Accommodating Variable Renewable Energy in the Integrated Planning Model

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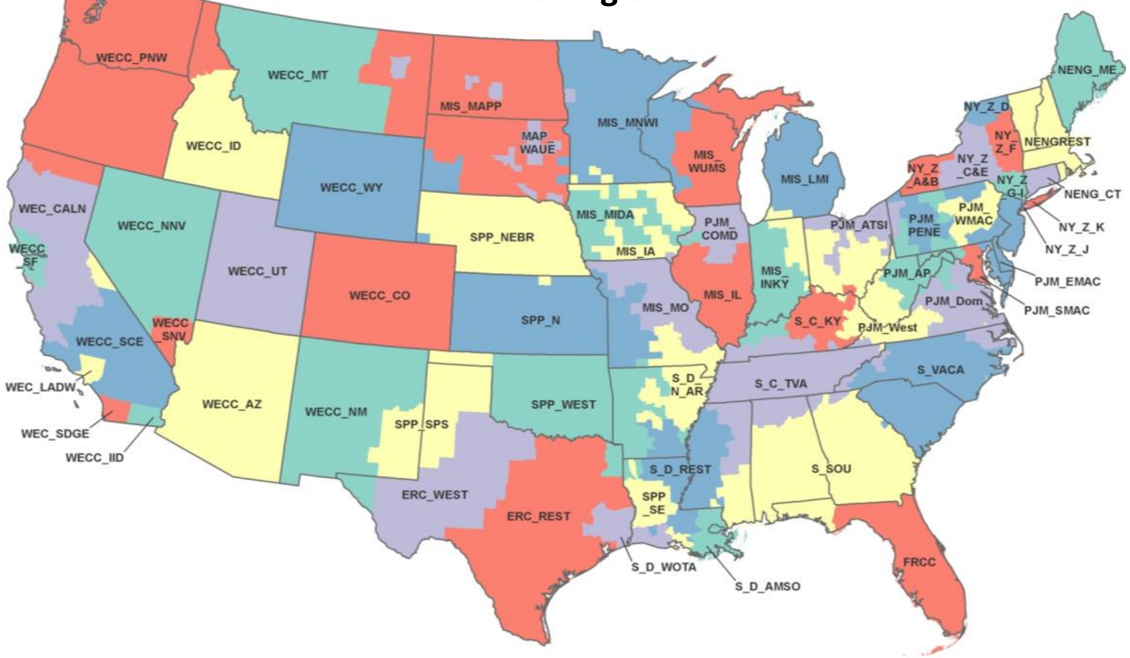
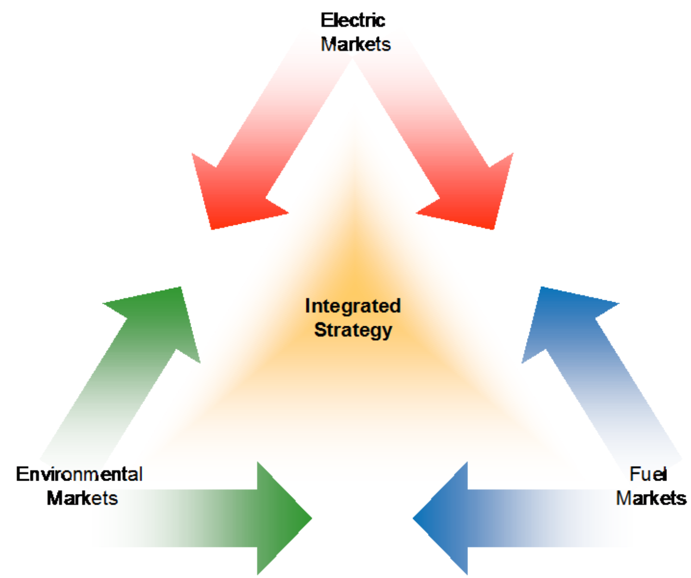
What is the Integrated Planning Model?

- The Integrated Planning Model (IPM) is a long-term capacity expansion and production costing model for analyzing the North American electric power sector.
  - Multi-regional, deterministic, dynamic linear programming model.

IPM v5 Regions





- Finds the least-cost solution to meeting electricity demand subject to environmental, transmission, fuel, reserve margin, and other system operating constraints.

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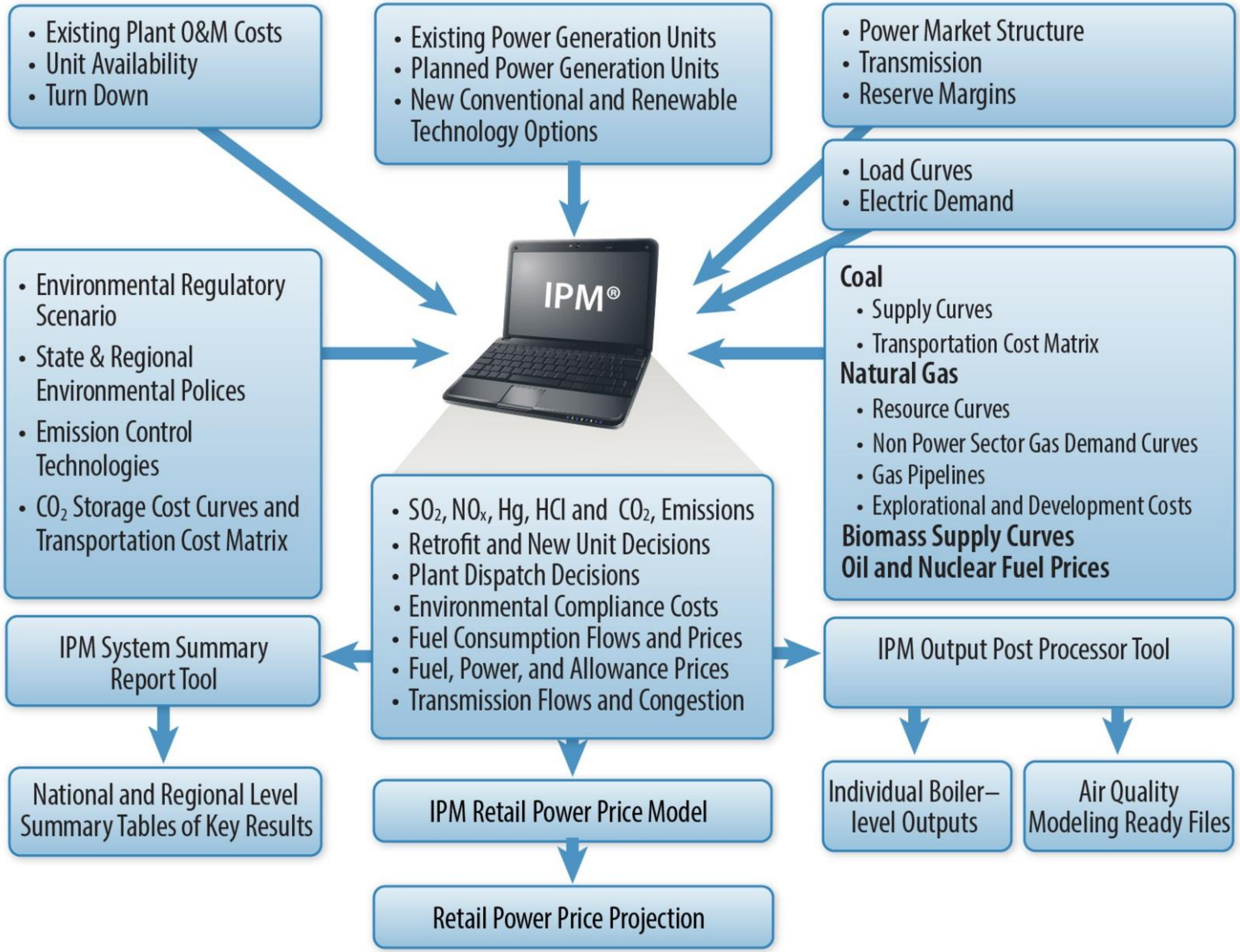
Inputs and Outputs of IPM



This graphic was obtained from ICF International

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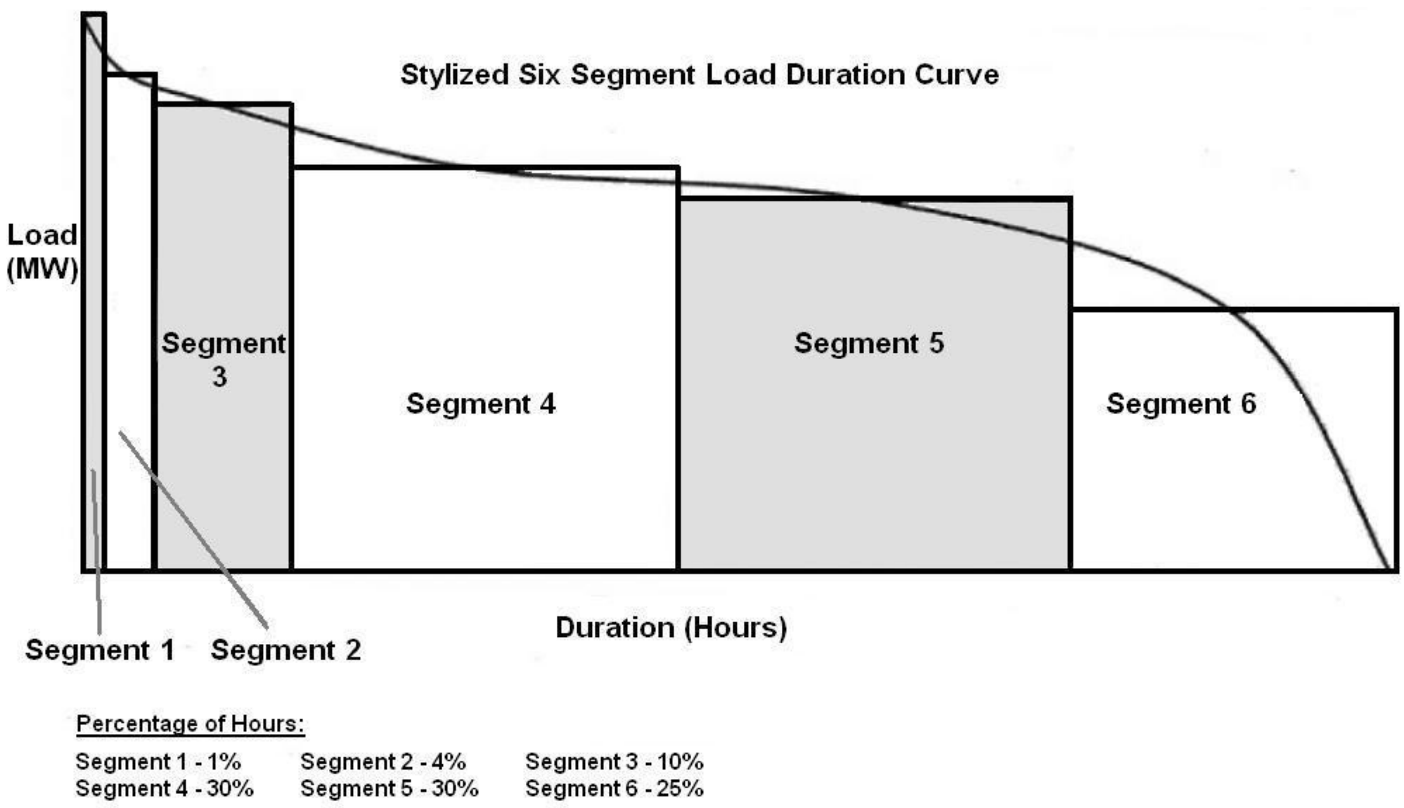
Key Methodological Features of IPM

- IPM is a flexible modeling tool for obtaining short- and long-term projections of production activity in the electric generation sector.
  - **Model run years**
  - **Model plants**
  - **Endogenous fuel modules**
  - **Perfect competition**
  - **Solves with perfect foresight by time segment**



Key Methodological Features of IPM: Transmission

- IPM represents power transmission as energy and capacity transfers among the IPM regions.
- Projected transfers are determined by the IPM optimization subject to constraints on the maximum flow on a transmission link.
  - Constraints are based on public sources, where possible
  - Two types of constraints – bilateral and joint
- IPM's also includes interregional transmission losses, wheeling charges, and congestion costs.
- IPM may allow, or disallow, new interregional transmission build options.
  - Disabling this capability under high VRE scenarios would increase system costs through the development of inferior resources, increased congestion costs, etc.

Variable Renewable Energy in IPM

- IPM currently contains build options for utility-scale solar photovoltaic (PV), concentrated solar power (CSP), and wind technologies.
- NREL data serve as the primary source for many of the characteristics of wind and solar build options, including:
  - Capital and fixed costs
  - Total resource availability
  - Performance
    - Average annual capacity factor
    - Hourly generation profiles
- Build options for new renewable energy are provided at the smaller of the state- or IPM region-level.

Modeling High VRE Scenarios: Variability

- Recognizing the variable nature of RE, wind and solar capacity in IPM is assigned partial credit towards satisfying a region's reserve margin requirements.
  - The capacity credit associated with wind and solar is dependent on the seasonal average generation available per MW of capacity and the shape of the hourly generation profile (i.e., a peak-coincident resource like solar is assigned a higher contribution to reserve)
- The cost of each IPM region meeting the reserve margin requirement is reflected in seasonal capacity prices, expressed in $/kW-yr
  - Variable RE only receive capacity revenues associated with their contribution to the reserve margin

Modeling High VRE Scenarios: Capital Cost

- The EPA's version of IPM contains short-term capital cost adders through 2030 that apply if the new capacity deployed in a model run year exceeds certain upper bounds.

ID Number	Plant Type		2016			2018			2020			2025			2030		
			Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
1	Biomass	Upper Bound (MW)	658	438	-	1,315	877	-	1,315	877	-	3,288	2,192	-	3,288	2,192	-
		Adder ($/kW)	-	1,285	3,322	-	1,285	3,322	-	1,285	3,322	-	1,285	3,322	-	1,285	3,322
2	Coal Steam	Upper Bound (MW)	6,913	4,609	-	13,826	9,218	-	13,826	9,218	-	34,566	23,044	-	34,566	23,044	-
		Adder ($/kW)	-	916	2,370	-	916	2,370	-	916	2,370	-	916	2,370	-	916	2,370
3	Combined Cycle	Upper Bound (MW)	46,157	30,771	-	92,314	61,542	-	92,314	61,542	-	230,784	153,856	-	230,784	153,856	-
		Adder ($/kW)	-	313	809	-	313	809	-	313	809	-	313	809	-	313	809
4	Combustion Turbine	Upper Bound (MW)	23,668	15,778	-	47,335	31,557	-	47,335	31,557	-	118,338	78,892	-	118,338	78,892	-
		Adder ($/kW)	-	200	518	-	200	518	-	200	518	-	200	518	-	200	518
5	Fuel Cell	Upper Bound (MW)	600	400	-	1,200	800	-	1,200	800	-	3,000	2,000	-	3,000	2,000	-
		Adder ($/kW)	-	2,215	5,727	-	2,215	5,727	-	2,215	5,727	-	2,215	5,727	-	2,215	5,727
6	Geothermal	Upper Bound (MW)	314	210	-	629	419	-	629	419	-	1,572	1,048	-	1,572	1,048	-
		Adder ($/kW)	-	2,140	5,535	-	2,133	5,517	-	2,133	5,517	-	2,113	5,465	-	2,088	5,400
7	IGCC and Advanced Coal with Carbon Capture	Upper Bound (MW)	2,400	1,600	-	4,800	3,200	-	4,800	3,200	-	12,000	8,000	-	12,000	8,000	-
		Adder ($/kW)	-	944	2,441	-	944	2,441	-	944	2,441	-	944	2,441	-	944	2,441
8	Landfill Gas	Upper Bound (MW)	600	400	-	1,200	800	-	1,200	800	-	3,000	2,000	-	3,000	2,000	-
		Adder ($/kW)	-	2,708	7,003	-	2,701	6,987	-	2,701	6,987	-	2,683	6,939	-	2,660	6,879
9	Nuclear	Upper Bound (MW)	11,244	7,496	-	22,488	14,992	-	22,488	14,992	-	56,220	37,480	-	56,220	37,480	-
		Adder ($/kW)	-	1,789	4,626	-	1,789	4,626	-	1,789	4,626	-	1,789	4,626	-	1,789	4,626
10	Solar Thermal	Upper Bound (MW)	920	614	-	1,841	1,227	-	1,841	1,227	-	4,602	3,068	-	4,602	3,068	-
		Adder ($/kW)	-	1,382	3,575	-	1,357	3,511	-	1,334	3,450	-	1,273	3,292	-	1,208	3,125
11	Solar PV	Upper Bound (MW)	7,441	4,961	-	14,882	9,922	-	14,882	9,922	-	37,206	24,804	-	37,206	24,804	-
		Adder ($/kW)	-	607	1,569	-	521	1,347	-	436	1,128	-	396	1,025	-	355	919
12	Onshore Wind	Upper Bound (MW)	15,700	10,466	-	31,399	20,933	-	31,399	20,933	-	78,498	52,332	-	78,498	52,332	-
		Adder ($/kW)	-	523	1,352	-	514	1,330	-	507	1,310	-	492	1,274	-	485	1,253
13	Offshore Wind	Upper Bound (MW)	600	400	-	1,200	800	-	1,200	800	-	3,000	2,000	-	3,000	2,000	-
		Adder ($/kW)	-	1,589	4,111	-	1,504	3,891	-	1,421	3,674	-	1,248	3,226	-	1,207	3,122
14	Hydro	Upper Bound (MW)	1,451	967	-	2,902	1,934	-	2,902	1,934	-	7,254	4,836	-	7,254	4,836	-
		Adder ($/kW)	-	504	1,303	-	504	1,303	-	504	1,303	-	504	1,303	-	504	1,303

- Additionally, wind and solar resource totals are divided into cost steps, which represents a variety of factors that affect development cost, including distance to transmission, topography, population density, etc.
  - At high levels of penetration may double the cost of accessing that resource.

Modeling High VRE Scenarios: Future Approaches

- The translation of grid integration challenges into the IPM modeling framework can take two forms – costs and constraints.
- Future modeling approaches are contingent on available data and suitability for the IPM modeling platform, but may include:
  - Instituting grid integration cost curves for high levels of penetration
  - Introduction of distributed generation technologies
  - Expansion of energy storage technologies
  - Evaluating the costs, non-cost barriers, and opportunities for transmission expansion

EPA's Power Sector Modeling

Additional information can be found at:

https://www.epa.gov/airmarkets/power-sector-modeling

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