ISO new england

memo

To: NEPOOL Participants Committee Working Session

From: Market Development

Date: April 8, 2021

Subject: Storage Resources and Pathways to a Future Grid

As the ISO and its stakeholders evaluate pathways to a future grid, a key consideration is the role of storage resources in this transition, and the extent to which the frameworks being evaluated facilitate their participation in the decarbonization of the region's energy sector. While this discussion in ongoing, the ISO prepared this memorandum in order to offer some practical observations about the implications of various treatments for energy storage, including if it is eligible to receive clean energy certificates under an forward clean energy market (FCEM) framework,[1] and how it participates in a net carbon pricing framework.

To evaluate these treatments, the memorandum introduces a series of numerical examples that consider storage's impact on production costs, clean energy production, and carbon emissions. These examples then evaluate storage's compensation under current market rules, an FCEM framework considering cases where storage does and does not receive clean energy certificates, and net carbon pricing.

These examples, summarized in Table 1 below, find that storage resources are compensated for their marginal contributions to clean energy production via increased energy market revenues under an FCEM framework. As such, it is most consistent with sound market design to not award clean energy certificates to storage resources as this would lead them to be compensated at a rate above their clean energy contributions. The examples also find that a net carbon pricing approach that does not charge storage resources for carbon emissions will appropriately compensate them for its contributions to carbon emissions reductions.

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[1] In this document, the FCEM refers generally to the forward clean energy procurement framework as has been discussed recently at the NEPOOL Participants Committee and is outlined in the scoping memo, available at https://nepool.com/wp-content/uploads/2021/03/1a-FCEM-Scoping-Memo_vfinal.pdf. The observations provided in this memo apply equally whether the forward procurement of clean energy occurs outside of the Forward Capacity Market (where this is commonly referred to as the FCEM framework), or if this procurement is instead integrated with the Forward Capacity Market (where this approach is commonly referred to as the Integrated Clean Capacity Market, or ICCM).

Table 1: Summary of Examples

	Market Rules	Storage's Impact on Outcomes	Key Takeaways
Example a1	Current Market Rules	Storage transfers production from peaker to clean baseload resource	Storage is compensated for its contributions to reducing production costs.
Example b1	FCEM	Storage transfers production from non-clean peaker to clean baseload, increases clean energy production.	Storage is compensated for its contributions to reducing production costs and increasing clean energy production without being awarded clean energy certificates.
Example b2	FCEM	Storage transfers production from non-clean peaker to non-clean baseload, does not increase clean energy production.	Storage is compensated for its contributions to reducing production costs without being awarded clean energy certificates.
Example c1	Net Carbon Pricing	Storage transfers production from carbon emitting peaker to non-emitting baseload, reduces carbon emissions.	Storage is compensated for its contributions to reducing both production costs and carbon emissions.
Example c2	Net Carbon Pricing	Storage transfers production from carbon emitting peaker to less carbon emitting baseload, reduces carbon emissions.	Storage is compensated for its contributions to reducing both production costs and carbon emissions. While storage transfers energy production in same manner as Example b2 (where it does not increase clean energy production), under a carbon price framework, it reduces carbon emissions and is compensated as such.

1. Storage's role in the region's decarbonization

Storage's role in energy production differs from that of other technologies, as it charges (withdraws / consumes) during lower priced periods and then discharges (injects / generates) during higher priced periods. Thus, rather than producing energy like a traditional generator, energy storage enhances the market's efficiency by allowing some of the peak load, which is typically supplied by high-cost peaking generation, to be met by lower cost generation stored during off-peak hours. In addition to lowering costs, storage can play an important role in the region's decarbonization. For example, it may allow generation to be shifted from peak hours, where the marginal energy supplier emits greater levels of carbon for each MWh of energy produced, to off-peak hours, where the marginal energy supplier may emit relatively less carbon.[2]

By transferring the energy production to lower emitting resources, storage can help to reduce the region's total carbon emissions. Applying similar logic, storage resources may increase the region's production of clean energy if it shifts energy generation from peak hours when the marginal resource is not producing clean energy to off-peak hours when it is. It is therefore appropriate to evaluate the potential treatment of storage resources under an FCEM or net carbon pricing framework to determine what approach most

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[2] While storage may also provide other benefits that help to facilitate the region's decarbonization, such as reliability services, these are outside the scope of this memo.

appropriately compensates them for their environmental contributions in a manner that is commensurate with other resource types.

2. Numerical Examples

While the numerical examples make a number of simplifying assumptions, their findings generalize to a broad set of market and resource conditions. They consider two hours – an off-peak hour when energy demand is low, and an on-peak hour when energy demand is high. They assume that there are two generating resources that can meet this demand. The first generator is a lower cost "baseload" resource, B, which has 100 MW of capacity. This resource is assumed to be marginal during off-peak hours, as its capacity exceeds energy demand, and its offer therefore sets the clearing price in this hour. However, during on-peak hours, it is infra-marginal as demand exceeds its maximum output. In these examples, we consider outcomes when the baseload resource is one of two different kinds of technologies: a clean, non-emitting resource (examples a1, b1, and c1), and a (relatively) low emission, natural gas generator (examples b2 and c2).

The second generator is a higher cost "peaker" resource, P, which also has 100 MW of capacity. This generator does not run during the off-peak hour (as demand can be met entirely by the lower cost "base" resource), but it is needed to meet the higher energy demand during the on-peak hour. In this on-peak hour, resource P is the marginal resource, and its offer sets the clearing price.

Finally, each example considers two cases. In case 1, energy demand in both hours is met entirely by these two generators. In case 2, we introduce a storage resource, S, that charges at a rate of 10 MW during the off-peak hour (meaning total energy supplied from the non-storage generators increases by 10 MWh during this hour), and discharges at a rate of 10 MW during the on-peak hour (meaning total energy supplied by the non-storage generators decreases by 10 MWh).[3]

For simplicity, we assume that this storage resource incurs no costs except for those associated with buying energy during the off-peak hour. In each example, we compare outcomes between these two cases, with a focus on how storage's participation impacts the production costs incurred to meet electricity demand, clean energy production, and carbon emissions.

These assumptions are summarized in Table 2 below.

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[3] We assume for simplicity that storage resource is a price-taker as demand in the off-peak hour, and is a price-taker as supply in the on-peak hour. Moreover, for simplicity, we assumes S incurs no losses between charging and discharging. However, the key observations would apply even when storage is not 100 percent efficient.

Table 2: Example Assumptions		
Assumptions Applicable to Both Cases		
Baseload capacity	100 MW	
Peaker capacity	100 MW	
Off-peak demand	80 MWh	
On-peak demand	150 MWh	
Assumptions that Vary Between Cases		
	Case 1: No Storage	**Case 2: Storage**
Off-peak (non-storage) generation	80 MWh	90 MWh
On-peak (non-storage) generation	150 MWh	140 MWh
Total generation	230 MWh	230 MWh

After evaluating storage resource's impact on production costs and environmental outcomes, we consider the storage resource's compensation under case 2. For the FCEM, this includes consideration of market rules that do not award storage clean energy certificates as well as those that do award it such certificates. This analysis seeks to determine which set of market rules better aligns storage's compensation with its marginal contributions to reducing production costs and increasing clean energy production.

a. Compensation for storage resources under current market rules

We begin with an example that employs the current market rules. More specifically, this example assumes that neither an FCEM nor a net carbon price framework is in effect.

Example a1: Storage shifts energy production from the on-peak hour to the off-peak hour

In this example, we assume that the baseload resource B is a clean resource that has "physical" marginal costs[4] of producing electricity of $0 per MWh, and the peaker resource P is a combustion turbine generator with "physical" marginal costs of producing electricity of $100 per MWh. Market outcomes under cases with and without the participation of storage resource S are illustrated in Table a1.1 below.

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[4] We define "physical" marginal costs as the costs that the resource incurs to produce electricity before consideration of any environmental costs or rebates. We will use these costs to determine the production costs that are considered in addition to environmental costs or benefits in the examples throughout.

Table a1.1: Energy Awards and Production Costs

Case 1: No Storage

		Generation *[MWh]*	Production Costs *[$]*
[1]	Off-peak	80 MWh	$0 *[80 MWh × $0/MWh]*
[2]	On-peak	150 MWh	$5,000 *[100 MWh × $0/MWh + 50 MWh × $100/MWh]*
[3]	Total	230 MWh	$5,000

Case 2: Storage

		Generation *[MWh]*	Production Costs *[$]*
[4]	Off-peak	90 MWh	$0 *[90 MWh × $0/MWh]*
[5]	On-peak	140 MWh	$4,000 *[100 MWh × $0/MWh + 40 MWh × $100/MWh]*
[6]	Total	230 MWh	$4,000

Change in Costs Due to Storage Participation

		Generation *[MWh]*	Production Costs *[$]*
[7]		0 MWh	($1,000)

Case 1 is given in the top panel of the table (rows [1] through [3]), where storage resource S does not participate. In this case, the 80 MWh of demand in the off-peak hour is met by the base resource B (row [1]) and the entire 150 MWh of demand in the on-peak hour is met by generation in that hour (row [2]). This results in total production costs of $5,000, where, because the base resource has physical marginal costs of $0 per MWh, these costs come entirely from the 50 MWh provided by peaker P during the on-peak hour. The total generation and production costs are summed across the off- and on-peak hours in row [3].

Case 2 is illustrated in the second panel of the table (rows [4] through [6]), where storage resource S consumes electricity during the off-peak hour, thus increasing off-peak demand by 10 MWh to 90 MWh, as shown in row [4], and discharges this energy during the on-peak hour, thereby reducing on-peak generation by this same 10 MWh to 140 MWh (row [5]).

The impact of the storage resource's participation, measured as its total reduction in production costs, is illustrated in the row [7]. In this example, storage reduces the production costs to meeting demand across these two hours by $1,000 ($100/MWh × 10 MWh) as the costly peaker P now only provides 40 MWh of energy, 10 MWh less than in Case 1. This reduction in production costs is calculated by subtracting the total production costs without storage participation (row [3]) from those with storage participation (row [6]).

In this example, storage resource S is compensated for its contributions to reducing production costs based on the difference between energy prices when it charges and discharges. More specifically, as shown in Table a1.2 below, storage incurs no costs when charging in the off-peak hour because it consumes 10 MWh of electricity at a price of $0 per MWh (row [1]). It then receives total payments equal to $1,000 during the on-peak hour when it discharges because it produces 10 MWh of energy that is sold at $100 per MWh (row [2]). Thus, storage resource S receives total compensation of $1,000 (row [3]), equal to its revenues from energy sold less its costs from energy bought. This compensation is commensurate with the degree to which its shifting energy production from the higher cost peaker P to base resource B reduces the total production costs, as shown by comparing production costs between the cases in Table a1.1 (rows [3] and [6]).[5] Under these current market rules, which do not compensate resources for either for clean energy production or reductions in carbon emissions, storage does not receive any additional compensation for its contributions to these environmental objectives.

Table a1.2: Storage Revenues			
	[a]	*[b]*	*[c] = [a] × [b]*
	Energy Clearing Price	Cleared Supply	Storage Net Revenues
	[$/MWh]	*[MWh]*	*[$]*
[1] Off-peak	$0/MWh	-10 MWh	$0
[2] On-peak	$100/MWh	10 MWh	$1,000
[3]	Total	0 MWh	$1,000

b. Storage's compensation under an FCEM

We now consider a pair of examples that are similar to that presented above, except they now presume that an FCEM is in place and consider two additional factors – how storage contributes to the production of clean energy, and how storage's compensation changes with the introduction of this new market. In each case, we assume that the FCEM specifies a value of $10 per MWh of clean energy produced.[6]

Additionally, consistent with the cost allocation methodology put forth in the straw FCEM framework, we presume that the new costs associated with procuring clean energy certificates are allocated to Real-Time

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[5] The energy market price is based on marginal costs and as such, a resource's profits from the energy market are based on its contributions to reducing production costs at the margin. In this example, and those that follow, these profits are also equal to the storage resource's total contributions to reducing production costs (and improving environmental outcomes) because the storage resource's participation does not change the marginal resource in either the off- or on-peak hour, and as a result, its first MWh charged/discharged yields the same reduction in production costs as its last. Thus, while resources are generally compensated based on their marginal contribution to production costs (and environmental outcomes), the assumptions in this example lead the storage resource's compensation to also equal its total contribution to production costs (and environmental outcomes). This assumption helps to simplify the comparison of storage's compensation and contributions to production costs (and environmental outcomes).

[6] The example's takeaways would hold under a range of assumed clean energy certificate prices, where this price reflects the value of a certificate as specified during the delivery period.

Load Obligation (RTLO). This approach does not allocate these new clean energy costs to storage resources when they are charging.[7]

In the first of these examples, we assume that baseload resource B produces clean energy, whereas in the second, we presume that it is an efficient gas-fired combined cycle plant that does not produce clean energy.

Example b1: Storage increases clean energy production

In this example, baseload resource B again produces energy with phystical marginal costs of $0 per MWh. However, these MWh are now considered clean, and thus produce clean energy certificates that are valued at $10 per MWh. This is reflected Table b1.1 below, which builds appears similar to Table a1.1 from the earlier example. This table includes a new column that calculates the total benefit from clean energy production as the product of baseload resource B's production and $10 per MWh (column [c]).[8] In case 1 (no storage participation) where B produces a total of 180 MWh across the two hours, the total clean energy benefit provided is $1,800, equal to the product of 180 MWh of energy generated by clean resource B and the $10 per MWh value associated with this clean energy.

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[7] While the memo does not explicitly evaluate approaches that would allocate clean energy costs to storage, such approaches do not appear well-equipped to robustly compensate storage commensurate with their clean energy contributions across a range of market and resource conditions.

[8] Thus, these calculations assume that consistent with the payment rate of $10 per MWh of clean energy production provided to suppliers, the social benefits from an incremental 1 MWh of clean energy production are $10.

Table b1.1: Energy Awards, Production Costs, and Clean Energy Benefits

	[a]	*[b]*	*[c]*	*[d] = [b] - [c]*
		Case 1: No Storage Participation		
	Generation *[MWh]*	Production Costs *[$]*	Clean Energy Benefit *[$]*	**Total Costs *[$]***
[1] Off-peak	80 MWh	$0 *[80 MWh × $0/MWh]*	$800 *[80 MWh × $10/MWh]*	**($800)**
[2] On-peak	150 MWh	$5,000 *[100 MWh × $0/MWh + 50 MWh × $100/MWh]*	$1,000 *[100 MWh × $10/MWh]*	**$4,000**
[3] Total	230 MWh	$5,000	$1,800	**$3,200**
		Case 2: Storage Participation		
	Generation *[MWh]*	Production Costs *[$]*	Clean Energy Benefit *[$]*	**Total Costs *[$]***
[4] Off-peak	90 MWh	$0 *[90 MWh × $0/MWh]*	$900 *[90 MWh × $10/MWh]*	**($900)**
[5] On-peak	140 MWh	$4,000 *[100 MWh × $0/MWh + 40 MWh × $100/MWh]*	$1,000 *[100 MWh × $10/MWh]*	**$3,000**
[6] Total	230 MWh	$4,000	$1,900	**$2,100**
		Change in Costs and Benefits due to Storage Participation		
	Generation *[MWh]*	Production Costs *[$]*	Clean Energy Benefit *[$]*	**Total Costs *[$]***
[7]	0 MWh	($1,000)	$100	**($1,100)**

Observe that in this example, where the FCEM values clean energy at a price of $10 per MWh, the clean energy benefit is $100 greater in case 2 than in case 1, as shown in row [7]. This increase in the clean energy benefit occurs because the storage resource shifts 10 MWh of production from peaker P, which does not produce clean energy to baseload resource B, which does produce clean energy. In total, clean energy generation from baseload resource B therefore increases by 10 MWh with the participation of storage.

Thus, when we consider storage's impact on total costs, which are equal to the production costs less the clean energy benefits, the participation of storage reduces total costs by $1,100, equal to the difference between the total costs in cases 1 and 2 (rows [7], column [d]). Storage's benefit in this example is greater than that estimated in example a1 because storage not only reduces production costs by $1,000 (the same amount as in example a1), but it now also increases clean energy production by 10 MWh, which when valued at the $10 per MWh of clean energy, yields an incremental clean energy benefit of $100.

With the understanding that storage reduces total costs by $1,100, we now consider how two different FCEM eligibility criteria would impact storage's compensation, and how each relates to its contributions to reducing costs, as measured using both production costs and clean energy production.

To do so, we must first consider the impact of the FCEM on energy market prices. Recall from the earlier example that the baseload resource B that sets the clearing price during the off-peak hour has physical marginal costs of producing this energy of $0 per MWh. Under current market rules, we would expect this resource to offer into the energy market at these costs, and because it is the marginal resource in this hour, the off-peak clearing price would therefore be $0.

Under the FCEM, where the value of clean energy is assumed to be $10, we expect resource B to internalize this revenue in its energy offer price. More specifically, rather than offering at $0, its competitive offer price would decrease to –$10 per MWh because for each MWh of energy produced, it receives a clean energy certificate valued at $10.[9] As a result, in this example, the introduction of the FCEM would reduce the energy clearing price in the off-peak hour by the price of the clean energy certificates to –$10 per MWh.

Table b1.2 illustrates the total compensation to storage under two potential FCEM eligibility treatments. Under the first treatment, storage is not directly credited with certificates for clean energy production for each MWh of energy it supplies during the peak hour (illustrated in column [c]). Under the second treatment, storage is credited with clean energy certificates for this supply (column [e]). Observe that in both treatments, the storage resource is paid $100 to consume 10 MWh of energy in the off-peak hour, as the energy price in this hour is -$10 per MWh.

Table b1.2: Storage Revenues with and without Clean Energy Credits

	[a]	*[b]*	*[c] = [a] × [b]*	*[d]*	*[e] = [c] + [d]*
	Energy Clearing Price	Cleared Supply	**Storage Net Revenues without Clean Energy Credits**	Storage Clean Energy Credit Revenues	**Storage Net Revenues with Clean Energy Credits**
	[$/MWh]	*[MWh]*	***[$]***	*[$]*	***[$]***
Off-peak	-$10/MWh	-10 MWh	**$100**	$0	**$100**
On-peak	$100/MWh	10 MWh	**$1,000**	$100	**$1,100**
Total		0 MWh	**$1,100**	$100	**$1,200**

Under the first treatment, where storage is not directly credited with clean energy production, its compensation is nonetheless greater than it would be under current market rules. More specifically, its total net revenues increase by $100 from $1,000 to $1,100. This increase in revenues paid to the storage resource appropriately accounts for its contributions to clean energy production, as this $100 in additional revenues is equal to the product of the incremental clean energy facilitated by the resource (10 MWh) and the value associated with this clean energy ($10 per MWh).

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[9] This reduction in offer prices is consistent with those observed for other programs for environmental attributes such as Renewable Energy Certificates (RECs) and production tax credits, where resources with low physical marginal costs lower their offer prices to reflect the value of these credits and this results in negative offer prices.

Importantly, this property will hold more generally. Storage resources will facilitate additional clean energy production when they charge during periods where the marginal resource produces clean energy, and when they discharge during periods where the marginal resource does not produce clean energy. In such cases, the energy price when the storage resource charges (that is, the price the storage resource pays to consume electricity) will decrease relative to current market rules because the marginal resource's energy offer price will be reduced to reflect the value of of clean energy certificates. However, there will not be a corresponding decrease in the price the storage resource is paid to discharge because the marginal resource in this hour is not clean, and it therefore does not reduce its energy offer price. Thus, storage's net revenues would increase because the spread between the price it is paid to supply energy, and the price it is charged to consume energy increases.

We now consider the second treatment, where storage is also credited with clean energy certificates for the energy it provides during the on-peak hour. Under this scenario, the storage resource's net revenues increase by another $100 relative to the first treatment to reflect the fact that it is awarded clean energy certificates for its 10 MWh of energy that it supplies during the on-peak hour. In this second treatment, the storage resource is effectively compensated twice for its contributions to clean energy production. It is compensated indirectly via greater energy market revenues than under current market rules because of the impact of the clean energy certificates on the energy market clearing price. Under this treatment, it is now also compensated a second time via revenues from clean energy certificates.

In this example, the storage resource helps to facilitate greater clean energy production by transferring generation from the non-clean peaker P to the clean base resource B. Yet, it is appropriately compensated for these contributions under the first treatment when it is not awarded a clean energy certificate for the energy it discharges. In fact, when it is credited with providing clean energy, as occurs in second treatment, its total compensation exceeds its contributions to the region's clean energy production because it effectively gets paid twice for its contributions to clean energy production – once via increased revenues from the energy market, and a second time via clean energy certificates.

Based on these observations, this example suggests that to awarding clean energy certificates to storage resources would not align the FCEM framework with sound market design, as they are already appropriately compensated for their clean energy contributions in the energy market. Moreover, such an approach helps to prevent consumers from "paying twice" for 10 MWh of clean energy that is produced by clean base resource B in the off-peak hour, consumed by storage resource S in this same hour, and then discharged by S in the on-peak hour.

Example b2: Storage does not increase clean energy production

The assumptions in this example mirror those from b1, with one key difference. The baseload resource is no longer a clean resource that has physical marginal costs of $0 per MWh. Rather, it is now a combined cycle resource that emits 3 units of carbon per MWh and therefore does not receive clean energy certificates. This resource has physical marginal costs of $30 per MWh. As with example b1, peaker P has physical marginal costs of $100 per MWh, where this corresponds with carbon emissions of 10 units per MWh.

Table b2.1 below shows energy awards, production costs, and clean energy benefits under cases with and without storage participation. Observe that in this example, where neither the baseload nor peaker unit produces clean energy, the total clean energy production is equal to 0 MWh under both cases, and thus there is no clean energy benefit with or without the participation of the storage resource (this is shown in column [c]).

Table b2.1: Energy Awards, Production Costs, and Clean Energy Benefits

	[a]	*[b]*	*[c]*	*[d] = [b] - [c]*
Case 1: No Storage Participation				
	Generation *[MWh]*	Production Costs *[$]*	Clean Energy Benefit *[$]*	Total Costs *[$]*
[1] Off-peak	80 MWh	$2,400	$0	$2,400
[2] On-peak	150 MWh	$8,000	$0	$8,000
[3] Total	230 MWh	$10,400	$0	$10,400
Case 2: Storage Participation				
	Generation *[MWh]*	Production Costs *[$]*	Clean Energy Benefit *[$]*	Total Costs *[$]*
[4] Off-peak	90 MWh	$2,700	$0	$2,700
[5] On-peak	140 MWh	$7,000	$0	$7,000
[6] Total	230 MWh	$9,700	$0	$9,700
Change in Costs and Benefits due to Storage Participation				
	Generation *[MWh]*	Production Costs *[$]*	Clean Energy Benefit *[$]*	Total Costs *[$]*
[7]	0 MWh	($700)	$0	($700)

In this example, while storage does not impact the clean energy benefit (which is $0 across all hours), it does reduce production costs by $700 by shifting energy production from the higher cost peaker to the lower cost baseload unit (shown in row [7], column [b]).

Table b2.2 considers the storage resource's total compensation under these same two eligibility treatments, where the first treatment does not credit storage with clean energy production for each MWh of energy it supplies during the peak hour (column [c]), and the second treatment does (column [e]).

Table b2.2: Storage Revenues with and without Clean Energy Certificates

	[a]	*[b]*	*[c] = [a] × [b]*	*[d]*	*[e] = [c] + [d]*
	Energy Clearing Price	Cleared Supply	Revenues without Clean Energy Certificates	Storage Clean Energy Certificate Revenues	Storage Net Revenues with Clean Energy Certificates
	[$/MWh]	*[MWh]*	*[$]*	*[$]*	*[$]*
Off-peak	$30/MWh	-10 MWh	($300)	$0	($300)
On-peak	$100/MWh	10 MWh	$1,000	$100	$1,100
Total		0 MWh	$700	$100	$800

As occurred with the first treatment in example b1, if storage is not credited with delivering clean energy, its total net revenues are equal to the benefits it provides when accounting for both production costs and clean energy. This compensation is equal to $700, the amount by which it reduces total costs (in this case, just through reduced production costs), as shown by comparing total costs in cases 1 and 2 in row [7] of Table b2.1. Importantly, under a clean energy framework, while the storage resource reduces carbon emissions by shifting production from peaker P, which emits 10 units of carbon per MWh of energy produced to baseload resource B, which only emits 3 MWh, it receives no incremental revenues for these contributions because these contributions do not increase clean energy production. As explained later in example c2, a carbon price would allow the storage resource to be compensated for these carbon emisison reduction contributions.

However, if storage is also credited with delivering clean energy as occurs under the second eligibility treatment, it would instead receive total compensation of $800, where this additional $100 corresponds with the value of these certificates. This value exceeds the benefits that it provides, as measured using the FCEM framework which values clean energy production at $10 per MWh, but does not directly value carbon emissions reductions. More specifically, it compensates the storage resource as if it increased the region's clean energy output by 10 MWh, even though the storage resource's participation has no impact on clean energy production.

This example again illustrates an instance where storage is appropriately compensated for its contributions to reducing system production costs and clean energy production when it is not credited with providing clean energy. If it was credited with providing clean energy, this would result in the storage resource receiving compensation that exceeds its contributions to system efficiency, as it would incorrectly indicate that storage's participation increased clean energy production.

Awarding clean energy certificates to storage could undermine FCEM's effectiveness in increasing clean energy production

As examples b1 and b2 illustrate, directly crediting storage resources with clean energy certificates would lead such resources to be compensated at a level that exceeds their contributions to clean energy production. By overcompensating storage resources when they cycle, this approach would create financial incentives for storage resources to charge and discharge (cycle) in order to receive clean energy certificates, including instances when this cycling does not benefit the system, as measured by production costs, clean energy production, or carbon emissions reductions.[10]

Additionally, by overcompensating storage resources, this approach may undermine the FCEM's ability to increase actual clean energy production, as this increased cycling by storage resources would reduce the number of certificates available for other types of clean generation. While states may adjust clean energy targets upwards to account for storage activity, forecasting the quantity of clean energy certificates

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[10] Taken to its extreme, if storage receives clean energy certificates for its energy supplied, a facility with two adjacently-located storage assets could be simultaneously charging one while discharging the other. Because this energy is simply being transferred back and forth between the facilities, it provides no value to the system. However, the asset could profit from the clean energy certificates it is awarded.

awarded to storage resources would likely prove challenging and may therefore increase uncertainty about the states' ability to achieve their desired environmental outcomes in a cost-effective manner.

As illustrated in examples b1 and b2, not awarding clean energy certificates to storage resources compensates storage resources for their contributions to reducing production costs and increasing clean energy production. By not compensating storage resources above their contributions, it avoids creating these perverse incentives for storage resources to cycle to receive clean energy certificates even when this act does not reduce system production costs, increase clean energy production, or reduce carbon emissions.

c. Storage's compensation under a net carbon price

This section now considers storage's contributions and compensation under a net carbon pricing framework. It uses the same pair of numerical examples as are presented in section b, where, rather than employing an FCEM, there is now a carbon price of $1 per unit of carbon emitted. In this example, when the baseload resource is a clean resource, as occurs in example c1, it produces no carbon emissions and thus does not increase its offer price to reflect a cost for emitting carbon.

The peaker resource is a combustion turbine generator that emits 10 units of carbon per MWh of energy produced. To account for the cost associated with these emissions, this unit adds a $10 per MWh to its energy offer.

Similar to the discussion of the FCEM framework above, these examples assume that any new revenue that is collected via a net carbon price is rebated to RTLO, where this distribution does not extend to storage resources.[11]

Example c1: Storage shifts generation to non-emitting resources

This example mirrors examples a1 and b1, where the base resource B is clean and does not emit carbon. Rather than including a clean energy benefit as is consistent with an FCEM construct, this example considers the costs associated with carbon emissions in a manner consistent with a net carbon pricing framework, which effectively assigns a cost to carbon emissions. This results in carbon costs being added to the production costs to produce total costs, whereas in the earlier examples the clean energy benefits were subtracted from the production costs.

As previously, case 1 reflects the total system costs when the storage resource does not participate, and case 2 illustrates the costs when the storage resource does participate.

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[11] While the memo does not explicitly consider approaches that would rebate carbon revenues to storage, such approaches appear to be less effective in compensating storage for their contributions to carbon reductions.

Table c1.1: Energy Awards, Production Costs, and Carbon Emissions Costs

		[a]	*[b]*	*[c]*	*[d] = [b] + [c]*
			Case 1: No Storage Participation		
		Generation *[MWh]*	Production Costs *[$]*	Carbon Emissions Costs *[$]*	Total Costs *[$]*
[1]	Off-peak	80 MWh	$0 *[80 MWh × $0/MWh]*	$0 *[80 MWh × $0/MWh]*	$0
[2]	On-peak	150 MWh	$5,000 *[100 MWh × $0/MWh + 50 MWh × $100/MWh]*	$500 *[100 MWh × $0/MWh + 50 MWh × $10/MWh]*	$5,500
[3]	Total	230 MWh	$5,000	$500	$5,500
			Case 2: Storage Participation		
		Generation *[MWh]*	Production Costs *[$]*	Carbon Emissions Costs *[$]*	Total Costs *[$]*
[4]	Off-peak	90 MWh	$0 *[90 MWh × $0/MWh]*	$0 *[90 MWh × $0/MWh]*	$0
[5]	On-peak	140 MWh	$4,000 *[100 MWh × $0/MWh + 40 MWh × $100/MWh]*	$400 *[100 MWh × $0/MWh + 40 MWh × $10/MWh]*	$4,400
[6]	Total	230 MWh	$4,000	$400	$4,400
			Change in Costs due to Storage Participation		
		Generation *[MWh]*	Production Costs *[$]*	Carbon Emissions Costs *[$]*	Total Costs *[$]*
[7]		0 MWh	($1,000)	($100)	($1,100)

As can be seen by comparing total cost between cases (row [7], column [d]), the participation of the storage resource reduces total costs by $1,100, where $1,000 of this cost reduction comes via lower production costs (consistent with examples a1 and b1 and shown in column [b]), and the remaining $100 comes via reduced carbon emissions (as illustrated in column [c], 10 MWh of generation that produce 100 units of carbon at total cost of $100 are replaced by non-emitting generation).

We now consider storage resource S's revenues under such a framework which depend on the energy prices in the off- and on-peak hours. Importantly, the baseload resource B will offer its energy at a price of $0, to reflect the fact that it has physical marginal costs of $0, and it incurs no incremental costs associated with the carbon price. Thus, in the off-peak hour, the energy price will be $0 per MWh. The peaker P will set the energy price at $110 per MWh, reflecting its physical marginal costs of $100 and a carbon adder of $10 per MWh.

These revenues are shown in Table c1.2, where storage resource S is appropriately compensated for the $1,100 reduction in costs it provides, as this revenue accounts for both the decrease in production costs, and the value associated with storage resource S's role in reducing carbon emissions. In this example, the introduction of a carbon price has no impact on storage's costs to buying energy during the off-peak hour relative to current market rules because the marginal resource (clean resource B) does not emit carbon.

However, the carbon price increases its revenues during the on-peak hour because the marginal resource, peaker P, does emit carbon and thus increases its energy offer price. As a result, its total compensation accounts for its contributions to reducing carbon emissions, as the net carbon price leads it to receive higher revenues when discharging without impacting its costs to charge.

Table c1.2: Storage Revenues under Net Carbon Pricing

	[a]	*[b]*	*[c] = [a] × [b]*
	Energy Clearing Price	Cleared Supply	Storage Net Revenues without Clean Energy Credits
	[$/MWh]	*[MWh]*	*[$]*
Off-peak	$0/MWh	-10 MWh	$0
On-peak	$110/MWh	10 MWh	$1,100
Total		0 MWh	$1,100

Thus, a net carbon price leads the marginal carbon emissions rate to be incorporated in the energy price in the hours when storage is charging and discharging. This leads the storage resource's profits to include its marginal contributions to reducing carbon emissions.

Example c2: Storage shifts generation to lower-emitting resources

Finally, we consider the example where the base resource B is no longer clean, and instead is a combined cycle resource that emits 3 units of carbon per MWh of energy produced. As a result, in this example, base resource B adds $3 per MWh to its energy offer to account for the cost associated with its carbon emissions under this net carbon pricing framework, resulting in an energy offer of $33 per MWh.

This example is analogous to example b2, except that we now assume a carbon price is in place rather than an FCEM. The impact on total costs, including those associated with carbon emissions, is included in Table c2.1.

	[a]	*[b]*	*[c]*	*[d] = [b] + [c]*
Case 1: No Storage				
	Generation *[MWh]*	Production Costs *[$]*	Carbon Emissions Costs *[$]*	Total Costs *[$]*
[1] Off-peak	80 MWh	$2,400	$240	$2,640
[2] On-peak	150 MWh	$8,000	$800	$8,800
[3] Total	230 MWh	$10,400	$1,040	$11,440
Case 2: Storage				
	Generation *[MWh]*	Production Costs *[$]*	Carbon Emissions Costs *[$]*	Total Costs *[$]*
[4] Off-peak	90 MWh	$2,700	$270	$2,970
[5] On-peak	140 MWh	$7,000	$700	$7,700
[6] Total	230 MWh	$9,700	$970	$10,670
Change in Costs due to Storage Participation				
	Generation *[MWh]*	Production Costs *[$]*	Carbon Emissions Costs *[$]*	Total Costs *[$]*
[7]	0 MWh	($700)	($70)	($770)

As shown in row [7], the participation of the storage resource in this example reduces costs by $770, where $700 of this cost reduction stems from decreased production costs, and the remaining $70 comes from a decrease in carbon emissions.

As illustrated in table c2.2, a carbon price framework would appropriately compensate the storage resource for these contributions, as its net revenues are equal to this reduction in total costs. In this example, the storage resource's costs associated with consuming energy during the off-peak hour increase relative to current market rules because the marginal resource increases its offer price by $3 per MWh to reflect the costs associated with its carbon emissions. However, this increase in costs is more than offset by an increase in revenues during the on-peak hour, where the price increases by $10 per MWh, thus indicating that storage is shifting energy production from a higher emitting resource (peaker P) to a lower emitting resource (baseload B).

Table c2.2: Storage Revenues under Net Carbon Pricing

	[a]	*[b]*	*[c] = [a] × [b]*
	Energy Clearing Price *[$/MWh]*	Cleared Supply *[MWh]*	Storage Net Revenues without Clean Energy Credits *[$]*
Off-peak	$33/MWh	-10 MWh	-$330
On-peak	$110/MWh	10 MWh	$1,100
Total		0 MWh	$770

Importantly, the carbon price framework more directly connects compensation to carbon emissions, rather than employing a binary eligibility criteria to determine what technologies are clean. This allows the storage resource (and other lower emitting resources that are not characterized as clean) to be compensated for their contributions to reducing carbon emissions, even if they do not increase the quantity of clean energy produced. This can be seen in the above example in which the net carbon pricing framework leads the storage resource to receive $70 for its contribution to reducing carbon emissions.

3. Conclusion

The memorandum highlights how storage contributes to clean energy production or reduction in carbon emissions by shifting energy production from higher emitting resources during on-peak hours to lower- or non-emitting resources during off-peak hours. It then considers a series of examples to assess how storage are appropriately compensated for these contributions under FCEM and net carbon pricing frameworks using a series of numerical examples.

Examples b1 and b2 find that storage resources would be appropriately compensated for their contributions to reducing production costs and increasing clean energy production under an FCEM framework if they are not awarded clean energy certificates. This outcome occurs because the energy market revenues storage receives would reflect its contribution to clean energy production because the price it pays to consume electricity and that it receives for discharging electricity both account for the clean energy contributions of the marginal resource.

In fact, if energy supply provided by storage resources was awarded clean energy certificates under an FCEM framework, storage's compensation would exceed its clean energy contribution. This outcome would adversely impact the region's ability to cost-effectively meet its environmental objectives via an FCEM and create incentives for storage resources to cycle even when doing so did not reduce production costs or increase clean energy production. Thus, awarding storage resources clean energy certificates in the FCEM framework is inconsistent with sound market design.

The memorandum also shows that a net carbon pricing framework is well situated to appropriately compensate storage resources for their contributions to reducing carbon emissions. Under this framework, both the price storage pays to consume electricity and the price it is paid to discharge electricity include carbon costs associated with the emissions rate of the marginal resource. Thus, if storage is shifting energy production from a higher emitting resource to a lower emitting resource, the higher carbon adder will be included in the energy price it is paid, and the lower carbon adder will be embedded in the energy price it is charged. This outcome is illustrated in Examples c1 and c2.

The examples also illustrate instances where different pathways the region is evaluating, an FCEM and net carbon pricing, produce dissimilar outcomes for storage resources based on the new product definitions. More specifically, examples b2 and c2 identify an instance where storage's participation has no impact on clean energy production, but it would reduce carbon emissions by transferring generation from a higher emitting resource to lower emitting (but not a carbon-free) resource. Storage would be compensated for this contribution under a net carbon pricing framework, as its contributions are consistent with the environmental attribute targeted – carbon emissions reduction. However, under an FCEM approach it would not be compensated for this contribution because its participation does not impact clean energy production.