# Fuel Constrained Bidding

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**MIWG**
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# Purpose of today's discussion

- **The purpose of today's discussion is to:**
  - ***Review bidding designs and design functionalities***
  - ***Review timelines for implementation***
  - ***Review Fuel Cost and Efficiency Curve research outcomes***
  - ***Review Limited Energy and Level Schedule Bidding***
  - ***Next steps***

# Terminology

- **Total Energy Curve Qualified Resource (TEC Resource) – a single resource registered with NYISO to use the Total Energy Curve Bidding functionality**
- **Total Energy Curve Group (TEC Group) = portfolio of resources (multiple PTID) bidding a shared Total Energy Curve**

# Fuel Constrained Bidding Designs and Sub-functionalities

**Designs:**

- **Total Energy Curve (BIC Approved)**
- **Fuel Cost and Efficiency Curve**

**Sub-functionalities:**

- **Limited Energy Bidding – can be used with both designs above**
- **Level Schedule Request – could be used with or without both designs above**

***All functionalities described above apply to DAM bidding only, are optional, and available year-round***

# Review of Market Rules from 2/23 MIWG

- **NYISO must approve TEC resources and groups**
- **Resources in TEC groups must belong to the same bidding and billing entity**
- **A single resource can be a part of only one approved TEC entity in a single electric day**
- **NYC resources can only be grouped with other NYC resources; if in NYC the resources must exist within the same load pockets and sub load pockets**
- **Under the TEC design, no single, or combination of cost offers shall exceed the energy offer cap or be below the negative offer cap**
- **Bid validation will ensure that the TEC reflects the total available capability reflected in hourly bids***
- **Base DAM bids (no adders) will be converted to RT bids – MPs will be responsible for updating RT bids**
- **BPCG and DAMAP will be netted over constraint hours/resources under the constraint**
  - ***BPCG and DAMAP for reliability-committed resources will be calculated independently with TEC costs prorated over reliability MWs in a methodology to be discussed at a later MIWG***
  - ***Example calculations and formula revisions to be discussed at a later MIWG***

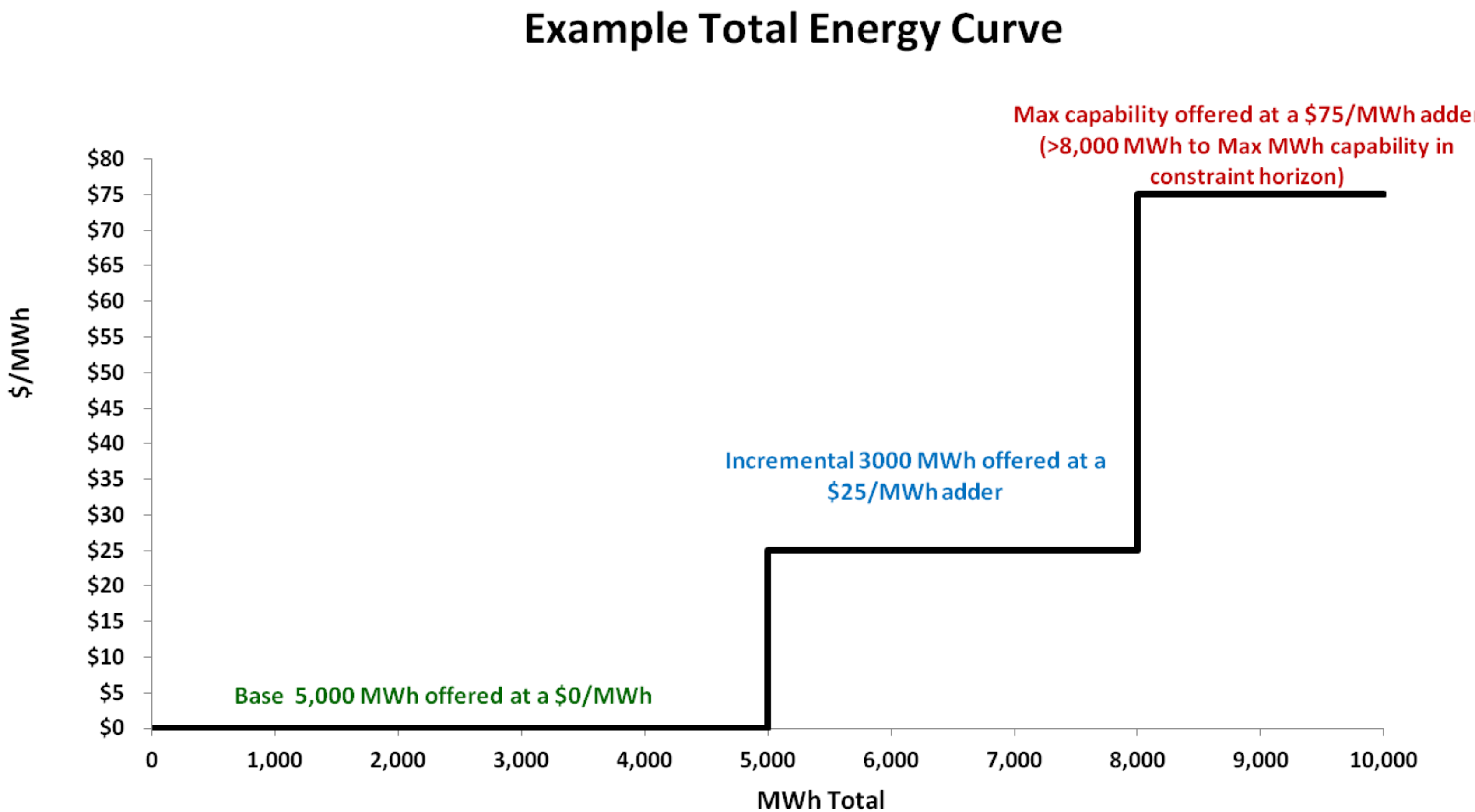
***Note: We will discuss Limited Energy Bidding in subsequent slides where this would not apply***

# Total Energy Curve
# (BIC Approved Design; MWh Constraint)

# Total Energy Curve Design

- **This design would allow the MP to submit for the electric day or subset of hours in the electric day:**
  - ***Hourly three-part bids for a TEC resource or TEC Group***
  - ***A cost curve reflecting total energy capability in the timeframe (MWh) and cost to produce those MWhs ($/MWh) for the TEC resource or TEC Group***

# Total Energy Curve Example




| Total Energy Curve Bids | MWh 1 | $/MWh 1 | MWh 2 | $/MWh 2 | MWh 3 | $/MWh 3 |
|---|---|---|---|---|---|---|
| | 5,000 | $0 | 8,000 | $25 | 10,000 | $75 |

**Note: Existing bid features will not change. Hourly three-part bids for each generator are still submitted in conjunction with this offer**

# Total Energy Curve Development Timeline

- **The NYISO expects that implementation of this design could be achieved by 2019 at the earliest**
  - ***This design requires extensive bid to bill impacts detailed on the following slide***
  - ***A large share of resources necessary for this implementation, especially in 2018, will be dedicated to the EMS/BMS upgrade project***
- **The NYISO estimates following timeline until implementation for this design:**

| Target Date | Estimated Time to Complete | Activity |
|---|---|---|
| December 2016 | 9 months | Tariff and Functional Requirements |
| April 2017 | 4 months | FERC Filing |
| October 2017 | 6 months | Draft Use Cases |
| Spring 2019 | 10 - 16 months | Development |
| Fall 2019 - Winter 2019 | 6 - 10 months | Testing/Deployment |

- **The NYISO also anticipates the Total Energy Curve design (MWh constraint) will be leveraged to implement a storage optimization bidding design to be addressed through the Energy Storage Optimization project**

# Total Energy Curve Development Timeline

- **Initial list of system and interface changes associated with implementation of this design**

| Description of Changes | Details |
|---|---|
| New bid screens | · Bidding interface for select TEC resource or TEC group<br>· Funtionality to specify constraint hours and associated price-quantity pairs |
| Additional bid validations | · Resource can belong to only one TEC entity in the market day<br>· Offer cap validations<br>· Hourly Offers v. capability reflected on TEC |
| New tables for mapping TEC Resources and TEC Groups to generators | |
| New tools for users to administer mappings of TEC Resources and TEC Groups to generators | |
| New tables for TEC offers | |
| Revised MIS conduct testing (data fed to SCUC and Billing software for automated mitigation processes) | Additional conduct test for the TEC |
| Revised reliability committed unit mitigation processes | |
| Revised logic to pull MIS bids into OISR | |
| Logic revision to account for TEC offers in objective function | |
| Revised Automated Mitigation logic | |
| New multi-hour, multi-unit references for each TEC resource or group | A single TEC reference for each TEC resource or group |
| Revise BPCG/DAMAP eligibility coding | |
| Revise BPCG/DAMAP calculation coding | |
| Additonal logic to account for reliability committed resource make-whole payments | |
| Revise automated guarantee payment mitigation coding | |
| New displays for multi-unit/multi-hour settlement components | |
| New masked bid report structure to accomodate TEC offers | |

# Fuel Cost and Efficiency Curve

# Fuel Cost and Efficiency Curve Design

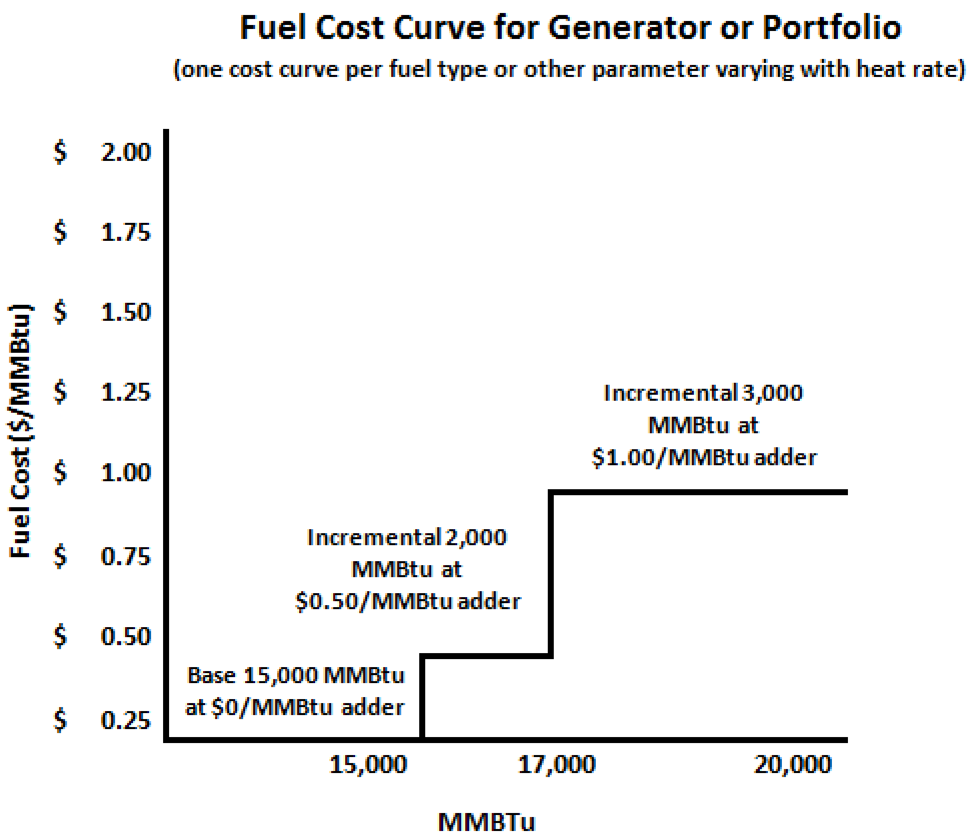
- NYISO committed to researching this design further at BIC
- This design would break down cost components of hourly offers that vary with resource heat rate and fuel burn into separate offers
- The optimization would select the least cost solution by evaluating the interaction of costs and resource efficiencies at different operating points for a single resource or group of resources

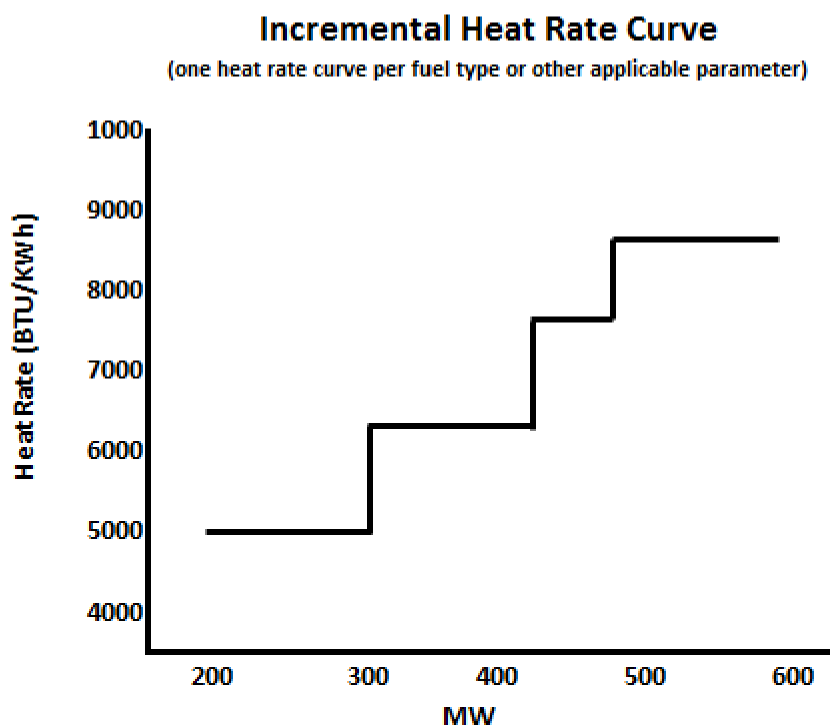
# Fuel Cost and Efficiency Curve Design

- **This design would allow the MP to submit:**
  - ***Hourly three-part bids for a generator or each generator in a portfolio***
  - ***A cost curve reflecting incremental fuel purchases (eg. MMBtu) and cost to procure incremental volumes of fuel ($/MMBtu) for the generator or portfolio****
  - ***Fuel input at Minimum Generation (eg. MMBtu/Hour) for each generator****
  - ***Incremental heat rate curve reflecting the conversion between fuel (eg. BTU/KWh) and output (MW) for the generator or each generator in the portfolio****

**(*) Separate cost curves, heat rate curves, and fuel input at Min Gen would be submitted for each cost parameter that is variable with heat rate (eg. each fuel type). If heat rates vary over the course of the day due to temperature or humidity, the incremental heat rate curves and fuel input at Min Gen may vary by hour**

# Fuel Cost and Efficiency Curve Example



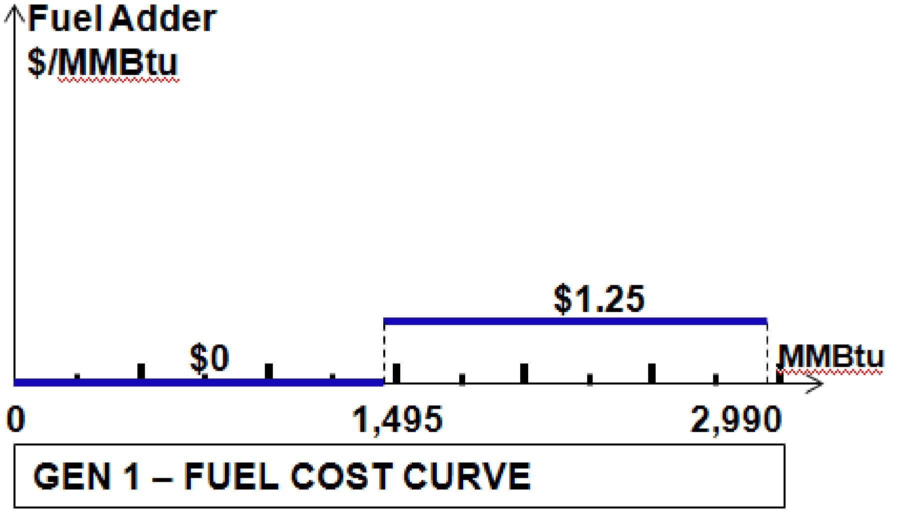



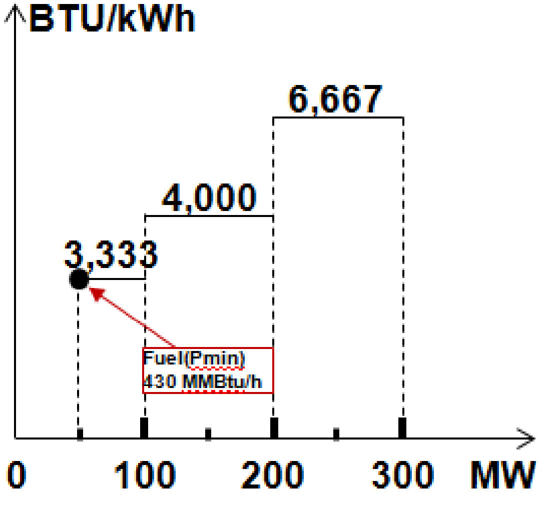

Note: Fuel Input at Min Gen will also be submitted

**Note: Existing bid features will not change. Hourly three-part bids for each generator are still submitted in conjunction with this offer**

# Fuel Cost and Efficiency Curve Design Research – Numerical Example

- **We compared Fuel Cost and Efficiency Curve simulation outcomes to Total Energy Curve outcomes in two different scenarios***
  - *Gen 1 with UOL of 300MW has a fuel constraint and is gas-only*
  - *Natural gas is $7.50/MMBtu in the two hour period*
  - *Heat input at Min Gen (50MW) is 430MMBtu/h*
  - *Assume Gen 1's Incremental Heat Rate Curve and Fuel Cost curves are as depicted below (these are submitted inputs)*
    - Gen 1's Fuel Cost and Efficiency Curves are uniform for a two hour period (based on running on gas)
    - The fuel cost curve reflects cost adders above a base gas cost




**TEC assumptions are based on the results of Appendix A: Examples 1 and 2 in the BIC Fuel Constrained Bidding presentation 11/13/2015 but with an added Min Gen Cost assumption; TEC assumptions and outcomes can also be found in Appendix 2 and 3 of this presentation*

# Fuel Cost and Efficiency Curve Design Research – comparison to TEC

- **Based on the resource's incremental heat rate offer and calculated efficiency at different operating points, we can construct what a Total Energy Curve would look like subject to different operating efficiencies (detailed conversions are in Appendix 1):**

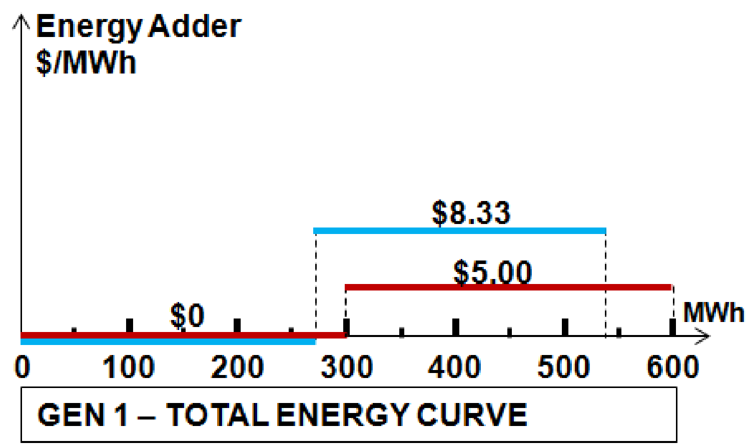
| Break Point, MW | Incremental Heat Rate, BTU/kWh | Fuel consumption, MMBTU/h | Average Heat Rate, BTU/kWh | Efficiency, % | TEC Breakpoint 1, MWh | TEC Breakpoint 2, MWh | Cost Adder, $/MWh |
|---|---|---|---|---|---|---|---|
| 50 | 2,667 | 430 | 8,600 | 40% | 174 | 348 | 3.33 |
| 100 | 3,333 | 597 | 5,967 | 57% | 251 | 501 | 4.17 |
| 200 | 4,000 | 997 | 4,983 | **68%** | **300** | **600** | **5.00** |
| 300 | 6,667 | 1,663 | 5,544 | **62%** | **270** | **539** | **8.33** |

**GEN1 Fuel Cost Curve**

| | MMBTU1 | MMBTU2 | $/MMBTU2 |
|---|---|---|---|
| GEN1 | 1,495 | 2,990 | $ 1.25 |

First breakpoint on TEC is calculated as MMBTU1/(Avg Heat Rate/1000)

Second breakpoint on TEC is calculated as MMBTU2/(Avg Heat Rate/1000)




- **Different efficiency assumptions may translate to different breakpoints and costs reflected on the TEC**

# Ex 1 -- 68% Efficiency Conversion

- **Suppose Gen 1 bids reflecting 68% efficiency in a Total Energy Curve (corresponds with a $5 adder on any MWh scheduled beyond 300MWh)**
- **In both the TEC and Fuel Cost and Efficiency curve outcomes, the resource was scheduled to 450MWh. At this schedule, the resource actually incurs a $8.33 fuel adder (schedule requires 2327 MMBtu) as reflected in its Fuel Cost and Efficiency Curve offers**
- **We compare the Total Energy Curve outcome of reflecting 68% efficiency in the TEC offer to the Fuel Cost and Efficiency Curve outcomes:**
  - ***No differences in gen schedules or actual production costs in both scenarios (bid production costs do increase in the Fuel Cost and Efficiency Curve scenario)***
  - ***This example shows a higher net revenue for Gen 1 using the Fuel Cost and Efficiency Curve. This is because the resource reflects the wrong efficiency in the TEC (chooses efficiency associated with a $5/MWh adder) rather than the actual outcome ($8.33/MWh). Actual efficiency is captured by the Fuel Cost and Efficiency Curve scenario.***
  - ***Load payments increased under the Fuel Cost and Efficiency Curve outcome. This is because Gen 1 was marginal in HB1 and set price with a $8.33 adder rather than the $5 under the TEC scenario***

| Gen 1 Strategy | Gen 1 Actual Production Cost | Total System Production Cost | Load Payment | Gen 1 Net Revenue | Gen 2 Net Revenue |
|---|---|---|---|---|---|
| Adder in Total Energy Curve | $ 18,490 | $ 25,490 | $ 31,250 | $ 5,260 | $ 500 |
| Adder in Fuel Cost Curve | $ 18,490 | $ 25,490 | $ 32,083 | $ 6,093 | $ 500 |
| Delta (Fuel Cost - Total Energy) | $ - | $ - | $ 833 | $ 833 | $ - |

# Ex 2 -- 62% Efficiency Conversion

- **Suppose the resource bids reflecting 62% efficiency in its Total Energy Curve (corresponds with a $8.33 adder on any MWh scheduled beyond 270MWh)**
- **In both the TEC and Fuel Cost and Efficiency curve outcomes, the resource was scheduled to 310MWh. At this schedule, the resource actually incurs a $5 fuel adder (associated with 68% efficiency) as reflected in its Fuel Cost and Efficiency Curve offers**
- **We compare the Total Energy Curve outcome of reflecting 62% efficiency in the TEC offer to the Fuel Cost and Efficiency Curve outcomes**
  - ***There were no differences in gen schedules or production costs in both scenarios (bid production costs were higher in the TEC scenario)***
  - ***This example shows a higher net revenue for Gen 1 in HB1 in the TEC scenario. This is because the resource reflects the wrong efficiency (chooses efficiency associated with a $8.33/MWh adder) in the TEC rather than the actual outcome ($5/MWh) but is still scheduled as the lowest cost resource. Actual efficiency is captured by the Fuel Cost and Efficiency Curve scenario.***
  - ***Gen 1 earns higher net revenues in the TEC scenario, but the resource's bid costs and thus costs reflected in LBMP are higher than actual. This could be inefficient for the resource owner if their higher offers prevented a schedule or resulted in a lower schedule***
  - ***Load payments decreased under the Fuel Cost and Efficiency Curve outcome. This is because Gen 1 was marginal in HB1 and set price with the actual $5 adder rather than $8.33 under the TEC scenario***

| Gen 1 Strategy | Gen 1 Actual Production Cost | Total System Production Cost | Load Payment | Gen 1 Net Revenue | Gen 2 Net Revenue |
|---|---|---|---|---|---|
| Adder in Total Energy Curve | $ 12,423 | $ 19,423 | $ 21,716 | $ 1,793 | $ 500 |
| Adder in Fuel Cost Curve | $ 12,423 | $ 19,423 | $ 21,350 | $ 1,427 | $ 500 |
| Delta (Fuel Cost - Total Energy) | $ - | $ - | $ (366) | $ (366) | $ - |

# Numerical Example Conclusion

**There are risks presented when a resource does not reflect the correct operating efficiency in a Total Energy Curve offer:**

1. **A resource risks reflecting too low of a cost adder: Gen1 anticipated that it would run at 68% efficiency where it would incur $5.00/MWh fuel cost adder. In reality the market scheduled Gen 1 at 62% where it incurred $8.33/MWh cost adder. It did not fully reflect its costs in offers using a TEC.**

1. **A resource risks reflecting too high of a cost adder: Gen 1 anticipated that it would run at 62% efficiency where it would incur $8.33/MWh cost adder. In reality the market scheduled Gen 1 at 68% where it only incurred $5.00/MWh cost adder. LBMPs may reflect too high of a cost, or the resource may risk not receiving a schedule.**

# Fuel Cost and Efficiency Curve Design Research – Additional Observations

- **The small-scale simulation we ran assumed the fuel constrained resources was a single fuel resource**
- **There are added modeling complexities needed to address resources that can operate on more than one fuel**
  - ***This would require the resource offer to include detailed unit characteristics and associated costs in all operating configurations***
  - ***Even with a single fuel offer, complexities are introduced when emission costs are tied to fuel consumption***
    - **Resources would have to submit emission characteristic offers that are related to fuel burn, which may include multiple emissions costs ($CO_2$, NOx, SOx)**
  - ***This complexity would require extended time to conceptualize, model, and test***
- **Implementation of this design would impact downstream processes that utilize bid data as each system would have to be capable of calculating a variety of bid costs in different configurations**
  - ***This is a driver behind an extended timeline for developing requirements***

# Conclusion

- **Both TEC and Fuel Cost and Efficiency Curve designs eliminate the risk of guessing where and when to impose cost adders in hourly bids**
  - ***Total Energy Curve (output constraint) accurately optimizes the limited energy available to the generator(s)***
  - ***Fuel Cost & Efficiency Curve (input constraint) further optimizes the limited fuel available to the generator(s).***
- **If the generator/portfolio efficiency is uniform, the two designs are identical**
- **The Fuel Cost & Efficiency Curve eliminates risk of reflecting the wrong operating efficiency in TEC offers**
- **Both risks described above are faced today when resources are bidding to reflect fuel or energy limitations**
- **Both designs provide appreciable benefits from the current bid construct**

# Fuel Cost and Efficiency Curve Development Timeline

- **The NYISO foresees that implementation of this design would extend beyond 2019 into 2020 due to more extensive bid to bill impacts than the TEC design which would require:**
  - ***Extended time to conceptualize design components, develop market rules, tariff amendments and functional requirements***
  - ***Extended development and testing***
- **The NYISO estimates the following timeline until implementation for this design:**

| Target Date | Estimated Time to Complete | Activity |
|---|---|---|
| October 2017 | 18 months | Tariff and Functional Requirements |
| February 2017 | 4 months | FERC Filing |
| August 2018 | 6 months | Draft Use Cases |
| April 2020 | 12-16 months | Development/Testing (likely would not begin until 2019) |
| Late 2020 | | Deployment |

# Fuel Cost and Efficiency Curve Development Timeline

- **Initial summary of system and interface changes associated with implementation of this design**
- **Items in blue highlight differences compared to the TEC design**

| Description of Changes | Details |
|---|---|
| New bid screens | · Bidding interface for select resource or group<br>· Funtionality to specify constraint hours and associated fuel cost/efficiency curves<br>· Additional inputs must be accounted for to allow for submission of multiple parameters that vary with heat rates |
| Additional bid validations | · Resource can only belong to one approved bid entitiy in a market day<br>· Offer cap validations - additional complexity to account for the computation of costs between the fuel cost and efficiency parameters<br>· Hourly Offers v. Capability Reflected in Fuel Cost and Efficiency Curve validations - additional complexity to account for the computation of potential energy capability as reflected in fuel and heat rate offers |
| New tables for mapping bid entities to specific generators | |
| New tools for users to administer mappings of generators and bid entities | |
| New tables for fuel cost and efficiency curve offers | Additional complexity to reflect potentially multiple cost and efficiency curves |
| Revised MIS conduct testing (data fed to SCUC and Billing software for automated mitigation processes) | Additional complexity to perform conduct tests across potentially multiple cost offers |
| Revised reliability committed unit mitigation processes | |
| Logic revision to account for fuel cost and efficiency curve offers in the objective function | Additional complexity to account for potentially multiple cost and efficiency curves; costs are calculated within the optimization |
| Revised Automated Mitigation logic | |
| New multi-hour, multi-unit references for each resource or group | Multiple components of references for each resource or group |
| Revise BPCG/DAMAP eligibility coding | |
| Revise BPCG/DAMAP calculation coding | |
| Revise Automated GP Mitigation coding | |
| New displays for multi-unit/multi-hour settlement components | |
| New data structure to accomodate fuel cost and efficiency curve offers for masked bid reporting | Must consider what the masked bids should look like |

# Limited Energy Bidding

# Background

- The NYISO is currently pursuing the Total Energy Curve bidding design
- All examples presented to MPs have shown this design as a way to more efficiently reflect opportunity costs across a resource(s)' <u>full potential capability</u> as reflected in hourly three-part bids
  - *Bid validation was presented to ensure this condition is met*
- The NYISO has stated that this design should not be used in place of taking an outage; this still holds true
- At the last MIWG, MPs expressed that there is value to allowing resources to reflect a "hard" limit on energy using this design
  - *We noted to MPs that we would discuss this topic at a future MIWG*

# Limited Energy Bidding Concept

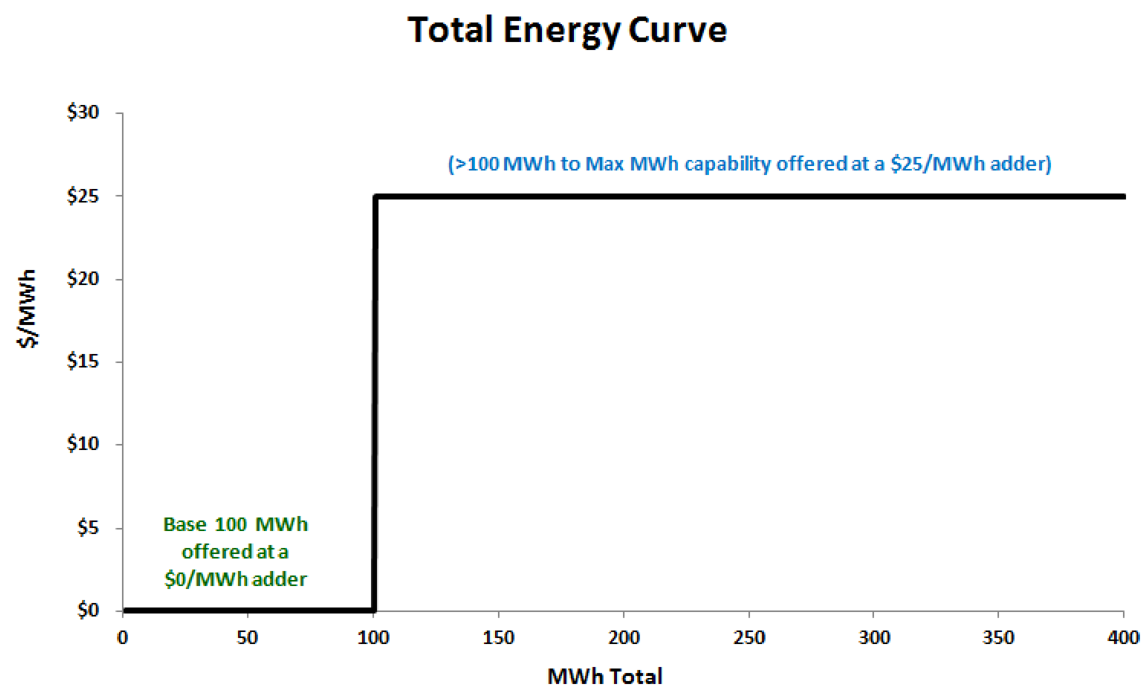
- **Using this functionality, the TEC resource or TEC group could submit:**
  - ***Hourly three-part bids for all resource-hours covered by the constraint***
  - ***Total Energy Curve reflecting limited energy and associated adder costs***
    - ***The last MWh point on the Total Energy Curve could be less than the total MWh reflected in hourly offers***
- **This would allow the optimization to schedule the resource(s) in the most optimal hours subject to the limited energy reflected on the TEC**
- **The benefit is that the resource would not have to guess in which hours to bid (reflect availability)**

# Limited Energy Bidding Concept

Hourly IE Offers

| Hour | MWh 1 | $/MWh 1 |
|---|---|---|
| HB00 | 100 | $15 |
| HB01 | 100 | $15 |
| HB02 | 100 | $15 |
| HB03 | 100 | $15 |
| HB04 | 100 | $15 |
| HB05 | 100 | $15 |
| HB06 | 100 | $15 |
| HB07 | 100 | $15 |
| HB08 | 100 | $15 |
| HB09 | 100 | $15 |
| HB10 | 100 | $15 |
| HB11 | 100 | $15 |
| HB12 | 100 | $15 |
| HB13 | 100 | $15 |
| HB14 | 100 | $15 |
| HB15 | 100 | $15 |
| HB16 | 100 | $15 |
| HB17 | 100 | $15 |
| HB18 | 100 | $15 |
| HB19 | 100 | $15 |
| HB20 | 100 | $15 |
| HB21 | 100 | $15 |
| HB22 | 100 | $15 |
| HB23 | 100 | $15 |

- **Total Capability Reflected in Hourly Bids = 2400MWh**
- **Total Actual Capability Reflected on TEC = 400MWh**
- **The resource can be scheduled for <=400MWh total over the day**




| Total Energy Curve | MWh 1 | $/MWh 1 | MWh 2 | $/MWh 2 |
|---|---|---|---|---|
| | 100 | $0 | 400 | $25 |

# Limited Energy Bidding Concept

- **The NYISO has determined that this capability does provide additional market efficiency and proposes to pursue this sub-design as part of the Fuel Constrained Bidding effort**
- **This design provides benefits in comparison to current options:**
  - ***A resource can guess in which hours would be most optimal to run and bid only in those hours, and report an outage for other hours***
    - ***A resource risks guessing wrong; the optimization may have scheduled the resource in a more optimal hour, but instead must schedule a more costly resource***
  - ***A resource can bid in more hours than capable, then take a forced outage if it cannot meet that schedule***
    - ***This may result in more costly resources making up for the resource's schedule in RT***
- **The following provisions will be enforced for resources using this functionality:**
  - ***Resources must still report their anticipated de-rate to outage scheduling as done today***
  - ***Based on outage records and DAM offers, MMA will still check that ICAP resources are meeting their DAM bid, schedule, notify obligation***
  - ***Using this feature to withhold available capability from the Energy and Ancillary Service markets will result in review for possible physical withholding***
  - ***This MWh limitation will also serve as a cap on the total of energy, spin, and non-spin reserve schedules***

# Level Schedule Request Feature

# Background

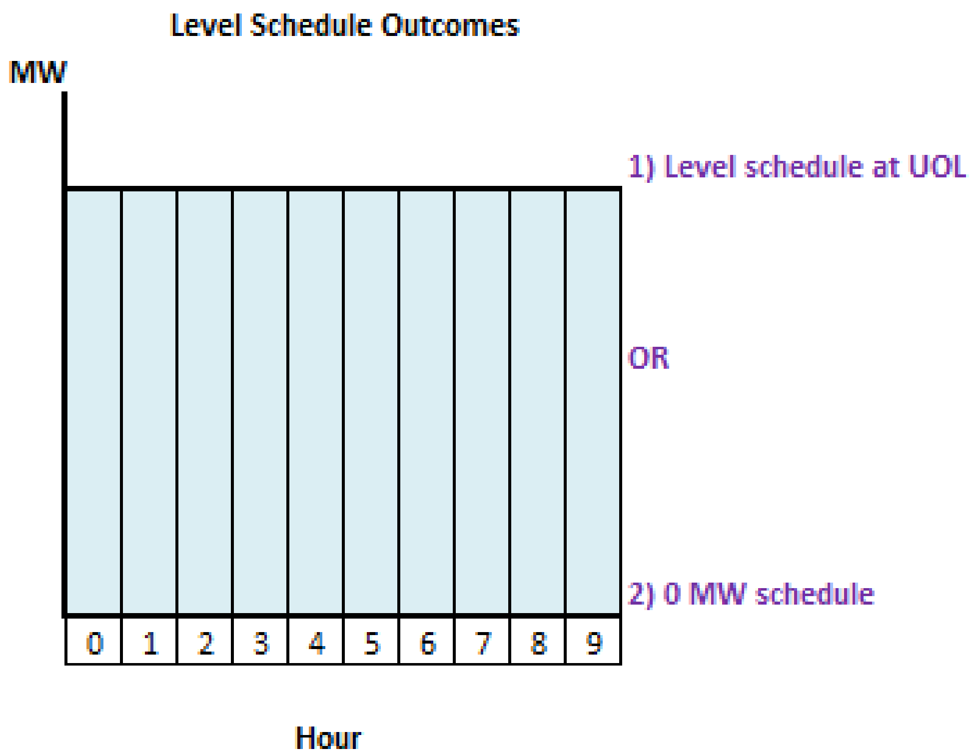
- This feature is currently part of the high level design approved at BIC
- Bidding functionality to allow resources to more efficiently reflect 1/24th OFO constraints in day-ahead offers is recommended in 2013/14 State of the Market reports
- Though discussions with resource bidders, this functionality is desirable to help reflect costs better in energy offers when a 1/24th OFO is anticipated

# Level Schedule Concept

- **This feature does not have to be used with a Total Energy Curve, though it is a multi-hour constraint**
- **Using this functionality, a resource could submit:**
  - ***Hourly three-part bids for all resource-hours covered by the constraint***
  - ***Request to enforce a level schedule for specified hours***
  - ***OPTIONAL: Total Energy Curve***
- **This would allow the optimization to schedule the resource(s) flexibly, but to enforce a level schedule if scheduled**
- **This feature would give resources an alternative to self-scheduling to achieve a level schedule**
  - ***A resource can be evaluated economically for a level schedule as opposed to offering as a price taker in order to guarantee a level schedule***

# Level Schedule Request Concept

- Single block-loaded resource with level schedule request over HB 00-09:



# Level Schedule Request Concept

- **NYISO proposes that this sub-design be available for single, block loaded resources only**
  - ***Historically, MPs have inquired about how to reflect OFO-related costs across block-loaded resources, not flexible resources***
  - ***Single resources in a portfolio can bid with this request to achieve a portfolio-level, level schedule***
  - ***A resource requesting a level schedule may still belong to a TEC group***
  - ***NYISO is interested in hearing feedback on whether this functionality would be beneficial for flexible scheduled resources as well***
- **These resources could bid in the ISO Flex or ISO Fixed bid mode and will be eligible for BPCG as the decision to schedule the resource would be an economic decision**
- **For block-loaded resources, this request is essentially an on/off decision and NYISO will assume that a resource's UOL offers are reflective of a level fuel draw**
- **Resources using this feature will be precluded form providing reserves in the constraint timeframe**

# Solicitation of generator bidder/scheduler feedback

- **The NYISO plans to conduct an informative WebEx for resource bidders and conduct a follow-up survey to determine design preferences and quantify perceived benefits of each design and sub-functionality**
- **The following questions will be addressed:**
  - ***How beneficial is the design or sub-functionality to your generation fleet?***
  - ***How often would this design or sub-functionality be used?***
  - ***Where do preferences lie?***
- **The results of this survey will be discussed at an April MIWG**
- **This feedback will help inform us of which design components to prioritize**

# Next Steps

- **Currently soliciting MP feedback**
  - ***Please e-mail any questions or comments to csanada@nyiso.com***
- **Conduct a WebEx to solicit feedback from resource bidders/schedules to gauge design preferences**
- **March - May**
  - ***Continuation of discussions on market rules for the TEC design***
- **Q2-Q3 2016**
  - ***Tariff language development***
  - ***BIC Vote on Market Design and Tariff Language***
- **Q4 2016**
  - ***Draft and approve functional requirements (Internal)***

# APPENDIX 1 – Conversion of Incremental Heat Rate Curve to Operating Point Efficiency

# Conversion of Incremental Heat Rate Curve to Operating Point Efficiency

- Assume the resource's Fuel Input at Min Gen (50MW) is 430MMBtu/h. Fuel consumption is calculated at each point of the incremental heat rate curve. We can construct the resource's input/output curve as follows:

**Input/Output Curve**

| MW | $/MWh | BTU/kWh | Conversion to Fuel Consumption, MMBtu/h | Fuel Consumption, MMBtu/h |
|---|---|---|---|---|
| 50 | $ 20 | 2667 | 430MMBtu/h | 430 |
| 100 | $ 25 | 3333 | 433MMBtu/h + [(3333Btu/kWh * 1/1000) * (100MW - 50MW)] | 597 |
| 200 | $ 30 | 4000 | 3333MMBtu/h + [(4000Btu/kWh * 1/1000) * (200MW - 100MW)] | 997 |
| 300 | $ 50 | 6667 | 4000MMBtu/h + [(6667Btu/kWh * 1/1000) * (300MW - 200MW)] | 1663 |

- From here, we can calculate the resource's average heat rate and calculate a % efficiency at each operating point, used in the analysis

**Average heat rate and efficiency**

| MW | Fuel Consumption, MMBtu/h | Conversion to Average Heat Rate, BTU/kWh | Average Heat Rate, BTU/kWh | Conversion to Efficiency | Efficiency, % |
|---|---|---|---|---|---|
| 50 | 430 | (430MMBtu/h)/50MW * 1000 | 8600 | (3412 Btu/hr) / (8600 Btu/kWh) | 40% |
| 100 | 597 | (597MMBtu/h)/100MW * 1000 | 5970 | (3412 Btu/hr) / (5970 Btu/kWh) | 57% |
| 200 | 997 | (997MMBtu/h)/200MW * 1000 | 4985 | (3412 Btu/hr) / (4985 Btu/kWh) | 68% |
| 300 | 1663 | (1663MMBtu/h)/300MW * 1000 | 5543 | (3412 Btu/hr) / (5543 Btu/kWh) | 62% |

# APPENDIX 2 – TEC/Fuel Cost and Efficiency Curve Comparison Example 1 Details

# TEC/Fuel Cost and Efficiency Curve Comparison – Example 1

- **TEC inputs and outcomes:**

**Offer curves**

| Name | Hour | MW1 | $/MWh1 | MW2 | $/MWh2 | MW3 | $/MWh3 | MW4 | $/MWh4 |
|---|---|---|---|---|---|---|---|---|---|
| GEN1 | 1 | 50 | $ 20 | 100 | $ 25 | 200 | $ 30 | 300 | $ 50 |
| GEN1 | 2 | 50 | $ 20 | 100 | $ 25 | 200 | $ 30 | 300 | $ 50 |
| GEN2 | 1 | 100 | $ 60 | 300 | $ 65 | 500 | $ 70 | 600 | $ 100 |
| GEN2 | 2 | 100 | $ 45 | 300 | $ 50 | 500 | $ 70 | 600 | $ 100 |

**Gen 1 Total Energy Curve**

| | MW1 | $/MWh1 | MW2 | $/MWh2 |
|---|---|---|---|---|
| GEN1 | 300 | $ - | 600 | $ 5.00 |

**Load**

| Hour 1 | Hour 2 |
|---|---|
| 250 | 350 |

**LBMPs**

| HB1 | HB2 |
|---|---|
| **$ 55.00** | **$ 50.00** |

**Schedules**

| Name | HB1 | HB2 | MWH Total | MMBTU Fuel |
|---|---|---|---|---|
| GEN1 | 250 | 200 | **450** | **2,326.7** |
| GEN2 | 0 | 150 | **150** | - |

**Gen Payment**

| Name | HB1 | HB2 | Total |
|---|---|---|---|
| GEN1 | $ 13,750 | $ 10,000 | **$ 23,750** |
| GEN2 | $ - | $ 7,500 | **$ 7,500** |

**Actual Production Cost (not bid production cost)**

| Name | HB1 | HB2 | Constraint Cost | Total |
|---|---|---|---|---|
| GEN1 | $ 9,975 | $ 7,475 | $ 1,040 | **$ 18,490** |
| GEN2 | $ - | $ 7,000 | | **$ 7,000** |

**Net Revenues**

| Name | HB1 | HB2 | Constraint Cost | Total |
|---|---|---|---|---|
| GEN1 | $ 3,775 | $ 2,525 | $ (1,040) | **$ 5,260** |
| GEN2 | $ - | $ 500 | | **$ 500** |

**Load Payment**

| HB1 | HB2 |
|---|---|
| $ 13,750 | $ 17,500 |

**Mingen Cost**

| |
|---|
| $ 3,225 |

# TEC/Fuel Cost and Efficiency Curve Comparison – Example 1

- **Fuel Cost and Efficiency Curve inputs and outcomes:**

**Offer curves**

| Name | Hour | MW1 | $/MWh1 | MW2 | $/MWh2 | MW3 | $/MWh3 | MW4 | $/MWh4 |
|---|---|---|---|---|---|---|---|---|---|
| GEN1 | 1 | 50 | $ 20 | 100 | $ 25 | 200 | $ 30 | 300 | $ 50 |
| GEN1 | 2 | 50 | $ 20 | 100 | $ 25 | 200 | $ 30 | 300 | $ 50 |
| GEN2 | 1 | 100 | $ 60 | 300 | $ 65 | 500 | $ 70 | 600 | $ 100 |
| GEN2 | 2 | 100 | $ 45 | 300 | $ 50 | 500 | $ 70 | 600 | $ 100 |

**Gen 1 Incremental Heat Rate Curve**

| | MMBTU1 | $/MMBTU1 | MMBTU2 | $/MMBTU2 |
|---|---|---|---|---|
| GEN1 | 1,495 | $ - | 2,990 | $ 1.25 |

**Gen 1 Total Fuel Curve**

| | MMBTU1 | $/MMBTU1 | MMBTU2 | $/MMBTU2 |
|---|---|---|---|---|
| GEN1 | 1,495 | $ - | 2,990 | $ 1.25 |

**Load**

| Hour 1 | Hour 2 |
|---|---|
| 250 | 350 |

**LBMPs**

| **HB1** | **HB2** |
|---|---|
| **$ 58.33** | **$ 50.00** |

**Schedules**

| Name | HB1 | HB2 | **MWH Total** | **MMBTU Fuel** |
|---|---|---|---|---|
| GEN1 | 250 | 200 | **450** | **2,326.7** |
| GEN2 | 0 | 150 | **150** | - |
| *GEN1(MMBtu)* | *1330* | *999.65* | | ***2,329.7*** |

**Gen Payment**

| Name | HB1 | HB2 | **Total** |
|---|---|---|---|
| GEN1 | $ 14,583 | $ 10,000 | **$ 24,583** |
| GEN2 | $ - | $ 7,500 | **$ 7,500** |

**Actual Production Cost (not bid production cost)**

| Name | HB1 | HB2 | Constraint Cost | **Total** |
|---|---|---|---|---|
| GEN1 | $ 9,975 | $ 7,475 | $ 1,040 | **$ 18,490** |
| GEN2 | $ - | $ 7,000 | | **$ 7,000** |

**Net Revenues**

| Name | HB1 | HB2 | Constraint Cost | **Total** |
|---|---|---|---|---|
| GEN1 | $ 4,608 | $ 2,525 | $ (1,040) | **$ 6,093** |
| GEN2 | $ - | $ 500 | | **$ 500** |

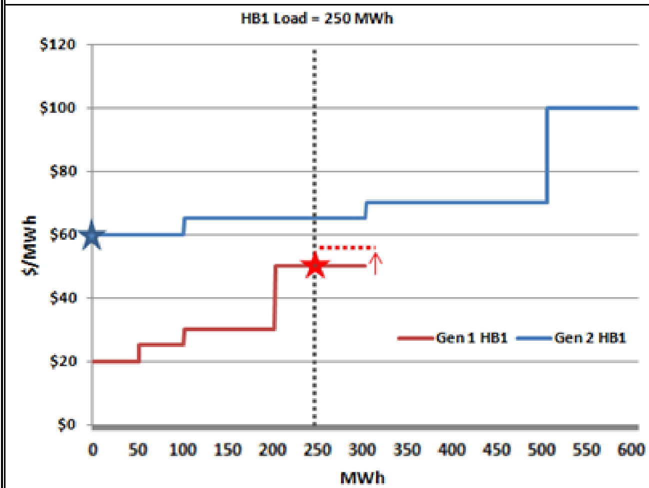
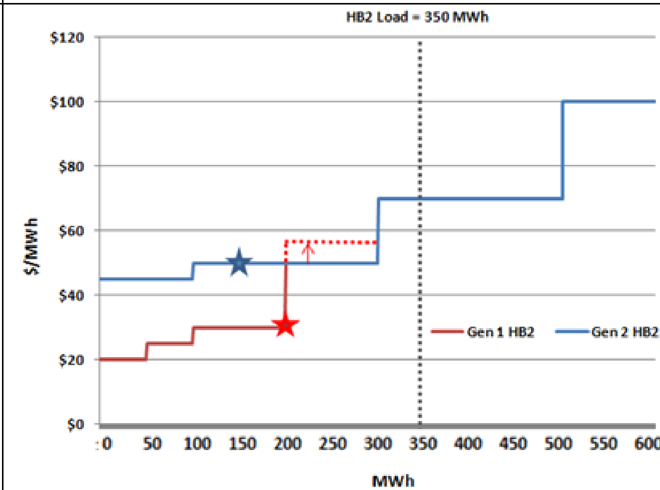
**Load Payment**

| HB1 | HB2 |
|---|---|
| $ 14,583 | $ 17,500 |

**Mingen Cost**

| |
|---|
| $ 3,225 |

# Example 1 – Fuel Cost and Efficiency Curve Market Clearing

| HB1 | HB2 |
| --- | --- |
|  |  |
| In HB1, load is 250MWh. To meet load, the optimization schedules:<br><br>From Gen 1: 50MW at $20 + 50MW at $25 + 100MW at $30 + 50MW at $50<br><br>From Gen 2: 0MW<br><br>The LBMP in HB1 is set by Gen 1 (next MWh costs $50 with an $8.33 adder). This is cheaper than Gen 2's next MWh in this hour ($60). | In HB2, load is 350MWh. To meet load, the optimization schedules:<br><br>From Gen 1: 50MW at $20 + 50MW at $25 + 100MW at $30<br><br>From Gen 2: 100MW at $45 + 50MW at $50<br><br>The LBMP in HB2 is set by Gen 2 at $50. (The next MWh from Gen 1 would cost $50 + $8.33 adder) |

# Example 1 Comparison of Outcomes

- **Actual production costs for Gen 1 and Gen 2 over both hours is calculated as:**

| | HB1 | HB2 | Constraint Cost | Total |
|---|---|---|---|---|
| Gen 1 | \$3,225/h + 50MW× \$25 + 100MW×\$30 + 50MW×\$50 | \$3,225/h + 50MW× \$25 + 100MW×\$30 | max(0, (2,326.7 MMBtu – 1,495 MMBTU) x \$1.25/MMBtu) | \$18,490 |
| Gen 2 | - | 100MW×\$45 + 50MW×\$50 | N/A | \$7,000 |
| **System Production Cost:** | | | | \$25,490 |

- **Comparison of results:**

| Gen 1 Strategy | Gen 1 Actual Production Cost | Total System Production Cost | Load Payment | Gen 1 Net Revenue | Gen 2 Net Revenue |
|---|---|---|---|---|---|
| **Adder in Total Energy Curve** | **\$ 18,490** | **\$ 25,490** | **\$ 31,250** | **\$ 5,260** | **\$ 500** |
| **Adder in Fuel Cost Curve** | **\$ 18,490** | **\$ 25,490** | **\$ 32,083** | **\$ 6,093** | **\$ 500** |
| **Delta (Fuel Cost - Total Energy)** | **\$ -** | **\$ -** | **\$ 833** | **\$ 833** | **\$ -** |

# APPENDIX 3 – TEC/Fuel Cost and Efficiency Curve Comparison Example 2 Details

# TEC/Fuel Cost and Efficiency Curve Comparison – Example 2

- TEC inputs and outcomes:

**Offer curves**

| Name | Hour | MW1 | $/MWh1 | MW2 | $/MWh2 | MW3 | $/MWh3 | MW4 | $/MWh4 |
|---|---|---|---|---|---|---|---|---|---|
| GEN1 | 1 | 50 | $ 20 | 100 | $ 25 | 200 | $ 30 | 300 | $ 50 |
| GEN1 | 2 | 50 | $ 20 | 100 | $ 25 | 200 | $ 30 | 300 | $ 50 |
| GEN2 | 1 | 100 | $ 60 | 300 | $ 65 | 500 | $ 70 | 600 | $ 100 |
| GEN2 | 2 | 100 | $ 45 | 300 | $ 50 | 500 | $ 70 | 600 | $ 100 |

**Gen 1 Total Energy Curve**

| | MW1 | $/MWh1 | MW2 | $/MWh2 |
|---|---|---|---|---|
| GEN1 | 270 | $ - | 539 | $ 8.33 |

**Load**

| Hour 1 | Hour 2 |
|---|---|
| 110 | 350 |

**LBMPs**

| HB1 | HB2 |
|---|---|
| **$ 38.33** | **$ 50.00** |

**Schedules**

| Name | HB1 | HB2 | MWH Total | MMBTU Fuel |
|---|---|---|---|---|
| GEN1 | 110 | 200 | **310** | **1,633.3** |
| GEN2 | 0 | 150 | **150** | - |

**Gen Payment**

| Name | HB1 | HB2 | Total |
|---|---|---|---|
| GEN1 | $ 4,216 | $ 10,000 | **$ 14,216** |
| GEN2 | $ - | $ 7,500 | **$ 7,500** |

**Actual Production Cost (not bid production cost)**

| Name | HB1 | HB2 | Constraint Cost | Total |
|---|---|---|---|---|
| GEN1 | $ 4,775 | $ 7,475 | $ 173 | **$ 12,423** |
| GEN2 | $ - | $ 7,000 | | **$ 7,000** |

**Net Revenues**

| Name | HB1 | HB2 | Constraint Cost | Total |
|---|---|---|---|---|
| GEN1 | $ (559) | $ 2,525 | $ (173) | **$ 1,793** |
| GEN2 | $ - | $ 500 | | **$ 500** |

**Load Payment**

| HB1 | HB2 |
|---|---|
| $ 4,216 | $ 17,500 |

**Mingen Cost**

| |
|---|
| $ 3,225 |

# TEC/Fuel Cost and Efficiency Curve Comparison – Example 2

- Fuel Cost and Efficiency outcomes:

**Offer curves**

| Name | Hour | MW1 | $/MWh1 | MW2 | $/MWh2 | MW3 | $/MWh3 | MW4 | $/MWh4 |
|---|---|---|---|---|---|---|---|---|---|
| GEN1 | 1 | 50 | $ 20 | 100 | $ 25 | 200 | $ 30 | 300 | $ 50 |
| GEN1 | 2 | 50 | $ 20 | 100 | $ 25 | 200 | $ 30 | 300 | $ 50 |
| GEN2 | 1 | 100 | $ 60 | 300 | $ 65 | 500 | $ 70 | 600 | $ 100 |
| GEN2 | 2 | 100 | $ 45 | 300 | $ 50 | 500 | $ 70 | 600 | $ 100 |

**Gen 1 Incremental Heat Rate Curve**

| | MMBTU1 | $/MMBTU1 | MMBTU2 | $/MMBTU2 |
|---|---|---|---|---|
| GEN1 | 1,495 | $ - | 2,990 | $ 1.25 |

**Gen 1 Total Fuel Curve**

| | MMBTU1 | $/MMBTU1 | MMBTU2 | $/MMBTU2 |
|---|---|---|---|---|
| GEN1 | 1,495 | $ - | 2,990 | $ 1.25 |

**Load**

| Hour 1 | Hour 2 |
|---|---|
| 110 | 350 |

**LBMPs**

| HB1 | HB2 |
|---|---|
| $ 35.00 | $ 50.00 |

**Schedules**

| Name | HB1 | HB2 | MWH Total | MMBTU Fuel |
|---|---|---|---|---|
| GEN1 | 110 | 200 | **310** | **1,633.3** |
| GEN2 | 0 | 150 | **150** | - |
| *GEN1(MMBtu)* | *636.65* | *999.65* | | ***1,636.3*** |

**Gen Payment**

| Name | HB1 | HB2 | Total |
|---|---|---|---|
| GEN1 | $ 3,850 | $ 10,000 | **$ 13,850** |
| GEN2 | $ - | $ 7,500 | **$ 7,500** |

**Actual Production Cost (not bid production cost)**

| Name | HB1 | HB2 | Constraint Cost | Total |
|---|---|---|---|---|
| GEN1 | $ 4,775 | $ 7,475 | $ 173 | **$ 12,423** |
| GEN2 | $ - | $ 7,000 | | **$ 7,000** |

**Net Revenues**

| Name | HB1 | HB2 | Constraint Cost | Total |
|---|---|---|---|---|
| GEN1 | $ (925) | $ 2,525 | $ (173) | **$ 1,427** |
| GEN2 | $ - | $ 500 | | **$ 500** |

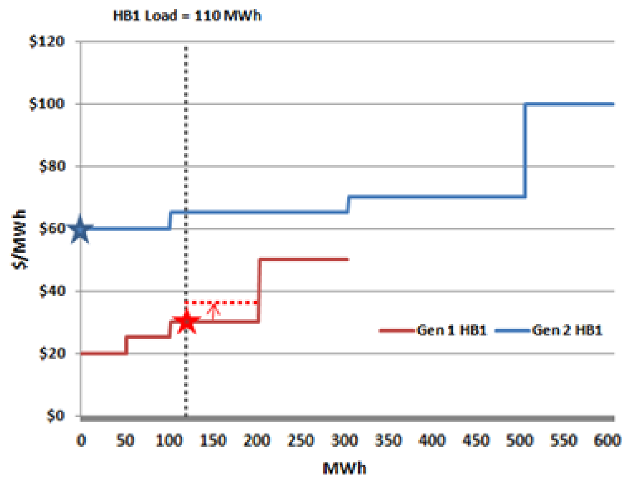
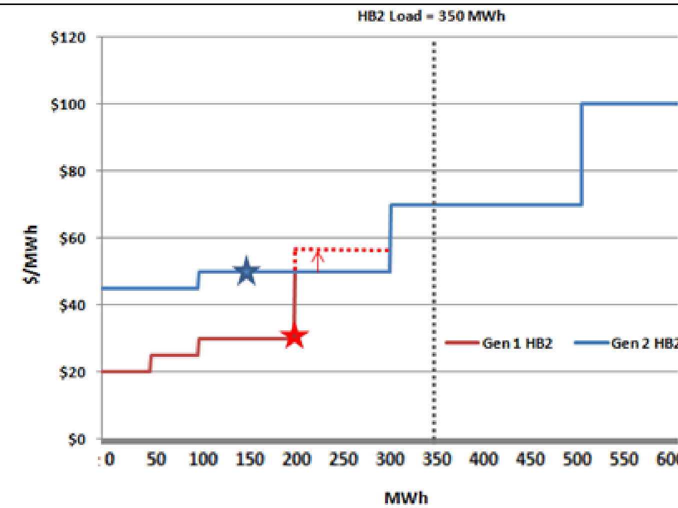
**Load Payment**

| HB1 | HB2 |
|---|---|
| $ 3,850 | $ 17,500 |

**Mingen Cost**

| |
|---|
| $ 3,225 |

# Example 2 – Fuel Cost and Efficiency Curve Market Clearing

| HB1 | HB2 |
|---|---|
| <br>In HB1, load is 110MWh. To meet load, the optimization schedules:<br><br>From Gen 1: 50MW at $20 + 50MW at $25 + 10MW at $30<br><br>From Gen 2: 0MW<br><br>The LBMP in HB1 is set by Gen 1 at $35. (Gen 1 is scheduled into its $30 segment, but incurs a $5 fuel adder) | <br>In HB2, load is 350MWh. To meet load, the optimization schedules:<br><br>From Gen 1: 50MW at $20 + 50MW at $25 + 100MW at $30<br><br>From Gen 2: 100MW at $45 + 50MW at $50<br><br>The LBMP in HB2 is set by Gen 2 at $50. |

# Example 2 Comparison of Outcomes

- **Actual production costs for Gen 1 and Gen 2 over both hours is calculated as:**

| | HB1 | HB2 | Constraint Cost | Total |
|---|---|---|---|---|
| Gen 1 | $3,225/h + 50MW× $25 + 10MW×$30 | $3,225/h + 50MW× $25 + 100MW×$30 | max(0, (1,633.3 MMBtu – 1,495 MMBTU) x $1.25/MMBtu) | $12,423 |
| Gen 2 | - | 100MW×$45 + 50MW×$50 | N/A | $7,000 |
| **System Production Cost:** | | | | $19,423 |

- **Comparison of results:**

| Gen 1 Strategy | Gen 1 Actual Production Cost | Total System Production Cost | Load Payment | Gen 1 Net Revenue | Gen 2 Net Revenue |
|---|---|---|---|---|---|
| **Adder in Total Energy Curve** | **$ 12,423** | **$ 19,423** | **$ 21,716** | **$ 1,793** | **$ 500** |
| **Adder in Fuel Cost Curve** | **$ 12,423** | **$ 19,423** | **$ 21,350** | **$ 1,427** | **$ 500** |
| **Delta (Fuel Cost - Total Energy)** | **$ -** | **$ -** | **$ (366)** | **$ (366)** | **$ -** |