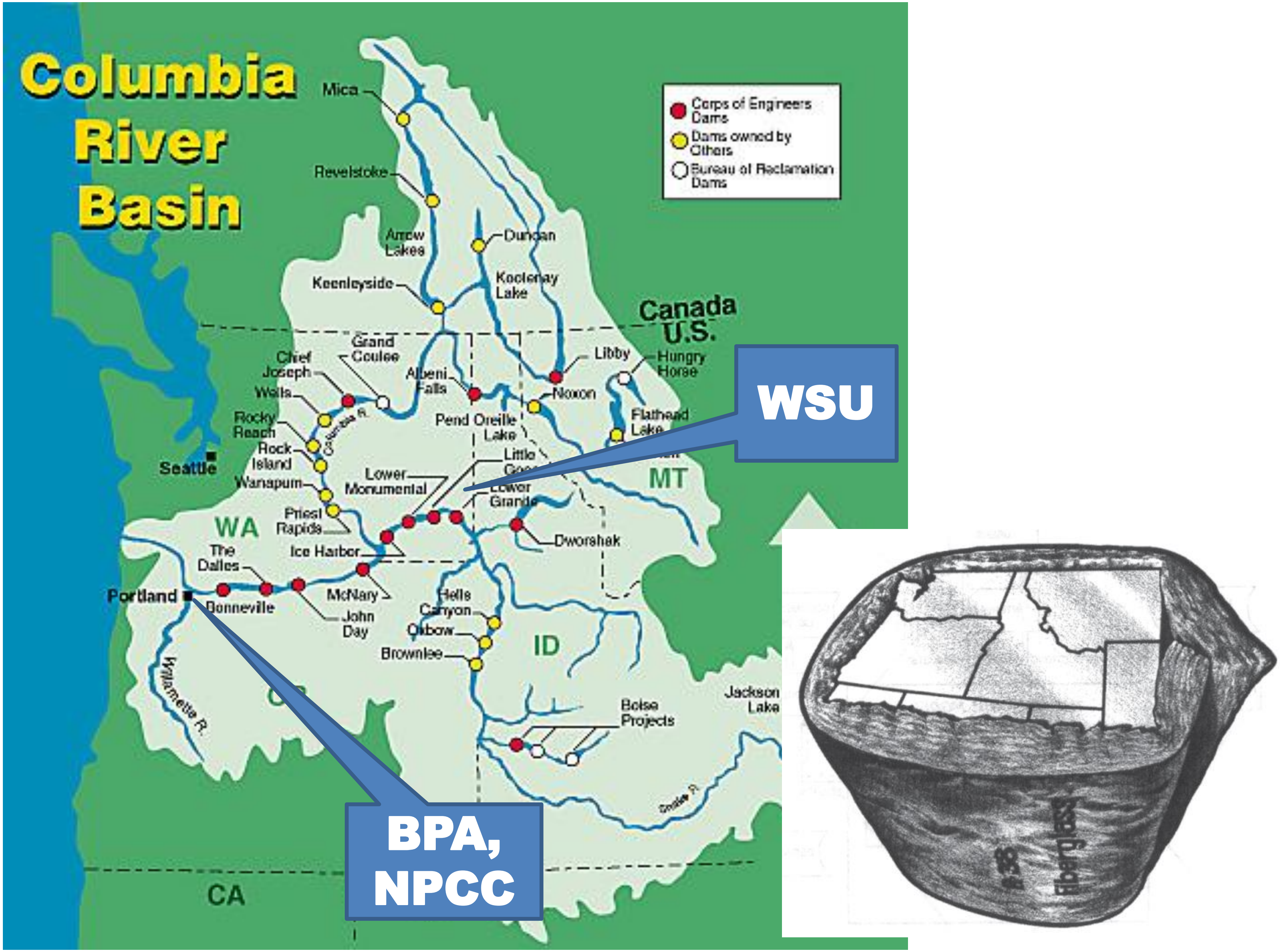
# Systems Modeling
# to
# Support Energy Planning

Presentation at the Mowat Energy Workshop,

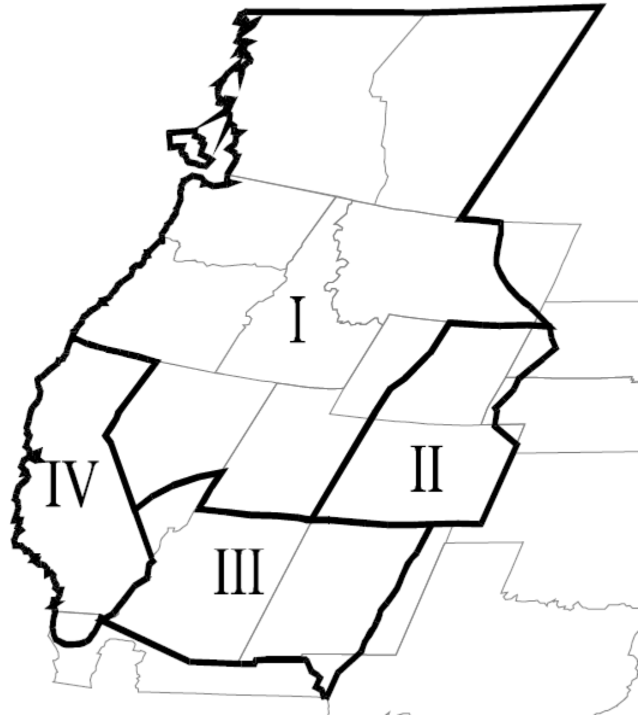
University of Toronto

September 2013

Professor Andrew Ford
School of the Environment
Washington State University



Columbia River Basin
Corps of Engineers Dams
Dams owned by Others
Bureau of Reclamation Dams
Mica
Revelstoke
Arrow Lakes
Duncan
Keenleyside
Kootenay Lake
Canada
U.S.
Libby
Hungry Horse
Grand Coulee
Chief Joseph
Wells
Albeni Falls
Noxon
Rocky Reach
Rock Island
Pend Oreille Lake
Flathead Lake
Seattle
Wanapum
Lower Monumental
Little Goose
Lower Granite
MT
WA
Priest Rapids
Ice Harbor
Dworshak
The Dalles
Portland
Bonneville
McNary
John Day
Hells Canyon
Oxbow
Brownlee
ID
Willamette R.
Jackson Lake
Boise Projects
Snake R.
CA
WSU
BPA, NPCC
Fiberglass




ELSEVIER

Energy Policy 36 (2008) 443–455

ENERGY POLICY

www.elsevier.com/locate/enpol

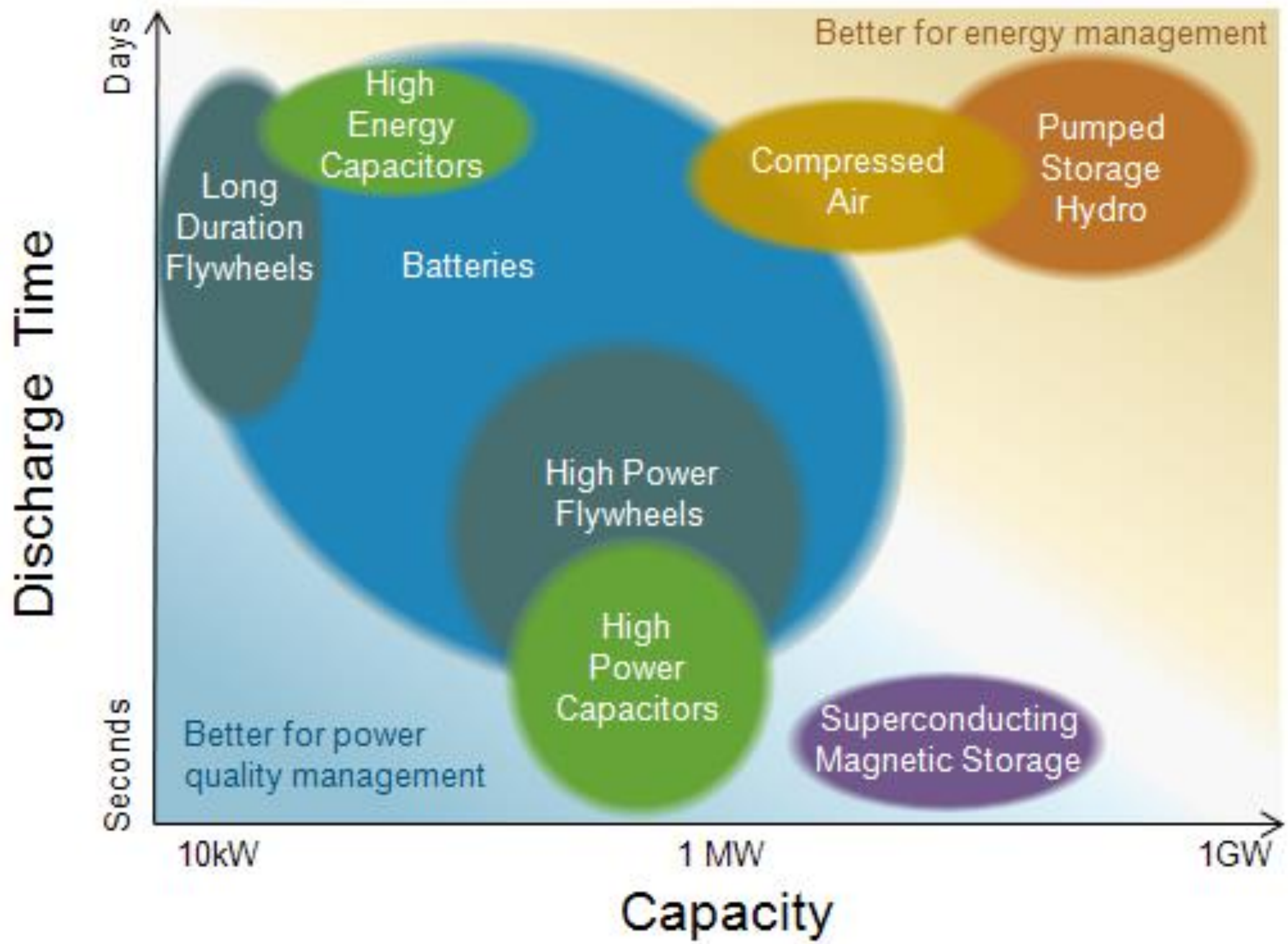
# Simulation scenarios for rapid reduction in carbon dioxide emissions in the western electricity system

Andrew Ford

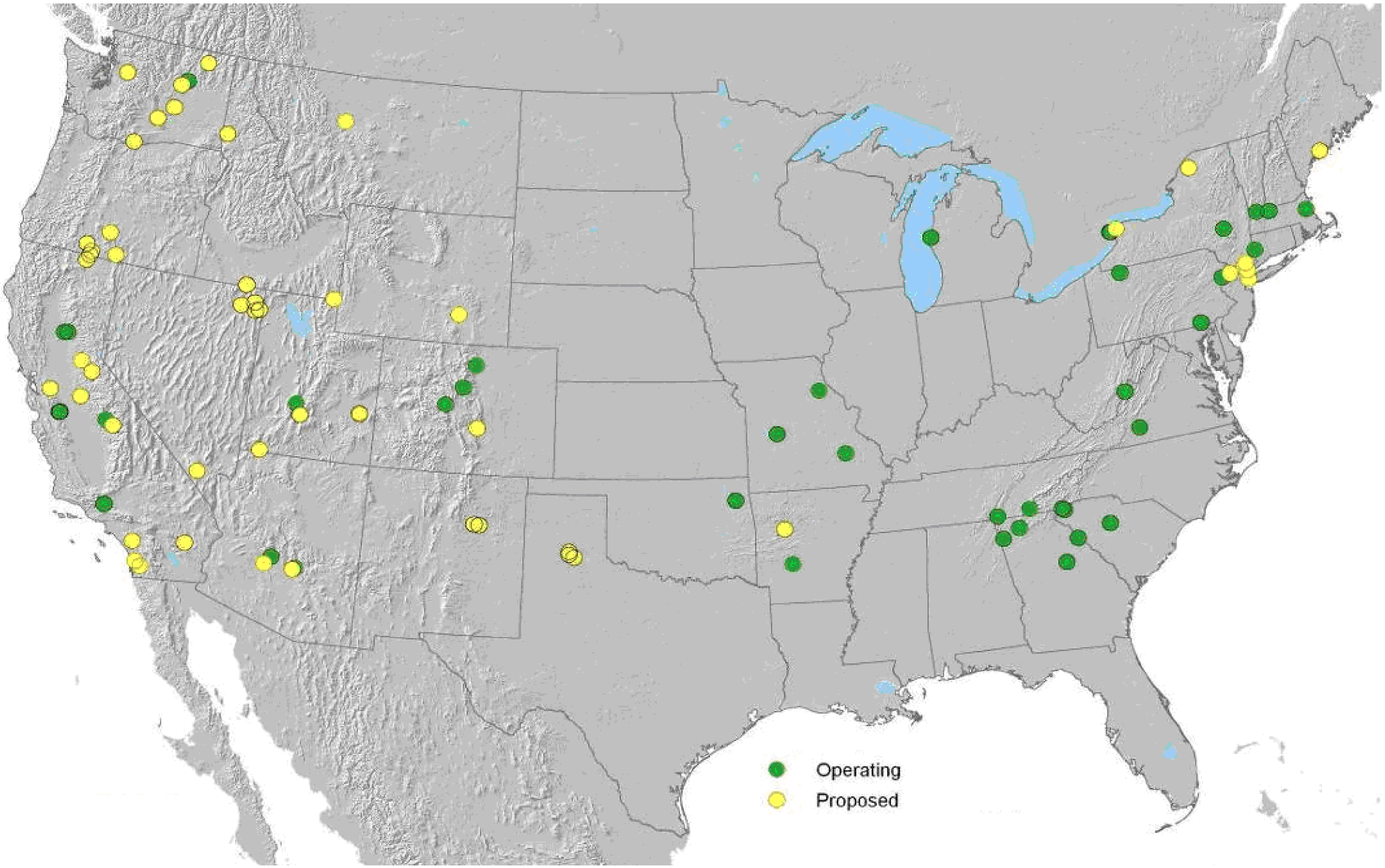
*School of Earth and Environmental Sciences, Washington State University, Pullman, WA 99164-4430, USA*

Received 29 July 2007; accepted 17 September 2007
Available online 5 November 2007

# Energy Storage

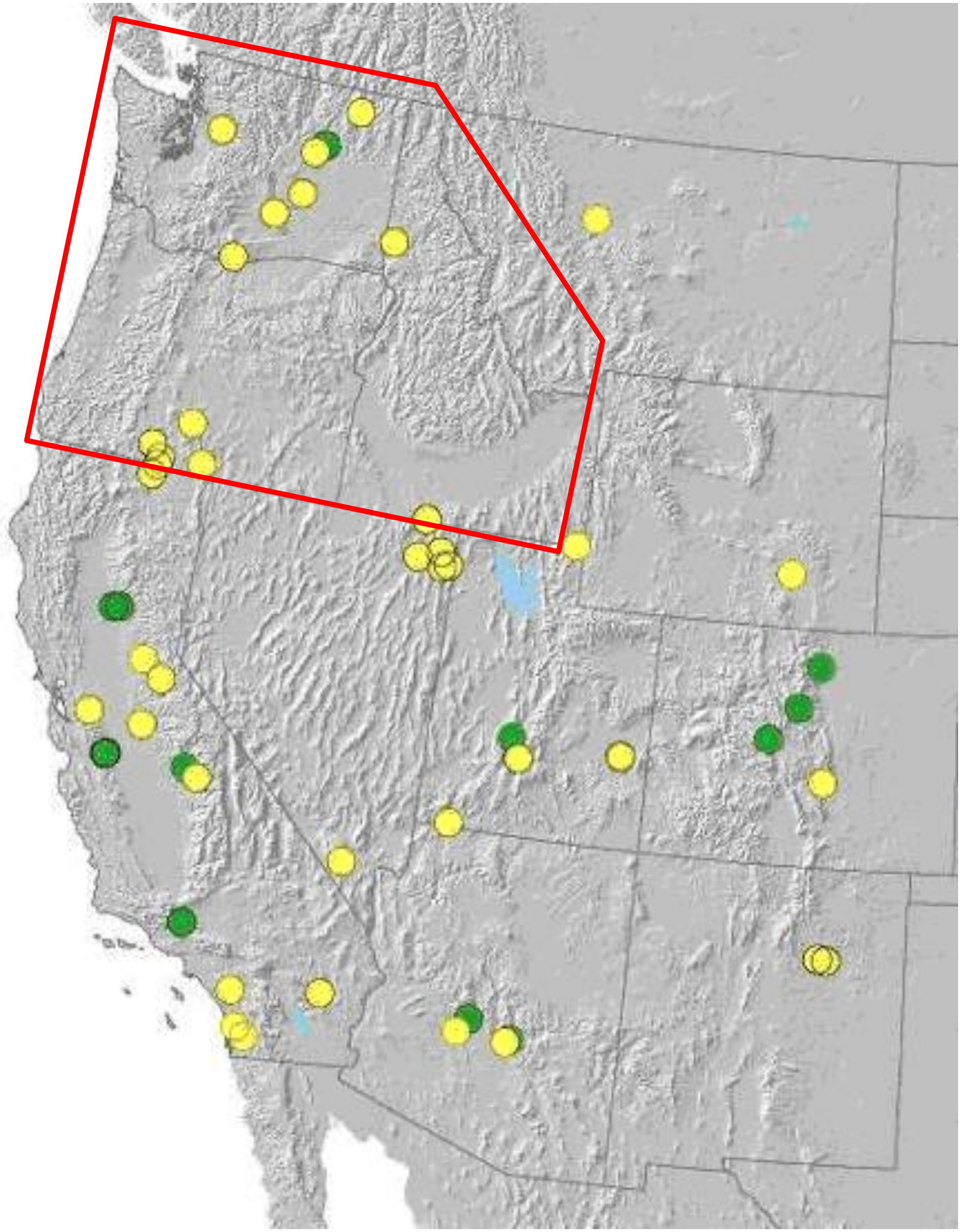


# Interest in Pumped Storage is Exploding

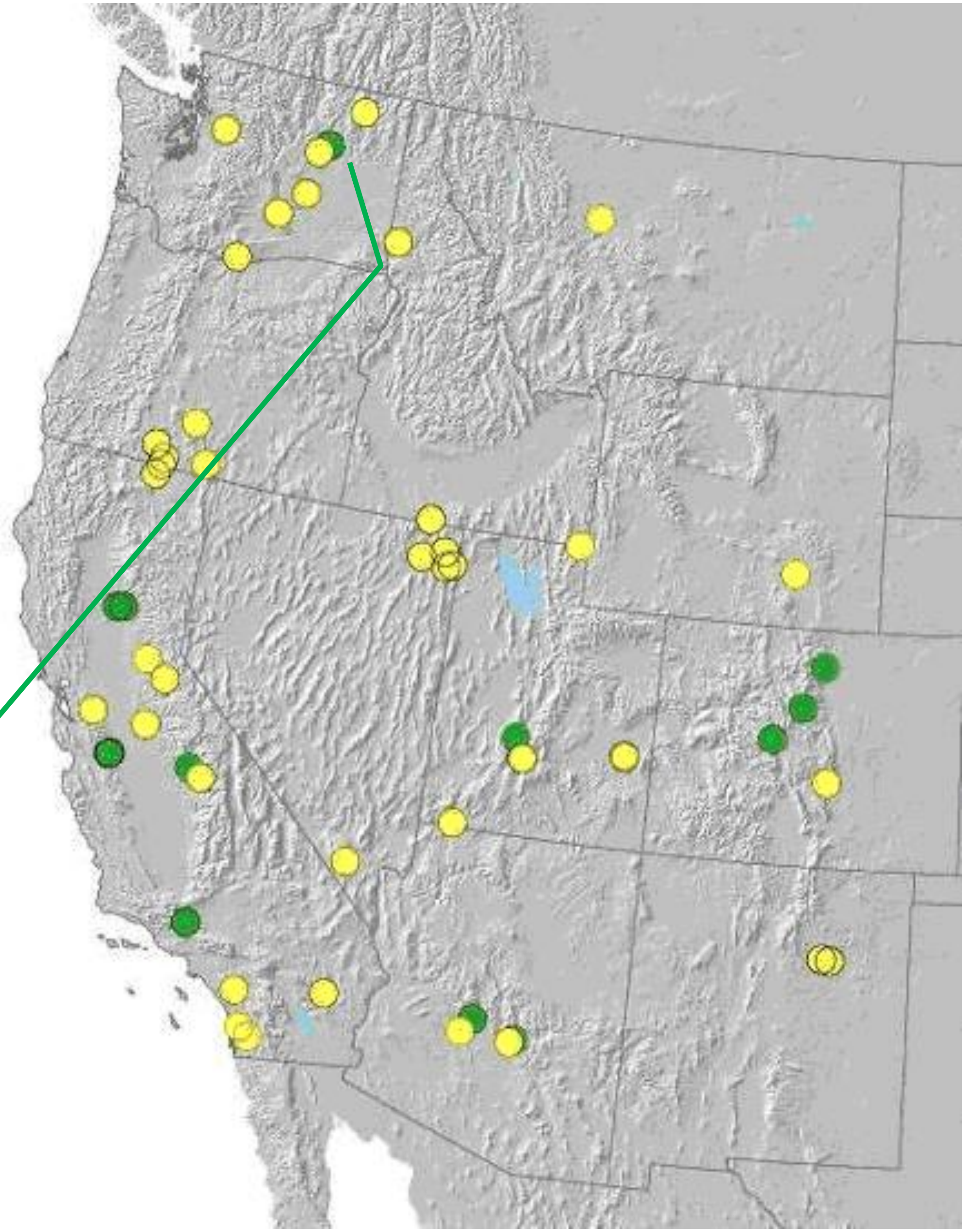


# Pumped Storage in the West

**The proposed facilities in WA/OR/ID alone would expand storage in the entire west by 4 fold**

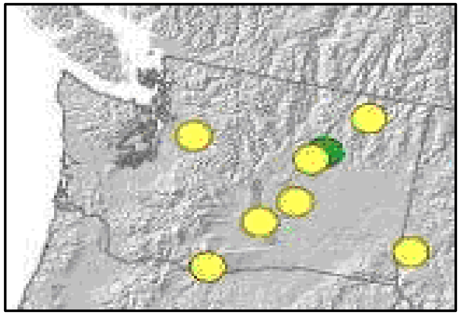


# Pumped Storage in the West

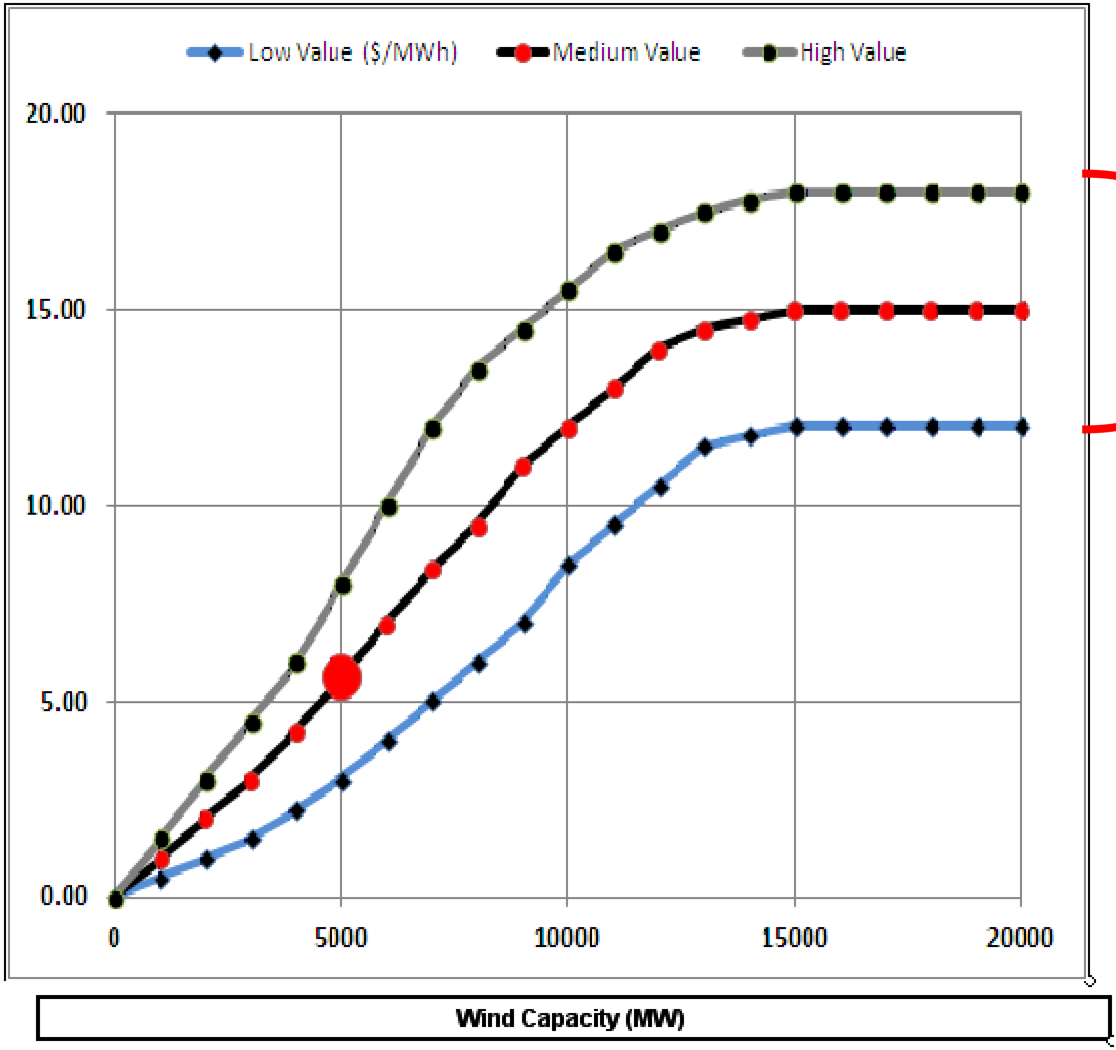


**Grand Coulee on the Columbia: System Dynamics Model by Tyler Llewellyn**

# Wind Integration Costs



**BPA: $1.23 per kw per month, translates to $5.60 per MWh of wind generation.**




**Long-term will be higher: (loss of flexibility)**

**Costs might range from $12 to $18 per MWh**

(based on Lawrence Berkeley Laboratory National Lab summary of wind integration studies and Integrated Resource Plans in the West.)

# Do the Storage Proposals have Sufficient Value?

- A dozen or more modes of value can be described
- But they are seldom quantified
  - either Individually or jointly
  - and their value is seldom embedded within the larger system
- The modeling methods are not up to the task

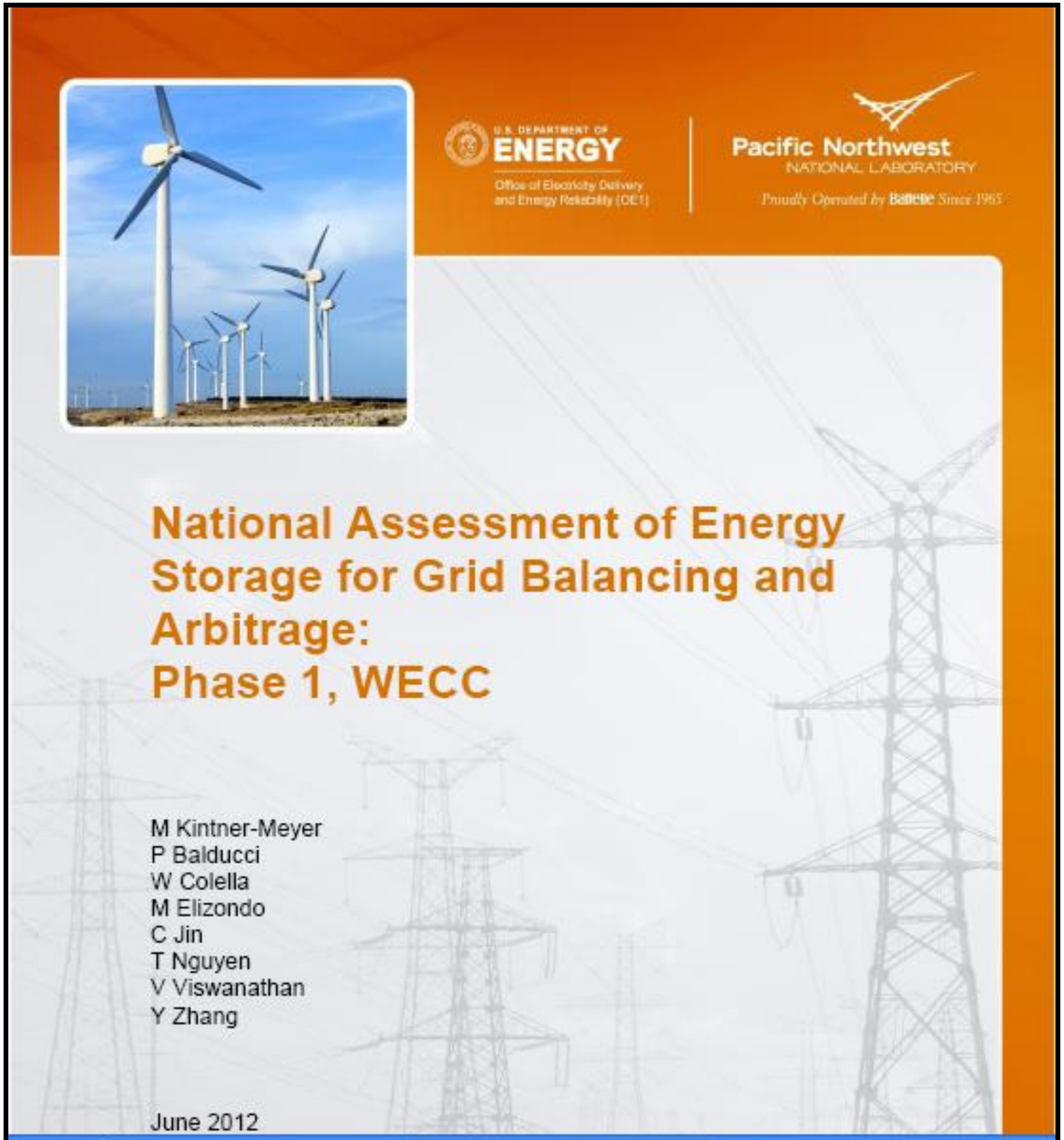
# California Public Utilities Commission Assigned Commissioner's Ruling

**3. Market Barriers to Emerging Storage Technologies**

The market barriers hindering broader adoption of emerging energy storage technologies have been identified and discussed in Phase 1 of this proceeding:

1. Lack of definitive operational needs;
2. Lack of cohesive regulatory framework;
2. Evolving markets and market product definition;
3. Resource Adequacy accounting;
4. Lack of cost-effectiveness evaluation methods;
5. Lack of cost recovery policy;
6. Lack of cost transparency and price signals (wholesale and retail);
7. Lack of commercial operating experience; and

**Models are "first of their kind"**



U.S. DEPARTMENT OF ENERGY
Office of Electricity Delivery and Energy Reliability (OE1)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

**National Assessment of Energy Storage for Grid Balancing and Arbitrage: Phase 1, WECC**


M Kintner-Meyer
P Balducci
W Colella
M Elizondo
C Jin
T Nguyen
V Viswanathan
Y Zhang


June 2012

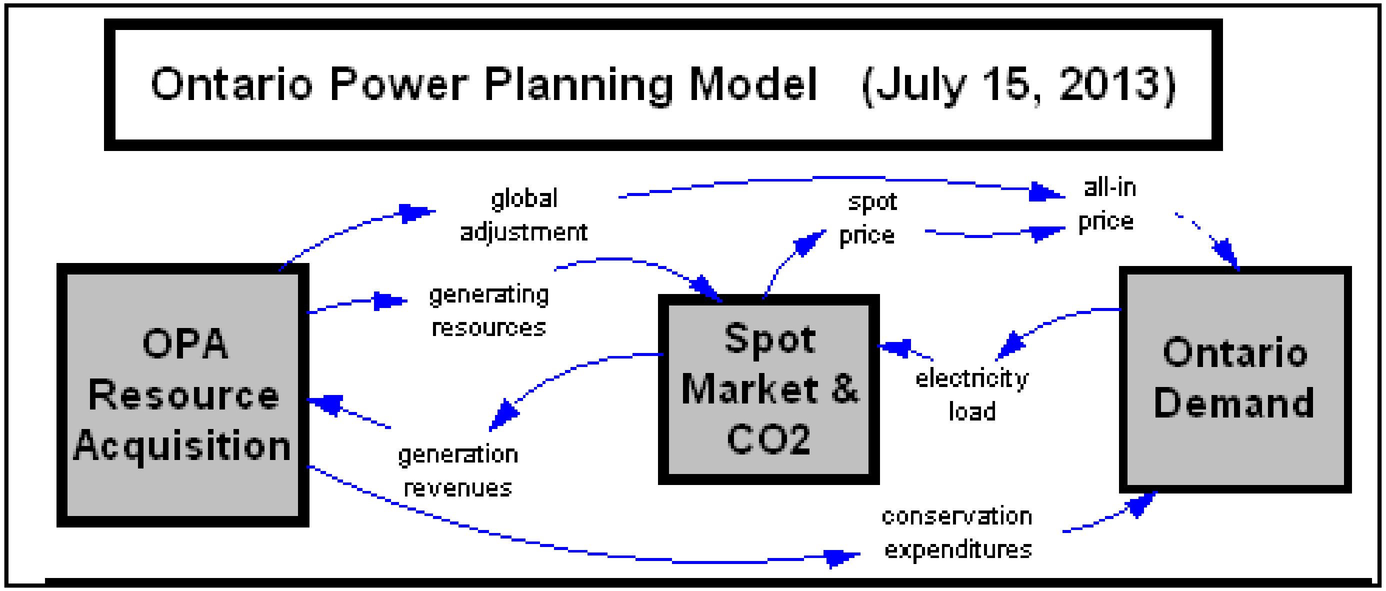
## Grid Balancing & Arbitrage:

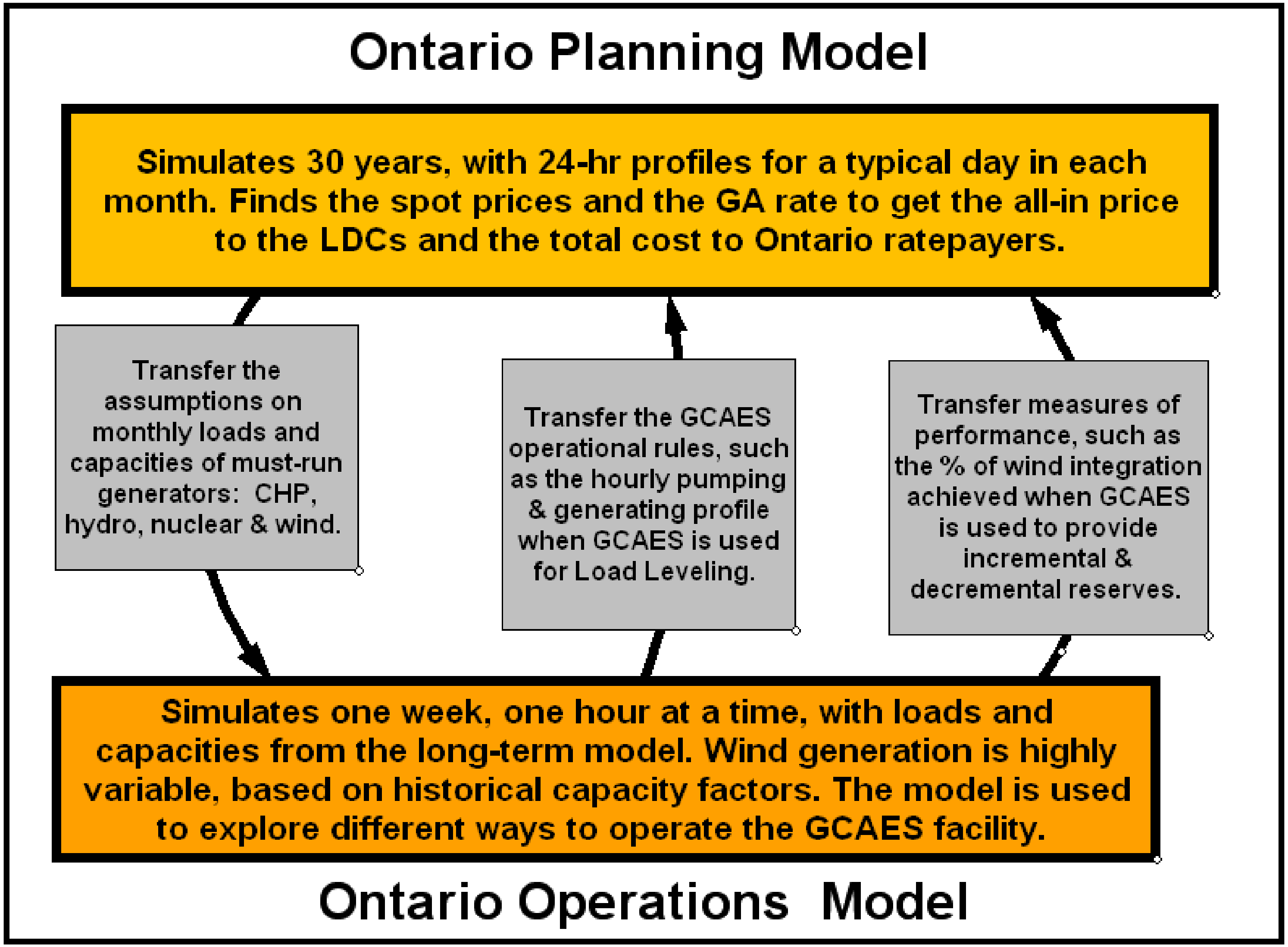
## That's all???

## Rule of Thumb:

an extra 10,000 MW of wind capacity would mean an extra 1,000 MW of balancing

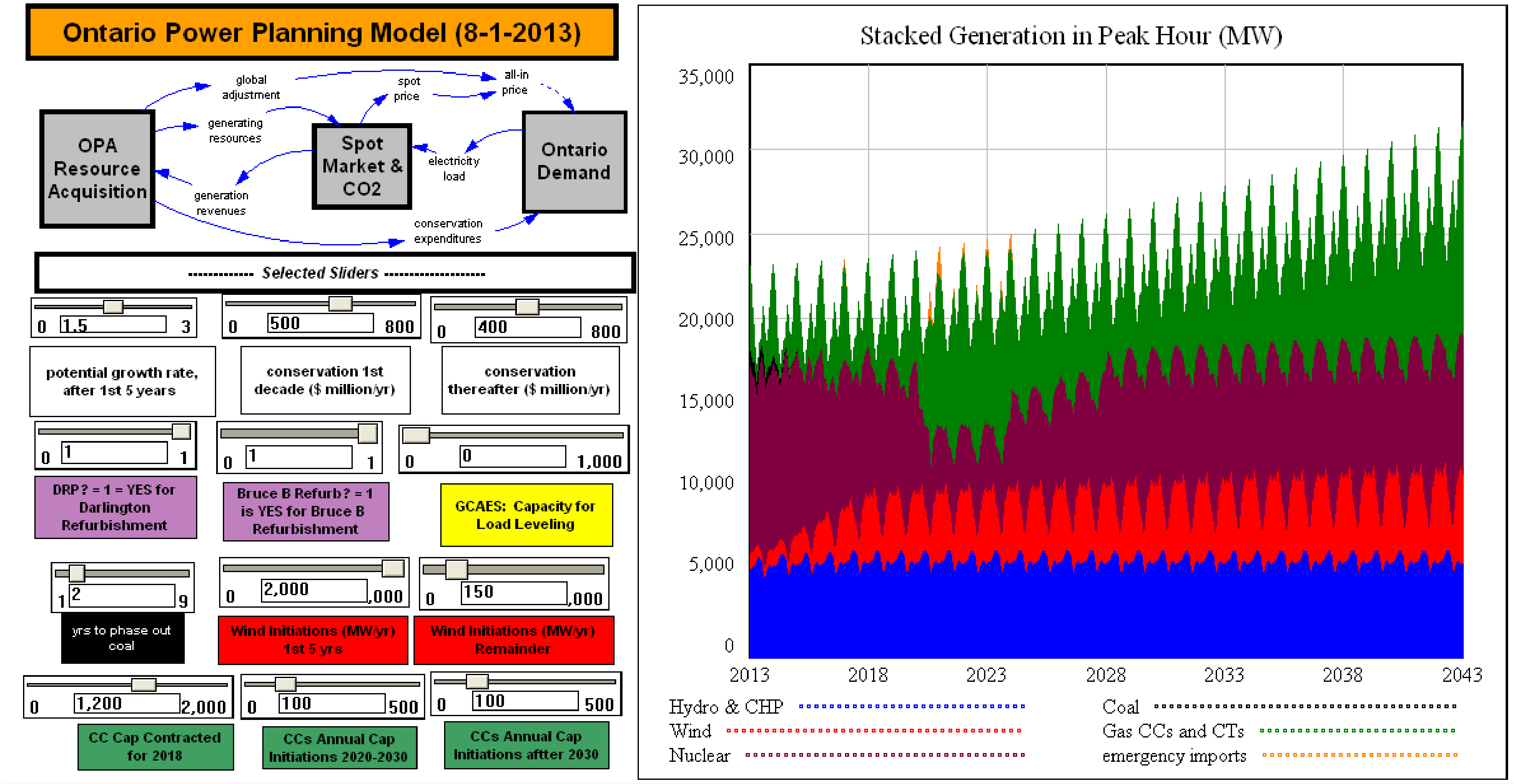
# A Systems Approach to Support Long-Term Planning



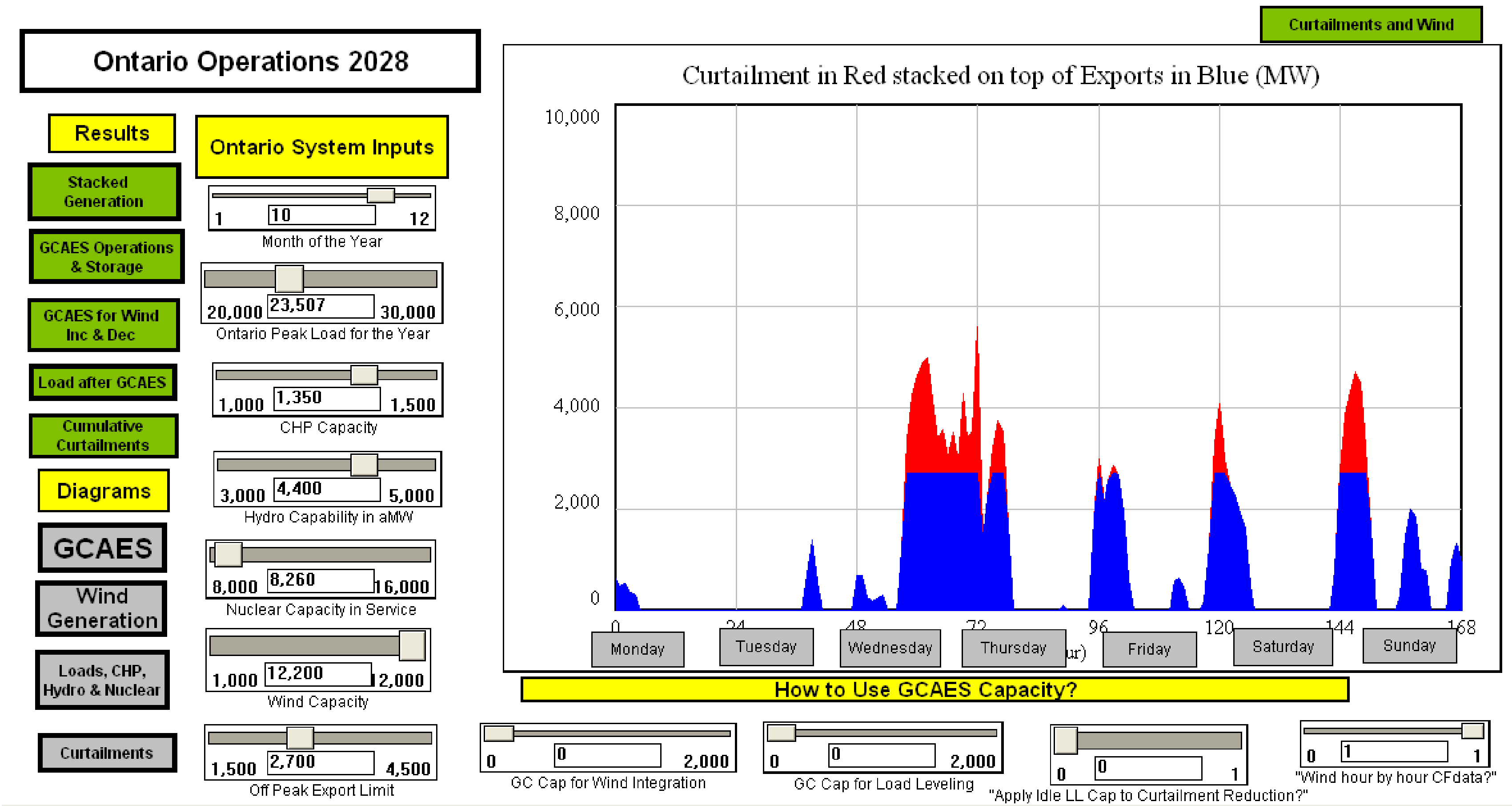

Ontario Planning Model
Simulates 30 years, with 24-hr profiles for a typical day in each month. Finds the spot prices and the GA rate to get the all-in price to the LDCs and the total cost to Ontario ratepayers.
Transfer the assumptions on monthly loads and capacities of must-run generators: CHP, hydro, nuclear & wind.
Transfer the GCAES operational rules, such as the hourly pumping & generating profile when GCAES is used for Load Leveling.
Transfer measures of performance, such as the % of wind integration achieved when GCAES is used to provide incremental & decremental reserves.
Simulates one week, one hour at a time, with loads and capacities from the long-term model. Wind generation is highly variable, based on historical capacity factors. The model is used to explore different ways to operate the GCAES facility.
Ontario Operations Model

# GCAES: General Compression Advanced Energy Storage: an example of fuel-free, bulk storage

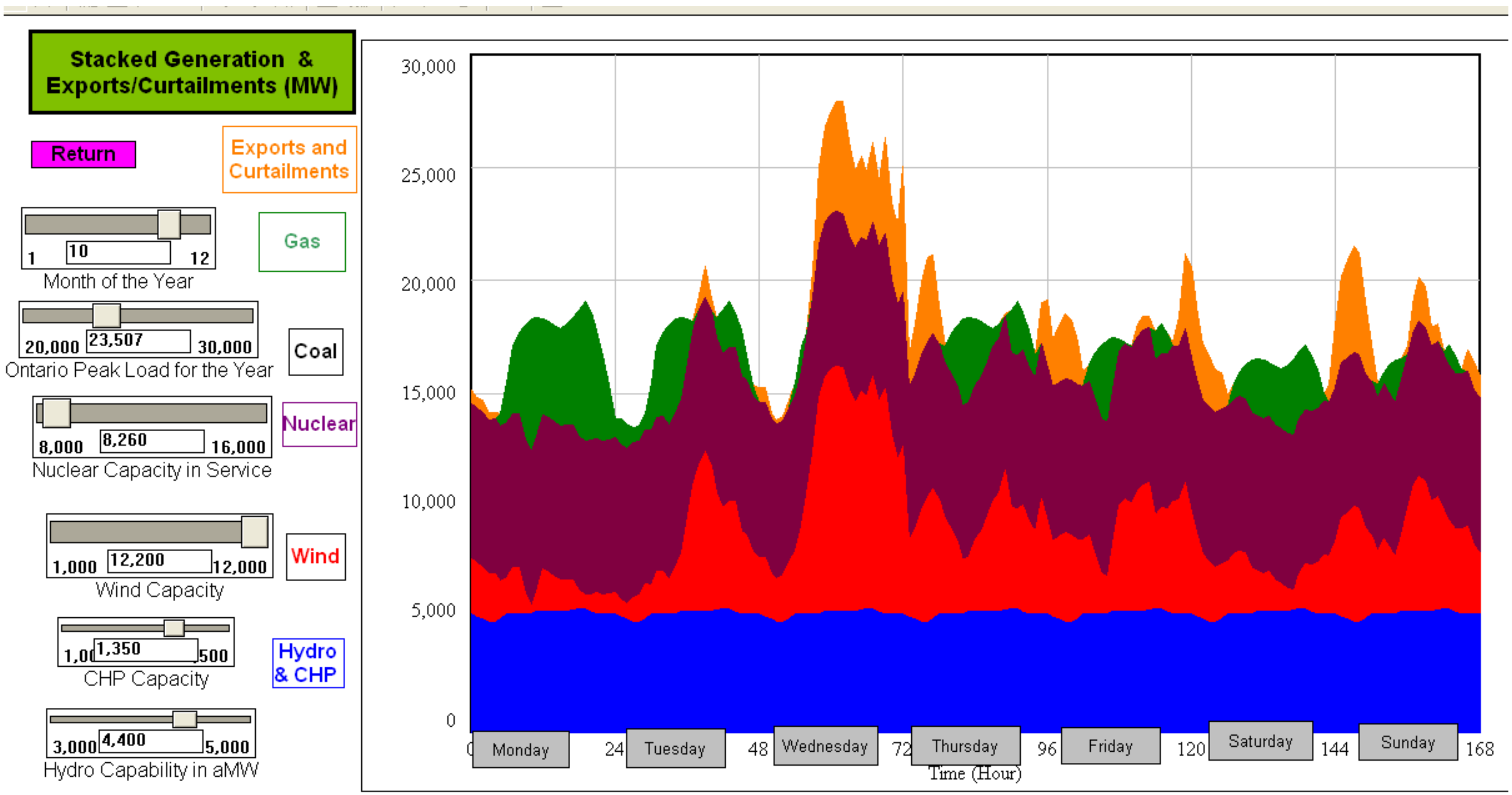
# Opening View of the Long-term Model



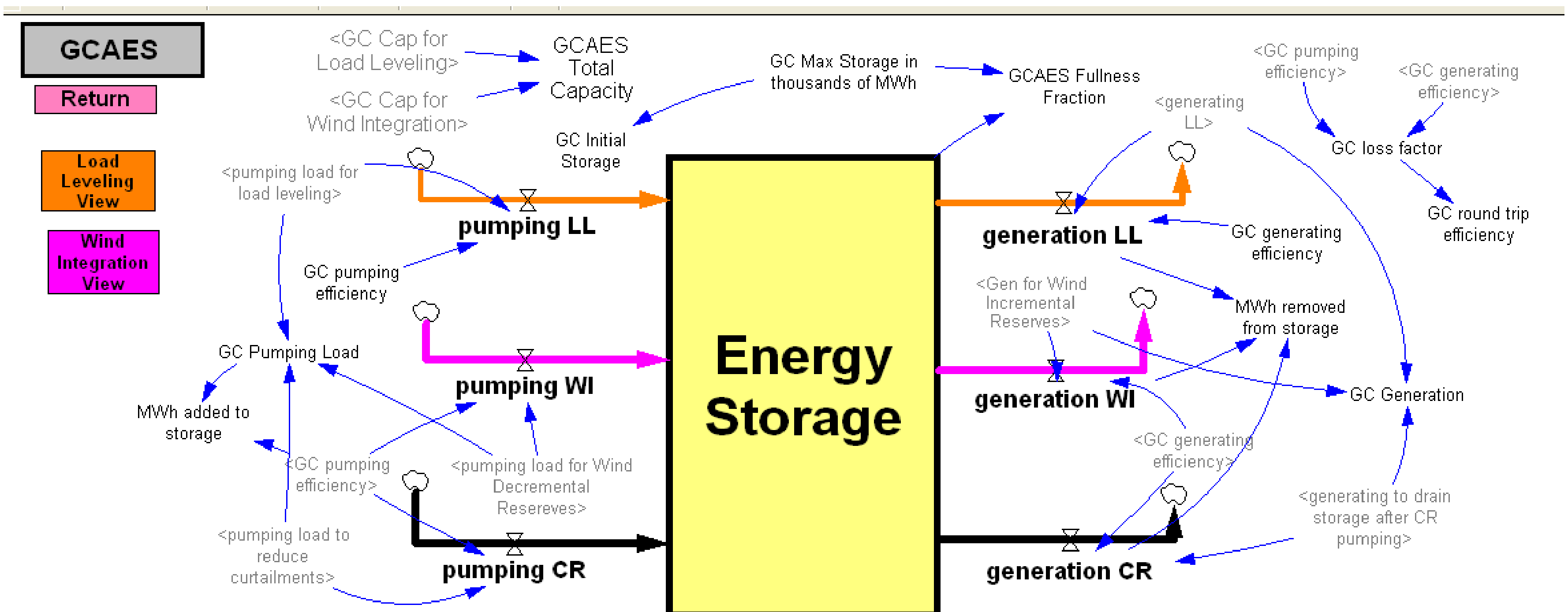
# Opening View of the Short-term Model



# Stacked Generation in the Short-Term Model



# Stocks and Flows in the Short-Term Model

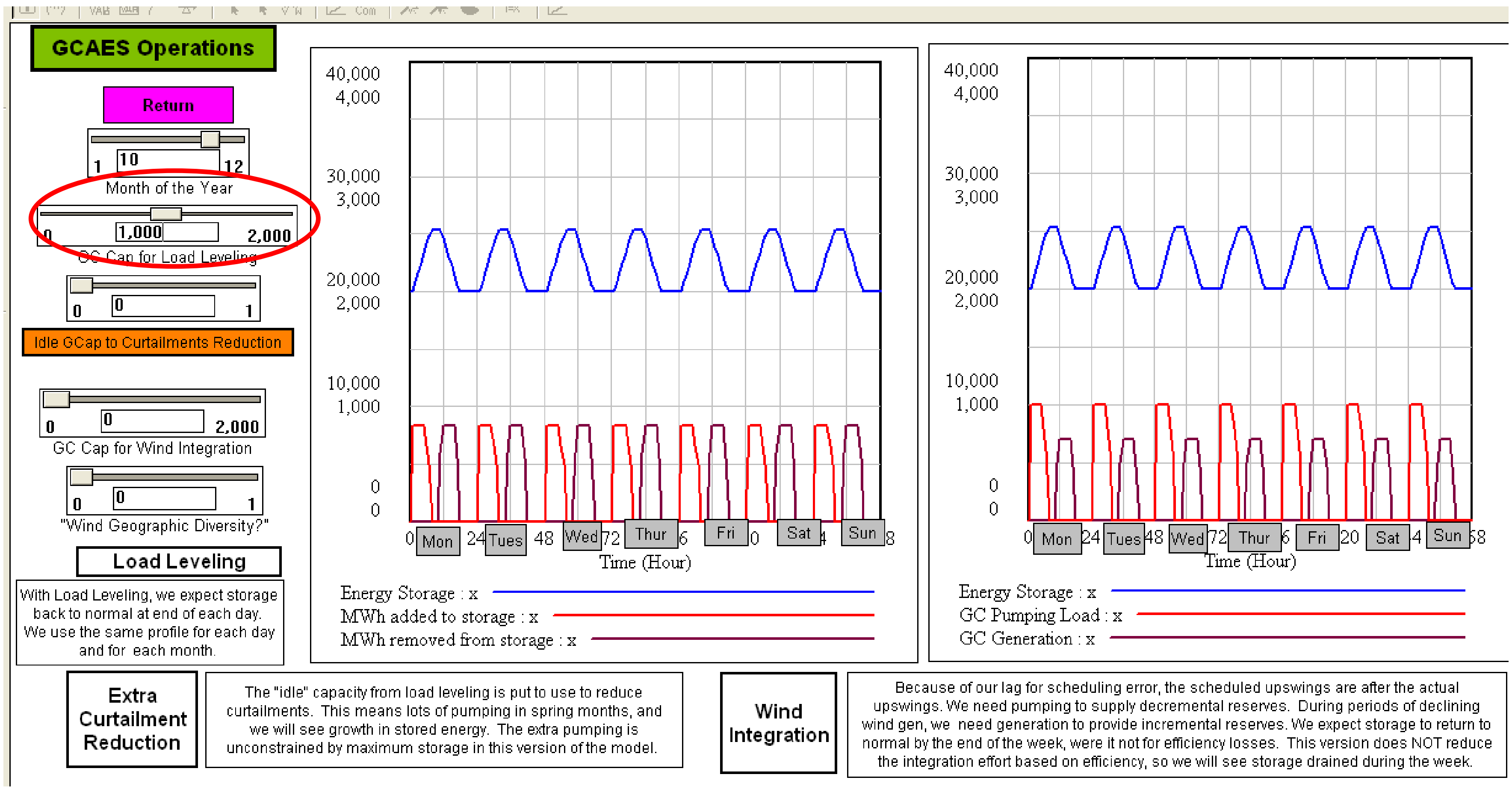



**Orange flows are LOAD LEVELING (generate during peak hours, pump during min hours)**

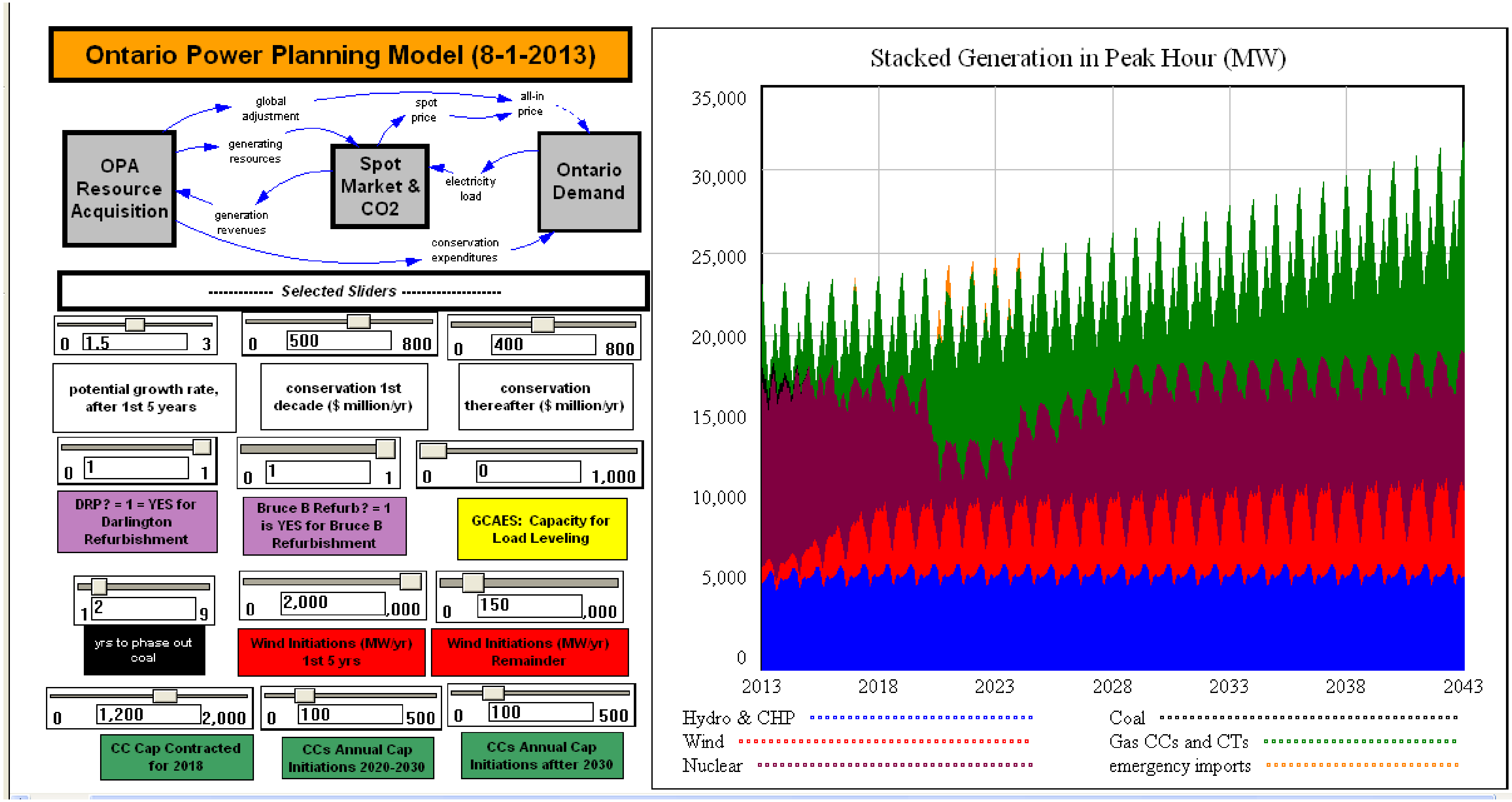
**Purple flows are for WIND INTEGRATION: Pump when wind gen > scheduled gen. Generate when wind gen < scheduled gen.**

**Black flows use "Idle Capacity" from Load Leveling to further Reduce Curtailments**

# Short-term Model shows storage used for "Load Leveling"



# Back to the Long-Term Model



# Back to the Long-Term Model

## Spot Market Navigation

Opening View

Assumptions Notes

**Model Diagrams**

- Loads & Capacity
- Hydro & Wind Generation
- Spot Market Prices
- Spot Market Bid Prices
- Thermal Cap Availability
- Generation and Spot Rev Returned to OPA
- CO2 Emissions

**Results at Peak Hour**

- Stacked Generation
- Loads
- Peak Loads & Capacity

**Results at Min Hour**

- Stacked Generation
- Loads
- Minimum Load and Base Generation
- SBG Comparison and Exports
- Stacked Exports & Curtailments

**Views of 24-hour Dispatch & Spot Prices**

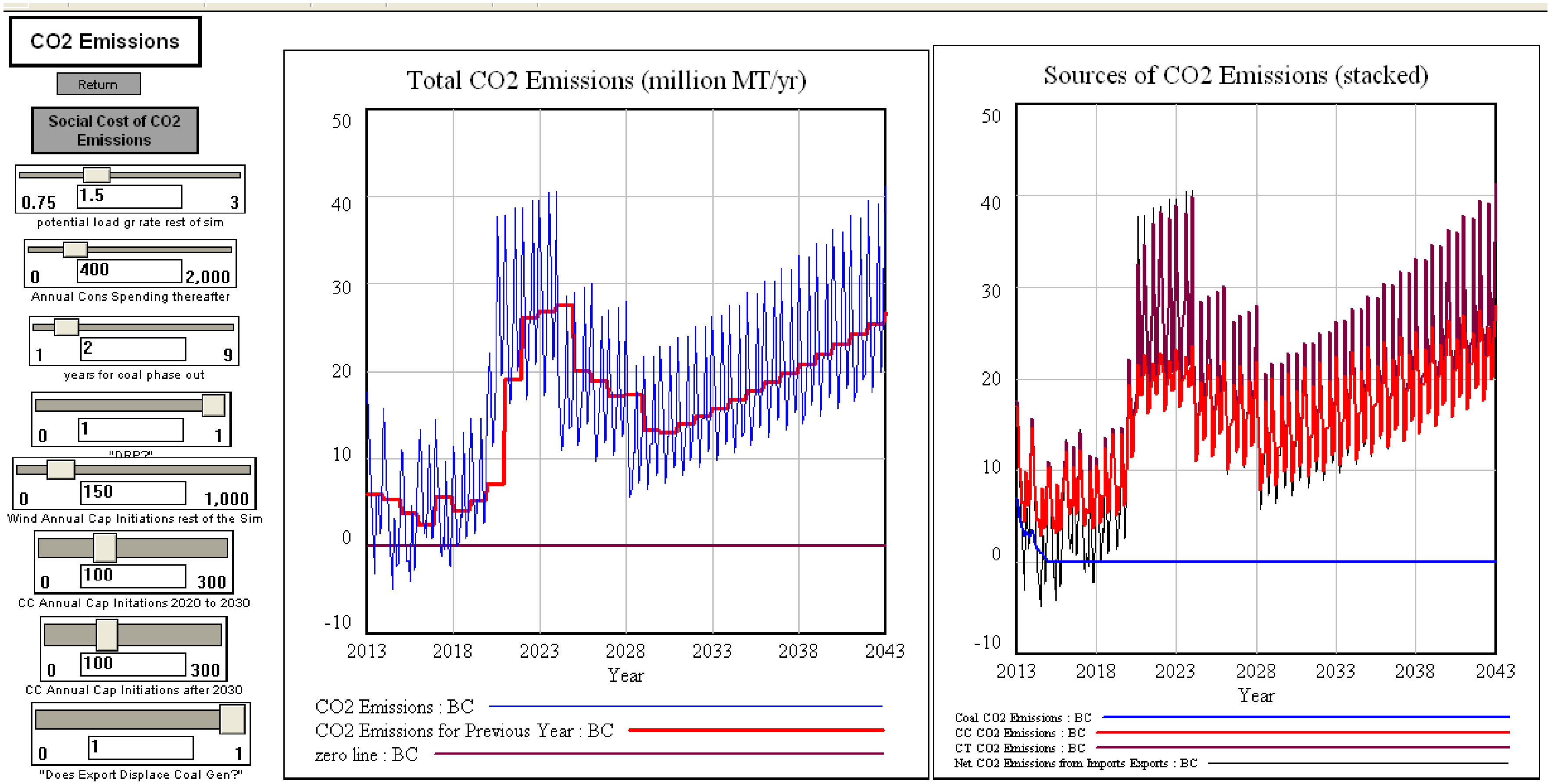
- *January 2023: Previous example with major imports*

Spot Prices at peak hours minimum hour

Weighted Average Spot Prices

CO2 Emissions

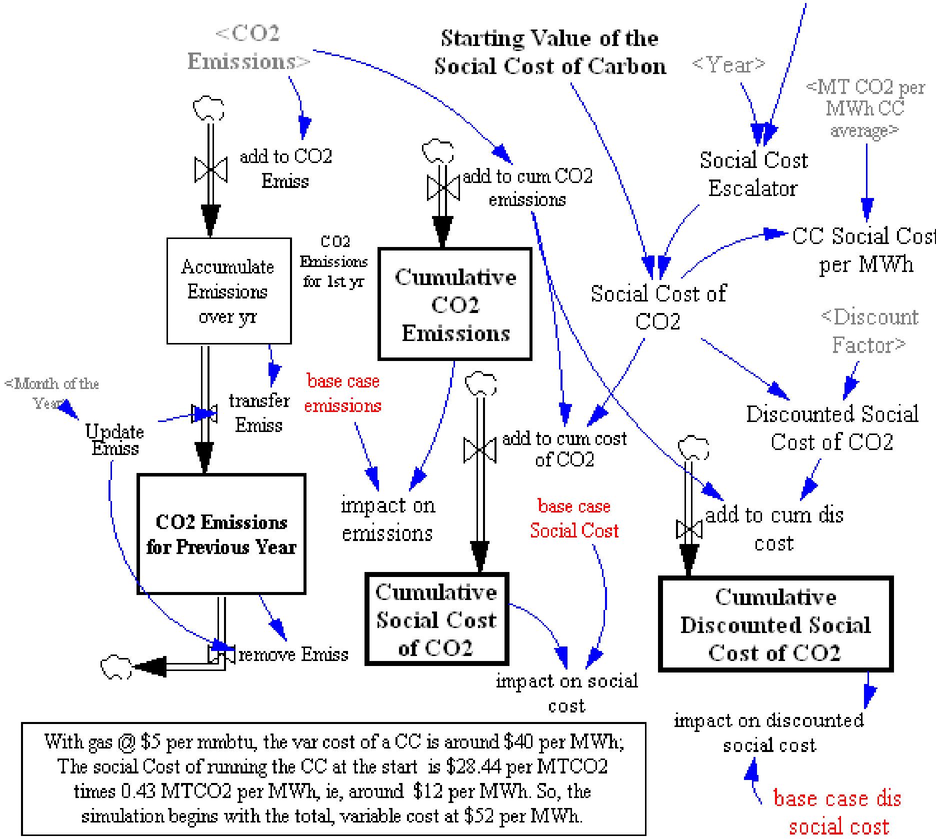
# CO2 Emissions (millions of MT/yr)



# Social Cost of CO2 Emissions: grow to over $50 billion

**Accumulate Emissions & the Social Cost of Emissions**

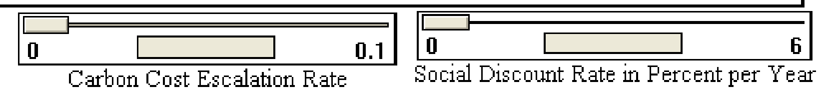
**Return to CO2 Emissions**



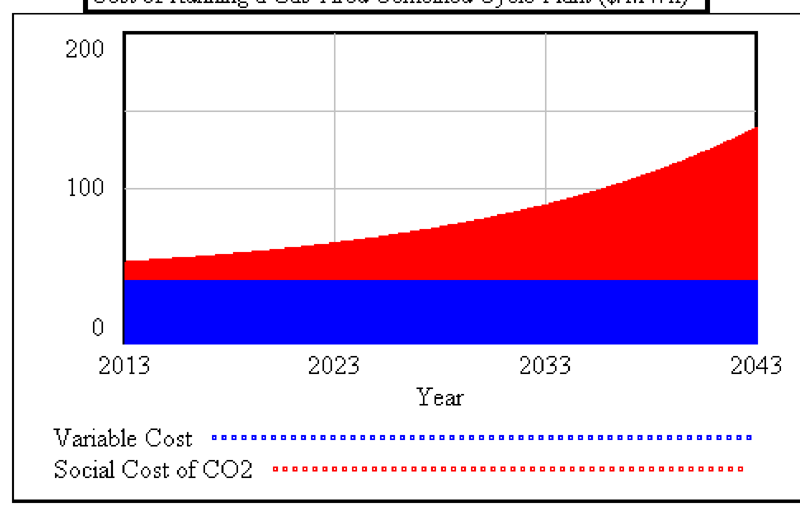

With gas @ $5 per mmbtu, the var cost of a CC is around $40 per MWh; The social Cost of running the CC at the start is $28.44 per MTCO2 times 0.43 MTCO2 per MWh, ie, around $12 per MWh. So, the simulation begins with the total, variable cost at $52 per MWh.

**Cumulative CO2 Emissions (millions of MT CO2) & Cumulative Social Cost ($ billions)**

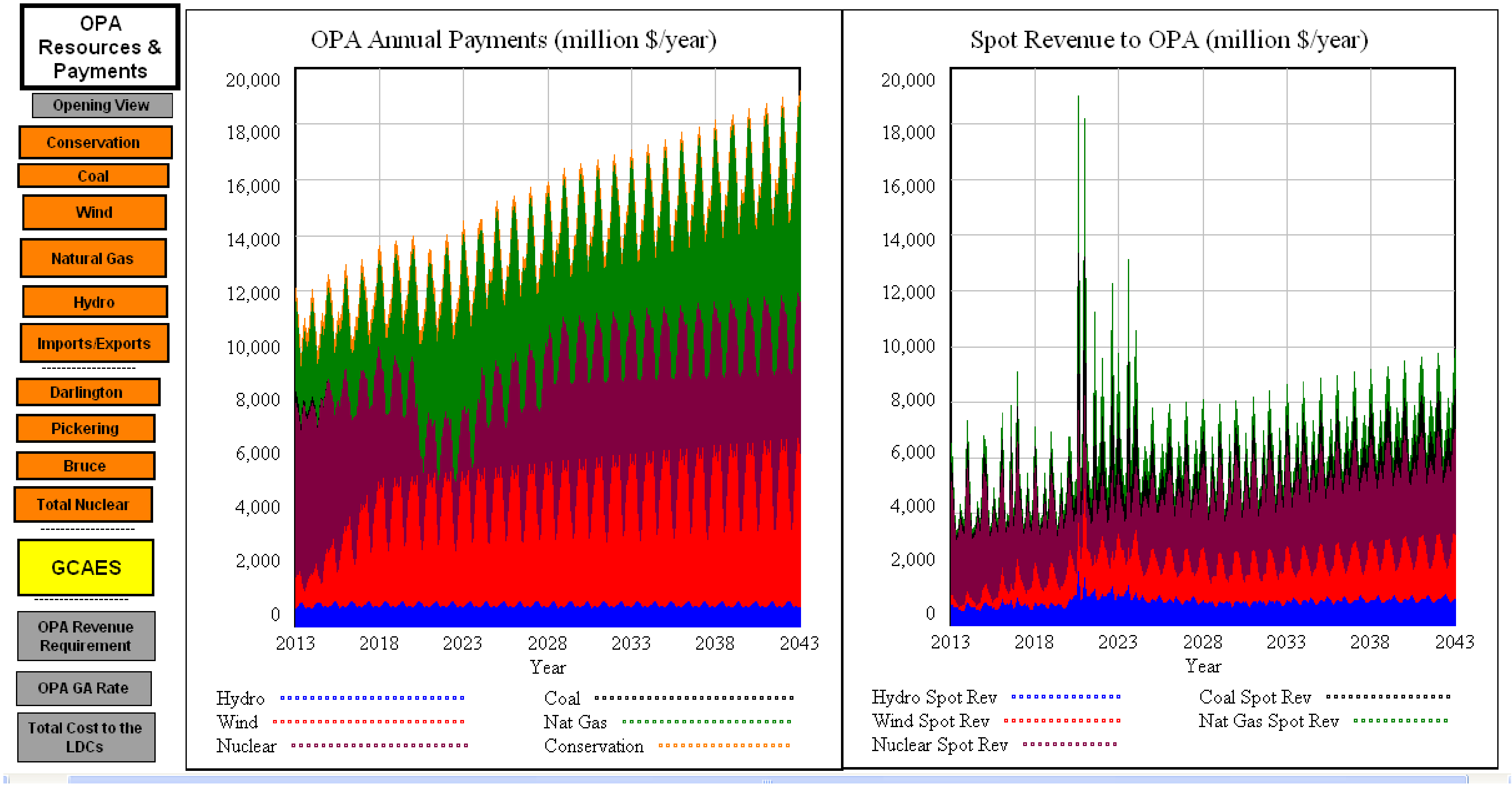
| Year | 2013 | 2023 | 2033 | 2043 |
|---|---|---|---|---|
| Emissions | 0.00 | 107.97 | 279.12 | 495.07 |
| impact on emissions | -495.07 | -387.10 | -215.95 | -0.00 |
| Social Cost | 0.00 | 5.08 | 18.74 | 55.71 |
| Impact on Social Cost | -55.71 | -50.63 | -36.97 | 0.00 |
| Discounted Social Cost | 0.00 | 4.08 | 12.81 | 29.88 |
| Impact on Dis. Social Cost | -29.88 | -25.80 | -17.07 | -0.00 |



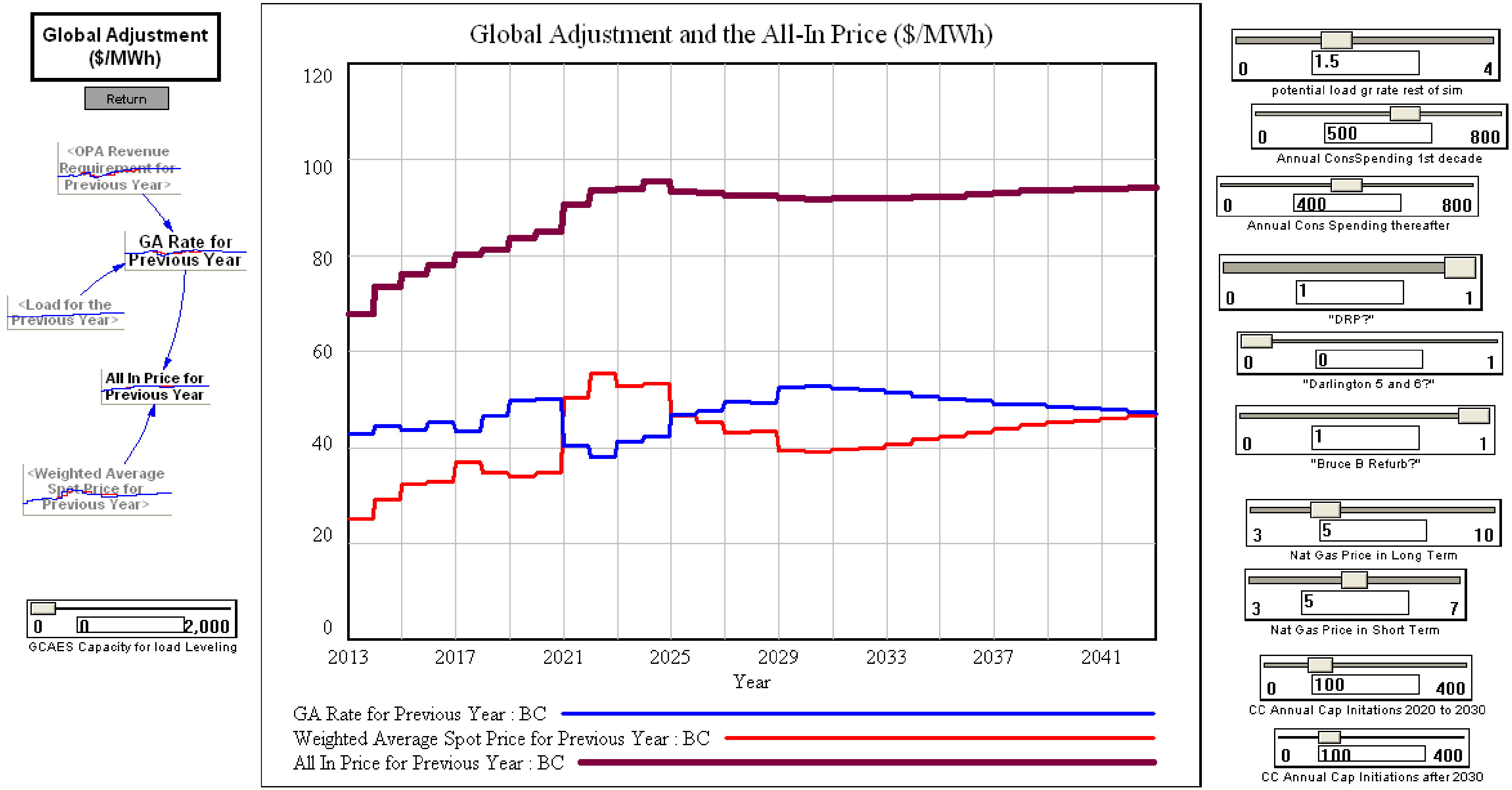

Cost of Running a Gas-Fired Combined Cycle Plant ($/MWh)



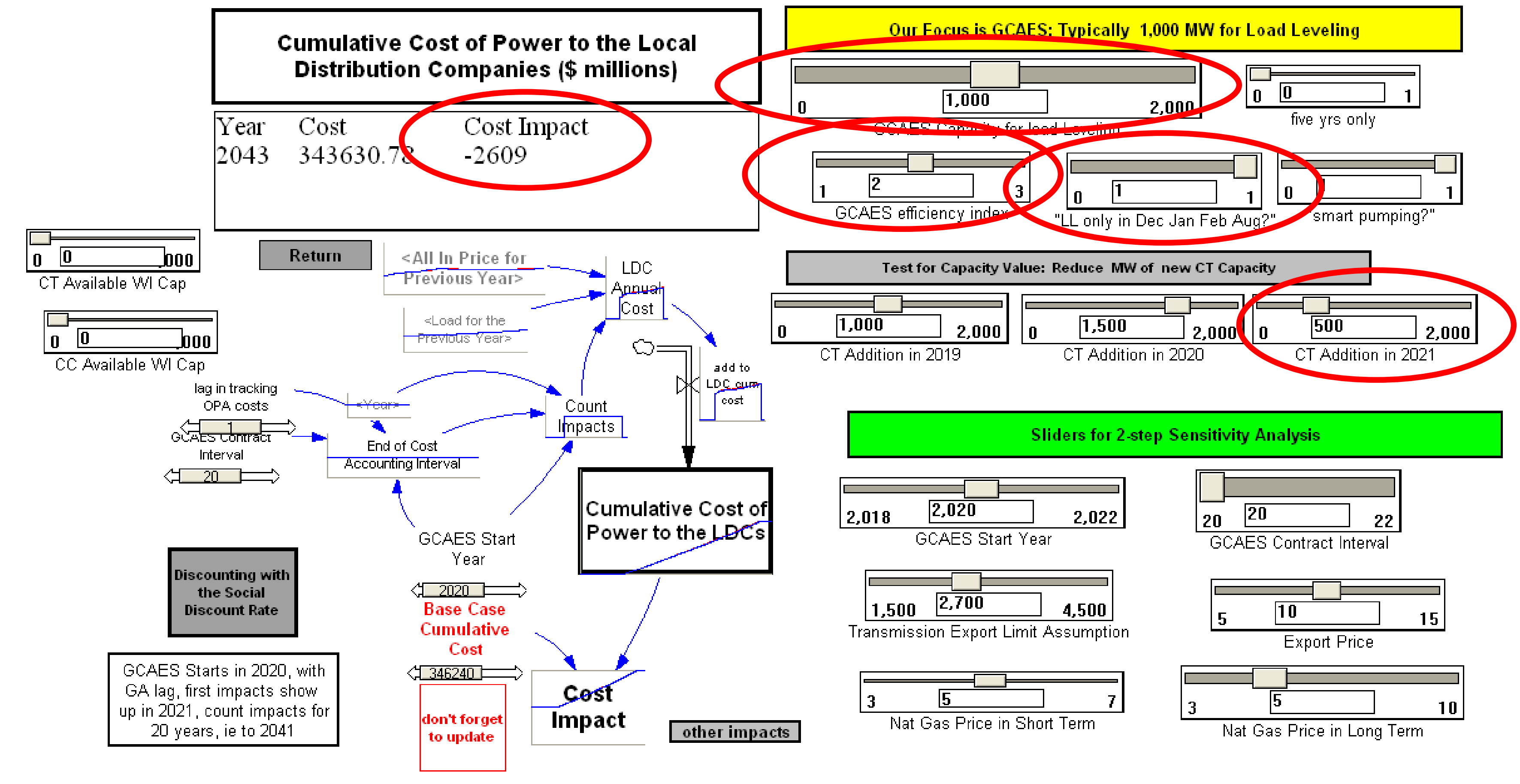
# Opening View of the OPA Sector



# All-In Price = Spot Price + GA Rate



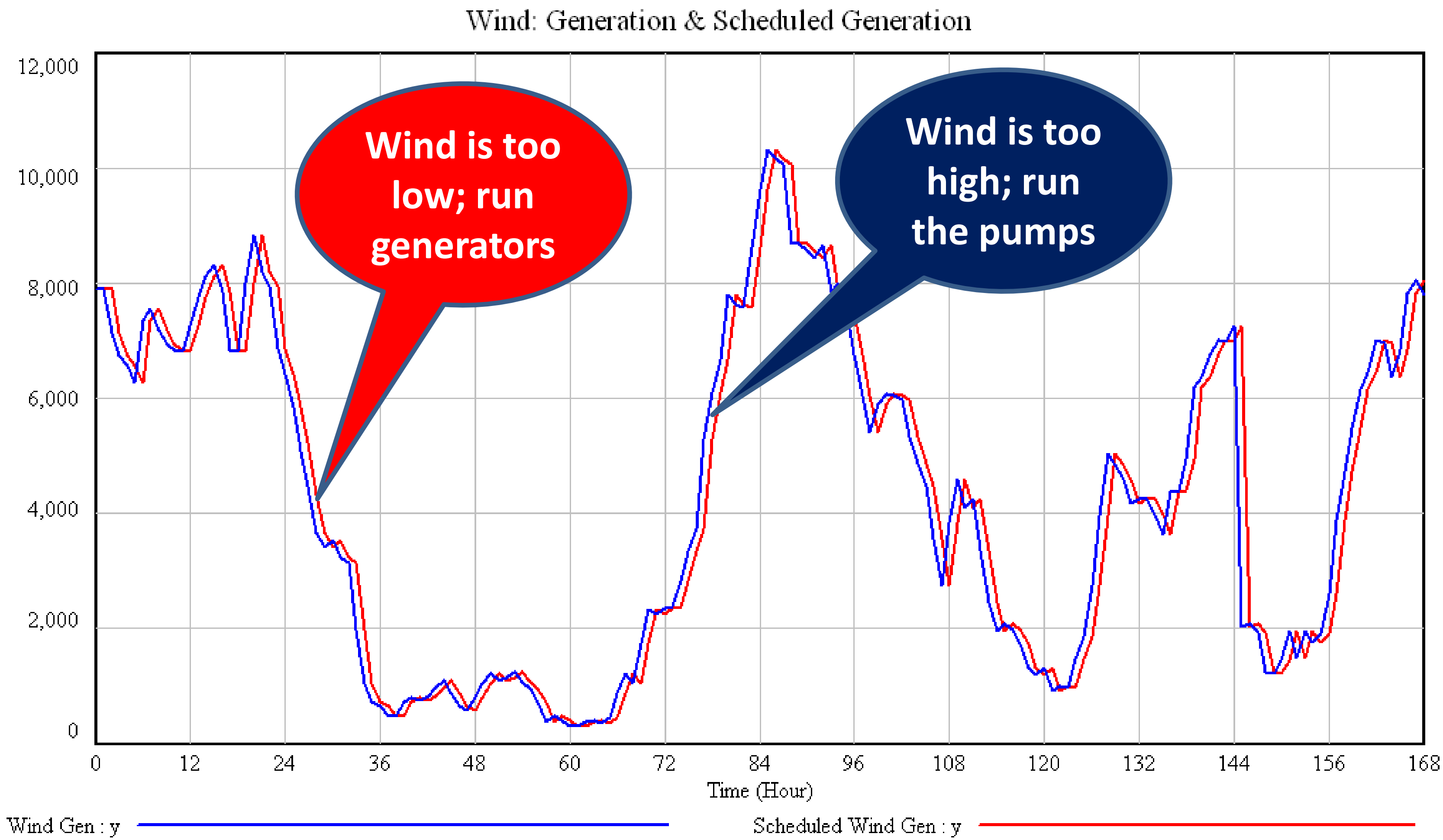
# Value of a 1,000 MW Storage: Load Leveling and CT Displacement



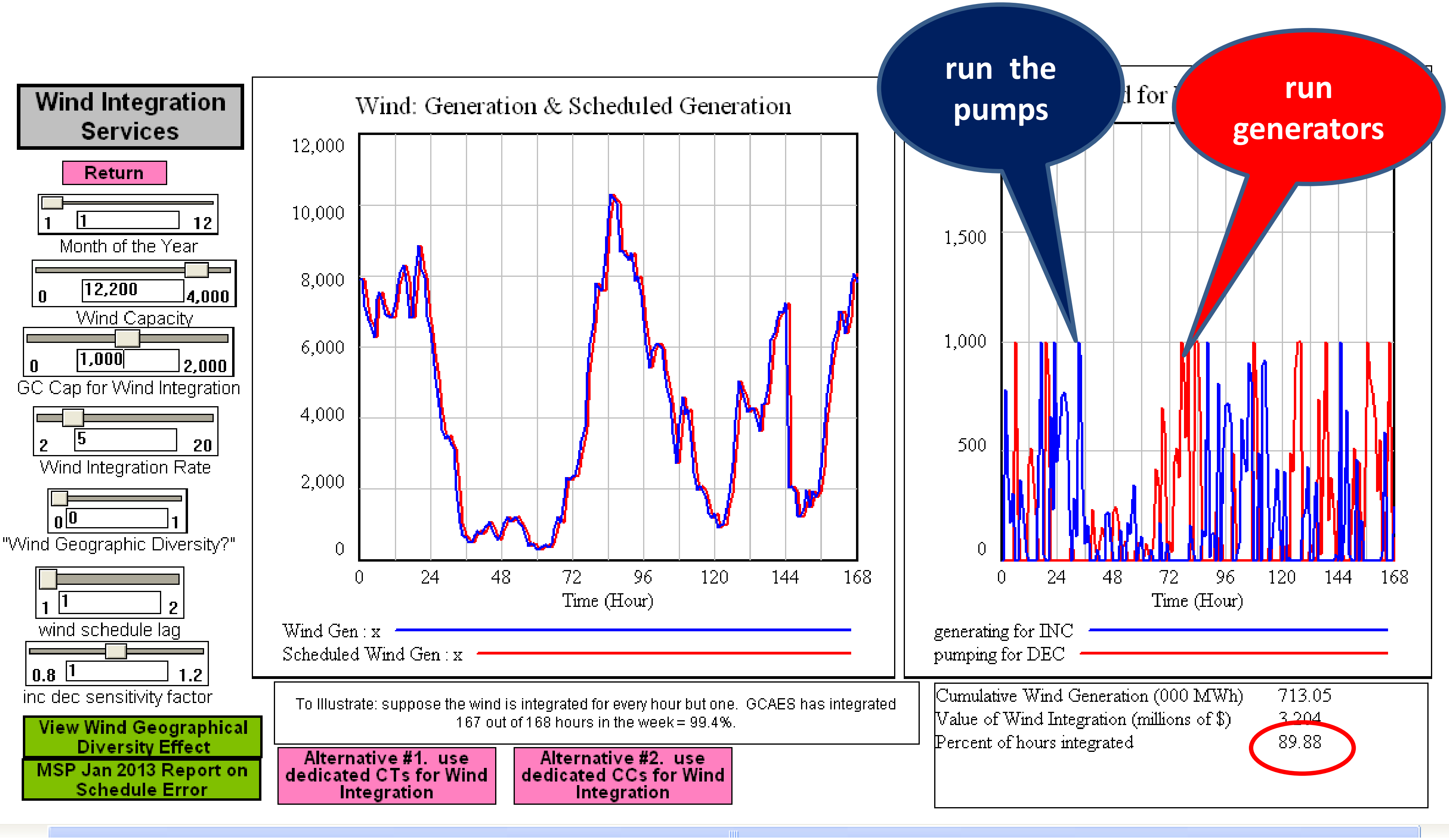
# $2.6 Billion  in Value so Far

- The team (& the agencies) agree with this finding
- Typical of other studies (where the value would not cover the annual capacity payments to the investor.)
- Additional Value:  **Wind Integration**

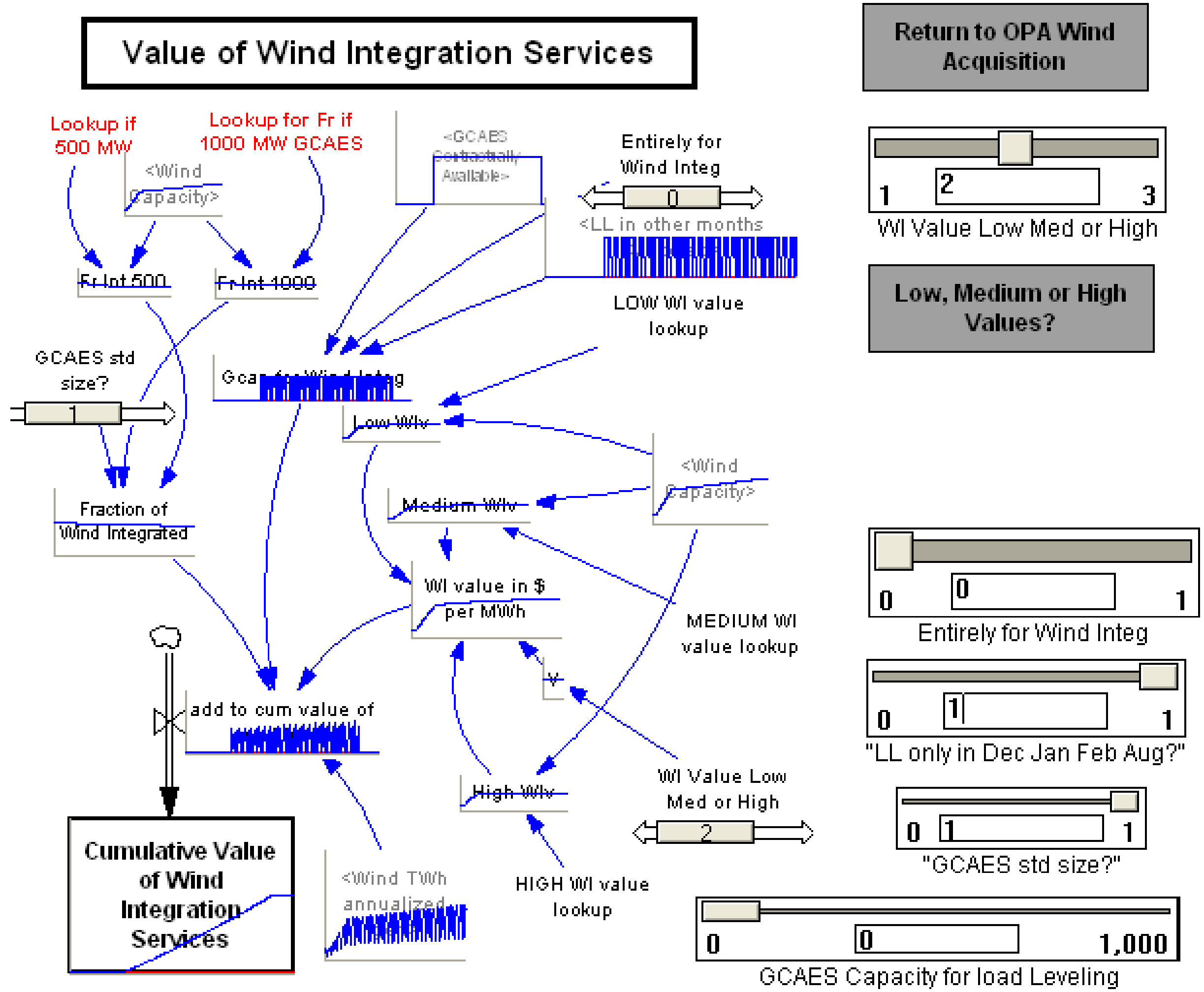
# Integrating the Wind with GCAES



# January 2028 Result: 90% Wind Integration



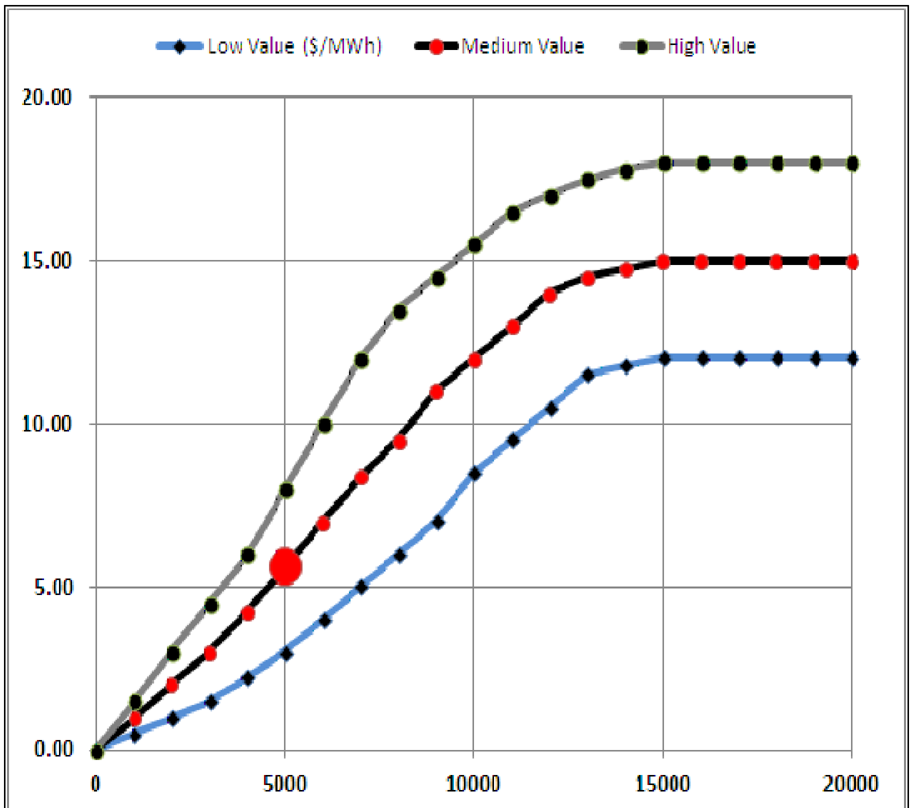
# Simulating the Value of Wind-Integration in the long-term model



# What $/MWh should be assigned?

Three Assumptions on $/MWh Value of Wind Integration

Return to Estimate of Total Value of Wind Integration




Wind Capacity (MW)

With little wind capacity, integration can be done at little cost. We believe it will be more costly to integrate the wind with greater wind capacity in the control area.

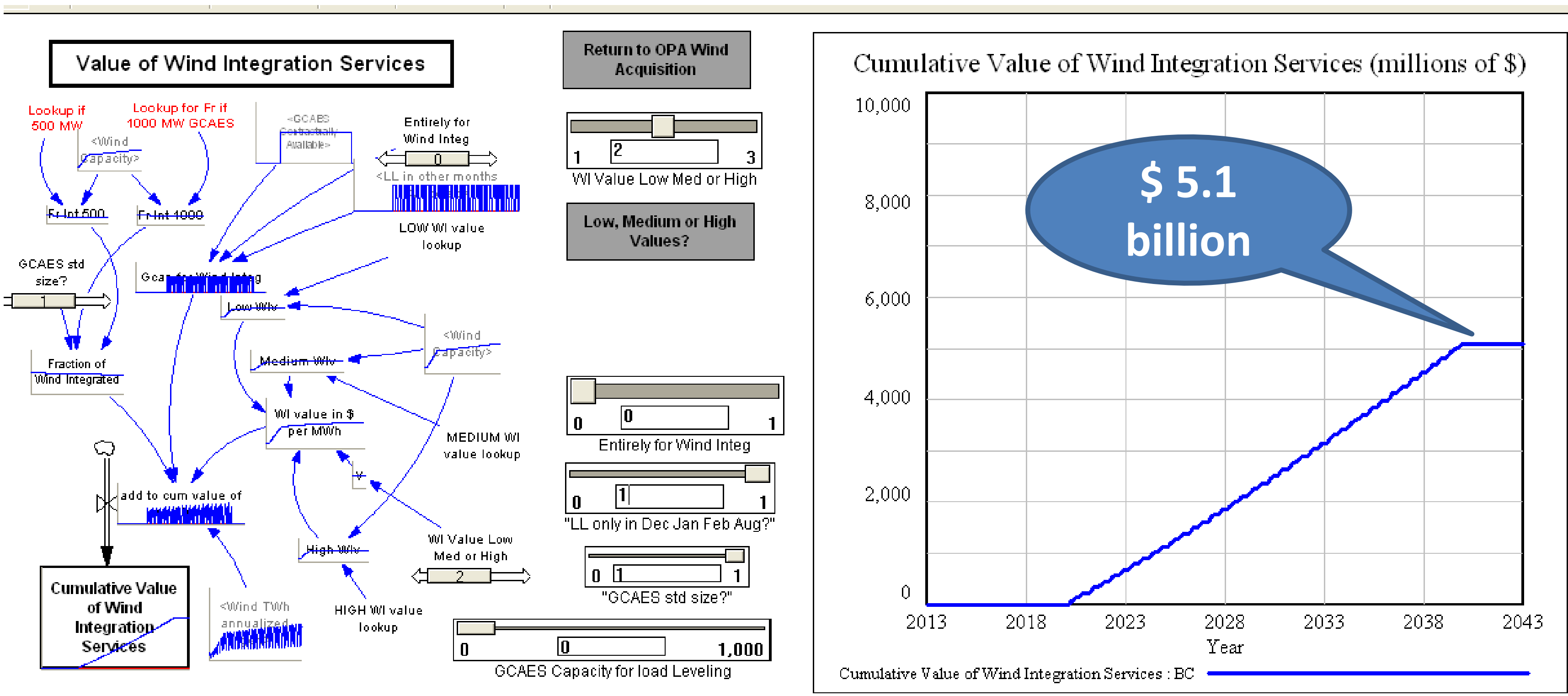
The medium cuve is our base case estimate. The large red circle is based on the BPA published wind services rate in 2012 (around 5,000 MW of wind capacity in the BPA control area). The rate was $1.23 per kw per month. Based on a wind capacity factor of 30%, the rate translates into $5.60 per MWh of wind generation.

BPA's resource program warns that Bonneville is losing flexibility on its system (a system with large hydro generation and large storage). So it is reasonable to expect higher costs in the future.

The three curves level show higher costs with more wind capacity. The curves level off at $12, $15 or $18 per MWh. The $18 comes from the highest estimate of wind integration costs in a LBL review of treatment of wind in "Resource Plans" and in "Integration Studies."

The curves reach the upper llimit with 15,000 MW of nameplate capacity. if the peak load were 24,000, the wind capacity would be over 60% of peak. This level of penetration is seldom covered in "integration studies" or in "IRP, planning studies."

# The Value of Wind-Integration viewed in the long-term model




Entirely for Wind Integ? = 1, wind integration every month of the year. Use the fraction integrated obtained from the Operations Model

The other option is to use the 1,000 MW for wind integration in the 8 months per year when we are not load leveling

| Year | Value of Wind Integration | Discounted Value of Wind Integration |
|---|---|---|
| 2043 | 5092 | 3063 |

Combined Value in the Base Case:
$7.7 billion

Sensitivity Testing Confirms
Substantial Value

Further exploration of fuel-free,
bulk storage is warranted

# Acknowledgements


- WSU Students
- General Compression (Boston, MA)
- Ontario energy agencies many suggestions: IESO, OPG, ORB, OPA & the Ministry of Energy
- NRStor (Toronto, ON)
  - Alex McIsaac
  - Annette Verschuren