Electricity Markets Design Challenge

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Agenda

The agenda for today is to provide an overview of this potential prize:

- Structure of the competition
- What it takes to participate
- How are we thinking of evaluating a market design proposal

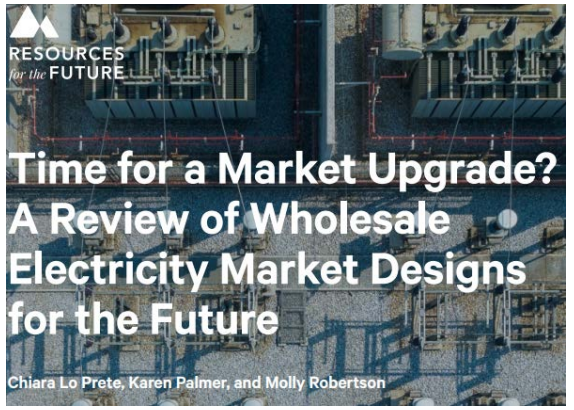
At the end of the webinar, we'll be asking all of you to provide feedback and gauge interest based on what you see from this webinar.

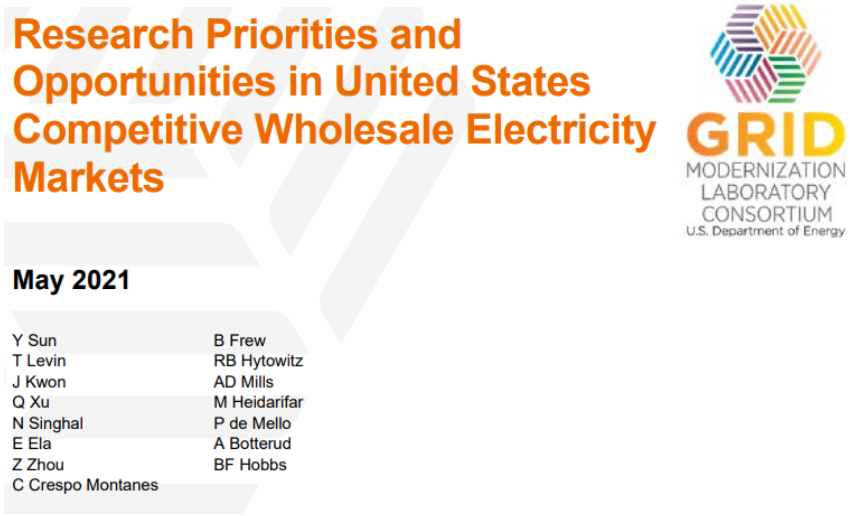
To make sure we go through the slides, we will take questions after the presentation, or you can type your questions in the chat, and we'll either address them at the end or my colleagues may be able to answer them along the way.

1. Background

Questions about the sustainability of current electricity markets

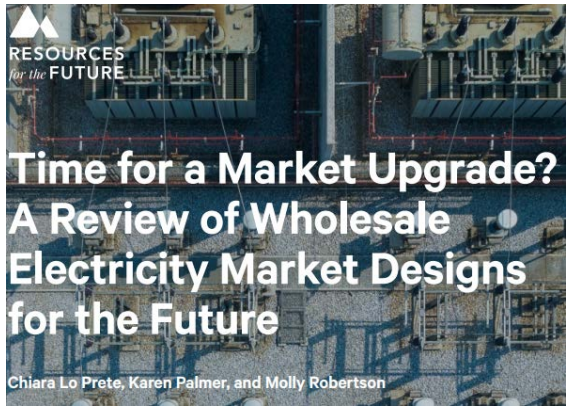
- The electricity sector is undergoing rapid transition towards a future with diverse resource mix.
- Many of these new resources have distinct features from traditional generators, such as relatively small or even zero variable costs.
- Current electricity markets in most US Independent System Operators (ISOs) are largely based on marginal cost pricing for energy.
- This may result in more frequent lower and less predictable energy prices, making developing new generation sources prohibitive, therefore impact grid reliability.
- This raises the question of whether the current electricity market design is sustainable in a future of predominantly low-variable costs resources.

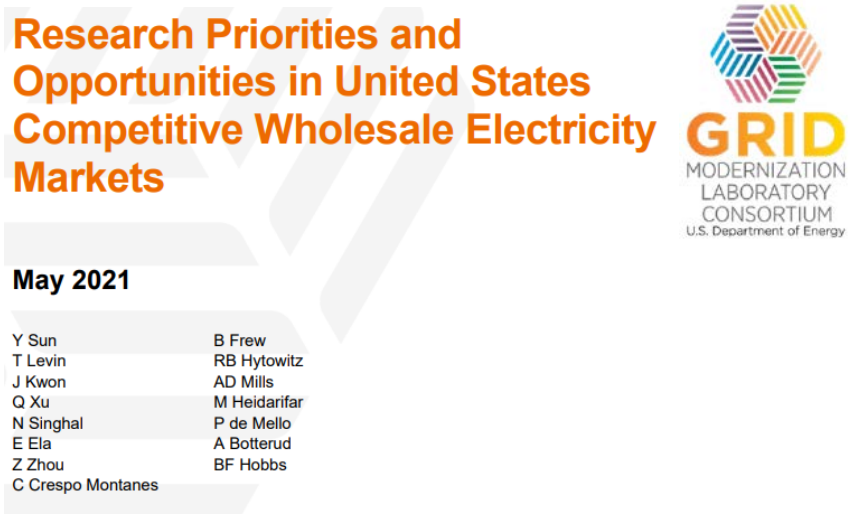




Competition can address important questions about future electricity market designs

- WPTO and NREL are exploring a potential prize competition of electricity market design for future power grid.
- The goals of this potential competition are:
  - Raise awareness of the important role of electricity market design in a future power grid with diverse resource mix.
  - Solicit innovative ideas of how to efficiently compensate generation and storage resources (such as run-of-river and pumped storage hydropower) for their essential grid services to maintain grid reliability.
  - Compare various market design concepts using a consistent set of metrics.
- This workshop will review the proposed evaluation framework and seek feedback/gauge interest for this potential competition.



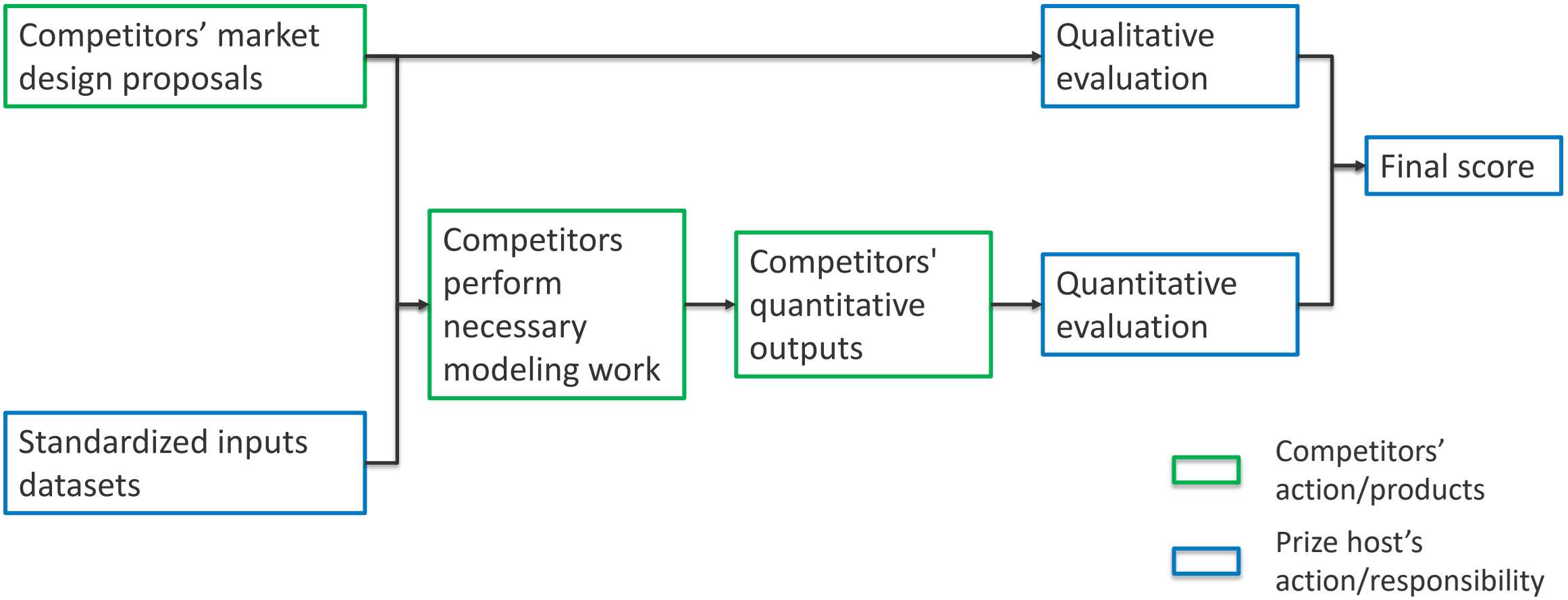


Evaluation should provide flexibility to competitors within a common format

The prize host will provide maximum flexibility for competitors to explore diverse future market designs, but under a common evaluation framework. Therefore, we propose the following evaluation :

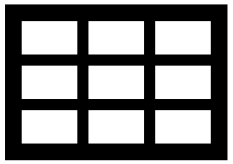
- A combination of **qualitative** and **quantitative** evaluation.
- Prize host **provide all necessary datasets**.
- **Competitors provide quantitative results** on the resources mix, commitment, dispatch, price formation etc. under their design proposals (in prize host-specified format).
- **Prize host calculate evaluation metrics** (verify system operation, revenue sufficiency etc.) based on the quantitative results from competitors.

High-level evaluation approach



2. Input Datasets

Prize host provides input dataset on electricity network



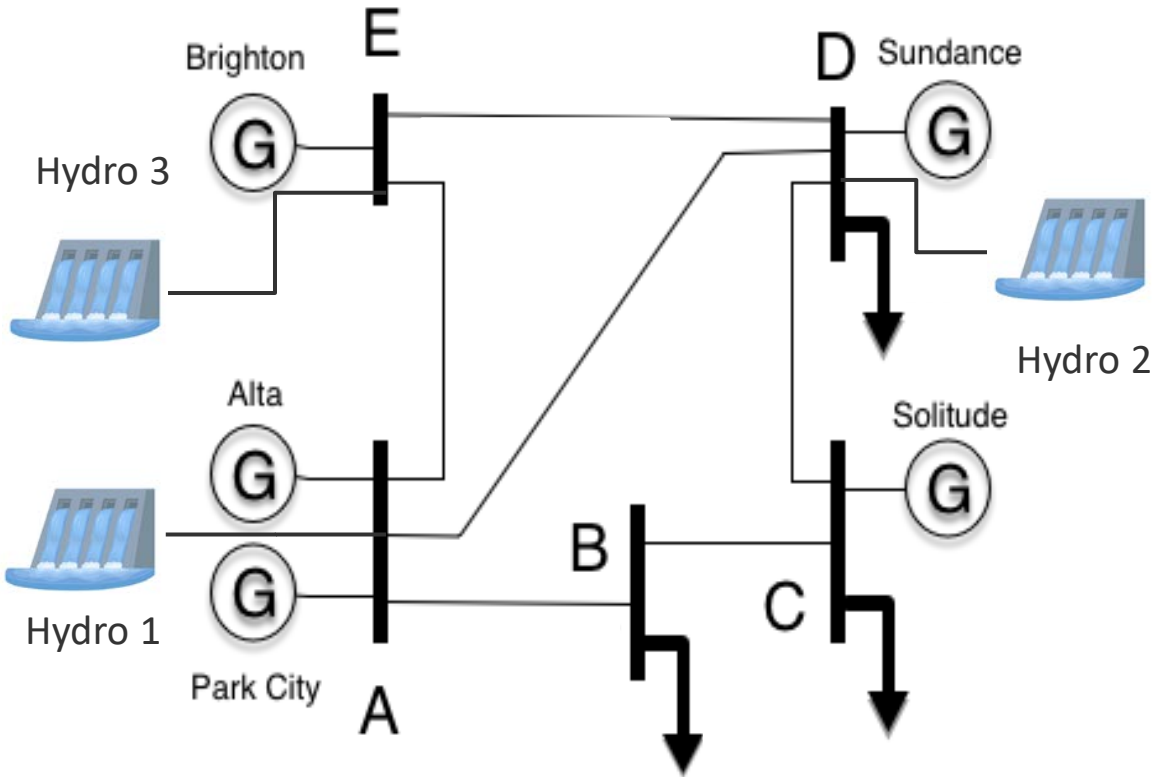
The prize host will provide a standardized inputs dataset (in json format), minimally including:

- Technical parameters for existing and new resources (including min/max capacity, ramp rate, storage duration etc.)
- Economic parameters for existing and new resources (including variable and fuel costs, fixed o&m, capex, lifetime etc.)
- Transmission network parameters (including network configuration, line capacity, line susceptance etc.)
- Electricity load and variable generation resources profiles (one-year of hourly data)
- Consumer characteristics (e.g., annual income, etc.) for energy burden evaluation

Propose for competition to use modified PJM 5-bus system

Widely used test system in industry and academic publication for decades

Modification adds a few hydro units



Modified PJM 5-bus system (resource mix subject to change)

- 3 load (at Bus B, C and D) with hourly load profiles for an entire year.
- 5 buses connected by 7 transmission lines (two lines between Bus C and D)
- **Competitors have the ability to retire existing resources and build new ones under their proposed market design!**
- **New option resources will include Gas-CC, Gas-CT, Solar PV, Wind, Battery, and Pumped Storage Hydro.**

Simplifications

Given the potential complexity of the competition, the prize host will make the following simplifications for the initial phase of the proposed prize:

- No uncertainty on load and variable generation resources profiles (also no extreme events).
- Only one-year load and variable generation resources profiles are used as representative.
- No demand-side flexibility.
- A simple 5-bus system.
- Do not consider transmission expansions.

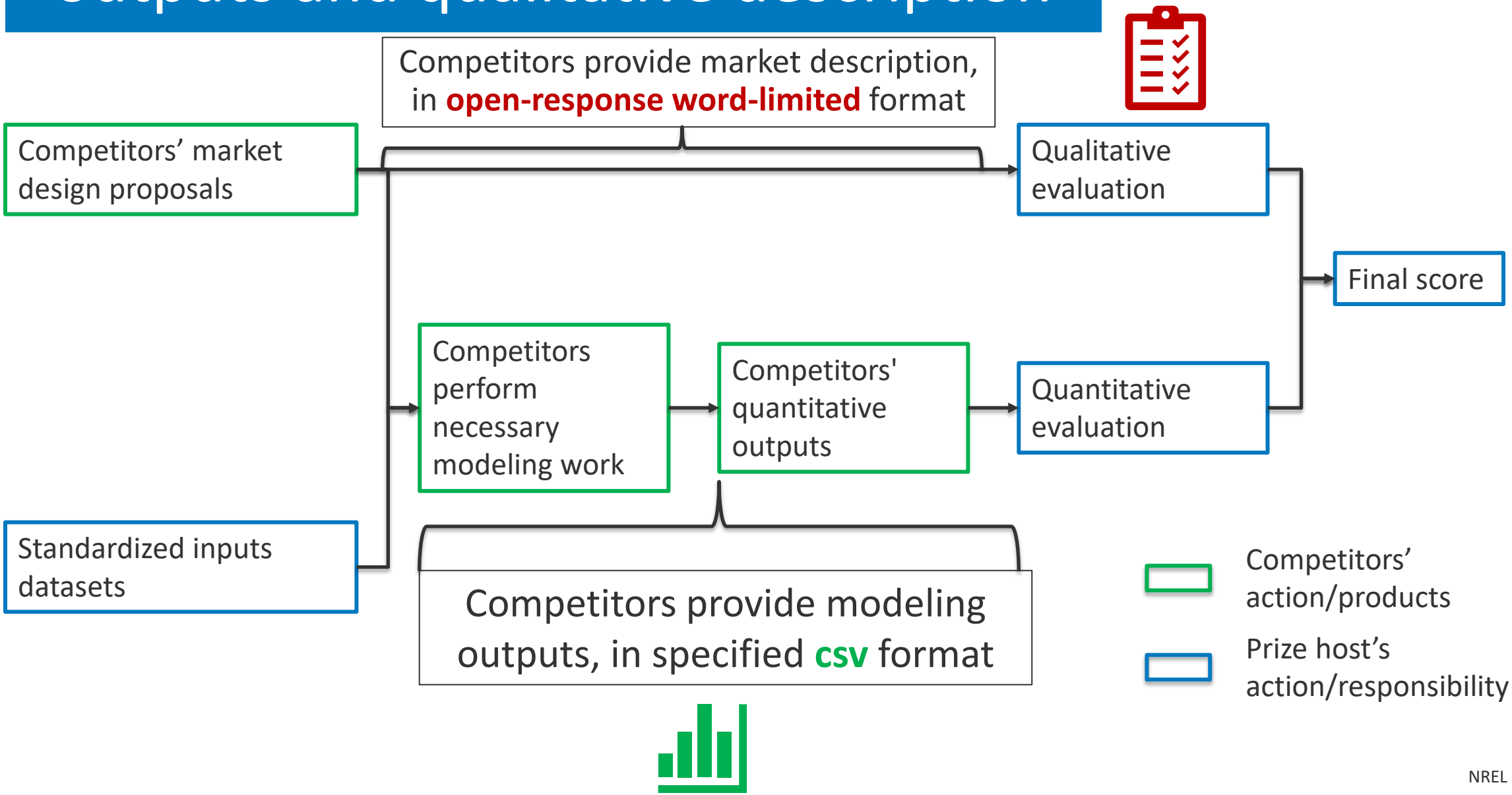
We may address these simplifications in potential subsequent phases of the competition!

3. Competitors’ Submissions

Competitors' Submissions

- Based on the above datasets, competitors are expected to perform necessary modeling of their proposed market design concept, and produce a submission package as described below.
- Competitors' submission package shall include a document describing their market design concept, as well as a set of CSV files (in specific format) for quantitative evaluation. We may also request competitors to submit their modeling approach.

Competitors submit quantitative outputs and qualitative description

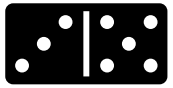


Propose competitors' qualitative description cover a few major areas

The document describing market design concept shall cover the following points:

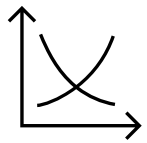
How feasible and scalable it is to implement the proposed market design?

How can the proposed market design incentivize competitive behavior from market participants, including potential technology innovation and consideration for market power mitigation?



How is investment risk borne under the proposed market design?

How does the proposed market design provide incentives that align procurement with dispatch?



How does the proposed market design ensure long-term resource adequacy?

Competitors' quantitative submission will have a few files

The set of **.csv files** needed for quantitative evaluation includes:

- products.csv
- resource_mix.csv
- dispatch.csv
- commitment.csv
- prices.csv
- procurement_supply.csv
- procurement_demand.csv

Each of these files are described in more detail on subsequent slides…

Market products are defined in products.csv

- “products.csv” defines the market products under the proposed market design concept.
- A product needs to be specified by its name and procurement units. Procurement units must include a time dimension (e.g., day, hour) on which the product is to be procured.
- For example, market design with an energy market and a capacity market shall fill this csv file as follows:

Name	Unit
Energy	MWh
Capacity	MW-day

- **Competitors shall define these products based on their creative market design ideas!**

resource_mix.csv defines the generation and storage units included in the competitors' system

- "resource_mix.csv" contains the resulting generation and storage resource mix under the proposed market design concept.
- A resource needs to be specified by the following fields:
  - **GEN ID:** unique name for the resource
  - **Bus ID:** which bus (location in the power system) the resource is connected to
  - **Vintage:** is this an "Existing" or a "New" resource
  - **Unit Type:** technology type of the resource
  - **Capacity** (units): nameplate generation capacity of the resource.
- An example of three resources is shown below:

GEN UID	Bus ID	Vintage	Unit Type	Capacity (MW)
Hydro_1	1	Existing	hydro	75
Gas_CT_2	2	Existing	gas_ct	35
Solar_3	3	New	pv	10

dispatch.csv has the energy output of the competitors' system

- "dispatch.csv" contains the resulting energy dispatch (MWh) for each timestamp of all resources defined in "resource_mix.csv" under the proposed market design concept. This file is used to evaluate physical constraints violation as well as production costs.
- An example of dispatch is shown below:

TimeStamp	Hydro_1	Gas_CT_2	Solar_3
2020-01-01T00:00:00.0	60.5	35.0	0.0
2020-01-01T01:00:00.0	60.5	35.0	0.0
	…		
2020-12-30T23:00:00.0	55.7	35.0	0.0

commitment.csv has the commitment status of fossil units in competitors' system

- "commitment.csv" contains the resulting commitment status for each timestamp of all fossil units defined in "resource_mix.csv" under the proposed market design concept. This file is used to evaluate physical constraints violation as well as production costs.
- An example of commitment is shown below:

TimeStamp	Gas_CT_2
2020-01-01T00:00:00.0	0
2020-01-01T01:00:00.0	1
…	
2020-12-30T23:00:00.0	1

prices.csv includes prices for all products in applicable timestamps

- “prices.csv” contains the resulting prices ($/unit) for each product defined in “products.csv” under the proposed market design concept.
- Prices for each product is defined for each location by default. If the prices of certain product do not vary by location, simply put the same prices across all locations.
- Also note that the “TimeStamp” defined here needs to match the ones defined in “procurement_supply.csv” and “procurement_demand.csv” for each product.
- An example of prices for an energy market and a capacity market in a 5-bus system is shown below:

Product	TimeStamp	bus_1	bus_2	bus_3	bus_4	bus_5
Energy	2020-01-01T00:00:00.0	30.0	30.0	30.0	30.0	30.0
		…				
Energy	2020-12-30T23:00:00.0	29.0	29.0	40.0	30.0	30.0
Capacity	2020-01-01	25.0	25.0	25.0	25.0	25.0
		…				
Capacity	2020-12-30	25.0	25.0	25.0	25.0	25.0

procurement.csv reflects market procurement of all products in applicable timestamps

- "procurement_supply.csv" contains the resulting procurement (in unit defined in "products.csv") from each resource for all products under the proposed market design concept.
- Note that "procurement_supply.csv" may or may not be the same as "dispatch.csv" depending on the proposed market design.
- An example of procurement from supplying resources is shown below:

Product	TimeStamp	Hydro_1	Gas_CT_2	Solar_3
Energy	2020-01-01T00:00:00.0	60.5	35.0	0.0
	…			
Energy	2020-12-30T23:00:00.0	55.7	35.0	0.0
Capacity	2020-01-01	65.0	35.0	3.0
	…			
Capacity	2020-12-30	65.0	35.0	3.0

procurement.csv reflects market procurement of all products in applicable timestamps

- “procurement_demand.csv” contains the resulting procurement (in unit defined in “products.csv”) by each load for all products under the proposed market design concept.
- An example of procurement by load is shown below:

Product	TimeStamp	bus_1	bus_2	bus_3	bus_4	bus_5
Energy	2020-01-01T00:00:00.0	10.0	30.0	30.0	20.0	5.0
		…				
Energy	2020-12-30T23:00:00.0	9.7	25.0	25.0	15.0	16.0
Capacity	2020-01-01	10.0	35.0	35.0	20.0	3.0
		…				
Capacity	2020-12-30	10.0	35.0	35.0	20.0	3.0

4. Evaluation Metrics

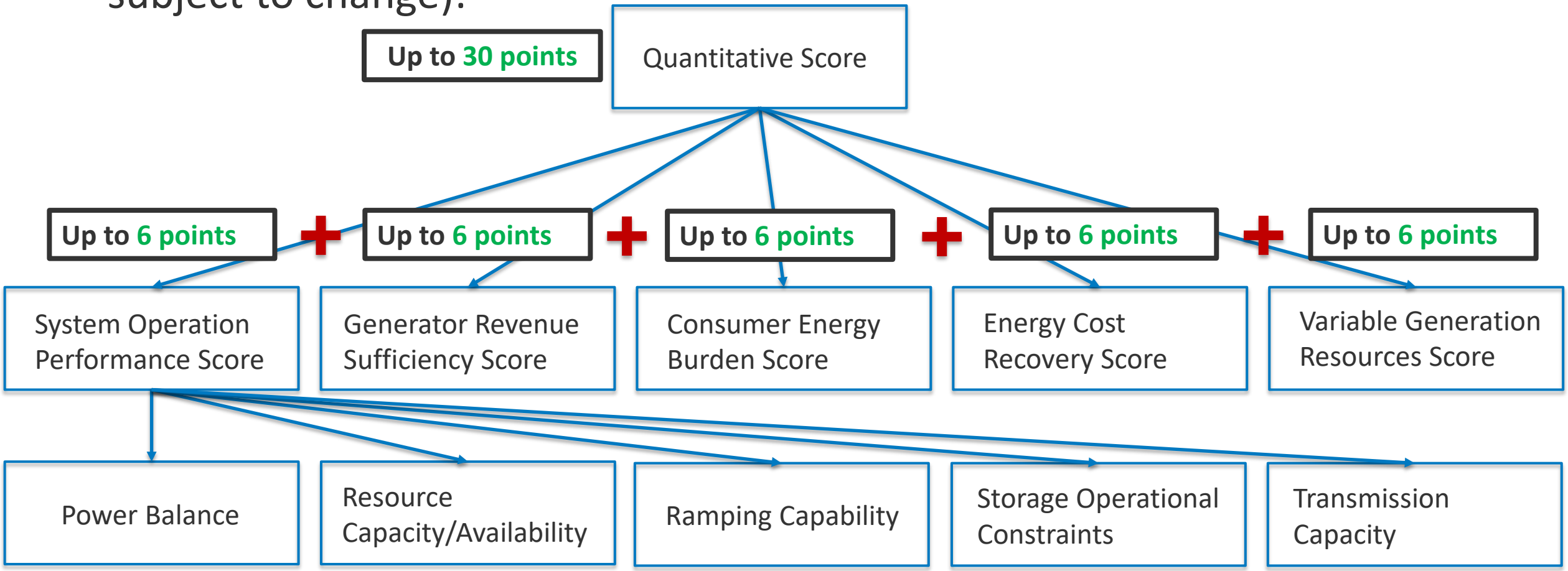
Qualitative Scoring

- Final scores for each submission consist of a qualitative score and a quantitative score.
- Qualitative scores are based on the guidance below:

Suggested Contents Competitors Should Provide	Each Statement Is Scored on 1–6 Scale (Up to 30 points)
• How feasible and scalable it is to implement the proposed market design? • How can the proposed market design incentivize competitive behavior from market participants, including potential technology innovation and consideration for market power mitigation? • Who bears the investment risk under the proposed market design? • How does the proposed market design provide incentives that align procurement with dispatch? • How does the proposed market design ensure long-term resource adequacy?	• The proposed market design is feasible and scalable to implement in practice. • The proposed market design demonstrates a reasonable mechanism to incentivize competitive behavior, including the potential to incentivize technology innovation and the consideration for market power mitigation. • Professional investors rather than regular consumers bear the risk of investment. • The proposed market design aligns product procurement with dispatch. • The proposed market design demonstrates a mechanism that ensures long-term resource adequacy.

Quantitative Scoring

- Quantitative scores are based on the following criteria (weights/points subject to change):



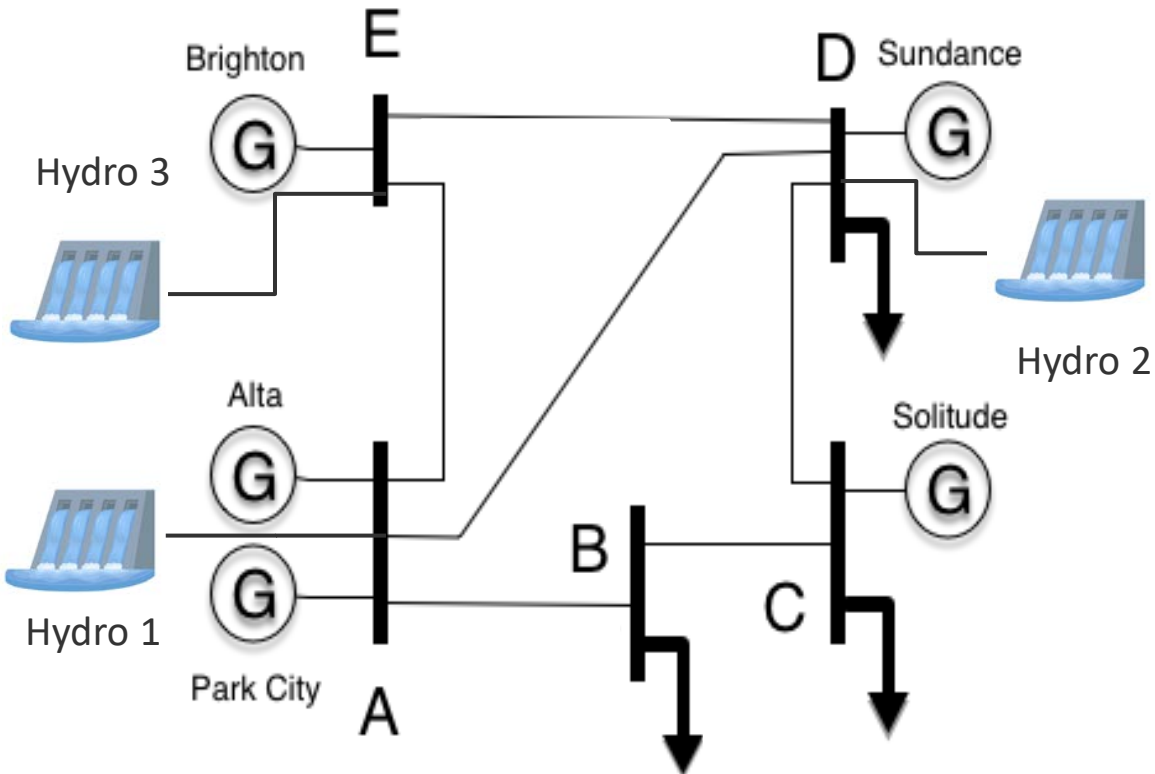
5. Quantitative Evaluation Demonstration

Propose for competition to use modified PJM 5-bus system

Widely used test system in industry and academic publication for decades

Releases of datasets available with open-source tools like NREL's Sienna

Modification adds a few hydro units



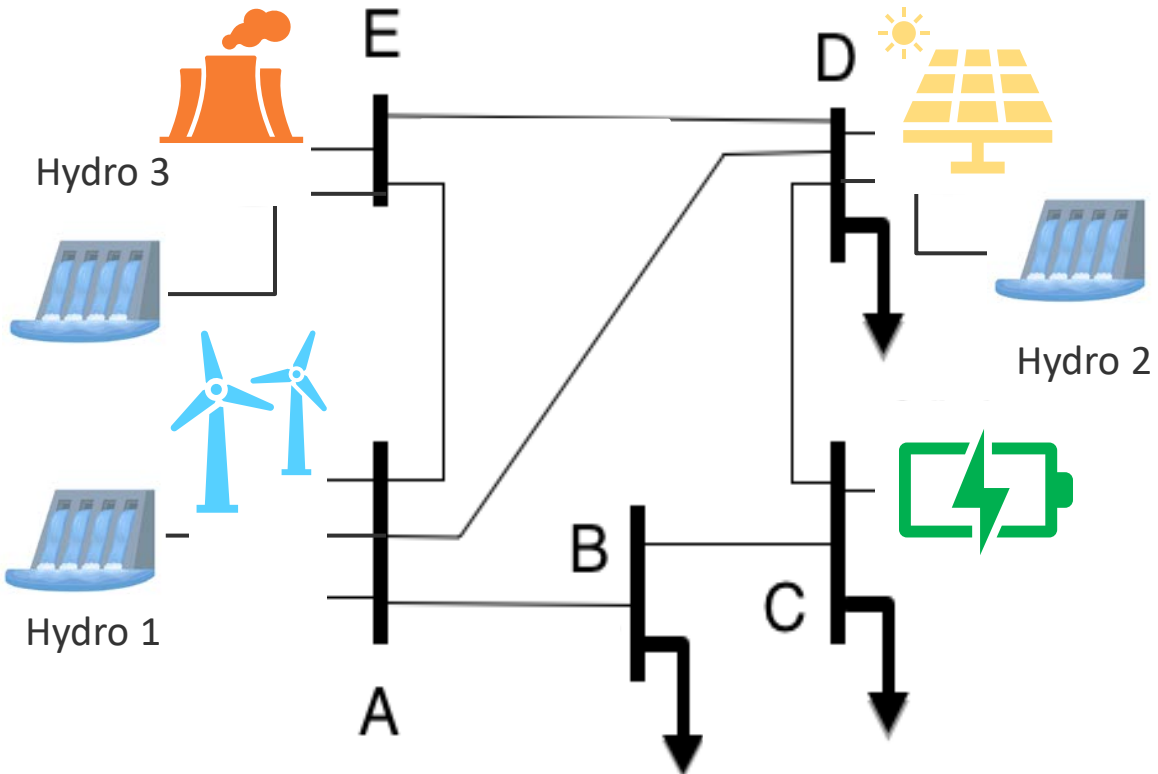
Modified PJM 5-bus system (resource mix subject to change)

- 3 load (at Bus B, C and D) with hourly load profiles for an entire year.
- 5 buses connected by 7 transmission lines (two lines between Bus C and D)
- **Competitors have the ability to retire existing resources and build new ones under their proposed market design!**

NREL team can create new submissions with arbitrary generation capacity to test scoring platform

- Use load and line ratings from 5-bus test system
- Retire 5-bus generators, add new-build gas, battery, wind, solar PV
- Keep added hydro units

Sienna



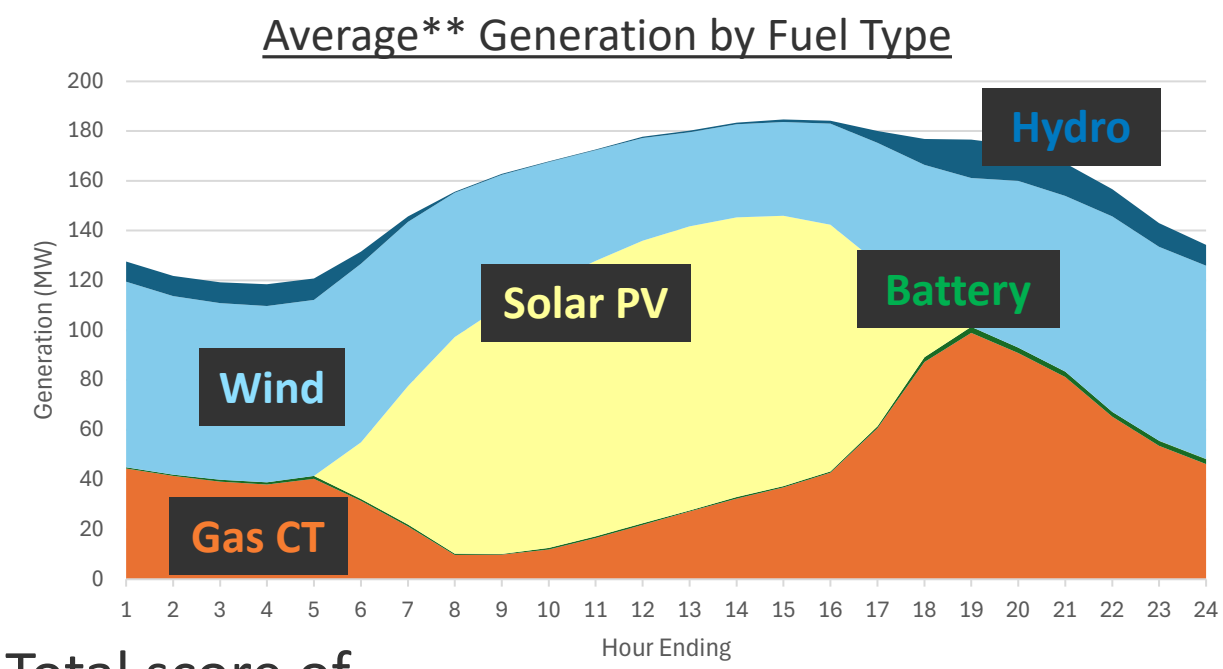
<u>Modified PJM 5-bus system with changed resource mix</u>

- 3 load (at Bus B, C and D) with hourly load profiles for an entire year.
- 5 buses connected by 7 transmission lines (two lines between Bus C and D)
- **Add new-build wind, solar, battery, and gas generators!**

Simulated Submission

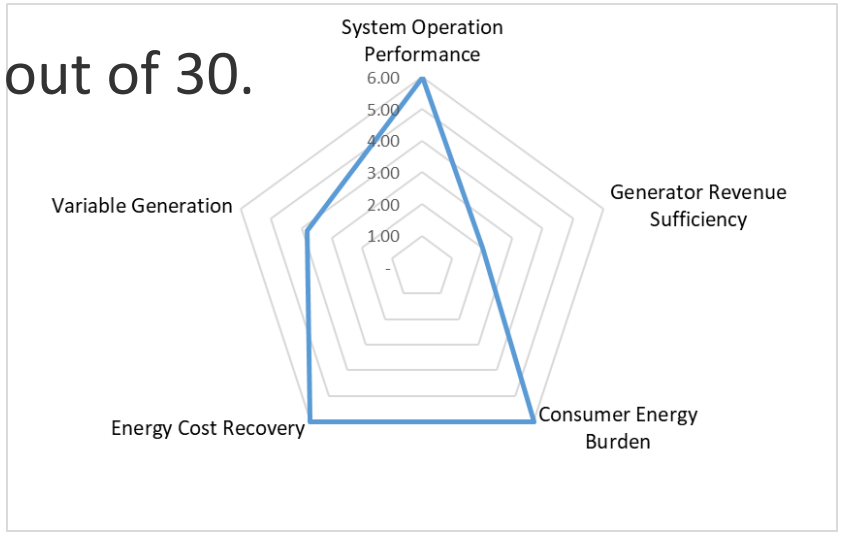
- For the simulated submission, we assume an energy-only market (products.csv), where energy prices are determined similar to how the locational marginal prices (LMPs) are set today in most North American wholesale electricity markets.
- The test system (resource_mix.csv) is simulated in production cost model (PCM) software (Sienna) for one year, with the following outputs:
  - commitment.csv: same as resource unit commitment outcomes from PCM.
  - dispatch.csv: same as resource dispatch outcomes from PCM.
  - prices.csv: similar to LMP calculation, which is based on dual variables of PCM outcomes.
  - procurement_supply.csv: assume to be the same as resource dispatch results.
  - procurement_demand.csv: assume to be the same as load profiles.

NREL Example Demonstration



Total score of

23.63 out of 30.



- This simulated submission achieves near perfect system operation performance score, which is not surprising, given that all evaluated constraints are being enforced in PCM.
- Energy cost recovery score is also perfect, indicating that costs charged to load is enough to cover payments to generation resources.
- High consumer energy burden score indicates the costs spent on electricity are affordable for consumers with assumed characteristics in this case.
- However, the generator revenue sufficiency score of this submission is relatively low, suggesting payments to generators are not enough to cover their costs (variable and fuel costs, fixed o&m, capex etc.) under this market design.

**Generation by fuel type is simple average across 365 days in each hour

Feedback & Thoughts

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Appendix: Detailed Quantitative Evaluation Metrics

System Operation Performance

- System operation performance score measures how well competitors' resource dispatch schedules satisfy resource and system operational constraints.
  - Power Balance
  - Resource Capacity/Availability
  - Ramping Capability
  - Storage Operational Constraints
  - Transmission Capacity
- Both constraints violation frequency and magnitude are evaluated and normalized.
- Final system operation performance score is further normalized to a value between 0 and 6, with 6 being no system operational violation and 0 indicating worst constraints violation (frequency and magnitude) as defined by the prize host.

Generator Revenue Sufficiency

- r: discount rate
- g: generator
- s: storage
- d: demand
- p: product
- t: time step

- Generator revenue sufficiency score measures if total revenues earned by generating (and storage) resources are sufficient to cover all their costs (variable and fuel costs, fixed o&m, capex etc.)

$$\text{Total Annual Profit} = \sum_{p,t} (\text{Price}_{g/s,p,t} \times \text{Procurement}_{g/s,p,t}) - \text{Variable Cost} - \text{Fixed O\&M}$$

$$\text{NPV(Total Profit)} = \text{Total Annual Profit} \times \frac{1 - (1 + r)^{-\text{Lifetime}}}{r}$$

$$\text{Revenue Insufficiency} = \min(0.0, \text{NPV(Total Profit)} - \text{Capital Costs})$$

$$\text{Normalized Revenue Insufficiency} = \min\left(1.0, \frac{|\text{Revenue Insufficiency}|}{\text{Capital Costs}}\right)$$

- Final generator revenue sufficiency score is normalized to a value between 0 and 6, with 0 being completely revenue insufficient and 6 being perfectly revenue sufficient.

Consumer Energy Burden

- Consumer energy burden score measures the affordability of energy (electricity) costs.
- Energy burden is calculated as the ratio of total annual electricity billings and consumers' annual income (or portion of income):

$$\text{Total Annual Electricity Billings} = \sum_{p,t} (\text{Price}_{d,p,t} \times \text{Procurement}_{d,p,t})$$

$$\text{Energy Burden} = \min\left(1.0, \frac{\text{Total Annual Electricity Billings}}{\text{Annual Incomes}}\right)$$

- Final consumer energy burden score is normalized to a value between 0 and 6, with 0 being the least affordable and 6 being very affordable for electricity.

Energy Cost Recovery

- Energy cost recovery score measures whether customers' billings are sufficient to cover payouts to generators.

$$\text{Energy Cost Recovery Insufficiency} = \min\left(0.0, \sum_{d,p,t}(\text{Price}_{d,p,t} \times \text{Procurement}_{d,p,t}) - \sum_{g/s,p,t}(\text{Price}_{g/s,p,t} \times \text{Procurement}_{g/s,p,t})\right)$$

$$\text{Normalized Energy Cost Recovery Insufficiency} = \min\left(1.0, \frac{|\text{Energy Cost Recovery Insufficiency}|}{\sum_{g/s,p,t}(\text{Price}_{g/s,p,t} \times \text{Procurement}_{g/s,p,t})}\right)$$

- Final energy cost recovery score is normalized to a value between 0 and 6, with 6 being customers' billings are sufficient to cover payouts to generators, and 0 being otherwise.

Variable Generation Resources Metric

- Variable generation resources score measures the total variable generation as a percentage of total load.
- This score is then normalized to a value between 0 and 6, with 0 indicating a “floor” percentage of variable generation set by the prize host, and 6 indicating 100% variable generation.