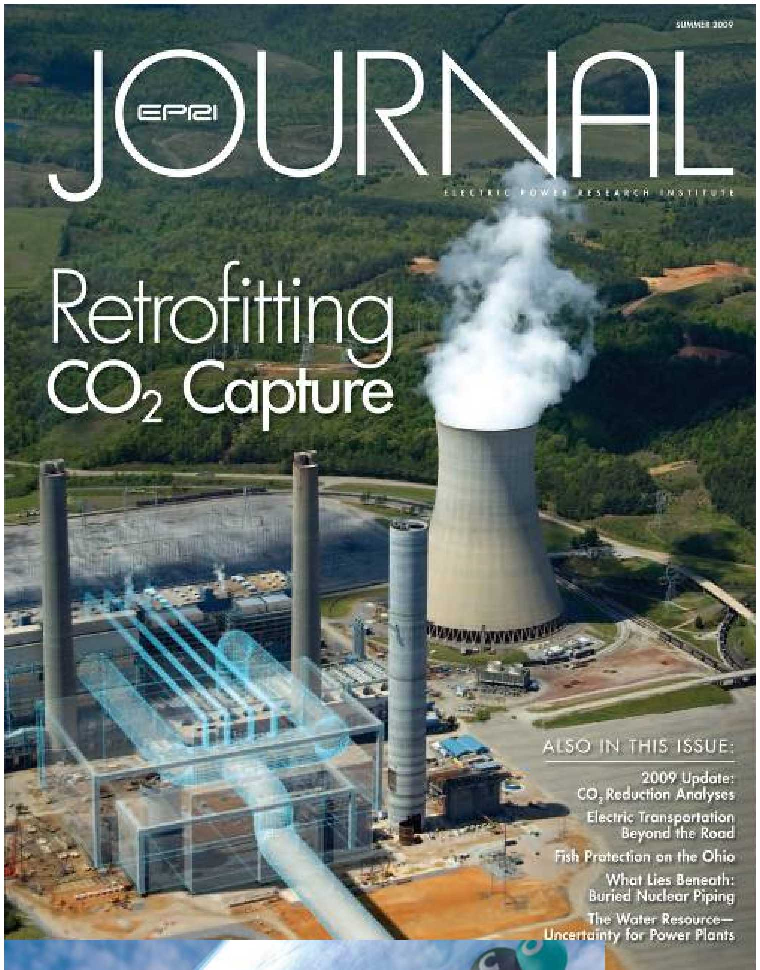

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CO_2 Capture and Storage Economics and Technology

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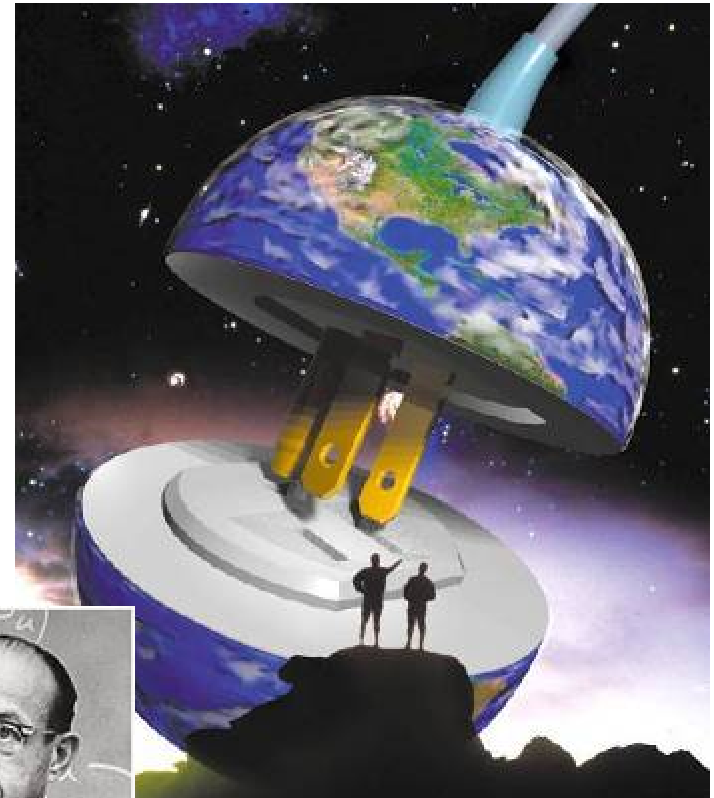
UN ECE Ad Hoc Group of Experts on Cleaner Electricity Production from Coal and Other Fossil Fuels

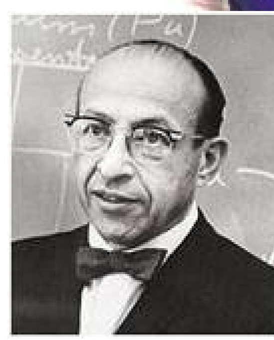
Geneva, Switzerland

16, November 2009

About EPRI …

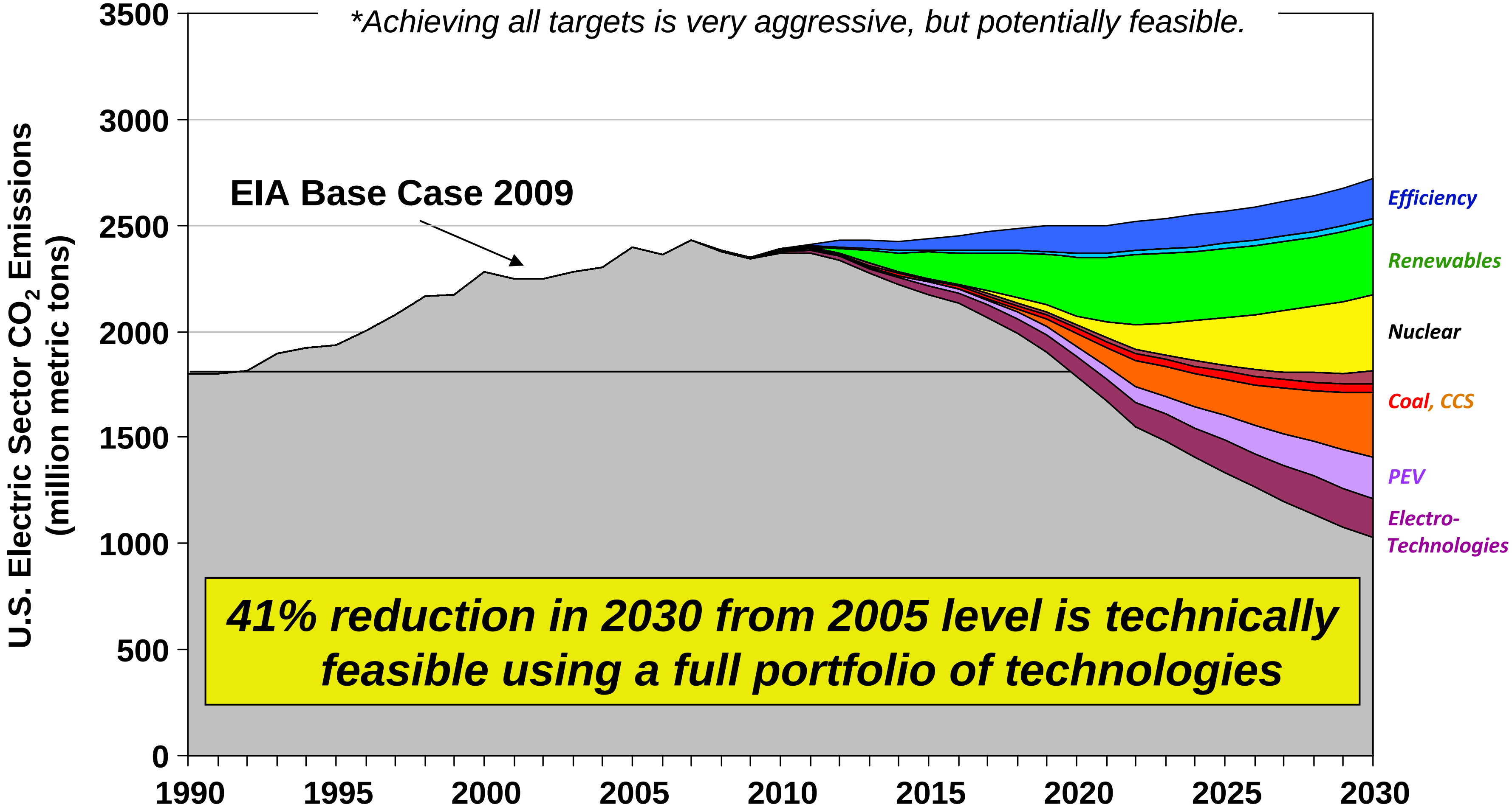
- Founded in 1973
- Independent, nonprofit center for public interest energy and environmental research
- 450+ collaborative participants in more than 40 countries
  - EPRI members generate more than 90% of U.S electricity
- Major offices in Palo Alto, CA; Charlotte, NC; Knoxville, TN
  - Laboratories in Knoxville, Charlotte and Lenox, MA





EPRI's Founder Chauncey Starr

EPRI Prism:
Technical Potential to Achieve CO_2 Reductions *



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2009 Prism Technology Targets

	Technology	EIA AEO Base Case	EPRI Prism Target
	Efficiency	Load Growth ~ +0.95%/yr	Load Growth ~ +0.47%/yr
	T&D Efficiency	None	20% Reduction in T&D Losses by 2030
	Renewables	60 GWe by 2030	135 GWe by 2030
	Nuclear	12.5 GWe New Build by 2030	No Retirements; 64 GWe New Build by 2030
	Fossil Efficiency	40% New Coal, 54% New NGCCs by 2030	+3% Efficiency for 75 GWe Existing Fleet 49% New Coal; 70% New NGCCs by 2030
	CCS	None	90% Capture for All New Coal + NGCC After 2020 Retrofits for 60 GWe Existing Fleet
	Electric Transportation	None	PEVs by 2010; 40% New Vehicle Share by 2025 3x Current Non-Road Use by 2030
	Electro-technologies	None	Replace ~4.5% Direct Fossil Use by 2030

MERGE Input: Technology Portfolios

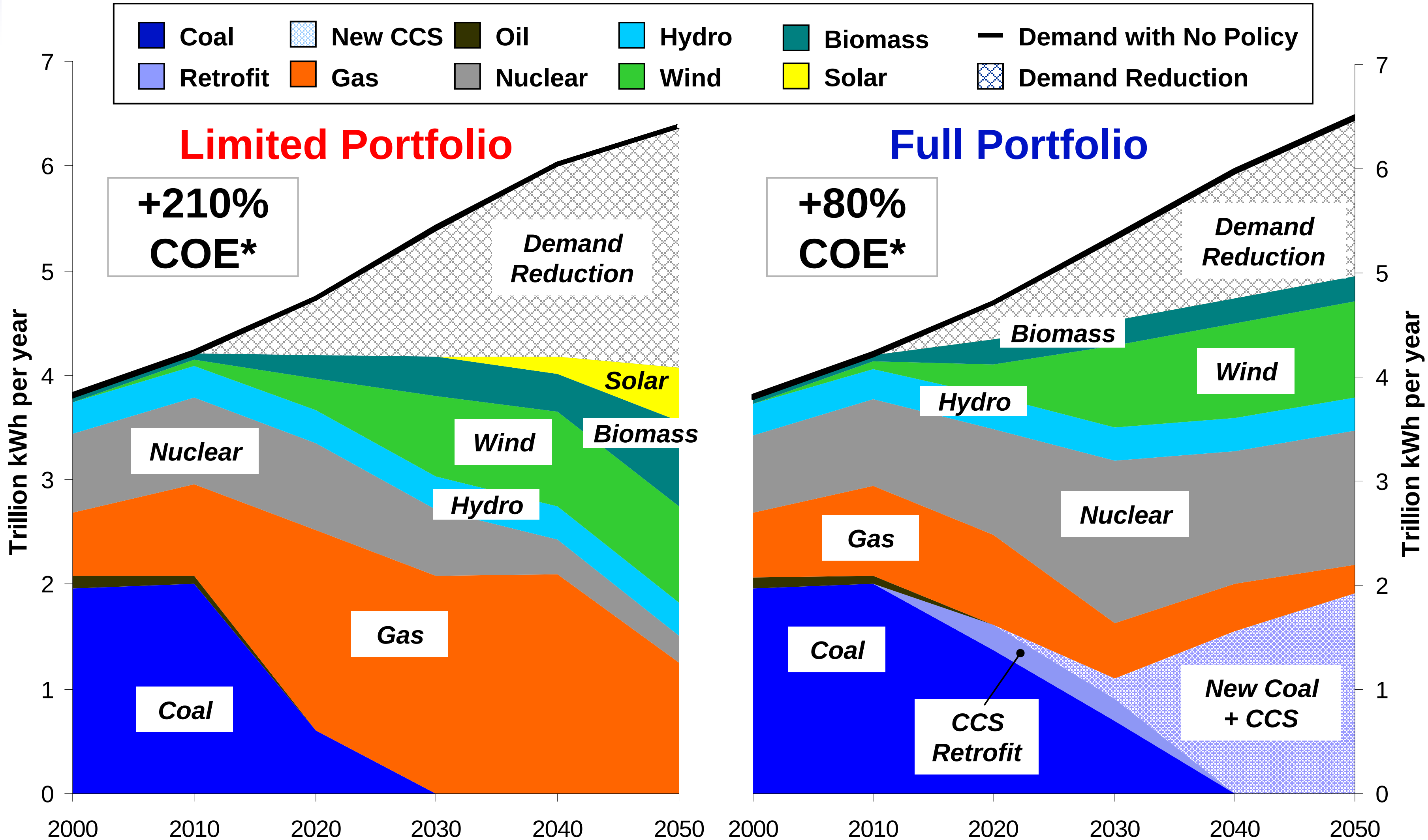
Limited Portfolio

- No CO_2 capture and storage (CCS)
- No plug-in electric vehicles (PEV's)
- Nuclear generation remains at existing levels

Full Portfolio

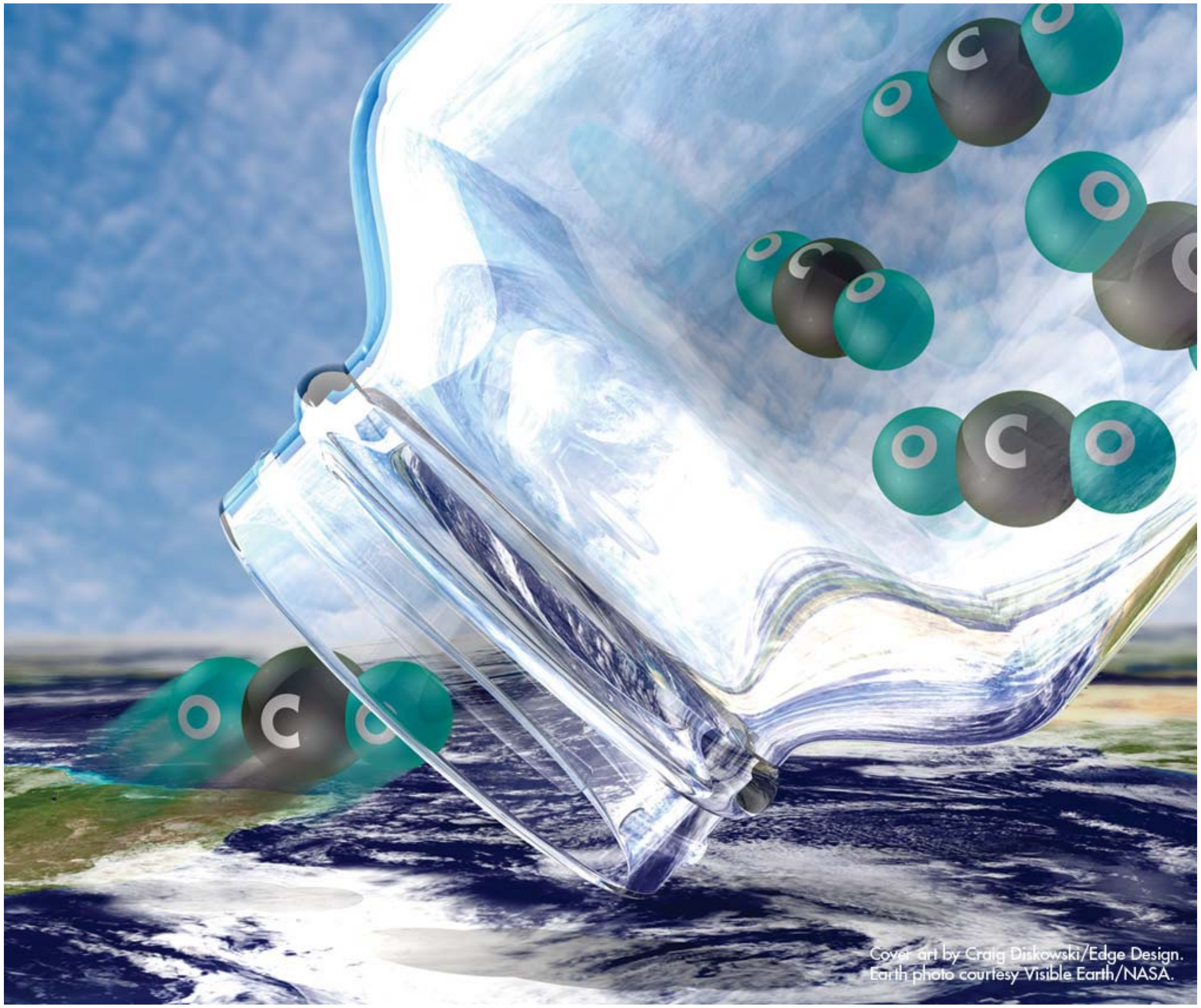
- Coal and Gas CCS available
- Accelerated end-use efficiency
- PEV's can expand
- Nuclear production can expand

MERGE U.S. Electric Generation Mix

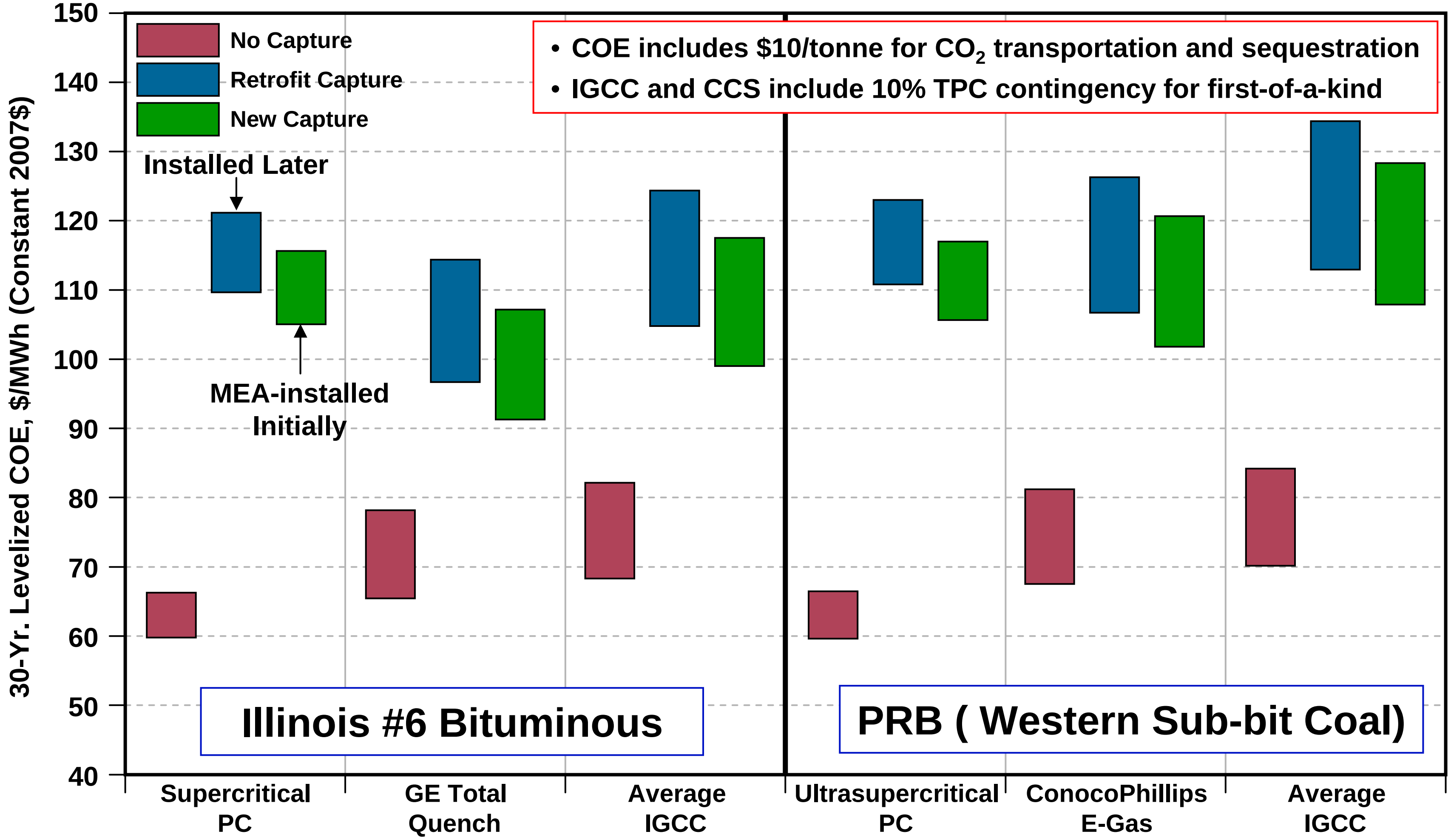


* *Cost of electricity increase relative to 2007*

Coal and CO_2 Capture



PC vs. IGCC with CO_2 Capture – No Clear Winners in Current Designs



Mid-2007 costs. Absolute values may differ today, but relative values probably unchanged

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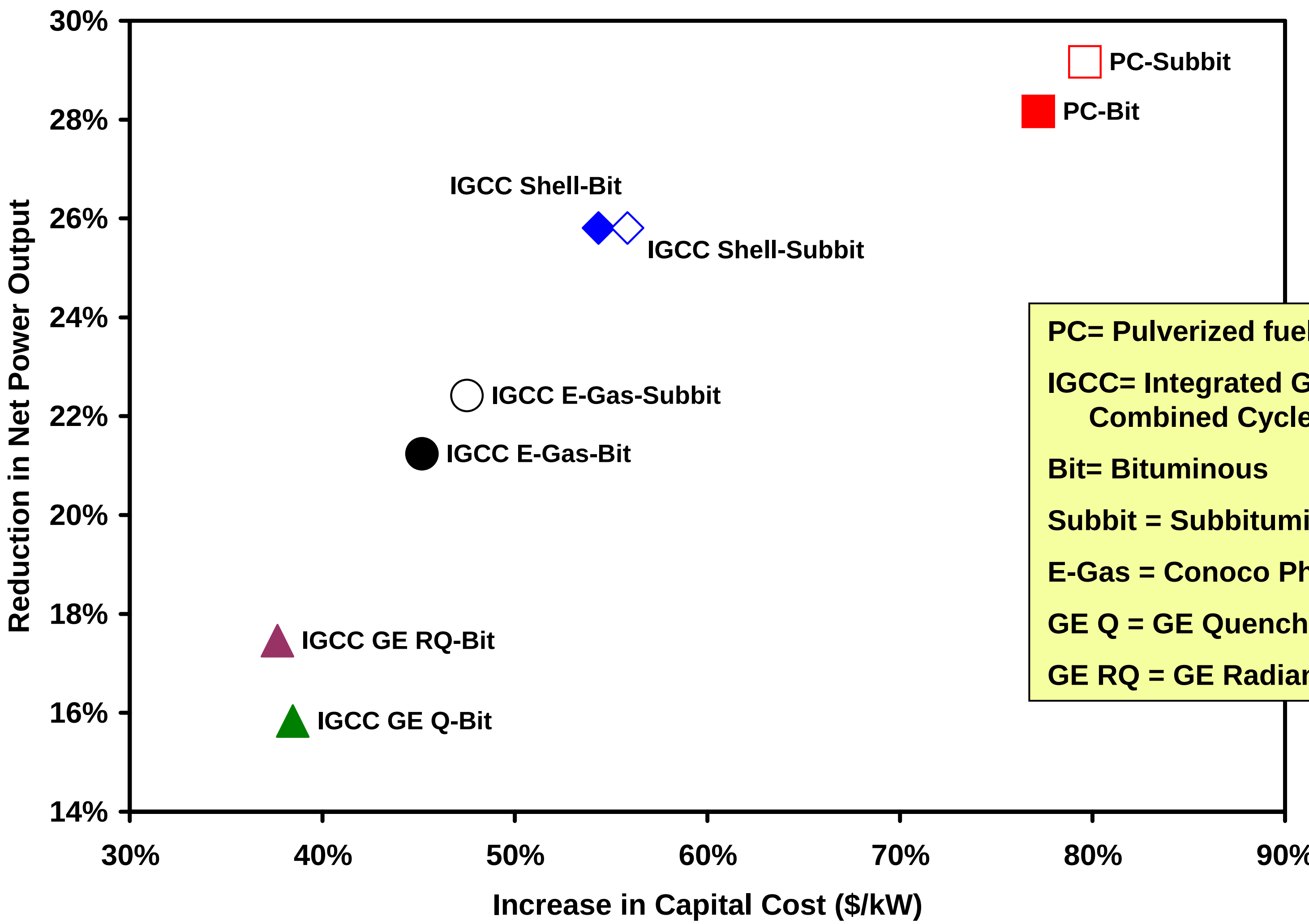
Retrofit Cost & Performance Penalties for CO_2 Capture *(today's technologies)*



PC= Pulverized fuel

IGCC= Integrated Gasification Combined Cycle

Bit= Bituminous

Subbit = Subbituminous

E-Gas = Conoco Phillips

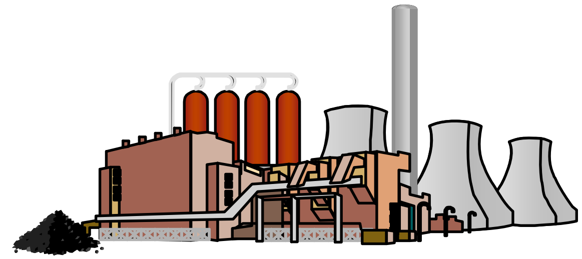
GE Q = GE Quench

GE RQ = GE Radiant Quench

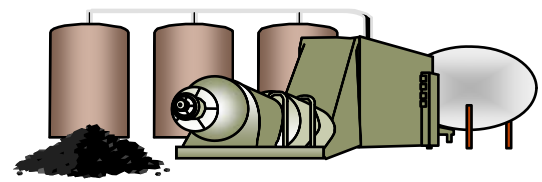
CO_2 Capture Can Be Done Today, But….

- **Significant increase in cost of electricity**
  - **60-80% increase vs. high efficiency supercritical pulverized coal (SCPC) with no capture**
  - **Cost delta for integrated gasification combined cycle (IGCC) less than SCPC, but IGCC base cost is higher**
- **Concerted RD&D effort expected to dramatically decrease cost and energy impacts**

Key Advanced Coal Technology Challenges



- New pulverized coal (PC)
  - Increase plant efficiency
  - Reduce energy penalty of CO_2 capture
- Existing PC
  - Retrofit CCS in existing plants

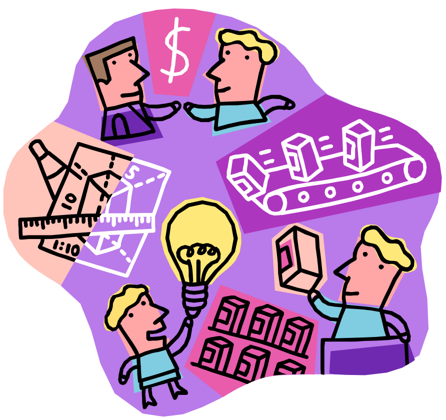


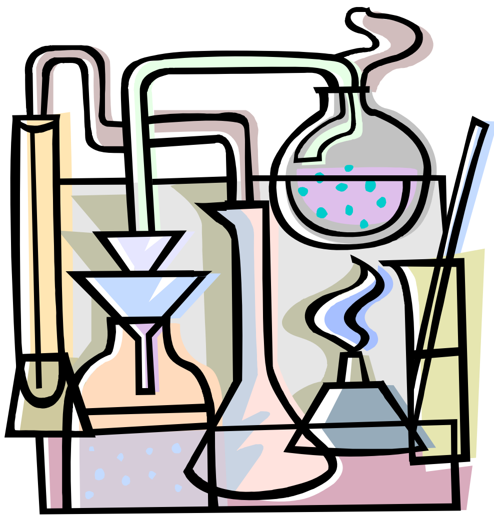
- Integrated gasification combined cycle (IGCC)
  - Integrate CCS in optimized plant design
- Oxy fired/ oxy fuel – enriches CO_2 but likely requires CO_2 purification
- Confirm long term CO_2 storage

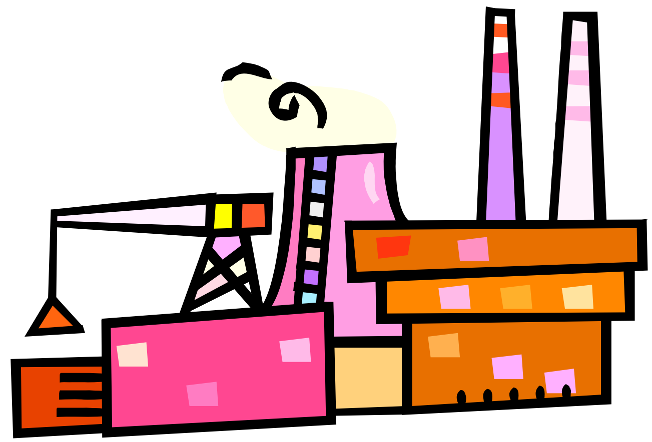
Goals: Reduce costs and demonstrate the technologies

Demonstrations of CCS and Related Technology

Idea → Lab/Pilot → **Demonstration**







Chilled Ammonia Pilot Plant at We Energies

- 37 U.S. and international utilities participated in collaborative
- Designed to capture up to 90% of CO_2 from flue gas treated
- Plant shut down October 2009
  - Lab reaction rates, energies confirmed
  - Operability demonstrated
- Developing techno-economic analysis to scale the system for commercial applications

We Energies Pleasant Prairie Power Plant (P4)

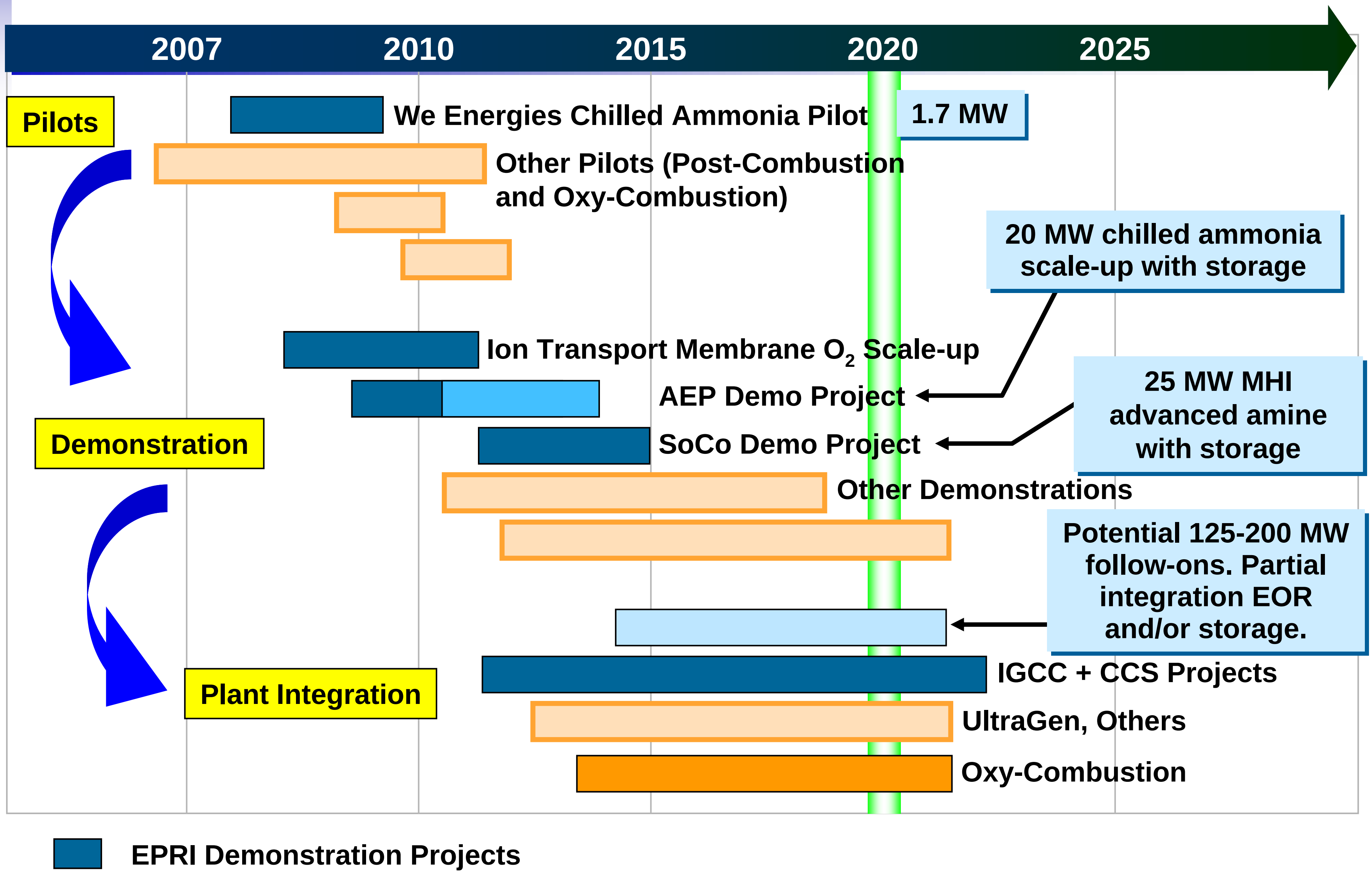
Project a success

Generation Industry Technology Demo Projects

Four project groups comprise seven projects:

Description	Size
Post-Combustion (PC) with Carbon Capture and Storage (CCS): American Electric Power (AEP)	~100,000 ton-CO_2/year (20 MW_e)
PC with CCS: Southern Company Services (SCS)	~150,000 ton-CO_2/year (25 MW_e)
Ion Transport Membrane (ITM) for Low-Cost Oxygen Production	150 ton-O_2/day
Integrated Gasification Combined Cycle (IGCC) with CCS Project 1	TBD
IGCC with CCS Project 2	~1,000,000 ton-CO_2/year
IGCC with CCS Project 3	~3,500,000 ton-CO_2/year
Solar Thermal Hybrid	TBD

Roadmap for CCS Commercialization



Post-Combustion Retrofit: Selected North American Host Sites

- Objective (Supplemental Project Notice 1016525)
  - Investigate thermal and economic impacts of retrofitting an advanced amine CO_2 capture process to an existing PC plant
  - Also, to guide the design of plants currently under development
- Details
  - Builds on knowledge from EPRI PCC CO_2 study for new plants
  - EPRI team will evaluate nominated sites and determine the size and cost of CO_2 capture plants that can be retrofitted and integrated with various types of PC plants

- Owner: **Nova Scotia Power**
- Location: **Nova Scotia**

- Owner: **Intermountain Power**
- Location: **Utah**

- Owner: **Great River Energy**
- Location: **North Dakota**

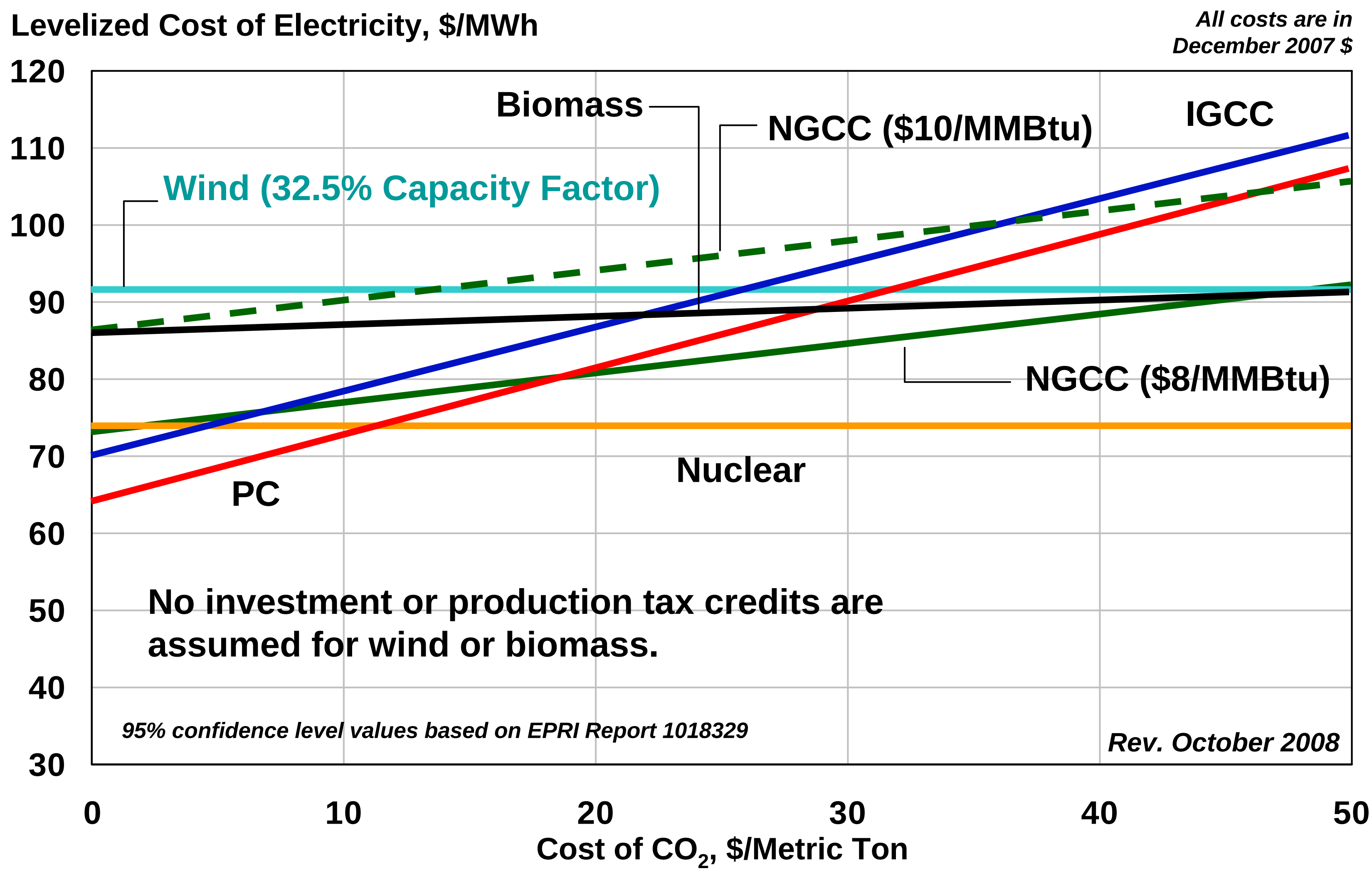
- Owner: **MidWest Generation**
- Location: **Illinois**

- Owner: **FirstEnergy**
- Location: **Ohio**

Comparing Various Projected Costs of Power

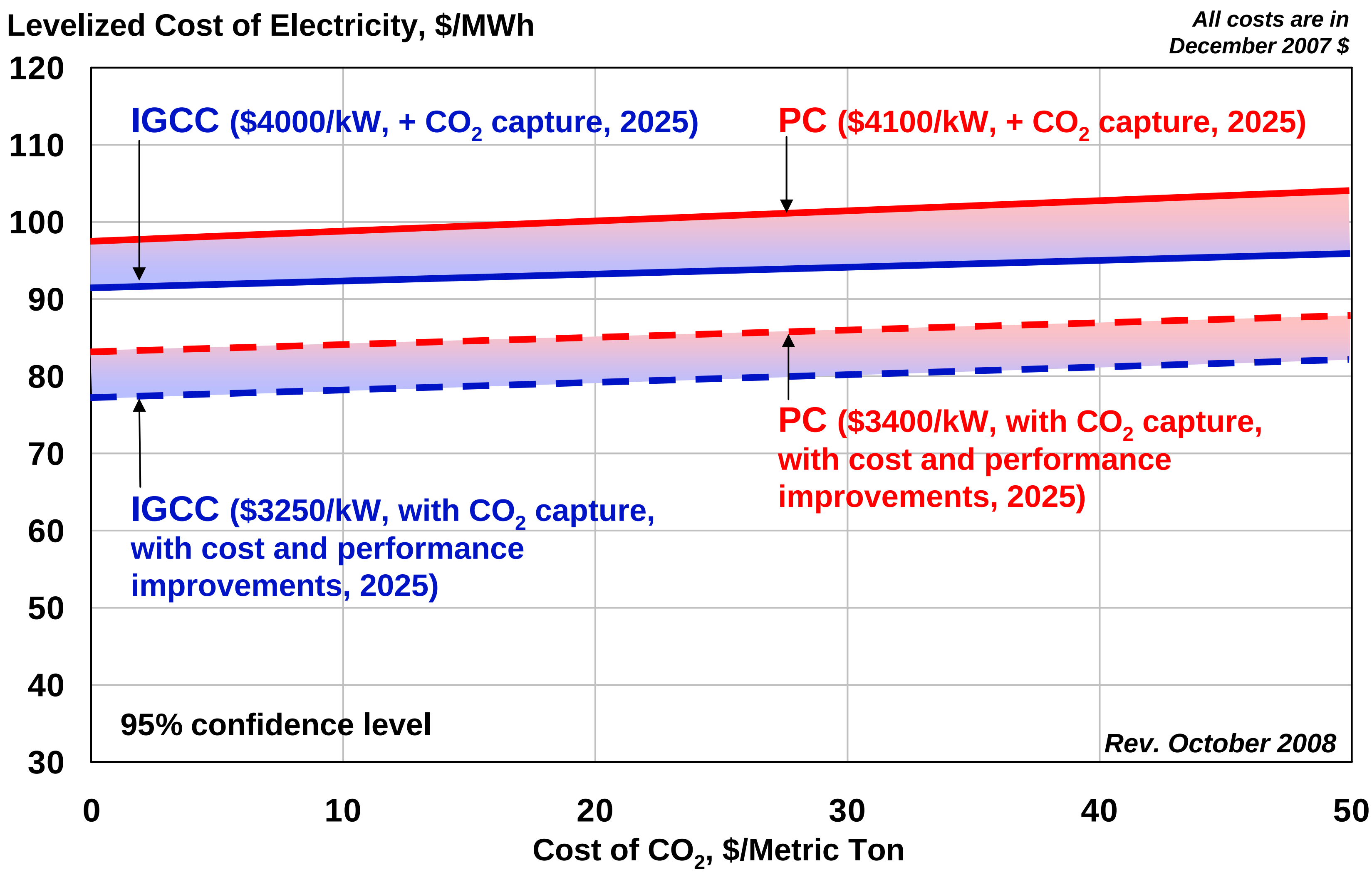
Cost of Electricity (Generic, Wholesale) Near-Term: 2015

Comparative Levelized Costs of Electricity – 2015



Longer-Term: 2025

Impact of CO_2 Removal and Cost and Performance Improvements on Levelized Cost of Electricity



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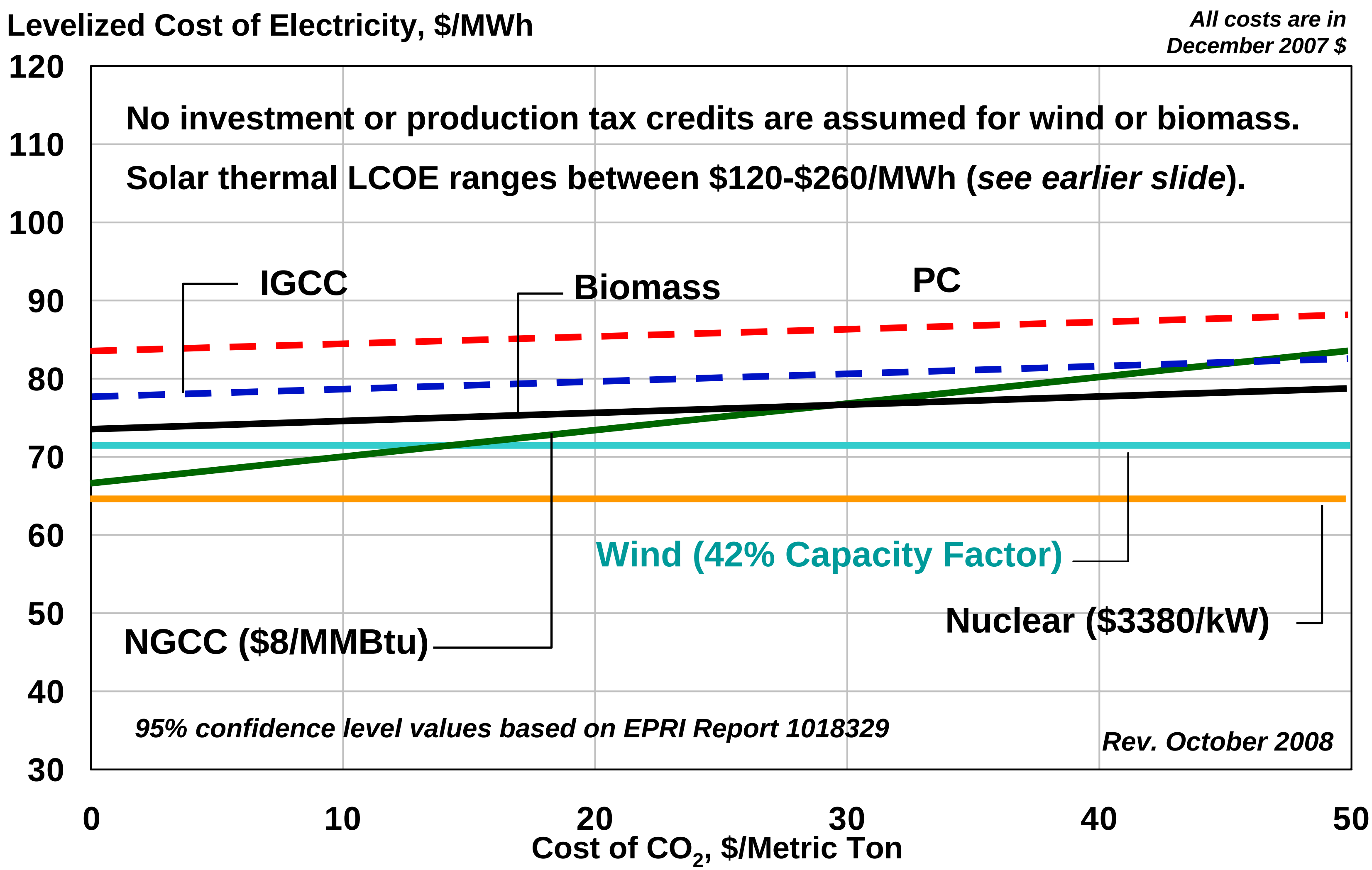
Comparative Levelized Costs of Electricity – 2025 (Low Carbon Options)



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What Incentives/ CO_2 prices Will it Take to Enable CCS?

Example Cost and Performance Parameters: Supercritical PC/PF with and without CCS (2010$)

	Conventional Supercritical PC	SPC with CCS
Capital Cost ($/kW) [a]	**2,115**	**3,540** [b]
Dispatched Capacity Factor	**92 %**	**65-88 %** [c]
Heat Rate (MMBtu/kWh)	**9000**	**12,650**
Variable O&M (non-fuel – $/MWh)	**8.50**	**24.66**
Fixed O&M ($/kW/Year)	**38**	**40**
CO_2 emissions (tons/MWh)	**0.860**	**0.124**

a. Does not include 10% owner's cost or interest during construction.
b. Assumes an amine-based capture system.
c. The base scenario assumes that the conventional PC plant is available 92% of the time. The PC+CCS plant is assumed to have 65% availability in year 1, 70% in year 2, 75% in year 3, 80% in year 4, 85% in year 5, and 88% in years 6-30. Both units are assumed to be dispatched whenever available.

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Key Financial Assumptions for Different Project Owners

	Investor-owned Utility (IOU)	Independent Power Producer (IPP)	Public
Fraction Debt	**55 %**	**70 %**	**100 %**
Cost of Debt	**6.5 %**	**8.0 %**	**4.5 %**
Cost of Equity	**11.5 %**	**13.0 %**	**N/A**
Tax Rate	**39.2 %**	**39.2 %**	**0 %**
Inflation Rate	**2% For All**		

Cost of Electricity (COE) Estimates for SPC with and without CCS ($/MWh)

$15/ton CO_2 Case	IOU	IPP	Public
Supercritical PC	$ 97	$ 98	$ 85
SPC w/ CCS	$130	$131	$104
COE Gap @ $15/ton CO2	$ 34	$ 32	$ 20

$30/ton CO_2 Case	IOU	IPP	Public
Supercritical PC	$121	$122	$111
SPC w/ CCS	$134	$134	$108
COE Gap @ $30/ton CO2	$ 13	$12	-$ 3

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Government Incentives Can Help Close The Gap In Some Cases

	Value of the Incentive, $ per MWh		
	IOU	IPP	Public
Loan Guarantee (w/ no fee)	$ 1	$ 3	$ 0
Direct Loan	$ 4	$ 8	$ 0
Cost Sharing (30% w/o repay)	$15	$15	$ 7
Investment Tax Credit (20%, without accelerated depreciation)	$ 6	$ 6	$ 0*
Production Tax Credit ($20 per MWh for 10 years)	$ 9	$ 9	$ 0*
Accelerated Depreciation (20 year to 5 year)	$ 6	$ 6	$ 0
Availability Insurance (shortfall from 88% x debt service)	$ 1	$1	$ 1
COE Gap at $15/ton CO2	$34	$32	$20
COE Gap at $30/ton CO2	$13	$12	-$3

*Comparable incentive can be made available.

Packages of Incentives Could Reduce or Eliminate the COE Gap

- Packages of incentives can address specific risks, e.g.,
  - Cost share can provide initial capital
  - Availability insurance can provide cash if the technology fails to operate
  - Production tax credit can reward CCS operation when CO2 price is not sufficient

	Value of Incentive Package, $/MWh		
	IOU	IPP	Public
20% ITC + Accelerated Depreciation	$12	$12	$ 0
30% Cost Share + $20 PTC	$15	$15	$ 7
40% Cost Share + $30 PTC	$33	$34	$10
30% Cost Share + $20 PTC + Enhanced Availability Insurance	$29	$30	$ 8
COE Gap at $15/ton CO2	$34	$32	$20
COE Gap at $30/ton CO2	$13	$12	-$ 3

Petroleum Industry Cost Gaps, $/ton CO_2 Avoided

- \$15 CO_2 Case: CO_2 Market = \$22.39 per ton (levelized)
- \$30 CO_2 Case: CO_2 Market = \$44.78 per ton (levelized)

	Natural Gas SMR	H_2 Plant Vent	Modern H_2 Plant	Heaters	NGCC (550MW)	Cogen (50MW)
Project Cost	\$45	\$45	\$104	\$179	\$123	\$291
Cost Gap at \$15/ton CO_2	\$22	\$22	\$82	\$157	\$100	\$269
Cost Gap at \$30/ton CO_2	\$ ~	\$ ~	\$60	\$135	\$ 78	\$246

~ = small positive value

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Estimated Value of Incentives ($/ton CO_2)

	Natural Gas	H_2 Plant Vent	Modern H_2 Plant	Heaters	NGCC (550MW)	Cogen (50MW)
Loan Guarantee	$ ~	$ ~	$ 1	$ 2	$ 1	$ 3
Direct Loan	$ 1	$ 1	$ 2	$ 5	$ 3	$ 9
30% Cost Share	$ 6	$ 6	$14	$28	$16	$52
20% ITC	$ 2	$ 2	$ 5	$10	$ 6	$19
$20 PTC	$12	$12	$12	$12	$12	$12
Accelerated Depreciation	$ 2	$ 2	$ 6	$12	$ 7	$22
Cost Gap at $15/ton CO_2	$22	$22	$82	$157	$100	$269
Cost Gap at $30/ton CO_2	$ ~	$ ~	$60	$135	$78	$246

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Summary

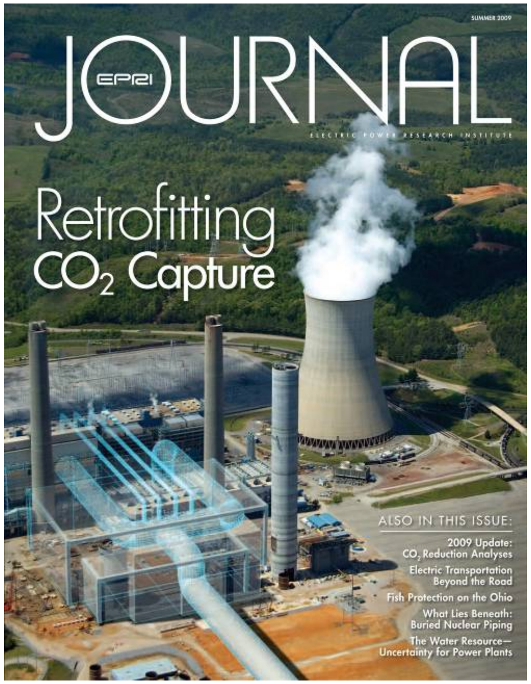
- Advanced coal technologies are critical for an affordable low-carbon future

- Global efforts indicate global commitment to achieving CCS

- EPRI research and industry demonstration projects will help make it happen by 2020

Additional Information

- *EPRI Journal* Summer 2009 1019554
- EPRI Prism/MERGE 2009 1019563
- EPRI Report on Integrated Generation Technology Options 1018329
- Advanced Coal Power Systems with CO2 Capture: EPRI's CoalFleet For Tomorrow Vision 1016877
- Incentives Presentation by EPRI's Tom Wilson available now, discussion paper later
- All public reports above available at www.epri.com – search for number and download
- Stuart Dalton – 1.650.855.2467/ sdalton@epri.com



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