

FACETS Modeling for Dane County Climate Council

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Presentation outline

- What FACETS does
- How FACETS does it
- Illustrative results: MPSC analysis
- Dane County analysis process



What FACETS does

- FACETS integrates assumptions about fuel markets, technologies, demands, and policies
- It finds a cost effective configuration of the US energy system under these assumptions
- A typical FACETS analysis involves dozens of scenarios permuting uncertainty and policy dimensions, allowing us to:
 - Understand relationships within the energy system and how the system responds to policy incentives
 - Identify the key risks and develop strategies to address them



FACETS uses powerful graphics to extract insights from many scenarios

- The motion charts shown here are time-animatable scatterplots, showing CO2 emissions versus covered steam generation in 2030
- Each colored "bubble" is a scenario
- In the top panel, the scenarios are colored by compliance pathway
- The bottom plot is identical, except that the scenarios are colored by gas price sensitivity





FACETS uses web tools to involve stakeholders in analysis

Results Portal F17_01Sep17





Annualized Investment Costs









Total System Cost and Inter-Grid Transmission -



Diff from Ref Set Reference Scenario Set

Cc80.GpL.ReB.ScB.N60N.GeY : CO2 - 80 | GasP - L | Nuc60 - N | StgCost - B | GE - Y | StgCost - B | RECost - B |

CO2 00 80 90 95 80-00 90-00 90-80 95-00 95-80 95-	90 StgCost B L L-B	Nuc60 N Y Y-N
GasP B H L H-B L-B L-H	RECost B H L H-B L-B L-H	GE N Y Y-N



Select Scenario

using results portals like this one

http://beta.vedaviz.com/Portal/Playground.aspx?p=F17 01Sep17&g=dcdc39

Recent FACETS analyses

- Midcontinent Power Sector Collaborative
 - Midcentury power sector and transport electrification and decarbonization analysis
- Vermont Total Energy Study
 - Policy and technology options to meet Vermont's GHG emissions reduction and renewable energy goals
- Clean Power Plan
 - Dozen of variations combining different compliance pathways with variations in fuel and technology costs, and energy efficiency accomplishment
- Cross-sector NOx abatement for industry and power generation for EPA
- Energy Modeling Forum shale gas, power sector, and carbon tax scenarios



How FACETS does it

- FACETS is a technologicallydetailed, transparent
 optimization model
- It's built in the TIMES energy modeling framework, used in more than 70 countries around the world





FACETS represents a network of fuels, devices, and demands



- FACETS calculates the least cost pathway through the network to satisfy all demands, subject to any policies
- The level of detail is flexible
 - 11,000 individual power plants
 - Vehicles by size class, type, and state/region
- Each device has explicit technical parameters, for example:

Allen S King 1915_B_1	
Capacity (MW)	510
Heat Rate (Btu/kWh)	9920
Maximum Availability (%)	78
FixOM (2012\$)	70.7
VAROM (2012 mills/kwh)	4.7
NOx Post-Comb Control	SCR
SO2 Control	Dry Scrubber
ACI Mercury Control	ACI





Power generation is represented within detailed regions that can trade with each other

2050 generation and trade flows

<u>raujors</u>

Example analysis: MPSC

- Goals
 - To map out and assess plausible futures in the electricity and lightduty vehicles sectors for the Midcontinent region
 - To understand the potential role and impacts of electric vehicles in decarbonization futures
 - To understand what uncertainties and risks these futures are subject to and how they may be influenced by policy
- Process
 - Examine a range of scenario, with and without a carbon cap/price, varying assumptions about:
 - Fuel prices
 - Technology costs
 - Nuclear lifetimes
 - Consumer vehicle preferences
 - EV charging times



FACETS energy system network for MPSC analysis



Results: In response to uncertainties, we see a wide range of "BAU" national CO2 emissions (MMT)



...ranging 23-60% below 2005 levels.



National generation mix (TWh) varies with gas price and wind/PV costs





H-H



H-L

L-L

6K Wind is competitive in all cases, and PV unless its costs are High When gas prices are High, coal persists and there is more EE 4.5K 4.5K 4.5K Sum(Twh) Sum(Twh) 3K 3K 1.5K 1.5K 1.5K 2018 2021 202 2030 2035 2040 2045 2045 2050 2016 2016 2018 2021 2025 2030 2035 2040 2016 2018 2021 2025 2030 2035 2040

сн вк When gas prices are Low, most new generation is₀€rom gas, and coal declines

Coal





PV is competitive only when its costs are Low



Wind

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EE 📕 Gas-NCC 📕 Gas-NCT 📕 GasOil-O 📕 Hydro 📕 Nuclear-O 📒 Solar



H-B

Scenarios are labeled first by gas prices (Base/High/Low), then RE costs

MISO region 2 generation mix under the same scenarios















Coal



5 Note: in the scenarios shown, nuclear units retire at 60 years. We have also run life extension scenarios

MISO region 2 emissions across the full range of "no policy" scenarios



Dane County modeling process

- 1. Break out Dane County from surrounding model region
 - Electricity generating capacity
 - Electricity load
 - Existing light duty vehicle fleet?
 - Light duty VMT
- 2. Track and project additional energy consumption and emissions
- 3. Add Council-designed projects, programs, and policies for testing
- 4. Run "BAU" and measures against regional electricity and LDV scenarios
- 5. Evaluate and interpret results with Council. Rinse and repeat.

calibrate to inventory where possible



Additions to the Dane County Reference Energy System



Potential dimensions for analysis

- Measures
 - Energy efficiency programs and projects
 - Methane capture for vehicles and power generation
 - Electric vehicle charging infrastructure and promotion of EVs
 - Additional renewable installations
 - Improved building codes
 - and...?
- State-of-the-world uncertainties
 - Fuel prices: natural gas, petroleum fuels
 - Cost and performance of key technologies
 - Consumer acceptance of electric vehicles





For More Information about FACETS

See <u>http://www.facets-model.com</u> or contact <u>Evelyn.L.Wright@gmail.com</u>



Appendix: Additional FACETS details and data



Model details: Power sector technology options

- Existing capacity
- Wind and solar (data from NREL)
- Coal and gas with CCS (data from EIA and EPA, under review)
- Nuclear (define cost range)
- Biomass, geothermal, new hydro (data from EIA, EPA)
- Build rate constraints
- Transmission
- Storage
- Smart grid/demand response/load shifting



All FACETS data is open, explicit, and available for adjustment

Unit						Input Data						В	AU generat	tion (GWh)		BAU fuel consumption (TBTU)					
Unit Name	Unit Number	On Line Year	Capacity (MW)	Heat Rate (Btu/kWh)	Availability/ Capacity Factor	Modeled Fuels	FixOM (2012\$)	VAROM (2012 mills/kwh)	NOx Post- Comb Control	SO2 Control	Mercury Control	2017	2022	2027	2032	Fuels	2017	2022	2027		
Covanta Hennepin Energy	10013_B_1	1989	16.9	16297	90.0	MSW	25.3	9.4		Dry Scrubber		118.9	118.9	118.9	82.9	Municipal Waste	1.94	1.94	1.		
Covanta Hennepin Energy	10013_B_2	1989	16.9	16297	90.0	MSW	25.3	9.4		Dry Scrubber		118.9	118.9	118.9	82.9	Municipal Waste	1.94	1.94	1.		
Taconite Harbor Energy Center	10075_B_1	1957	65.0	11797	83.7	Subbituminous	63.6	4.7	SNCR	Dry Scrubber	ACI	476.6	476.6	476.6	476.6	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	5.62	5.62	5.		
Taconite Harbor Energy Center	10075_B_2	1957	67.0	11566	83.7	Subbituminous	63.6	4.7	SNCR	Dry Scrubber	ACI	491.2	491.2	491.2	491.2	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	5.68	5.68	5.		
Taconite Harbor Energy Center	10075_B_3	1967	68.0	11736	83.7	Subbituminous	63.6	4.7	SNCR	Dry Scrubber	ACI	222.2	222.2	222.2	249.3	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	2.61	2.61	2.		
Rapids Energy Center	10686 B 5	1980	11.2	13179	83.0	Biomass	19.7	7.5				81.8	81.8	81.8	81.8	Biomass	1.08	1.08	1.		
Rapids Energy Center	10686 B 6	1980	11.2	13179	83.0	Biomass	19.7	7.5				81.8	81.8	81.8	81.8	Biomass	1.08	1.08	1.		
Rapids Energy Center	10686 B 7	1969	3.5	11511	92.4	Natural Gas	28.2	3.2													
Rapids Energy Center	10686 B 8	1969	3.5	11511	92.4	Natural Gas	28.2	3.2													
Silver Bay Power	10849 B BLR1	1955	36.0	9693	85.3	Subbituminous	53.6	1.728				268.9	268.9	268.9	268.9	Western Med, Sulfur Subbit., Western Low Sulfur Subbit.	2.61	2.61	2.		
Silver Bay Power	10849 B BLR2	1963	69.0	9693	85.3	Subbituminous	53.6	1.7				515.3	515.3	515.3	515.3	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	5.00	5.00	5.		
Fox Lake	1888 B 1	1950	12.7	14500	89.5	Natural Gas. Residual Fuel Oil	28.2	3.2								,					
Fox Lake	1888 B 2	1951	11.6	14500	89.5	Natural Gas, Residual Fuel Oil	28.2	3.2													
Fox Lake	1888 B 3	1962	84.9	13040	89.5	Natural Gas, Residual Fuel Oil	28.2	3.2													
Fox Lake	1888 G 4	1974	18.8	17500	89.2	Distillate Fuel Oil	4.0	6.5				0.6	0.6	0.6	0.5	Distillate Fuel Oil	0.01	0.01	0.		
Hills	1889 G 1	1996	2.0	15663	89.2	Distillate Fuel Oil	4.0	6.5				0.1	0.1	0.1	0.1	Distillate Fuel Oil	0.00	0.00	0.		
Hills	1889 6 2	1960	2.0	15663	89.2	Distillate Fuel Oil	4.0	6.5				0.1	0.1	0.1			0.00	0.00			
Sul Lockin	1901 B 1	1952	55.0	12585	74.7	Bituminous, Subbituminous	52.6	1 72	SNICP			256.0	256.0	256.0	256.0	Wastern Med. Sulfur Subbit, Wastern Low Sulfur Subbit	4.60	4.60			
Sul Laskin	1991 8 2	1953	55.0	12505	74.7	Bituminous, Subbituminous	53.6	1.73	SNCR			356.9	356.9	249.9	256.0	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	4.60	4.60			
Clay Reswell	1091_0_2 1902_0_1	1955	60.0	10963	89.0	Subbituminous	53.0	1.7	SNCR			530.9	530.9	510.0	530.9	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	5.94	5.94			
Clay Boswell	1003 0 3	1950	60.0	10005	89.0	Subbituminous	53.0	1.7	SNCR			537.9	537.9	537.9	537.9	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	5.64	5.64	5.		
Clay Boswell	1992 8 2	1972	250.5	10364	89.0	Subbituminous	62.6	2.4	SCD	Wet Scrubber	AC1	2722.7	2722.7	2722.7	2722.7	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	29.22	29.22	20		
Clay Boswell	1095_B_5	1975	530.5	10304	89.0	Subbituminous	62.6	3.4	SNCP	Wet Scrubber	ACI	4062.5	4062.5	4062.5	4062.5	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	20.52	46.14	20.		
Clay Boswell	1093_0_4	1980	525.0	11115	89.0	Subbituminous	03.0	3.4	SINCK	wet scrubber		4062.5	4062.5	4062.5	4062.5	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	40.14	40.14	40.		
M Ulikhard	1007 8 2	1980	22.2	14500	03.2	Distriate Puer On	10.7	0.5				242.1	242.1	242.1	242.1	Distriate ruer on	2.51	2.51	0.		
M L Hibbard	1097_B_5	1900	15.3	14500	83.0	Biomass	19.7	7.5				242.1	242.1	242.1	242.1	Diomass	3.51	5.51	5.		
M L HIDDard	1897_8_4	1988	15.3	14500	83.0	Biomass	19.7	7.5				111.2	111.2	111.2	111.2	Biomass	1.61	1.61	1.		
Black Dog	1904_8_3	1955	94.0	11312	68.4	Bituminous, Subbituminous	65.3	1./													
Black Dog	1904_B_4	1960	165.0	10431	68.4	Bituminous, Subbituminous	65.3	1./													
Black Dog	1904_G_2	1954	85.0	/644	84.6	Natural Gas, Distillate Fuel Oil	13.6	5.6	SCR			1207.0		650 C		Natural Co.			_		
Black Dog	1904_G_5	2002	195.0	7644	84.6	Natural Gas, Distillate Fuel Oil	13.6	5.6	SCR			1287.9	839.9	650.6	406.2	Natural Gas	9.84	6.42	4.		
Granite City	1910_G_1	1969	14.0	1/656	89.2	Natural Gas, Distillate Fuel Oil	4.0	6.5				0.5	0.5	0.4		Natural Gas	0.01	0.01	0.		
Granite City	1910_G_2	1969	15.0	1//29	89.2	Natural Gas, Distillate Fuel Oil	4.0	6.5				0.5	0.5	0.4		Natural Gas	0.01	0.01	0.		
Granite City	1910_G_3	1969	15.0	1//92	89.2	Natural Gas, Distillate Fuel Oil	4.0	6.5				0.5	0.5	0.4		Natural Gas	0.01	0.01	0.		
Granite City	1910_G_4	1969	15.0	17757	89.2	Natural Gas, Distillate Fuel Oil	4.0	6.5				0.5	0.5	0.4		Natural Gas	0.01	0.01	0.		
High Bridge	1912_G_7	2008	321.0	7942	84.6	Natural Gas	13.6	5.6	SCR			1784.9	1070.9	1070.9	668.7	Natural Gas	14.18	8.51	8.		
High Bridge	1912_G_8	2008	321.0	7942	84.6	Natural Gas	13.6	5.6	SCR			1784.9	1070.9	1070.9	668.7	Natural Gas	14.18	8.51	8.		
Inver Hills	1913_G_1	1972	58.5	19476	90.8	Natural Gas, Distillate Fuel Oil	4.0	6.5				2.0	2.0	2.0	0.9	Natural Gas	0.04	0.04	0.		
Inver Hills	1913_G_2	1972	56.0	18413	90.8	Natural Gas, Distillate Fuel Oil	4.0	6.5				1.9	1.9	1.9	0.8	Natural Gas	0.03	0.03	0.		
Inver Hills	1913_G_3	1972	58.0	18026	90.8	Natural Gas, Distillate Fuel Oil	4.0	6.5				2.0	2.0	2.0	0.8	Natural Gas	0.04	0.04	0.		
Inver Hills	1913_G_4	1972	58.0	17615	90.8	Natural Gas, Distillate Fuel Oil	4.0	6.5				2.0	2.0	2.0	0.8	Natural Gas	0.03	0.03	0.		
Inver Hills	1913_G_5	1972	58.5	18438	90.8	Natural Gas, Distillate Fuel Oil	4.0	6.5				2.0	2.0	2.0	0.9	Natural Gas	0.04	0.04	0.		
Inver Hills	1913_G_6	1972	61.0	18111	90.8	Natural Gas, Distillate Fuel Oil	4.0	6.5				2.1	2.1	2.1	0.9	Natural Gas	0.04	0.04	0.		
Inver Hills	1913_G_7	1997	1.8	15364	89.2	Distillate Fuel Oil	4.0	6.5				0.1	0.1	0.1	0.1	Distillate Fuel Oil	0.00	0.00	0.		

Sample unit-level data



The FACETS power system is represented in a grid of 134 regions



Transmission

- New inter-regional transmission capacity can be endogenously chosen
 - NREL investment costs
 - Costs of connecting wind and solar to grid are included in unit costs
- Specific new projects can be added/tested
- Regions can be allowed to share reserves across transmissions links





Time is represented by dividing up the year into slices

- The year is divided into a user-specified number of *time slices* at the season, week, and/or time-of-day level
- Can range up to 8760 slices in a year, but usually somewhere between 9 and 40
- All model equations are enforced at the time slice level



Technical University of Denmark TIMES-DK model

IEW Stuttgart - Germany TIMES model

224 time slices



Technology costs

• Costs and performance for technologies other than wind and solar are derived from AEO 2017

		Base	Capital (Cost (\$/K	(W) –						
		regio	onal mult	tipliers a	pply		FIXOM	VAROM		Effic	iency
	2017	2020	2025	2030	2040	2050	\$/KW-yr	\$/MWh	2017	2020	2025 onward
Coal with 30% CCS	5030	4984	4746	4434	3991	3585	69.56	7.1	35%	35%	37%
Coal with 90% CCS	5562	5511	5249	4904	4413	3965	80.78	9.5	29%	29%	37%
Comb. Turb	1092	1088	1046	987	908	835	17.39	3.5	34%	35%	36%
Adv. CT	672	667	636	580	505	454	6.76	10.6	35%	36%	40%
Comb. Cyc	969	965	929	876	806	741	10.93	3.5	52%	52%	54%
Adv CC	1094	1088	1041	963	857	778	9.94	2.0	54%	54%	55%
Adv CC with 90% CCS	2153	2122	2003	1833	1589	1390	33.21	7.1	45%	45%	46%
Nuclear	5880	5815	5164	4804	4283	3810	99.65	2.3	33%	33%	33%
Biomass	3790	3760	3587	3363	3048	2762	110.34	5.5	25%	25%	25%
Biomass w 90% CCS	7458	7337	6900	6402	5651	4931	369	20	21%	21%	21%
Landfill Gas	8623	8593	8264	7800	7172	6597	410.32	9.1	19%	19%	19%



Wind and solar costs come from NREL's ATB (Hi/Mid/Low scenarios)



Detailed wind and solar resource data from NREL

- Potential, grid integration cost, and typical hourly generation by region and class
- 10565 onshore wind options, in 356 supply regions

Region Class	1	2	3	4	5	6	7	8	9	10	11 1	2 13	3 14	15	16	17 :	8 19	20	21	22	23	24 2	25 2	5 27	28	29	30	31 32	33	34	35 36	37	38 39	40	41 4	42 4	3 44	45	46 47	7 48	49	50 5	1 52	53	54 5	5 56
212 class1	0.24	0.22	9,21	9.26	0.39		0.85	0.85	0,85	0.85	0.85 0	UIS 03	83 0.63	0.34	0,40	0.50	9.52 0.	27 0.14	0.09	0.08	0,16	0.26	R.32 Ø.	40 0,48	0.52	0.79	0.84	0.82 0.84	0.69	0.77	0,82 0,8	0.84	0.79 0/	18 0.60	0.66	0.23 4	30 0.62	9.66	0.85 0.	15 0.8:	0.85	0.85 0	84 0.8Z	0.63	0.57 0.	.55 0.53
212 class2	0.25	0.23	0.21	0.26	0.40	0.7	0.85	0.85	0.85	0.85	0.85 0	UNS 0.	82 0.62	0.35	0,41	0.50	0.52 0.	27 0.14	0.09	0.07	0.17	0.27 0	1.33 0.	41 0.49	0.52	0.69	0.82	0.80 0.83	0.68	0.75	0.79 0.8	0.83	0.77 0.5	17 0.60	0.65	0.24 0	31 0.62	0.66	0.85 0.	15 0.8	0.85	0.85 0	A2 0.86	0.62	0.57 0.	.55 0.54
212 class4	8.35	8.36	0.3	0.43	0.52	6.7	0.82	0.84	0.82	1.80	0.78 0.	3) (K	77 B.65	0.44	0,47	0.53	0.55 0.	38 0.28	0.23	0.23	0.31	0.40 0	0.43 0.	47 0.51	0.53	D.en	0.76	0.74 0.78	K 0.89	0.54	0.75 0.7	0.82	0.78 0.1	80.0	8.68	0.44 0	43 0.51	0.52	0.65 00	0.7	0.75	0.79 0	RI 0.75	0.63	8.62 0.	61 0.63
212 class5	0.60	0.63	0.64	0.69	0.71	0.0	0.82	0.84	0.82	0.79	0.77 0	.78 0.	72 0.60	0.43	0.33	0.32	1.30 0.	25 0.22	0.25	0.31	0.43	0.47 0	2,48 0.	51 0.53	0.52	0.55	0.60	0.61 0.65	7 0.67	0.71	0.72 0.77	0.83	0.80 0.7	16 0.78	0.76	0.71 0	66 0.63	6.63	0.68 0.	10 0.7	0.74	0.79 0	42 0.77	0.72	0.73 0.	.72 0.72
212 class6	0.99	0.58	0.56	0.63	0.64	8.7	0.77	0.78	0.76	0.74	0.75 0	.70 0,1	45 0.55	0.43	0.37	0.38	0.39 0.	15 0.35	0.40	0.43	0.46	0.49 0	5.48 Q.	47 0.46	0.43	0.42	0.50	0.47 0.50	0.46	0.53	0.52 0.54	5 0.60	0.55 0.4	19 0.51	0.53	0.49 0	49 0.47	0.52	0.58 0.	73 0.79	8.76	0.76 0	.7m 0.74	0.65	0.71 0.	89 0.68
212 class7	1.50	0.47	0,4	0.54	0.59	6.7	0.74	0.76	8.74	0.72	0.70 0	L66 B.	62 11.56	0.47	0,46	0.45	9.49 Q.	48 0.47	0.46	0.46	8,47	0.50 0	0,45 0.	41 0.36	0.33	0.29	0.35	0.31 0.33	2 0.30	0.37	0.35 0.34	s 0.39	0.33 0.3	9 0.31	0.36	0.35 0	38 0.39	0,47	0.53 0.	94 O.K	0.65	0.63 0	59 0.63	0.64	8.68 0.	67 0.63
212 class8	0.41	0.36	0.32	0.35	0.47	0.0	0.66	0.66	0.66	0.66	0.61 0	1.55 0.	53 0.37	0.25	0.35	0.36	0.42 0.	45 0.48	0.49	0.47	0.38	0.58 0	0.29 0.	25 0.21	0.22	0.18	0.23	0.21 0.24	0.21	0.27	0.29 0.3	\$ 0.27	0.25 0.3	14 0.21	0.26	0.27 1	.32 0.35	0.41	0.50 0.3	2.0 87	0.57	0.53 0	.50 0.61	0.62	0.66 0.	64 0.59
212 class9	0.33	0.27	0.21	0.24	0.29	0.4	0.56	0.56	0.57	0.57	0.51 0	147 0.	42 0.27	0.16	0.35	0.32	5.43 0.	52 0.60	0.63	0.59	0.41	0.38 0	1.26 0.	19 0.13	0.17	0.13	0.17	0.15 0.16	0.13	0.20	0.24 0.1	0.20	0.22 0.2	8 8.14	0.17	0.15 0	.19 0.22	0.28	0.43 0.	44 ().44	0.49	0.47 0	44 0.61	0.64	0.68 0.	62 0.57
213 class5	2.68	0.59	0.4	0,49	0.33	0.28	0.26	0.11	9.22	0.28	0.35 0	1)2 ())	08 0.22	8.41	0.53	0.63	1.76 0.	75 0.48	0.76	0.02	11.84	0.84 0	5.84 0.	NZ 0.75	11.64	0.75	0.88	0.77 0.77	0.83	0.82	0.72 0.7	4 0.KI	0.84 0.1	0.80	0.85	0.85 6	85 0.84	0.83	0.84 00	NO 0.61	6.72	0.83 8	85 D.84	0.84	8.56 0.	29 0.36
213 class6	0.47	0.40	0.54	0.45	0.44	0.41	0.38	0.34	0.37	0.37	0.40 0.	36 0.	43 0.48	0.55	0.63	0.63	0.74 0.	72 0.68	0.68	0.72	0.80	0.81 0	1.80 0.	75 0.68	0.58	0.56	0.58	0.57 0.53	0.52	0.52	0.45 0.3	0.31	0.31 0.3	9 0.32	0.29	0.30	34 0.34	0.45	0.59 00	13 0.5	0.60	0.70 0	75 8.77	0.80	0.70 0.	43 0.62
213 class7	0.29	0.23	0.18	0.28	0.25	0.1	0.12	0.19	0.23	0.25	0.22 0	126 0.4	.48 0.41	0.42	0.52	0.51	1.54 0.	49 0.50	0.47	0.51	0.60	0.66 0	1.72 O.	73 0.70	0.66	0.69	0.65	0.63 0.63	2 0.59	0.56	0.57 0.4	5 0.32	0.23 0.3	15 0.17	0.17	0.13	.22 0.19	0.22	0.37 0.	57 0.6	0.66	0.66 0	47 D.64	0.63	0.61 0.	61 0.58
213 class8	0.19	0.15	0.12	0.17	0.22	6.3	0.10	0.18	0.22	0.24	0.21 0	124 0.3	м 0.33	0.51	0.39	0.38	0.38 0.	0.36	0.36	0.58	0.44	0.52 0	0.55 0.	56 0.58	0.57	0.61	0.56	0.55 0.56	0.52	0.48	0.50 0.4	0.28	0.21 0.1	4 0.17	0.20	0.16	23 0.20	0.20	0.27 0.	2.0 0	0.57	0.55 0	.52 0.54	0.53	0.48 0	48 0.46
214 class3	0.72	0.62	0.53	0.71	0.71	0.7	0.62	0.78	0.69	0.68	0.60 0	.59 0.	.58 0.57	0.57	0.56	8.49	1.45 0.	33 0.32	0.21	0.15	0.15	0.22 0	1.38 0.	35 0.32	0.36	0.32	0.38	0.40 0.63	0.67	0.73	0.82 0.8	5 0.KS	0.84 0.3	13 0.84	0.83	0.76 0	62 0.57	0.55	0.55 0.	59 0.63	0.65	0.63 0	45 0.69	0.77	±.77. 0.	69 0.74
214 class4	0.70	0.63	0.51	0.69	0,63	0.0	0.68	0.80	0,75	0.73	0.69 0		68 0.68	0.67	0.72	0.68	0.00	46 0.46	0.36	0.30	0,27	0.29	1.36 0.	36 0.35	0.38	0,37	0.50	9.53 9.74	0.71	0.73	0.78 0.8	0.81	6.79 6.1	0.74	0.74	0.62 4	49 0.47	6.47	0.47 0.	10 0.5	0.54	0.57 0	.58 0.59	0.64	0.66 0.	58 0.64
214 class5	0.65	0.66	0.62	0.61	0.00	0.75	0.76	0.80	0.79	0.72	0.53 0	.62 9,7	.72 0.74	0.73	0,76	0.72	9,73 0.	65 0.83	9.58	0.54	0.52	0.53 0	0.53 0.	46 0.39	0.35	0.38	0.54	0.59 0.67	0.63	9,67	9.79 0.64	9 0.68	0.70 0.7	2. 0.71	0.72	9,72 0	67 0.68	0.68	0.69 0.	70 .0.7	0.71	0.71 0	69 D.68	0.09	0.70 0.	67 0,69
214 class6	8.45	8.43	0.3	0.41	0.50	0.05	0.62	0.57	0.56	0.52	0.48 0	151 0,	49 8.43	0.33	0.31	0.38	1,44 0.	37 0.30	0.23	0.24	0.33	0.44 0	0.44 0.	43 0.42	0.42	0.40	0.44	0.39 0.43	2 0.37	0.46	0.56 0.6	61.0	0.57 0.5	8 0.42	0.58	0.32 4	.30 0.25	0.29	0.35 0.	36 0.5	0.65	0.64 0	.61 0.43	0.49	11.56 0.	48 0,43
214 class7	0.50	0,47	0.4	0,43	0.50	0.61	0.66	0.65	0.67	0.66	0.64 0	.64 0.	59 0.54	0.49	0.48	0.43	0.51 0.	56 0.56	0.55	0,55	0.53	0.55 0	0.50 0.	42 0.35	0.32	0.26	0.32	0.29 0.25	0.27	0.34	0.37 0.39	0.40	0.41 0.4	0.33	0.38	0.36 0	.39 0,41	0.46	0.53 0.	58 0.6	0.65	0.63 0	40 0.67	0.69	0.71 0.	AN 0.64
214 class8	0.39	0.36	0,34	0.38	0.43	E 0.4	0.56	0.56	0.55	0.54	0.50 0	150 0,	45 0.38	0.32	0.32	0.30	138 0.	42 0.43	0.44	0.44	0.40	6.42 0	1.39 0.	32 0.26	0.25	0.20	0.25	0.23 0.24	0.22	0.29	0.30 0.3	5 0.40	0.38 0.3	6 0.29	0.34	0.32 (36 0.38	8.44	0.49 0.1	2.0 17	82.0	0.60 0	60 0.65	0.63	0.66 0.	.60 0.56
214 class9	8.37	0.32	0.29	0.32	0.36	0.43	0.48	0.55	0.52	8.52	0.47 0	147 87	44 8.37	0.31	0.29	0.28	2.36 0.	43 0.47	0.48	0.47	0.42	0.46 0	0.46 0.	56 0.27	0.26	0.21	0.24	0.20 0.20	0.17	0.22	0.22 0.2	5 0.35	0.33 8.3	13 0.25	0.28	0.28 4	29 0.29	0.34	0.36 0.	19 0.4	0.50	0.54 0	55 8.62	0.61	8.64 8	60 0.55
215 class6	0.36	8,47	0.59	0.59	0.34	6 83	0.58	0.74	0.83	0.83	0.84 0	184 0.1	84 0.83	0.83	0.82	0.82	9,74 0.	51 0,39	0.25	0.13	0.05	0.62 0	1.03 0.	19 0.42	0.51	0.55	0.52	0.56 D.M	0.64	6,73	0.75 0.8	0.84	0.83 0.0	13 0.34	0.84	0.84 0	84 0.34	0.84	0.84 0,	15 0.8	0.85	0.85 0	85 0.85	6.85	0.83 0	AR 0,40
215 class7	0.31	0.33	0.34	0.41	0.49	0.54	0.64	0.73	0.79	0.78	0.77 0	L79 B3	80 0.79	8.76	0.76	0.68	2.57 0.	54 0.50	0.44	0.45	0.46	0.49 0	1.47 0.	47 0.48	0.46	0.44	0.45	0.59 0.43	2 0.40	0,44	0.47 0.5	0.54	0.48 0.4	12 0.47	0.51	0.45 0	151 0.51	0.55	0.54 0.	57 0.6	0.64	0.63 0	.62 0.64	0.62	0.56 0.	.52 0.43
215 class8	0.33	0.25	0.18	0.30	0.40	0.6	0.74	0,78	0.82	0.82	0.82 0	01 01	xi 0.76	8.70	0.62	0.41	1.52 0.	63 0.54	0.47	0,49	0.51	0.55 0	0.48 0.	40 0.33	0.25	0.23	0.31	0.26 0.24	0.18	0.24	0.21 0.2	0.26	0.22 0.3	8 0.21	0.26	0.24 0	28 0.28	0.56	0.42 0.	6 0.4	0.52	0.50 0	48 0.62	0.65	8.67 0.	67 0.58
216 class4	2.60	0.39	0.22	0.16	0.40	0.6	0.57	0.25	0.19	0.18	0.12 0	L19 0.	37 0.43	0.50	0.76	0.84	1.85 0.	85 0.85	0.85	0.85	0.85	0.85 0	1.85 0.	85 0.85	0.85	0.85	0.85	0.82 0.73	5 0.64	0.42	0.46 0.7	2 0.76	0.73 0.7	0.82	0.83	0.42 (0.0 0.00	0.85	0.85 0.	65 O.R	0.85	0.85 0	85 0.84	0.80	0.69 0.	68 0,76
216 class5	0.01	0.00	0.04	0.00	0.00	0.0	0.01	0.90	0.00	8.11	0.39 0.	54 0.3	36 0.36	0.37	0.53	0.30 1	.28 0.	47 0.50	0.22	0.09	0.08	0.00	0.15 Q.	22 0.29	0.76	0.77	0.75	0.68 0.58	0.53	0.58	0.48 0.5	7 0.30	0.35 0.4	13 0.42	0.48	0,40 0	40 0.45	0.09	0.80 0.	12 0.8	0.79	0.73 0	.64 0.73	0.31	0.21 0.	.06 0.01
216 class6	8.97	0,06	0.05	0.05	0.07	0.0	0.08	0,06	0.07	0.12	0.29 0	.39 0.	28 0.28	0.28	0.42	0.29	9.51 0.	42 0.43	0.22	0,14	0.14	0.15 0	0.18 0.	21 0.25	0.65	0.86	0.64	0.35 0.46	5 0,41	0.43	0.36 0.3	2 0.30	0.51 0.3	13 11,38	0.45	0.34 (34 0.39	0.60	0.69 0.	N7 0,64	0.65	0.58 0	49 0.57	0.27	0.19 0.	10 0.09
216 class7	0.18	0.39	0.26	0.26	0.28	0.2	0.29	0.35	0.35	0.39	0.43 0	L45 0.	.39 0.35	0.31	0.36	0.29	9.25 0.	28 0.28	0.23	0.22	0.22	0.25 0	124 0.	22 0.23	0.32	0.33	0.34	0.50 0.21	7 0.26	0.31	0.28 0.3	0.38	0.34 0.3	1 0.37	0.43	0.39 (.39 0.44	0.52	0.57 0.	55 0.6	0.63	0.60 0	.55 0.58	0.53	0.54 0.	48 0,43
216 class8	0.14	0.17	0.22	0.26	0.29	0.5	0.37	0.46	0.45	0.47	0.48 0	L48 0.	.44 0.38	0.30	0.31	0,29	9.27 0.	23 0.23	0.22	0.20	0.19	0.22 0	0.23 0.	23 0.27	0.27	0.21	0.23	0.21 0.23	0.22	0.27	0.24 0.3	0.40	0.33 0.3	27 0.31	0.38	0.33	.36 0.41	0.43	0.48 0.	50 0.5	0.57	0.57 0	.54 0.52	0.54	0.57 0.	51 0.50
216 class9	0.07	0.11	0.16	0.21	0,27		0.40	0.51	0.53	0.55	0.58 0	(J) ()	51 0.39	0.27	0.25	0.24	0.18 0.	14 0.13	0.12	0.11	6,10	0.12 0	0.13 0.	15 0.22	0.18	0,11	0.15	0.13 0.14	0.15	0.19	0.15 0.2	0.27	0.21 0.1	17 0.17	0.24	0.23 4	28 0.34	0.37	0.39 0.4	46 0.5	0.55	0.51 0	46 0.37	0.37	0.39 0.	34 0,34
217 class6	9.77	9.76	0.69	0.65	0.77		0.81	0.82	0.83	0.84	0.83 0	U83 (D.)	84 ILK3	0.82	0.83	0.82	9,74 QJ	61 0.35	0.34	0.64	0.71	0.73 0	0.74 0.	73 8.72	0.65	0.56	0.58	0.47 0.36	5 0.31	0.36	0.36 0.44	0.43	0,48 0.3	14 0.38	0.44	0.34 0	.41 0.44	0.51	0.57 0.	66 0.7	0.69	0.71 0	.73 0.82	0.83	0.84 0.	80 0.81
217 class7	0.42	0.47	0.5	0,48	0.58	0.6	0.73	0.76	0.82	0.83	0.83 0	0.0	84 0.63	0.80	0.82	0.79	2.67 83	50 0.31	0.22	0.22	0.20	0.29 0	0.20 0.	21 0.26	0.32	0.31	0.34	0.29 0.33	0.35	0.40	0.39 0.5	0.64	0.62 0.5	10.04	0.68	0.67 0	.78 0.79	0.73	0.74 0.	76 0.7	0.78	0.78 0	.79 0.82	0.80	0.70 0.	34 0,46
217 class8	0.50	0.35	0,41	0.35	0.41	0.5	0.64	0.72	0.78	0.83	0.80 0	US2 0.1	82 0.79	0.72	0.75	0.59	3,48 0.	54 0.45	0.38	0.37	0.34	0.56 0	1,35 0.	33 0.31	0.27	0.24	0.28	0.22 0.23	5 0.24	0.29	0.29 0.3	4 0.47	0.48 0.3	88 0.47	0.53	0,51 0	55 0.54	0.59	0.63 0.	15 .0.6	0,71	0.70 0	69 0.76	0.74	8.67 0.	.57 0.51
217 class9	0.23	8.24	0.21	0.21	0.31	0.4	0.64	0.75	0.72	0.76	0.69 0	177 8.	.78 81.70	0.58	0.59	0.35	0.29 0.	66 0.70	0.87	0.71	0.68	0,75 0	8.71 0.	63 0.48	0.33	0.25	0.29	0.23 0.16	5 0.11	0.17	0.18 0.11	0.18	0.24 0.3	NB 0.13	0.19	0.16 0	17 0.13	0.22	0.29 0.3	12 0.3	0.44	0.42 0	40 0.60	0.63	0.72 0.	85 0.64
218 class5	0.46	0.52	0.51	0.64	0.63	8.4	0.51	0.75	0.85	0.85	0.85 0	U85 0,1	35 0.85	0.84	0.84	0.84	5.82 0.	72 0.51	0.21	0.05	0.01	0.01 0	0.81 0.	02 0.27	0.26	0.16	0.27	0.16 0.21	0.28	0,39	0.50 0.5	7 0.65	0.65 0.0	18.0 24	0.82	0.82 0	48. 0.35	0.85	0.85 0.	15 O.R	6365	0.85 0	35 0.84	0.85	0.83 0.	81 0.78
218 class6	0.55	0.56	0.5	0.53	0.57	0.5	0.60	0.71	0.76	0.76	0.75 0	176 0.	.76 8.76	0.75	0.80	0.79	0.75 0.1	67 0.50	0.33	0.33	0.33	0.34 0	2.36 0.	37 0.43	0.44	0.40	0.45	0,36 0,33	5 0,39	0.50	0.54 0.5	5 0.66	0.67 0.0	17 0.69	0.66	0.65 0	.68 Q.68	0.71	0.73 0.	73 0.78	0.78	0.78 0	78 D.NI	0.83	0.79 0	ty 0.75
218 class/	0.51	0.53	0.5	0.44	0.54	t 0.5	0.63	0.69	0.79	0.82	0.81 0	081 03	80 0.79	0.75	0.80	0.76	5.09 0.	56 0.38	0.24	0.23	0.26	0.27 0	1.28 0.	28 0.28	0.29	0.27	0.31	0.25 0.25	5 0.31	0.41	0.39 0.4	5 0.56	0.55 0.5	15 0.91	0.62	0.61 4	64 0.65	84.0	0.70 0.	70 O.T.	0.75	0.75 0	.75 0.79	2.79	0.75 0.	65 0.65
218 class8	0.56	0.40	0,4	0.35	0,43	0.6	0,48	0.58	0.63	0.71	0.75 0	174 0.7	.74 0.71	0.64	0.68	0.58	0.44 (0.	35 0.24	0.16	0.10	0.16	0.29 0	0.21 0.	2) 0.21	0.20	0.16	0.16	0.15 0.15	5 (0.20	0.26	0.27 0.3	5 0.61	0.44 0.4	18 0.57	0.61	0.60 0	063 0.63	0.65	0.67 0.	68 - 0,7	0.72	0.72 0	.73 0.73	0.74	0.73 0.	61 0.47
219 class6	0.29	0,47	0.56	0.68	0.79	0.8	0.82	0.82	0.82	0.83	0.83 0	061 -00	0.80	0.79	0,77	0.74	9,61 0.	45 0.30	0.22	0.15	0.12	0.23 0	1.42 0.	56 0.67	0.67	0.67	0.74	0.73 0.72	2 0.71	0.73	0.75 0.76	0.69	0.70 0.1	73. 0.72	0.71	0,71 4	(73 0.73	0.76	0.78 0.	6 ().7	0.78	0.79 0	.60 0.79	0.09	0.43 0.	38 0.63
219 class/	0.24	0.35	0,41	0.59	0.37	0.8	E: 0.84	0.84	0.84	1.85	0.85 0	00 03	82 0.HI	6.79	0.75	0.70	1.57 0.	43 0.32	0.23	81.0	0.17	0.25 0	5.40 0.	54 0.65	0.64	0.65	0.70	0.68 0.61	0.86	0.69	0.68 0.6	2 0.67	0.67 0/	17 0.69	0.68	D.6K C	.68 0.05	0.72	0.75 0.1	75 0.71	8.79	0.7X D	.37 0.76	0.65	0.43 0.	41 0.47
220 classo	0.63	0.69	9,72		0.80		0.85	0,84	0,85	0.85	0.85 0	U\$5 0.1	85 0.84	0.84	0.84	0.82	5.80 0.	KI (0.79	0.90	0.79	0,82	0.83 0	1.50 0.	68 0.50	0.34	0.23	0.32	0.31 0.16	5 0.06	0.18	0.15 0,1:	5 0.33	0.06 0.0	11 0.07	0.05	0,03 0	.10 0.13	0.24	0.43 0.	53 0.5	0.56	0.58 0	.40 0.73	0.73	0.83 0.	43 0,79
220 Class7	0.53	0.32	0.5	0.63	0.78	0.8	0.84	0.84	0.83	0.85	0.85 0	0.15 0.2	84 0.84	0.63	0.03	0.77	0.70 0.	81 8.79	0.75	0.74	0.79	0,80 0	2.70 0.	56 0.39	0.26	0.15	0.26	0.26 0.14	4 0.96	0.16	0.12 0.0	0.07	0.04 0.1	12 0.09	0.04	0.04 0	.10 0.11()	0.25	0.40 0.	47 6.0	0.53	0.54 0	34 0.66	0.71	0.81 0.	k3 0.75
221 Class5	0.20	0.40	0.65	0.65	0.5	-	0.82	0.84	0.84	ILAS.	0.85 0	(45 0)	34 0.84	6.03	0.81	0.75	a,73 0.	52 0,34	0.28	0.18	0.21	0.59 0	0.62 0.	0.75	0.75	0,78	0.79	0,77 0.96	0.82	6.37	0.77 0.88	0.79	0.78 0.7	7 0.00	.0.162	0.78 0	(78 0.78	0.75	0.74 0.	14 0.5	8.74	0.73 0	44 0.62	0.53	6.33 0.	24 0.15
221 classo	0.21	0.34	0.5	0.58	0.68	07	0.78	0.89	0,78	0.79	0.79 0	UND DJ	80 0.79	0.78	0.78	0.73	2.66 0.	e9 0.35	0.29	0.23	0.26	0.37 4	0.51	57 0.62	0.64	0.65	0.71	0.69 0.65	0.69	0.67	0.65 0.64	5 0.64	0.64 83	13 0.64	0.63	0.64 0	0.65 0.65	0.66	0.70 0.	0.2	0.74	0.71 0	40 0.59	22.0	0.40 0.	32 0.28
221 class7	0.34	0.33	0.4	0.50	0.56	0.71	0.72	0.76	0.73	0.75	0.73 0	673 0.	.73 0.70	C.F.S	0.74	80.0	3.56 Q.	42 0.33	0.50	0.25	0.28	0.34 0	1.14 0.	46 0.52	0.54	0.53	9.37	0.58 0.51	0.54	0.54	0.52 0.5	2 0.51	0.51 0.5	0.51	0.51	0.50 0	031 031	0.52	0.56 0.5	1 0.9	0.57	0.49 0	34 0.33	0.31	0.27 0.	26 0.25
222 class5	0.28	8.46	0.64	0.57	0.73		0.18	0.84	0.0	1.15	e.as e	7	A3 11,63	0.84	1.00	0.0	1. O.	6 0.30	0,46	0.39	0.45	0.37 0		72 0.75	0.6)	0.60	0,43	6.39 Q.66	8.77	0.A1	0.64 0.7	0.71	0.66 87	1 0.7	0.76	0.66	A7 0.64	0.60	0.60 0.	58 (0.6)	0.60	0.37 0	42 0,38	0.32	0.17 0.	11 0,07
222 Classo	0.23	0.38	0.5	0.50	0.65	8.7	0.77	9,83	2.03				84 0.83	2.83	2.45		2.72 0.	0.43	0.39	10.0	0.33	0.47 0		0.5 0.64	0.56	0.56	0.61	0.01 0.06	0.76	243	260 8.7	0.70	0.67 0.5	9.71	8.74	0.86	0.61	0.62	0.02 0.1	0.6	1.63	0.00	.50 0.45	0.37	8.21 0.	13 0.06
222 class/	eine	0.17	0.3	0.38	6.41			O.A.					4.77	8.75	0.13		eret 0.	0.13	0.85	0.01	0.00	9.42 0	0.		0.57	0.54	0.07			0.00		0.05	0.00 0.0				4.45		00	0.8	0.00	000	0.64	0.49		0.03
223 class0	0.37	0.48	0.5	0,47	0.68	0.5	0.66	0.0	0.82		0.00		10 11.83	6.83	2.85	2.84		61 D.MA	0.83	0.05	0.70	0.00		0.66	0.33	6.29	0.00	0.4)	0.62	0.5	9.57 0.4	0.42	0.05 0.0	0,33	0.58	0.98	0.37	#28	0.04 0.	or 0.3	6.33	0.00 0	2/ 0.20	0.21	0.13 0.	Ar 0.11
223 class7	0.12	0.20	0.54	0.37	0.43	0.5	0.61		0.18	0.82			.75 8.70	6.85	0.05	0.56	0.42 0.	50 0.31		0.20	0.50	0.41 0	aer 0.	34 0.61	0.48	0.33	0.43	0.50 0.63	0.75	Care.	0.0	0.67		0.71	0.75		0.43	0.62	0.00	0 0.6	-3.50	0.52 0	0.25	0.21	0.09 0.	10 0.03
224 class7	0.36	6.43	0.5	0.52	0.00		0.76	4.73	0.57				45 0.KS	0.54		0.01	0.	0.64		4.17	W.FF	0.00		0.04	0.42	0.00	0.00	0.13 0.33	0.91	6.77	0.0 0.0	0.38	0.09 0.0	0.32	0.03	0.00 0	0.19	0.13	0.17 0.		0.14	0.17 0	20 0.18	0.09	0.14 0	10 0.04
224 clase9	0.39	0.42	0,4)	9.50	0.50		0.68	0.53	0.48			03	60 0.01	0.55	0.41	4.34	0.01	0.41	0.10	.9.57	0.35	0.35		33 0.40	0.52	0.09	4.57	0.50 0.50	0.58	0.33	4.03 0.34	0.36	4.64	N2 0.34	0.53	0.50 1	0.00	0.29	0.00 0.0	9.2	0.25	0.15 0	21 0.22 A2 A.T	0.00	0.15 0.	20 0.22
224 010350	0.20	0.22	0.25	0.31	6.29	2.40	6.43	0.34	0.58	1.82			6.6	0.50	0.43	1.29	nad 0.	0.18	0.14	0.18	0.10		ned i O	ar: d33	0.37	0.42	0.47	201 0.31	0.52	0.52	9.57 0.5	0.69	0.56 0.3	0.51	0.52	w.0 (0.53			0.59	6.58 0	0.40	0.58	-24 0.	10 0.26



Fuel prices

- Coal supply curves come from EPA IPM v5.16
 - 70 coal types from 37 supply regions
 - Plant-level transportation costs
- Gas supply curves are calibrated to AEO 2017 resource scenarios
 - Regional gas delivery costs are based upon regional electric sectors markups over Henry Hub prices in AEO 2017
- Realized prices are a model result, based on where along the supply curve the model winds up
- Motor gasoline and diesel at AEO delivered prices







Foresight

- Previous runs were done with full foresight across the entire model horizon
- TIMES also allows limited, overlapping foresight windows
- The model solves with full foresight for the first window, then freezes the results for a portion of the foresight window, moves forward in time, and solves again
- This facility can be used to "surprise" the model with a new policy or a change in costs and evaluate the "regret" costs of myopia
- In these runs we've used it to reduce model size

Periods	2016	2018	2021	2025	2030	2035	2040	2045	2050			
Years	2016	2017-2019	2020-2022	2023-2027	2028-2032	2033-2037	2038-2042	2043-2047	2048-2052			
SOLVES			FIRST PASS									
	frozen to first SECOND PASS											
	frozen to second THIRD PASS											



Retirement

• When the model is given the option to economically retire existing units, it compares the net present value of keeping the existing unit in place (considering its fixed costs and operating and fuel costs) against the NPV of alternatives for meeting load



Storage

- Storage is modeled by specifying costs, charging rates, and losses
- Storage can be defined at the season, week, or time-of-day level
 - It links inputs and outputs across time slices in the model equations
- Storage technologies are characterized by specifying costs, charging/discharging rates, losses, and contribution to meeting reserve requirements, if any
- Any device (e.g., vehicles) can have storage capability added
- A range of storage costs/capabilities will be tested in scenarios



Battery costs from NREL 2017 ATB



Figure 31. Battery system capital costs for an 8-hour battery on a \$/kW basis (left) and a \$/kWh basis (right) for the low, mid, and high trajectories.

We are using the Mid and Low cases for these runs.



Model details: Light Duty Vehicles

Vehicle types

Gasoline ICE Vehicles TDI Diesel ICE Ethanol-gasoline Flex Fuel ICE Natural Gas ICE Natural Gas-gasoline Flex fuel ICE Electric-Diesel Hybrid Electric-Gasoline Hybrid Plug-in Gasoline Hybrid All Electric Vehicle

Vehicle Size Classes

Mini-compact Cars
Subcompact Cars
Compact Cars
Midsize Cars
Large Cars
Two Seater Cars
Small Pickup
Large Pickup
Small Van
Large Van
Small Utility
Large Utility

Starting data from AEO, with scenario analysis on key technologies

