Transmission Investment Assessment Under Uncertainty

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Outline

1. What is the impact of model simplifications?
(a) Uncertainty, (b) Generator flexibility constraints, (c) KVL?

2. Should we build the Champlain-Hudson line now?
***Or* wait 10 years (or more)?**

3. How does including physical line options change the optimal mix of transmission?

4. Do plans based on a few extreme ("stratified") scenarios perform as well as (or better than!) full stochastic programming?

5. Would co-optimization lead to different transmission plans for the 2011 EIPC project?

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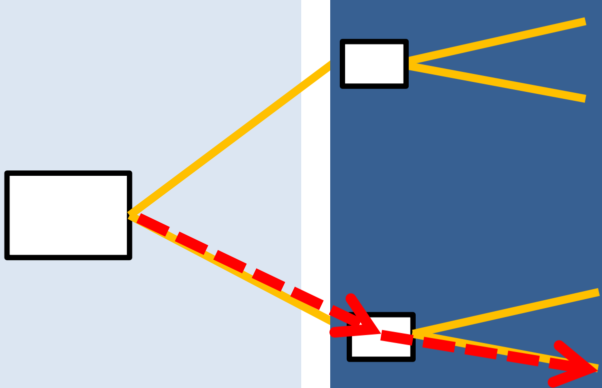
Method: JHSMINE

(Johns Hopkins Stochastic Multi-stage Integrated Network Expansion)

Stage 2014:
"Today's Choices"

Stage 2024:
"Tomorrow's Choices"



Choose Yr 10 Investments in:
- Transmission
- Generation

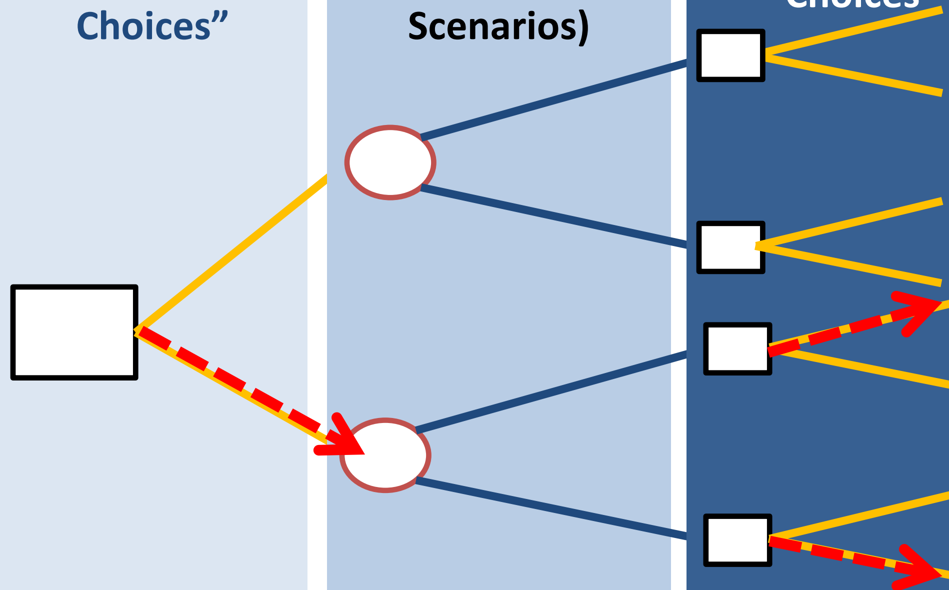
- Choose Yr 20 Investments in trans / gen
- Operations

Deterministic Approach:
One model for each scenario

Stage 2014:
"Today's Choices"

Uncertainty (Multiple Scenarios)

Stage 2024:
"Tomorrow's Choices"



Choose Yr 10 investments in:
- Transmission
- Generation

Scenarios of
- $ Fuels
- Load growth
- Technology
- Policies

- Choose Yr 20 investments in trans / gen
- Operations

JHSMINE: Solve all cases at once in one model

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JHSMINE Structure: Mixed Integer LP

Optimize the objective:

Minimize (probability-weighted, present worth) of cost over 40 yrs

By choosing values of decision variables:

- Transmission investment (0-1)
  - 10 yr "portal" (optional) lines (in addition to Common Case lines)
  - 20 yr lines
- Gen investment & dispatch *(co-optimized)*

Respecting constraints:

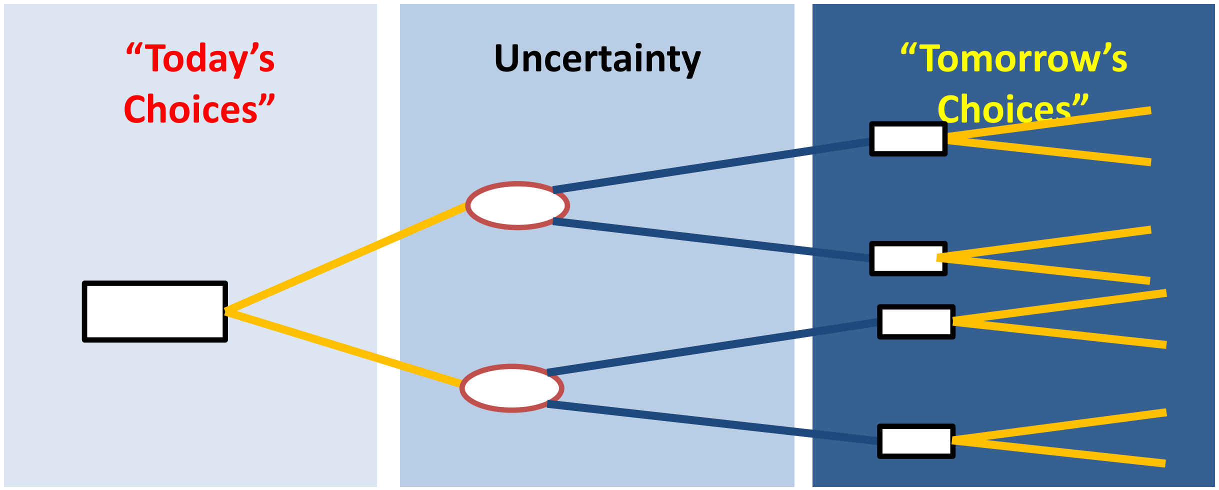
- Kirchhoff's laws (linear OPF)
  - Load by hour
- Generator operating constraints
  - Variable renewable availability by hour
- RPS
- Siting restrictions

Accounting for uncertainties:

- load/renewable conditions (hourly variability)
- *IN STOCHASTIC MODEL:* long-run study cases

Mathematical structure

(van der Weijde & Hobbs, 2012; Munoz et al. 2014)



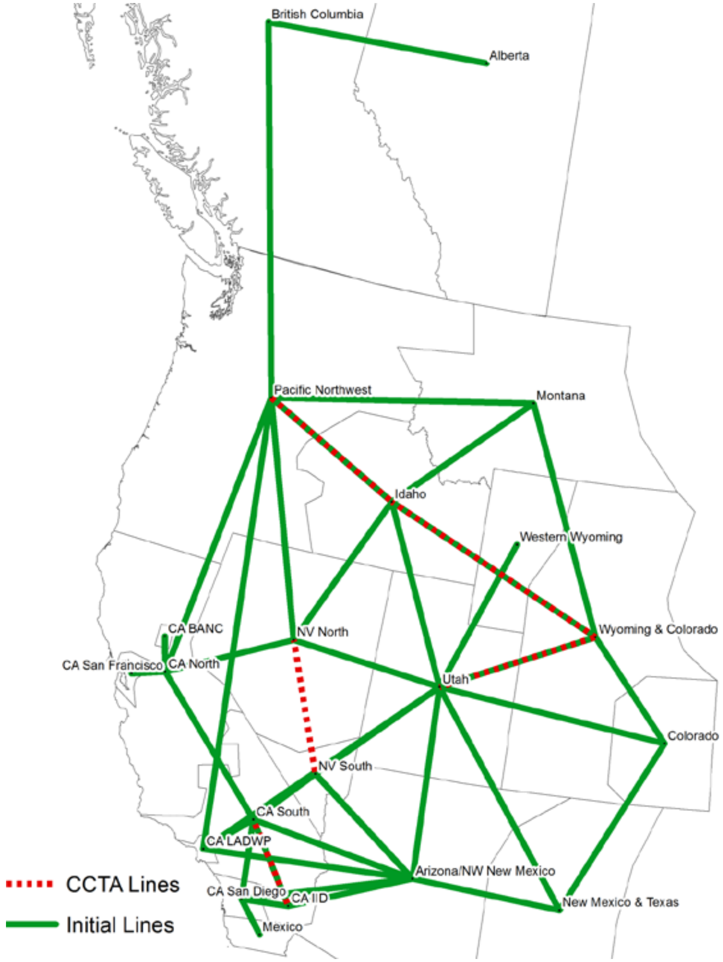
$$\text{MIN} \quad C_1 X_1 + \Sigma_{\text{scenarios } S} P_S * C_2 X_{2,S}$$

$$A_{1,1} X_1 \leq B_1$$

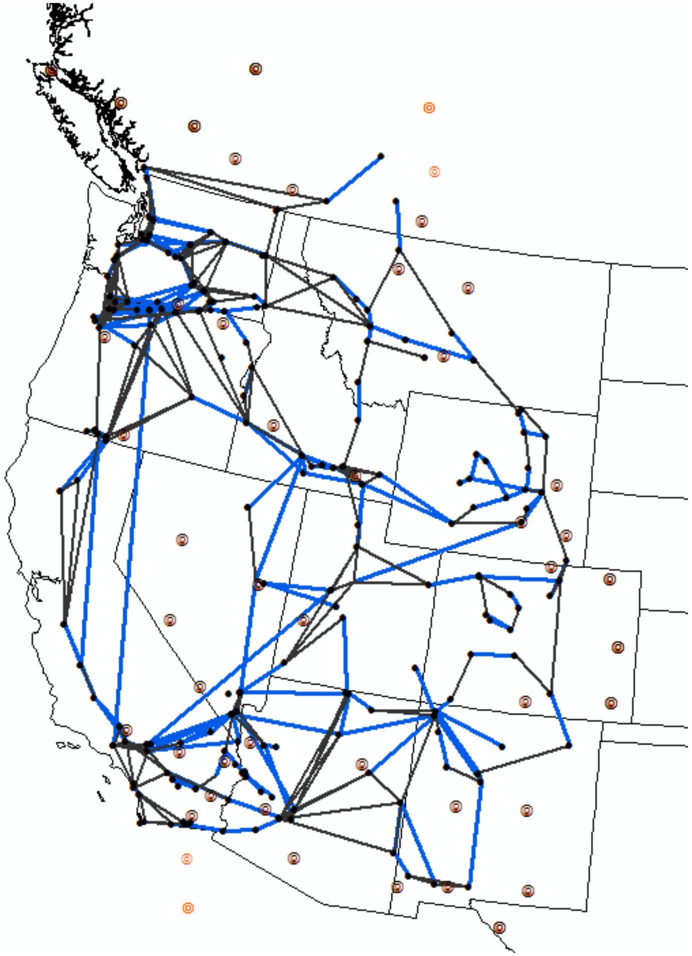
$$\{A_{2,1,S} X_1 + A_{2,2,S} X_{2,S} \leq B_{2,S}\}, \forall S$$

Two versions of JHSMINE-WECC

21 TEPPC Zone "Pipes-&-Bubbles"



300 bus network: Both Linearized DC OPF & "Pipes-&-Bubbles" versions (Thanks Yujia Zhu & Dan Tylavsky!)



1(a) Do solutions change if we ignore:

- **Uncertainty?**
  - **Deterministic vs. stochastic** ***YES***
  - **Effect of # of scenarios** ***NOT MUCH***
  - **Effect of probability of scenarios** ***LITTLE***

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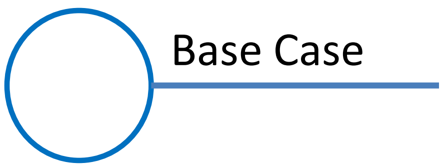
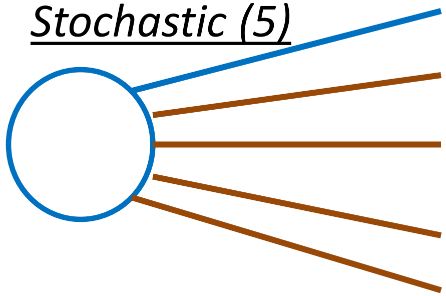
Alternative Study Case/Scenario Sets: *1, 5, and 20*

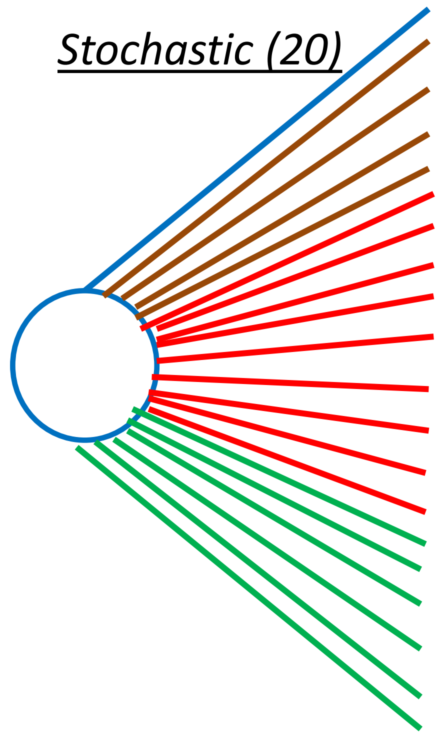
Deterministic



Stochastic (5)



Stochastic (20)



Three groups of uncertain parameters (24 parameters):

- *P-Carbon, P-Gas, Energy growth*
- *RPS, Renewable capital cost*
- *Peak growth, storage*

Example: Optimal "Portal" 10 yr Transmission (21 Zone model)

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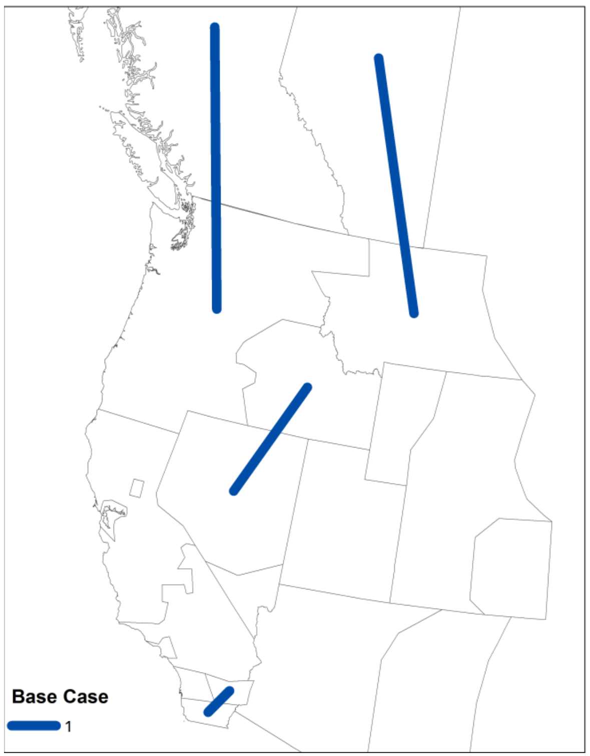
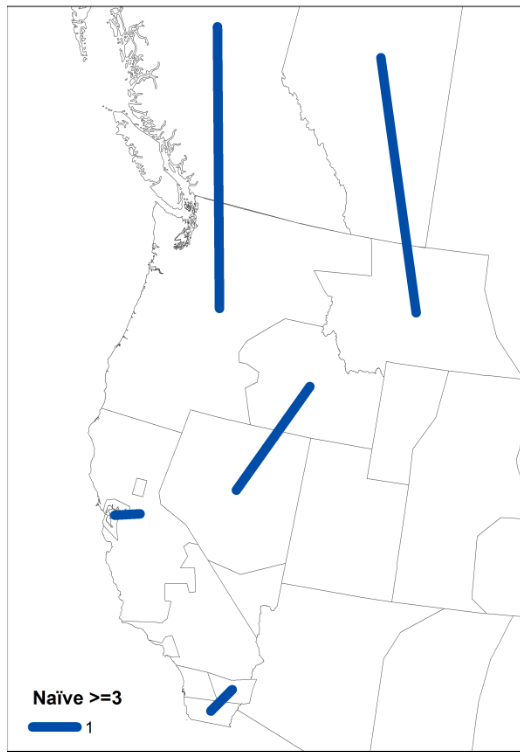
Optimal under just ***Base Case*** (100% probability)

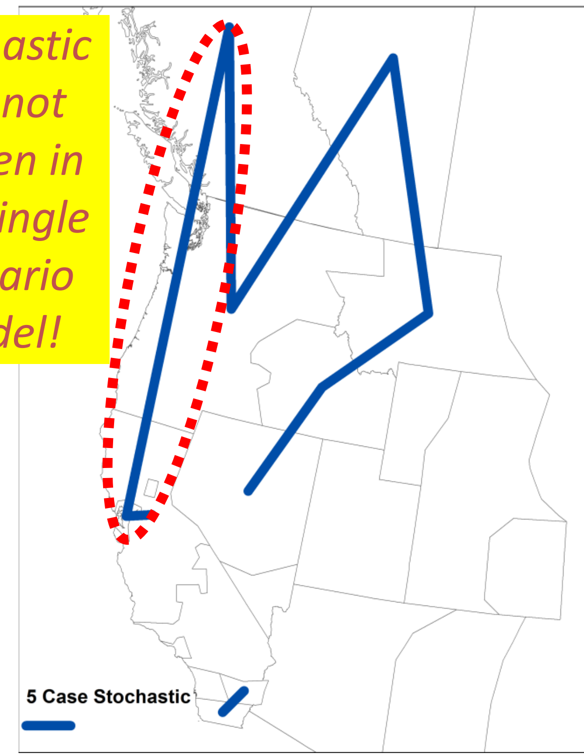
Heuristically combine deterministic results: Optimal in $\geq$3 of 5 2013 Study Case models

Stochastic Optimum under 5 (and also 20) study cases (equal chance of each scenario)





Stochastic line not chosen in <u>any</u> single scenario model!



<u>Expected PW cost under 20% chance of each of 5 study cases:</u>

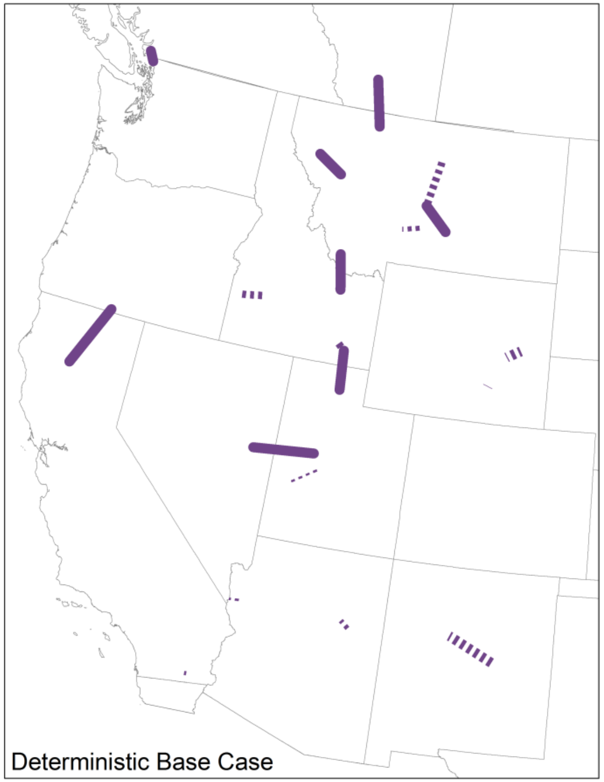
$681.4B $680.3B $678.5B (optimal)

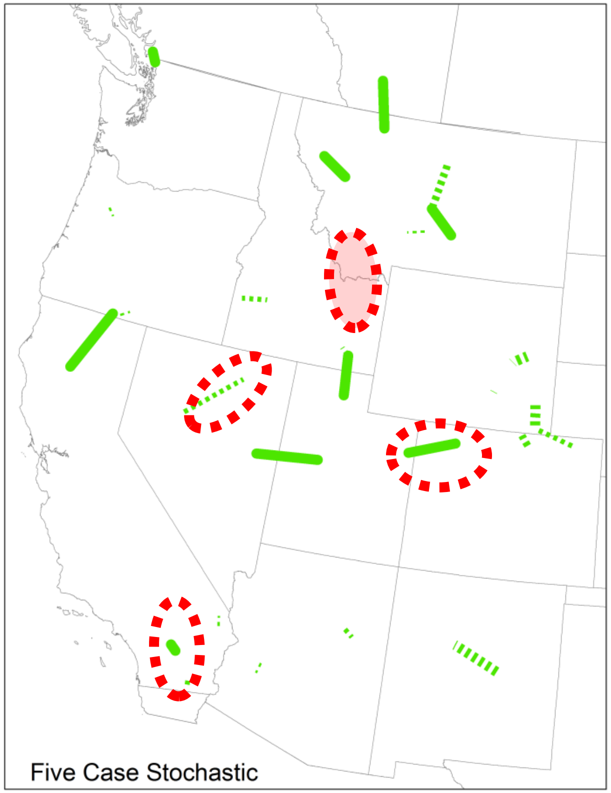
Compare Yr 10 Lines Under Alternative Scenario Sets (300 bus case)

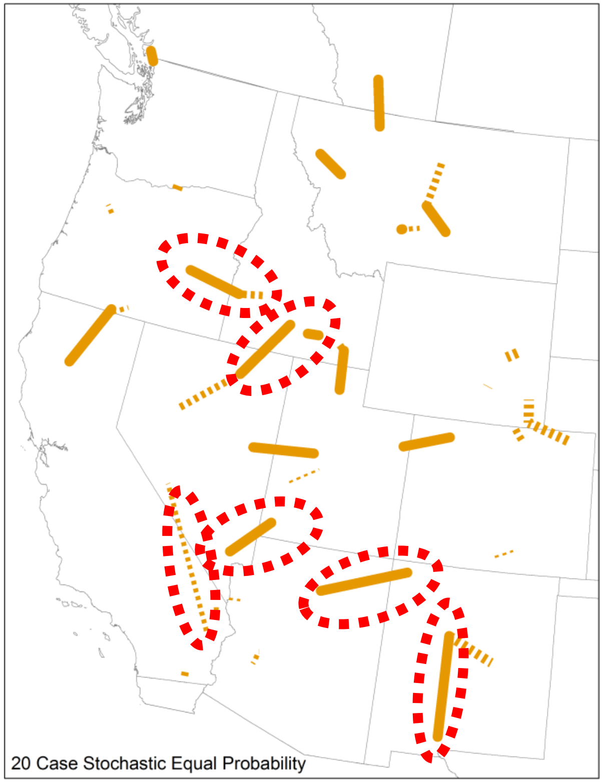
Optimal under ***Base Case***

Optimal under ***5*** Scenarios (20% Probability Each)

Optimal under ***20*** Scenario Case (5% Probability each)





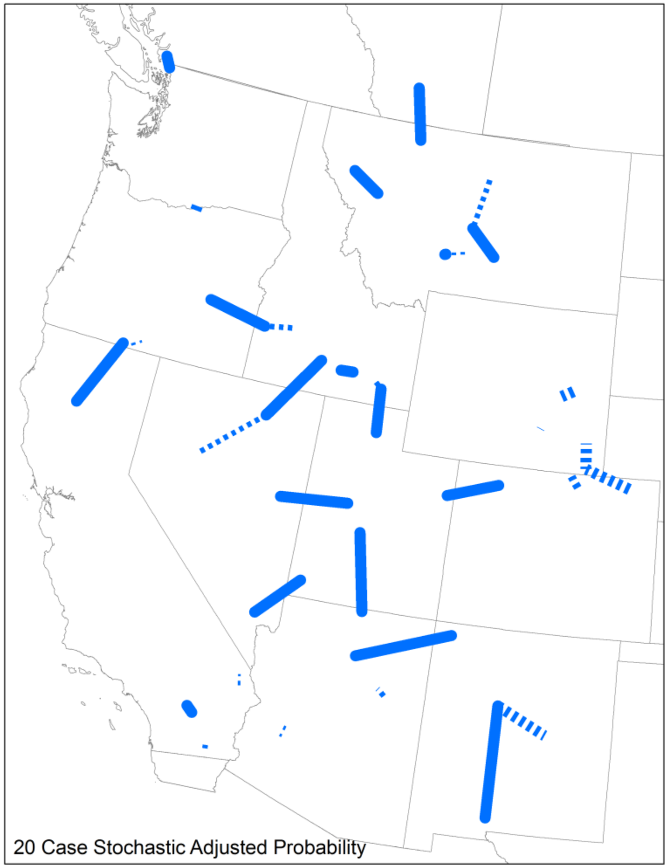


Expected suboptimality cost penalty under 5% chance of each of 20 scenarios:

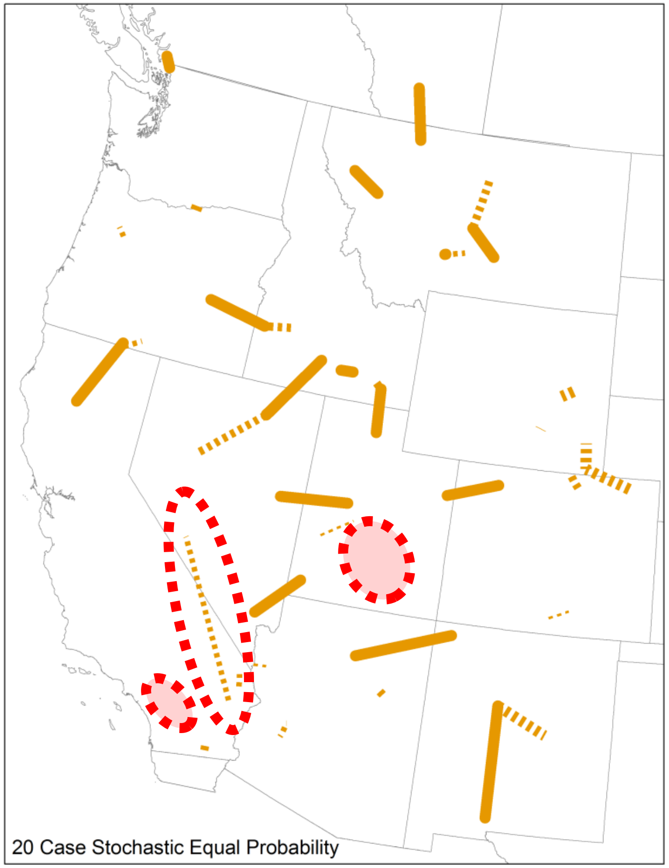
$14.2B $1.8B $0B Optimal

Compare 1st Stage Lines Under Alternative Probabilities of 20 Scenarios (300 bus network)

Differentiated Probabilities for 20 Scenarios



Equal Probabilities



1(b) Do solutions change if we ignore unit commitment constraints on generator flexibility? *In some cases*

What if we include Generating Unit Commitment constraints?

- What is impact of more accurate production costing upon 1st and 2nd stage transmission?

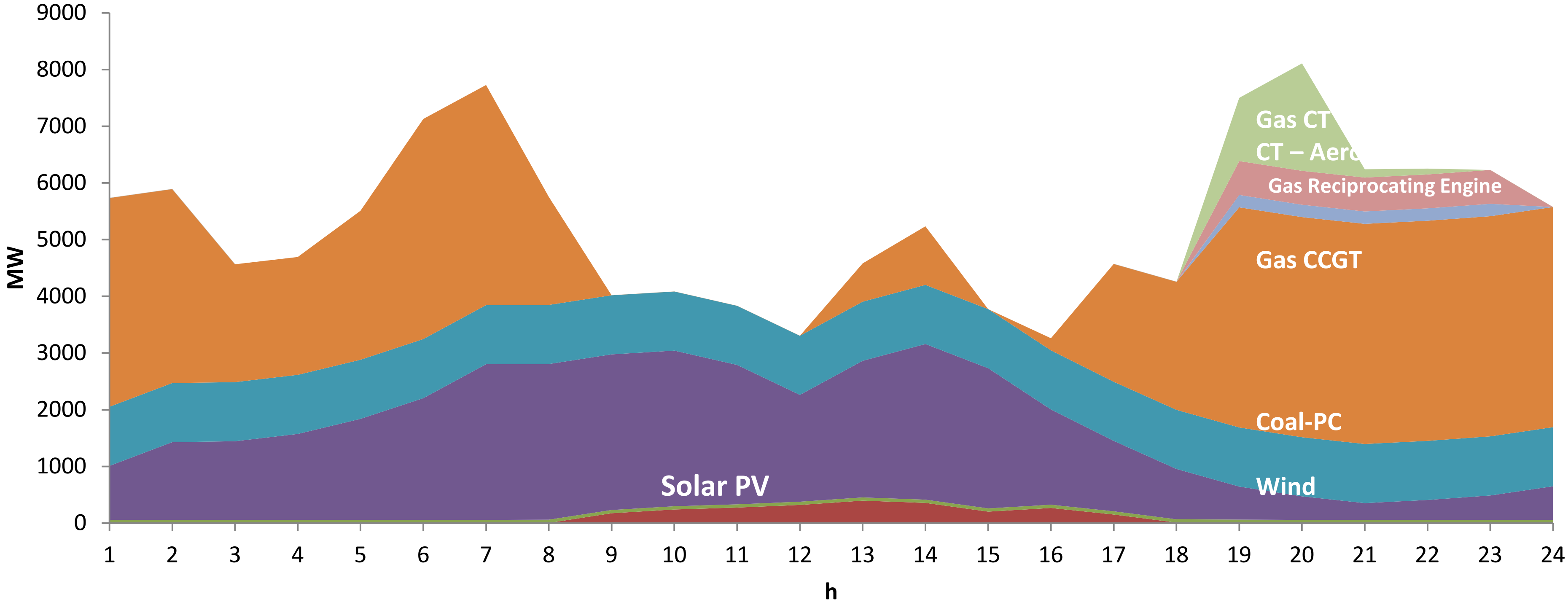
  Simple "load duration curve" method (assumes infinite flexibility)

  versus

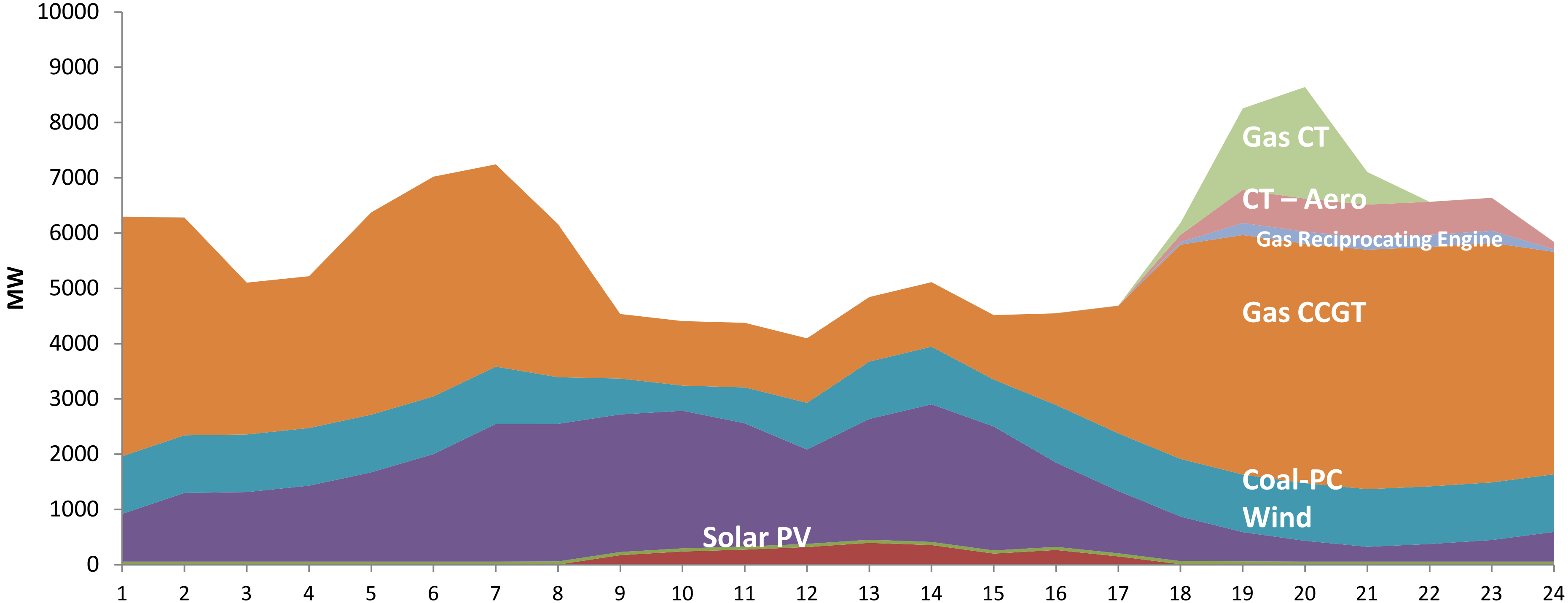
  Unit commitment (UC) approximation (captures flexibility limits)

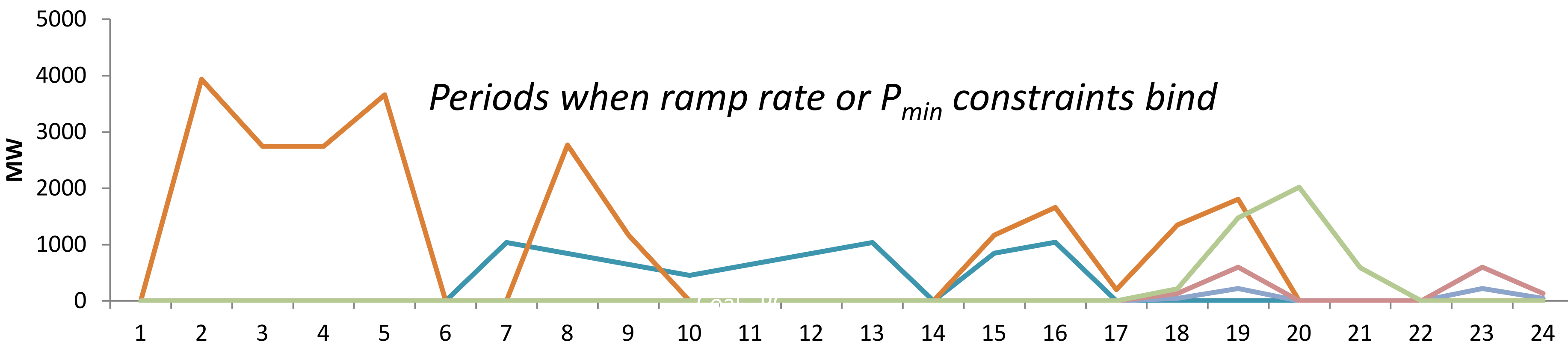
- Simplified "relaxed" UC preserves computational efficiency of linear program (Kasina, Wogrin, Hobbs, 2014)
  - Approximates start-up costs, Pmin constraints
  - Imposes ramp constraints
  - 72 hours (3 days) x 5 scenarios x 2 stages x 21 zones

Sample 24 hr energy profile from Colo.: *Without* UC operational constraints (2035, Econ Recovery Scenario)



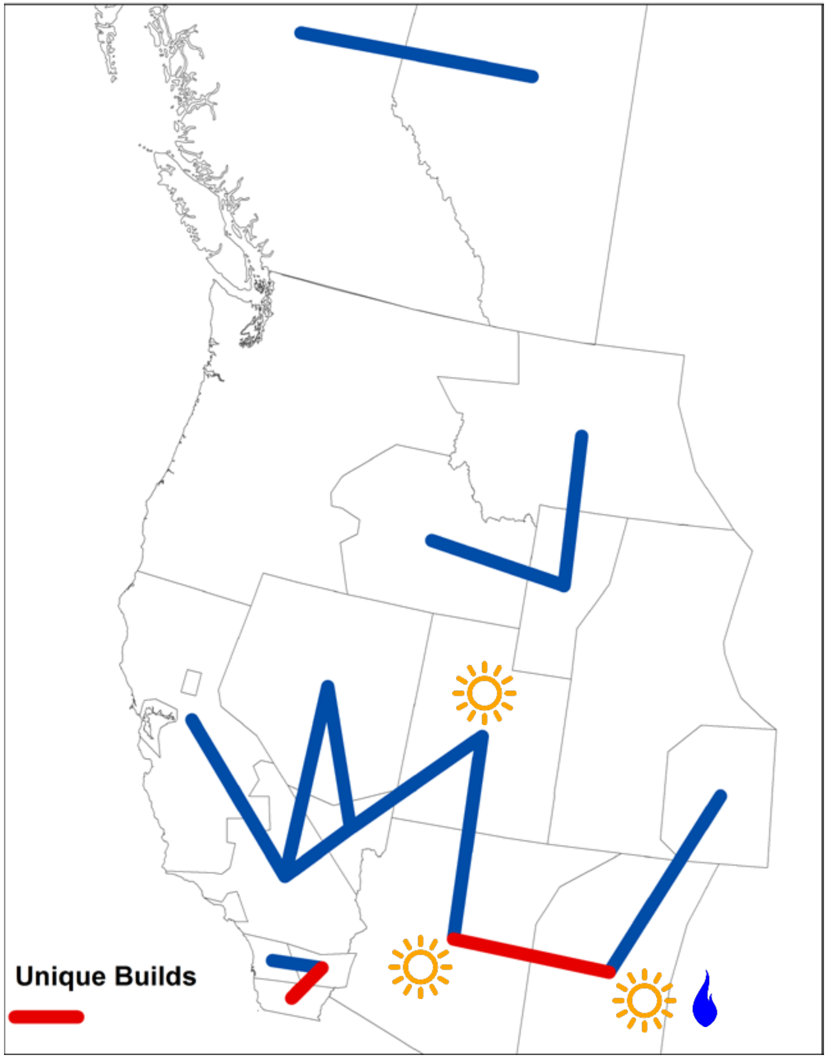
Example gen profile (CO) *with* UC operational constraints



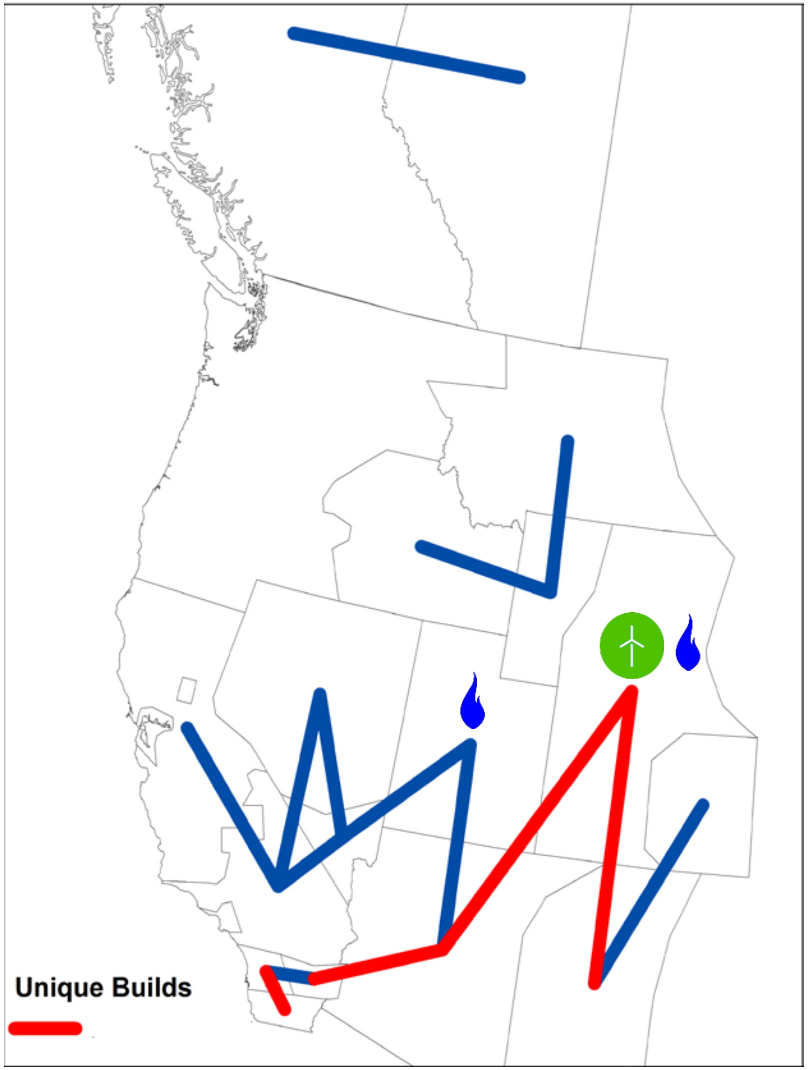


No change in 2025; 2035 Transmission change with UC constraints (Econ Recovery Scenario)

No UC



With UC



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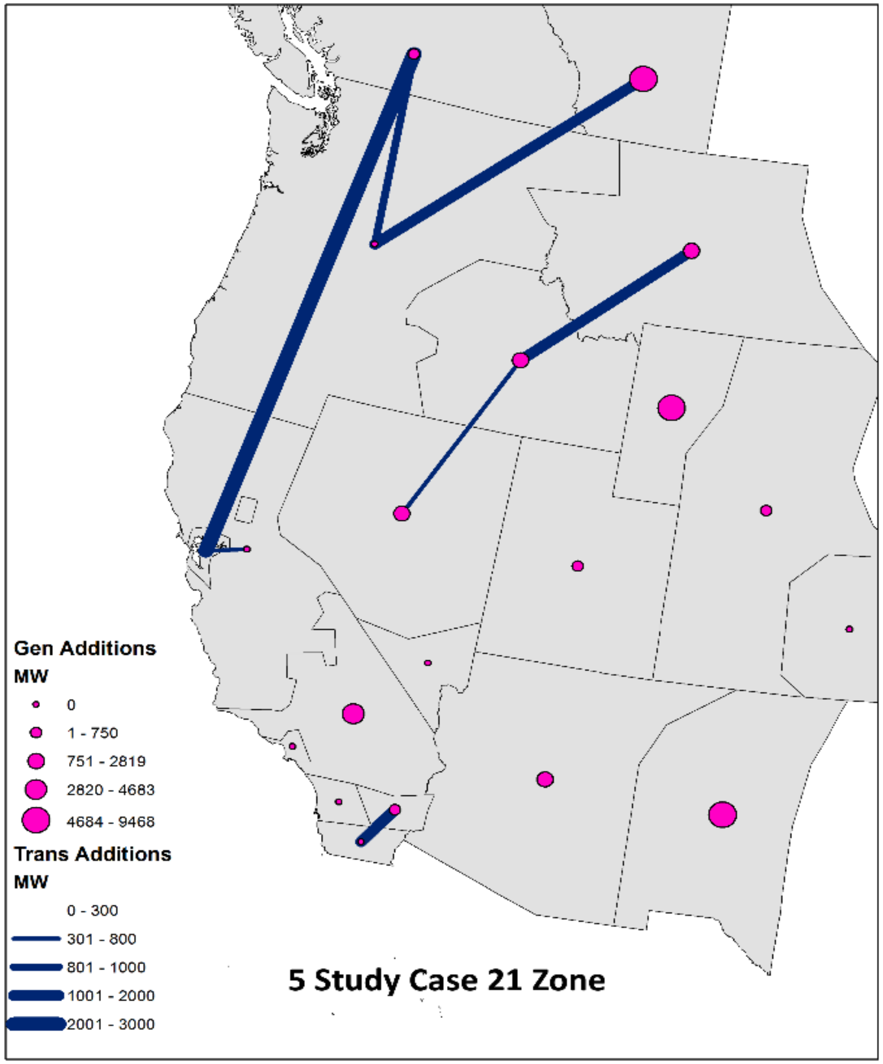
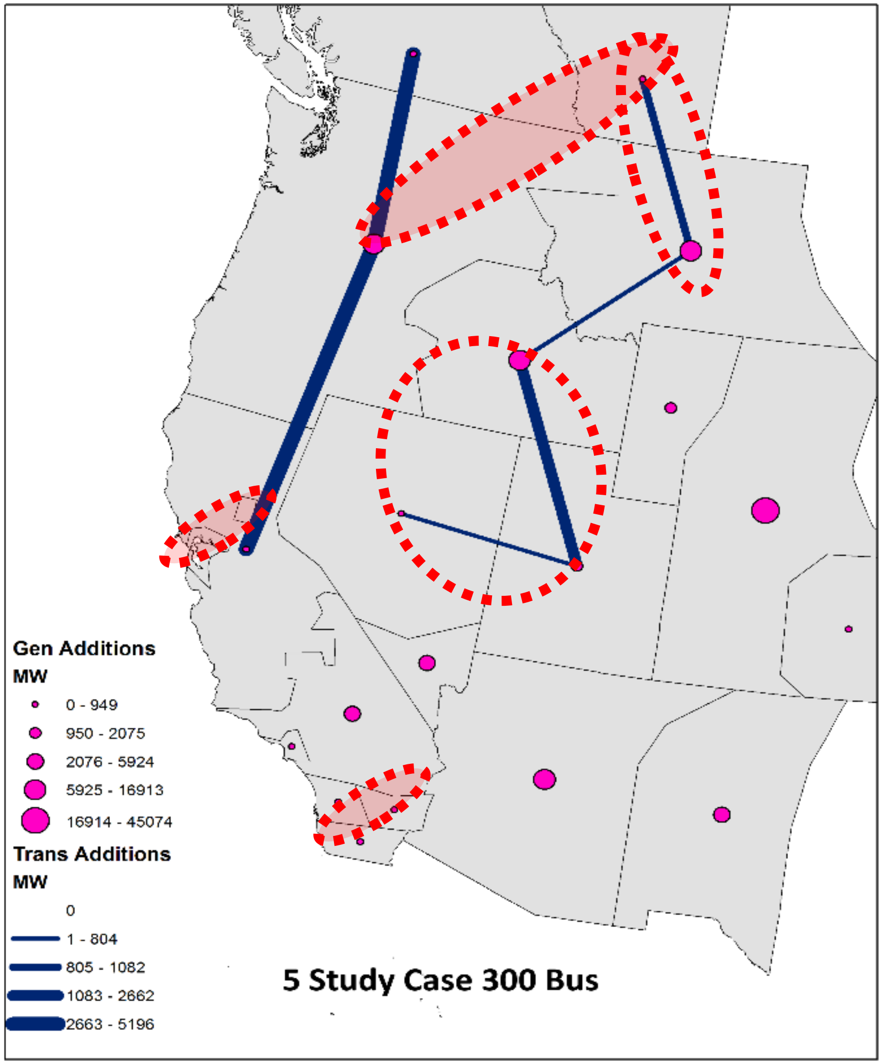
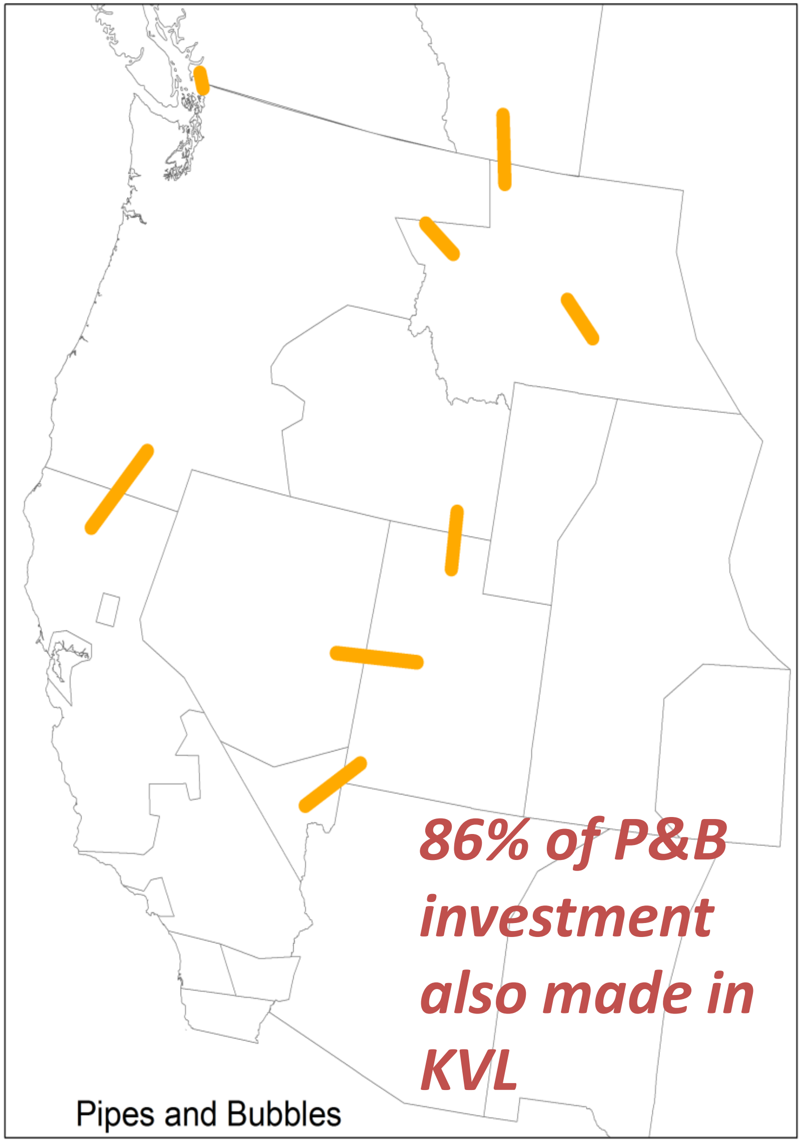
1(c) Do solutions change if we ignore KVL? *YES*

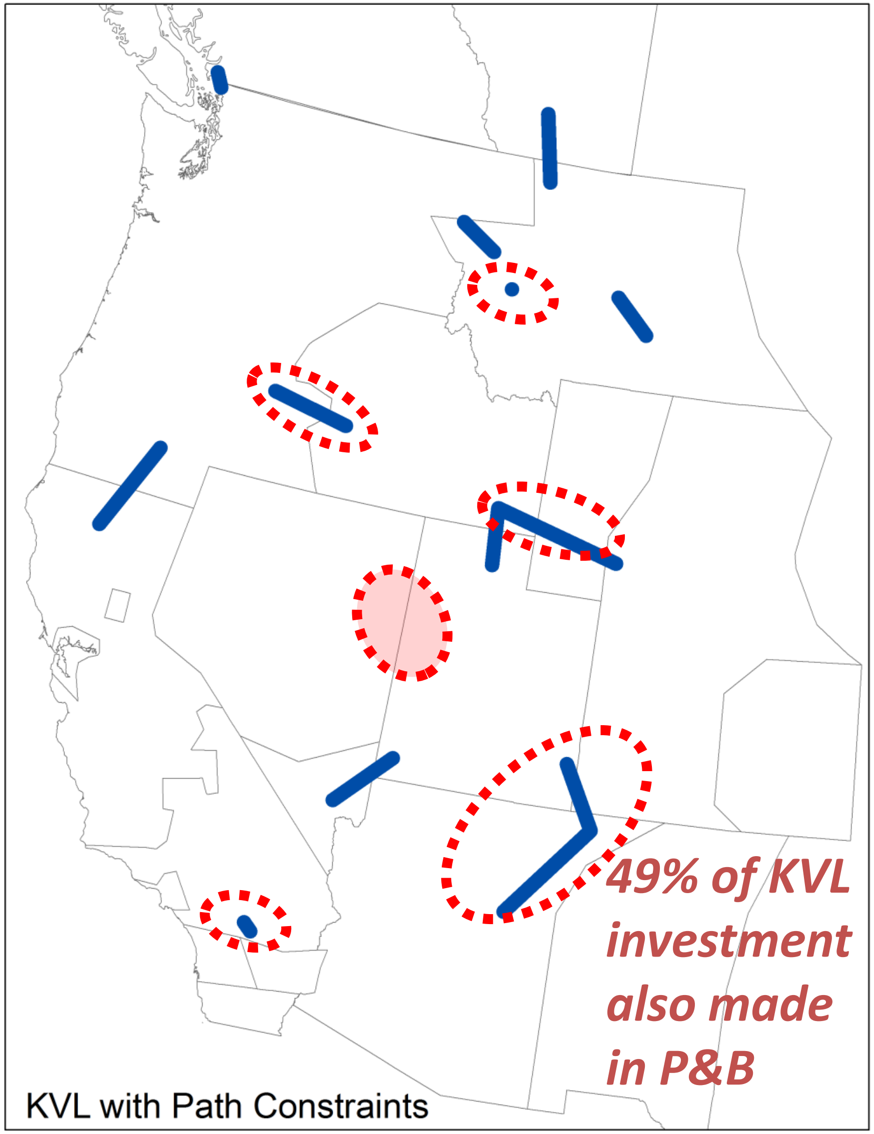
21 vs 300 bus network: Recommended regional interconnections

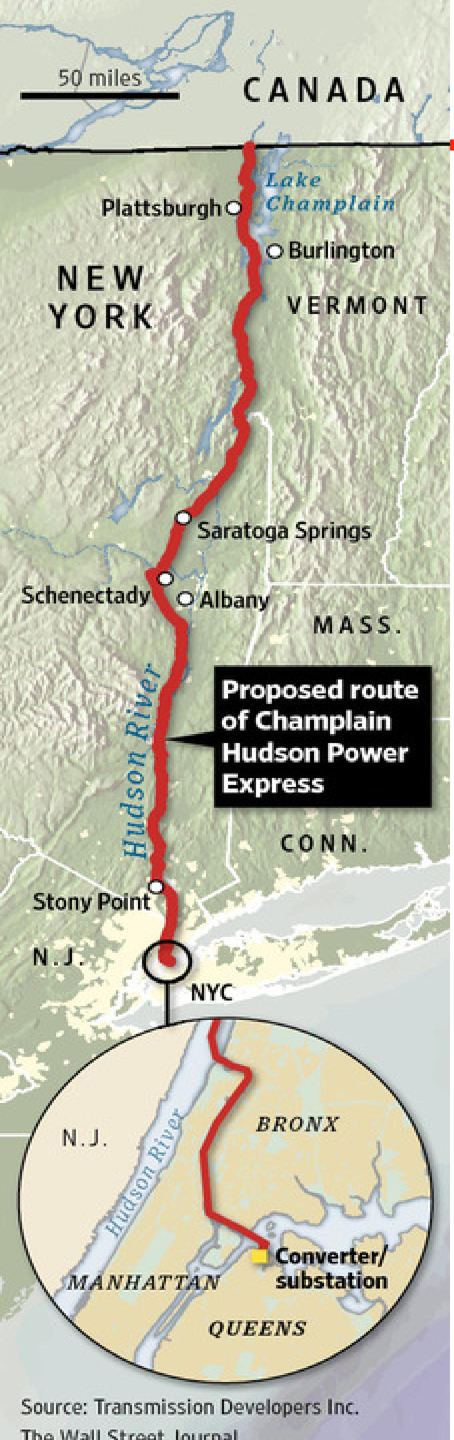




Compare 300 bus network: “Pipes & bubbles” vs. KVL







2. Champlain-Hudson Power Express: E4ST-Based Real Options Analysis

Should we build the CHPE now? ***No***

Or **should we wait 10 yrs, and see what happens to Indian Point, P_{gas}, P_{CO2}?** ***Yes***

Biao Mao, Dan Shawhan, William Schulze, Ray Zimmerman
Cornell University

Saamrat Kasina, Ben Hobbs
Johns Hopkins University

Real Options Analysis

Assumptions

1. Transmission is longest lived & most irreversible investment. We decide whether to build it now, wait 10 years to build (depending on what is learned), or never build

2. Gen investment & operations "follows" transmission. We anticipate how the CHP line affects both

3. Gas & Carbon prices, and Indian Point Retirement decisions are uncertain

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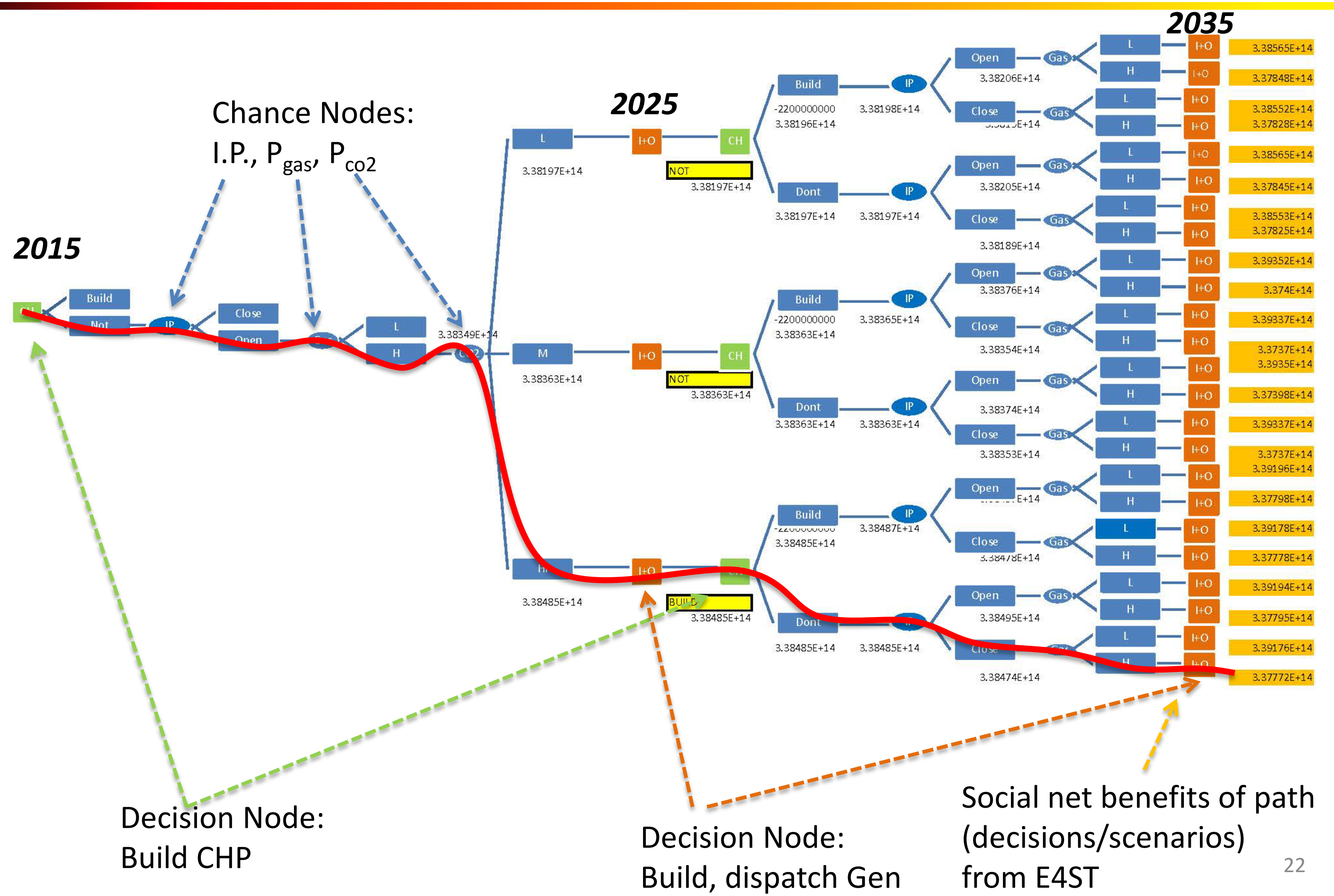
(Partial) Decision Tree



Socially Optimal 2nd Stage (2035) CHP Decisions, Conditioned on 2025 Uncertain Outcomes

(Tentative results, not for citation)

If line costs $0B:

Chance Node Outcomes in 2025		Indian Point and Gas Price Outcomes			
		IP Open		IP Closed	
		L P_{gas}	H P_{gas}	L P_{gas}	H P_{gas}
Carbon Price Outcomes	L P_{co2}				
	M P_{co2}				
	H P_{co2}				

If line costs $1.5B:

Chance Node Outcomes in 2025		Indian Point and Gas Price Outcomes			
		IP Open		IP Closed	
		L P_{gas}	H P_{gas}	L P_{gas}	H P_{gas}
Carbon Price Outcomes	L P_{co2}				
	M P_{co2}				
	H P_{co2}				

If line costs $3B:

Chance Node Outcomes in 2025		Indian Point and Gas Price Outcomes			
		IP Open		IP Closed	
		L P_{gas}	H P_{gas}	L P_{gas}	H P_{gas}
Carbon Price Outcomes	L P_{co2}				
	M P_{co2}				
	H P_{co2}				

Optimal Policy for $1.5B line

- Wait for now
- Then build for 2035 :
  - IF gas prices go up, OR
  - IF {IP open & CO2 price high}

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3. Options in Transmission Line Design

Does including physical options change the optimal mix of transmission lines? ***YES***

Pearl Donohoo-Vallett

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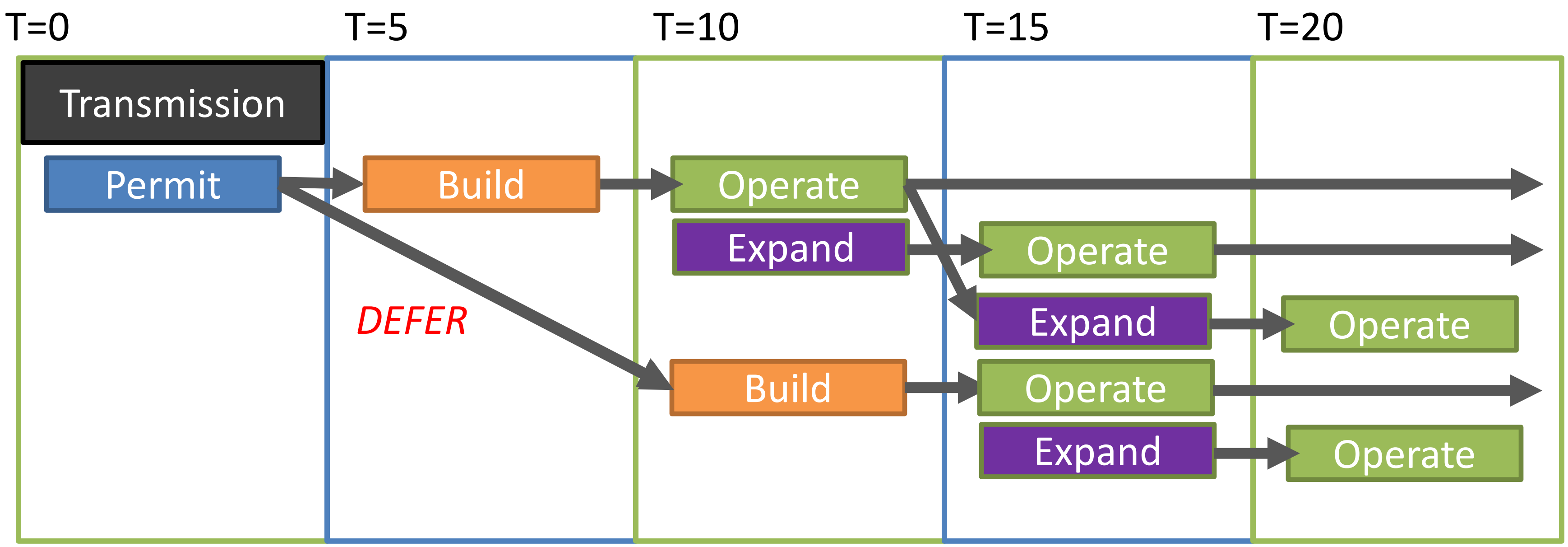
Decision Sequence



Includes "*Flexible Expand*" option of 2-circuit towers but only install conductors for single circuit

- *Gives option of cheap 2nd circuit addition later*

Optimized using 5-stage optimization (MILP)

- *~1M variables for California*

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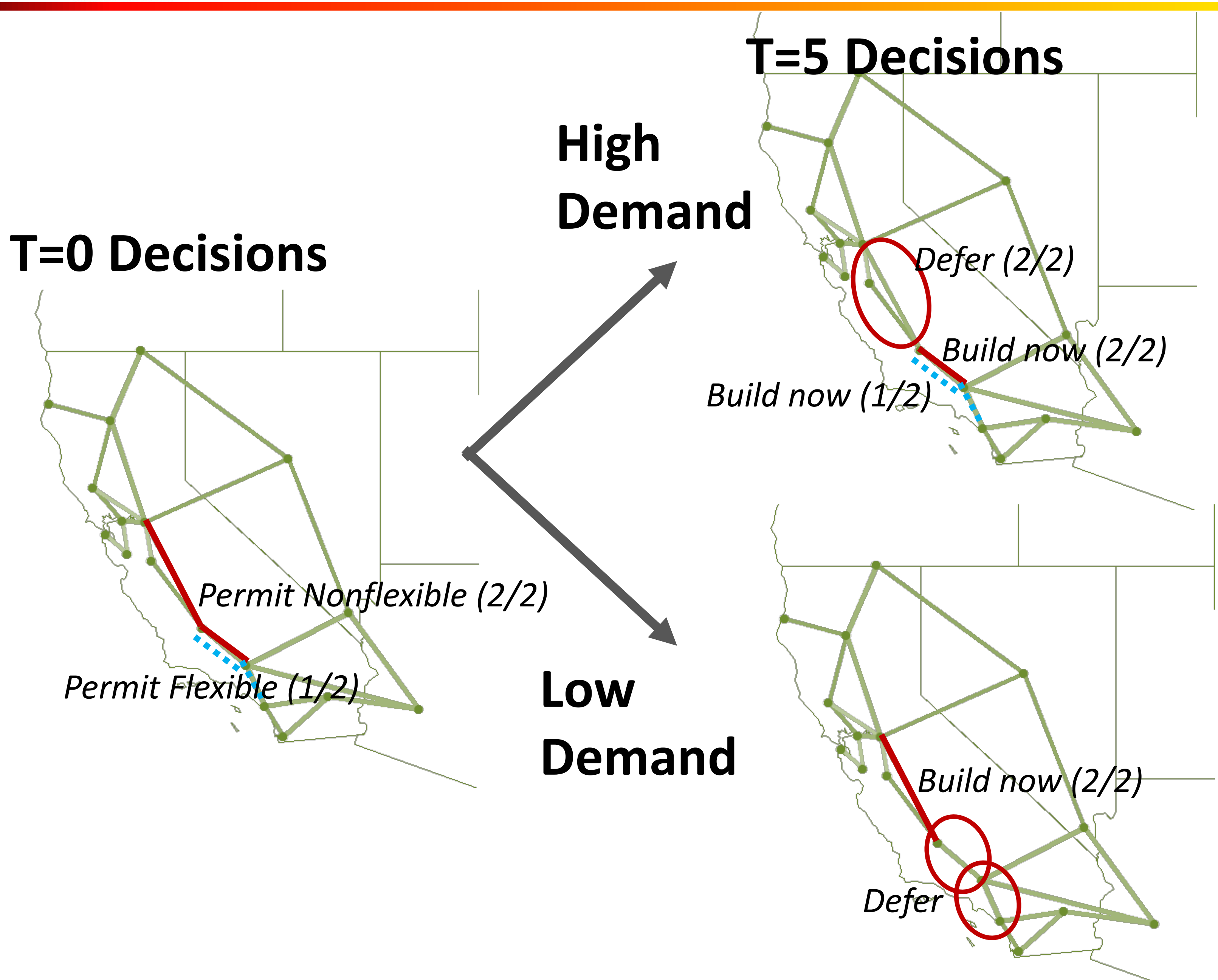
Preliminary Results (Not to be cited)



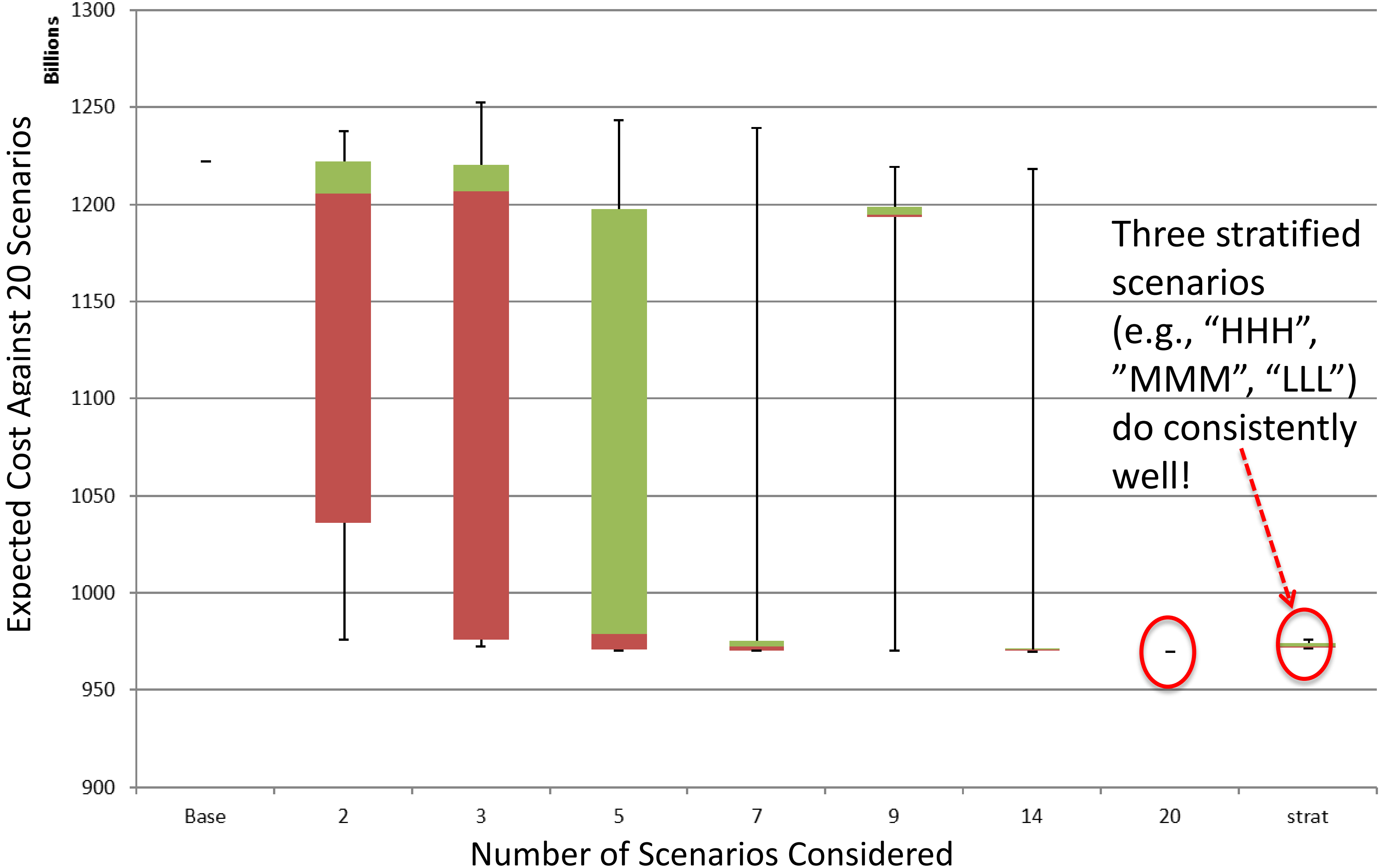
4. Clever Selection of Scenarios

Do plans based on a few extreme ("stratified") scenarios perform as well as full stochastic programming? ***Almost***

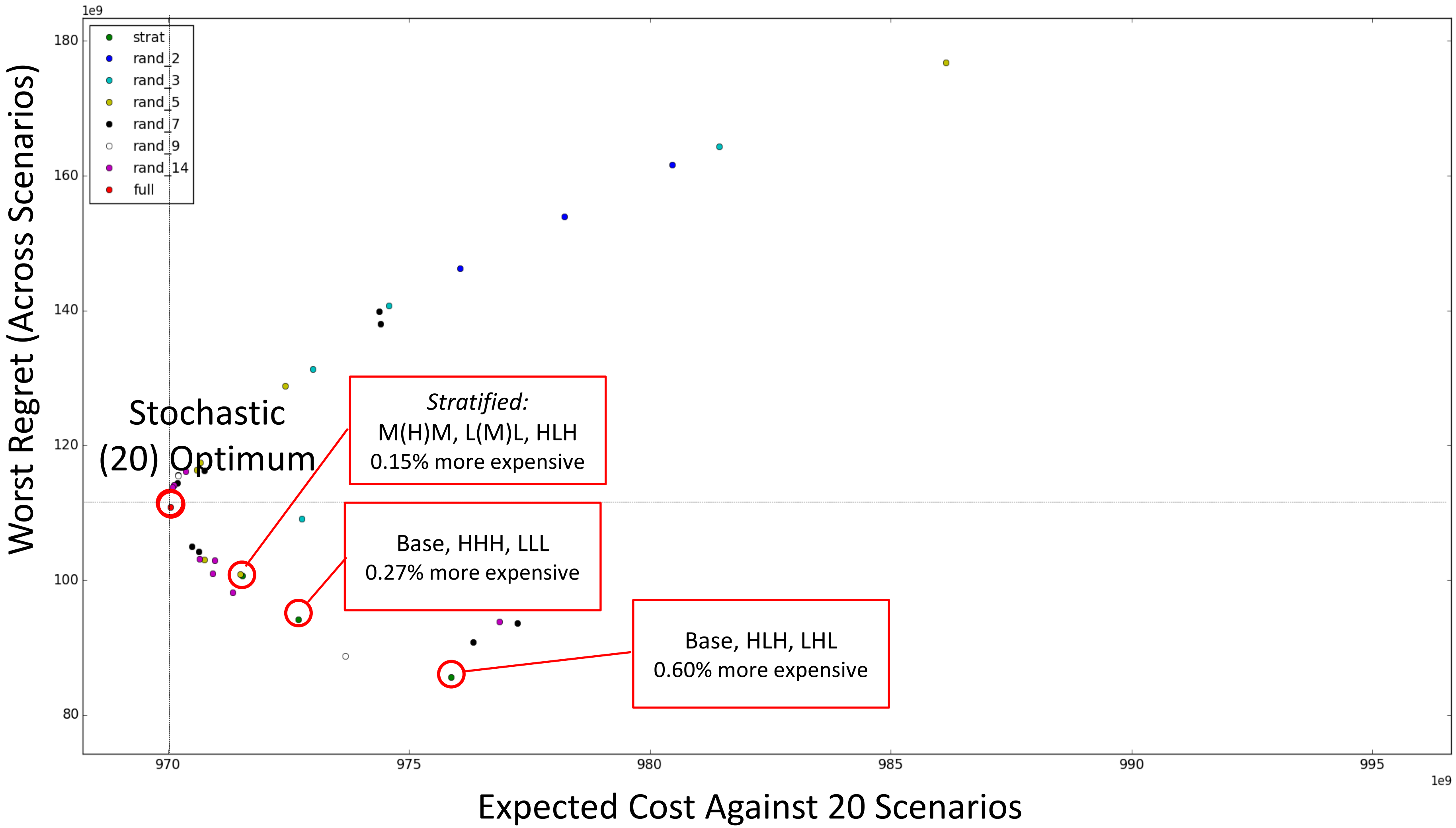
Or even better (in terms of min-max regret)? ***Yes***

Sang Woo Park and Pearl Donohoo

Actual Performance (against 20 Scenarios) of First Stage Transmission & Generation Plans



Stratified (3 Scenario) Plans Do *Better* than Stochastic (20 Scenario) in "Min Max Regret"



Next: **More cases to establish robustness of (& reasons for) stratified solution performance**

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5. Eastern Interconnection Proactive Planning

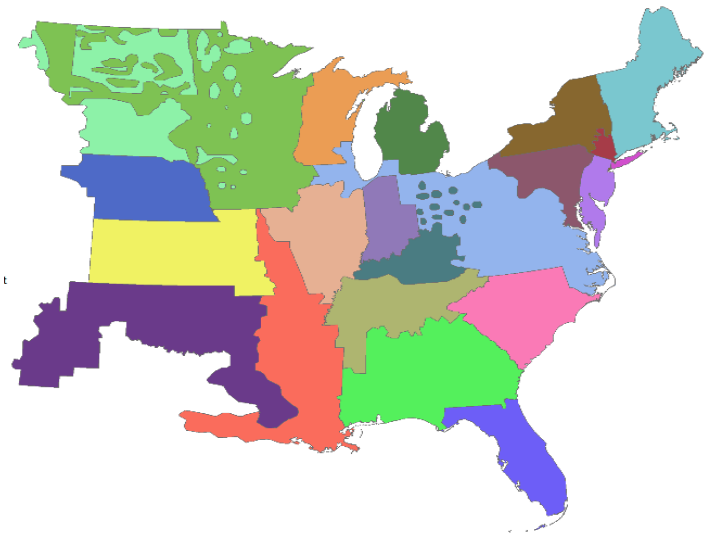
Would co-optimization lead to different transmission plans & costs for the 2011 EIPC project (under the high carbon future)?

YES

Evangelia Spyrou & Jonathan Ho

Eastern Interconnection project

(joint with R. Johnson [Energy Exemplar], J. McCalley [ISU])



- ❖ Strategic transmission planning for the Eastern Interconnection:
  - Planning horizon: 2011-2030
  - High carbon tax scenario:
    $27/t (2015) → $140/t (2030)
  - Declining load
- ❖ Eastern Interconnection:
  - 24-node transportation network
  - 47 interfaces
- ❖ Mixed-Integer LP:
  - Lumpy investments
  - Linear dispatch meeting a 20-block load duration curve

R. Johnson, A. Baechert, S. Koppolu, E. Spyrou, J. Ho, B.F. Hobbs, J. McCalley, A. Figueroa, and S. Lemos-Cano, ***Co-optimization of Transmission and Other Resources Study***, Final Report, Prepared by Energy Exemplar, LLC, The Johns Hopkins University, and Iowa State University, Submitted to the Eastern Interconnection States Planning Council and National Association of Regulatory Utility Commissioners, Washington, DC, January 26, 2015, www.naruc.org/Grants/Documents/NARUC-EISPC%20Co-Optimization%20Final.pdf

Compare 3 Approaches to Coordinating Gen and Trans

Traditional Planning

Generation Planning

↓ Generation Siting/Mix Scenario

Transmission Planning

↓ Transmission Plan

Iterative Cooptimization

Optimize Generation

↓ Generation Scenario

Optimize Trans

↓ Transmission Expansion

Optimize Generation

↓ Generation Scenario

Optimize Trans

↓ Transmission Expansion

⋮ ***Etc.***

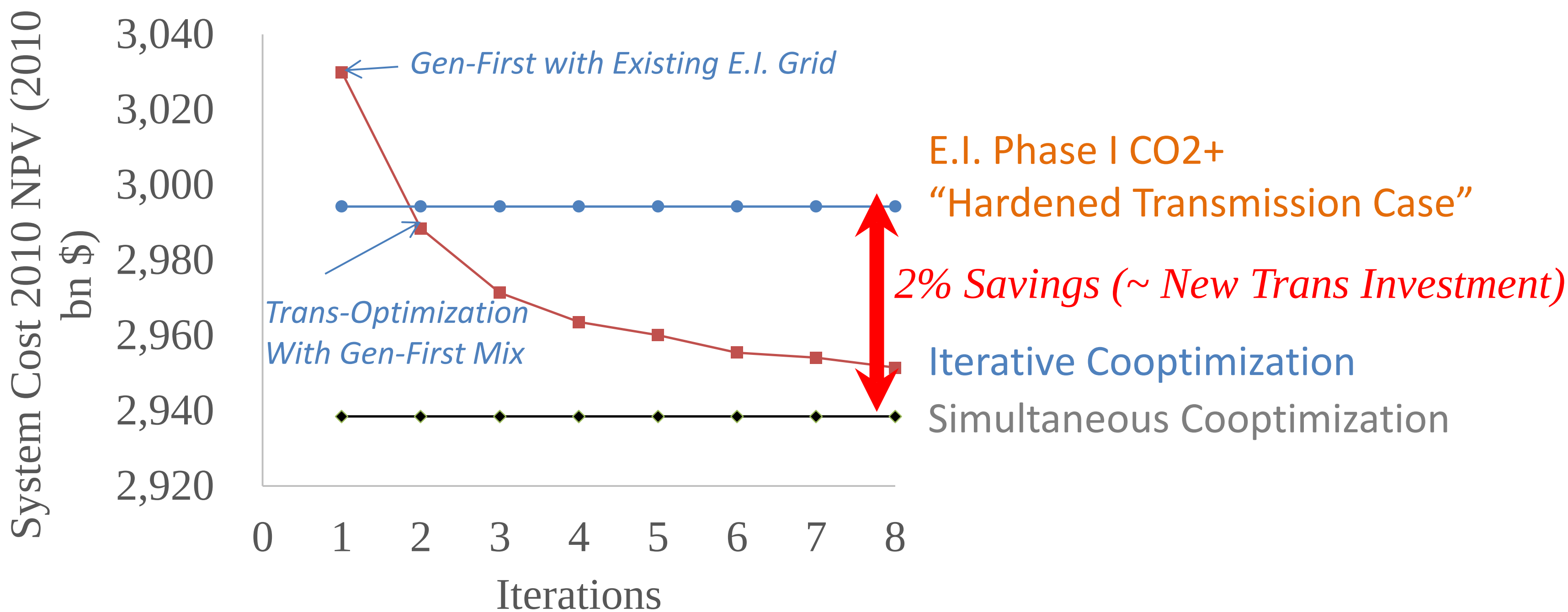
Simultaneous Cooptimization = Proactive Planning

Optimize Generation & Transmission Investment *Together*

↓ Transmission Plan & Consistent Generation Siting/Mix

Simulates "proactive planning" (Sauma & Oren)

Eastern Interconnection results



- Anticipative/Proactive planning saves:
  - ~56 $bn compared to EIPC approach
  - ~13 $bn compared to iterative approach
- Savings achieved by investment in more & higher quality wind:
  - Avoided fuel and carbon tax costs
  - But increased capital costs

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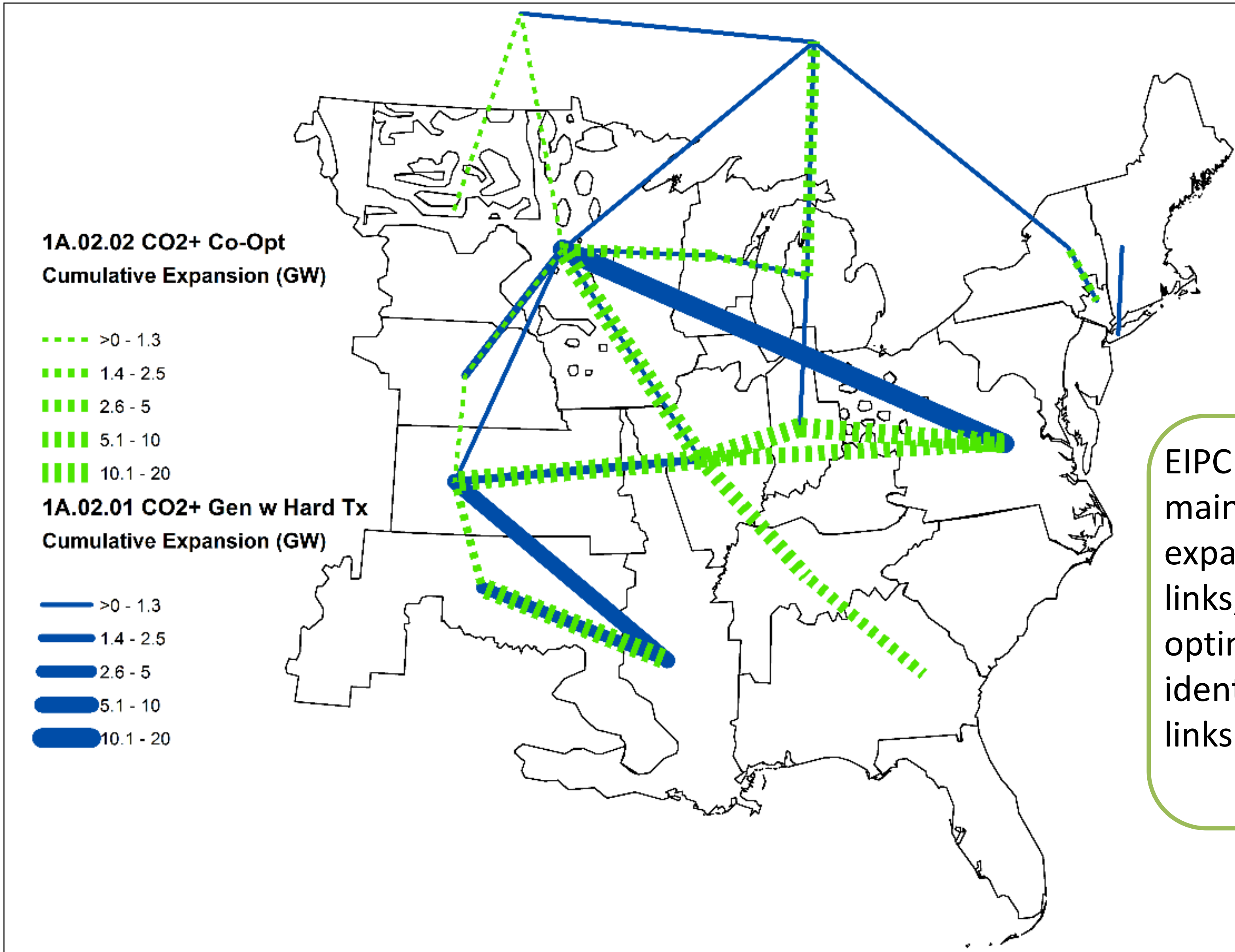
Eastern Interconnection results



EIPC heuristics mainly identified expansions of direct links, while co-optimization identified indirect links

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Conclusions

- **Stochastic plans are different & likely better**
  - *Distinct lines not picked by deterministic models*
  - *\$3B-\$14B is value of better near-term decisions in WECC – even under scenarios not considered!*
  - *"Robust planning" (pick lines that look good under most deterministic runs) falls short*
- **Stochastic planning is practical**
  - *Get most of benefits by including just a few scenarios*
- **Other approximations as important as assuming certainty**
  - *Failing to co-optimize*
  - *Network aggregation (21 vs 300)*
- **Next:**
  - *Economic cost of simplifications*
  - *Detailed regional study for BPA*
  - *Complete CHP analysis & line option analyses*