FACETS Modeling for Dane County Climate Council

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December 8, 2017

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

Select Scenario

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

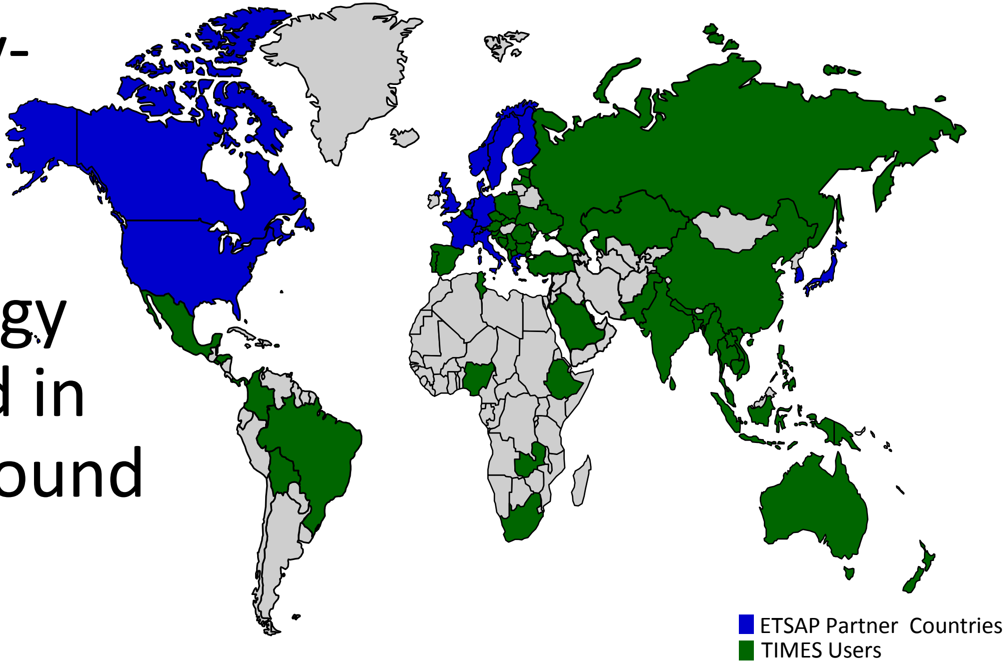
using results portals like this one
http://beta.vedaviz.com/Portal/Playground.aspx?p=F17_01Sep17&g=dcdc39

Recent FACETS analyses

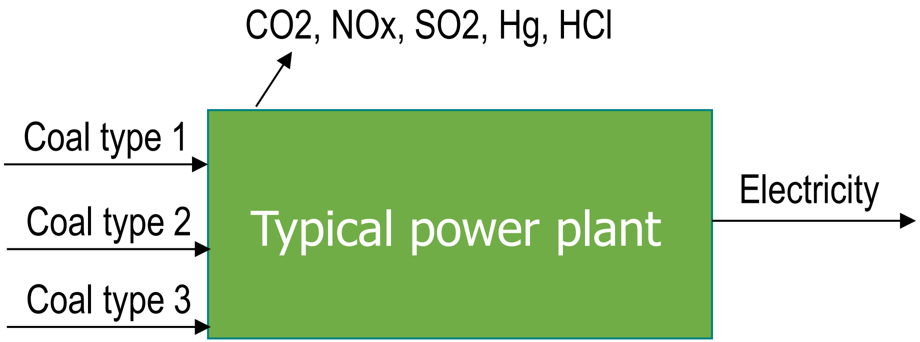
- Midcontinent Power Sector Collaborative
    - Midcentury power sector and transport electrification and decarbonization analysis
- Vermont Total Energy Study
    - Policy and technology options to meet Vermont’s GHG emissions reduction and renewable energy goals
- Clean Power Plan
    - Dozen of variations 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 technologically-detailed, 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



CO2, NOx, SO2, Hg, HCl

Coal type 1

Coal type 2

Coal type 3

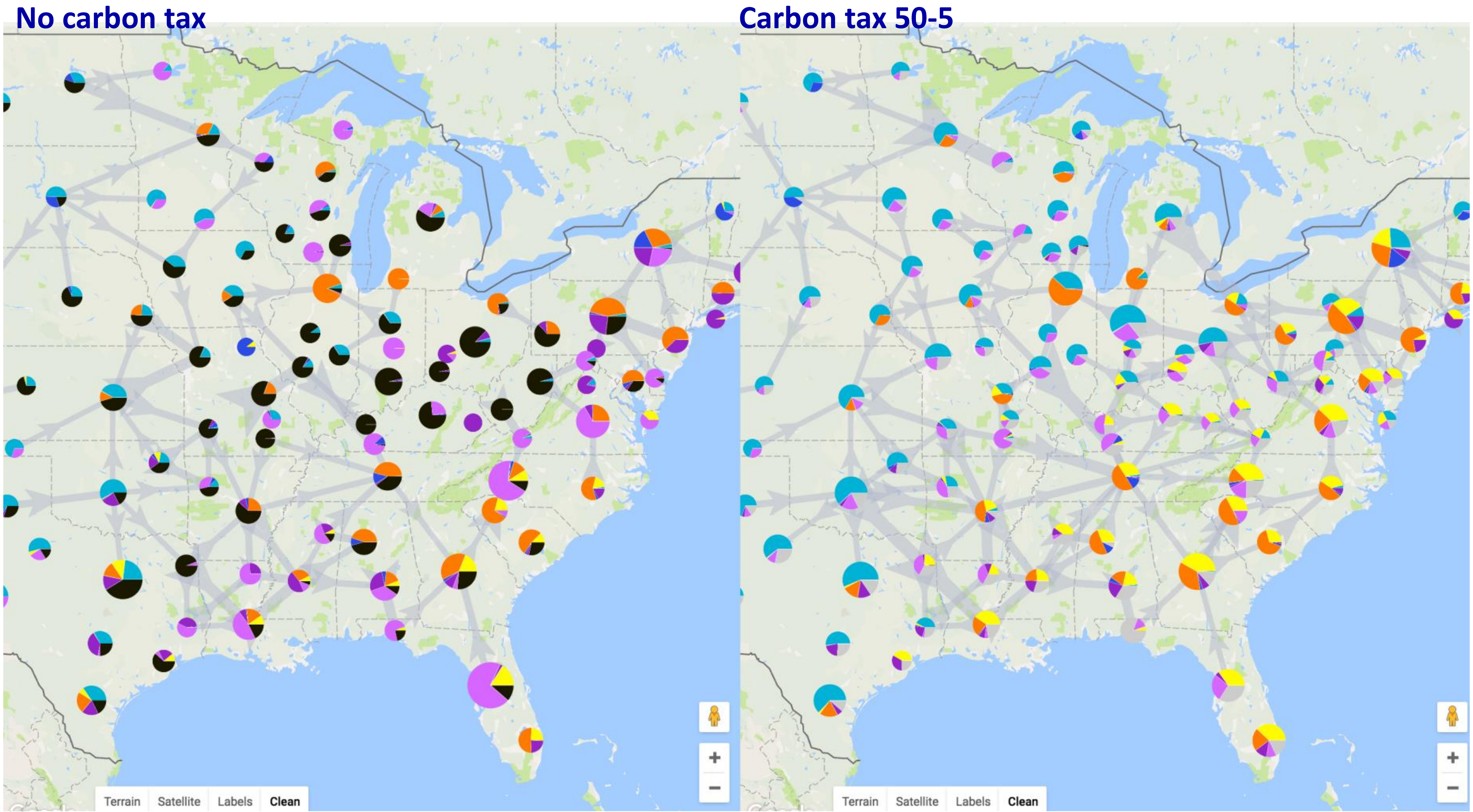
Typical power plant

Electricity

- 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



No carbon tax

Carbon tax 50-5

2050 generation and trade flows

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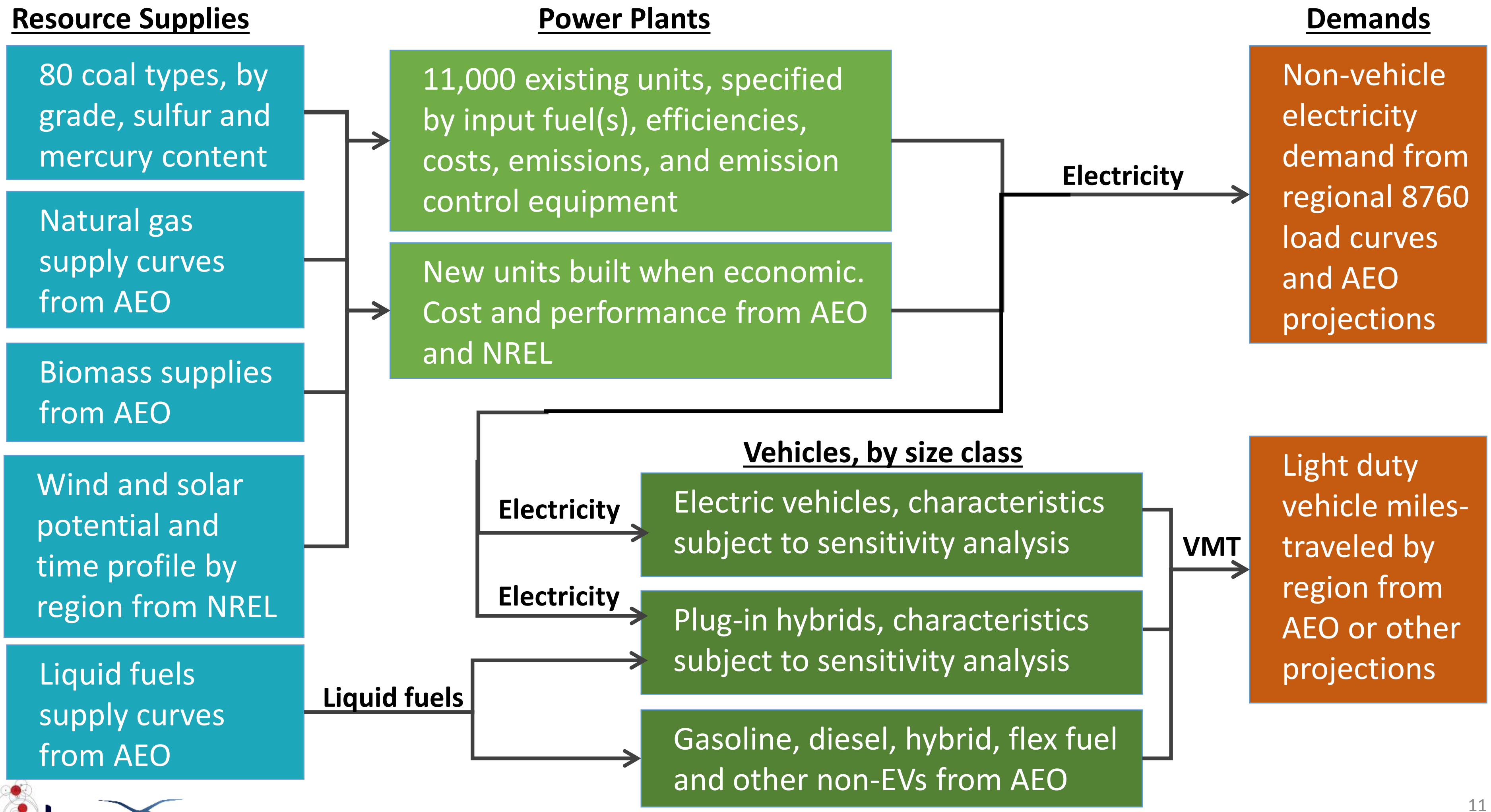
Example analysis: MPSC

- Goals
  - To map out and assess plausible futures in the electricity and light-duty 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



Resource Supplies

80 coal types, by grade, sulfur and mercury content

Natural gas supply curves from AEO

Biomass supplies from AEO

Wind and solar potential and time profile by region from NREL

Liquid fuels supply curves from AEO

Power Plants

11,000 existing units, specified by input fuel(s), efficiencies, costs, emissions, and emission control equipment

New units built when economic. Cost and performance from AEO and NREL

Vehicles, by size class

Electric vehicles, characteristics subject to sensitivity analysis

Plug-in hybrids, characteristics subject to sensitivity analysis

Gasoline, diesel, hybrid, flex fuel and other non-EVs from AEO

Demands

Non-vehicle electricity demand from regional 8760 load curves and AEO projections

Light duty vehicle miles-traveled by region from AEO or other projections

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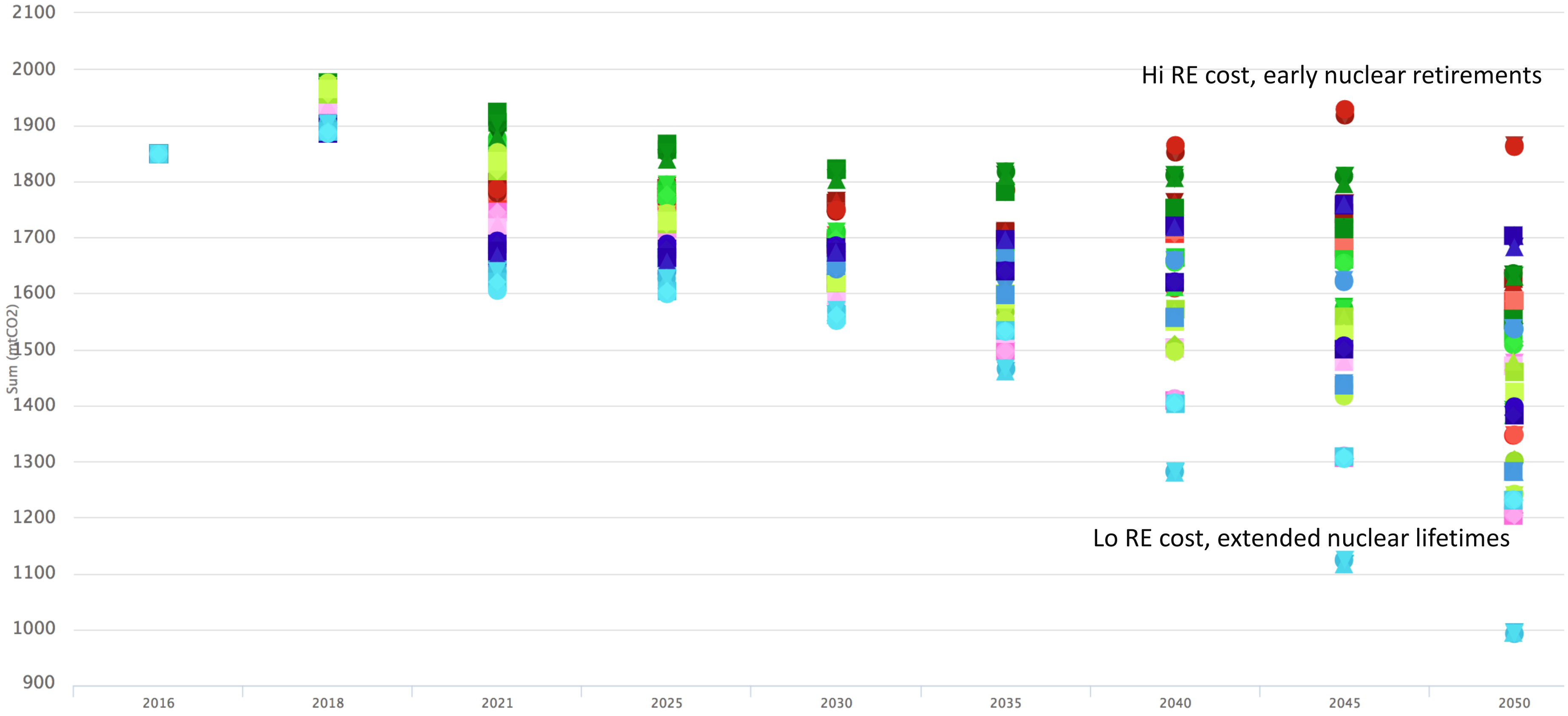
Results: In response to uncertainties, we see a wide range of "BAU" national CO2 emissions (MMT)

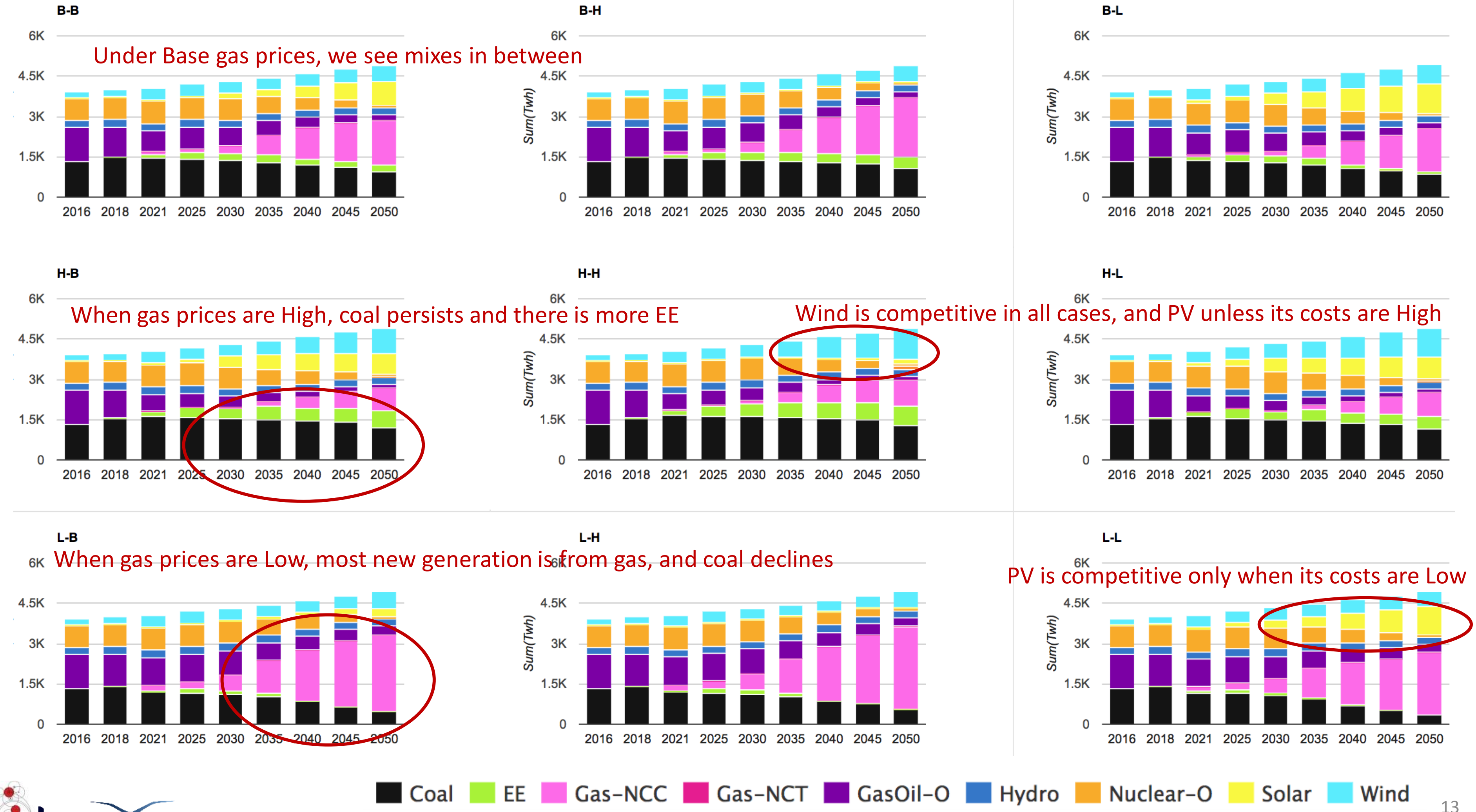


Hi RE cost, early nuclear retirements

Lo RE cost, extended nuclear lifetimes

…ranging 23-60% below 2005 levels.

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



Under Base gas prices, we see mixes in between

When gas prices are High, coal persists and there is more EE

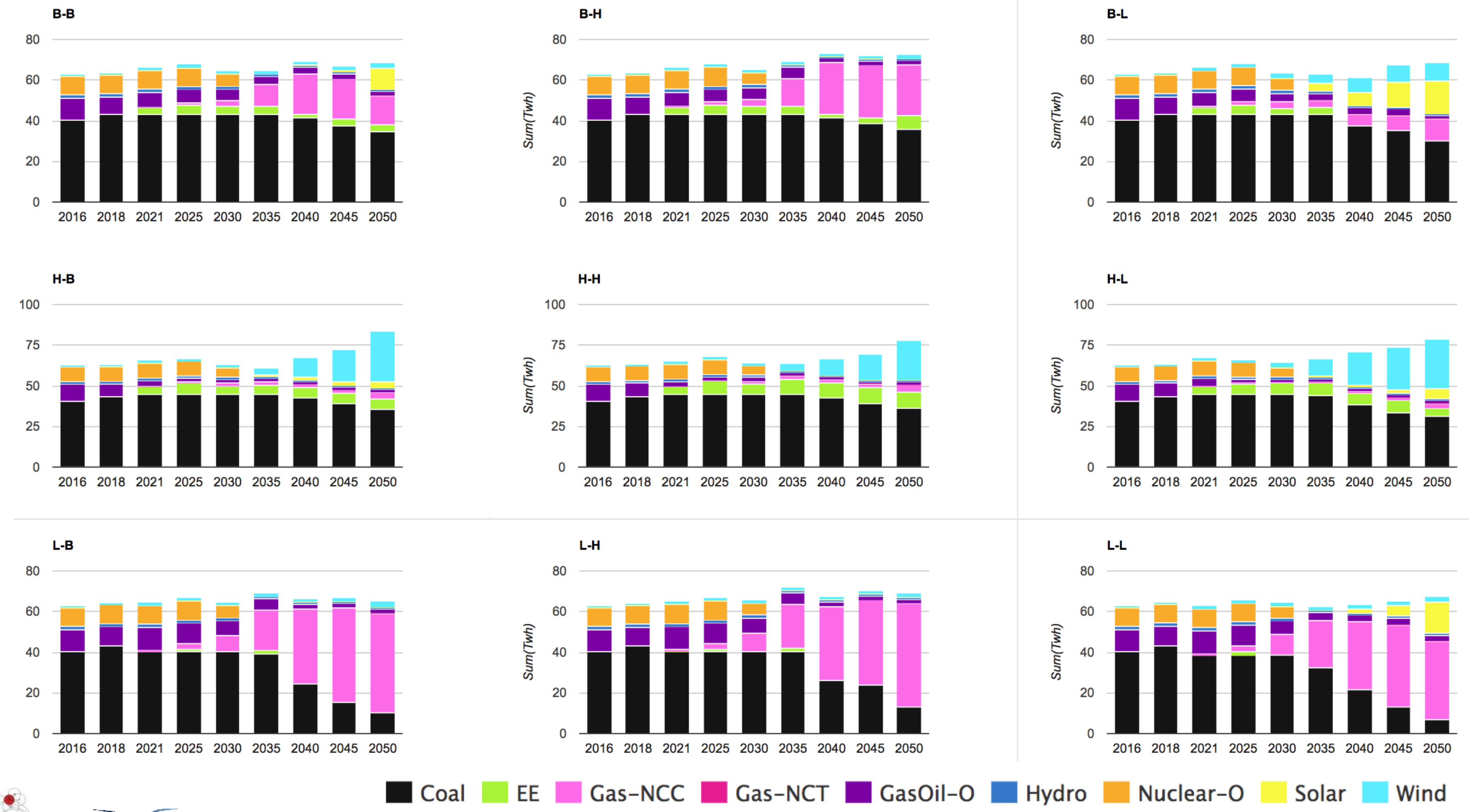
Wind is competitive in all cases, and PV unless its costs are High

When gas prices are Low, most new generation is from gas, and coal declines

PV is competitive only when its costs are Low

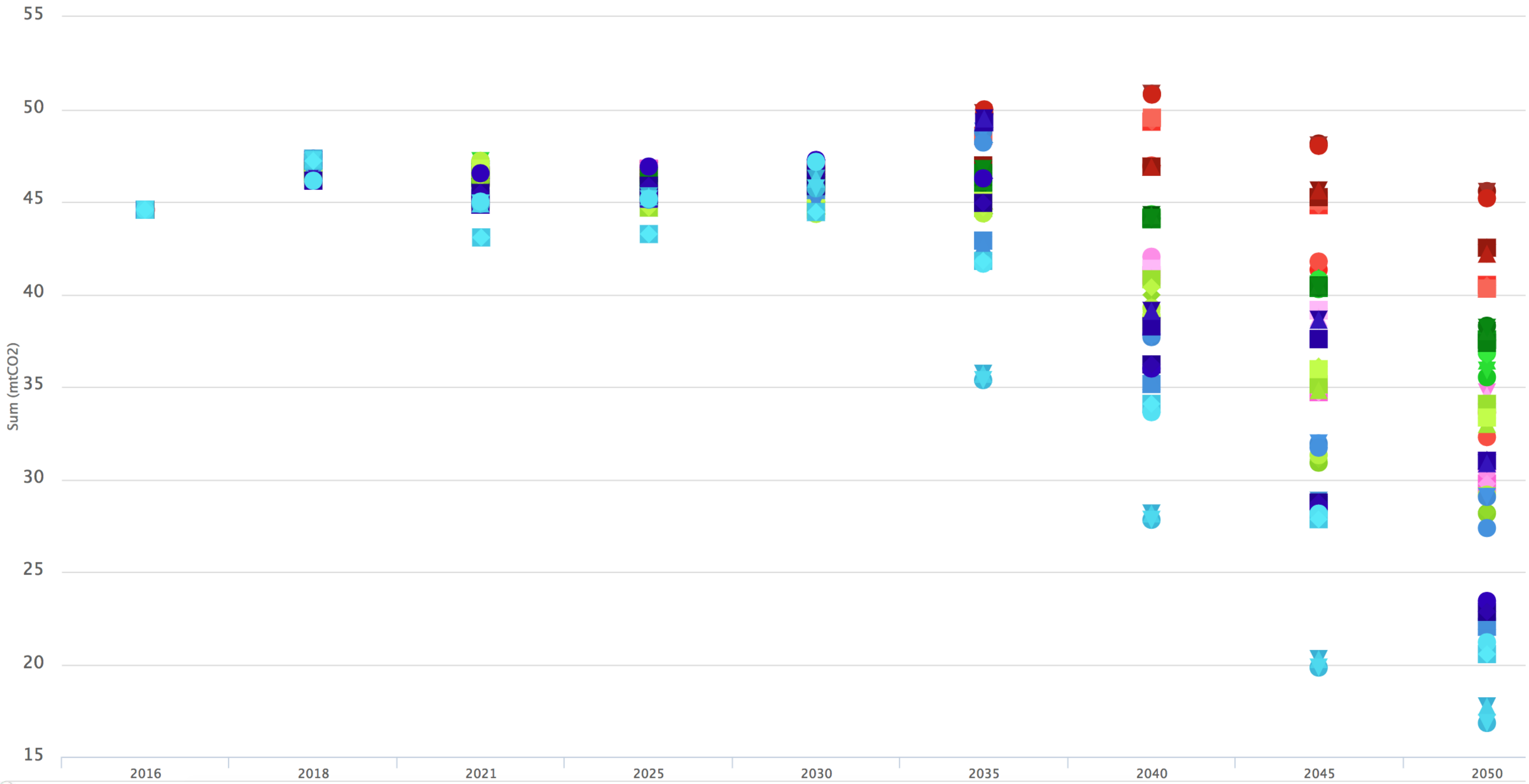
Scenarios are labeled first by gas prices (Base/High/Low), then RE costs

MISO region 2 generation mix under the same scenarios



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



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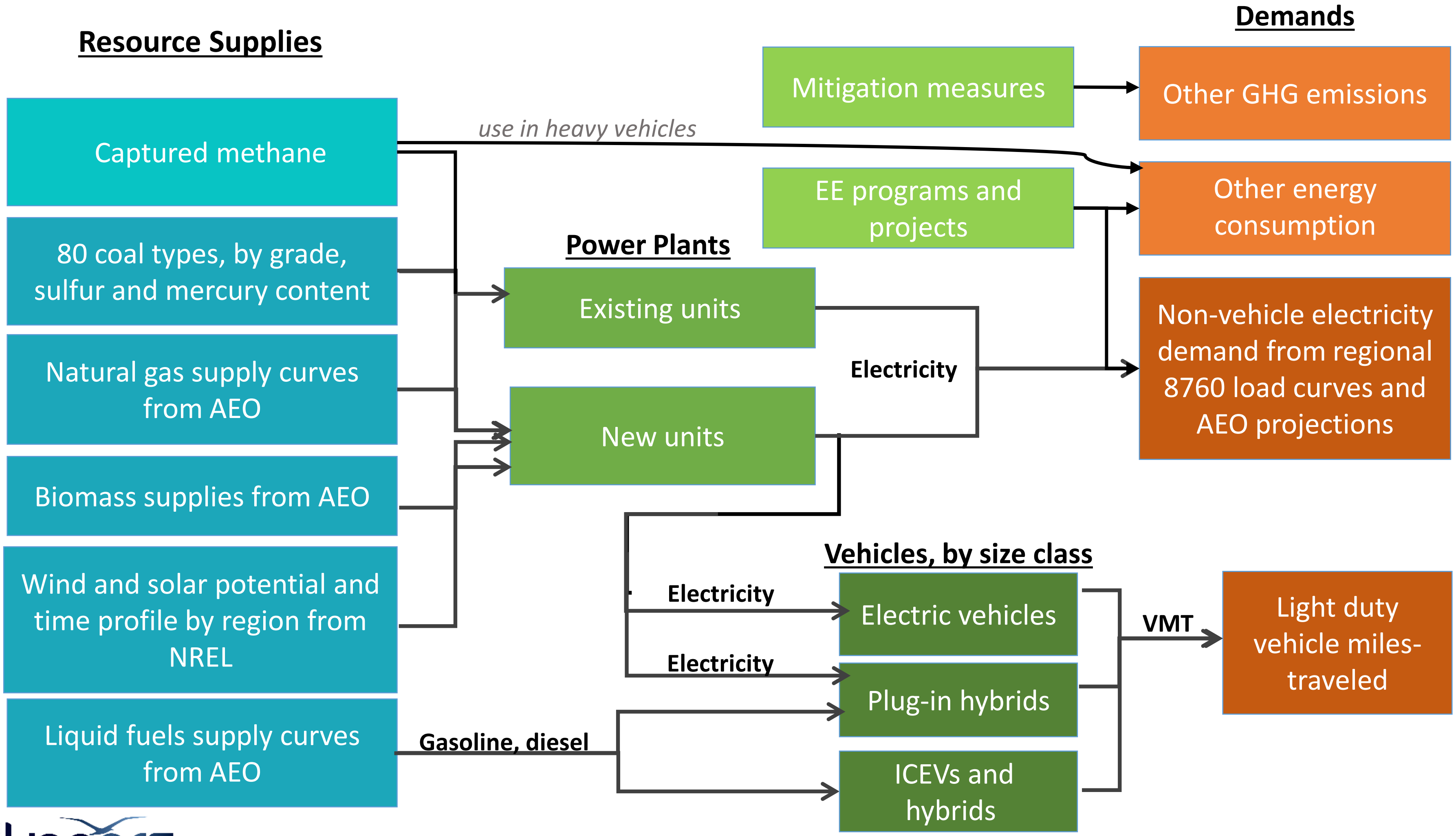
Dane County modeling process

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



Resource Supplies

Captured methane

80 coal types, by grade, sulfur and mercury content

Natural gas supply curves from AEO

Biomass supplies from AEO

Wind and solar potential and time profile by region from NREL

Liquid fuels supply curves from AEO

Power Plants

Existing units

New units

Vehicles, by size class

Electric vehicles

Plug-in hybrids

ICEVs and hybrids

Demands

Other GHG emissions

Other energy consumption

Non-vehicle electricity demand from regional 8760 load curves and AEO projections

Light duty vehicle miles-traveled

Mitigation measures

EE programs and projects

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

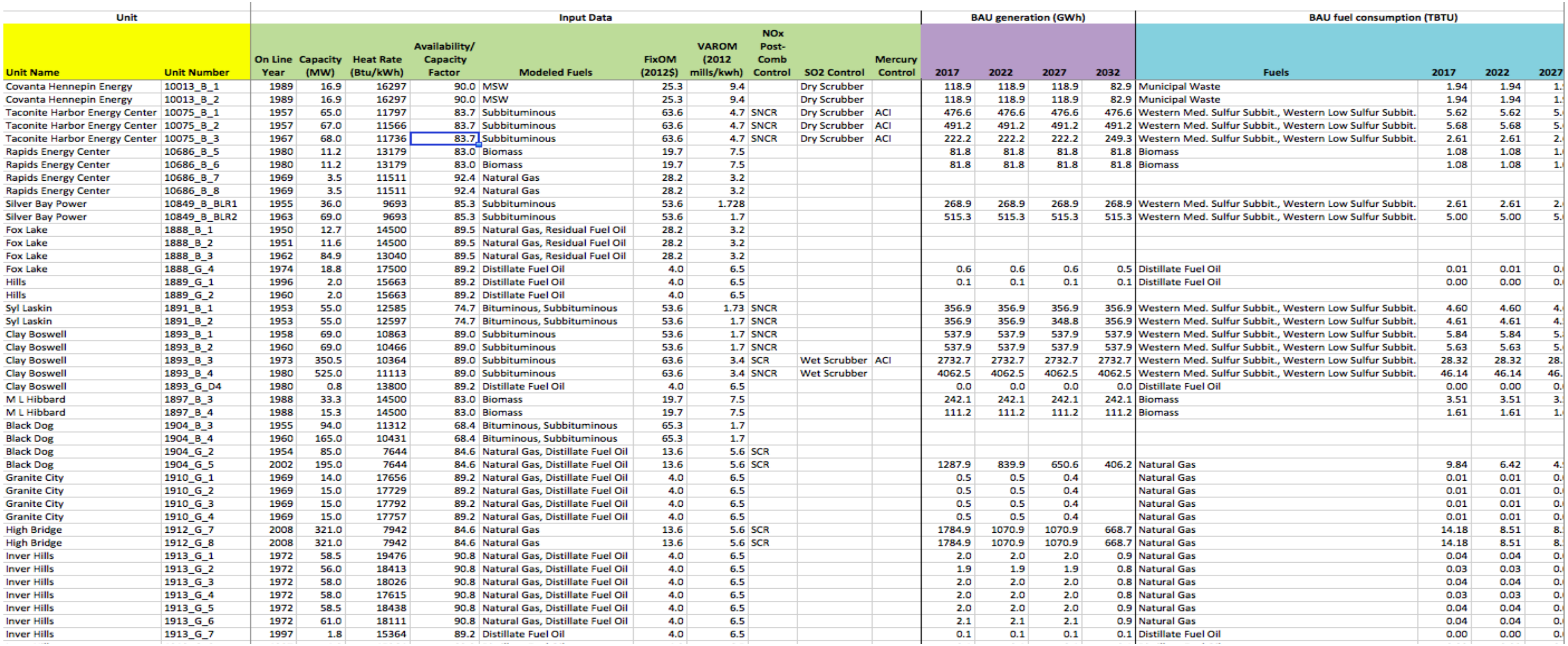
See http://www.facets-model.com or contact Evelyn.L.Wright@gmail.com

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

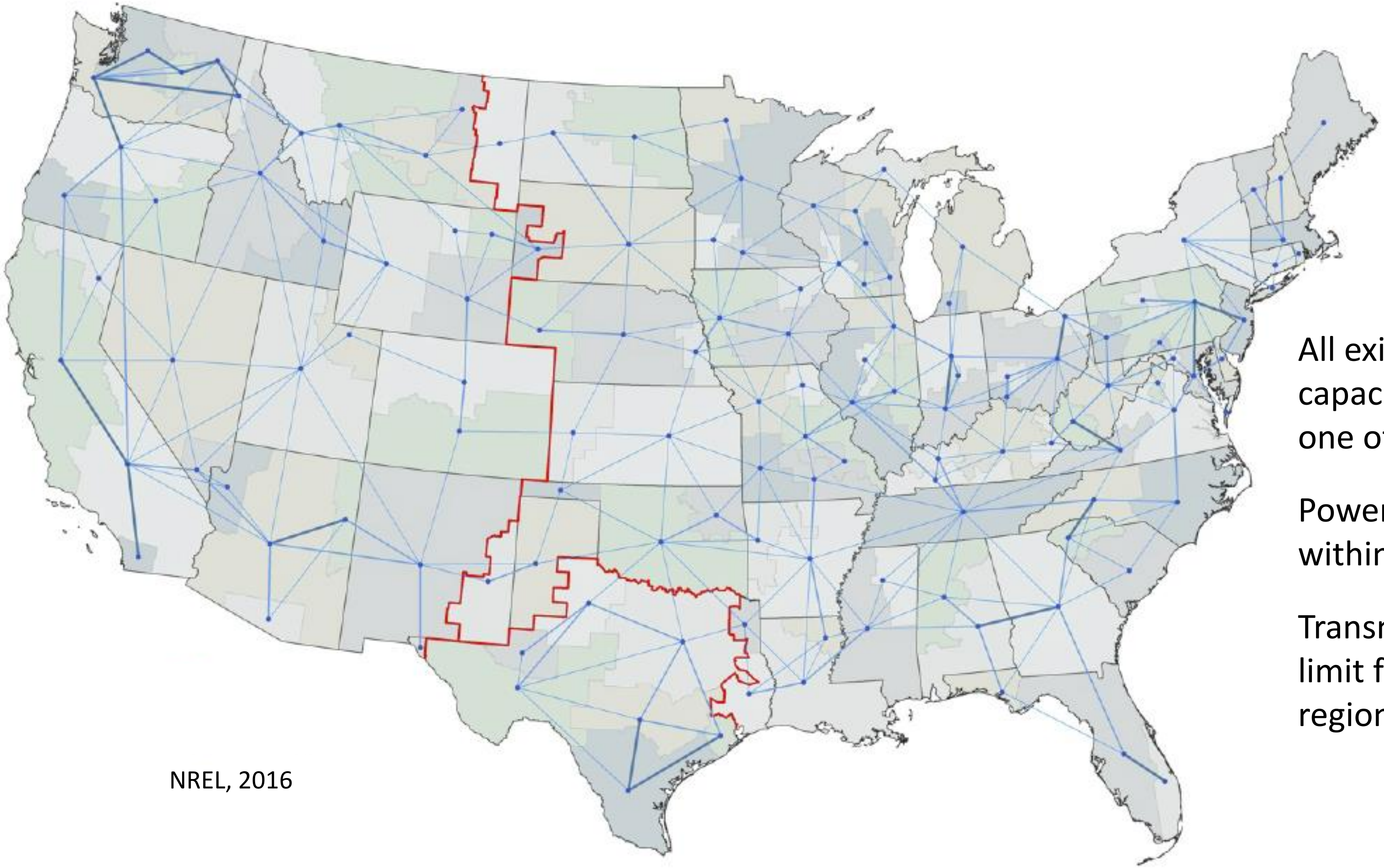
All FACETS data is open, explicit, and available for adjustment



Unit		Input Data										BAU generation (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_G_2	1960	2.0	15663	89.2	Distillate Fuel Oil	4.0	6.5											
Syl Laskin	1891_B_1	1953	55.0	12585	74.7	Bituminous, Subbituminous	53.6	1.73	SNCR			356.9	356.9	356.9	356.9	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	4.60	4.60	4.
Syl Laskin	1891_B_2	1953	55.0	12597	74.7	Bituminous, Subbituminous	53.6	1.7	SNCR			356.9	356.9	348.8	356.9	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	4.61	4.61	4.
Clay Boswell	1893_B_1	1958	69.0	10863	89.0	Subbituminous	53.6	1.7	SNCR			537.9	537.9	537.9	537.9	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	5.84	5.84	5.
Clay Boswell	1893_B_2	1960	69.0	10466	89.0	Subbituminous	53.6	1.7	SNCR			537.9	537.9	537.9	537.9	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	5.63	5.63	5.
Clay Boswell	1893_B_3	1973	350.5	10364	89.0	Subbituminous	63.6	3.4	SCR	Wet Scrubber	ACI	2732.7	2732.7	2732.7	2732.7	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	28.32	28.32	28.
Clay Boswell	1893_B_4	1980	525.0	11113	89.0	Subbituminous	63.6	3.4	SNCR	Wet Scrubber		4062.5	4062.5	4062.5	4062.5	Western Med. Sulfur Subbit., Western Low Sulfur Subbit.	46.14	46.14	46.
Clay Boswell	1893_G_D4	1980	0.8	13800	89.2	Distillate Fuel Oil	4.0	6.5				0.0	0.0	0.0	0.0	Distillate Fuel Oil	0.00	0.00	0.
M L Hibbard	1897_B_3	1988	33.3	14500	83.0	Biomass	19.7	7.5				242.1	242.1	242.1	242.1	Biomass	3.51	3.51	3.
M L Hibbard	1897_B_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_B_3	1955	94.0	11312	68.4	Bituminous, Subbituminous	65.3	1.7											
Black Dog	1904_B_4	1960	165.0	10431	68.4	Bituminous, Subbituminous	65.3	1.7											
Black Dog	1904_G_2	1954	85.0	7644	84.6	Natural Gas, Distillate Fuel Oil	13.6	5.6	SCR										
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	17656	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	17729	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	17792	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



NREL, 2016

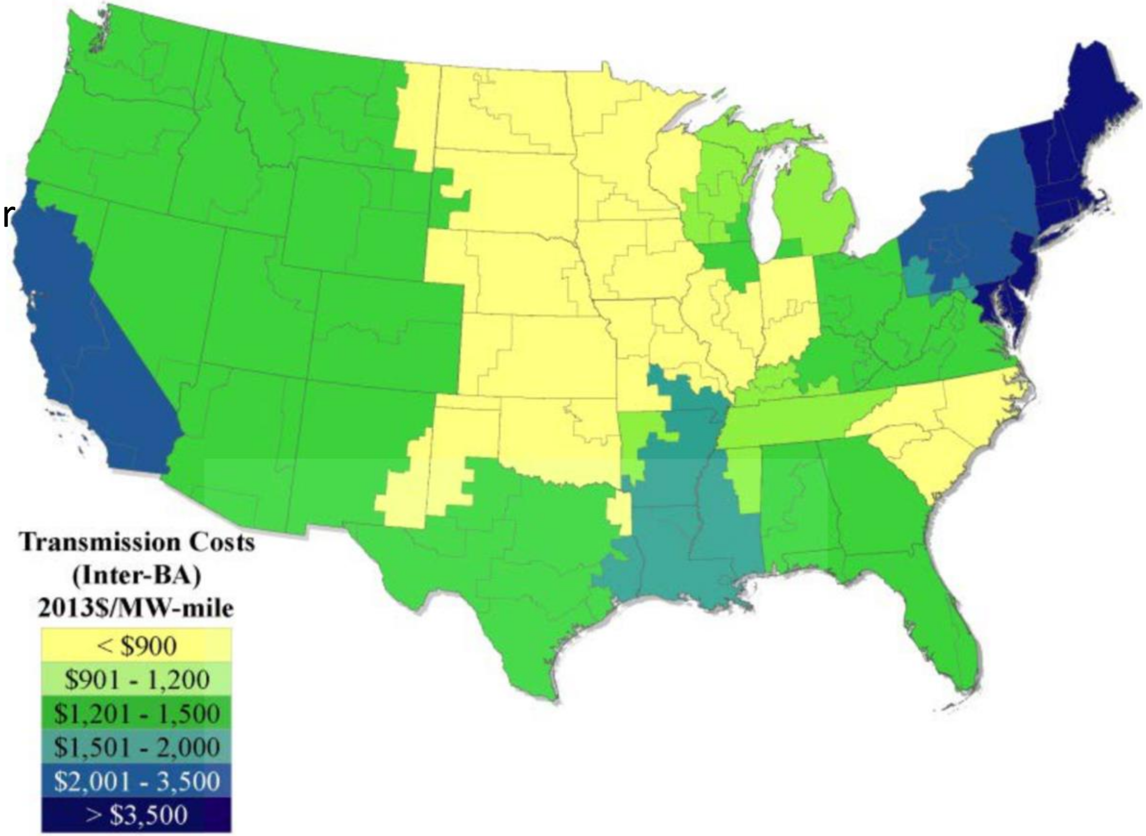
All existing and new capacity is located in one of these regions.

Power can flow freely within each region.

Transmission "pipes" limit flows between regions.

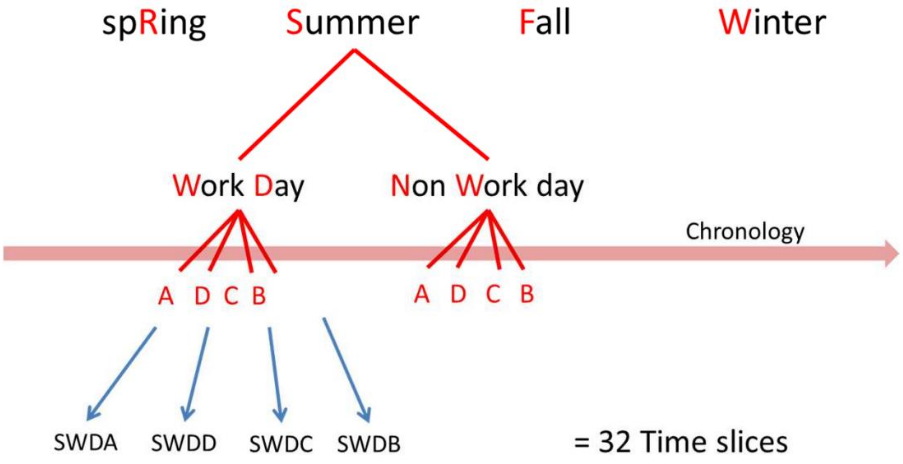
Transmission

- 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

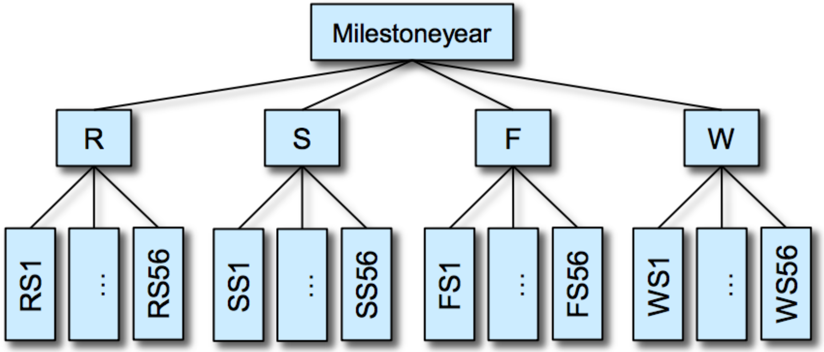


Time is represented by dividing up the year into slices

- 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

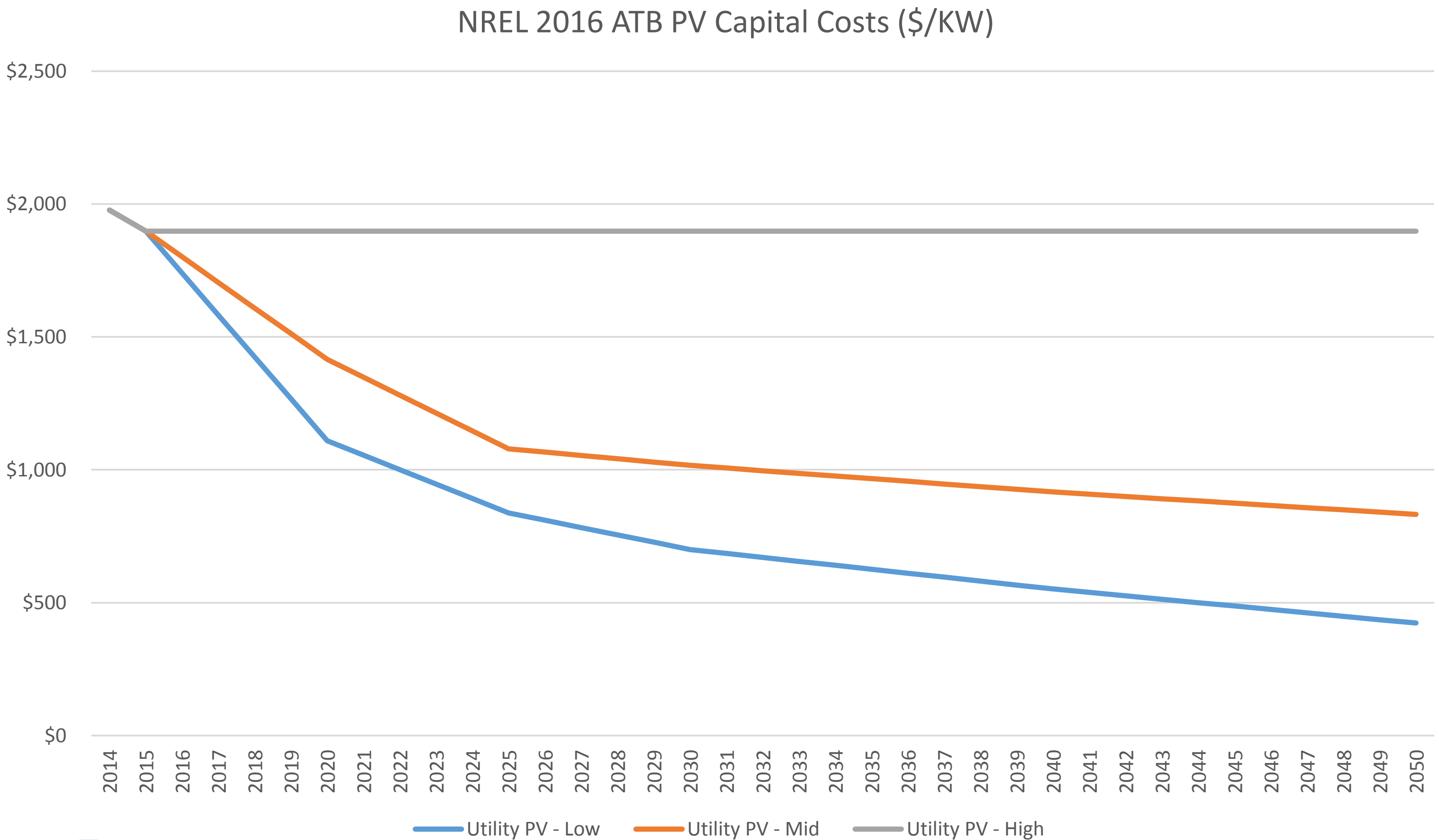
224 time slices

Technology costs

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

	Base Capital Cost ($/KW) – regional multipliers apply						FIXOM	VAROM	Efficiency		
	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)



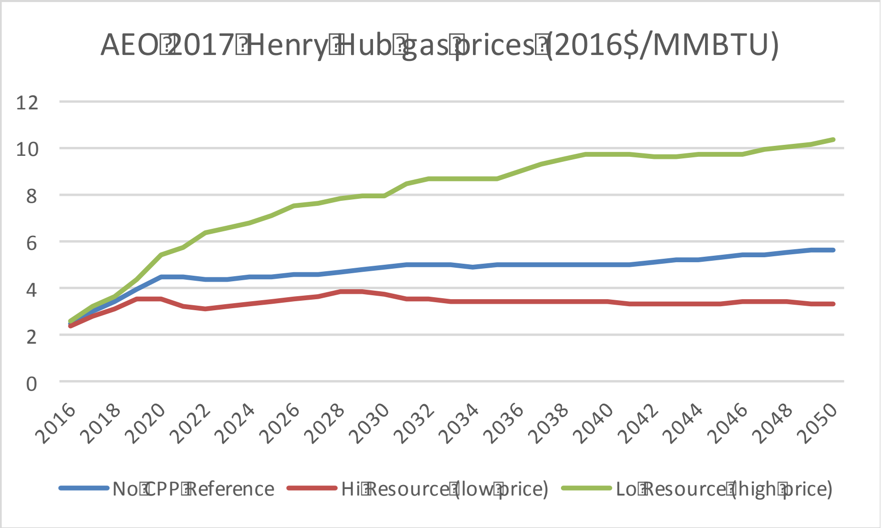
Detailed wind and solar resource data from NREL

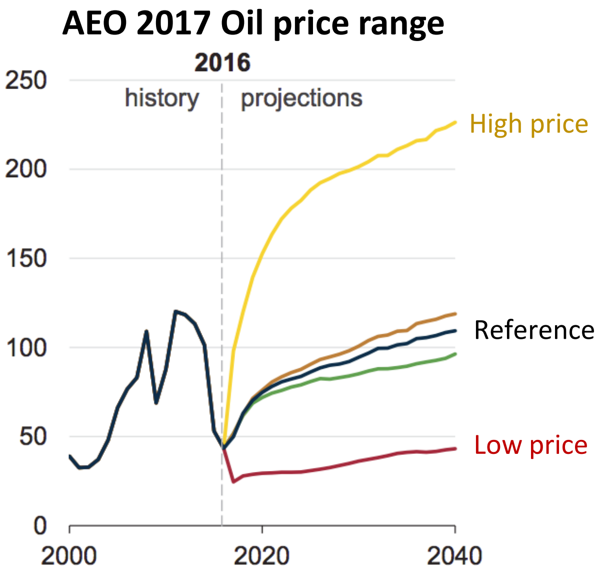
- Potential, grid integration cost, and typical hourly generation by region and class
- 10565 onshore wind options, in 356 supply regions

Region	Class
212	class1
212	class2
212	class4
212	class5
212	class6
212	class7
212	class8
212	class9
213	class5
213	class6
213	class7
213	class8
214	class3
214	class4
214	class5
214	class6
214	class7
214	class8
214	class9
215	class6
215	class7
215	class8
216	class4
216	class5
216	class6
216	class7
216	class8
216	class9
217	class6
217	class7
217	class8
217	class9
218	class5
218	class6
218	class7
218	class8
219	class6
219	class7
220	class6
220	class7
221	class5
221	class6
221	class7
222	class5
222	class6
222	class7
223	class6
223	class7
224	class6
224	class7
224	class8

Fuel prices

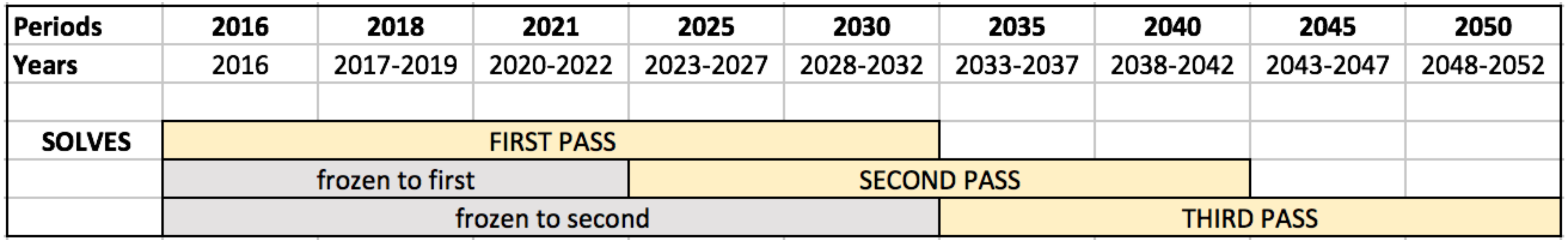
- Coal supply curves come from EPA IPM v5.16
  - 70 coal types from 37 supply regions
  - Plant-level transportation costs
- Gas supply curves are calibrated to AEO 2017 resource scenarios
  - Regional gas delivery costs are based upon regional electric sectors markups over Henry Hub prices in AEO 2017
- 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

Electricity in - Summer morning

Battery storage

Electricity out - Summer peak

Efficiency of Electricity out/Electricity in
Capital cost/MWh capacity

Battery costs from NREL 2017 ATB

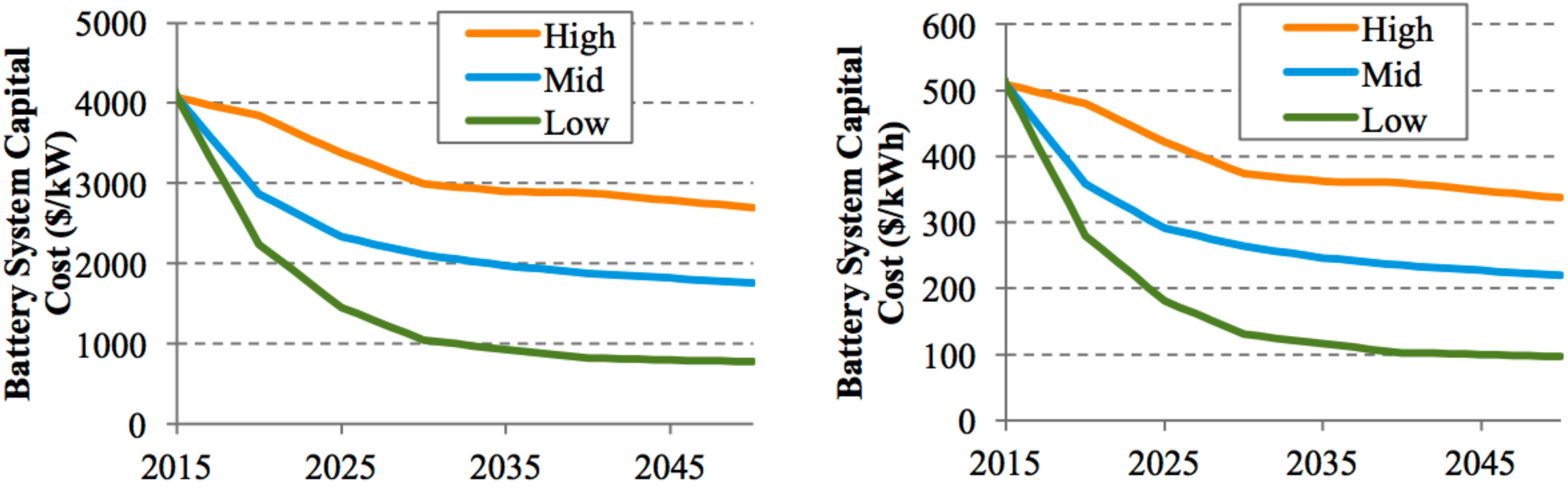


Figure 31. Battery system capital costs for an 8-hour battery on a $/kW basis (left) and a $/kWh basis (right) for the low, mid, and high trajectories.

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