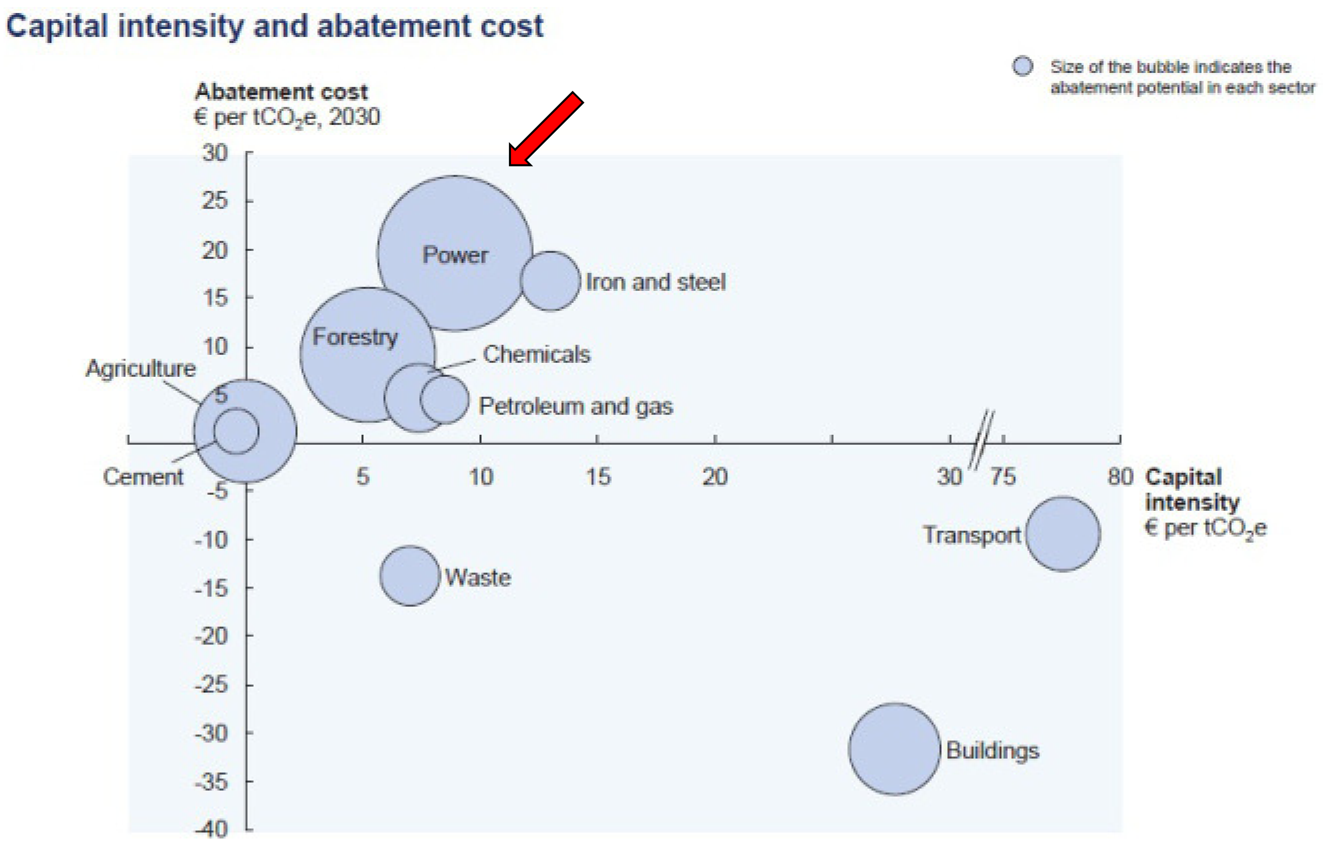
Efficient Abatement
But Power is High Cost Sector



Source: McKinsey & Company, *Pathways to a Low Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*, 2009

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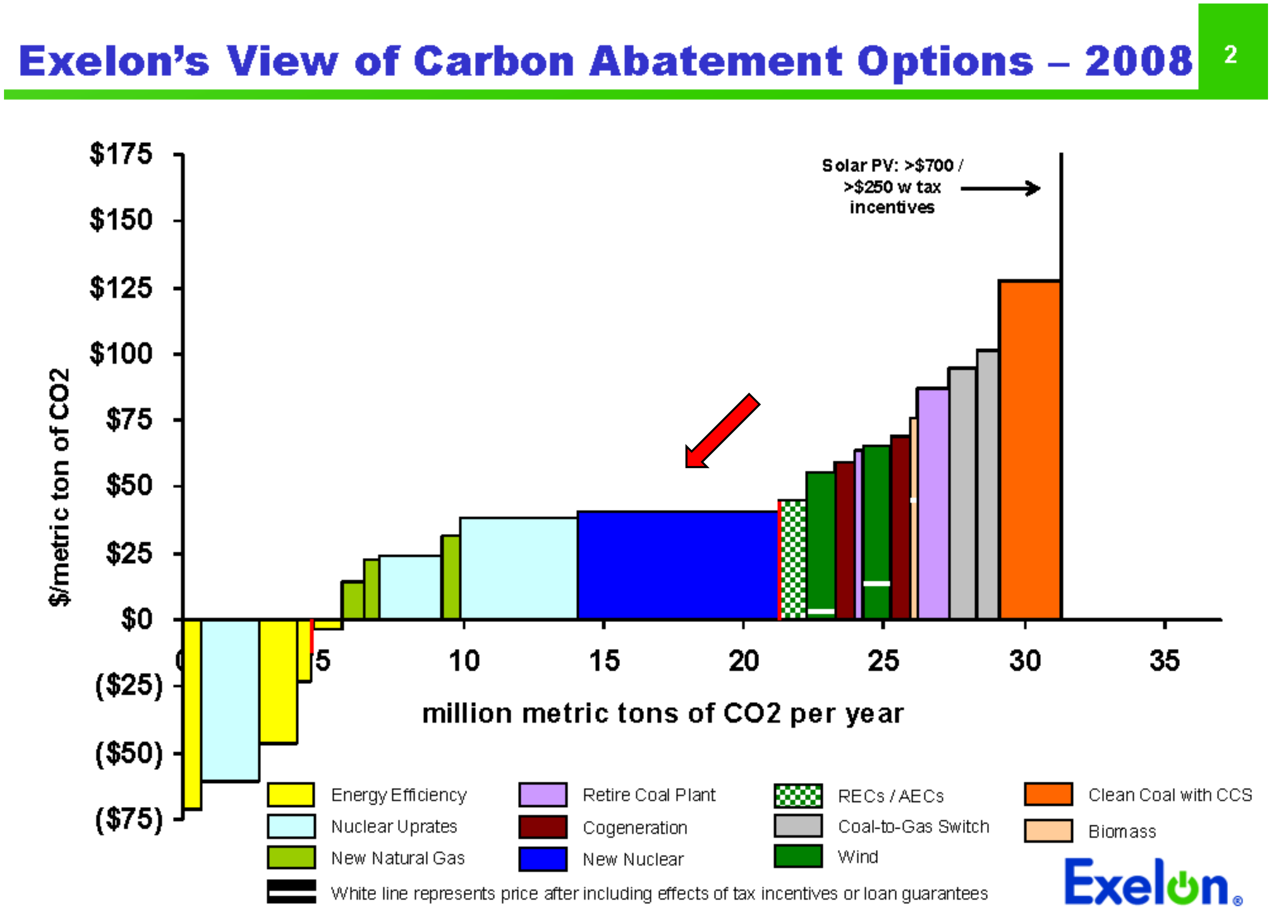
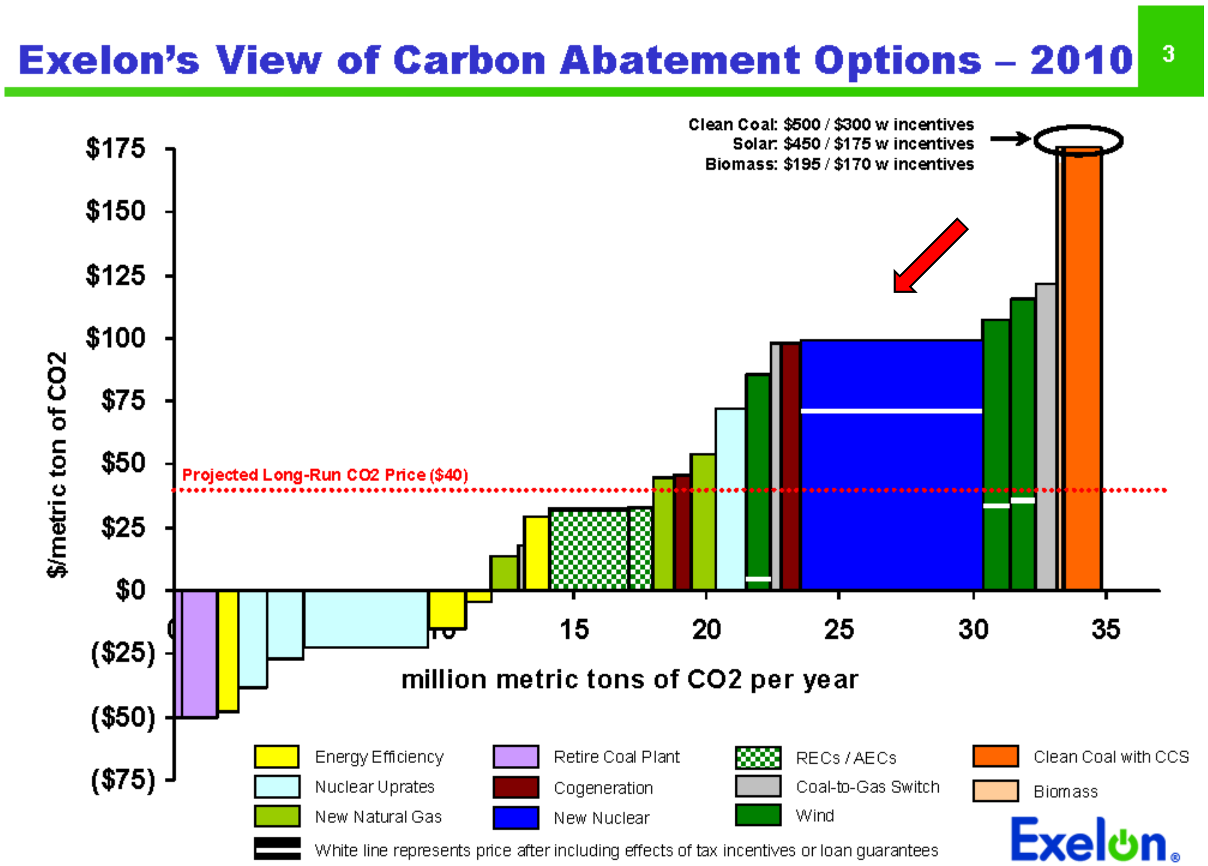
Efficient Abatement in *Power Sector* - 2008

Exelon Less Rosy on Nukes Than McKinsey



Source: John W. Rowe, Chairman and CEO, Exelon Corporation "Fixing the Carbon Problem Without Breaking the Economy," Resources for the Future Policy Leadership Forum Lunch, May 12, 2010

Efficient Abatement in *Power Sector* – 2010
And Getting Less So…



Source: John W. Rowe, Chairman and CEO, Exelon Corporation "Fixing the Carbon Problem Without Breaking the Economy," Resources for the Future Policy Leadership Forum Lunch, May 12, 2010

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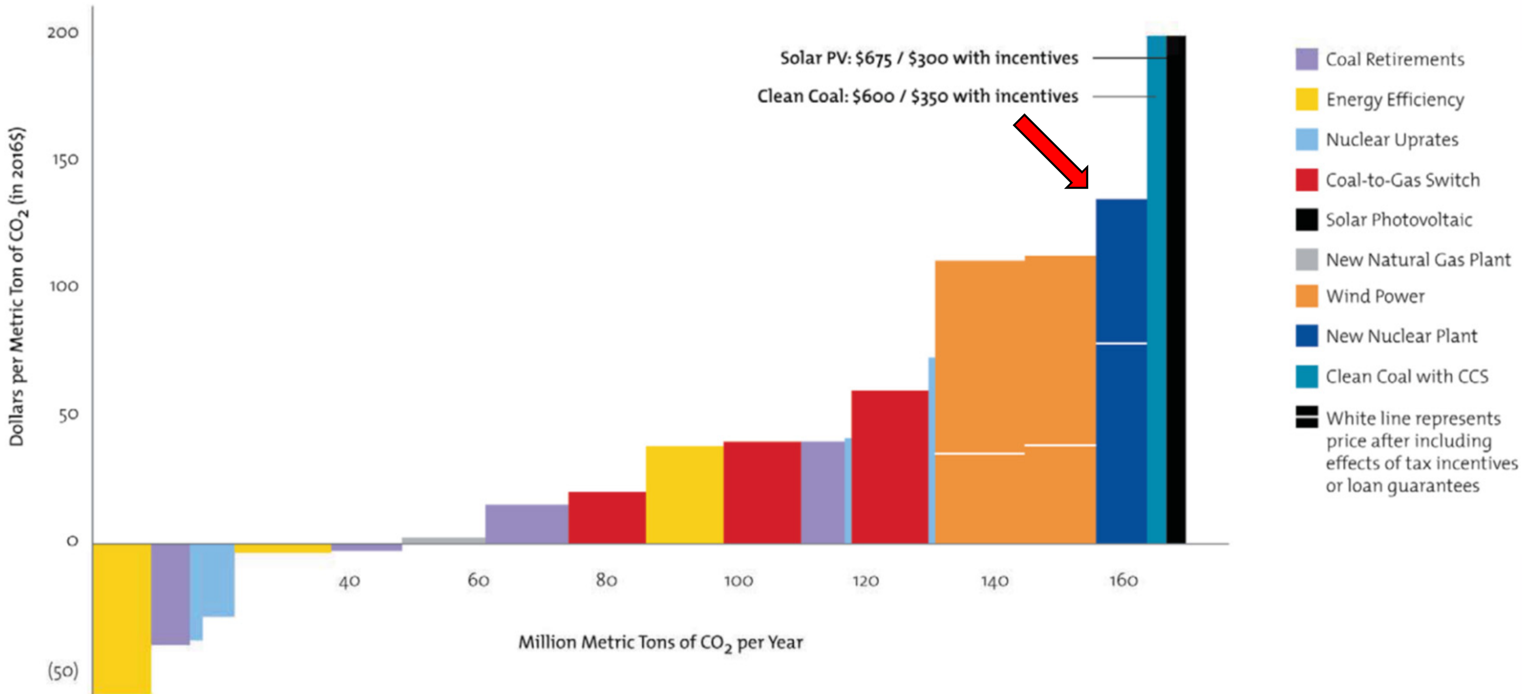
Efficient Abatement in *Power Sector* – 2011

And Worse: Wind Pulls Ahead

Cost Per Avoided Ton of CO2 of Clean Energy Options in PJM



Note: Assumes that EPA adopts a MACT standard to control emissions of hazardous air pollutants. Emissions reduction estimates for new generation capacity represent emissions reduced in the market as a result of the project less emissions introduced due to the project.

Technology cost assumptions (in 2016 $/kw):
- Combined-cycle gas turbine: $1,300 - $1,700
- Wind: $2,000 - $2,500
- Nuclear: $5,000 - $6,000
- Clean coal with CCS: $5,500 - $6,500
- Solar photovoltaic: $3,000-$4,000

PJM coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.

Source: John W. Rowe, Chairman CEO, Exelon Corporation, "Energy Policy: Above All, Do No Harm," American Enterprise Institute, Washington, DC, March 8, 2011.

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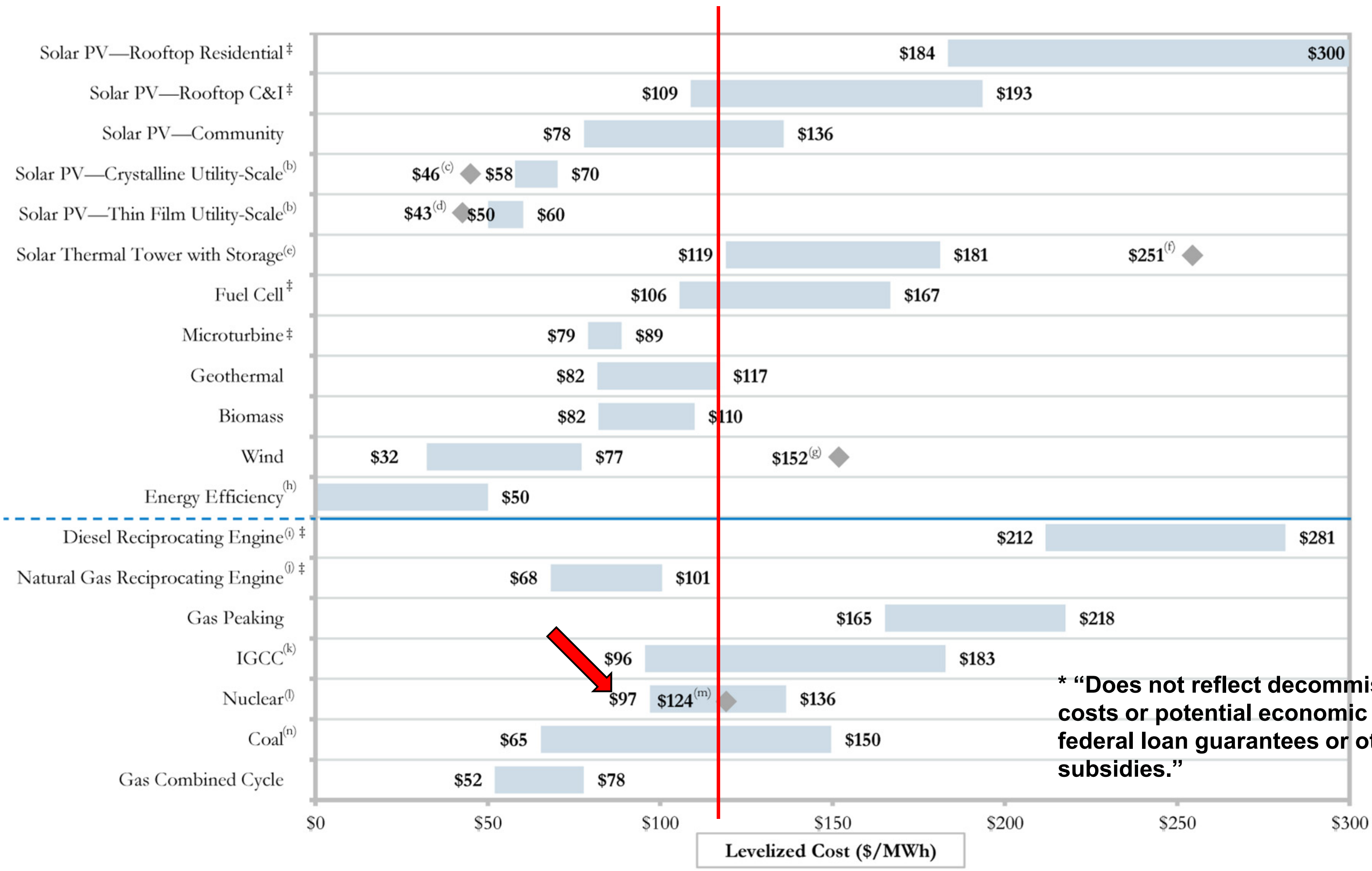
“Unsubsidized”* LCOE, 2015
Wind, Centralized Solar, Gas Cheaper than Nuclear



*** “Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.”**

Source: Lazard, *Lazard’s Levelized Cost of Energy Analysis – Version 9.0*

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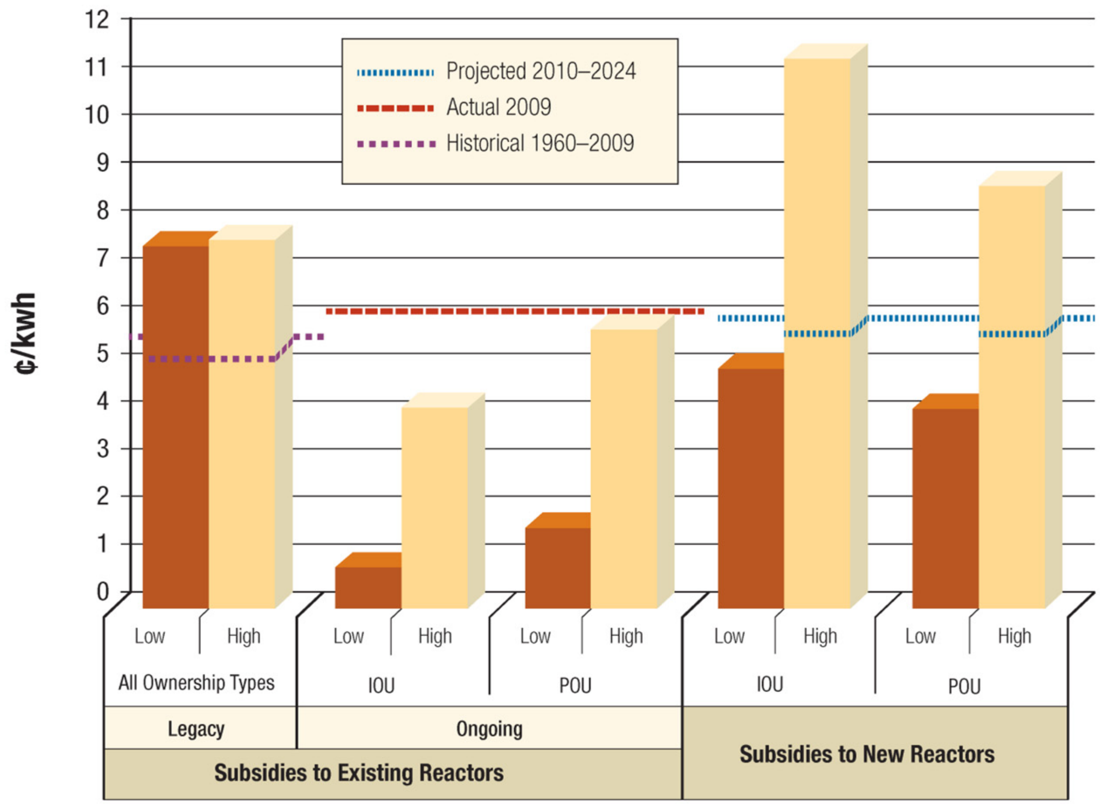
But Nuclear *is* Heavily Subsidized



Note: Legacy subsidies are compared to the Energy Information Administration (EIA) average 1960–2009 industrial power price (5.4 ¢/kWh). Ongoing subsidies are compared to EIA 2009 actual power prices for comparable busbar plant generation costs (5.9 ¢/kWh). Subsidies to new reactors are compared to EIA 2009 reference-case power prices for comparable busbar plant generation costs (5.7 ¢/kWh).

- Financing (LG, CWIP, tax exempt debt for POUs)
- Accident risk
- Waste management
- Decommissioning
- PPAs (mostly abroad)
- R&D
- Enrichment (historical)

Source: Doug Koplow, *Nuclear Power Still Not Viable Without Subsidies*, (Cambridge, MA: Union of Concerned Scientists), 2011.

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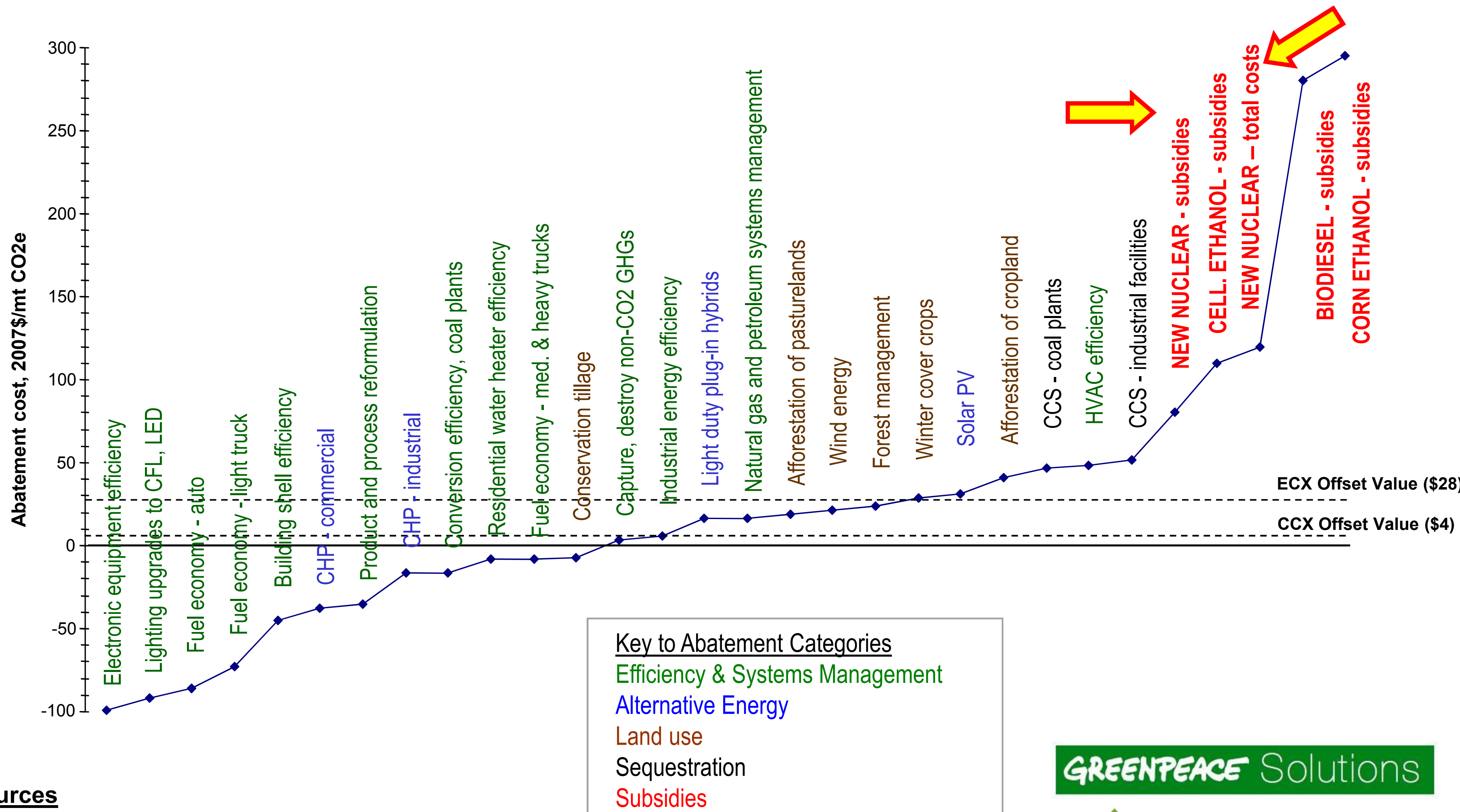
Including Nuclear Subsidies in McKinsey Data

Abatement Case for New Nuclear Worsens



Sources

Abatement technologies: McKinsey & Company, 2007, mid-range case.
Offset prices: Average of contract values from CCX (2008-10) and ECX (2008-12).
Subsidy data: Earth Track, Inc.

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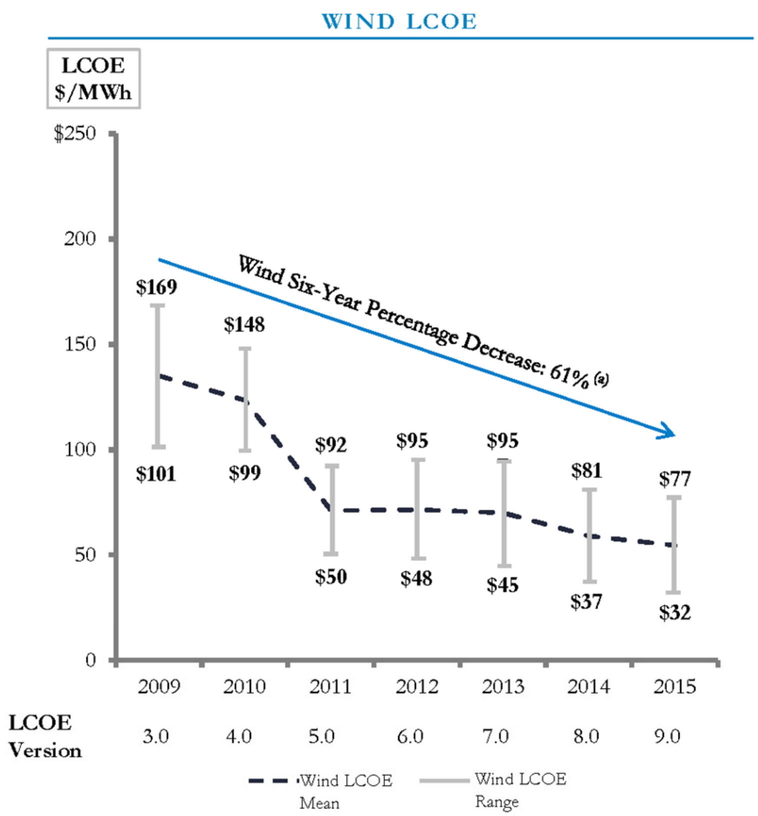
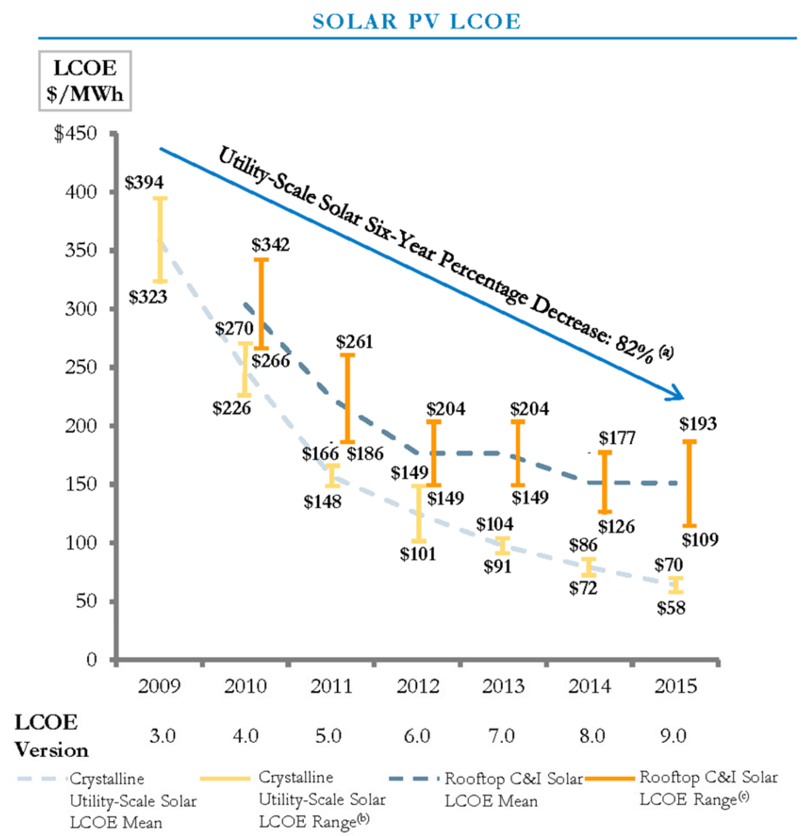
Nuclear Competitors are Not Standing Still

Costs Falling Steadily for Wind and PV





Source: *Lazard estimates.*

(a) Represents average percentage decrease of high end and low end of LCOE range.

(b) Low end represents crystalline utility-scale solar with single-axis tracking in high insolation jurisdictions (e.g., Southwest U.S.), while high end represents crystalline utility-scale solar with fixed-tilt design.

(c) Lazard's LCOE initiated reporting of rooftop C&I solar in 2010.

Source: Lazard, *Lazard's Levelized Cost of Energy Analysis – Version 9.0*

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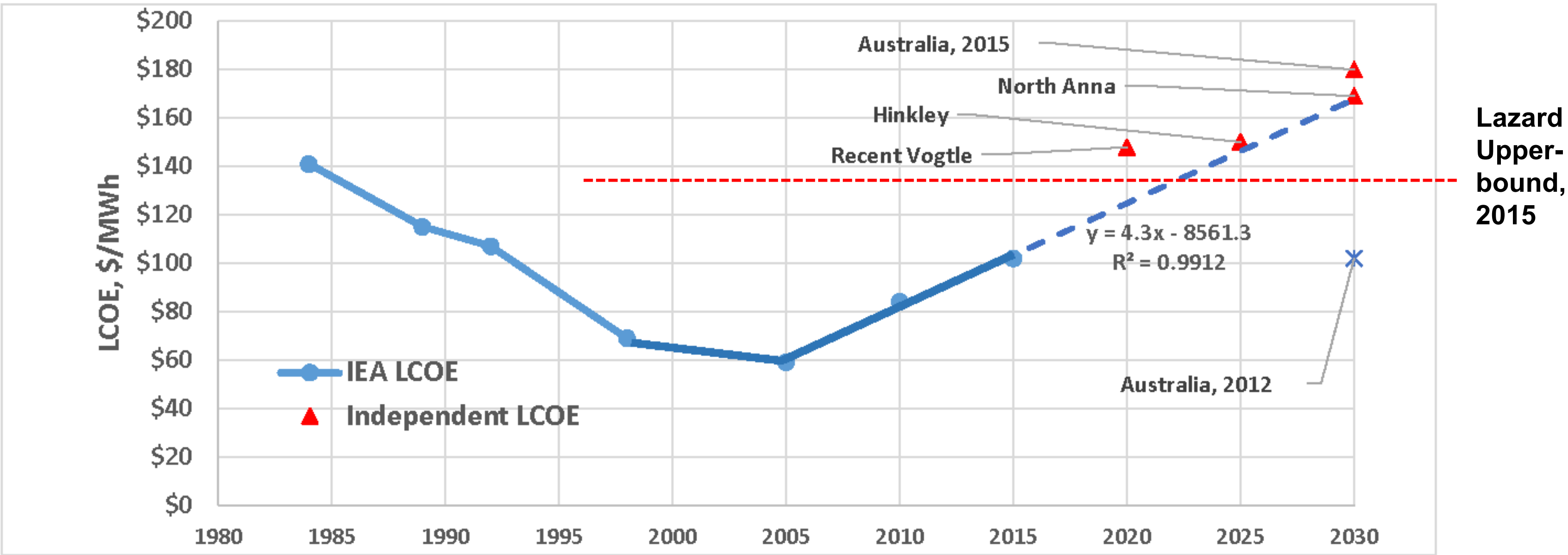
Nuclear Competitors

Oft-Cited Cost Reductions from Learning in Nuclear Sector Remain Stuck in Reverse

Levelized Cost Estimates



Source: "The Economic and Institutional Foundations of the Paris Agreement on Climate Change: The Political Economy of Roadmaps to a Sustainable Electricity Future," working paper by Mark Cooper, Vermont Law School, Jan. 2016.

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Nuclear Competitors

Reactor Construction in West is Flailing

Reactor	Cost Escalation	Delays (years)
Vogtle 3 & 4 (Georgia, USA)	$14.1b (2009) to $22b (2016)	3
Summer 2 & 3 (South Carolina, USA)	$9.8b (2012) to $11b (2016) - overnight costs only	3-4
Olkilioto 3 (Finland)	$3.6b (2005) to $9.5b (2015)	10
Olkilioto 4 (Finland)	Cancelled due to unit 3 problems	n/a
Flamanville (France)	€3b to €10.5b in 2016	6

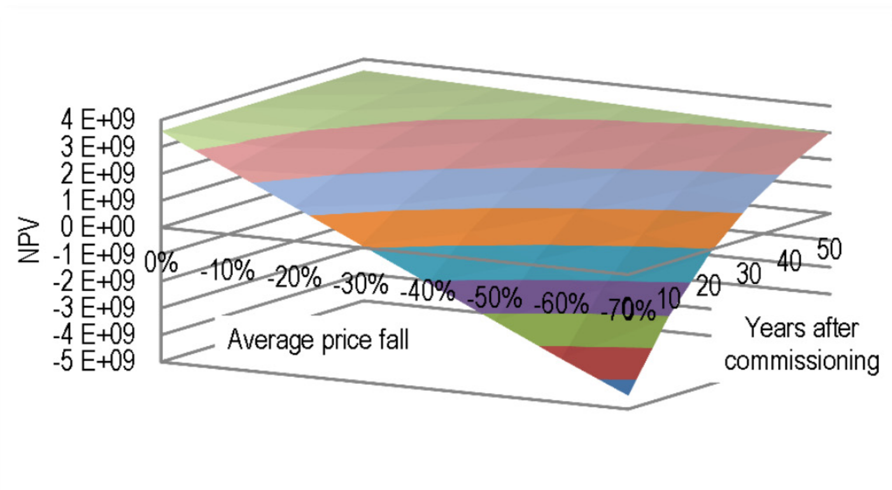
- Overruns not really just regulatory nuisance.
- China and Russia: really cheaper or just less transparent?
- SMRs to the rescue? Reversing 60 years of economies of scale.

Nuclear Competitors

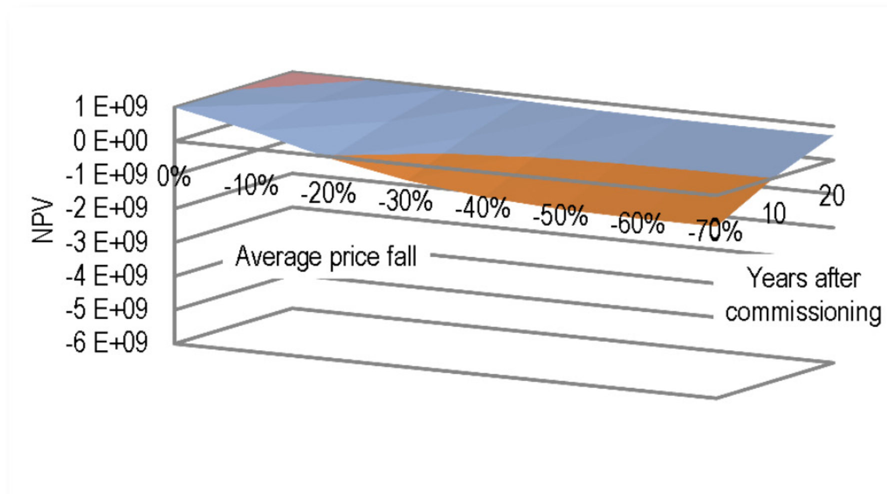
Market Price Risk Much Worse for Nuclear

- Market price declines hurt nuclear more and for longer than competing forms of energy.
- Solution? Shift risk to the State via 35-yr price guarantees (Hinkley Pt. C).

The NPV of an NPP based on a fall in electricity prices and the onset of the price fall years after commissioning (r = 3%)



The NPV of a gas-fired power plant based on a fall in electricity prices and the onset of the price fall years after commissioning (r = 3%)



Source: Nuclear Energy Agency, *Nuclear New Build: Insights into Financing and Project Management*, 2015.

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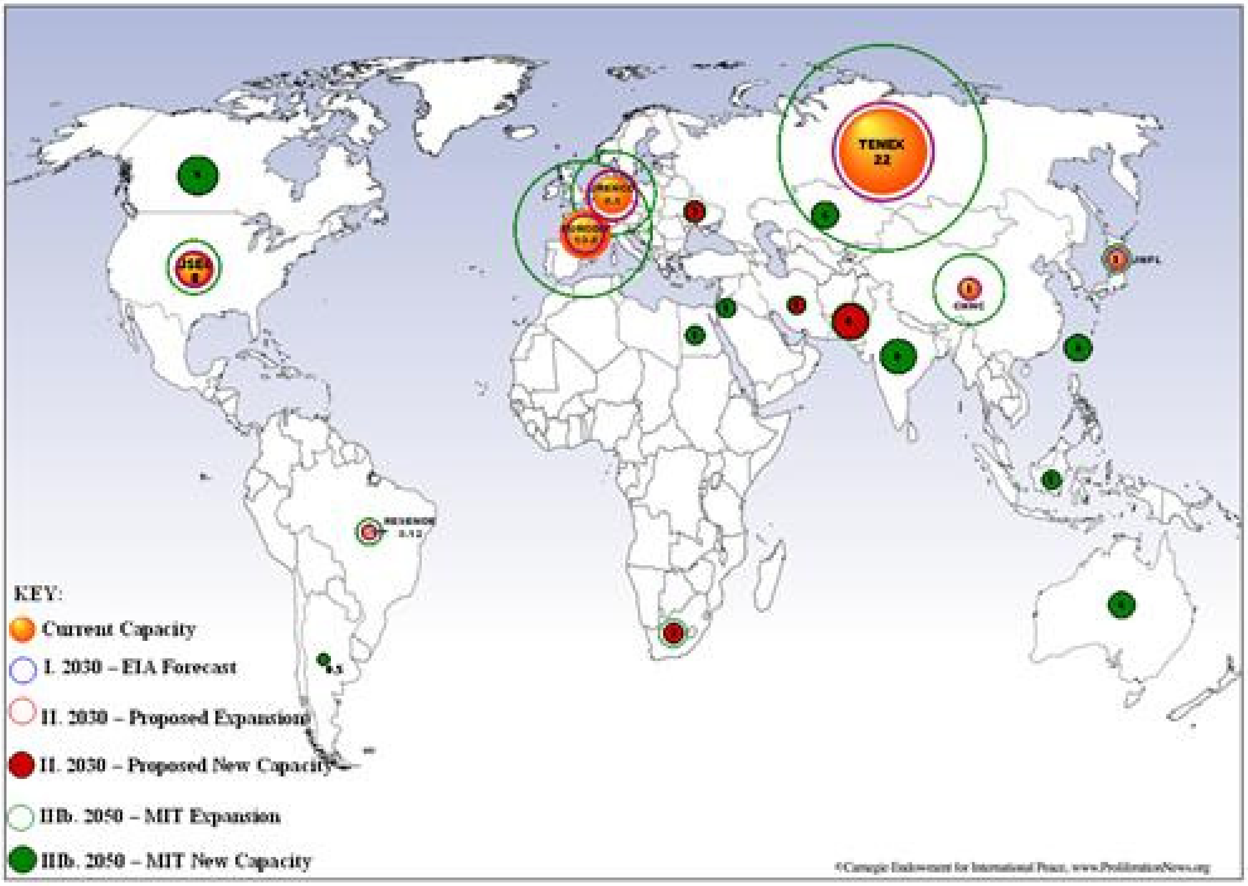
Nuclear Externalities
Illustrative Uranium Enrichment Expansion out to 2050



Source: Squassoni with Jones and Gerami (Carnegie) for NPEC, "Mapping Global Nuclear Expansion," 2008.

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Lot Size Matters: Incremental Innovation and the Fight for Baseload

Nuclear Reactor Market Size

580 - 775 - Number of new reactors built to supply this target. Nuclear role down significantly since NEA's 2010 review. Nearly half are replacing retiring units.

$4.4 *trillion* - Estimated investment over the next **35 years** to build these reactors per the NEA estimates; cost ignores most of the existing subsidies.

22 - Average number of reactors per year being built around the world; country-specific requirements and competing designs mean reactor lot sizes will be even smaller.

100% - Share of reactors that appear to be supported by significant government financing or other support.

0 - Number of repositories for permanent disposal of high level nuclear waste currently operating in the world. Vast majority of costs and risk borne by taxpayers.

Battery Market Size

Key market segments:

- **293,245** – Number of plug-in electric vehicles, each of which contains multiple batteries, sold worldwide during 2014. Trending higher.
- **148 million** - Number of laptop computers shipped by original device manufactures (the firms supplying most of the major brand names) in 2013.
- **230 to 285 million -** Estimated number of tablet computers shipped during 2014.
- **1.3 billion** - Number of smart phones shipped during 2014.
- **6.8 billion** - Number of cell phone lines in the world as of February 2014, nearly all of which have an associated mobile device and battery.

14 seconds - Amount of time for the lot size of batteries produced for the above devices alone to equal the number of nuclear reactors that would be built ***over the next 35 years*** under the NEA scenario.

Source: Doug Koplow, "The Simple Reasons Nuclear Will Lose the Battle for Our Energy Future to Companies Like Tesla," www.earthtrack.net, 2015.

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ghg Reduction

Manhattan Project is the Wrong Analogy

Analog	**Manhattan Project**	**Standard Setting in Computer Industry**	**Dynamic Competition**
Application	Key bottlenecks where gaps in basic understanding will constrain most or all responses to transition from oil.	Deficits in market structure that impede proper allocation of research and investment dollars, and slow the deployment of existing or near term technologies.	Multiple pathways exist to meet policy end-points, but it is difficult to identify the optimal (cost, time, skills, environmental impact) ahead of time.
Possible Examples	-Basic science of CCS, climate change, energy storage. -Core grid operating rules, interconnections to make fluid market entry, exit possible.	-Standardization of rules for rapid grid entry, exit. -Pricing transparency (nodal pricing, carbon tax, desubsidization, retail price differentiation). -Standardized metrics of impact. -Visual energy operating cost data in real estate sale and rental markets. -Policy neutrality (including demand side). -Property rights regimes for public sector R&D.	-Most situations where technologies are one of multiple options for addressing oil consumption. -Government rules may be needed to set competitive parameters and endpoints. -Can use subsidies; they should just be competitively tendered (e.g., alt fuels, drive trains, fleet management, improved efficiency).

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