Decision Making Under Uncertainty

Center for Climate and Energy Decision Making

Decision support for CAA Section 111d

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111(d) Building Blocks

Block 1

Increase coal boiler heat rate efficiency

Block 2

Re-dispatch to lower CO_2 emitting sources

Block 3

Create low/zero carbon generating sources

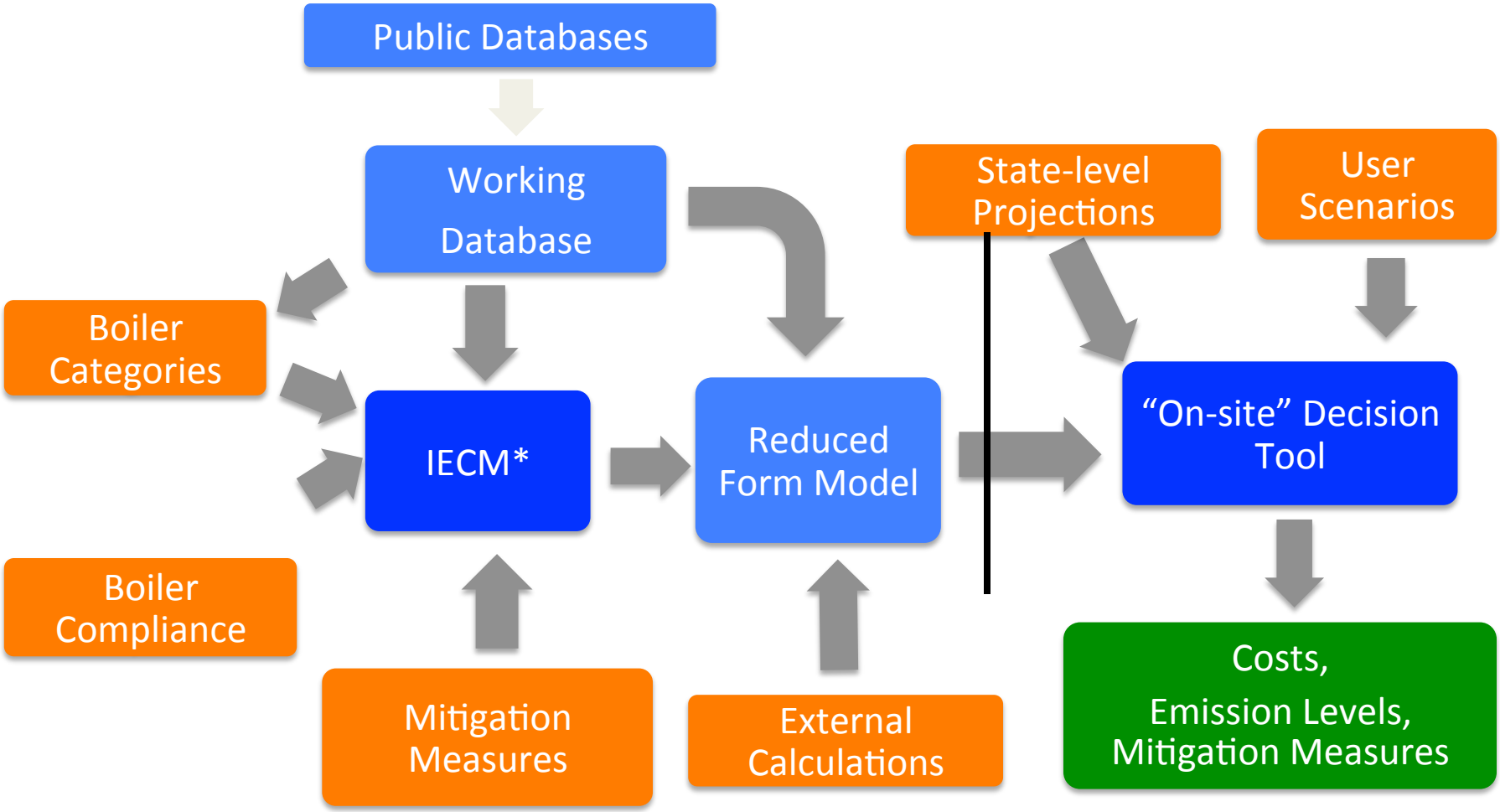
Block 4

Improve electricity efficiency

EPA State 2030 CO_2 emission "goal"

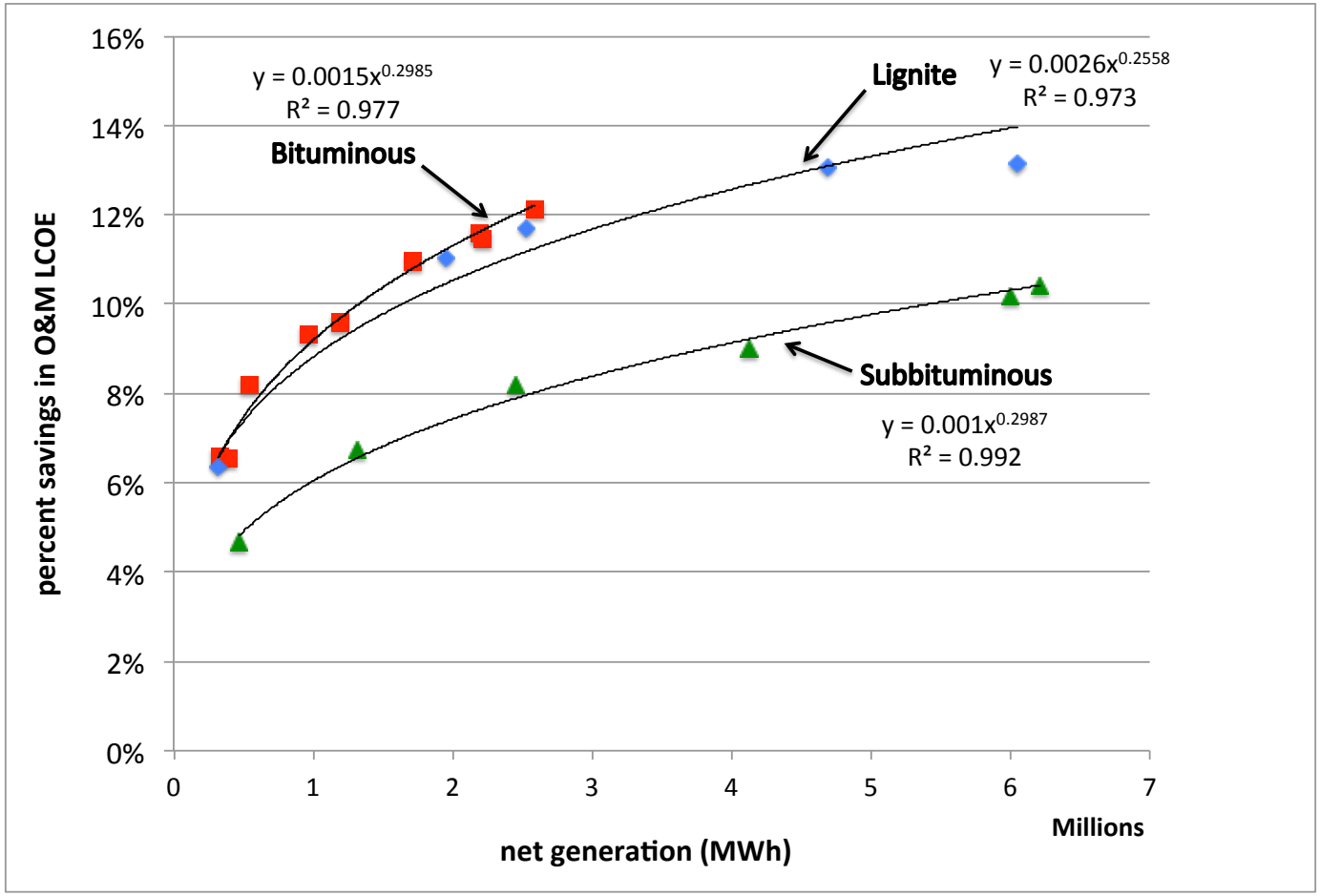
$$\frac{\text{Pounds of } CO_2 \text{ emissions from fossil fuel}}{\text{MWh from (fossil fuel + New \& 6\% "At Risk" Nuclear + non-Hydro Renewable + Electricity Efficiency Saving)}}$$

Decision tool task structure



Boiler upgrade calculation

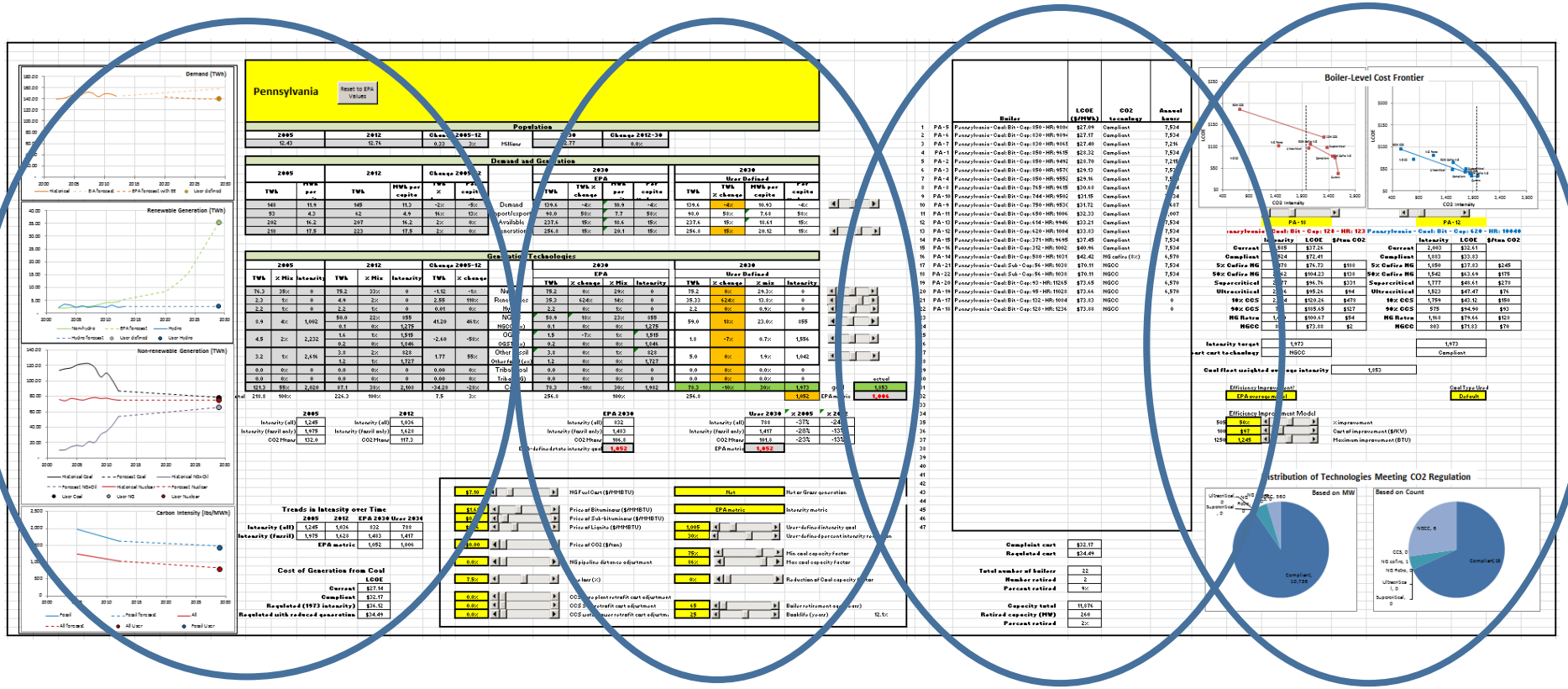
Subcritical to Ultra-supercritical (LCOE % change)



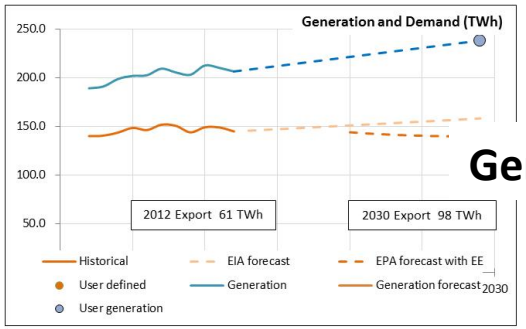
Overview of interactive tool

- Tool is built using "vanilla" Excel
  - Completely interactive: output reflects changes immediately
  - All data is visible and modifiable
- Boiler-level analysis for each state
  - Detailed engineering model of emission compliance and CO_2 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

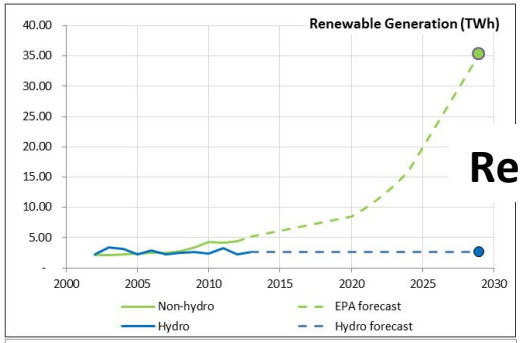
User interface



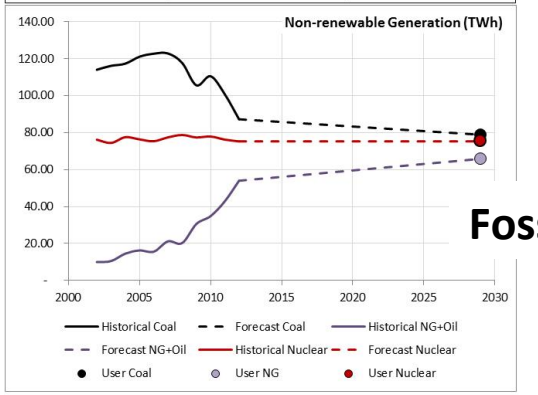
Historical data & trends



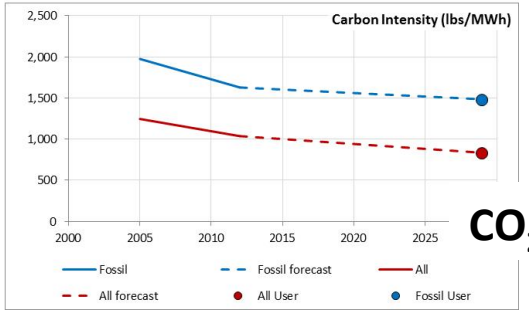
Generation & Demand



Renewables



Fossil & Nuclear



CO_2 Intensity

State specific

Pennsylvania Reset to EPA Values

2005	2012	Change 2005-12		
12.43	12.76	0.33	3%	Millions

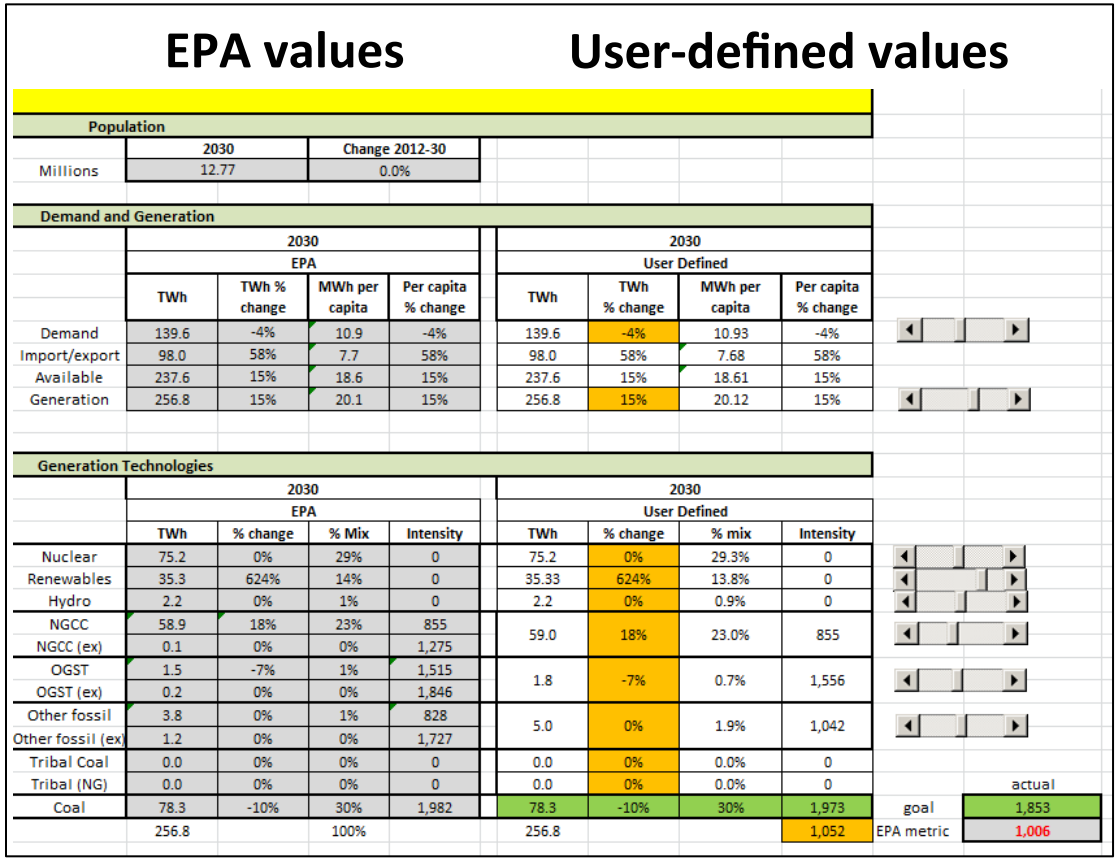
2005		2012		Change 2005-12		
TWh	MWh per capita	TWh	MWh per capita	TWh % change	Per capita % change	
148	11.9	145	11.3	-2%	-5%	Demand
53	4.3	62	4.9	16%	13%	Import/export
202	16.2	207	16.2	2%	0%	Available
				2%	0%	Generation

2005-2012 comparison

2005			2012			Change 2005-12		
TWh	% Mix	Intensity	TWh	% Mix	Intensity	TWh	% change	
76.3	35%	0	75.2	33%	0	-1.12	-1%	Nuclear
2.3	1%	0	4.9	2%	0	2.55	110%	Renewables
2.2	1%	0	2.2	1%	0	0.01	0%	Hydro
8.9	4%	1,002	50.0	22%	855	41.20	461%	NGCC
			0.1	0%	1,275			NGCC (ex)
4.5	2%	2,232	1.6	1%	1,515	-2.60	-58%	OGST
			0.2	0%	1,846			OGST (ex)
3.2	1%	2,616	3.8	2%	828	1.77	55%	Other fossil
			1.2	1%	1,727			Other fossil (ex)
0.0	0%	0	0.0	0%	0	0.00	0%	Tribal Coal
0.0	0%	0	0.0	0%	0	0.00	0%	Tribal (NG)
121.3	55%	2,020	87.1	38%	2,108	-34.28	-28%	Coal
218.8	100%		226.3	100%		7.5	3%	

	2005		2012
Intensity (all)	1,245	Intensity (all)	1,036
Intensity (fossil only)	1,975	Intensity (fossil only)	1,628
CO2 Mtons	132.0	CO2 Mtons	117.3

2030 Forecast



EPA values **User-defined values**

Population

	2030	Change 2012-30
Millions	12.77	0.0%

Demand and Generation

	2030 EPA				2030 User Defined			
	TWh	TWh % change	MWh per capita	Per capita % change	TWh	TWh % change	MWh per capita	Per capita % change
Demand	139.6	-4%	10.9	-4%	139.6	-4%	10.93	-4%
Import/export	98.0	58%	7.7	58%	98.0	58%	7.68	58%
Available	237.6	15%	18.6	15%	237.6	15%	18.61	15%
Generation	256.8	15%	20.1	15%	256.8	15%	20.12	15%

Generation Technologies

	2030 EPA				2030 User Defined			
	TWh	% change	% Mix	Intensity	TWh	% change	% mix	Intensity
Nuclear	75.2	0%	29%	0	75.2	0%	29.3%	0
Renewables	35.3	624%	14%	0	35.33	624%	13.8%	0
Hydro	2.2	0%	1%	0	2.2	0%	0.9%	0
NGCC	58.9	18%	23%	855	59.0	18%	23.0%	855
NGCC (ex)	0.1	0%	0%	1,275				
OGST	1.5	-7%	1%	1,515	1.8	-7%	0.7%	1,556
OGST (ex)	0.2	0%	0%	1,846				
Other fossil	3.8	0%	1%	828	5.0	0%	1.9%	1,042
Other fossil (ex)	1.2	0%	0%	1,727				
Tribal Coal	0.0	0%	0%	0	0.0	0%	0.0%	0
Tribal (NG)	0.0	0%	0%	0	0.0	0%	0.0%	0
Coal	78.3	-10%	30%	1,982	78.3	-10%	30%	1,973
	256.8		100%		256.8			1,052

actual

goal 1,853

EPA metric 1,006

Population

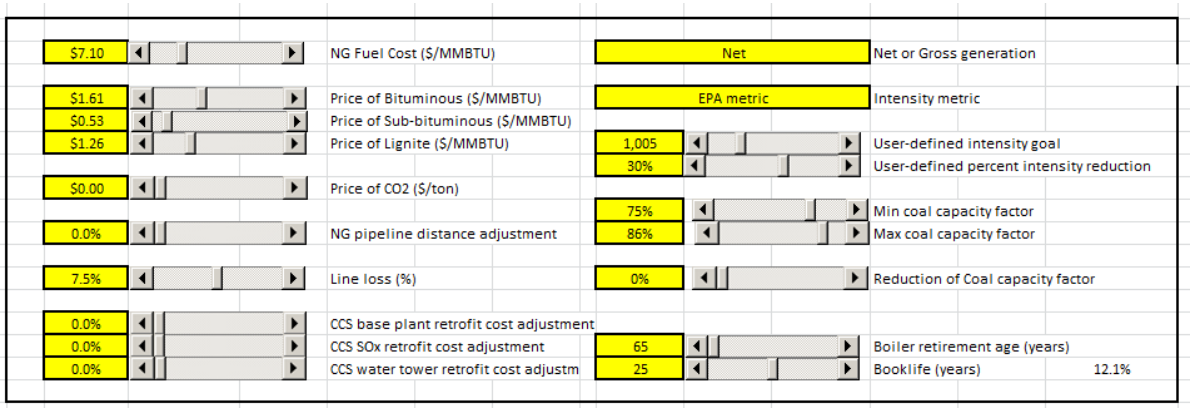
Generation and demand

Generation mix

Available options

User-controlled parameters

Prices



Intensity goal selection

Capacity factors

Model details (e.g., CCS, retirement age, line loss)

Engineering assessment mitigation measures

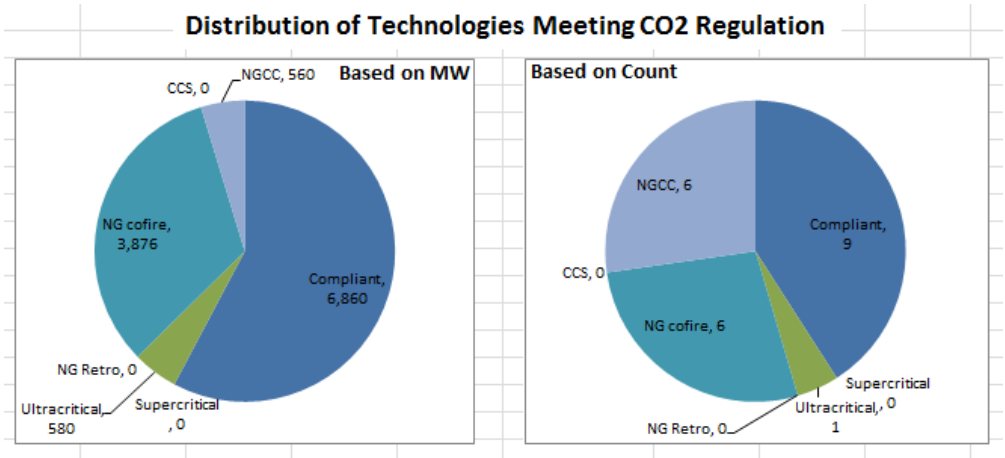
- Coal rank change
- Boiler upgrade
  - Supercritical boiler
  - Ultra-supercritical boiler
- Cofire with natural gas (5% to 50%)
  - Pipeline
  - Boiler modification
- Conversion to 100% gas-fired boiler
  - Pipeline
  - Retrofit
- Replace with NGCC
- Carbon Capture System (CCS) from 10% to 90%
  -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

State-level summary

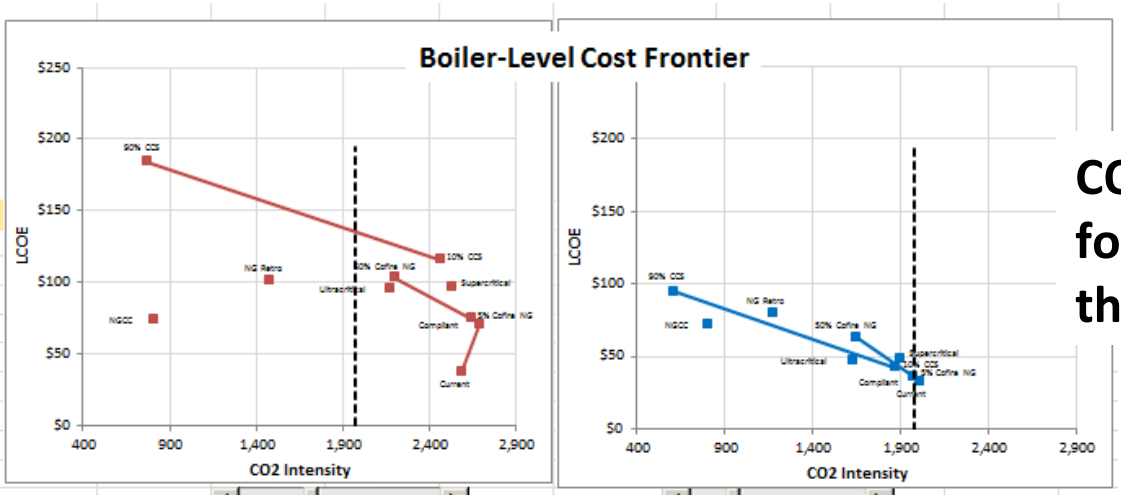
		Boiler	LCOE ($/MWh)	CO2 tecnology	Annual hours
1	PA - 7	Pennsylvania - Coal: Bit - Cap: 830 - HR: 9865	$26.45	Compliant	7,216
2	PA - 1	Pennsylvania - Coal: Bit - Cap: 850 - HR: 9615	$27.44	Compliant	7,534
3	PA - 2	Pennsylvania - Coal: Bit - Cap: 850 - HR: 9492	$27.73	Compliant	7,215
4	PA - 3	Pennsylvania - Coal: Bit - Cap: 850 - HR: 9570	$28.26	Compliant	7,534
5	PA - 4	Pennsylvania - Coal: Bit - Cap: 850 - HR: 9552	$28.29	Compliant	7,534
6	PA - 8	Pennsylvania - Coal: Bit - Cap: 765 - HR: 9615	$29.64	Compliant	7,534
7	PA - 10	Pennsylvania - Coal: Bit - Cap: 744 - HR: 9502	$30.08	Compliant	7,534
8	PA - 9	Pennsylvania - Coal: Bit - Cap: 750 - HR: 9530	$30.46	Compliant	6,687
9	PA - 6	Pennsylvania - Coal: Bit - Cap: 830 - HR: 9894	$31.04	NG cofire (5%)	7,534
10	PA - 5	Pennsylvania - Coal: Bit - Cap: 850 - HR: 9804	$31.19	NG cofire (5%)	7,534
11	PA - 13	Pennsylvania - Coal: Bit - Cap: 614 - HR: 9946	$36.35	NG cofire (5%)	7,534
12	PA - 15	Pennsylvania - Coal: Bit - Cap: 371 - HR: 9695	$36.40	Compliant	7,534
13	PA - 12	Pennsylvania - Coal: Bit - Cap: 620 - HR: 10040	$36.76	NG cofire (5%)	7,534
14	PA - 11	Pennsylvania - Coal: Bit - Cap: 650 - HR: 10063	$38.36	NG cofire (11%)	7,007
15	PA - 16	Pennsylvania - Coal: Bit - Cap: 312 - HR: 10023	$45.47	NG cofire (9%)	7,534
16	PA - 14	Pennsylvania - Coal: Bit - Cap: 580 - HR: 10319	$49.31	Ultracritical	6,570
17	PA - 21	Pennsylvania - Coal: Sub - Cap: 56 - HR: 10386	$70.11	NGCC	7,534
18	PA - 22	Pennsylvania - Coal: Sub - Cap: 56 - HR: 10386	$70.11	NGCC	7,534
19	PA - 20	Pennsylvania - Coal: Bit - Cap: 93 - HR: 11265	$73.65	NGCC	6,570
20	PA - 19	Pennsylvania - Coal: Bit - Cap: 95 - HR: 11028	$73.66	NGCC	6,570
21	PA - 17	Pennsylvania - Coal: Bit - Cap: 132 - HR: 10846	$73.83	NGCC	0
22	PA - 18	Pennsylvania - Coal: Bit - Cap: 128 - HR: 12364	$73.88	NGCC	0

Retired boilers

Complaint cost	$31.09
Regulated cost	$35.38
Total number of boilers	22
Number retired	2
Percent retired	9%
Capacity total	11,876
Retired capacity (MW)	260
Percent retired	2%



Boiler-level details



PA - 18

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

	Intensity	LCOE	$/ton CO2
Current	2,585	$37.24	
Compliant	2,685	$70.31	
5% Cofire NG	2,636	$74.76	$182
50% Cofire NG	2,193	$103.16	$134
Supercritical	2,528	$96.75	$337
Ultracritical	2,166	$95.24	$96
10% CCS	2,459	$115.69	$401
90% CCS	770	$184.01	$119
NG Retro	1,470	$100.67	$50
NGCC	803	$73.88	$4
Intensity target	1,973		
Least cost technology	NGCC		
Coal fleet weighted average intensity	1,949		

PA - 12

Pennsylvania - Coal: Bit - Cap: 620 - HR: 10040

	Intensity	LCOE	$/ton CO2
Current	2,003	$32.60	
Compliant	2,003	$32.60	
5% Cofire NG	1,968	$36.76	$240
50% Cofire NG	1,640	$63.34	$169
Supercritical	1,890	$48.60	$283
Ultracritical	1,620	$47.45	$78
10% CCS	1,866	$42.66	$147
90% CCS	606	$95.27	$90
NG Retro	1,168	$79.66	$113
NGCC	803	$71.83	$65
	1,973		
	NG cofire (5%)		

CO_2 mitigation-LCOE frontier for any two boilers in the state

Details of mitigation alternatives

Details with transparency

Each row a different boiler

		1	2	3					max HR	1,255	max given							
							Fully		allowable move	50%	0% to 100%	These three cells are named						
		HR Change if not compliant					compliant		cost $/kW	$100	0 to 450							
Peak summer time Capacity (MW)	Heat Rate (Btu/kWh)	SO2	NOX Post	Mercury	Total update Change given existing plant	Updated Heat Rate with Efficiency mitigation option	Updated Heat Rate	Heat Rate decrease from newly built (%)	Heat Rate delta from newly built (Btu/kWh)	allowable change HR	adjusted percent HR improvement	cost of effiiciency improvement ($/MWh)	Change in fuel for EE ($/MWh)	delta CO2 intensity	delta LCOE for efficiency change	$/tonne CO2 avoided	Code for EE improvement
254	9,992	1.9%	0.6%	0.0%	2.5%	10,853	10,239	6.0%	614	614	6.0%	$0.06	-$1.01	130	-$0.95	-$16.07	1111
243	10,006	1.9%	0.6%	0.0%	2.5%	10,869	10,253	6.0%	615	615	6.0%	$0.06	-$1.01	128	-$0.95	-$16.30	1111
254	9,837	1.9%	0.6%	0.0%	2.5%	10,684	10,079	6.0%	605	605	6.0%	$0.06	-$0.99	131	-$0.93	-$15.67	1111
256	9,928	1.9%	0.6%	0.0%	2.5%	10,783	10,173	6.0%	610	610	6.0%	$0.06	-$1.00	135	-$0.94	-$15.32	1111
254	9,843	1.9%	0.6%	0.0%	2.5%	10,690	10,085	6.0%	605	605	6.0%	$0.06	-$0.99	143	-$0.93	-$14.38	1111
256	9,766	1.9%	0.6%	0.0%	2.5%	10,606	10,006	6.0%	600	600	6.0%	$0.06	-$0.98	137	-$0.92	-$14.81	1111
842	9,772	1.9%	0.6%	0.0%	0.0%	10,358	9,772	6.0%	586	586	6.0%	$0.06	-$0.96	116	-$0.90	-$17.03	1112
138	10,133	1.9%	0.6%	0.0%	1.9%	10,945	10,326	6.0%	620	620	6.0%	$0.06	-$1.02	130	-$0.96	-$16.20	1111
137	10,188	1.9%	0.6%	0.0%	1.9%	11,005	10,382	6.0%	623	623	6.0%	$0.06	-$1.02	150	-$0.96	-$14.13	1111

Heat rate impact of getting plant compliant

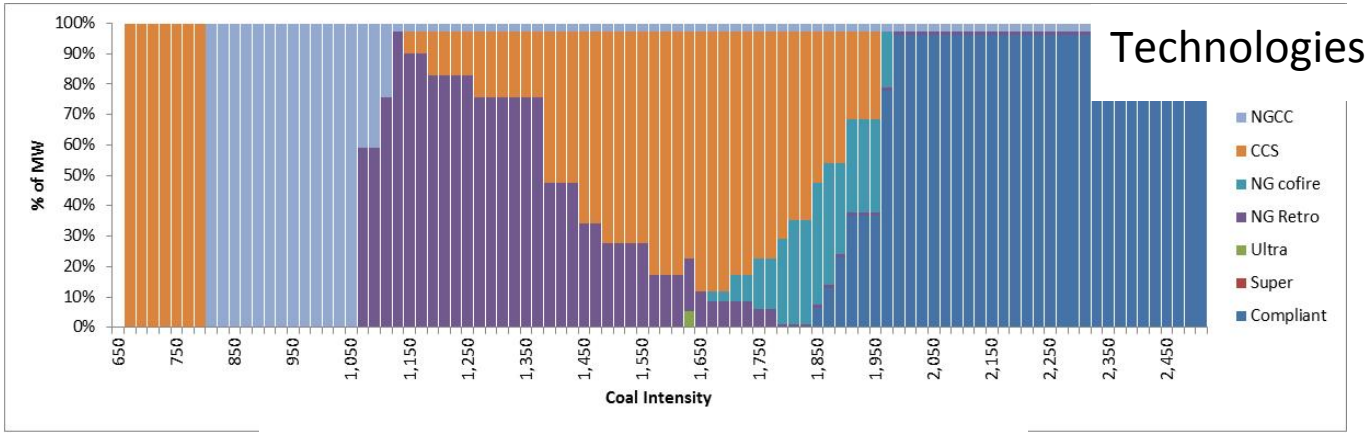
LCOE impact of improved heat rate

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 CO_2 mitigation strategies are needed to meet EPA goal under different scenarios and at what cost?

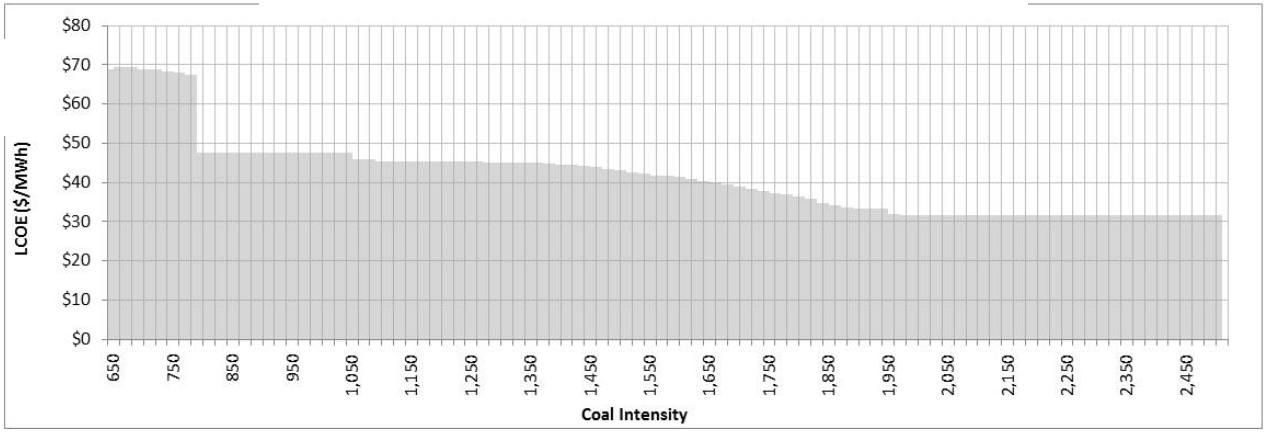
What would Pennsylvania do to meet different carbon limits?

Technologies



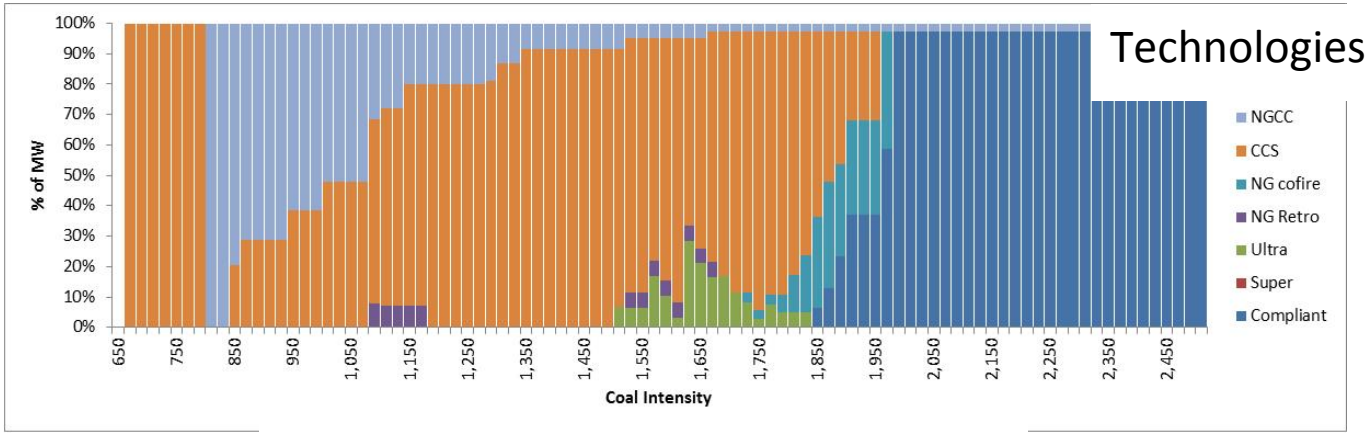
<= Less carbon from coal

Cost



What would Pennsylvania do to meet different carbon limits?

Technologies



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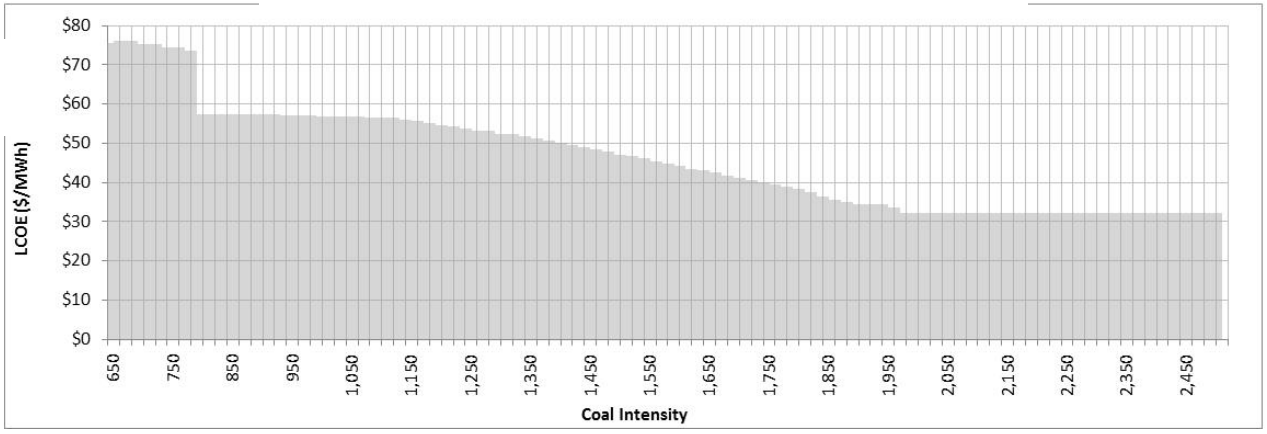
Cost



Insights

- The EPA "Building Blocks" approach is potentially problematic
  - Over-power-production
- EPA intensity definition not standard. Comparisons between states and over time impossible
- Applying 6% efficiency improvement maybe too simplistic to be of use
- Decreased capacity factor for all coal boilers from re-dispatch may not be the most economic solution for lowering CO_2 intensities

Insights (cont.)

- If over generation from the building blocks is accounted for, inefficient coal plants can be retired resulting in …
  - Good plants running more, bad plants retiring
  - Plants that would benefit the most from heat-rate improvement would most likely be retired
  - Mitigation options likely not required
  - Effect on reserve margin

- Opportunity for coal CO_2 mitigation technologies when renewables or energy efficiency goals are not reached, or resource mix is changed
  - Possible solutions that lead to greater CO_2 reduction for less cost

Plans for future work

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

- How would assumptions/forecasts change?
  - Forecasting uncertainties
  - The more believable a forecast, the more likely it is to be wrong
  - Impact on other models/research (very different generation mix)
- How would plants dispatch?
  - States may group resources and trade CO_2
  - A significant role for affordable carbon-mitigated coal?
  - Competitiveness of NGCC in a high-price NG world
  - Meeting peak demand during renewable droughts
  - Back-up plans for loss of nuclear generation
  - Effect on reserve-margin calculations
- Can states meet their renewable goals?
  - State-level wind farm analysis
  - Evaluation of 1,500 potential sites
  - Over 200 variables for each site including probability of opposition, land use/change, and economic impact on local communities