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Transmission Super Highways:
Assessing the Potential Benefits of Extra-High-Voltage Transmission Overlays in the Midwest

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for

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This presentation should be reviewed in conjunction with its accompanying report for added detail. The analysis and views contained in this report are solely those of the authors and do not necessarily reflect the views of *The Brattle Group, Inc*. or its clients. For more information, contact Judy Chang at judy.chang@brattle.com (617-864-7900).

Purpose of Study

- Identify and quantify the potential benefits of implementing a *Green Power Express* Extra-High-Voltage (EHV) transmission overlay on reaching renewable energy at remote locations in the Midwest

- Discuss how EHV transmission overlays can help advance US energy and environmental policies

Study Approach

1. Created two scenarios to compare an EHV transmission overlay similar to the *Green Power Express* (which we call "High Transmission") with currently projected MISO MTEP transmission expansions ("Low Transmission") - studied MAPP and MAIN regions only

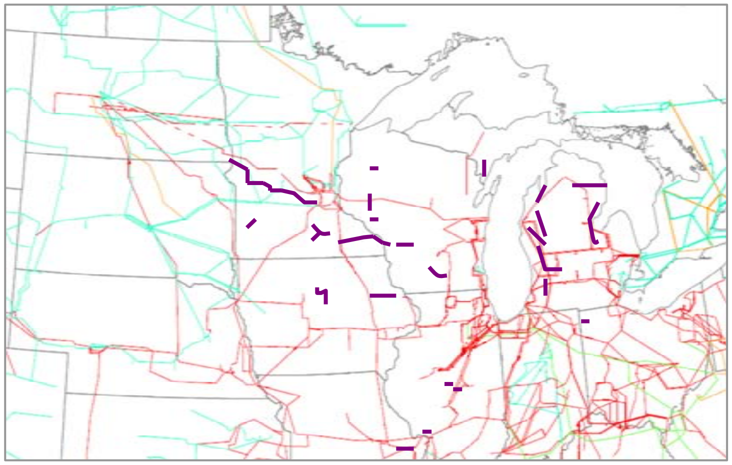
2. Simulated least-cost generation mix under High vs. Low Transmission scenarios - analysis based on generation costs only

3. Evaluated fuel used for electricity generation under the High and Low Transmission scenarios

4. Evaluated and quantified the environmental benefits associated with EHV transmission overlays such as the *Green Power Express*

Overview of Transmission Scenarios

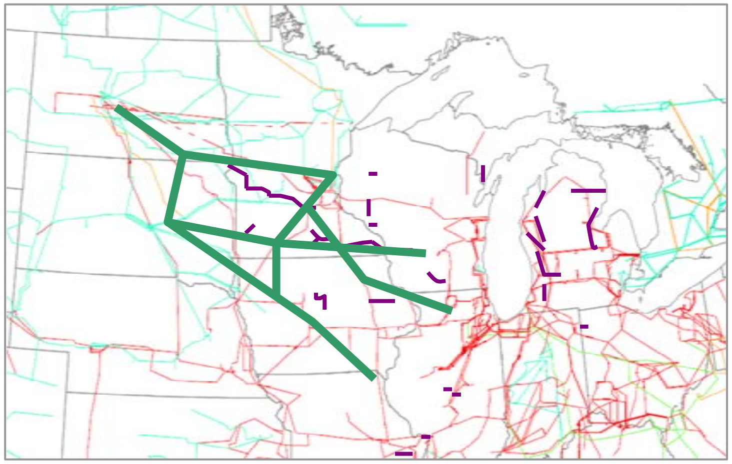
Low Transmission Scenario	*Incremental upgrades to existing system*



- Incremental transmission upgrades to existing system are made for reliability and interconnection purposes
- Sufficient renewable generation to meet the regional RPS, but the wind that reaches the grid has a lower capacity factor (e.g., 32%)

Sample MTEP08 Board Approved Upgrades

High Transmission Scenario	*EHV Transmission Overlay*



- Transmission overlay assumed to be in service in 2020
- Higher class of wind resources in the Dakotas becomes accessible via EHV overlay (e.g., 765 kV *Green Power Express Concept)*
- This is simulated by higher capacity factor (42%) wind accessible in 2020

Sample MTEP08 Board Approved Upgrades
Green Power Express Concept

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Summary of Findings

- ♦ EHV grid additions that increase access to higher-quality wind resources, along with expected carbon prices, enable renewable resources to become cost-competitive with conventional power, excluding transmission cost differences.
  - Our simulations show over 20,000 MW of wind capacity *over and above current RPS mandates* will be built between 2020 – 2030 in the Midwest if transmission access is available.
  - Regional expansion using all this wind would save approximately 6,600 million MMBTUs of fuel and 370 million metric tons of CO_2 through 2030.
  - EHV additions provide other system benefits, such as greater reliability, diversity, and market liquidity – not quantified in this study.
- ♦ This preliminary analysis suggests that EHV overlays can provide substantial benefits. This conclusion should be confirmed through a more complete least-cost regional expansion analysis for a precise EHV configuration.

How Do EHV Overlays to Wind-Rich Areas Reduce Conventional Power Generation?

The combination of carbon prices and access to economical wind causes utilities to:

- Retire old, inefficient coal and oil units sooner.
  - There are about 2,000 MW of conventional coal retirements in both scenarios but they occur much sooner in the High Transmission Scenario.
- Replace retired units with wind plus more efficient gas plants.
- Choose to build wind plants combined with gas power plants instead of integrated gas combined cycle (IGCC) units.
- Use inefficient coal plants less intensively during off-peak periods.
  - This increases CO_2 savings, substituting off-peak wind for off-peak coal-based energy.
- These factors account for the bulk of the added economical wind built in the High Transmission Scenario.

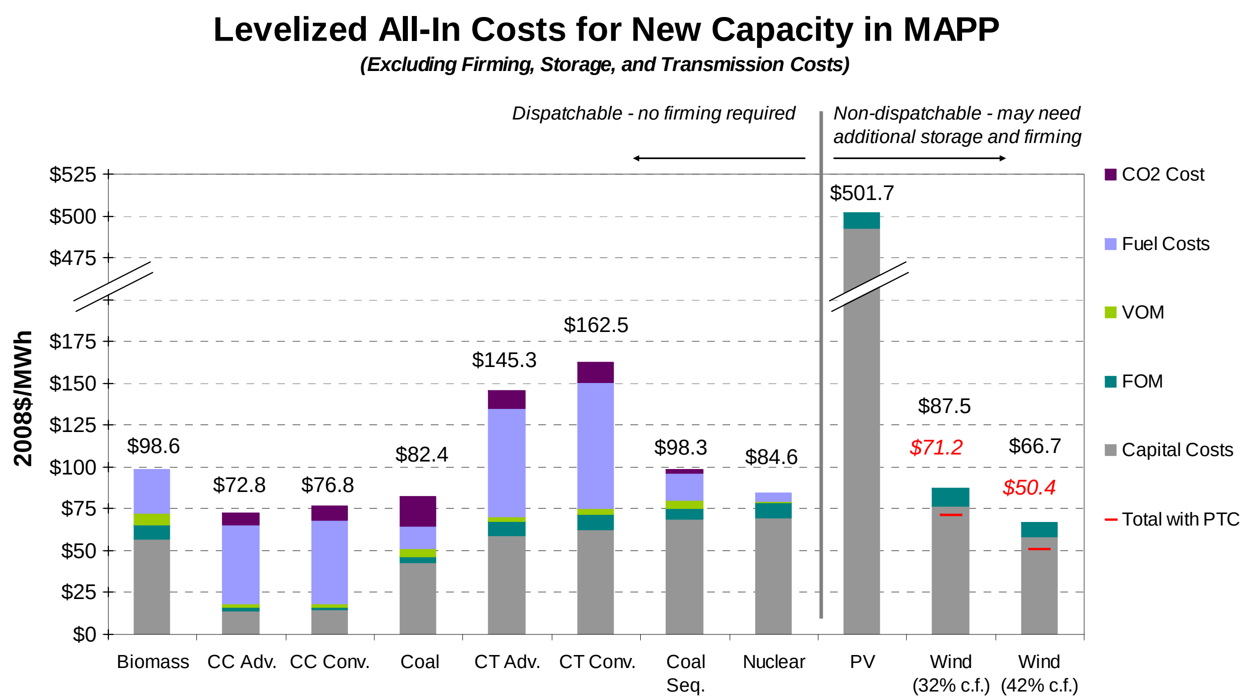
Important Assumptions and Caveats

- Least-cost regional expansion modeled with the following assumptions:
  - Fuel prices and electricity sales growth from EIA 2008 Annual Energy Outlook
  - CO_2 prices start at $10/metric-ton in 2012, rising to $50/metric-ton in 2030 (in $2008)
  - Current renewable portfolio standards are met
  - New wind capacity of 32% in the Lower Midwest and 42% in Upper Midwest
  - Wind profile from NREL to set the shape of wind power production
  - New Unit costs are from *Brattle*'s Edison Foundation Study and EIA
- All calculations reflect generation and carbon costs only using a simplified generation expansion model.
  - Proper regional planning also incorporates transmission and distribution costs.
  - *Brattle*'s RECAP model is a simplified generation expansion model – see appendix for more details.
  - Our results point to the need for full consideration and evaluation of EHV overlays.

New Resource Cost Assumptions

The same capital cost assumptions were used for both scenarios with the exception of higher capacity factor wind in the High Transmission Scenario which has a significant impact on the average annual cost of wind power.

- Capital costs include interconnection costs and interest during construction.
- Production tax credits or other types of subsidies for wind were not included in the simulation but are shown for reference and were estimated from 2009-2018 levels.



Summary of New Generation Capacity Build-out Initiated by EVH Overlays

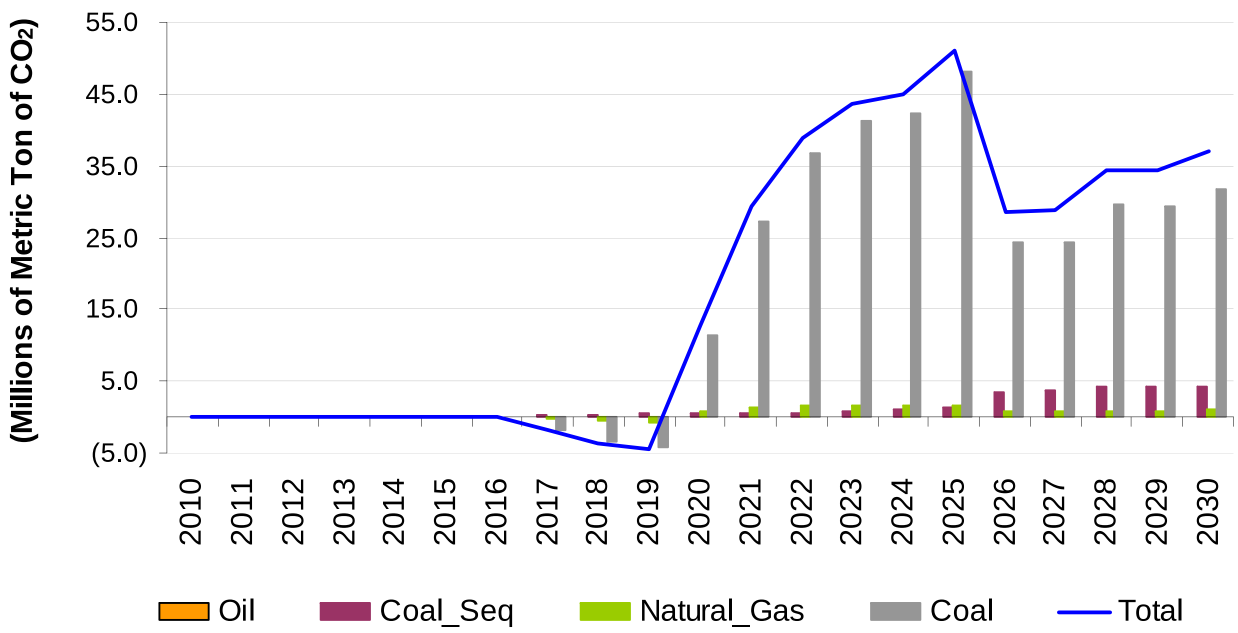
Change in Economic New Generation Resources Due to Multiple EHV Overlays, 2010-2030 (MW)							
	CC	**CT**	**Biomass**	**Coal + Seq**	**PV**	**Wind**	**Total**
Low Transmission Scenario	3,052	1,067	982	7,006	70	19,375	31,551
High Transmission Scenario	2,484	2,249	838	896	70	43,176	49,713
Change in Economic Generation Resources Due to Multiple EHV Overlays	(568)	1,182	(144)	(6,110)	-	23,801	18,162

- A significant amount of new wind resources become competitive with conventional fuels.
- Some factors that could change this result include:
  - Integration of wind requires additional dispatchable and flexible generation such as CCs and CTs
  - Increased demand for wind could significantly increase the cost of wind resources
- However, the overall observation is that wind in the Dakotas can compete with other resources given a moderate CO_2 price path and transmission access and provides resource locational diversity.

Fuel and CO_2 Emissions Savings Through 2030

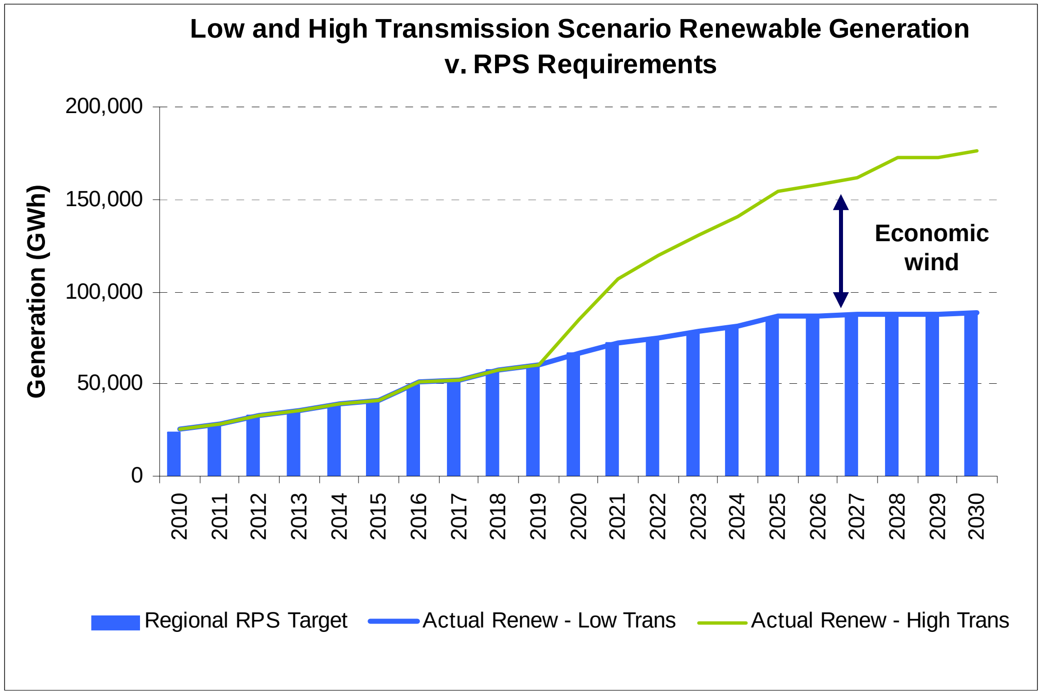
Total Net Fuel and CO_2 Emissions Savings Due to Multiple EHV Overlays, 2010-2030			
Increase in New Wind Generation (MW)	**Total Net Fuel Savings (Millions MMBTU)**	**CO_2 Emissions Savings (Million Tons)**	**Value of CO_2 Emissions Savings (2008$ Billion)**
23,801	6,692	373	$14.9

Annual CO_2 Savings (Emissions) by Fuel, 2010-2030
(High Transmission Scenario Over Low Transmission Scenario)



Renewable Energy Resources Growth

- The graph below shows the RPS requirement in terms of generation (GWh) in bars for the studied regions.
- The lines on the graph represent the actual generation from renewables that can be used to meet RPS requirements.
  - Note that RECAP assumes that sufficient renewable generation is built to meet current state RPS requirements. To the extent that utilities are not able to meet these targets, the additional renewable builds would widen the gap shown below as "economic wind."



Note that the RPS requirement is met with a mix of existing and new renewable capacity.

Generation that contributes to the RPS include biomass, a portion of small hydro facilities, solar photovoltaic, and wind.

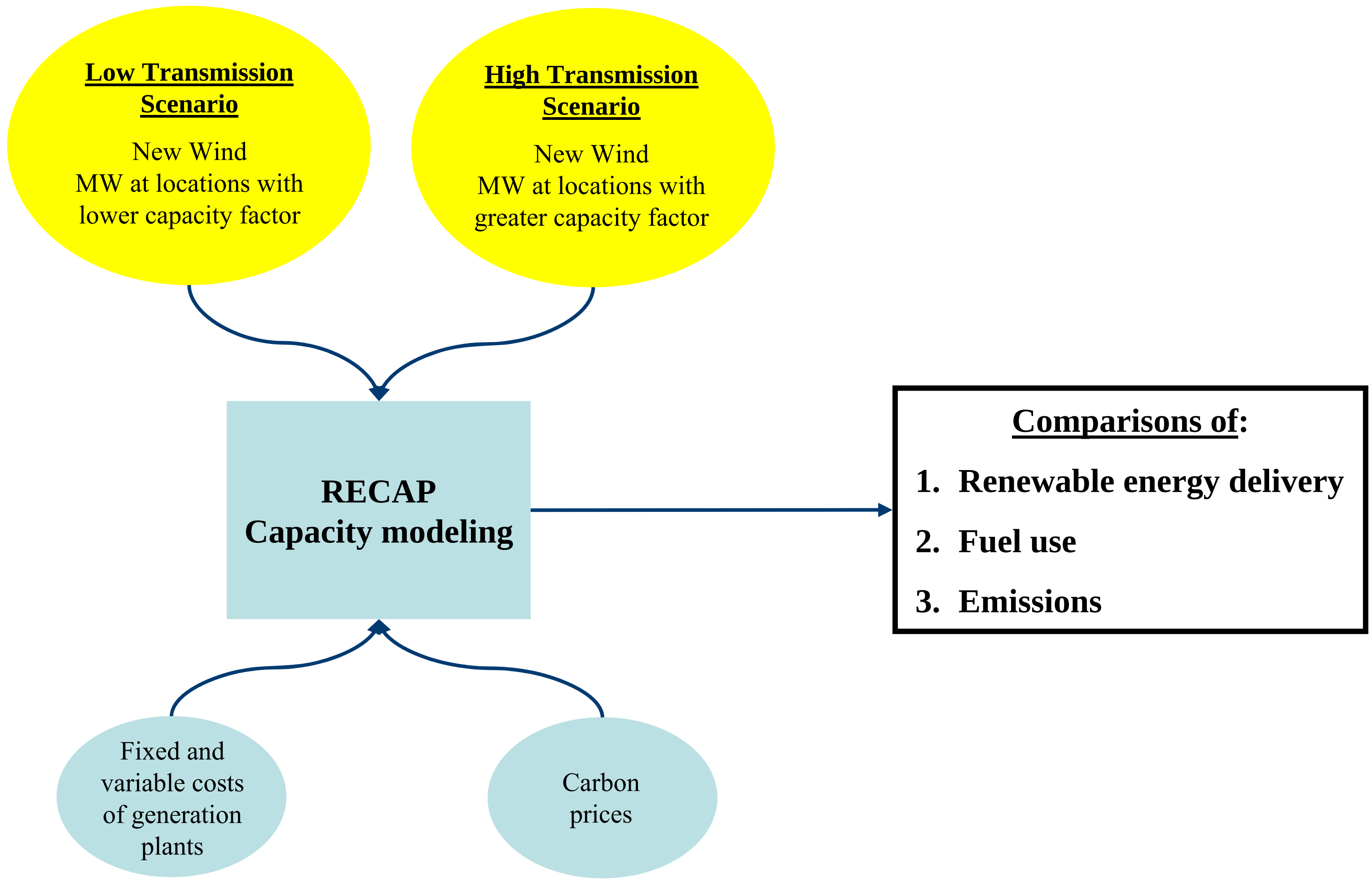
Additional Benefits of EHV Transmission

- Complements and supports the nation's climate change policy goals including state renewable portfolio standards and possible future legislation on federal renewable portfolio standards or CO_2 prices
- Other benefits include:
  1. Increased system reliability
  2. Increased power market liquidity and competition
  3. Greater fuel and load diversity; improved resource utilization
  4. Economic benefits from construction and taxes
- These benefits have not been quantified in our study

Appendix

Technical Information and Modeling Details

Analytical Approach



Key Regional Capacity Expansion (RECAP) Model-Attributes and Assumptions

RECAP is a simplified least-cost regional generation expansion planning model

- The model does not include transmission limits or costs
- The model allows continuous unit sizes and allows coal units to cycle

General Inputs (existing capacity, outage rates, load forecast, etc.)

- Based on assumptions in the 2008 Annual Energy Outlook (AEO) published by the US Department of Energy's Energy Information Administration (EIA), and data from Energy Velocity

Renewable and nuclear capacity

- Our expansion simulation assumes that utilities will build at least the minimum amount of renewables to meet the region's RPS requirement, which is a weighted average of each state's RPS
- Additional renewable capacity above required minimum built solely based on cost competitiveness
- Nuclear capacity is capped at all plants current applying for licenses

Load Growth and DSM Forecast

- Load grows about 0.7% per year. Additional DSM incremental to AEO forecast is based on EPRI projection used in recent *Brattle Group* analysis for Edison Foundation*

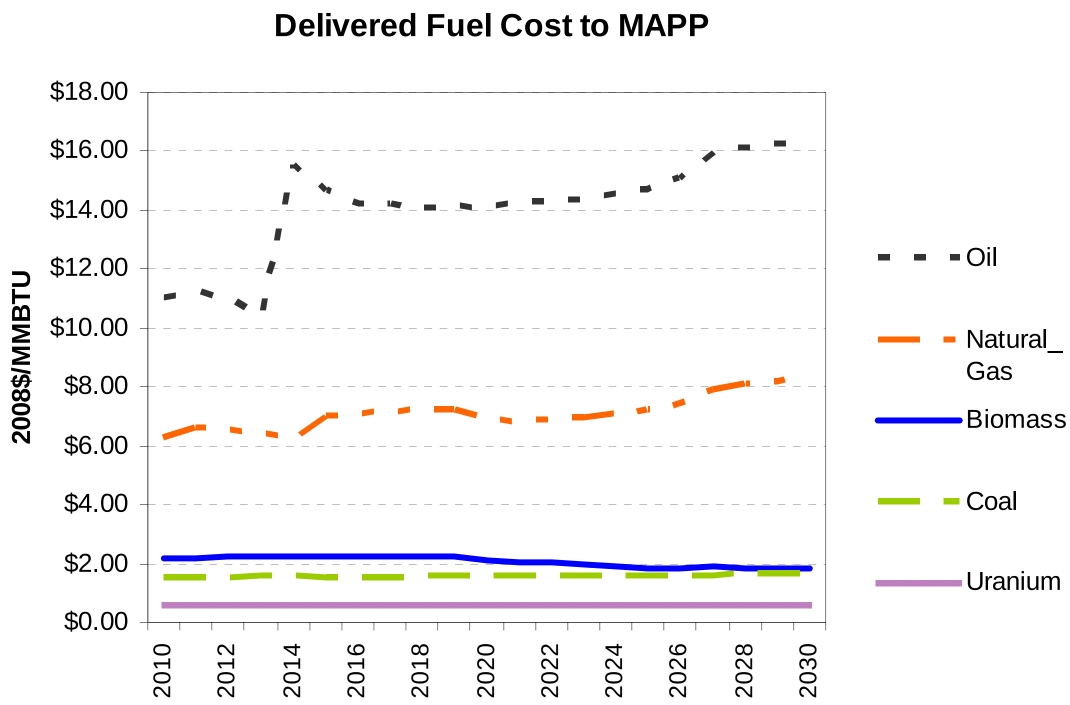
Wind Resource Characteristics

- All wind resources in the Low Transmission Scenario have 32% capacity factor consistent with current wind installs in MAPP and MAIN
- New wind annual average capacity factors for the High Transmission Scenario increases to 42% (starting in 2020), consistent with Class 5 wind in the Dakotas
- Assume the EHV overlays reach optimal wind location

* Marc Chupka, Peter Fox-Penner, Ryan Hledik, and Robert Earle. "Transforming America's Power Industry: The Investment Challenge 2010-2030." Edison Foundation, November 10, 2008 (http://www.eei.org/ourissues/finance/Documents/Transforming_Americas_Power_Industry.pdf).

Fuel Cost Assumptions

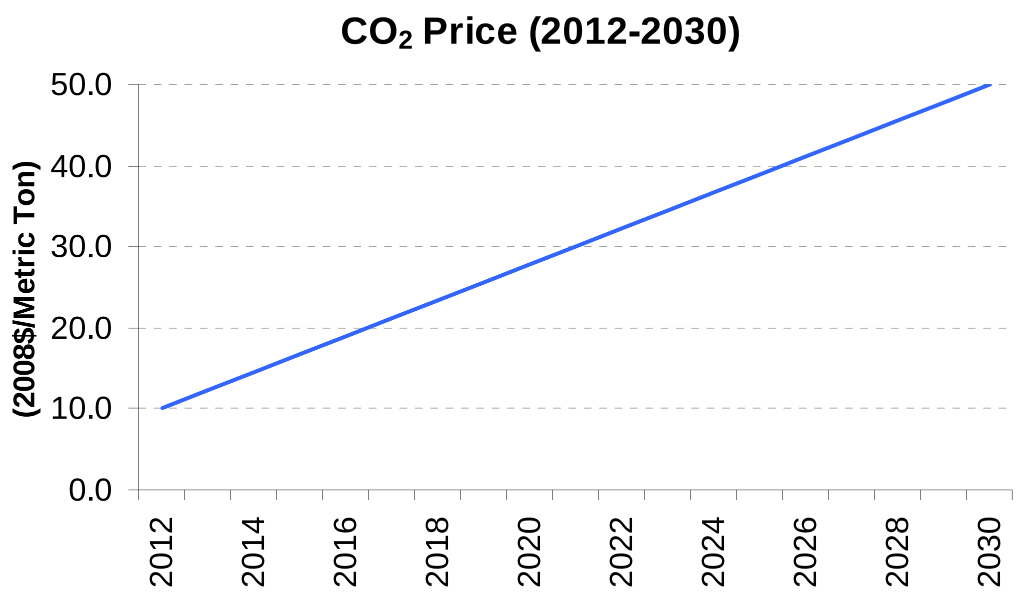
- The delivered fuel prices shown below for the MAPP region were unchanged between the two scenarios.
- January 2009 oil and natural gas futures were used in the near-term (up to 2013 and 2014, respectively) to capture the current downward trend. After that time, it is expected that the markets will reach higher delivered fuel costs. Other fuel costs were held more or less constant in real terms.



CO_2 Price Assumption

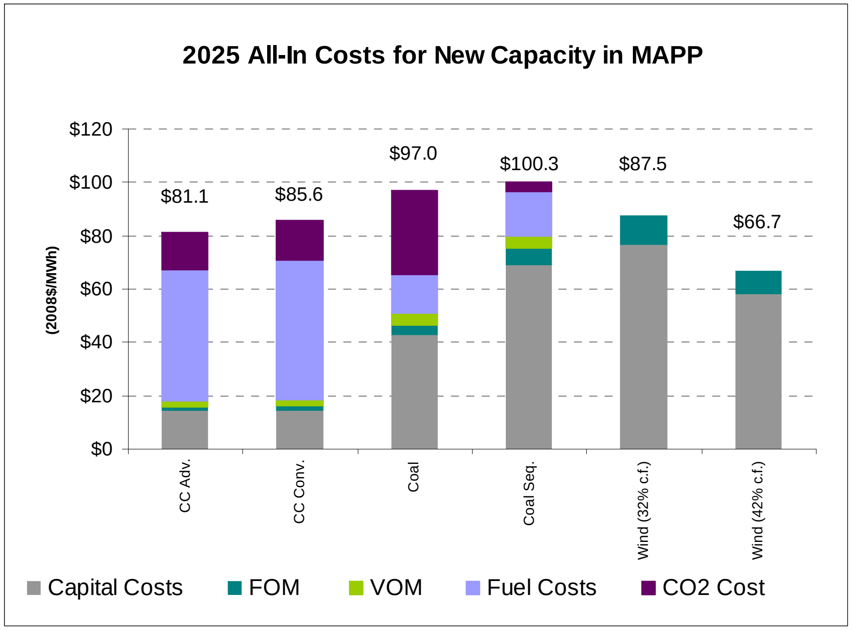
- The same CO_2 assumption is used in both High and Low Transmission scenarios.
- This is considered a modest carbon price – starting at $10/metric ton in 2012.

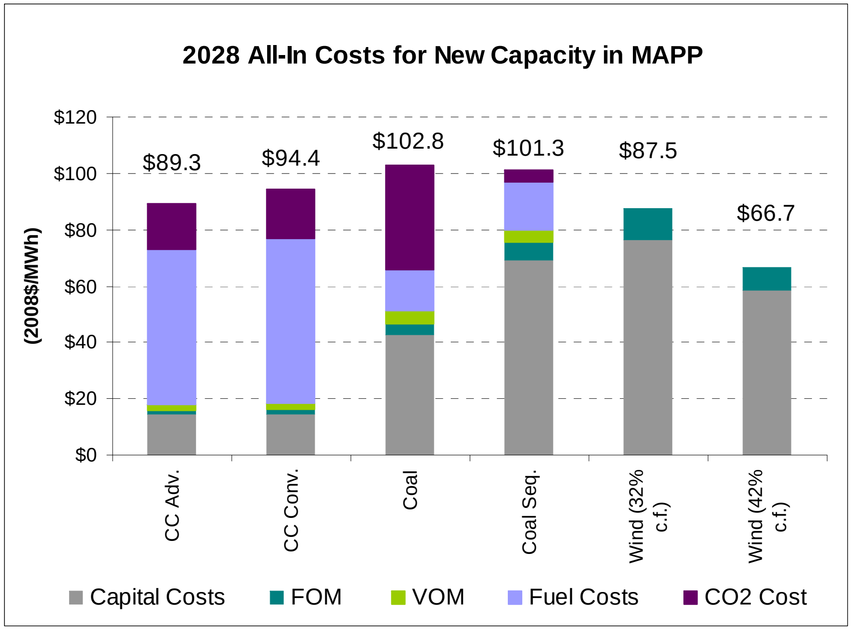
Fuel Type	CO_2 (lb/MMBTU)
Coal	200
Oil	160
Natural Gas	117
Biomass	0
IGCC	20



New Resource Cost Assumptions – Single Year Analyses

Since CO_2 costs rise over time, the graphs below compare the all-in costs for those generation technologies that are impacted by a rising CO_2 cost versus wind generation in 2025 and 2028.





Fuel Cost Assumptions Details

- The delivered fuel prices shown below for MAIN and MAPP were unchanged between the two scenarios.
- January 2009 oil and natural gas futures were used in the near-term (up to 2013 and 2014, respectively) to capture the current downward trend. After that time, it is expected that the markets will recover and we return to higher delivered fuel costs. Other fuel costs were held more or less constant in real terms.

Delivered Fuel Price Forecasts with Adjustments to 2030
Units: $/MMBtu
Year Dollars: 2008

Fuel	Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Coal	MAIN	1.81	1.82	1.82	1.83	1.80	1.79	1.77	1.78	1.77	1.77	1.77	1.77	1.78	1.79	1.79	1.80	1.80	1.81	1.82	1.83	1.84
Coal	MAPP	1.51	1.52	1.52	1.53	1.53	1.52	1.51	1.51	1.54	1.54	1.55	1.54	1.55	1.56	1.56	1.57	1.58	1.59	1.60	1.60	1.61
Natural_Gas	MAIN	5.78	6.08	6.03	5.92	5.81	6.47	6.57	6.67	6.70	6.77	6.59	6.47	6.53	6.60	6.74	6.84	7.02	7.41	7.63	7.73	7.82
Natural_Gas	MAPP	6.26	6.58	6.52	6.38	6.28	6.96	7.07	7.15	7.17	7.21	6.94	6.77	6.85	6.92	7.07	7.19	7.42	7.85	8.05	8.18	8.31
Oil	MAIN	10.94	11.19	10.92	10.32	15.27	14.35	13.93	13.94	13.80	13.91	13.88	14.07	14.04	14.12	14.30	14.47	14.86	15.71	15.89	15.96	15.93
Oil	MAPP	10.98	11.24	10.98	10.37	15.59	14.65	14.20	14.20	14.06	14.15	14.09	14.26	14.24	14.33	14.51	14.70	15.10	15.95	16.13	16.22	16.21
Biomass	MAIN	2.19	2.20	2.24	2.27	2.26	2.26	2.25	2.25	2.34	2.40	2.34	2.34	2.33	2.33	2.32	2.32	2.33	2.32	2.31	2.32	2.32
Biomass	MAPP	2.19	2.20	2.24	2.27	2.26	2.26	2.25	2.25	2.24	2.24	2.10	2.06	2.01	1.96	1.91	1.86	1.86	1.88	1.86	1.85	1.85
Uranium	MAIN	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Uranium	MAPP	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52

Resource Cost Assumption Details

The same capital cost assumptions were used for both scenarios with the exception of higher capacity factor wind in the High Transmission Scenario which has a significant impact on total costs.

- Capital costs include interconnection costs and interest during construction

		MAPP										
Capital Costs ($/kW to $/MWh)		Biomass	CC_Adv	CC_Conv	Coal	CT_Adv	CT_Conv	IGCC	Nuclear	PV	Wind (32% c.f.)	Wind (42% c.f.)
All-In Costs	(2008$/kW)	3,549	906	919	2,768	697	734	4,484	4,635	6,665	2,210	2,210
Capital Costs	(2008$/MWh)	56.9	14.4	14.6	42.7	59.3	62.4	69.2	69.9	493.0	76.5	58.3
FOM ($/kW-yr to $/MWh)												
FOM	(2008$/kW-yr)	65.7	11.9	12.7	28.0	10.7	12.3	46.4	69.2	11.9	30.9	30.9
FOM	(2008$/MWh)	8.8	1.6	1.7	3.8	8.2	9.4	6.2	8.8	8.8	11.0	8.4
VOM ($/kW-yr to $/MWh)												
VOM	(2008$/MWh)	6.8	2.0	2.1	4.7	3.2	3.6	4.5	0.5	0.0	0.0	0.0
Fuel Costs ($/MMBtu to $/MWh)												
Fuel Cost	(2008$/MMBtu)	2.13	6.91	6.91	1.54	6.91	6.91	1.54	0.52	0.00	0.00	0.00
Heat Rate	(Btu/kWh)	12,200	6,812	7,260	9,000	9,289	10,833	10,600	10,300	n/a	n/a	n/a
Fuel Costs	(2008$/MWh)	26.0	47.1	50.2	13.8	64.2	74.9	16.3	5.4	0.0	0.0	0.0
CO2 Costs ($/ton to $/MWh)												
CO2 in Fuel	(lb/MMBtu)	0	117	117	200	117	117	20	0	0	0	0
CO2 Emissions	(Metric tons/MWh)	0	0	0	1	0	1	0	0	0	0	0
CO2 Cost	(2008$/Metric Ton)	21	21	21	21	21	21	21	21	21	21	21
CO2 Cost	(2008$/MWh)	0.0	7.7	8.2	17.4	10.5	12.2	2.0	0.0	0.0	0.0	0.0
Levelized Fixed Costs	($2008/MWh)	**98.6**	**72.8**	**76.8**	**82.4**	**145.3**	**162.5**	**98.3**	**84.6**	**501.7**	**87.5**	**66.7**
Total with PTC	($2008/MWh)	0	0	0	0	0	0	0	0	0	**71.2**	**50.4**

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