



engineering and public policy

Preparing Technical Leaders to Address Policy Issues
that Involve Science and Technology.



Decision support for implementing the EPA Clean Power Plan Proposed Rule

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EPA Regulatory Authority and Plan Background

Clean Air Act (1970)

- Section 111(b)—New Standards of Performance

- **Proposed limits**

- 1,100 lbs/MWh (new coal-fired)
- 1,000 lbs/MWh (new gas-fired)

*Source: Shear, Michael D. "Administration Presses Ahead With Limits on Emissions From Power Plants." *The New York Times*, 20 Sep., 2013. Web. 1 Oct. 2013.

**Source: <http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html>.

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- Section 111(d)—Existing Standards of Performance

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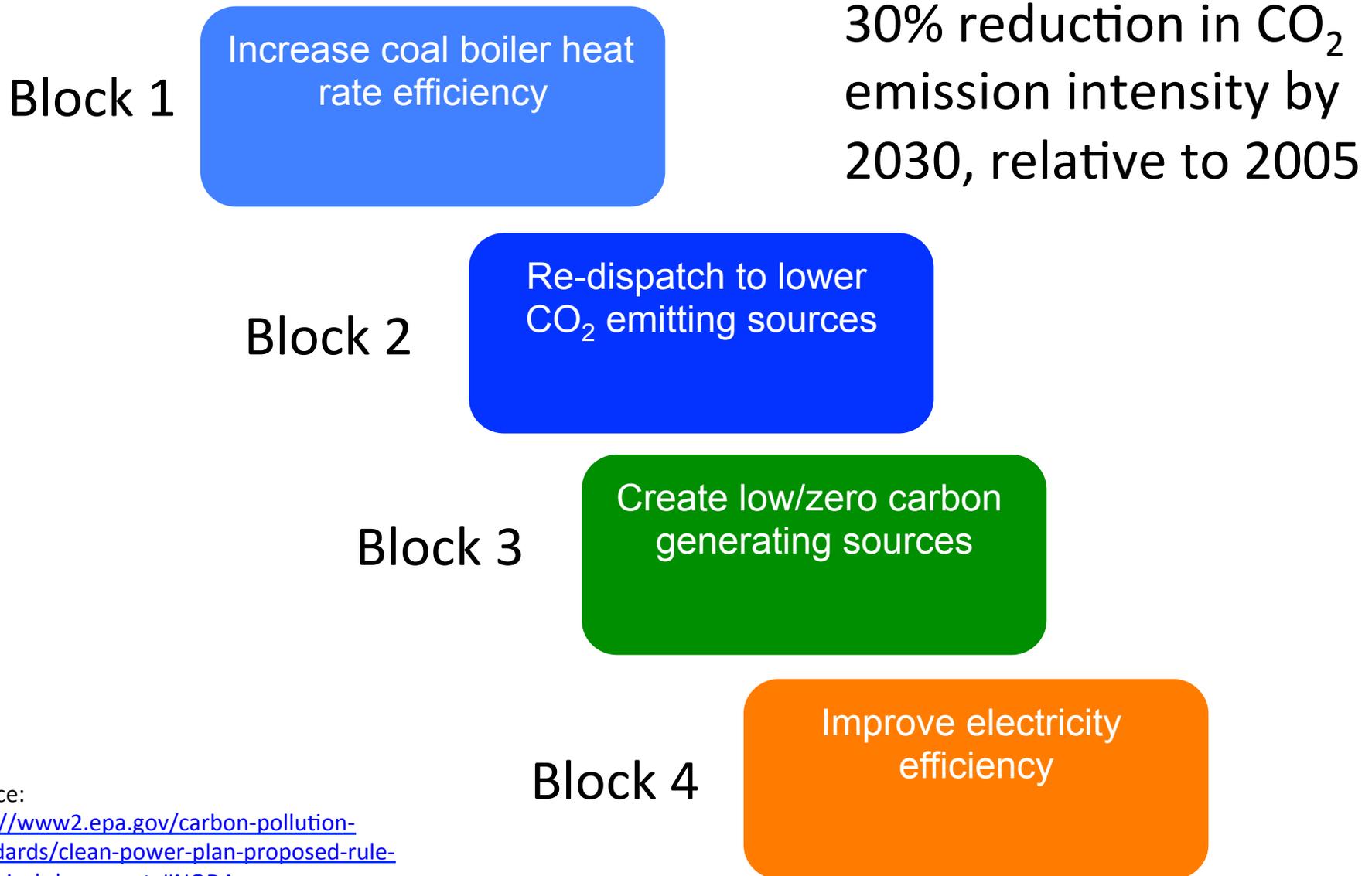
Current Coal Plant Emissions

- 1,800 lbs/MWh (advanced coal-fired)*
- 2,249 lbs/MWh (existing coal fleet)**

*Source: Shear, Michael D. "Administration Presses Ahead With Limits on Emissions From Power Plants." *The New York Times*, 20 Sep., 2013. Web. 1 Oct. 2013.

**Source: <http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html>.

Clean Power Plan Building Blocks



Source:
<http://www2.epa.gov/carbon-pollution-standards/clean-power-plan-proposed-rule-technical-documents#NODA>

EPA State 2030 CO₂ emission “goal”

Pounds of CO₂ emissions from fossil fuel

MWh from (fossil fuel + New & 6% “At Risk” Nuclear + non-Hydro Renewable + Electricity Efficiency Saving)

Clean Power Plan Limitations

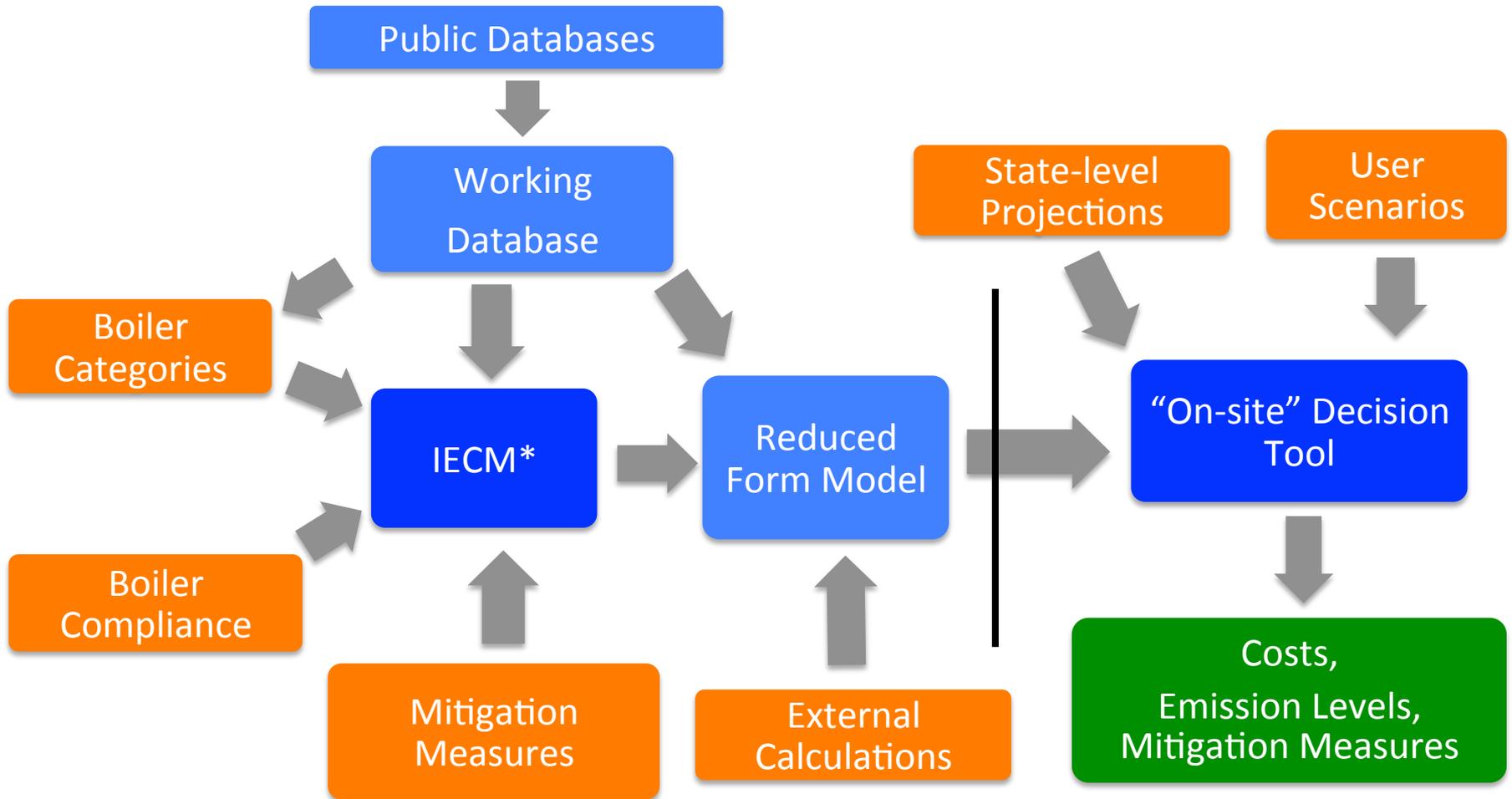
Building blocks are flexible but...

- Emission “goal” needs translation
- Heat rate improvement based upon national averages
- Other mitigation options mentioned and dismissed
- Targets and prices based upon data aggregated at national or regional level
- No guidance given for when targets are not met

Decision support elements

- 1) Evaluate the potential for a range of “on-site” mitigation technologies to reduce CO₂ emissions from existing U.S. coal-fired power plants and estimate the associated costs
- 2) Identify cost-effective mitigation technology frontiers for different levels of CO₂ emission reductions
- 3) Identify viable mitigation option(s) for alternative regulation scenarios

Decision Tool Task Structure



*Integrated Environmental Control Model

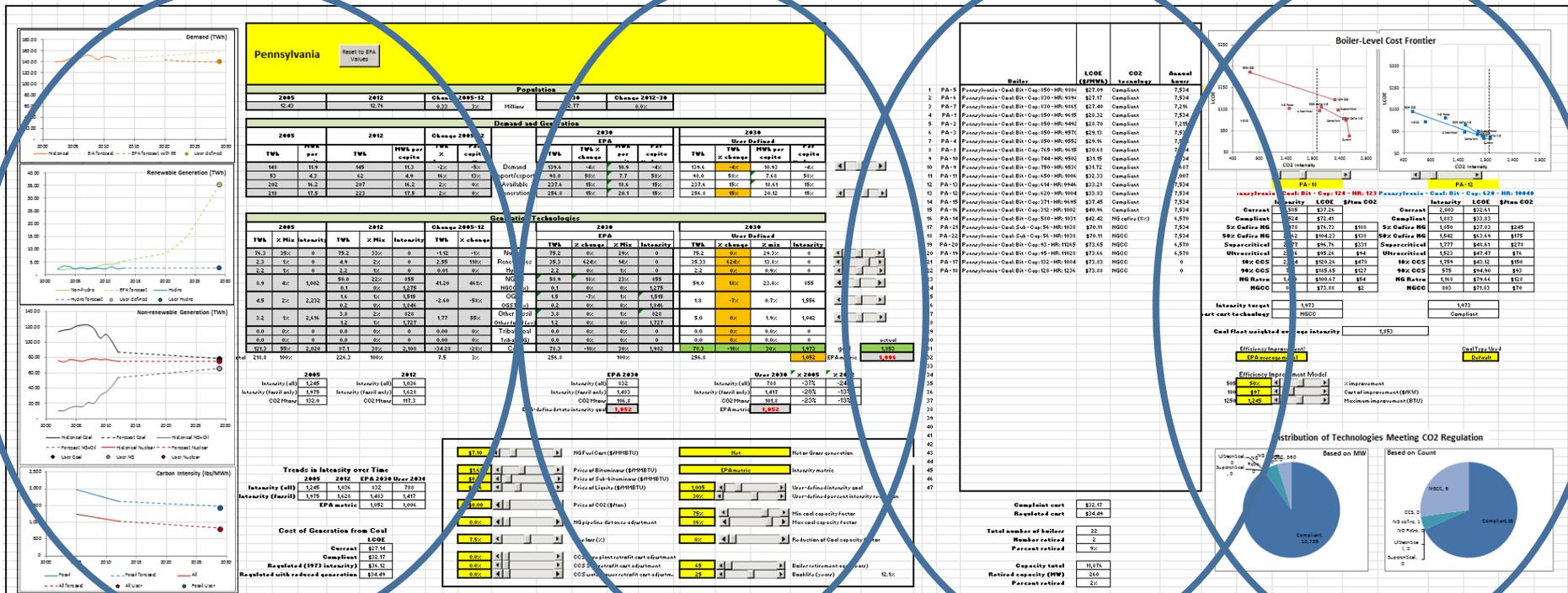
Engineering Assessment Mitigation Measures

- Coal rank change
- Boiler upgrade
 - Supercritical boiler
 - Ultra-supercritical boiler
- Cofire with natural gas (5% to 50%)
 - Pipeline
 - Boiler modification
- Conversion to 100% gas-fired boiler
 - Pipeline
 - Retrofit
- Replace with Natural Gas Combined Cycle (NGCC)
- Carbon Capture System (CCS) from 10% to 90%
 - Power source
 - Pipeline
 - Retrofit

Overview of Interactive Tool

- Tool is built using “vanilla” Excel
- Completely interactive: output reflects changes immediately
- Boiler-level analysis for each state
 - Detailed engineering model of emission compliance and CO₂ mitigation
- Users have many opportunities to explore future scenarios of their design
- Provides historical context in which to understand future scenarios
- User-specified, state-level policies can be compared and evaluated

User Interface—ISOMAP*



Historical Context

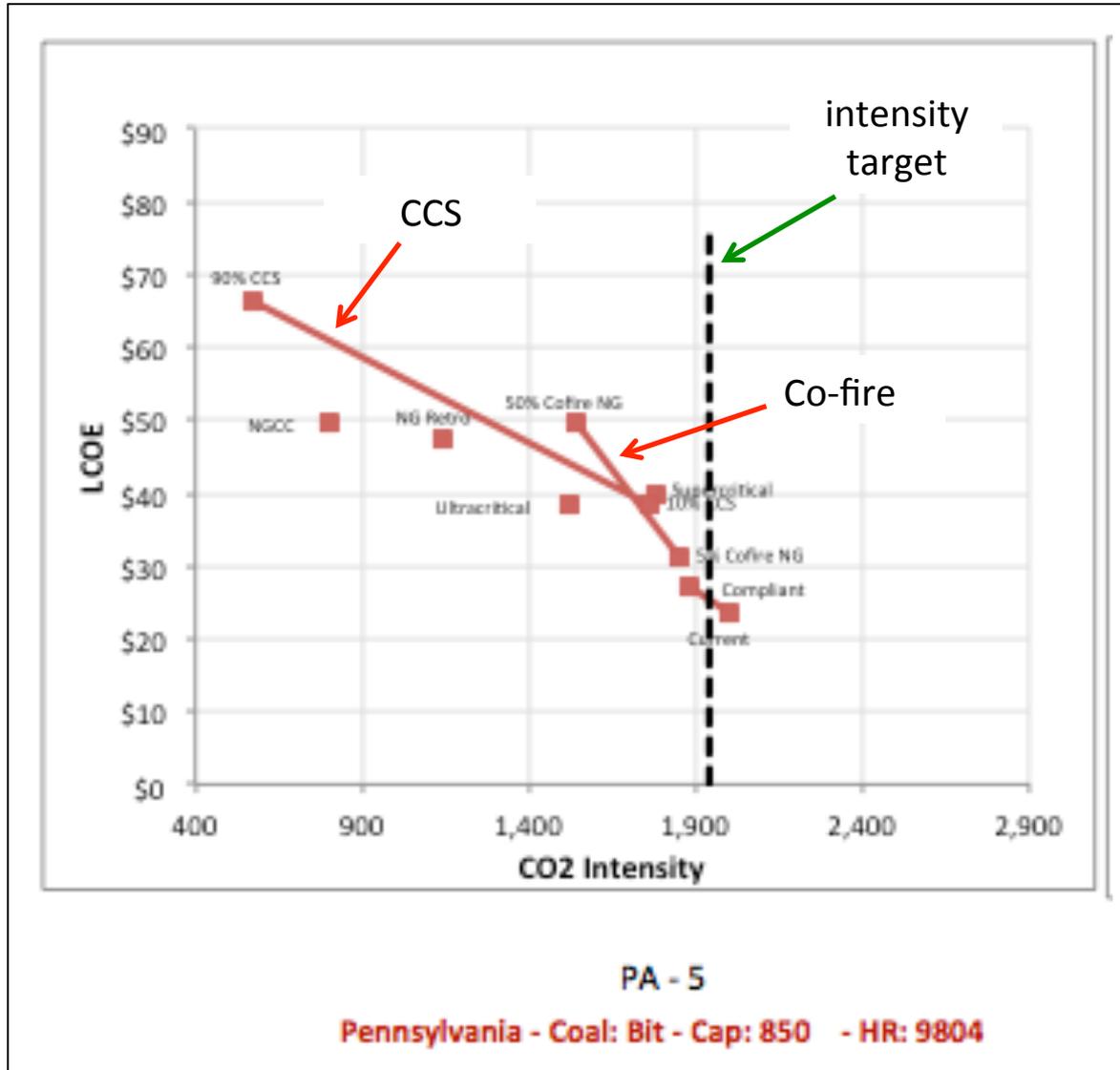
2030 Forecast

State-level details

Boiler-specific details

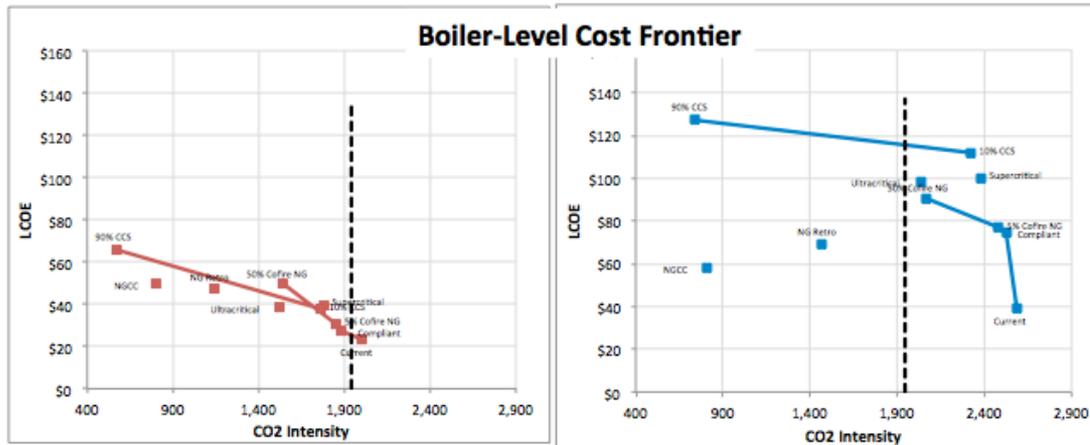
*Interactive State “On-site” Mitigation and Analytical Policy tool
 Source: <http://www.cmu.edu/energy/CleanPowerPlanTool/>

Boiler-level Details



CO₂ mitigation-LCOE frontier

Boiler-level Details



CO₂ mitigation-
LCOE frontier
for any two
boilers in
the state

PA - 5

Pennsylvania - Coal: Bit - Cap: 850 - HR: 9804

	Intensity	LCOE	\$/ton CO2
Current	2,001	\$23.40	
Compliant	1,882	\$27.23	
5% Cofire NG	1,851	\$31.05	\$245
50% Cofire NG	1,544	\$49.93	\$134
Supercritical	1,776	\$39.56	\$232
Ultracritical	1,522	\$38.36	\$62
10% CCS	1,759	\$38.11	\$177
90% CCS	576	\$66.03	\$59
NG Retro	1,141	\$47.47	\$55
NGCC	803	\$49.53	\$41

Intensity target	1,944
Least cost technology	Compliant

Coal fleet weighted average intensity 1,856

PA - 18

Pennsylvania - Coal: Bit - Cap: 128 - HR: 12364

	Intensity	LCOE	\$/ton CO2
Current	2,585	\$39.26	
Compliant	2,524	\$74.55	
5% Cofire NG	2,478	\$77.11	\$111
50% Cofire NG	2,062	\$90.73	\$70
Supercritical	2,377	\$100.03	\$346
Ultracritical	2,036	\$98.53	\$98
10% CCS	2,324	\$111.94	\$373
90% CCS	736	\$127.25	\$59
NG Retro	1,470	\$69.42	-\$10
NGCC	803	\$58.05	-\$19

Intensity target	1,944
Least cost technology	NGCC

Details of
mitigation
alternatives

Model Evaluation of Policy Questions

- What happens to coal generation if ...
 - EPA forecasts are not accurate?
 - Heat rate improvement (6% at \$100/kW) cannot be achieved (Block 1)
 - Re-dispatch because of NGCC increased capacity factor (Block 2)
 - Increase in renewables (Block 3)
 - Decrease in demand because of efficiency improvements (Block 4)
 - Nuclear generation (economic retirement, not renewed, major maintenance)
 - The price of fuel higher or lower?
- Which CO₂ mitigation strategies are needed to meet EPA goal under different scenarios and at what cost?

Model Evaluation of Policy Questions

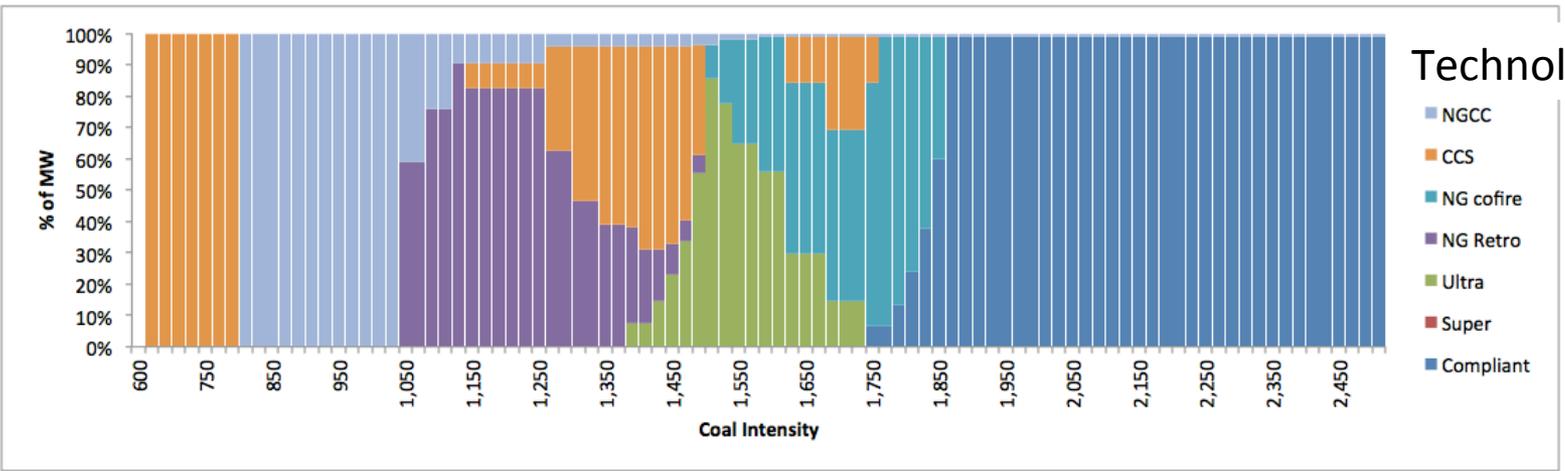
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Let's look at Pennsylvania

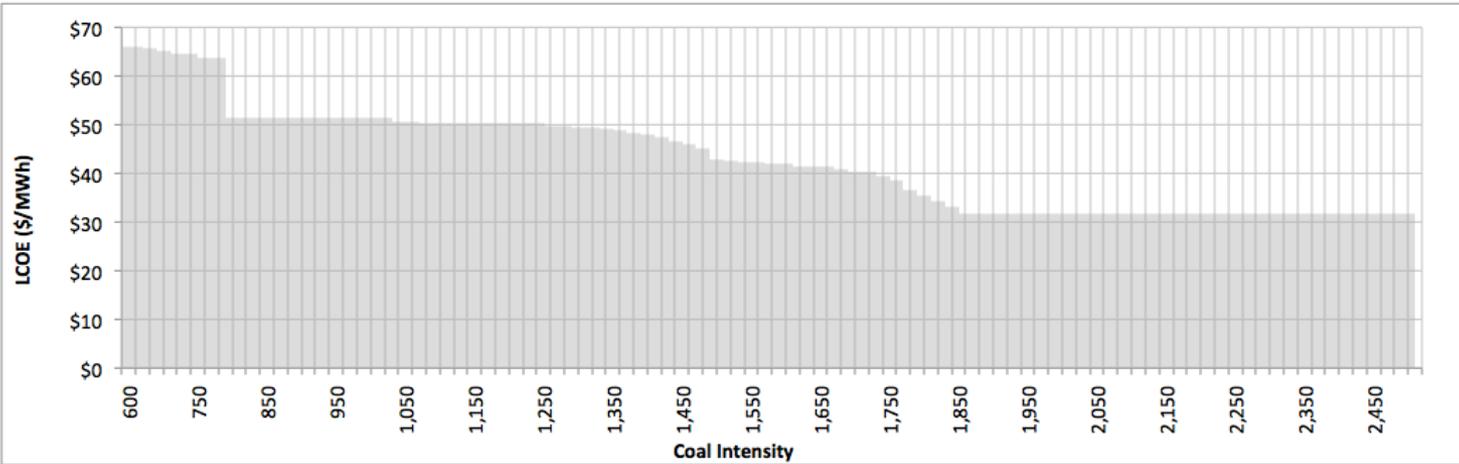
What would Pennsylvania do to meet Different Carbon Limits?

Base: \$4.50/MMBTU

% Capacity
(% MW)



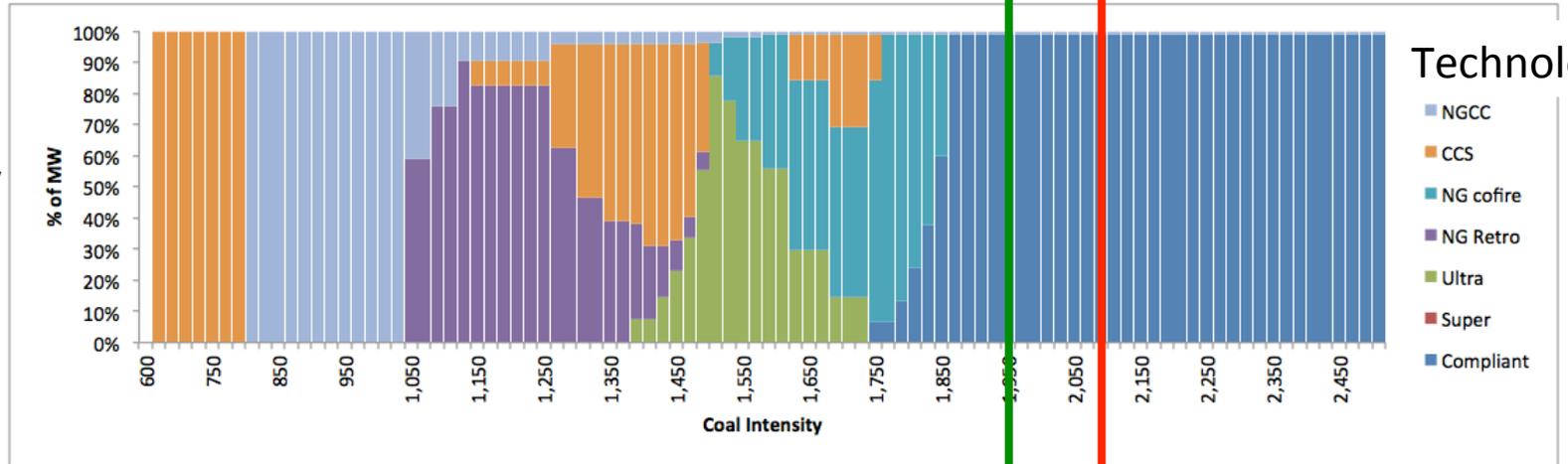
Cost
(\$/MWh)



<= Less carbon from coal

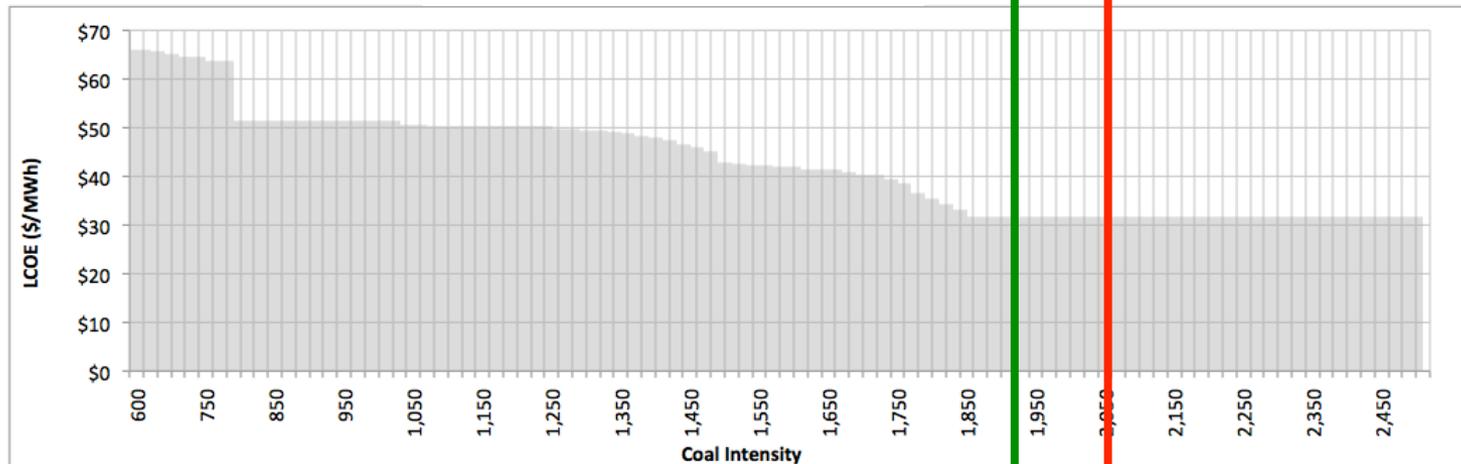
What would Pennsylvania do to meet Different Carbon Limits?

Base: \$4.50/MMBTU



% Capacity (% MW)

2030 intensity (lbs/MWh) →



Cost (\$/MWh)

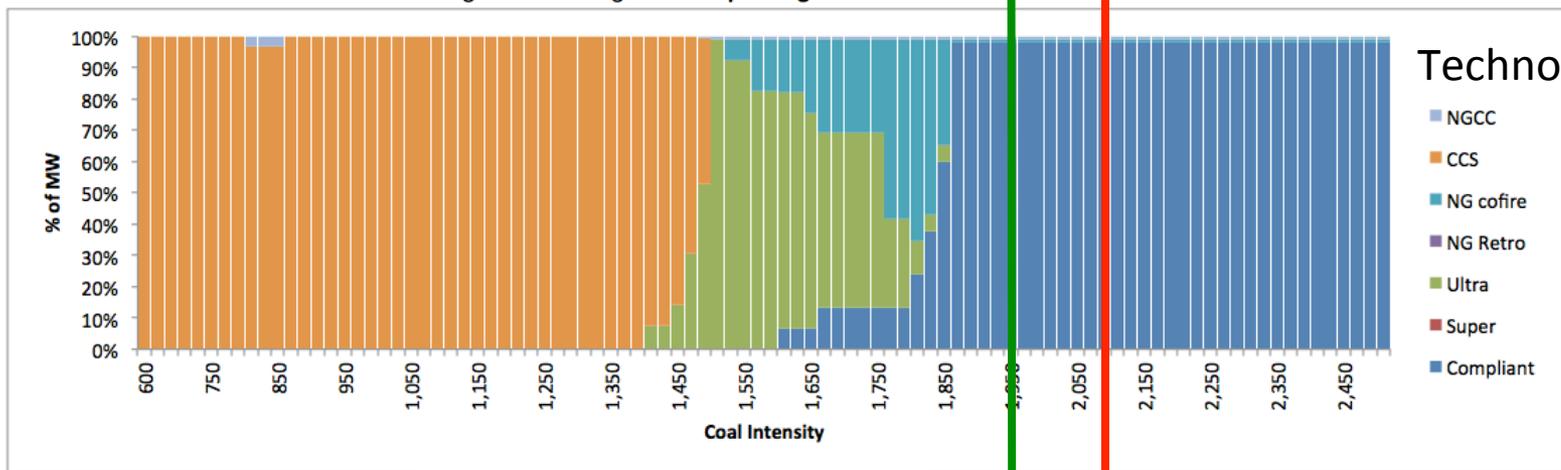
≤ Less carbon from coal

← 2012 intensity (lbs/MWh)

What Would Pennsylvania Do to Meet Different Carbon Limits, with more expensive NG?

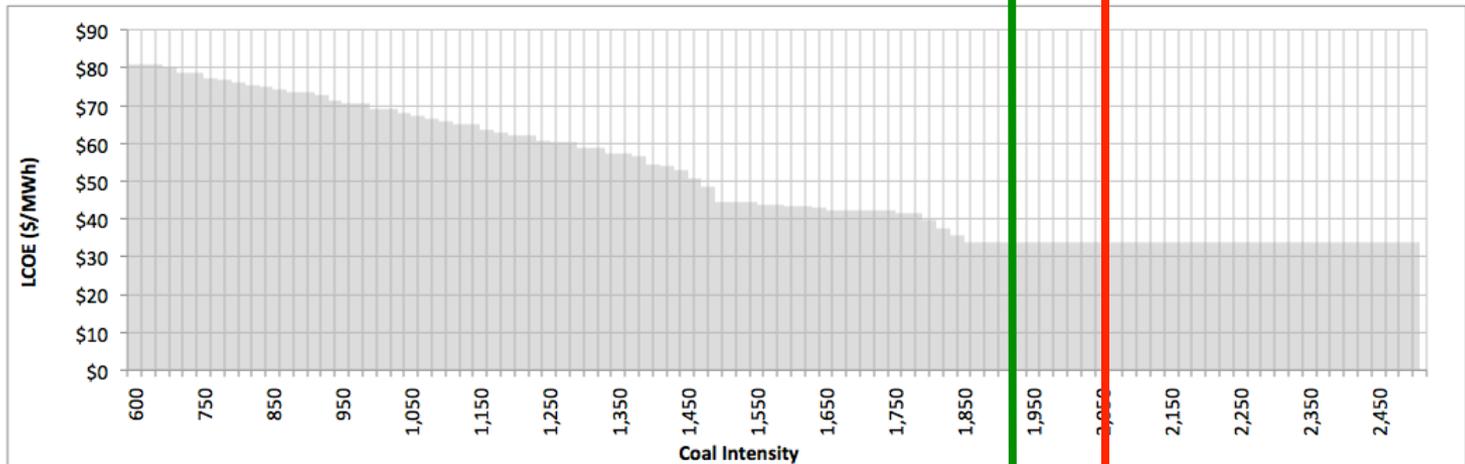
Base: \$4.50/MMBTU

New: \$9.00/MMBTU



% Capacity (% MW)

2030 intensity (lbs/MWh) →



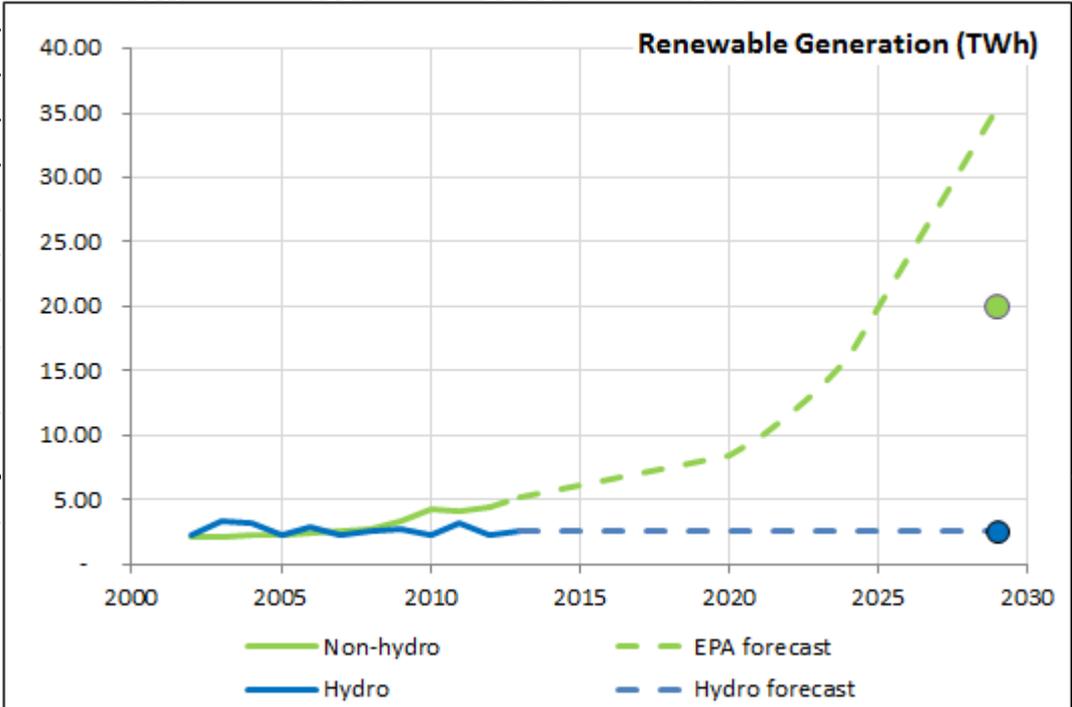
Cost (\$/MWh)

≤ Less carbon from coal

← 2012 intensity (lbs/MWh)

What if ... Renewable generation is not as expected?

Pennsylvania					CO2	
	TWh	% change	% Mix	Intensity	lbs (million)	TWh
Nuclear	75.2	0%	29%	0	-	4.5
Renewables	35.3	624%	14%	0	-	35.3
Hydro	2.2	0%	1%	0	-	
NGCC	58.9	18%				
OGST	1.5	-7%				
Other fossil	3.8	0%				
Coal	78.8	-9%				
	TWh					
	EIA BAU	Demand				
Demand	158.0	139.6				



Required coal emission
intensity: 1,618 lbs/MWh

Base case 35 TWh

CO₂ mitigation options under two different renewable penetrations

LCOE (\$/MWh)	CO2 technology	Annual hours
\$27.23	Compliant	8,147
\$27.44	Compliant	8,147
\$28.19	Compliant	7,216
\$28.33	Compliant	8,147
\$28.93	Compliant	8,147
\$29.00	Compliant	8,147
\$29.39	Compliant	7,215
\$30.86	Compliant	8,147
\$31.28	Compliant	8,147
\$32.54	Compliant	6,687
\$33.74	Compliant	7,640
\$34.19	Compliant	7,725
\$35.60	NG cofire (5%)	7,007
\$36.35	Compliant	8,147
\$38.97	Compliant	8,147
\$46.66	NG cofire (15%)	4,544
\$50.65	NGCC	8,147
\$50.96	NGCC	8,021
\$58.05	NGCC	0
\$71.91	NGCC	0
\$73.06	NG Retro	0
\$74.63	NGCC	0

Base case 35 TWh

Less Renewables 20 TWh

CO₂ mitigation options under two different renewable penetrations

LCOE (\$/MWh)	CO2 technology	Annual hours	LCOE (\$/MWh)	CO2 technology	Annual hours
\$27.23	Compliant	8,147	\$38.36	Ultracritical	8,147
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\$28.33	Compliant	8,147	\$39.41	Ultracritical	7,796
\$28.93	Compliant	8,147	\$39.64	Ultracritical	8,147
\$29.00	Compliant	8,147	\$39.75	Ultracritical	8,147
\$29.39	Compliant	7,215	\$40.03	Ultracritical	7,796
\$30.86	Compliant	8,147	\$40.28	NG cofire (20%)	8,147
\$31.28	Compliant	8,147	\$42.40	NG cofire (25%)	7,796
\$32.54	Compliant	6,687	\$43.12	Ultracritical	8,147
\$33.74	Compliant	7,640	\$45.65	Ultracritical	7,796
\$34.19	Compliant	7,725	\$46.16	NG cofire (31%)	8,147
\$35.60	NG cofire (5%)	7,007	\$46.83	Ultracritical	7,796
\$36.35	Compliant	8,147	\$47.61	Ultracritical	7,796
\$38.97	Compliant	8,147	\$50.65	NGCC	8,147
\$46.66	NG cofire (15%)	4,544	\$50.96	NGCC	8,021
\$50.65	NGCC	8,147	\$51.62	NG cofire (44%)	8,147
\$50.96	NGCC	8,021	\$51.84	NGCC	7,796
\$58.05	NGCC	0	\$51.85	NGCC	7,796
\$71.91	NGCC	0	\$52.00	NGCC	7,796
\$73.06	NG Retro	0	\$52.08	NGCC	7,796
\$74.63	NGCC	0	\$52.40	NGCC	7,796

Base case 35 TWh

Less Renewables 20 TWh

CO₂ mitigation options under two different renewable penetrations

LCOE
Base

Complaint cost	\$32.14
Regulated cost	\$31.95

Less

Complaint cost	\$31.93
Regulated cost	\$43.60

weighted averages

LCOE (\$/MWh)	CO2 technology	Annual hours
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Clean Power Plan Insights from ISOMAP

- EPA intensity definition not standard. Comparisons between states and over time impossible
- Applying fleet-wide averages maybe too simplistic
- Decreased capacity factor for all coal boilers from re-dispatch may not be the most economic solution for lowering CO₂ intensities
- Inefficient coal plants can be retired resulting in ...
 - Lower emitting plants running more, higher emitting plants retiring
 - Mitigation options likely not required
- Plan is flexible—opportunity for coal CO₂ mitigation technologies when renewables or energy efficiency goals not reached, or resource mix is changed

Modelling Insights—ISOMAP Integration

- ISOMAP is bottom-up
- ISOMAP inputs can use national/region modelling
 - Integrated Planning Model (IPM)
 - National Energy Modeling system (NEMS)
 - Haiku (Resources for the Future)
- State, regional or national scenarios
 - Aggregated state response
 - Non aggregated electricity generating unit response—different solutions
- Sensitivity Analysis
 - NG price, carbon price, capacity factors
 - Regional and national scenarios can take many hours to run
 - ISOMAP real time

Modelling the “Clean” future— Uncertainty

Given a carbon-constrained power generation system, what would happen?

- Uncertainty of upcoming Clean Power Plan changes
- Ambiguity in interpreting current/upcoming Clean Power Plan
- Forecasts are already difficult to make
- How would assumptions/forecasts change given a regulation?
 - Forecasting uncertainties
 - Impact on other models/research (very different generation mix)
- How would plants dispatch?
 - States may group resources
 - Trading CO₂
- Is there a significant role for affordable carbon-mitigated coal?
 - Competitiveness of NGCC in a high-price NG world
 - Competitiveness of coal in a low-price NG world
- Can states meet their renewable goals?

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Micro view of ISOMAP and macro view of regional models

Thank you.

Principal Investigators:

- Dr. Paul Fischbeck
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Plan for the day

08:30 – 09:15	Overview of >25 years of HDGC, CDMC and CEDM – Granger Morgan
09:15 – 10:00	Uncertainty in energy efficiency, Part 1: technologies, strategies, behavior and policy – Inês Azevedo
10:00 – 10:30	Uncertainty in energy efficiency, Part 2: technologies, strategies, behavior and policy – Alex Davis
10:45 – 11:15	Coffee break
11:15 – 11:45	Decision support for implementing the EPA Clean Power Plan Proposed Rule – Jeff Anderson
11:45 – 12:30	Marginal emissions factors, health and climate change co-benefits and trade-offs - Inês Azevedo
12:30 – 13:30	Lunch break
13:30 – 13:55	Insights from twenty years of work on expert elicitation and projections – Granger Morgan
13:55 – 14:05	Transitioning to a low carbon economy, Part 1: Insights from the RenewElec Project – Granger Morgan
14:05 – 14:30	Transitioning to a low carbon economy, Part 2: Insights from ITC and BC’s Climate Policy – Hadi Dowlatabadi
14:30 – 15:10	Strategies for supporting investment decisions about large energy infrastructure in the face of regulatory and other uncertainty – Dalia Patiño
15:10 – 15:40	Coffee break
15:40 – 16:00	Reflections on Research and Governance wrt Albedo Modification – Granger Morgan
16:00 – 16:45	Insights From Our Experience in Building and Using ICAMs – Hadi Dowlatabadi
17:45 – 17:00	Muddling through on climate policy: good, but not good enough to avoid the risk of dead ends – Granger Morgan
17:00 – 17:30	Discussion and round table on what investigators in CEDM might best work on in the next several years to be most useful to the IA and energy modeling communities.



Our presentations & a few papers can be found at:

<https://www.dropbox.com/sh/9skgog59wdd3m4x/AAQzsPhamXaRmGOIOhyz7Dpa?dl=0>